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SOIL REPORT
PART I
PROPOSED FLAMBEAU PROJECT
GREAT LAKES EXPLORATION CO.
LADYSMITH, WISCONSIN

SOIL TESTING SERVICES, OF WISCONSIN INC.

Consulting Soil and Foundation Engineers

SOIL REPORT

PART I

PROPOSED FLAMBEAU PROJECT

GREAT LAKES EXPLORATION CO.

LADYSMITH, WISCONSIN

SOIL TESTING SERVICES
OF WISCONSIN, INC.
540 LAMBEAU ST. GREEN BAY, WIS. 54303

December 12, 1972

Great Lakes Exploration Company
102 West Second Street North
Ladysmith, Wisconsin 54848

Attention: Mr. Edwarde R. May,
Project Geologist

STS Job 4970

Re: Soil report for Proposed Flambeau Project near Ladysmith, Wisconsin.

Gentlemen:

In accordance with the agreement of September 11, 1972, we have completed the subsurface investigation for the above project. This investigation entailed studies of the proposed open pit mine, plant site, and solid waste disposal area.

This report is divided in Parts I and II. Part I includes a written description of the soil and ground water conditions encountered, and presents an evaluation of the sites with respect to the proposed construction and performance criteria that has been established. Part II includes the detailed description of each of the soil borings, and data from the field and laboratory tests performed. Thus Part I and Part II, combined, comprise the final report. Twenty copies of this report have been sent to the above address.

If there are any questions relative to this report, or if we can be of further service to you on this project, please do not hesitate to contact us.

Yours very truly,

SOIL TESTING SERVICES OF WISCONSIN, INC.

William M. Perpich
Registered Professional Engineer, Wisconsin

WMP/pk

INTRODUCTION

The Flambeau Project is a proposed copper mine development in Rusk County, Wisconsin. The mine will be an open pit located in Section 9 of Grant Township. This open pit will extend in a northeasterly-southwesterly direction as shown in Figure 1. This will encompass an area of approximately 40 acres. It is intended to utilize the overburden soils for construction of the mill yard, roadways, and waste haul road to the solid disposal area, and dikes for the solid waste disposal reservoir. The bottom of the pit will extend to about elevation 840 or about 300 feet below the higher area in the northeast.

This report describes what soils in the mine area could be best utilized for construction of roadways, the mill yard, and the reservoir dike. Also included is a recommended sequence of pit excavation in order that the best materials will occur as needed.

The mill site has not, as yet, been definitely established, but it is expected that it will be located on the southerly side of the open pit, in the vicinity of borings ST9-12 and ST9-13. The mill site will be comprised of various structures with relatively heavy loads, ore silo storage, and crusher buildings. However, the preliminary details for the plant, such as structural loads, locations, and elevations, have not as yet been determined. Therefore, the discussion and recommendations in this report for this part of the development are general and should be defined in more detail once the design details have been developed. Preliminary foundation recommendations and foundation construction problems are presented for the mill site.

The waste haul road will extend approximately 1 1/4 miles from the open pit to the solid waste disposal area. The preliminary location of the waste haul road is shown on Figure 3. It is the intention that this haul road will follow the general topography with a minimum amount of cut and fill, although some fill will be required to cross the small stream along coordinate 37,000 N. It is anticipated that trucks with a gross load of 60 tons and axle loads of about 40 tons will be using this waste haul road. It is also desired that the waste haul road be designed to function as an all-season road with no weight restrictions or shut downs caused by climatic influences on the road section. Consequently the design criteria for this road has been to provide an all-season road to function properly, especially during melting temperatures following prolonged freezing.

The solid waste disposal area will be constructed in Section 21, Grant Township. This site was considered because it appeared to have certain favorable soil conditions to minimize the amount of leakage out of the solid waste disposal reservoir. This disposal area will encompass approximately 240 acres and will be used to store the waste tailings from the mine and also waste mine rock. It is anticipated that tailings will amount to about 800 tons per day and the tailings will be quite fine with only 5 to 7% retained on the No. 200 sieve. The waste rock to be disposed of in this area will amount to about 4000 tons per day. The tailings will initially be discharged at a point discharge, probably on the northerly end. Once the initial berm has been constructed, a rim discharge of the tailings will be used. Consequently it is expected that the material up against the dikes will be slightly coarser with the fines extending towards the center of the pond. The tailings pond will have an anticipated pH of about 11.7.

A preliminary design has the top of the dike at elevation 1192, so this would result in a dam height of 60 to 65 feet. It is desired to develop the interior face as steep as possible while the exterior face will be terraced to allow tree planting as shown in Figure 4. These five terraces on the dike will be constructed at intervals of 2 or 3 years with the first terrace constructed initially. In order to develop the terraces, it appears that the downstream slope will be in the range of 3.4:1 to 3.6:1.

The design criteria established for the solid waste disposal reservoir would be to develop a dike section and reservoir bottom that will minimize the amount of seepage not only during the operational period of the solid waste disposal area, but also during the life of the structure or after it has been completely filled. It is also desired to construct a stable dike section, under the anticipated loadings and possible seepage.

This report presents recommendations as to what materials to use for the various components of the dike section, including the impervious core. The report also describes anticipated seepage losses from the reservoir in various areas and discusses methods that should be undertaken for the site preparation to minimize seepage losses out of the reservoir.

SUBSURFACE INVESTIGATION PROCEDURES

Borings were made in essentially four areas which consisted of the mine area, plant area, along the centerline of the waste haul road, and in the solid waste disposal area. Most of the borings were made with a truck mounted Joy Model 12-B drilling rig, although in the solid waste disposal area, because of the impassable conditions, some borings were made with a Joy Model 12-B drill rig mounted on a tractor towed wide track vehicle. Most of the bore holes were advanced to various depths by means of continuous flight augers. The shallower borings made within the solid waste disposal reservoir were advanced to the full depth by means of continuous flight augers. However, deeper borings required the use of various cutting bits and circulating wash water. Steel NX casing also had to be placed in many of the bore holes to maintain the bore hole open during the sampling operation. In borings made in the mine area, 5 inch diameter casings were used in an attempt to obtain larger diameter tube or pitcher samplers of the underlying soils.

Most of the soil samples were obtained by using either the split spoon or Shelby tube sampling methods following the ASTM Specifications D-1586-63T and D-1587-63T. In the split spoon sampling method, a 2" OD split barrel sampler is driven into the soil with a 140 pound hammer freefalling 30 inches and the blows per one-half foot are recorded for driving the sampler 18 inches. The blow count for the final 12 inches is termed the standard penetration resistance value. This value can be used to provide a qualitative indication of the in-place relative density of non-cohesive soils. A representative portion of each of the split spoon samplers was placed in glass jars and returned to the laboratory for further examination. In the Shelby tube sampling method, a thin walled steel tube with sharp cutting edges is pushed hydraulically into the soil so that a relatively undisturbed sample could be obtained. These tube samples were sealed in the field with rubber caps to prevent moisture loss and then returned to the laboratory.

Both in the mine area and along the centerline of the solid waste disposal dike, 3 inch diameter Shelby tubes were also obtained. Attempts were also made in the mine area to obtain pitcher samplers of the underlying saprolite formation. However, generally poor recovery was obtained by this method. Consequently, to obtain adequate recovery of the underlying soils at a depth, a 2" ID split spoon sampler was used to provide this recovery. In the mine area, all of the soil recovered was placed in watertight bags, identified, and returned to the laboratory. In the mine area, if extremely hard drilling was encountered, some rock coring was done, in order to ascertain that a solid rock form was reached.

In addition, numerous field permeability tests were conducted in the solid waste disposal area. This consisted of using a falling head or rising head method. In all cases, the permeability tests were conducted inside of 3 inch ID casing. A summary of these field tests is shown on Figure 8.

LABORATORY TESTING PROGRAM

The laboratory testing program consisted of performing tests on either undisturbed soils, or on remolded samples for the dike or roadway construction, and on tailings materials.

The laboratory tests conducted on undisturbed soil samples were mainly those taken from under the dike section of the solid waste disposal area. These undisturbed samples were subjected to shear strength tests, such as the unconfined compressive strength test. In this test, the shear strength of the soil can be obtained by axially loading a trimmed soil sample until failure is obtained. Failure is taken as the maximum deviator stress or the stress at 20% axial strain. Water content and dry density tests were also made on these tube samples.

Consolidation tests were conducted on some of the organic soils found in the vicinity of boring ST21-15. In this test the geological loading history of the soil can be estimated by loading the sample in small increments until full consolidation occurs and then plotting a void ratio pressure curve. The plot of this curve is enclosed in Part II.

In addition, permeability tests were conducted on selected undisturbed tube samples as taken from inside the reservoir. These samples were left in the tube, and either a constant head or falling head method was employed. Generally, the constant head method was used because of the low permeability of most of the soil samples.

In addition, grain-size analysis and Atterberg limit tests were conducted on various samples for identification and classification purposes. In the Atterberg limit test, both the plastic and liquid limit were determined. These tests are plotted on the boring logs or listed on the appropriate test sheet.

Grain-size distribution curves were obtained by using the washed gradation method. The material passing the No. 200 sieve was obtained. The plot of the grain-size distribution curve is also included in Part II.

Various tests were conducted on remolded samples for the dike and roadway construction. For materials to be used in the dike, both strength tests, compaction, permeability, and grain-size analysis tests were conducted. The strength tests consisted of consolidated undrained triaxial tests on the compacted saprolite materials, mainly the more plastic clays and also the talcy silt (sericite) or ML type. In the triaxial tests, 3 specimens of the soil were prepared at equal water content and density. Each sample was then subjected to a predetermined lateral confining stress and then loaded axially until failure was obtained. Pore water pressure measurements were taken during each of these tests and these are also plotted.

Permeability tests were conducted on compacted samples anticipated for use in the dike construction. This consisted mainly of permeability tests on compacted samples of the saprolite formation. Compaction generally was to 95% of the ASTM D-698-70 maximum dry density. The results of all the laboratory permeability tests are summarized in Figure 7 of Part I.

California Bearing Ratio tests were also conducted on compacted samples of sands or sand and gravel taken from the overburden in the mine area. The purpose of these tests was to ascertain the characteristics of these soils when compacted and soaked, for construction of the roadway, especially for the base and subbase courses.

In addition, grain-size analysis tests were conducted on overburden materials for roadway construction to determine their suitability, especially regarding susceptibility to frost action.

Laboratory moisture-density relationship tests by ASTM D-1557-70 were also conducted on the proposed roadway materials. These tests are included in Part II.

On tailings samples obtained from Kennecott Copper Corporation in Salt Lake City, Utah, permeability tests were conducted. The tailings sample used was representative of the material to be discharged into the solid waste disposal area.

Permeability tests were conducted at two different densities to ascertain the permeability of the tailings in a very loose state and also in a somewhat consolidated state which would be the case of tailings that were in-place for several years and allowed to consolidate. The results of these tests are also in the summary of laboratory permeability test results.

Each of the soil samples obtained in all the borings was reviewed by a soils engineer and classified as to the major soil component and minor soil gradations, and also regarding color and any conspicuous lenses or seams. These classifications were done with the aid of the grain-size analysis and Atterberg limit tests. Thus, the written soil description on the boring logs represent the soil identification as determined by the soils engineer. The capitalized symbol in parentheses on the boring logs is the appropriate group symbol following the Unified Soil Classification Method. A chart describing the soil properties for each one of these groups is enclosed. The stratification lines indicated on the boring logs were also determined by the soils engineer after grouping the soil samples.

SITE CONDITIONS

General Topography The proposed mine and plant area are located just to the east of the Flambeau River. The mine area is generally 20 to 50 feet above the river and the plant area is about 60 feet above the river. The ground surface in the mine area is descending to the southwest or towards the river and there are several intermittent drainage courses extending from about the center of the mine area to the southwest. Then site plateaus at about +1140. This elevation is maintained throughout most of the northeastly half of the mine area. This site is characterized by both wooded and open areas with numerous unimproved roads through the site.

The plant site is located on a plateau surrounded by contour of 1150. The ground surface at the proposed plant site varies from about 1150 to 1155.

The soil conditions in the mine and plant area are similar. These consisted of granular soils deposited as either alluvium in abandoned river beds or outwash plains, or as glacial till material. These soils were deposited over the residual soils that were derived from extreme weathering of the bedrock in-place.

At the surface there was generally 3 to 8 feet of a silty fine sand material. This generally graded to gravelly fine to medium or fine to coarse sands with occasional boulders and cobbles. The alluvium or outwash was generally found in ST9-6 and ST9-7, whereas in the other borings, a dense slightly cemented silty fine to medium sand with varying amounts of gravel was encountered. This tended to represent more of a glacial till deposit, although there were zones of 10 to 15 feet in thickness of the cleaner gravelly coarse sand outwash material. Also some of the sand deposits do not contain much gravel, but are rather finer sands with only traces of silt, thus being very uniformly graded. These granular deposits extended to depths varying from 15 to 63 feet or from elevation 1103 to 1072. Underlying the granular soils was a light brown to white very poorly cemented sandstone. The sandstone varied in thickness from 5 to 20 feet, but no evidence of sandstone was found in ST9-2 and 9-4. Underlying the sandstone was a saprolite formation. This is actually a residual soil caused from extreme weathering of the parent bedrock. The saprolite was generally classified as a multi-colored silt with varying amounts of clay and angular rock fragments. Some of the silt had a talcy feeling caused by sericite. As indicated by the Atterberg limit tests, this deposit was generally of low plasticity with liquid limits in the range of 25 to 30%, and plastic limits of about 20 to 25%. The natural water content of this silt was generally in the range of 8 to 13%, although in areas of slightly more clay, the water content increased. The major exception to this was in ST9-7 where the saprolite was a reddish brown highly plastic clay with a liquid limit of 56% and a plastic limit of about 30%. Correspondingly, the natural water content of this material was much higher, in the range of about 25 to 33%.

The saprolite formation extended to the end of the mine borings and generally became denser with depth. In a few of the borings the saprolite was very well cemented with characteristics of rock rather than residual soil. The change from the residual soil to the rock was generally gradual as indicated by the increasing density with depth.

In the plant area, the soils again consisted of an upper layer of silty fine sand to about the 7 foot depth. This deposit was underlain by cleaner gravelly fine to coarse or fine to medium sands. However, in both ST9-12 and ST9-13, clay deposits were found in the range of about 20 to 35 feet. The clays were generally quite firm in ST9-12 as indicated by the low water contents and unconfined strengths in excess of 4.5 TSF. In ST9-13, at about 25 to 30 feet, the clays had a much higher water content and lesser unconfined strengths. These soils were underlain by dense silty and clayey sands or silty sands with varying amounts of gravel that either extended to the poorly cemented sandstone at 48 feet in ST9-12, or to 60 feet in ST9-13.

Ground water was found at relatively shallow depths in the borings made in this area in the range of 4 feet to 5 feet. The high ground water table is due to a perched water table. The observation wells (note wells #3 and #4) installed by Great Lakes Exploration Co., indicated a hydrostatic water table quite deep at about 1110 to 1130. However, the pervious sands overlying the impervious very dense silty sands and clays in the plant area have caused the water tables to deviate from a uniform drainage pattern. That is, clay soils inhibit vertical drainage, and therefore tend to hold ground water at higher elevations,which is especially true at the plant site in ST9-12 and ST9-13 where the water was found at only 5 feet below the surface. The water is held in the more pervious and cleaner sands above the impervious silty and sandy clays or clayey sands, unless lateral drainage can occur.

In the waste haul road the soil conditions in the upper 6 feet varied from silty fine sands (SM), to silts (ML), and clayey silts (CL-ML). Therefore, the soils that will be the subgrade for the haul road were generally fine grained soils and would be considered as highly frost susceptible.

Along the haul road, ground water was found in some of the borings within the 6 foot augered depth. Ground water was generally found at a level of about 4 to 5.5 feet, although a number of the auger borings were dry to the full depth. Therefore, it appears there is a perched ground water table within the zone of frost penetration for the haul road in certain areas.

Solid Waste Disposal Area The general topography of the solid waste disposal area is a descending ground surface to the approximate center of the site where a drainage course extends to the west. The drainage course has been improved, and is presently a ditch that flows intermittently. The drainage comes from a swampy area to the east and across Highway 27, and extends into a lower swampy area to the west of the solid waste disposal. This area is characterized by a tag alder swamp. This swamp continues towards the east and eventually develops into a slowly moving stream that crosses the town road between Section 19 and 20, or about one mile to the west of the site.

The ground surface on the north end of the solid disposal area is at about 1150 at the highest point and descends to the south. The ground surface on the southerly end is at about 1144 or 1138 and also descends at a slight grade to the north or towards the drainage course.

In the vicinity of coordinate 31,000 N and 39,500 E, ground water seepage was noted coming out of a natural slope. The seepage is extending to the swampy area to the northwest, but the source is thought to be ground water from a higher swampy area in the vicinity of coordinate 30,000 N and 41,000 E. It appears that this slope extends through some of the more pervious sands causing a slight amount of seepage to occur. No other natural seeps or springs were noted within the solid waste disposal area during inspection trips or by drilling personnel.

The solid waste disposal area is generally characterized by open areas either under cultivation or used as pasture. There are some wooded areas with slight amount of small hardwoods or swamp brush.

The soil profile in the solid waste disposal area is characterized by a mantle of a silt, clayey silt, or fine sandy silt that underlies the topsoil. The depth of this layer varied from about 3 to 4.5 feet, although there were several areas where the layer was slightly thicker to about 5 feet and also there were two areas where the layer was only from 2 to 2.5 feet. This was at ST21-15 where an organic clay was found to 10 feet and in ST21-52 and ST21-59 where the very fine sandy silts or silts extended to depths of about 8 to 12 feet. A soils map showing a general distribution of the soils in the upper 6 feet is shown on Figure 4, Part I.

The silts were generally softer in the upper 2 feet as indicated by the higher water contents in excess of 20%. The samples from 2 to 4 feet were firmer as indicated by lower water contents and a higher dry density.

In most of the borings, these finer grained soils were underlain by fine to medium or fine to coarse sands with varying amounts of silt and gravel. Generally the amount of silt as indicated on the grain-size analysis curves exceeded 20%. This deposit was considered a dense glacial till that extended to the end of the borings. In a few of the borings, the soil actually graded into a silty and sandy clay or clayey sand till, but was still in a dense condition. These soils extended to the end of the borings at either 15 or 30 feet. In general, the glacial till deposits were quite dense in nature. The exception to this was ST21-18 where silty very fine sands in a medium dense condition were found to the end of this boring at 17 feet. This condition extended to ST21-19, but access to this boring could not be gained and therefore it was advanced only to 10' by hand augers. However, the sandy silts were found underlying the silty and clayey sands in ST21-63 which was advanced by a truck mounted drill rig.

Within these silty sand till deposits were found sands with considerably less silt,(less than 10%) and therefore would greatly affect the permeability. Such a sand deposit was found in an occasional boring, but was continuously found starting at boring ST21-36, proceeding to the north to ST21-9, and then to the east to ST21-14. These sands consisting of a fine to medium sand with varying amounts of gravel and only traces of silt. This condition was confirmed in additional borings ST21-65, and ST21-66, but in ST21-67, a clean sand deposit was not encountered.

Zones of this cleaner sand were found at about the 4 to 9 or 12 foot level from ST21-44 to ST21-50 and onto ST21-58. However, borings adjacent to this zone did not encounter any of these cleaner sand deposits. This clean sand was also found at the 6 to 9 foot level at ST21-28 and ST21-29, and also at deeper depths in ST21-22. There appear to be isolated areas of this cleaner, more permeable sand deposit, but such sands were generally not found at the surface, and in all cases were overlain by a more impervious silt or clayey silt.

In borings made along the alternate centerline of the dike (ST21-62 and ST21-61) or in the open swampy area to the soutwest, the soil conditions were similar except for a four foot layer of peat over a clayey sand.

Ground water was encountered at various elevations in the bore holes while augering, although there is one area where many of the bore holes were dry to the full depth. This would be on the northerly area between borings ST21-11 and 21-14 and from ST21-54 and ST21-56. This is in the higher area of the site and no ground water was encountered in these borings to elevation 1123 to 1137. However, in borings made in the lower terrain to the west of this area, ground water was found from about 1124 to 1127 which indicates ground water at about the level of the swampy area to the west. In the other areas of the waste disposal area, the ground water table was found from 1130 to 1134, indicating that the ground water table is relatively uniform throughout most of the area and is descending towards the westerly swamp at about 1128. There were local variations in the water table, and these are due to the variations in permeability of the soil that cause variations of the ground water seepage patterns. That is, where more permeable soils were underlain by impermeable soils, ground water tables tended to be higher, but the reverse situation tended to depress the ground water table. Generally, it appears that the ground water movements are to the west with the exception of the northwest corner, where there appears to be some ground water movement to the north. This is evident by the swampy area that extends to the north across County P and towards the Flambeau River. Therefore, there may be a minor ground water divide in this area.

ANALYSIS AND RECOMMENDATIONS

Plant Site Based on the soil conditions found in the preliminary borings, ST9-12 and ST9-13, made near the plant site area, the proposed plant could be supported on a normal footing or mat type foundation with soil bearing pressures in the range of 4000 to 7000 PSF. Modification of this soil bearing pressure may be necessary, dependent upon the elevation of the footing or mat and the magnitude of the structural loads. That is ST9-12 indicates relatively dense sands over hard clays. Therefore, these recommended bearing pressures should be applicable for the zone of 5 feet below the surface and deeper. However, in ST9-12 the clays from 25 to 35 feet were not as firm, and therefore a soil bearing pressure in the lower range of 4000 PSF may be necessary for any footings or mats extended deeper. However, the sands in the range of 5 feet to 25 feet are dense and therefore utilization of a higher soil bearing pressure should be applicable in this range.

In any case, we recommend that exterior footings or mats, or foundations in unheated buildings be kept at least 5 feet below the final outside grade to provide adequate frost protection.

Another consideration for the design of any facility at this site would be the apparent high perched ground water table which was found at approximately elevation 1144 to 1142 in this area. Although we would expect this ground water table to be depressed once dewatering of the open pit mine is underway, and evaluation should be made to determine the depth the water table will be depressed from the dewatering procedures. The ground water table will have its major effect on the design of any tanks, pits, or basements that will extend below the water table, thus requiring either waterproofing and/or design for hydrostatic lateral and uplift pressures. Also the relatively high ground water table will make a problem with construction of any facilities extending below the ground water table. The difficulties or extent of dewatering may be partly dependent upon the construction sequence, in relation to the dewatering of the open pit mine.

The soils in the upper 5 feet at this site consists of silty very fine sands which are highly frost susceptible and can create severe frost action, especially with the high perched ground water table. A large loss in strength of these soils is expected during the thawing temperatures following prolonged freezing. Since heavy truck traffic is anticipated in the plant site area, an adequate subbase course would be required over these soils to provide all-season trafficability. For areas where heavy truck traffic would be expected in the plant site area, the same recommendation as for construction of the waste haul road should be followed. The exception would be in areas which would be limited to only automobile or light truck traffic. The subbase course thickness in areas restricted to automobile traffic could be decreased to 20 inches of the gravelly sands (AASHO Specification M 147-65, gradation D) with the exception the material passing the No. 200 sieve should be in the range of 0-12%. The gravelly fine to coarse sands as found in boring ST9-7 should satisfy this requirement, although this sand would be found in lesser extent in other borings. The major consideration is that the amount of fines (material passing the No. 200 sieve) in this subbase material is limited to avoid serious frost action. If a paved surface is required, we recommend that over this subbase, 6 inches of a crushed stone or crushed gravel base course be used that complies with gradation #2 of the Wisconsin Division of Highways, with at least 2 inches of an asphalt surface course.

The above pavement recommendation is only applicable for the case where the final grade will be near the existing grade, or on the frost susceptible subgrade. If the parking lot grade is raised, and a suitable sand fill is used, then the thickness of the subbase course could be reduced.

Because of the importance of the ground water table for deeper structures, and the presence of the clay layers found in ST9-12 and 9-13, we recommend that additional borings and testing be done once the location and elevation of the plant facilities have been determined. The number of additional borings should be based on the preliminary structural details for the plant.

Waste Haul Road The waste haul road will be constructed over subgrade soils that have a high potential for severe frost action, that is, the silty fine sands, silts, and clayey silts, with a ground water table in some areas at 3 to 5 feet in depth. Because of this high ground water table and the prevailing soil conditions, we recommend that the final roadway design for this haul road avoid cuts, especially in lower areas, but rather the road be built with a slight fill section. The materials for building the road should be the gravelly fine to coarse sands as shown from 5 to 20 feet in boring ST9-7 in the mine area. Such soils were also found at a depth of about 3 to 15 feet in ST9-6, and in lesser amounts in the other borings in the mine area. As can be seen, the CBR of the gravelly sands from 5 to 22 feet in ST9-7 was 44% which is moderately high and could provide an adequate subbase material.

The design criteria used for the waste haul road was that the road was to be an all-season road for 60 ton gross load trucks from the mine with minimum maintenance throughout the year and that there is to be no paved surface.

Using this criteria, the roadway design was approached from two standpoints; one is a design for reduced subgrade strength due to frost action, and the second design is to limit the frost penetration into the subgrade. For the design using the reduced subgrade strength, due to frost action, this would require a subbase thickness of 30 inches of the select gravelly sand (SW-GW), CBR value of at least 44%, and no more than 12% passing the No. 200 sieve. Such material should satisfy grading D of AASHO Specification M 147-65 with the exception that the material passing the No. 200 sieve should be 0-12% (see Appendix for this gradation). However, if the excavated materials in the mine areas would result in better gradings, such as B or C, these also could be used for this subbase material. The materials should be placed in horizontal lifts not exceeding 9 inches in loose thickness and mechanically compacted to at least 98% of the maximum density as determined by the Modified Proctor test (ASTM Specification D-1557-70). Over this subbase we recommend using 12 inches of a crushed stone or crushed gravel base course that is also compacted to 98% of the Modified Proctor maximum density. This material should satisfy gradation #2 for crushed gravel or crushed stone as defined under the 1969 edition of the Specifications for Road Construction, Wisconsin Division of Highways. We suggest that road oil be applied to this crushed gravel surface to reduce dust.

For the second design of limiting frost penetration into the subgrade, this would require a greater thickness of the subbase material, although the subbase material would not have to be as high in quality, but should be non-frost susceptible sands. Therefore, the fine sands or fine to medium sands without gravel, but with less than 12% passing the No. 200 sieve could be used. The total thickness of the pavement should be 54 inches. The lower subbase should be 24 inches of the clean sand; the next subbase should be 18 inches of the modified AASHO grade D material; and the surface 12 inches of the gradation #2 for crushed gravel or crushed stone base course. Again, for this alternative we suggest that road oil be applied to the surface to reduce dust. The gradations for the various alternatives are summarized in the Appendix of Part I.

For the road design, we recommend that adequate ditch sections be used throughout since accumulations of water near the shoulders could eventually create frost action. An adequate crown for the roadway surface should also be used to promote adequate surface drainage to remove as much water as possible off the base course materials.

Compaction of all of the subbase and base course materials should be to at least 98% of the maximum dry density as determined by the Modified Proctor test (ASTM D-1557-70). In areas where fill sections will be greater than the recommended thickness of the subbase and base course materials, the sands as excavated from the open pit mine could be utilized and compaction should be to at least 95% of the maximum dry density as determined by the Modified Proctor test (ASTM D-1557-70).

Waste mine rock could also be used for construction of roadways carrying heavy truck traffic, but it appears that the sequence of materials available will preclude the use of the waste mine rock, at least for use in the waste haul road.

Solid Waste Area The design criteria established for the solid waste disposal area is to provide a completed dike and reservoir that is relatively impermeable and will minimize the amount of seepage losses during the operation of the mine and also after the dam has been completed. Also required is a dike section that will be stable and terraced to allow plantings on the downstream slope.

The proposed solid waste area in Section 21 has favorable characteristics for construction of the solid waste disposal reservoir without excessive leakage. Because of the consistent upper layer of the silts, clayey silts, or sandy silts over the surface of the reservoir, this should maintain leakage out of the reservoir at a minimum. All of the testing consistently showed that the permeability of this layer was quite low, and in fact, the underlying soils generally had quite low permeabilities. This was due to the high percentage of silt and generally dense nature of these till soils. The major exception to this was the layer of the cleaner sands found along the northerly section of the dike and in the northwest area lying between borings ST21-36, to the north to ST21-9, and to the east to ST21-14.

In order to minimize seepage out of the solid waste disposal reservoir, certain features should be incorporated into the design of the dikes and reservoir. Considering the dike section to be built as shown on Figures 5 and 6, an impervious core (soil 2) should be used . This core should consist of impervious material, mainly the saprolite as will be obtained from the excavation in the open pit mine area. We recommend that this core be at least 40 feet wide and be positioned in the dike as shown on Figure 5. This material should be placed in lifts not exceeding 12 inches in loose thickness and mechanically compacted to at least 95% of the maximum dry density as determined by the Standard Proctor test (ASTM D-698-70). This material should be placed and compacted with the moisture content carefully controlled. The moisture should be within ± 3% of the optimum moisture content as determined by ASTM D-698-70.

For the shell materials of the dike (soil 1), we recommend that the gravelly sands, silty sands, or competent mine rock as excavated from the open pit mine be used for this shell material. Compaction should be to at least 90% of the maximum dry density as determined by the Modified Proctor dry density (ASTM D-1557-70). This material should be placed in horizontal lifts not exceeding 12 inches in loose thickness and compacted in-place.

The foundation preparation for the dike section should consist of stripping all topsoil that is in excess of 6 inches in thickness. All peat in the low areas should be excavated within the dike section and to where the toe of the dike will intersect the final ground surface. The foundation soils therefore should be the silts or clayey silts.

A computer study of the stability of this dike section using these materials and considering a 1:1 upstream slope and a 3.4:1 downstream slope, indicates that the stability is quite adequate considering some seepage through the dike. The stability is adequate because the foundation soils at depth are generally of high strength and, secondly, the dike will be built in stage construction to allow some consolidation of the soils. The soil parameters used are shown on Figure 6. Triaxial tests performed on the compacted saprolite samples indicate that an effective angle of friction for the compacted silt saprolite was 30°, whereas for the compacted plastic clay saprolite it was only 19° with an effective shear strength of 0.35 kg/cm^2. Since the silt appeared to be the predominant saprolite material in the mine area, its properties were used in the stability analysis.

The problem was analyzed for the softer clays that were found in boring 15 on the north end of the dike and at ST21-19, to determine the total settlement of the dike. For a dike height of 62 feet in this area, total settlements could be in the range of 12 to 18 inches for an organic layer of 10 feet thick, but may be slightly more than this for greater clay thicknesses. However, larger clay thicknesses were not found in the other borings. However, these settlements will occur slowly and will occur only as each tier of the dike is applied. Considering 5 tiers, these settlements should occur only in 2 to 4 inch increments as the dike is constructed. We feel that these settlements would not be excessive and should be relatively uniform. However, if this amount of settlement should be excessive this would require undercutting of these organic soils and replacement with the compacted saprolite material. Since this organic deposit does not appear extensive, undercutting should be limited in extent.

To analyze the potential seepage out of the completed dike section, that is a reservoir filled with tailings, a model of the completed dike was used as shown in Figure 5. The important features of this model are that a relatively low permeability was used for the 40 foot wide pervious core (soil 2) and for a layer of silt at the base of the reservoir (soil 4). Both of these features must be incorporated in the dike design. The permeabilities used in the model for these soils were consistently established by the laboratory and field permeabilities conducted. These two soil zones almost completely control the amount of seepage through and under the dike. This model of the dike will probably occur only on the northerly end of the section where the pervious sand soils, depicted by soil 5, were found. In other areas where soil 5 was absent, but rather the silty sands underly the silt, seepage losses would be much less than predicted from this model.

In the computer study, using this model, the seepage rate through the six foot layer of pervious sands (soil 5) was determined to be 12.9 gallons per day per lineal foot of dike. If this sand layer was thicker, of the order of 12 feet, we do not expect twice as much seepage, since leakage is still controlled by the impervious silt layer (soil 4 of the model). We estimate that in areas where soil 5, or the cleaner sands, was 12 feet in thickness, there would be 18 to 20 gallons per day per lineal foot of dike. The direction of the leakage through this zone was almost horizontal. Lateral seepage through the lower zone (soil 6 of the model) was considerably less, of the order of 0.05 gallons per day per foot of dike.

It is our opinion that this amount of seepage loss out of the dike is not excessive. This rate of 13 gallons per day would only amount to 0.25% of the total water in a 6 foot sand layer under the dike section. Also the seepage along the northerly end will proceed to the north in this layer and will tend to dissipate since the ground surface to the north rises. The seepage through this sand layer to the west will enter the swampy area, but we do not expect this seepage to rise to the surface and form springs or seeps, but rather will tend to dissipate in this layer and into ground water. Therefore, this seepage loss should be adequately dilluted by the ground water and should not rise to the surface and flow in open water, or form a spring, due to the soil profile and topography of this area.

If this estimated rate of seepage loss in the completed reservoir is not desirable, then we recommend that a cutoff trench be utilized through the soil 5 zone. The trench would have to be excavated to a depth of about 13 to 15 feet and should start between ST21-35 and 21-36, extend to the north to ST21-9, then to the east, terminating between ST21-14 and 21-15. This is the area where the permeable sands were consistently found underneath the impervious silts. There is another area of cleaner sands that occurred at 6 to 9 feet in 21-28 and 21-29, so this area will also have to be treated if these seepage losses are considered to be excessive.

The cutoff trench, therefore, would have to extend to a depth of 13 to 15 feet from the present ground surface, to be below the permeable sands to the underlying impermeable dense silty sands. This cutoff trench should be centered under the impervious core of the dike. The trench should be a minimum of 10 feet wide, or the width of a tractor blade to make the excavation. For convenience there should be some side sloping so the trench would be slightly wider at the top. The trench should be backfilled to the original ground surface with the compacted saprolite. The compaction again, should be to at least 95% of the maximum dry density as determined by the Standard Proctor test (ASTM D-698-70).

In most areas we do not anticipate any difficulty in making this cutoff trench since bore holes 21-11 through 21-14 were dry. However, there likely will have to be some dewatering from 21-34 to 21-10. Also, dewatering would be required in the area of 21-28 and 21-29. This dewatering could be accomplished with adequately sized sump pumps. It is important that the excavation be as dry as possible to allow adequate compaction of the saprolite material. For this cutoff trench, we suggest that the ML or silt type of saprolite be used since there may be some difficulty in compacting the plastic clay saprolite under wet conditions.

To minimize seepage loss, it is recommended that the reservoir cleaning and preparation be done with certain restrictions. Firstly, we recommend only cutting and removing the larger trees and brush, but no grubbing of the stumps or vegetation be done. That is, the clearing should be done so to preserve the natural density and continuity of the upper layers of silts and clayey silts which provide the impervious surface in the entire reservoir. Consequently, we recommend that none of the topsoil be stripped out of the interior of the reservoir since this layer is relatively silty and has some clay and therefore has a relatively low permeability, as shown in some of the tests. Therefore, stripping of the topsoil and grubbing should only be done under the dike sections where stability is a factor. It would be important that all of the peat under the dike section be removed as this could affect the stability.

In most cases, the borings revealed at least 3.5 to 4.0 feet of the impervious silts or clayey silts. Only two interior borings 21-44 and 21-45 had less than this amount, these being 2.5 and 2.0 feet, respectively. Therefore, we have concluded that there is no need for surface treatment in these areas, unless during construction these areas are skinned of the silt layer. This should be replaced with either compacted silt or the compacted saprolite. The only other area where we recommend that some treatment be performed would be the existing drainage ditch. This ditch should be cleaned as well as possible of any stones, trees, and debris, and filled with an impervious compacted soil such as the compacted saprolite. It would be preferable to use the CH material from ST9-7 through this ditch section.

To facilitate growth and vegetation or trees on the terraces, we recommend that the silty sands found in the upper 5 to 10 feet in the mine area be used here. Since the silty sands will be excavated initially from the mine, it would be desirable to place these silty sands in stockpiles at the mine after the mine construction commences and then transport this material for finishing the terraces. These silty sands will tend to hold moisture better and should provide better growth. However, it is not absolutely necessary to do this rehandling. If commercial fertilizers are used on the terraces, any of the sandy soils should sustain vegetation.

Construction of the dike would present no serious problems as natural moisture contents of the saprolite materials appear to be within 3% of the optimum moisture content as determined by the laboratory moisture content relationship test according to ASTM D-698-70. The exception to this was the plastic clay saprolite as found in ST9-7. Therefore, some drying of the plastic clay saprolite may be required in certain areas. Since most of the saprolite appears to be the drier silts, such drying should be limited. Adequate sloping of the working surface should be done to prevent precipitation from ponding. For compaction of the saprolite, we recommend that this be done with either a sheepsfoot roller or rubber tired roller of adequate size. Compaction should be done in maximum lifts of 12 inches unless the contractor can demonstrate with his equipment that he can adequately compact a thicker lift. The shell material essentially will be the granular soils such as sands and gravelly sands and therefore compaction should be preferably done with a vibratory roller. Again, lifts should be limited to 12 inches of loose thickness unless the contractor can demonstrate otherwise.

Compaction of the initial lift of dike over the suface layer of silts and clayey silts may be difficult if the construction coincides with a period of heavy precipitation. Therefore, any extremely wetted and mired silts should be removed and replaced with compacted saprolite, or the silts should be air dried and recompacted in place.

<u>Mine Excavation</u> The sequence of mine excavation should be done to obtain the most favorable materials for road and dike construction. The first material that will be necessary would be the gravelly coarse sands to comply with AASHO grading D for the subbase of the waste haul road construction. This type of material appeared more prevalent in ST9-7 and ST9-6 and therefore these areas should be excavated initially to obtain adequate subbase material for the waste haul road. The siltier sands as found in the upper 5 to 10 feet throughout the entire mine area could be used in larger fill areas such as the creek crossing, or where the fills are greater than the required subbase and base thickness. Siltier sands could be used for the subgrade material 3.5 to 4.5 feet below the finished roadway grade, depending on the road design used.

As the excavation for the mine extends deeper, some of the saprolite will have to be excavated to start construction of the impervious core of the dike. The sands can also be used on the downstream portion of the dike up to the impervious saprolite core. After the core is made in the initial lift, the sands could also be used on the upstream face. It is not known if the poorly cemented sandstone, as encountered above the saprolite, can be successfully utilized since no samples could be obtained. If by on-site experience, the sandstone can be adequately compacted, this material, possibly, could be placed in the downstream dike section or in the roadway fill sections. The use of the sandstone will be greatly determined by its susceptibility to breakdown from factors such as seeping water or frost action.

We recommend that as much dewatering, as possible, be done prior to excavation of the mine so that the moisture content of the materials will be controlled and not allowed to become excessively wet, causing difficulties in compaction. Particularly important would be the saprolite, since the silts or plastic clays, as excavated, could gain moisture if adequate dewatering is not performed. Therefore, it would be important to keep as much water as possible off the saprolite. The saprolite could be greatly affected by increases in water content. The cleaner gravelly sands should be well drained and would not be as greatly affected, but it would be best to keep these materials also at the optimum moisture content to facilitate the compaction.

It may be necessary to segregate some of the gravelly sands for the roadway work or yard development of the plant site. If at all possible the gravelly sand should be segregated from the siltier sands since the former is much more suitable for subbase materials of roads or yard. The siltier sands in the upper 5 to 10 feet may be immediately placed in the larger fill sections or used on the downstream portion of the dikes. We suggest that the second tier or lift of the dike be started instead of stockpiling extra material that eventually would have to be placed on the dike anyway. The siltier sands cannot be readily used for any other type of construction.

To reiterate, the gravelly sands should be obtained first and used in the haul road. Extra quantities of this material should be stockpiled and used in the most advantageous manner, such as for roadway or yard development. If certain areas have sufficient quantities of coarser gravel and cobbles, such materials could also be considered for concrete aggregate.

The saprolite will also have to be stockpiled as it is removed since this will be used for the construction of the clay core in the upper tiers of the dike. This could either be done at the mill site or near the solid waste disposal area. It would be best to place the saprolite in an area with good surface drainage to avoid excessively increasing the water content of the stockpiled saprolite. Although there will be some increase of the water content at the surface, with an adequately sloped stockpile such increases could be minimized, provided the stockpile is in an area where surface drainage is continually away from the stockpile.

Although no stability studies were made of the open pit mine, the haul roads into the mine should be adequately designed over the saprolite layer, especially the plastic clay saprolite as found in ST9-7. This layer with its high water content could undergo significant loss of strength under a certain number of freeze-thaw cycles. Therefore, an adequate subbase and base must be provided for roads crossing the saprolite layer.

GENERAL

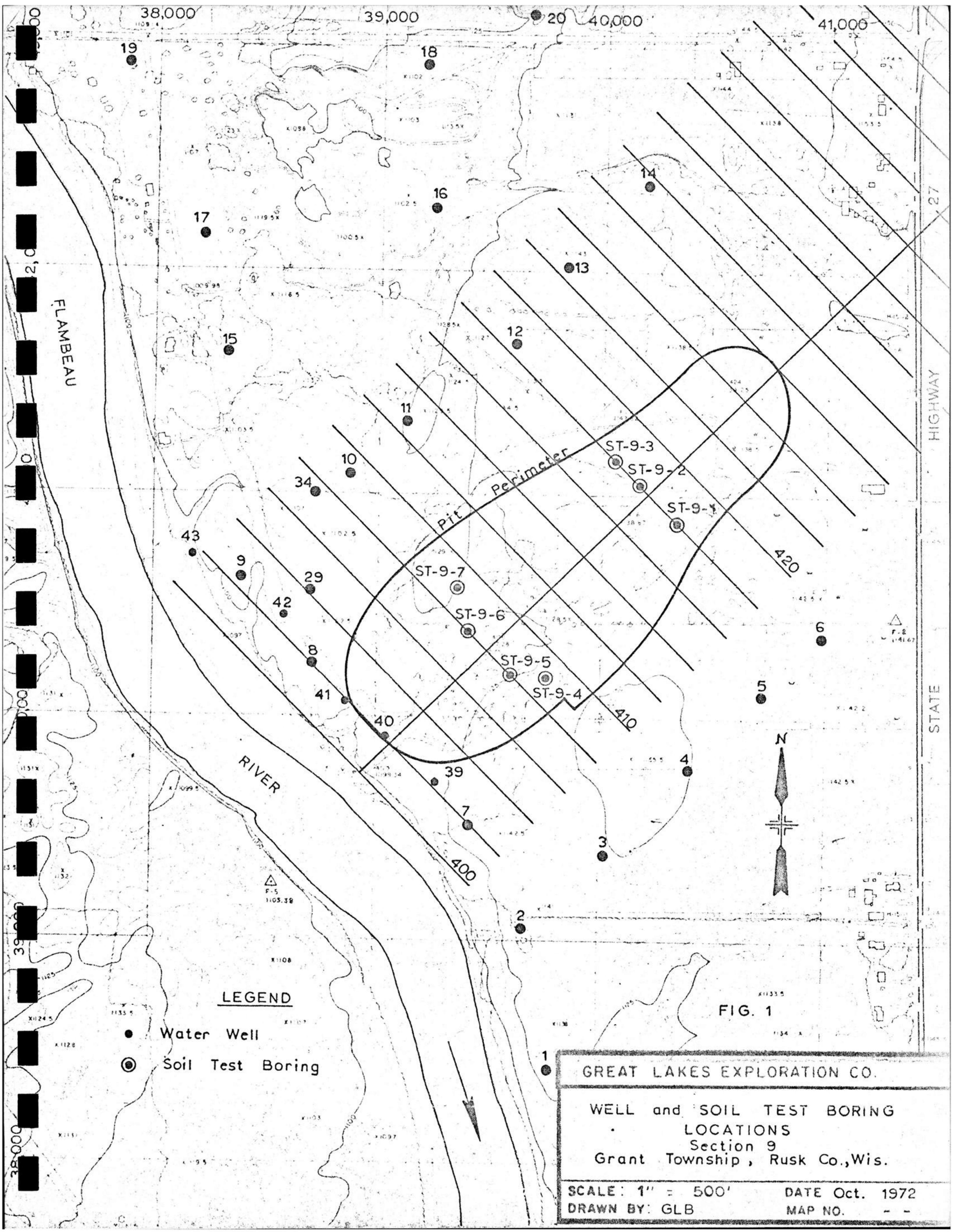
This report has been prepared based upon the soil and ground water conditions found in the borings as made in the project area, and the design criteria as established in communications with personnel of the Great Lakes Exploration Company. Since there could be important variations of the soil conditions between the borings made, we recommend that an inspection of the foundation or earthwork construction for this project be done under the supervision of a soils engineer to verify that the soils are as anticipated in the design. This should include an inspection as to compliance of materials to be used for the roadway, that adequate compaction and correct utilization of the materials in the dike section of the solid waste disposal area is achieved. Also, an inspection of the foundation excavations for the plant site should be done. This would be to verify that the soils as excavated are as anticipated from the borings and the foundations are supported on the proper soils.

If there are any major changes in the concept of the project such as location, elevations, magnitude of structural loads, or design criteria as outlined in this report, we ask that we be so informed to determine if any of our recommendations should be revised. We also would welcome the opportunity to review the final plans and specifications for this project as they are prepared so we might have an opportunity to comment upon the effect of the soil and ground water conditions on the final design.

APPENDIX

Part I

1. Figure 1, Location Plan, Mine Area
2. Figure 2, Location Plan, Solid Waste Disposal Area
3. Figure 3, Location Plan, Waste Haul Road
4. Figure 4, Model for Seepage Analysis
5. Figure 5, Model for Stability Analysis of Dike Section
6. Figure 6, Summary of Laboratory Permeability Tests
7. Figure 7, Summary of Field Permeability Tests
8. Figure 9, Summary of Materials for Waste Haul Road



38,000
39,000
40,000
41,000
FLAMBEAU
RIVER
STATE HIGHWAY 27
Pit Perimeter
ST-9-1
ST-9-2
ST-9-3
ST-9-4
ST-9-5
ST-9-6
ST-9-7
400
410
420
N
LEGEND
Water Well
Soil Test Boring
FIG. 1
GREAT LAKES EXPLORATION CO.
WELL and SOIL TEST BORING LOCATIONS
Section 9
Grant Township, Rusk Co., Wis.
SCALE: 1" = 500'
DATE Oct. 1972
DRAWN BY: GLB
MAP NO. - -

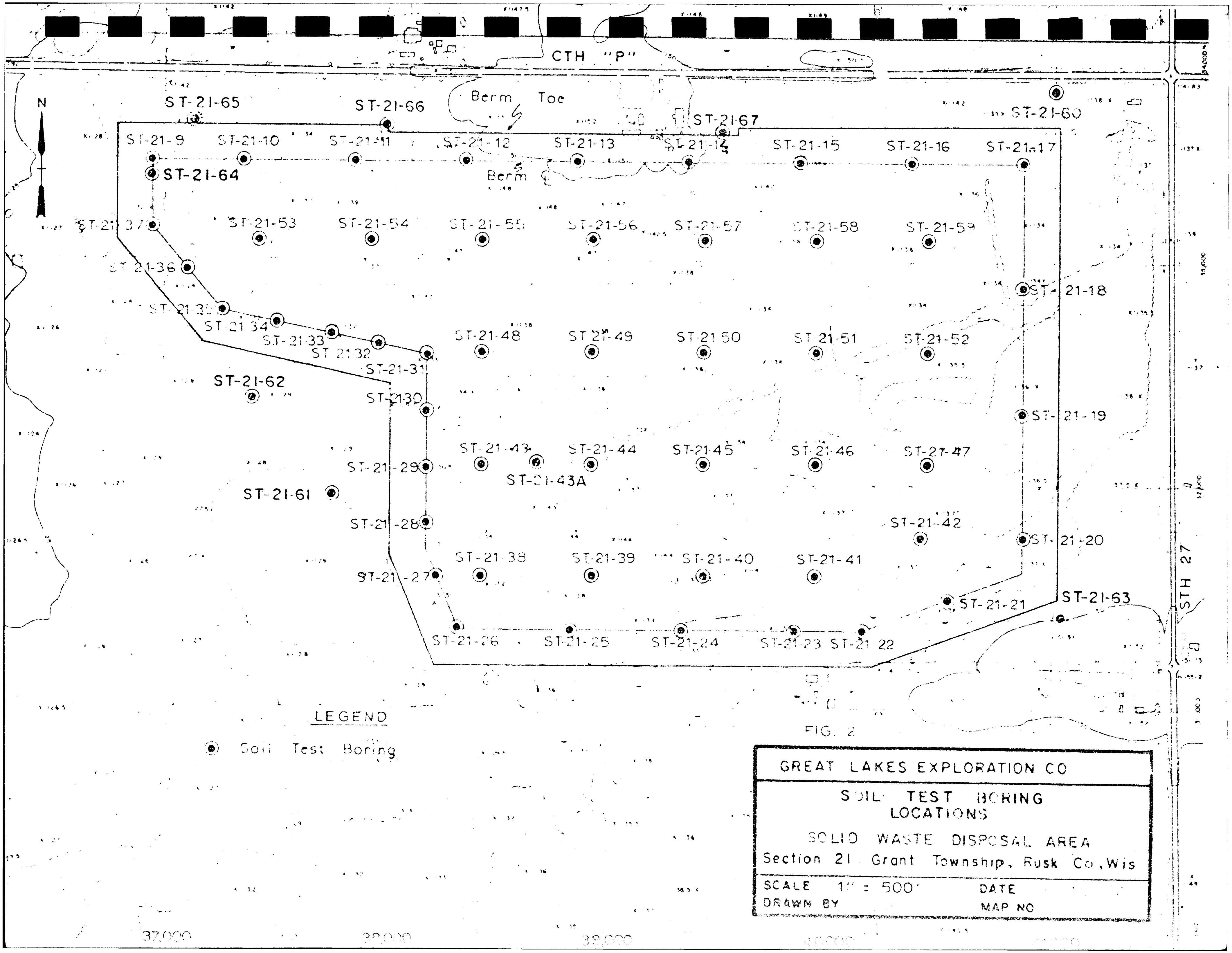


FIG. 2

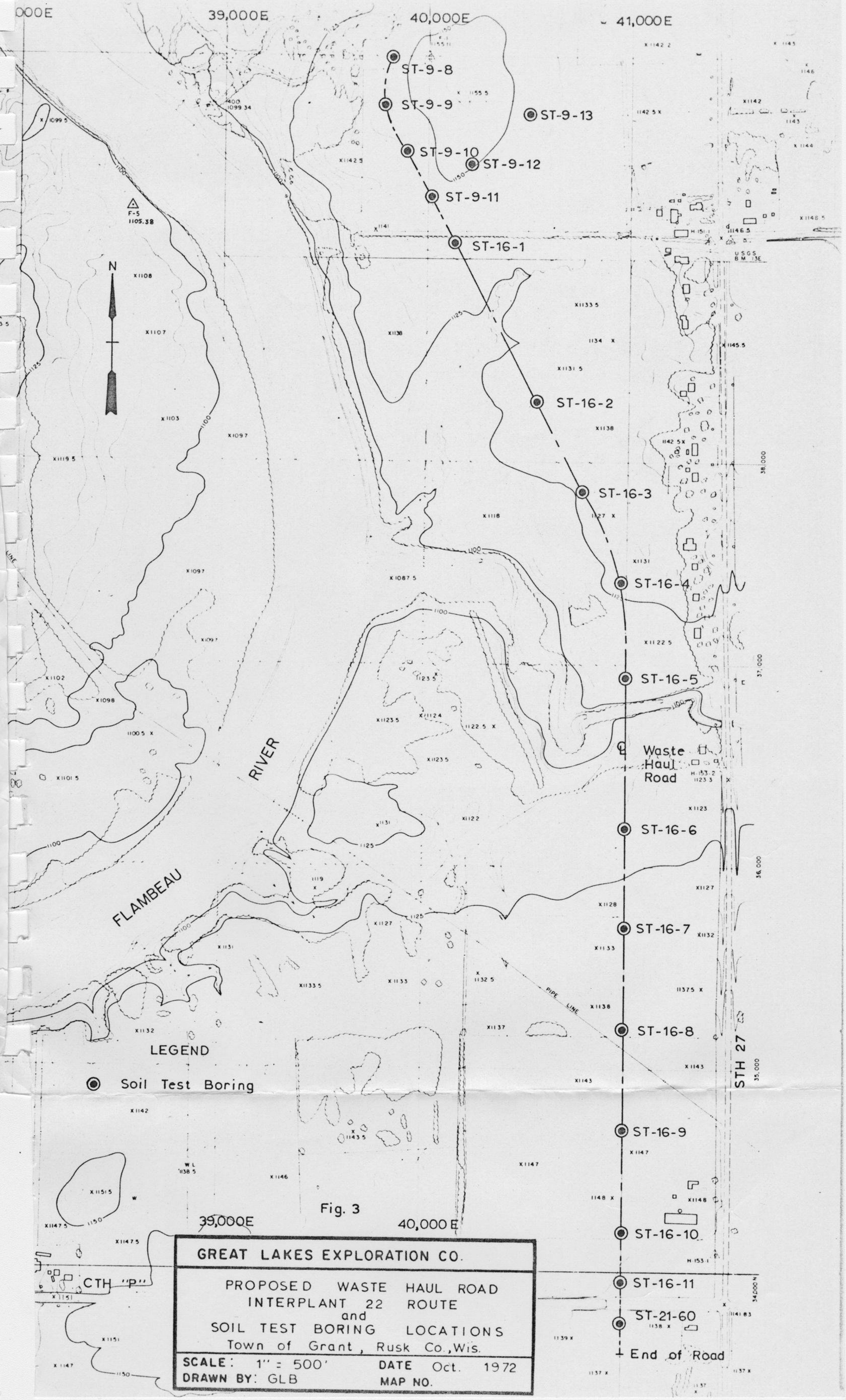
GREAT LAKES EXPLORATION CO

SOIL TEST BORING LOCATIONS

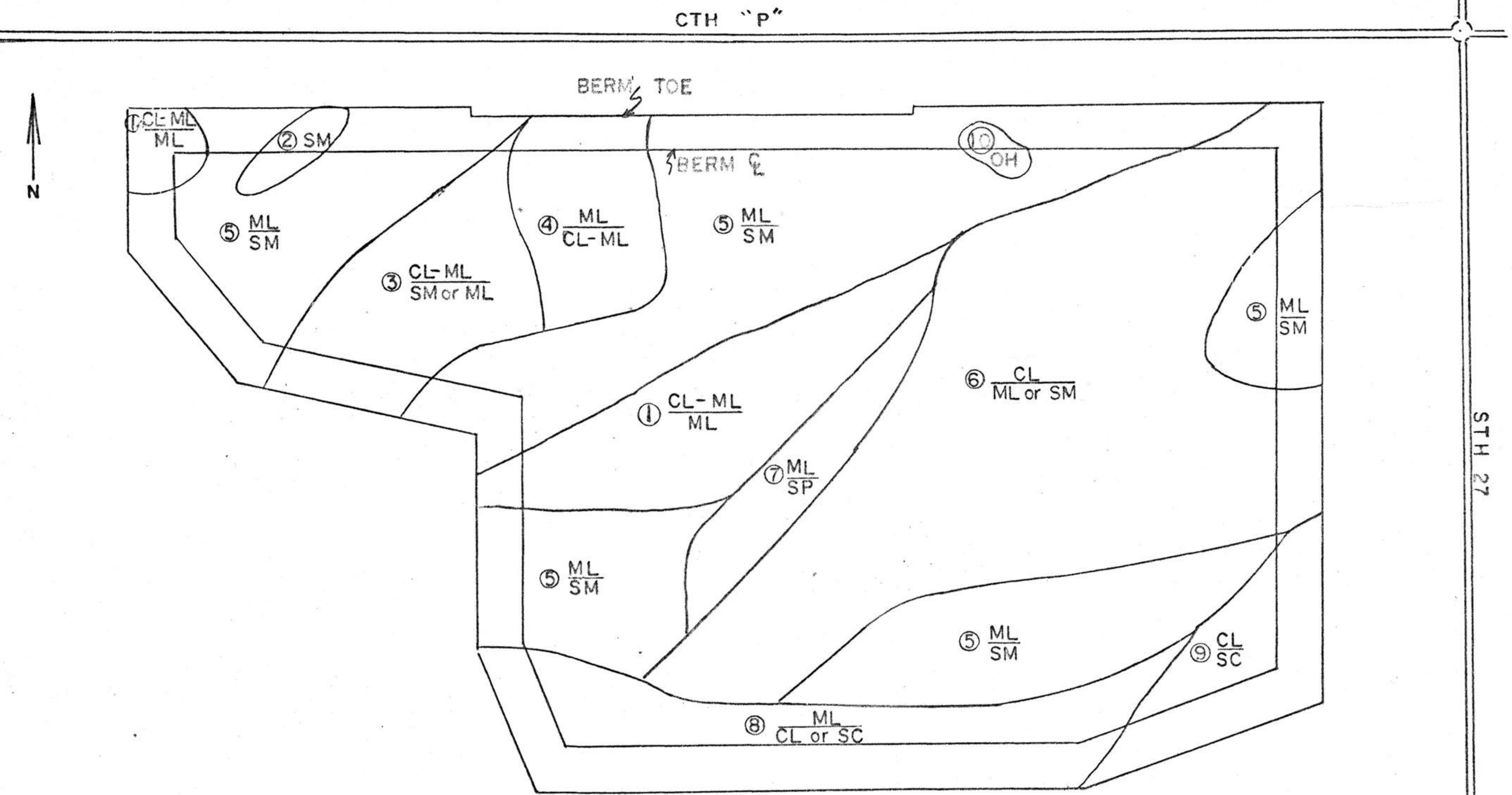
SOLID WASTE DISPOSAL AREA

Section 21 Grant Township, Rusk Co, Wis

SCALE 1" = 500'	DATE
DRAWN BY	MAP NO



39,000E
40,000E
41,000E
ST-9-8
ST-9-9
ST-9-13
ST-9-10
ST-9-12
ST-9-11
ST-16-1
ST-16-2
ST-16-3
ST-16-4
ST-16-5
Waste
Haul
Road
ST-16-6
ST-16-7
ST-16-8
ST-16-9
ST-16-10
ST-16-11
ST-21-60
End of Road
N
F-5
1105.38
FLAMBEAU
RIVER
PIPE LINE
USGS
B.M. 13E
STH 27
CTH "P"
LEGEND
Soil Test Boring
Fig. 3
GREAT LAKES EXPLORATION CO.
PROPOSED WASTE HAUL ROAD
INTERPLANT 22 ROUTE
and
SOIL TEST BORING LOCATIONS
Town of Grant, Rusk Co., Wis.
SCALE: 1" = 500'
DATE Oct. 1972
DRAWN BY: GLB
MAP NO.



①	CL-ML / ML	clayey silt over silt
②	SM	silty sand
③	CL ML / SM or ML	clayey silt over silty sand or silt
④	ML / CL ML	silt over clayey silt
⑤	ML / SM	silt over silty sand
⑥	CL / ML or SM	silty clay over silt or silty sand
⑦	ML / SP	silt over clean sand
⑧	ML / CL or SC	silt over silt clay or clayey sand
⑨	CL / SC	silty clay over clayey sand
⑩	OH	organic clay

FIGURE 4

GREAT LAKES EXPLORATION CO.

GENERALIZED SOIL MAP
OF UPPER 5'
SOLID WASTE DISPOSAL AREA
Section 21, Grant Township, Rusk Co. Wis.

SCALE: 1" = 500'   DATE: 12-11-72
DRAWN BY: GLB

FIGURE 5

SEEPAGE ANALYSIS

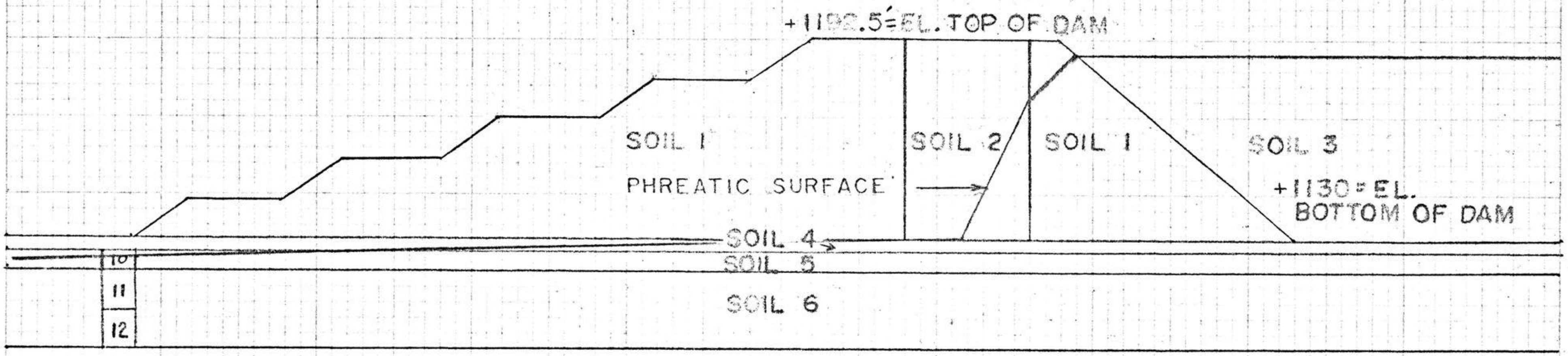
PROPOSED TAILINGS DAM – LADYSMITH, WIS.

SOIL DATA:

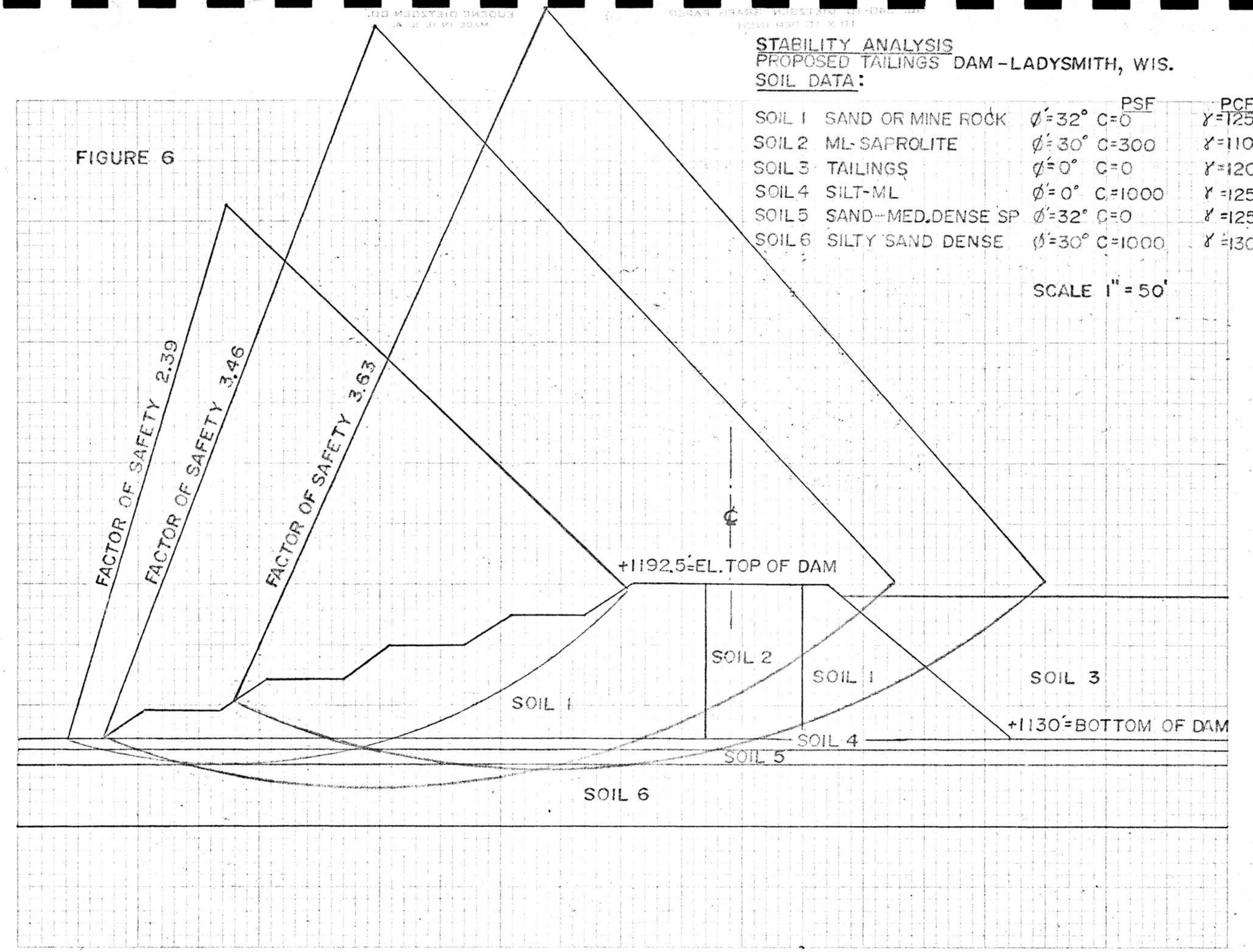
		PERMEABILITY CM/SEC.
SOIL 1	SAND OR MINE ROCK	1×10^{-2}
SOIL 2	ML SAPROLITE	1.1×10^{-6}
SOIL 3	TAILINGS	3.5×10^{-4}
SOIL 4	SILT–ML	1.0×10^{-6}
SOIL 5	SAND–MED. DENSE SP	1.0×10^{-3}
SOIL 6	SILTY SAND DENSE	1.0×10^{-6}

AVERAGE LOSS THROUGH ELEMENT 10 = 12.9 GAL./DAY/FOOT OF DAM.

AVERAGE LOSS THROUGH ELEMENTS 11 & 12 = 0.05 GAL/DAY/FOOT DAM



SCALE 1" = 50'


STABILITY ANALYSIS
PROPOSED TAILINGS DAM - LADYSMITH, WIS.
SOIL DATA:
PSF
PCF
SOIL 1 SAND OR MINE ROCK Ø'=32° C=0 γ=125
SOIL 2 ML-SAPROLITE Ø'=30° C=300 γ=110
SOIL 3 TAILINGS Ø'=0° C=0 γ=120
SOIL 4 SILT-ML Ø'=0° C=1000 γ=125
SOIL 5 SAND-MED.DENSE SP Ø'=32° C=0 γ=125
SOIL 6 SILTY SAND DENSE Ø'=30° C=1000 γ=130
SCALE 1" = 50'
FIGURE 6
FACTOR OF SAFETY 2.39
FACTOR OF SAFETY 3.46
FACTOR OF SAFETY 3.63
℄
+1192.5'=EL. TOP OF DAM
SOIL 2
SOIL 1
SOIL 1
SOIL 3
+1130'=BOTTOM OF DAM
SOIL 4
SOIL 5
SOIL 6

SUMMARY OF LABORATORY PERMEABILITY TESTS

Figure 7

Location	Samples	Depth	Soil Description	Permeability CM/Sec	Remarks
ST9-1	9,10,& 11	52'-58'	Saprolite (ML)	1.1×10^{-6}	Compacted Sample
ST9-2	14,15,16,17 & 18	65'-77'	Saprolite (ML)	5.0×10^{-6}	Compacted Sample
ST9-3	14,15,16 & 18	65'-75'	Saprolite (ML)	6.4×10^{-6}	Compacted Sample
ST9-4 ST9-5 ST9-6 ST9-7	1 & 2 2 1 1A	0-6.5'	Silty fine to medium sand(SM)	1.4×10^{-4}	Combined Compacted Sample CBR=4.5%
ST9-4	7,9,10 & 11	32'-43'	Saprolite (ML)	1.1×10^{-6}	Compacted Sample
ST9-5	7,8,9,12 & 13	31'-41'	Saprolite (ML)	6.1×10^{-5}	Compacted Sample
ST9-7	2,3,3A,4 & 5	5'-23'	Gravelly fine to coarse sand(SW)	4.3×10^{-4}	Compacted Sample CBR=44%
ST9-7	12B,15,18 & 19	45'-53'	Saprolite (CH)	2.5×10^{-8}	Compacted Sample
ST21-27	4	6'-7'	Silty fine sand (SM)	6.5×10^{-7}	Tube Sample,Natural Density
ST21-33	2	2'-3.5'	Fine sandy silt (ML)	1.1×10^{-6}	Tube Sample,Natural Density
ST21-38	1	0-2'	Black silty topsoil(OL)	1.3×10^{-6}	Tube Sample,Natural Density
ST21-38	2	2'-4'	Silt and very fine sand(SM-ML)	1.5×10^{-6}	Tube Sample,Natural Density
ST21-38	3	4'-6'	Silty fine-medium sand-trace to some gravel(SM)	2.5×10^{-6}	Tube Sample,Natural Density
ST21-38	4	6'-8'	Silty fine-medium sand-trace to some gravel (SM)	1.8×10^{-6}	Tube Sample,Natural Density
ST21-40	1	0-2'	Silt (ML)	6.2×10^{-7}	Tube Sample,Natural Density

Figure 7, Cont'd.

Location	Samples	Depth	Soil Description	Permeability CM/Sec	Remarks
ST21-40	2	2'-4'	Silt-trace fine sand and clay(ML)	2.2×10^{-8}	Tube Sample, Natural Density
ST21-40	5	10'-11.5'	Silty fine medium sand-trace to some gravel-trace clay(SM)	2.1×10^{-6}	Tube Sample, Natural Density
ST21-48	1	0-2'	Topsoil and silt(ML)	* 1.6×10^{-3}	Tube Sample, Natural Density
ST21-48	2	2'-3.5'	Fine sandy silt-trace gravel and clay(ML)	2.2×10^{-7}	Tube Sample, Natural Density
ST21-48	3	4'-5.5'	Fine sandy silt-trace gravel and clay(ML)	3.0×10^{-8}	Tube Sample, Natural Density
ST21-48	4	6'-7'	Silty fine coarse sand-trace to some gravel(SM)	3.1×10^{-6}	Tube Sample, Natural Density
ST21-48	5	10'-11'	Silty fine coarse sand-trace to some gravel(SM)	5.4×10^{-6}	Tube Sample, Natural Density
ST21-53	2	2'-4'	Fine sandy silt(ML)	6.6×10^{-8}	Tube Sample, Natural Density
ST21-53	3	4'-5'	Silty fine coarse sand-trace gravel(SM)	1.1×10^{-4}	Tube Sample, Natural Density
ST21-65	2	2'-3.5'	Silt-trace very fine sand and clay(ML)	1.5×10^{-7}	Tube Sample, Natural Density
ST21-66	2	2'-4'	Fine sand and silt-trace gravel and clay(SM-ML)	2.1×10^{-5}	Tube Sample, Natural Density
Processed Tailings			93% p. #200 60% p. #400	7.9×10^{-5}	Dry Density=82 PCF
Processed Tailings			93% p. #200 60% p. #400	3.5×10^{-5}	Dry Density=111 PCF

* Possible side leakage

FIELD PERMEABILITY TESTS

Figure 8

Location	Depth, Feet	Soil Description	Test Method	Duration of Test, Min.	Permeability cm/sec.	Remarks and Date of Test
ST 21-29	1.7	Silt-trace clay (ML)	Falling Head	4020	1.9×10^{-7}	10-20-72
ST 21-33	2.0	Fine sandy silt-trace clay (ML)	Falling Head	4010	9.1×10^{-8}	10-20-72
ST 21-38	6.0	Silty fine medium sand-trace gravel (SM)	Rising Head	200	7.3×10^{-4}	9-27-72
ST 21-38	1.7	Fine sandy silt (ML)	Falling Head	4015	2.1×10^{-7}	9-27-72
ST 21-40	12.5	Silty fine-medium sand-trace to some gravel-trace clay (SM)	Rising Head	185	2.6×10^{-4}	10-2-72
ST 21-40	12.5	Silty fine-medium sand-trace to some gravel-trace clay (SM)	Rising Head	230	2.5×10^{-4}	10-5-72
ST 21-40	1.5	Silt-trace fine sand and clay (ML)	Falling Head	165	2.5×10^{-6}	10-2-72
ST 21-40	1.5	Silt-trace fine sand and clay (ML)	Falling Head	230	0.7×10^{-6}	10-5-72
ST 21-44	6.5	Fine to medium sand-trace silt (SP)	Rising Head	12	9.9×10^{-4}	10-16-72 (Sand up in casing on second run
ST 21-44	6.5	Fine to medium sand-trace silt (SP)	Falling Head	60	2.2×10^{-4}	10-20-72
ST 21-48	2.0	Silt-trace fine sand (ML)	Falling Head	3900	1.1×10^{-6}	10-21-72
ST 21-48	14.3	Silty fine to coarse sand-trace to some gravel (SM)	Rising Head	180	1.6×10^{-4}	10-20-72
ST 21-48	14.3	Silty fine to coarse sand-trace to some gravel (SM)	Rising Head	323	7.7×10^{-5}	10-24-72
ST 21-53	2.0	Silt-trace fine sand (ML)	Falling Head	1300	5.7×10^{-8}	10-20-72
ST 21-53	13.5	Silty fine-medium sand-trace gravel (SM) lenses of fine-medium sand-trace silt (SP)	Rising Head	321	1.7×10^{-4}	10-20-72
ST 21-53	13.5	Silty fine-medium sand-trace gravel (SM) lenses of fine-medium sand-trace silt (SP)	Falling Head	345	1.1×10^{-4}	10-23-72
ST 21-64	1.7	Silt (ML)	Falling Head	525	7.0×10^{-7}	10-19-72

SUMMARY OF MATERIALS FOR WASTE HAUL ROAD

Figure 9

1. Design for Reduced Subgrade Strength
   Total Thickness = 42 inches

   A. Sub-base, 30 inches, (Modified Grading D, AASHO Specification M-147-65)
      Compaction to 98% of ASTM D-1557-70 Maximum Dry Density

Sieve Size	% Passing
1"	100
3/8"	60-100
#4	50-85
#10	40-70
#40	25-45
#200	0-12

   B. Base Course 12 inches, (Gradation #2, Wisconsin Division of Highways)
      Compaction to 98% of ASTM D-1557-70 Maximum Dry Density

Sieve Size	% Passing
1"	100
3/8"	50-85
#4	35-65
#10	25-50
#40	10-30
#200	3-10

2. Design for Limited Frost Penetration into Subgrade
   Total Thickness = 54 inches

   A. Lower Sub-base, 18 inches
      Compaction to 98% of ASTM D-1557-70 Maximum Dry Density

Sieve Size	% Passing (For portion passing #4 sieve)
#4	100
#40	0-75
#100	0-20
#200	0-12

   B. Upper Sub-base, 24 inches (Modified Grading D,AASHO Specification M-147-65)
      Compaction to 98% of ASTM D-1557-70 Maximum Dry Density

Sieve Size	% Passing
1"	100
3/8"	60-100
#4	50-85
#10	40-70
#40	25-45
#200	0-12

   C. Base Course, 12 inches, (Gradation #2,Wisconsin Division of Highways)
      Compaction to 98% of ASTM D-1557-70 Maximum Dry Density

Sieve Size	% Passing
1"	100
3/8"	50-85
#4	35-65
#10	25-50
#40	10-30
#200	3-10

Tentative Method for

PENETRATION TEST AND SPLIT-BARREL SAMPLING OF SOILS[1]

ASTM Designation: D 1586 – 63 T

ISSUED, 1958; REVISED, 1963.[2]

This Tentative Method has been approved by the sponsoring committee and accepted by the Society in accordance with established procedures, for use pending adoption as standard. Suggestions for revisions should be addressed to the Society at 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method describes a procedure for making soil borings with a split-barrel sampler in order to obtain representative samples of soil for identification purposes and other laboratory tests and to obtain a record of the resistance of the soil to penetration of the sampler.

Apparatus

2. (*a*) *Drilling Equipment.*—Any equipment shall be acceptable that provides a reasonably clean hole before insertion of the sampler to insure that the penetration test is performed on undisturbed soil, and that will permit the driving of the sampler to obtain the sample and penetration record in accordance with the procedure described in Section 3. The stiffness of the drill rod used during sampling is believed to have a relationship to the *N* value obtained, especially because a light drill rod "whips" under the blows of the hammer. It is suggested that the drill rod have a stiffness equal to or greater than the A-rod. A stiffer drill rod is suggested for holes deeper than 50 ft. When drilling in sand or in soft clay or other material that will not allow a hole to stay open, casing or drilling mud shall be used. If caving occurs with drilling mud, casing shall be used. The hole shall be limited in diameter to between $2\frac{1}{4}$ and 6 in.[3]

(*b*) *Split-Barrel Sampler.*—The sampler shall be constructed with the dimensions indicated in Fig. 1. The drive shoe shall be of hardened steel and shall be replaced or repaired when it becomes dented or distorted. The coupling head shall have four $\frac{1}{2}$-in. (minimum diameter) vent ports or shall contain a ball check valve and no ports. Substitution of a split-barrel sampler other than 2-in. OD shall be made only with the permission of the engineer in charge. If other sizes are permitted, the size shall be conspicuously noted on all penetration records.

(*c*) *Drive Weight Assembly*, consisting of a 140-lb weight with a 30-in. free fall and a driving head. Special precaution shall be taken to insure that the energy of the falling weight is not reduced by friction between the drive weight and the guides. For driving the casing, a heavier hammer is permitted.

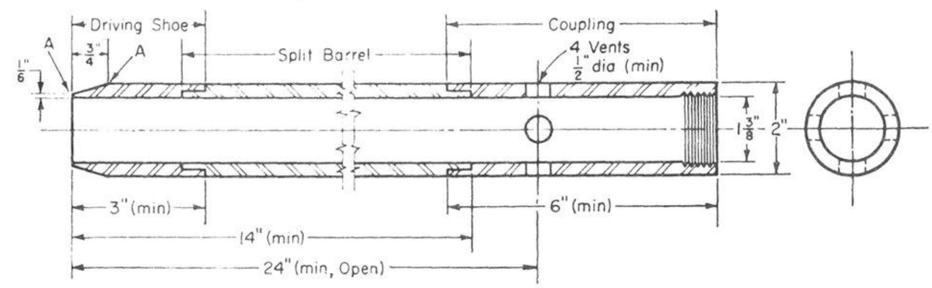
(*d*) *Accessory Equipment.*—Labels data sheets, sample jars, and other necessary supplies.

Procedure

3. (*a*) *Preparing Hole.*—Clean out the hole to sampling elevation using whatever equipment is preferred that will insure that the material to be sampled is not disturbed by the operation. In saturated sands and silts withdraw the drill bit slowly to prevent loosening of the soil around the hole.

In no case shall a bottom-discharge fishtail bit be permitted. (Side-discharge fishtail bits are permissible.) The process of jetting through an open-tube sampler and then sampling when the desired depth is reached shall not be permitted. Take samples at every change in stratum and at intervals not greater than 5 ft (or less if specified). Where casing is used, it shall not be driven below the sampling elevation. Any loss of circulation in drilling fluid during advancing of hole shall be noted for recording on the log.

(*b*) *Obtaining Samples.*—With the sampler resting on the bottom of the hole, seat the sampler 6 in. with blows from the 140-lb hammer falling 30 in. Proceed with driving the sampler until



NOTE 1.—A coupling head with a check valve and a minimum of 0.6 sq in. venting to outside above check valve may be substituted for coupling shown above to improve sample recovery.

NOTE 2.—Split barrel may be $1\frac{1}{2}$ in. ID and may contain a liner.

NOTE 3.—A spring-type core catcher in the driving shoe to prevent loss of sample is permitted.

NOTE 4.—Corners at A may be slightly rounded.

FIG. 1.—Standard Split-Barrel Sampler Assembly.

[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-18 on Soils for Engineering Purposes.

[2] Revision Accepted by the Society at the Annual Meeting, June, 1963.

Published first as information, in the compilation of "Procedures for Testing Soils," April, 1958.

[3] M. J. Hvorslev, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," *The Engineering Foundation*, 345 East 47th Street, New York 17, New York.

it has been driven an additional 12 in., or until 100 blows have been applied. Record the number of blows required to effect each 6 in. of penetration. The first 6 in. of drive is considered to be a seating drive. The total number of blows required for the second and third 6 in. of penetration shall be termed the penetration resistance, N. If the sampler is driven less than 18 in. total, the penetration resistance shall be for the last foot of penetration (if less than 1 ft is penetrated, the logs shall state the number of blows and the fraction of a foot penetrated). If specified, more than 100 blows may be used for specific types of work. Refusal shall be considered to have been reached when the rate of advance is less than 1 in. for 50 blows.

(*c*) *Removal and Labeling.*—Raise the sampler to the surface and open it. Place typical sample or samples of soils from the opened split barrel into jars without ramming. Note on the jar the origin of the sample, and store the jars in suitable containers for shipment to the laboratory or the client. The jars shall have a self-sealing top or shall be sealed with wax to prevent evaporation of the soil moisture. Labels shall be affixed to the jar or notations shall be scratched on the covers (or both) bearing job designation, boring number, sample number, depth, penetration record, and length of recovery. Samples shall be protected from freezing and shall not be placed in the sun.

(*d*) *Field Observations.*—Record water table information on the field logs, including ground water level, elevations at which the drilling water was lost, or elevations at which water under excess pressure was encountered. Measure ground-water levels before and after pulling the casing, where used. In sands, determine the level as the casing is pulled and then measure at least 30 min after the casing is pulled; in silts, at least 24 hr after the casing is pulled; in clays, no accurate water level determination is possible unless pervious seams are present. However, the 24-hr level shall be recorded for clays. When drilling mud is used and the water level is desired, casing perforated at the lower end shall be lowered into the hole and the hole bailed down. Determine ground-water levels after bailing at time intervals of 30 min and 24 hr after all traces of drilling mud are removed from inside the casing.

Report

4. (*a*) Data obtained in borings shall be recorded in the field and shall include the following:

(*1*) Date of boring,
(*2*) Reference datum,
(*3*) Job identification,
(*4*) Boring number,
(*5*) Drilling method,
(*6*) Sample elevations,
(*7*) Limits of strata,
(*8*) Water data,
(*9*) Soil identification,
(*10*) Penetration records, and
(*11*) Casing used.

(*b*) The data thus obtained shall be prepared in final form as a soil profile to show the nature and extent of the soil strata over the area under consideration.

Tentative Method for

THIN-WALLED TUBE SAMPLING OF SOILS[1]

ASTM Designation: D 1587 – 63 T

ISSUED, 1958; REVISED, 1963.[2]

This Tentative Method has been approved by the sponsoring committee and accepted by the Society in accordance with established procedures, for use pending adoption as standard. Suggestions for revisions should be addressed to the Society at 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) This method of sampling of foundation soils is designed to secure relatively undisturbed samples suitable for laboratory tests. It is intended as a guide to more complete specifications to meet the needs of a particular job. It is not implied that if this method is followed, the samples are necessarily sufficiently undisturbed to be suitable for all types of laboratory tests under all field conditions.

(*b*) There are in general two types of samplers that use thin-walled tubes for sampling, namely, open-tube samplers, and piston samplers. In general, fixed-piston samplers are better and can be used in almost all soils. However, open-tube samplers are satisfactory for many soils. Since the thin-walled tube requirements are the same for both types of samplers, the method described applies equally to both.[3]

Apparatus

2. (*a*) *Drilling Equipment.*—Any equipment may be used that provides a reasonably clean hole before insertion of the thin-walled tube, and does not disturb the soil to be sampled, and that can effect continuous and rapid penetration of the tube into the sampled soil.

NOTE.—Where casing is used, the equipment must be capable of driving and removing casing, and must include a pressure pump for clean-out operations. Where drilling fluid is used, a suitable mud pump is required. Where augers are used for clean-out purposes, no special equipment other than that for sampling is generally required.

(*b*) *Thin-Walled Tubes.*—Tubes 2 to 5 in. in outside diameter and made of any materials having adequate strength and resistance to corrosion will be satisfactory (Fig. 1). Adequate resistance to corrosion can be provided by a suitable coating. Sizes other than these shall be used only by order of the person responsible for the boring program. Though these sizes do not necessarily insure undisturbed samples, tubes smaller than 2 in. are considered unsatisfactory for obtaining specimens for compression tests. Tubes shall be of such a length that between five and ten times the diameter is available for penetration into sands and between ten and fifteen diameters is available for penetration into clays. Tubes shall be reasonably round and smooth, without bumps, dents, or scratches. Seamless or welded tubes are permissible, but welds must not project at the seam. The tubes shall have a thickness not greater than No. 16 gage for tubes 3 in. and under in diameter, not greater than No. 14 gage for tubes 3 to $4\frac{1}{2}$ in. in diameter, and not greater than No. 11 gage for tubes 5 in. in diameter. The cutting edge shall be machined as shown in Fig. 1. The inside clearance ratio shall be between 0.5 and 3 per cent. Small clearances are desirable in sands; and clearances up to 3 per cent are required for good recovery in clays depending on the soil type, tube length and method of driving. Unless otherwise specified, an inside clearance ratio of 1.0 per cent shall be supplied Two vent holes ($\frac{3}{8}$ in. minimum) shall be provided in the sampler head. A coupling head with a check valve and a

TABLE I.—STANDARD THIN-WALLED STEEL SAMPLE TUBES.[a, b, c, d]

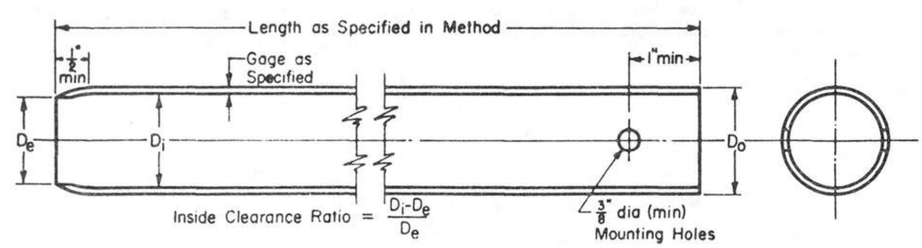
Outside diameter, in.	2	3	5
Wall thickness:			
Bwg	18	16	11
In.	0.049	0.065	0.120
Tube length, in.	36	36	54
Clearance ratio, per cent	1	1	1

[a] Tubes are designed to fit either open or piston standard thin-wall sampler heads of the Diamond Core Drill Manufacturers Assoc.

[b] Alternate materials, sizes, lengths, and clearances are available. Intermediate diameters should utilize intermediate thicknesses and tube lengths.

[c] The 2-in. OD tubes have not been standardized by the Diamond Core Drill Manufacturers Assoc., but are in such common use that they are considered standard. The 2-in. OD tubes are considered a minimum acceptable diameter for sampling, using this method. The DCDMA has standardized the $2\frac{1}{8}$-in. OD, 18-gage tubing, which is considered fully acceptable for sampling using this method.

[d] The three diameters recommended in Table I are indicated for purposes of standardization, and are not intended to indicate that sampling tubes of intermediate or larger diameters are not acceptable. Frequently $2\frac{1}{8}$-in. OD, and $2\frac{1}{2}$-in. OD samplers are used. It should be pointed out that the larger diameters give the least sample disturbance and provide the better samples.



NOTE.—Minimum of 2 mounting holes on opposite sides for 2- to $3\frac{1}{2}$-in. sampler. Minimum of 4 mounting holes spaced at 90 deg for samplers 4 in. and larger. Tube held with hardened screws.

FIG. 1.—Thin-Walled Tube for Sampling.

[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-18 on Soils for Engineering Purposes.

[2] Revision accepted by the Society at the Annual Meeting, June, 1963.

Published first as information in the compilation of "Procedures for Testing Soils," April, 1958.

[3] M. J. Hvorslev, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," *The Engineering Foundation*, 33 W. 39th St., New York 18, N. Y.

minimum of 0.6 sq in. venting to outside above check valve can be used to improve sample recovery. Tubes shall be clean, smooth, and free of rust and dirt. The cutting edges shall be sharp and free from nicks. Coating the tubes with lacquer or suitable plastic by dipping after thorough cleaning is recommended for obtaining the best possible samples. Table I shows the dimensions of suitable thin-wall sample tubes.[4]

(*c*) *Sealing Material.*—Any wax that does not have appreciable shrinkage, or does not permit evaporation from the sample, shall be permitted. Microcrystalline waxes are preferable to paraffin. Thin discs of steel or brass that are slightly smaller than the inside diameter of the tube are desirable for plugging both nds before sealing with wax. Cheeseclothe and tape are needed. Suitable expanding packers may be used.

(*d*) *Accessory Equipment.*—Labels, data sheets, shipping containers, and other necessary supplies.

Procedure

3. (*a*) *Preparing Hole.*—Clean out the hole to sampling elevation using whatever method is preferred that will insure that the material to be sampled is not disturbed by the operation. In saturated sands and silts withdraw the drill bit slowly to prevent loosening of the soil around the hole. Where casing is used, clean out the hole to the bottom or just below. (A clean-out auger shall be used to clean the bottom of the hole when necessary.)

(*b*) *Obtaining Sample.*—With the sampling tube resting on the bottom of the hole and the water level in the boring at the ground-water level or above, push the tube into the soil by a continuous and rapid motion, without impact or twisting, a distance not greater than 15 diameters for cohesive soils, 10 diameters for cohesionless soils and 5 diameters in very loose soils such as loess. In no case shall the tube be pushed further than the length provided for the soil sample. Allow about 3 in. in the tube for cuttings and sludge. The time and pressure, whenever measured, required to obtain penetration shall be noted. When the soils are so hard that a pushing motion will not penetrate the sampler sufficiently for recovery, and where recovery by pushing in sands is poor, a heavy weight may be used to drive the sampler. In such a case, the weight, height, and number of blows shall be recorded. Before pulling the tube turn it at least two revolutions to shear the sample off at the bottom. In very loose saturated sands and silts, the use of a piston sampler is often necessary to secure a suitable undisturbed sample. In intermittent sampling, the soil shall be sampled at every change in stratum and at intervals no larger than 5 ft. within continuous strata.

(*c*) *Preparation for Shipment.*—Upon removal of the sampler tube, measure and record the length of sample in the tube and also the length penetrated. Completely remove the disturbed material in the upper end of the tube before applying wax, and record the length of disturbed soil removed. Ream the lower end to a depth of at least 1 in. and insert an impervious disc. Seal both ends with wax applied in a way that will prevent wax from entering the sample. Where tubes are to be shipped some distance, tape the ends to prevent breakage of the seals. It is advisable to place cheesecloth around the ends after sealing and dip the ends several times in the melted wax.

(*d*) *Labeling and Shipping.*—Tubes shall be labelled as to job designation, boring number, sample number, depth, date, and description of the soil. Duplicate marking of the tube and boring number shall be required. Tubes shall not be permitted to freeze and shall be stored in a cool place out of the sun at all times. Tubes shall be shipped in such a way as not to cause shock and vibration or to disturb the sample in any other way. Samples shall be shipped protected with suitable resilient packing material to reduce shock. On sands and silts it may be necessary to make volume and weight determinations in the field or to arrange for delivery by other than public carriers, since these soils are sometimes very sensitive to vibration.

(*e*) *Field Observations.*—Record type and size of sampler and water table information on the field logs, including ground-water level, elevations at which the drilling water was lost, or elevations at which water under excess pressure was encountered. Measure ground-water levels before and after pulling the casing, where used. In sands, determine the level as the casing is pulled and then measure at least 30 min after the casing is pulled; in silts at least 24 hr after the casing is pulled; in clays, no accurate level determination is possible unless pervious seams are present. However, the 24-hr level shall be recorded for clays. When drilling mud is used, and the water level is desired, casing perforated at the lower end shall be lowered into the hole and the hole bailed down. Determine ground-water levels after bailing at time intervals of 30 min and 24 hr after all traces of drilling mud are removed from inside the casing. Record additional water-table information where encountered.

Report

4. (*a*) Data obtained in borings shall be recorded in the field and shall include the following:

(*1*) Depth of top and bottom of sample,
(*2*) Drilling methods,
(*3*) Method of advancing sampler,
(*4*) Water data,
(*5*) Casing used, and
(*6*) Date.

(*b*) The data thus obtained shall be prepared in final form to show the nature and extent of the soil strata over the area under consideration.

[4] The dimensions have been adopted as standard by the Diamond Core Drill Manufacturers Assoc.