CATARAQUI REGION
CONSERVATION AUTHORITY

Appendix 'I': Requirements for Geotechnical Investigation

This document should be read in conjunction with Section 3.3 of the CRCA Planning Policy.

1.0 PURPOSE

This document is intended to summarize the recommendations of the Cataraqui Region Conservation Authority (CRCA) for the preparation of geotechnical investigations by qualified Professional Engineers and Geoscientists for areas within its jurisdiction. It is intended to facilitate the preparation of reports that will meet the intent of provincial policy, thereby ensuring sound development practice within an expedient review time period. The guidelines reflect the current knowledge of the CRCA, and may or may not satisfy the specific requirements of other agencies. This document will be updated from time to time.

These guidelines include a glossary which defines all words in italics, exclusive of those defined by the Provincial Policy Statement (PPS) (Ontario 2005).

2.0 POLICY CONTEXT

As stated in the PPS:

> "Development shall be directed away from areas of natural or human-made hazards where there is an unacceptable risk to public health or safety or of property damage."

Hazards addressed by the PPS include dynamic beach hazards, flooding hazards, and erosion hazards. The preference is to avoid the hazard entirely, thereby avoiding or minimizing the potential for property damage or risks to personal health and safety. The PPS allows for some flexibility for development and site alteration in those situations in which the *hazard is* considered to be minor and can be addressed in an environmentally sound manner.

The specific interests of the CRCA include the following:

- The effect of increases in loading on slope stability/failure;
- The effect of infiltration of surface water on slope stability/failure;
- Evaluation of the susceptibility of slopes above or adjacent to a development to collapse; and
- The use of appropriate and environmentally-sound protection works.

3.0 GUIDELINES

Detailed technical guidelines have been prepared to establish standards and procedures for regional and site-specific investigations. These include the Natural Hazards Training Manual (NHTM) (MNR 1997), and the Geotechnical Principles for Stable Slopes (GPSS) (Terraprobe, Aqua Solutions 1998) prepared as part of the Great Lakes-St. Lawrence River System and Large Inland Lakes Technical Guideline (GL-SL TG) (MNR, 2001).

The NHTM (1997) and GL-SL TG (2001) were developed by the Ministry of Natural Resources to help implement the natural hazards component of the PPS. These documents define the *erosion hazard* limit for all areas of the province while allowing for further refinement through regional or site-specific analyses. Within the CRCA jurisdiction, the *erosion hazard* limit has been further defined for the Lake Ontario and St. Lawrence River shoreline (J.D. Paine 1995 - see Appendix 'C'). If development is proposed within these established limits, there will be a requirement for a site specific geotechnical investigation.

An investigation is required primarily to examine the erosive potential of the *hazardous lands*. The NHTM has determined three differing areas of *hazardous lands* interest; the *Great Lakes-St. Lawrence River System* and *River and Stream Systems* are the two which are found within the Cataraqui Region. Each area has established criteria for examination to determine the extent of *erosion hazards*. The Great Lakes criteria includes a *stable slope allowance* plus the expected recession over a period of 100 years or an *erosion allowance*. The River and Stream criteria include *stable slope allowance* plus a *toe erosion allowance* plus an *erosion access allowance*. These are defined in Table 1 of the NHTM.

Suggested Report Format

The study report should include the content and general format that is outlined in the GPSS Sections 8 and 9. We suggest that the report could be broken into two parts. Part One would include the factual data itself, such as:

- Terms of reference
- Details of field investigations, site conditions
  - slope configuration/profile - height, inclination andshape, scaled cross-section drawing
  - subsurface conditions (actual and inferred) - soil stratigraphy and layering, soil type and composition, soil density and strengths, groundwater levels/observations, seepage
  - external loadings - structures, traffic, earthquakes, trees, fill
  - site drainage - surface runoff, ditches, channels, seepage, creeks, rivers, lakes, excavation
  - erosion - location, extent, severity, rates, wave action
  - vegetative cover and species
  - history of instability
  - site inspection record
- Results of testing
- Laboratory test results
- Photographs
- Borehole logs and piezometer monitoring data
- Discussion of site inspection and measurements taken

- Scaled site plan, with the relation to:
  - existing and proposed structures
  - current water's edge
  - top of bank, toe of slope, and other topographic information
  - required water or top of bank setbacks as specified in the applicable Zoning By-law
  - regulatory floodplain (where defined)
  - drainage features, erosion features, indicators of past instability or movement
  - vegetation cover

The GPSS includes a sample Slope Inspection Record form (Table 7.4, attached) and a Slope Stability Rating Chart (Table 8.1, attached), both of which should be completed and included with the report . These items aid in determining the required level of investigation.

Part Two would include recommendations based on the proposed construction, such as:

- Design bearing values
- Caisson/pile designs
- Potential settlement
- Potential causes of instability
- Safe slopes of banks and excavation walls
- Earth pressures for shoring
- Soil stabilization methods and comparison of benefits
- Relation of hazards to proposed development
- Long-term stable slope crest position and inclination
- Factor of safety
- Failure surfaces
- Reference to stable slope, erosion allowances etc. as outlined in NHTM and Technical Guidelines
- Methods for soil erosion/sedimentation control
- Methods by which to minimize impact on vegetation, and root systems
- Timing of site works
- Long term monitoring requirements

The report is to make <u>explicit</u> reference to the PPS, NHTM, and Technical Guidelines, all of which are available for viewing at the CRCA office near Glenburnie, Ontario (north of Kingston on Division Street). Only SI (metric) units should be used. The CRCA assesses a fee for our review of this type of report. The fee assessed will be that in place at the time of report submission.

The report will require the stamp and signature of a Professional Engineer or Professional Geoscientist as per GPSS Section 8.2.

Reports which do not include the above content may not be reviewed until the appropriate information has been included.

For more information, please contact the CRCA Watershed Engineer at (613) 546-4228 or via fax (613) 547-6474.

DEFINITIONS

Additional definitions are found in Section 4.0 of the CRCA Planning Policy. It is intended that the definition of these and other terms be consistent with the definitions listed in the Provincial Policy Statement, as amended.

Erosion: means the loss of land, due to human or natural processes.

Erosion Allowance: a horizontal allowance measured landward from the toe of shoreline cliff, bluff, or bank reflecting the possible erosion of the slope over a 100 year period.

Erosion Access Allowance: a horizontal allowance measured from the top of the stable slope, including toe erosion allowance, to provide access to the site for emergencies, regular maintenance, or unforeseen conditions.

Stable Slope Allowance: a horizontal allowance measured landward from the toe of the shoreline cliff, bluff, or bank reflecting a long-term stable state of the existing slope material.

Toe Erosion Allowance: a horizontal allowance measured landward from the toe of the shoreline cliff, bluff, or bank reflecting the possible erosion of the toe of the slope.

TABLE 8.1 - SLOPE STABILITY RATING CHART

Site Location:
Property Owner:
Inspected By:
File No.
Inspection Date:
Weather:

				Rating Value
1.	**SLOPE INCLINATION**			
		degrees	**horiz. : vert.**	
	a)	18 or less	3 : 1 or flatter	0
	b)	18 - 26	2 : 1 to more than 3 : 1	6
	c)	more than 26	steeper than 2 : 1	16
2.	**SOIL STRATIGRAPHY**			
	a)	Shale, Limestone, Granite (Bedrock)		0
	b)	Sand, Gravel		6
	c)	Glacial Till		9
	d)	Clay, Silt		12
	e)	Fill		16
	f)	Leda Clay		24
3.	**SEEPAGE FROM SLOPE FACE**			
	a)	None or Near bottom only		0
	b)	Near mid-slope only		6
	c)	Near crest only or, From several levels		12
4.	**SLOPE HEIGHT**			
	a)	2 m or less		0
	b)	2.1 to 5 m		2
	c)	5.1 to 10 m		4
	d)	more than 10 m		8
5.	**VEGETATION COVER ON SLOPE FACE**			
	a)	Well vegetated; heavy shrubs or forested with mature trees		0
	b)	Light vegetation; Mostly grass, weeds, occasional trees, shrubs		4
	c)	No vegetation, bare		8
6.	**TABLE LAND DRAINAGE**			
	a)	Table land flat, no apparent drainage over slope		0
	b)	Minor drainage over slope, no active erosion		2
	c)	Drainage over slope, active erosion, gullies		4
7.	**PROXIMITY OF WATERCOURSE TO SLOPE TOE**			
	a)	15 metres or more from slope toe		0
	b)	Less than 15 metres from slope toe		6
8.	**PREVIOUS LANDSLIDE ACTIVITY**			
	a)	No		0
	b)	Yes		6

	SLOPE INSTABILITY RATING	RATING VALUES TOTAL	INVESTIGATION REQUIREMENTS	TOTAL
1.	Low potential	< 24	Site inspection only, confirmation, report letter.	
2.	Slight potential	25-35	Site inspection and surveying, preliminary study, detailed report.	
3.	Moderate potential	> 35	Boreholes, piezometers, lab tests, surveying, detailed report.	

NOTES:
a) Choose only one from each category; compare total rating value with above requirements.
b) If there is a water body (stream, creek, river, pond, bay, lake) at the slope toe; the potential for toe erosion and undercutting should be evaluated in detail and, protection provided if required.

9. GEOTECHNICAL REPORT GUIDELINES

It is important that detailed geotechnical reports on slope stability contain the necessary information to permit the reader to fully evaluate the slope stability and possible consequences of failure. The reports should be as complete as possible in collecting and summarizing all available factual information on a site. The following section describes the typical requirements for detailed geotechnical investigations of slope stability, the general approaches available, and the issues which should be discussed.

9.1 Review of Available Data

Regional geology should be considered at the outset of any slope stability investigation, along with any records of past slope instability situations. MNR geological mapping (bedrock geology and bedrock topography or drift thickness, Quaternary geology (see enclosed Map 2556), and MOE water well records) is available for many areas of the province, including most urbanized centres.

As well, many urbanized areas have had topographic mapping prepared from air photography interpretation and this is often available from the Engineering or Public Works Department in the municipal level government offices. The mapping should preferably be at a scale of 1:500 or 1:1000 in order to show sufficient detail of the slope profile. These government offices sometimes also possess records of historical air photographs which may document conditions of erosion, slope instability, land development, or land filling.

The Metropolitan Toronto Archives (and the University of Toronto, Robarts Library) has such air photographs for the Toronto-centred area which are available from 1947 on almost an annual basis. These air photographs are at a scale of about 1:4800. Conservation Authorities also have files which document past reports of slope failures or erosion.

9.2 Site Inspection and Mapping

As discussed in Section 8, a site inspection is always required when assessing slope stability, which produces an extensive basis of factual information for relatively little cost. A variety of other data including aerial photographs, topographic maps and so on can be used to support the field data.

The completion of the Site Inspection Record from a field investigation is very important because it establishes vital factual information on the slope height, slope inclination, exposed soil stratigraphy (if visible), vegetation cover, structures near the slope, and other important features which are relied on by the stability analysis in attempting to model or simulate the actual forces and strength resistance conditions at a site. A photographic record (still or video) should also be taken of the site slope conditions.

The Site Inspection Record (see next page) has the following components to be recorded about the site. Further description is found on Table 7.4.

- File No.
  record date and time of inspection, including weather conditions and visibility, site accessibility

- Site Location
  describe site location with respect to major roads or regional features; provide sketch

- Watershed
  record name of watershed site is located in

- Property Ownership
  obtain name and address of property owner, and legal description for property; describe current land-use of site and adjacent properties

- Slope Data
  record vertical height of slope from toe to crest; describe slope inclination (horiz. to vert. or angle from horizontal) and shape (also provide sketch at end of report and take photographs), whether slope angle is uniform or composite

- Slope Drainage
  describe locations and amounts of any seepage on the slope face or near the slope crest or toe; note location of any 'piping' if occurring, also provide sketch at end of report and take photographs

- Slope Soil Stratigraphy
  where visible or exposed, describe soil stratigraphy (location, thickness, colour of soil layers) and soil types (sand, clay, rock) if possible, also show on sketch and take photographs

- Water Course Features
  indicate location and proximity of any nearby drainage features or water bodies (marshy ground, swale, channel, gully, springs, stream, creek, river, pond, bay, lake), show on sketch

- Vegetation Cover
  describe location, amount, and types of vegetation cover on the slope (crest, face, toe) and on adjacent properties; show sketches, take photographs; grasses, weeds, shrubs, saplings, trees

- Structures
  describe location, types, and size of any man-made structures on the slope face or near the slope crest or slope toe; show on sketches, take photographs; buildings, retaining walls, fences, roads, stairs, decks, towers, bridges, buried utilities

- Erosion Features
  describe location, types, and size of any erosion features on the slope face or near the slope crest or slope toe; show on sketches, take photographs; bare exposed soil, rills, gully, toe erosion, scour, undercutting, piping

- Slope Slide Features
  describe location, types, and size of any past slope movements on the slope face or near the slope crest or slope toe; show on sketches, take photographs; tension cracks, scarps, slumps, bulges, ridges, bent tree trunks or stands of dead trees

- Comments
  record any other general observations

- Plan View Sketch
  show locations of slope crest, toe, structures, vegetation, stratigraphy, seepage, erosion, water course features

- Profile Sketch
  show slope height, inclination, and shape

TABLE 7.4 - Slope Inspection Record

1. FILE NAME / NO.
INSPECTION DATE (DDMMYY):
WEATHER (circle): ○ sunny ○ partly cloudy ○ cloudy
○ calm ○ breeze ○ windy
○ clear ○ fog ○ rain ○ snow
○ cold ○ cool ○ warm ○ hot
estimated air temperature:
INSPECTED BY (name):

2. SITE LOCATION (describe main roads, features)

SKETCH

3. WATERSHED

4. PROPERTY OWNERSHIP (name, address, phone):

LEGAL DESCRIPTION
Lot
Concession
Township
County

CURRENT LAND USE (circle and describe)
○ vacant - field, bush, woods, forest, wilderness, tundra,

○ passive - recreational parks, golf courses, non-habitable structures, buried utilities, swimming pools,

○ active - habitable structures, residential, commercial, industrial, warehousing and storage,

○ infra-structure or public use - stadiums, hospitals,
schools, bridges, high voltage power lines, waste management sites,

5. SLOPE DATA
HEIGHT ○ 3 - 6 m ○ 6 - 10 m ○ 10 - 15 m ○ 15 - 20 m
○ 20 - 25 m ○ 25 - 30 m ○ > 30 m
estimated height (m):

INCLINATION AND SHAPE

○ 4:1 or flatter 25 % 14°	○ up to 3:1 33 % 18½°	○ up to 2:1 50 % 26½°
○ up to 1:1 100 % 45°	○ up to ½:1 200 % 63½°	○ steeper than ½:1 > 63½°

6. SLOPE DRAINAGE (describe)
TOP

FACE

BOTTOM

7. SLOPE SOIL STRATIGRAPHY (describe, positions, thicknesses, types)
TOP

FACE

BOTTOM

8. WATER COURSE FEATURES (circle and describe)
SWALE, CHANNEL

GULLY

STREAM, CREEK, RIVER

POND, BAY, LAKE

SPRINGS

MARSHY GROUND

9. VEGETATION COVER (grasses, weeds, shrubs, saplings, trees)
TOP

FACE

BOTTOM

10. STRUCTURES (buildings, walls, fences, sewers, roads, stairs, decks, towers,)
TOP

FACE

BOTTOM

11. EROSION FEATURES (scour, undercutting, bare areas, piping, rills, gully)
TOP

FACE

BOTTOM

12. SLOPE SLIDE FEATURES (tension cracks, scarps, slumps, bulges, grabens, ridges, bent trees)
TOP

FACE

BOTTOM

13. PLAN SKETCH OF SLOPE

14. PROFILE SKETCH OF SLOPE

9.3 Site Plan and Profile

If there is insufficient existing topographic mapping on a site (at 1:500 scale or better), then detailed topographic surveying will be necessary to establish positions of surface features (slope crest, toe, structures and fences, vegetation and trees, drainage or seepage, scarps, ridges), as well as to measure slope profile (cross-section) or configuration (inclination). The plan should also show the locations of boreholes, auger holes, or test pits. The profile should show the soil stratigraphy (see enclosed examples and Figure 80).

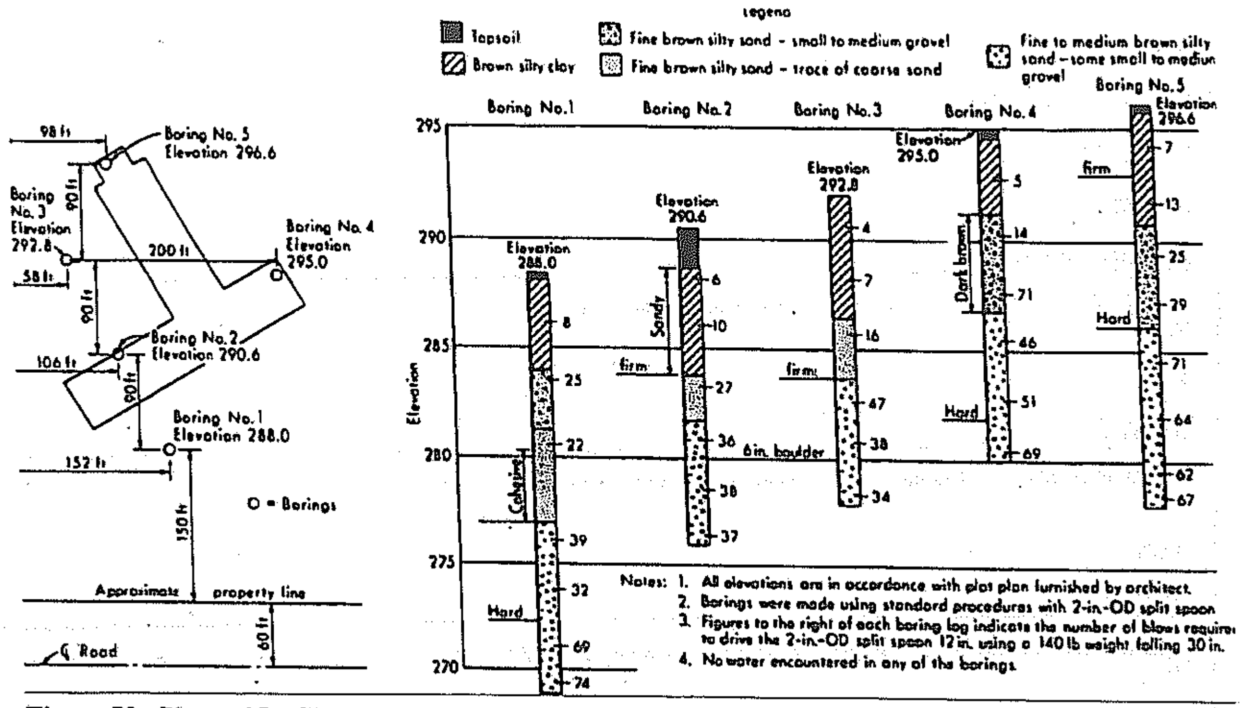


Figure 79 - Plan and Profile

9.4 Boreholes

The subsurface conditions of the slope should be investigated with boreholes and piezometers, to accurately establish the soil types, soil stratigraphy, soil relative density or consistency, groundwater levels, and obtain soil samples. Boreholes are more suitable for investigation than test pits, because excavated test pits are limited by the equipment to maximum depths of 3 to 5 m. Conventional boreholes can be drilled to depths of 30 m or more.

One or two boreholes may be sufficient for many small and simple sites, while many boreholes may be required for larger sites or complex site conditions. For example, boreholes for other engineering projects are often spaced as follows:

Road Pavements and Sewers	50 to 150 m
Buildings	10 to 30 m.

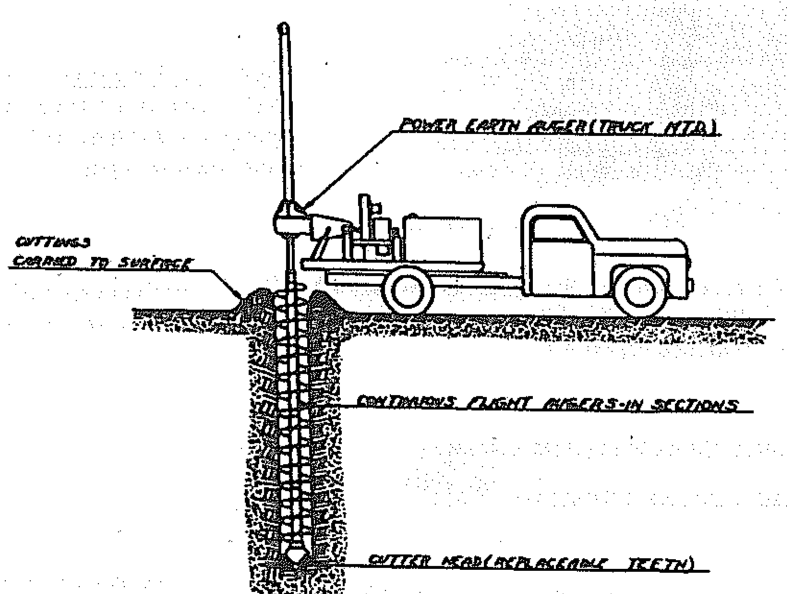
For uniform slope conditions, a reasonable maximum spacing of boreholes along the slope crest would be about 100 m (a closer spacing may be necessary for complex sites).

Generally the ground conditions should be established for the full height of the slope. Some judgement can be used where previous information is available, or where rock or other competent material is found at a shallower depth.

There are several methods of advancing boreholes,

- hand augers
- wash boring
- rotary auger (continuous flight)
  - solid stem
  - hollow stem.

The borehole is usually advanced by continuous flight solid-stem augers (see Figures 81 and 82) which are extracted at each depth interval to permit the insertion of a sampling device or test apparatus. These solid-stem augers typically result in borehole sizes of about 125 mm diameter. Hollow-stem augers (continuous flight) do not require extraction at depth intervals because a central hollow core serves as a casing to support the borehole. Sampling and testing equipment can be inserted through the augers to the bottom of the borehole. In very deep boreholes, the torque required to turn the augers may not be available and other means of borehole advancement are required.



Soil boring using auger method.

Figure 80 - Borehole Drilling

Figure 81 - Photo, Borehole Drill Rig

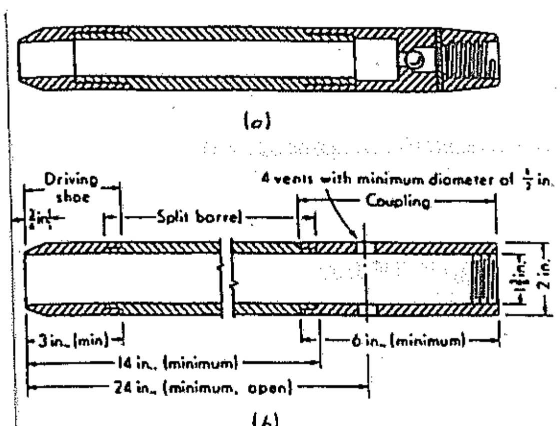
Another standard method of advancing boreholes (through very slow) is "wash boring" which involves the insertion of pipe casing to support the hole and the use of a chopping bit on drill rods to dislodge the soil at the bottom of the borehole. Water is pumped under pressure through the drill rods and chopping bit to wash out the dislodged soil. The casing is driven to the bottom successively as required.

Portable tripod equipment can be used in difficult access areas (i.e. on slope face), to advance boreholes to moderate depths such as 5 to 10 m. This is very slow work.

Boreholes can also be drilled off-shore in standing water (lake, river, pond, bay) with the aid of a barge or platform to carry the drilling equipment.

Shallow hand auger holes can also be carried out (1 m depths) on steep slopes or in difficult access areas, but these are of limited value due to the shallow depth.

The most common test in the borehole is the Standard Penetration Test (S.P.T.) which consists of driving a standard split-spoon sampler (50 mm diameter, 600 mm long) into the bottom of the borehole with a falling weight of 67 kg dropping over a height of 0.75 m (see Figure 83).



Soil-sampling tools. (a) Standard split-spoon sampler; (b) dimensions of the standard split-sampler assembly

Figure 82 - Standard Penetration Test

This test is repeated at increasing depths as the borehole is augured out in increments of 0.75 to 1.5 m. The sampler penetration into the ground is measured and the number of blows required to obtain penetration increments of successive 150 mm are counted and recorded ("N" value). The "N" value or standard penetration resistance is expressed in blows per 0.3 m penetration. The initial 150 mm penetration is usually disregarded due to possible weakening or disturbance at the borehole bottom.

The measured "N" value provides a relative indication of penetration resistance which has been correlated to other soil properties such as density and shear strength. The Standard Penetration Test is commonly used in almost all ground conditions, except soft clay. The S.P.T. samples are considered disturbed due to the high area ratio of the sampler to the sample diameter.

In soft cohesive soils, thin-walled Shelby tubes are used for the extraction of relatively undisturbed samples(see Figure 84). The field vane apparatus is also used in soft, cohesive soils, in order to obtain shear strength values of the soil. The field vane consists of a vane-like device on the end of drill rods, which is inserted into the soil at the borehole bottom and then turned at the ground surface. The torque required to turn the vane is measured. The measured torque can be related to undrained shear strength based on the shape and size of the field vane.

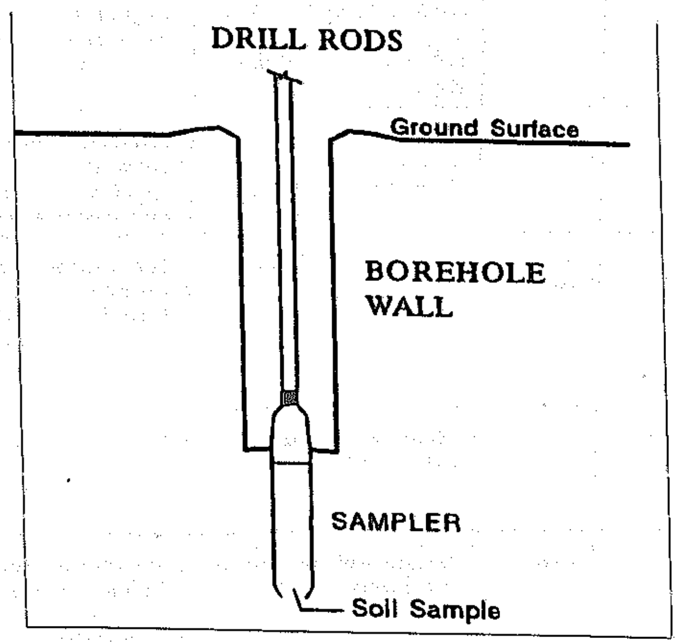


Figure 83 - Shelby Tubes

Other types of penetration resistance testing can be carried out (dynamic cone, static cone) and these are summarized on the following Table 9.1 (ref. Cdn.Fdn.Man.),

TABLE 9.1 - Borehole Test Methods

Type of Test	Type of Soil		Properties Obtainable	Remarks	References
	Best For	Not For			
1. Standard Penetration Test	Sand	Clay	Qualitative evaluation of compactness; comparison of subsoil stratification.	(See Section 4.5.1.1)	1) CSA A119.1 2) ASTM D1586 3) Fletcher (1965) 4) Peck et al (1963) 5) Tavenas (1971) 6) ISSMFE (1977)
2. Dynamic Cone Test	Sand and Gravel	Clay	Qualitative evaluation of compactness; comparison of subsoil stratification.		1) ISSMFE (1977)
3. Static Cone Test	Sand		Continuous evaluation of density and strength of sands and gravel; undrained shear strength in clays.	Test is best suited for design of piles in sand. Tests in clay only reliable with vane tests.	1) Sanglerat (1972) 2) Schmertmann 1970) 3) Ladanyi & Eden (1969) 4) ISSMFE (1977)
4. Plate Bearing Test	Sand		Modulus of subgrade reaction. Ultimate bearing capacity.	Strictly applicable in uniform deposits. Size effects must be considered in other cases.	
5. Vane Test	Clay	Silt Sand Gravel	Undrained shear strength c_u.	Test should be used with care particularly in fissured, varved and highly plastic clays.	1) ASTM D 2573 2) Bjerrum (1972) 3) Aas (1965) 4) Lo (1972) 5) Schmertmann 1975) 6) Lemasson (1976)
6. Pressure - meter Test	Soft rock Sand	-	Ultimate bearing capacity and compressibility	(See Section 4.5.1.3)	1) Menard (1965) 2) Eisenstein (1973) 3) Tavenas (1971) 4) Baguelin 1978)
7. Permeability Test	Sand and Gravel	Clay	Evaluation of co-efficient of permeability	Variable head tests in BH's have limited accuracy. Results reliable to one order of magnitude obtained only from long term large scale pumping tests.	1) Hvorslev (1949) 2) NAVFAC DM7 3) Sherard

The field technician keeps records of the drilling and sampling operations, along with sample descriptions and stratigraphy. The soil samples should be sealed and transported to a geotechnical laboratory for testing of index properties as noted below (see Figure 84).

Class	Sample Quality	Identification	Properties that can be measured: Stratigraphy	Stratification	Organic Content	Grain Size Distribution	Atterberg Limits	Specific Gravity	Water Content	Unit Weight	Permeability	Compressibility	Shear Strength	Note
1	Undisturbed	a - Block samples b - Stationary piston sampler 8 cm (3") minimum diameter	+	+	+	+	+	+	+	+	+	+	+	1 - 4 - 6
2	Slightly disturbed	Open thin-walled tube sampler 5 cm (2") minimum diameter	+	+	+	+	+	+	+	+	+	+	+	2 - 3 - 4 - 5 -6
3	Substantially disturbed	Open thick-walled tube sampler such as split-barrel sampler	+	+	+	+	+	+	+					3
4	Disturbed	Random samples collected by auger or in pits	+	+	+	+	+	+						

NOTES

1. Block samples are best when dealing with sensitive, varved or fissured clays. Whenever possible block samples should be taken in such soils.

2. 8 cm (3") diameter stationary piston samples may be impossible to obtain in some materials such as very stiff clays. If shear strength and compressibility of such materials are required they may be determined using class 2 samples but due consideration must be given to the lower quality of such samples.

3. Samples of classes 1b and 2 must be taken with tubes conforming to the following geometric requirements:
   The area ration $I = \frac{D^2_e - D^2_i}{D^2_i} < 12\%$ where D_e = outside diameter of the tube
   The inside clearance $0.5\% < \frac{D_i - D_c}{D_i} < 1\%$ D_i = inside diameter of the tube
   The angle of the cutting edge must not be greater than 30° D_c = inside diameter of the cutting edge

Figure 84 - Appropriate Lab Tests for Field Samples

Enclosed are samples of field borehole logs and the office report logs (see Figure 85).

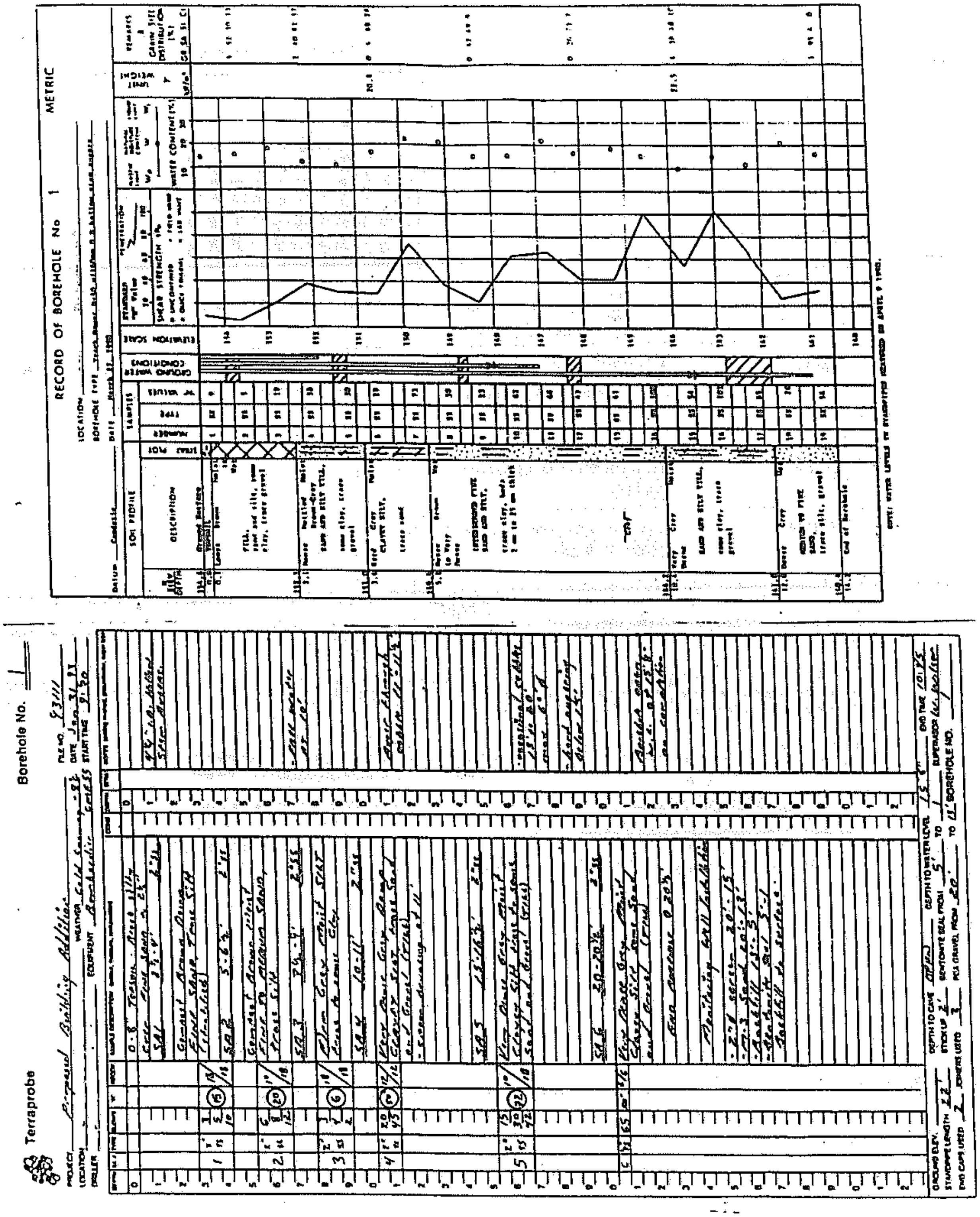


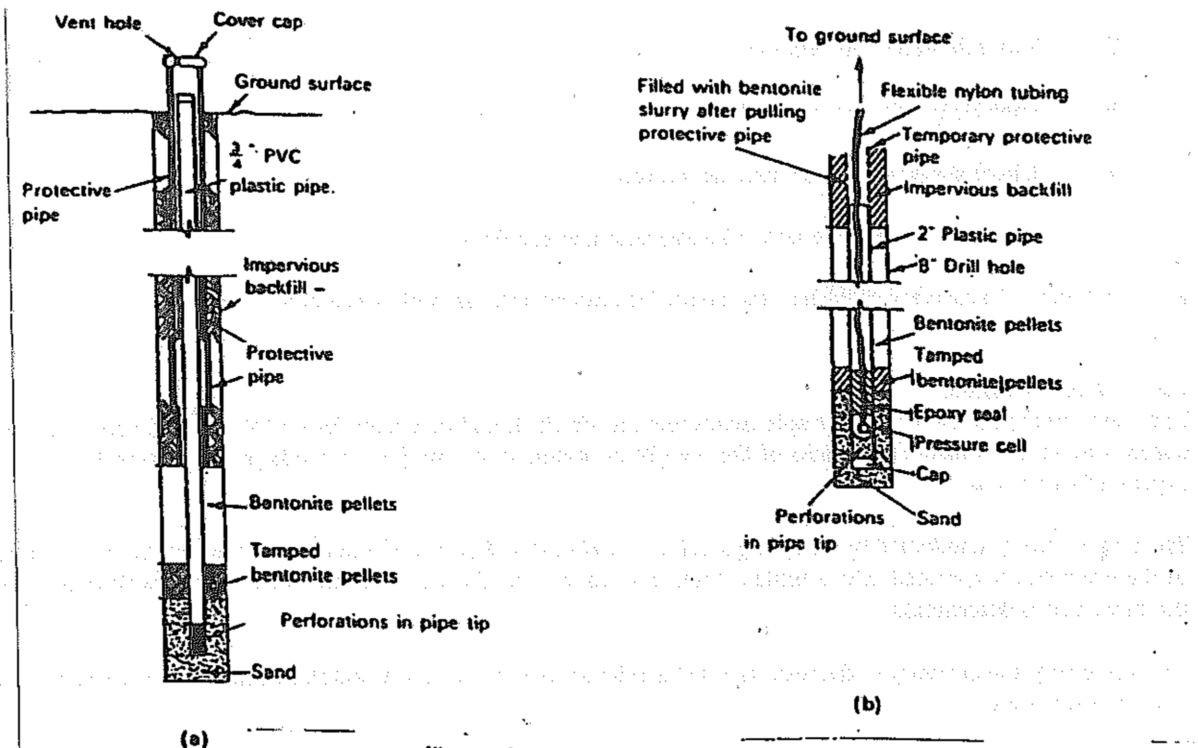
Figure 85 - Borehole Logs

9.5 Piezometers

Groundwater conditions are often measured by standpipe piezometers consisting of hollow plastic pipe or tubing (10 to 50 mm diameter), which are installed in the boreholes on completion of drilling (see Figure 87). Monitoring of groundwater levels is conducted after borehole drilling.

The most common standpipe installation consists of small diameter tubing which extends down to a filtered porous (or perforated) tip that is surrounded with granular material (sand or fine gravel). Groundwater is allowed to enter the standpipe through the filtered porous or perforated tip, and to rise to its static hydrostatic or piezometric level inside the piezometer tubing or piping. The groundwater level inside the tubing can be measured by lowering a calibrated coaxial cable with low electrical current (or other device) down to the water level.

A bentonite clay seal (swelling or expansive clay) is typically provided just above the filtered tip, to ensure that the measured hydrostatic pressure is representative for the level of the piezometer tip (protects against influence from different pressures at different depths. After backfilling the borehole to near the ground surface, an additional bentonite clay seal is usually provided, to protect against surface infiltration down the backfilled borehole.



Illustrations of piezometer types: (a) open tube type for use in permeable soil; (b) pressure cell for use in impermeable soil.

Figure 86 - Piezometers

Other remote monitoring types of piezometers are available, such as pneumatic, or electric. The advantages of standpipe piezometers include inexpensive cost, no de-airing required, no calibration required.

Most standpipes are backfilled with the native soil, when the monitoring after drilling does not extend beyond a few months. For long-term monitoring (many months) the piezometer installations should be grouted to protect against backfill settlement and damage to the tubing or connections.

9.6 Laboratory Testing

In the geotechnical laboratory, the soil samples should all be subject to tactile examination by an experienced engineer who confirms the field descriptions on the borehole log, and who selects representative samples for detailed testing. There are several common laboratory tests to establish index properties of soils. The behaviour of soils types are often estimated on the basis of their measured index properties.

The most common laboratory tests and their recommended testing frequency for samples are:

A. Water contents, all samples

B. Atterberg Limits, cohesive strata

C. Grain size distribution, all strata

D. Soil unit weight, as required

E. Specific gravity, as required

F. Direct shear test, sand strata, as required

G. Triaxial compression test, cohesive strata, as required.

The following is a summary of each of the above laboratory tests, as well as example test results.

9.6.1 Water Content

The water content is a relatively simple measurement which should be undertaken on all borehole soil samples. The water content is defined as the ratio of the weight of water, to the weight of solids in a soil sample, and is often expressed in percent.

The test is usually conducted by weighing a sample in it's natural state, and then drying the sample in a oven until all of the water has evaporated. The sample is then re-weighed, and the weight of the water loss as well as the weight of the dried soil is determined.

The variability and accuracy of the measurement is relevant only to one digit, and should never be reported to more than one decimal point.

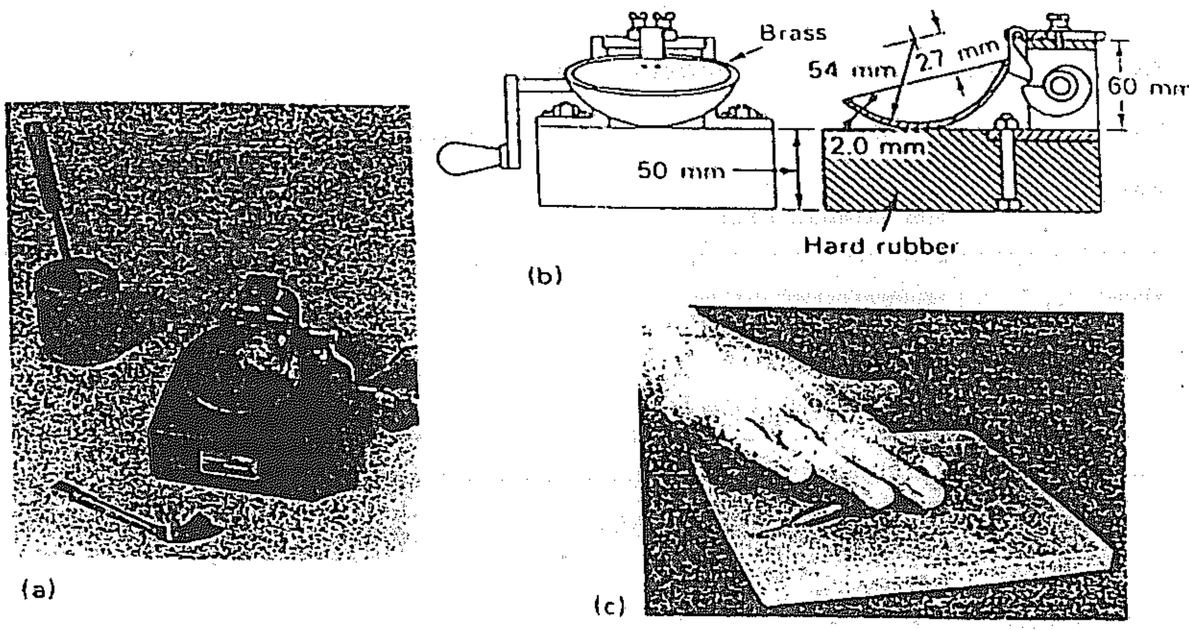
The limits on the water content are indirectly controlled by the void ratio or porosity within the soil mass, that being, the available void space between the individual soil particles. A soil is considered to be "saturated" if all of the void space has been filled with water. In natural environments, the water content of a soil mass may be saturated if natural water infiltration is present, or it may be partially saturated and consisting of air and water in the void space. For comparison, the saturated water content of various soil types are as follows (see Table 9.2).

TABLE 9.2 - Saturated Soil Water Contents

SOIL TYPES	SATURATED WATER CONTENT
sand and gravel	5 - 7 % by weight
sand	8 - 10 %
silt	16 - 20 %
clayey silt	20 - 30 %
clay	30 - 40 %

9.6.2 Atterberg Limits

The Atterberg Limit test is an empirical type test measuring the consistency of fine grained soils. Samples of a soil are mixed to a wide range of water contents and measurements of the water content are taken for ranges of the soil's consistency; 'liquid' or 'plastic'. Atterberg Limits consists of the liquid limit and the plastic limit, each representing a boundary or limit of water content that produces a different behaviour. Various tools and test equipment are used to conduct the Atterberg Limits test (see Figures 88 and 89).



(a) Liquid limit trial being performed; (b) details of liquid limit device; (c) soil thread being rolled to determine plastic limit.

Figure 87 - Atterberg Limits

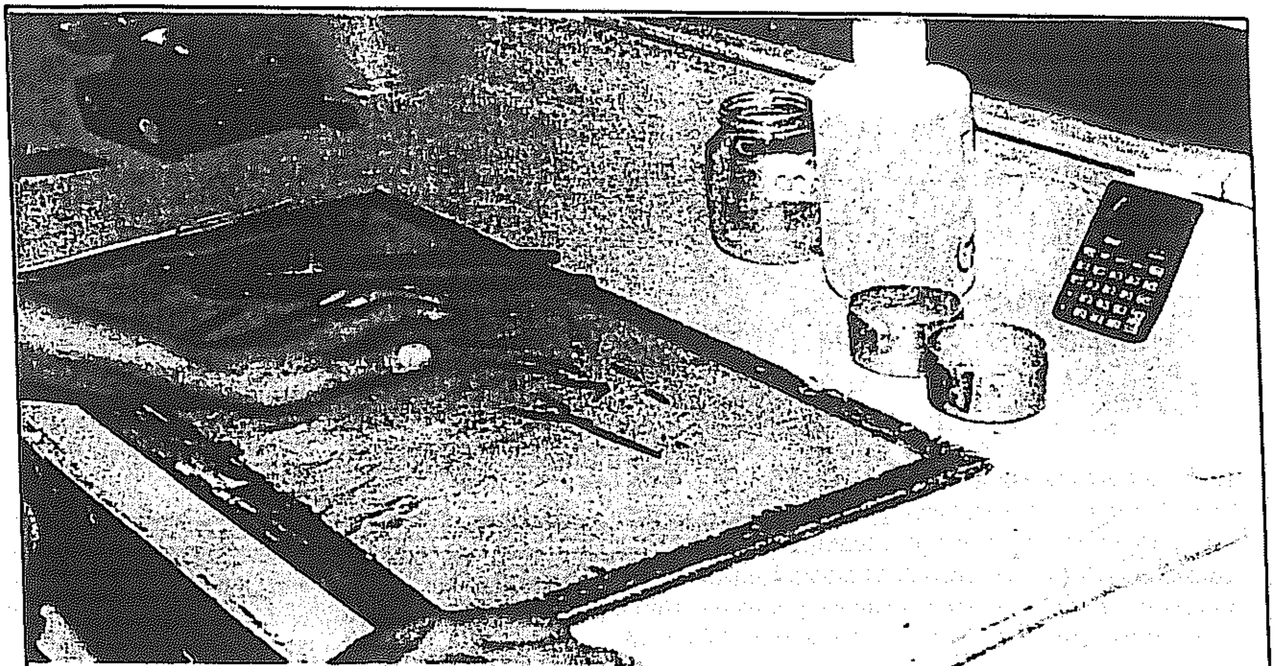


Figure 88 - Photo, Atterberg Limits

The following Table 9.3 describes the different behaviour for the different limits.

TABLE 9.3 - Consistency / Behaviour of Cohesive Soil

Stage	Description	Boundary or Limit
liquid	slurry, vicious liquid, pea soup to soft butter	
		liquid
plastic	deforms but will not crack, soft butter to stiff putty	
		plastic
semi solid	deforms permanently but cracks, cheese	
		shrinkage
solid	fails completely upon deformation, hard candy	

The liquid limit is defined as the water content at which a pre-shaped groove cut in a moist soil contained in a specifically shaped cup, closes after 25 taps on a hard rubber plate. The plastic limit is the water content at which the soil begins to break apart and crumble when rolled by hand into threads 3 mm in diameter. The shrinkage limit is the water content at which the soil reaches its theoretical minimum volume as it drys out from a saturated condition. The difference between the liquid and plastic limits is termed the plasticity index, which represents the range of water contents through which the soil is in a plastic state.

The Atterberg Limits serve as indexes to other significant properties of the soil which are useful. For example, the liquid limit has been found to be proportional to the compressibility of the soil.

The Atterberg Limits are relevant only to fine grained soils possessing cohesion (i.e. having a significant percentage of clay-size particles), and are most relevant to weaker cohesive soils, as opposed to very stiff to hard cohesive soils. Soil classifications have also been developed based on plasticity (see Figure 90).

Primary letter		Secondary letter	
G:	Gravel	W:	Well graded
S:	Sand	P:	Poorly graded
M:	Silt	M:	With non-plastic fines
C:	Clay	C:	With plastic fines
O:	Organic soil	L:	Of low plasticity (LL < 50)
Pt:	Peat	H:	Of high plasticity (LL > 50)

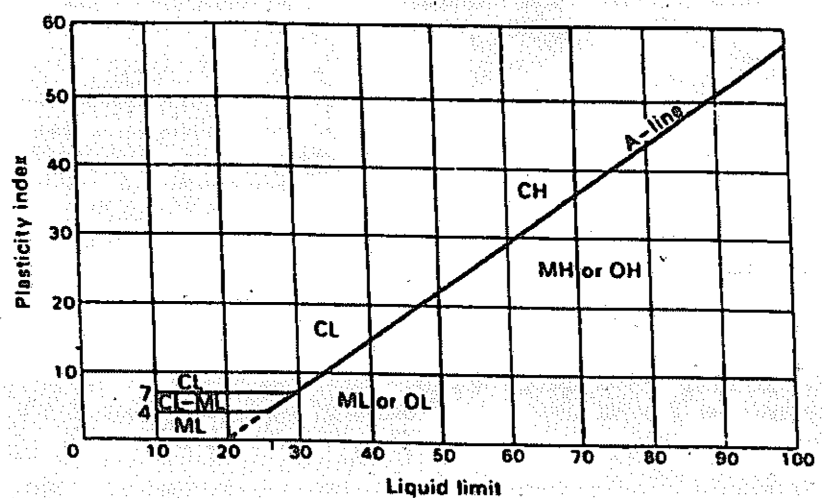


Figure 89 - Plasticity

9.6.3 Grain Size Analysis

There are 2 common methods of grain size analysis, depending on the range of the particle size being analyzed; these are mechanical sieve analysis and, hydrometer analysis.

Cohesionless soils, those being comprised of fine sand, sand, gravel, and coarser particle sizes, are commonly sieved mechanically, through a graduated series of sieves. Each sieve has a finer mesh than the one proceeding it (see Figures 91 and 92). The weight of the sample retained on each sieve is compared to the total weight as a percentage.

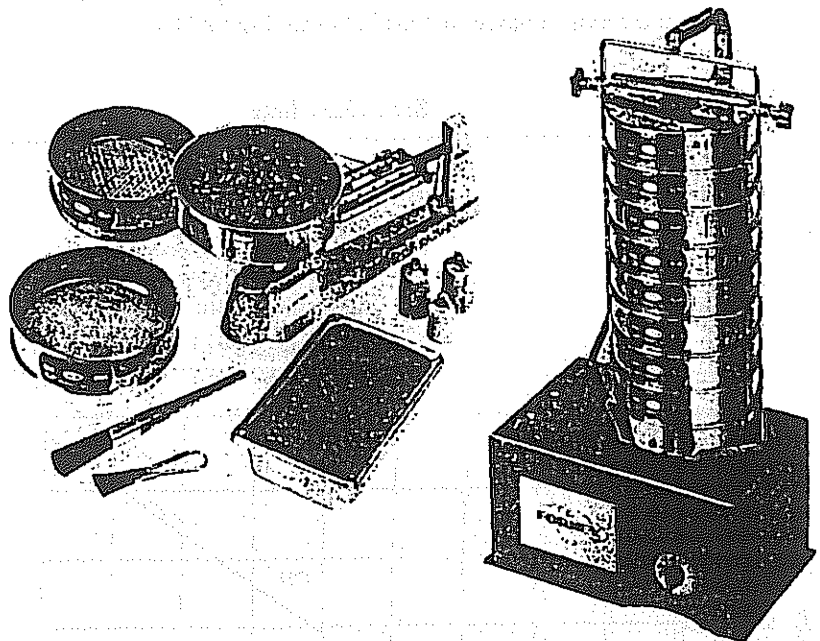


Figure 90 - Mechanical Sieves

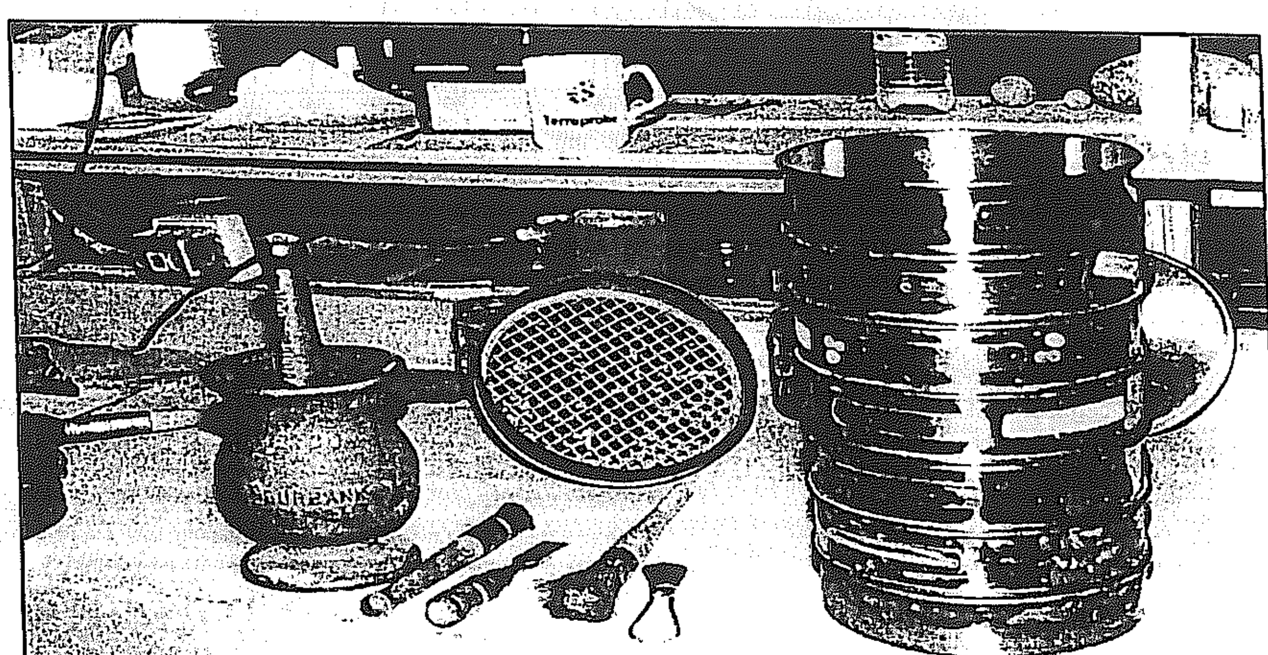


Figure 91 - Photo, Mechanical Sieves

Grain size distributions for fine grained soils (finer than fine sand) are analyzed through a sedimentation experiment. The sedimentation procedure is referred to as a hydrometer analysis.

In a hydrometer analysis, fine grained soil is first dried, and broken down to it's natural particle size. The fine powder is then saturated and treated with a chemical deflocculating agent which will break up clumps, or flocs, of fine soil particles, and keep individual soil particles separate.

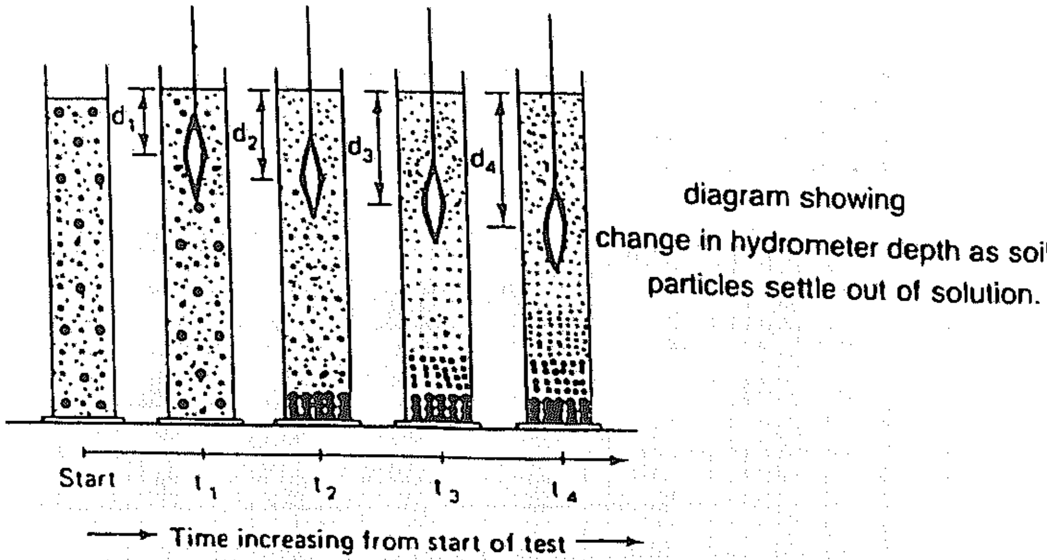


Figure 92 - Hydrometer Analysis

After treatment with the deflocculating agent, water is added to the sample to produce a fixed volume and the mixture is shaken into suspension thoroughly. The procedure is conducted using a glass cylinder, which is then set upright and a hydrometer is used to measure the density of the suspension (see Figures 93 and 94). Measurements of the suspension density, or specific gravity, are taken at time intervals which have been calibrated to various particle sizes falling through the water suspension. This permits similar calculation of weight of particle sizes as a percent of the total sample.

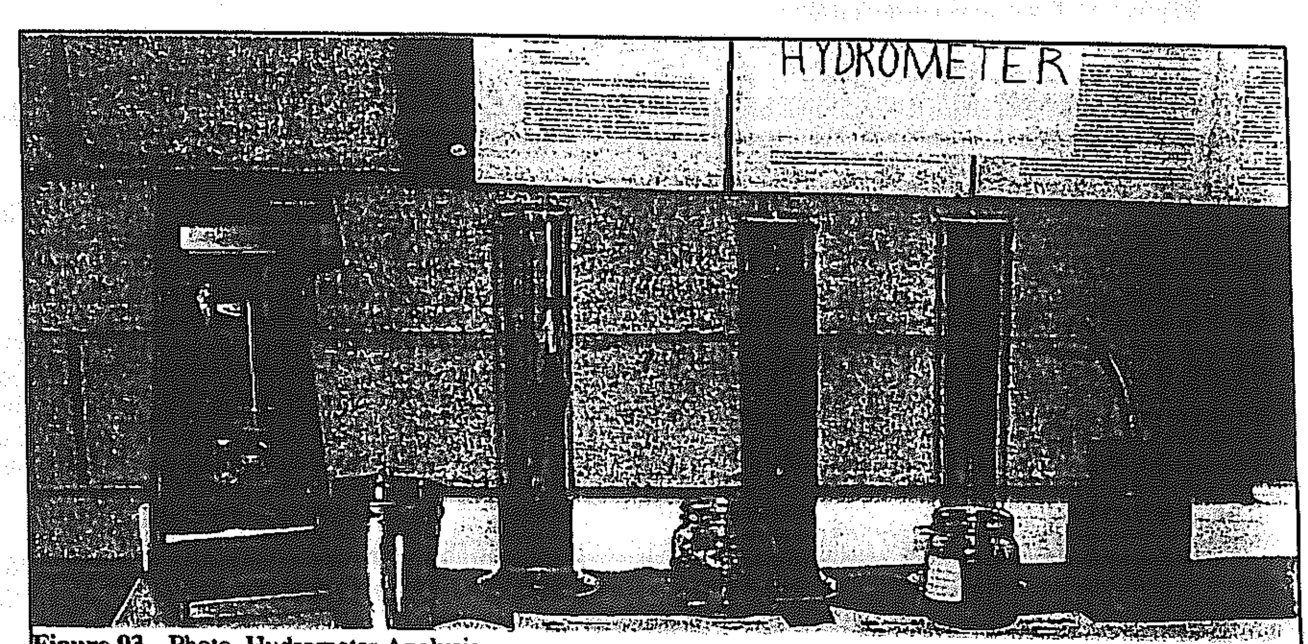


Figure 93 - Photo, Hydrometer Analysis

Both the sieve analysis and hydrometer analysis may be required for soil types that includes sand and gravel as well as silt and clay sizes. The grain size distribution is often plotted on a semi-log graph, represented by gradation curves of particle size versus percentage by weight of the total soil sample (see Figure 94).

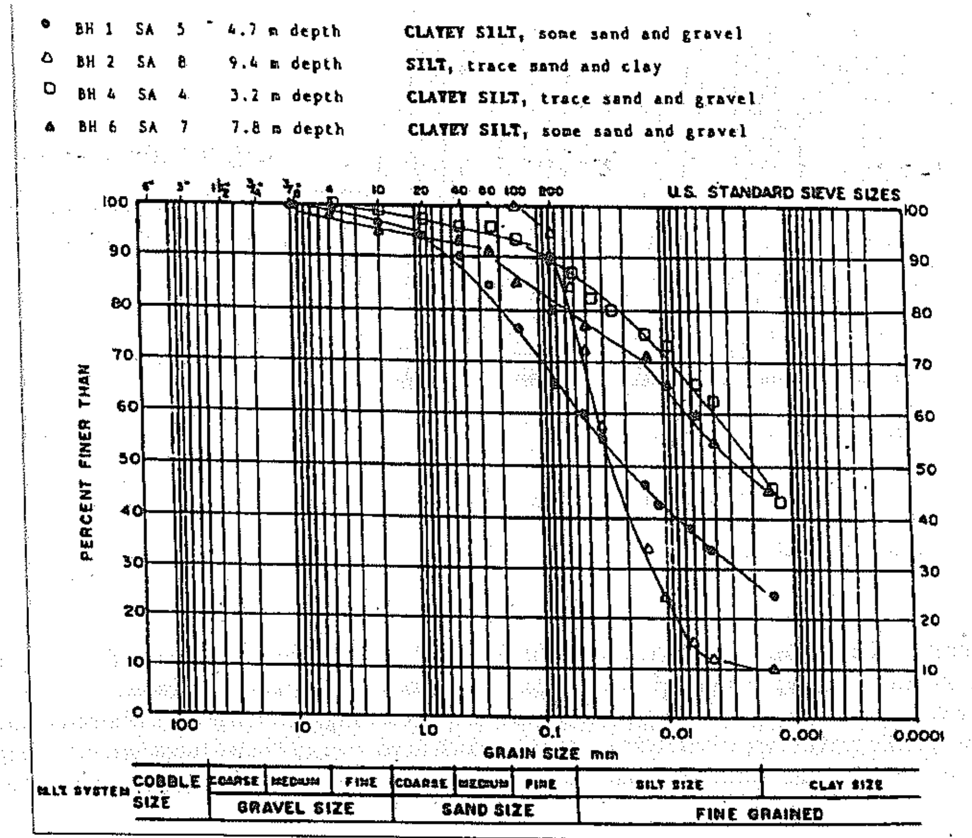


Figure 94 - Grain Size Gradation Graph

Grain size distributions may range from uniform (all of a similar particle size), to well graded (a range for various soil particle sizes), to gap graded, which is a combination of two or more uniform soil sizes.

The grain size distribution of a soil type helps to classify the soil and gives insight as to other properties of the soil such as permeability and density, as well as shear strength.

9.6.4 Soil Unit Weight

The soil unit weight is a direct measurement of the unit weight or density of the whole soil sample (soil particles, moisture, voids). This measurement is usually taken on uniformly shaped soil samples, either directly from split spoons or from shelby tubes samples obtained from boreholes. Samples are typically cylinder shaped, of a relatively constant diameter, and of different lengths. The unit weight can be measured directly by a physical measurement of the dimensions and weighing the sample and obtaining a unit weight, or by waterproofing the sample and weighing it in air and weighing it submerged in water to get a unit weight.

For most of the soil types, the range of unit weight is relatively narrow, between about 17 and 20 kN / m^3. The density will vary, partly dependant on the compactness or consistency of the soil mass, as well as the water content of the soil mass, and specific gravity of the individual soil particles.

9.6.5 Specific Gravity

The specific gravity test is a measurement of the unit weight or density of the individual soil particles rather than the aggregate soil mass. The individual particles are often made up of other minerals such as calcite and quartz. The specific gravity has been well established for various soil types, and has been found to be generally about 2.65 to 2.67 for cohesionless sandy type soils, and can vary from about 2.68 to 2.72 for clay mineral type soils.

9.6.6 Direct Shear Test

Direct shear tests are usually carried out on cohesionless soils, such as sands or silts. The tests are normally undertaken in dry conditions from dry samples and consists of placing and compacting the soil mass in thin layers into a square mould, placing a predetermined confining weight onto the sample, and measuring subsequent displacement. The mould is split in the centre so that it can be sheared along a constant plane, and measurements of the shearing resistance and deformation rate are obtained (see Figure 95).

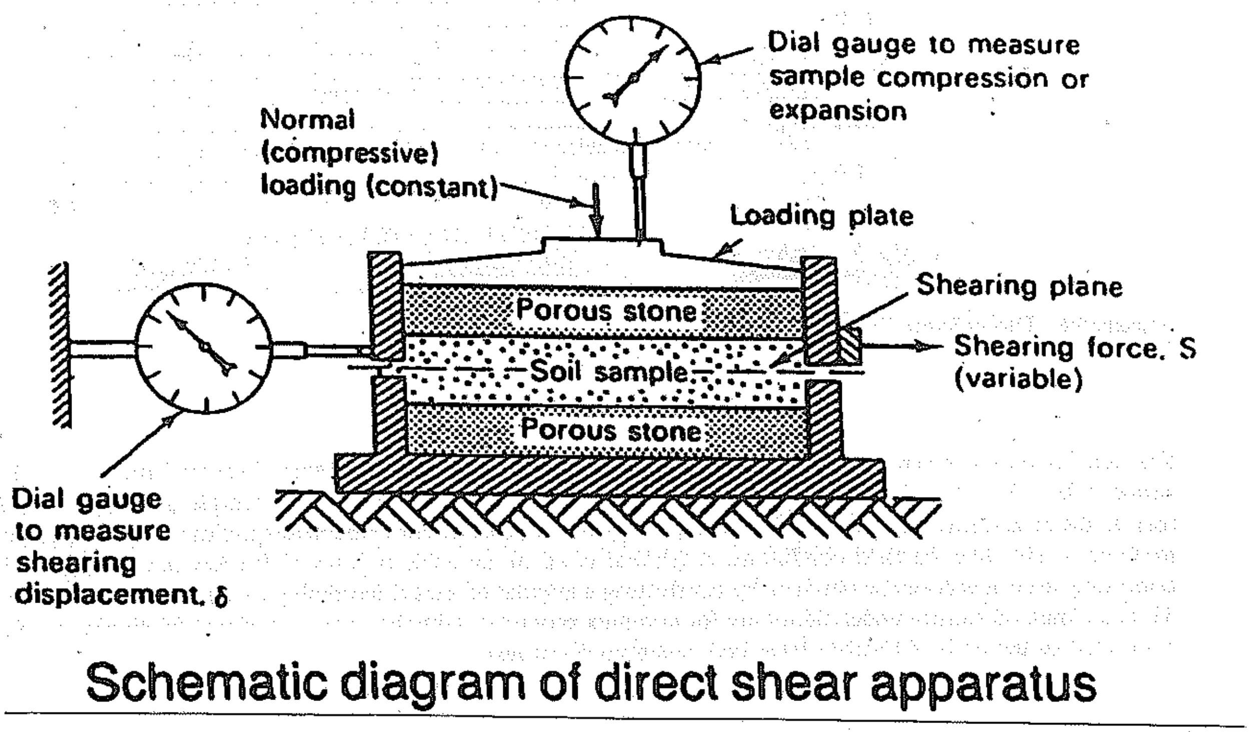


Figure 95 - Direct Shear Test

The test permits the testing of the shear stress at different levels of confining stress to obtain a straight line or slight curve referred to as a Mohr-Coulomb plot. This plot of shear stress versus confining stress, or normal effective stress, permits the direct measurement of the angle of internal friction phi, ϕ'.

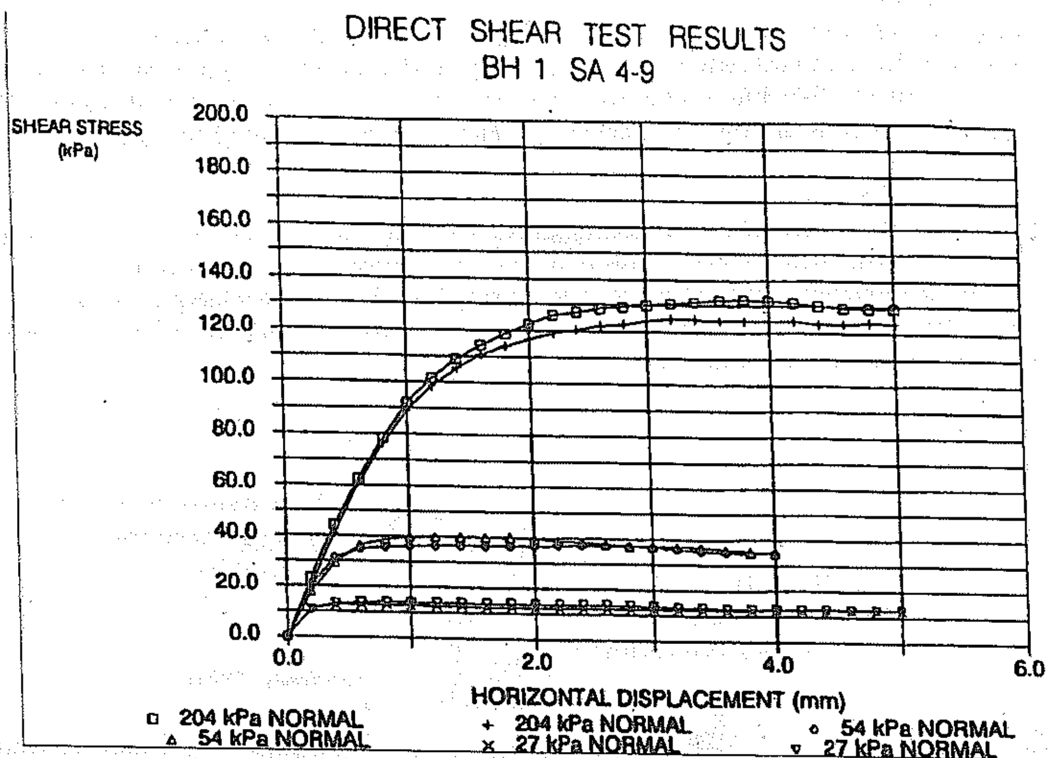
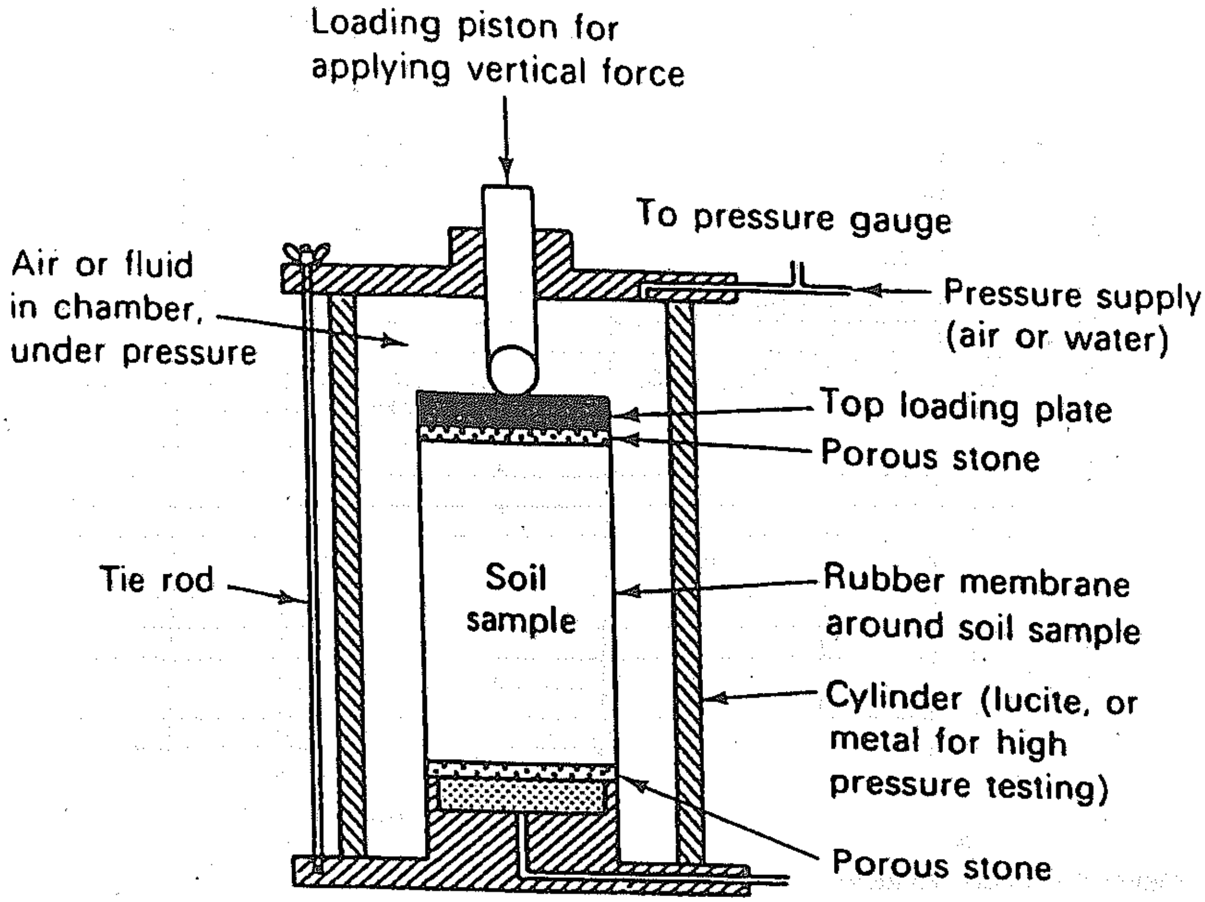


Figure 96 - Direct Shear Test Results

This test provides a general indication of the angle of internal friction for a soil type. In some instances, such as very dense soils, it is difficult to reproduce the level of density in the preparation of the sample during the test. For this reason, the measurement of the true friction angle may not be possible due to the inadequacies of the test equipment and methods to simulate the field conditions. A general trend of the angle of internal friction in the higher density or confining stress levels can be obtained by conducting a number of tests at increasing confining levels (see Figure 96). This test method usually undertaken only for complex problems, with the angle of internal friction more commonly estimated on the basis of borehole standard penetration test results.

9.6.7 Triaxial Compression Tests

The 'effective stress' shear strength parameters of ϕ' and c' for cohesive soils are commonly measured in the triaxial apparatus. The triaxial test is conducted on relatively undisturbed soil samples obtained from the field using thin walled Shelby tubes. This limits the triaxial testing to soils which can be sampled using Shelby tubes. Only firm to stiff or softer cohesive soils can be tested. Very stiff to hard consistency soils can not be sampled using shelby tubes due to their dense nature.



Schematic diagram of triaxial compression test apparatus

Figure 97 - Triaxial Test Apparatus

Properties for very stiff to hard soil types are often estimated on the basis of standard penetration test results or on previous triaxial testing on soils of a softer or less dense consistency.

The test consists of the extrusion of a cylindrical shaped sample from a Shelby Tube, and enveloping the sample with a rubber membrane. Permeable platens are placed at each end of the sample, to permit pore water drainage, and the application of loads to the sample. The entire sample with rubber membrane and platens (see Figure 97) is placed in a plastic cell which can be filled with fluid to apply a confining pressure to the entire sample during axial loading.

This configuration permits the saturation of samples which are not fully saturated. Saturation is required to simulate the weakest possible soil strengths. This test also permits the measurement of pore water pressure so that the drained values for shear strength and internal friction can be measured. The triaxial test can typically take several days to complete, while the direct shear test can usually be completed in one day (see Figure 98).

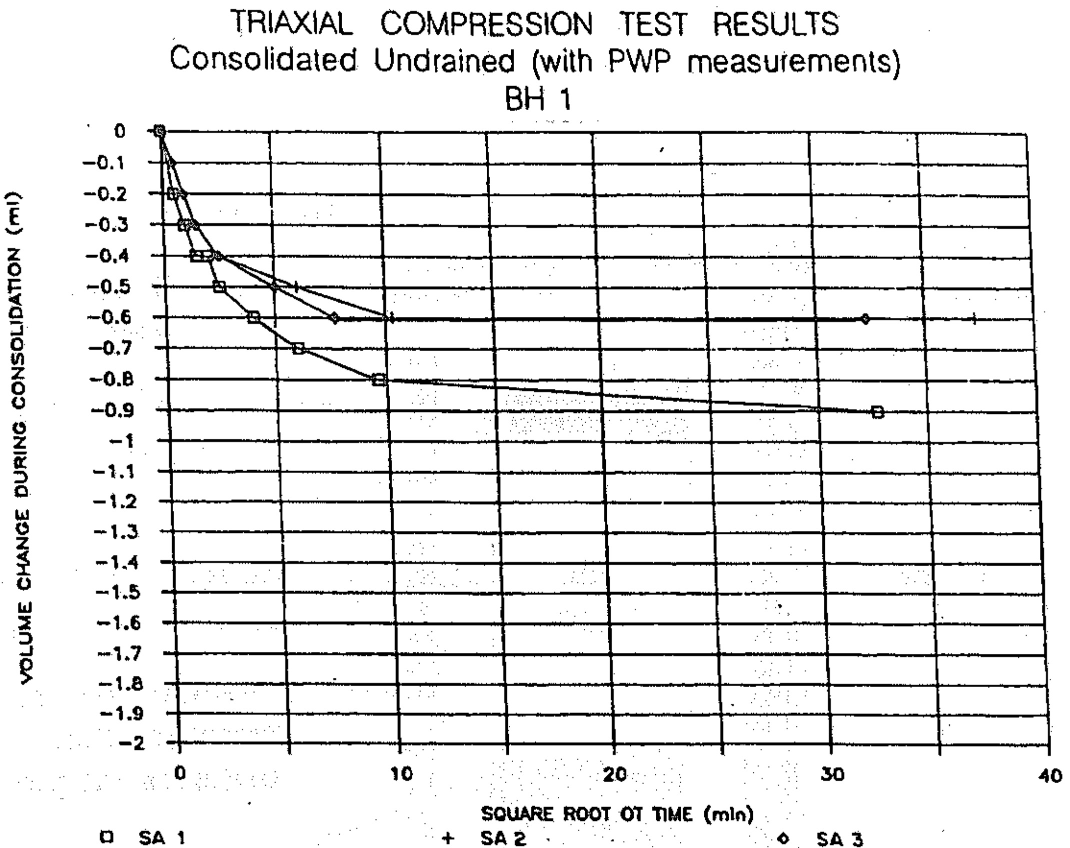


Figure 98 - Triaxial Test Results

9.7 Engineering Analysis

The engineering analysis should be conducted with a recognized method (Bishop's, Janbu, Morgenstern-Price, Spencer, Sarma) in accordance with the guidelines provided in the previous Section 6. The geotechnical report should provide details on the analysis method, the model basis and all assumptions made, and the extent of calculations with an overall summary. Both in the report text and on suitable figures or drawings the following basic information and discussion should be provided,

a) slope height, slope inclination,

b) location of structures near slope,

c) assessment of erosion risks,

d) soil stratigraphy and strength,

e) groundwater conditions and drainage,

f) vegetation cover and species,

g) Factor of Safety calculations,

h) potential causes of instability,

i) alternative slope stabilization methods, and comparison of benefits,

j) discussion of erosion on or near the site; locations, extent, severity, rates, suitable protection alternatives

k) discussion of potential impacts on surrounding properties

l) if required, discussion of cost-benefit analysis of stabilization measures including:

- 'do nothing'
- partial stabilization
- full stabilization

m) long-term stable slope crest position and inclination, based on engineering analysis.

Following is a suggested outline for Terms of Reference as seen in Figure 99 for a detailed geotechnical investigation and report on slope stability (Level 3).

SLOPE STABILITY STUDY
GEOTECHNICAL TERMS OF REFERENCE

TABLE OF CONTENTS

1. PURPOSE

The purpose of the slope stability study for (site location): ________________ is to review and determine the long term stable slope inclination and slope crest position for the section of slope along the (river /lake /pit). The study will also evaluate various alternative stabilization measures which should be considered by the proponent. The study will collect and review existing available information for the existing slope conditions as well as analyzes the proposed changes in land use and long term conditions in the slope area.

The study will review, update, and expand the factual information data base as to the causes, effects, extent and associated hazard in connection with erosion or slope instability along the study area. As well as reviewing various alternative solutions, the study will recommend a optimum solution and will develop a final design for stabilization and protection of the sloped areas.

2. STUDY AREA LOCATION

The study area is located:

The slope area to be considered has a length of about m and the condition and land use on neighbouring properties should also be considered (see Figure for location).

3. BACKGROUND

The study area is comprised primarily of (residential neighbourhood/industrial land/park) and is located along . Based on existing information, the site area has been subject to past erosion or slope instability.

4. SCOPE OF WORK

The study should be carried out as three general sections,

1. A geotechnical site investigation.
2. Engineering analysis and Preliminary design.
3. Recommended stabilization works and final design recommendations.

4.1 Geotechnical Site Investigation

This section of the study includes the following:

a. Review existing air photography for the site as well as any previous reports or mapping carried out in the site vicinity.

Figure 99 - Geotechnical Terms of Reference

b. Conduct field mapping of the existing conditions of the slope area and record for reporting the general slope conditions including height, inclination, seepage, vegetation, bare areas, structures, erosion features, filling, and any visible stratigraphy. Evaluate any indicators of slope movement including scarps, tilted structures or trees or irregular topography. Evaluate surface drainage conditions.

c. Boreholes should be drilled from near the slope crest to the full depth to the bottom of the slope. At least one borehole should be drilled for small sites and boreholes should be spaced at about 100 m along the slope or closer if site conditions require. The boreholes should include sampling at depth intervals of not more than 1.5 m. The sampling should consist of Standard Penetration Tests or Shelby Tubes if appropriate including field vanes. On completion of drilling and sampling of the boreholes, one or more piezometers should be installed in the borehole and backfilled to permit monitoring of ground water levels at various depths within the borehole. Bentonite clay seal should be provided near the ground surface to prevent excessive infiltration into the piezometer installation. Protective caps and concrete may be adviseable at the ground surface to protect against vandalism. The horizontal location and the vertical elevation of the ground surface at the borehole locations shall be surveyed. Where possible and if accessible several shallow hand auger probes should be put down through the slope face to confirm shallow soil conditions on the slope face as well as along the slope toe.

d. The borehole samples shall be tested in a GEOTECHNICAL laboratory for basic index properties as well as any additional appropriate tests. These will include water content, Atterberg Limits, grain size distribution, unconfined compressive strength, direct shear tests, over triaxial compression test.

e. Several representative slope cross sections should be surveyed to accurately determine the slope profile; inclination and height. On a site plan of the study area, a report of the surveyed slope inclinations and height shall be summarized along with the results of the visual mapping carried out including vegetation cover, bare areas, erosion or slope instability features, structures, slope inclinations, seepage, drainage and borehole locations.

f. Prepare detailed borehole logs summarizing the soil stratigraphy, field test data, laboratory test data, piezometer installation, ground water levels, site plans and profiles showing slope crest position, slope toe position and ground water levels.

4.2 Geotechnical Laboratory Testing

Promptly after transportation of the borehole samples (jars and shelby tubes) to the geotechnical laboratory, a testing schedule shall be prepared. Water contents shall be measured for all samples. Representative samples shall be tested for basic index properties;

- grain size distribution
- Atterberg Limits, if cohesive
- unit weight
- specific gravity

Figure 100 - Geotechnical Terms of Reference

- Direct Shear Test, if cohesive
- Triaxial Compression, Consolidated Undrained with Porewater Pressure Measurements; for undisturbed cohesive soils, stiff or softer consistency.

4.3 Section 1 - Engineering Analysis and Preliminary Design

In this section an engineering analysis should be carried out of the existing Factor of Safety as well as the Factor of Safety for different stages of the proposed development or work including short term stability and long term stability. An accepted slope stability analysis method shall be used and details should be provided of the basis, and assumptions, and background for the method. Engineering analysis of slope stability shall include incorporation of the information from mapping, surveying, borehole drilling, laboratory testing, and previous available information, and ground water monitoring. The various special information will be used to model or simulate the site conditions on which to carry out calculate Factor of Safety and sensitivity analysis to the different factors.

The analysis shall be carried out to determine the minimum Factors of Safety for existing conditions, as well as conditions in the long term, and the minimum Factors of Safety for possible alternatives or solutions for stabilization. Other external factors should also be considered such as potential for erosion or other phenomena. The study should include consideration of various levels of solution including the following options,

a) Do nothing and allow for self stabilization to occur by the slope and environmental factors,

b) Two partial stabilization to reduce or minimize the amount of addition future slope movement,

c) Or be full stabilization to preserve and protect existing conditions and minimize loss of property.

Various types or methods can be used in consideration in either of the above three options or solutions. For each consideration prepare and present a rough concept sketch or drawing and short description of the method and benefits. The report to be prepared at this stage of all the findings and considerations of alternatives and solution shall include description of the site conditions, mapping of field work conducted, the results of the field work, description of the soil stratigraphy and soil types, ground water levels, laboratory tests, results and surveying information and summary of previous available information. The model for slope stability analysis should be presented on a diagram as well as discussed and the results of the Factor of Safety calculation shall be presented in table form and discussed as well. The discussion should include the Factor of Safety for all conditions including temporary short term conditions, existing conditions, construction conditions, and long term conditions. The site conditions and analysis results shall be shown on site plans and profiles.

The final report will also include comments and recommendations for construction procedure including possible set backs or erosion protection. The engineering analysis should also include consideration for construction accessibility, aesthetics, environmental impacts, future maintenance, MNR Policy, safety. The final report will also discuss the potential failure mechanism or failure modes as well as the extent of susceptible areas. Hazard consideration to existing buildings dwelling or structures should be clearly be identified as well as criteria for risk assessment.

Figure 100 Geotechnical Terms of Reference Continued

9.8 Long Term Monitoring

For site conditions where safety may be critical and ground movements sensitive, long-term monitoring may be appropriate to assist in warning of dangerous ground movements. Instrumentation can be installed to permit monitoring of slope (ground) movements. This monitoring can be undertaken by measuring the horizontal position of surface features on or near a slope, with respect to bench marks or datum points that are located well outside the possible areas of movement. This can be accomplished by tape measurements or optical survey instruments such as electronic distance measurements (EDM) and lasers.

As well, tilt meters can be used to detect tilt or rotation of fixed points. These tilt meters are usually utilized in rock slope environments.

Monitoring of ground movements can assist in accurately defining the actual mode of failure, thereby permitting the most appropriate modelling for analysis and design of stabilization. Further, it is common that very small ground movements precede larger movements (i.e., tension cracks, bulging, creep, etc.) and therefore monitoring may provide a means of warning of a larger ground movement. This warning may allow evacuation or stabilization prior to a catastrophe. Slope inclinometers are commonly used for the monitoring of slope movements.

Slope inclinometers consist of the installation of a grooved casing in a borehole, to permit the insertion of an electronic probe that can measure small changes in inclination of the casing. They are regularly used to monitor the performance of slopes, retaining walls, sheet piling and shoring (see Figure 101).

Should ground movements occur, they would cause tilting or deformation of the casing, that can be measured by the sensor probe. Successive measurements over time permits the detection of even small ground movements around the casing. The casing is available in aluminium or plastic and is grouted into the borehole at the completion of drilling.

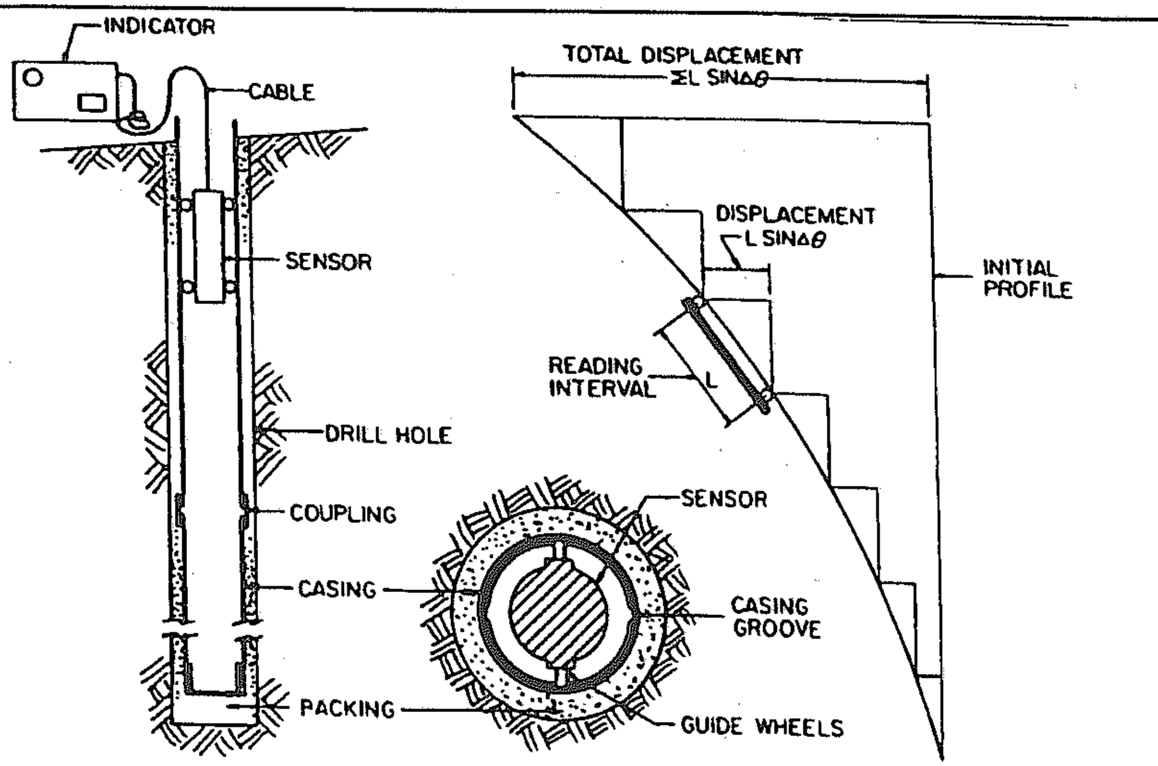


Figure 101 - Slope Inclinometer

8. SUGGESTED LEVEL OF GEOTECHNICAL INVESTIGATION REQUIRED TO ASSESS SLOPE STABILITY

The following section describes the reasoning and basis for a suggested method of site evaluation to assist regulating agencies within MNR in determining the level of geotechnical investigation required to assess slope stability. In all cases, the responsibility for providing the geotechnical investigation is that of the proponent who might be a land developer, a pit operator, or a government agency. Part of the proposed development may be located close to a slope crest and there may be concerns about risks of ground loss in the event of a slope slide.

The level of geotechnical investigation required to determine the stability of a slope involves an understanding of:

- the physical and hydrological site conditions
- the type of development or land-use proposed, which may be put at risk.

8.1 Physical and Hydrological Site Conditions

Slope stability analysis and the calculation of Factors of Safety, requires certain basic information that can be determined in several manners or can be estimated with reasonable accuracy;

a) the slope configuration; height and inclination or shape. These can be estimated visually, or determined from topographic mapping, or measured by on-site survey of slope cross-sections (profiles).

b) the subsurface conditions within the slope; soil stratigraphy (types and layering), soil strengths (density and shear strength), groundwater levels. These can be determined in a general manner by visual inspection of exposed soil on the slope, or on the basis of geologic mapping. More specific information can be obtained by drilling boreholes (unlimited depth), or digging test pits (max. depth 3 to 5 m), or hand auger holes (max. 1 to 2 m depth).

c) any external loadings to the slope; structures, traffic, earthquakes,

d) site drainage and erosion conditions; surface run-off, ditches, channels, seepage, creeks, rivers, lakes,

e) vegetation cover.

The decision to use simple investigation (based on site inspection only) versus a detailed investigation (including boreholes, surveys or mapping) depends mostly on

- the slope height
- the consequence of slope failure on the adjacent land-use.

8.2 Suggested Procedure To Determine The Level of Investigation Required

To assist in determining the suggested level of investigation required, a "Slope Stability Rating Chart" is provided. This Rating Chart can used by either those reviewing proposals or by a proponent, however a site visit is required to complete the Chart. The Rating Chart must be completed for all slope assessments and be retained by the reviewer. The Rating Chart has 7 components that together provide a reasonable assessment of the slope stability. Some calibration may be required of the values in the chart, on the basis of extensive experience with its use. The 7 components are;

1. **Slope Inclination**
   - The angle from the horizontal of the slope face, measured from the toe to the crest. If the slope is comprised of several different inclinations, provide details on each. Estimate visually, or use hand inclinometer to measure approximate inclination, or survey (also refer to available mapping).

2. **Soil Stratigraphy**
   - Soil layering and soil types composing the slope. Confirm if visible in bare exposed areas. Refer to previous nearby boreholes or well established local geology. If several soil layers are present, provide details on each.

3. **Seepage from Slope Face**
   - The quantity and location of groundwater on the slope face. Visually inspect slope for surface seepage (springs, streams, creeks).

4. **Slope Height**
   - Measurement of the vertical height between the toe (bottom) and the crest (top) of the slope. Estimate visually, or measure by surveying, or refer to available mapping.

5. **Vegetation Cover on Slope Face**
   - Indication of the type and extent of vegetation cover (trees, grass).

6. **Table Land Drainage and Gullies**
   - Indication of surface infiltration and run-off over the slope face, which may cause a potential for surface erosion. Describe whether table land drains towards slope and whether drainage/erosion features are present.

7. **Previous Landslide History**
   - Indicates past instability. Visually inspect slope for evidence or indicators of past instability (scarps, tension cracks, slumped ground, bent or bowed or dead trees, leaning structures such as walls etc.).

Toe Erosion

- Recognizes the presence of and potential for continued slope instability. Toe erosion must be eliminated or solved prior to solving slope instability.

The Rating Chart provides a general indication of the stability of a slope. Based on this chart, the level of investigation required, can be assessed. The chart is a guideline or tool only. In all cases, the consequences of slope failure must be carefully considered and may be an over-riding factor. The chart is not intended as a replacement to the judgement of experienced and qualified geotechnical engineers.

The Rating Chart identifies 3 levels of stability and associated investigation requirements. The three levels are:

1. Stable / Site Inspection Only

A rating of 24 or less, suggests stable slope conditions,

- no toe erosion,
- good vegetation cover
- no evidence of past instability
- no structures within ½ (slope height) of the crest

and that no further investigation (beyond visual inspection) is needed. This should be simply confirmed through a visual site inspection and estimate of the slope configuration and slope stratigraphy and drainage (i.e. no measurements). Confirmation of the slope stability should be provided in the form of a letter (signed and sealed with A.P.E.O. stamp) from an experienced and qualified geotechnical engineer. The letter should include a summary of the site inspection observations which could be recorded on a Slope Inspection Form (see enclosed) and should clearly identify;

- slope height and inclination,
- vegetation cover on slope face,
- toe erosion, or surface erosion on slope,
- structures near slope crest or on slope,
- drainage features near slope crest, on slope face, or near slope toe.

2. Slight Potential / Site Inspection, Preliminary Study

A rating between 25-35 suggests the presence of several surface features that could create an unstable slope situation. The stability of the slope should be confirmed through a visual site inspection only, without boreholes. In addition to recording the visual observations outlined in the section above, some direct measurements of site features are required.

The slope height and inclination should be determined either with a hand inclinometer, or by 'breaking slope', or from mapping, or by surveying. As well, more information about the soil stratigraphy of the slope, should be obtained (without drilling boreholes) based on either previous or nearby subsurface investigations, or geologic mapping, or hand augering or test pits to determine shallow depth soil type(s). Measurements should be taken (by hand tape or surveying) of the locations of structures relative to the crest, and other features such as vegetation, past slide features (tension cracks, scarps, slumps, bulges, ridges), and erosion features. If available, historical air photographs should be examined for evidence of any past instability over the long-term. Confirmation of the slope stability should be provided in the form of a detailed report (signed and sealed with A.P.E.O. stamp) from an experienced and qualified geotechnical engineer.

This report will include:

- Slope Inspection Record (Appendix)
- a Site Plan and a Slope Profile indicating the positions of the various measurements taken on site (slope crest, slope toe, location of structures relative to crest, drainage features, erosion features, vegetation cover, indicators of past instability or movements)
- photographs of the site and slope conditions
- a discussion of the site inspection and measurements taken, review of previous information
- preliminary engineering analysis of slope stability (i.e. calculation of Factor of Safety) based on the above information and measurements, but utilizing conservative soil strength parameters and groundwater conditions since boreholes were not carried out.

3. Moderate Potential / Borehole Investigation

A rating of more than 35 suggests a moderate potential for instability. This may result if the slope is either steep, high and/or has several features that could create an unstable slope situation. The stability of the slope should be assessed more precisely through topographic survey of slope configuration and boreholes for slope stratigraphy and penetration resistance tests. Piezometers must be installed in the boreholes and measurements must be taken for groundwater levels. Laboratory testing on the borehole samples must be conducted to measure Basic Index Properties (water contents, unit weights, grain size distribution, Atterberg Limits) described in Appendix D, or other properties as required.

A detailed engineering stability analysis must be conducted to determine if the Factor of Safety for the original slope conditions equals or exceeds a design minimum Factor of Safety. The analysis should be based on the information obtained from the site survey and the borehole information. Historical data such as air photographs should also be reviewed. Confirmation of the slope stability or instability (and the stable slope inclination) should be provided in the form of a detailed report (signed and sealed with A.P.E.O. stamp) from an experienced and qualified geotechnical engineer. This report will include:

- Slope Inspection Record (Appendix)

- a Site Plan and a Slope Profile indicating the positions of the various measurements taken on site (slope crest, slope toe, location of structures relative to crest, drainage features, erosion features, vegetation cover, indicators of past instability or movements)
- photographs of the site and slope conditions
- a discussion of the site inspection and measurements taken, review of previous information
- Borehole logs and piezometer monitoring data
- Laboratory test results (water contents, unit weights, grain size distribution, Atterberg Limits)
- the results of the detailed engineering Stability Analysis (Factors of Safety, failure surfaces, assumed slope data), stabilization alternatives, long-term stable slope inclination.

Where the local geology is well known (exposed stratigraphy or nearby boreholes), the requirement for numbers or depths of boreholes should be reviewed and possibly reduced.

Following is the Slope Stability Rating Chart (see Table 8.1).

TABLE 8.1 - SLOPE STABILITY RATING CHART

Site Location:
Property Owner:
Inspected By:
File No.
Inspection Date:
Weather:

			Rating Value
1.	**SLOPE INCLINATION**		
	degrees	**horiz. : vert.**	
a)	18 or less	3 : 1 or flatter	0
b)	18 - 26	2 : 1 to more than 3 : 1	6
c)	more than 26	steeper than 2 : 1	16
2.	**SOIL STRATIGRAPHY**		
a)	Shale, Limestone, Granite (Bedrock)		0
b)	Sand, Gravel		6
c)	Glacial Till		9
d)	Clay, Silt		12
e)	Fill		16
f)	Leda Clay		24
3.	**SEEPAGE FROM SLOPE FACE**		
a)	None or Near bottom only		0
b)	Near mid-slope only		6
c)	Near crest only or, From several levels		12
4.	**SLOPE HEIGHT**		
a)	2 m or less		0
b)	2.1 to 5 m		2
c)	5.1 to 10 m		4
d)	more than 10 m		8
5.	**VEGETATION COVER ON SLOPE FACE**		
a)	Well vegetated; heavy shrubs or forested with mature trees		0
b)	Light vegetation; Mostly grass, weeds, occasional trees, shrubs		4
c)	No vegetation, bare		8
6.	**TABLE LAND DRAINAGE**		
a)	Table land flat, no apparent drainage over slope		0
b)	Minor drainage over slope, no active erosion		2
c)	Drainage over slope, active erosion, gullies		4
7.	**PROXIMITY OF WATERCOURSE TO SLOPE TOE**		
a)	15 metres or more from slope toe		0
b)	Less than 15 metres from slope toe		6
8.	**PREVIOUS LANDSLIDE ACTIVITY**		
a)	No		0
b)	Yes		6

	SLOPE INSTABILITY RATING	RATING VALUES TOTAL	INVESTIGATION REQUIREMENTS	TOTAL
1.	Low potential	< 24	Site inspection only, confirmation, report letter.	
2.	Slight potential	25-35	Site inspection and surveying, preliminary study, detailed report.	
3.	Moderate potential	> 35	Boreholes, piezometers, lab tests, surveying, detailed report.	

NOTES:
a) Choose only one from each category; compare total rating value with above requirements.
b) If there is a water body (stream, creek, river, pond, bay, lake) at the slope toe; the potential for toe erosion and undercutting should be evaluated in detail and, protection provided if required.

8.3 Levels of Investigation

If a site slope is higher than 2 m and steeper than 3 to 1 (horiz. to vert.), an assessment of slope stability is warranted. Three basic levels of investigation have been identified, to be used in evaluating slope stability of sites. The Slope Rating Chart above is an aid to determine the appropriate level of investigation for a site, based on the physical features of the site slopes which are important to slope stability (height, inclination, groundwater, etc.).

The results of carrying out a Level 1 or Level 2 investigation may be that a Level 3 investigation is required. In general terms, the levels of investigation have been chosen on a basic premise that low height or gentle slopes can be analyzed sufficiently by general or observational methods, and that as slopes become higher and steeper more rigorous and intensive methods are required. The amount of field investigation increases with each level as follows,

Level 1 - site visit and inspection by engineer

Level 2 - site visit and inspection, mapping and site survey/measurements of physical features

Level 3 - site visit/inspection, mapping/surveying, borehole drilling.

For purposes of comparison only, the approximate engineering fees (1998 $Cdn.) for evaluating a single house lot on a slope site is estimated as follows;

Level 1	$ 500 - 1000
Level 2	$ 1,000 - 2,000
Level 3	$ 2,500 - 10,000 and up.

Some complex site conditions may result in higher costs for investigation than indicated above.

The following flow chart (see Figure 79) shows the typical steps that are taken in selecting an appropriate level of investigation for slope stability.

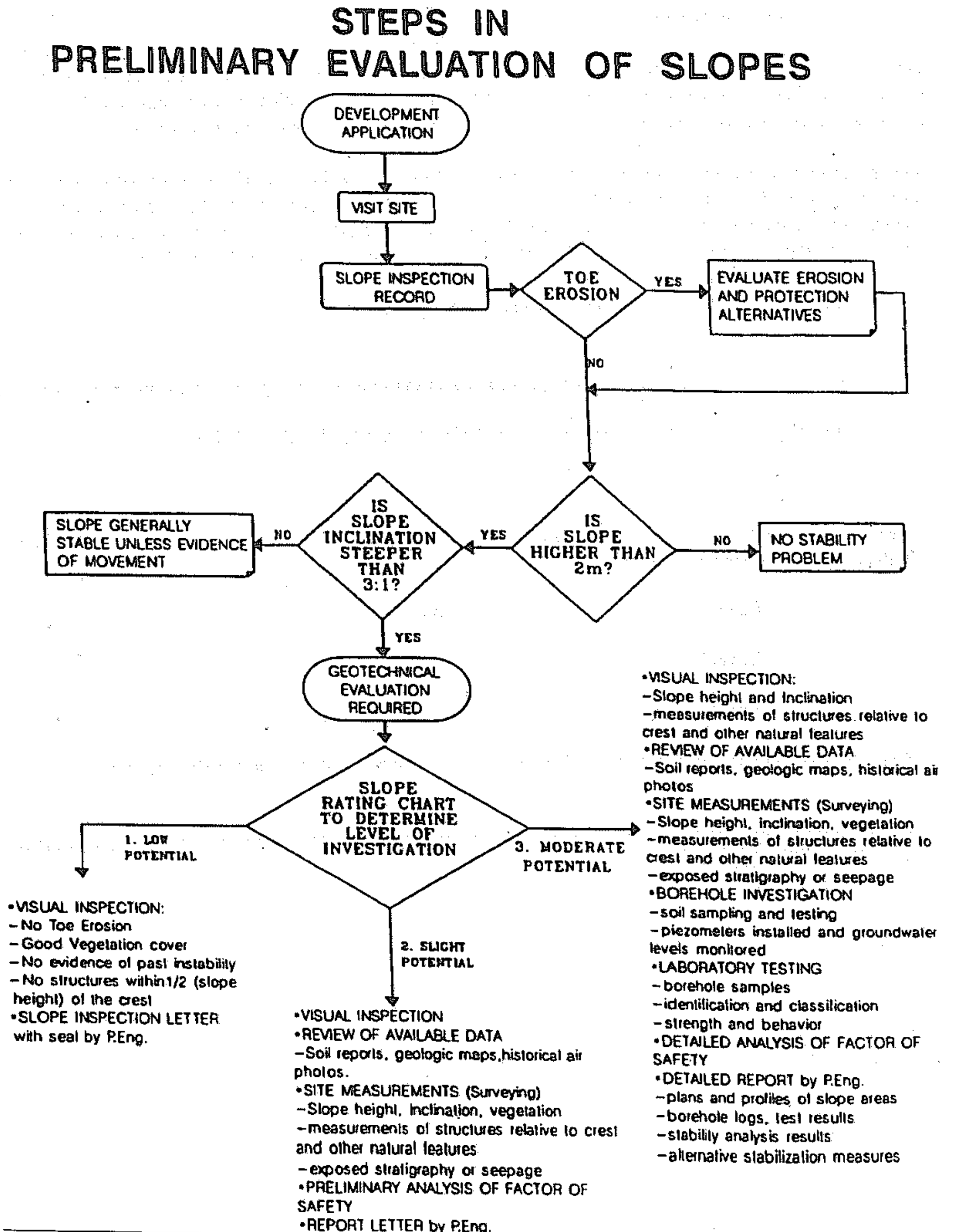


Figure 78 - Preliminary Evaluation Steps