What is soil plasticity? How does it allow you to prevent slope failures?

Hardy Bartle

Inexpensive management of surface water could have prevented the slope failures illustrated in Figure 1. The slides occurred upon a creek escarpment on the east coast of Graham Island, Queen Charlotte Forest District. Since it was harvested in the early 1990's this escarpment has produced an estimated 50 landslides, from 20 slide zones. Slope stability investigations have revealed that the escarpment is composed of medium plastic till. The till is among the most plastic (clay-like) of the soils a forestry worker can reasonably expect to encounter along coastal British Columbia. Inexpensive management of surface water would have prevented the worst of the slope failures upon the escarpment. Had the rock quarries in Figure 2 been built to be free draining, the slides in Figure 1 should not have occurred.

Preventing landslides upon such terrain is simple and cost effective. Forestry workers need to:

- know how to detect similar soils (Figures 3 to 7),
- be aware of the slope stability significance of their observations (see below), and
- take appropriate remedial actions.

Once similar soils have been detected, the measures outlined below will prevent most landslides on clay-like terrain:

- ensure ditches and rock quarries are free draining,
- conduct wet season road inspections to detect, and remedy in a timely manner any seasonal areas of water ponding or concentrated natural slope drainage,
- be generous with cross drains, culverts, and cross ditches when building or deactivating road in similar terrain,

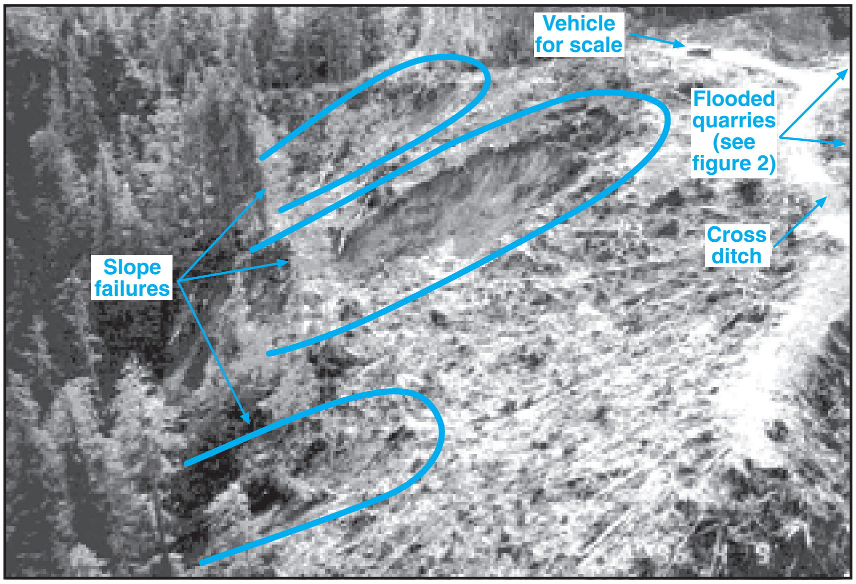

Figure 1. Large slope failures in a plastic or clay-like till. Notice the flooded quarries and cross ditch above the slide headwalls that chronically moistened and softened the clay-like soil.

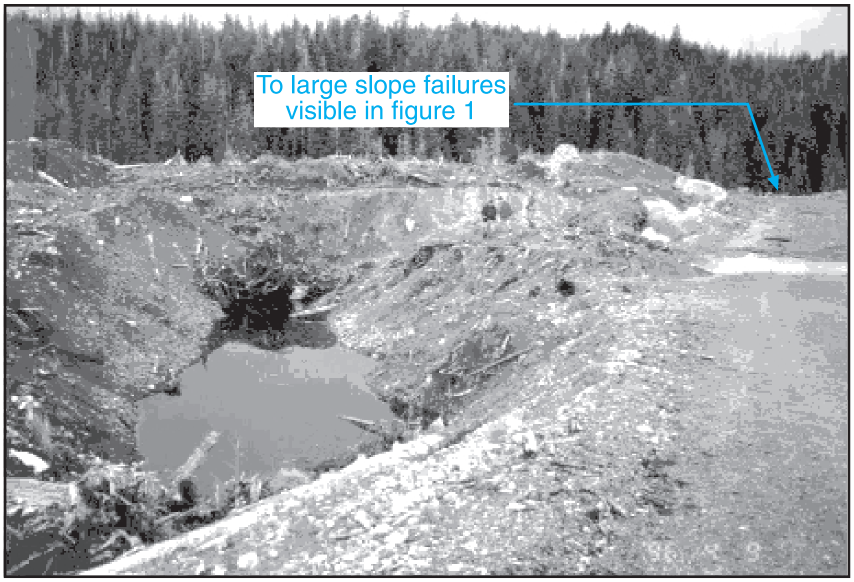

Figure 2. Flooded quarry above headwall of largest slide visible in figure 1. Immediately to the right of this photograph there was a second flooded quarry (see figure 1).

- build height of land or 'ridge top' roadways to minimize road induced disturbance of natural slope drainage,
- deactivate roads upon similar terrain in a timely manner. Pay special care and attention to conservation of natural slope drainage when working in clay-like soils, and
- ensure that skidder and back spar trails do not inadvertently concentrate surface water.

Such measures are inexpensive, effective landslide mitigation techniques.

The balance of this paper elaborates upon the principles, technical issues and soil assessment procedures summarized above.

What is soil plasticity?

Soil plasticity is an engineering concept borrowed from the pottery industry about a hundred years ago (Holtz, R.D. et al. 1981). Plasticity testing enables inexpensive identification of the:

- least stable and water tolerant of the fine-grained soils and
- somewhat more stable and water tolerant, silty soils. Silty soils may be fine grained but do not exhibit clay-like behaviour.

The engineering community's interest in plasticity testing was driven by the timeless observation that some fine-grained soils lose and subsequently regain approximately 99% of their inherent shear resistance to sliding as they absorb or lose water (Carter, M. 1991). Significantly plastic soils can be transformed from a solid, to a putty-like and ultimately fluid-like state by adding water to the matrix of the soil. In the language of geotechnical engineering increasing the moisture content of a plastic soil reduces the soil's shear resistance to sliding. High plasticity soils (soils most similar to high quality pottery clay) turn into sticky mud when mixed with water. The pottery industry supplied the engineering community with a host of field and laboratory procedures to detect and rank such soils (Holtz, R.D. et al. 1981).

Early identification and extra diligent management of surface water on plastic or pottery clay-like terrain is well advised in order to ensure hillslope work does not turn to mud and consequently flow away.

Without substantial local experience it is easy to mis-identify such soils. Hence the engineering community's enthusiasm for the pottery industry's soil plasticity detection and ranking procedures.

The above principles correlate quite well with many forestry workers' field experience. Slope failures which initiate below cross ditches are a leading source of deactivation related landslides. Fine-grained soils are frequently associated with such slope failures (Prov. of B.C., 1997). Chatwin et al. (1994) have also noted that slope failures, in fine-grained soils, tend to:

- be unusually large and frequent,
- occur upon unusually gentle sideslopes, and
- be associated with cohesive soils.

The phrase 'cohesive soil' is one of many technical and practical terms a forestry worker might use to describe a significantly plastic soil. As this article is an attempt to translate technically advanced engineering details into concepts and techniques useful to every day forest workers, these terms are not used in a technically or scientifically precise manner. Although many other terms exist, for the purposes of this article I will use the terms plastic or clay-like interchangeably.

Field identification of plastic (clay-like) soils

In general, glaciomarine (salt or brackish water) or glaciolacustrine (lake) deposits are the only clay-like soils that can be readily identified by solely visual means. The failure prone, clay-like, behavior of these materials is well known to most forestry workers.

The field identification of clay-like tills is more problematic. The occurance of clay-like tills, in select portions of B.C. is well documented (Chatwin et al. 1994). A host of field indicators and laboratory testing procedures have been developed to detect soils.

The most widely used field procedures to detect clay-like soils in the forest sector are the cast and ribbon tests. Figures 3 and 4 illustrate these test procedures. The samples were prepared, in general accordance with the United States Corps of Engineers (USCE) field procedures, by:

- successively moistening and remolding the sample, and
- picking the sand and gravel large enough to interfere with the tests (about 0.5 to 1.0 mm in diameter) from the sample using one's fingers during remolding.

When remolded at an appropriate moisture content the till produces an excellent cast (Figure 3) and a strong, ~15 cm long, soil ribbon (Figure 4). Therefore, the till is a clay-like soil.

Supplemental, field orientated testing procedures referred to but not described within Appendix 1 of the Forest Road Engineering Guidebook include the USCE's Dilatancy, Toughness and Dry Strength tests (Office, Chief Engineers 1953).

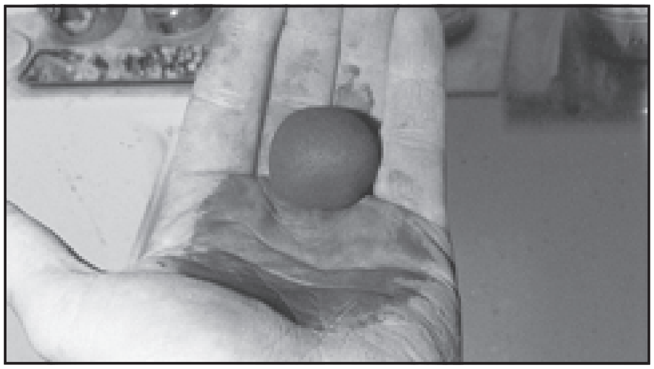

Figure 3. The clay-like tills responsed to the cast test. Tills form a strong, durable, cast which can be repeatedly throw from hand to hand without breakage. Silty or granular (non-plastic) tills may form a weak cast but readily fragment with handling.

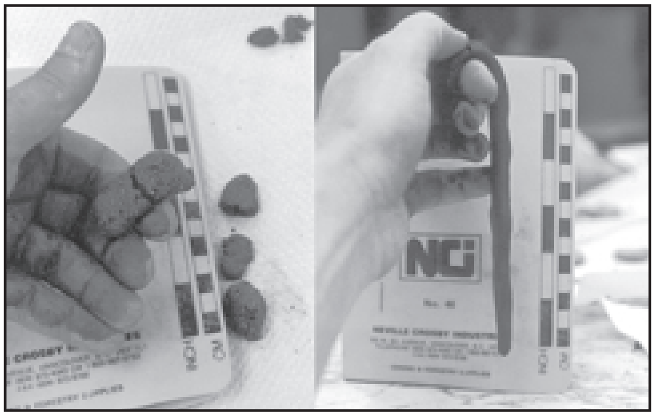

Figure 4. A silty and the clay-like till responsed to the ribbon test. The soil on the left is a silty till. Soil on the right is a medium plastic till. The test is a crude measurement of the soil's plasticity (how clay-like the soil is) at a specific moisture content. At appropriate soil moisture content the soil on the right is sufficiently clay-like to support it own weight to a length of approximately 15 cm. Silty or non-plastic soils typically form ribbons two to three cm long. Soils that produce ribbons longer than about three cm are usually somewhat to significantly plastic. The longer the soil ribbon the greater the plasticity and the more clay-like the soil.

The clay-like till extracted from the slope failure illustrated in Figure 1:

- Exhibited almost no reaction (shine or glossy coating) in response to shaking of a hand sample (Figure 5). This negative reaction to the Dilatancy Test suggests the fines fraction of the soil is clay-like rather than silty or granular.
- Could be readily worked into quite a long, tough soil worm, (Figure 6). This positive response to the toughness test suggests the till is a significantly plastic or clay-like soil. Non-plastic or granular soils can not be worked into a soil worm. Weakly plastic soils can be worked into, weak, fragile, soil worms.

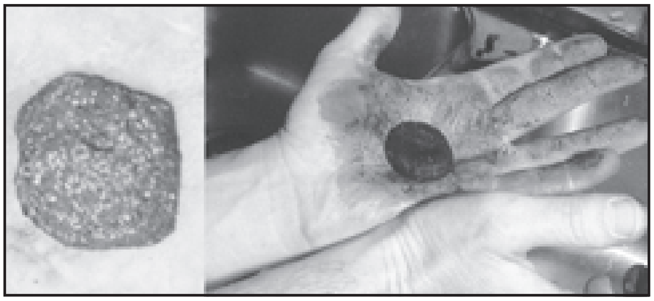

Figure 5. An example of the dilatancy (jarring or shaking) test. The dilatancy test is a crude measure of how silt-like a soil is. Granular and silty soils, as characterized and defined in engineering literature, slightly decrease in volume (compact) with shaking. As silty soils decrease in volume any resulting "excess" water flushes to the surface of the freshly compacted soil. This gives the surface of the soil sample a shiny or glossy appearance (see photo on left above). To conduct a dilatancy test a pat of moist soil is placed in one hand and struck by the opposing hand (see photograph on right above). If the soil develops a shiny or glossy "liver-like" appearance upon striking, the fines fraction of the soil is predominately granular or silt-like in nature. How readily water flushes to the surface of a soil sample is an indicator of the soil's plasticity. High plasticity or pottery clay-like soils will not develop a shiny surface despite repeated striking. Silty soils will readily develop a shiny surface. Very fine beach sand is the classic example of a soil which responds well to the Dilatancy Test; shaking loose, moist, beach sand with your foot produces a readily apparent "flush" of water towards the ground surface. Pottery clay does not develop a shiny surface upon striking.

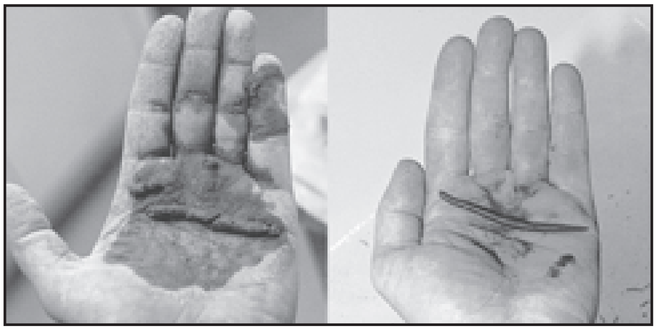

Figure 6. A silty and a clay-like tills response to the toughness test. The soil on the left is a silty or silt-like till. Soil on the right is the clay-like till collected from the sidewall of the largest slope failure shown in figure 1. At appropriate soil moisture content both soils can be rolled out to form thin (approximately 3-mm diameter) soil worms. The soil worm on the left (the silty soil) is very fragile; the soil worm on the right (the medium plastic or clay-like till) is quite durable. Clay-like soils can be rolled out into a soil worm and remolded many times before they refuse to form a coherent soil mass. Ideal granular (non-plastic) soils, such as gravel or sand can not be rolled out into a soil worm. Silty soils can generally be rolled out into weak, fragile, soil worms which quickly lose their ability to form a coherent soil mass with subsequent remolding and rolling.

- Was quite resistant to crushing and powdering when thoroughly air-dried (Figure 7). Such a response to the Dry Strength Test suggests the till is a medium to high plasticity.

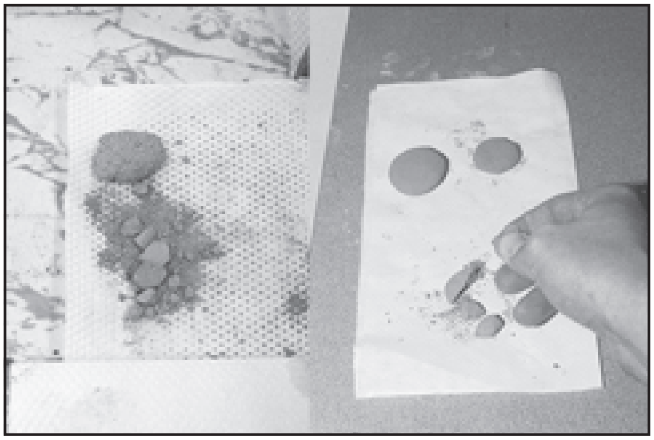

Figure 7.

A silty and the clay-like tills response to the dry strength test. The soil on the left is a silty till. The soil on the right is the medium plastic or clay-like till. The dry strength test is a crude measurement of a soil's unconfined compressive strength at the soil's lowest reasonable moisture content (thoroughly air-dried). The soil cakes on the left broke into many granular fragments under modest to substantial finger pressure; this is typical of a silty soil containing a modest quantity of a clay binder. The soil cakes on the right generally required two handed finger pressure to break; in some cases the soil cakes on the right could not be broken by crushing under intense, two handed, finger pressure. When the soil cakes on the right could be crushed they generally broke into sizeable fragments which were difficult to powder with finger pressure. Such difficult to crush and powder soil cakes are typical of a soil which possesses a moderate to high degree of soil plasticity (i.e. are significantly clay-like). Soil cakes formed from a high plasticity soil generally can not be broken or crushed under finger pressure.

What is the practical significance of soil plasticity?
Most coastal B.C. tills are granular or silty soils. However, some tills exhibit plastic or clay-like behaviour (Chatwin et al. 1994). In a laboratory setting, increasing the soil moisture content of the more plastic tills, by a modest 12 to 20% (Clague J.J. 1989) reduces the soils inherent shear resistance to sliding by ~99%. In other words adding a bit of water to significantly plastic or clay-like tills can induce slope failures on almost flat hillslopes. Chatwin et al. (1994), reports slope failures in such soils upon sideslopes as low as 5%. In reality such extreme, deep-seated, softening of clayey tills rarely occurs; unweathered clay-like tills are typically too impermeable for redirected surface water to penetrate without considerable, persistent human assistance. Forestry related slides upon clay-like terrain tend to occur within the near surface weathered till. Weathered clay-like tills typically fail long before they reach the levels of soil softening which can be created within a soils laboratory.

In contrast silty and granular soils lose very little, if any, of their inherent shear resistance to sliding by simply adding water to the soil mass. Gravel is an example of an ideal non-plastic soil. Adding water to gravel does not cause gravel to spontaneously soften or turn to mud and flow away. However, due to the flotation effects of water, all soils including gravel lose about 50% of their apparent shear resistance to sliding when fully saturated. In essence soil, like a person, has a tendency to be partially supported or float when placed in a swimming pool. It follows that terrain composed of silty or granular tills should only be able to lose a comparably modest 50% of its total (inherent plus apparent) shear resistance to sliding due to modifications of natural hillslope drainage. In contrast plastic soils, including clay-like tills, could lose 99.5% of their total shear resistance to sliding due to equally modest alterations of slope drainage. Terrain composed of clay-like soils should be more failure prone to modest changes in natural hillslope drainage than identical terrain composed of silty or granular soils.

As a consequence, cross ditches, culverts, flooded quarries or water ponded ditch lines should cause more slides on clay-like terrain than equivalent forestry practices on silty or granular terrain.

The Time Dependant Nature of Plastic Soil Behaviour
In general water softening (or hardening) of a plastic soil within a hillslope is a slow process. Turning a lump of dry pottery clay into mud, without the use of a

blender and a significant quantity of water, is a slow process. Conversely drying out a bowl full of fluidized pottery clay is best done with a great deal of patience. The installation of drain pipes into a clay-like soil can take months or years to dewater a slide mass (Chatwin et al., 1994), whereas the process of working excess surface water into a clay-like hillslope can take months or years to occur.

Abandoned, flooded, rock quarries (Figure 2) are a good method of injecting water into a clay-like hillslope. Naturally occurring tension, and sidecast road fill 'settlement', cracks have similar effects. Cross drains (culverts or cross ditches), which constantly moisten specific points upon a hillslope, can produce a similar, albeit, more localized softening effect. The water filled quarries associated with the slides in Figure 1 were probably flooded and softening the adjacent hillslope for about seven years before the largest of the slides occurred. This is in general accordance with the rules of thumb for water table fluctuations to soften, or harden, clay-like hillslopes (Chatwin et al.,1994).

Conclusions

Soil plasticity is a field indicator of slope stability. The engineering concept of soil plasticity has evolved to explain why some soils are more failure prone than others. Plastic soils exhibit clay-like behavior. Adding even modest quantities of water to such soils may cause unusually large and frequent slope failures. Forestry workers should:

- Know how to identify plastic or clay-like soils.
- Be extra diligent with their efforts to conserve natural hillslope drainage upon such terrain.

There are a number of field methods to detect such soils (see figures 3 to 7 above).

The nature of clay-like terrain creates opportunities for unusually cost effective forestry operations. Where terrain is composed of such soils there are opportunities to harvest potentially unstable terrain with fewer slope failures.

Acknowledgments

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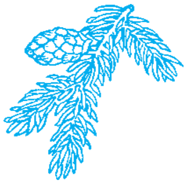

Technical Tip

Erosion Protection of a Clay Bank of Keogh River Using Spurs (Debris Groins)

Mike Feduk

As part of the watershed restoration efforts in the Keogh watershed, a high clay bank in the lower Keogh River was recommended for bank protection. The works were to meet the objectives of limiting sediment recruitment from the high bank, improving rearing habitat, and providing an opportunity to test a unique bank protection technique using large woody debris (LWD) as the primary construction material. This article covers some basic technical theory in the design and layout of spurs (debris groins) for bank protection and follows with the case study at the Keogh River clay bank.

A spur is a structure that projects from a stream bank into the river channel and causes redirection of water away from the bank towards the tip of the spur. This characteristic of spurs can benefit the stream by:

- protecting stream banks from erosion and limiting sediment recruitment,
- reducing velocities near the banks,
- creating still water areas that encourage deposition, and
- channeling flows to reduce widths and create a defined channel.

These features are illustrated in Figure 1, which shows a typical LWD installation.

Many factors govern the use of spurs at a particular location. Criteria related to the design of spurs for traditional river engineering applications have been developed by government transportation agencies (U.S. Dept. of Transportation, 1991; Neill, 1973) . Using these established techniques as a basis for