Introduction

Highly plastic clays have been responsible for many slope problems due to loss of strength over time, creep, and progressive failure. Standard laboratory tests and stability analysis procedures that provide reliable results for other types of soils are often insufficient for slopes in highly plastic clays. Experience has shown that it is necessary to recognize the propensity of highly plastic clays to suffer strength loss and progressive failure in order to design slopes that remain stable over long periods of time.

Studies of slopes in the stiff fissured London clay in the 1950s and 1960s showed that the clay around some of these slopes became weaker over time, to the point that their strengths were as low, or nearly as low, as the same material normally consolidated. This condition was termed "fully softened." Studies in the 1970s showed that highly plastic clays in embankments that were subject to cyclic drying and wetting sometimes suffered similar loss of strength. It appears that after many cycles of wetting and drying, the clays at shallow depths within these slopes had reached the "fully softened" state, with strengths that were essentially the same as the strengths of these materials when normally consolidated.

Further loss of strength, beyond the fully softened condition, is possible where sliding has already taken place. After about ten inches of shear displacement on a sliding surface, plate-shaped clay particles become aligned parallel to the direction of sliding, forming polished surfaces called "slickensides." The shear strength on these slickensided surfaces is reduced to the "residual" value, owing to the low angle of friction between the polished surfaces.

As illustrated by the stress-displacement curves in Figure 1, three categories of drained strength can be defined for clays:

(1) Peak strength is the strength that can be mobilized in undisturbed test specimens from naturally occurring clays, or from compacted clay fills. Back analysis of slides in non-fissured clays indicates that the peak strength can be mobilized along very nearly the entire length of a slip surface (Skempton 1964).

(2) Fully softened strength is the strength that can be mobilized around excavations in fissured clays, and in desiccated and cracked compacted clay embankments, where infiltration of water along the fissures or cracks has resulted in higher water contents, higher void ratios, and correspondingly lower shear strength. "Fully softened" indicates the end result of the softening process and the greatest amount of reduction in shear strength due to increase in water content and void ratio.

(3) Residual strength is the strength that can be mobilized after large shear displacements have occurred on a slip surface, and plate-shaped clay particles have become oriented parallel to a slip surface forming polished "slickensided" surfaces. The displacement required to reach residual strength is on the order of 10 inches – Skempton (1985) indicates the required displacement ranges from four inches to 20 inches.

The distinction between "fully softened" strength and "residual" strength, as described above, is critically important. Residual shear strength is only appropriate where large shear displacements have aligned particles.

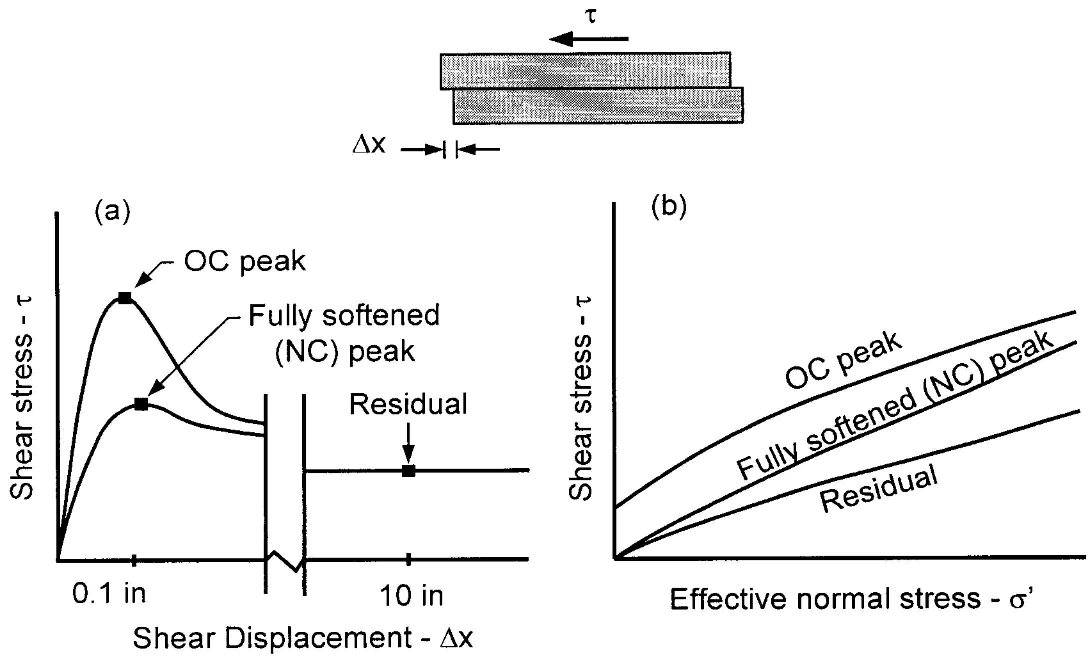

Figure 1 (a) Stress-displacement curves for overconsolidated and fully softened (normally consolidated) test specimens, and (b) overconsolidated peak, fully softened peak and residual strength envelopes.

Throughout the workshop discussions, and in this report, the term "fully softened strength" implies the strength envelope, rather than a discrete value of strength. In most instances using "strength" to imply "strength envelope," causes no confusion. In the some cases, such as embankment foundations, the distinction is important, especially when considering where the use of a fully softened strength envelope is appropriate.

Purpose of the Workshop

While there is agreement that residual strength should be used on pre-existing slip surfaces, it is less clear under what conditions fully softened shear strength should be used for slopes that have not failed. The workshop was organized to bring together a knowledgeable and experienced group of geotechnical engineers, with these objectives:

- to address the use of fully softened strengths for slopes in clays,
- to pool their experiences with slopes in highly plastic clays,
- to discuss the current state of practice for design of slopes in highly plastic clays in various parts of the United States,
- to reach consensus where possible on the causes and limitations of softening,
- to reach consensus where possible on the use of fully softened strength for design of excavation slopes and embankment slopes,
- to reach consensus where possible on the most effective methods of measuring fully softened strength,
- to clarify what pore-water pressures should be used for slope stability analyses with fully softened strengths,
- to discuss what factors of safety are appropriate for design with fully softened strengths,
- to define differences of opinion clearly where there was no consensus, and
- to describe the research needed to answer the questions that cannot be answered at present.