Issues and Techniques for Sampling Overconsolidated Clays

KENNETH L. MCMANIS AND DAVID E. LOURIE

Obtaining high-quality samples in stiff, overconsolidated clay requires attention to many key issues. The sampling techniques used along the Louisiana and Texas Gulf Coast are compared with those found in the state-of-the art literature. Many of these conventional methods do not strictly follow recommended standards such as those presented by ASTM. However, evidence in the literature is sufficient to support several differences. The effects of sample size, extrusion, packaging, and storage on the engineering properties of stiff, overconsolidated clays found in Louisiana are summarized.

Stiff, overconsolidated clays are common in the United States and elsewhere. Their characteristic features often include a network of fissures caused by desiccation and other postdepositional occurrences. Many of the practices and methodologies used to sample soft clays do not work particularly well in stiff, overconsolidated clays. The anomalies of the soil structure and the effects of sampling techniques can make it difficult to determine their engineering properties.

The two most common concerns in geotechnical investigations involving overconsolidated clays are the occurrence of fissures and swell potential (*1*). The stiff, overconsolidated clays found in the Louisiana-Texas Gulf Coast are known for their heterogeneous characteristics and complex soil structure. Joints, fissures, silt and sand seams, root holes, and other irregular features are common characteristics of the soil macrostructure. These features can greatly affect the strength and drainage characteristics of the soil mass.

This paper's objectives are to

- Review the effects of conventional, undisturbed sampling techniques on stiff, overconsolidated clays;
- Present the authors' Louisiana and Texas Gulf Coast sampling experiences and the results of other sampling investigations in similar soils; and
- Identify the methods commonly used and some of the issues and concerns in the sampling of overconsolidated clays.

SAMPLING METHODS: STATE OF THE ART VERSUS PRACTICE

Geotechnical literature contains many references to soil sampling practices. However, sampling's influence on measured soil properties is still an issue that must be addressed. The following section reviews the state-of-the-art information and compares it with the commonly used sampling practices in the Louisiana-Texas Gulf Coast.

Literature: State of the Art

Hvorslev's (*2*) work is one of the earliest studies to evaluate sampling. Since then, numerous studies have been completed that continue to support and update Hvorslev's information.

Borehole Drilling

Sampling activities normally consist of a combination of borehole advancement and sampling. The borehole is usually advanced with an auger or by rotary drilling methods. Auger borings are commonly used in soils of medium to stiff consistency and sands above the water table. Rotary drilling methods are used in all soils and rock.

In the rotary drilling process, the drilling fluid, circulated down the drill pipe, serves two purposes: (a) it seals and stabilizes the borehole, and (b) it carries the soil cuttings in suspension to the surface. The borehole's advancement and penetration rate depend on the material being penetrated. To remove cuttings in a clay soil, they must be small enough to be carried to the surface by the drilling fluid. Improper cleaning of the borehole can result in inadequate removal of soil cuttings, leading to accumulation of cuttings at the bottom of the borehole and in the top portions of the sample. In clay soils, studies conducted by the Bureau of Reclamation (*3*) found that it was effective to use a bit rotation of 200 to 300 rpm with a penetration rate of 25 to 50 mm (1 to 2 in.) per minute.

Soil Samplers

The thin-walled tube sampler (ASTM D 1587) is used most often in obtaining undisturbed samples in clays with consistencies that range from soft to very stiff (*1,4,5*). This method is generally considered to produce a quality sample that is suitable for quantitative testing. Hvorslev (*2*) arbitrarily identified a thin-walled sampler as one whose area ratio does not exceed 10 percent. Area ratio is a comparison of the projected cross-sectional area of the sampler with that of the soil specimen. The ASTM tube's cutting edge is sharp and crimped to a smaller diameter to allow an inside clearance. However, a large inside clearance has also been found to be detrimental with respect to swelling and expansion in fissured soils (*6,7*).

The sample's length and degree of disturbance is influenced by the speed and continuity of motion with which the sampler is forced into the soil. Hvorslev (*2*) recommended fast pushing with a uniform and uninterrupted advance of 0.15 to 0.31 m/sec (0.5 to 1.0 ft/sec). However, in measuring the forces developed during sampling with an open-drive sampler in stiff clay, Lang (*8*) used a penetration rate of 0.02 to 0.05 m/sec (0.06 to 0.18 ft/sec).

K.L. McManis, Civil and Environmental Engineering Department, University of New Orleans, New Orleans, La. 70122. D. E. Lourie, Lourie Consultants, Metairie, La. 70002.

As noted above, thin-walled push samplers can be used over a fairly wide range of soil consistencies. However, the penetration resistance of a very stiff to hard clay may be too great for such samplers, which can be damaged in the process. Solutions are to increase the tube's wall thickness or use a double-tube core barrel sampler.

Double-tube core barrel samplers are designed to recover samples from formations that are too hard or brittle for thin-walled tube samplers. Core drilling differs from push sampling in that sampling and borehole advancement occur simultaneously. A stationary sampling tube located inside the rotating cutter barrel contains the sample. The cuttings are removed by circulating drilling fluid or air. Table 1 provides guidelines for selecting the sampler type, drive length, and inside clearance for different clays (*3*).

Sample Size

Lo et al. (*9,10*) found that for a stiff, fissured clay, the effect of sample size was the single most important factor in influencing the shear behavior. Rowe (*11*) emphasized the importance of the natural soil fabric as a guide for site investigations in the selection of the quality and size of specimens and boring technique (Table 2). To achieve relevant laboratory test results for clay soils that exhibit layered fabrics (varves, silt, and organic inclusions or fissures), large-diameter specimens are needed. Hand-cut or large block samples are generally considered to provide the least disturbed sample.

Practice: Typical Gulf Coast Procedures

Along the Gulf Coast, most of the sampling of cohesive soils is done using a 75-mm (3-in.) diameter thin-walled tube sampler that is pushed into the soil. However, the standard thin-walled tube and borehole advancement methods may differ somewhat from those specified in ASTM 1587.

In general, most geotechnical drilling operations consist of advancing the borehole using a combination of dry-auger and wet-rotary drilling methods. The dry-auger method is used to advance the borehole to the depth where water is encountered. After obtaining water level readings, the driller continues the drilling using wet-rotary methods.

In wet-rotary drilling, the borehole is usually advanced to the desired depth by using a bottom-discharge bit. The driller typically obtains soil samples at about 0.6-m (2-ft) intervals to about 3-m (10-ft) depth and at 1.5-m (5-ft) intervals below 3 m (10 ft). When the desired sampling depth is reached, the driller obtains undisturbed samples by hydraulically pushing a 76-mm (3-in.) diameter thin-walled tube sampler about 0.6 m (24 in.) into the soil. Many commercial firms extract the tube from the borehole without rotation.

TABLE 1 Sample and Sampling Procedures for Overconsolidated Clays (*3*)

	Soil Type	Clay & Shale	OC Clays		Expansive Clay
	Moisture Condition	Dry to Saturated	Moist	Saturated	Wet to Saturated
	Soil Consistency	Hard	Firm	Firm	
SAMPLERS	Open-Drive Samplers	Not Suitable			
	Bit Clearance Percent of Tube Diameter		½ to 1	0 to 1	½ to 1
	Drive Length, cm		46	46 to 61	46 to 61
	Recovery		Good	Good	Good
	Fixed-Piston Samplers	Not Suitable			
	Bit Clearance Percent of Tube Diameter		½	½	½ to 1-1/2
	Drive Length, cm		61	61	46 to 61
	Recovery		Good	Good	Good
	Double-Tube Samplers without Core Catchers				
	Recovery	Fair to Good	Good	Good	Good

TABLE 2 Specimen Sizes (*11*)

EXCEPTIONS: DEPOSITS TOO { WEAK VARIABLE
STRONG STONY }

CLAY TYPE	MACRO FABRIC	MASS k m/s	PARAMETER SPECIMEN	IZE, mm*
NON-FISSURED SENSITIVITY < 5	NONE	10^{-10}	c_u, $c'\phi'$ m_v, c_v	37 76
	PEDAL, SILT, SAND LAYERS, INCLUSIONS. ORGANIC VEINS	10^{-9} -10^{-6}	c_u $c'\phi'$ m_v c_v	100-250 37 75 250
	SAND LAYERS 2mm 0.2 m SPACE	10^{-6} -10^{-5}	$c'\phi'$ m_v	37 75
SENSITIVITY > 5	CEMENTED WITH ANY ABOVE		c_u, $c'\phi'$, m_v, c_v	50-250 ‡
FISSURED †	PLAIN FISSURES	10^{-10}	c_u $c'\phi'$ m_v c_v	250 100 75
	SILT OR SAND FILLED FISSURES	10^{-9} -10^{-6}	c_u c_v $c'\phi'$ m_v	250 100 75
JOINTED	OPEN JOINTS		ϕ'	100
PRE-EXISTING SLIP			$c_r \phi_r$	150 OR REMOULDED

Minimum Sizes of Specimens from Quality I Thin Walled Piston Samples of Natural Clay Deposits. Foundations for Buildings, Bridges, Dams, Fills. Stability of Natural Slopes, Cuts Open or Retained.

* 75 mm samples for continuous Quality 2-4 samples for fabric examination, strength as index test, c_u and $c'\phi$ for intact low sensitivity.
† Size and orientation dependent on fissure geometry.
‡ Tube area ratio 4%, sample dia. 260 mm.

After recovery of the sampler, the logger removes the soil specimen in the field. The logger then examines the specimen, visually classifies it, and preserves representative portions of each specimen for laboratory testing. Sample preservation methods vary, but they typically consist of wrapping a portion of the undisturbed specimen in plastic wrap, aluminum foil or both. The wrapped specimen is then placed in a protective container for shipment to the laboratory. Often a disturbed but representative portion of the sample is placed in glass or plastic containers.

Variations from ASTM Procedures

The sampling methods used along the Gulf Coast have evolved over the years in response to subsurface conditions and acquired experience. Therefore, they differ somewhat from the ASTM methods. Some of these variations are:

- Advancing the borehole using a bottom-discharge bit rather than a side-discharge bit as required by ASTM;
- Use (by many commercial firms) of a thicker thin-walled tube with no internal clearance (a 14-gauge thin-walled tube is used by many firms in the Gulf Coast; in contrast, the ASTM thin-walled tube is a 16-gauge tube with an inside clearance ratio of 1 percent;
- Removing the tube from the ground without rotation (a common practice by many commercial firms); ASTM requires rotating the tube before it is extracted from the bottom of the borehole; and
- Extruding the samples in the field; ASTM procedures specify sealing the tube in the field with wax and shipping the tube to the laboratory for later sample extrusion.

Many of the variations from the ASTM guidelines are due to efforts to obtain better-quality samples than can be obtained by strictly following ASTM's guidelines. Other changes, however, are done for productivity and cost reasons.

The thicker tubes are used by some because of the strength of the overconsolidated clays, the presence of calcareous and ferrous nodules, and the presence of cemented zones. Experience with the ASTM tubes indicates that they can become crimped near the sampling end and they can become out-of-round. In some cases, the extraction of the tube or rotation process has caused the top of the ASTM tubes to shear off. Many of the Gulf Coast overconsolidated clays are expansive and contain slickensides and fissures. Studies suggest that inside clearance ratios in these soils may be detrimental (*6,7,12*).

Drilling with a side-discharge bit in stiff clay is slower than drilling with a bottom-discharge bit. One commercial firm with which the authors are familiar has estimated that drilling with side-discharge bits is about 20 to 30 percent slower than drilling with bottom-discharge bits. The primary reason for this is that side-discharge bits tend to plug in stiff clays because the cleaning action of the drilling fluid on the bit is reduced by the deflectors welded onto the bit.

Field extrusion and packaging are standard Gulf Coast practices; ASTM recommends performing these operations in the laboratory. There appear to be several good reasons for using field extrusion methods. One is cost considerations and the other reasons are technical. Field extrusion allows for the immediate reuse of the sampling tube. If the tube had to be extruded in the laboratory, many more tubes would be required at a significant cost. Also, a full sample tube is quite heavy and takes up more space than the extruded specimen. This would likely cause increases in the costs associated with sample shipping and handling. By extruding the sample in the field, the logger is able to visually examine it and if necessary make adjustments to the sampling program.

Laboratory Testing Methods

For most routine to moderately complex geotechnical projects involving overconsolidated clays, undrained shear strength is usually the most important engineering parameter. Soil compressibility, drained-strength parameters, and other properties usually are of less concern. Measurements of undrained shear strength usually consist of unconfined compression tests or unconsolidated-undrained triaxial compression tests on undisturbed samples. The confining pressure in the triaxial test is usually equal to or slightly more than the effective overburden pressure. The triaxial test is believed to give a better overall indication of the undrained strength, probably because of compensating errors. Some firms remold overconsolidated clays before they perform undrained strength tests. In slickensided or fissured clays, this procedure would eliminate the influence of the structure on measured strength.

SAMPLING ISSUES

Since 1965 the Louisiana Department of Transportation (LDOT) has conducted studies involving methods for site investigations (*4,13–15*). Louisiana soils were transported and deposited in waters during the early Tertiary and Quaternary periods. Depositional conditions involved marine, deltaic, and continental environments. The layering and thickness of the strata and type of sediments found are the result of sea-level fluctuations and local and regional structural movement. The types of cohesive soils range from soft organic silty clays to stiff fissured clays. The softer sediments often are Holocene (Recent) sediments, whereas the stiffer materials often are Pleistocene deposits. The stiff clays are generally weathered at the surface and weakened by a network of fissures and slickensides created through severe periods of desiccation (Figure 1).

Sampling Disturbance

In undrained strength tests it has been observed that sampling disturbance can produce two opposing outcomes with test specimens of stiff fissured clays. Tube sampling can partially remold the fissures and strengthen the test specimen. However, stress release is most critical for a stiff, fissured clay. Removal of the confining support and the sampling activities can cause the fissures to separate and weaken the soil.

Excessive strains that occur with sampling can also have a profound effect on the engineering properties of nonfissured, overconsolidated soils. A comparison of the strength determined with specimens of varying quality demonstrated just the opposite of the strength found for the stiff fissured clays (*16*). Hand-cut blocks and larger-diameter tube samples of overconsolidated clays with a medium consistency provide a better representation of in situ conditions (Figure 2).

Stress Release

Removal of the sample from the ground reduces the total stresses to zero. As the sample attempts to rebound or dilate, a pore pressure less than atmospheric is developed in saturated soils. In sampling an overconsolidated clay sample under ideal conditions, the resulting effective stress, σ'_{ps}, for the "perfect sample" is (*18*)

$$\sigma'_{ps} = \sigma'_{vo}\,[1 + A(K_o - 1)] \tag{1}$$

where

σ'_{vo} = effective overburden stress,
A = pore pressure parameter, and
K_o = coefficient of lateral earth pressure at rest.

Under normal field sampling and laboratory conditions, the actual residual effective stress, σ'_r, has been found to be significantly smaller than σ'_{ps}. The above equation assumes a continuous soil specimen and probably does not accurately portray conditions for a fissured specimen. However, without fissures, the change in stress has little effect on the undrained strength of a saturated clay if there are no changes in moisture content or mechanical damage to the test specimen (*17*).

Disturbance of Soil Structure

Most sampling disturbance is attributed to changes in the soil structure, that is, strain. The soil structure is disturbed in the top and bottom portions of the sample during the boring activities and separation

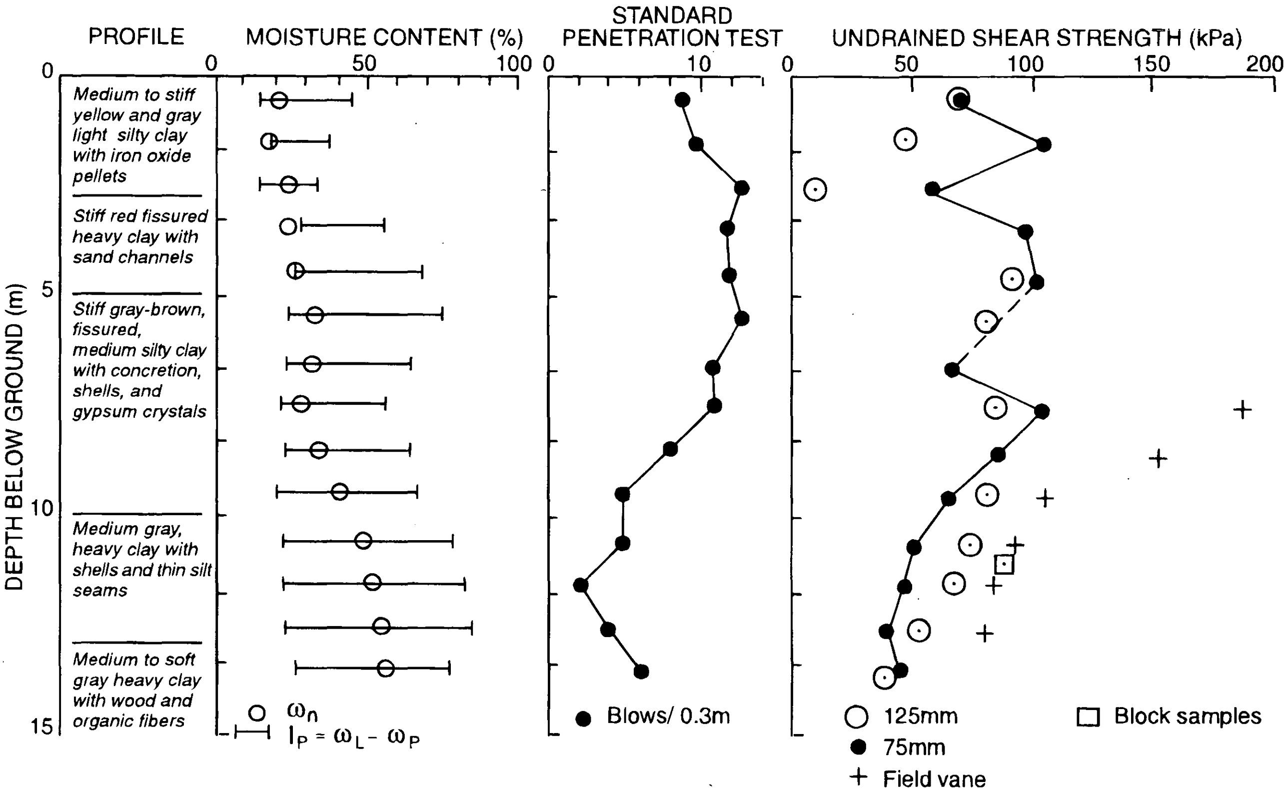

FIGURE 1 Typical soil profile, southwest Louisiana.

from the parent material with sampling. Structural disturbances may also result from friction turn down at the sample edge, planes of failure, and distortion or changes in thickness of soil layers (*2,18*). Internal and external friction between the soil and the sampler is a major source of structural disturbance, producing variations in strength along the sample's length and cross section. Lang (*19*) concluded that the specimen strength and deformation measured from the lower portion of the sample of a stiff, residual clay taken with an auger core soil sampler was more representative of the natural soil.

Baligh (*20*) used the strain path method to evaluate the strain history of Boston blue clay during sampling of a normally consolidated and overconsolidated (OCR = 4) sample. The resulting implications were that, even under ideal conditions, thin-walled sampling caused serious disturbances in overconsolidated specimens and unacceptable disturbance in normally consolidated specimens.

Test Scatter

A comparison of unconsolidated-undrained strength test results demonstrates the scatter typical of a fissured soil (Figure 3). As noted in Figure 3, the tests reported include undisturbed, remolded, and driven samples. The undisturbed specimens were tested within 14 days of sampling or subjected to extended storage periods of 30 days and longer. Much of the scatter in the undisturbed samples can be attributed to the extended storage time. However, the major cause of the test scatter is the frequency and presence of fissures in a particular test specimen.

The deformed shape of the failed specimen in many of the tests followed the irregular orientation of the fissure geometry. A number of the larger samples (125-mm diameter cores and hand-cut blocks) failed when attempts were made to trim them. The analysis of only those test results plotted in Figure 3 is probably biased, since they do not include those 125-mm diameter samples that failed before testing. A few of the 75-mm diameter samples became fragmented while handling, but most of these had long storage periods. Smearing on the periphery of the 75-mm diameter samples hid discontinuities from visual inspection and provided artificial bonding across fissures. Trimming the periphery and removing the remolded portion of the larger samples (125-mm diameter) caused many samples to fail before they could be tested.

Complete remolding seems to generally produce higher values of undrained strength for individual samples. Sensitivity of the test specimens ranged from 0.6 to 1.4. In most of these tests, the remolded strength equaled or exceeded the undisturbed strength.

Sampling with a split-barrel (split-spoon) sampler in the standard penetration test (SPT) (ASTM D 1586) also remolds, compacts, and bonds fissures to produce a stronger, more uniform specimen. The measured undrained strength of the SPT specimens has the highest range of all sample types.

X-Ray Radiography

ASTM methods for x-ray radiography of soil samples (D 4452) are particularly valuable in determining the quality of undisturbed soil samples to be selected for critical testing (*18,21*). X-ray radiography provides many benefits, including identifying the features outlined below:

- Heterogeneity and distribution of anomalous features;
- Internal failure modes of soil specimens, not routinely discernible to the naked eye;

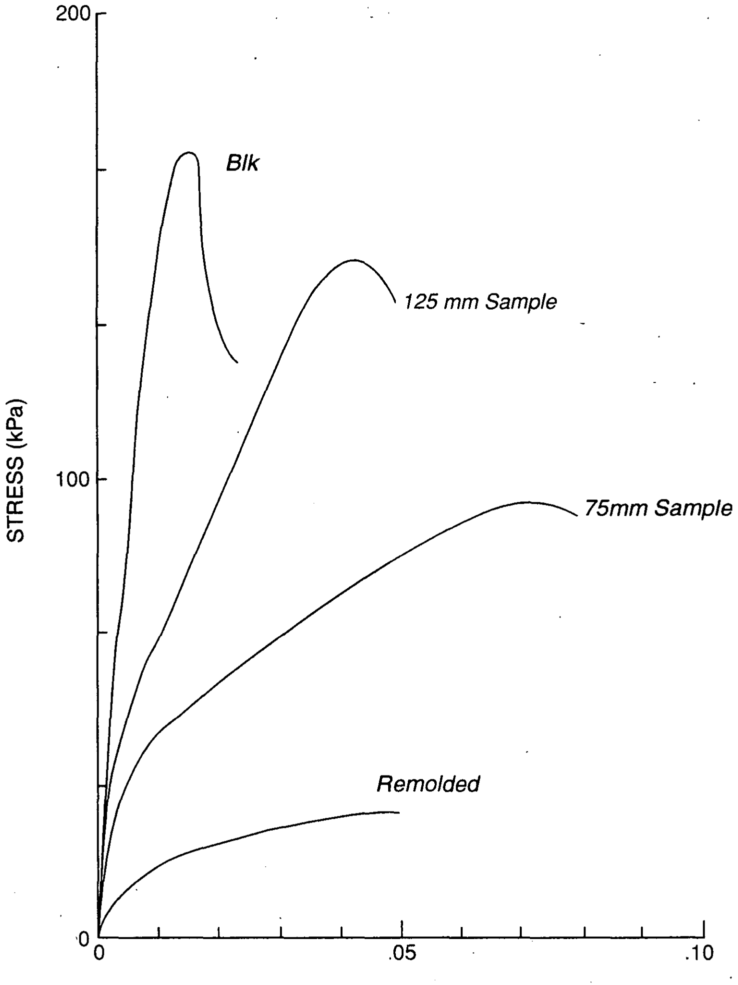

FIGURE 2 **Typical stress/strain curves for triaxial undrained compression test.**

- Naturally occurring cracks and those produced by sampling (i.e., failure planes, the additional separation of the existing laminations, and fissures during the sampling procedures).

Radiographs have also been useful for predicting the potential for fluid migration in the stiff clays typical to Louisiana and the Gulf Coastal Plain (*22*). A detailed X-ray radiographic analysis identified the presence of a permeable structure in the sediments, thus helping to support the interpretation of fluid movement through the low-permeability clays that contain these permeable conduits. The X-ray radiographs revealed a network of iron-lined fissures, concretions, and roots throughout the affected zone. X-ray radiography is a technique that can support the analysis and evaluation of test data for critical geotechnical projects.

Sample Type and Size

The need for larger samples and field testing has been cited (*9,23*). However, the selection of sampler type and size is still largely controlled by local practice. Lang (*8*) recommended that the trimmed surfaces be as small as possible in relation to the original size of the specimen. Figures 1 and 2 demonstrate the improved test performance achieved with better-quality samples of a medium-to-stiff, overconsolidated clay and the absence of fissures.

According to Rowe (*11*), the sample diameter appropriate for stiff, fissured clays ranges from 75 to 250 mm (3 to 10 in.) and depends on the engineering property of interest (Table 2). Figures 1 and 3 demonstrate a range of test results typical for desiccated soils and sample types. These variations are attributed to (a) the remolding of fissures in the smaller, more proportionally disturbed tube samples and (b) the frequency of fissure occurrence [i.e., the probability that less fissures occur in smaller samples (*21*)].

Extrusion Effects

Studies have shown that extruding the samples in the laboratory caused more disturbance than extruding in the field (*24,25*). In stiff clays, this disturbance is caused by overcoming the adhesion between the sample and the sample tube. The pressure required to extrude the sample often exceeds the unconfined compressive strength of the sample (*8,13,18*).

Pressurized water or hydraulic rams are the methods used to extrude soil cores from sampling tubes in the field. It is generally conceded that there are many negatives in extruding the soil using

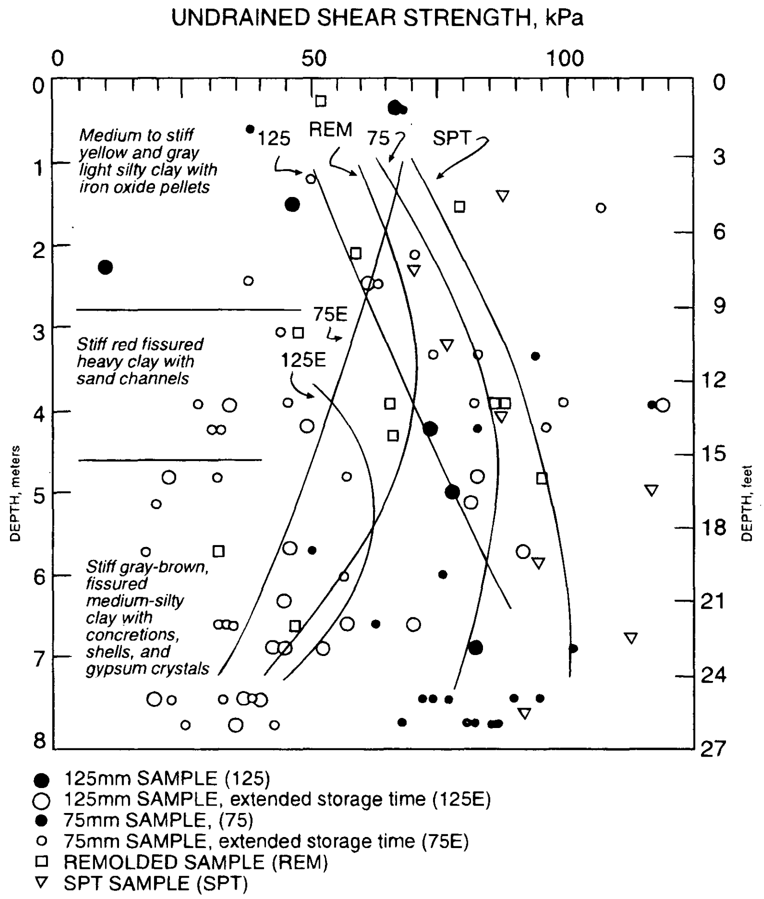

FIGURE 3 **Typical fissured soil tests.**

the pressurized system of the circulating fluid, and this method is not recommended. LDOTD conducted a study on the effects of extrusion using the hydraulic ram (*4*).

Replicate samples were obtained with a 75-mm (3-in.) diameter thin-walled tube from overconsolidated clay formations. Some cores were extruded in the field and placed in protective packaging. Others were sealed in the tubes. All samples were promptly transported to the laboratory.

In all cases, the applied stress during laboratory extrusion of the sampler exceeded the unconfined compressive strength of the soil by as much as 900 percent. The maximum strain measured before the sample began to move in the tube was about 0.5 percent during extrusion. Sone (*12*) evaluated the extrusion of a silty clay. The pressure to extrude the soil was several times larger than the unconfined strength and produced a compressive strain of 1 percent. The driving forces measured by Lang (*8*) while sampling a stiff clay exceeded the shear strength by 13.4 times.

Sample Protection

Sample packaging in the field is required when field extrusion of the samples occurs. Traditionally, many geotechnical groups used paraffin wax as the sealant. Laboratory observations indicated that even experienced and careful technicians had difficulties when removing the hardened paraffin without damage to the samples. Also noted was sweating under the paraffin. A sample from a depth of 12 m (40 ft) has a body temperature of about 18°C (65°F). When it is wrapped in foil and dipped in hot paraffin (49°C), considerable sweating results, with an increase of moisture content in a zone adjacent to the outer surface of the sample. Another study known to the authors showed that waxed clay samples had temperatures 12° to 16°C higher than ambient air temperature 4 to 5 hr after the samples were sealed with wax. Therefore, it seems reasonable to expect heat to cause redistribution of moisture within a sample. The potential sudden effects of water migration on the pore pressure and moisture distribution, as well as the homogeneity of the soil, are undesirable. Water entering the cracks of a fissured clay causes it to soften and swell unequally and results in further destruction of the sample.

More recently, other forms of sample packaging have become popular. In general, the newer packaging consists of wrapping the sample in plastic, aluminum foil, or both, and placing the wrapped sample in a sample container.

In the LDOTD study (*4*), two methods of protective packaging for field-extruded cores were reviewed with respect to moisture content variations. The coating of undisturbed samples with paraffin had been accepted as one method of preserving sample integrity. A second technique uses aluminum foil and plastic film as a protective coating. The wrapped specimens are then placed in cylindrical-formed styrofoam boxes to secure the specimen for shipment and storage.

The natural moisture contents of sampled specimens were determined immediately upon their arrival in the laboratory. Both the paraffin-coated and the foil/plastic-wrapped specimens were stored at 100 percent humidity and at 22°C (72°F). After storage periods that ranged from 14 to about 30 days, the two specimens of a set were tested for moisture content from each whole section. The results indicated that the foil/plastic wrapping maintained the moisture content of a specimen just as well as the paraffin coating.

After these tests, the Louisiana Department of Highways adopted the use of foil/plastic protection instead of paraffin. Some commercial firms now use only single plastic bags for sample storage. However, reported moisture loss using this method was found by others to be significant (*26*).

Sample Storage

The quality of stiff, fissured clay samples deteriorates rapidly with extended storage time. Removal of the confining pressure through sampling permits the clay to expand, and fissures to open. Many stiff, fissured cores that were stored over longer time periods became fragmented when handled, including hand-cut block samples. The combined negative effects of stress release and storage time were much more severe for the stiff, fissured clays than for other soils.

The effects of long storage on the strength and consolidation characteristics of a nonfissured to slightly fissured, overconsolidated clay of medium to stiff consistency were compared with three different types of samples: 300-mm (12-in.) wide hand-cut block samples, 125-mm (5-in.) diameter thin-walled tube samples, and 75-mm (3-in.) diameter thin-walled tube samples (Figure 4).

The results of the early (4 to 7 days) undrained triaxial shear strength tests on specimens from the 125-mm diameter cores were slightly lower than those from the large hand-cut blocks. Specimens from the 75-mm diameter cores had much lower strengths (Figure 4). Such effects were attributed to disturbances of the outer zones during tube sampling and core extrusion.

The remaining samples were stored at 22°C (72°F) and 100 percent humidity in field-applied packaging and were tested at the end of different time periods. Only samples with similar moisture contents, densities, and classifications were used. A small decrease in shear strengths was observed for tube-sampled specimens through the first 10 days of storage. However, the specimen strength of both the 75- and 125-mm diameter cores seemed to deteriorate at an increasing rate after the first 10 days (Figure 4). Extended storage times also caused a reduction of the measured preconsolidation pressure by as much as 30 percent for specimens from the tube cores.

Sampling and In Situ Testing

Using significantly higher-quality soil boring and sampling techniques often is cost-prohibitive for routine to moderately complex projects. However, in situ testing offers some opportunities to cost-effectively improve the quality of a subsurface investigation program in overconsolidated soils. For the stiff, overconsolidated clay soils typically encountered in the Louisiana-Texas Gulf Coast, in situ tests are useful (Figure 1). They can help to better define strength profiles and soil stratigraphy while reducing scatter in the data.

Since in situ tests do not collect soil samples, they need to be used in conjunction with traditional drilling and sampling methods. The data interpretation should be based on correlations with site-specific conditions. These tools also do not directly measure all routine geotechnical parameters such as moisture content, unit weight, soil compressibility, and plasticity. However, they can provide detailed information about subsurface conditions.

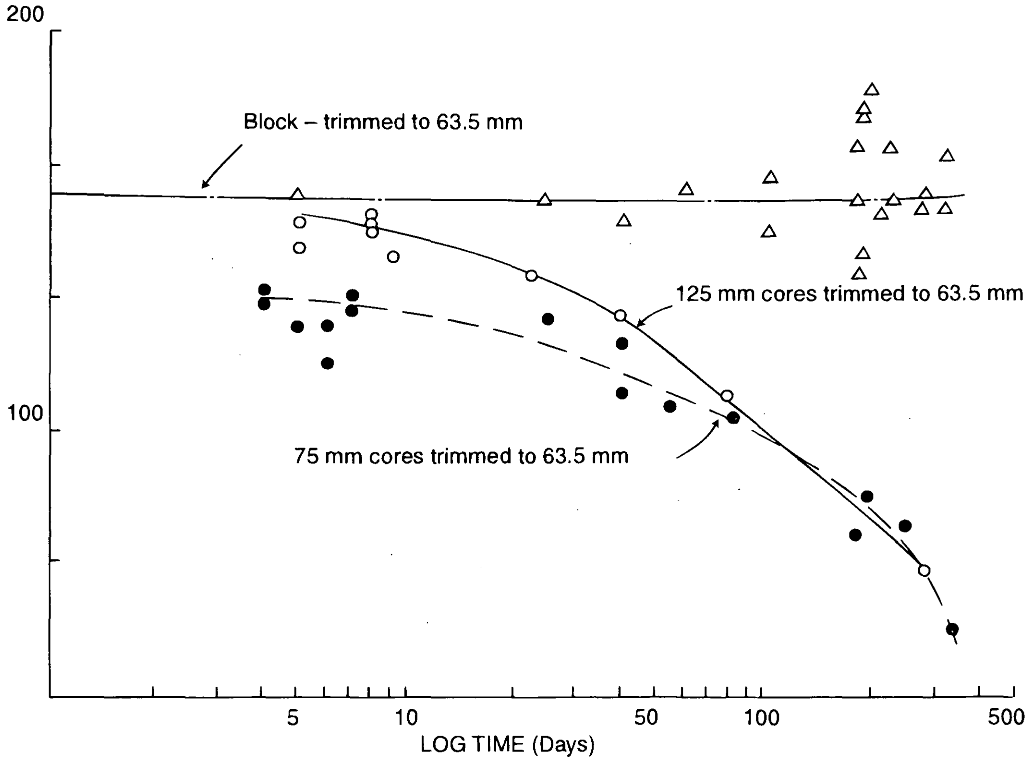

FIGURE 4 Storage time versus undrained triaxial strength.

CONCLUSIONS AND RECOMMENDATIONS

Stiff, overconsolidated clays present challenges for obtaining quality undisturbed samples. These soils require careful attention to sampling techniques as well as sample handling and storage practices. Each project often has its own special requirements that must be considered when developing a data-gathering program. This paper identifies many of the issues associated with sampling these soils, and it presents information about practices in the Louisiana-Texas Gulf Coast. It also summarizes the results of several assessment programs on Louisiana soils.

Most of the sampling disturbance in stiff, fissured clays is caused by the discontinuous structure (fissures) and stress release. Remolding of fissures (mechanical disturbance) produces misleading test information with higher undrained strengths and less permeable characteristics of the soil mass. However, a reduction in the sample quality of a nonfissured, medium to stiff clay specimen produces a reduction of strength. X-ray radiography has been demonstrated to be a useful tool for selecting representative specimens, evaluating sample quality, supporting the analysis of tests results, and reviewing the soil's fabric (macrostructure).

The wide variation in undrained strength tests conducted on stiff, fissured clays is largely influenced by the frequency and geometry of the fissures. Larger samples aid in evaluating the presence and frequency of fissures and their effects on the mass permeability and the shear mechanics of the soil mass.

In medium to stiff, overconsolidated clays, variation between sample types in the laboratory and field tests is attributed to sample quality and the extent of mechanical (sampling) disturbance. Larger, quality samples also provide better estimates of in situ performance of nonfissured, medium to stiff clays.

Extended storage causes reduction in strength (fissured and nonfissured). However, it appears to be most critical for fissured clays (i.e., prolonged removal of total stress).

Obtaining high-quality samples in stiff, overconsolidated clay requires attention to many key issues, including drilling procedures, selection of the proper sampling equipment, and careful extrusion, handling, packaging, and storage practices.

Some of the data-gathering practices used in the Gulf Coast do not strictly follow recommended standards such as those presented by ASTM. However, evidence in the literature is sufficient to support several differences. The inside clearance on sample tubes recommended by the standard procedures may be detrimental to sample quality of expansive and fissured clays. The thicker walls on the thin-walled tubes used by some organizations may result in less sample disturbance than what would occur with thinner-walled tubes recommended in certain standards. Field extrusion usually is not recommended by most standards. The standards usually indicate that sample extrusion should occur in the laboratory. However, studies show that laboratory extrusion causes more sample disturbance than extruding in the field. Some of the currently used sample packaging methods compare favorably with the traditional sample waxing methods for both short- and long-term sample storage. In addition, the newer packaging methods may actually reduce sample disturbance caused by heat and moisture migration.

Most standard geotechnical sampling uses 75-mm (3-in.) diameter samples. Evidence suggests that larger-diameter samples can improve sample quality. However, the field and laboratory costs associated with large-diameter samples can be prohibitive. As an alternative, in situ testing can be used to supplement a traditional soil boring program and cost-effectively improve the quality of data obtained. Although higher-quality studies are desirable, many foundation capacity procedures and other geotechnical analysis methods are empirical. Therefore, changes in data acquisition methods may require adjustments in the empirical procedures. However, the confidence level in the empirical procedures should increase if consistent and better-quality data are obtained.

ACKNOWLEDGMENTS

Much of the information utilized was conducted in research financed by the Louisiana Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

REFERENCES

1. Mayne, P. *Survey of DOT Geotechnical Practice for Overconsolidated Stiff Soils.* TRB Committee A2L02, National Research Council, Washington, D.C., January 1992.
2. Hvorslev, M. J. *Subsurface Exploration and Sampling of Soil for Civil Engineering Purposes.* U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, Miss., 1949.
3. Clark, K. R. Mechanical Methods of Undisturbed Soil Sampling. *Symposium on Soil Exploration.* SPT No. 351. ASTM, Philadelphia, Pa. 1963, pp. 86–95.
4. Arman, A., and K. McManis. *The Effects of Conventional Soil Sampling on the Engineering Properties of Cohesive Soils in Louisiana.* Engineering Research Bulletin No. 117. Louisiana State University, Baton Rouge, 1977.
5. Kallstenius, T. Appendix II—Report of Subcommittee on Problems and Practice of Soil Sampling. In *Proc., 6th Conference of International Society for Soil Mechanics and Foundation Engineering,* Montreal, Canada, 1965.
6. Kallstenius, T. Studies on Clay Samples Taken With Standard Piston Sampler. *Proceeding 21*, Swedish Geotechnical Institute, 1963.
7. Kallstenius, T. Secondary Mechanical Disturbance; Effects in Cohesive Soil Samples. In *Quality in Soil Sampling: Proceedings of Specialty Session, Fourth Asian Conference*, ISSMFE, Bangkok, July 1971, pp. 30–39.
8. Lang, J. G. Forces On An Open Drive Sampler In Stiff Clay. In *Quality in Soil Sampling: Proceedings of Specialty Session, Fourth Asian Conference*, ISSMFE, Bangkok, July 1971, pp. 21–29.
9. Lo, K. Y., J. I. Adams, and J. I. Seychuk. The Shear Behavior of a Stiff Fissured Clay. In *Proc., Seventh International Conference on Soil Mechanics and Foundation Engineering*, Mexico city, 1969, Vol. I, pp. 249–255.
10. Lo, K. Y., J. L. Seychuk, and J. I. Adams. A Study of the Deformation Characteristics of a Stiff Clay. *Sampling of Soil and Rock.* ASTM STP 483, June 1970, pp. 60–76.
11. Rowe, P. W. The Relevance of Soil Fabric to Site Investigation Practice. In *Geotechnique*, Vol. 22, No. 2, June 1972, pp. 195–300.
12. Sone, S. The Deformation of a Soil Sample During Extrusion from a Sample Tube. In *Quality in Soil Sampling: Proceedings of Specialty Session, Fourth Asian Conference*, ISSMFE, Bangkok, July 1971, pp. 1–6.
13. Higgins, C. M. Pressuremeter Correlation Study. *Research Report No. 13*, Louisiana Department of Highways, 1968.
14. Arman, A., J. Poplin, and N. Ahmad. Evaluation of the Vane Shear Test in Louisiana. *Engineering Research Bulletin No. 118*, Louisiana State University, December 1978.
15. Tumay, M. T. *Field Calibration of Electric Cone Penetrometers in Soft Soil.* Report No. FHWA/LA/LSU-GE-85/02. Louisiana Transportation Research, July 1985.
16. McManis, K. and A. Arman. Evaluation of Design Parameters Obtained by Conventional Sampling. In *Proc., Seventh European Conference on*

Soil Mechanics and Foundation Engineering, Brighton, England, September 1979.

17. Ladd, C. C., and T. W. Lambe. The Strength of 'Undisturbed' Clay, Determined from Undrained Tests. In *Laboratory Shear Testing of Soil*, ASTM STP 361, 1963, pp. 342–371.
18. Arman, A., and K. L. McManis. Effects of Storage and Extrusion on Sample Properties. In *Soil Specimen Preparation for Laboratory Testing*. ASTM STP 599, 1976, pp. 66–87.
19. Lang, J. G. Variations of Soil Disturbance Within Tube Samples. In *Proc., Fifth Australia-New Zealand Conference on Soil Mechanics and Foundation Engineering*, Auckland, 1967, pp. 39–42.
20. Baligh, M. M. Strain Path Method. *Journal of Geotechnical Engineering Division*, ASCE, Vol. 111, No. 9, Sept. 1985, pp. 1108–1136.
21. McManis, K. L., and A. Arman. Sampling and Testing in Stiff Crustal Clays. *Geotechnical Aspects of Stiff and Hard Clays*. Geotechnical Special Publication No. 2, ASCE, 1986, pp. 1–13.
22. Ferrell, R., Jr., A. Arman, and J. Grosch. X-Ray Radiographic Investigation of Perchloroethylene Migration at the Livingston Derailment Site. *Geotechnical Testing Journal*, ASTM GTJODJ, Vol. 12, No. 2, June 1989, pp. 119–125.
23. Bishop, A. W. The Strength of Soils as Engineering Materials. In *Geotechnique*, Vol. 16, 1966.
24. Semple, R. M., and J. W. Johnston. Performance of 'Stingray' in Soil Sampling and In Situ Testing. *Proceedings of International Conference on Offshore Site Investigation*, London, 1979.
25. Raymond, G. P., D. L. Townsend, and M. J. Lojkasek. Evaluation of Sample Quality on Undrained Soil Properties. In *Quality in Soil Sampling: Proceedings of Specialty Session, Fourth Asian Conference*, ISSMFE Bangkok, July 1971.
26. Welch, R. C., and S. I. Thornton. *Arkansas Bridge Foundation: Field Procedures*. Interim Report, Highway Research Project 39, Arkansas Highway and Transportation Department, 1977.