SUGGESTED METHOD

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Suggested Test Method for Determination of Degree of Saturation of Soil Samples by *B* Value Measurement

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ABSTRACT: Three methods are proposed for using Skempton's *B* parameter for determining levels of soil saturation. In the first method, achievement of a specified *B* value is required before consolidation of the test specimen. In the second, achievement of a specified *B* value is required after consolidation of the test specimen. In the third method, the *B* value remains constant when plotted against increasing back pressure. The detrimental effect of performing a *B* value test on a partially saturated specimen is discussed, along with methods for increasing specimen saturation by flushing with carbon dioxide gas and increasing back pressure. Data are also presented on recommended *B* criteria as a function of soil type and saturation level, along with typical times required to flush samples.

KEY WORDS: soil tests, saturation, pore pressures, triaxial tests, laboratory tests

1. Scope

1.1 This method presents procedures for determining the level of saturation of soil samples using a triaxial pressure cell. The methods are based on the determination of the *B* parameter as presented by Skempton [*1*]. The *B* parameter is defined as the ratio of the change in pore water pressure in an undrained triaxial specimen to an incremental change in the cell pressure, and may be related to the degree of saturation S_r.

1.2 Three methods are provided for using *B* to determine S_r. The first two methods (A and B) permit the determination of *B* for relatively loose cohesionless soils or soft clay specimens. The third method (C) is an extension of Method B for the special case in which dense sands and stiff clays are being tested. These methods are as follows:

1.2.1 *Method A*—This method requires a specified *B* value to be achieved before consolidation of the test specimen. It is used for determining the saturation level of loose to medium dense cohesionless soil or normally consolidated clay specimens that will be subjected to high effective consolidation stresses (≥517 kPa [75 psi]).[3]

1.2.2 *Method B*—This method requires a specified *B* value to be achieved after consolidation of the test specimen. It is used for determining the saturation level of loose to medium dense cohesionless soil or normally consolidated clay specimens that have been subjected to relatively low effective consolidation stresses (≤517 kPa [75 psi]).

1.2.3 *Method C*—This method requires that the *B* value remain constant when plotted against increasing back pressure. It is used to confirm that a fully saturated condition exists for dense cohesionless soil and overconsolidated stiff clay specimens when a lower than normal *B* value is determined (less than about 90%).

2. Significance and Use

The test methods presented here are used to determine the level of saturation of laboratory soil specimens confined in a triaxial pressure cell.

3. Apparatus

3.1 The apparatus shall consist of the following:

3.1.1 *Pressure Transducer*—An electrical single-port pressure transducer or differential pressure transducer capable of measuring pressure with an accuracy of ±0.5% full scale for combined linearity and hysteresis shall be used.

3.1.2 *Digital Readout*—An electrical display capable of resolution to three digits shall be used. A three-digit display has a resolution of 0.1% of full scale.

3.1.3 *Other Equipment*—A triaxial pressure cell with associated accessories is also needed.

4. Procedure

4.1 *Method A*

NOTE 1—For many clay specimens that are very close to being fully saturated flushing is not required.

NOTE 2—Caution should be exercised when flushing soil specimens because of the possibility of (1) localized liquefaction of loose sands, (2) changing the electrolytic nature of the pore fluid, (3) decreasing the existing specimen saturation if the water used for flushing is not perfectly deaired, and (4) leaching of soluble salts in the specimen.

4.1.1 Initially flush the sample with deaired water, using the smallest pressure gradient required to achieve flow. Maintain cell pressure during this step either at one half the final effective stress planned during consolidation or at a value that will prevent the specimen from swelling, whichever is less. At all times during the flushing operation the cell pressure must be greater than the

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[3] Original data were given in English customary units.

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back pressure, to prevent destruction of the specimen. A pressure gradient of about 6.89 kPa (1.0 psi) is typically used. Typical flushing times for different classes of soil and specimen sizes are presented in Table 1.

4.1.2 After flushing the specimen reduce the pressure gradient to zero and allow the specimen to reach equilibrium.

4.1.3 Close the specimen drainage valves.

4.1.4 Increase the cell pressure by about 34.5 kPa (5.0 psi).

4.1.5 Allow the specimen to reach equilibrium under the imposed stress condition as indicated by a constant pore water pressure reading. Typical times to reach equilibrium are approximately 1 min for sands, 3 min for silts, and 10 min for clays.

4.1.6 Record all data on a form such as that shown in Fig. 1 and calculate the corresponding *B* value.

4.1.7 Reduce the cell pressure by 34.5 kPa (5.0 psi).

4.1.8 Open specimen drainage lines.

4.1.9 Check to see whether the *B* criterion has been achieved. Typical *B* criteria for different classes of soil and saturation levels are presented in Table 2 [2]. If the criterion has been achieved, consolidate the sample under the required effective stress. If an acceptable *B* value is not achieved repeat the procedure, starting from 5.1.1.

NOTE 3—This method presents a significant problem in that low *B* values are typically measured initially, resulting in a cycling of the effective consolidation stress. Refer to Section 6.3 for a more detailed discussion. An alternative procedure to reduce the cycling of the effective consolidation stress is to go to a relatively high back pressure ($\simeq$690.0 kPa [100 psi]) before performing a *B* value test.

Using a high back pressure will increase the saturation level of the specimen. Guidelines are presented for the appropriate back pressure in Fig. 2 [3] and for the time required to ensure various levels of saturation for different initial levels of saturation in Fig. 3.

BACK PRESSURE (psi)	CELL PRESSURE (psi)	AXIAL LOAD (lb)	DVM READING			B-VALUE
			BACK PRESSURE (psi)	CELL PRESSURE (psi)	EFFECTIVE PRESSURE (psi)	

PROJECT NUMBER ____________ COMPUTED BY ____________ DATE ____________

BORING NUMBER ____________ CHECKED BY ____________ DATE ____________

SAMPLE NUMBER ____________ TRIAL NUMBER ____________

DEPTH INTERVAL ____________

REMARKS ____________

FIG. 1—*Computation of* B.

4.2 *Method B*

4.2.1 Refer to Note 2 on the effect of flushing a specimen before beginning this step. Initially flush the specimen with deaired water, using the smallest pressure gradient required to achieve flow. A pressure gradient of 6.89 kPa (1.0 psi) is typically used. Typical flushing times for different classes of soil and specimen sizes are presented in Table 1. Maintain cell pressure during flushing at one half the final effective stress planned during consolidation or at a value that will prevent the specimen from swelling, whichever is smaller. At all times during the flushing operation the cell pressure must be greater than the back pressure, to prevent destruction of the specimen.

TABLE 1—*Typical flushing times for different classes of soil and specimen sizes.* [a]

Soil Class	Sample Diameter, mm (in.)	Flushing Time, min (h)
Soft [b]	35.6 (1.4)	... [c]
Soft [b]	63.5 (2.5)	... [c]
Silts	35.6 (1.4)	833 (14)
Silts	63.5 (2.5)	1533 (25)
Sands	35.6 (1.4)	8
Sands	63.5 (2.5)	25

[a] Flushing times for sands and silts are based on the time required for 100 mL of water to pass through each unit area of the specimen. A 13.8 kPa (2.0 psi) gradient across the specimen is assumed.

[b] Normally consolidated clays.

[c] Clays typically cannot be thoroughly flushed in a reasonable time. It is recommended that filter strips be used on the outside of the specimen and that the specimen be flushed for 8 h.

4.2.2 After flushing the specimen reduce the pressure gradient to zero and allow the specimen to reach equilibrium.

4.2.3 Increase the back pressure to 138 kPa (20.0 psi) and the cell pressure to the value required to give the desired effective consolidation stress. The cell pressure and back pressure should be increased in increments of about 34.5 kPa (5.0 psi). The cell pressure should always be maintained greater than the back pressure. Refer to Note 3 on the effect of conducting a *B* value test on a soil with initial low saturation.

4.2.4 Allow the specimen to reach equilibrium under the imposed stress conditions, as indicated by either a relatively constant pore water pressure response with time if the back pressure value is closed momentarily or the end of primary consolidation.

4.2.5 Close the drainage valves and increase the cell pressure by an amount equal to one half the effective stress or by about 69 kPa (10.0 psi), whichever is smaller. Allow the specimen to reach an equilibrium state and note the corresponding change in pore pressure.

4.2.6 Record all data on a form such as that shown in Fig. 1 and calculate the resulting *B* value.

4.2.7 Reduce the cell pressure to the value obtained in 4.2.3.

4.2.8 Open the specimen drainage lines.

4.2.9 Check to see whether the *B* value criterion has been

TABLE 2—B *values for different types of soil at complete and nearly complete saturation* [2].

Soil Class[a]	e[b]	C_d, 1/kPa (in.^{2}/lb)[b]	B Values		
			$S_r = 100\%$	$S_r = 99.5\%$	$S_r = 99.0\%$
Soft	2.0	0.145×10^{-2} (1×10^{-2})	0.9998	0.992	0.986
Medium	0.6	0.145×10^{-3} (1×10^{-3})	0.9988	0.963	0.930
Stiff	0.6	0.145×10^{-4} (1×10^{-4})	0.9877	0.69	0.51
Very stiff	0.4	0.145×10^{-5} (1×10^{-5})	0.9130	0.20	0.10

[a] Soil class designations are as follows: soft = normally consolidated clays; medium = compacted clays; stiff = stiff clays and sands; and very stiff = very high consolidated pressures.

[b] Approximate values only are given for void ratio e and compressibility of soil structure C_d.

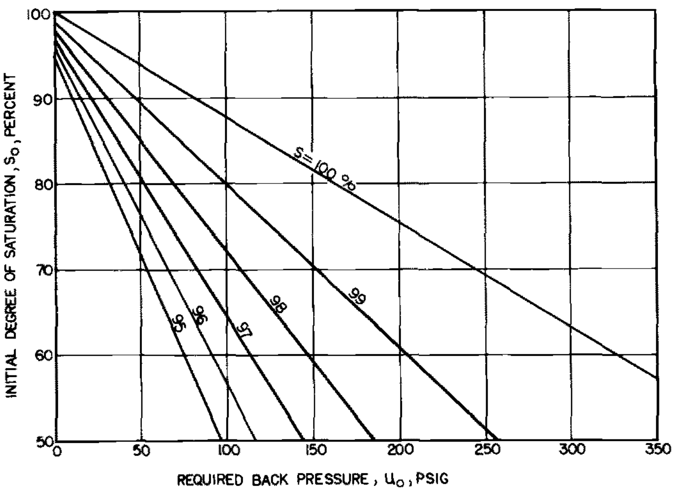

FIG. 2—*Back pressure required to attain various degrees of saturation (after Ref* 3).

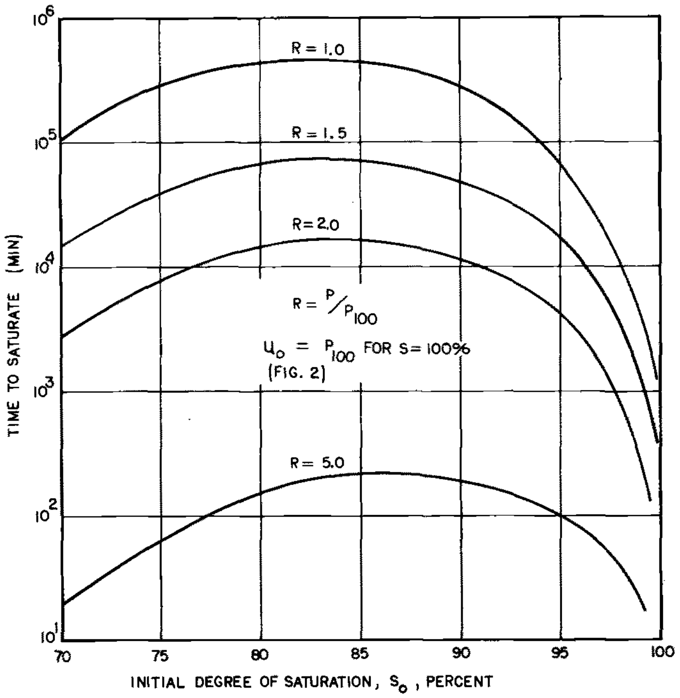

FIG. 3—*Time needed to saturate sample by using back pressure (after Ref* 2).

achieved. If so, conduct the required test. If not, go to Item 4.2.10.

4.2.10 Increase the back pressure by one half the effective stress or about 69 kPa (10.0 psi), whichever is smaller. Increase the cell pressure by an amount equal to the increase in back pressure.

4.2.11 Continue the procedure specified in Step 4.2.10 until the back pressure has been increased by approximately 138 kPa (20.0 psi) over the back pressure measurement at the start of the previous B value test.

4.2.12 Repeat steps 4.2.5 through 4.2.11 until an acceptable B value is achieved. If the pressure limit of the system is reached without achieving an acceptable B value, then reflush the specimen with deaired water without reducing the pressure. If this operation is still not successful, do either of the following: (1) let the specimen remain at high pressure for a period of time (12 h max) and periodically monitor the B value until an acceptable condition is reached, or (2) remove the pressure on the specimen and start again at 4.2.1.

4.3 *Method C*

4.3.1 Follow steps 4.2.1 through 4.2.12 of Method B with the addition that results are plotted on a form such as that shown in Fig. 4. The criterion for full saturation ($S_r \simeq 100\%$) is that the plot of B versus back pressure becomes flat with increasing back pressure, as shown in Fig. 5 (Curve 1). In addition to the curve for the fully saturated case, two other typical curves are presented in Fig. 5—one for an unsaturated material (Curve 2) and one for a specimen that is experiencing membrane leak (Curve 3).

5. Calculations

5.1 Calculate the B value of the specimen by dividing the change in back pressure by the change in cell pressure. This relationship is given as:

$$B = \Delta u / \Delta \sigma_3$$

where

Δu = change in back pressure and
$\Delta \sigma_3$ = change in cell pressure.

If a differential pressure transducer is used then use the following expression:

$$B = 1.0 - \Delta\bar{\sigma}/\Delta\sigma_3$$

where $\Delta\bar{\sigma}$ = change in effective stress.

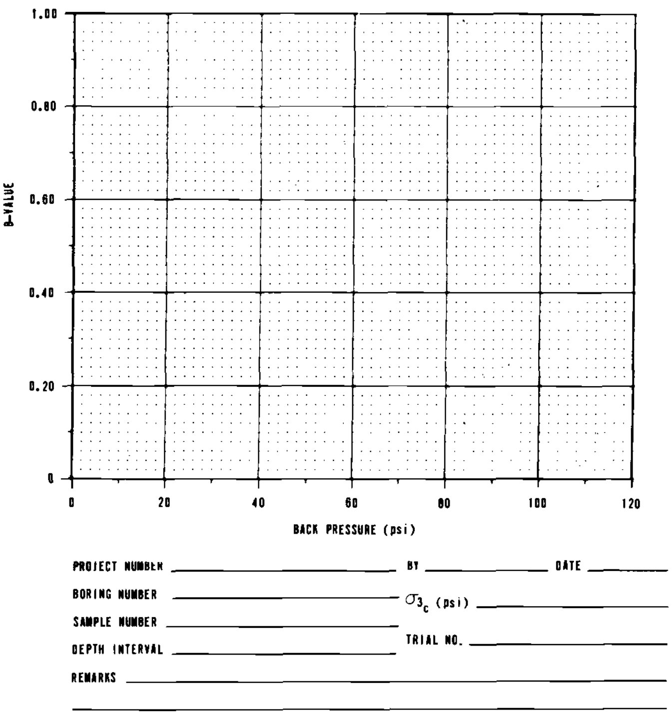

FIG. 4—*Plot of* B *versus back pressure.*

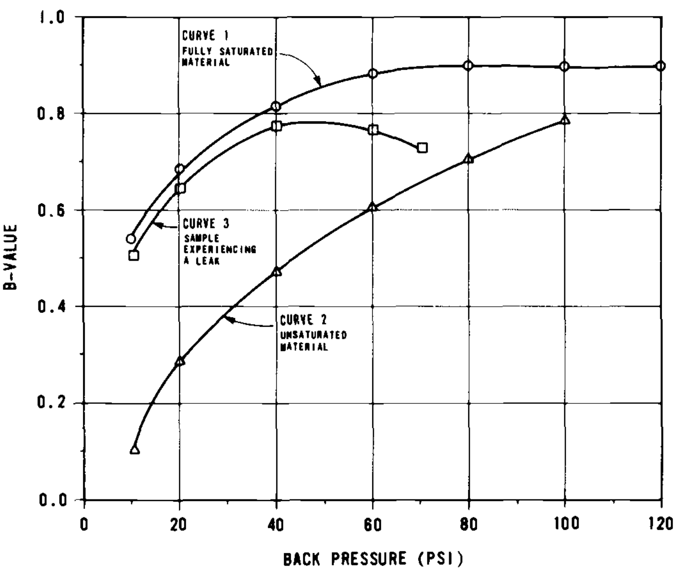

FIG. 5—*Plot of* B *versus back pressure with typical sample responses.*

6. Comments

6.1 The *B* parameter has been shown by various authors to be a function of the soil's porosity, the compressibility of the soil structure, the compressibility of the pore water, the absolute pressure existing in the pore fluid, and the degree of saturation. The *B* parameter may be expressed as a function of these variables by using the equation below [*4*].

$$B = \frac{1}{1 + nS_r(C_w/C_d) + (n/C_dP_a)(1 - S_r)}$$

where

C_w = compressibility of water,
C_d = compressibility of the soil structure,
P_a = absolute pressure in the pore liquid, and
n = porosity of the specimen.

According to this equation *B* will decrease below unity for specimens that are either not fully saturated or very stiff. To demonstrate the effect of specimen stiffness, *B* is presented in Fig. 6 as a function of the theoretical degree of saturation for Monterey No. 20-30 sand at relative densities of 53 and 93% for P_a = 446 kPa (64.7 psi) (344 kPa [50.0 psi] gage pressure) [*5*]. Values of C_d given in Fig. 6 were estimated from experimental test results presented by Lee et al [*6*]. A review of Fig. 6 shows that for a given S_r the corresponding *B* value for a relative density D_r of 53% is higher than for D_r = 93.5%. To handle the problem of very stiff soils Wissa [*7*] and Lee et al [*6*] have both recommended determining *B* at several successively higher back pressures while keeping the effective consolidation pressure approximately constant. A measured *B* value that is constant and independent of the magnitude of the back pressure indicates full saturation ($S_r \simeq 100\%$).

6.2 For more rapid achievement of high *B* values in partially saturated cohesionless specimens, flush initially with carbon dioxide (CO_2) gas before flushing with deaired water. This procedure was developed by Chan.[4] In practice the CO_2 gas should be applied to the bottom specimen platen and vented from the top platen into a beaker of water that is open to the atmosphere. For maximum effectiveness the CO_2 gas should be applied at

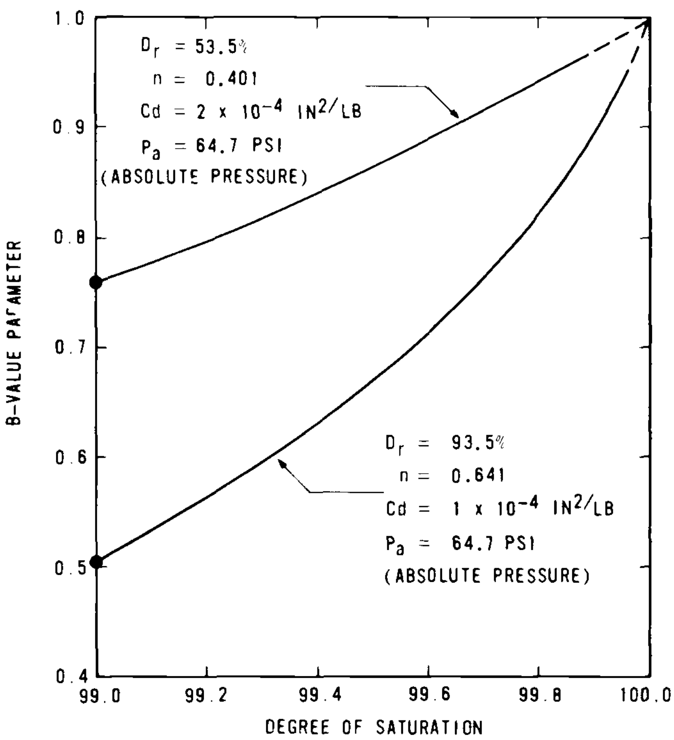

FIG. 6—B *versus* S_r (*after Ref* 5).

[4]Personal communication with C. K. Chan, University of California at Berkeley, 1972.

very low pressures to prevent trapping unwanted air. This procedure should not be used with soils where reaction to CO_2 is possible, such as those containing lime or limestone sands. Limestone is known chemically as calcium carbonate ($CaCO_3$).

6.3 If a B value test is performed on a partially saturated specimen the effective consolidation stress will undergo an increase and then decrease in magnitude (cycling). The magnitude of the stress involved can be given for a loose sand or soft clay by the equation below (For stiffer materials the effect of C_d must be included.):

$$\Delta\bar{\sigma} = \Delta\sigma_3(1.0 - B)$$

The physical effect of cycling of the effective consolidation stress is depicted schematically in Fig. 7. A review of Fig. 7 shows that on the first application of the cell pressure increment $\Delta\sigma_3$ on a partially saturated soil the initial effective consolidation stress $\bar{\sigma}_i$ imposed on the specimen is increased by an amount designated $\Delta\bar{\sigma}_1$. This increase in effective stress results in a decrease in the specimen's void ratio from e_i to e_1. Then, upon removal of the increment $\Delta\sigma_3$ corresponding to $\Delta\bar{\sigma}_1$, the sample rebounds to a void ratio e_2, which is greater than e_1. If the B criterion is not met the

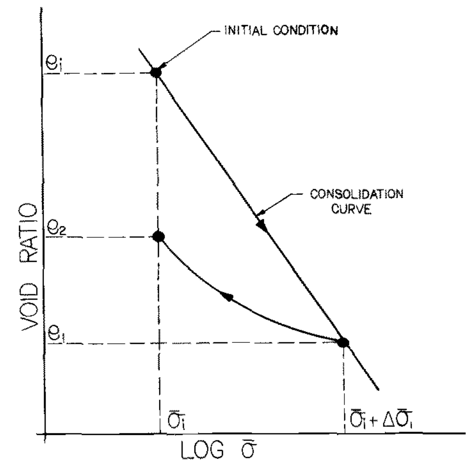

FIG. 7—*Schematic behavior of partially saturated soil during successive B tests.*

specimen is then flushed or the back pressure raised or both in an attempt to increase the level of saturation, and the B test is performed again. As a result of this series of B tests the specimen is effectively undergoing a slow cyclic loading. As a consequence the strength behavior of the specimen is altered, as has been demonstrated by Ladd [*8*] and Drnevich [*9*].

Acknowledgments

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References

[*1*] Skempton, A. W., "The Pore Pressure Coefficients A and B," *Geotechnique,* Vol. 4, No. 4, Dec. 1954, pp. 143–147.
[*2*] Black, D. K. and Lee, K. L., "Saturday Laboratory Samples by Back Pressure," Proceedings Paper 9484, *Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers,* Vol. 99, No. SM 1, Jan. 1973, pp. 75–93.
[*3*] *Laboratory Soils Testing,* EM1110-2-1906, U.S. Army AG Publications Center, Baltimore, Nov. 1970.
[*4*] Lade, P. V. and Hernandez, S. B., "Membrane Penetration Effects in Undrained Tests," Proceedings Paper 12758, *Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers,* Vol. 103, No. GT 2, Feb. 1977, pp. 109–125.
[*5*] Chaney, R. C., "Saturation Effects on the Cyclic Strength of Sands," *Proceedings of the ASCE Geotechnical Engineering Division Specialty Conference on Earthquake Engineering and Soil Dynamics,* Vol. 1, American Society of Civil Engineers, New York, 1978, pp. 342–358.
[*6*] Lee, K. L., Morrison, R. A., and Haley, S. C., "A Note on the Pore Pressure Parameter B," *Proceedings of the Seventh International Conference on Soil Mechanics and Foundation Engineering,* Vol. 1, Institute of Civil Engineers, London, 1969, pp. 231–238.
[*7*] Wissa, A. E. Z., "Pore Pressure Measurement in Saturated Stiff Soils," Proceedings Paper 6670, *Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers,* Vol. 95, No. SM 4, July 1969, pp. 1063–1073.
[*8*] Ladd, R. S., "Cyclic Behavior of Sands as Determined in the Laboratory for Earthquake Analysis," unpublished lecture notes on Quality Geotechical Laboratory Testing, University of Missouri, Rolla, Mo., May 1976.
[*9*] Drnevich, V. P. and Massarsch, K. R., "Effect of Sample Disturbance on Stress-Strain Behavior," Preprint 3440, *Proceedings of Specialty Session on Soil Sampling and Its Importance to Dynamic Laboratory Testing,* American Society of Civil Engineers, New York, 1978, pp. 212–243.