PDHonline Course C264 (4 PDH)

Laboratory Testing and Interpretation of Rock Properties

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CHAPTER 8.0

LABORATORY TESTING FOR ROCKS

8.1 INTRODUCTION

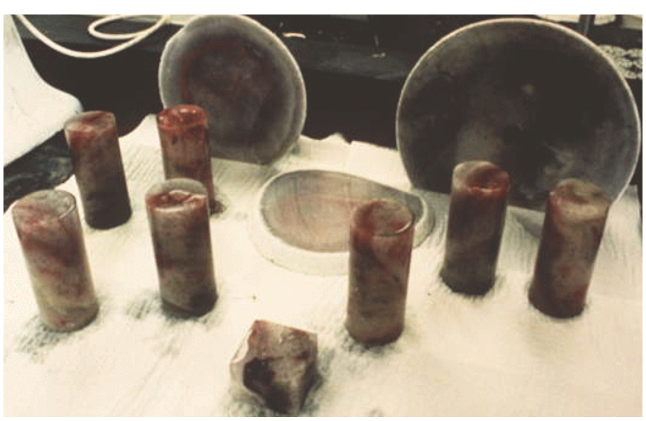
Laboratory rock testing is performed to determine the strength and elastic properties of intact specimens and the potential for degradation and disintegration of the rock material. The derived parameters are used in part for the design of rock fills, cut slopes, shallow and deep foundations, tunnels, and the assessment of shore protection materials (rip-rap). Deformation and strength properties of intact specimens aid in evaluating the larger-scale rock mass that is significantly controlled by joints, fissures, and discontinuity features (spacing, roughness, orientation, infilling), water pressures, and ambient geostatic stress state.

8.2 LABORATORY TESTS

Common laboratory tests for intact rocks include measurements of strength (point load index, compressive strength, Brazilian test, direct shear), stiffness (ultrasonics, elastic modulus), and durability (slaking, abrasion). Table 8-1 gives a summary list of laboratory rock tests and procedures by ASTM. Brief sections discuss the common tests (denoted with an asterisk*) useful for a standard highway project involving construction in rock.

8.2.1 Strength Tests

The laboratory determination of intact rock strength is accomplished by the following tests: point load index, unconfined compression, triaxial compression, Brazilian test, and direct shear. The uniaxial (or unconfined) compression test provides the general reference value, having a respective analogy with standard tests on concrete cylinders. The uniaxial compressive strength ($q_u = F_u$) is obtained by compressing a trimmed cylindrical specimen in the longitudinal direction and taking the maximum measured force divided by the cross-sectional area. The point load index serves as a surrogate for the UCS and is a simpler test in that irregular pieces of rock core can be used. A direct tensile test requires special end preparation that is difficult for most commercial labs, therefore tensile strength is more often evaluated by compression loading of cylindrical specimens across their diameter (known as the Brazilian test). Direct shear tests are used to investigate frictional characteristics along rock discontinuity features.



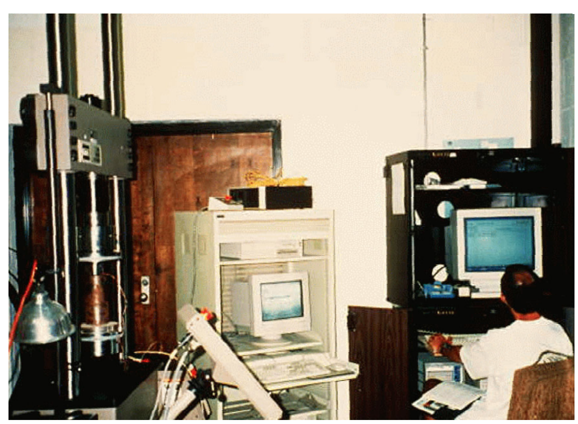


Figure 8-1: (a) Intact Rock Specimens for Laboratory Testing; (b) Compressive Strength Testing.

TABLE 8-1.

STANDARDS & PROCEDURES FOR LABORATORY TESTING OF INTACT ROCK

Test Category	*Name of Test*	*Test Designation*	
		AASHTO	*ASTM*
Point Load Strength	Method for determining point load index (I_s)	-	D 5731*
Compressive Strength	Compressive strength ($q_u = F_u$) of core in unconfined compression (uniaxial compression test)	-	D 2938*
	Triaxial compressive strength without pore pressure	T 226	D 2664
Creep Tests	Creep-cylindrical hard rock core in uniaxial compression	-	D 4341
	Creep-cylindrical soft rock core in uniaxial compression	-	D 4405
	Creep-cylindrical hard rock core, in triaxial compression	-	D 4406
Tensile Strength	Direct tensile strength of intact rock core specimens	-	D 3936
	Splitting tensile strength of intact core (Brazilian test)	-	D 3967*
Direct Shear	Laboratory direct shear strength tests - rock specimens, under constant normal stress	-	D 5607*
Permeability	Permeability of rocks by flowing air	-	D 4525
Durability	Slake durability of shales and similar weak rocks	-	D 4644*
	Rock slab testing for riprap soundness, using sodium/magnesium sulfate	-	D 5240*
	Rock-durability for erosion control under freezing/thawing	-	D 5312*
	Rock-durability for erosion control under wetting/drying	-	D 5313
Deformation and Stiffness	Elastic moduli of intact rock core in uniaxial compression	-	D 3148*
	Elastic moduli of intact rock core in triaxial compression	-	D 5407
	Pulse velocities and ultrasonic elastic constants in rock	-	D 2845*
Specimen Preparation	Rock core specimen preparation	-	D 4543
	Rock slab preparation for durability testing	-	D 5121

Note: *Routine rock test procedure described in this manual

Point Load Index (Strength)	
ASTM	D 5731
Purpose	To determine strength classification of rock materials through an index test.
Procedure	Rock specimens in the form of core (diametral and axial), cut blocks or irregular lumps are broken by application of concentrated load through a pair of spherically truncated, conical platens. The distance between specimen-platen contact points is recorded. The load is steadily increased, and the failure load is recorded. There is little sample preparation. However, specimens should conform to the size and shape requirements as specified by ASTM. In general, for the diametral test, core specimens with a length-to-diameter ratio of 1.0 are adequate while for the axial test core specimens with length-to-diameter ratio of 0.3 to 1.0 are suitable. Specimens for the block and the irregular lump test should have a length of 50±35 mm and a depth/width ratio between 0.3 and 1.0 (preferably close to 1.0). The test specimens are typically tested at their natural water content. Size corrections are applied to obtain the point load strength index, $I_{s(50)}$, of a rock specimen. A strength anisotropy index, $I_{a(50)}$, is determined when $I_{s(50)}$ values are measured perpendicular and parallel to planes of weakness.
Commentary	The test can be performed in the field with portable equipment or in the laboratory (Figure 8-1). The point load index is used to evaluate the uniaxial compressive strength (F_u). On the average, F_u . 25 $I_{s(50)}$. However, the coefficient term can vary from 15 to 50 depending upon the specific rock formation, especially for anisotropic rocks. The test should not be used for weak rocks where F_u < 25 MPa.

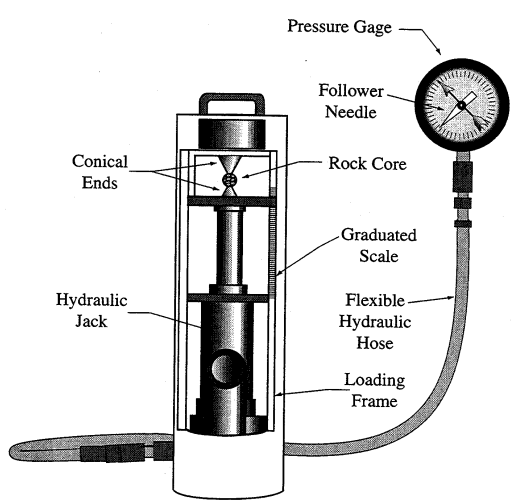


Figure 8-1: Point Load Test Apparatus. (Adopted from Roctest)

<table>
<tr><th colspan="2">Uniaxial Compression Test</th></tr>
<tr><td>AASHTO
ASTM</td><td>-
D 2938</td></tr>
<tr><td>Purpose</td><td>To determine the uniaxial compressive strength of rock ($q_u = F_u = F_C$).</td></tr>
<tr><td>Procedure</td><td>In this test, cylindrical rock specimens are tested in compression without lateral confinement. The test procedure is similar to the unconfined compression test for soils and concrete. The test specimen should be a rock cylinder of length-to-width ratio (H/D) in the range of 2 to 2.5 with flat, smooth, and parallel ends cut perpendicular to the cylinder axis. Originally, specimen diameters of NX size were used (D = 2⅛ in. = 44 mm), yet now the standard size is NQ core (D = 1⅞ in. = 47.6 mm).

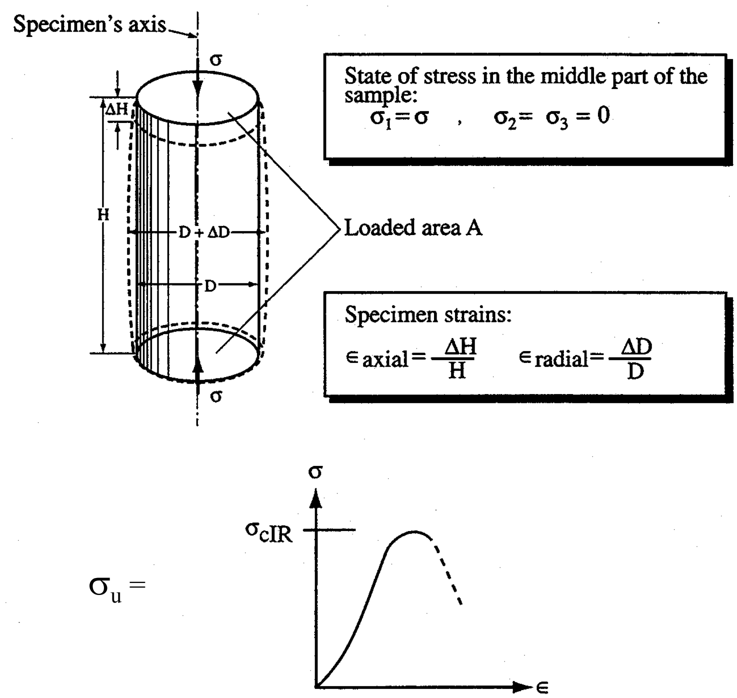
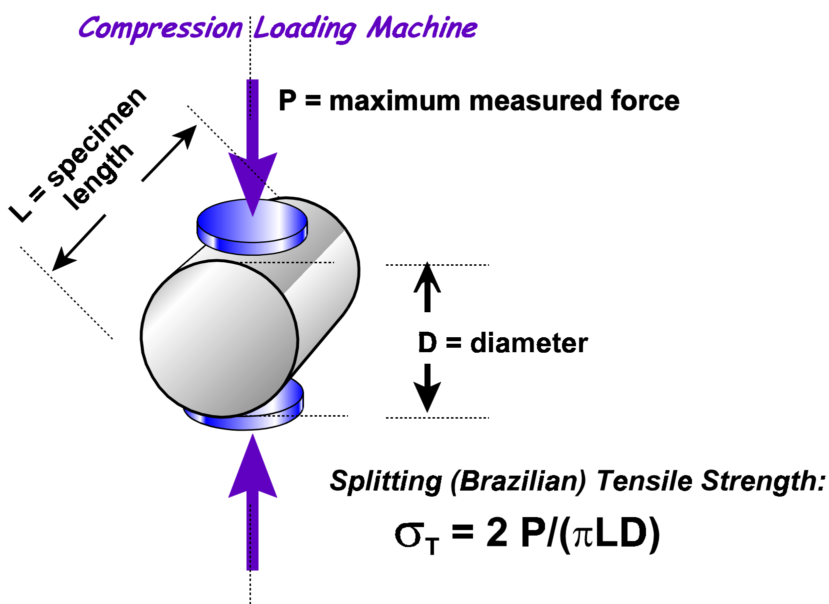
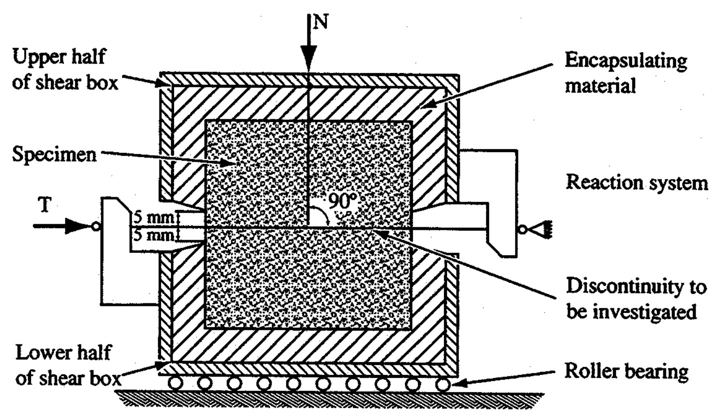
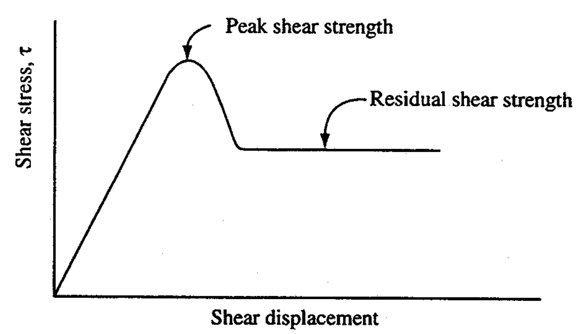
(a)

(b)

Figure 8-2: Uniaxial Compression Test on Rock with (a) Definitions of stress conditions and strains, (b) Derived stress-strain curve with peak stress corresponding to the uniaxial compressive strength ($q_u = F_u$)</td></tr>
<tr><td>Commentary</td><td>The uniaxial compression test is most direct means of determining rock strength. The results are influenced by the moisture content of the specimens, and thus should be noted. The rate of loading and the condition of the two ends of the rock will also affect the final results. Ends should be planar and parallel per ASTM D 4543. The rate of loading should be constant as per the ASTM test procedure. Inclined fissures, intrusions, and other anomalies will often cause premature failures on those planes. These should be noted so that, where appropriate, other tests such as triaxial or direct shear tests can be required.</td></tr>
</table>

Splitting Tensile (Brazilian) Test for Intact Rocks	
AASHTO ASTM	None D 3967
Purpose	To evaluate the (indirect) tensile shear of intact rock core, F_T.
Procedures	Core specimens with length-to-diameter ratios (L/D) of between 2 to 2.5 are placed in a compression loading machine with the load platens situated diametrically across the specimen. The maximum load (P) to fracture the specimen is recorded and used to calculate the split tensile strength.  **Figure 8-3. Setup for Brazilian Tensile Test in Standard Loading Machine.**
Commentary	The Brazilian or split-tensile strength (F_T) is significantly more convenient and practicable for routine measurements than the direct tensile strength test (T_0). The test gives very similar results to those from direct tension (Jaeger & Cook, 1976). It is a more fundamental strength measurement of the rock material, as this corresponds to a more likely failure mode in many situations than compression. Also, note that the point load index is actually a type of Brazilian tensile strength, that is correlated back to compressive strength. Additional details on tensile strengths of rocks is given in Chapter 10.

Direct Shear Strength of Rock	
AASHTO ASTM	- D 5607
Purpose	To determine the shear strength characteristics of rock along a plane of weakness.
Procedure	The laboratory test equipment is shown below in Figure 8-4. The specimen is placed in the lower half of the shear box and encapsulated in either synthetic resin or mortar. The specimen must be positioned so that the line of action of the shear force lies in the plane of the discontinuity to be investigated, and the normal force acts perpendicular to this surface. Once the encapsulating material has hardened, the specimen is mounted in the upper half of the shear box in the same manner. A strip approximately 5 mm wide above and below the shear surface must be kept free of encapsulating material. The test is then carried out by applying a horizontal shear force T under a constant normal load, N.  (a)  (b) **Figure 8-4: (a) General Set-up for Direct Shear Strength Testing of Rock** (Wittke, 1990) **(b) Derived Shear Stress vs. Shear Displacement Curve.** (ASTM D 5607, 1995)

	(Direct Shear Testing of Rock - Continued)
Commentary	Determination of shear strength of rock specimens is an important aspect in the design of structures such as rock slopes, foundations and other purposes. Pervasive discontinuities (joints, bedding planes, shear zones, fault zones, schistosity) in a rock mass, and genesis, crystallography, texture, fabric, and other factors can cause the rock mass to behave as an anisotropic and heterogeneous discontinuum. Therefore, the precise prediction of rock mass behavior is difficult. For nonplanar joints or discontinuities, shear strength is derived from a combination base material friction and overriding of asperities (dilatancy), shearing or breaking of the asperities, rotations at or wedging of the asperities (Patton, 1966). Sliding on and shearing of the asperities can occur simultaneously. When the normal force is not sufficient to restrain dilation, the shear mechanism consists of the overriding of the asperities. When the normal load is large enough to completely restrain dilation, the shear mechanism consists of the shearing off of the asperities. Using this test method to determine the shear strength of intact rock may generate overturning moments that induce premature tensile breaking. Thus, the specimen would fail in tension first rather than in shear. Rock shear strength is influenced by the overburden stresses; therefore, the larger the overburden stress, the larger the shear strength. In some cases, it may be desirable to conduct tests in-situ rather than in the laboratory to more accurately determine a representative shear strength of the rock mass, particularly when design is controlled by discontinuities filled with very weak material.

8.2.2 Durability

The evaluation of rock durability becomes an issue when the materials are to be subjected to the natural elements, seasonal weather, and repeated cycles of temperature (e.g., flowing water, wetting and drying, wave action, freeze and thaw, etc.) in its proposed use. Tests to measure durability depend on the type of rock, on its use in construction, and on the elements to which the rock will be subjected. The basis for durability tests are empirical and the results produced are an indication of the rock's resistance to natural processes; the rock's behavior in actual use may vary greatly from the test results. These tests, however, provide reasonably reliable tools for quality control. The suitability of various types of rock for different uses should, in addition to these test results, depend on their performance in previous applications. An example of the use of rock durability tests is in the evaluation of shale in rock fill embankments.

<table>
<tr><th colspan="2">Slake Durability</th></tr>
<tr><td>AASHTO
ASTM</td><td>-
D 4644 (for shales and similar weak rocks)</td></tr>
<tr><td>Purpose</td><td>To determine the durability of shale or other weak or soft rocks subjected to cycles of wetting and drying.</td></tr>
<tr><td>Procedure</td><td>In this test dried fragments of rock of known weight are placed in a drum fabricated with 2.0 mm square mesh wire cloth. Figure 8-4 shows a schematic of the test apparatus. The drum is rotated in a horizontal position along its longitudinal axis while partially submerged in distilled water to promote wetting of the sample. The specimens and the drum are dried at the end of the rotation cycle (10 minutes at 20 rpm) and weighed. After two cycles of rotating and drying the weight loss and the shape and size of the remaining rock fragments are recorded and the Slake Durability Index (SDI) is calculated. Both the SDI and the description of the shape and size of the remaining particles are used to determine the durability of soft rocks.

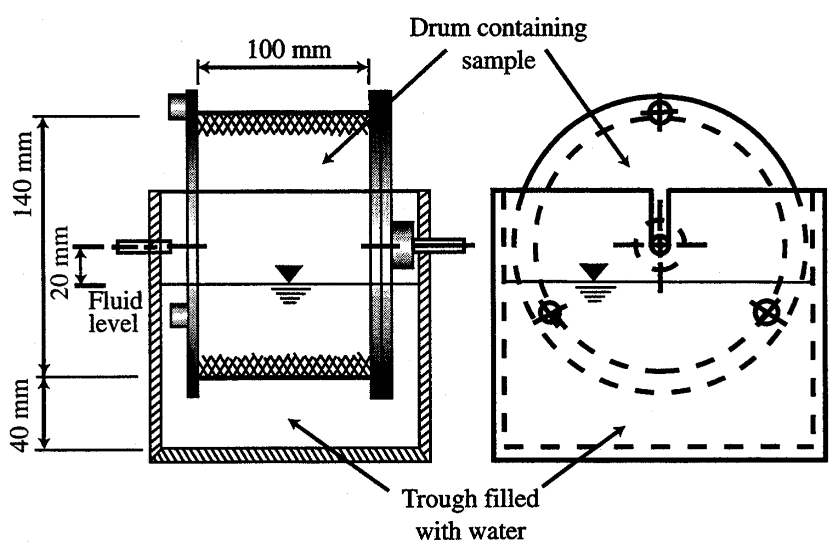


Figure 8-5: Rotating Drum Assembly and Setup of Slake Durability Equipment. (ASTM D 4644, 1995)</td></tr>
<tr><td>Commentary</td><td>This test is typically performed on shales and other weak rocks that may be subject to degradation in the service environment. When some shales are newly exposed to atmospheric conditions, they can degrade rapidly and affect the stability of a rock fill or cut, the subgrade on which a foundation is to be placed, or the base and side walls of drilled shafts prior to placement of concrete.</td></tr>
</table>

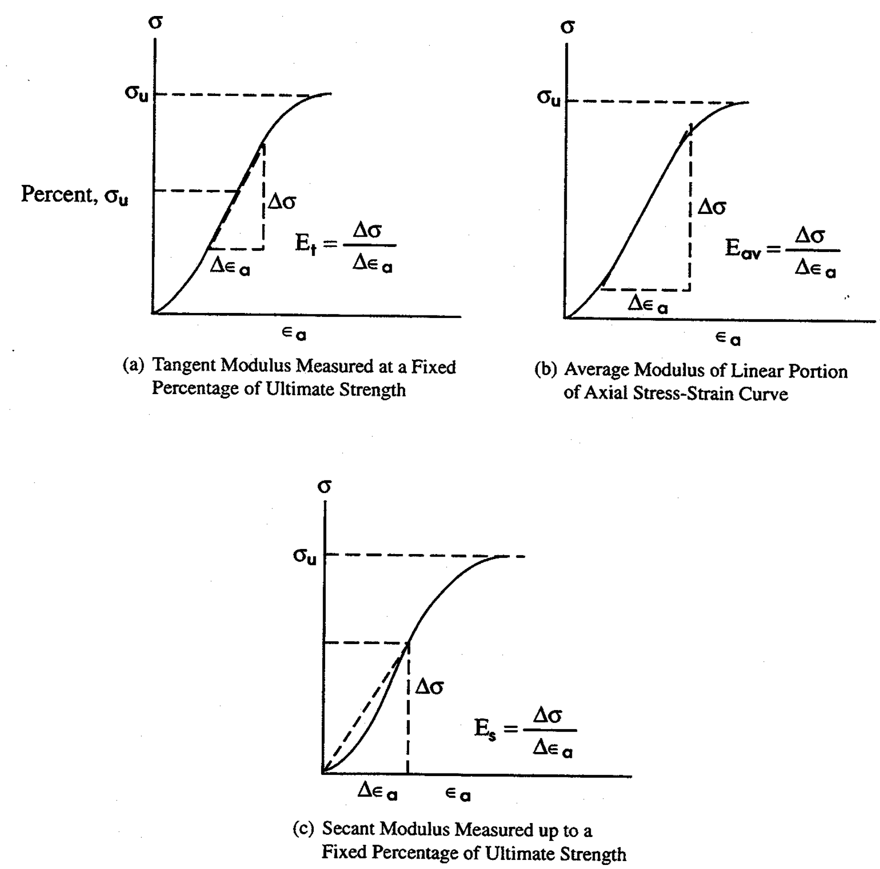
Soundness of Riprap	
AASHTO ASTM	- D 5240
Purpose	To determine the soundness of rock subjected to erosion.
Procedure	The procedure is known as the Rock Slab Soundness Test. Two representative, sawed, rock slab specimens are immersed in a solution of sodium or magnesium sulfate and dried and weighed for five cycles. The percent weight loss as a result of these tests is expressed as percent soundness.
Commentary	One of the most effective means to control erosion along riverbanks and coastal beaches is by covering exposed soil with rip-rap, or a combination of geosynthetics and rip-rap. Rock or stone used in this mode is subject to degradation from weathering effects due to repeated cycles of wetting & drying, as well as repeated exposure to salts used in de-icing of roadways. This test is used to estimate this type of degradation. A similar test for aggregates is available through ASTM C 88.

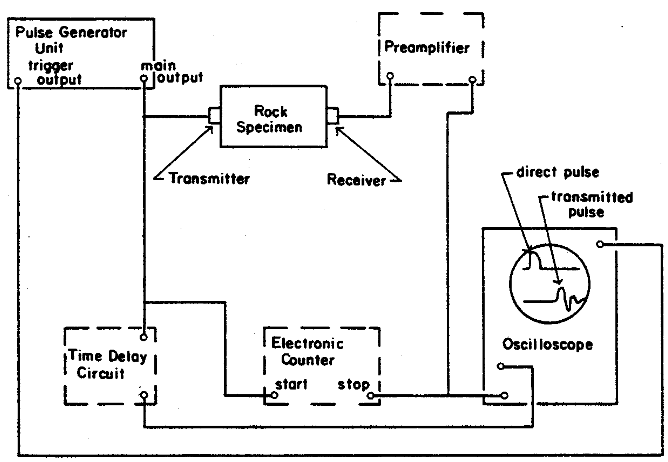
Durability Under Freezing and Thawing	
AASHTO ASTM	- D 5312
Purpose	To determine the resistance of rock used for erosion control to repeated cycles of freezing and thawing.
Procedure	Slabs of representative rock specimens are subjected to freezing and thawing cycles in the laboratory. The loss of dry weight at the end of five successive cycles of freezing, thawing, and drying is expressed as percent loss due to freeze/thaw.
Commentary	This test is useful in assessing the durability of rock due to weathering effects, in particularly for stone and gravel aggregates used in northern climates where seasonal winters will degrade their use in highway construction. It can also be used to assess the durability of armor stones placed for shore protection or rip-rap placed for shoreline protection or dam embankment protection.

As discussed above, none of these tests provide results which can be used independent of each other or independent of other tests and experience. Often the behavior of rip-rap stone in actual use will vary widely from the laboratory behavior.

8.2.3. Deformation Characteristics of Intact Rocks

The stiffness of rocks is represented by an equivalent elastic modulus at small- to intermediate-strains.

Elastic Moduli	
AASHTO ASTM	- D 3148
Purpose	To determine the deformation characteristics of intact rock at intermediate strains and permit comparison with other intact rock types.
Procedure	This test is performed by placing an intact rock specimen in a loading device and recording the deformation of the specimen under axial stress. The Young's modulus, either average, secant, or tangent moduli, can be determined by plotting axial stress versus axial strain curves.  **Figure 8-6: Definitions for Determining Elastic (Young's) Modulus from Axial Stress-Strain Measurements During Compression Loading ,** including (a) Tangent, (b) Average, and (c) Secant Values. (ASTM D 3148)
Commentary	The results of these tests cannot always be replicated because of localized variations in the each unique rock specimen. They provide reasonably reliable data for engineering applications involving rock classification type, but must be adjusted to take into account rock mass characteristics such as jointing, fissuring, and weathering.

Ultrasonic Testing	
AASHTO ASTM	- D 2845
Purpose	To determine the pulse velocities of compression and shear waves in intact rock and the ultrasonic elastic constants of isotropic rock.
Procedure	Ultrasound waves are transmitted through a carefully prepared rock specimen. The ultrasonic elastic constants are calculated from the measured travel time and distance of compression and shear waves in a rock specimen. Figure 8-7 shows a schematic diagram of typical apparatus used for ultrasonic testing.  Note: Components shown by dashed lines are optional, depending on method of travel-time measurement and voltage sensitivity of oscilloscope. **Figure 8-7: Schematic Diagram of the Ultrasonics Apparatus (ASTM D 2845)**
Commentary	The primary advantages of ultrasonic testing are that it yields compression (P-wave) and shear (S-wave) velocities, and ultrasonic values for the elastic constants of intact homogeneous isotropic rock specimens. Elastic constants for rocks having pronounced anisotropy may require measurements to be taken across different directions to reflect orthorhombic stiffnesses and moduli, particularly if pronounced foliation, banding, layering, and fabric are evident. The ultrasonic evaluation of elastic rock properties of intact specimens is useful for rock classification purposes and the evaluation of static and dynamic properties at small strains (shear strains < 10^{-4} %). Older equipment only provides ultrasonic P-waves measurements, while new designs obtain both P- and S-wave velocites. When compared with wave velocities obtained from field geophysical tests, the ultrasonics results provide an index of the degree of fissuring within the rock mass. This test is relatively inexpensive to perform and is nondestructive, thus may be conducted prior to strength testing of intact cores to optimize data collection.

8.3 QUALITY ASSURANCE FOR LABORATORY TESTING OF ROCKS

In general, the general quality assurance guidelines presented previously on the laboratory testing of soils (Chapter 7) also apply for laboratory testing of intact rock. Herein, certain precautions applicable to laboratory rock testing are presented.

8.3.1 Cautions

Omissions or errors introduced during laboratory testing, if undetected, will be carried though the process of design and construction, possibly resulting in costly or unsafe facilities. Table 8-2 lists topics that should be considered and given proper attention in order that a reasonable assessment of the rock will be ascertained and an optimization of the geotechnical investigation can be realized in terms of economy, performance, and safety. Guidance in the proper handling and storage of rock cores may be found in ASTM D 5079 (Preserving & Transporting Rock Core Samples).

TABLE 8-2.

COMMON SENSE GUIDELINES FOR LABORATORY TESTING OF ROCKS

1. Provide protection of samples to avoid moisture loss and structural disturbance.
2. Clearly indicate proper numbering and identification of samples.
3. Storage of samples in controlled environments to prevent drying, overheating, & freezing.
4. Take care in the handling & selection of representative specimens for testing.
5. Consult the field logs while selecting test specimens.
6. Recognizing disturbances & fractures caused by coring procedures.
7. Maintain trimming & testing equipment in good operating condition.
8. Use of proper fittings, platens, o-rings, & membranes in triaxial, uniaxial, and shear tests.
9. Careful tolerances in trimming of ends and sides of intact cores.
10. Document frequency, spacing, conditions, & infilling of joints and discontinuities.
11. Maintain calibration of instruments used to measure load, deflections, temperatures, & time.
12. Use of properly-determined loading rate for strength tests.
13. Photo documentation of sample cores, fracture patterns, & test specimens for report.
14. Carefully align & level all specimens in directional loading apparatuses and test frames.
15. Record initial baselines, offsets, and eccentricities prior to testing.
16. Save remnant rock pieces after destructive testing by uniaxial, triaxial, & direct shear.
17. Conduct nondestructive tests (i.e., porosity, unit weight, ultrasonics) prior to destructive strength testing (compression, tensile, shear).