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Standard Test Method for
In Situ Stress and Modulus of Deformation Using the Flatjack Method[1]

This standard is issued under the fixed designation D 4729; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The flatjack test measures stress at a rock surface. The modulus of deformation and the long-term deformational properties (creep) may also be evaluated.

1.2 *Limitation*—The flatjack test measures stresses only at the surface of the test chamber. Undisturbed stress levels must be determined by theoretical interpretations of these data.

1.3 *Assumptions and Factors Influencing the Data*:

1.3.1 The stress relief is assumed to be an elastic, reversible process. In nonhomogeneous or highly fractured materials, this may not be completely true.

1.3.2 The equations assume that the rock mass is isotropic and homogeneous. Anisotropic effects may be estimated by testing in different orientations.

1.3.3 The flatjack is assumed to be 100 % efficient. The design and size requirements of 5.1 were determined to satisfy this requirement to within a few percent.

1.3.4 The jack is assumed to be aligned with the principal stresses on the surface of the opening. Shear stresses are not canceled by jack pressure. Orientating the tests in three directions in each plane tested prevents the misalignment from being excessive for at least one of the tests.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions:*

2.1.1 *cancellation pressure*—the pressure in the flatjack required to return the rock to its initial position.

2.1.2 *skin stress*—the tangential stress at the surface of an opening.

2.1.3 *undisturbed stress*—the stress field existing in a rock mass prior to excavation of an opening.

3. Summary of Test Method

3.1 The in situ stress in the rock mass is relieved by cutting a slot into the rock perpendicular to the surface of the test adit. The deformation caused by this stress relief is measured. A hydraulic flatjack is placed into the slot and is pressurized until the above-measured displacement is canceled. This reapplied stress is approximately equal to the stress in the rock mass at the test location in a direction perpendicular to the plane of the jack. The deformational characteristics of the rock mass are evaluated by incrementally loading the flatjack and measuring the deformation.

4. Significance and Use

4.1 *Tests in Orthogonal Directions*— The flatjack most accurately determines the stress parallel to the long axis of the adit, because this stress is the least affected by the presence of the opening. (The other tangential stress is highly concentrated.) In addition, if the adit is in a stress field where one of the stresses is significantly larger than the others (3 or 4 times), certain locations in the adit may be in very low compressive or even tensile stress. Flatjack tests in these locations can give anomalous and misleading results. Because of these factors, the test adit should have at least two, and preferably three, long (at least 4 to 5 times the diameter), straight sections at about 90° to each other. Testing should be distributed evenly in all three sections to provide redundant data and, if results in one section are anomalous, to allow the program to produce sufficient usable data.

5. Interferences

5.1 *Personnel Prequalification*:

5.1.1 *Test Personnel*—All personnel involved in performing the test, including the technicians and test supervisor, shall be formally prequalified.

5.1.2 *Drilling Personnel*—Quality drilling is important to achievement of successful flatjack tests. The drilling personnel should be capable of the precision drilling necessary to successfully produce the slot and instrument holes.

5.2 *Equipment Performance Verification*— The compliance of all equipment and apparatus with performance specifications apparatus shall be verified. If no requirements are stated, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard procedures.

5.3 *Local Geologic Features*—Local features, particularly faults, shear zones, etc., can influence the local stress field. Large inclusions in the rock can affect both the stress and deformational properties. Test locations should be carefully selected so that the effects of such features are minimized or, if they are the features of interest, accounted for fully.

5.4 *Influence of Excavations*—Other excavations intersecting the test adit will cause complex stress concentration effects by superposition. Flatjack tests should be located at least three diameters of the intersecting feature away from that feature. If the test adit is excavated by conventional methods, then the surfaces for testing should be further excavated by nonblasting techniques to remove loose material resulting from stress relief or blasting.

6. Apparatus

6.1 *Flatjacks*—Flatjacks shall be designed to operate at pressures of several thousand pounds per square inch when properly installed. The jacks shall be constructed so that the two main plates move apart in essentially a parallel manner over the range of the jack. The range shall be at least 0.25 in. (6 mm). The jacks should be square and no less than 2 ft (0.6 m) wide.

6.2 *Transducers*:

6.2.1 *Pressure*—Electronic transducers or hydraulic gages may be used to monitor flatjack pressure. The pressure transducer shall have an accuracy of at least ± 20 lb/in.^{2} (± 0.14 MPa), including errors introduced by the readout system and a sensitivity of at least 10 lb/in.^{2} (0.069 MPa).

6.2.2 *Deformation*—Deformation transducers include dial gages, Whittemore-type strain gages, and electronic transducers such as LVDT's or linear potentiometers. The transducer shall have an accuracy of at least ± 0.0001 in. (± 0.0025 mm) and a sensitivity of at least 0.00005 in. (0.0013 mm).

6.2.3 *Internal Gages*—Strain gages inside the flatjack shall be calibrated prior to installation in the jack. The effects of the hydraulic oil and ambient pressure increase on the gages shall be determined prior to testing.

6.3 *Mortar*—If mortar is used to cement the flatjack into the slot, a high-early strength, nonshrink material shall be used. The mortar may include up to 50 % clean sand by weight, with grain size between 20- and 60-mesh. Clean, potable water shall be used for the mortar. The cured mortar shall have a strength greater than the stress applied by the flatjack. The modulus of the mortar may be required to be removed from some of the determinations of rock modulus.

6.4 *Sawing Equipment*—Equipment used to saw a slot in the rock should be of a type where large center or end holes are not required. These large holes can cause serious changes in the stress field to be measured.

7. Procedure

7.1 *Groups at Each Test Station*—At least one group of jacks should be tested in each adit section. Each group should have three flatjacks installed horizontally inclined 45° and vertically. The jacks in each group should all be placed in one part of the adit within 20 ft (6.1 m) of each other along the length of the adit.

7.2 *Surface Preparation*:

7.2.1 *Rock Quality*—The flatjack and deformation transducers should not be installed. Loose, broken, or drummy material may be detected by a dull, hollow sound when struck with a hammer; such material should be removed.

7.2.2 *Dimensions*—The prepared surface shall extend at least 1 ft (0.30 m) past either end of the flatjack slot and at least 1 ft (0.30 m) past the furthest measuring points. The transducers or flatjack shall be 1 ft (0.30 m) inside the prepared surface at any point (see Fig. 1).

7.2.3 *Method*—Drilling to a uniform depth may be required to prepare the rock face. Residual rock between the drill holes may be removed by moving the bit back and forth until a smooth surface is achieved. Alternatively, in hard, competent rock, controlled blasting with very small charges may be used to remove the residual rock. In softer material, coarse grinding, chipping, or cutting devices may be required.

7.2.4 *Smoothness*—Ideally, the prepared surface shall be a plane. The difference between the highest and lowest points on the prepared surface shall be not greater than 2 in. (50 mm).

7.3 *Transducer Installation*—Transducers shall be installed on the centerline normal to the flatjack, either at the surface or at depth. Transducers for stress determination shall be installed within $L/2$ of the flatjack slot, where L is the width of the flatjack.

7.4 *Slot Cutting*—The slot can be formed by sawing or by drilling overlapping holes in weak or highly fractured material. Vibration should be minimized. The slot shall be no more than 3 in. (74 mm) wide, and extend no more than 3 in. (75 mm) past the edges of the flatjack. It shall be deep enough that the flatjack may be inserted 3 in. (75 mm) beyond the lowest point on the rock fact adjacent to the slot. If drilled, care shall be taken that the holes are straight and parallel to keep the bottom of the slot open to receive the jack. The slot shall be washed clean of all dirt and cuttings, using clean water.

7.5 *Relaxation Measurements*—Deformation shall be measured immediately upon completion of slot cutting and again
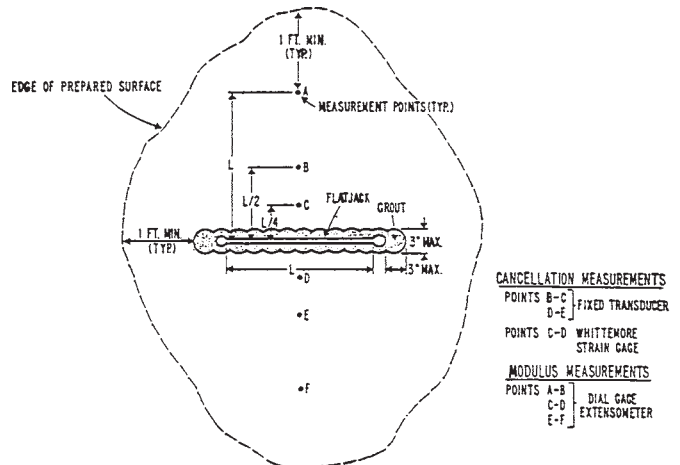

FIG. 1 Recommended Flatjack Measurement Array, Surface Measurements

immediately prior to testing. If the rock undergoes strain under constant load over a period of time, several intermediate readings shall be taken to evaluate this effect.

7.6 *Flatjack Installation*—Flatjacks shall be centered in the slot and recessed 3 in. (75 mm) from the face of the excavation to minimize the possibility of rupture during pressurization. The mortar, if used, should surround the jack and shall be free from voids. The jack shall be installed to allow sufficient time for the mortar to attain compressive strength greater than maximum anticipated jack stress.

7.7 *Flatjack Testing*—The flatjack pressure shall be raised in 100 lb/in.^{2} (0.7 MPa) increments until cancellation of all measuring points has been achieved. Deformation shall be read after each pressure increment. The peak pressure shall be maintained for 15 min to check for time-dependent deformation; deformation readings shall be taken every 5 min. The pressure shall be reduced in 100 lb/in.^{2} (0.69 MPa) decrements to zero, with deformation read after every decrement. Zero pressure shall be maintained for 15 min to check for time-dependent deformation; deformation readings shall be taken every 5 min. The cycle shall be repeated at least two more times using equal pressure increments and decrements. The peak jack stress of these cycles should be as high as possible and be determined by the test engineer in the field depending on the jack and rock strength and the cancellation pressure.

7.8 *Data Recording Requirements*—The data shown on Fig. 2 and Fig. 3 shall be recorded as a minimum.

8. Calculation

8.1 *General*—The calculation of stress and modulus of deformation from flatjack data is influenced by the complex loading geometry of the test. In addition, the load applied by the flatjack is not the same as the load originally acting on the rock. The jack expands in one direction only, so lateral and shear components are not restored. This is particularly significant when the jack is not aligned with a principal stress.

In Situ Stress and Modulus of Deformation Determination
Using the Flatjack Method

Test Data Sheet

FIG. 2 Test Data Sheet

FIG. 3 Test Data Sheet

Several elastic models and assumptions have been used to compensate for these factors, leading to varied and sometimes contradictory methods of data reduction. The equations presented here are among those more widely accepted and have been found to produce results comparable with those of other in situ methods. The analysis of data, however, is dependent on site-specific factors such as geology and the existing stress field. In the future, individualized analysis of each test by numerical techniques such as finite element methods may prove to be the most effective approach.

8.2 *Cancellation Pressure*—The cancellation pressure is not necessarily equal to the skin stress because of the factors discussed in 8.1. Skin stress calculations fall into two major categories: one in which deformations are measured on one side of the flatjack slot, and one in which deformations are measured across the slot.

8.2.1 When deformation is measured between points on one side of the flatjack slot, the skin stress is calculated using elastic theory and strain. Tincelin[2] found that the strain caused by cutting the slot was similar to the strain produced by a long elliptical opening in an elastic plate, and the strain produced by the flatjack was similar to that caused by uniformly loading the edge of a semi-infinite plate. The ratio of actual stress to cancellation pressure is shown in Table 1 for cancellation measured at various distances from the slot, and from several Poisson's ratios. These factors were derived by Tincelin for a

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[2] Tincelin, M. E., "Mesure des pressions de terrains dans les mines de fer de l'Est: Annales de l'Institut Technique de Batiment et des Travaux Publics," serie: *Sols et Foundations*, No. 58, pp. 972–990. Translated by S. H. Britt, U.S. Geological Survey open file report No. 28927, Washington, DC, 1953.