Designation: D 4645 – 04

Standard Test Method for Determination of the In-Situ Stress in Rock Using the Hydraulic Fracturing Method[1]

This standard is issued under the fixed designation D 4645; 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 This test method covers the determination of the in-situ state of stress in rock by hydraulic fracturing.

NOTE 1—Hydraulic fracturing for stress determination is also referred to as hydrofracturing, and sometimes as minifracing. Hydraulic fracturing and hydrofracturing may also refer to fracturing of the rock by fluid pressure for the purpose of altering rock properties, such as permeability and porosity.

1.2 Hydraulic fracturing is the widely accepted field method available for in situ stress measurements at depths greater than 50 m. It can be used in drill holes of any diameter.

1.3 Hydraulic fracturing can also be used in short holes for which other stress measuring methods, such as overcoring, are also available. The advantage of hydraulic fracturing is that it yields stresses averaged over a few square metres (the size of the induced hydraulic fracture) rather than over grain size areas, as in the case of overcoring techniques.

1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.4.1 The method used to specifiy how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *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. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock and Contained Fluids
D 2113 Practice for Diamond Core Drilling for Site Investigation
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D 5079 Practices for Preserving and Transporting Rock Core Sample
D 6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 For terminology used in this test method, refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *breakdown pressure*—the pressure required to induce a hydraulic fracture in a previously intact test interval.

3.2.2 *in-situ stress*—rock stress measured in situ (as opposed to by remote sensing).

3.2.3 *secondary breakdown (or fracture reopening, or refrac) pressure*—the pressure required to reopen a closed, previously induced hydrofracture after the test interval pressure has been allowed to return to its initial condition.

3.2.4 *shut-in pressure (or ISIP (instantaneous shut-in pressure))*—the pressure reached when the induced hydrofracture closes back after pumping is stopped.

3.2.5 *vertical and horizontal principal stresses*—the three principal stresses in situ are generally assumed to act one in the vertical direction and the other two in the horizontal plane.

4. Summary of Test Method

4.1 A section of the borehole is isolated by pressurizing two inflatable rubber packers. The fluid pressure in the sealed-off interval between the two packers is raised by pumping fluid into it at a controlled rate until a fracture occurs in the borehole wall. Pumping is stopped and the pressure in the interval is allowed to stabilize. The pressure is then reduced to the pore pressure level of the rock formation, and the pressurization process is repeated several times maintaining the same flow rate. Additional pressure cycles can be conducted at different flow rates. The magnitudes of the principal stresses are calculated from the various pressure readings. The orientation

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard.

of the fracture is detected in order to determine the orientation of the transverse principal stresses. A typical pressure versus time, flow rate versus time record for a test interval is shown in Fig. 1.

5. Significance and Use

5.1 *Limitations*:

5.1.1 The depth of measurement is limited only by the length of the test hole.

5.1.2 Presently, the results of the hydraulic fracturing method can be interpreted in terms of in-situ stresses only if the boreholes are approximately parallel to one of the three principal in-situ stresses. Unless evidence to the contrary exists, vertical boreholes are assumed to be parallel to one of the in-situ principal stresses.

5.1.3 When the principal stress parallel to the borehole axis is not the least principal stress, only the two other principal stresses can be determined directly from the test. If the minimum stress acts along the borehole axis, fractures both parallel and perpendicular to the axis of the borehole are sometimes induced by the test, allowing for the determination of all three principal stresses.

5.1.4 In the unlikely event that the induced fracture changes orientation away from the borehole, its trace on the borehole wall cannot be used in stress determinations.

5.2 *Assumptions*:

5.2.1 The rock tested is assumed to be linearly elastic, homogeneous, and isotropic. Any excessive departure from these assumptions could affect the results.

5.2.2 Vertical boreholes are assumed to be substantially parallel to one of the in-situ principal stresses, since it has been established from many geological observations and stress measurements by other methods that in most cases one of the principal stresses is vertical to subvertical.

5.3 Hydraulic fracturing determination of in-situ stresses can be complicated by rock matrix porosity, naturally occurring fractures, the presence of nearby underground openings, and local variations in the stress field.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection, etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

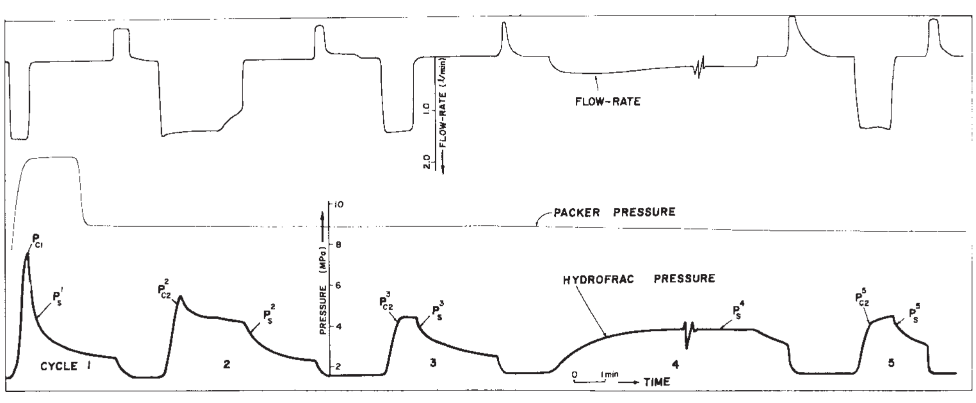
6. Apparatus

6.1 *Tripod or Drilling Rig*—Equipment for lowering the hydraulic fracturing tool into and lifting it from the test hole is necessary. To facilitate the lowering and lifting of the downhole hydrofracturing tool, a tripod or a drilling rig is set up on top of the test hole. When high-pressure tubing or drilling pipes (rods) are used for lowering the tool, it is necessary to use a drilling rig with a derrick and hoist capable of lifting the combined weight of the pipe and instruments. When a wireline-flexible hose system is used for hydrofracturing, a well-designed tripod capable of carrying the weight of the testing tool, wireline, and hoses is employed.

6.2 *Straddle Packer*—Borehole sealing is accomplished by two inflatable rubber packers, spaced apart a distance equal to at least six hole diameters, and interconnected mechanically and hydraulically to form one unit called the straddle packer.

6.3 *High-Pressure Tubing or Hose*—Packer and test-interval pressurization is accomplished either by a high-pressure tubing (drilling rod is often a good substitute) or by high-pressure hose, or by a combination of the two (where tubing is used to pressurize the interval, and the hose, which is strapped to the outside of the tubing facilitates packer inflation). The hose or the tubing, or both, are connected hydraulically at one end to pumps or pressure generators (0.70 MPa, 0 to 25 L/min are recommended ratings), and at the other to the straddle packer and the test interval between the packers (Fig. 2). It has been found that pump capacities similar to those given here can overcome almost any common rock permeability and facilitate pressurization.

6.4 *Pressure Transducers and Flow Meter*—Pressure transducers (10 to 70 MPa) are used to monitor the test interval pressure either on the surface or at the test depth (or both). In some setups, the packer pressure is also monitored in the same way as the test interval. A flow meter is used to monitor the flow rate of fluid into the test interval. The sensing devices feed into multichannel analog time-base recorders for real-time



NOTE 1—In this test the flow rate was maintained constant during the first three cycles. In the fourth cycle a very slow flow rate was maintained such that the top level of the pressure–time curve could be considered as the upper limit for the shut-in pressure.

FIG. 1 Typical Pressure – Time, Flow Rate – Time Records During Hydrofracturing

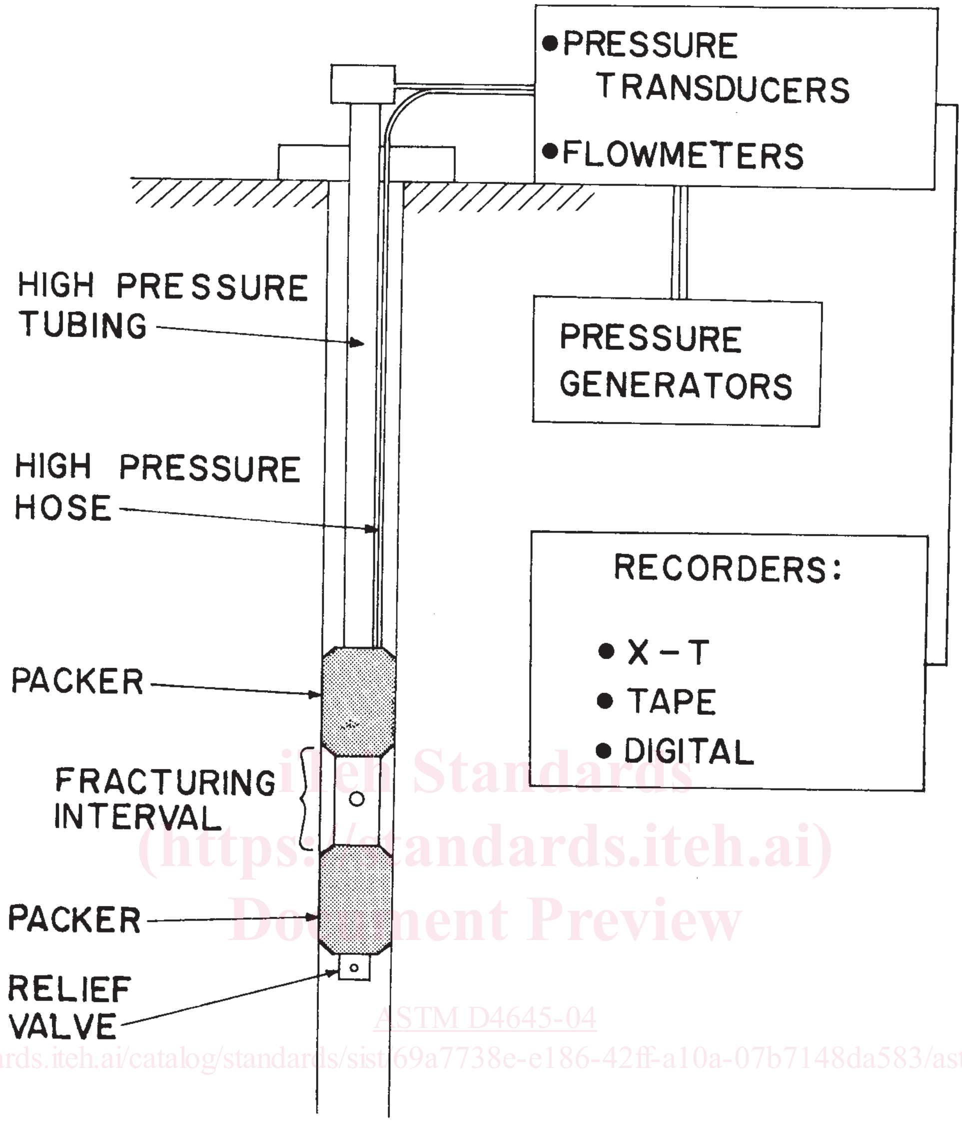


FIG. 2 Suggested Schematic Downhole and Surface Equipment Set Up for Hydraulic Fracturing

continuous permanent recording. Digital computer recording is carried out for the storage of test pressure and flow rate information which can later be used to provide a thorough analysis of the test data.

6.5 *Hydrofracture Delineation Equipment*:

6.5.1 *Impression Packer*—The presence and orientation of the induced hydrofracture is commonly recorded by the use of an impression packer, which is an inflatable packer with an outer layer of very soft semicured rubber. An orienting device, in the form of a magnetic borehole surveying tool or a gyroscopic borehole surveying tool, is used to determine the direction and inclination of the hydrofracture traced on the impression packer (Fig. 3).

6.5.2 *Borehole Televiewer*—An alternative to the oriented impression packer is the borehole televiewer, which is a sonic logging tool that takes an oriented acoustic picture of the borehole wall. This tool is considerably faster than the impression packer because it can take readings from an entire test hole in one trip. The impression packer requires retrieval after each test so that the outer cover can be properly marked or replaced before lowering the tool to the next zone. However, the borehole televiewer is considerably more expensive to own or rent, does not always discern hydrofractures that have closed tightly after the pressurization stage of the test, and requires a fluid filled borehole.

7. Personnel Prequalification and Equipment Verification

7.1 *Test Personnel*—The performance of a hydraulic fracturing test may vary from location to location, and from one rock type to the next. Quick decisions, which are often required in the field, may change the outcome of the tests. Hence, the test supervisor should be a person who thoroughly understands the theoretical aspects of the test method, and who has had substantial experience in conducting such tests in a variety of rock types, depths, and locations.

7.2 *Drilling Personnel*—Quality drilling is important to maintaining a reasonably straight vertical hole and in keeping a nearly circular cross-section.

7.3 *Equipment Verification*—The compliance of all equipment and apparatus with performance specifications shall be

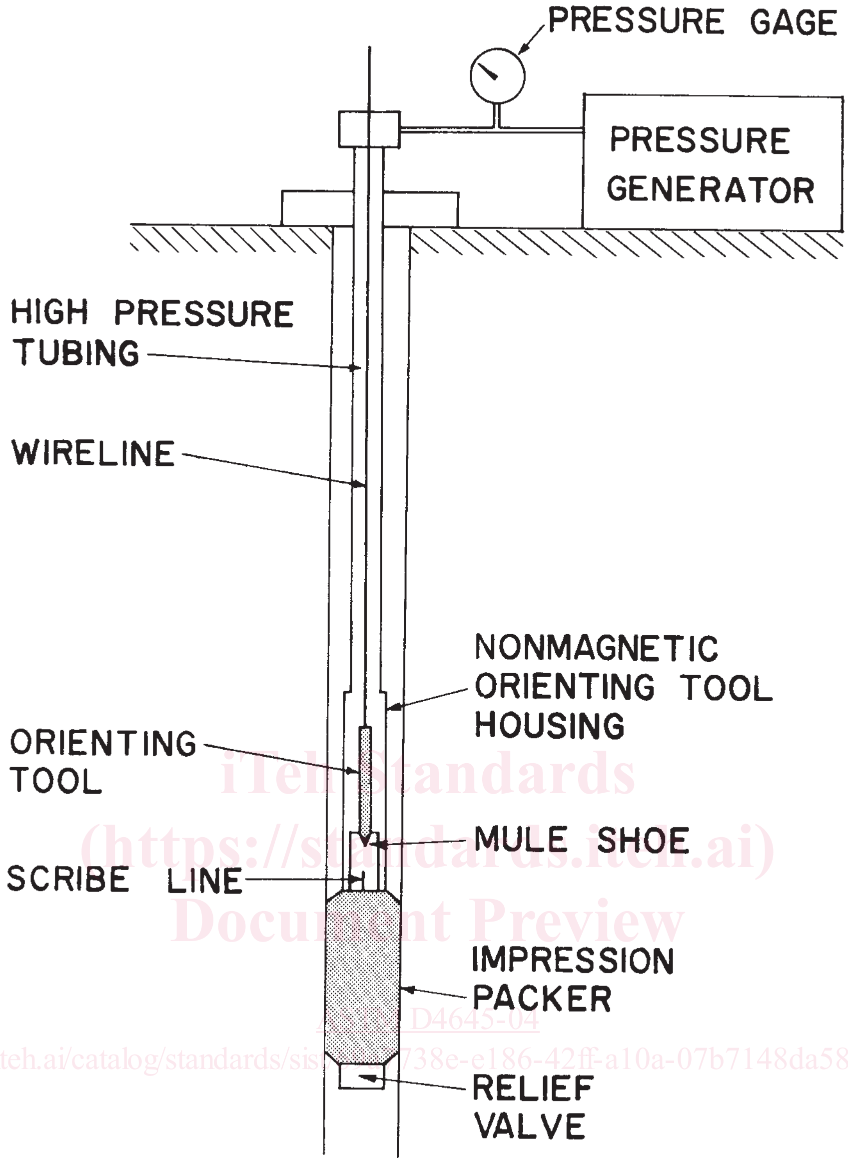


FIG. 3 Suggested Schematic Downhole and Surface Equipment Set Up for Taking a Packer Impression of the Hydraulic Fracture

verified. Performance specification is generally done by calibrating the equipment and measurement systems.

8. Procedure

8.1 Drill a borehole (in most cases in the vertical direction) to the depth of interest. Diamond bit coring is recommended because it yields a continuous core and leaves a smooth and uniformly circular borehole wall.

8.2 Select testing zones of solid unfractured rock within the drilled hole, making use of the core, if available, or one or more geophysical logs (such as caliper, density, borehole televiewer) if they have been run.

8.3 To seal off the test interval, lower the straddle packer to the predetermined depth of testing and pressurize hydraulically so as to inflate packers onto the wall of the borehole. The pressurization, typically using water, is generated on the surface by a high-pressure pump and is conveyed to the packer by means of tubing or flexible hose.

8.4 With the packers well anchored to the sidewalls (a packer pressure of 3 MPa is usually sufficient at this stage of the test), pressurize hydraulically (typically using water) the test interval between the packers at a constant flow rate. This rate may change from one test hole to the next, often depending on the permeability of the rock (the higher the permeability the higher the rate). The general principle is to affect hydrofracturing within a minute or so from the beginning of interval pressure rise. Throughout the interval pressurization, maintain packer pressure at a level of about 2 MPa higher than the interval to ensure that no leak-offs occur. As the rock hydrofractures, the breakdown pressure is reached. If pumping is then stopped without venting the hydraulic line, the pressure will suddenly drop and settle at a lower level called the shut-in