Developments in Triaxial Testing Technique

John A. Franklin and Evert Hoek

Rock Mechanics
Volume 2, Pages 223-228, 1970

Summary

A simple triaxial cell is described together with details of the technique employed for triaxial testing. Triaxial strength results for 254 specimens of eight rock types are tabulated.

The triaxial cell

Conventional triaxial testing apparatus is often expensive and slow to operate. Twenty or more triaxial tests may be required to predict the strength of a rock sample with satisfactory accuracy, the number of tests depending on the homogeneity of the sample and the scatter of the data. A simpler design of cell was developed (Hoek and Franklin, 1968), primarily to speed up the testing procedure.

This cell is illustrated in Figure 1. It applies a confining pressure only, and is used in conjunction with a conventional compression testing machine to apply axial force to the specimen. The axial force is applied via two spherically seated platens in order to minimise bending stresses. The main feature of the cell design is a one-piece synthetic rubber sleeve that retains an annulus of fluid while the specimen is inserted, tested to failure and then extruded. No time is lost in dismantling the cell between tests. A single sleeve proves sufficiently strong to withstand the testing of over one hundred specimens.

The cell body, weighing only 5 kg and comprising a cylinder onto which screw two end caps, is machined from mild or alloy steel. The version used for the current series of tests was designed to accept 38 mm (1 ½ in) diameter specimens with a length:diameter ratio of 2 : 1. Different sizes of cell are required to test different sizes of core, and a range of sizes are now in commercial production[1]. Some early commercial models did not seal satisfactorily, but these maunfracturing problems have now been largely overcome. The cell is designed to apply confining pressures of up to 70 MN/m^2 (10 000 lbf/in^2), selected as the maximum likely to be encountered in engineering practice since it is approximately equivalent to the vertical stress under 3000 m (10 000 ft) of overburden. Cell pressure is provided from a hydraulic pump connect to an oil inlet in the cell wall. A further oil inlet, not shown in Figure 1, is used to provide a tapping for oil pressure measurement, also for bleeding air from the cell. Quick release self-sealing couplings are used at both hydraulic connections.

In use the cell has proved quick and convenient; students have found it possible to test at least eight specimens in the course of half hour laboratory session. It is portable and should allow field testing, preferred to laboratory testing since the deterioration of specimens is minimised and also since a close correlation may be maintained between test results and in situ geological observations. The cell design also facilitates strain measurement under conditions of triaxial stress, since leads from strain gauges may pass

[1] The cell is available from Engineering Laboratory Equipment ltd. and from Clockhouse Engineering Ltd. in the United Kingdom, and from Terrametrix Incorporated in the United States.

between specimen and jacket. Most conventional cells require that such leads be passed through the confining fluid, with consequent problems of experimentation. The cell has also been used by Robertson Research company for creep testing for periods up to four months at confining pressures of up to 28 MN/m^2 (4000 lbf/in^2). A cell of similar design may also be used for permeability testing, acting to seal the cylindrical surface of a rock core while water is forced through in the axial direction.

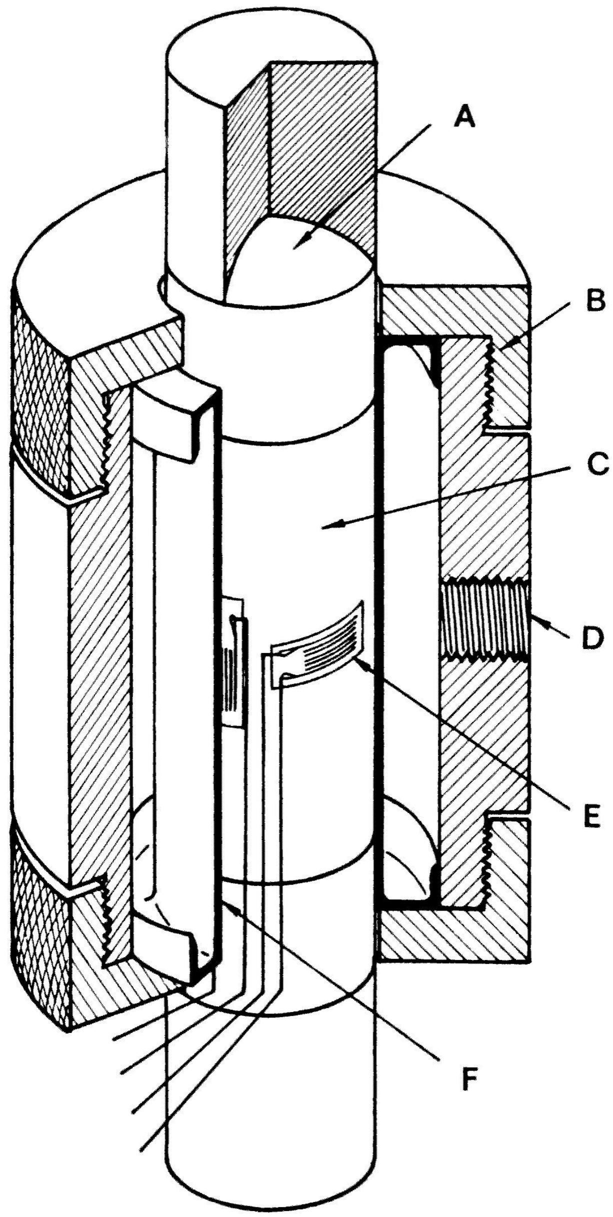

Figure 1. Triaxial cell

A - Hardened and ground spherical seats; B – Mild steel cell body; C – rock specimen; D – Oil inlet; E – Strain gauges; F- Synthetic rubber sealing sleeve.

Figure 2 a

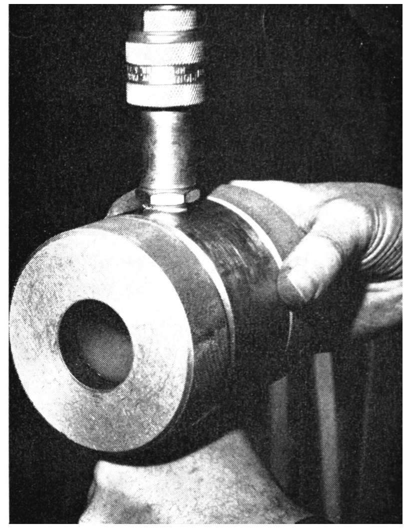

Figure 2 b

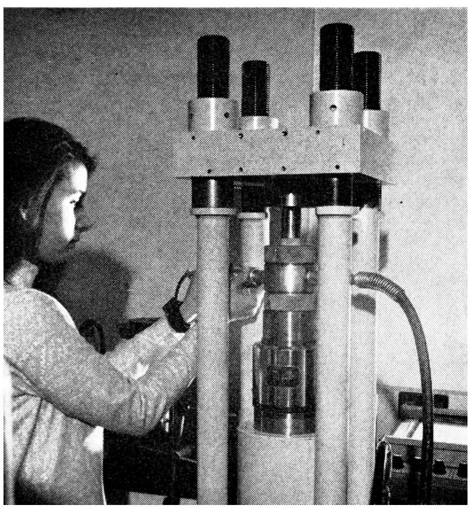

Figure 2 c

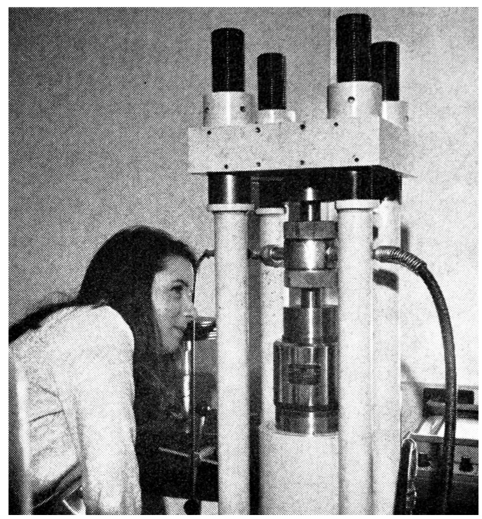

Figure 2 d

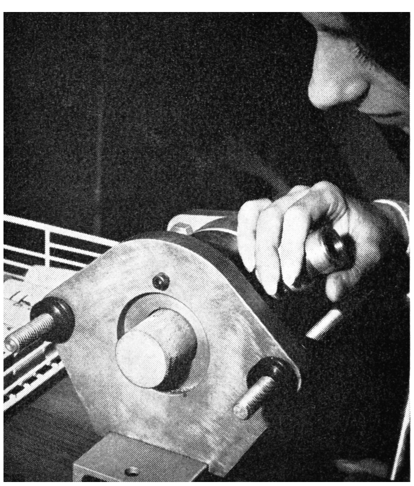

Figure 2 e

Figure 2 f

Figure 2: Triaxial testing procedure.

Testing procedure

Preparing the cell: the cell is cleaned, assembled (Figure 2 a), and filled with pressurising fluid. It should be re-bled periodically (Figure 2 b) to remove air; highly compressed air is a considerable experimental hazard. Bleeding should not be required more frequently than once every twenty tests, and if excessive leakage or entry of air is experienced the sleeve should be removed, cleaned and checked for damage.

Setting up the axial loading system: the lower spherical seat is placed in its locating recess and the cell is lowered over the seat until it rests on the lower platen of the testing machine. The specimen is taken from storage and inserted in the cell. The upper spherical seat is placed in position on top of the specimen; convex halves of the spherical seats should face towards the specimen. The ram is extended until the top seat locates in its recess, and a *small* retaining force is applied. The alignment of the specimen with top and bottom seats is checked, the retaining force being removed to adjust alignment if this proves necessary.

Setting up the cell: with a small axial force preventing loss of specimen alignment, the pressure hose and transducer or gauge are connected to the cell (Figure 2 c). The cell is raised to its operating position, ensuring that spherical seats protrude equally top and bottom. A small cell pressure is applied to clamp the cell in position (Figure 2 d).

Testing: axial force and cell pressure are increased from their initial values until the specimen fails. Force and pressure values at failure are noted. With softer rocks, or at higher cell pressures the failure may be inaudible, but may be detected from the sudden surge in cell pressure that accompanies dilation at the instant of failure. After failure the axial force and the cell pressure are removed simultaneously to avoid damage to the sleeve caused by intrusion into the cracked rock or between specimen and platens. Excessive deformation should be avoided where possible, since grossly deformed specimens are difficult to remove from the cell.

Extrusion: with cell pressure and axial force at zero, the pressure hose and transducer are uncoupled from the cell. One end cap is removed. The threaded portion of the cell is placed in the locating recess for the extruder and the specimen slowly extruded from the cell (Figure 2 e). The cell is replaced on the bench and wiped clean of grit (Figure 2 f). The cap is replaced and the cell is now ready for further testing. Where the specimen has been grossly deformed and will not extrude, the cell must be drained, the sleeve removed and the specimen broken up with a hammer. The sleeve is then washed, checked for damage and replaced.

Test Results

Eight samples comprising 254 rock specimens were tested to evaluate equipment and techniques, also to provide data for a comparison of various strength criteria and for a comparison and classification of various rocks on the basis of their triaxial strength performance. Results are presented in Tables 1 and 2.

Table 1. Rock samples tested at Imperial College

Sample	Porosity $	P-Wave Velocity m/sec	Rock Name
98	0.4	5400	Granite, Blackingstone quarry, Devon
200	12.1	4683	Limestone, Portland, Block 1
201	12.1	4683	Limestone, Portland, Block 2
202	16.1	2840	Sandstone, coarse grained, Derbyshire
204	0.0	5928	Quartz dolerite, Northumberland
207	12.6	2614	Sandstone, Darley Dale, Derbyshire
208	0.1	6198	Marble, Carrara, Italy
209	0.2	5028	Sandstone, Pennant, Wales

Table 2. Triaxial Test Results

σ_3	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3	σ_1
Sample 98				strengths in MN/m^2							
9.3	309.3	0.0	171.5	43.5	541.0	38.1	543.7	29.4	485.8	21.7	415.9
43.2	539.8	6.5	273.3	0.0	179.3	22.9	409.9	12.8	269.9	33.0	440.1
55.8	569.5	0.0	135.9	0.0	111.3	27.1	392.8	49.3	488.4	16.4	340.4
2.8	249.0	5.0	293.1	1.6	234.3	13.2	359. 0	18.0	410.7	8.7	318.5
0.0	197.3	7.8	276.8	19.7	406.5	28.5	486.8	0.0	195.9	9.9	312.1
21.4	407.6	33.9	453.9	0.0	202.5	7.8	283.0	28.8	458.0	45.5	566.0
10.7	316.0	0.0	213.6	25.8	431.1	39.2	480.8	0.0	196.1	7.4	284.4
34.8	512.7	51.7	523.9	0.0	193.4	15.1	330.1	5.3	270.5	17.7	362.3
Sample 200											
39.2	212.0	9.7	126.2	32.4	182.1	0.0	42.3	14.0	115.4	43.7	249.3
31.7	194.4	19.5	165.3	39.5	270.2	5.0	118.8	13.5	155.1	20.0	201.8
5.7	116.8	30.5	231.9	1.6	98.6	35.6	216.2	16.0	192.6	30.9	207.3
28.1	194.2	2.7	115.8	17.1	156.1	26.3	186.8	29.1	192.9	46.6	234.2
22.1	171.3	41.8	207.3	0.0	76.2	38.5	220.4	9.1	126.2	33.5	206.8
Sample 201											
35.7	195.3	18.5	114.1	9.6	118.1	23.3	143.8	20.7	143.8	13.4	119.9
16.6	127.5	8.9	82.4	30.7	146.8	5.8	81.5	33.5	141.9	34.8	151.9
11.7	99.5	15.8	102.1	25.3	132.9	14.1	109.3	36.6	138.8	16.4	107.6
4.8	58.2	30.7	144.0	20.2	98.9	6.5	76.4	10.6	410.7	12.8	70.6
7.5	86.8	20.0	97.3	10.4	94.2	3.2	49.9	7.4	72.2	15.1	89.5
5.1	59.6	11.2	95.8	2.9	69.9						
Sample 202											
14.5	153.2	25.0	204.5	31.1	220.2	42.1	249.1	19.5	178.0	5.0	105.0
8.2	125.4	11.5	145.0	0.0	55.6	0.0	58.8	49.3	285.6	38.3	236.6
51.7	263.3	0.0	54.1	2.9	82.3	0.0	37.2	0.0	45.5	0.0	41.1
34.5	203.7	0.0	51.4	24.1	185.5	0.0	67.7	3.5	79.1	11.0	127.0
0.0	58.6	0.0	57.7	46.3	260.9	0.0	51.6	6.9	106.7	31.7	217.4
0.0	49.8	0.0	55.4	28.3	253.0						

Table 2. (continued)

σ_3	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3	σ_1
Sample 204											
5.0	333.8	1.3	328.3	34.7	498.9	42.9	514.8	0.0	331.8	2.4	341.0
0.0	315.0	0.0	315.7	20.2	410.9	13.7	380.7	7.4	344.6	37.0	512.7
23.9	453.6	28.3	474.6	0.0	305.1	0.0	210.7	3.5	284.7	0.0	214.4
0.0	311.4	31.0	496.4	10.3	341.9	0.0	275.8	0.0	267.5	13.9	364.0
0.0	314.4	17.2	422.6	34.5	497.8	0.0	312.0	0.0	299.7	0.0	273.7
6.9	290.5	42.1	552.2	0.0	272.9	21.7	461.2	27.6	489.0	0.0	278.9
20.7	457.1	44.1	561.2								
Sample 207											
22.5	201.9	41.3	287.3	0.0	74.9	6.9	120.9	21.5	199.2	42.5	290.2
0.0	80.3	9.8	236.6	3.2	94.8	46.9	298.9	0.0	79.7	4.4	117.3
35.5	264.3	50.3	319.0	0.0	83.2	21.7	210.3	30.2	240.8	52.8	315.5
0.0	82.4	7.8	136.0	24.4	228.9	44.7	301.7	14.1	169.2	15.6	177.2
14.3	183.5	20.3	210.3	28.5	243.2						
Sample 208											
30.9	205.9	16.2	156.4	39.1	234.4	10.5	131.1	35.2	199.2	25.5	188.1
3.9	229.1	2.2	111.6	21.8	179.2	47.5	263.1	51.7	292.2	0.0	93.8
0.0	93.1	0.0	90.3								
Sample 209											
41.9	439.7	28.4	114.1	15.7	305.6	4.9	248.0	21.5	342.0	44.0	438.3
24.7	362.0	7.0	244.5	35.4	406.0	42.3	422.4	44.9	428.8	49.9	440.2
20.9	331.8	51.5	458.9	15.6	312.2	7.7	237.7	33.0	398.8	42.3	441.6
25.6	346.0	2.9	211.3	12.2	298.1	19.4	322.3	30.5	378.2	37.2	401.3
10.3	290.6	5.2	251.8	1.3	205.2	50.1	452.9	0.0	197.2	0.0	197.9
0.0	195.8										

Reference

Hoek, E., and J.A. Franklin (1968). A simple triaxial cell for field and laboratory testing of rock. *Trans. Inst. Mining & Metallugy*. Vol.77, pp A22-A26.