UNDERGROUND MEASUREMENT OF FRACTURE PERMEABILITY OF COAL WITHIN A SHAFT PILLAR

D. J. Reddish and S. F. Smith

Department of Mining Engineering
University of Nottingham, Nottingham, UK.

ABSTRACT

The paper describes the work undertaken to determine the in situ permeability of coal in a virgin seam. The installation and testing procedures are outlined. The results are analysed to evaluate the effect of localised fractures and fissures on the seams' permeability. An estimation of the size of a localised fracture is made from the results using a method developed by Barker [1].

INTRODUCTION

The work undertaken is part of a long term study into the permeability of Coal Measures rocks. This work is aimed at gaining a greater understanding of the way in which water flows around longwall excavations. Previous work at Nottingham University has concentrated on investigating the changes in Coal Measures rocks permeability induced by the passing of a longwall face. [2,3] This work has concentrated on obtaining a useful understanding of the range of permeabilities that can be expected from a virgin coal seam. The values obtained are of interest for the design of pillars to separate waterlogged workings, [4] for the understanding of flows around longwall faces, and for calculating working parameters for new modern coal mining methods.

SITE DETAILS

The site selected was in the Top Hard Seam within a shaft pillar at Rufford Colliery, North Nottinghamshire Area of the National Coal Board (see Figure 1). This location combined easy access with minimum disturbance to the normal workings of the mine. The roadway from which the tests were conducted was driven pre-1918 where very little roadway closure has occurred, and is still supported by the original square timber work. The site was dry with a temperature of 21°C.

Good access to services was available and any water created by the tests could be expected to drain into local shaft sumps. The two shaft sections (Figures 2 and 3) show local geological details of the seam. No faults occur in the immediate area although a good cleat and fracture pattern was present in the seam.

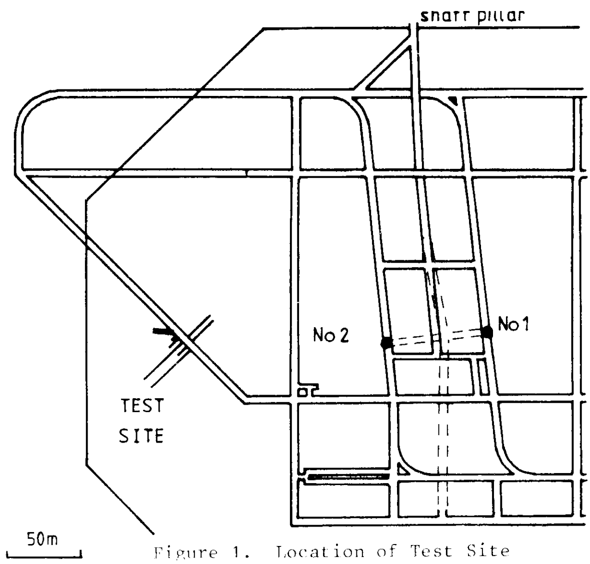

Figure 1. Location of Test Site

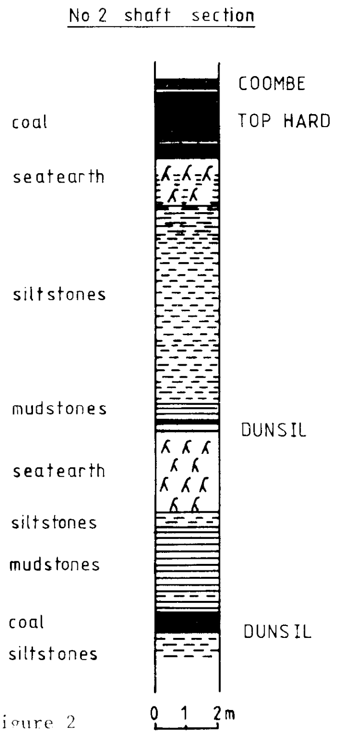

Figure 2

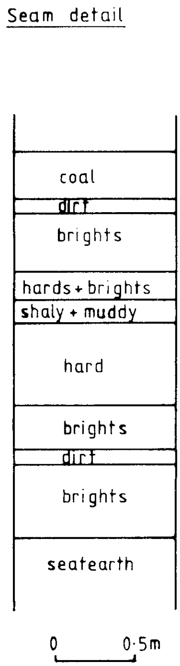

Figure 3

INSTRUMENTATION SCHEME

The instrumentation scheme used in this investigation is very similar to that used by Neate [2]. The holes were initially to be drilled at 90 mm diameter but collapse of the holes, led firstly to trials of a 60 mm diameter hole size, and then finally to a 75 mm diameter hole size. Casing was used to protect the badly fractured first 2 m of the holes. Vertical control in particular for the longer holes proved to be a problem, the proposed 40 m holes having to be stopped at 37 m due to hitting the underlying strata of the seam. The hole layout is shown in Figure 4.

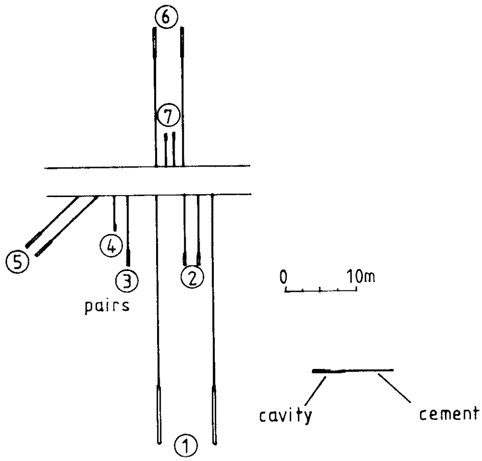

Figure 4. Test site

A grout inflated packer was initially tried but proved to be difficult to pressurise with the available pumps. The packer design was altered until suitable for air inflation with a simple hand pump to a predetermined pressure.

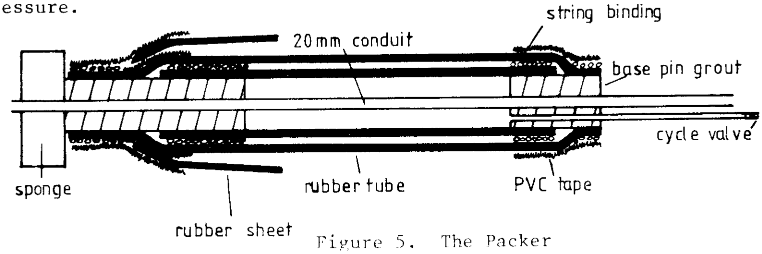

Figure 5. The Packer

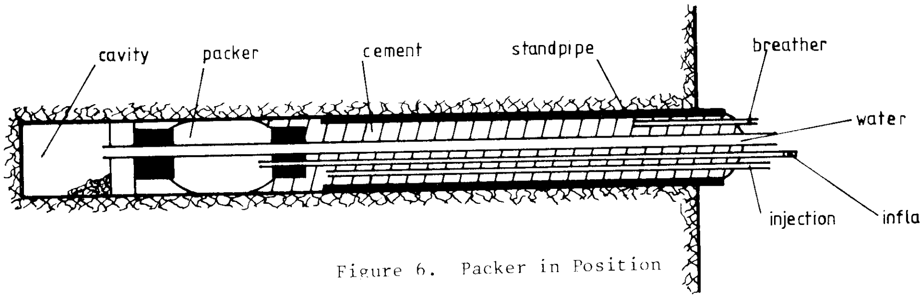

Figure 6. Packer in Position

Figure 7 shows the sealing of the hole. The inflation pipe to the packer was sealed using M100 grout and a small hand pump. High pressure fittings were placed on the conduit in such a position that after grouting this weak connection would be embedded in grout thus ensuring that the weak joint could not develop a leak outwards towards the hole entrance.

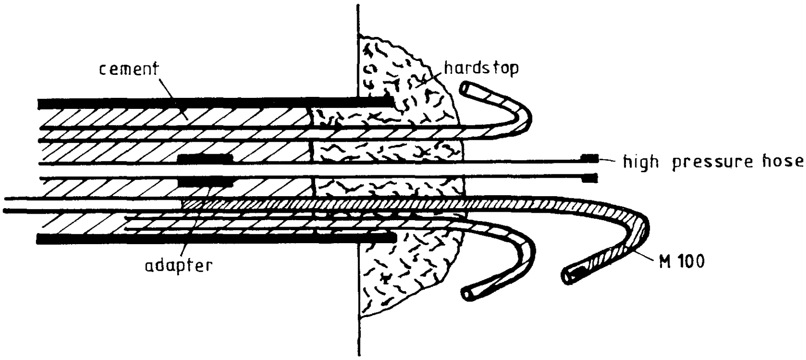

Figure 7. Detail of seal on hole entrance

TEST PROCEDURE

The flow measuring apparatus (Figure 8) was designed to accept water from the colliery mains water supply system at a pressure of 5.44 MPa and supply it to the borehole cavity at a measurable rate, with pressures ranging from 0.2 to 2.0 MPa.

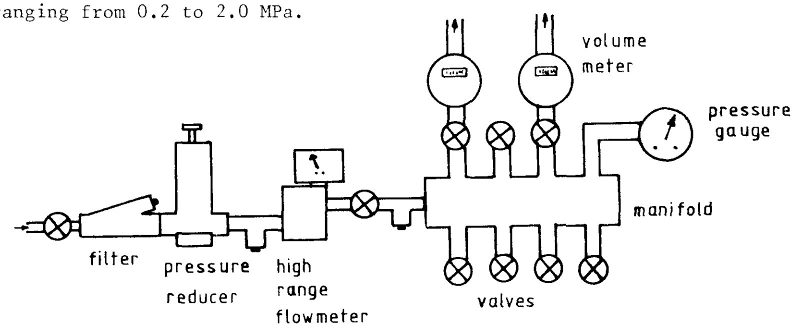

Figure 8. Flow measuring apparatus

Initial trials with 0-90 litres/minute Conflow meter showed that a lower range meter was required. Low range rotameters could not withstand the pressures of 2 MPa. A displacement pump was tried, but this proved to be mechanically unreliable in the corrosive water conditions encountered. Domestic water meters were tried and proved to be both accurate and able to withstand pressures of 2 MPa. These meters could be left for a known time, and the number of litres passing through them could be read from the dials, thus giving the flow rate.

A test consisted of the following steps :

(i) Turn on the water supply to the flow measuring apparatus and operate the valve to the hole being monitored.

(ii) To adjust the pressure reducer until steady pressure was attained.

(iii) Check the pressure for approximately thirty minutes until a constant pressure was attained.

(iv) Monitor the time, meter reading and pressure gauge at the beginning of the test.

(v) Monitor time, meter reading and pressure gauge at the end of the time.

(vi) To observe any outflow from fissures or other holes.

RESULTS

The results consisted of measurements of flow rates (cm^3/sec) at a constant pressure head (MPa).

Two methods of calculating permeability are used. One considers the coal to be isotropic, the other anisotropic.

For a constant head test in an isotropic material the coefficient of permeability is given by the following equation. See Hoek [5].

$$K = \frac{q}{FH_c} \tag{1}$$

where K = hydraulic conductivity (m/s)
q = flow rate (m^3/s)
H_c = constant water head (m)
F = shape factor

The shape factor depends upon the hole geometry. For the isotropic coal the shape factor is given below.

$$F = \frac{2\pi L}{\log e(2L/D)} \tag{2}$$

where L = cavity length (m)
D = cavity diameter (m)

This equation was substituted into equation (1) to calculate the first isotropic permeability value.

For the anisotropic case the shape factor becomes

$$F = \frac{2\pi L}{\log e(2m\ L/D)} \tag{3}$$

If L > 4D and where $m = (k_v/k_h)^{\frac{1}{2}}$.

If this equation is substituted into equation (1) then

$$K_v = \frac{q \ \log e \ ((K_v/K_h)^{\frac{1}{2}} \ 2L/D}{H_c \ 2\pi L} \qquad (4)$$

where K_v = vertical hydraulic conductivity (m/s)
q = flow rate (m^3/s)
H_c = head (m)
L = length cavity (m)
D = diameter cavity (m)
K_v/K_h = ratio vertical to horizontal hydraulic conductivities

Equation (4) was used to calculate the second permeability value in the results summary (Table 1).

A value of 500 was used for the ratio of K_h/K_v. This was obtained from laboratory experiments on a sample from the site.

Table 1

Rufford Colliery top Hard Seam "Permeability Tests"

Hole No	Length (m)	Flow Rate (1/m)	Permeability (m/s 10^{-5})		Remarks
			K_i	K_v	
1 r	40	3.65	0.0046	0.0019	Short test
1 ℓ	40	1.10	0.0009	0.0004	3 hour test
2 r	10	28.10	0.3017	0.0659	Weekend test
2 r	10	53.80	0.8087	0.1766	1 day washout of cracks
3 b	10	64.00	0.4810	0.1050	Rapid outflow
4 b	5	4.43	0.1370	0.0074	1 day, with pump
4 b	5	17.00	0.1169	0.0063	3 day test
4 b	5	19.30	0.1038	0.0056	1 day test
5 ℓ	12	2.05	0.0118	0.0026	Short test
5 ℓ	12	2.07	0.0141	0.0031	1 day
5 r	12	77.80	0.7796	0.1702	Short test
6 r	20	21.50	0.4744	0.0159	3 hour test
7 r	5	35.50	0.2928	0.0158	1 day test

1 millidarcy = 0.96 m/s   1 m/s = 1.03971 millidarcys

DISCUSSION OF RESULTS

Tests were conducted on all fourteen holes, five holes yielding no results. Three holes were too highly fractured to take flow measurements and two holes were blocked because of packer failure, possibly due to hole collapse.

Two permeability values have been calculated, one assuming the coal to be isotropic, and the other calculating the vertical permeability, assuming an anisotropic coal with a horizontal to vertical permeability ratio of 500 (from laboratory results). It is thought that most flow through coal takes place via microfissures within the material these microfissures being very common along the horizontal bedding planes and relatively rare in the vertical direction. This distribution of microfissures would explain the large difference in vertical and horizontal permeabilities.

A cavity within coal will intercept these microfissures, and the flow from this cavity will be proportional to the number of microfissures it encounters. A long horizontal hole will encounter a large number of vertical microfissures but relatively few horizontal microfissures. If an equation assuming the coal to be isotropic is then used to calculate the permeability of the coal around this cavity, it will give a low result representing more vertical permeability than horizontal permeability. If an equation taking anisotropy into account is used then it will allow for this hole geometry and calculate the vertical permeability.

A shorter horizontal cavity would encounter fewer vertical microfissures but the same number of horizontal microfissures, hence an isotropic calculation would produce a result representing the horizontal permeability to a greater extent than for longer holes. A long vertical cavity would intercept very few vertical microfissures but a large number of horizontal microfissures hence an isotropic calculation would produce a result representing the horizontal permeability to a large extent.

Isotropic calculations on the results from long horizontal holes would give a result close to the vertical permeability, whereas isotropic calculations on results from long vertical holes would give a result closer to the horizontal permeability. As the test conducted used horizontal cavities an overhaul bias in isotropic results towards the vertical permeability must be expected.

The above effects can be seen in the Results Summary, Table 1. Calculations assuming isotropy produce higher values for permeability in the short holes than the long holes.

The values for vertical permeability range from 1.7×10^{-6} m/s to 4.0×10^{-9} m/s. The high value results arose because of the presence of large local fissures. Allowance being made for this, the most meaningful results lie in the range 7.0×10^{-7} to 4.0×10^{-9}, a good central value being approximately 2.0×10^{-7}. For the vertical in situ permeability and 1.0×10^{-4} m/s for the horizontal in situ permeability. These results should only be used in calculations where the factors being calculated are required to an order of magnitude rather than a precise value.

ESTIMATION OF EQUIVALENT FRACTURE SIZE

Hole 5 ℓ shows normal permeability whereas hole 5 r has intercepted a fracture and shows very high permeability. Considering these holes are of the same geometry and very close together an estimation of the fracture size can be made.

If one assumes that the 5 ℓ holes permeability is due mainly to intergranular flow paths, and that the 5 r holes permeability is due to intergranular and fracture flow paths, an estimation of the fracture size can then be made.

The intergranular permeability values are :

$$K_{iv} = 2.8 \times 10^{-8} \text{ m/s}$$

$$K_{ih} = 500 \times K_{iv}$$

$$= 1.4 \times 10^{-5} \text{ m/s}$$

Fissure Transmissivity T_i is given by : See Barker [1]

$$T_i = \frac{Q}{2\pi H}\left[\log_e\left(\frac{T_i}{r(K_{iv}K_{ih})^{\frac{1}{2}}}\right) \quad 0.5772\right] \qquad (5)$$

where T_i = contribution fissure makes to the formation transmissivity in (m^2/sec)
Q = flow rate (m^3/s)
H = water head (m)
r = hole radius (m)

This equation is solved iteratively. Initial value for $T_i = 0.6 \times 10^{-5}$. Three iterations result in the transmissivity of the crack.

$$T_i = 1.087 \times 10^{-5} \text{ m}^2\text{/s}$$

Permeability of the crack assuming intercepted length equals the circumference of the hole. (Crack vertical and perpendicular to hole).

$$T_i = \frac{1.087 \times 10^{-5}}{\pi \times 0.075} \text{ m/s}$$

$$= 4.6132 \times 10^{-5} \text{ m/s}$$

For a planar array of smooth parallel cracks, permeability parallel to the cracks is given by : Hoek [5]

$$K = \frac{g\ e^3}{12v.b}$$

where g = 9.81 m/s^2
e = crack opening (m)
b = crack spacing (m)
v = coefficient of kinematic viscosity
= 0.0101 cm^2/sec at 20°C

Assuming the crack spacing is approximately equal to the cavity length (i.e. cavity has intercepted one crack) two meters.

$$4.6132 \times 10^{-5} = \frac{9.81\ e^3}{12 \times 0.0101 \times 10^{-4} \times 2}$$

$$e = 4.85 \times 10^{-4} \text{ m}$$

Crack size is approximately half a millimeter.

This calculation gives an approximate idea of the fracture size at the Rufford test site.

GENERAL DISCUSSION

During the Rufford tests water was seen to migrate a considerable distance in a comparatively short space of time. Figure 9 shows how the water travelled down a slope towards the shaft sumps. The mechanism of this travel is not completely clear, but it is thought that the water travelled a proportion of the way along the roadway floor, and drained in to the siltstones under the Top Hard Seam and proceeded, trapped by the underlying mudstones, to emerge some distance beyond the seam at the shaft sump. It is interesting to note that the water travelled some 200 m in approximately one week.

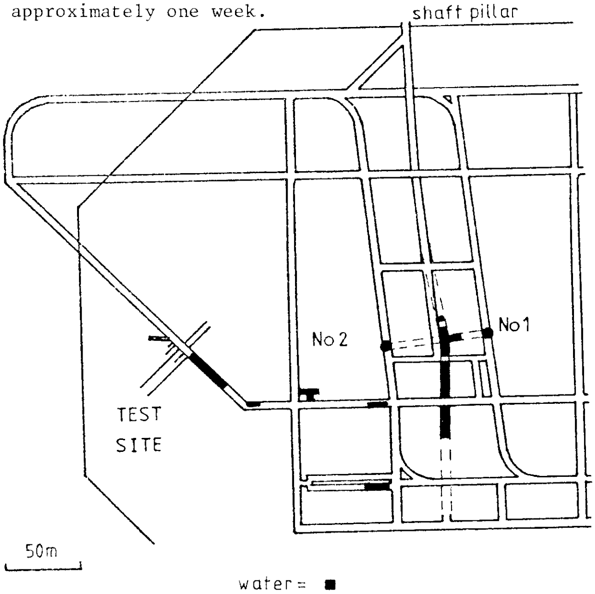

Figure 9 Water drainage

By observing the seam during tests some idea of the mechanisms by which water travels through in situ coal was gained. Many cracks and fissures provide the easiest escape path for the water. Although these cracks were initially rough and filled with debris they washed out after a period of 24 hours, and the permeability then drastically rose to high levels (too high in fact for the apparatus to measure). These large cracks (0.5 cm wide, 2 meters long in the roadway) tended to be vertical. The water also exploited the smaller natural bedding planes in the coal and particularly a dirt parting towards the base of the seam from which water could be seen emerging. Very little flow occurred in an upward direction, indicating that at these injection pressures (0.2 - 2.0 MPa) gravity still played an important role. Most of the water was seen to emerge near the coal seams floor, and none at the roof level.

CONCLUSION

The in situ permeability of coal varies greatly due to local fracturing but even so, a good assessment of the magnitude of the permeabilities can be made.

The results of the coal permeabilities obtained from this investigation could be applied to problems encountered in other similar situations. The results of this investigation can be used to estimate the magnitude of flows that might be expected to occur.

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