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EFFECT OF STRATA PERMEABILITY ON THE RADIAL HYDROSTATIC PRESSURES ON MINE SHAFT LININGS

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ABSTRACT

The radial hydrostatic stresses acting on shaft linings in aquifer rocks should reduce by about 10% when the ratio between lining and strata permeability coefficients is 10^{-2}. Reductions of 40% might be expected if this ratio fell to 10^{-1}. The possibility of achieving reductions of this order by grouting is discussed.

INTRODUCTION

During design of mine shaft linings in saturated strata, the reasonable assumption is made that the full peizometric pressure acts on the lining. To justify this, it is necessary to assume that there is a high permeability mismatch between the lining material and the surrounding rock, and this is usually the case. In some circumstances, however, it may be reasonable to consider the imposition of a zone of grouted ground of intermediate permeability interposed between the lining and the rock. The possibility of the reduction of lining pressures through the imposition of a permeability "gradient" of this type around a shaft may be worth considering in deeper shafts.

RELATIONS BETWEEN PERMEABILITY AND LINING PRESSURE

Water flow into a vertical shaft is likely to be from a confined aquifer. If the usual simplifying assumptions are made: that the aquifer *rock* is homogeneous, isotropic, saturated and incompressible; that the *fluid* is homogeneous and incompressible; the *flow* is laminar; that a steady state situation exists and that the well penetrates the full aquifer thickness; then an equation for *radial* flow into an unlined shaft of radius, r_j, will be given by a version of Theim's equation.

$$\frac{Q}{h} = \frac{2\pi k_2(h_e-h_1)}{\ln(r_e/r_1)} \tag{1}$$

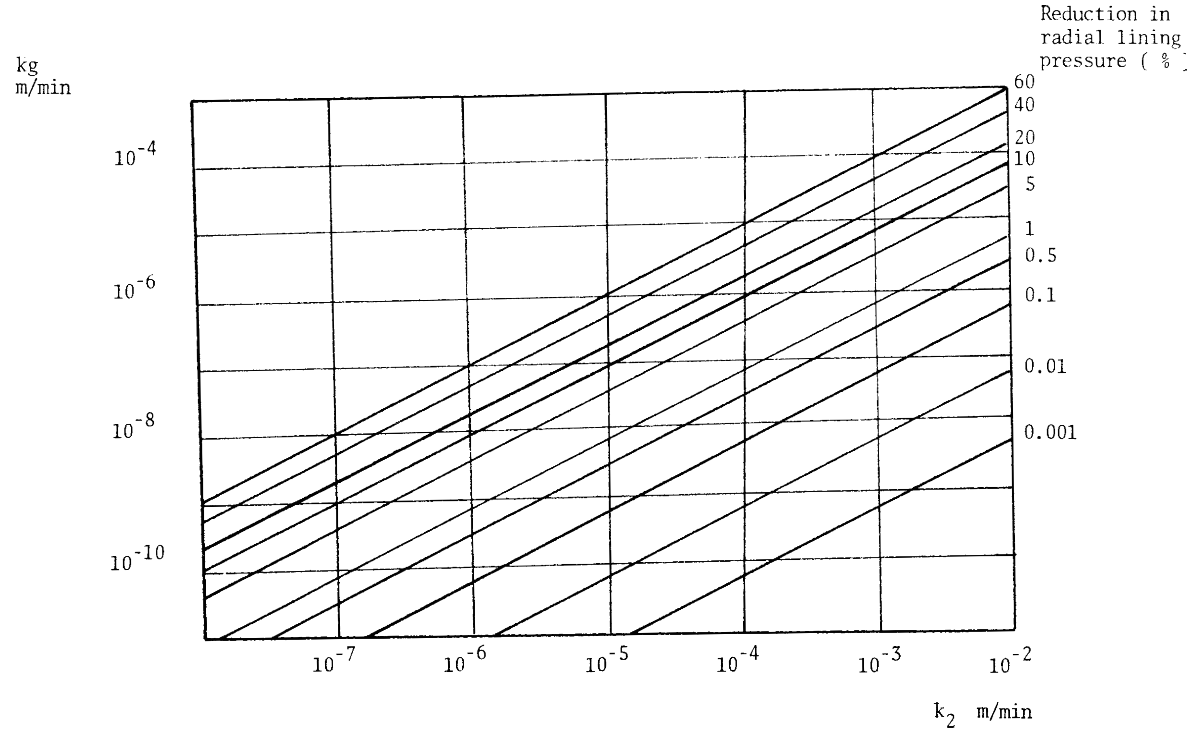

Fig.1 Relations between lining permeability coefficient k_1 and rock permeability coefficient k_2 required to obtain reductions in the radial pressure at the lining-rock interface. (r_1 = 3.57m; r_2 = 4.37;) lining thickness = 0.8m; r_e = 50m

In situ pump-in packer permeability tests at boreholes in the Selby coalfield demonstrate typical Coal Measure rock permeabilities: (Table 1).

Table 1

In-Situ Permeability of rock at Selby Coalfield

Rock	Depth m	Permeability m/min
Bunter Sandstone	42-52	2.89×10^{-4}
	131-144	1.04×10^{-4}
	201-211	1.21×10^{-4}
Lower Magnesian	344-356	4.02×10^{-6}
Limestone	356-372	5.22×10^{-6}
	372-387	6.84×10^{-6}
	387-405	6.90×10^{-6}
	405-424	7.56×10^{-6}
Basal Permian Sands	424-432	2.16×10^{-5}
Coal Measures	479-505	4.98×10^{-6}
	557-570	2.32×10^{-4}
	647-664	1.08×10^{-6}

The basic problem can best be illustrated by a series of questions:

(1) What effect will the ratio of concrete lining permeability to aquifer rock permeability (k_1/k_2) have on the pressure at the back of the lining? This is answered - albeit in a complex way by the nomography in Figure 1. To reduce pressure by 10% in a rock of permeability coefficient 10^{-6} m/min would require a concrete permeability of 10^{-8} m/min. Since the minimum acceptable permeability coefficient of good quality concrete would be 10^{-10} m/min. this is not feasible.

(2) How effective will grouting have to be to reduce the pressure at the back of the lining? This is illustrated in Figure 2 - similar to Figure 1 but with r_e reduced from 50 to 10 m (the effect is illustrated in Figure 2) to allow for the extended grout zone. To reduce pressure by 5% would require a reduction in permeability to about 10^{-7} m/min and by 10% to 10^{-8} m/min. This is possible, but barely feasible in rocks such as the Bunter Sandstone where grout would have to penetrate pore space. It is more feasible to think in terms of reducing the permeability coefficient of fissured rocks such as limestones. Here the rock material is virtually impermeable and water flow through quite large and well spaced fissures is often responsible for very concentrated flows. Blocking of these fissures by cementation grouting can often have a quite dramatic effect on rock permeability, and by extrapolation, on lining pressure. Although there have been measurements of full hydro-

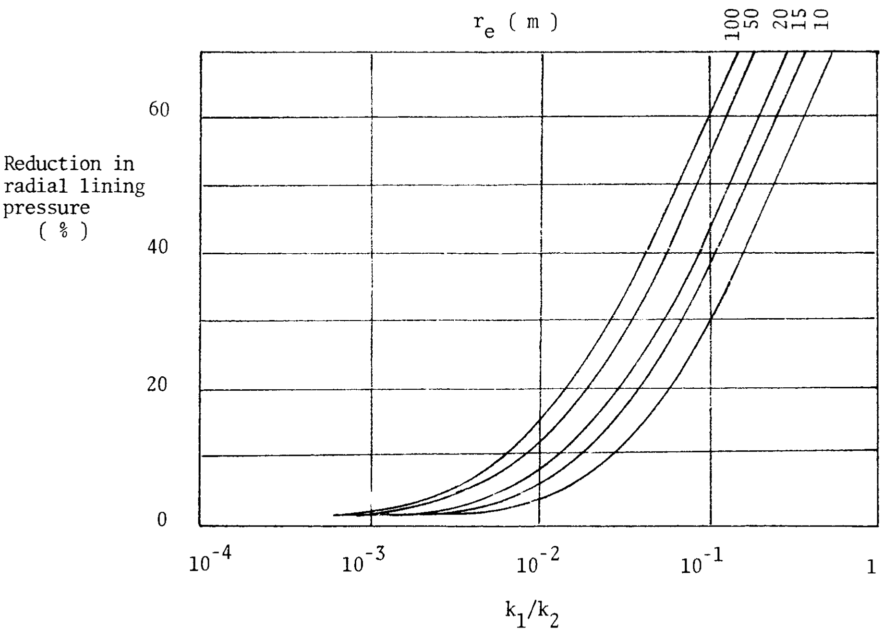

Fig.2 Relation between the percentage reduction in pressure at the lining-rock interface and the ratio of lining (k_1) to rock (k_2) permeability coefficient for various values of re based on the data in Fig.1.

static stress on shaft linings in Bunter Sandstone (summarized in Farmer, 1984 there are no records of radial stresses on shaft linings in grouted fissured rocks. There is a conviction among mining engineers that grouting does relieve radial stresses in these rocks, which may indicate a need for research.

Probably the nearest to a direct comparison are measurements of linings stresses on the segmental cast-iron lining (Altounyan and Farmer, 1981) of the Gascoigne Wood drift through Permian Strata. Data obtained two years after construction may be summarized as:

Table 2

Reduction in Radial Pressure in Shaft Lining due to Grouting

Station	Depth m	Permeability m/min.	Treatment	Strata	Reduction in radial pressure* %
1	98	-	Dry	Middle Permian Marl	-
2	134.5	6.0×10^{-4}	Grouted	Lower Magnesian Limestone	24
3	158	6.0×10^{-4}	Grouted/ Frozen	Lower Magnesium Limestone	18
4	168	2.70×10^{-4}	Frozen	Basal Permian Sands	10
5	171	2.70×10^{-4}	Frozen	Basal Permian Sands	12

* below estimated hydrostatic

It is noticeable, but not conclusive that there was higher reduction in lining stress at the grouted limestone rings than at others. Whilst some of the reduction in radial pressure is probably attributable either to errors in estimation or to leakages through or along the lining, it is significant that the reduction in lining pressure in the limestone is greater. The frozen limestone section was also grouted - it was frozen because of its proximity to the Basal Permian Sands. If the 10% residual reduction in lining pressure the sands assumed constant for all strata, there is an additional reduction of the order of 10% in the grouted limestone, which may be attributed to a reduction in pressure resulting from a change in rock permeability due to grouting.

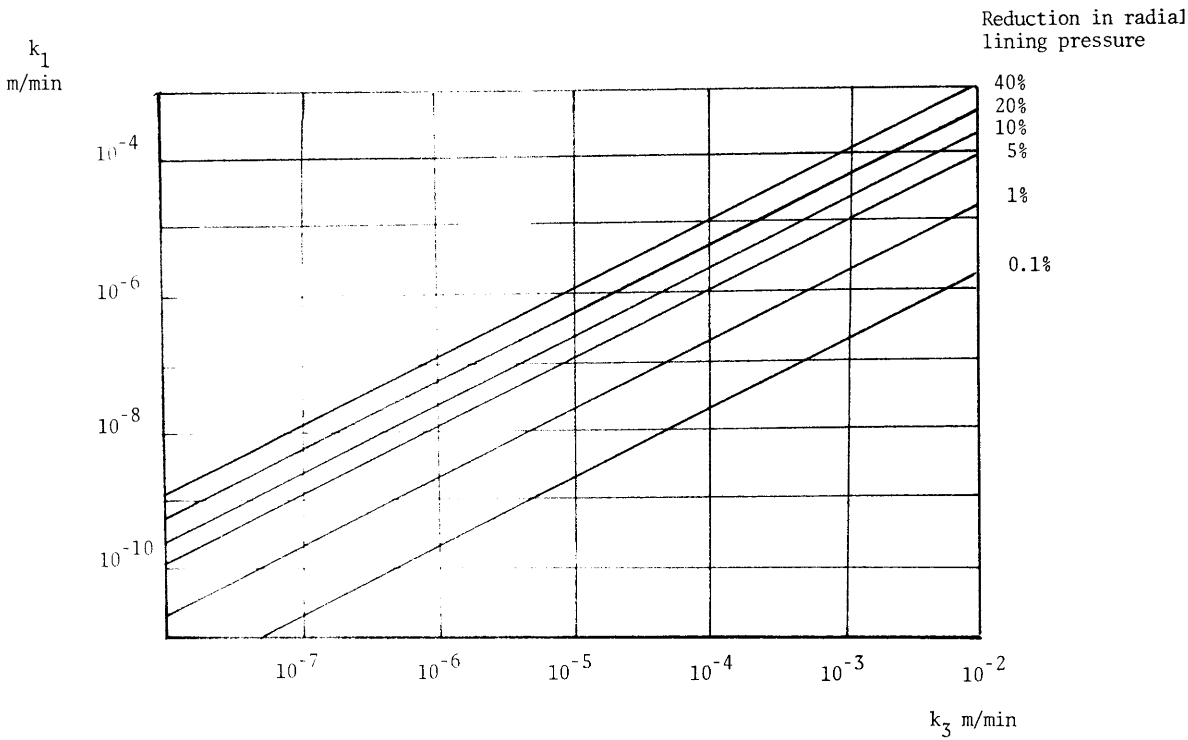

Fig.3 Relations between lining permeability coefficient k_1 and grouted rock permeability coefficient k_3 required to obtain reductions in radial pressure at the lining-rock interface (r_1 = 3.57m; r_2 = 4.37m; r_e = 10m)

$$\frac{Q}{h} = \frac{2\pi k_2(h_e - h_1)}{\ln(r_e / r_1)} \tag{1}$$

where k_2 is the permeability coefficient of the aquifer rock, h is the aquifer thickness, h_1 is the head of water at the shaft wall and h_e is the head of water at the edge of the zone affected by the shaft and at a distance r_e from it.

Some of the assumptions made are too simplistic. For instance nonsteady state flow will result in decreasing flow rates with time. Similarly isotropy in sedimentary rocks and blast damage or loosening near to the shaft will increase permeability. It should also be remembered that numerical methods of flow regime modelling using finite element or finite difference analysis can include many of these variables.

Although there is probably little justification for using simple conceptual models in design, they can be used to illustrate basic concepts. Theim's equation can be expanded (see Muskat, 1946) to allow for radial variations in permeability, by considering the shaft to be surrounded by two concentric annuli. These represent the concrete lining of internal radius r_1 and external radius r_2 and the aquifer rock of internal radius r_2 and external radius r_e. The respective permeability coefficients are k_1 (concrete) and k_2 (rock).

Then if it is assumed that the pressure distributions in the annuli possess the same radial symmetry as in the unlined and extended condition, the modified equation for the composite system is:

$$\frac{Q_L}{h} = \frac{2\pi k_1(h_e - h_1)}{\ln(r_2 / r_1) + k_1 / k_2 \ln(r_e / r_2)} \tag{2}$$

and the ratio of Q_L/Q is given by:

$$\frac{Q_L}{Q} = \frac{(k_1/k_2)\ln(\ln(r_e / r_2)}{\ln(r_1 / r_2) + (k_1 / k_2)\ln(r_e / r_1)} \tag{3}$$

By assuming a radial logarithimic symmetry for the pressure distributions in each of the annular regions, a parallel relation between permeability and pressure can also be obtained:

$$\frac{k_1}{k_2} = \frac{(h_e / h_1)\ln(r_2 / r_1) - \ln(r_2 / r_1)}{\ln(r_e / r_2)} \tag{4}$$

to give a relation between the ratio between k_1 (concrete) and k_2 (rock) and the pressure, h_1, at the concrete/rock interface.

CASE HISTORY ILLUSTRATING THE LINING PRESSURE REDUCTION

A particular application chosen for illustration is the shaft linings in the Selby coalfield. These have encountered water bearing sandstones and limestones to depths of 640 m. Greater depths are envisaged at other developments in Britain.

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