Rationalized charts for the method of fragments applied to confined seepage

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The Author very effectively presents dimensionless charts for determining the form factor for a number of confined seepage fragments and a chart for estimating vertically emerged exit gradients. The charts are applicable to transversely isotropic aquifers.

The beauty of the fragment method lies in the fact that the solutions for each individual fragment can be determined independently. By assembling solutions for individual fragments, estimates of flow rate, exit gradient and porewater pressure along the uppermost impervious surface can be obtained in an analytical manner. It is not necessary that the number of flow channels n_f be a constant in each fragment as is stated by the Author. The expressions for calculating the flow rate and the head loss in a fragment (equations (6) and (13) respectively in the Paper) can be written in the following general form, which includes seepage through fragments of different permeabilities

$$Q = \sum_{i=1}^{n} \bar{k}_i h_i \Big/ \sum_{i=1}^{n} \phi_i \qquad (1)$$

$$h_i = H \Big/ \sum_{m=1}^{n} \frac{\phi_m}{\phi_i} \frac{\bar{k}_i}{\bar{k}_m} \qquad (2)$$

where n is the total number of fragments and $\bar{k}$ is the equivalent coefficient of permeability for a transversely isotropic aquifer, $\bar{k} = (k_h k_v)^{\frac{1}{2}}$.

Owing to the nature of its solution procedure, the method of fragments provides only solutions to an overall domain—either a given fragment or the entire aquifer. As a result, quantities such as the uplift pressure along an impervious base cannot be obtained without making additional assumptions. The Author states 'in the method of fragments, a linear loss of head is assumed within each fragment'. The assumption is valid if the fragment does not have any cut-off walls. The head loss rate is much smaller in the corner region where there is a sharp change in flow direction. In any case, it should be noted that in calculating the rate of head loss the horizontal length should be taken as that of the transformed geometry, RL, rather than the original width L.

One major restriction in applying the method of fragments to the seepage problem is that it requires the boundary conditions of each fragment be known *a priori*, i.e. the solution to the Laplace equation should exist for the fragment. For practical purposes, the aquifer is generally fragmented by assuming vertical equipotential lines at selected points such as the pile tip. This assumption is clearly not true for a non-symmetric aquifer in which the equipotential line at the pile tip sways in the flow direction. Fig. 1 demonstrates the effect of pile penetration depth s on the head loss in fragment C, h_m, of a double-wall sheet pile coffer-dam. The values of h_m are obtained by using the form factors provided by Figs 5 and 8 in the Paper. It is seen that, with the assumption of a vertical equipotential line at the pile tip, the head loss h_m increases as s/T increases, reaching a maximum

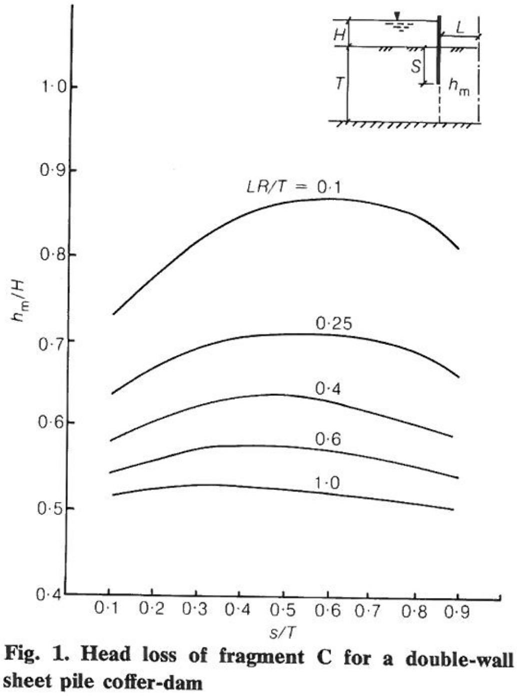

Fig. 1. Head loss of fragment C for a double-wall sheet pile coffer-dam

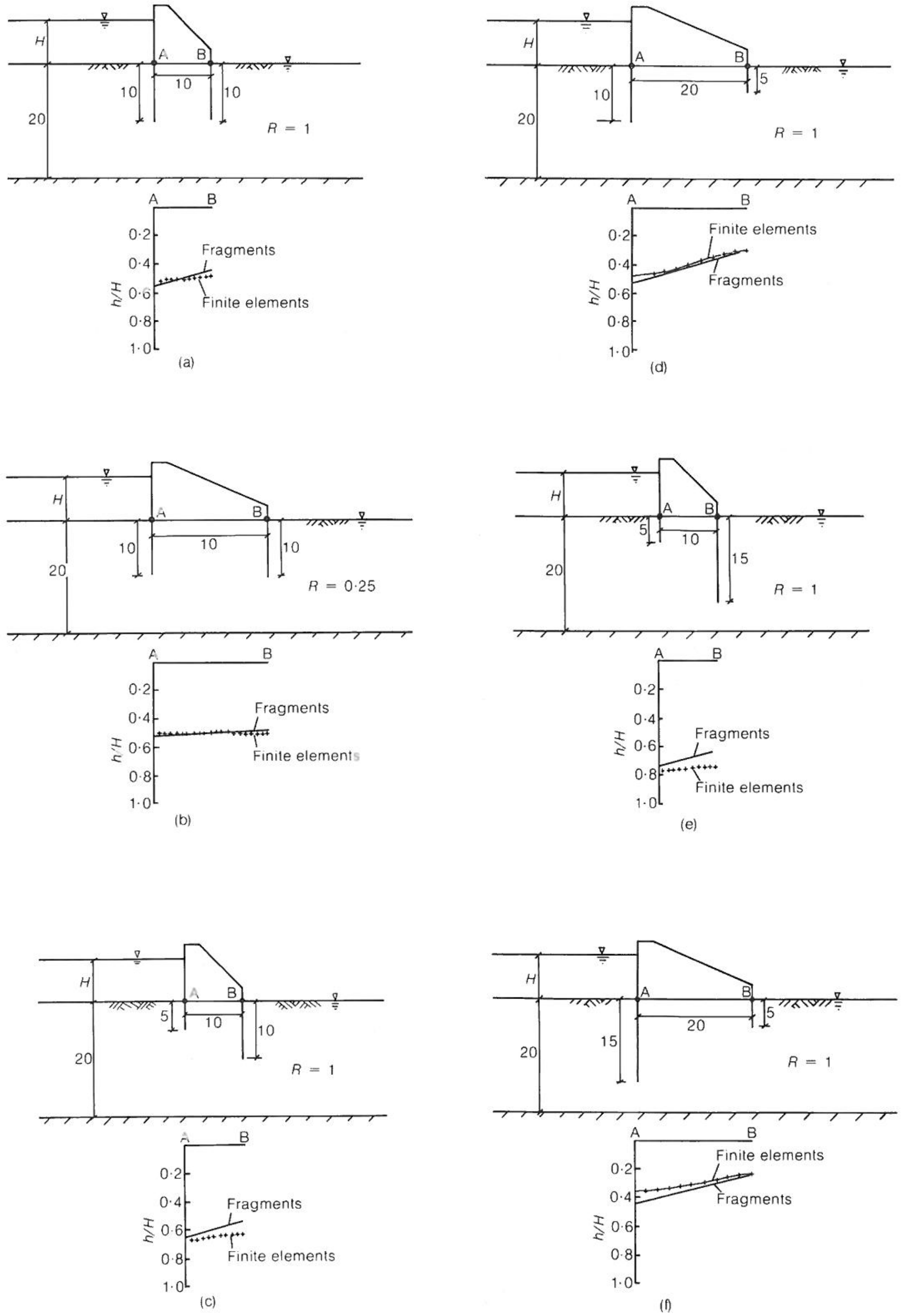

Fig. 2. Comparison of full solution with fragments for uplift pressures on a dam

value at roughly $s/T = 0{\cdot}5$, and then decreases. The effect is more pronounced for smaller values of LR/T as the swaying of the equipotential line is more significant.

Author's reply

The discussion questions the assumption of linear loss of head within fragments. Finite element checks have been made (Li, 1985) using the mesh of Fig. 10 of the original Paper. The results of Fig. 2 compare the computed head along the line AB in a variety of dams with that obtained assuming a linear variation within the fragment. The results indicate that the method of fragments does account for the retardation in the rate of head loss in a type B fragment, even when significant cut-off walls are present. The 'worst' cases are shown in Figs 2(c) and 2(e) where the dam is short relative to the depth of the permeable layer. In these cases, the uplift pressure by the method of fragments was slightly unconservative, but still within 10% of the more rigorously obtained finite element values. In spite of this, all the solutions presented give uplift predictions that are adequate for engineering purposes.

Figure 1 shows the predicted head loss in a type C fragment for different depths of penetration of a symmetrical double-wall coffer-dam. Some of these results, especially for low LR/T, could not have been obtained from Fig. 8 of the original Paper as is claimed. For $LR/T = 0{\cdot}1$, the form factor is increasing so rapidly with s/T that the highest value available in the figure is for $s/T = 0{\cdot}4$. The validity of extrapolating such a steep line is certainly questionable.

It is accepted, however, that even for larger LR/T values a slight fall in the head loss of fragment C is predicted by the charts as s/T increases. For $LR/T = 0{\cdot}25$, for example, this fall represents no more than 5% of the total head.

What is important for design is the ability of the method to give reasonable predictions of exit gradients. Comparisons of exit gradients predicted by the charts have been satisfactorily compared with full finite element solutions in Figs 12 and 14 of the original Paper.

Finally, the discussion presents modifications to equations (6) and (13) accounting for fragments of different permeabilities. If identifiable changes in soil permeability coincided with fragment boundaries, such modifications would be of value.

REFERENCE

Li, C. O. (1985). *Numerical analysis of seepage and rapid draw-down.* Transfer report for the degree of PhD, Simon Engineering Laboratories, University of Manchester.