

DISCUSSION

Experiments on piping in sandy gravels

A. W. SKEMPTON and J. M. BROGAN (1994). *Géotechnique* **44**, No. 3, 449–460

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In geotechnical engineering practice, piping is a very dangerous issue but is not really understood and controlled. The Authors have provided important insight on the mechanism of the migration of fines through the soil matrix and their experimental results are a great step forward. They give hope that some day piping may really be controlled.

It seems clear that in the Paper the term 'critical gradient' is used to qualify two different mechanisms

- (a) the migration of fines through the coarse material
- (b) instability which occurs when, at any depth, the pore pressure exceeds the vertical effective stress.

Critical gradient may be appropriate for the first mechanism, but for the second one the term 'overall stability' may be more accurate.

I would suggest that in the tests made by the Authors, if the top of the samples had been loaded, the general collapse of samples C and D would have occurred at a higher gradient than that stated. The Authors' analysis tends to this view when, in discussion of the test on sample A, they try to evaluate the overburden load carried by the fines.

Accordingly I feel that the Authors may agree that two different mechanisms operate in the differing circumstances. If this is so, would they present more information on the migration of fines through the gravels, in tests on samples A and B, where there is no evidence for determining if migration is controlled by the gradient (mechanism (a)) or by the fact that the fines carry only a fraction of the overburden load (mechanism (b)). From the discussion of the results of test A, it seems that the Authors are of the opinion that mechanism (b) governs the migration.

Opening of cracks in the sample, and subsequently a modification of the flow conditions, might be forecast as soon as the pore pressure exceeds the minimum effective stress, i.e. as soon as the pore pressure exceeds the horizontal effective stress. In the tests, samples A and B collapsed

at too low a gradient to allow such a condition. In the tests on samples C and D, as the general instability occurred at a pore pressure close to the value of the vertical effective stress, at some moment during the experiments, the increasing pore pressure has exceeded the effective horizontal stress.

As a modification of the flow conditions appeared in the test on sample C at a gradient of 0.55, is there evidence to indicate whether this modification is controlled by the value of the Reynolds number rather than by the horizontal effective stress?

J. H. Loveless and G. T. Grant, *University of Bristol*

The paper reports an interesting study of the nature of the internal instability exhibited by gap-graded sediments. This phenomenon, besides being important to the design of dams and barrages, is also important in the design of sea walls and breakwaters and in the selection of sediments for physical models of sand and shingle beaches.

We have carried out similar experiments which were prompted by research into the erosion of beaches in front of coastal structures, including the selection of appropriate sediments to use in physical models. At present, models which are used to predict the performance of shingle beaches often use a method developed by Yalin (1963) which suggests using lightweight material such as coal, having a specific gravity of about 1.4. The critical hydraulic gradient for piping for such a uniform material has been confirmed in tests here to be only 0.25. As vertical hydraulic gradients in excess of 0.25 can occur under the troughs of waves, this means that models using coal will be subject to large-scale effects, even when they are modelling uniform material. The findings of the Paper suggest that to use coal to model shingle beaches containing sand may be even more susceptible to misinterpretation.

A limited number of tests were performed in the permeameter shown in Fig. 16. The apparatus was of a similar type to that used by the Authors, but had different dimensions. In the tests the hydraulic gradient was averaged across four

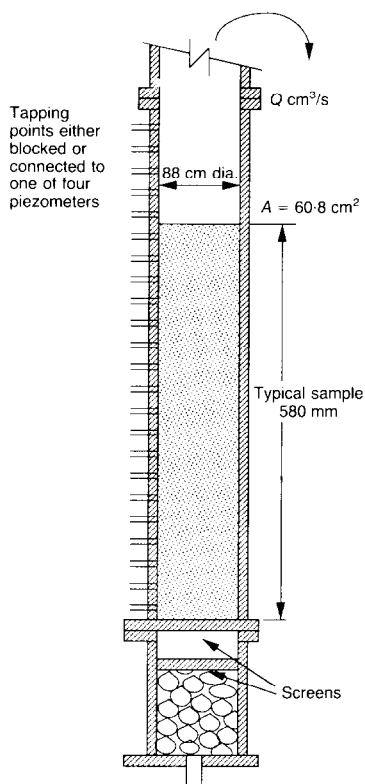


Fig. 16. Test apparatus

tapping points in the side of the cylinder. The top tapping point was 5.0 cm below the top of the sample; thus the hydraulic gradient measured was that present in the body of the sample, not across the whole sample. The specifications of the samples tested are

- (a) sample 1: coarse 6 mm gravel
- (b) sample 2: 15% 1–2 mm sand and 85% 6 mm gravel
- (c) sample 3: 25% 1–2 mm sand and 75% 6 mm gravel
- (d) sample 4: 25% 1–2 mm sand and 75% 10 mm gravel

(see Fig. 17).

Samples 1–3 were chosen because they were composed of a uniform sand and gravel with $f = 4$ (i.e. just fulfilling the filter law). The minimum material stability index $(H/F)_{\min}$ found among the three samples was 3.68 for sample 3. Although boiling occurred at about unity for samples 1 and 2, for sample 3 boiling occurred at $i = 0.8$, when a volume increase also occurred. This slightly lowered critical hydraulic gradient may perhaps be an indication that, although the sample nominally has a safe material stability

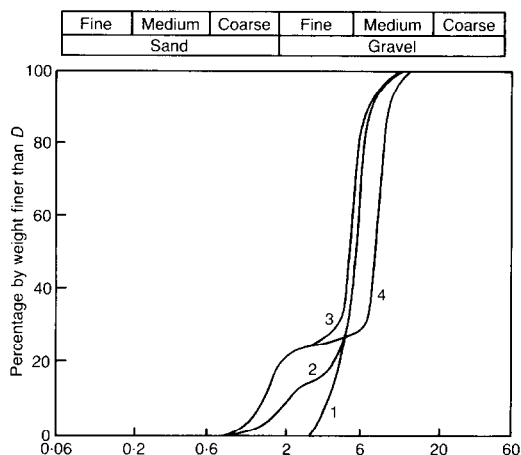


Fig. 17. Grain size distribution of test samples

index, because of the uniformity of both fractions it is in reality close to internal instability.

Sample 4 was found to have $(H/F)_{\min} = 0.86$, and the resulting critical hydraulic gradient was 0.26. This result was plotted in Fig. 13 and provided a good correlation with the Authors' work.

Our experiments confirm the Authors' findings that, for certain gap-graded sediments, the critical hydraulic gradient for segregation piping is much lower than that for a uniform or uniformly graded sediment. This finding has far-reaching consequences for the design of coastal structures in addition to the situations noted by the Authors.

Authors' reply

Mr Monnet asks whether the migration of fines in tests on samples A and B is controlled by the critical gradient or by the fact that the fine grains carry only a small fraction of the overburden load. We consider that these are not alternative mechanisms, but rather that the small critical gradient at which migration of the fines takes place is a consequence of the small effective pressure acting on the sand grains in materials which exhibit internal instability.

The migration of fines, and piping at a free surface, will always occur when the pore pressure exceeds the vertical effective stress. The difference in behaviour between these two samples and samples C and D is that in the latter pair of internally stable materials the original overburden load is distributed in an approximately uniform manner among all the particles, thus conforming to the (implicit) assumption in conventional piping theory, which predicts a critical gradient of about 1.0, as was found in tests on samples C and D.

Table 5. Summary of piping tests

Sample	A	4	B	C	D	3
Sand D_{50} : mm (per cent in sample)	0.15 (15)	1.5 (25)	0.25 (15)	0.5 (15)	0.5 (10)	1.5 (25)
Gravel D_{50} : mm (per cent in sample)	4.2 (85)	9.0 (75)	4.2 (85)	4.2 (85)	4.2 (90)	5.5 (75)
Filter ratio D'_{15}/d'_{85}	11	4.1	3.9	3.2	3.2	2.1
Stability index $(H/F)_{\min}$	0.14	0.86	0.98	1.6	2.8	3.7
Critical gradient i_c	0.20	0.26	0.34	1.0	1.0	0.8

Mr Monnet also refers to the change in flow conditions in the test on sample C at a gradient of 0.55. This can be attributed to the onset of turbulent flow. Piping occurs at a higher gradient of 1.0 exactly, as would be the case in tests on sand of the same porosity, in which laminar (non-turbulent) flow conditions obtained up to the point before piping started.

The tests described by Messrs Loveless and Grant provide valuable additional data, in so far as they relate to a coarser sand fraction than that used in our experiments, and to a higher propor-

tion of sand (25% instead of 15%). We have added the results of tests 3 and 4 to our own in Table 5. Test 3 shows that even with a coarse sand in a marginally unstable material (as judged by a Kenney index of 0.86) piping of the sand grains can occur at a gradient as low as 0.26.

REFERENCE

- Yalin, M. S. (1963). A model shingle beach with permeability and drag forces reproduced. *Proc. 10th Congr. Int. Assn Hydraul. Res., London*, 167-175.