Transition in oscillatory flow over rippled beds

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The Author is to be congratulated on his successful series of experiments related to such a complex phenomenon. Oscillatory flow occurs in a variety of engineering problems, and it is therefore of considerable importance that further experimental and physical data have been realized.

39. In addition to wave-induced currents and bottom sediment motion cited by the Author as examples of oscillatory flow, the civil engineer may well encounter the same phenomenon in the context of estuarine studies, tidal models, seiches or even unsteady pipe flow. The nature of the bed surface, whether it is smooth or rippled, is relevant to all these problems. The only additional complication caused by the presence of the free surface is when the thickness of the oscillatory boundary layer attains to the whole depth of flow. The division of the flow into two horizontal layers (§ 16) is easily managed. A two layer model for oscillatory flow in open channels which includes both of these features has been developed by Agnew¹⁴ and the physical characteristics of his solution are examined in reference 15.

40. In the light of Agnew's work, would the Author like to comment on the physical significance of his dimensionless groups? For example, using y_0 to represent the total depth of flow in an open channel, the parameter $U_\infty/(\omega\nu)^{1/2}$ could become $(U_\infty y_0/\nu)/(\beta y_0/\sqrt{2})$, and a/L could become $(U_\infty T/y_0)(y_0/L)/2\pi$, where T is the period. Thus the factors governing oscillatory flow are clearly

$$\left\{ \frac{U_\infty y_0}{\nu}, \frac{U_\infty T}{y_0}, \frac{y_0}{L}, \beta y_0 \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

41. The first two may be thought of as a Reynolds number and a Strouhal number. In open channel flow work it is usual to replace U_∞ , a surface velocity, by a depth-mean velocity. Thus the only effect of a rippled bed is the inclusion of the term y_0/L .

42. In Fig. 7 the form of solution is only presented for h/L down to 0.1. Has the Author extended this diagram to include all possible cases, with smooth as well as rippled beds? Presumably the curves could be extended to include the data relating to the transition phenomenon over smooth beds, thus illustrating the importance of the term y_0/L . The transition problem is difficult to represent on a single dimensionless plot for all these cases. However, if achieved, this would help considerably in the design of small-scale models, some of which might well have a rigid rather than a mobile boundary.

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As Dr Knight points out, it is necessary to take account of the parameter y_0/L when the oscillatory boundary layer thickness is comparable with the depth of flow y_0 . In this case, the dimensionless groupings proposed in equation (4) seem most appropriate. In the case considered in the Paper the depth is much greater than the oscillatory boundary layer thickness and consequently does not affect the velocity distribution near the bed. In that case the parameter y_0/L is irrelevant. The transition between these two cases is well illustrated by Knight,¹⁵ making use of Agnew's model.

44. As far as the physical significance of the various groups is concerned, it may readily be seen that $U_\infty/(\omega\nu)^{1/2}$ is a Reynolds number based on the thickness of the oscillatory boundary layer. The parameter a/L is a Strouhal number based on the ripple wavelength. Since $U_\infty/(\omega\nu)^{1/2} = \beta L(2)^{1/2}(a/L)$, it could be said that in the case considered in the Paper, the only effect of a rippled bed is the inclusion of the term a/L and, of course, h/L .

45. Curves for values of $h/L < 0.1$ were not included in Fig. 7 because no test was carried out at very small values of h/L . However, the limiting case of a flat bed has been widely studied and the various measurements are discussed in reference 8. For a smooth flat bed there is little reason to doubt the value $U_\infty/(\omega\nu)^{1/2} = 400$ obtained for transition to turbulence by Li.¹ For flat beds of sand or gravel the limit is less well established. However, it is my belief (which requires further experimental verification) that a reasonable estimate of the onset of fully-developed turbulence under these conditions is given by the fully-developed mixing curve in reference 8 through Manohar's² and Li's¹ measurements. In the present notation this curve may be written, for $0.19 < \beta D < 31$, as

$$\frac{U_\infty}{(\omega\nu)^{1/2}} = 75.9 \left(\frac{a}{D}\right)^{0.225} \dots \dots \dots (5)$$

where D is the median grain size of the sand or gravel. The limits on the value of βD correspond to $2.0 < a/D < 1450$. Although the form of this curve is similar to that of the curves in Fig. 7, it should be remembered that the bed geometry is very different in the two cases. Also, this curve corresponds to the condition for fully developed turbulence, whereas the curves in Fig. 7 are for initial instability. The parameter y_0/L does not appear in equation (5) because the measurements were made with oscillatory boundary layer thickness very much smaller than y_0 . The case where this is not true requires further investigation.

References

14. AGNEW R. A two layer theory for unsteady flow. *Proceedings of the 2nd Australasian conference on hydraulics and fluid mechanics, December, 1965*, A97-A115.
15. KNIGHT D. W. Velocity and shear stress distributions in oscillatory flow. Paper A9, XVIth Congress I.A.H.R., Sao Paulo, Brazil, 1975, 66-72.