CHAPTER 30

THE THRESHOLD OF MOVEMENT OF COARSE MATERIAL IN OSCILLATORY FLOW

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ABSTRACT

Experimental results are presented from which it is now possible to predict the threshold of movement of shingle.

Introduction

The experiments were conducted in an Oscillating Water Tunnel, (Ref. 1), on the threshold of movement of shingle size material. The Tunnel simulates the oscillatory water motion at the sea bed due to wave action with a semi-orbit range of 0-4.5 metres and a period range of 5-15 seconds. Additionally, a uni-directional current of up to 0.6 m/sec can also be superposed upon the oscillatory motion.

Although limestone chips of between 0.32 cm and 2.5 cm diameters were the basic material tested, other materials such as coal and sand were examined in order to observe the effects of the various parameters over a wider range.

The Experiments

The various materials were placed in a bed 2.44 m. long and 45 cm, wide, with smooth wooden ramps at each end and in all cases was made at least 3 or 4 particles deep with a minimum depth of 5 cm. In some cases, for reasons of economy, a smaller bed 30 cm. long by 45 cm, wide was used: for example when glass spheres and concrete cubes were studied. To generate the appropriate boundary layer conditions within such a short bed, limestone chips of appropriate sizes were set into bitumen, on boards either side of the test material.

At the beginning of the study, it was thought to be desirable to define the initiation of movement in some precise way rather than rely upon a purely visual assessment. A method, analagous to the zero transport approach, was carried out for a number of test runs by initially marking a band across the bed and subsequently noting the number and position of particles which had moved out of the marked area. This type of test was carried out for various amplitudes, at set periods for a common number of oscillations.

From the distribution curves, the probability of a particle moving from its initial position to a position within the range x to $(x + \delta x)$ was determined. The standard deviations of the probability curves thus found were plotted against amplitude and the intercept of the curve, passing through these points, with the axis taken to be the threshold condition. Simply plotting the number of particles moved against amplitude yields an ill-conditioned curve for the determination of the point of intersection.

Obviously a great deal of work was entailed in the determination of a single value of threshold. However, observation showed three distinct phases in bed movement. Firstly, a broad band of conditions existed in which particles rocked to and fro without actually moving position. Secondly, one or two particles would be dislodged and move a few places downstream and finally, with a small increase in velocity and acceleration many particles moved. It was the second condition that was found to equate with the deduced limit of threshold. After a few tests the observer was able to decide upon the limiting conditions which were consistently in agreement with the calculated values. Thus having 'calibrated' the observer, all subsequent determinations were carried out visually: only at the extremes with relatively small and relatively large particles was it considered difficult to assess the limiting conditions with reasonable accuracy.

Since the period of oscillation may be varied while the machinery is running it was found expedient for visual determinations, to fix the amplitude and gradually decrease the cycle period until the threshold was reached.

The Results

The independent variables describing the purely oscillatory motion are

a, the semi-orbit length,
T, the period
ρ, the density of the fluid (water)
μ, the viscosity of the fluid (water)
ρ_s, the density of the grains,
d, the equivalent sphere diameter of the grains
and g.

Apart from the sands, all materials were classified by their average equivalent sphere diameters, i.e. the diameter of the sphere of equivalent volume. This was considered to avoid the introduction of spurious shape factors and give a more direct representation of gravitational force when combined with the specific weights.

An acceptable grouping of the variables into dimensionless parameters is

$$\frac{a^2}{g'T^2d}, \quad \frac{ad}{T\nu}, \quad \frac{a}{d} \quad \text{and} \quad \frac{\rho_s}{\rho},$$

where $g' = \frac{\rho_s - \rho}{\rho}.g$ and $\nu = \frac{\mu}{\rho}$ the Kinematic viscosity. The first and second parameters are the grain Froude number and the grain

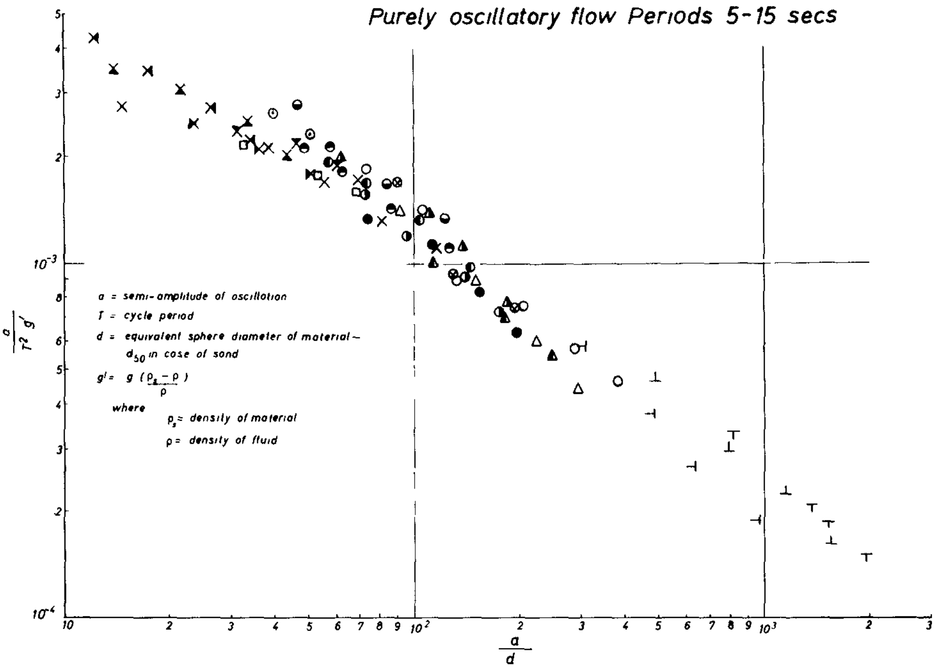

FIG. 1. THRESHOLD OF MOVEMENT OF COARSE MATERIAL IN OSCILLATORY FLOW

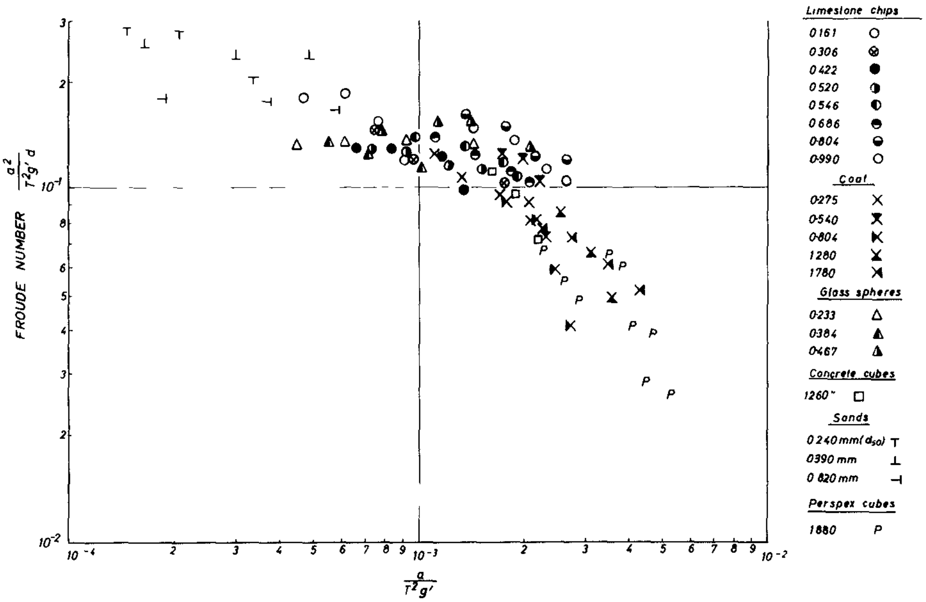

FIG. 2. PLOT OF FROUDE NUMBER v ACCELERATION NUMBER

Reynolds number respectively and one is tempted to plot one of these parameters against the other; analagous to the work in uni-directional flow. The remaining two parameters would then be expected to give rise to families of curves at constant values of $\frac{a}{d}$ and $\frac{\rho_s}{\rho}$. However, such a plot unnecessarily exaggerates the experimental error and the influence of the other parameters becomes indiscernible.

An alternative is to replace the Fr. No. by an acceleration number a/T^2g': this represents the ratio of the acceleration forces to the gravity forces. A plot of this parameter against a/d is shown in Fig. 1. The influence of viscosity appears as an increase in the scatter on the right hand side of the plot in the region where drag forces predominate. So far, insufficient data has been collected to enable lines of constant Re. No. to be drawn in with any degree of certainty. It is only in the other extreme of high acceleration numbers and low a/d numbers that one might expect the fourth parameter, ρ_s / ρ to exert any influence. Again no conclusive evidence on this effect has been observed so far.

The particular plot given in Fig. 1 does not illustrate the relative importance of drag forces and acceleration forces although the parameter a/d may be considered to be the ratio of the two. The comparison is best made by plotting the Fr. No. against the acceleration number as shown in Fig. 2. This plot shows clearly, despite the scatter, that neither drag force not acceleration force can be considered insignificant in any part of the range: even with sand where Manohar (Ref. 2) considered it safe to account for drag forces only.

The foregoing discussion has assumed that the effects of acceleration are the result of an acceleration force. This is not necessarily so since the rate at which work is done on the grain is possibly more important. If insufficient work is done in each cycle the grain will fall back into its original position. Thus the significance of the acceleration number is possibly an expression of the time variation of velocity rather than an expression of acceleration force.

Although it would appear that drag forces cannot be completely ignored within the range of conditions tested, it was surprising that the superposition of uni-directional flow did not markedly change the oscillatory conditions necessary for the initiation of movement. Unfortunately the introduction of yet another variable makes the analysis of results extremely difficult and impossible to present in a simple plot as in Fig. 1.

A few experiments with graded materials showed that the threshold value was appropriate to the d_{50} size.

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