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WAVE INDUCED WATER PARTICLE MOTION

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SUMMARY The paper illustrates velocity profiles induced by a wave field measured in a laboratory experiment and compares them with theoretical representations. Most of the observations relate to intermediate water depth conditions.

The velocity measuring technique is the suspension wire device based on a drag principle. The suitability of such a device for measurement of orbital velocities very near to the crest of a wave is studied and for the first time velocities in the wave crest are reported. The probe is exposed to atmosphere periodically and the experiments confirm the suitability of the device under such conditions.

The results illustrate that the settling time for recording the response from air to water is about 0.1 sec. Thus the determination of total wave characteristics is possible by this method and the potential for studying in detail the breaking wave is evident.

1 INTRODUCTION

A range of theories are available to describe wave motion. They can be confined to progressive regular waves, involve complex irregular waves or may be related to isolated waves. The objective is to be able to describe naturally occurring waves in the ocean or the laboratory generated variety which attempt to simulate those waves. The easily observed wave height is a good basis for verifying theory but the motions beneath the surface must also be known and indeed the activity at or near the bed may be paramount in matters relating to mass transport for example.

Experimental observations have relied on techniques which involve following the motion of a tagged particle, such as a dye or droplet as reported by Le Méhauté et al(1981), Kolpak and Eagleson (1970) and Iwagaki and Sakai (1970). In recent times higher technology has allowed electromagnetic methods as described by Sand (1979) and Chakrabarti (1980) and doppler techniques according to Tsuchiya and Yamaguchi (1972), Miller and Zeigler (1964), Steer (1972), Thornton (1969) and Lee et al (1974) to be used in addition to the traditional current meters. Drag devices as described by Haritos and Sharp (1977), Beardsley et al (1963) and Sleath (1969) have been used with varying success.

The success of newer methods has yet to dominate the release of date either in a laboratory or field environment and this paper presents some results derived using a simple drag device as reviewed by Sharp (1981) and referred to as a suspension wire.

The investigations in the A.G.M. Michell Laboratory wave tank of wave forces on structures, reflections from beaches and mass transport, have necessitated a close study of the velocity fields associated with the wave motion.

A complete picture of the velocity field would include observations in the crest of the wave and as this has recently been attempted with the suspension wire the paper includes some data in this zone.

2 WAVE THEORIES

The wave tank work has been limited to intermediate type waves approaching shallow water in some cases.

The ranges of periods and amplitudes studied since the wave research facility has been operating are shown in the table below.

TABLE 1

PERIOD-AMPLITUDE RANGES

Period (seconds)	Amplitudes h/λ	 H/H_b
1 to 3.33	.037 to .492	.05 to .33

where λ is the wave length, h the still water depth, H the wave height and H_b the breaking wave height according to Stokes' criteria applied to solitary wave theory.

The theories which have been compared with the experimental results are the Stokes I, Stokes III (see Skjelbreia (1959) and Tsuchiya and Yashuda (1981)) and Cnoidal wave theory (see Keulegan and Patterson (1940)) where appropriate.

The need to establish the suitability of wave theory is related to the research currently in progress. In one case the forces on surface piercing cylinders have been measured and it has been found that an incomplete description of the wave current field leads to an under-estimation of certain forces. In another case the research on mass transport requires both Lagrangian and Eulerian measurements to a high degree of repeatability and the suitability of wave theory for this research is closely related to the restraints of the laboratory environment.

3 SOME PRELIMINARY STUDIES

In Figure 1 the wave tank configuration is shown with leading dimensions.

As reported elsewhere, McNamee et al (1983), earlier work in approximately 1 m depth of water with h/λ varying from 0.15 to 0.5 showed that the Airy theory tended to predict the correct relative amplitude of the two components but it over-estimated the individual components.

The time variation of the water particle velocity vector as shown in one example in Figure 2 is indicative of the intermediate wave type studied at that time.

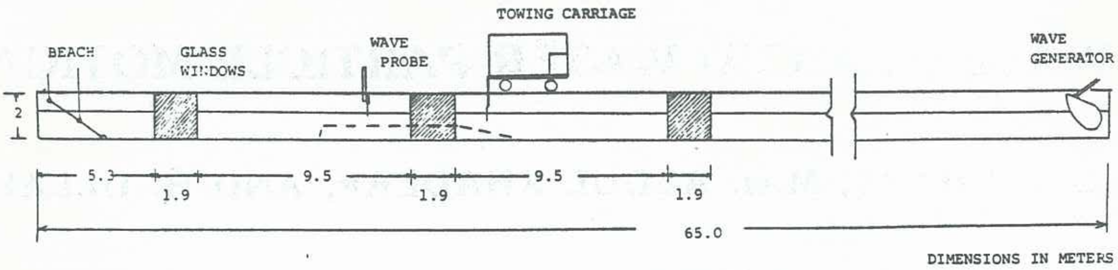

FIG.1

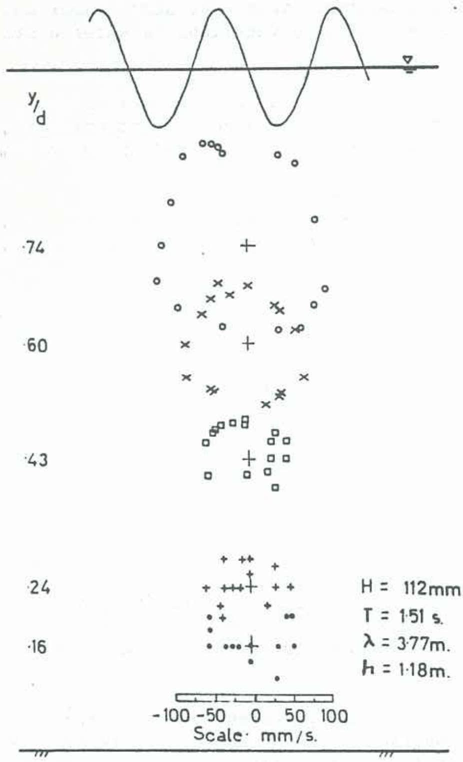

FIG.2

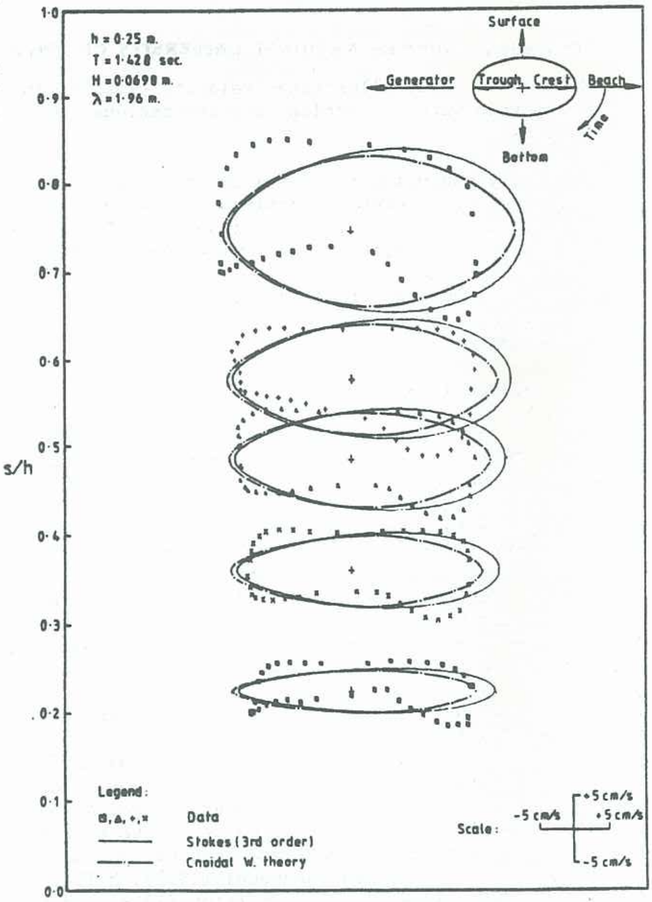

FIG.3

More recent studies in a shallow depth (0.25 m) with typically a h/λ of approximately 0.125 yielded results such as is shown in Figure 3. There is a strong second harmonic in this set which can be seen in the individual velocity components over one wave cycle as shown in Figures 4 and 5, but the relative amplitudes of the maximum velocity components are still well predicted by higher order theory as shown.

The second harmonic is mainly due to the partitioning of the tank to develop a section for shallow water waves as shown by the dash lines in Figure 1.

Whilst these results are not suitable for certain studies, the ability to measure the individual water velocity components is evident. The measurements cited above were all taken below the wave trough.

4 OBSERVATIONS IN THE WAVE CREST

Any device fixed in elevation and monitoring conditions in the crest of a wave will be periodically exposed to air and be subject to dynamic conditions in transition both of which impose problems and the usefulness of the device will depend on its dynamic response characteristics. The response may be described in terms of "settling time".

Figure 6 shows an enlarged plot of several wave lengths of data including the wave elevation and the longitudinal velocity component (unlinearized).

The heavy horizontal line in (a) is approximately the still water level with the wave travelling from left to right (time, right to left).

The velocity in (b) is positive downwards and the instrument location is shown by the dashed line with vertical lines indicating the time when the instrument passes into and out of the crest. The "negative" velocity excursions are irrelevant because the device is exposed. There is clearly very little deterioration in signal as the device moves from water to air whereas there is equally clearly a "settling time" in the reverse case. The average "settling time" is approximately 0.1 seconds.

In this record the instrument is recording satisfactorily for 0.58 seconds in a wave period of 1.25 seconds, losing 0.10 seconds of record only.

5 OVERALL VELOCITY VARIATION

In Figures 7 and 8 are shown a sequence of readings at several levels over the full depth, in this case the raw analogue data from a UV recorder. The vertical velocity component is also included and both velocity components are unlinearized.

The above records and others in the same set enable the distribution of maximum velocity with depth to be derived as shown in Figure 9.

There is some scatter in the results, but generally the form of the distribution is established.

The wave theory appropriate to the above conditions would be either Stokes III or Cnoidal wave theory, that is, higher order theory than Stokes I. Whereas Stokes I (Airy) theory requires a 90° (or T/4) phase shift in the maximum velocity components over the full depth, the higher order theories show different phase shifts.

In the data above it is possible to deduce the phase shift variation with depth and this is plotted in Figure 10. The higher order wave theories are shown and it is evident that there are significant differences.

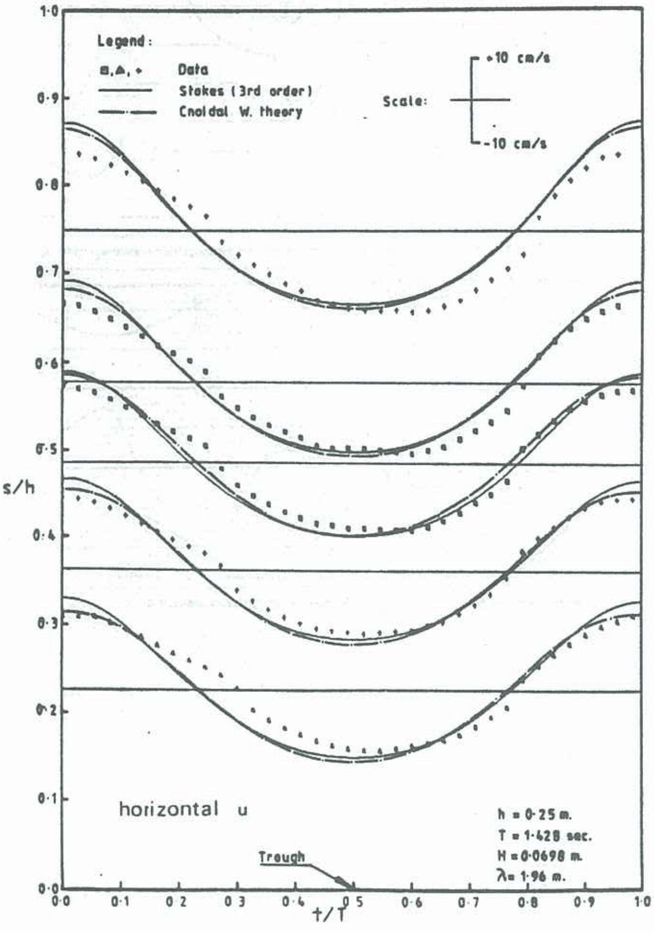

FIG 4

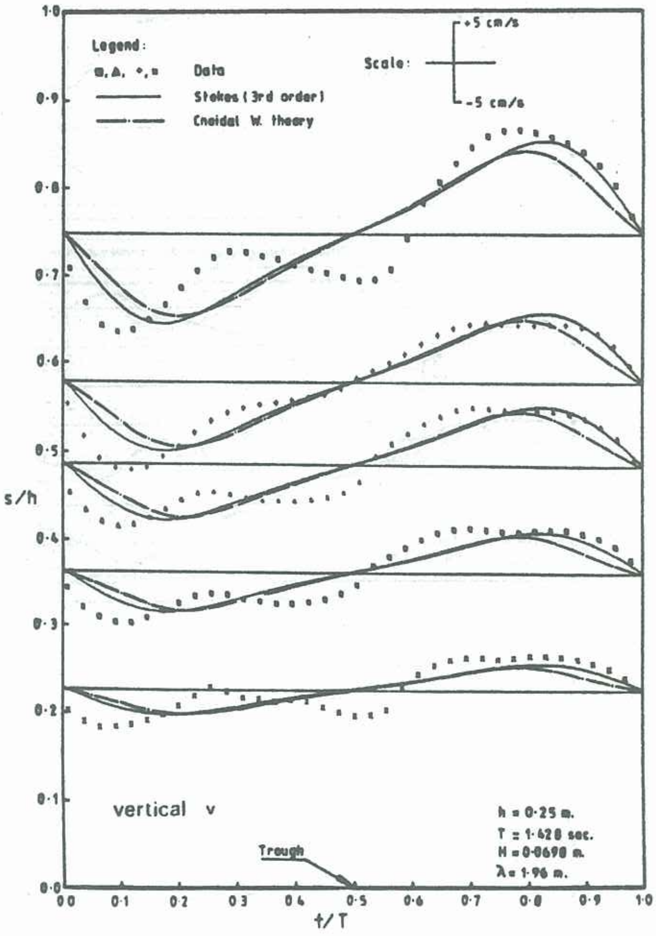

FIG.5

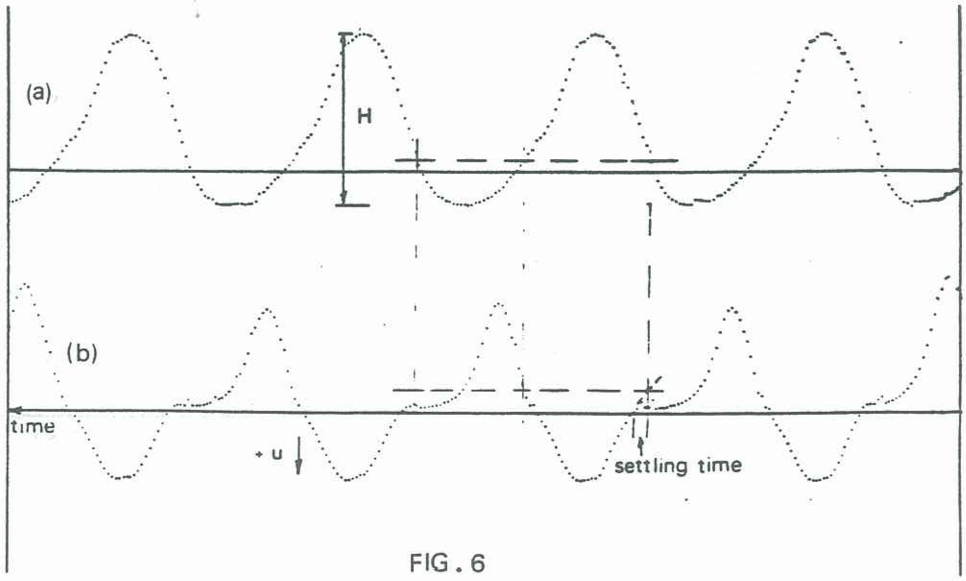

FIG. 6

6 CONCLUSIONS

Recent measurements of wave velocity components have been extended to include conditions in the wave crest.

In general, there is accord between wave theory and experiment in predicting the water surface elevation but the wave velocity components indicate significant differences.

Research which requires a proper definition of the wave field must therefore take note of the possible inadequacy of even higher order wave theory in these respects.

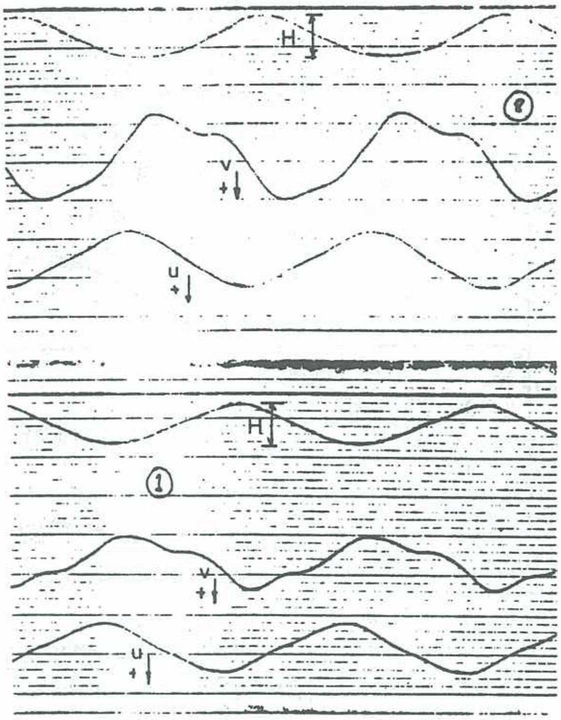

FIG. 7

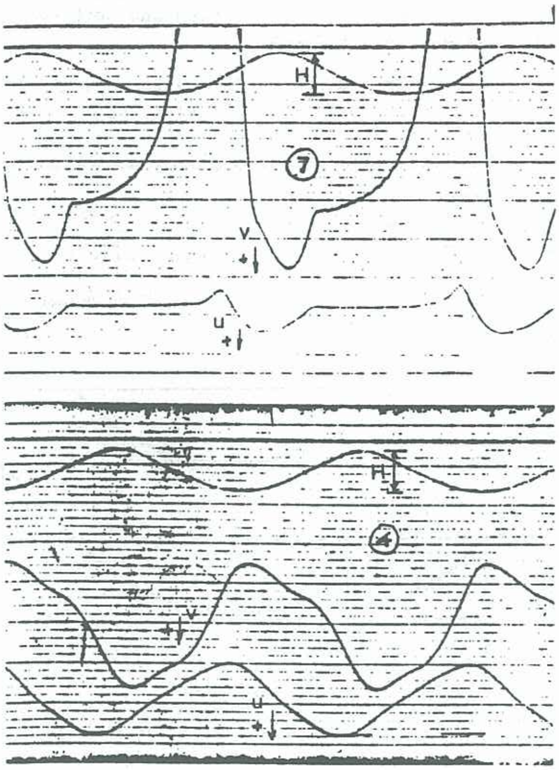

FIG. 8

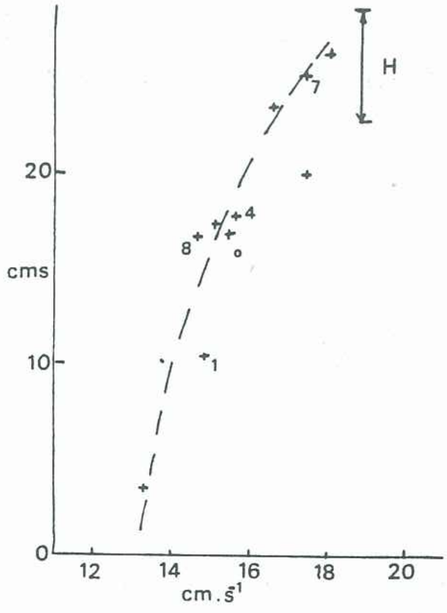

FIG. 9

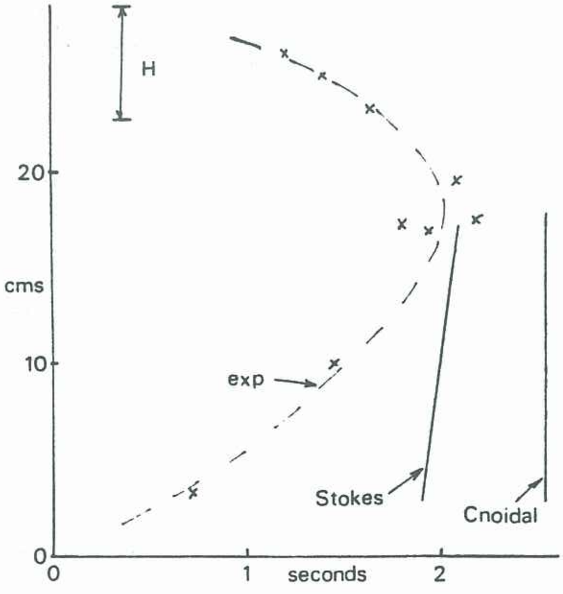

FIG. 10

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