CHAPTER 8

NEAR-SURFACE ORBITAL VELOCITIES IN IRREGULAR WAVES

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ABSTRACT

The paper deals with measurements of horizontal orbital velocities near the surface of mechanically generated waves in a wave flume.

Due to the characteristics of most velocity probes, it is difficult or impossible to measure with a fixed probe in the area above the lowest trough. As the probe is not submerged continuously, failures or uncertainties in the measurements may occur.

To overcome these limitations, a movable frame for the velocity probe was designed, which can be moved vertically up and down with the surface elevation by a disc rotor servo motor, controlled by a wave gauge. By that continuously velocities up to 3 cm below the surface could be measured.

Theoretical velocities have been calculated for comparison with different simulation methods for irregular waves, based on linear wave theory.

INTRODUCTION

Investigations and measurements of orbital velocities have been conducted for a long time. Whereas the most earlier publications were related to investigations in regular waves to check the various wave theories, the subsequent dealt with the development of simulation methods for the theoretical treatment of irregular waves. Especially the velocities in very steep and breaking waves have always been an important subject of investigations and the research on the influence of the directionality will extend, as adequate test facilities for the generation of directional waves are available now.

Due to the characteristics of most velocity probes, however, in general measurements close to the surface of the waves, especially in the wave crests, are difficult or impossible when the probe is fixed at a certain height above the lowest trough. The sensor is submerged then only a short time (especially in scaled model tests) what might create problems due to the time constants of the instrumentation or disturbing air enclosures.

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Earlier own measurements in irregular waves with inductive type probes had to be restricted to this area, too, and recently in a publication of SVENDSEN (1986) on surf zone turbulence it is summarized that "all investigations have concentrated on the region below trough level where measurements are available".

To overcome these limitations and to be able to perform investigations on velocities in the crest area of irregular waves, a vertical movable frame for the velocity probe was constructed. This frame can be moved up and down with the variation of the water surface by a disc rotor servo motor controlled by the output of a wave gauge. So the velocity probe is always submerged and able to measure velocities very high in the wave crest.

INSTRUMENTATION

The vertical movable frame was designed for measurements in hydraulic models with wave heights up to about 0.50 m, equivalent to the range of the often used wave gauges of the DELFT type.

It consists of a U-profiled aluminium bar sliding between guide rollers and driven via toothed rack and pinion directly connected to the servo motor (120W rated output power). A flat coil spring is used to compensate for the weight of the movable parts and the velocity probe.

Figure 1 gives a principal sketch of the set-up in the wave flume.

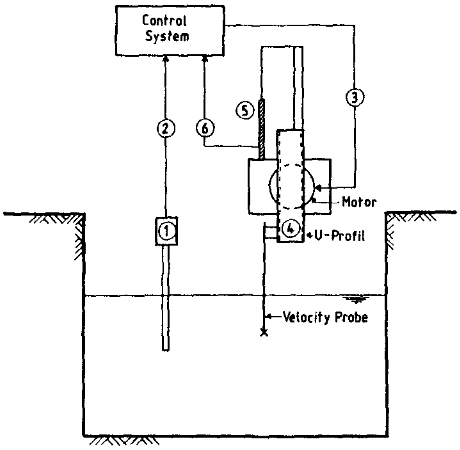

Fig. 1: Principal sketch of set-up of vertical movable frame in the wave flume

The wave gauge (1) measures the actual surface elevation of the water. Its output signal (2) provides the electronic control system which generates the set value (3) for the servo motor. The U-profiled aluminium bar (4) with the velocity probe fixed at the lower end (and connected to the motor via toothed rack and pinion) is moved up and down by the servo motor following the set value (3). The potentiometer transducer (5) gives the actual position (6) of the U-profile (4) to the control system (actual value) and allows also to compare surface elevation and position of the probe for analysis purpose.

Figure 2 shows the device and the electronic control system, Figure 3 the set-up in the wave flume, fixed to a measuring carriage.

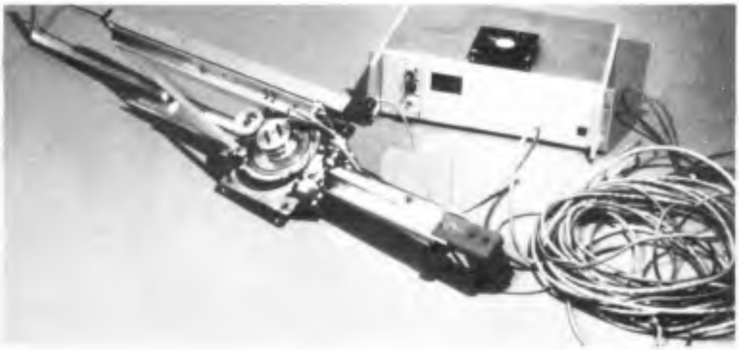

Fig. 3: Set-up of vertical movable frame in the wave flume

For a certain test, the movable frame is mechanically placed in a middle position and the velocity probe is shifted to the pretended submerged depth in still water conditions. After starting the tests the probe is then moved up and down with the surface elevation, measuring in positions approximately parallel to the surface.

Due to the characteristics of the electronic control system, the measured location is not exact constant below the wave surface. However, from the potentiometer transducer, the position of the probe can always be determined and related to the signal from the wave gauge. So the exact position as a function of time is available.

As an example, which demonstrates at the same time the limits of the system, in Figure 4 the time series of water level and probe location, and the difference between both signals, are plotted. The wave train was measured in the area of a 1:30 slope and contained steep and some breaking waves.

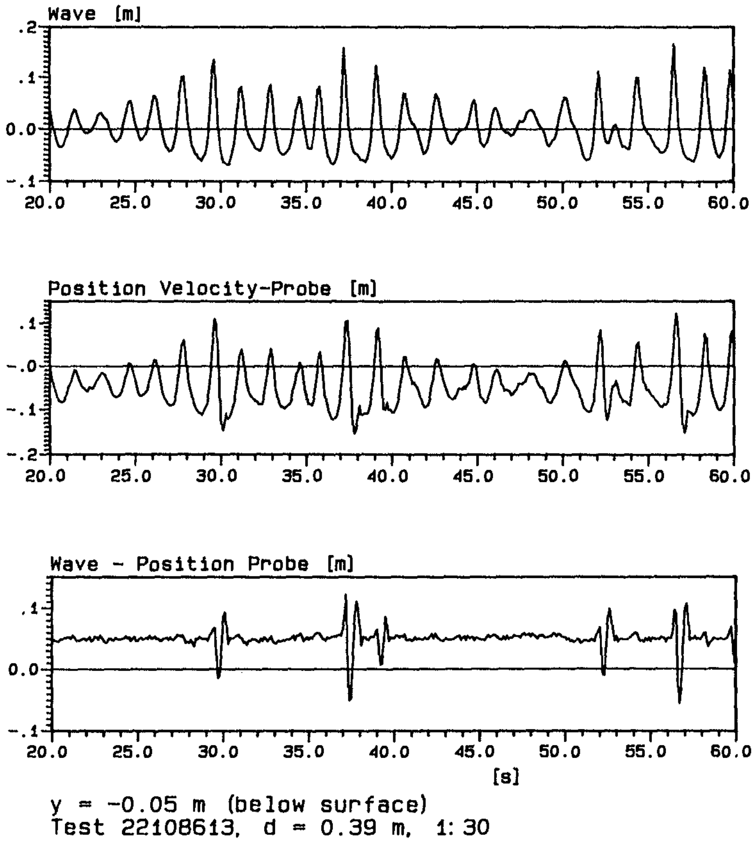

Fig. 4: Comparison of surface elevation and probe location

In the not extreme steep waves the system works with deviations of less than 1 cm. However, in the very steep waves, with the present layout of the motor and the control electronics, the system works not yet satisfying. For further measurements in steep and breaking waves, the system has to be improved by taking a stronger motor and a controller of better quality.

Finally in Figure 5 examplarily maxima (crest) and minima (trough) of the wave time-series and of the time-series of the position of the probe are compared in scatter plots.

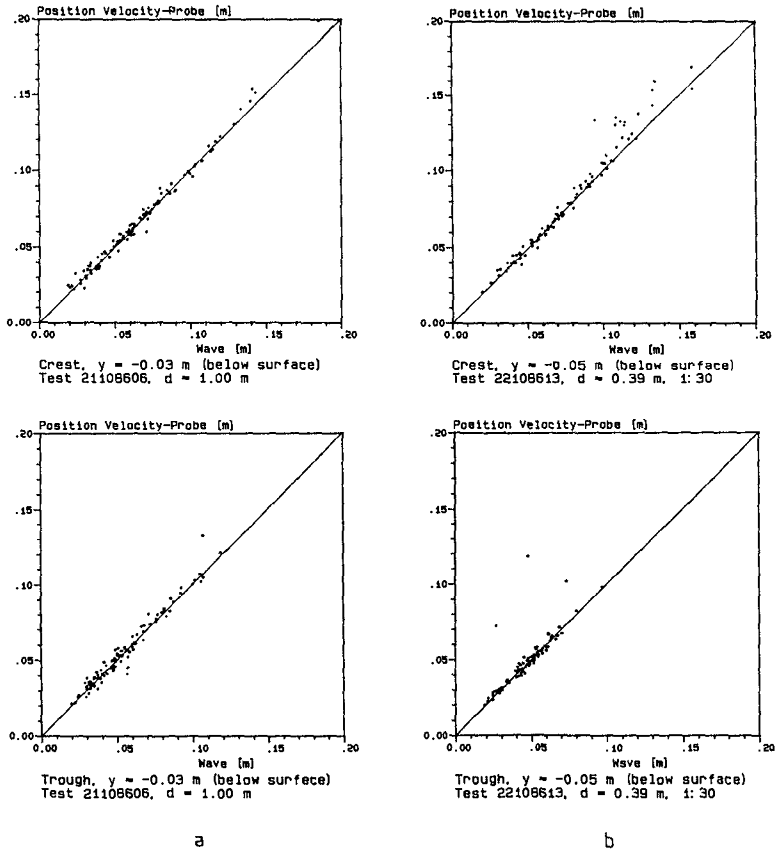

Fig. 5: Comparison of extremal values of wave surface in crest and trough and pertinent position of the probe
a) moderate wave conditions, design condition for equipment
b) very steep and breaking waves

As the motor of the system can be controlled by any external signal, the equipment can also be used for a dynamic calibration of the velocity probes. For the tests discussed in the following, a Delft Propeller Probe was used as a velocity probe. However, also a Minilab SD-12 system was available and included in the test series.

HYDRAULIC BOUNDARY CONDITIONS

The measurements discussed in the following were performed in the wave flume of the FRANZIUS-INSTITUT. The total length is about 120 m, the width 2.20 m. At the end of the flume a 1:30 slope is installed. The water depth during the tests was 1.0 m in the horizontal part.

The results presented here are from a JONSWAP spectrum with

- Peak enhancement factor $\gamma = 3.3$
- Spectral peak period $T_p = 1.8$ s
- Significant wave height $H_{m0} = 0.18$ m

The control signals for the wave machine were calculated according to the random phase spectrum method with a sequence length of 204.8 s for pusher movement of the wave paddle.

Measurements were taken in two sections:

- water depth d = 1.00 m horizontal slope (no breaking waves)
- water depth d = 0.39 m 1:30 slope (some waves breaking)

The submerged depth of the velocity probe was 3, 5, 10, and 15 cm below actual water surface with the moving frame and for comparison, 25 cm and 50 cm below mean water with a fixed height of the probe.

RESULTS OF THE TESTS

During the tests, time-series of waves, horizontal velocities, and probe locations were measured simultaneously. An HP1000/A600+ computer system was used for data acquisition and analysis.

Theoretical results, based on linear wave theory, have been calculated for comparison, with simulation methods described in detail in earlier publications (DAEMRICH, EGGERT, KOHLHASE (1980), DAEMRICH, EGGERT, CORDES (1982)).

In general for the analysis of such tests the transfer function method (or linear filtering method) would be prefered. With this method the theoretical velocity is calculated from the FOURIER coefficients of the wave train, by applying the linear transfer function and getting the time-series by an inverse FOURIER transformation.

For the measurements with the probe location varying with the surface elevation, however, this method leads to a considerable extension of the computer work, and it was decided to use for the present the complementary method, a simulation method in the time domain, which gives results of similar quality, at least in the more pronounced waves. In this method, the maxima of the orbital velocities under crest and trough of a wave were calculated from half-wave parameters. For the horizontal velocities, this half-wave parameters are the amplitude of a wave crest or a wave trough (zero crossing wave crest height a_C and zero crossing wave trough excursion a_T) and the pertinent half-period (crest period T_C and trough period T_T). The parameter designation is according to the List of Sea State Parameters, IAHR (1986). For further explanations and definition sketches see DAEMRICH et al.(1980), (1982).

As an example, in Figure 6 measured and calculated horizontal velocity maxima for a constant submerged depth of the probe of y = 0.25 m below the mean water level are computed and plotted in scatter diagrams. It is obvious, that there is not to much difference in the tendency.

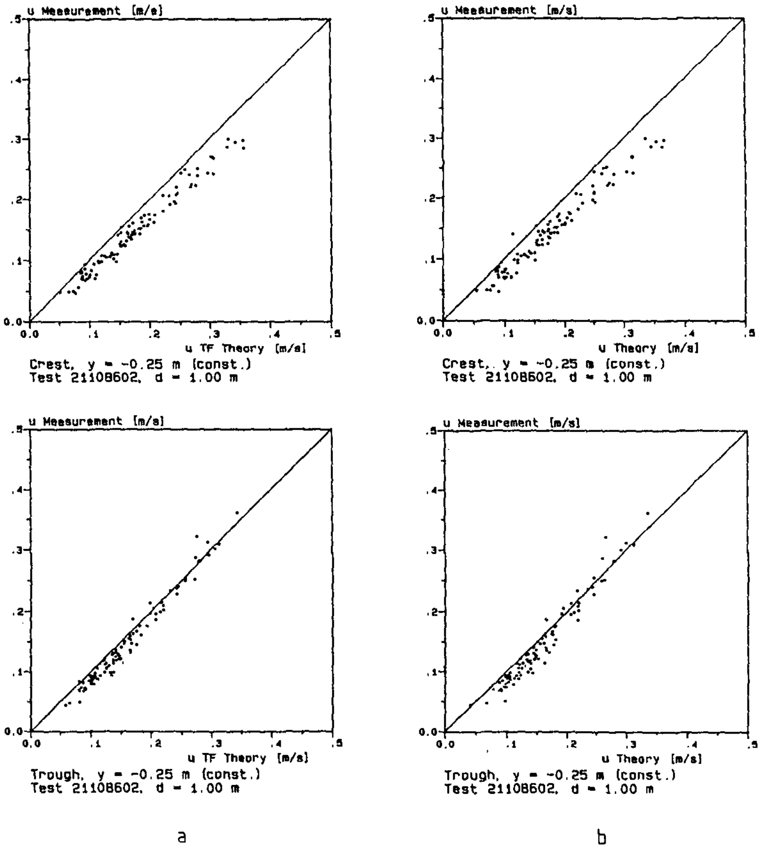

Fig. 6: Comparison of measured and calculated maxima of horizontal orbital velocities in constant submerged depth (y = 0.25 m)
a) Transfer function method b) Complementary method
upper Part: Velocities under the crests
lower Part: Velocities under the troughs

Well known and typically is the tendency of overestimating the velocities under the crests and underestimating the velocities under the troughs, which is somewhat more pronounced in the complementary method. This general deviation in the theoretical results is due to using linear wave theory without any modifications as e.g. stretching of coordinates.

In Figure 7 a part of a measured wave time-series is plotted together with theoretical velocity profiles for crests and troughs of individual waves and measured velocities 3, 5, 10, and 15 cm below the actual surface elevation. For comparison results from measurements in constant submerged depths of 25 and 50 cm below mean water level are inserted.

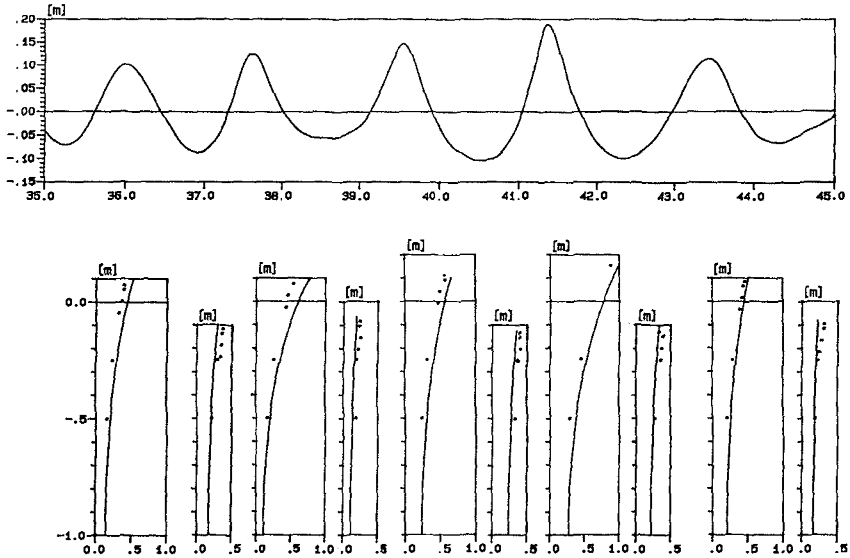

Fig. 7: Velocity profiles in crests and troughs of irregular waves (Theory: Complementary method)

The overestimation of velocities under the crests and the underestimation under the troughs are clearly visibel, however, under these wave conditions there is no change in the general trend closer to the surface.

In Figure 8 and 9 results from the complete time-series are shown as scatter plots. Compared are maxima of measured and theoretically calculated velocities in various submerged depth (upper part: wave crest data, lower part: wave trough data).

Figure 8 gives results measured in the horizontal section of the flume (water depth of 1.0 m), 10, 5, and 3 cm below the surface. The scatter of the data is not too high, also compared to earlier measurements. Overestimation and underestimation are more pronounced closer to the surface.

In Figure 9 similar results are plotted from measurements with the same wave train, but measured in 0.39 m waterdepth in the area of the 1:30 slope. Due to the steeper waves the minimum submerged depth of the velocity probe was 5 cm to avoid surfacing, the maximum submerged depth was 10 cm to avoid bottom contact. To show the trend, results from measurement in a constant submerged depth of 25 cm were added. The scatter of the data measured near the surface has increased due to some very steep or just breaking waves. The highest velocities are measured in a few just breaking waves.

MODIFICATION OF LINEAR WAVE THEORY

To consider the problem of overestimation and underestimation for design purpose the theoretical calculations were conducted exemplarily with a modification of the linear wave theory, similar to the stretching of coordinates (WHEELER (1969)).

Instead of using the actual location of the velocity probe to calculate theoretical values, e.g. 3 cm below surface elevation, we have assumed a constant location of the probe of 3 cm below mean water level for the calculation of the maxima of the near-surface orbital velocities. By this modification, the trend of over- and underestimation is clearly diminished in the complementary method and almost compensated when using the transfer function method as a simulation method.

In Figure 10 scatter diagrams are plotted exemplarily with results of those calculations.

Methods of modification of wave theories, however, have to be tested further for general application. But with the results of several contributions presented at this conference, there seems to be a good chance for simulation methods on the basis of linear wave theories.

ACKNOWLEDGEMENT

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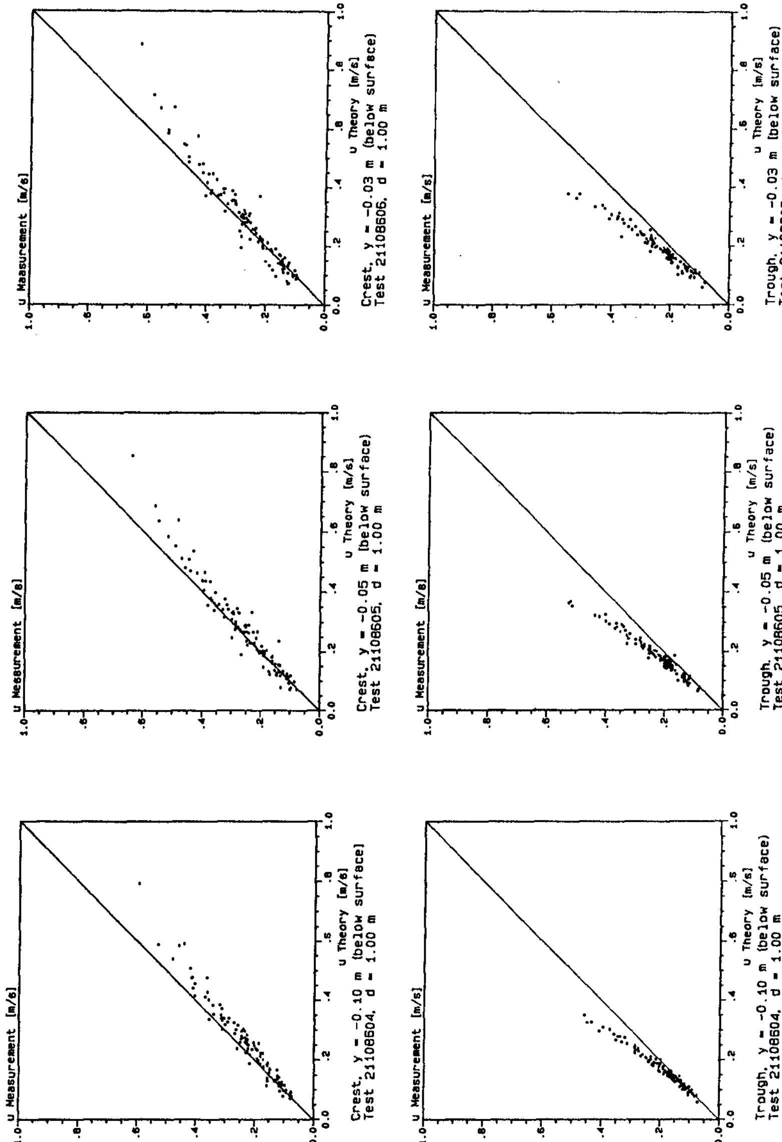

Fig. 8: Comparison of measured and calculated maxima of orbital velocities (d=1.00m)
upper part: wave crest data, lower part: wave trough data

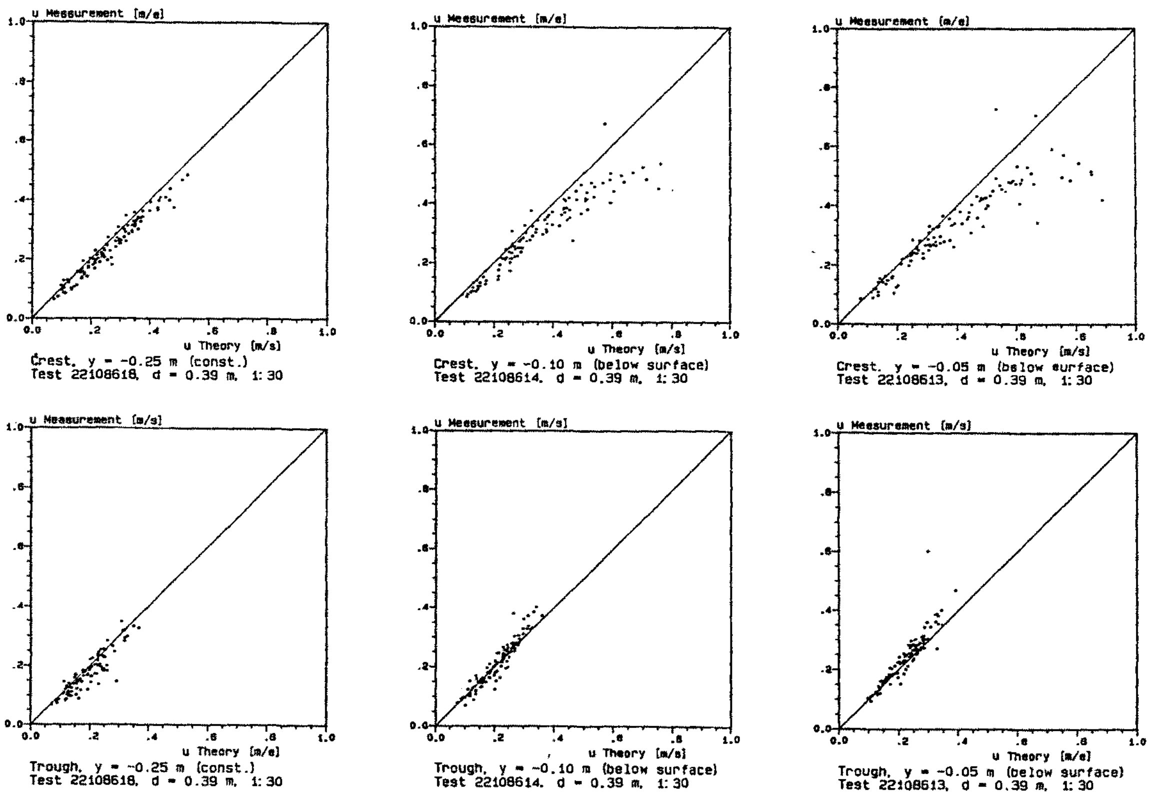

Fig. 9: Comparison of measured and calculated maxima of orbital velocities (d=0.39m)
upper part: wave crest data, lower part: wave trough data

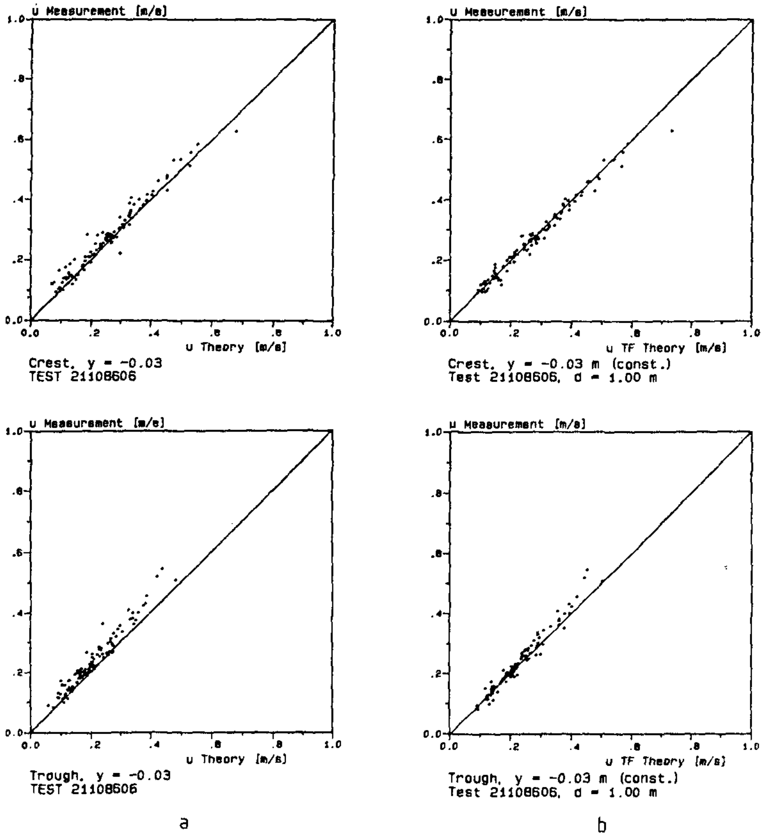

Fig. 10: Effect of modification of linear wave theory
a) Complementary method b) Transfer function method

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