INVESTIGATIONS ON ORBITAL VELOCITIES AND PRESSURES IN IRREGULAR WAVES

by

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ABSTRACT

This paper deals with the results of hydraulic model investigations of orbital velocities and pressures in irregular waves. Different simulation methods in the time and frequency domain were checked or developed, and the theoretical results compared with measurements. Using simulation methods based on linear wave theory, results with good correlation are obtained. At locations near the water surface, however, a tendency towards over- or underestimation exists.

1. INTRODUCTION

Orbital velocities and pressures are important input values for many dimensioning methods in coastal engineering. For regular waves, these values can be calculated using the various wave theories for given wave parameters. Although earlier test results confirm the theories only in a few cases, more recent results provide better agreement, due most probably to better equipment and an advanced control signal generation for the wave machines.

The aim of the investigations described in the following was to develop or check simulation methods which enable orbital velocities and pressures in irregular waves to be calculated theoretically from the wave time-series. The simulation methods were developed in accordance with analysis methods, and are so far based upon linear wave theory.

2. INSTRUMENTATION AND HYDRAULIC BOUNDARY CONDITIONS

The investigations were performed in the FRANZIUS-INSTITUT wave channel. The channel, which is equipped with a servo-controlled, hydraulically driven wave generator, is about

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120 m long and 2.2 m wide. The water depth was 1.0 m in all tests. The control signals for the paddle movement of the wave machine are generated by a Wave Synthesizer (Wallingford type).

The wave spectra were JONSWAP spectra with significant wave heights in the range of 8 to 25 cm and with mean periods of 1.5 to 1.9 sec. The sequenth lengths of the wave time-series were typically about 4 to 5 minutes, depending upon the mean periods.

The velocity components and pressures were measured at 0.25m, 0.50 m and 0.85 m below the mean water level (submerged depth). For the orbital velocity measurements, a COLNBR00K inductive-type probe for two components (horizontal and vertical) was used; for the measurement of the wave trains, resistance wave probes (Delft GHM) were installed. The waves and the corresponding velocities and pressures were measured simultaneously in the same cross-section.

3. SIMULATION METHODS

Initial results of the velocity measurements have already been presented at the recent ICCE in Sydney (DAEMRICH, EGGERT, KOHLHASE (1980)), together with a discussion of three simulation methods. To avoid repetition only a brief description is given here. It should be pointed out that the major objective was to calculate and compare the maximum positive and negative velocity components or pressures in every individual wave of the wave train.

The first method, relating to the superposition method with theoretical TRANSFER FUNCTIONS, is based on frequency domain analysis. The FOURIER components of the wave train are calculated and each frequency component is multiplied by the pertinent value of the theoretical transfer function according to linear wave theory. Finally, using an inverse FOURIER-transformation, the theoretical time-series is recalculated or superposed. From this theoretical time-series, positive and negative amplitudes of the individual waves are determined and compared to the measured values.

The next simulation method is based upon time-series calculations. In this method, regular wave parameters must be defined for each individual irregular wave. Following the most common method, the ZERO-DOWNCROSSING parameters for wave height and period (according to IAHR definition) were used to calculate positive and negative maximum velocities and pressures by means of linear wave theory.

Owing to the fact that a comparison between the measured results and those obtained theoretically from the zero-downcrossing method showed very low correlations compared to the transfer function method, the COMPLEMENTARY method was developed. This method is very similar to the zero-downcross-
ing method, but makes use of other definitions for the wave parameters - typically half-waves and pertinent periods. Generally speaking the complementary method involves taking a more effective geometrical part of the wave in the physical sense and completing it, for the theoretical calculation, to a sine wave (or a higher order regular wave).

A definition sketch of the complementary parameters for velocity and pressure simulation is given in Fig. 1.

Fig. 1: Definition sketch for determining wave parameters according to the complementary method

4. RESULTS OF THE ORBITAL VELOCITY INVESTIGATIONS

In Fig. 2, measured and theoretical horizontal velocity amplitudes (submerged depth of the velocity probe: 0.25 m) are compared using the three simulation methods. The results are divided into positive (upper part) and negative amplitudes (lower part of the figure).

The transfer function method and the complementary method both show a reasonable correlation, whilst the scatter in the results obtained from the zero-downcrossing method is markedly higher, and in most cases excludes the application for the calculation of single velocity events.

In the results from the transfer function method and the complementary method there is a general tendency that the measured horizontal velocities are lower than the theoretical ones under a wave crest, and higher than the theoretical ones under a wave trough. From Figs. 3 and 4, which show similar results from measurements for submerged depths of 0.50 and 0.85 m, it may be seen that this tendency decreases with increasing submergence and is no longer present near the bottom for this spectrum.

By comparing the results of calculations based upon higher
Fig. 2: Comparison between measured horizontal velocities and those calculated by different simulation methods (submerged depth = 0.25 m)
Fig. 3: Comparison between measured horizontal velocities and those calculated by different simulation methods (submerged depth 0.30 m; u = 1.3 m/sec; scale 1:10)
Fig. 4. Comparison between measured horizontal velocities and those calculated by different simulation models. (GOWAP spectrum, $n = 3.3$, $y = 0.85$ m/s, scale 1:20).
order wave theories and from the assumption of small amplitudes for the validity of the linear wave theory, it becomes evident that the latter tendency can be attributed to nonlinear effects.

For further details relating to the results of vertical velocity measurements, the reader is referred to the Proceedings of the ICCE, Sydney (DAEMRICH, EGGERT, KOHLHASE (1980)).

5. RESULTS OF THE PRESSURE INVESTIGATIONS

Corresponding results obtained from the simulation of pressure amplitudes in irregular waves are shown in Fig. 5, 6 and 7. As before, the scatter in the results calculated by the transfer function method and the complementary method is distinctly smaller than that arising from the zero-downcrossing method. Compared to the velocity measurements, the scatter in pressure amplitudes obtained from the transfer function method is notably smaller.

The tendency to overpredict pressures under the wave crest and to underpredict pressures under the wave trough is similar to that obtained in the horizontal velocity measurements. Considering the results obtained from the complementary method in more detail, it can be seen that the majority of the data points exhibit a very low scatter and a well-defined trend. A small number of points, however, are clearly overestimated. A visual inspection of the time-series at the relevant positions provides a seasonable explanation. This may be seen for example in Fig. 8, which shows a wave together with its pertinent pressure time-series (submerged depth 0.50 m).

The amplitude marked by an arrow is typical of an overestimated event. Clearly, the influence of the higher frequency component of about twice the basic frequency in this case cannot be neglected when estimating the maximum pressure amplitude. In other words, the actual half-wave form in this case is not properly represented by the complementary parameters, and a modification of the original parameters should be considered.

6. SIMULATION OF WAVE AMPLITUDES FROM PRESSURE MEASUREMENTS

For the recalculation of wave data from pressure measurements, the same simulation methods can be applied. Since, however, the value of the theoretical transfer function at the high frequency end of the spectrum can be exceedingly large, caution is necessary to avoid an upscaling of system noise.

In Fig. 9, a measured wave spectrum is compared with the wave spectrum calculated from the pressure spectrum using
Figure 5: Comparison between measured pressures and those calculated by different simulation programs (depth 0.25 m, scale 1:20)
Fig. 6. Comparison between measured pressures and those calculated by different simulation methods (underwater, depth 50 m, scale 1:20).
Fig. 7: Comparison between measured pressures and those calculated by different simulation methods (submerged depth 0.85 m) (JONSWAP spectrum $\gamma = 3.3$, $U = 13.8$ m/sec., scale 1:20)
Fig. 9: Calculation of wave spectrum from pressure spectrum
Fig. 10: Comparison between measured wave amplitudes and those calculated by different simulation methods (submerged depth 0.25 m, \( g = 13.8 \text{ m/s}^2 \), scale 1:20).
Fig. 11: Comparison between measured wave amplitudes and those calculated by different simulation methods (submerged depth 0.50 m) (JONSWAP spectrum $\gamma = 3.3$, $U = 13.8$ m/sec., scale 1:20)
Fig. 12: Comparison between measured wave amplitudes and those calculated by different simulation methods (submerged depth 0.85 m) (JONSWAP spectrum $\gamma = 3.3$, $U = 13.8$ m/sec., scale 1:20)
the theoretical transfer function. The increasing energy at the high frequency end of the calculated wave spectrum clearly indicates the point at which system noise starts to be dominant and from which point the frequency components should be suppressed (the location is marked by an arrow).

Figs. 10 and 11 show results based upon measurements with submerged depths of the pressure cell of 0.25 m and 0.50 m. Although best results are obtained when the pressure meter is situated near the mean water level, the results are also acceptable in a medium water depth for the spectrum considered. With the pressure meter located near the bottom, however, the scatter in the data was found to be relatively high (Fig. 12).

In deciding whether or not pressure meters may be used as wave gauges and at what depth they should be located, it is necessary to consider both the quality of the measuring and data acquisition systems and the desired accuracy of wave measurements.

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8. REFERENCES