INVESTIGATIONS ON ORBITAL VELOCITIES AND PRESSURES
IN IRREGULAR WAVES

by

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ABSTRACT

This paper deals with the results of hydraulic model investi-
gations of orbital velocities and pressures in irregular
waves. Different simulation methods in the time and frequen-
cy domain were checked or developed, and the theoretical re-
sults 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 unterestimation 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 vari-
ous 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 meth-
ods 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 (Walling-
ford 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 COLNBROOK
inductive-type probe for two components (horizontal and verti-
cal) was used; for the measurement of the wave trains, re-
sistance wave probes (Delft GHM) were installed. The waves
and the corresponding velocities and pressures were measured
simultaneously in the same cross-section.
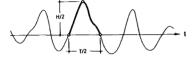

3. SIMULATION METHODS

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 simu-
lation methods. To avoid repetition only a brief description
is given here. It should be pointed out that the major ob-
jective was to calculate and compare the maximum positive and
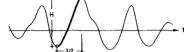negative velocity components or pressures in every individual
wave of the wave train.

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 cal-
culated and each frequency component is multiplied by the
pertinent value of the theoretical transfer function accord-
ing 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 deter-
mined and compared to the measured values.

The next simulation method is based upon time-series calcu-
lations. In this method, regular wave parameters must be de-
fined 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 re-
sults and those obtained theoretically from the zero-down-
crossing method showed very low correlations compared to the
transfer function method, the COMPLEMENTARY method was de-
veloped. 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).
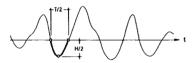
A definition sketch of the complementary parameters for velocity and pressure simulation is given in Fig. 1.
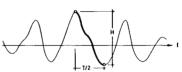

DEFINITION FOR HORIZONTAL POSITIVE VELOCITIES AND POSITIVE PRESSURES

DEFINITION FOR VERTICAL POSITIVE VELOCITIES

DEFINITION FOR HORIZONTAL NEGATIVE VELOCITIES AND NEGATIVE PRESSURES

DEFINITION FOR VERTICAL NEGATIVE VELOCITIES

Fig. 1:   Definiton sketch for determining wave parameters according to the complementary method
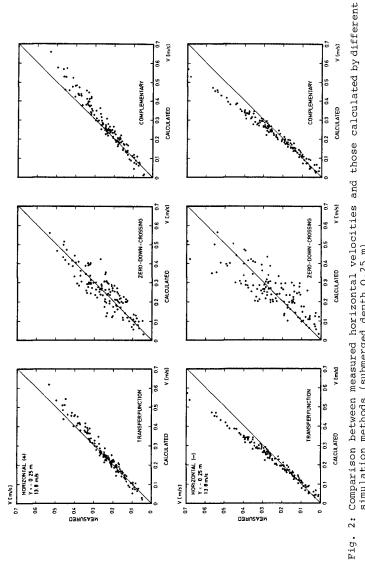
4. RESULTS OF THE ORBITAL VELOCITY INVESTIGATIONS

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 devided into positive (upper part) and negative amplitudes (lower part of the figure).
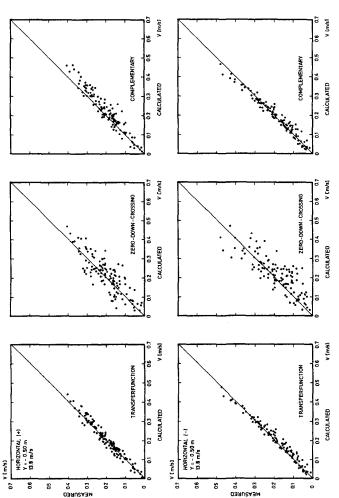
The transfer function method and the complementary method both show a reasonable correlation, whilst the scatter in the results obtained from the zero-downcrossing method is markedly higher, and in most cases excludes the application for the calculation of single velocity events.

In the results from the transfer function method and the complementary method there is a general tendency that the measured horizontal velocities are <u>lower</u> than the theoretical ones under a <u>wave crest</u>, and <u>higher</u> than the theoretical ones under a <u>wave trough</u>. 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.

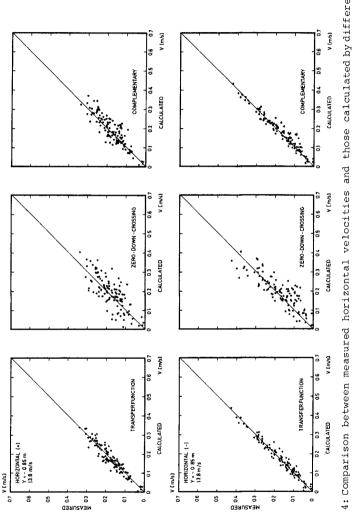By comparing the results of calculations based upon higher

Fig. 2: Comparison between measured horizontal velocities and those calculated by different simulation methods (submerged depth 0.25 m) (JONSWAP spectrum γ = 3.3, U = 13.8 m/sec., scale 1:20)

Fig. 3: Comparison between measured horizontal velocities and those calculated by different simulation methods (submerged depth 0.50 m) (JONSWAP spectrum γ = 3.3, U = 13.8 m/sec., scale 1:20)

Fig. 4: Comparison between measured horizontal velocities 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)

order wave theories and from the assumption of small ampli-
tudes for the validity of the linear wave theory, it becomes
evident that the latter tendency can be attributed to non-
linear effects.

For further details relating to the results of vertical ve-
locity measurements, the reader is referred to the Proceed-
ings of the ICCE, Sydney (DAEMRICH, EGGERT, KOHLHASE (1980)).

5. RESULTS OF THE PRESSURE INVESTIGATIONS

Corresponding results obtained from the simulation of pres-
sure amplitudes in irregular waves are shown in Fig. 5, 6
and 7.

As before, the scatter in the results calculated by the trans-
fer function method and the complementary method is distinct-
ly smaller than that arising from the zero-downcrossing meth-
od. Compared to the velocity measurements, the scatter in
pressure amplitudes obtained from the transfer function meth-
od is notably smaller.

The tendency to overpredict pressures under the wave crest
and to underpredict pressures under the wave trough is simi-
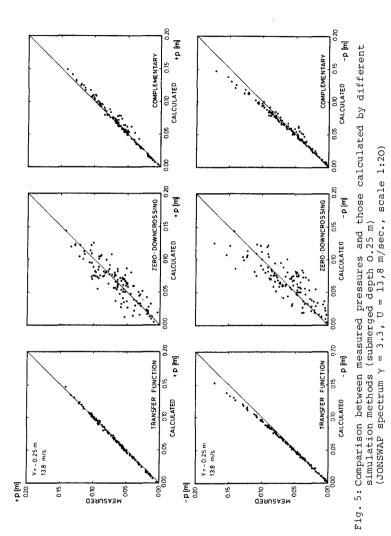lar to that obtained in the horizontal velocity measurements.

Considering the results obtained from the complementary meth-
od 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 over-
estimated. 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 to-
gether with its pertinent pressure time-series (submerged
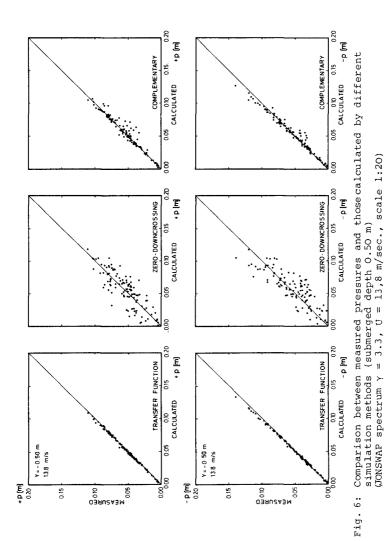depth 0.50 m).

The amplitude marked by an arrow is typical of an overesti-
mated 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 am-
plitude. In other words, the actual half-wave form in this
case is not properly represented by the complementary para-
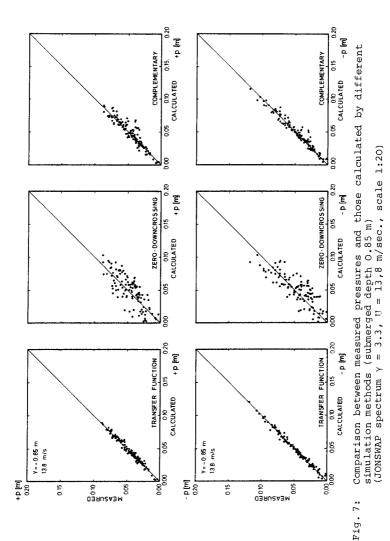meters, and a modification of the original parameters should
be considered.

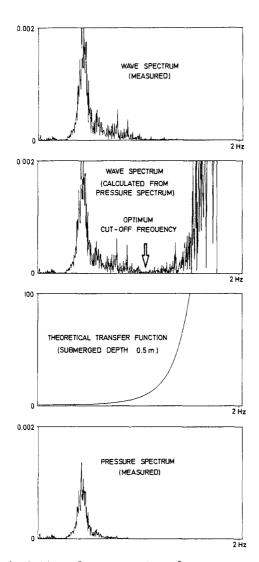## 6. SIMULATION OF WAVE AMPLITUDES FROM PRESSURE MEASUREMENTS

For the recalculation of wave data from pressure measure-
ments, 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
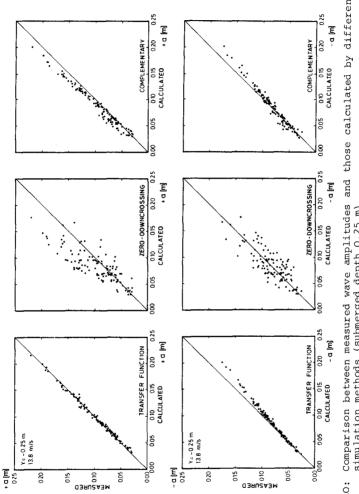wave spectrum calculated from the pressure spectrum using

Fig. 5: Comparison between measured pressures and those calculated by different simulation methods (submerged depth 0.25 m) (JONSWAP spectrum γ = 3.3, U = 13,8 m/sec., scale 1:20)

Fig. 6: Comparison between measured pressures and those calculated by different
simulation methods (submerged depth 0.50 m)
(JONSWAP spectrum γ = 3.3, U = 13,8 m/sec., 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. lO: Comparison between measured wave amplitudes and those calculated by different simulation methods (submerged depth 0.25 m) (JONSWAP spectrum γ = 3.3, U = 13.8 m/sec., scale 1:20)

Fig. 11: Comparison between measured wave amplitudes and those calculated by different simulation methods (submerged depth 0.50 m) (JONSWAP spectrum γ = 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 γ = 3.3, U = 13.8 m/sec., scale 1:20)

WAVE
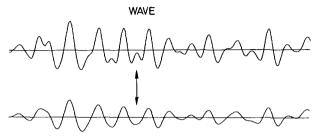

PRESSURE

Fig. 8: Wave and pressure time-series
        (location of pressure overestimation given by
        complementary method is marked by an arrow)

the theoretical transfer function. The increasing energy at
the high frequency end of the calculated wave spectrum clear-
ly 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 aquisition systems and the desired accuracy of wave
measurements.

7. ACKNOWLEDGEMENT

8. REFERENCES
DAEMRICH, K.-F., EGGERT, W.-D. and KOHLHASE, S. (1980):
Investigations on Irregular Waves in Hydraulic Models.
Proc. 17th Conference on Coastal Engineering, Sydney