

Measurement and prediction of regular and irregular wave kinematics

J.O. de KAT and J.E.W. WICHERS

Maritime Research Institute Netherlands (MARIN), P.O. Box 28, 6700 AA Wageningen, The Netherlands

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1. INTRODUCTION

The objective of this study is to compare wave kinematics measurements with predictions from some well-established and more recent theoretical methods. Two different test series were conducted: (1) LDV measurements in regular waves around the mean water level, (2) pressure measurements in regular and irregular waves. In the evaluation of the various theoretical approaches we focus on the horizontal velocities in the crest and trough regions.

2. EXPERIMENTAL SETUP

All tests were carried out in MARIN's High Speed Basin, which measures 200 m x 4 m. The water depth is variable up to 3.70 m. A hydraulic wave generator is located at one end, and a sloping wave absorbing beach at the opposite end. For the waves considered the wave reflection is approximately 4%. The water depth used for the LDV tests was 2.70 m, while for the pressure measurements the depth was 3.70 m.

2.1. LDV measurements

Recently developed Laser Doppler equipment at MARIN allows one to measure fluid velocities in three orthogonal directions simultaneously, while avoiding any disturbances to the fluid itself. Measurements were performed between +0.1 and -0.7 m with respect to MWL at 0.1 m intervals. Each particle passing through the (five) intersecting laser beams creates a backscatter burst signal, which is recorded and analyzed by a Burst Spectrum Analyzer (BSA) to determine the frequency shift. This method allows the signal to be discontinuous, as is the case in the wave crest region, where accurate measurements can be made during short time spans.

2.2. Wave pressure measurements

The second series of experiments consisted of the determination of the dynamic pressures in regular and irregular waves. The test setup was as follows. Membrane-type pressure transducers are located above the still water level, and connected via thin tubes located in a vertical, streamlined strut with openings at five levels underneath the MWL.

3. THEORETICAL APPROACHES

The following methods are applied for a given wave height and period: (1) Linear (Airy or Stokes

I), (2) Stokes V (5th order), (3) Fourier V (5th order) and (4) 3-D higher order panel method.

An overview of the first three methods is given by Sobey et al. (1987). Comparisons between experiments and theory are many. Recent publications include Skjelbreia et al. (1991), Sobey (1990), Gudmestad et al. (1988). For some test conditions a higher order panel method is applied. In this approach surface panels are distributed along one wave length, and the velocity potential is solved at discrete locations using a boundary integral approach. This method has been developed to numerically simulate highly nonlinear waves.

For the irregular wave experiments, linear superposition is used to model the sea state and to estimate the pressure at different levels. Two wave spectra are considered with a full scale duration of 15 min. Computed standard deviations are compared with the experimental data.

4. DISCUSSION OF RESULTS

In this abstract we focus on crest and trough velocities. Measurements and computations have been carried out for four regular waves in a water depth of 108 m (at scale 1 to 40): (1) $T = 7.6$ s, $H = 7.9$ m; (2) $T = 11.4$ s, $H = 9.4$ m; (3) $T = 11.4$ s, $H = 12.5$ m and (4) $T = 11.4$ s, $H = 18.0$ m. H represents the crest-to-trough wave height.

The three velocity components in xyz are u , v and w . Long-crested waves are assumed, so that the transverse velocity, v , is not of interest; the measurements show that this component can indeed be neglected in the analyses. This is illustrated in Fig. 1, which shows the measured wave elevation and velocities in the tip of the crest of Wave No. 2.

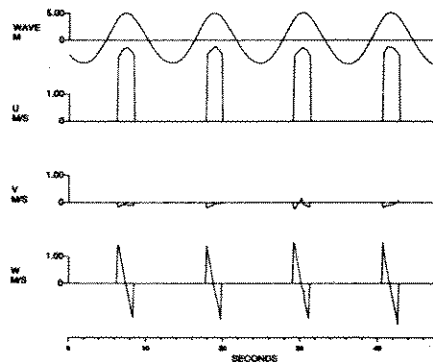


Fig. 1 Measured crest velocities ($z = +4$ m; $T = 11.4$ s; $H = 9.4$ m)

Small fluctuations occur in wave height due to the wave generator and tank wall influence. This results in velocities with slightly time-varying amplitude, as is illustrated in Fig. 2 where u and w are plotted for a number of oscillations at $z = -8$ m of Wave No. 2. The theoretical wave height was taken as the average of the wave heights determined for 20 oscillations.

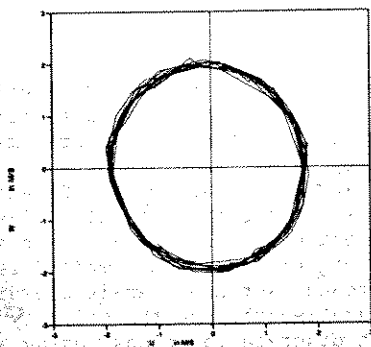


Fig. 2 Combined horizontal and vertical velocities ($z = -8$ m; $T = 11.4$ s; $H = 9.4$ m)

Fig. 2 also shows that the average horizontal velocity is negative, i.e., a back-flowing current is present. This is typical for all measurements considered here and is attributed to the basin being closed, so that the wave drift toward the beach is compensated by a return current and no net mass transport occurs. Gudmestad et al. (1988) suggest that a return current is not necessarily related to the basin, but will also occur for ocean wave conditions. In the application of the higher order wave theories, Stokes' second definition of wave celerity is used (no mass transport). Stokes V and Fourier V predictions closely match the measured profile, while linear (Stokes I) theory shows larger deviations.

In general, Stokes V theory gives the best estimates of the crest velocities, where in most cases the velocity is overpredicted by around 5%.

Only for Wave No. 1 are the predicted values in the crest 2% smaller than the measured velocities. Fourier V theory gives very similar results - differences with Stokes V are typically less than 0.5%. Stokes I theory tends to yield 5 to 10% higher velocities than the higher order predictions. Measured and computed velocities are shown in Fig. 3 for Waves No. 1 and 4.

For the trough velocities tendencies are somewhat different, as values predicted by linear theory are closer to those from higher order methods. In some cases linear theory even yields better velocity predictions. Differences between measurement and prediction are around $\pm 10\%$. Measured and computed velocities are shown in Fig. 4 for Waves No. 1 and 4.

5. CONCLUSIONS

Higher order theories tend to yield somewhat better predictions of crest velocities than linear theory; higher order theory tends to overpredict velocities by around 5%, while this amounts to 15% for linear theory. In the trough regions deviations between prediction and measurement were approximately the same for all theories.

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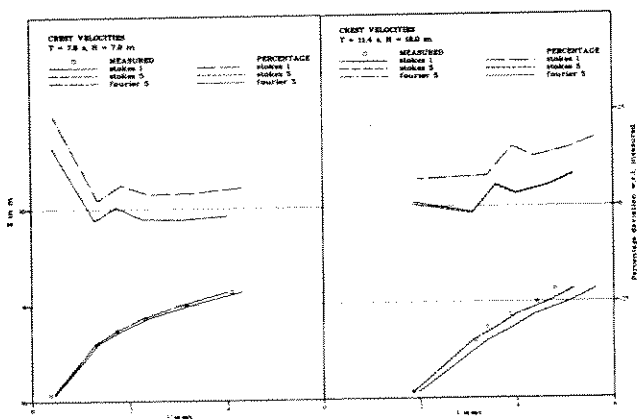


Fig. 3 Measured and theoretical crest velocities

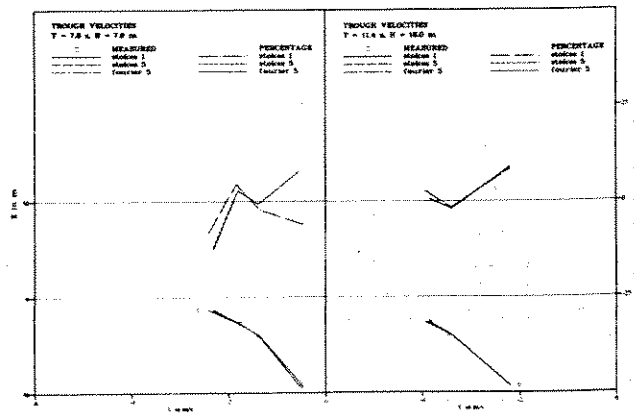


Fig. 4 Measured and theoretical trough velocities