On the New Year Wave at Draupner in the central North Sea in 1995

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A giant wave was recorded at the Draupner platform in the North Sea in a 20 minute record starting at 15:20 on 1st January 1995. In a sea-state with a significant wave height of approximately 12*m*, this had a peak elevation of 18.5*m* above still water level. This paper examines the shape of this large event, showing that at least one feature related to the shape of the wave is peculiar when classical wave theory is applied. We also discuss a possible explanation, which is that classical wave theory is no longer valid in this particular wave, according to the "particle escape" criterion developed by Rainey at earlier Workshops. This criterion holds out the promise that it may be able to identify sea-states in which such anomalous waves are to be expected, and to give their probability of occurrence.

1. The data records

The Draupner platform is situated in the Norwegian sector of the North Sea in water of 70m depth. Two twenty minute surface elevation time series from the Draupner platform were considered in this study, each having an average wave period, T_Z, of 12.5 seconds. The first time series, recorded from 15:20 on the 1st January 1995, contains the New Year wave, and the second was recorded one hour later from 16:20. The data were measured using a downward looking laser device, at a sampling rate of 2.1 Hz. Based on their standard deviations, the significant wave heights for the 15:20 and 16:20 data sets are 11.92*m* and 12.04*m* respectively, implying a steady significant wave height of about 12.0*m*.

The time series plots for the two Draupner wave records are shown in Figure 1.

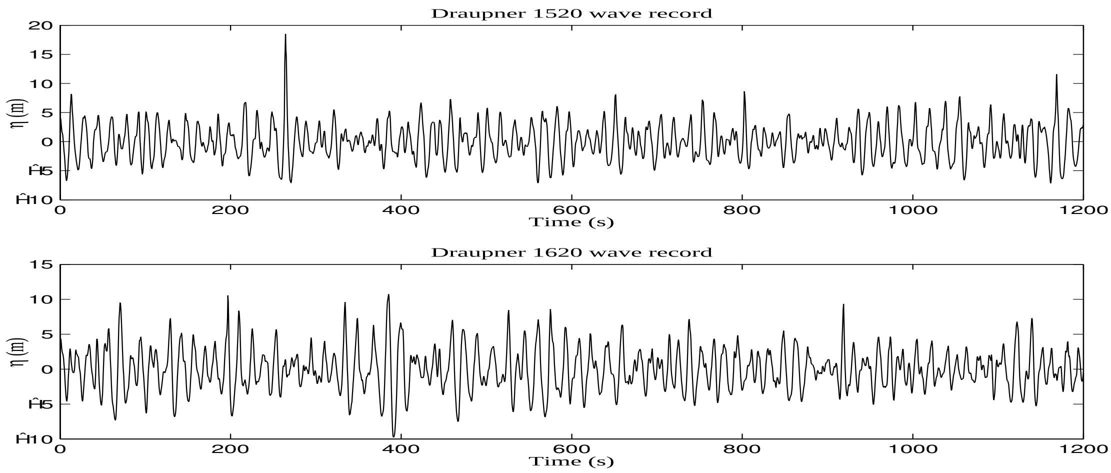

Figure 1. Time series plots for the Draupner 15:20 and 16:20 wave records.

2. Estimating the probability of the New Year Wave, using NewWave

If this wave data fits the classical theory, then a NewWave model (i.e. a wave group of the same shape as the autocorrelation function, with some classical nonlinear terms added afterwards) should be a good local model of an extreme wave. Figure 2 shows both the detailed time history of surface elevation around the large crest, and a NewWave model of this crest, based on the wave spectrum also shown in Figure 2 (the autocorrelation function is, by definition, the Fourier Transform of the spectrum). The spectrum was obtained from the 15.20 wave record, and is conveniently limited (apart from a very small high-frequency "tail") by the frequencies 0.046 and 0.094 Hz.

Figure 2 shows the linear NewWave model, with the 2nd through 5th order sum contributions to the average time-history around the occurrence of a 14.7*m* linear crest. This linear elevation is chosen so that the nonlinear re-construction leads to the observed 18.5*m* crest elevation – it makes this single wave a 1 in 200,000 event. Since minor damage was done to equipment below deck level on the platform, we can be sure that 'green water' reached this 18.5*m* level. Superficially, a linear NewWave of the appropriate height with nonlinear Stokes-like corrections does a reasonable job at matching the local measured time-history. Note though that we have not included any 2nd order set-down in the NewWave model shown in Figure 2. If we do, the return rate for the linear part of the extreme crest is changed to smaller than 1 in 1,000,000 waves. To put this in context, each 20 min record contains approximately 100 waves, so 1,000,000 waves is about 3,000 hours.

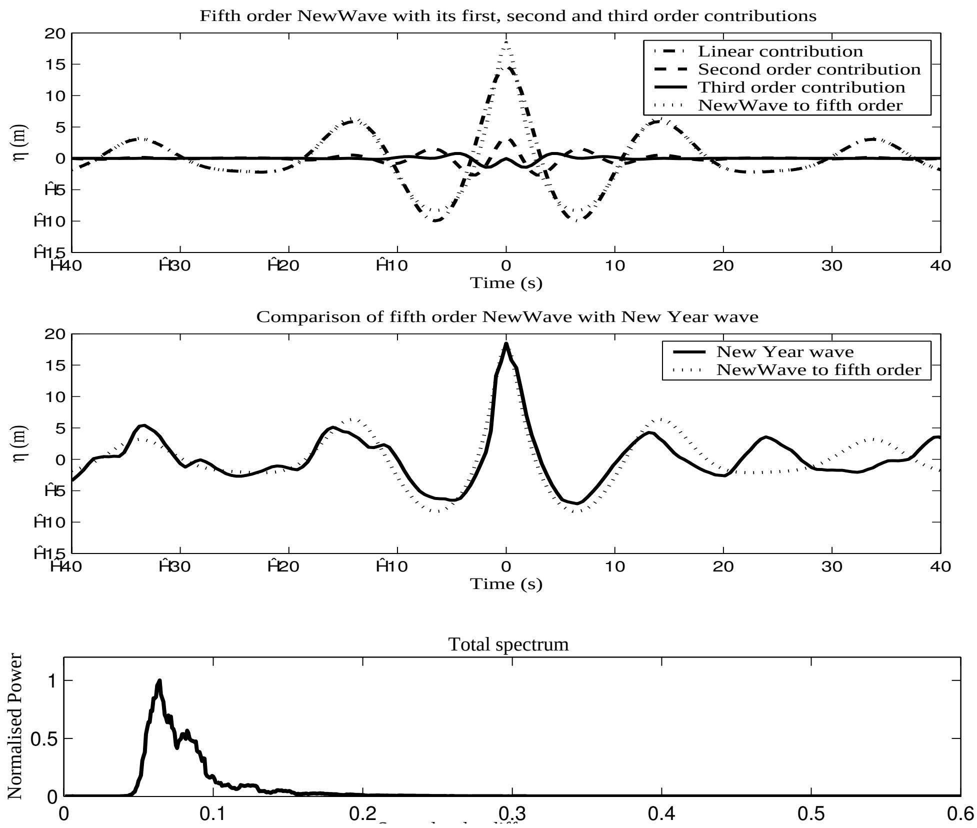

Figure 2. A comparison of the fifth order NewWave profile with its constituent contributions (1st, 2nd and 3rd order *sum* contributions only) and the New Year wave, with the estimated power spectrum for the 15:20 record (freq. Hz) below.

3. The anomalous set-up for the giant wave

A curious feature of the giant wave emerges if the record is low-pass filtered with a cut-off frequency of 0.04Hz well below the dominant contributions to the spectrum, Figure 3. The occurrence of all the largest crests in the 15:20 record can be associated with significant local set-downs (eg. at ~30, 790 and 1170*s* etc.) except for the largest crest which is associated with a large set-up. Also shown in Fig.3 is a crude approximation for the set-down based on the local wave envelope. The absence of a measured set-down perhaps justifies the use of the 5th order re-construction with the 2nd order difference term omitted, as shown in Figure 2.

The anomalous set-up is a robust feature of the record which persists as the cut-off frequency is lowered. It suggests that more than 2nd order theory is involved. M. Tulin has suggested that the set-up might be related to wave breaking – this may well be so, but evidently the wave has not yet broken at the position of the wave sensor.

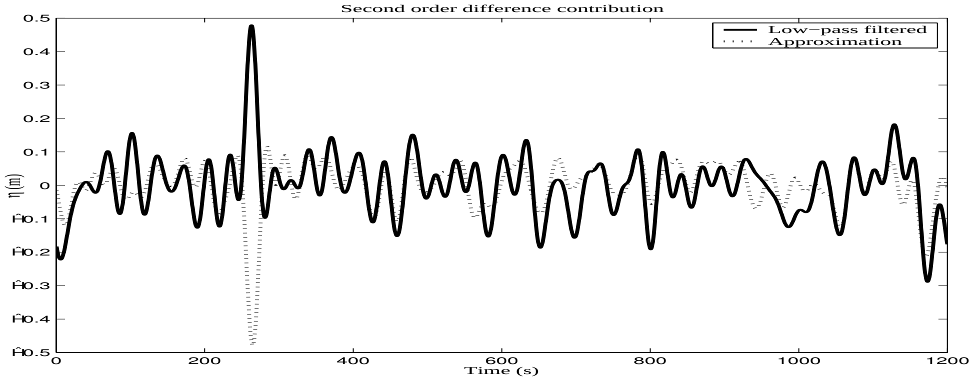

Figure 3. Low-pass filtered long wave contribution to the Draupner 15.20 time history

4. Particle "escape" in the NewWave model

Another indication that 2nd order theory may be breaking down comes from tracking particles moving in the 2nd order velocity field of another NewWave model, again based on the spectrum of Figure 1, again truncated at 0.046 and 0.094 Hz. In this model all the 2nd order terms are included, including the set-down and its velocity potential, but deep water is assumed and the classical 2nd order crest elevation is matched to the observed 18.5*m* crest elevation in Figure 2. Figure 4 shows a snapshot of a series of particles, which were placed initially on the zero-pressure surface of the NewWave model (calculated using the exact pressure formula, including the Bernouilli term), at the extreme trough which occurs 14s before the extreme crest.

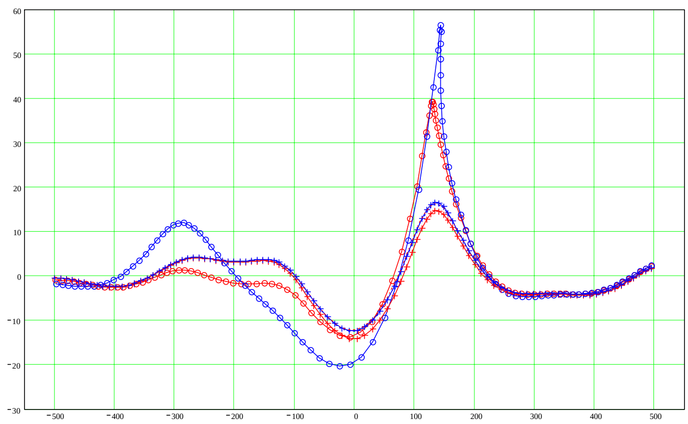

Figure 4. Position reached by particles initially on the zero-pressure surface
(o = particle, + = classical surface)

The particles are shown 6.5s after the extreme crest of the NewWave model. This is just before they "escape" to infinity, which first occurs 9s after the extreme crest. Also shown (apart from the 1st and 2nd order classical surfaces) are a similar series of particles moving in the 1st order velocity field of the New Wave model, starting again from the zero-pressure surface (this time evaluated without the contribution from the 2nd order potential). These do not quite "escape" – the threshold of "escape" in this case is a NewWave 2% higher. In the 2nd order case it is a NewWave 3% lower. The behaviour of the particles to the left of the crest in Figure 4 may appear anomalous – but the particles as a whole must bound a fixed volume of fluid, because Laplace's equation guarantees exact conservation of volume. If some go up, therefore, it is necessary that others must go down.

At the 2002 Workshop, Rainey argued that the "escape" of particles corresponds to wave breaking, and, for in pertinent cases, confirmed this experimentally (2003 Workshop) and by exact computation (2004 Workshop). Whether it corresponds to breaking in the present case is only a conjecture. What is not a conjecture, however, is that classical 2nd order theory is no longer valid when there has been an "escape". This is because the argument leading to the classical boundary conditions on the still-water level has broken down – it relies on either the dynamically-exact surface (Stokes' argument), or the kinematically-exact surface (Rayleigh's argument). The kinematic error on the former is infinite, and the latter has itself disappeared to infinity.

2. Frequency of particle "escape" in the Draupner sea spectrum

The frequency of particle "escape" in the Draupner sea spectrum can be established by Monte-Carlo simulation, tracking a large number of particles chosen at random. This is easiest with the second-order potential omitted. In 15,000 such simulations each 12,000 seconds long (i.e. 50,000 hours in all) there were 14 "escapes". Figure 4 is a Q-Q plot of the 14 durations (from the start of the simulation in which they occurred), against the exponential distribution. It confirms that they are occurring at random, and gives the mean time between "escapes" as approximately 4,000 hours. This is 1.2×10^6 waves, and will reduce to $(1.2\times10^6)^{0.95\times0.95}$ = 300,000 waves = 1,000 hours if we reckon on the "escape" occurring 5% sooner with 2nd order theory, as in Figure 3.

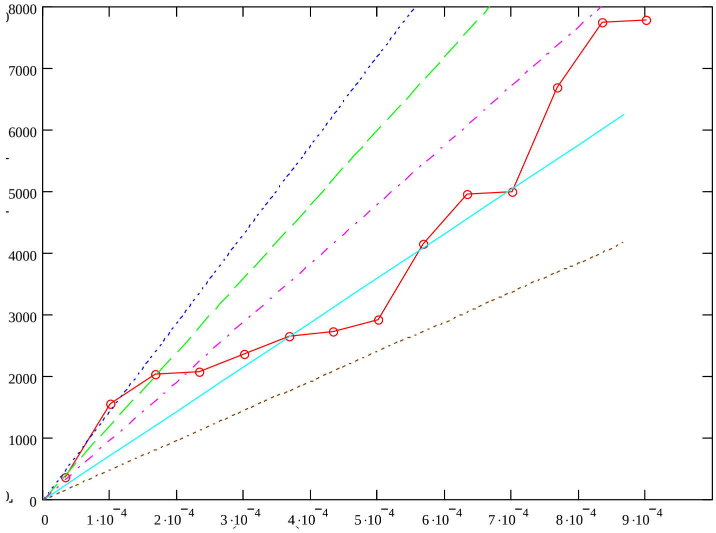

Figure 4. Q-Q plot of simulation duration before "escape" (vertical axis unit = 1.5s)

We are in the process of analysing more spectra from the Draupner field in a similar way, so see if the "New Year" storm had an exceptionally-high frequency of particle "escapes". If so, this methodology holds out the prospect of identifying sea-states in which freak waves are likely. This has obvious operational application – already there are old oil platforms in the North Sea where evacuation is extreme storms is being contemplated, because of fears of platform impact form extreme wave crests. The problem is that these old platforms have a reduced airgap, owing to subsidence under them as the oil reservoir has been depleted.

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