CHARACTERISTICS OF UNDERWATER NOISE GENERATED BY SINGLE BREAKING WAVE

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Investigations of acoustic noise under breaking waves were performed in the LARGE WAVE CHANNEL (GWK) in Hannover. The objective of the experiment was to obtain more precisely the variation in time of parameters of acoustic noise generated by breaking waves. The analysis of individual short-term noise events is presented. In addition, relationships of the noise on wave energy losses during wave breaking and properties of the spectral characteristics under breaker are investigated.

INTRODUCTION

From the time of classical work of Knudsen *et al.'s* (1948) on the relationship between the sea noise and the wind speed/ sea state we are aware of the close associations of sea surface dynamics with the ambient noise field. The sea noise, long time considered to be only as troublesomeness for signal transmission in last decades was suggested as the tool in investigations of many dynamic processes. We could remark that noise under breaking waves at the sea surface may give valuable information on the general properties of dynamical processes which are not easy to recognise using other methods. Passive acoustic techniques show also promises to be the good estimator of the air-sea gas exchange, mixing processes (Deane and Stokes, 2002) or wave breaking type (Means and Heitmeyer, 2002).

In this paper, we focus on the investigations of acoustical noise parameters under a single plunging breaker. The recent studies were conducted in the Large Wave Channel facility (GWK) in Hannover what gives a unique ability to work with breaking waves of high amplitude in controlled conditions. The earlier measurements in laboratories, however performed in better acoustic conditions were made with smaller scale waves (Medwin, Beaky, 1989, Lamarre, Melville, 1992, Dean and Stokes 2002). Our measurements included registrations of acoustics and surface wave characteristics from a set of wave gauges attached close to channel walls. The time dependence of noise parameters in the process of steepening and plunging a solitary surface wave has been analysed.

The experiments were performed in the wave channel filled with fresh water at temperature of 6 °C. To get the acoustical results rightly interpreted, the wave breaking was being filmed simultaneously.

Results must be considered as preliminary, since they are based on a small number of wave parameter measurements, but in our opinion they may be useful for prediction of ambient noise – wave height parameterisation.

1. SET-UP

1.1. Wave channel

The experiments were performed in the LARGE WAVE CHANNEL (GWK) in Hannover. The channel is the facility with the total length of 307m, 7m deep, and 5m wide. The facility is equipped with a set of measuring devices – wave gauges for recording water surface elevation. Single broad-frequency packets of surface waves were produced in the channel by a computer-operated wave-maker. Due to deep-water conditions for surface waves, the velocity dispersion has place. Therefore, the form of the packet changes with the distance and during the propagation compression of surface waves occurred. After compression of a packet, wave energy is cumulated in small volume, amplitude is growing and wave is breaking.

Wave parameters varied in the experiments were the amplitudes and their spectra. In the series of measurements, waves with height 0.8, 0.9, 1.0, 1.2 and 1.4m were generated. Identical wave trains were used in minimum of three the test runs. The form of waves was recorded using the set of 22 wave gauges attached to the channel walls. Wave gauge measurements both upstream and downstream of breaking event enabled to estimate the packet energy dissipation due to breaking.

1.2. Acoustic records

Noise recordings were made from the two omnidirectional hydrophone placed at the depth of 2 m below the mean surfacewith horizontally distance between them equal 4 m. Both hydrophones were located very close to the breaking area deployed from moving observational platform above the most intensive breaking area. The location of the hydrophones in the channel changed from approximately 110 m from the wave-maker to 130, with constant water depth in the main body of the channel equal 4m. To diminish the hydrodynamic pressures from the surface wave motion, the high-pass analogue filter was set at the input to the preamplifier of the hydrophone. The bandwidth of the preamplifier was in the range from 350 Hz to 35 kHz. The noise signal was converted into a digital form using two channel 16bit ADC (50 kHz sampling rate), and subjected to appropriate antialiasing filtering. The ADC memory was capable storing approximately 1.8 seconds before it was necessary to transfer data to the computer memory. To avoid pauses between fragments of registration the repetitions were needed to fill the gaps in data series (look into Figure 3).

We could notice that, due to the wave generation by a programmable wave maker the noise series at the point were highly repeatable.

2. WAVE DATA

The examples of surface elevation time series registered by the consecutive wave-meters in wave packets used in the study at selected locations are shown in Fig.1. The gauges were located at distances from the wave-makers – 84.85, 90.29, 118.0, 126.22, 151.20, and 176.30 meters respectively. The signals from the set of the wave-meters were sampled simultaneously with rate 200 Sample/s and with 16-bit resolution in each channel. The surface elevation series used in

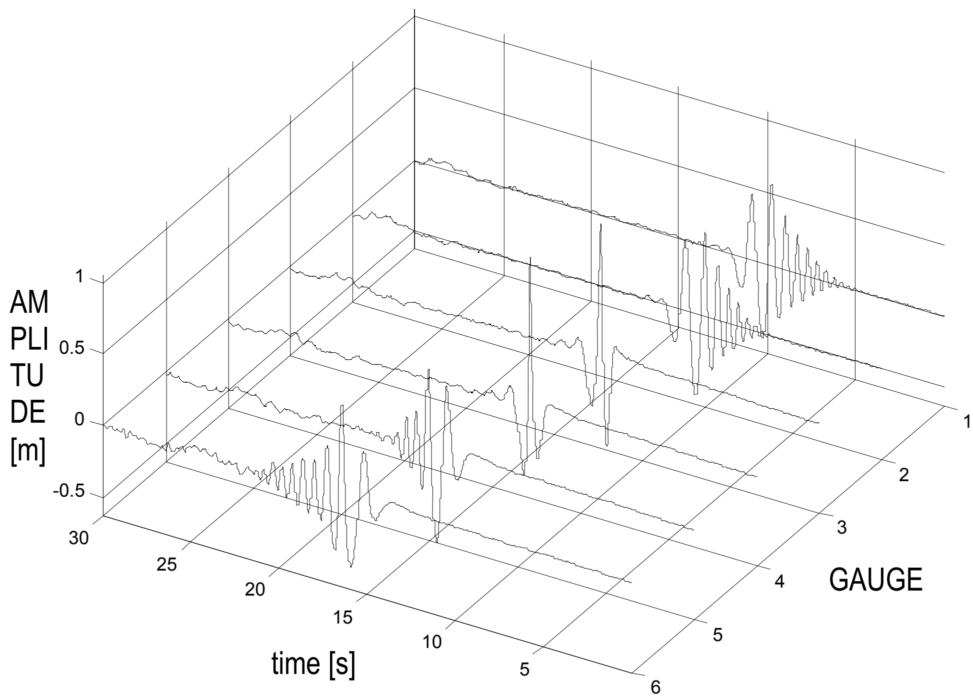

Fig. 1. Example of time series of water surface elevation during the passage of a wave packet. Presented records were made from the six wave gauges with distances from wave-maker given in the text.

further analysis are obtained after a post-processing smoothing procedure – low-pass filtering of the collecting the raw gauge meter data.

The Figure 1 presents the evolution of water surface profile in time for the wave group with the wave parameters i.e. the period in the range from $T=1.29$ *to* $T=4.28\ s$ and the wave height $H=1.2m$. This is representative of the packets that were generated during the experiment and illustrate some of their important features. The wave packet is compressing in space to the solitary wave with the highest amplitude when the breaking takes place. This feature is apparent between gauges 3 and 4. In all the experiments, after plunging, the waves evolved into spilling waves – bora-like type. The approximately 30-min pause was between each test run to allow calming all waves in the channel.

The time series obtained from the set of wave-meters offer possibility to determine group wave velocity using a time lag in cross-correlation series and a distance between the gauges. It allows monitoring the time history of the noise.

3. ANALYSIS OF WAVE BREAKING NOISE IN SHALLOW WATER

The noise records in digital form were stored on disk and postprocessed using MATLAB procedures. At the first stage, the noise spectrum and statistical moments analysis have been applied to characterize the noise.

Time-frequency analysis was applied to the process of estimating the time-varying spectral content of nonstationary signals. Presented below spectral chracteristics were obtained for sub-samples of signals consisted each of 1500 points and averaged in 512 frequency bands. We assumed the quasi-stationary conditions in each of sub-series, which notably simplified the data analysis.

Breaking waves produce broadband noise in all audio frequency range from a few tens of hertz the lower ultrasound range. The noise intensity presented here is in a frequency range from 300 Hz to 20 kHz. Units are in dB re 1V.

Our task was to define the characteristics of these signals i.e. frequency band, signal intensity, and others parameters of the spectra.

A set of parameters of instantaneous spectra was used to characterise the time evolution of a noise signal before and after breaking. Moments of spectra were estimated according to the definitions (Michaelov, 1999) - $m_r = \int_o^{\infty} \omega^r S(\omega \mid t) d\omega \approx \int_{\omega_1}^{\omega_2} \omega^r S(\omega \mid t) d\omega$

Where m_r - spectral moment of r-th order.

In time evolution analysis of noise in each of breaking events were employed:

1. central frequency (or mean frequency) – m_1
2. process bandwidth $\delta(t) = \int_{\omega_1}^{\omega_2} (\omega - \langle\omega\rangle)^2 S(\omega \mid t) d\omega$
3. bandwidth factor $Q(t) = \sqrt{1 - \frac{m_1^2}{m_0 m_2}}$
4. spectral skewness $\gamma(t) = \frac{m_3}{(m_2)^{3/2}}$

Additionally, the time variations of the noise spectrum slope, estimated above maximum in dB per octave and rates of noise intensity between selected octave bandwidths were investigated.

4. CHARACTERISTIC PROPERTIES OF ACOUSTICAL SIGNAL

Despite the close distance of the hydrophones to the breaker's area and relatively high intensity of the dynamic noise, the data at frequencies below 500 Hz were strongly influenced by the traffic noise. In addition, squeaks from the wave-maker are clearly distiguished in the higher frequency band. The wave-maker signals are similar to a set of multifrequency chirps of variable length no longer than a few ten milliseconds in duration. They are perfectly recognised in records, but quite hardly to remove using automatically working algorithms. Another source of unwanted noise, were the supports of the wave gauges.

In some time series of noise, we observe the presence of spikes, probably associated with hydrophones jerking in turbulent wave stream. They were removed before the further analysis has been applied.

Some examples of evolution in time of the level noise intensity in selected octaves with central frequencies of 400, 1600 and 12800 Hz under breakers with heights of 0.9 and 1.2 m represented by mean squares of voltage are presented in Fig.2.

The main differences in noise between the two breakers with different amplitudes seen in Fig. 2 are the values of intensities proportional to the wave amplitude, and the duration of signal. Clearly visible in higher frequency band a sharp onset of noise intensity could be explained as the puls of the jet of water on the water surface.

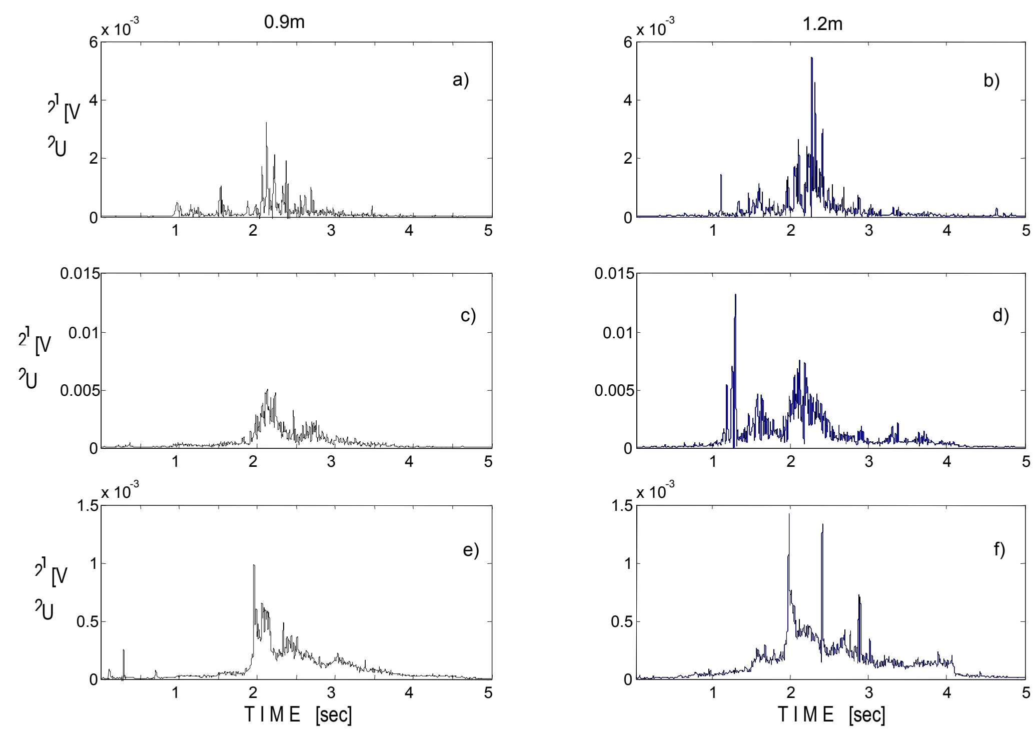

Fig. 2. Examples of evolution of the noise intensity in selected octaves with central frequencies of 400, 1600 and 12800 Hz under breakers with heights of 0.9 (on the left) and 1.2 m (on the right) represented by mean squares of voltage in octave.

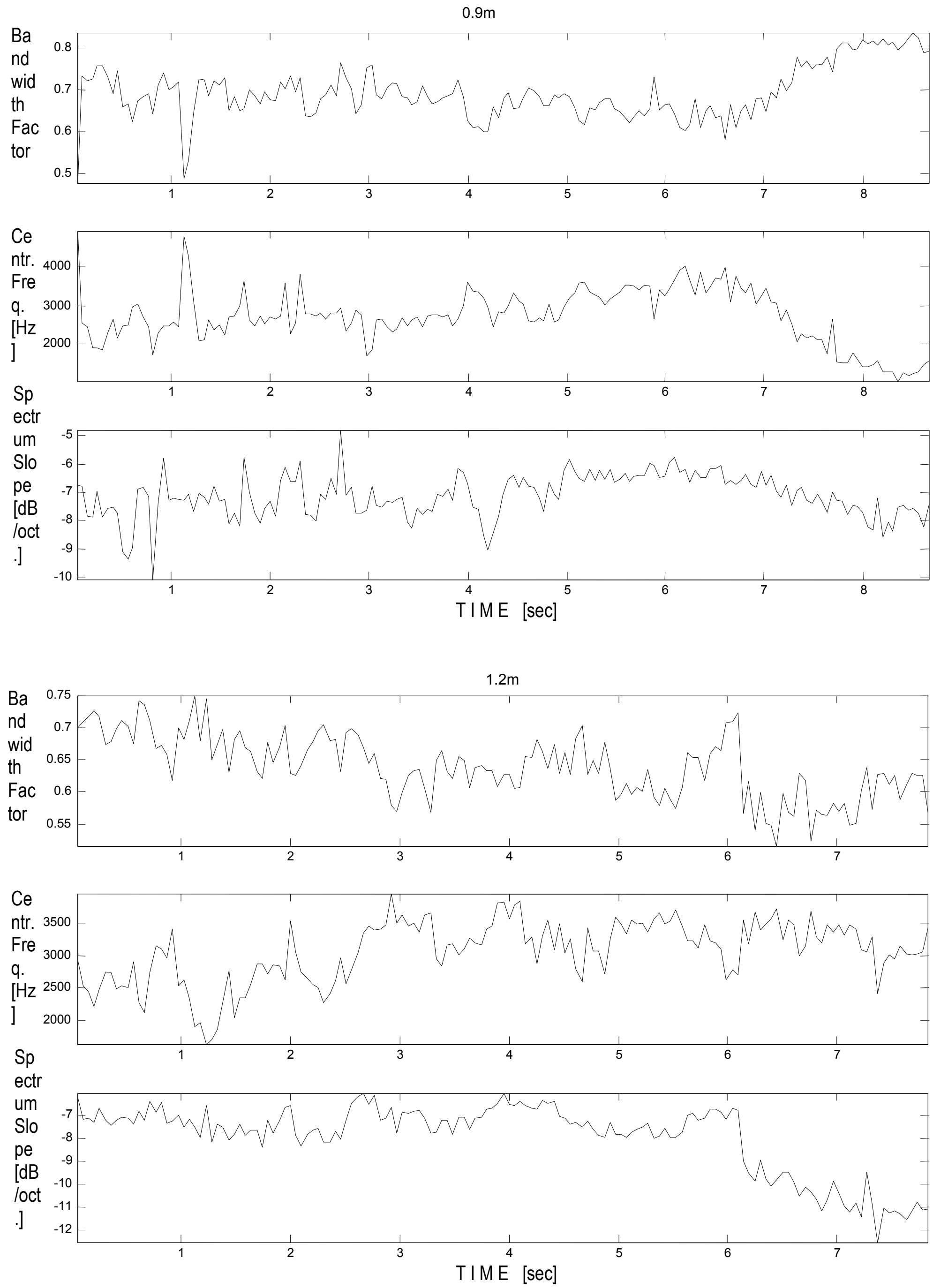

Fig. 3. Time history of selected parameters of the noise series under breakers with different heights. In the upper part - for wave height of 0.9m and in the bottom - for 1.2m.

The mean frequency of the noise, bandwith factor in the analysed frequency range and the spectrum slope are summarised in Fig.3. The showed data were received from signals registered under breaker as in Fig. 2. In the upper time series after first second, there is a short break in the data connected with the procedure of acquiring the data.

In one of the previous studies by Bass and Hay (1998) it was shown that during wave breaking, time series of noise intensity are asymmetrical around the moment of wave plunging. It was explained as a result of directionality of dipole noise sources placed distributed in a thin layer under sloped wave surface. The reflection from directed noise towards the point of observation at the stage of wave arriving and deflected noise from hydrophone when the wave is departing. The interesting point in our record is that opposite to Bass and Hay observations the increasing sound intensity is more rapid than the decay. In our opinion, it may be connected with the declining number of acoustically excited bubbles rising to the water surface after breaking. The maximum of noise intensity is associated with the hitting of water jet from the wave crest onto the water surface. It was registered that the integrated in all frequency band noise intensity of the plunging event exceeds the level of background noise on 25 dB. The mean frequency of the noise has a tendency to increase at the second stage of the breaking process.

In our experiment, the frequency range where 1/f is dominant is usually above 2 kHz. For frequency range from 2.0 up to 25 kHz an acoustic spectral slope of the registered signals is close to the observed in the ocean values. The spectrum slope holds the lowest values in the most active phase of water mixing and afterward increases from the -6dB/octave in the moment of breaking, to –8db/octave at the end of time series. The interpretation of this phenomena could be as follows - newly born bubbles are mixed downward by the turbulence forming clouds through which sound (at the surface) propagates. The smallest bubbles will remain in the water longest, due to buoyancy, and thus the attenuation is greatest at the higher frequencies.

The conditions of propagation in the wave guide is quickly changing so accurate estimates of the form of spectral density of the source are very complicated.

Figure demonstrates influence of a different wave height on the noise intensity in different parts of spectrum. Increase of sound level is correlated with the wave height.

SUMMARY AND CONCLUSIONS

In this paper, the introduction to the analysis of behaviour of noise parameters in the process of breaking single waves in controlled experiment is presented. We believe that further improvements on understanding the sound generation could be performed introducing more complex experiment pointed towards determination of parameters such as spectrum of bubbles size, cloud bubbles dimension or the turbulence intensity during the breaking. Although the general picture of relationships between the noise and wave characteristics seems to be established more data need to be collected in another environment with a different surface wave spectrum.

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