1 Near implosion of Waverider hatch

When retrieving a buoy, the University of Hawaii discovered that the hatch was deformed. The deformation was not in the form of a dent, like it would occur when a buoy was hit, but was regularly shaped. This equal deformation suspects the cause to be uniform pressure. Could it be that the buoy was submerged in such a way that the water pressure caused this deformation?

The typhoon Neoguri crossed this buoy in July 2014. Data shows that iridium and HF suddenly stopped transmitting and that Hs decreased from 4 to 0.4meters. After 1,5 hours the signal recovers. Could this occurrence explain the deformation of the Hatchcover.

1.1 Estimation of depth based on measured wave parameters

The significant wave height is at a constant of approximately 4m, until the buoy is (most likely) submerged and the wave height is suddenly reduced to 0.4m. Tp remains fairly constant at approximately 13 seconds.
Based on the period, the wave number can be determined;

$$k = \frac{2\pi}{\lambda} = \frac{4\pi^2}{gT^2}$$

Also, the wave height before and during submersion is known. This should be related to the wavenumber and the submerged depth by (Airy wave theory);

$$\frac{H_{s,submerged}}{H_{s,before}} = e^{-kz}$$

From this, the depth z can be estimated. This results in a depth of approximately 93 meters.

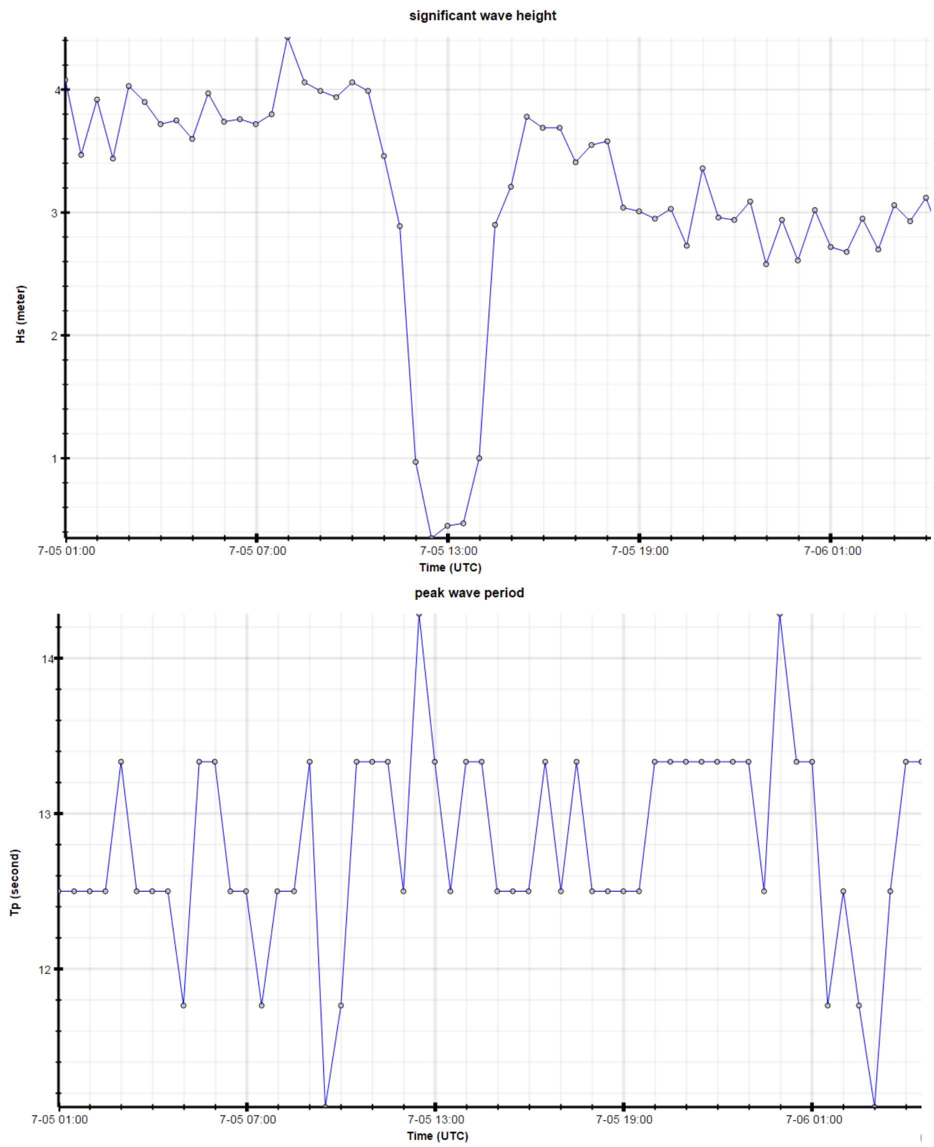

Figure 1 – CDIP data from the moment the buoy was submerged.

1.2 Theoretical deformation of Waverider hatch based on submersion depth

In the previous paragraph, the submerged depth was estimated at 93m. Could this depth explain the deformed hatch?

At a depth of 93 meters, the pressure caused by the water is;

$$p_{93meters\ deep} = \rho g h = 0.91MPa$$

In other words; 9 times the atmospheric pressure. Also, the hatch is clamped with bolts all around. This means that there is a situation of a circular clamped plate under uniform pressure. A standard formula to determine the deformation in such a situation is known. (Circular Kirchhoff-Love plate);

$$w(a) = -\frac{q}{64D}(a^2 - r^2)^2$$

w is the deformation on distance *a* from the centre, *r* is the radius of the plate, *q* is the uniform pressure and *D* is the flexural strength. *D* is given as;

$$D = \frac{Et^3}{12(1 - \nu^2)}$$

E stands for Young's modulus, t for the thickness of the plate and v for the Poisson ratio. In Stainless steel, *E*=193GPa and ν=0.3. The flange has an inner dimension of 415mm and the hatch is 5mm thick. As we are only interested in the deformation in the middle, the deformation formula reduces to;

$$w(a = 0) = \frac{qr^4}{64D}$$

This results in an inflection of 11.9mm, which corresponds nicely to the measured 11.5mm. With this calculation, it should be kept in mind that the calculated indentation was based on elastic deformation, and performed in an ideal clamp, while the measurement was based on a plastic deformation and a curved flange.

The depth can also be estimated based on the measured indentation of the flange. Again, it is assumed that the measured deformation is equal to the elastic deformation. When a deformation of 11.5mm is submitted in the formula, this results in a pressure of 0.88MPa which corresponds to a depth of 89m.

2 Spectrum analysis

Except from a couple of wave parameters, an analysis can also be made from looking at the spectrum and raw data. Spectrum/raw data can be downloaded through the following link:

http://ilikai.soest.hawaii.edu/~ksm/WB_data/2016/201602_Ipan_Ritidian/

Using W@ves21, this data can be read and analysed. Figure 2 shows two spectra. In one figure, the buoy is submerged and in the other it is not submerged yet. A couple of things stand out; The variance spectral density decreases significantly. The spectrum appears to become relatively lower frequent. Further, the direction in the low frequent area (West) remains the same, but the direction of the spectrum in the high frequency area shifts from North-East to South-West.

2.1 Variance spectral density

What is the variance spectral density? In short, this is the variance of the amplitude at every frequency. Figure 2 shows a couple of these spectra.

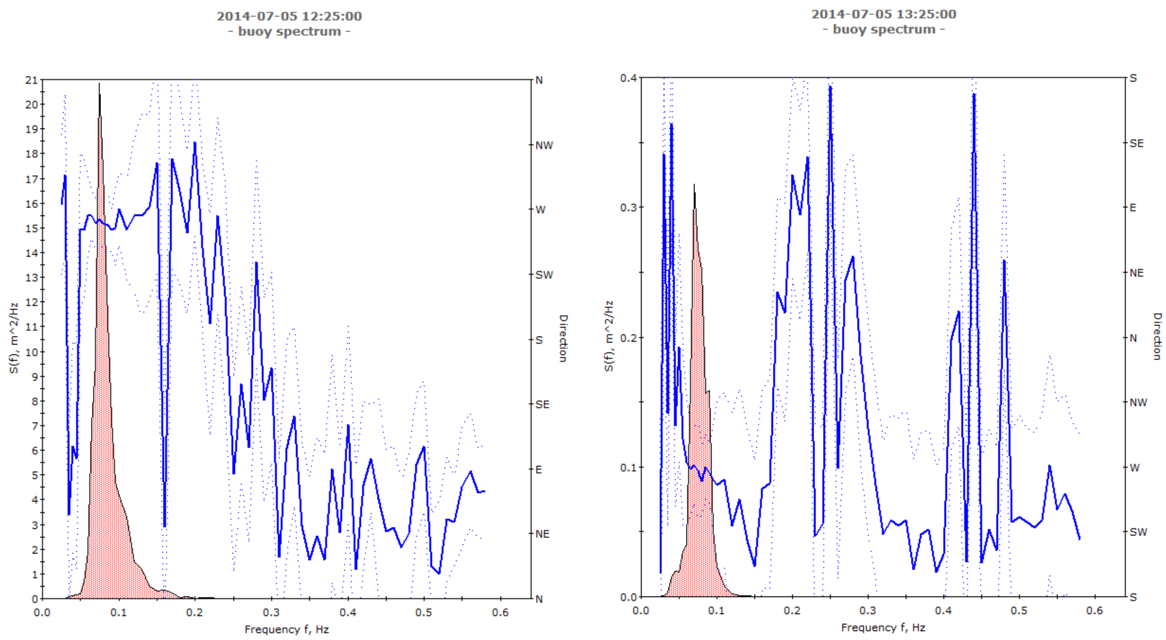

Figure 2 – Spectra from W@ves21. Left; just before the buoy is submerged. Right; when the buoy is submerged. NB: Mind the vertical axis; the 'variance spectral density' S decreases by approximately factor 100.

To make a spectrum out of raw data, a couple of steps have to be completed. The first step is to present the raw Heave data shown over time, a(t). To make a spectrum out of this data, the FFT (Fast Fourier Transform) has to be applied. This will result in a set of amplitudes shown against the corresponding frequencies;

$$\underline{a}(f_i) = FFT(a(t))$$

From this, the variance density can be estimated.

$$E(f) = \frac{1}{\Delta f_i} E\left\{\frac{1}{2}\underline{a}_i^2\right\}$$

This is the discrete definition. At a continuous division, the limit $\Delta f_i \rightarrow 0$ is taken. *E(f)* is the variance density spectrum. From this, various moments of the spectrum can be determined.

$$m_n = \int_0^\infty f^n E(f) df$$

From these moments, various characteristic properties can be obtained like;

$$H_s = 4\sqrt{m_0}$$

$$\overline{T_0} = \sqrt{\frac{m_0}{m_2}}$$

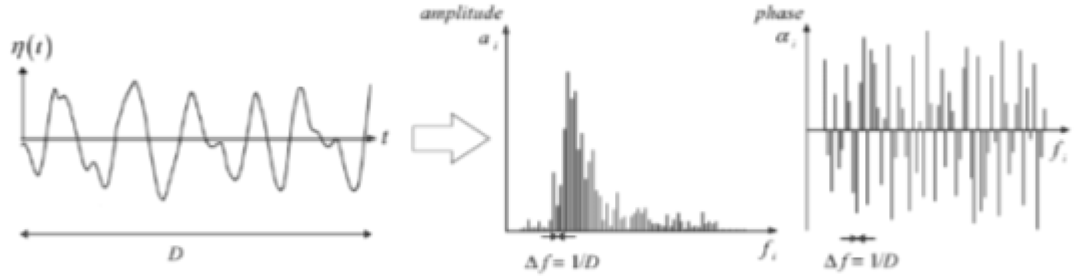

Figure 3 – The observed surface elevation and its amplitude and phase spectrum

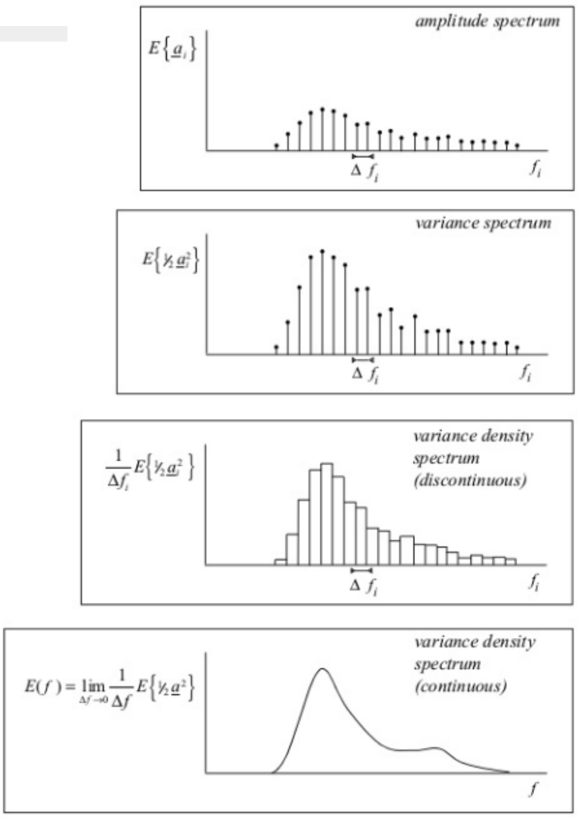

Figure 4 – From amplitude spectrum to variance density spectrum (continuous and discrete).

2.2 Spectrum analysis of the submerged buoy

The data provides a spectrum from each half hour of data. To make an analysis of the submerged buoy, spectra of before, during and after submersion have been taken. The data are from July 5th 2014 from 10h55 to 15h55. In figure 5 and 6 spectra over time are respectively shown normalised and absolute. This gives a similar view as in figure 2, except that the spectra are now presented simultaneously. Because the order of magnitude is so different over the frequency range, it could be clearer to look at the data at a logarithmic scale, as is shown in figure 7 and 8. These figures clearly show a difference in variation especially in the high frequency part of the spectrum between the submerged and floating buoy. This is to be expected as the high frequency waves tone down more with depth than low frequency waves. Also, in the logarithmic scale, the data before and after submersion nicely coincide. The different spectra of the submerged buoy coincide nicely as well.

The variance density spectrum can also be transformed to an amplitude spectrum. One way to do this is by;

$$a_i = \sqrt{2S(f_i)\Delta f}$$

Where $S(f_i)$ is the variance density at frequency f_i, and Δf the difference between the points. This results in a spectrum like figure 9. From this, a frequency dependant depth estimation can be made, like in 1.1. The wavenumber can be directly determined from the frequency, and for the amplitude ratio a reference amplitude per frequency has to be chosen. In figure 10, the amplitude spectrum from 15h25 has been chosen as reference. (Different times can be chosen as well, as long as it is probable that the buoy wasn't submerged at that time).

Figure 10 roughly shows three trends; one of the submerged buoy (top group of lines), the transition and one where the buoy just floats. At the low frequency part, (<0.05Hz) the results become instable and values of between -100 and +500 meters deep are shown. This is independent from the buoy situation. From approximately 0.05Hz to approximately 0.15Hz, the three situations (submerged, transmission and surface) are clearly visible. At frequencies above 0.15Hz, all lines convert to the direction of 0.

Figure 11 shows the same plot, except that the depth is now shown against the wave period, instead of the frequency. This results in a better visibility of the plateau between 0.05 and 0.15Hz (6-20seconds). Over 20seconds results, again, become instable and below 6 seconds the result converts to 0.

The peak wave period is approximately 13 seconds. This contains the most energy. Around this period, the lines of the submerged buoy are approximately 80 meters. This is close to the earlier estimates from 1. A reason that the results at the outer ends of the spectrum converge or diverge could be that there is little energy at those areas which make the results more sensitive to noise or peaks.

Table 1 – Situation of buoy at every data set.

Data set	Situation
10h55	Before
11h25	Before
11h55	Before
12h25	Before
12h55	Transition
13h25	Submerged
13h55	Submerged
14h25	Submerged
14h55	Transition
15h25	After
15h55	After

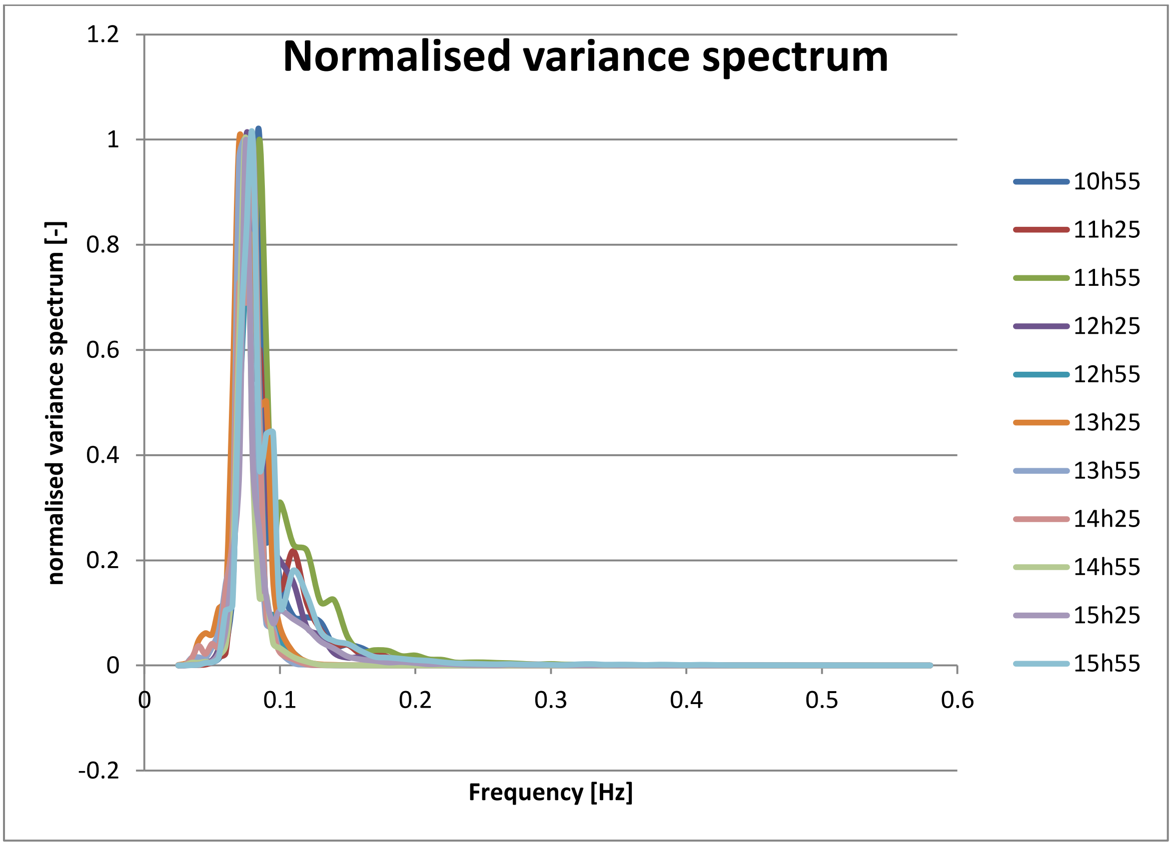

Figure 5 – Normalised variance density spectrum.

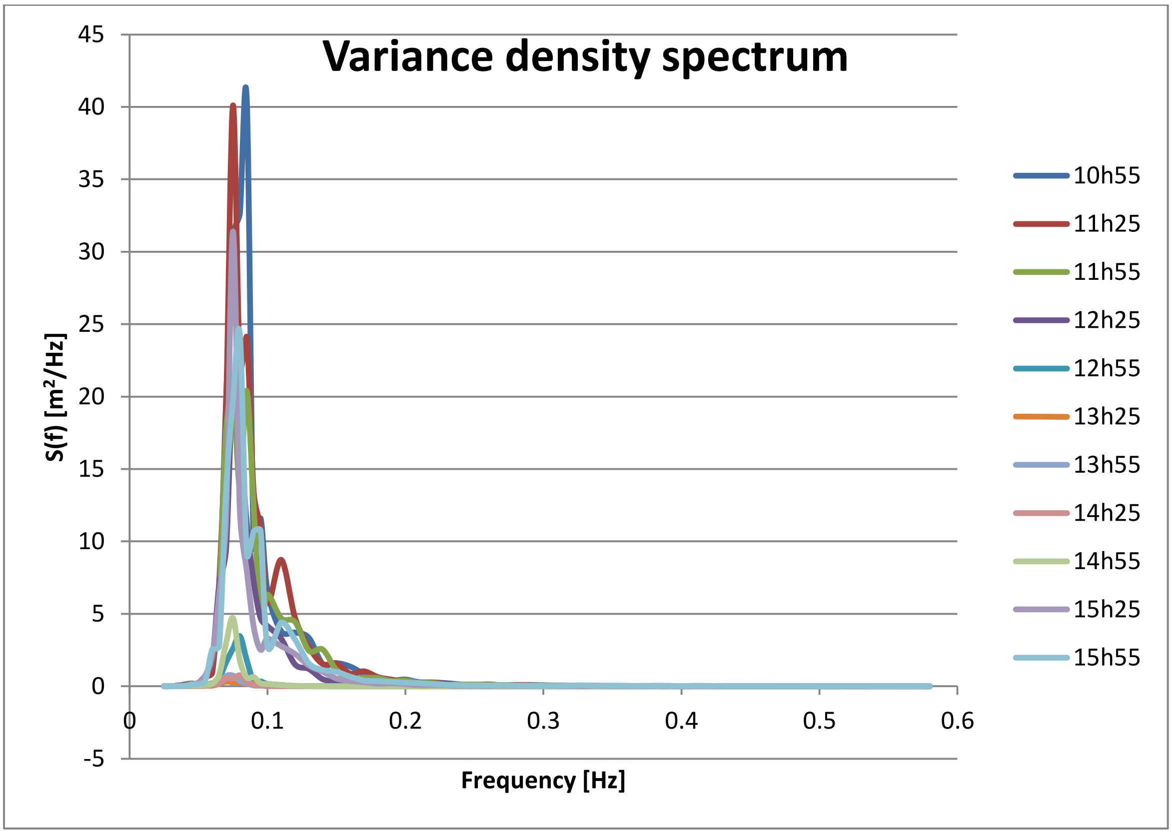

Figure 6 – Variance density spectrum

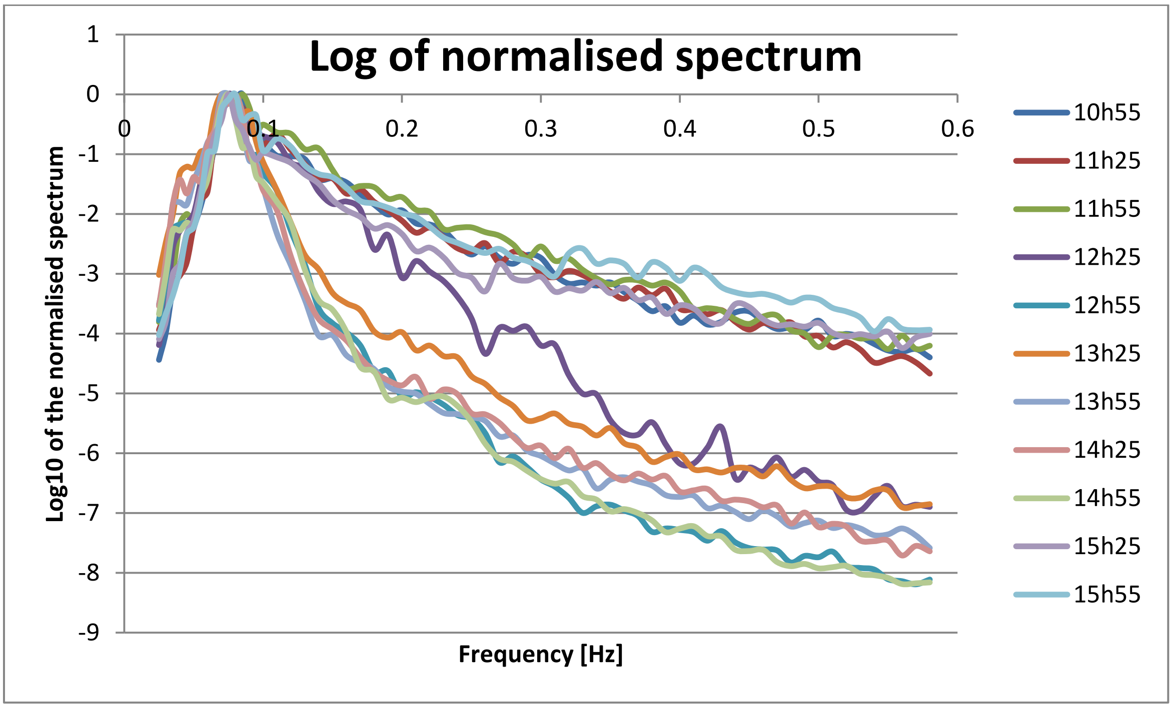

Figure 7 – Normalised variance density spectrum on a logarithmical scale.

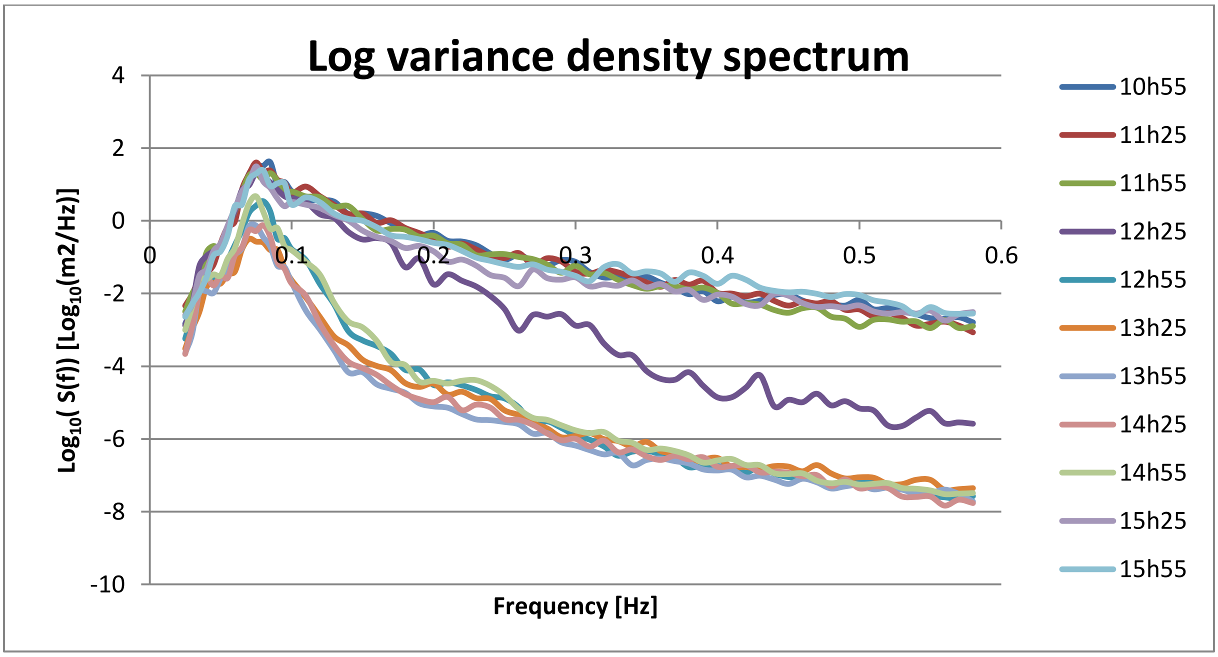

Figure 8 - Variance density spectrum on logarithmical scale.

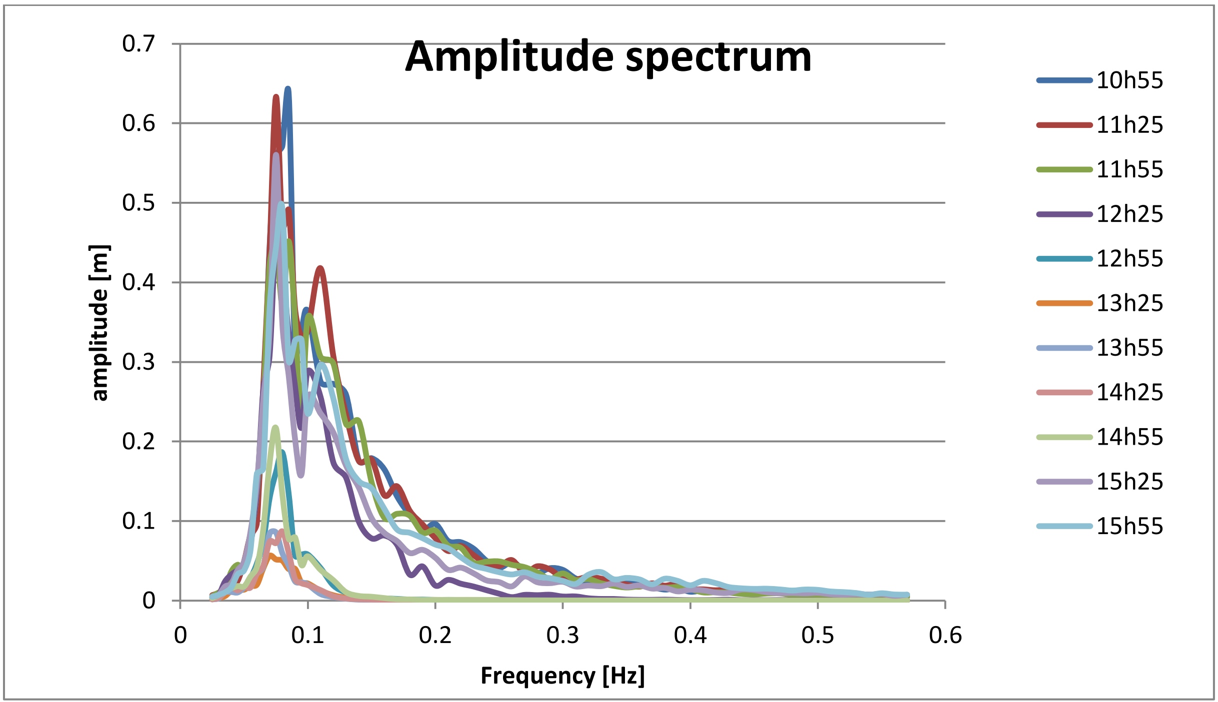

Figure 9 – Amplitude spectrum

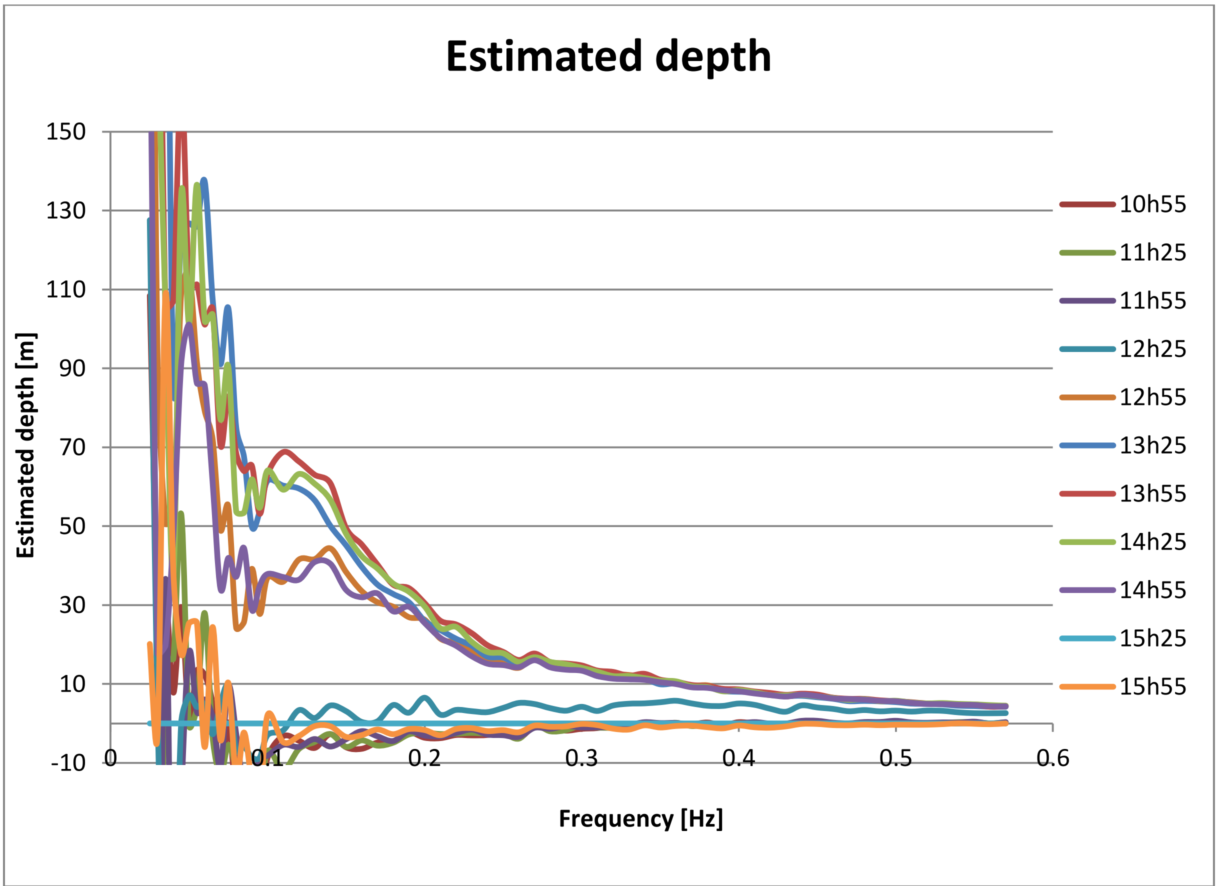

Figure 10 – Estimated depth based on amplitude and corresponding frequency.

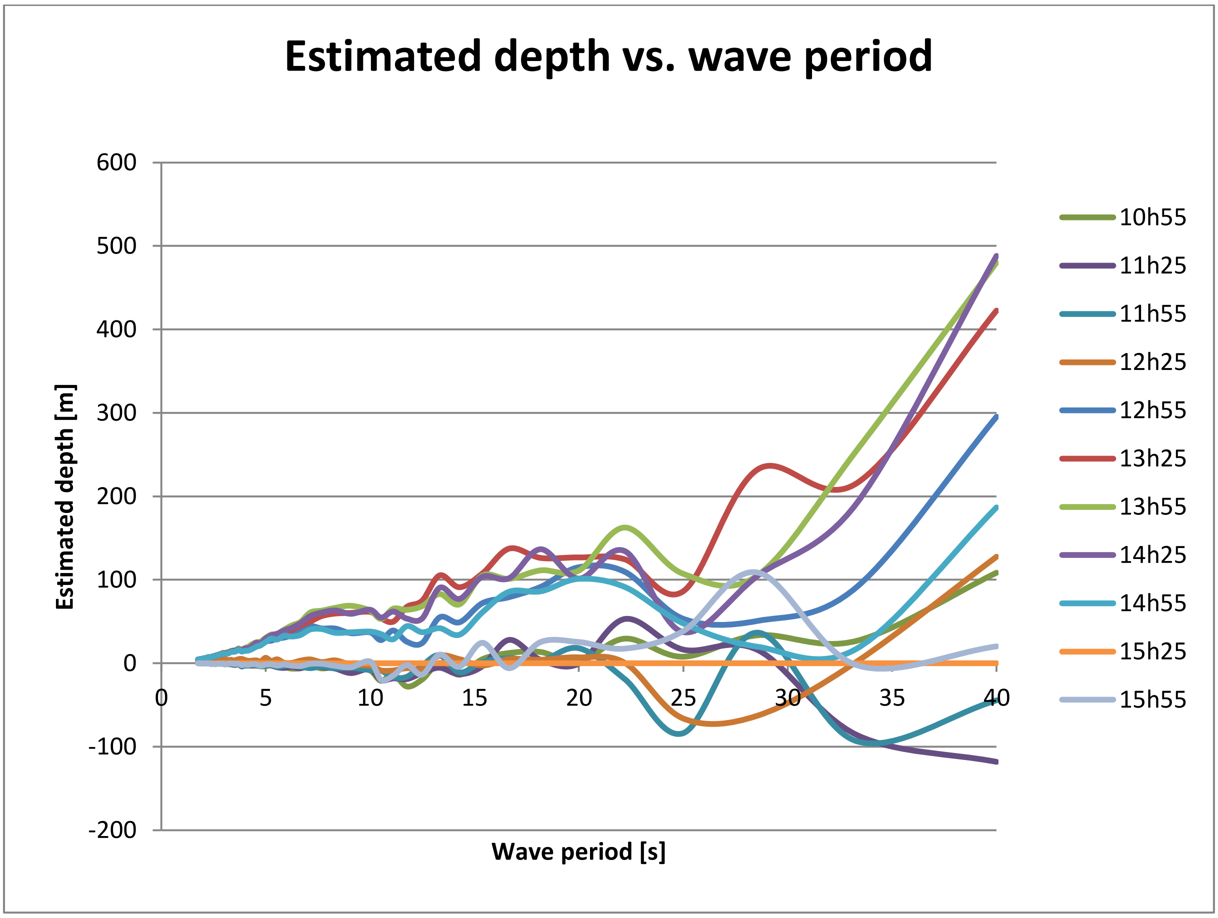

Figure 11 – Estimated depth based on amplitude and corresponding frequency shown against the wave period.

3 Conclusion

It appears that the buoy has indeed been submerged to about a depth of 90meter. This depth is estimated from the wave statistics, as the deformation of het hatchcover. Because of the amount of assumptions, this remains a rough estimate.

Also evaluated is the predicted depth dependent of the frequency. Around T_p, the estimate also shows 90 meter and is fairly stable. Higher frequent values convert in the direction of 0 and lower frequent values become instable and are estimated to approximately 500 meter depth. These discrepancies can occur because there is little energy in these areas which makes the influence of noise and other interruptions relatively large. In the low frequency area, the frequency of the platform itself (40 seconds) can also be of influence.