Ødegaard & Danneskiold-Samsøe A/S
Rådgivende Ingeniører - Støj og vibrationer

Report no. 00.877 (ØDS ref. 99.1314)

Offshore Wind-Turbine Construction

Offshore Pile-Driving Underwater and Above-water
Noise Measurements and Analysis

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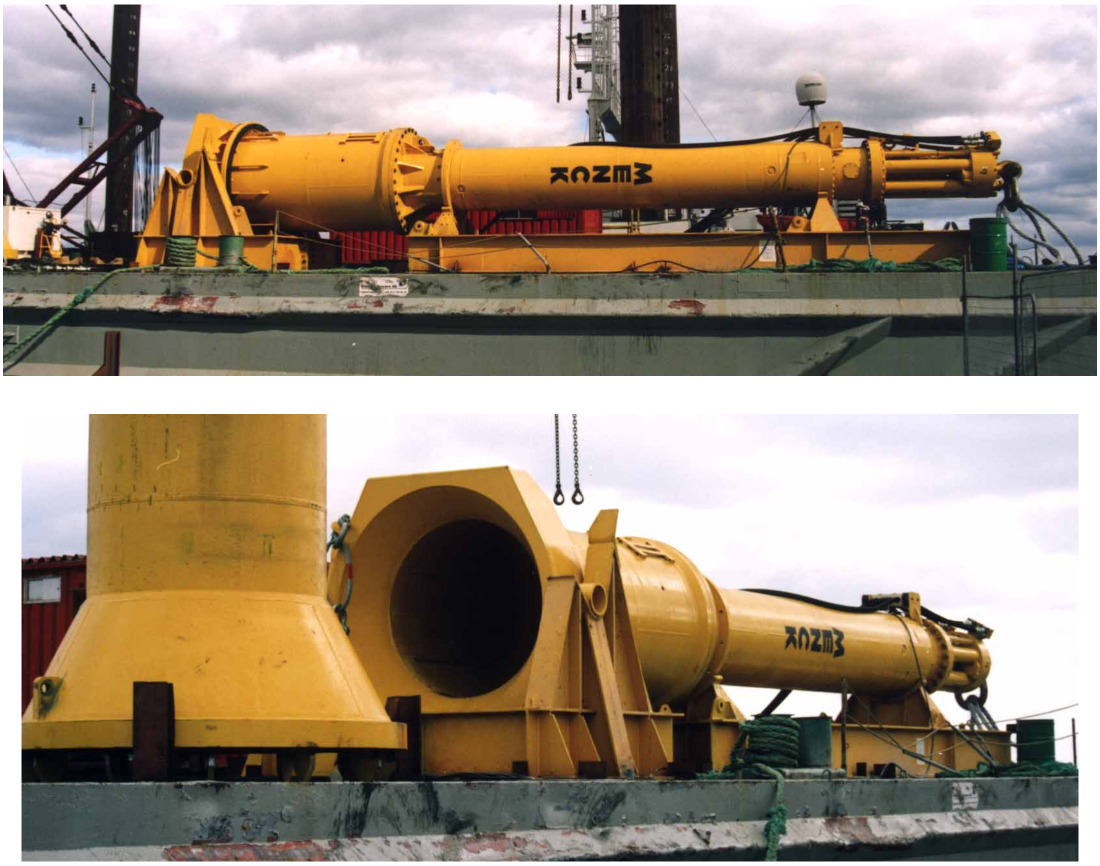
1 Introduction

On behalf of SEAS and Enron, Ødegaard & Danneskiold-Samsøe (ØDS) has performed an investigation of the noise emitted from offshore pile-driving operations which is used for the installation of offshore wind-turbines with “monopile” type foundations. The purpose of the investigation was to measure both the above-water and underwater noise levels emitted from an offshore pile-driving operation.

The measurements were performed at a wind-turbine park under construction in Sweden. The park is located between the Swedish mainland and the island Öland approximately 20 km east of the town Bergkvara. The measurements were performed on the evening of September 18th, 2000 during one (1) pile installation.

The results of the investigation can be used to estimate noise levels that could be expected from a similar construction method for planned offshore wind-turbines. However, it is important to note that underwater noise levels could vary significantly with different seabed conditions, depths, and temperatures. This needs to be considered when estimating underwater noise levels in different conditions.

These results of this analysis are subsequently going to form a base of the evaluation of the effect of noise on the marine animal life and nearest residences on land.



Pile-Driver

“Monopile” type-foundation

Figure 1
Pictures of the pile-driver used during noise measurements and the “Monopile” type foundation for offshore wind-turbines. (Bergkvara, Sweden)

2 Method

Underwater noise measurements were performed during pile-driving operations at four (4) different distances from the pile. Above-water noise measurements were performed at one (1) of these positions. Measurement positions and distances were determined with two GPS (Global Positioning System) positioning systems. Measurements were recorded on DAT tape recorders and the data was analysed in the ØDS laboratory.

2.1 Underwater Noise

The hydrophones were positioned 2 to 3 meters below the water surface, which was approximately halfway between the surface and the seabed. The frequency range of the measurements was 1 Hz to 20 kHz. Analysis has been performed in 1/3-octave band levels sound pressure levels (dB). The dB reference values is 1 μPa.

Average Sound Exposure Levels (SEL) were calculated for each of the measurement positions. The Sound Exposure Level (SEL) represents the total amount of energy measured during a single noise event, such as an individual impact of a pile driver, referenced to one second. Sound Exposure Level (SEL) is a useful quantity for calculating an Equivalent Continuos Sound Level (L_{eq}) for a given period of time with a specific number of noise events for that time. Equivalent Continuous Sound Level (L_{eq}) is the sound level of a steady-state sound that has the same total energy as the time-varying sound, over a specific time period. The relationship between the two terms is shown in the following equation:

$$L_{eq}\ (T) = SEL + 10\ Log\ (N/T)$$

T is the period of time in seconds and *N* is the number of events occurring during the time period.

As well, a time history analysis was performed for several individual impacts to show the time characteristic of the noise from the pile-driving impacts.

The methodology can be summed up and presented in the following stages:

1. Measurements on existing offshore pile-driving:
   - Measurement of underwater noise at 30, 320, 490, and 720 meters distance from the pile-driving.
   - Measurement of ambient (background) levels.
2. Assess frequency spectre of pile-driving:
   - Compare measured noise levels with ambient levels and determine frequency range of pile-driving noise.
3. Sound Exposure Level (SEL) Calculations:
   - Analyse measurement recordings and calculate the average SEL for an individual pile-driving impact for the different measurement positions.
4. Time History and Spectrogram:
   - Analyse measurement recordings to show the overall noise time history and spectrogram showing frequency decay of individual impacts.
5. Assessment of underwater noise propagation characteristics:
   - Perform an initial review of the underwater noise propagation based on the measurement results to identify the major influencing conditions.

2.2 Above-water noise

Above-water noise from offshore pile-driving was measured at 320 meters distance downwind from the pile. The frequency range of the measurements was 16 Hz to 20 kHz. Analysis has been performed in Linear and A-weighted 1/3-octave band sound pressure levels (dB). The dB reference values is 20 μPa.

Noise measurement levels were analysed for Peak Sound Pressure level and Sound Exposure Level (SEL). The Peak Sound Pressure levels is the highest instantaneous sound pressure that occurs during a given time period. The Sound Exposure Level (SEL) represents the total amount of energy measured during single event, such as an individual impact of a pile driver, referenced to one second. The SEL can be used to estimate Equivalent Continuous Sound Level (L_{eq}) knowing the number of events over a specific period of time. The L_{eq}

descriptor can be compared to environmental noise limits. The relationship between L_{eq} and SEL is described in the previous section. A-weighted sound pressure levels are adjusted to human hearing response and are used for assessing noise impact on people. Linear sound pressure levels will be used to assess the above-water noise influence on nearby animals such as seals.

Knowing the distance from the pile-driving to the measurement position, above-water Average Sound Power Levels (L_W) were calculated. The Sound Power Level is a measure of the quantity of acoustic energy radiated by a sound source and is often used in predicting Sound Pressure Levels. The relationship between Sound Power Level to Sound Pressure Level (L_P) for hemispherical propagation downwind over a reflecting plane is found in the following equation for a given distance (*d*) in meters:

$$L_P(d) = L_W - 10 \, Log \, (2 \, \pi d^2) - \Delta L_A(d)$$

ΔL_A is a correction for atmospheric absorption in dB and *d* is the distance from the pile to the point of prediction. An example of octave band atmospheric absorption coefficients for temperature of 15° C and relative humidity (RH) = 70 % is shown in the following table.

Octave band centre Frequency (Hz)	<125	250	500	1000	2000	4000	8000
Atmospheric absorption (dB/meter)	0	0.001	0.002	0.004	0.007	0.017	0.056

(Ref.: Bekendtgøelse nr 304 af 14 maj 1991 fra det danske Miljøministerium. "Bekendtgørelse om støj fra vindmøller")

Table 1

Coefficients for sound absorption in air for temperature of 15° C and relative humidity (RH) = 70 %

The methodology can be summed up and presented in the following stages:

1. Measurements of existing offshore pile-driving:
   - Measurement of above-water noise at specific distance from the pile.
2. Sound Exposure Level (SEL) Calculations:
   - Analyse measurement recordings to calculate an average SEL for one pile driving impact at a specific distance from the pile.
3. Peak Sound Pressure Level:
   - Analyse measurement recordings to show an average peak noise level of the pile-driving impacts at the same specified distance.
4. Calculate Peak and SEL Sound Power Levels:
   - Based on the measured levels and distance from the pile-driving, calculate the Peak and SEL Sound Power Levels (L_W Peak, L_{WA} SEL).

2.3 Pile-Driving Impact Rate

Based on our measurement recordings and general observations, we estimated the rate of pile-driving impacts (impacts/minute) and total number of pile driving impacts for this individual pile.

2.4 Measurement Arrangement

The measurements were performed with the use of hydrophones when measuring underwater noise and microphones when measuring noise above the water's surface. The signals were recorded on a DAT-tape recorder. Subsequently the analyses have been performed with a frequency analyser.

The following is a drawing of the field test set-up at the offshore wind turbines:

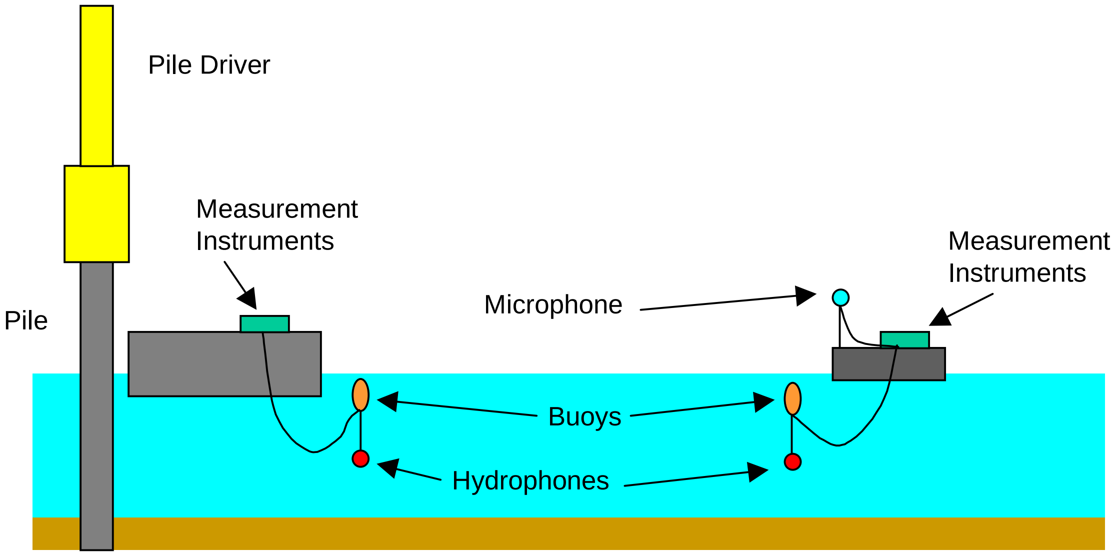


Figure 2

The field-test set-up

The following measurement equipment has been used:

- B&K 8101 hydrophone with preamplifier
- B&K 8100 hydrophone
- B&K 5935 power supply
- B&K 2692 Nexus charge amplifier
- B&K 4223 hydrophone calibrator
- B&K 4165 microphone with preamplifier
- B&K 4188 microphone with 2671 preamplifier
- B&K 2693 Nexus Deltatron amplifier
- B&K 4231 sound pressure calibrator
- TEAC 8 channel DAT-tape recorder (RD-130T)
- SONY 8 channel DAT-tape recorder (PC208AX)
- B&K Frequency Analyser (2143)
- 2 Garmin Global Positioning System (12XL)

2.5 Measurement Conditions

The measurements were performed at a wind-turbine park under construction in Sweden. The park is located between the Swedish mainland and the island Öland approximately 20 km east of the town Bergkvara. Measurements were performed between 21:00 and 23:00 on the evening of September 18th, 2000. There was and Easterly wind with a speed ranging from 1 to 4 m/s. The temperature was approximately 8 ^{o}C with a partially overcast sky. Wave height ranged from 0.5 to 1.5 meters.

3 Hydrophone Measurement Results – Underwater Noise

3.1 Frequency Range (Underwater Noise)

Underwater noise measurements were performed with equipment that could measure the frequencies from 1 Hz to 20 kHz. By comparing the measured noise levels from the pile-driving to ambient (background) noise levels, the frequency range of the pile-driving noise that exceeds the existing ambient was determined. An average of Peak measurement levels taken at 320 meters from the pile-driving, compared with an ambient noise at the same location is shown in Figure 3.

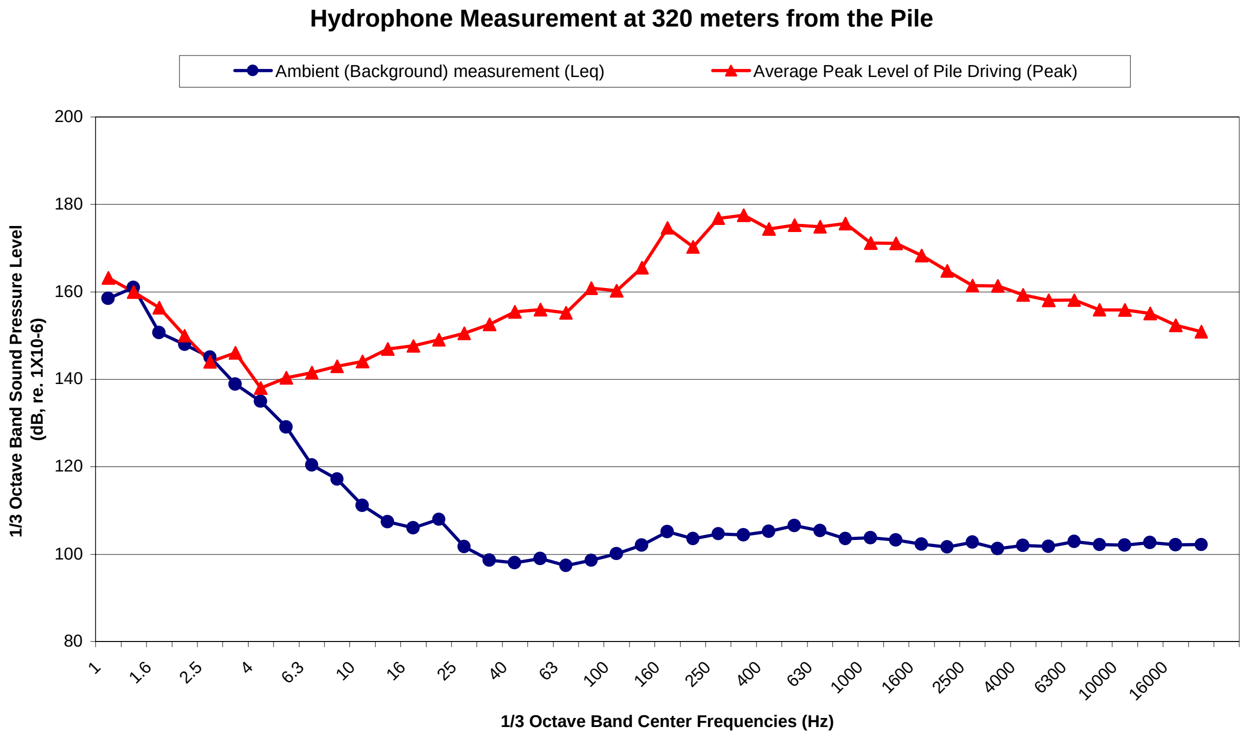


Figure 3

Underwater noise measured 320 meters from the pile-driving and ambient noise (background). 1/3 Octave Band Sound Pressure Level in the frequency range from 1 Hz to 20 kHz (dB re. 1 μPa.).

From Figure 3, it can be seen that in the frequency range from 1 to 4 Hz, the average measured Peak noise levels during the pile driving impacts do not exceed the ambient (background) levels. Thus the noise generated from the pile-driving is less than the ambient noise levels at the frequencies from 1 to 4 Hz. For frequencies above 4 Hz the noise from the pile driving impacts can clearly be seen. Therefore, the analysis of the noise measurement data addresses the frequency range of 4 Hz to 20 kHz.

3.2 Sound Exposure Level (Underwater Noise)

The Average Sound Exposure Levels (SEL) of one pile-driving impact at four (4) different distances are shown in Figure 4 and Table 2.

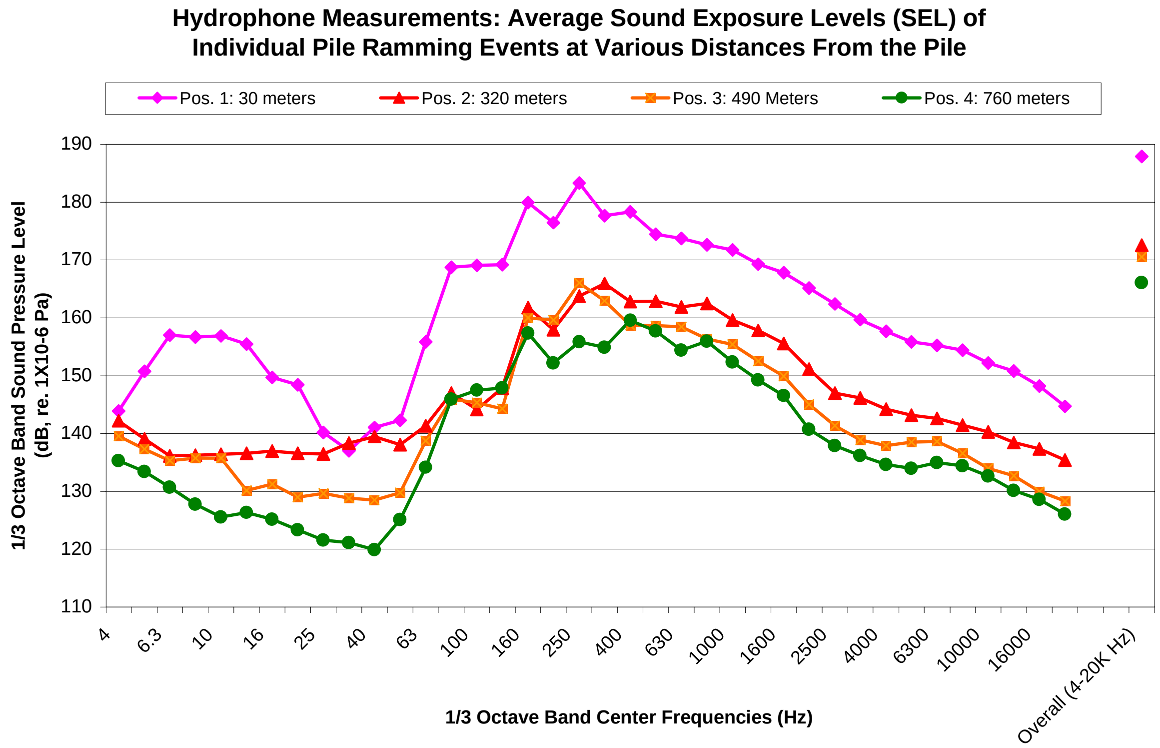


Figure 4

The Average Underwater Sound Exposure Levels (SEL) of one pile-driving impacts at four different distances from the pile.

(dB re. 1 μPa.)

Position	Distance from Pile-driving	Overall (4 Hz - 20 kHz) Average Sound Exposure Level (SEL, dB, re. 1 μPa.)
1	30 meters	188 dB
2	320 meters	173 dB
3	490 meters	171 dB
4	720 meters	166 dB

Table 2
Overall (4 Hz - 20 kHz) Average Sound Exposure Level (SEL) at
four different distances from the pile-driving

3.3 Pile Driving Impact Time History (Underwater Noise)

A time history analysis of three individual pile-driving impacts at two (2) measurement positions is shown in the next series of figures. Figure 5 and 6 shows the overall (4 Hz –20 kHz) time history plot for the measurement locations positioned 30 and 320 meters from the pile-driving. The three different time history curves for each position show the similarity in level and time history characteristic of different individual impacts.

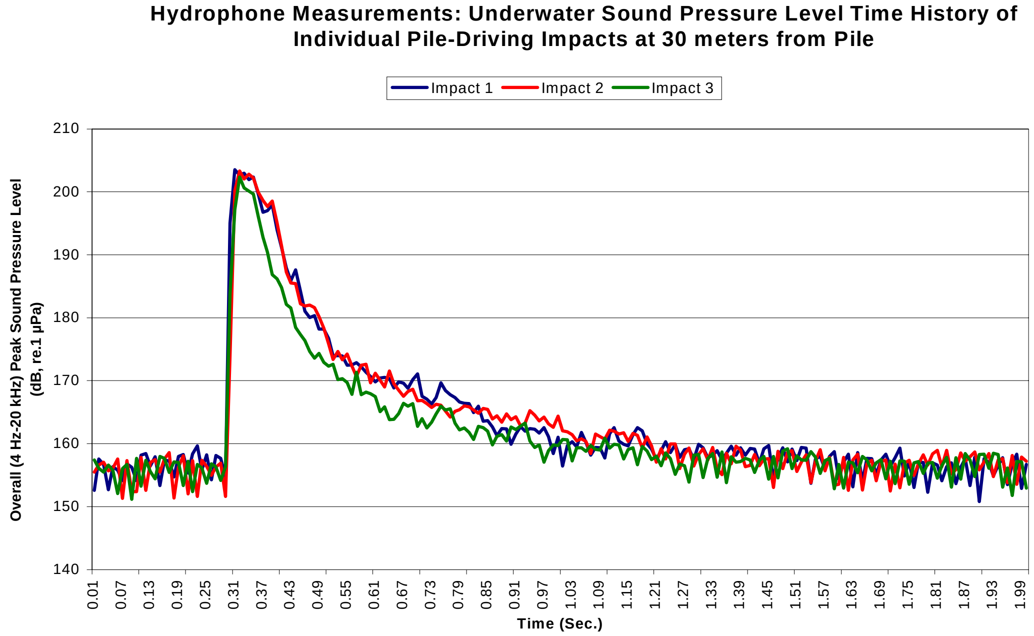


Figure 5

Overall (4 Hz - 20 kHz) Peak Sound Pressure Level time history plots: Position 1, 30 meters from pile-driving (dB, re. 1 μPa.)

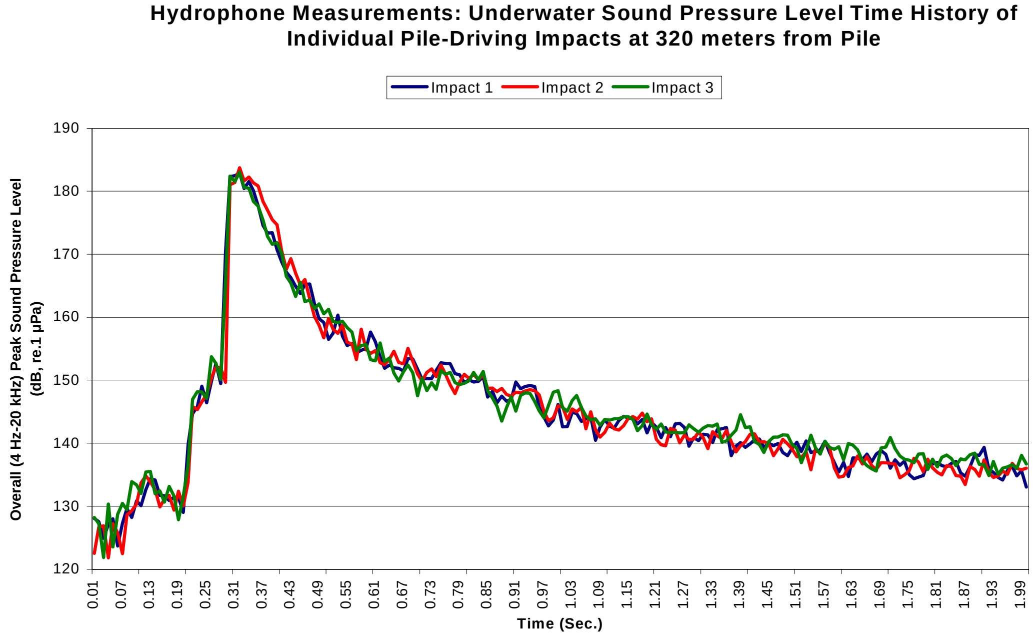


Figure 6

Overall (4 Hz - 20 kHz) Peak Sound Pressure Level time history plots: Position 2, 320 meters from pile-driving (dB, re. 1 μPa.)

The next two (2) figures show examples of the spectrogram time history of Impact 1 from the same individual pile-driving impact at the same two (2) measurements. These figures show the frequency content of the rise and the decay of the noise from an individual impact.

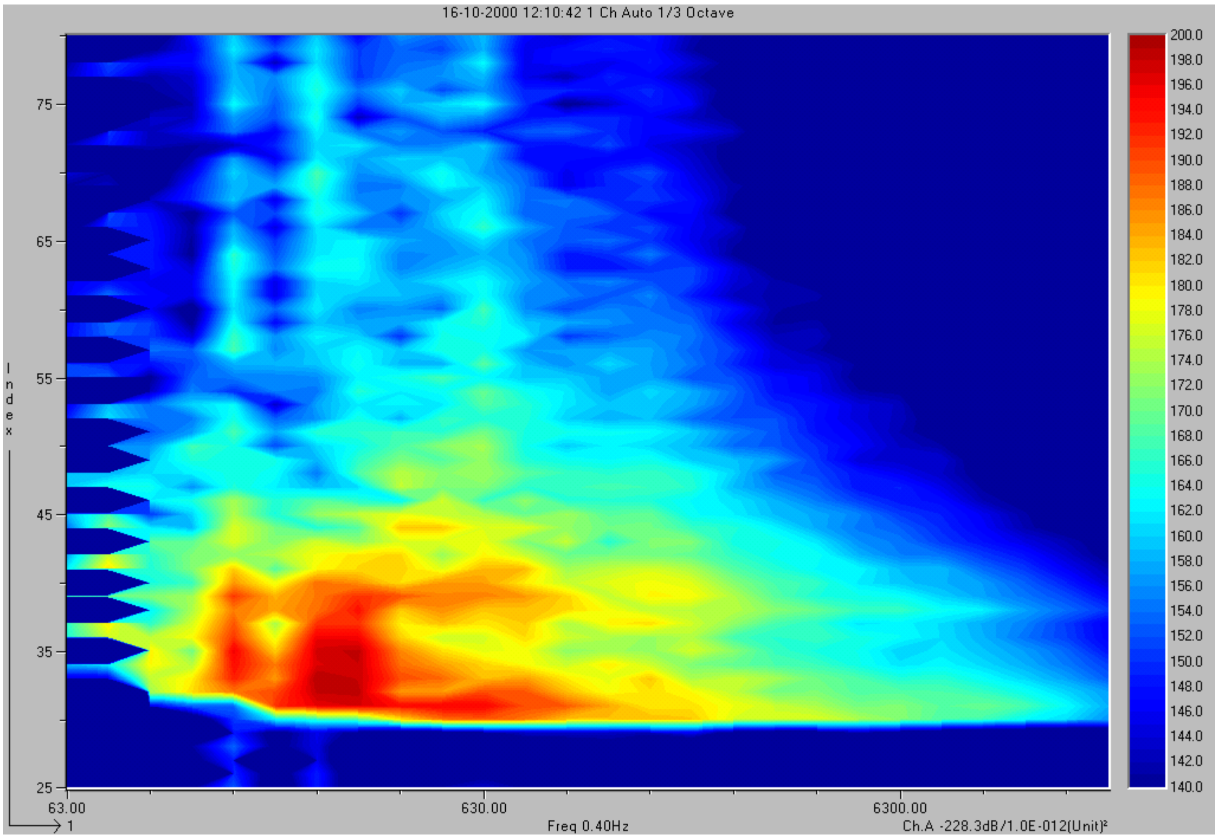


Figure 7

Spectrogram for Impact 1, Position 1; 30 meters from pile

(1/3-octave band frequency levels vs. Time 1/100 sec., dB re. 1 μPa.)

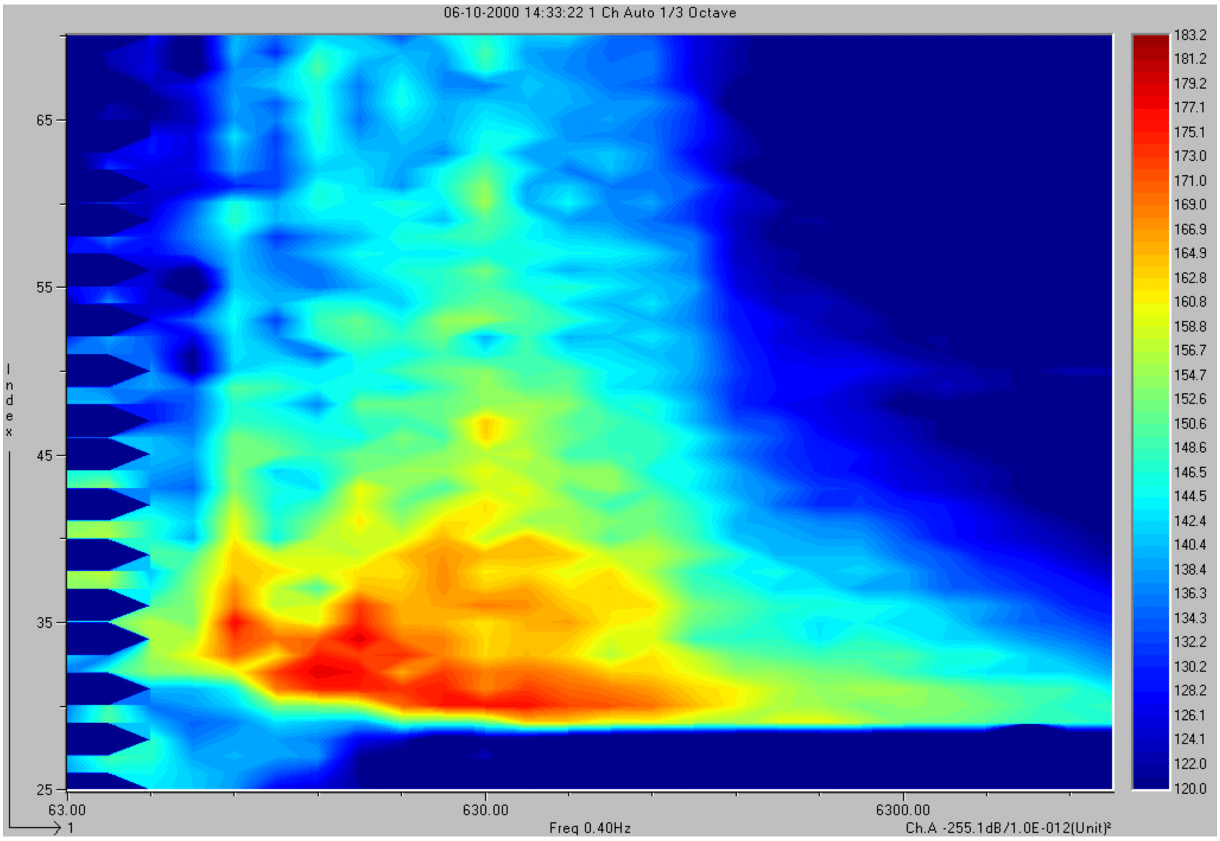


Figure 8

Spectrogram for Impact 2, Position 2; 320 meters from pile

(1/3-octave band frequency levels vs. Time interval 1/100 sec., dB re. 1 μPa.)

3.4 Underwater sound propagation

ØDS performed an initial review of the underwater noise propagation characteristics based on the noise level decay or "drop-off" from the measurements at different distances from the pile. The propagation rate, or divergence, from the noise source is not consistently cylindrical or hemispherical across its frequency range. This indicates that the seabed and possibly other conditions are significantly influencing the propagation of sound. Therefore, the propagation rate from these measurements should not be directly used for other sea depth and seabed conditions without considering the differences. For example, depending on the seabed conditions, the underwater noise levels could vary as much as 18 dB at 2000 meters from the pile-driving.

4 Microphone Measurements Results – Above-water

Above-water noise from offshore pile driving was measured at one (1) position 320 meters downwind from the pile. The frequency range of the measurements was 16 Hz to 20 kHz. Analysis has been performed in both Linear and A-weighted 1/3-octave band levels sound pressure levels (dB(A)). The dB reference values is 20 μPa.

Noise recordings were analysed for Peak Sound Pressure level and Sound Exposure Level (SEL). The Peak Sound Pressure level is the highest instantaneous sound pressure that occurs during a given time period. The Sound Exposure Level (SEL) represents the total amount of energy measured during one (1) single event, such as an individual impact of a pile driver, referenced to one (1) second.

From the SEL and Peak Sound Pressure Levels and the distances to the pile-driving, Sound Power Levels (L_W) were calculated. By knowing the number of events over a specific period of time and the distance to the receptor, the SEL power levels can be used to estimate sound pressure levels (L_{eq}) which can be compared to environmental noise limits. In the same way, Peak Sound Power Levels can be used to estimate Sound Pressure Levels (Peak) and can be compared to ambient levels for audibility. A-weighted sound pressure levels are adjusted to human hearing response and are used for assessing noise impact on people. Linear sound pressure levels will be used to assess the above-water noise influence on nearby animals such as seals.

4.1 Measured Sound Exposure Level (Above-water)

The average overall A-weighted Sound Exposure Level (SEL) of individual pile-driving impacts at 320 meters distance was 80 dB(A). The following figure shows the A-weighted 1/3-octave band levels.

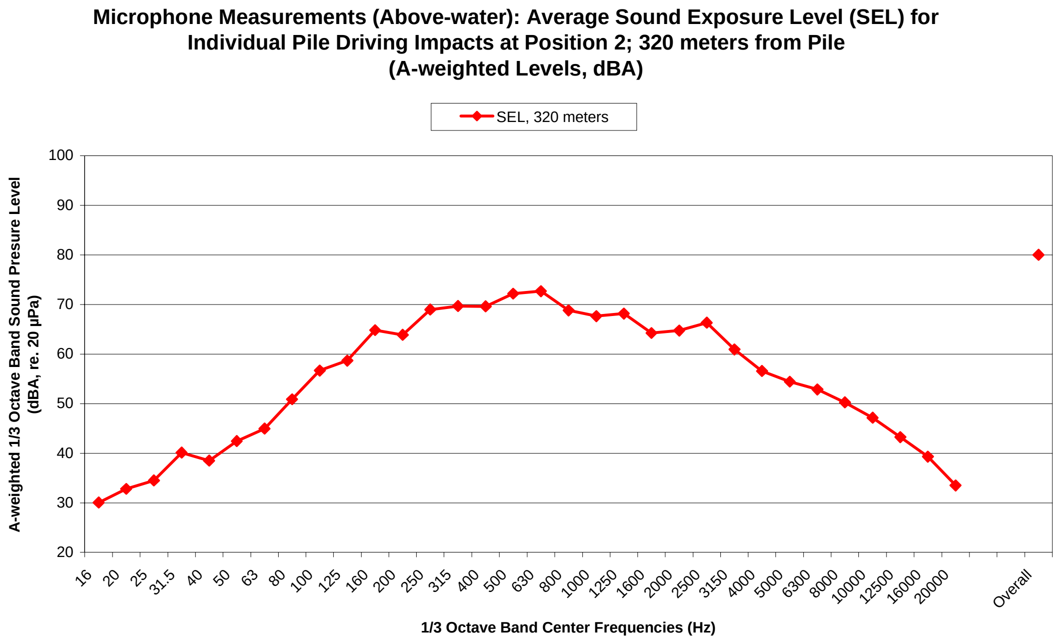


Figure 9

The average A-weighted Sound Exposure Level (SEL) of individual pile-driving impact events at 320 meters (dBA re. 20 μPa.)

The average overall Linear Sound Exposure Level (SEL) of individual pile-driving impacts at 320 meters distance was 91 dB. The following figure shows the Linear 1/3-octave band levels.

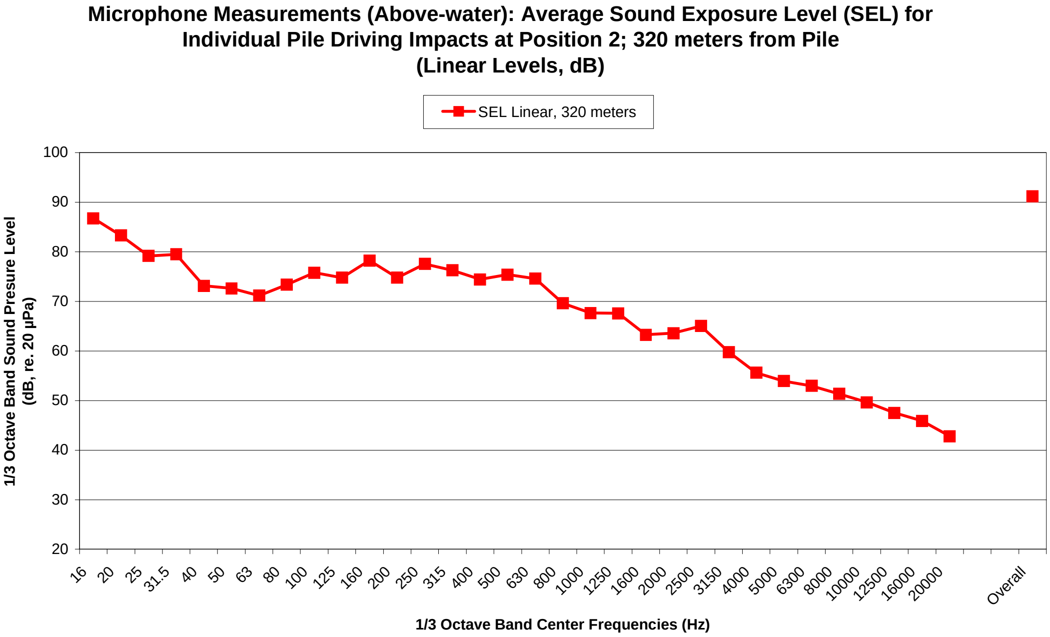


Figure 10

The average Linear Sound Exposure Level (SEL) of individual pile-driving impact events at 320 meters (dB re. 20 μPa.)

4.2 Peak Sound Pressure Level (Above-water)

The average overall A-weighted Peak Sound Pressure Level (Peak) of individual pile-driving impacts at 320 meters distance was 88 dB(A). The following figure shows the A-weighted 1/3-octave band levels.

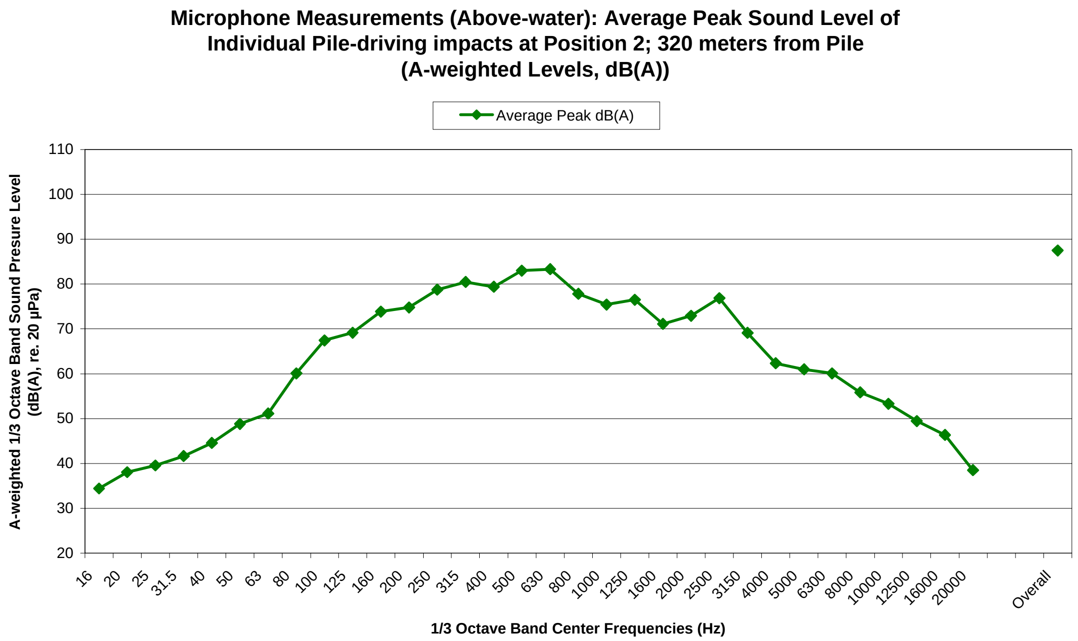


Figure 11

The average A-weighted Peak Sound Pressure Level (Peak) of individual pile-driving impact events at 320 meters (dB(A) re. 20 μPa.)

The average overall Linear Peak Sound Pressure Level (Peak) of individual pile-driving impacts at 320 meters distance was 98 dB. The following figure shows the Linear 1/3-octave band levels.

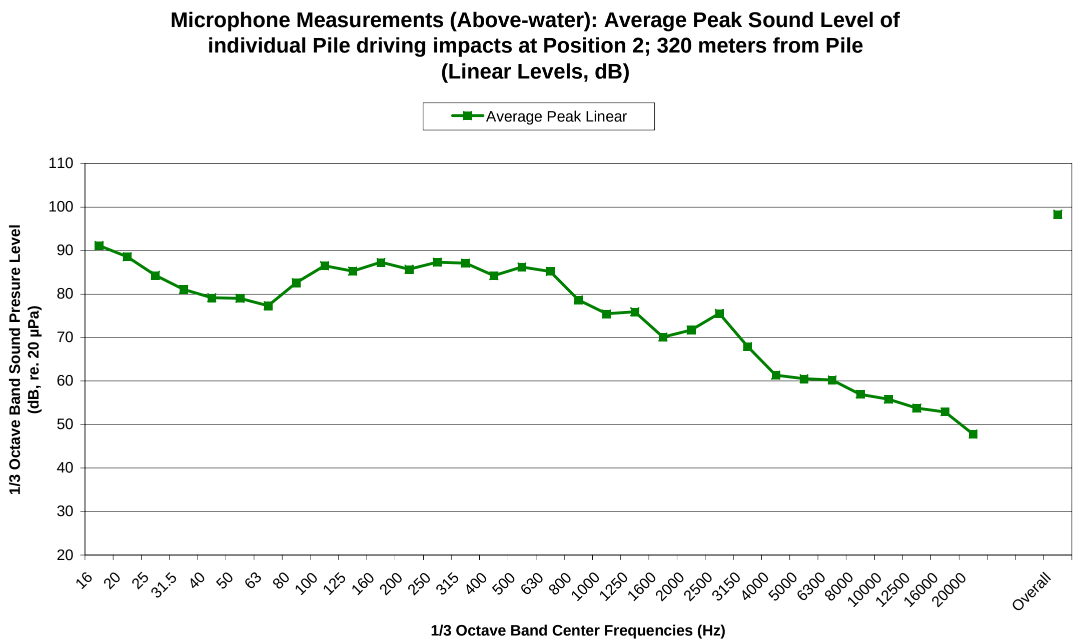


Figure 12

The average Linear Peak Sound Pressure Level (Peak) of individual pile-driving impact events at 320 meters (dB re. 20 μPa.)

4.3 Calculated Sound Power Level (Above-water)

From the SEL and Peak Sound Pressure Levels and the distance to the pile, Sound Power Levels (L_W) were calculated. As discussed in Section 2, knowing the number of events over a specific period of time and the distance to the receptor, SEL Power Levels can be used to estimated Sound Pressure Levels (L_{eq}) which can be compared to environmental noise limits. In the same way, Peak Sound Power Levels can be used to estimate Sound Pressure Levels (Peak) and can be compared to ambient levels for audibility.

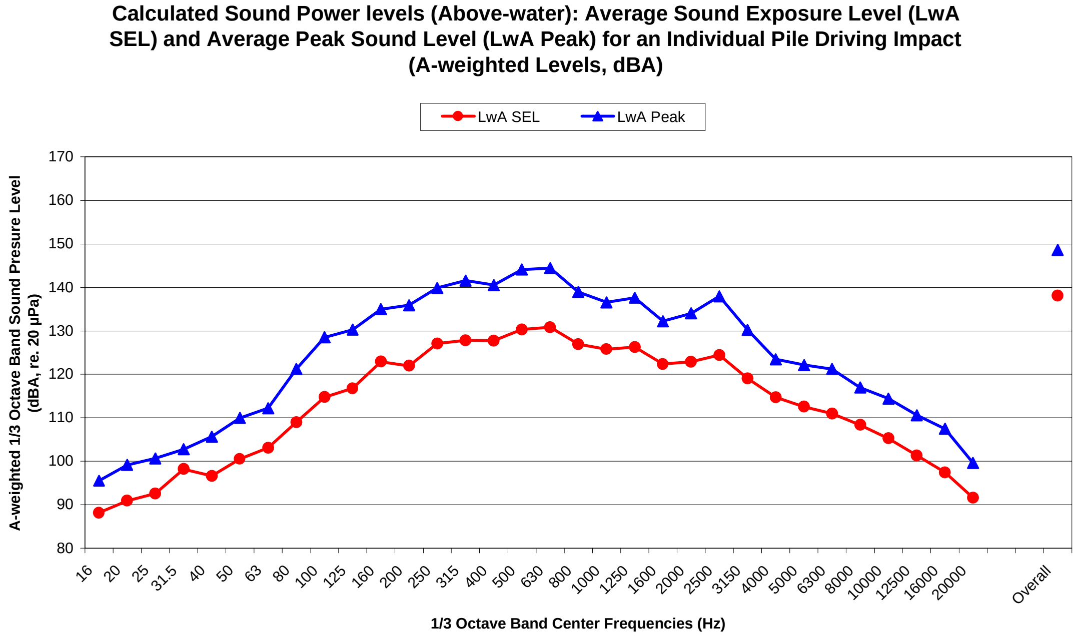


Figure 13

Microphone Above-water A-weighted Sound Power Levels;

SEL, Peak (dB(A), re. 20 μPa.)

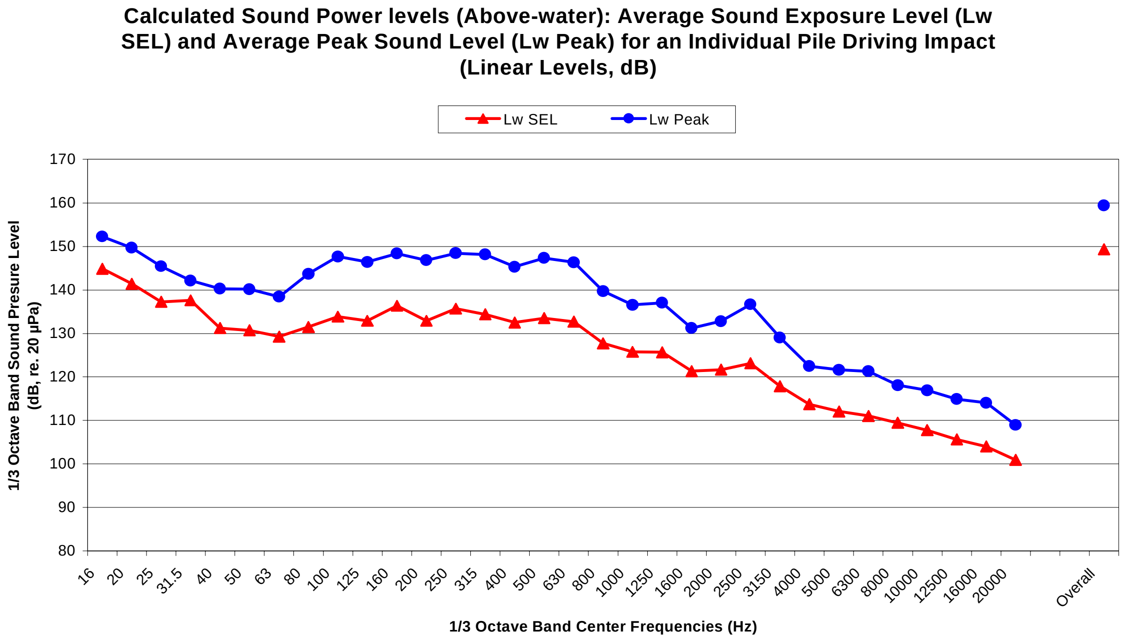


Figure 14

Microphone Above-water Linear Sound Power Levels;

SEL, Peak (dB, re. 20 μPa.)

Overall SEL Sound Power Level (L_W) SEL	Overall Peak Sound Power Level (L_W Peak) dB
138 dB(A)	149 dB(A)
149 dB (Linear)	159 dB (Linear)

Table 3

Microphone Above-water overall

A-weighted and Linear Sound Power Levels;

SEL, Peak (dB, re. 20 μPa.)

5 Offshore Pile Driving Impact Rate

Based on our measurement recordings and observations, we estimated the rate of pile driving impacts (impacts/minute) and total number of pile driving impacts for this particular pile. The approximate time for this specific pile to be driven in was 1 hour 30 minutes. The number of impacts was counted over a 15-minute period to estimate an average rate for each 15-minute period as shown in the following figure. The rate of impacts per minute varies throughout the 1.5 hours. The average rate ranged from 2 impacts per minute to 30 impacts per minute. The slower rates were at the beginning of the pile-driving and increased throughout the 1.5 hour period.

Time (hour:minutes)	**Impacts per minute**	**Number of Impacts**
Start 0:00 to 00:15	2	30
00:15 to 00:30	4	60
00:30 to 00:45	5	75
00:45 to 01:00	25	375
01:00 to 01:15	28	420
01:15 to 01:30 finish	24	360
Total Impacts	----	1320

Table 4

Offshore pile-driving rates and number of impacts for the specific pile driven on September 18th, 2000 (Bergkvara, Sweden)

This data is from one (1) pile and it is likely that the rates and overall time could vary significantly depending on the ground and weather conditions, for example. Some of the personnel from the pile-driving operations said that driving an individual pile could range from 1 to 4 hours. However, these rates can be used in conjunction with the SEL levels to calculate sound pressure levels (L_{eq}) for a given period of time.

6 Example Calculations

Using the equations mentioned in Section 2 both the Above-water and Underwater Sound Pressure Levels can be estimated.

6.1 Underwater

For the underwater estimations, we must assume the exact same sea and seabed conditions as the measurement location. Estimation of sound pressure levels for distances further away from the pile-driving than the measurement positions would need to consider the seabed and sea conditions.

The underwater Leq sound pressure level at 720 meters (Position 4) for the duration of 1 pile being driving from beginning to end (1.5 hours, 5,400 seconds) with 1320 driver impacts with an SEL of 166 dB can be estimated with the equation shown in Section 2.1:

$$L_{eq}\ (T) = 166 + 10\ Log\ (1320/5400)$$

T is the period of time in seconds and *N* is the number of events occurring during the time period. The resulting overall L_{eq} is 160 dB (re.1 μPa.) at 720 meters from pile-driving.

6.2 Above-water (A-weighted)

As well, Above-water Sound Pressure L_{eq} and Peak Levels can be calculated with the same information using the equations in Section 2.2 and 2.3. The sound propagation in air, as underwater noise, can vary significantly depending on the exact conditions - particularly with meteorological conditions. In Danish environmental noise legislation, however, the meteorological conditions for external noise calculations are predefined. Therefore, the above-water sound propagation can be determined at greater distances assuming predefined conditions and atmospheric absorption. Atmospheric absorption (ΔL_A) is a frequency dependent correction and thus, calculations must be performed for each octave band and then be summated (dB addition) for and overall level.

For example, the Above-water Sound Pressure L_{eq} can be estimated for various distances for the duration of one (1) pile to be completely driven. Thus, the assumption of 1.5 hours (5,400 seconds) duration and 1320 pile-diver impacts is used from survey data. With the octave band frequency SEL Sound Power Levels from Section 4.3, the octave band L_{eq} Sound Power Level can be calculated with the following equation:

$$L_{eq}\ (T) = SEL + 10\ Log\ (N/T)$$

Again, T is the period of time in seconds and N is the number of events occurring during the time period. The octave band Leq Sound Power Level, as well as, the octave band Peak Sound Power Level (Section 4.3) can be used to estimate the L_{eq} and Peak Sound Pressure Level at various distances with the following equation:

$$L_P(d) = L_W - 10\ Log\ (2\ \pi d^2) - \Delta L_A(d)$$

ΔL_A is a frequency dependent correction for atmospheric absorption in dB and d is the distance from the pile to the point of prediction. Calculations must be performed for each octave band and then be summated (decibel addition) to calculate an overall level.

As shown in Section 2.2, an example of octave band atmospheric absorption coefficients for temperature of 15° C and relative humidity (RH) = 70 % is shown in the following table.

Octave band centre Frequency (Hz)	<125	250	500	1000	2000	4000	8000
Atmospheric absorption (dB/meter)	0	0.001	0.002	0.004	0.007	0.017	0.056

(Ref.: Bekendtgøelse nr 304 af 14 maj 1991 fra det danske Miljøministerium. "Bekendtgørelse om støj fra vindmøller")

Table 5

Coefficients for sound absorption in air for temperature of 15° C and relative humidity (RH) = 70 %

Thus, assuming the same pile-driving operations, the estimated above-water sound pressure levels for various distances are shown in the following table:

Distance (km)	Overall L_{eq} Sound Pressure Level, dB(A)	Overall Peak Sound Pressure Level, dB (A)
2	54	73
4	45	64
8	34	53
12	27	47

Table 6
Estimated above-water overall A-weighted sound pressure levels at various distances from pile-driving (assuming same pile-driving operations);
L_{eq}, Peak (dB(A), re. 20 μPa.)

These estimated levels presented in Table 6 are based on the observed pile-driving impact rates and the overall duration of a single pile-driving. Pile-driving rates and duration may vary at significantly between piles and/or at other locations. These factors need to be considered when estimating noise levels.

6.3 Above-water (Linear)

Above-water Linear Sound Pressure L_{eq} and Peak Levels can be calculated with the same information and equations described in the previous section. Thus, the assumption of 1.5 hours (5,400 seconds) duration and 1320 pile-diver impacts is used from survey data. Therefore, the above-water sound propagation can be determined at greater distances assuming predefined conditions and atmospheric absorption. Atmospheric absorption (ΔL_A) is a frequency dependent correction and thus, calculations must be performed for each octave band and then be summated (dB addition) for and overall level.

With the octave band frequency SEL Linear Sound Power Levels from Section 4.3, the octave band L_{eq} Linear Sound Power Level can be calculated. The octave band L_{eq} Linear Sound Power Level, as well as, the octave band Peak Linear Sound Power Level (Section

4.3) can be used to estimate the Linear L_{eq} and Linear Peak Sound Pressure Level at various distances.

Assuming the same pile-driving operations, the estimated 1/3-octave band and overall above-water Linear L_{eq} and Peak Sound Pressure Levels for various distances are shown in the following two figures and table:

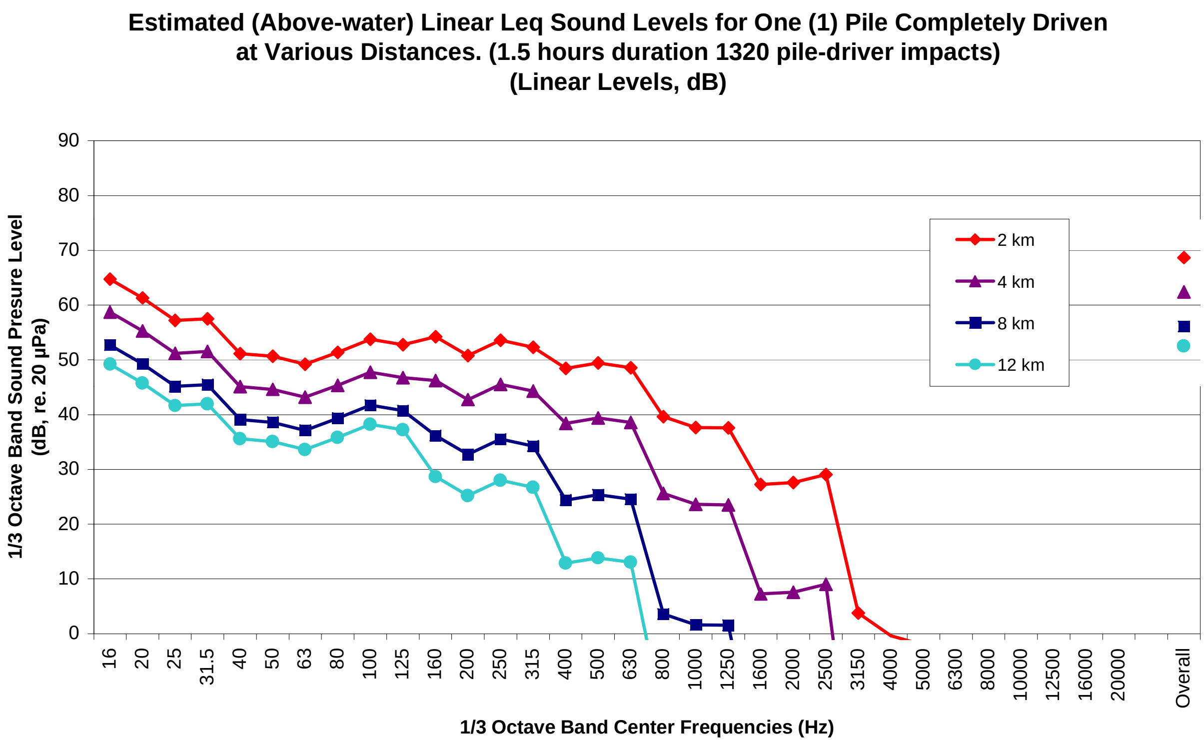


Figure 15

Estimated above-water 1/3-octave band Linear Leq sound pressure levels at various distances from pile (assuming same pile-driving operations);

L_{eq}, Peak (dB, re. 20 μPa.)

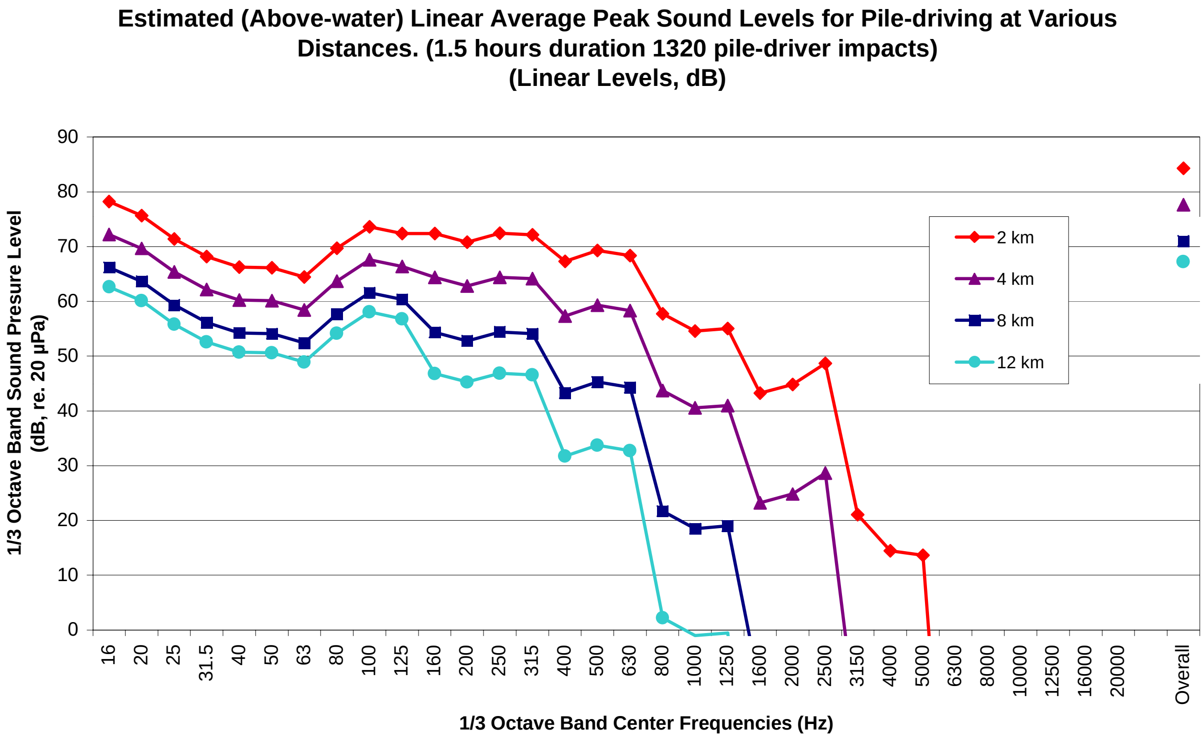


Figure 16

Estimated above-water Linear 1/3 octave band Peak sound pressure levels at various distances from pile (assuming same pile-driving operations);

L_{eq}, Peak (dB, re. 20 μPa.)

Distance (km)	Overall Linear L_{eq} Sound Pressure Level, dB	Overall Linear Peak Sound Pressure Level, dB
2	69	84
4	62	78
8	56	71
12	53	67

Table 7

Estimated above-water overall Linear sound pressure levels at various distances from pile (assuming same pile-driving operations);

L_{eq}, Peak (dB, re. 20 μPa.)

7 Discussion and Conclusion

On behalf of SEAS and Enron, Ødegaard & Danneskiold-Samsøe has performed an investigation of the noise emitted from offshore pile-driving operations which is used for the installation of offshore wind-turbines with “monopile” type foundations. The purpose of the investigation was to measure both above-water the and underwater noise levels emitted from an existing offshore pile driving operation.

The measurements were performed at a wind-turbine park under construction in Sweden. The park is located between the Swedish main land and the island Öland approximately 20 km east of the town Bergkvara. The measurements were performed on the evening of September 18th, 2000 during one pile installation. The results are subsequently going to form a base of the evaluation of the effect on the animal life.

The results of the investigation can be used to estimate noise levels that could be expected from a similar construction method for the planned offshore wind turbines. However, it is important to note that underwater noise levels could vary significantly with different ground conditions, depths, and temperature. These need to be considered when estimated underwater noise levels in different conditions.

The following conclusions can be drawn from the pile-driving noise measurements:

- Measured underwater noise from the offshore pile-driving is not higher than the ambient noise in the frequency range below approximately 4 Hz.

- Measured underwater noise emitted from the offshore pile-driving is higher than the ambient noise in the frequency range above approximately 4 Hz.

- As requested by the marine biologist, average underwater Sound Exposure Levels (SEL) at various distances from the pile are calculated from the measurement results. These results can be used to assess propagation characteristics of underwater noise where the measurements were performed.

- As requested by the marine biologist, time history analysis of individual pile-driving impacts were performed and stated in this report.

- Above-water noise measurement levels were analysed for Peak and Sound Exposure Level (SEL) and were used to calculate Sound Power Levels.

- The above-water SEL Sound Power Levels can be used to estimate Sound Pressure Levels (Leq), knowing the number of events (impacts) over a specific period of time and the distance to the receptor can be compared to environmental noise limits. In the same way Peak Sound Power Levels can be used to estimate Peak Sound Pressure Levels which can be compared to ambient levels for audibility.

- Based on our measurement recordings and observations, we estimated the rate of pile driving impacts (impacts/minute) and total number of pile driving impacts for this individual pile. These rates can be used in conjunction with the SEL levels to calculated Sound Pressure Levels (Leq) for a given period of time.

- Review of the underwater propagation indicated that the seabed and possibly other conditions are influencing the propagation of sound. Therefore, the propagation rate from these measurements should not be directly used for other sea depth and seabed conditions without considering the differences.