Assessment of cumulative Sound Exposure Levels (SEL) for marine piling events

P A Lepper[1], S P Robinson[2], M A Ainslie[3], P D Theobald[2], C A F de Jong[4]

[1]Loughborough University, Leicestershire, U K, p.a.lepper@lboro.ac.uk

[2]National Physical Laboratory, Teddington, UK, stephen.robinson@npl.co.uk

[3]TNO Sonar Department, The Hague, The Netherlands, michael.ainslie@tno.nl

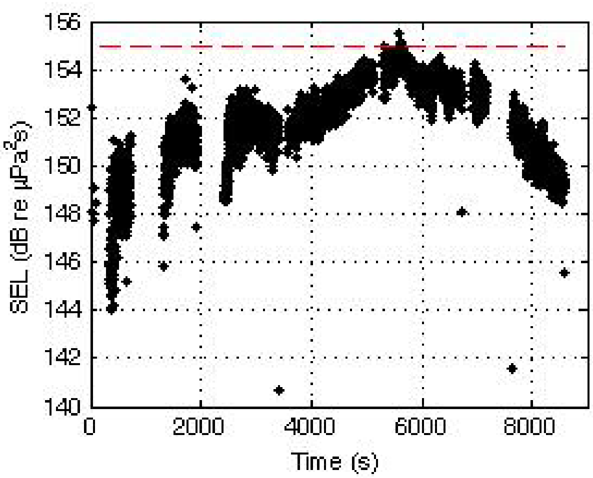
[4]TNO Monitoring Systems, Delft, The Netherlands, christ.dejong@tno.nl

1 Introduction

The installation of off-shore wind farms in European waters and the scale of the planned activity have led to concern over the generation of noise and its potential impact on marine life. Much of this concern is centred around the noise generated by pile driving, which is used for the installation of the turbine foundations, and its potential impact on marine life (Thomsen et al. 2006). The noise generated by pile driving has the potential to cause injury, induce temporary or permanent hearing loss, and evoke avoidance reactions. One injury criterion for marine mammals is defined as the on-set of auditory permanent threshold shift (PTS) (Southall et al. 2007), which is governed by either an instantaneous peak pressure an integrated sound exposure level;. The latter is the total noise energy to which the mammal is exposed during a given duration – which for a pile driving source would be either the duration of the piling or the time over which the mammal is in auditory range and is known as sound exposure level (SEL). In this case, cumulative exposure can be a useful parameter. This paper considers a summation of the SEL's for which the animal is exposed during the entire piling sequence.

2 Fleeing animal model

The levels at the receptor (un-weighted received levels for a single hammer strike, indicated by SEL_0) used in this paper are based on predictions calculated from a typical piling sequence measured in UK coastal waters. This allows the calculated cumulative exposures to be compared to the thresholds obtained from the literature, for example from the criteria published by Southall et al. (2007). To do this, a trajectory is chosen for each animal whereby the animal swims away (fleeing) from the source in a straight line at constant speed, heading and depth. To calculate the cumulative SEL_{cum}, the energy received level is calculated for each individual hammer strike and the animal's potential position at that time these are then summed over the entire piling sequence.



Fig, 1. SEL_0 (single strike, un-weighted) Received Level piling sequence at a fixed location for a marine mono-pile in shallow water. The dashed line shows a maximum Received Level of 155 dB re 1 μPa^2·s.

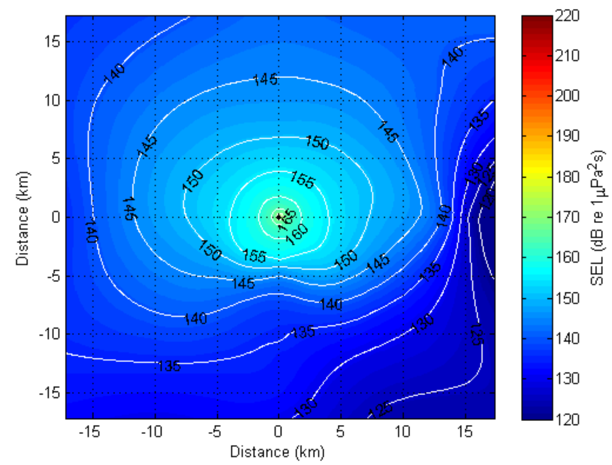


Fig. 2. Two dimensional model of received level SEL_0 at a given depth surrounding a mono-pile source in a range dependent bathymetry.

Figure 1 shows recorded SEL_0 received level at a single location for a complete piling sequence of 4362 hammers strikes for a mono-pile in about 15 m of water. In this case the total piling sequence took around 2 hours 20 minutes with around a 8 dB increase in received level from the start to maximum observed SEL_0 received level of around 155 dB re 1 μPa^2·s around two thirds of the way through the sequence. Using range dependent modelling taking into account bottom bathymetry, the transmission loss on a bearing from the source at various ranges can then be estimated. Figure 2 shows an estimate of received level at a specific depth for a given source level as a two-dimensional profile around a source.

Using this approach and the source variation data taken from figure 1 the likely received level at the animal can be estimated for each hammer strike at any range and bearing from the pile location.

3 Cumulative exposure calculated for marine piling

Using the methodology described in section 2, the fleeing mammal model has been used to calculate the cumulative exposure assuming a number of conditions. Figure 3 shows an example estimate of the un-weighted cumulative exposure (SEL_{cum}) for a maximum energy Source Level of 210 dB re 1 μPa^2·s·m^2 (Ainslie et al, 2010) for the sequence given in figure 1, a specific start distance from the source in this example of 100 m, and an animal swim speed of 1.5 m s^{-1}.

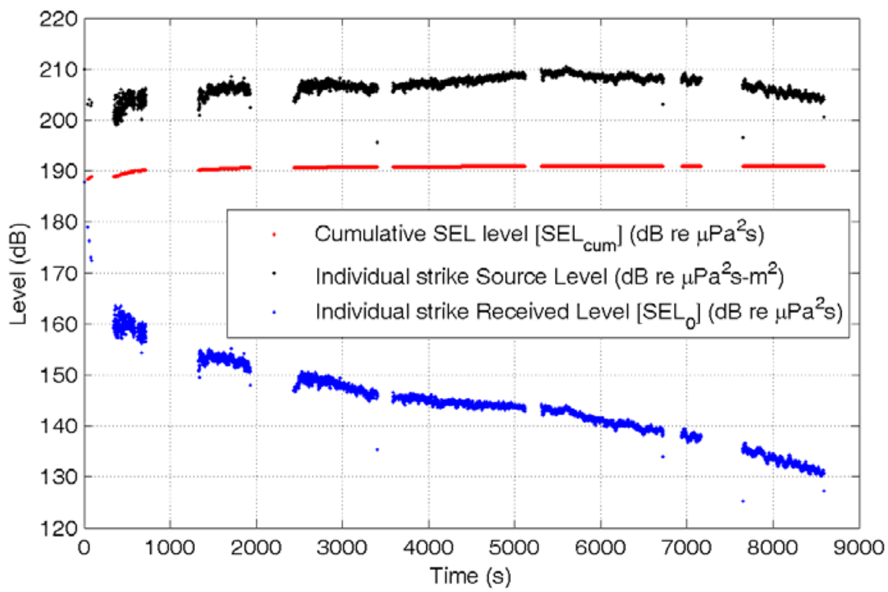


Fig. 3. Individual strike Source level (black dots), un-weighted received level SEL_0 (blue dots) and cumulative exposure at receptor SEL_{cum} (red dots) for a given piling sequence. Receptor assumed to start at 100 m from source and swim away at a constant speed of 1.5 m s^{-1}.

Using the sequence time and amplitude data the variation in Source Level for each hammer strike is calculated representing the changes in source levels seen over time (soft-start) or gaps (slow-start) in specific piling sequences (shown as the upper trace –black dots, figure 3). The individual SEL_0 received level (lower trace – blue dots, figure 3) at the animal is then estimated for an animal swimming away from the source. The total exposure for each successive strike (middle trace, red dots, figure 3) is then added to give the total cumulative exposure for the entire piling sequence. This figure can then be compared to known impact criteria threshold for cumulative exposure.

4. Impact zone prediction

The range from a source at which an animal starts, remains, or transects through and area allowing an exposure in excess of a predefined impact criteria often form the basis of impact assessments. In the case of a fleeing animal the total cumulative exposure can be estimated for a given piling sequence on a known transect and start position. These models are then used to find a start range outside which the total exposure is kept below a predefined threshold. Figure 4. shows the effect of start range on total cumulative SEL_{cum} (weighted and un-weighted) for the example piling sequence shown in Figure 1. with a maximum example source level of 210 dB re 1 $\mu Pa^2 \cdot s \cdot m^2$ and a swim speed of 1.5 ms^{-1} applied to frequency weighted functional hearing groups for marine mammals in both static and feeing animal models as outlined by (Southall et al. 2007). In this case the difference in the static and fleeing animal models show a marked increase in minimum start range to avoid exposure.

Conclusions

Both the fleeing and static model method has been used to calculate the cumulative exposure/SEL_{cum} for a typical piling event during the installation of a wind turbine mono-pile in shallow water. The actual sequence timing, number of hammer strikes and variation in source level and shallow water propagation loss properties are considered. Example total exposures for functional hearing groups proposed by Southall et al. 2007 are given for each functional hearing group. This approach has also been applied to model variation in total source level (use of barrier methods) and effectiveness of soft-start as an aid to development of mitigation strategies of various marine operations.

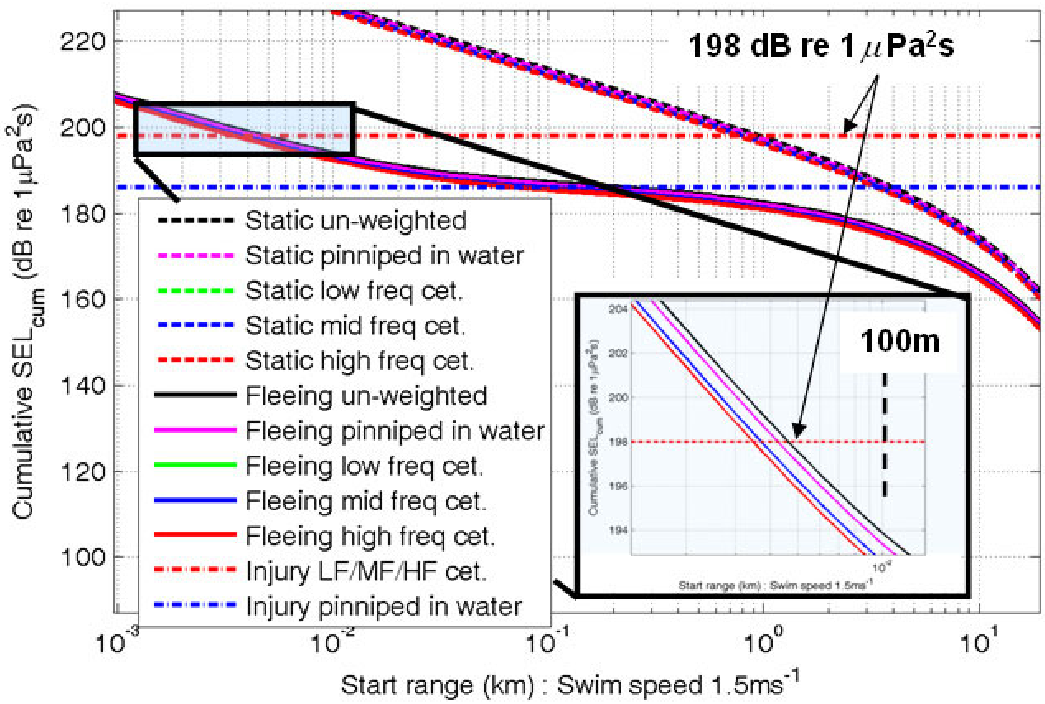


Fig. 4. Total cumulative SEL_{cum} versus start range for a typical piling sequence applied to different marine mammal functional hearing groups for both static and fleeing animal scenarios.

References

Ainslie MA, de Jong CAF, Robinson SP, Lepper PA (2010) What is the Source Level of Pile Driving Noise in Water?. In this volume.

Madsen PT (2005) Marine mammals and noise: problems with root mean square sound pressure for transients, J. Acoust. Soc. Am, 117, pp. 3952-3957.

Southall BL, Bowles AE, Ellison WT, Finneran JJ, Gentry RL, Greene Jr. CR, Kastak D, Ketten DR, Miller JH, Nachtigall PE, Richardson WJ, Thomas JA and Tyack PL (2007) Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations, Aquatic Mammals, 33 (4), pp. 411-509.

Thomsen F, Ludemann K, Kafemann R and Piper W (2006) Effects of offshore wind farm noise on marine mammals and fish, COWRIE Ltd.

FIGURE LEGENDS

Fig. 1. SEL_0 (single strike, un-weighted) Received Level piling sequence at a fixed location for a marine mono-pile in shallow water.

Fig. 2. Two dimensional model of received level SEL_0 at a given depth surrounding a mono-pile source in a range dependent bathymetry.

Fig, 3. Individual strike Source level (black dots), un-weighted received level SEL_0 (blue dots) and cumulative exposure at receptor SEL_{cum} (red dots) for a given piling sequence. Receptor assumed to start at 100 m from source and swim away at a constant speed of 1.5 m s^{-1}.

Fig. 4. Total cumulative SEL_{cum} versus start range for a typical piling sequence applied to different marine mammal functional hearing groups for both static and fleeing animal scenarios.