Underwater radiated noise level database collected in shallow water in Baltic Sea

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Abstract

Underwater radiated noise level (LRN) of vessels needs to be measured in Finland using methods designed for shallow waters (30–70 m). Such method is published by DNV (Det Norske Veritas). There is very little published LRN data of vessels in Finland, which were determined using DNV method. Such knowledge is needed in maritime industry since IMO has advised maritime industry to reduce the LRN of new vessels. Our purpose is to report how this method was applied in Finland to collect LRN data of vessels. All measurements were undertaken within 10 – 20 000 Hz using hydrophone recorders. Measurement stations complying with the "DNV shallow" method were placed along busy shipping lanes. The coordinates of vessels passing through the stations were obtained from AIS system. Vessel passes which took place sufficiently close to the station were accepted and analyzed. So far, 645 passes have been analyzed. The database consists of 164 different vessels. The final database will be available at the end of 2027.

Keywords: underwater noise, radiated noise level, shallow water, hydrophone measurement

1. Introduction

Underwater noise emission of vessels is usually declared by radiated noise level (LRN). The global maritime industry is increasingly interested in combating underwater noise, as the IMO (International Maritime Organization) has encouraged all member countries and maritime companies to reduce LRN [1]. There are also beliefs that IMO may in the future set quantitative LRN limits for vessels.

Underwater noise is deemed as an issue along some waterways. However, there are probably no such shipping lanes where LRNs are controlled by LRN measurements and exceedance of limit values are penalized by authorities or other parties.

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Maritime standardization body DNV (Det Norske Veritas) has published an LRN target value called "Silent" [5]. Falling below this value entitles the reception of "DNV Silent" label for the ship. This target value is applied in such businesses, where the shipowner might benefit from such label. The existence of DNV Silent concept indicates that awareness of underwater noise problems is sufficiently broad among maritime industry.

Since propulsion is the main source of noise, noise control design has increased among propulsion system manufacturers for more than 20 years.

Still, there are many countries, such as Finland, who has not conducted LRN measurements for any vessels. In such situation, the starting point is to improve the measurement capacities and basic and local knowledge related to the factors that affect LRN. As a part of this progress, it is useful that the LRN of vessels sailing in Finnish seas are extensively mapped to have a proper understanding of current LRNs and to be able to make fact-based plans for future noise abatement programs.

LRN of vessel depends, in large perspective, on three factors: vessel type, draft, and speed [2, 3]. However, propulsion solutions and noise abatement solutions are vessel-specific, so that the LRN of a specific vessel may not be precisely predicted based on vessel type, draft, and speed.

Our purpose was to describe the method which was recently applied in Finland to measure LRN of vessels in shallow waters, and to demonstrate the data obtained so far.

2. Materials and methods

2.1 Measurement apparatus

Hydrophone recorders (SoundTrap ST600 HF, Ocean Instruments) were used in the underwater sound measurements. Our main interest was on frequency range 10–20 000 Hz. Therefore, the recording was made at a sampling frequency of 48 kHz. The recording is stored in SUD format, which contains an X3-compressed signal. When the data is extracted from the recorder to acoustic analysis, it is converted to WAV format.

The hydrophones were calibrated before every measurement using the internal calibration method. In addition to that, the hydrophones passed our internal calibration procedure, which took place in loud diffuse

airborne sound field (pink noise played in reverberation room). The sound pressure levels (SPL) of the hydrophones were compared with traceably calibrated microphone-analyzer combination while setting the reference pressure to 1 μPa both in the microphone and hydrophones. In such comparison, it is desirable that the SPLs of microphone and hydrophone deviate very little from each other.
The recorders were installed directly against the seabed according to the DNV method (Figure 1). The distance between the hydrophone and the reflective plate was 70 mm, which fulfills the DNV's minimum requirement of 200 mm. We used plywood plate against the seabed because of two reasons. First, seabed of Baltic Sea is often muddy. We wanted to avoid mud contact on hydrophones. Second, the reflection from seabed depends on material. Using plywood, the absorption coefficient is close to zero, as the -5 dB correction in Eq. (1) expects.
Because the hydrophone was against seabed, and a surface buoy could not be applied, hydrophone was always paired with an acoustic releaser (LRT 7986, Solardyne), whose hook could be opened by remote acoustic transmitter.

2.2 Measurement stations

Measurement stations were erected on 3 shipping lanes in Southern coast of Finland. The lanes lead to major Finnish harbors in Turku, Porvoo, and Kotka. Stations were located far away from harbor, where the vessels usually navigated at constant speed and heading. The location of the station was selected on the shipping lane in such position where the vessels are likely to sail. This was checked using the AIS history of previous year. In each station, two hydrophones were installed at the station as shown in Figure 2.

2.3 LRN method

LRN measurements were carried out using the DNV shallow water method [4] which is designed for sea depth range 30–150 meters. Shallow water method must be applied since the average sea depth in Baltic Sea is 55 m.
In the LRN test setup, the vessel must be located at a horizontal distance of 100–200 m from the hydrophone. In our study, distance range 50–200 m was accepted, because we could not see any significant differences between the LRN results for the same pass, if the horizontal distance was 50–100 m or 100–200 m.
Figure 2 shows the DNV measurement principle for the situation, where the vessel speed exceeds 5 knots and the vessel length is L. The measurement duration is defined as the time for the vessel to propagate two vessel lengths (t_{2L}) as shown in Figure 3.
Vessels passing the measurement station were identified using AIS (Automatic Identification System). AIS data was obtained from the Finnish Transport Infrastructure Agency. AIS data includes following data: time stamp, vessel's IMO identification information, position, and speed. Class A vessels transmit AIS messages every 2–10 seconds depending on their speed.
Data handling of AIS database was programmed with Matlab. The handling consisted of the following checks: distance between the vessel and the hydrophone (r_{CPA}) is within 50 – 200 m; other vessels are beyond 2000 m distance from any hydrophone (control of background noise); noise exceeds ambient background noise in the audio data within the pass-by time window given by AIS coordinates; and vessel has an IMO number. If these conditions were fulfilled, the acoustic analysis was conducted.
The horizontal distance between the vessel heading and hydrophone, i.e., the distance with closest point of approach, r_{CPA} [m], was determined using hydrophone coordinates and vessel's AIS data.

Figure 1. Hydrophone measurement unit. Hydrophone recorder (right) and release transponder (left) attached to the hook of the 15 mm plywood plate. There is a 15 kg concrete weight below the plate (not visible). The plate was used to avoid any contact between the hydrophone and seabed mud. The rope ends to a buoy (now shown) that keeps the package in upright position.

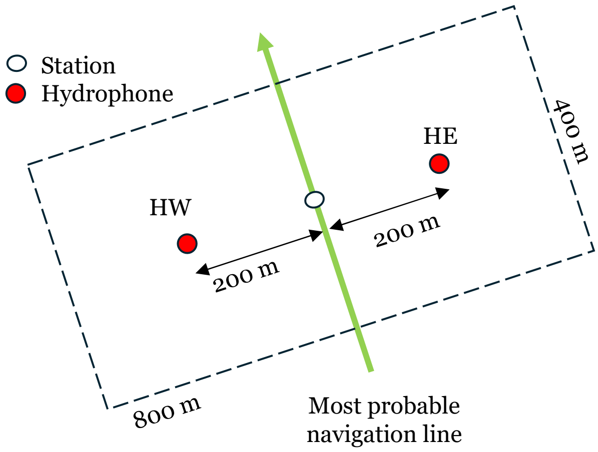

Figure 2. Each measurement station consisted of two hydrophone measurement units placed on both sides of the most probable navigation line. Using this setting, all vessels passing through the dashed line area could be analyzed with at least one hydrophone.

2.4 LRN calculation

Radiated noise level, L_{RN}, is the SPL of a point-like sound source measured at 1-m-distance from the source in free field. LRN was determined by [4]

$$L_{RN} = 20 \cdot log_{10}\left(\frac{p_{rms}}{p_0}\right) + 18 \cdot log_{10}\left(\frac{r}{r_0}\right) - 5 \quad (1)$$

where p_{rms} [Pa] is the root-mean-square sound pressure during time t_{2L}, p_0 [Pa] is the reference sound pressure, 1.00 µPa, r_0 [m] is the reference distance (1.00 m), and r [m] is the distance between the vessel and hydrophone:

$$r = \sqrt{s^2 + r_{CPA}^2} \quad (2)$$

where s [m] is the sea depth at hydrophone position.

The method attempts to take the directivities of sound from different vessel components into account by conducting the measurement during the time of two vessel lengths as shown in Figure 3. However, the directivities are differently considered if the vessel is close (100 m) or far (200 m): the width of sector 2L becomes larger when the vessel is closer to the hydrophone. Based on our calculations, the energy remaining outside the period t_{2L} is significant if the vessel is far. Therefore, we wanted to determine the LRN based on the whole event to avoid any dependence of the test result on horizontal distance.

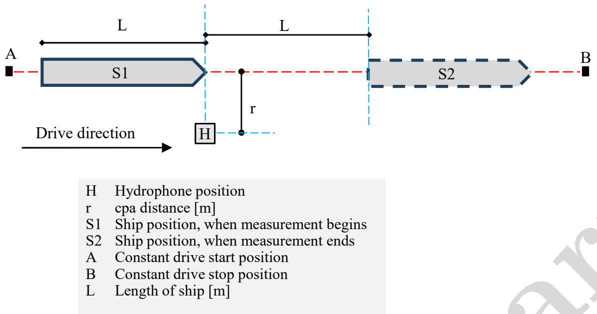

Figure 3. DNV measurement principle, when vessel speed exceeds 5 kn (9.3 km/h).

First, we determined the sound exposure level, L_E, of the pass-by event using pass-by time t_{4L}. This longer period always contained nearly all the sound energy of the whole event (longer measurement time influenced L_E less than 0.1 dB). Second, the equivalent SPL was determined for the period t_{2L} as required by DNV. The mathematic steps are shown in Equations (3–6):

$$L_{eq,t4L} = 20 \times log_{10}\left(\frac{p_{rms}}{p_0}\right) \quad (3)$$

$$L_E = L_{eq,t4L} + 10 \times log_{10}\left(\frac{t_{4L}}{t_0}\right) \quad (4)$$

$$L_{eq,t2L} = L_E - 10 \times log_{10}\left(\frac{t_{2L}}{t_0}\right) \quad (5)$$

$$L_{RN} = L_{eq,t2L} + 18 \cdot log_{10}\left(\frac{r}{r_0}\right) - 5 \quad (6)$$

where $L_{eq,T}$ [dB re 1 µPa] is the equivalent SPL during time T (either t_{4L} or t_{2L}), L_E [dB re 1 µPa] is the sound exposure level of the event lasting t_{4L}, t_{XL} [s] is the time taken for the vessel to sail X vessel lengths (XL/v); t_0 [s] is the reference time, 1.00 s, $L_{eq,XL}$ [dB re 1 µPa] is the equivalent SPL during time taken to sail X ship lengths, v [m/s] is the vessel speed during the pass-by (speed over the ground), and L [m] is the vessel length.

The measurement principle of DNV in Figure 3 expects that the measurement operator knows the exact position of the vessel bow. However, this information is not available in AIS data. The position of the GPS antenna is highly vessel specific. Some vessels are longer than 300 m. Therefore, the lack of GPS antenna position information is a source of uncertainty in DNV measurement principle.

In addition, the position of the noisiest component in the vessel is vessel specific. The measurement arrangement of Figure 3 does not express when the loudest noise component passes the closest point of approach.

To minimize measurement uncertainties related to abovementioned factors, we decided to analyze the vessel passes by focusing on the period where the SPL is the largest and ignoring the exact position of the vessel bow as suggested in Figure 3. Our method of finding the maximum SPL (midpoint) is shown in Figure 4. The midpoint (loudest SPL) was determined using three steps in a Matlab routine. First, we identified the point where the SPL reached maximum. Second, we determined the start and end points (A, B) where the SPL is 10 dB below the maximum SPL. Third, we defined the midpoint exactly between points A and B.

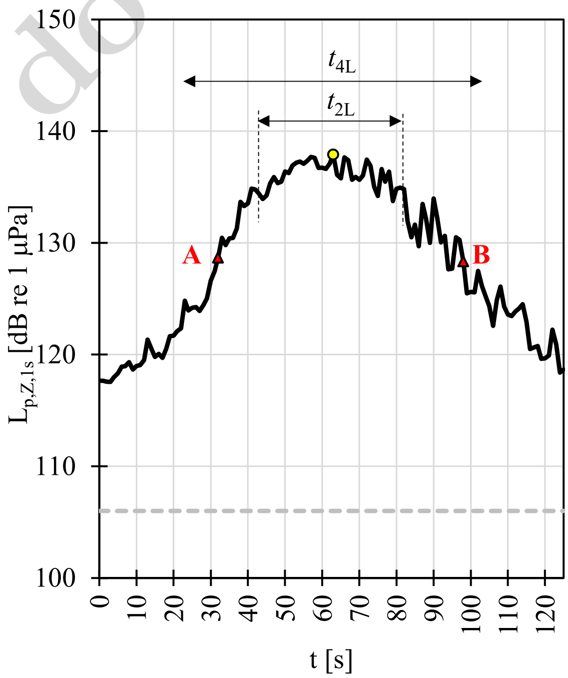

Figure 4. An example of the SPL time profile measured by the hydrophone during a vessel pass. We conducted the analysis from the time window t_{2L}, where the loudest SPL (yellow circle) was centralized. In this example, t_{2L}=40 s, since the speed was 21 kn (38.9 km/h). A and B indicate the times, where the SPLs fall 10 dB below the loudest SPL. Grey dashed line is the SPL of ambient background noise. The SPL in the y-axis corresponds to the total unweighted SPL within 10–20 000 Hz.

3. Results

The description of our database is summarized in Table 1. The frequency dependent LRN values for all approved passes are shown in Figure 5 for all vessel types.

Certain vessels passed the measurement station several times so that the overview of our data may give a biased picture of the distribution of LRNs among the studied vessel types.

Table 1. Description of the data collected at the measuring station. Other vessels include, for example, tugboats, fishing vessels or research vessels. $L_{RN,tot}$ involves the whole frequency range 10–20 000 Hz.

	Ferry	Cargo	Tanker	Other vessel
No. of passes	128	130	374	13
No. of vessels	5	49	102	8
Speed [kn]	12.4–21.4	8.3–17.8	3.2–15.4	4.7–10.7
$L_{RN,tot}$ [dB re 1 µPa]	164–183	163–189	156–193	162–180

4. Discussion

Our study reports the first LRN database created from vessels operating in Finnish seas using DNV shallow method. Our database is significantly smaller than, e.g., the ECHO database published by MacGillivray et al. [2]. Therefore, we are continuing the material collection during 2026–2027 to extend our database by at least 200%. Thereafter, we will test the LRN prediction models of Ref. [3].

Although many territorial waters or ports favor low-noise vessels or low-noise modes of transport, they generally do not set general quantitative noise guidelines that would be monitored by measurements. For example, in Finland, there are no target values for the underwater noise emission of vessels. However, underwater environmental effects are carefully investigated if underwater construction work is planned due to, e.g., bridges or wind turbines. If the construction work requires blasting, noise control measures are required to protect aquatic life.

We believe that our data will be very valuable if IMO sets quantitative target values for LRN in the future. Our database can be used to assess how the current vessels are related to the target values and how much noise control is needed. In addition, our data can be used to assess which components of the vessel are critical for noise control.

5. Acknowledgements

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6. References

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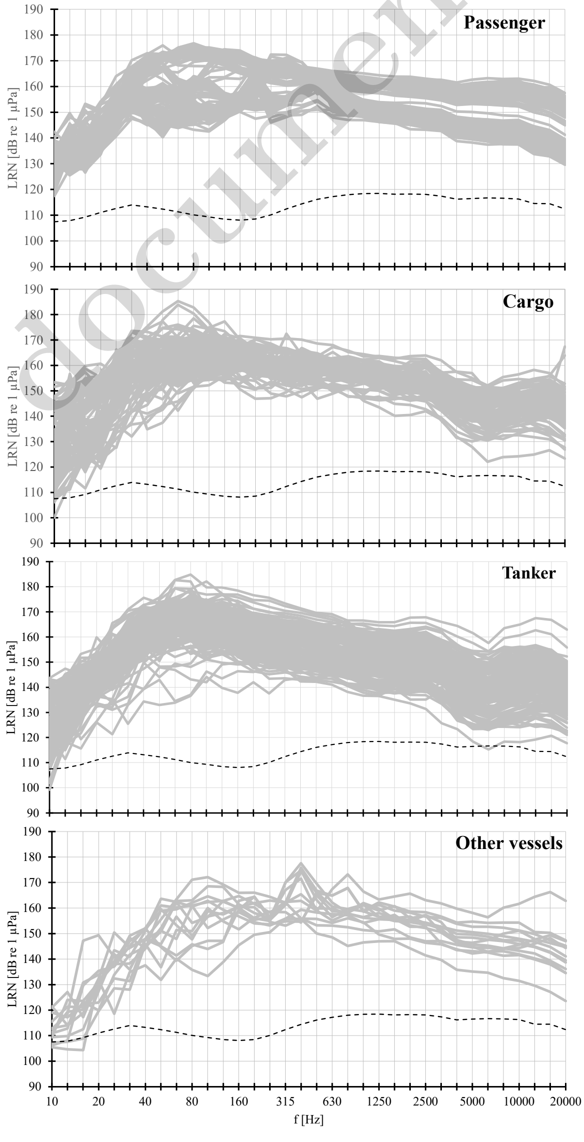

Figure 5. The dependence of radiated noise level, L_{RN}, on frequency, *f*, for all approved passes among the four vessel types. The grey lines represent individual passes. Dashed line is the LRN without any vessel nearby (background).