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STATISTICAL ANALYSIS OF A NOISE MEASUREMENTS FOR THE SERIES OF RORO SHIPS

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The importance of noise and vibration measurements during the sea trials is significant, especially now when noise limits are getting more restrictive and ship-owners demand to obey those noise limits. For a new-built vessels the normal procedure is to perform noise forecast at design stage. Taking into account weight limiting the passive noise insulation becomes a very important issue, therefore in order to avoid solutions which are not effective one should base on a realistic noise excitation data. Noise forecasts are mostly based on initial documentation and characteristics of main sources e.g. engines, generator sets, propellers etc, which are provided (measured or calculated) by manufacturers. Ship noise prediction might differ from real on-board noise situation. The question is what is a standard deviation between forecast and noise measurement. Normally for noise prediction analysis the worst case scenario is taken into account, so one can expect that real on-board noise levels will be lower then forecasted. However, when weight limits are taken into account in standard work case scenario the real on-board noise levels are more or less the same as forecasted. The question is how much is it "more or less"? Conducting the measurements onboard of a series of ships creates the convenient opportunity to perform statistical analysis of the results. The paper focuses on statistical analysis of noise measurements performed for the series of ro-ro ships.

Keywords: ship noise, vibroacoustic.

1. Introduction

1.1. Car carrier description

Roll-on/roll-off (RORO or ro-ro) ships are designed to carry wheeled cargo such as automobiles, trailers or railway carriages. This is in contrast to lo-lo (lift on-lift off) vessels which use a crane to load and unload cargo. RORO vessels have built-in ramps which allow the cargo to be efficiently "rolled on" and "rolled off" the vessel when in port. While smaller ferries that operate across rivers and other short distances still often have built-in ramps, the term RORO is generally reserved for larger ocean-going vessels [1]. And for this particular kind of vessels noise measurements were executed as a part of Sea Trials Measurements performed by Ship Structure Division of Ship Design and Research Centre.

The studied series of ro-ro ships were build in Stocznia Gdynia S.A. In Fig. 1 one can find a photo of a ro-ro ship.

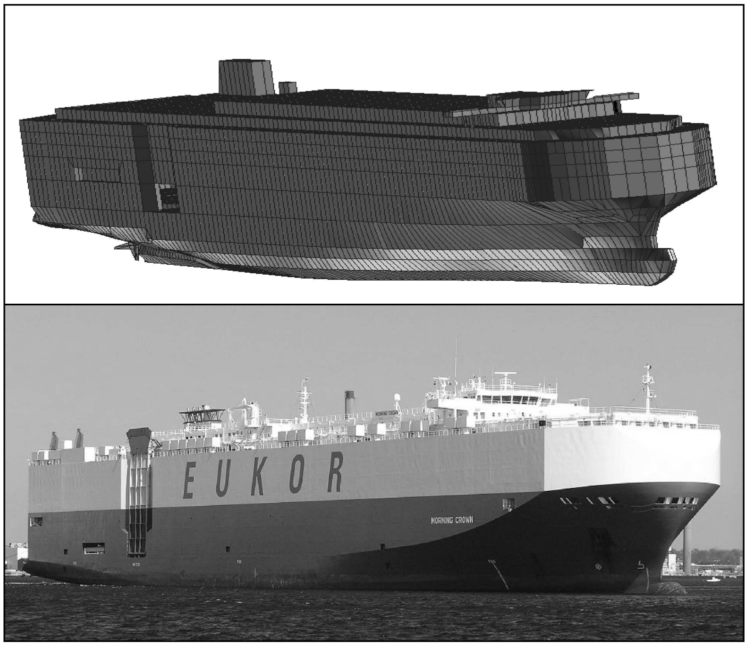

Fig. 1. RORO ship "MORNING CROWN" with Finite Element Model.

1.2. Noise issues in marine industry

From the acoustical point of view ship is a very difficult object to analyse. It is a rigid structure with many noise sources, flanking paths, discontinuities etc.

As far as ship is concerned, noise in compartment is a result of different kind of equipment and machinery noise influence. These noise sources are commonly located in aft part of the ship (i.e. ro-ro ship) or in the midship part (i.e. ferry), which affects all compartments. The most important noise sources on a ship are:

- main engine and generator sets,
- gearboxes,
- propellers (cavitation effect),
- exhaust systems with engine room ventilation,
- auxiliary mechanism such as hydraulic systems, pumps,
- ventilation and air-conditioning systems.

Participation of particular noise source on total noise in analysed compartment depends on a ship structure, power and structure of mechanisms, their foundation, distance between noise source and analyzed compartment. In compartments, where noise sources are installed in (i.e. engine room, pump room, bow thrusters room), the most influence on total noise brings a machinery **air-borne noise** (noise which is fundamentally transmitted by way of the air). In compartments that are located at some distance from noise sources, **structure-borne noise** (noise which is generated by vibrations induced in the structure – these vibrations excite partitions in ship structure and cause them to radiate noise) dominates.

Generally, noise present on a ship is mostly structure-borne noise. Air borne noise is present especially in compartments, which are adjacent to engine room, exhaust system, or on decks in the chimney neighbourhood (Fig. 2).

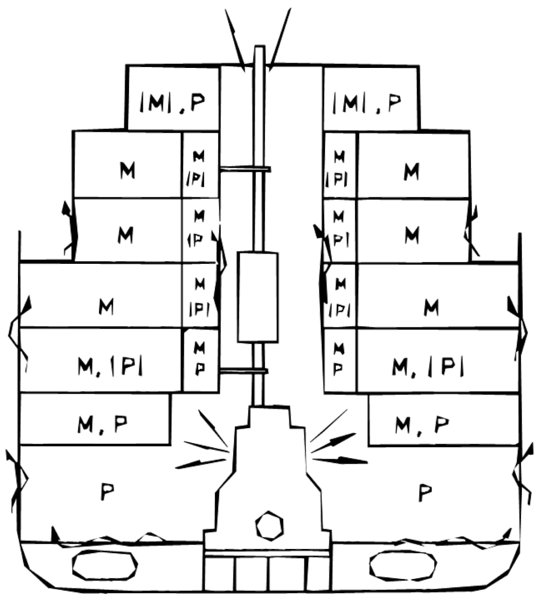

Fig. 2. Structure-borne (M) and air-borne (P) noise influence on compartments.

2. Noise measurements during sea trials on ro-ro series

2.1. Noise measurement requirements

One of the most important document describing and providing standards to prevent the occurrence of potentially hazardous noise levels on board ships is IMO Resolution A.468 "Code on Noise Levels on Board Ships". According to this document, among many conditions which have to be obeyed like ship's speed, power, measurement equipment etc. there are also environmental conditions. It is stated that meteorological conditions such as wind and rain, as well as sea state, should be such that they do not influence the measurements. Wind force 4 and sea state 3 should not be exceeded.

2.2. Case description

As it was mentioned before, for a new-built vessels the normal procedure is to perform noise forecast at design stage. There are different noise forecast methods like SEA, FEM, BEM, etc. Every method has it's own limitation but in the end forecast results are being compared with real on-board measurements. For a series of ships one can expect similar noise results for a number of identical ships and identical excitation of main noise sources. All noise measurements were performed as $L_{eq}(A)$ – equivalent noise level weighted with curve A. Measurements were performed at Engine room and Deck 13 (where all cabins are located).

2.3. Results

In this case noise levels on 8 serial ro-ro ships (A÷H) were measured and analyzed. Measurements were performed at the same 89 locations (Engine Room, Living Deck, Wheelhouse, Navigating bridge wings). In Fig. 3 standard deviation at 89 measurement locations for 8 serial ro-ro ships is presented.

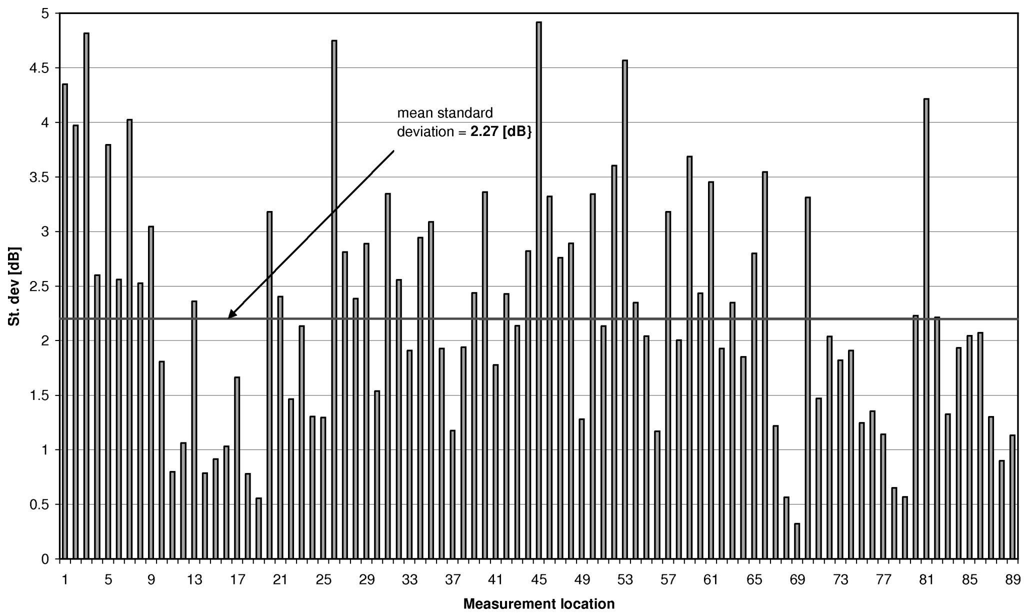

Fig. 3. Standard deviation at 89 measurement locations for 8 serial ro-ro ships.

Maximum standard deviation for these measurements doesn't exceed 5 dB. The biggest standard deviation values are present at some "cabin locations", "wheelhouse", "engine control room" and "bridge wings".

In Fig. 4 weather conditions, which were present during noise measurements, are presented. Weather conditions are very important as far as ship's vibrations are concerned. Vibration amplitude levels become higher with increasing of sea state and wind (e.g. slamming impacts). This situation occurs especially in lower frequencies (upto 10 Hz). The question is what kind of influence weather conditions have on on-board noise.

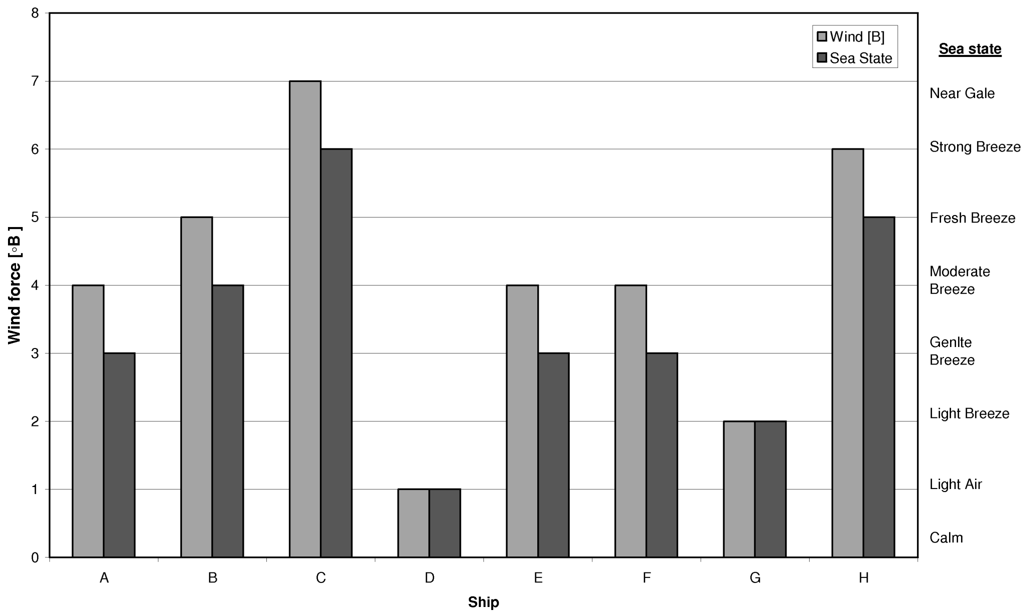

Fig. 4. Weather conditions (wind force and sea state) during noise measurements.

In Table 1 one can see correlation factors between weather conditions and on-board noise measurements. In this case “Noise correlation factor” is a correlation factor between noise measurement results in chosen location and wind force, for first analysis, and sea state for second analysis. This factor is calculated according to below given formula:

$$\rho_{x,y} = \frac{Kow(X,Y)}{\sigma_x \cdot \sigma_y}\,. \tag{1}$$

Table 1. Noise correlation factors for environmental parameters.

Measurement location	Wind correlation factor	Sea state correlation factor
Cabins (adjacent to outer wall)	−0.52	−0.58
Engine Control Room	−0.31	−0.34
Bridge Wing PS	0.12	0.05
Bridge Wing SB	0.07	−0,03

3. Conclusion

As one can see from Fig. 3 maximum standard deviation doesn't exceed 5 dB. For "cabin locations" st. dev is about 5 dB. During noise measurements in "cabin locations" the ventilation system is normally set to full, however minimum differences in air velocity flowing out of an air grate can have a great influence on total noise level in compartment. Noise measurements in "wheelhouse" are performed with background noise coming from radio-telephone machines and this nonstationary noise can affect noise measurements app. 3 dB.

Measurements on "bridge wings" are taken on the leeside of the ship. Therefore noise measurement differences can occur depending on ventilation system loading.

For all measurements mean standard deviation is **2.27 dB**. This value is a great indication, telling what kind of tolerances noise forecasts should have (upto 3 dB).

Very interesting results were obtain with weather conditions and noise measurements correlation analysis. As one can see from Table 1 four locations were analysed. In "brige wings" locations (portside and starboard) both correlation factors (wind and sea state) are near 0. This is due to the fact that measurements are taken on the leeside of the ship. Both correlation factors for "cabins" adjacent to outer side and "engine control room" results as negative small-medium correlation. This result has to be investigated with more detailed narrow band analysis.

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