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EFFECTS OF SHIP VIBRATION FROM THE POINT OF VIEW OF MARINE LIFE, CREW AND SHIP STRUCTURE

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ABSTRACT

In this paper, we are trying to analyse what excessive ship noise and vibration can cause from multiple points of view. Firstly, from a biological point of view, we can observe that a lot of sea species are affected by the vibration caused by ships along the modern trade routes. Secondly, from the construction point of view, we can see that bad engineering can lead to a lot of problems, later in the ship lifetime. And the last point of view we analysed is the crew, which can suffer a lot of health problems if the noise and vibrations regulations are not followed.

1. Introduction

Vibration, by definition, is defined as the oscillatory motion of an object or system around a central equilibrium point. We can divide vibration in two types, deterministic vibration if the oscillation is characterized precisely, or random vibration if the oscillation can only be analysed statistically. Also, vibration can be desirable, like the motion of a tuning fork, but in many cases, vibration is undesirable, like the vibration of an engine. Undesirable vibration is noise, which is an unwanted, harmful sound. Both noise and desired sound are vibration, but the difference appears in our brain perception of vibration.

Vibration being a mechanical oscillation means that all the law of physics describing elastic waves are applied to it. In this case, vibration has some characteristic parameters such:

- Frequency: number of complete oscillations per seconds, measured in Hertz [Hz];
- Amplitude: the distance between equilibrium and position at a given time, measured in [Pa], [m/sec];
- Harmonics: integer multiples of a given frequency.

Humans perceive sounds with the ear, hearing is often considered as the second most used sense. The human ear can hear sounds from approximatively 20 μPa to 200 Pa. In order to avoid inconvenient values, the scale used to measure sound pressure level is dB (decibel)..

1.1. Effects of noise and vibration from a biological point of view

Since the dawn of history humans have sailed. At first using ships made of reeds and rafts across rivers, then learning how to build ships out of wood that could traverse the ocean. With the industrial revolution of the 19th century, humans build the first steel ships powered, at first, by steam and afterwards by diesel. Although steel ships provide a great advantage to modern trade, and military forces, they come with a disadvantage, namely pollution. Besides air pollution, ships are creating noise pollution from the machinery that affects not only the crew onboard the ship, but also the marine environment.

Noise pollution, from the marine environment side, apparently is not as bad as the pollution caused by exhaust or different leaks from the ship. But as more studies emerge, the situation gets more complicated. An article published by the International Chamber of Shipping estimates that: "11 billion tons of goods are transported by ship each year. This represents an impressive 1.5 tons per person based on the current global population" [1].

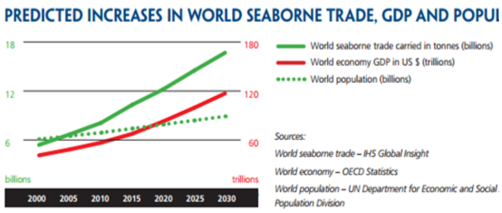

Fig.1 Graph to show the predicted increases in world seaborne trade GDP and population [2].

Fig.2 Chart showing the decibel levels in dB [4].

By looking at the numbers, we can conclude that the commercial shipping causes the greatest noise pollution. In a study for Wildlife Conservation Society Canada, William D. Halliday (PhD) states that: "Shipping noise can be very loud averaging around 175-180 dB" [2]. Also, he states that we need to take into account that: "sound in water is measured using a different reference pressure level than sound in air, and cannot be directly compared (...). For example, a rock concert may be 120 dB in air, which is equivalent to 180 dB in water" [3].

We must take into consideration that a lot of maritime creatures communicate via sound. Ship noise covers their single way to communicate and blocks them from finding food, reproducing and navigating. Also, as in the case of humans, excessive noise elevates the level of stress, the same happens with marine mammals. In an article published in Natural Resources Defence Council, Regan Nelson states: "Hundreds of studies have demonstrated how ship noise adversely impacts marine species: increased stress hormones in critically endangered North Atlantic right whales, affecting reproduction and immunity, reduced foraging by Southern Resident orcas, who are already facing scarce prey resources, narwhals becoming motionless, sinking and falling silent at relatively low levels of noise (...). The list goes on and on, and what we know likely only scratches the surface" [5].

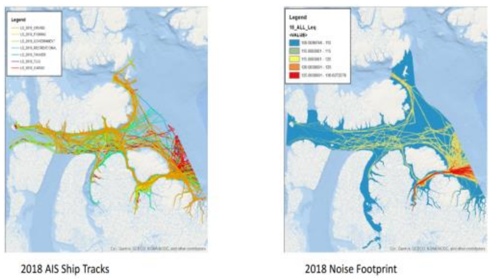

Fig.3 Map showing shipping routes (left) vs Ship noise footprint in 2018 [3].

1.2. Effects of noise and vibration from a ship building point of view

Every ship during the period of operation is subjected to different forms of vibration. These are caused mainly by three main sources: the diesel engine, the propeller and waves. The vibration caused by the main engine of the ship is going to produce resonance mainly in the structure of the ship, primarily the hull girders, superstructure or in the engine room foundations. The propeller, on the other hand, causes vibration through the shell of the hull and the shaft line. We must note that this type of vibration can be excluded during the ship design only if the hull wake is uniform, because otherwise the vibration of the propeller increases drastically.

The last type of vibration is caused by the waves. Usually, waves create vibration in the ship's hull through impacts, called slamming or whipping. This vibration is transmitted through the hull girder structure. The vibration caused by waves can be avoided if the ship changes its course and speed in order to avoid the waves, and should not pose a problem for the ship structure.

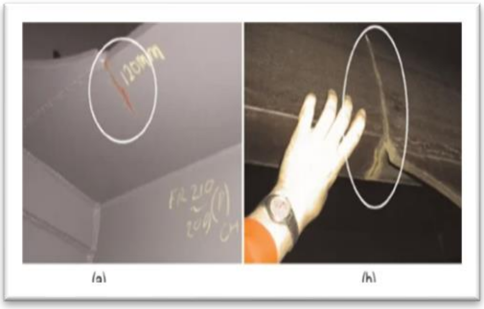

Fig.4 Cracks in ship structure caused by vibrations [6].

1.3. Effects of noise and vibration from the crew point of view

The evolution of the shipbuilding industry brought new challenges, not only for the engineers, but also for the crew on board the ships. One of these challenges is adapting to a working environment with a lot of noise and vibration. Working for a long time in this type of environment can cause several health problems.

Moreover, we must take into the account the infrasounds caused by working machinery during the rest period, that can lead to serious health issues in time. Judging by the place in which the vibration can affect the body, we have two types of effects: local health effects and whole body vibrations.

The first type usually involves damage caused by working with different vibrating tools, and can cause vascular symptoms and neurological disorders like: „white fingers", osteoarthritis, carpal tunnel syndrome, etc. The most common damage, both for crewman working the power tools and engine-crew that are in constant presence of vibrating surfaces is hand-arm vibration syndrome. In a review paper titled: "Vibration on board and health effects", written by Anker Jensen and Jørgen Riis Jepsen in 2014, in the cases of HAVS regarding machinist, they state that: "The generally accepted magnitude of vibration of surfaces on ships from a technical point of view seems to be well above the magnitude that is prone to induce HVAS for frequencies above 10 - 15 Hz. Consequently, health effects on the lower extremity after prolonged standing on vibrating surfaces on ships might be a possible outcome" [7].

Fig.5 "White Fingers" Effect [8].

In the paper: "Evaluation of the human discomfort caused by ship Vibrations" [9], published in 2021 in the Journal of marine science and technology, Laurentiu Picu and Eugen Rusu conducted a study in which they analysed how different crewmen react to transient vibration that could be present in the work environment. The results from the experiment were analysed using two methods: the Likert scale and the Semmes-Weinstein monofilament method. For the experiment they took ten adult males aged between 28 and 42, with different medical backgrounds. The subjects were tested on a plate, mounted on a vibratory system. Although this is a case study, and the human body reacts differently, when the vibration parameters increased, the discomfort of the participant increased, too.

2. Creating the ship model

2.1. Main characteristics

The ship chosen for this paper is an oil tanker. The main mission of an oil tanker is to transport large quantities of oil products across the seas and the ocean. Oil tankers can be divided into categories according to what type of products is transported (refined oil products or raw oil products) and the size of the ship. The categories are:

1. Only for refined oil products:
   - General Purpose, GP, with a deadweight around 10000 to 25000 t;
   - Medium Range, MR, with a deadweight around 25000 to 45000 t;
2. For refined and raw oil products:
   - Long Range 1, LR1, with a deadweight around 45000 to 80000 t;
   - Panamax, these ships are designed to navigate through the Panama Canal, with a deadweight around 55000-80000 t;
   - Aframax, these ships are designed to navigate through ports with a draft not to deep, with a deadweight around 80000-120000 t;
   - Suezmax, these ships are designed to navigate through the Suez Canal, with a deadweight around 120000-160000 t.
3. Only for raw oil products:
   - Very large crude carrier, VLCC, with a deadweight around 160000 - 320000 t;
   - Ultra large crude carrier, ULCC, with a deadweight around 320000 - 550000 t, [10].

The ship modelled in this paper has a 28000 dwt, so it belongs in the Medium Range (MR) type. The main dimensions are given below in Table 1.

Tabel 1. Main Dimension

L_{OA}	176	[m]
L_{WL}	169.5	[m]
L_{BP}	167	[m]
B	28	[m]
D	14.1	[m]
T	9.2	[m]
∇	36000	$[m^3]$
D_W	28000	[dwt]
A_{WL}	4175.83	$[m^2]$
A_M	248.84	$[m^2]$
v	14	[kn]
A	10000	[Mm]

2.2. Rules and regulations

We aim to see the effects of vibration in the wheelhouse of the ship. The position of the wheelhouse deck is determined in height by the Regulation 22 from SOLAS Chapter V which states that: "The view of the sea surface from the conning position shall not be obscured by more than two ship lengths or 500 m, whichever is less, forward of the bow." According to this rule, in the case of this ship, the position of the wheelhouse deck is at 25530 mm from the baseline.

When modelling the wheelhouse, two main classification rules were followed. The first rule is Regulation 22 from SOLAS, Pt. I, Ch. V regarding the angle of incline for the windows, which states that the windows of the wheelhouse must be inclined at an angle from 10º up to 25º, measured in the vertical plane.

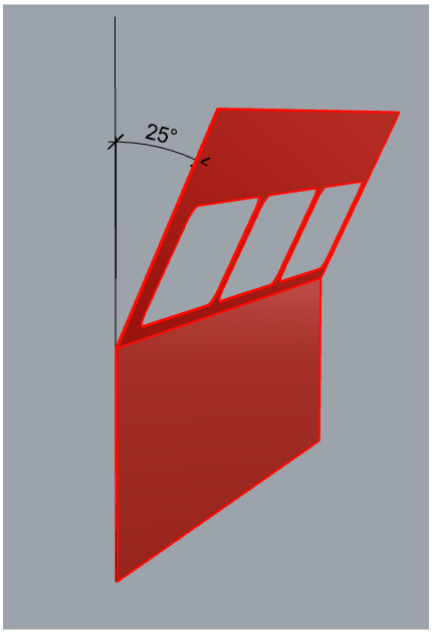

Fig.6 Example of a wall with windows following Reg.22 from SOLAS

The second rule followed defines the minimum thickness of the superstructure and deckhouses, from Bureau Veritas, NR467 Part B Hull and Stability, Chapter 8, Section 4 – Superstructure and deckhouses:

$$(4 + 0{,}01 * L) * k^{\frac{1}{2}} - t_c$$

Where L is the length of the ship, k is the steel quality factor and t_c is the Rule corrosion addition. For our example, k is equal to 1 and t_c is 0.5. With these values the result of our equation is 3 mm, which means the plates of the superstructure need to be thicker than 3 mm.

2.3. Rules and regulations used in vibration measurement

For analysing the vibration aboard the ship, regarding the wellbeing of the crew, we may use two ISO standards, ISO 6954:1984 and ISO 6954:2000. There are four main differences between the two standards.

The first one concerns the methodology and the evaluation: ISO 6954:1984 used more general evaluation curves in order to determine the acceptable level of vibration; while ISO 6954:2000 comes with a more detailed analysis with an accent upon the frequency spectrum and direct impact of vibration on the crew.

The second difference is about the frequency and amplitude of vibration. ISO 6954:1984 focuses more on middle values without a strict correlation with the human perception or with the impact of vibration on the comfort. ISO 6954:2000 includes details about how the frequency of vibration impacts the human body, and how to limit the discomfort.

The third difference is the scope of the standard. The scope of ISO 6954:1984 is more technical, with a lot of attention to protect the equipment and the structure of the ship form the effects of vibration. ISO 6954:2000 aims at protecting the crew and the passengers aboard the ship, aligning more with the modern requests regarding the comfort and health.

The last difference between the two standards is the regulation and the implementation. ISO 6954:1984 is easier to apply while ISO 6954:2000 needs more advanced equipment.

There are numerous reasons why 6954:1984 is still applied to this day. There are a lot of ships built using this standard and upgrading them to the new standards is expensive. Also, it is easier to apply and in some areas where there is a limited access to advanced measuring equipment, 6954:1984 can be more practical.

Still, for the new ships and in the modern naval industry, ISO 6954:2000 is preferred for the more detailed analysis which is aligned with the norms of comfort and safety.

2.4. The virtual model

The program used for modelling the virtual model is Rhinoceros 7. The preliminary arrangement is shown in Fig. 7. There are reserved spaces for the wheelhouse equipment, radio console, chart table, pantry and lounge area, a bathroom, a storage space.

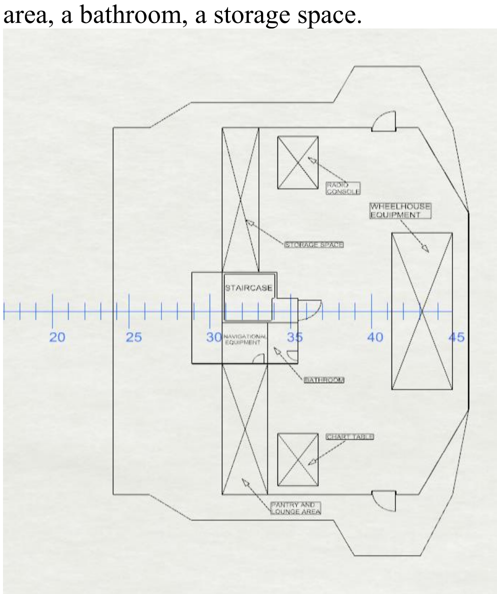

Fig. 7. Isometric view

While designing the virtual model, all the main things discussed before were followed. Therefore, the shell of the wheelhouse represented with red has a thickness of 8 mm, while the other plates have a thickness of 5 mm. The main isometric view is presented in Fig. 8. The shell is presented in Fig. 9; the shell is angled at a 25° angle (see Fig.6), also cuts for the windows were provided. The door frame is made from 5 mm plates as the stiffeners around the windows. In Fig. 10 the longitudinal frames are presented. They were modelled from 5 mm plates. The main enforced longitudinal has a T section profile with a height of 395 mm and a width of 100 mm. In Fig. 11 are shown the frames, modelled the same as the longitudinal.

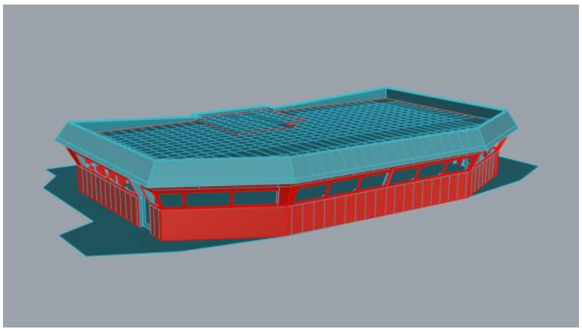

Fig. 8. Isometric view

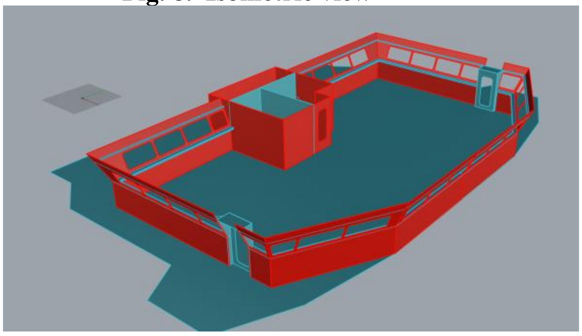

Fig. 9. Shell and deck

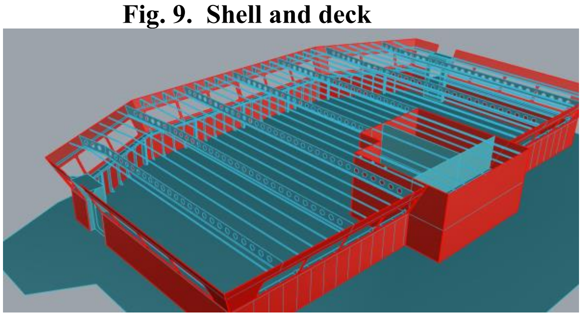

Fig. 10. Shell and deck

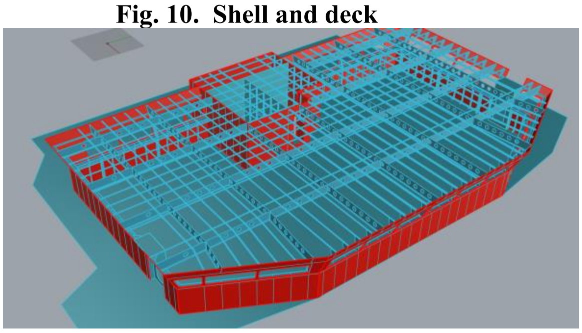

Fig. 11. Frames

3. Conclusions

In conclusion, there are three main categories when we are talking about the effects of vibration. From a biological point of view, the vibration caused by the ship can alter the marine life and may destroy the ecosystem if left unchecked. Excessive vibration aboard the ship may lead to structure failure or mechanical damage to certain equipment. Finally, vibration and noise can produce numerous health problems and fatigue to the crew.

This study is under development, and it presents an introductive part of a more complex analysis which will include more sources of noise and vibration modelled in FEM, using the virtual model presented.

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