METHODOLOGY FOR NOISE EVALUATION IN OFFSHORE UNITS

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Abstract. *This paper discusses a new approach for the noise problem in offshore installations (supply ships and platforms).The methodology includes the noise prediction of the units in design stage regarding machinery, layout and insulation materials. From noise predicted values and considering the crew work profile, it is possible to estimate hearing damage of workers, in accordance with ISO 1999. This International Standard takes into account age, sex, noise exposure and some statistical considerations. The expected noise-induced threshold permanent shift (NITPS) is calculated for four different classes of workers. Noise measurements were performed in a Platform Supply Vessel and the results were compared to ISO 1999 requirements. Differences were detected between the measured values compared with ISO criteria and the same results compared with other regulations. Finally, it was presented the main factors that, according to the authors, must be considered in noise analysis of the offshore structures.*

Keywords*: Noise, Offshore, Prediction*

1. INTRODUCTION

Sound pollution can be seen as a side effect of technological development. In an industrial environment, noise affects significantly the life quality and the worker performance. The noise disturbing effects also increase the risks of work accidents.

The world production of goods is directly related to the new technologies. Researches have been performed to avoid that sound pollution increases in direct proportion to production. One of these studies involves the use of tools to predict noise.

In new installation design is possible to estimate the level of noise expected in each environment and, occasionally, take action in order to control the layout and the types of insulation materials. Noise prediction is a more intelligent and cheaper methodology due to the fact that, whenever the units are changed while operating, the economical and operational impacts are more harmful than when it is done in the project stage.

Some noise prediction methods have been developed and it may be said that one of most relevant criteria used in the choice of a method is the relation between its efficiency and the complexity of the model to be created. Methods of high precision and that involve Herculean effort are not feasible in offshore platforms since that is necessary to model more than hundreds of noise sources and rooms.

In fact, the target of the noise problems is the life preservation and the comfort of the crew. The importance of noise analysis is reduced in places where only machines exist. As far as it is concerned, the increase in the number of the machines remotely controlled also contributes to the reduction of the noise exposure.

2. NOISE PROBLEM AND OFFSHORE INSTALLATIONS

Figures 1 and 2 illustrate the two types of platform which are widely used in offshore basins in Brazil: Semi-submersed and FPSO (Floating, Production and Storage Offshore Unit). Considering distribution, the machinery area is predominantly under the living quarters in the FPSO types, whereas the machines of semi-submersed types are distributed in other regions, which are further from the accommodation. In both types, the more recently designed units are meant for a production of more than 150.000 barrels per day, including turbines which generate energy superior to 40 MW. Due the exploration in deep water upper than 2000 meters, it was necessary to use of compressors driven by high power turbines (turbo-compressors) to inject gas into the oil wells. This operational configuration gives us an idea of the high noise level expected in these units. Measured values in supply vessels engine rooms and utility plants of the offshore platforms are, in general, above 110 dB (A).

Figure 1. FPSO Units

Figure 2. Semi-submersed Units

3. HEARING DAMAGE

The terms *sound* and *noise* are used in different ways, but *sound* is usually used to describe or is associated to a pleasant sensation such as listening to somebody speaking or to music; *noise*, on the other hand, is used to describe undesirable sounds, such as the horn of a car, the noise of the traffic and machineries. For a sound to be heard it needs to be within the frequency range captured by the human ear.This range varies from 20Hz to 20 kHz.

Hearing damage as a result of continuous occupational exposure to high/intense levels of noise is nominated as noise-induced threshold permanent shift (NITPS), according to the National Commitee of Noise and Hearing Preservation. The NITPS is defined as a gradual loss of the hearing acuity due to continuous exposure to high levels of sound pressure, doing harm to external and internal ciliated cells in the organ of Corti. It is characterized by an irreversible sensorineural hearing loss, which is almost always bilateral and symetrical, not higher than 40 dB(A) in low frequency and 75 dB(A) in high frequency . It takes place at first in 6000Hz, 4000Hz and/or 3000 Hz, but it can be extended to 8000Hz, 2000Hz, 1000Hz, 500Hz and 250Hz.

Among the factors which influence the risk of contracting the NITPS are mostly the physical characteristics of the noise (type, spectrum and level of sound pressure), the time of exposure to the noise and the individual susceptibility to the disease. The NITPS is one of the most prevalent diseases in workplaces, with an aggravating problem that is its irreversibility.

In agreement with LACERDA (1971): "Noise affects the human body in several ways. It can harm not only the processing of the auditry system, but also altering the physical, physiological and mental activities of the individuals exposed to it".

Noise can produce damages at different levels. The most widely studied is its harmful effect on the auditory system. Accordingg to KINSLER (1982), hearing damage is a broad term to specify the loss of the ability to hear. This loss can occur in two ways. The first is traumatic, due to proximity with high noise levels, causing a breaking of the eardrum, destroying the sensorial cells or causing collapse in section of the Organ of Corti, and this type is associated to a specific event. The other manner in which the loss can happen is through aggressions of smaller intensity; however with great frequency that is the case of the long exhibition to the noise.

4. SOME NOISE REGULATIONS

The unhealthy activities and operations are regulated by NR15 regulation. Appendix 1 establishes a maximum limit of continuous or intermittent noise, tolerated for 8 hours, 85 dB(A). Not appropriately protected individuals are not allowed to be exposed to levels of noise higher than 115 dB(A). Appendix 2 regards 130 dB (Linear) as the maximum limit tolerated for impact noise. In the intervals between the peaks, the existing noise should be evaluated as continuous noise. In case there is no equipment for measuring the sound pressure level with a circuit of response to impact , it is possible to validate the result in the fast response (FAST) and the compensating circuit, taking 120dB(C) as the limit.

The World Health Organization considers that the beginning of the hearing stress occurs with the exposure to 55dB. The Brazilian Legislation, by means of the NORMA REGULAMENTADORA NR 15- Appendix 1 (MTb, 1996), establishes that the levels of continuous or intermittent noise have to be measured in decibel with an instrument of level of sound pressure operating in the circuit *A* (dBA) and slow response. The readings have to be done near the worker's ear.

The NR 15 uses the percentage of daily exposure to the noise as criteria. The daily dose can be determined by the following expression:

$$NoiseDose = \left(\frac{C_1}{T_1} + \frac{C_2}{T_2} + .. \frac{C_n}{T_n} \right) \times 100 \qquad (1)$$

Where:
C_n = total daily time the worker is exposed to a specific noise level
T_n = maximum daily time allowed at this level, according to table 1

It is important to notice that the levels lower than 80 dB(A) are not being taken into consideration in the calculation of the dose.

Table 1: Maximum Noise Exposure

Noise Level dB(A)	Maximum Daily Exposure
85	8 hours
86	7 hours
87	6 hours
88	5 hours
89	4 hours and 30 minutes
90	4 hours
91	3 hours and 30 minutes
92	3 hours
93	2 hours and 40 minutes
94	2 hours and 15 minutes
95	2 hours
96	1 hour and 45 minutes
98	1 hour and 15 minutes
100	1 hour
102	45 minutes
104	35 minutes
105	30 minutes
106	25 minutes
108	20 minutes
110	15 minutes
112	10 minutes
114	8 minutes
115	7 minutes

IMO A.468 regulation determines upper noise limit (dBA global value) for each room, considering the nature of the activity related to these rooms. Table 2 presents some these levels.

Table 2. IMO Noise Limits

IMO Maximum Global Noise Levels	
Engine Room (Manned)	90 dBA
Engine Room (Unmanned)	110 dBA
Central Control Room	75 dBA
Workshops	85 dBA
Radio Room	60 dBA
Cabin	60 dBA
Hospital	60 dBA
Office	65 dBA
Mess Room	65 dBA

ISO 1999 presents, in statistical terms, the relationship between exposure to the noise and NITPS (noise-induced threshold permanent shift) in people of different ages. This regulation presents procedures to calculate NITPS of populations without previous hearing problems relative to the noise exposure (however the negative effects of the age are considered). NITPS is usually zero in the noise abstinence, and for any exhibition it has a range of positive values representing the variability of the damages caused by noise among the individuals of the population. NITPS is usually preceded by a reversible temporary effect. The severity will depend on the level and of the exposure time to the noise.

People regularly exposed to the noise can develop hearing loss of different severities. In reason of that, the understanding of conversations, speeches, daily acoustic signs or the appreciation of music can be harmed. The effect of the hearing loss demands time and it is progressive through months, years or decades of exposure.

Just analyzing an individual, it is not possible to determine precisely which changes in the hearing level are caused only by noise, and which are caused by other reasons. However, for a great population exposed to a specific noise, statistical changes in the distribution of the hearing level can be measured. Therefore, by this regulation, the term NITPS is applied to statistical distributions of the hearing loss induced by the noise.

This regulation presents two definitions of extreme importance for the understanding of the project:

First: Noise exposure level normalized calculation.

$$L_{ex,8h} = L_{Aeq,Te} + 10\log\left(\frac{T_e}{T_0}\right) \tag{2}$$

Where:

$L_{ex,8h}$ - Noise exposure level normalized to a nominal 8 h working day

$L_{aeq,\,Te}$ – Equivalent continuous A-weighted sound pressure level related to T_e hours

T_e – Effective hours

T_0 – Reference time of the working day (8 hours)

This pressure noise level, expressed in decibels, is the daily noise dose received by the worker expressed in 8 working hours, in other words, this expression makes calculations which would be the equivalent level, for 8 working hours that the person will be exposed when he/she has a working day larger than the 8 hours.

Second: Equivalent continuous sound pressure level

$$L_{aeq,T} = 10\log\left[\frac{\sum T_i.10^{0,1.L_{aeq,T_i}}}{T}\right] \tag{3}$$

Where:

$L_{aeq,\,T}$ = Equivalent continuous A-weighted sound pressure level

$T = \Sigma\, T_i$

This expression determines the equivalent noise level to which the person is exposed during his/her working day, in other words, when a parson is exposed to different noise levels with different exposure times, it must be calculated the equivalent level for his/her total day of work and from this result to study the case.

ISO 1999 takes into account the hearing loss related to the age (H). This approach is differentiated for three different population samples, where each sample has a natural hearing loss differentiated. In these three population fractiles (Q), we have Q=0.1, 0.5 and 0.9, where 0.9 represent the population with smaller value of natural hearing loss, and 0.1 represents the population with the largest values of natural hearing loss.

In this approach Y is the age of the person under analysis and $H_{0,50;18}$ represents the medium value of the hearing loss caused by a 18 year-old person and it is considered zero in agreement with to ISO 389. For illustration effect, the table 3 shows the calculation of the hearing loss for 55 years-old man, due to the aging.

Table 3. Hearing Damage for Age (H)

Gender: Man	Age:	55	
Fractiles Q:	0,1	0,5	0,9
125	16	4	-6
250	15	4	-5
500	15	5	-4
1000	16	5	-4
1500	20	8	-4
2000	24	10	-3
3000	35	16	-1
4000	45	22	1
6000	51	25	1
8000	61	30	2
Hearing Damage (dB)	**30**	**13**	**-2**

In accordance with table 3, a man with 55 year-old age has statically a hearing loss of 13 dB. If this person is more susceptible to the noise, this loss can reach to 30 dB. However, if he/she belongs to the class of the ones that have larger tolerance to the noise, he/she will not have relative hearing problems to the age (the negative value, -2, does not mean hearing improvement).

4. PRACTICAL CASE

The procedure was to identify the most suitable crew to be analyzed. It was decided to choose the two groups involving the higher and lower level of responsibility, respectively: Captain and Chief Engineer constitutes first category and Oiler and Ordinary Seaman the other one. This choice includes persons that work above and below the main deck.

First, it was important to define the exposure time of the crew. It was verified that the crew works in periods of 6 hours per 12 hours, that is, they work 6 successive hours and after they rest 12 hours. Then, it was considered total daily noise exposure time equal to 18 hours per day. Table 4 presents the exposure time of the workers in each room of the vessel.

Table 4 – Crew Working Day

Place	Leq (dBA)	Captain	Chief Engineer	Oiler	Seaman
Control Room	70		5.0	0.5	1.0
Engine Room	107		1.0	5.5	1.0
Change Room	78	0.5	0.5	0.5	0.5
216 - Cabin	57			6.0	6.0
217 - Laundry	72				0.5
Corridor M Deck	65				1.0
Mess Room	56	2.0	1.0	1.0	1.0
Dayroom	57	2.0		1.0	4.0
Galley	64		2.0	2.0	2.0
Air Conditioning	62		1.0	1.0	
Corridor 3rd Deck	60			0.5	0.5
Office	57	1.0	1.0		
WC	58	0.5	0.5		
Chief Engineer Cabin	54		6.0		
Captain Cabin	50	6.0			
Wheelhouse	57	6.0			0.5
Total		**18.0**	**18.0**	**18.0**	**18.0**

The noise measurement produced the values of noise pressure level for each room. However, as the work routine of the crew does the same person exposed at different noise levels and with different exposure times in each level. This way, it was necessary to obtain the noise pressure level for the routine of each crew member's eighteen hours.

Table 5 – Equivalent Noise Pressure Level – 18 hours

	Captain	Chief Engineer	Oiler	Ordinary Seaman
$L_{aeq,18}$(dBA)	63,6	81,5	88,8	81,4

Table 6 – Normalized Equivalent Noise Pressure Level – 8 hours

	Captain	Chief Engineer	Oiler	Ordinary Seaman
$L_{aeq,18}$(dBA)	67,2	85,0	92,4	85,0

In order to perform the analysis in this paper, it was considered that all the crew worked from the age of 30 to the age of 50. In relation to the hearing loss associated to the age, all of them will have the same results. Figure 3 presents total damage hearing for Engine Room Assistant.

Table 7 – Hearing Damage per Age

Gender: Man	Age:	50	
Fractiles Q	0,9	0,5	0,1
500	-4,7	3,6	13,5
1000	-4,5	4,1	14,3
2000	-4,3	7,2	20,5
3000	-2,9	11,8	28,5
4000	-1,5	16,4	36,4
6000	-1,8	18,4	41,1
Hearing Damage (dBA)	**-3,3**	**10,2**	**25,7**

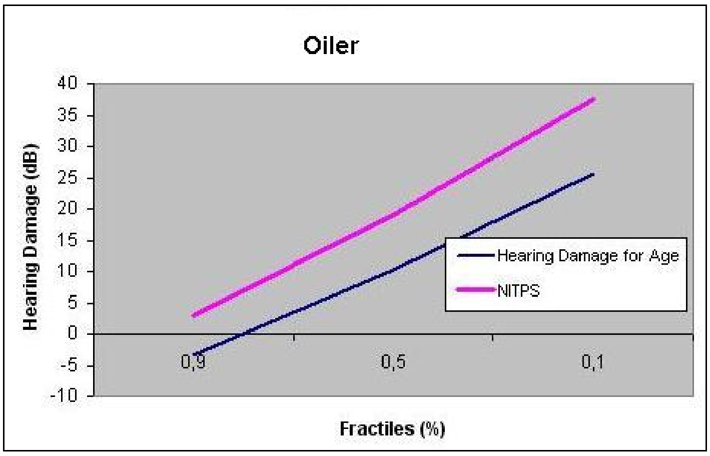

Figure 3: Hearing Damage Oiler

It was considered for the same example the approach suggested by NR 15: noise dose. Table 8 presents the results.

Table 8 – Noise Dose

Noise Dose (NR 15)	
Post	**Daily Dose (%)**
Captain	0
Chief Engineer	44,4
Oiler	244,4
Ordinary Seaman	44,4

The captain is not exposed at superior levels than 80 dB(A). Then, he doesn't need any attention in terms of noise time exposure. The chief engineer and seaman are exposed at the level of noise of 94 dB(A) for one hour only, while in accordance with noise regulation the maximum exposure is two hours and fifteen minutes. In other compartments the levels are below 80 dB(A). Therefore the daily dose is below the 50% and it is not necessary any action of the company in relation to the noise levels to which both are exposed.

The Oiler is exposed to a daily dose of 244,4%. For this reason, it is necessary a revision of its work conditions, as well as use of equipments of individual protection in order to person is adapted to the minimum requirements of noise exposure. This dose is high because this worker is constantly in engine room, exposed at the highest noise levels of the ship.

5. CONCLUSION

The comparison performed between the natural hearing damage due to ageing with the hearing losses induced by the noise demonstrated that only the captain does not suffer with the damages caused by work noise exposure. This happens because he works in the upper deck and his cabin is placed a deck just below. He keeps away to engine areas all day long. However, all other posts under analysis had larger hearing loss than the natural loss, indicating that when the workers are exposed to the existent noise in work routine, they would have damages even with the use of the hearing protection devices.

According to NR15, the Oiler is not complies with the requirements of the time exposure. The analysis demonstrates that, even in the compartments that do not exceed the limits suggested by IMO A.468, the exposed crew members in these rooms would not be free from hearing damage.

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