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A STUDY OF THE VIBRATIONS TRANSMITTED TO THE STAFF BY THE STRUCTURES OF THE RIVER SHIPS ON THE ROMANIAN DANUBE SEGMENT

phys. Laurentiu PICU
"Dunarea de Jos" University of Galati

ABSTRACT

This paper analyzes the vibrations transmitted to the entire human body by the equipment of a ship. The measurements were made on the Danube river, from the entrance to Romania to the point where the Danube Delta begins, along 1000km, for 6 runs. The vibrations of the navigation bridge, on the main deck and in the engines room were measured with the vibration meter Examiner 1000 and the vibrations transmitted to the human body, with vibrometer Maestro 01dB. It is found that if for navigation bridge and for the main deck, the average of these values is 0.932m/s^2, respectively 0.75m/s^2, for engines room this average is 5.707m/s^2 and for the staff on the navigation bridge and on the main deck, the average of these values is 2,221m/s^2, respectively 1,773m/s^2; for those in the engine room this average is 5,934m/s^2. It can be seen that absolutely all the values for the daily exposure action value, standardized to an eight hour reference (0.5m/s^2) are exceeded.

KEYWORDS: Danube, daily exposure, hand-arm vibrations, whole-body vibrations

1. INTRODUCTION

Nowadays, the health and safety of employees at the workplace is a major concern of all companies. Also, it is necessary that – in addition to a careful examination of the fulfillment of all conditions for these specific rules to be strictly observed – to increase and to diversify the number of mechanisms which reduce environmental pollution. One of the priority areas is vibration pollution, a field covered by this paper. The vibrations transmitted to workers by different equipment are extremely dangerous if work periods do not alternate with rest periods.

Thus, Directive 2002/44/EC [1] stipulates very clearly the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration).

For whole-body vibration:

- the daily exposure limit value standardized to an eight-hour reference period shall be 1.15m/s2 or, at the choice of the Member State concerned, a vibration dose value of 21m/s1,75;
- the daily exposure action value standardized to an eight-hour reference period shall be 0.5m/s2 or, at the choice of the Member State concerned, a vibration dose value of 9.1m/s1,75.

Unfortunately, there are many exceptions to this rule. The vibrations transmitted to the whole body or just to a part of the body lead to disturbances of the health status of the persons subjected to the vibration field [2] (states of fatigue and sleepiness, emotional states of fear or anxiety, headache, diminished attention and visual acuity, changes in tactile sensitivity, respiratory function, blood pressure, nausea, etc.). All these negative effects of vibrations on the human body lead to the decrease of the work capacity of the personnel, thus reducing its performance [3, 4]; work accidents may also occur. In this paper we intend to analyze the vibrations transmitted to the navigational staff of a river ship on the Danube.

There are a number of sources of vibration and noise present in a ship or marine vehicle.

Typically these may include: the prime movers-typically diesel engines; shaft-line dynamics; propeller radiated pressures and bearing forces; air conditioning systems; maneuvering devices such as transverse propulsion units; cargo handling and mooring machinery; vortex shedding mechanisms; intakes and exhausts; slamming phenomena [5].

Table 1
Main categories of shipboard vibrations [6]

1. Hull girder	a. longitudinal b. vertical	c. horizontal d. torsion
2. Major substructures	a. deckhouses b. masts	c. weapons systems d. boilers
3. Shipboard equipment	a. passive (control systems, switchboards, heat exchangers) b. active (generators, compressors, pumps)	
4. Propulsion system	a. longitudinal (axial) b. torsion c. lateral (whirling)	

Shipboard vibration has been a great concern in the design and construction of vessels as excessive ship vibration may cause undesired effects on humans, a fatigue failure of local structural members or malfunction of machinery and equipment [7].

2. Materials and methods

The Danube is Europe's second-longest river: 2857km, as well as flow: about 5600m3/s at the entrance to Romania and 6470m3/s at the entrance to the Danube Delta, after the Volga River.

It is located in Central and Eastern Europe. The river passes through or touches the borders of 10 countries, of which in Romania has the largest basin (29% of basin area), and Galati is the largest port on the Danube (fig. 1).

Fig.1. Course of the Danube River

The measurements were made in summer, on the Romanian part of the Danube (Tulcea - Baziaș and return) for a distance of 1000km. The speed of the towboat is about 8km/h and the duration of a road about 5 and half days. There have been 6 races of this type. During this period, the Danube had small and medium waves.

The vibrations measurements were made with Maestro 01dB (to measure the vibrations transmitted to the person - fig. 2) and with Examiner 1000 (to measure the vibrations produced by the equipment - fig. 3).

Fig. 2. Bridge vibrations measurement with Examiner 1000

A. Bridge vibrations measurements

In order to find the vibrations of the ship, equipments were placed on the navigating bridge, on the main deck and in the engines room (fig. 2 and 4). The determinations were made when the ship was sailing.

Fig. 3. Whole-body vibration measurement with Maestro 01dB

It has been found that the frequency of the vertical vibrations corresponding to the motors is in the range 5.5-6.5Hz, and for the transversal vibrations in the range 4.5-5.5Hz. The vibrations generated by waves of small amplitude propagating through the ship's hull were also measured; they are in the range (1-2)Hz.

Fig. 4. Railing vibrations measurement with Examiner 1000

Fig. 5. Hand-arm vibration measurement with Maestro 01dB

B. Whole-body vibration and hand-arm vibration measurements

Acceleration values from one-third-octave band analysis can be used to obtain the frequency-weighted acceleration a_{hw}. It will be obtained using:

$$a_{hw} = \left[\sum_{j=1}^{n}(W_{hj} \cdot a_{hj})^2\right]^{1/2} \quad (1)$$

where a_{hj} is the acceleration measured in the one-third octave band in m/s², and W_{hj} is the weighting factor for the one-third-octave band.

The evaluation of vibration exposure in accordance with SR ISO 2631-1 [8] is based on a quantity that combines all three axes. This is the vibration total value A_{WT} or weighted acceleration sum (WAS) and it is defined as the root-mean-square of the three component values:

$$A_{WT} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (2)$$

where a_{hwx}, a_{hwy}, a_{hwz} are frequency-weighted acceleration values for the single axes.

Whole-body vibration and hand-arm vibration measurements were performed with Maestro (fig. 3 and 5) using PCB Piezotronics 356A16 - Triaxial Accelerometers.

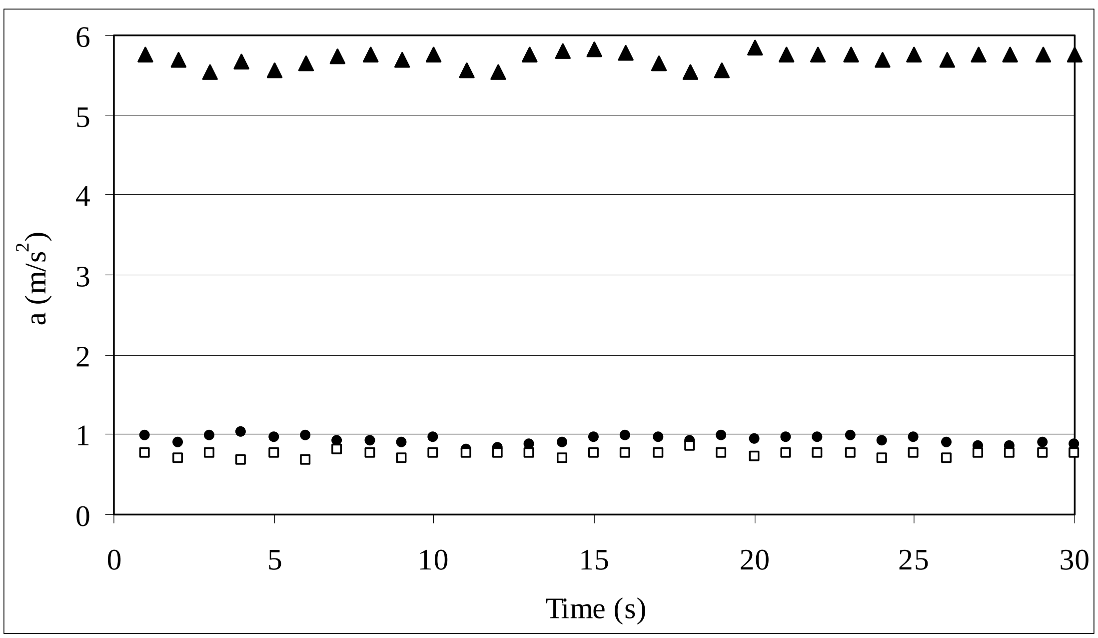

Fig. 6. Vibrations measurements on the navigation bridge (NB - ●), on the main deck (MD - □) and in the engines room (ER - ▲)

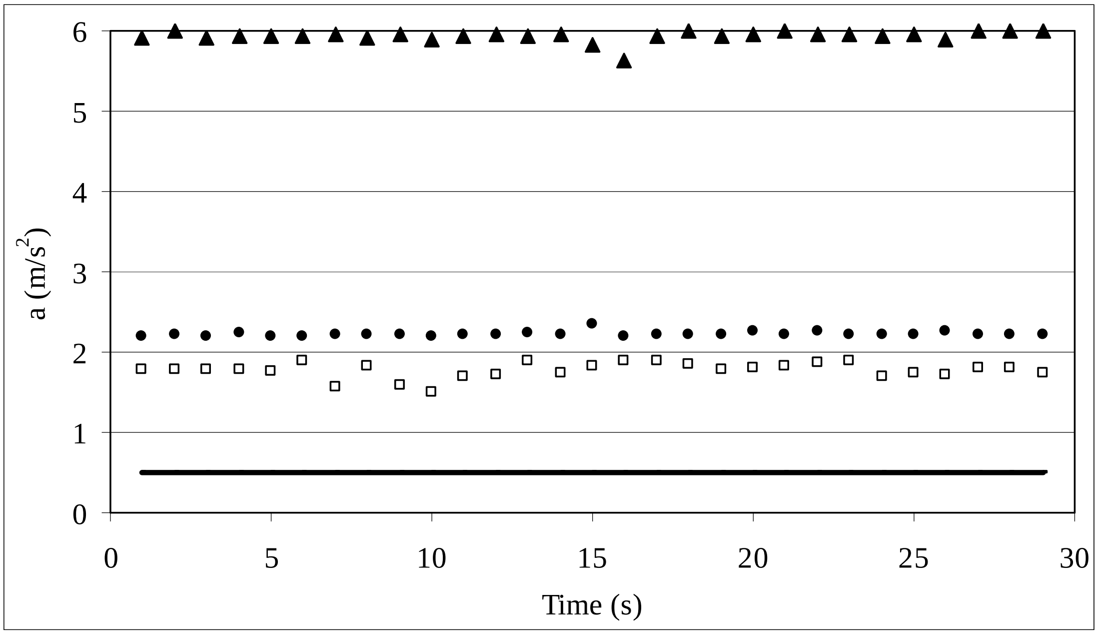

Fig. 7. Whole body vibrations measurements on the navigation bridge (NB - ●), on the main deck (MD - □) and in the engines room (ER - ▲). The continuous line (▬) is the limit value given in Directive 2002/44/EC

The equipment used for vibrations monitoring is part of the "Interdisciplinary Laboratory for Vibro-Acoustical Measurements in the Occupational Environment" of "Dunarea de Jos" University of Galati [9]. Each experiment lasts for 10 minutes [10, 11].

Table 2

Anthropometric data of test subjects

Subject	Age (years)	Weight (kg)	Height (m)	Smoking	Sedentary	Drinker
1	48	89	1.72	X		X
2	56	97	1.74	X		X
3	49	102	1.81	X		X
4	61	98	1.65			X
5	58	115	1.87			
6	43	87	1.55	X		X
7	65	102	1.67	X		X
8	62	97	1.55	X		X
9	56	72	1.51	X		X
10	34	89	1.62	X		X
11	49	88	1.65	X		
12	64	104	1.80		X	
13	63	101	1.74	X		X
14	59	98	1.81			X
15	61	102	1.71	X		X
16	52	98	1.84	X		X
17	59	112	1.92			
18	61	107	1.78	X	X	X

The measurements were made on a group of 18 subjects (Table 2). Each participant was asked to complete a health screening questionnaire, to give written consent for tests and was instructed in writing concerning the experiment. Participants were informed that they may abandon the experiment at any time for any reason [12].

The criterion for statistical significance was $p < 0.05$. The reported p values have been adjusted for multiple comparisons.

C. Discomfort determination using Likert scale

The second part of the experiment was to determine the subjects' discomfort exposed to stressors, using the Likert scale. Each subject was given a score for what he felt after the experiment ended [9].

The format of a typical five-level Likert item is shown in Table 3.

Table 3

Likert scale

Degree of discomfort	Scale
Very strongly	4÷5
Strongly	3÷4
Slightly	2÷3
A little	1÷2
Not at all	0÷1

3. RESULTS AND DISCUSSIONS

The results presented below represent averages of values recorded throughout the experimental determinations and for all subjects.

A. Bridge vibrations

Figure 6 shows the values measured with the Examiner for the navigation bridge, the main deck and in the engines room. It is noted that for the navigation bridge and for the main deck, the average of these values is 0.932m/s^2, respectively 0.751m/s^2, for the engines room this average is 5.707m/s^2, meaning 6.12 and 7.6 times higher. These values are reflected in the vibrations transmitted to the crew.

B. Whole-body vibration measurements

Figure 7 shows the whole body acceleration values measured with Maestro. It is noted that for the staff on the navigation bridge and on the main deck, the average of these values is 2.221m/s^2, respectively 1.773m/s^2, for those in the engine room this average is 5.934m/s^2. It can be seen that absolutely all values for the daily exposure action standardized to an eight-hour reference (0.5m/s^2) are exceeded.

C. Hand-arm vibration measurements

The Control of Vibration at Work Regulations 2005 requires one to take specific action when the daily vibration exposure reaches a certain action value [13]. The exposure action value (EAV) is a daily amount of vibration exposure above which employers are required to take action to control exposure. The greater the exposure level, the greater the risk and the more action employers will need to take to reduce the risk. For hand-arm vibration, the EAV is a daily exposure of 2.5m/s^2 A(8). There is also a level of vibration exposure that must not be exceeded. This is called the exposure limit value. The exposure limit value (ELV) is the maximum amount of vibration an employee may be exposed to on any single day. For hand-arm vibration, the ELV is a daily exposure of 5m/s^2 A(8).

It represents a high risk above which employees should not be exposed (fig. 8).

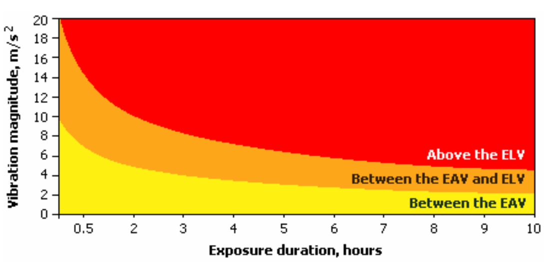

Fig. 8. Vibration level and duration affect exposure

Figure 9 shows the hand arm acceleration values measured with Maestro. For the staff on the navigation bridge and on the main deck, the average of these values is 1.921m/s^2, respectively 1.617m/s^2, for those in the engine room this average is 4.437m/s^2. To see how dangerous these vibrations are, the Hand-arm vibration exposure calculator is used.

Figure 9 shows that hand arm vibrations are not dangerous for people working on the navigation bridge and on the main deck; the time to reach the exposure action value (TEAV) is 13h and 19h respectively and the time to reach the exposure limit value (TELV) is > 24h for both situations. In these cases, partial exposure A(8)=1.9m/s^2, respectively A(8)=1.6m/s^2 (lower than the limit value 5m/s^2). For people working in the engine room, TEAV=2,5h and TELV=10h and partial exposure A(8)=4.4m/s^2 (very close to the limit value).

D. Discomfort results

Subjects were asked to define their discomfort (D) caused by vibrations after 8h of work using the Likert scale; the results are presented in fig. 9. It is noted that although the acceleration values are very high, the subjects did not feel that much: for the staff on the navigation bridge $\overline{D}$ =2.4, for the main deck $\overline{D}$ =1.96 and the engine room $\overline{D}$ =3.6. These values show that the discomfort was "Strongly" (D=3÷4) only for engine room staff; the rest chose "Slightly" (D=2÷3) and "A little" (D=1÷2).

4. CONCLUSIONS

As a result of these determinations, it is possible to say with certainty that the personnel on the ships under study are working in difficult conditions, as follows: the navigational bridge personnel work in an environment where the vibration value is almost 4.5 times higher than the one stipulated in the Directive 2002/44/EC; for the staff on the main deck, this is 3.5 times higher, and for those in the engine room, almost 12 times larger.

Since it was found that there is no correlation between the vibration values and the declared discomfort, a psychological test was also carried out. Only 11 people participated in this test; the others refused.

A psychological test is "an objective and standardized measure of a sample of behavior". The term sample of behavior refers to an individual's performance on tasks that have usually been prescribed beforehand. The samples of behavior that make up a paper-and-pencil test, the most common type of test, are a series of items. The performance on these items produces a test score. A score on a well-constructed test is believed to reflect a psychological construct such as achievement in a school subject, cognitive ability, aptitude, emotional functioning, personality, etc. The differences in test scores are thought to reflect individual differences in the construct the test is supposed to measure (Psychological testing, https://en.wikipedia.org/wiki/Psychological_testing).

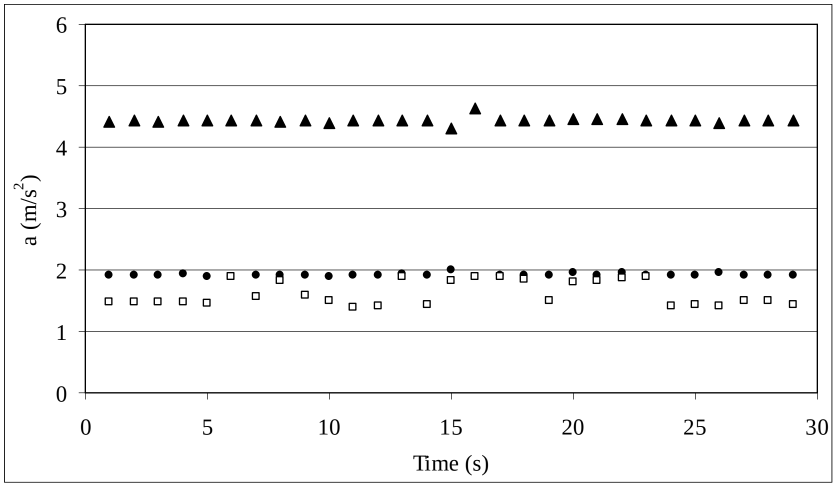

Fig. 9. Hand arm vibrations measurements on the navigation bridge (NB - ●), on the main deck (MD - □) and in the engines room (ER - ▲)

For this experiment, an "Ability-Potential" test was chosen; these tests are used for aptitude testing and career guidance. Scoring is on a scale from 1-10.

For this test no prior education, training, past experience or college degree provides an advantage to the results (http://www.abilitypotentials.com/test).

The results of the tests were the ones expected: although all people responded that they did not feel annoying discomfort, "Ability-Potential" tests showed the opposite. Fig. 12 shows that the subjects’ responses demonstrate fatigue, lack of attention and of concentration.

One of the 5 people on the navigation bridge (NB - //) refused to take this test; of the 8 people on the main deck (MD - □), 3 refused; of the 5 people in the engine room (ER - ■), 3 refused. The average of the scores obtained by the subjects is mediocre (Table 4).

From all these measurements it appears that subjects are tired, even if they are not aware of it or do not want to admit it.

Table 4
Score

For the subjects:	**Average score**
- on the navigation bridge	5.175
- on the main deck	4.62
- people in the engine room	3.30

These people work twelve-hour shifts, although the law stipulates only 8h of work. For these reasons, adding that they have an erratic life in which alcohol is just one of the negative factors, immediate action should be taken to ensure that these people do not become ill in the shortest possible time

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