Survey procedures and class notation harmonization for an effective quantification of passenger comfort

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Abstract. In order to assess passenger comfort on board of cruise ships, Classification Societies recommend that specific aspects of ship design and layout should comply with a set of suitable criteria, aiming at passengers' well-being improvement during the journey. Rule requirements take into account several environmental aspects such as whole-body vibrations, noise, indoor climate and lighting. However, among Societies and requirements, there is little harmonization with respect to both the environmental aspects which are considered and the breakdown into several comfort classes. Furthermore, the Classification Society, allow for the assessment of the different disturbing factors, very data short acquisitions times. This reduces the possibility of understanding the time evolution of the disturbances and the averaging effect of longer acquisition on the transient and variable ships operation and activities. The lack of stationarity in the acquired signals may have deleterious effect on the comfort assessment and the ship cabin classification.

Keywords. Comfort assessment, class notation, ship vibration, passenger ships, Classification Societies.

Introduction

In order to adequately assess passenger comfort on board of cruise ships, Classification Societies recommend that specific aspects of ship design and layout should comply with a set of suitable criteria, with the aim of improving passenger well-being during the journey. Rule requirements take into account several ambient environmental aspects contributing to perceived comfort. All the Classification Societies assess the potential impact on passengers of whole-body vibrations and noise, while other environmental aspects, such as indoor climate and lighting, are not always taken into account. Table 1 shows the environmental variables considered by the following Classification Societies: *Registro Italiano Navale* (RINA), *Lloyd's Register* (LR), *Det Norske Veritas – Germanischer Lloyd* (DNV-GL), *American Bureau of Shipping* (ABS) and *Bureau Veritas* (BV). Besides the differentiation among disturbing factors, there is the distinct breakdown of the cabin classes, resulting in potential Rule-depending class notation.
Since whole-body vibration (WBV) influence on passenger comfort is always considered and the lack of harmonization is especially evident, in the rest of the paper only vibrational aspects are taken into consideration, noticing that similar conclusions apply to the

other ambient aspects. The paper focuses on passenger cabins only; the crew accommodations follow different rules and limits and they are not considered in this work.

Table 1. Ambient environmental aspects considered by Classification Societies.

Classification Society	Whole-Body Vibration	Noise	Indoor Climate	Lighting
RINA	✓	✓	✓	
LR	✓	✓		
DNV-GL	✓	✓	✓	
ABS	✓	✓	✓	✓
BV	✓	✓		

1. ISO Guidelines and Rule Requirements

Both International Organization for Standardization (ISO) and Classification Societies require vibrations to be measured in ship longitudinal, transverse and vertical directions. Afterwards, Fourier analysis is to be performed on the recorded data and the perceived comfort is evaluated by means of quantities calculated from frequency spectra.

1.1. ISO Guidelines

Once desired quantities are derived from measured spectra, ISO provides guidelines for the habitability of passenger cabins by setting values above which adverse comments are probable and values below which adverse comments are not probable [1][2]. The zone between upper and lower values reflects the shipboard vibration environment commonly experienced and accepted. Table 2 contains the ISO limits for unweighted 0-peak value of harmonic components of structural acceleration (a_{peak}) and velocity (v_{peak}) in the frequency ranges from 1 to 5 Hz and from 5 to 100 Hz, respectively, for the overall frequency weighted RMS (root mean square) value of acceleration ($a_{RMS,w}$) and velocity ($v_{RMS,w}$) within the range of 1–80 Hz. The frequency-weighting curve W_m is defined in ISO 2631-2: 2003 and it is to be used irrespective of the measurement direction either for RMS vibration velocity or acceleration [3][4]. The more recent ISO 20283-5: 2016 introduces just one maximum value, instead of pairs of lower and upper values, representing the range of commonly accepted vibration magnitude [5]. Since it has not yet been implemented by Classification Societies, it has not been considered in this work.

Table 2. ISO guidelines for the habitability of passenger cabins.

Frequency Range	a_{peak} 1÷5 Hz	v_{peak} 5÷100 Hz	$a_{RMS,w}$ 1÷80 Hz	$v_{RMS,w}$ 1÷80 Hz
Upper Value	285 mm/s^2	9 mm/s	143 mm/s^2	4 mm/s
Lower Value	126 mm/s^2	4 mm/s	71.5 mm/s^2	2 mm/s

1.2. Rule Requirements

In order to assess ship comfort class, Classification Societies adopt various strategies:

- RINA [6] provides a breakdown into comfort classes based on peak values of acceleration and velocity harmonic components, a_{peak} and v_{peak}, respectively;
- LR [7] and DNV-GL [8] uses the RMS vibration level, $v_{RMS,w}$;
- ABS [9] classifies passenger ships by means of the multi-axis acceleration value, a_w, and the motion sickness dose value, $MSDV_z$;
- BV [10] allows to choose between two different methods, considering either peak values of harmonic components of acceleration and velocity, a_{peak} and v_{peak}, or vibration level, $v_{RMS,w}$.

Except for the multi-axis acceleration value (ABS), a worst-case approach is adopted, i.e. only the highest level of vibration occurring along one axis of the reference system is considered. Table 3 illustrates the main differences among considered Classification Societies.

Table 3. Main differences among considered Classification Societies. The superscript PK indicates the BV class notation obtained by means of peak values of harmonic components of acceleration and velocity.

Classification Society	Spectral Quantity	Frequency Range	Number of Comfort Classes	Superior/Standard Cabin Distinction
RINA	a_{peak} v_{peak}	1–5 Hz 5–100 Hz	3	Y
LR	$v_{RMS,w}$	1–80 Hz	3	Y
DNV-GL	$v_{RMS,w}$	1–80 Hz	3	Y
ABS	a_w $MSDV_z$	1–80 Hz 0.1–0.5 Hz	2	N
BV	$v_{RMS,w}$	1–80 Hz	3	Y
BV^{PK}	a_{peak} v_{peak}	1–5 Hz 5–100 Hz	3	Y

Multi-axis acceleration value is calculated from the root-sums-of-squares of the weighted RMS acceleration values obtained for each of the three axis of the ship reference system within the range of 1–80 Hz. The vertical motion sickness dose value ($MSDV_z$) is a cumulative measure of exposure to low frequency oscillations, that may be used to estimate the probable incidence of motion sickness. It is derived from the weighted vertical acceleration in the frequency range from 0.1 to 0.5 Hz. Table 4 and Figure 1 illustrate the breakdown into different comfort classes for all Classification Societies, except for ABS. As seen in Table 5, in order to obtain a notation of COMF, ABS sets out a threshold for multi-axis acceleration value. It is possible to obtain a notation of $COMF^+$, if the vessel complies with more stringent criteria, including motion sickness. It is worth noticing how the numerical values differ for analogous cabin classes.

Table 4. Breakdown into comfort classes according to different Classification Societies.

Classification Society	Comfort Class	Superior Cabin			Standard Cabin		
		a_{peak} [mm/s^2]	v_{peak} [mm/s]	$v_{RMS,w}$ [mm/s]	a_{peak} [mm/s^2]	v_{peak} [mm/s]	$v_{RMS,w}$ [mm/s]
RINA[*]	Upper	31.4	1.0		47.1	1.5	
	Mid	78.5	2.5		94.3	3.0	
	Lower	125.6	4.0		141.4	4.5	
LR	Upper			1.5			1.8
	Mid			1.8			2.1
	Lower			2.1			2.4
DNV-GL	Upper			1.5[**]			1.5
	Mid			1.5			2.0
	Lower			2.0			3.0
BV	Upper			1.7			2.0
	Mid			2.0			2.5
	Lower			2.2			3.0
BV^{PK}	Upper	48	1.5		64	2.0	
	Mid	64	2.0		80	2.5	
	Lower	80	2.5		96	3.0	

[*] Vibration limit levels at continuous service rate (CSR) condition: CSR is defined as 80% of maximum continuous rate (MCR).
[**] No single frequency component within the frequency range 6.3 Hz to 12.5 Hz shall exceed 1 mm/s RMS (weighted).

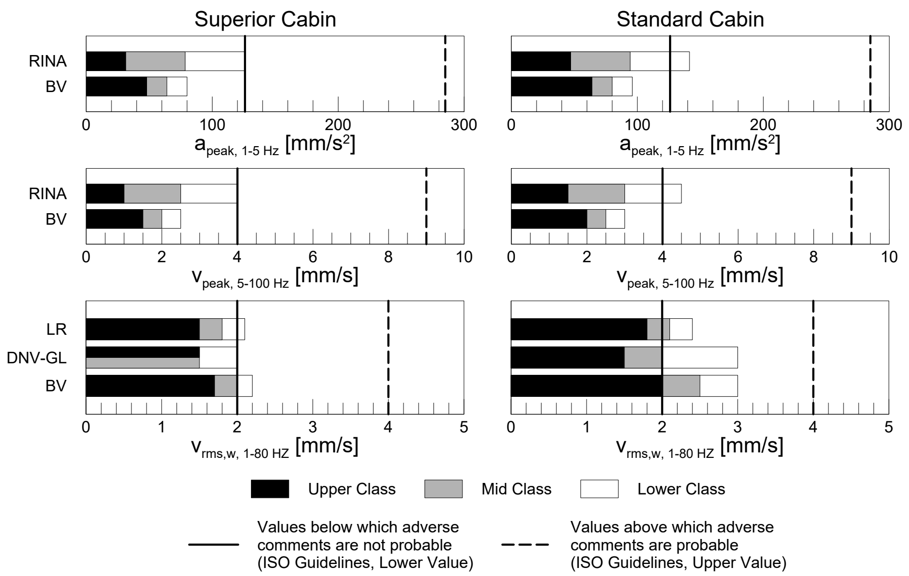

Figure 1. Breakdown into comfort classes according to different Classification Societies.

Table 5. ABS requirements for COMF and COMF$^+$ notation class (with respect to WBV).

Comfort Class	Maximum RMS Level	
	a_w [mm/s^2]	$MSDV_z$ [m/s$^{1.5}$]
COMF	71.5	
COMF$^+$	71.5	30

2. Measurement Procedure

According to considered Classification Societies, the measurement duration shall be at least 60 seconds. If there is no significant evidence of modulation in vibration levels, RINA allows measurements of 30 seconds. Requirements define also output spectra properties: a frequency resolution of at least 0.2 Hz is required and resulting linear or exponential averaged spectra are to be obtained through appropriate time signal windowing.

3. Analysis on synthetic data

Figure 2 illustrates two examples of synthetic data reproducing plausible shipboard vibration environment. The three signals are supposed to be accelerations recorded along the ship reference system axes x, y, z.

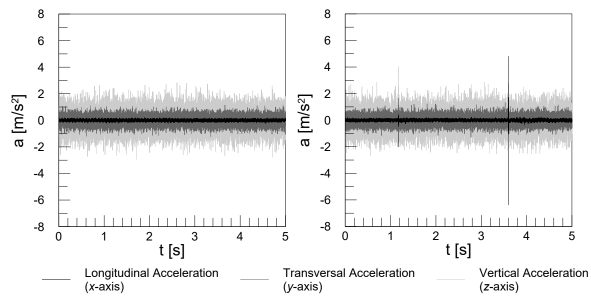

Figure 2. Examples of synthetic data, including transient phenomena.

3.1. The Effect of Signal Length

Classification Societies usually recommend that spectra shall be evaluated for a signal length T of 60 s and they require a frequency resolution of at least 0.2 Hz. The analysis has been performed using Hanning window on subintervals of 5 s with an overlap of 75%. In order to quantify the effect of signal length, main signals have been divided into intervals of length T. If necessary, an appropriate overlap was set, in order to obtain at least ten intervals. T has been assumed to be 30 s, 60 s, 120 s, 180 s, 300 s, 480 s and 600 s, ranging from the minimum accepted acquisition time of 30 s to ten times the suggested acquisition time of 60 s. For each interval, a_{peak}, v_{peak}, $v_{RMS,w}$ and a_w have been calculated. Table 6 contains the highest (Worst Case, WC) and the lowest (Best Case, BC) obtained results.

It is worth noticing that, if T increases, the difference between higher and lower results decreased as expected and obtained results are less affected by transient phenomena, as seen in Figure 3. It is worth noticing how higher values decrease more than lower values increase. This may affect the class notation: for instance, resulting comfort classes using a signal length of 60 s and 180 s are reported in Table 7 for a superior cabin. With shorter signal length, the class notation is affected by the selected interval. Moreover, obtained class notation changes when considering different Classification Societies, especially when calculated values are close to class boundaries.

Table 6. Obtained results with varying signal length T.

T [s]		a_{peak} [mm/s^2]	v_{peak} [mm/s]	$v_{RMS,w}$ [mm/s]	a_w [mm/s^2]
30	WC	14.16	0.39	1.75	40.43
	BC	10.67	0.28	1.40	36.83
60	WC	12.17	0.36	1.69	38.68
	BC	10.49	0.28	1.46	37.04
120	WC	11.50	0.36	1.64	38.08
	BC	10.58	0.29	1.51	37.32
180	WC	11.20	0.34	1.62	37.83
	BC	10.43	0.28	1.53	37.24
300	WC	10.91	0.31	1.58	37.60
	BC	10.34	0.29	1.53	37.51
480	WC	10.53	0.30	1.57	37.54
	BC	10.38	0.29	1.56	37.40
600	WC	10.38	0.29	1.56	37.40
	BC	10.38	0.29	1.56	37.40

Table 7. Resulting comfort classes for $T = 60$ s and $T = 180$ s for a superior cabin.

T [s]		RINA	LR	DNV-GL	ABS[*]	BV	BV^{PK}
60	WC	Upper	Mid	Lower	COMF	Upper	Upper
	BC	Upper	Upper	Upper	COMF	Upper	Upper
180	WC	Upper	Mid	Lower	COMF	Upper	Upper
	BC	Upper	Mid	Lower	COMF	Upper	Upper

[*] In order to obtain the class notation of COMF$^+$, $MSDV_z$ shall be calculated in addition to a_w.

3.2. *Frequency Spectra of Vibration Data*

In order to quantify the effect of the frequency-weighting curve and understand in which way energy is distributed among frequency bands, acceleration and velocity spectra are reported in Figure 4. Reference is made only to vertical vibrations due to their greater

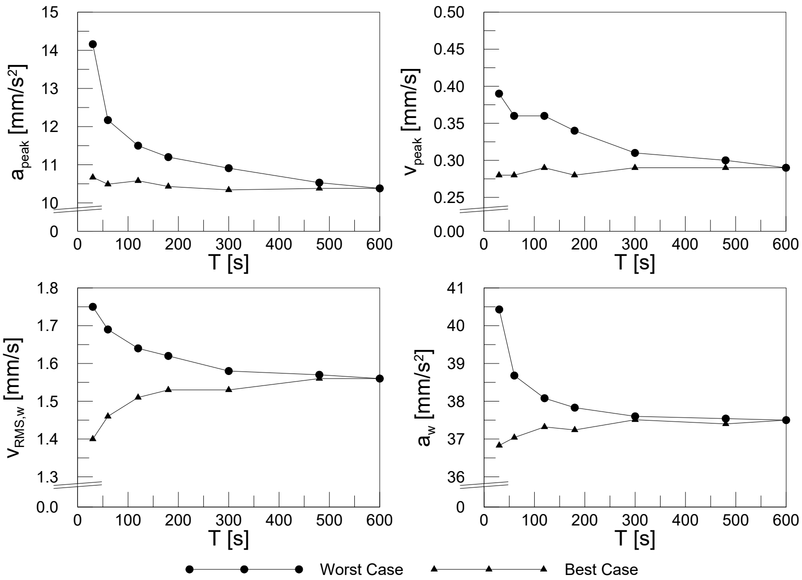

Figure 3. Obtained results with varying signal length T.

intensity. The effect of frequency filter is greater at higher frequencies, where harmonic components are significantly reduced. It has a considerable impact on acceleration spectrum, considering that spectral energy is almost equally distributed among entire considered frequency range 1–80 Hz. Instead, velocity spectral energy is concentrated at lower frequencies and, therefore, the effect of frequency-weighting curve is less important. Figure 5 illustrates acceleration and velocity spectra when considering different signal lengths. Lower frequency spectral components differ more than higher frequencies ones with varying signal length T and, therefore, the difference in calculated RMS values is mainly due to different amplitude of lower frequency harmonic components.

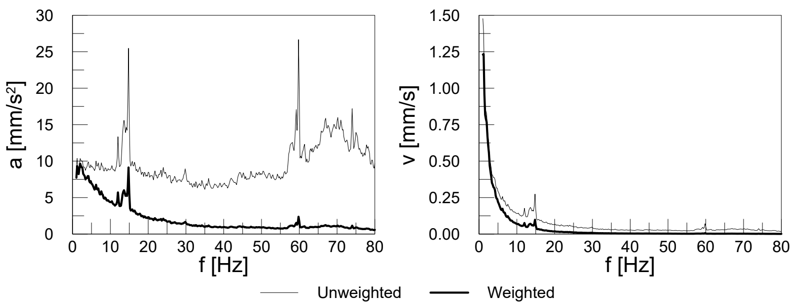

Figure 4. Unweighted and weighted acceleration and velocity spectra of vertical vibrations for T = 600 s.

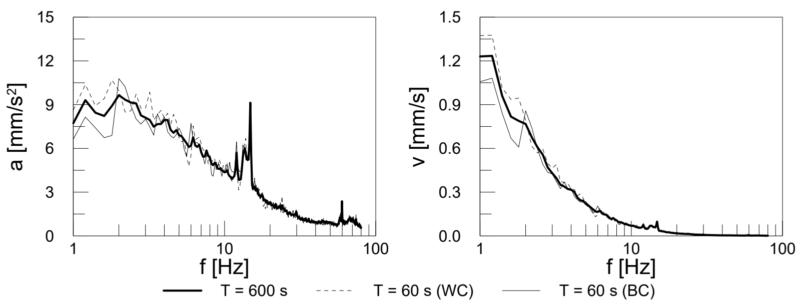

Figure 5. Weighted acceleration and velocity spectra of vertical vibrations for T = 600 s and T = 60 s.

Conclusions

The lack of harmonization among Classification Societies, with respect to either considered environmental aspects or the breakdown into comfort classes, leads to Rule-depending class notation. Each Classification Society establishes comfort class by means of different values calculated from recorded signals in different ways. As an example, comfort with regard to vibrations may be evaluated by means of harmonic components of acceleration and velocity, velocity RMS value or acceleration RMS value, alternatively. Moreover, even though longitudinal, transverse and vertical vibrations are recorded, a worst-case approach is adopted in the majority of cases, neglecting the effect of vibrations occurring along other axes. Signal acquisition length influences calculated values and, as such, comfort classification. It has been shown how increasing the sampling duration reduces the results variance while increasing the stability of notation class assessment. Particular attention is to be paid to data filtering as function of the requested parameters. Acceleration-based and velocity-based class assessments are differently influenced by the frequency filtering step.

The authors strongly suggest to review and harmonize class assessment quantities and criteria.

References

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