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PORT AND MARITIME PLANT NOISE: CHARACTERIZATION AND NORMALIZATION

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ABSTRACT
By means of a statistical processing of noise measurement carried out at Genova and Livorno ports and noise data collected from many other Italian ports, a typical port noise spectrum has been found. Such a spectrum has been converted into a distance insensitive one by normalization procedure (Normalised Port Noise Spectrum - NPNS). Noise measurement data show that each NPNS 1/3 octave band level differs less than 3dB from any port 1/3 octave band normalised noise spectrum level. NPNS has also been A-weighted. NPNS may be used for optimization of acoustical insulation systems against port noise. It may also be proposed to introduce an adaptation term (Cport) to evaluate sound insulation of buildings exposed to port noise.

1 - INTRODUCTION

Noise spectra measurements have been carried out in 27 sites located at Genova and Livorno ports in Italy. By means of a normalization procedure, noise data have been converted into a single typical port noise spectrum (Normalized Port Noise Spectrum − NPNS). NPNS is a A weighted distance insensitive spectrum and has been proven to be close to each port noise spectrum. NPNS may be used to evaluate 1/3 octave band noise spectrum due to a port source when only A weighted noise level is known. An adaptation term C_{port} has been proposed to evaluate sound insulation of buildings exposed to port noise. An experimental verification shows that a building wall sound reduction index R_i may be properly evaluated by means of the proposed C_{port}.

2 - NOISE DATA ANALYSIS

At Genova and Livorno ports a noise measurement investigation has been carried out to evaluate the characteristics of port noise source [1]. Noise spectra have been measured in 25 measurement sites (MS) located inside the Livorno port area and in 2 MS inside the Genova port area [1]. Each MS has been associated to a single port noise source, thus MS-source distance has been chosen in order to minimize the influence of other noise sources. A "0 dBA" normalized noise spectra may be found processing each noise spectra by the following 2 steps:
1) each noise spectra is A weighted; 2) each A weighted noise spectra must satisfy the following constraint:

$$10log\left(\sum_{i=1}^{n}10^{(K+L_i)/10}\right)=0 \quad (1)$$

Eq. (1) yields:

$$K=L_{eqA} \quad (2)$$

$$L_{ni}=L_i-L_{eqA} \quad (3)$$

Each normalized spectrum is MS-source distance insensitive. The 27 normalized noise spectra are shown in Tab. 1. The 25 Livorno port normalized spectra and the 2 Genova port normalized spectra have been separately averaged (energetic averaging); the two resulting averaged spectra are sketched in Fig. 1 and are numerically reported in Tab. 1. Although the two averaged spectra are derived by measurements carried out at the two different ports, the maximum difference between such spectra is 1,5 dBA which occurs at 200 Hz; thus a unique typical port noise spectrum (A weighted Normalized Noise Port Spectrum − NPNS), calculated as the average of the entire set of 27 spectra, may be used for port noise characterization. NPNS is sketched in Fig. 1. Tab. 1 also reports the square root of variance (SRV) calculated for each 1/3 octave band on the entire set of the 27 normalized noise spectra; the maximum value of SRV is 2,32 dBA which occurs at 1000 Hz; such a result demonstrates that NPNS is close to each normalized noise spectrum. NPNS may be used to estimate the A weighted noise spectrum distribution produced by port noise when only global A weighted noise level is known:

$$L_i = L_{eqA} + L^*_{n,i} \tag{4}$$

MS		L_{ni} [dBA]								
	Freq	100	125	160	200	250	315	400	500	630
Livorno	1	-20,3	-15,2	-13,9	-13,7	-15,4	-14,1	-12,1	-11,2	-8,7
	2	-18,5	-14,2	-12,8	-12,6	-14,6	-13,2	-11,6	-11,9	-9,9
	3	-35,2	-33	-33,3	-25,6	-21,5	-18,7	-13,2	-9,7	-8,1
	4	-19,1	-19,5	-16,8	-16,2	-15,4	-12,3	-12,5	-10,6	-10,5
	5	-22,2	-23,9	-19,8	-20,6	-18,4	-15,2	-12,7	-10,5	-8,8
	6	-21,2	-16,9	-17,8	-15,7	-16,1	-14,5	-14	-11,7	-10,7
	7	-19,9	-25,6	-18,6	-12,2	-13,9	-14,4	-12,9	-11	-8,3
	8	-24,4	-24	-20,6	-15,1	-14,8	-14,3	-12,6	-11,7	-9,5
	9	-21,7	-24,2	-18,2	-12,3	-13,8	-14,1	-12,9	-10,8	-8,4
	10	-22,5	-25,5	-20	-13,9	-15	-15,2	-13,1	-11,4	-8,8
	11	-26	-22,2	-25,5	-18,1	-12,3	-12,4	-10,5	-10,6	-10,1
	12	-27,7	-22,4	-19,7	-20,1	-14	-11,5	-11	-10	-10
	13	-25	-25,2	-16,7	-21,4	-16,5	-12,6	-12,2	-9,4	-10,5
	14	-27,5	-22,5	-18,1	-19,5	-13,7	-12,6	-12,3	-10,4	-10,4
	15	-22,4	-21,9	-23,3	-17,7	-14,6	-11,8	-12,6	-10,5	-10,9
	16	-19,7	-23,9	-22,2	-16,3	-13	-12,7	-12,9	-11,5	-10,6
	17	-19,2	-19,7	-22,9	-16,4	-15,5	-12,1	-10,6	-9,4	-11,2
	18	-26,1	-18,1	-21,8	-18,2	-16	-16,6	-14,1	-11,8	-10,2
	19	-25,3	-16,8	-18,8	-18,7	-17,8	-15,5	-11,9	-10,6	-9,9
	20	-21,4	-18,1	-18,8	-18,2	-16,3	-15,8	-13,8	-11,1	-10
	21	-15,7	-16,2	-9,8	-13,8	-14,4	-14,5	-13,6	-13,6	-10,3
	22	-12,7	-13,6	-15,5	-13,3	-13,3	-13	-11	-11,3	-10,5
	23	-24,2	-16,6	-15,6	-14,3	-12,3	-8,2	-11,3	-11,1	-9,5
	24	-17,2	-17	-12,4	-10,2	-11,9	-11,6	-11	-8,9	-10,3
	25	-21,4	-22,6	-20	-15,7	-8,3	-14,7	-14,5	-11,7	-9,8

MS		L_{ni} [dBA]								
	Freq	800	1000	1250	1600	2000	2500	3150	4000	5000
Livorno	1	-8,9	-9,4	-10,4	-11,9	-13,1	-14,9	-16,2	-16,8	-19,8
	2	-9,1	-9,3	-10,4	-12,1	-13,5	-15,1	-16,3	-17	-19,3
	3	-7,5	-6,5	-11	-12,9	-13,7	-13,9	-15,5	-18	-22,2
	4	-10,3	-9,7	-9,8	-10,6	-11,4	-12,7	-13,6	-15,2	-17,5
	5	-8,9	-7,6	-10,6	-11,8	-12	-12,7	-14	-15,6	-19,6
	6	-9,1	-8,4	-9,4	-10,8	-11,3	-13,1	-13,7	-15,7	-18,2
	7	-7,5	-9,7	-9,9	-11,3	-14	-15,8	-17,8	-20,5	-24
	8	-8,4	-9,1	-9,6	-9,9	-11,7	-14,3	-15,6	-18,2	-16,3
	9	-7,7	-9,7	-10,1	-11,4	-13,7	-15,7	-17,4	-19,2	-20,9
	10	-8	-8,6	-10,1	-10,5	-12,9	-14,7	-15,6	-17,4	-19,3
	11	-10,6	-9,9	-9,5	-10,7	-10,7	-12,9	-16	-16,7	-17,7
	12	-9,7	-10	-9,9	-10,7	-10,3	-13,5	-16,2	-17,5	-20,5
	13	-9,4	-9,9	-9,7	-9,2	-10,8	-13,2	-15,9	-18,3	-21,9
	14	-8,6	-8,7	-9,9	-9,8	-12,3	-14,2	-15,7	-17,8	-20,4
	15	-9,8	-8,5	-8,4	-10,6	-12,6	-13,2	-15,4	-16,8	-20
	16	-9,7	-8,6	-9,5	-10,5	-12	-13,9	-13,2	-14,9	-21,3
	17	-10,3	-9,5	-10,3	-11	-12,5	-13,4	-11,9	-15,9	-20
	18	-8,8	-8,4	-8,6	-10,1	-11,1	-12,9	-14,6	-16	-18,4
	19	-9,8	-8,7	-8,6	-10,6	-11,6	-13,1	-15,1	-16,6	-18,8
	20	-8,8	-9	-9,3	-10,1	-11,4	-12,6	-13,7	-16,4	-19,2
	21	-7,7	-8,4	-11,2	-12,2	-14,2	-15,9	-18,1	-19,7	-21,8
	22	-11	-11	-11,4	-12,4	-12	-14	-14,5	-14,9	-15,4
	23	-10,3	-10,4	-10,9	-12,6	-13,9	-14,9	-16,8	-18,9	-20,9
	24	-11,5	-12,1	-11,5	-12,7	-13,4	-15,1	-17,1	-19,5	-21,6
	25	-9,5	-10,1	-10,7	-9,9	-11,5	-14,3	-15,8	-16,6	-20,7

MS		L_{ni} [dBA]								
	Freq	100	125	160	200	250	315	400	500	630
Genova	26	-21,1	-18,7	-15,7	-16,8	-14,6	-14,7	-12,8	-10,8	-9,4
	27	-18,1	-17,1	-17,8	-16,6	-15,2	-14,3	-12	-11,3	-9,7
MS		L_{ni} [dBA]								
	Freq	800	1000	1250	1600	2000	2500	3150	4000	5000
Genova	26	-10,2	-10,5	-10	-9,7	-10	-12,5	-14,9	-17,1	-18,8
	27	-9,3	-9,1	-9,3	-10,1	-12,1	-14,2	-16,3	-15,8	-20,8

MS	L_{ni} [dBA]								
	100	125	160	200	250	315	400	500	630
Genova averaged [dBA]	-19,4	-17,8	-16,6	-16,7	-14,9	-14,5	-12,4	-11	-9,5
Livorno averaged [dBA]	-20,3	-18,9	-16,9	-15,2	-14,1	-13,2	-12,3	-10,8	-9,8
—Genova-Livorno— [dBA]	0,9	1,1	0,3	1,5	0,8	1,3	0,1	0,2	0,3
NPNS [dBA]	-19,8	-18,3	-16,7	-15,9	-14,5	-13,8	-12,3	-10,9	-9,6
SRV [dBA]	1,61	2,05	1,87	1,71	2,01	1,93	1,59	2,03	1,87
MS	L_{ni} [dBA]								
	800	1000	1250	1600	2000	2500	3150	4000	5000
Genova averaged [dBA]	-9,7	-9,7	-9,6	-9,9	-10,9	-13,3	-15,5	-16,4	-19,7
Livorno averaged [dBA]	-9,1	-9,1	-10	-10,9	-12,2	-13,9	-15,2	-17	-19,4
—Genova-Livorno— [dBA]	0,6	0,6	0,4	1	1,3	0,6	0,3	0,6	0,3
NPNS [dBA]	-9,4	-9,4	-9,8	-10,4	-11,5	-13,6	-15,3	-16,7	-19,5
SRV [dBA]	2,1	2,32	2,04	2,18	2,23	2,21	2,33	2,16	2,19

Table 1: A weighted normalized spectra of the 27 MS, averaged spectra, NPNS and comparison.

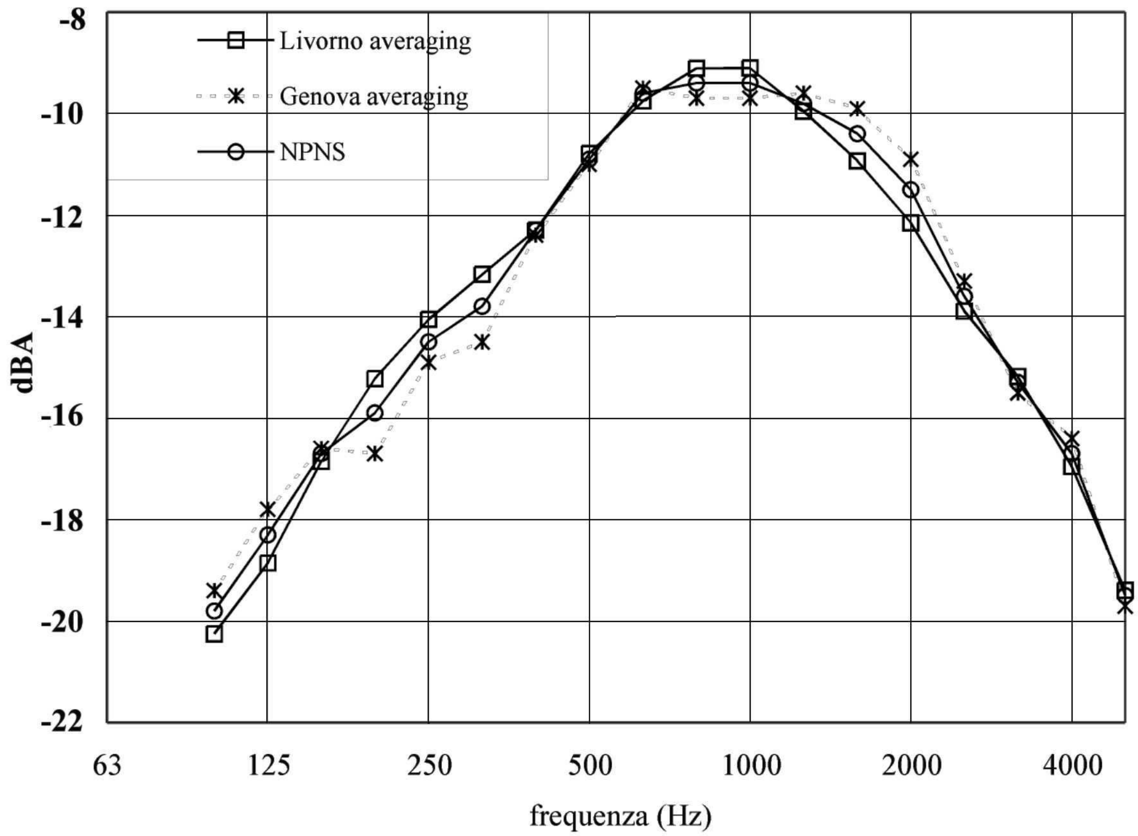

Figure 1: Genova and Livorno average spectra and NPNS.

3 - ADAPTATION TERM

ISO 717 introduces a method to calculate adaptation terms in order to find single number sound reduction index R_w of a building element when it is exposed to a particular noise spectrum; i.e. C_{tr} is the adaptation term for traffic noise [2]. According to ISO 717 method, an adaptation term for port noise C_{port} is proposed which may be calculated by the following equations:

$$C_{port} = R_{w,port} - R_w \tag{5}$$

where:

$$R_{w,port} = -10 log \sum_{i=1}^{n} 10^{(L_{ni}-R_i)/10} \tag{6}$$

4 - EXPERIMENTAL INVESTIGATION

A windowed building facade (WBF) sound reduction index has been measured at UNIPG Acoustic Laboratory test rooms [3] on two different cases: A) WBF exposed to white noise; B) WBF exposed to port noise. The shape and the volume of the UNIPG Laboratory test room satisfy the constraints of ISO 140/1 [1]. The WBF divides the emitting and the receiving room. Test room map and WBF sections are sketched in Fig. 2. Measurement instrumentation is a 2-channel real time FFT sound analyzer equipped with a custom software for R_w calculation [3]. The sound source is a Twelve Loudspeakers Omnidirectional Source (TLOS) home-made at the UNIPG Lab [3]. WBF is a sandwich structure made up by two single brick walls, the window is High Sound Insulation window equipped with an aerator [3]. Case A measurements have been performed according to ISO 140/3 procedure. WBF sound reduction index, single number sound reduction index and adaptation terms for traffic and port noise are reported in Tab. 2. C_{tr} and C_{port} have been calculated by means of equations (5) and (6) using respectively normalized traffic noise [2] and NPNS. Case B measurements have been performed generating, by means of TLOS, into the emitting room a noise spectrum shaped as like as NPNS. Such noise spectrum has been attained by properly equalizing white noise.

Freq [Hz]	100	125	160	200	250	315	400	500
R_i	14	18	17	19	24	24	25	27

Freq [Hz]	630	800	1000	1250	1600	2000	2500	3150
R_i	25	24	27	30	32	32	34	39

Table 2: Case A: WBW sound reduction index, C_{tr} and C_{port} (R_w =29, C_{tr}=-3.9, C_{port}=-4.2).

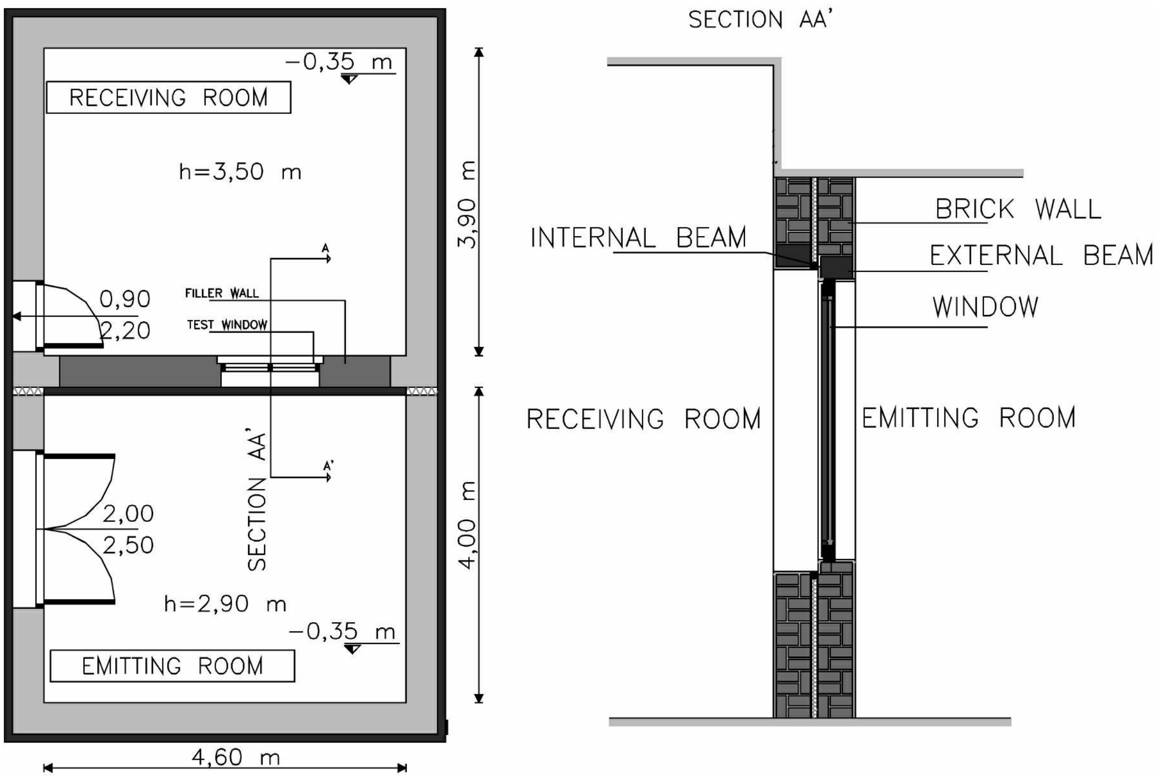

Figure 2: UNIPG acoustic laboratory test rooms map and WBW section.

In this case the global sound reduction index has been evaluated applying the following equation:

$$R = L_1 - L_2 + 10log\frac{S}{A} \tag{7}$$

L_1 = 98,8 dBA, L_2 = 69,5 dBA, A = 5,62 m^2. L_1 and L_2 are space averaged A weighted global noise levels of emitting and receiving room. The emitting and the receiving room measurements points are the same as case A which have been chosen according to ISO 140-3 [2]. It may be observed that equation (7) has been applied to global noise levels and not to each single 1/3 octave band; thus sound reduction index defined by (7) may be compared with single number sound reduction index found by case A measurements [4].

5 - RESULTS REMARKS

It must be observed that a comparison between case A sound reduction index and 1/3 octave band sound reduction index attained with port noise would not be possible, in fact both quantities would be the same for each 1/3 octave band because of linearity properties of WBF insulation performance. The only quantities which may be used to compare case A and case B measurements are R defined by (7) and $R_{w,port}$ defined by (6); in fact equation (6) represents the theoretical formulation of case B global sound reduction index R. Equation (7) gives R = 24,6 dBA which is sound reduction index evaluated by global noise levels when WBF is exposed to port noise. Case A measurement single number sound reduction index and adaptation term for port noise are respectively R_w = 29dBA (see Tab. 2) and C_{port} = -4.2 dBA; thus the $R_{w,port}$ is 24,8 dBA. The difference between case B R and case A R_w is 0,2 dBA; such a result may be considered an experimental validation of the proposed C_{port}.

6 - CONCLUSIONS

By means of a noise measurement campaign carried out in two Italian ports a Normalized Port Noise Spectrum (NPNS) was found. NPNS may be used for two purposes: **1)** the evaluation of 1/3 octave band noise spectra produced by a port source, when only global A weighted noise level is known; **2)** the evaluation of an adaptation term, C_{port}, to estimate the building facades insulation against port outdoor airborne noise. An experimental investigation demonstrates that C_{port}, calculated by means of NPNS is the effective correction which is to be applied to a facade sound reduction index when it is exposed to port noise.

7 - SYMBOLS

$\mathbf{K}$ = normalisation constant [dBA]; $\mathbf{L}_{\mathrm{eqA}}$ = A weighted global noise level [dBA]; $\mathbf{L}_{\mathrm{i}}$ = A weighted i-th band noise level [dBA]; $\mathbf{L}_{\mathrm{ni}}$ = normalized A weighted i-th band noise level [dBA]; $\mathbf{L*}_{\mathrm{ni}}$ = i-th band normalized port noise [dBA]; $\mathbf{C}_{\mathrm{traf}}$ = adaptation term for traffic noise [dBA]; $\mathbf{C}_{\mathrm{port}}$ = adaptation term for port noise [dBA]; $\mathbf{R}_{\mathrm{i}}$ = i-th band sound reduction index [dBA]; $\mathbf{R}$ = global sound reduction index [dBA]; $\mathbf{R}_{\mathrm{w}}$ = single number sound reduction index [dBA]; $\mathbf{R}_{\mathrm{w,port}}$ = global sound reduction index for port noise [dBA]; $\mathbf{L}_1$ = emitting room A weighted global noise level [dBA]; $\mathbf{L}_2$ = receiving room A weighted global noise level [dBA].

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