

# Port and maritime plant noise: characterisation and normalisation.

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## INTRODUCTION

Noise spectra measurements have been carried out in 27 sites located at Genova and Livorno ports in Italy. By means of a normalisation 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  $C_{port}$ .

## 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:

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

eq. (1) yields:

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

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

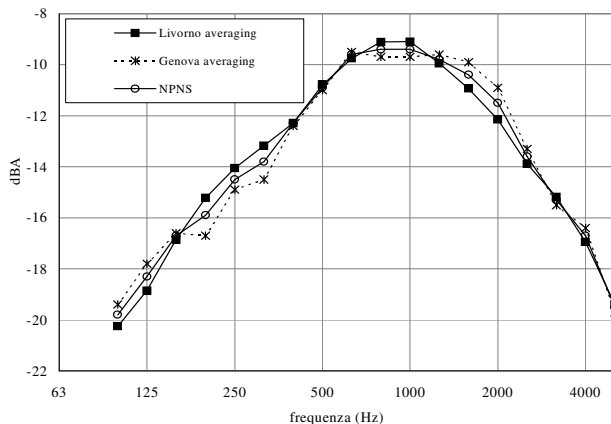
Each normalized spectrum is MS-source distance insensitive. The 27 normalized noise spectra are shown in Tab.1. The 25 Livorno port normalized spectra and the 2 Genova port normalized spectra have been separately averaged (energetic averaging); the two resulting averaged spectra are sketched in Fig.1 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:

$$L_i = L_{eqA} + L_{n,i}^* \quad (4)$$

**Tab. 1:** A weighted normalized noise spectra and normalized noise spectra of the 27 MS. Averaged single port spectra, NPNS and statistical comparison.

MS	$L_{ni}$ [dBA]																		
	Freq	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Livorno	1	-20,3	-15,2	-13,9	-13,7	-15,4	-14,1	-12,1	-11,2	-8,7	-8,9	-9,4	-10,4	-11,9	-13,1	-14,9	-16,2	-16,8	-19,8
	2	-18,5	-14,2	-12,8	-12,6	-14,6	-13,2	-11,6	-11,9	-9,9	-9,1	-9,3	-10,4	-12,1	-13,5	-15,1	-16,3	-17	-19,3
	3	-35,2	-33	-33,3	-25,6	-21,5	-18,7	-13,2	-9,7	-8,1	-7,5	-6,5	-11	-12,9	-13,7	-13,9	-15,5	-18	-22,2
	4	-19,1	-19,5	-16,8	-16,2	-15,4	-12,3	-12,5	-10,6	-10,5	-10,3	-9,7	-9,8	-10,6	-11,4	-12,7	-13,6	-15,2	-17,5
	5	-22,2	-23,9	-19,8	-20,6	-18,4	-15,2	-12,7	-10,5	-8,8	-8,9	-7,6	-10,6	-11,8	-12	-12,7	-14	-15,6	-19,6
	6	-21,2	-16,9	-17,8	-15,7	-16,1	-14,5	-14	-11,7	-10,7	-9,1	-8,4	-9,4	-10,8	-11,3	-14	-15,8	-17,8	-20,5
	7	-19,9	-25,6	-18,6	-12,2	-13,9	-14,4	-12,9	-11	-8,3	-7,5	-9,7	-9,9	-11,3	-14	-15,8	-17,8	-20,5	-24
	8	-24,4	-24	-20,6	-15,1	-14,8	-14,3	-12,6	-11,7	-9,5	-8,4	-9,1	-9,6	-9,9	-11,7	-14,3	-15,6	-18,2	-16,3
	9	-21,7	-24,2	-18,2	-12,3	-13,8	-14,1	-12,9	-10,8	-8,4	-7,7	-9,7	-10,1	-11,4	-13,7	-15,7	-17,4	-19,2	-20,9
	10	-22,5	-25,5	-20	-13,9	-15	-15,2	-13,1	-11,4	-8,8	-8	-8,6	-10,1	-10,5	-12,9	-14,7	-15,6	-17,4	-19,3
	11	-26	-22,2	-25,5	-18,1	-12,3	-12,4	-10,5	-10,6	-10,1	-10,6	-9,9	-9,5	-10,7	-10,7	-12,9	-16	-16,7	-17,7
	12	-27,7	-22,4	-19,7	-20,1	-14	-11,5	-11	-10	-10	-9,7	-10	-9,9	-10,7	-10,3	-13,5	-16,2	-17,5	-20,5
	13	-25	-25,2	-16,7	-21,4	-16,5	-12,6	-12,2	-9,4	-10,5	-9,4	-9,9	-9,7	-9,2	-10,8	-13,2	-15,9	-18,3	-21,9
	14	-27,5	-22,5	-18,1	-19,5	-13,7	-12,6	-12,3	-10,4	-10,4	-8,6	-8,7	-9,9	-9,8	-12,3	-14,2	-15,7	-17,8	-20,4
	15	-22,4	-21,9	-23,3	-17,7	-14,6	-11,8	-12,6	-10,5	-10,9	-9,8	-8,5	-8,4	-10,6	-12,6	-13,2	-15,4	-16,8	-20
	16	-19,7	-23,9	-22,2	-16,3	-13	-12,7	-12,9	-11,5	-10,6	-9,7	-8,6	-9,5	-10,5	-12	-13,9	-13,2	-14,9	-21,3
	17	-19,2	-19,7	-22,9	-16,4	-15,5	-12,1	-10,6	-9,4	-11,2	-10,3	-9,5	-10,3	-11	-12,5	-13,4	-11,9	-15,9	-20
	18	-26,1	-18,1	-21,8	-18,2	-16	-16,6	-14,1	-11,8	-10,2	-8,8	-8,4	-8,6	-10,1	-11,1	-12,9	-14,6	-16	-18,4
	19	-25,3	-16,8	-18,8	-18,7	-17,8	-15,5	-11,9	-10,6	-9,9	-9,8	-8,7	-8,6	-10,6	-11,6	-13,1	-15,1	-16,6	-18,8
	20	-21,4	-18,1	-18,8	-18,2	-16,3	-15,8	-13,8	-11,1	-10	-8,8	-9	-9,3	-10,1	-11,4	-12,6	-13,7	-16,4	-19,2
	21	-15,7	-16,2	-9,8	-13,8	-14,4	-14,5	-13,6	-13,6	-10,3	-7,7	-8,4	-11,2	-12,2	-14,2	-15,9	-18,1	-19,7	-21,8
	22	-12,7	-13,6	-15,5	-13,3	-13,3	-13	-11	-11,3	-10,5	-11	-11	-11,4	-12,4	-12	-14	-14,5	-14,9	-15,4
	23	-24,2	-16,6	-15,6	-14,3	-12,3	-8,2	-11,3	-11,1	-9,5	-10,3	-10,4	-10,9	-12,6	-13,9	-14,9	-16,8	-18,9	-20,9
	24	-17,2	-17	-12,4	-10,2	-11,9	-11,6	-11	-8,9	-10,3	-11,5	-12,1	-11,5	-12,7	-13,4	-15,1	-17,1	-19,5	-21,6
	25	-21,4	-22,6	-20	-15,7	-8,3	-14,7	-14,5	-11,7	-9,8	-9,5	-10,1	-10,7	-9,9	-11,5	-14,3	-15,8	-16,6	-20,7
26	-21,1	-18,7	-15,7	-16,8	-14,6	-14,7	-12,8	-10,8	-9,4	-10,2	-10,5	-10	-9,7	-10	-12,5	-14,9	-17,1	-18,8	
27	-18,1	-17,1	-17,8	-16,6	-15,2	-14,3	-12	-11,3	-9,7	-9,3	-9,1	-9,3	-10,1	-12,1	-14,2	-16,3	-15,8	-20,8	
Genova averaged [dBA]		-19,4	-17,8	-16,6	-16,7	-14,9	-14,5	-12,4	-11	-9,5	-9,7	-9,7	-9,6	-9,9	-10,9	-13,3	-15,5	-16,4	-19,7
Livorno averaged [dBA]		-20,3	-18,9	-16,9	-15,2	-14,1	-13,2	-12,3	-10,8	-9,8	-9,1	-9,1	-10	-10,9	-12,2	-13,9	-15,2	-17	-19,4
Genova- Livorno  [dBA]		0,9	1,1	0,3	1,5	0,8	1,3	0,1	0,2	0,3	0,6	0,6	0,4	1	1,3	0,6	0,3	0,6	0,3
NPNS [dBA]		-19,8	-18,3	-16,7	-15,9	-14,5	-13,8	-12,3	-10,9	-9,6	-9,4	-9,4	-9,8	-10,4	-11,5	-13,6	-15,3	-16,7	-19,5
SRV [dBA]		1,61	2,05	1,87	1,71	2,01	1,93	1,59	2,03	1,87	2,1	2,32	2,04	2,18	2,23	2,21	2,33	2,16	2,19



**Fig.1:** Genova and Livorno average spectra and NPNS

## 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:

$$C_{port} = R_{w,port} - R_w \quad (5)$$

where:

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

## EXPERIMENTAL INVESTIGATION

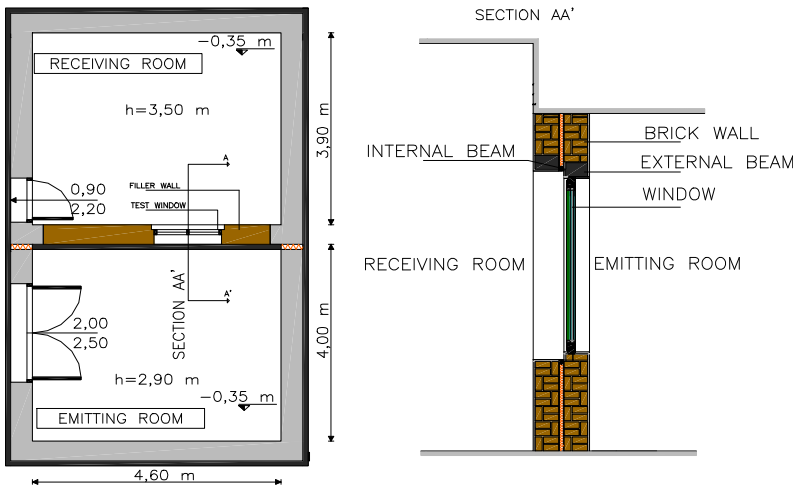
A windowed building facade (WBF) sound reduction index has been measured at UNIPG Acoustic Laboratory test rooms [3] on two different cases:

- 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

**Tab.2:** Case A WBW sound reduction index,  $C_{tr}$  and  $C_{port}$ .



**Fig.2:** UNIPG Acoustic Laboratory test rooms map and WBW section.

Freq. [Hz]	$R_i$ [dB]
100	14
125	18
160	17
200	19
250	24
315	24
400	25
500	27
630	25
800	24
1000	27
1250	30
1600	32
2000	32
2500	34
3150	39
$R_w = 29$	
$C_{tr} = -3.9$	
$C_{port} = -4.2$	

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

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

$L_1 = 98,8$  dBA,  $L_2 = 69,5$  dBA,  $A = 5,62$  m<sup>2</sup>.  $L_1$  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].

## 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  $R_w=29$ dBA (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  $C_{port}$ .

## 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.

## SYMBOLS

$K$  = normalisation constant [dBA];  
 $L_{eqA}$  = A weighted global noise level [dBA];  
 $L_i$  = A weighted i-th band noise level [dBA];  
 $L_{ni}$  = normalized A weighted i-th band noise level [dBA];  
 $L_{ni}^*$  = i-th band normalized port noise [dBA]  
 $C_{traf}$  = adaptation term for traffic noise [dBA];  
 $C_{port}$  = adaptation term for port noise [dBA];  
 $R_i$  = i-th band sound reduction index [dBA];  
 $R$  = global sound reduction index [dBA];  
 $R_w$  = single number sound reduction index [dBA];  
 $R_{w,port}$  = global sound reduction index for port noise [dBA];  
 $L_1$  = emitting room A weighted global noise level [dBA];  
 $L_2$  = receiving room A weighted global noise level [dBA].

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