



**Acoustics'08
Paris**
June 29-July 4, 2008

www.acoustics08-paris.org

Considerations about the acoustical properties of Teatro Nuovo in Spoleto after the restoration works

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In 2003 the municipality of Spoleto decided to stop all the performances held in the Teatro Nuovo - including the "Spoleto Festival" -, as it was necessary to modify some material, repair the floor, restore the paintings and so on: the first author, charged of all the acoustical aspects, decided to perform extensive acoustical measurements. During the measurement campaign, a flutter echo was detected in the stalls, so it became necessary to locate its origin and to carry out some modification to remove it. We have already presented our studies on this subject, from which emerged a new design of the orchestra pit. For fire safety reasons it was also necessary to remove some wooden elastic panels from the boxes and to adopt an acoustically equivalent technical solution. As the acoustical parameters revealed a particular predisposition for Italian Opera performances (the first author was invited also to deal with some of them), we also decided to renew the wall to wall carpet with a wooden solution, acoustically elastic, incorporating the heating plant. In this paper we will present the results of measurements performed after the opening of the theatre (a typical Italian Opera House of the end of the Eighteen Century) and some considerations about the acoustical results obtained.

1 Scheme of the two measurement campaign

The first measurement campaign in the theatre under test was carried out in 2002. The scheme used was based on setting three omni-directional sources (dodecahedron) in the opened pit, in the covered pit and on the stage, close to the proscenium arch, the position often used by opera singers. The receivers (binaural dummy head) were instead placed in 8 different positions in the stalls and in 30 different positions inside the boxes and the balcony: 6 receivers for each one of the 4 box tiers and 6 for the balcony. Thus, 38 receivers for each one of the 3 sources amount to 114 binaural impulse responses. For more specifications about the adopted measurement method see references [1].

Later, once the restoration works were completed, a new measurement campaign took place trying to maintain the same positions of the measurements carried out in 2002, in order to make a comparison between the two measurement campaigns and thus verify the differences due to the acoustical and architectural restoring works.

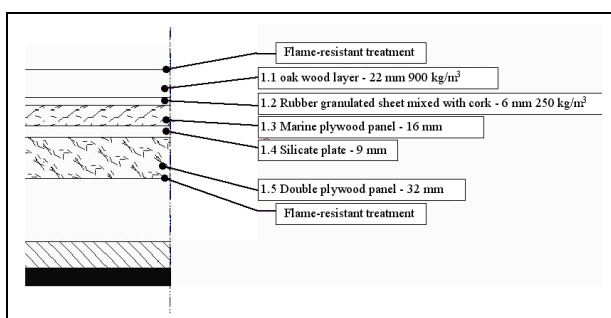


Fig.1 The various layers of the new flooring in the stalls.

2 The restoration works

The main restoration works in the "Teatro Nuovo" in Spoleto were the floor substitution in the stalls, the elastic connection of the ceiling cover in the boxes and the height variation of the orchestral pit.

The old concrete flooring in the stalls was changed with a completely new one built with various layers of different woods (Fig.1) structurally connected to the orchestra pit in order to make easier the vibrational transmission to the

chairs placed in the stalls and to support a more complete listening, typical of the theatrical acoustics technique [2]. Another significant work was carried out in the boxes, with the reclamation of its wooden structures and covering the ceiling with elastic, flame-proof, slabs (Fig.2).

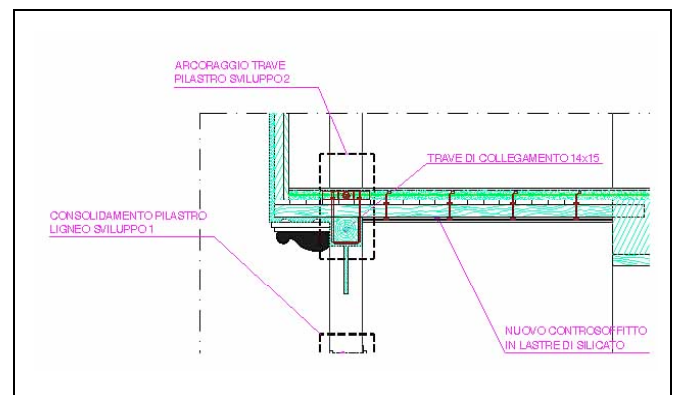


Fig.2 Section view of the elastic coupling structure regarding the box ceiling

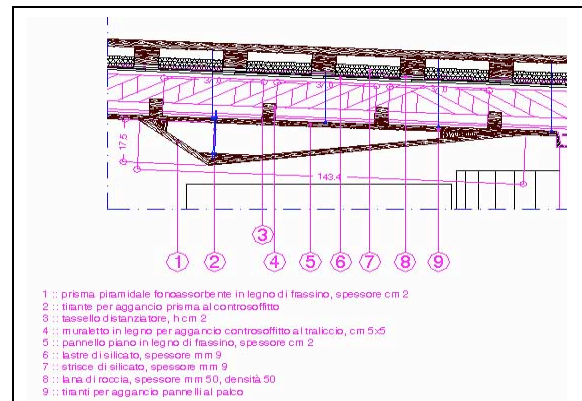


Fig.3 Section view of the diffusing element placed on the orchestral pit ceiling. 1: absorbent pyramidal prism in ash wood, thickness 2 cm. - 2: brace for prism coupling to the false ceiling. - 3: distancing plug, height 2cm. - 4: wood plug for the false ceiling coupling. - 5: wood ash flat panel, thickness 2 cm. - 6: silicate plate, thickness 9 mm. - 7: silicate strips, thickness 9 mm. - 8: rock wool, thickness 50 mm and density 50 kg/m³. - 9: brace for panel coupling to the stage.

Finally, even thanks to a particularly accurate analysis in the frequency domain directed to the orchestra pit in correlation with the temporal parameter *EDT*, developed by the second author [3] in his PhD Thesis, the height of the

orchestra pit was augmented (the orchestra pit surface is about 120 m² and has an almost constant height) and a new ceiling with diffusing elements (Fig. 3) was created to reduce the modal effects noticeable before its refurbishing.

3 Analysis of the more representative objective parameters: *G-Strength*

One of the parameters that were more modified by the restoration works was the *G-Strength*, as it can be seen from the differences shown in the diagrams in Fig.4. The graphs on the left column represent the average of the sources compared to the receivers placed in the stalls (left upper part) and those placed in the boxes (left lower part); the same order was used for the right part that represents the same parameter measured after the restoration works.

Besides the quantity of data underlining the clear improvement achieved with the new acoustical project in regard to the strength factor, the most important issue is represented by the uniformity of the graph lines for the receivers placed in the stalls.

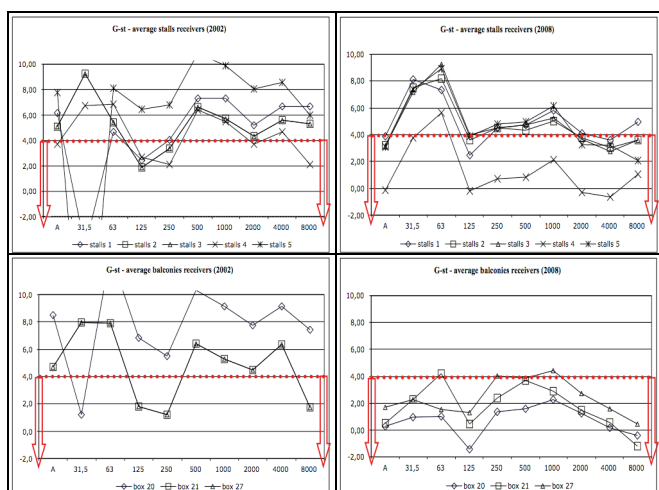


Fig.4 Comparison between *G-St* parameter measured before (2002) and after the restoring works (2008); all the values under the red line are usually acceptable.

By separating the two low frequency bands (31,5 Hz and 63 Hz) from the others, it can be seen that there is a good listening uniformity in the various positions in the stalls and on the various frequency bands. Instead, for what concerns the *G-St* in the boxes, the improvements are clear and evident in comparison with the 2002 measurements. In brief, before the restoration works the listening of the sound level presented a bad uniformity in almost all the frequency bands.

3.1 Clarity index *C-80*

Some changes between the results obtained with the restoration works and before it can be observed also in the objective parameter of the clarity index *C-80*, mostly – as already underlined by the *G-st* parameter – in the receivers

placed in the boxes, where there is a better clarity and intelligibility in comparison with the past.

Although, as it can be seen in Fig.5, the receivers placed in the stalls haven't suffered significant variations in comparison to the pre-restoring acoustical project, since both graphs show acceptable values, in the post-restoring graph it can be detected an opposite situation for what concerns the low frequency bands.

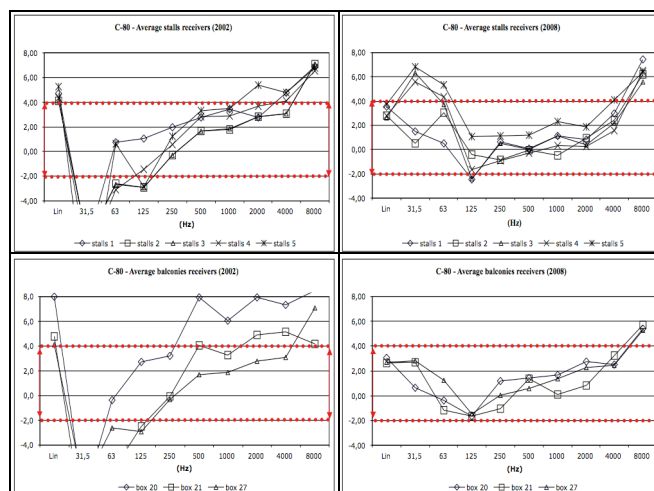


Fig.5 Comparison between *C-80* parameter measured before (2002) and after the restoring works (2008); all the values between the red lines are usually acceptable.

As a matter of fact in the 31,5 Hz and 63 Hz frequency bands it is evident a stronger direct sound than before the restoration works: a difference of 14 dB for the first low frequency band (31,5 Hz) and approximately 6 dB for the second low frequency band (63 Hz). Thus, on examining the facts and trying to look beyond the quantitative event itself, it must be noticed the clear difference for what concerns the pressure level of the low frequency bands in the post-restoring phase.

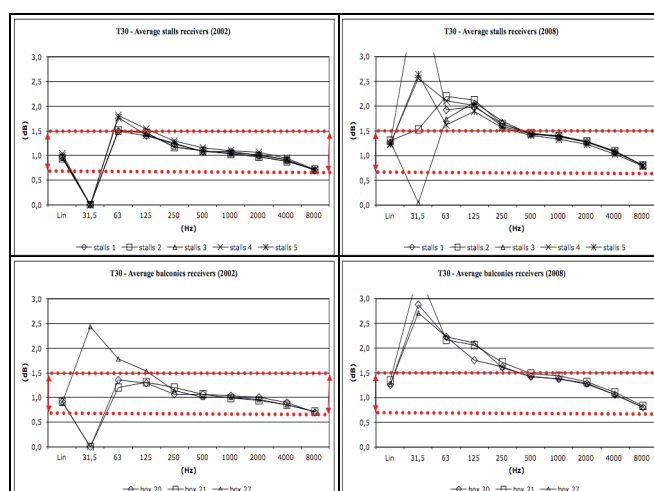


Fig.6 Comparison between *T30* parameter measured before (2002) and after the restoring works (2008); all the values between the red lines are usually acceptable.

On the contrary, for the receivers placed in the boxes, it must be emphasized a clear improvement regarding both the major quantity of acceptable values and their uniformity: the graph lines on the right column (2008) have

a rather homogeneous trend compared to the quasi random progress of the pre-restoring phase.

3.2 Reverberation time T_{30}

By comparing the $C-80$ of the previous paragraph and the T_{30} reverberation time it clearly results that the low frequency bands have a major amplitude not only in the direct sound but also in the reflected sound, or rather, the reverberation time.

In fact, as shown in the upper graphs on the right side of Fig. 5 and 6, it can be noticed that the 31,5 Hz band has a high value both as direct impulse (Fig.5) and reflected impulse (Fig.6).

Apart from that, the major differences between the pre-restoring and post-restoring phases regarding this parameter may be found in a general slight increase of the reverberation time, more evident in the low frequency bands.

From an empirical point of view, this difference has brought about an improvement, since the internal acoustical environment, during the rehearsal concerts, hasn't shown any particular effect typical of excessive reverberation at low frequencies, such as "sforzando" or "staccato" for instance; on the contrary, this increase has created an acoustical environment with a major warmth in the music listening; in fact there are no particular effects such as overlapping in passages of notes played fast, as already confirmed, by the clarity index parameter in Fig.5.

General recapitulation referred to the Prose and Opera						
Parameters	C 80	D	E.D.T.	T30	G	I.A.C.C.
Stalls (2002)	4,59	55,35	0,92	0,98	6,37	0,38
Stalls (2008)	2,17	45,35	1,32	1,52	5,37	0,76
Boxes 0 (2002)	6,10	62,53	0,80	0,88	4,99	0,43
Boxes 0 (2008)	1,05	41,71	1,59	1,58	6,38	0,82
Boxes 1 (2002)	6,50	64,18	0,79	0,88	4,86	0,40
Boxes 1 (2008)	2,04	46,90	1,46	1,55	3,09	0,81
Boxes 2 (2002)	6,50	66,04	0,76	0,86	4,86	0,23
Boxes 2 (2008)	1,46	41,94	1,51	1,64	1,22	0,68
Boxes 3 (2002)	5,40	62,12	0,93	1,00	6,45	0,16
Boxes 3 (2008)	1,32	41,18	1,51	1,51	1,87	0,48
AVERAGE (2002)	5,58	61,68	1,24	0,94	5,93	0,29
AVERAGE (2008)	1,61	43,42	1,48	1,56	3,59	0,71

Fig.7 General recapitulation about the most common objective parameters. The numbers in the coloured cells represent acceptable values.

4 Conclusions

In addition to the good impressions the conductor and the musicians had during the rehearsal concert in the Theatre under test, the objective parameters values shown in the general Tab (Fig.7) confirmed from a numerical point of view the empirical judgement expressed by the above-mentioned people. In short, it can be said there was a substantial improvement of both $G-St$ (Fig.4) and $C-80$ parameter (Fig.5) parameter; to be noticed that in the

previous measurement there wasn't any value that was included among the acceptable values (Fig.7).

Regarding the values of the temporal parameters such as the T_{30} (Figg.6-7) and $E.D.T.$ (Fig.7), as previously observed, it can be noticed an increase of about 0,5 s for the first one and 0,2 s for the second one; from this it arises that the decay curve, in the first 10 dB, remained substantially the same, while the final part, that is the tail of the sound, received a fairly good increase which gave raise to a pleasant musical sustain without reducing the clarity index, but on the contrary showed a gain for this parameter (see $C-80$ in Figg.5-7).

Probably the parameter that has mostly suffered from the restoration works is the $I.A.C.C.$ that shows a rather high average value, 0,7 vs. 0,3 of the previous measurement campaign; further investigations will be performed to try to understand the reasons of this change.

Instead the BIR frequency analysis directed to the sources placed in the orchestral pit, and above all to the close connection it has revealed with the $E.D.T.$ parameter through a specific analysis, will be presented in a next item.

Acknowledgment

We like to thank Lamberto Tronchin that performed all the measurements both before and after the restoring works.

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