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Comparison of Sound Transmission Loss of Panels Used in Ship Cabins for Field and Laboratory Measurements

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Abstract

In this paper, FSTL (Field Sound Transmission Loss) measured in a mock-up simulating ship cabins is studied. A mock-up is built by using 6 mm steel plate, and two identical cabins are made where 25 mm or 50 mm sandwich panel is used to construct wall and ceiling inside the steel structure. Various wall panels and ceilings are tested, where effects of wall and ceiling panel thickness, and presence of a unit toilet on FSTL are investigated. It is found that the effect of unit toilet on FSTL is at most 1 dB. From the comparison of FSTL for panels of the same thickness of 50 mm, it is observed that panel having inside air cavity of 10 mm shows higher STL than that of the panel without air cavity. Comparison of FSTL for panels of 50 mm and 25 mm thickness shows that dependency on surface density predicted by mass law is not observed. The sandwich panels act as a mass-spring system, which shows a resonant mode that cannot be explained by the mass law. It is also found that STL from laboratory test is higher than FSTL by 5- 10 dB, which can be explained by flanking structure-borne noise transmission path such as ceiling, floor and corridor-facing wall.

Keywords: *Field sound transmission loss, Mock-up, Sandwich panel*

I. Introduction

In many ships like cruise and military vessels, cabin noise is a critical issue, since high noise can cause severe annoyance to passengers and crews. In ships, there exist various paths for noise propagation. The basic structure of ship consists of steel decks and bulkheads, inside which cabins are constructed by using sandwich panels with thickness of 25 mm or 50 mm. Similar panels are used to form suspended ceilings below the steel deck, where HVAC duct, wires, and cables are located between deck and ceiling. The typical panels are of sandwich type which is composed of thin skin metal sheets and mineral wool as a core material.

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Since ship cabins are to meet noise criteria [1], wall and ceiling panels must have high performance in sound insulation. One can measure the STL (Sound Transmission Loss) of wall panel or ceiling panel in a laboratory test by using reverberation room in accordance with ISO standards 140-3 [2] and 140-9 [3], or in ship cabins for field measurements in accordance with ISO 140-4 [4]. ISO 140-14 [5] states guidelines for field measurements.

In general, the walls and ceiling of a reverberation room have sufficiently high sound insulation compared to that of the panel being tested so that sound can only propagate through the test area. However, in real ship cabins, walls and ceiling panels have similar structure, which means that sound may propagate comparably all over the walls and ceiling. In addition, there exist various flanking noise paths such as door, lighting connection, etc. Therefore, the field measurement of STL, which is called FSTL (Field Sound Transmission Loss), usually shows lower levels than that measured in a laboratory test. Weissenburger [6] has reported that differences of 5 to 10 dB between FSTL and STL are not uncommon. Diaz and Pedrero [7] measured field airborne and impact sound insulation between rooms, one on top of the other. They compared the measurements to the results obtained in the laboratory to find that field measurements show lower values than laboratory measurements do. Kang et al. [8] studied influence of sound leaks on *in situ* sound insulation performance. They measured FSTL of the cabin walls in a passenger ship, and compared the results to predictions. They concluded that small gaps found in wall panel joints, ceiling and floor are mainly responsible for poor performance of FSTL in high frequency ranges over 1000 - 2000 Hz. Joo et al. [9] investigated differences between FSTL and STL, where they measured onboard FSTL in passenger ship cabins as well as in a deckhouse mock-up. They found *in-situ* measured FSTLs are close to FSTL obtained in a deckhouse mock-up, while two kinds of FSTLs are lower than STL measured in a laboratory by 2-9 dB. They revealed that sound leakages through doors and ceiling apertures can severely degrade sound insulation performance, and improved FSTL by 3 dB by sequential aluminum taping over sound leakages.

In this paper, we study FSTL in a mock-up simulating ship cabins, and compare the results to the STL measured in a laboratory. A mock-up is built by using 6 mm steel plate, and two identical cabins are made where 25 mm or 50 mm sandwich panel is used to construct wall and ceiling inside the steel structure. Various wall panels and ceilings are tested, where effects of wall and ceiling panel thickness, and presence of a unit toilet on FSTL are investigated.

II. A Mock-up

In Fig. 1, we show sketch of the mock-up. The size of cabin is 4 m x 2.9 m x 2.1 m (length x width x height), where a unit toilet is located inside the cabin. In cruise ships, unit toilet which was pre-fabricated outside the ship is installed. Since the presence of a unit toilet may significantly affect the sound field inside cabin, we measure the STL with and without the unit toilet. In Fig. 1, we also mark speaker positions and moving microphone for room B, where for room A, they are symmetric with respect to the center wall panel. In Fig. 2, we show a measurement set-up inside the cabin, where an omni-directional speaker and moving microphone are found.

We constructed the mock-up such that configuration like mock-up size, wall and ceiling panel, door, unit toilet resembles a typical cruise ship cabin of economic class. We installed wall and ceiling panels in the same manner as in real ships. In Table 1, we

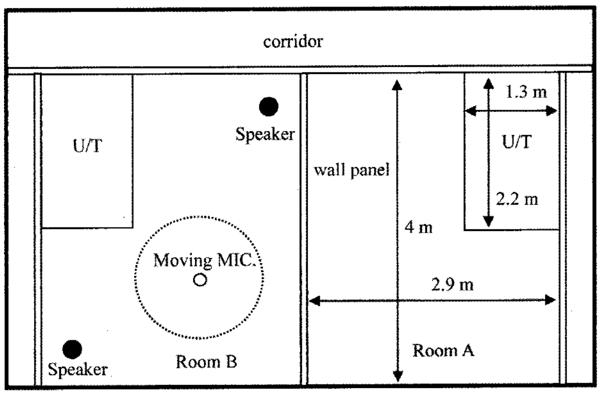

Fig. 1a. Upper view of the mock-up.

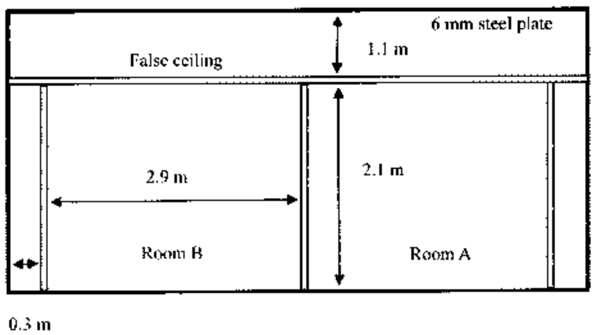

Fig. 1b. Front view of the mock-up.

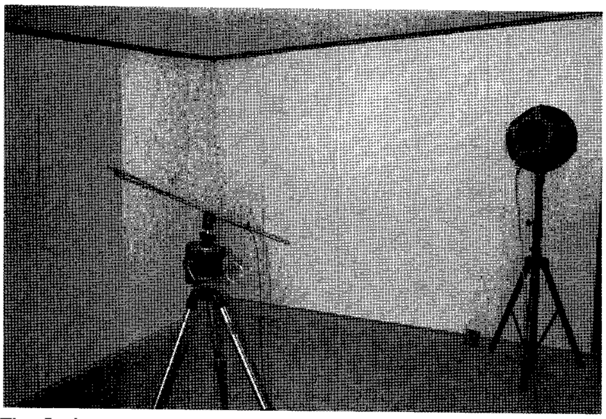

Fig. 2. A measurement set-up (speaker and a moving microphone).

list the wall and ceiling panels. The basic construction of sandwich wall panel is: skin plate + mineral wool (density is 140 kg/m^3) + skin plate, where skin plate is a 0.6 mm galvanized steel plate. Thickness of wall panel W-C50, W-50D, and W-C50E are 50 mm, while thickness of W-C25 is 25 mm. Ceiling panels are of two types: C-A25 (25 mm) and C-A50 (mm), in which only one skin plate is used in ceiling panels. Wall panel W-50D has an air cavity of 10 mm inside the panel. Wall panel W-50E has basically the same structure as W-C50, except that there is a cable conduit space (100 mm x 25 mm) inside the mineral wool.

III. FSTL Measurement

We measured FSTL of the wall panels listed in Table 1 in accordance with ISO 140-4 [4]. Guidelines in ISO-140-14 [5] recommends that if floor area is less than 50 m^2, number of speaker positions and rotating microphones should be two and one respectively. Since the floor area inside cabin is 11.6 m^2, we located the speaker in two corner points. In Fig. 3, we compared reverberation time of the cabin with and without a unit toilet, which shows that reverberation time without unit toilet is slightly larger than that with unit toilet. However, both reverberation times show irregular behaviors in the low frequency ranges 100 Hz 315 Hz, which may be

Table 1. Wall and ceiling panels.

	panel model	Remark
1	W-C50	skin + 49 mm MW + skin
2	W-C50D	Skin + 19 mm MW + 10 mm air cavity + 19 mm MW + skin
3	W-C50E	Same as C50 with cable conduit space
4	W-C25	skin + 24 mm MW + skin
5	C-A25	Skin + 24 mm MW
6	C-A50	Skin + 49 mm MW

(Note: skin plate is a 0.6 mm steel plate; MW denotes mineral wool).

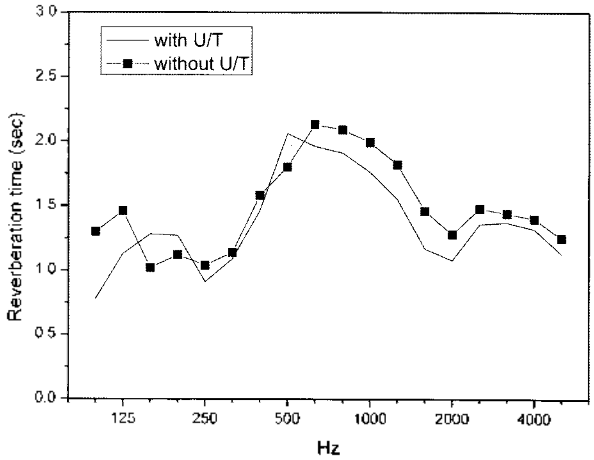

Fig. 3. Reverberation time of the cabin mock-up with and without unit toilet.

due to acoustic modes of the cabin. The eigenvalues of the cabin are 109 Hz, 131 Hz, 148 Hz,··· etc.

Table 2 shows FSTL measurements for walls with and without a unit toilet. Fig. 4 shows comparison of FSTL for W-C50 and W-C50D, while Fig. 5 shows for W-C50D + C50E and W-C25. It is found that FSTL is decreased by the presence of the unit toilet by 1 dB for W-C50D, while unchanged for other wall panels. We also measured FSTL of the corridor-facing wall by locating a speaker in the corridor. The corridor-facing wall is W-C50, and door is included in the wall. Fig. 6 shows that presence of a unit toilet increases FSTL by 3 dB, since sound needs to propagate additionally through a unit toilet wall, which in turn results in increase of STL. Note that unit toilet panel is W-C50.

In Fig. 7, we compared FSTL of the wall panels with same thickness of 50 mm. Since W-C50 and W-C50 + C50E have almost the same structure,

Table 2. FSTL with and without unit toilet (UT).

	wall panel	with UT	without UT
1	W-C50	25 dB	25 dB
2	W-C50D	31 dB	32 dB
3	W-C50D/C50E	30 dB	30 dB
4	W-C50/C50E	-	25 dB
5	W-C25	27 dB	27 dB

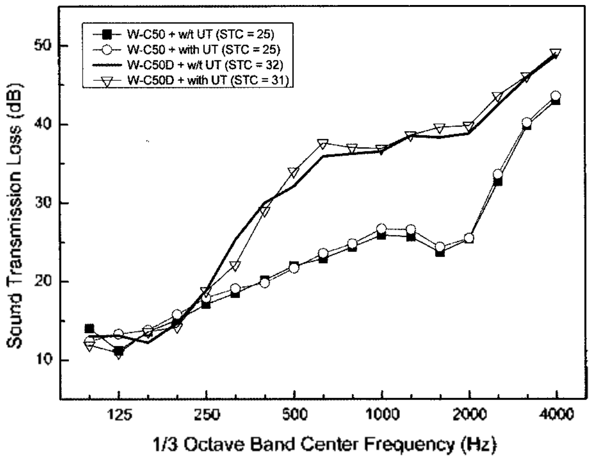

Fig. 4. Comparison of FSTL with and without a unit toilet (UT) for wall panel W-C50 and W-C50D.

FSTLs are almost identical. However, W−C50D shows better performance than W−C50 because W−C50D has an air cavity 10 mm inside the panel, which leads to double−leaf motion. It is well known that insertion of an air cavity inside sandwich panel increases STL [10], while panel thickness is kept the same. In Fig. 8, we compared FSTL for wall panel W−C25 (thickness: 25 mm, surface density: 18.0 kg/m^2) and W−C50 (thickness: 50 mm, surface density: 22.9 kg/m^2). According to the mass−law [10], STL is proportional to the surface density m and frequency f by,

$$STL = 20\log(mf) - 47 \text{ dB} \quad (1)$$

It is expected that W−C50 would show higher STL than that of W−C25 by 20log (22.9/18.0) = 2.1 dB. However, in Fig. 8, FSTL of W−C25 is 27 dB, whereas 25 dB for W−C50, which means that FSTL may not be governed by a mass law in this mock−up measurements. Generally, mass law holds for the panels composed of isotropic material. However,

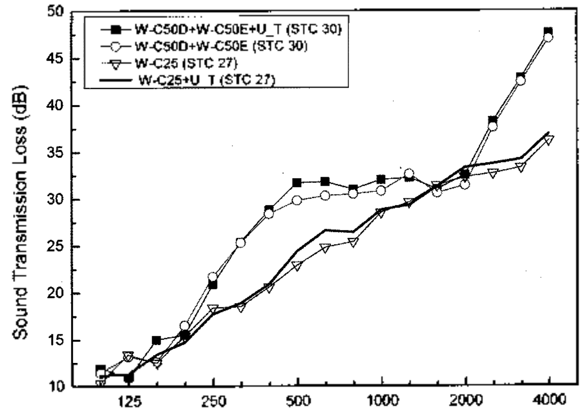

Fig. 5. Comparison of FSTL with and without a unit toilet (UT) for wall panel W-C50D + C50E and W-C25.

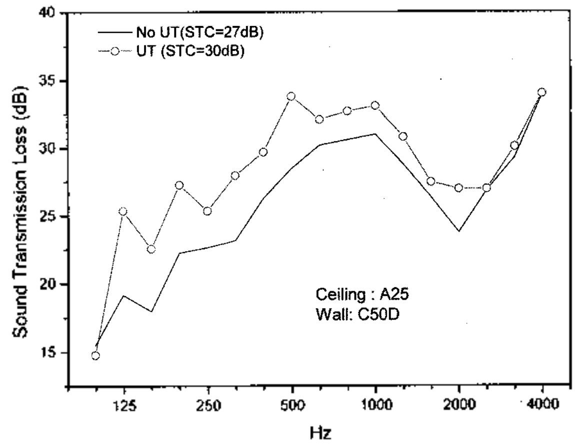

Fig. 6. Comparison of FSTL with and without a unit toilet (UT) for corridor-facing wall.

wall panels W−C25 and W−C50 are basically sandwich panels whose behaviors show resonant modes associated with mass−spring system, which may explain the discrepancy between measurements and mass law. In Figs. 4−8, ceiling panel is C−A25.

IV. Comparison of STL for Field and Laboratory Measurement

In Figs. 9−11, we compared STL for field measurement and laboratory test for wall panels W−C25, C50 and C50D. It is found that STL from laboratory test is higher than FSTL by 5−10 dB. In the mock−up, sound may propagate via ceiling and door, whose effect is negligible in a laboratory. In order to

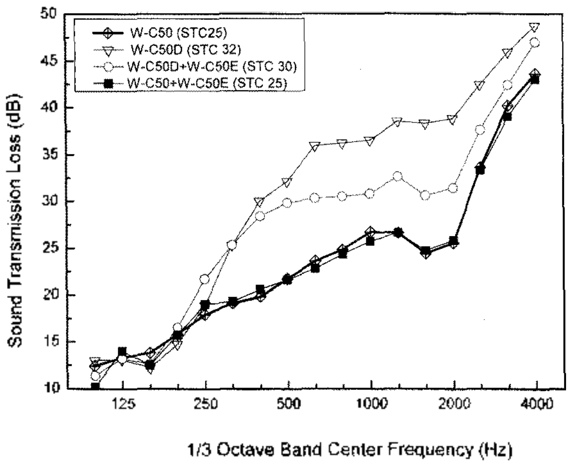

Fig. 7. Comparison of FSTL for wall panels with same thickness of 50 mm.

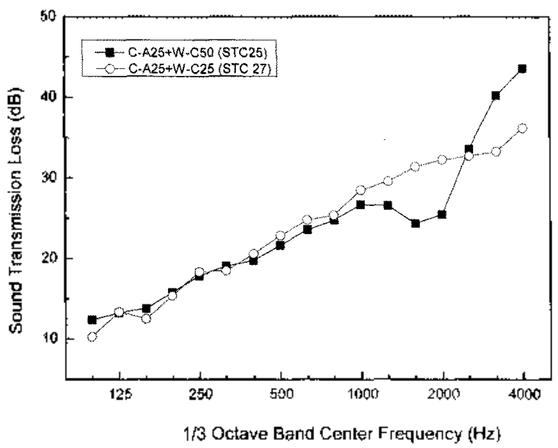

Fig. 8. Comparison of FSTL for wall panels with thickness 25 mm (W-C25) and 50 mm (W-C50).

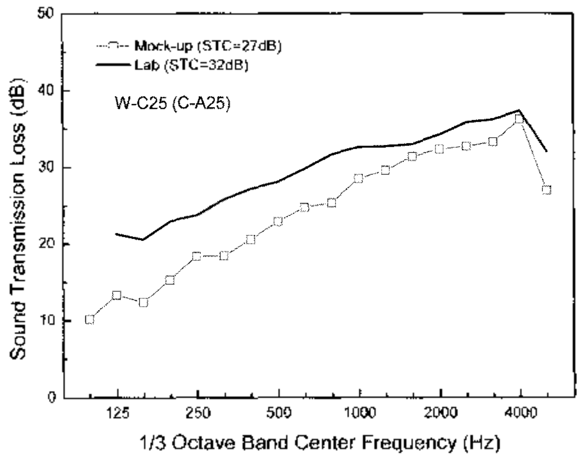

Fig. 9. Comparison of STL from field measurement and laboratory test for wall panel W-C25.

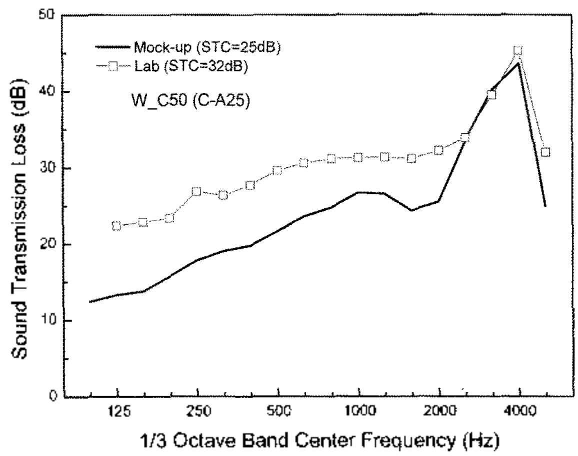

Fig. 10. Comparison of STL from field measurement and laboratory test for wall panel W-C50.

see the effect of ceiling, we changed ceiling panel from C−A25 (25 mm) to C−A 50 (50 mm). Figs. 12 and 13 show effects of ceiling thickness on FSTL in which wall panels are W−C25 and W−C50D respectively, from which it is found that changing ceiling thickness does not affect the FSTL. Since small gap can severely degrade FSTL, we sealed the joints between panels, ceiling and floor. In Fig. 14, we compared FSTL for W−C50D before and after sealing, which shows that sealing slightly increases FSTL over 2000 Hz by 1 − 2 dB, but STC is still the same as 32 dB.

The possible paths for sound transmission between room A and B are:

Path 1 : Room A − wall panel − room B

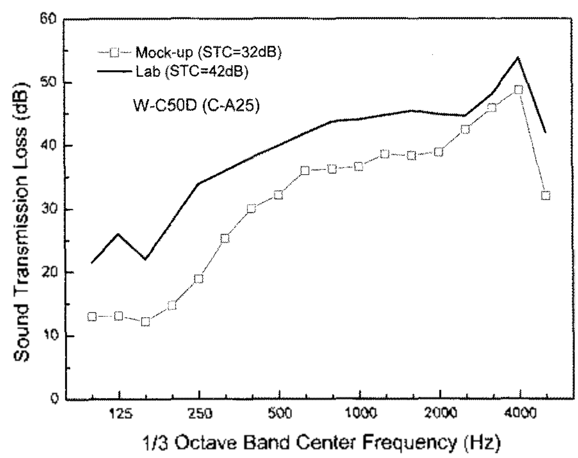

Fig. 11. Comparison of STL from field measurement and laboratory test for wall panel W-C50D.

Path 2 : Room A − corridor − room B

Path 3 : Room A − ceiling − room B

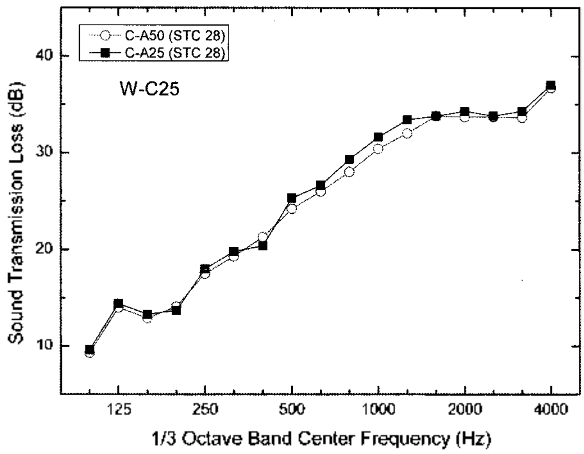

Fig. 12. Effect of ceiling thickness on FSTL for W-C25.

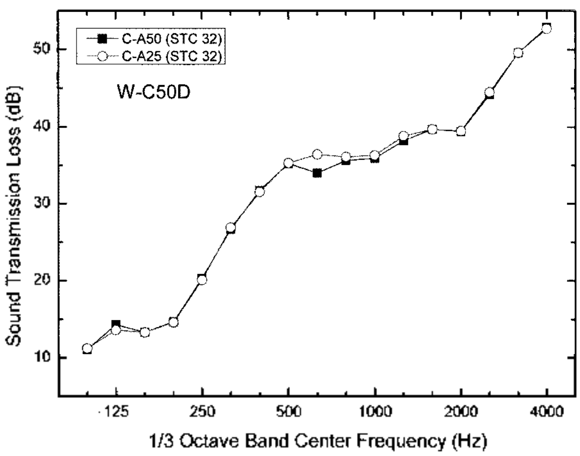

Fig. 13. Effect of ceiling thickness on FSTL for W-C50D.

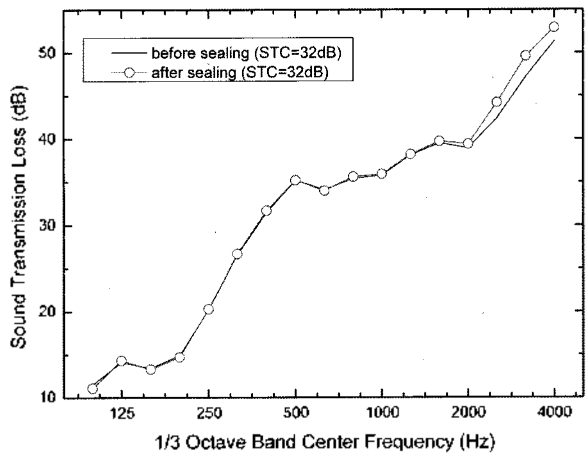

Fig. 14. Effect of sealing on FSTL for W-C50D.

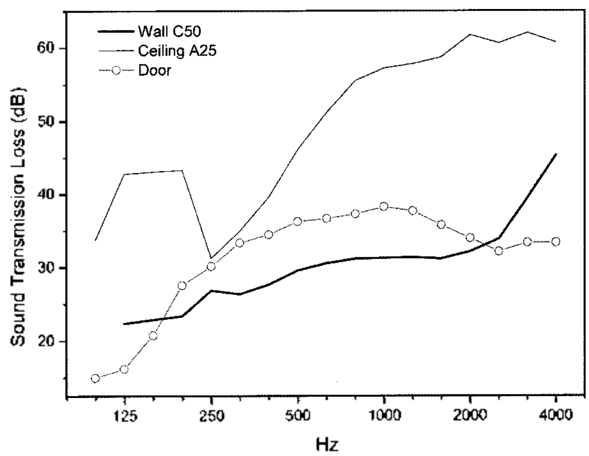

Fig. 15. Comparison of STL measured in a laboratory test for wall panel C50, ceiling A25, and door.

Sound may propagate between rooms, where air-borne noise as well as structure-borne noise (SBN) propagation is included. Fig. 15 shows comparison of STL measured in a laboratory for wall panel W-C50, ceiling C-A25, and door. The sound insulation of ceiling shows much higher value than wall STL, since sound needs to propagate twice through the ceiling when traveling from source room to receiver room. Note that STL of door is comparable to that of wall panel. In terms of airborne noise transmission, path 2 and path 3 can be neglected compared to path 1, because sound must penetrate twice through ceiling or corridor-facing wall. Figs. 12 and 13 also confirm that airborne path 1 is dominant.

The speaker in the source room induces SBN in the ceiling, floor, and corridor-facing wall, which in turn generates sound in receiving room. In laboratory test, unwanted SBN transmission is minimized so that sound only propagates though wall panel being tested. However, in the present mock-up, there are no special treatments for reducing SBN transmission via ceiling, floor, and wall facing corridor, which explains why FSTL is lower than STL measured in the laboratory.

V. Discussions and Conclusions

In field measurements of wall panel STL in a mock-up simulating ship cabins, it was found that the effect of a unit toilet on FSTL is at most 1 dB for wall panel W-C50D. From the comparison of FSTL for panels of same thickness 50 mm, it was observed that panel having inside air cavity of 10 mm shows higher STL than the panel having no air cavity. Comparison of FSTL for panels of 50 mm and 25 mm thickness showed that dependency on surface density predicted by mass law is not observed here. It was also found that STL from laboratory test is higher than FSTL by 5– 10 dB. It may be concluded that airborne noise transmission via ceiling and corridor–facing wall can be neglected in the mock–up measurement. In addition, sealing the gap between panels, ceiling and floor only slightly increased FSTL over 2000 Hz by 1 - 2 dB, which is not large enough to change STC value. However, flanking structure–borne noise transmission path such as ceiling, floor and corridor–facing wall can severely affect the FSTL of the wall panel. Although no SBN measurements were done in this study, we believe that for future study, measuring SBN of the walls, ceiling, and floor of the receiving room will reveal crucial information on how SBN affects the FSTL of the common wall panel.

Acknowledgements

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