Experimental Study on Sound Insulation Performance of Partition Walls Joined to Steel Beams

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ABSTRACT

An experimental study was conducted to confirm the sound insulation performance of a partition wall that was joined to a steel beam. Fireproofing protections, such as sprayed rock wool, are used to protect steel members from heat in the case of fire. However, the influence of transmitted sound from steel members with fireproofing protections and from joints of the partition wall and steel members has not been quantitatively investigated. Therefore, the sound transmission loss was measured using specimens that consisted of a partition wall and a steel beam, which was coated with sprayed rock wool. The results showed that the sound transmission loss of the specimen was lower than that of the partition wall element. It was inferred that the mass-spring-mass resonance of the fireproofing protections on the steel web reduced the sound insulation performance of the specimen. Moreover, the influence of the transmitted sound from the steel web was greater than that from the joints of the partition wall and the steel beam. In addition, when the gypsum board was added to the specimen as a ceiling, it was confirmed that the sound insulation performance of the specimens was equal to that of the partition wall element.

1 INTRODUCTION

For buildings, that require high sound insulation performance, such as hotels and complex housings, it is important to consider specifications that would address these requirements at the design stage. In steel-framed buildings, fireproofing protections are applied to protect steel members (columns and beams) from heat in case of fire. When constructing a partition wall between adjacent rooms, several joints exist between the partition wall and the fireproofing protection of the steel members. For example, when constructing a gypsum board wall under a

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steel beam, the upper part of the wall is joined to the fireproofing protection of the steel beam. In this case, when sprayed rock wool is applied as fireproofing protection, it is thought that sprayed rock wool of the joint part (wall–beam joint) will cause sound leakage between the adjacent rooms because its specific gravity is low. To prevent sound leakage, the following methods are often applied as sound insulation reinforcements: inserting the continuous steel plate under the steel beam, using a filler material with a high specific gravity at the wall–beam joint or applying fireproofing protection with a high specific gravity [1].

However, the sound insulation effect of these reinforcements has not been quantitatively investigated, and it is possible that these reinforcements become excessive specifications. Furthermore, apart from the transmitted sound from the wall–beam joint, the influence of the transmitted sound from the steel web portion has not been quantitatively investigated. In addition, when there is a ceiling, the sound insulation effect of the ceiling board is expected.

Therefore, the sound insulation performance of the partition wall joined to the steel beam has not been quantitatively investigated. In this work, to confirm the sound insulation performance of a partition wall that is joined to a steel beam, a specimen, which consisted of a partition wall and a steel beam, was constructed in the reverberation room; the sound transmission loss was measured; and the results are reported herein.

2 MEASUREMENT CONDITIONS

Figure 1 shows the cross section of the partition wall joined to a steel beam. As may be observed, there are sound propagation paths around the steel beam. Figure 2 shows the reverberation rooms used for the measurement of the sound transmission loss.

A specimen simulating the steel beam and the partition wall was constructed on an opening (width of 3,640 mm, height of 2,720 mm, and surface area of 9.9 m^2) between the reverberation rooms. Figure 3 shows the installation method of the specimen.

The specimen was modeled by rotating the beam by 90°, considering the workability and safety when constructing the steel beam in the reverberation rooms. The steel beam was modelled as a small beam (H-350 × 175 × 7 × 11; section with depth of 350 mm, flange width of 175 mm, web thickness of 7 mm, and flange thickness of 11 mm.), and three H steels were joined together with joint plates and bolts. The steel joint was left with a gap of 10 mm (beam–beam joint).

A partition wall, which is commonly used for hotels and complex housings, was selected as the specimen. The partition wall was a double-leaf gypsum board wall with a wall thickness of

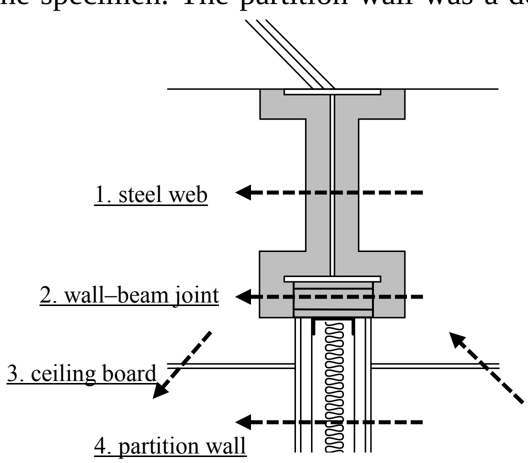


Figure 1 – Sound propagation paths around a steel beam.

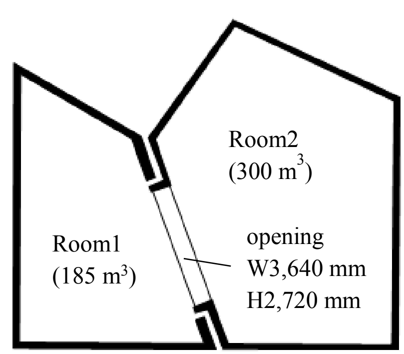
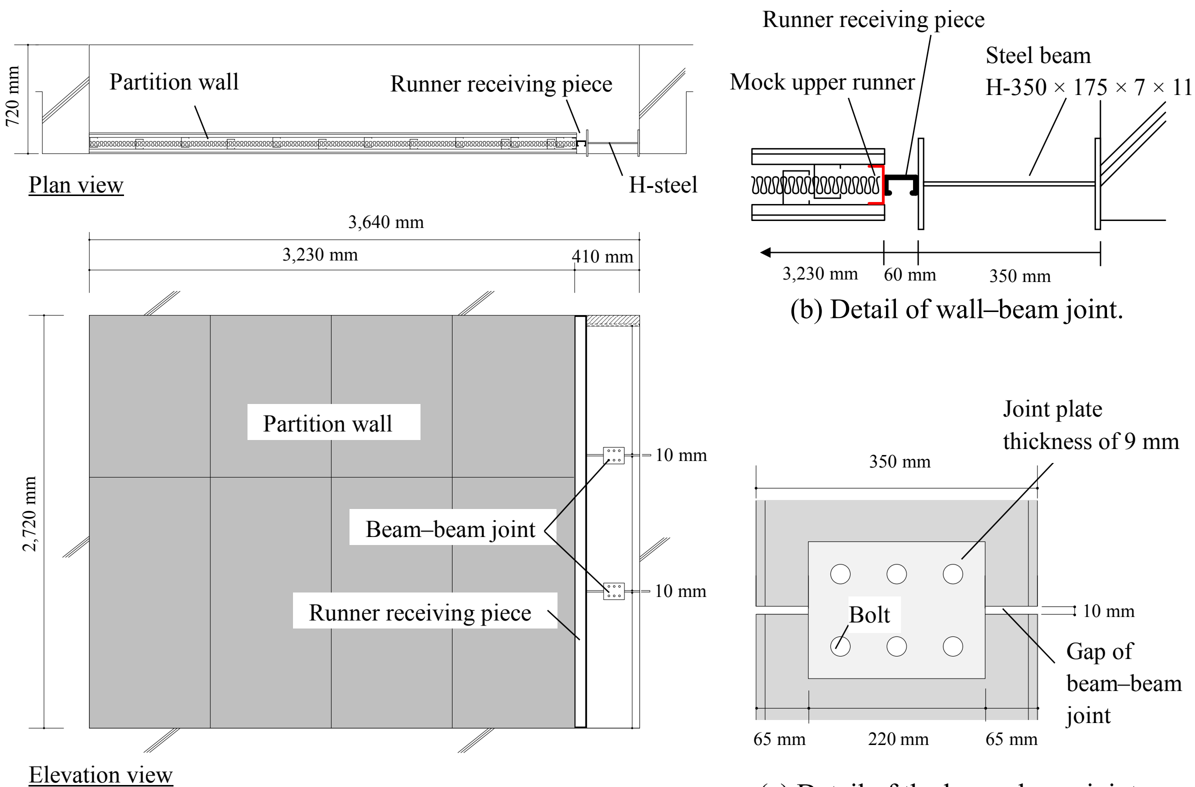


Figure 2 –Reverberation rooms.



(a) Specimen plan/elevation view.

(b) Detail of wall–beam joint.

(c) Detail of the beam–beam joint.

Figure 3 – Method of installation of the specimen.

138 mm; the inner air layer was filled with fiberglass (density of 24 kg/m^3 and thickness of 50 mm). For the construction of the partition wall, conventional construction methods were employed instead of rotating the partition wall by 90°. To simulate the actual wall–beam joint under the beam, a mock upper runner was inserted in end of the partition wall and it was screwed to the runner receiving piece.

The acoustic transmission loss was measured according to the method given in Reference [2]; the total sound transmission loss was evaluated considering the entire specimen, which consisted of the steel beam, the partition wall, and the joint portions.

The measurement frequency was set to a range of 100 Hz to 5 kHz at a 1/3 octave band center frequency. The sound transmission loss, *R*, was calculated by:

$$R = L_1 + L_2 + 10\log_{10}\frac{S}{A} \tag{1}$$

where L_1 and L_2 were the average sound levels (dB) in the sound-source room and sound-receiving room respectively, *S* was the surface area of the specimen (9.9 m^2) and *A* was equivalent absorption area of sound-receiving room.

3. Specifications of the specimen

The sound transmission loss was measured for the five specimens and is reported in this section.

Table 1 summarizes the specifications of each specimen; Figure 4 shows the details of each specimen.

Specimen 0 is to confirm the sound insulation performance of the partition wall element.

Specimens 1 and 2 are the partition wall joined to the steel beam before the application of the fireproof coating; these are to confirm the transmitted sound from the steel web and the wall–beam joint. A continuous C-steel with a thickness of 2.3 mm was applied as a runner receiving piece of Specimens 1 and 2. Specimen 1 has no gap filler, whereas for Specimen 2, oil clay was used to fill the beam–beam and wall–beam joint gap.

Specimen 3 represents the specification that is often used between the rooms where high sound insulation performance is required. Sprayed rock wool was applied as fireproofing protection. To prevent sound leakage from the wall–beam joint, a continuous C-steel with a thickness of 2.3 mm was used as a runner receiving piece; for the beam–beam joint, a non-flammable filler with a high specific gravity was used to fill the gap of the beam–beam joint.

Specimen 4 reproduce the specification that is not applying reinforcement of the sound insulation. The gap filling of the beam–beam joint was not filled; intermittent C-steels were used as the runner receiving piece of the wall–beam joint, which were installed at intervals of approximately 800–900 mm.

Sprayed rock wool for the fireproofing protection of Specimens 3 and 4 was applied, with a thickness of 45 mm. After spraying, the surface of the sprayed rock wool was finished with trowel. Then, the gap between the fitting part of the rock wool and the partition wall board was filled with a non-flammable filler.

For Specimens 3 and 4, the sound transmission loss was measured considering the effect of the ceiling, which was installed on the sound-source room and the sound-receiving room. The ceiling was made of gypsum boards with a thickness of 9.5 mm. A downlight (φ75 mm opening) and a heat or a smoke sensor (φ115 mm, or φ30 mm opening, respectively) were installed on the ceiling board of both the sound-source and the sound-receiving room sides.

Figure 5 shows the installation method of the ceiling. The acoustic transmission loss of the specimens with ceiling was calculated considering that the area of the specimens was the same as that of the specimens without ceiling.

Table 1 – List of specimens.

	Fire-proofing protection	Wall-wall joint	Wall-beam joint	Runner receiving piece	Ceiling board
Specimen 0	-	-	-	-	-
Specimen 1	-	-	-	Continuous C-steel thickness of 2.3mm	-
Specimen 2	-	Oil clay	Oil clay	Continuous C-steel thickness of 2.3mm	-
Specimen 3	Sprayed Rock Wool	Nonflammable filler	Nonflammable filler	Continuous C-steel thickness of 2.3mm	with/without
Specimen 4	Sprayed Rock Wool	-	Nonflammable filler	Intermittent C-steel thickness of 1.6mm	with/without

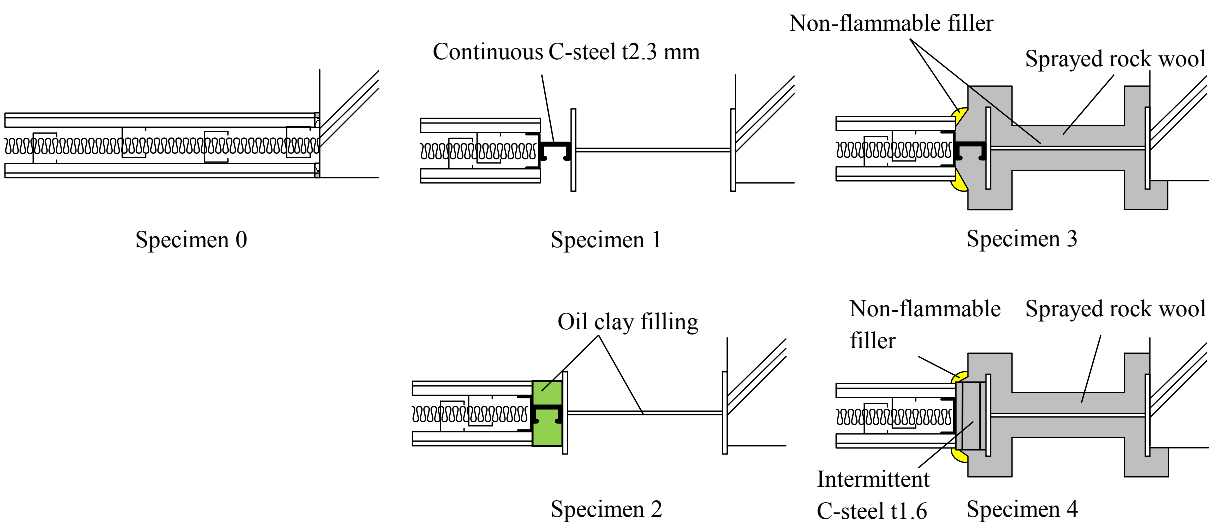


Figure 4 – Details of the specimens.

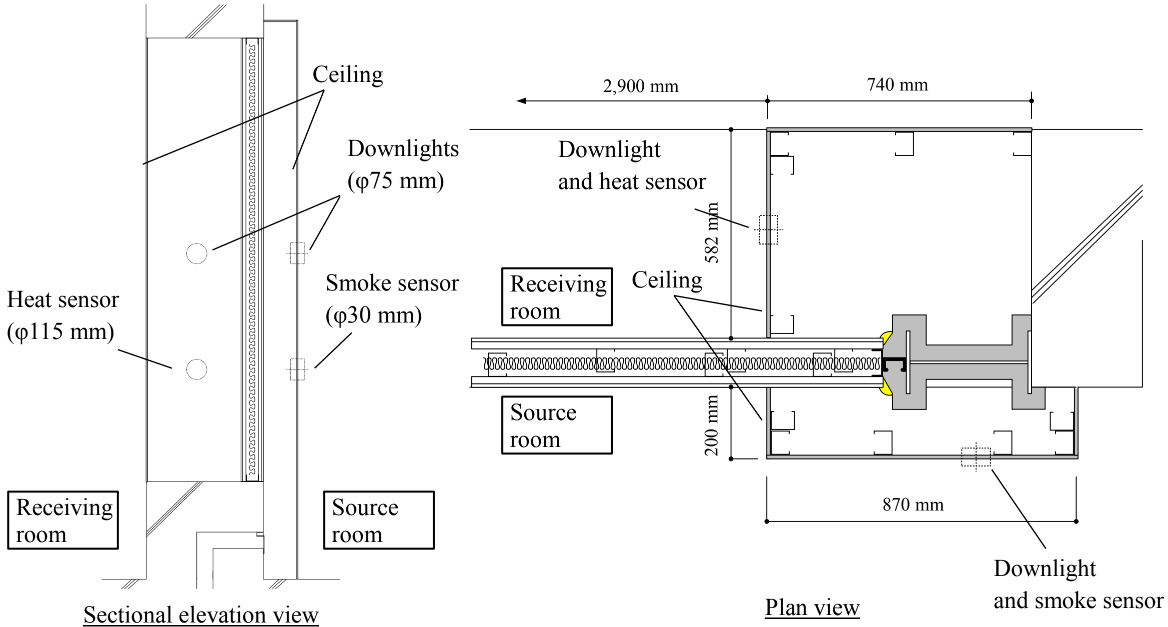


Figure 5 – Installation method of the ceiling (For Specimens 3 and 4).

4. Results and discussion

Figure 6 shows the measurements of the sound transmission loss for each test specimen before the ceiling construction.

Specimen 0 was a partition wall element; its results are the benchmark for comparing the results obtained from other specimens.

For Specimen 1, the value of the sound transmission loss in all frequency bands is approximately 30 dB owing to the transmitted sound from the gap of the beam–beam joint and from the runner receiving piece of wall–beam joint.

Regarding Specimen 2, because of the filling gap of the beam–beam joint and that of the wall–beam joint with oil clay, the measurements of the sound transmission loss greatly exceed those of Specimen 1 within the entire frequency band. Because the frequency that harmonizes the wavelength of the sound wave with the wavelength of the bending vibration of the iron plate that has the same thickness as that of the steel web (namely, 7 mm) is approximately 1.8 kHz, the sound transmission loss decreases within the 1.25 kHz and 2.5 kHz band.

For Specimens 3 and 4 with sprayed rock wool, the sound transmission loss has remarkably decreased in the vicinity of the 500 Hz – 1 kHz band. In this frequency range, the sound transmission loss is lower than that of Specimen 2. In the frequency range above 2.5 kHz, the value of the sound transmission loss is approximately the same as that of the partition wall element (Specimen 0). Specimens 3 and 4 have almost the same sound transmission loss; however, within the range of 100 – 630 Hz, the results obtained from Specimen 4 are 1 – 3 dB lower than those obtained from Specimen 3.

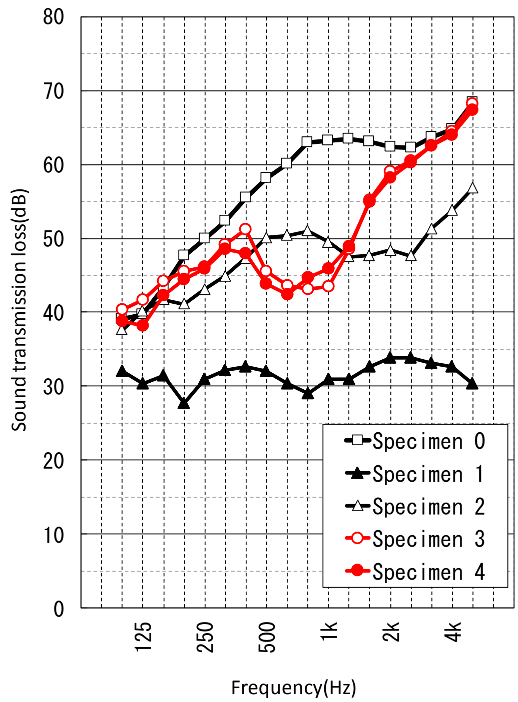


Figure 6 – Results obtained from the measurement of the sound transmission loss of each test specimen prior to the ceiling construction.

The results of investigating the sound leakage part of the Specimens 3 and 4 showed that the influence of the web part of the steel beam was substantial, and that the sound leakage from the wall–beam joint could not be confirmed audibly. To confirm the sound leakage from the web part of the steel beam, additional measurements were obtained using Specimens 3 and 4, from which the sprayed rock wool of the web was removed (the gap of the beam–beam joint was filled with oil clay). Figure 7 shows the additional specimens.

Figure 8 shows the results of the additional measurements compared with the those of Specimens 2, 3, and 4. After the removal of the sprayed rock wool of the web, the decrease in the sound transmission loss within the 500 Hz to 1 kHz band did not occur in the additional specimens, and the sound transmission loss was higher than that of Specimen 2 in for almost the entire frequency band.

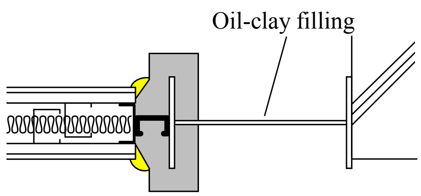
Because the surface of the sprayed rock wool was thinly hardened by the trowel finish, it was inferred that the cause of the decrease in the sound transmission loss within the band of 500 Hz to 1 kHz was due to the mass-spring-mass resonance of the fireproofing protections on the steel web (mass: the surface of sprayed rock wool that was thinly hardened by the trowel finish, spring: the sprayed rock wool, mass: the steel web).

On the other hand, the values obtained from Specimens 3 and 4, in which the sprayed rock wool of the web had been removed, were almost the same, and there was no significant difference whether the runner receiving piece had been applied as a continuous piece or intermittent piece.

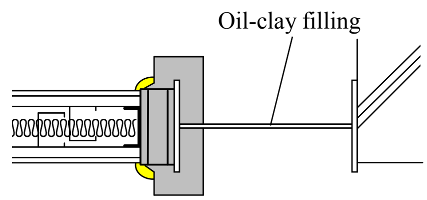
From the above, it was inferred that the reason why the sound transmission loss of the Specimen 4 was smaller than that of Specimen 3 below the 630 Hz band was not the influence of the runner receiving piece of the wall–beam joint, but due to the slight construction error of the spraying material.

Figure 9 shows the sound transmission loss of Specimens 3 and 4 with a ceiling. The difference in the sound transmission loss of the Specimens 3 and 4 is 0 to 2 dB, which is almost the same value as that of the partition wall element (Specimen 0). By adding a ceiling to the sound-source room and the sound-receiving room side in Specimens 3 and 4, the sound transmission loss increased by 10 dB to 20 dB in the 500 Hz – 1 kHz frequency region. Hence, it became clear that the sound insulation effect of the ceiling was very high.

From the above, regarding the state in which ceiling board was present in both the sound-source and the sound-receiving room, and the state in which the partition wall that had the same degree of sound insulating performance as that of this experiment, it can be said that there was no difference in the sound insulation performance according to the specification of the wall–beam joint and the beam–beam joint.



(a) Specimen 3; the sprayed rock wool of the steel web has been removed.



(b) Specimen 4; the sprayed rock wool of the steel web has been removed.

Figure 7 – Additional specimens; sprayed rock wool of the steel web has been removed from specimen 3 and 4.

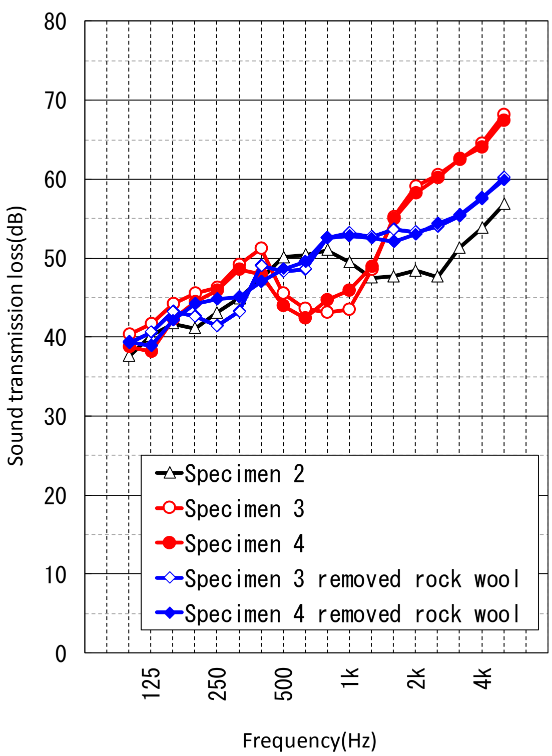


Figure 8 – Results of additional measurements from Specimens 3 and 4 (the sprayed rock wool of the web had been removed) compared with the results from Specimens 2,3, and 4.

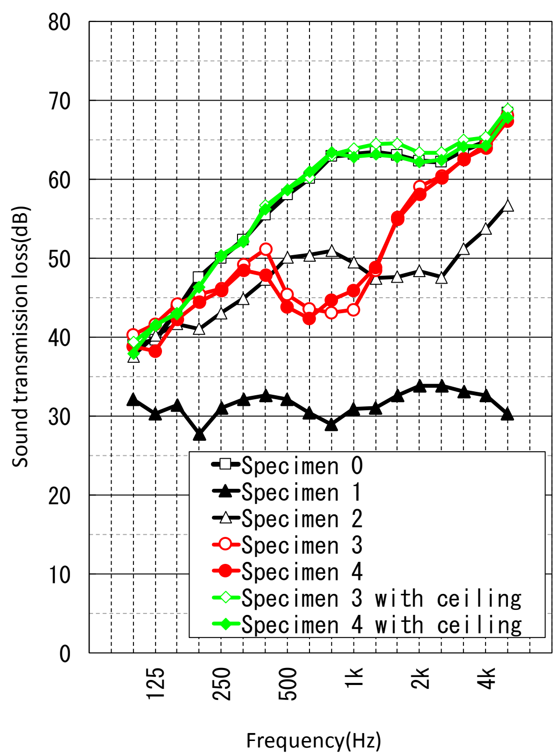


Figure 9 – Sound transmission loss of Specimens 3 and 4 with ceiling compared with the results obtained from other specimens.

5. Conclusion

To confirm the sound insulation performance of a partition wall that is joined to a steel beam, the sound transmission loss was measured using the specimen that represented the joint of the partition wall and the steel beam with sprayed rock wool.

The results obtained are summarized below.

1) When sprayed rock wool was used as fireproofing protection, the sound transmission loss remarkably decreased within the 500 Hz to 1 kHz band. This was attributed to the mass-spring-mass resonance of the fireproofing protections on the steel web.

2) Because the transmitted sound of the steel web portion was considerable, there was no significant difference in the sound insulation performance when the runner receiving piece was applied as a continuous or intermittent piece.

3) By adding a ceiling to the sound-source room and the sound-receiving room side in Specimens 3 and 4, the sound transmission loss increased by 10 dB to 20 dB in the 500 Hz – 1 kHz frequency region; therefore, it became clear that the sound insulation effect of the ceiling was very high.

From the above, considering the state in which the ceiling board was installed on both the sound-source and the sound-receiving room and the state in which the partition wall had the same degree of sound insulating performance as that obtained from the experiment, it may be observed that there was no difference in the sound insulation performance according to the specifications of the wall–beam joint and the beam–beam joint.

6 REFERENCES

[1]S. Hirano, “Construction of sound insulation/vibration isolation”, Tokyo: Rikohtosho (1994) [published in Japanese].

[2]JIS A 1416: 2000, “Acoustic-Method for laboratory measurement of airborne sound insulation of building elements”, Japanese Standard Association.