Measuring and Predicting Rainfall Noise-reduction Effects of Shizuka-Ace ®

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ABSTRACT We measured the noise of rain striking the metal roof of a martial arts gymnasium. This gymnasium is located in Tsuruoka-city Yamagata-prefecture in Japan. The points measured are two buildings: one is the main building of this gymnasium, and the other is an archery range annexed to the main building.

The roof of the main building is made of metal, which is steel laminated with our product Shizuka-Ace ® to increase its damping property.

The roof of the archery gymnasium is made of steel, but is not treated with a damping material (i.e., conventional metal roof). Through this measurement, we clearly confirmed the effectiveness of noise-reduction; the level of the noise at the roof treated with the damping material was around 3 dB lower than that at the conventional metal roof.

In addition to this result, we anticipated that the noise level would increase 5 dB if precipitation doubled.

From these results we estimated noise levels within a large space using a sound propagation equation from the plane sound source.

1. INTRODUCTION

The noise of rain striking a metal roof is much greater than that on a slate or tiled roof, and this may cause problems for a house-owner and neighbors. Therefore, there was demand for a metal roof that reduced this noise.

At Furukawa Electric, we have developed Shizuka-Ace, which is a heat-insulating material with damping properties for a metal roof that reduces the noise of rain and is also lightweight with good fabricating properties and ease of installation.

Shizuka-Ace is composed of three layers. The first is a layer of damping resin, the second is made of aluminum sheet, and the third is cross-linked polyethylene foam.

We laminate Shizuka-Ace directly to the inside surface of a metal roof by making use of the adhesive properties of the damping resin. The functions of Shizuka-Ace are obtained from the sandwiched structure, with the damping resin between the aluminum sheet and the metal of the roof. As a result, this structure can efficiently absorb vibrating energy caused by striking rain as internal attenuation.

In addition to this damping property, Shizuka-Ace also can function as a heat-insulator to prevent dew from being generated on the surface of a metal roof because of the

Photo 1 **View of Chouyo martial arts gymnasium (main building).**

Photo 2 **View of Chouyo martial arts gymnasium (archery building).**

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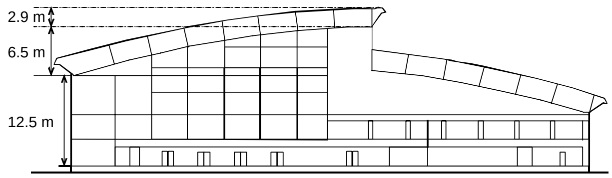

Figure 1 **Cross-section of Chouyo martial arts gymnasium.**

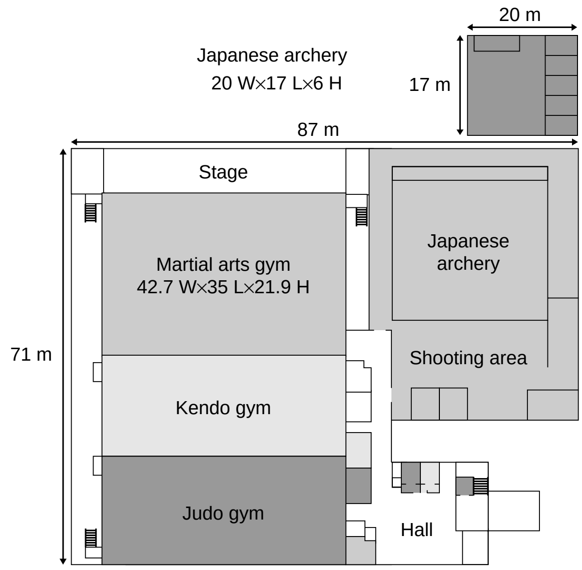

Figure 2 **Plan view of Chouyo martial arts gymnasium (1st floor).**

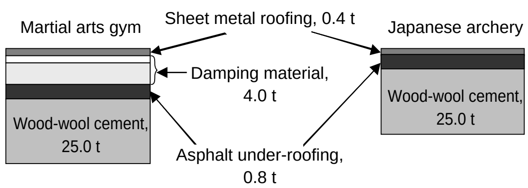

Figure 3 **Schematics of construction of roof structures.**

heat-insulating property of cross-linked polyethylene foam. So, Shizuka-Ace can function as both a damping and heat-insulating material for a metal roof.

We evaluated the properties of Shizuka-Ace in an experiment with a small sample using a water-drop vibrating source or artificial rainfall equipment; however, we have few measurements of its effectiveness when applied to actual buildings.

Fortunately, we had an opportunity to take measurements at a martial arts gymnasium, which is located in Tsuruoka-city, Yamagata-prefecture, Japan and in which Shizuka-Ace is applied. In this gymnasium, we simultaneously measured sound pressure levels at inside spaces of two buildings to compare the effects of damping treatment on a metal roof. One is the main building whose roof is treated with Shizuka-Ace, and the other is a building for Japanese archery annexed to the main buildings whose roof is not treated (i.e., conventional installation).

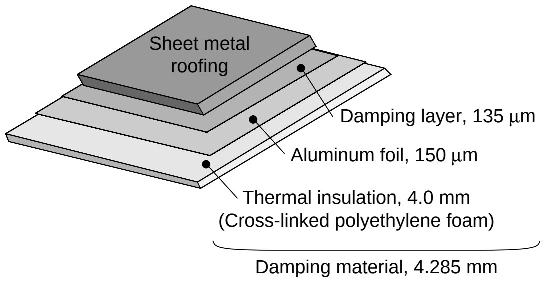

Figure 4 **Schematic illustration of constrained damping materials (Shizuka-Ace).**

2. Measurement

2.1 Specification of Measured Roof

We measured noise inside Chouyo martial arts gymnasium caused by rain striking the metal roof. Figures 1 and 2 are first floor plans of Chouyo martial arts gymnasium.

Measurements were taken at two buildings. One is in the main building where the roof of the main martial arts room is treated with Shizuka-Ace. The other is a room in the building for Japanese archery, where it is annexed to the main building and the roof is not treated with a damping material (i.e., conventional installation).

The dimensions of the measured space are as follows,

- Dimensions of main martial arts:
  42.7 W/ 35.0 L/ 21.9 H (23,730 m^2)
- Dimensions of Japanese archery gymnasium:
  20.0 W/ 17.0 L/ 6.0 H (2,040 m^2)

We divided the main martial arts room into small three spaces with mobile partitions for the convenience of measurements.

We show schematics of the construction of the roof structures in Figure 3, from which it can be seen that both structures are almost same except for the use of Shizuka-Ace; however, the building for Japanese archery has an air-space between the roof and the ceiling.

The specification of Shizuka-Ace, which is one of our heat-insulating products, is cross-linked polyethylene foam (4 mmt, 0.10 kg/m^2), aluminum sheet (0.15 mmt, 0.43 kg/m^2) for the constrained layer, acric resin (0.135 mmt, 0.15 kg/m^2) for viscoelastic damping treatment, and polyethylene-coated paper for separator. A schematic illustration of Shizuka-Ace is shown in Figure 4.

To show the damping property, we show the frequency dependency of the loss factor of Shizuka-Ace in Figure 5. These data are obtained from a test using a small steel-beam (0.4 mmt, 300 mm x 300 mm) by mechanical impedance method.

2.2 Measuring Method

We set three noise-meters along vertical positions under the measured parts of the roof as shown in Figure 6.The first noise-meter was set 0.3 m from the surface of the roof, the second was set at the middle of the space 5.0 m from the surface of the roof, and the third was set at a standing position 20 m from the surface of the roof. In the Japanese archery gymnasium we set one noise-meter 0.3

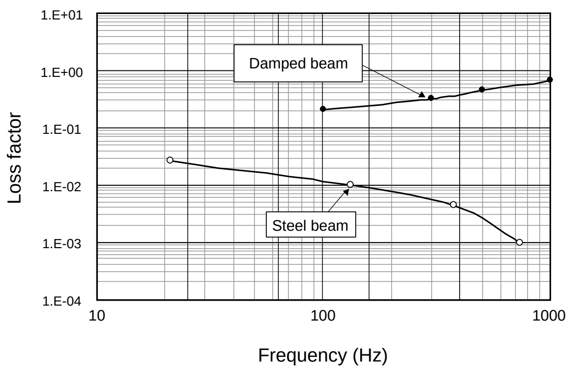

Figure 5 **Experimental results of loss factors for beam plates of damping material and steel roof.**

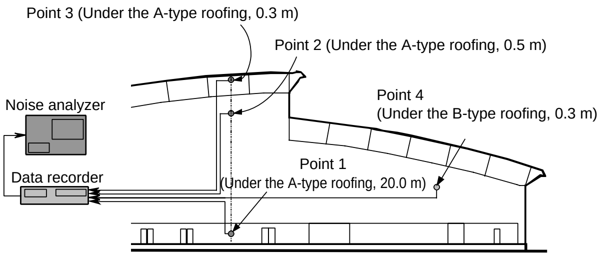

Figure 6 **Schematics of measurement position and set-up for measurements.**

m from the surface of the roof .

We used the same type of noise-meter produced by Rion Co. (Rion NL-05) and recorded the noise using a data recorder produced by Sony (PC208Ax). We also monitored precipitation using a rain collector produced by Davis. Then we measured rain noise simultaneously.

After gathering these data, we analyzed the noise by frequency using Rion Co. (Rion SA-30). We analyzed the sound pressure level and the A-weighted sound pressure level (we call this the noise level) according to the one-third-octave band.

Photos 3 and 4 were taken when the measurements were performed.

To check acoustic properties of the measured locations, we generated white noise from a speaker positioned at each location and calculated the reverberation time of the space from the acoustic property measurements as the all-path value after switching off the noise generator.

3. RESULTS OF MEASUREMENT

3.1 Frequency Dependency

When the precipitation reached 4.9 mm/hr, 7.7 mm/hr, 10.4 mm/hr, 15.7 mm/hr, and 17.1 mm/hr, we analyzed the noise measured at both locations --one treated with a damping material and one not treated, using a frequency analyzer. Then we evaluated the noise level at the frequency in accordance with the center frequency of the one-third-octave band. We show the noise level measured for the precipitation of 15.7 mm/hr in Figure 7. We can see a clear difference between the two types of roof with the exception of 800 Hz, especially at the medium and high bands of noise frequency. This result agreed with the frequency loss factor shown in Figure 5. In addition, we plot these data on the NC-Curve in Figure 8. From the plot, the noise level at the middle of the measured space and the standing position under the roof treated with damping material is at a low level of NC-50, and a level would not disturb our conversations in this space during heavy rain.

Photo 3 **Measurement points in the main building.**

Photo 4 **Measurement points in the Japanese archery building.**

3.2 Precipitation Dependency

We plot each noise level data for both types of roof in Figure 9 with an approximated curve and the equation on the plotted curve.

3.3 Reverberation Time

We show the reverberation time for each measured point in the martial art room and the Japanese archery gymnasium in Table 1 as all-path values. These values were calculated from acoustic property measurements as averages of values measured three times.

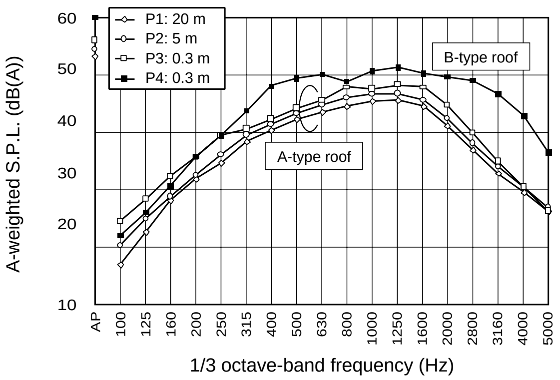

Figure 7 Results of typical one -third octave band frequency spectra.
A-weighted sound pressure level (Precipitation: 15.7 mm/hr)

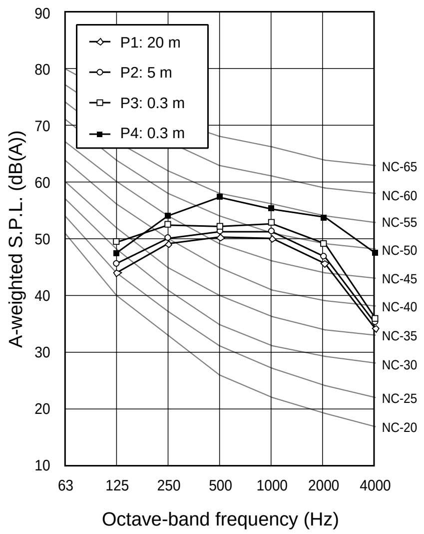

Figure 8 Determination of Noise Criterion at each position. (Precipitation: 15.7 mm/hr)

4. PREDICTION OF ROOM ACOUSTICS

4.1 Theory of Room Acoustics

If the measured room is assumed to be a perfect diffuse field, the energy density of noise generated by raindrops in the room is the same at all parts of the room. However, the noise level of the measured point, which is near the sound source of the roof, is actually higher than of all the others.

As the sound comprises direct sound from the sound source and reflected sound from the surrounding wall mixed in the actual room, the sound pressure level differs at different parts of the room. We can assume that the noise is radiated from the roof equally and the plane comprises infinite point sources on the roof.

As shown in Figure 10, in general, under a plane source having a rectangular shape ($a \times b$), the sound pressure

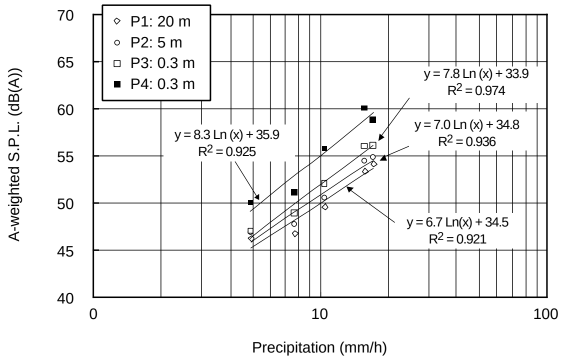

Figure 9 Relationship between fitting curve and overall A-weighted sound pressure level at each position as a function of precipitation.

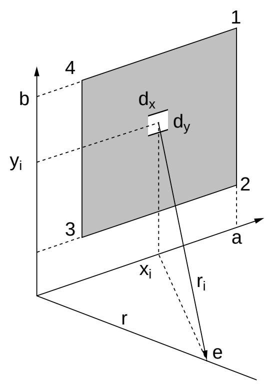

Figure 10 Calculation model for evaluating sound propagation from a finite large plane radiating source.

Table 1 Results of reverberation time at each measurement point.

Measurement points		Reverberation time	Absorption coeff.	Room constant	Room volume (m^3)	Room area (m^2)
A-type roof	P1 : 20m	2.98	0.274	2410	32730	6392
	P2 : 5m	2.51	0.325	3079		
	P3 : 0.3m	2.39	0.341	3314		
B-type roof	P4 : 0.3m	1.83	0.158	211	2040	1124

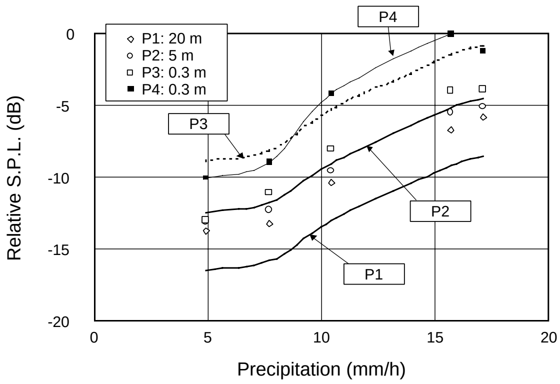

Figure 11 Comparison between predicted and measured relative sound pressure levels as a function of precipitation.

level of the observed point located *r* vertical distance from the sound source is given by the following equation.

$$L_r = L_w - 8 + 10\log_{10} U$$

Where,

L_r: Sound pressure level at the observed position (dB)

L_w: Power level of the sound source per unit area (dB)

U: Approximated equation of distance attenuation of the plane source having a rectangular shape

$$U = \pi/2 \ln \frac{(A+\sqrt{1+A^2})(B+\sqrt{1+B^2})}{A+B+\sqrt{1+A^2+B^2+kAB}}$$

$A = a/r,\ B = b/r$

$k = 0.727$

It is possible to predict the sound pressure level if the distance *r* from the plane source is given.

The sound power level of the sound source per unit area L_w given in the above formula can be calculated from the following procedure.

We calculate the total sound power level of the plane source from the measured sound pressure level in the diffuse field and the sound absorption level calculated by the reverberation method. Then, we convert the total sound power level into the power level of the sound source per unit area by dividing it by the area of the plane source.

4.2 Comparison of Predicted Value with Measured Value

First, we converted both the sound pressure level at each measured point and the predicted level into the A-weighted noise level and we standardized each level to be 0 dB in the case of the noise level of 15.7 mm/hr precipitation at the Japanese archery gymnasium. We show the comparison as the relative sound pressure level through the above standardization in Figure 11.

From this standardization, the predicted relative sound pressure level agreed with the measured one. (This is attributed to the fact that measurement was done at one point only.) In the martial arts main room, we found that the predicted values measured just under the roof, mid-way to the roof, and standing position, tended to decrease gradually by 3~4 dB.

5. DISCUSSION

In this measurement, we clearly confirmed that the effectiveness of the roof treated with a damping material was 3 dB lower than that of the roof not treated with damping material. Naturally, the effect varies whether or not there is a ceiling and depends on sound absorption. However, as we measured the noise level at just 0.3 m from the roof in both buildings, so we can easily isolate the effects of Shizuka-Ace.

Of course, increasing precipitation increases the overall A-weighted noise level, regardless of the types of roof. We estimate an increased level of 5 dB if precipitation is doubled. In addition, when comparing each coefficient of noise-increasing rate, the value is larger for the roof not treated with damping material than the roof treated with damping material. Therefore, the noise increase for the roof not treated with damping material is greater than that of the roof treated with damping material.

When we evaluated the sound pressure level for 15.7 mm/hr of precipitation, in the building for Japanese archery (roof treated with damping material) the NC value reached NC-55, but in the martial arts building the NC value was NC-52. This means that the sound power level from the roof was halved. The sound pressure level in the martial arts building just under the roof, the mid-way to the roof, and standing position each differed by 2 dB. If the roof of the martial arts building had not been treated with damping material, the NC value would have been over NC-50 mid-way to the roof and also at a standing position. We think that treating the roof with damping material keeps the NC value under NC-50. Therefore, we judge that noise level can be kept at a level at which our conversation would not be disturbed during heavy rain in the martial arts building at both positions: mid-way to the roof and at a standing position.

As shown the predicted value in Figure 10, in terms of relative sound pressure levels, these fit in the measured values, and the difference between the predicted value and the measured value is within 4 dB; however, we can see that the predicted values are overestimated by distance attenuation. Therefore, it is necessary to study further how to calculate the total sound power level from the roof, sound diffusion property, and reverberation property in the room.

6. SUMMARY

We confirmed that the noise level for the roof treated with damping material was 3 dB lower than that of the roof not treated with damping material, and that as precipitation increased, the noise level became higher.

Then overall A-weighted sound pressure level increased almost in proportion with precipitation.

We anticipated that the noise level would increase 5 dB if precipitation doubled.

Comparing the estimated noise level as relative sound pressure level with the measured data, it showed good agreement for the tendency of precipitation and the difference between the estimated level and measured data was within 4 dB.

7. FUTURE WORK

To develop damping materials and reduce cost, it is necessary to study the correlation between noise level and loss factor of damping material. When we design a building, as well as acoustic properties, it is possible to overestimate the effect of noise reduction if we adopt the same equation as that we introduced here, therefore, it is also necessary to introduce a more precise equation that considers the acoustical condition inside the building.

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