Generation and its control of impact sound by stick-slip phenomenon in buildings
- (1) Property of impact sound and vibration -

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This paper describes the basic study on unknown structure-bone sound generated in buildings. In the early investigation of these impact sounds, the cause of generation was related to the repeated friction motion at the concrete beam joint induced by the thermal stress of the sunshine (Generation and the measures of impact sound by stick-slip phenomenon at beam joint in buildings (the first report), Meeting of the Acoustical Society of America, June, 2007) [1]. In this study, many kinds of data of the impact sound and vibration had been gathered and more investigation was carried out. The typical impact sound and vibration and their frequency characteristics were discussed in detail based on the hypothesis that most of the causes of the generation of unknown sound in buildings depends mainly on the stick-slip phenomenon.

1 OUTLINE

The inhabitants of high-rise apartment buildings registered some loud and unidentified sounds. We observed the sound several times over an hour which was at most about 70dB A-SPL in the room. We observed the weather conditions (daylight and temperature). We thought the cause of this sound was friction force due to the thermal expansion of the concrete. We focused on measuring the vibrations several times. We estimated the position of the waveform generated from the arrival time differences (Fig. 5). The position was determined from the structure of the building's outer frame. It was generated from the joint portion of the verandah beam. After carefully measuring the vibration frequency, we could clearly specify that the cause

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of generation was "stick-slip phenomenon" which was due to the thermal expansion of the concrete structure.

2 INVESTIGATION OF SOUND AND VIBRATION

2.1 Method of research

In the case of solid-borne sound it is difficult to determine the direction of the sound by just measuring it. Therefore, in order to identify the source of the vibration in a plane slab we focused on the vibration-wave form (phase), which was being generated from an unknown source and then propagated in the building frame. We indicate the measurement location in Fig. 1.

2.2 Property of sound and vibration

This sound was being generated frequently in several rooms in the upper floors of the high-rise apartment building. It occurred when the largest number of vibrations was more than 30 times a day at its peak. The biggest sound level was 72dB A-scale (vibration acceleration level 96dB) in the room. The Table 1 shows the measurements of the sound and vibration and the frequency characteristics can be seen in the graphs (Fig. 3, Fig. 4).
The sound waveform had a uniform level of frequencies from low to high which is the nature of the impulse (Fig. 8, Fig. 9).

3 ESTIMATION OF CAUSE

3.1 The method of search for the source of the sound

The vibration accelerometers were arranged in two-dimensional distribution on the floor slab. We could calculate the occurrence of vibration from the phase differences between the wave forms of the observed vibrations. We show the estimated position in Fig.7. That position is near an outside beam joint where we found a tiny crack. A part of the verandah beam (6m in length, 5t in weight) was not fixed completely (Fig. 7). We have judged that the contact points of the beam joints continue to expand and contract with changes in temperature.

3.2 Structure of the outer frame of the building

The beam joint is vertically connected by a metal plate and bolt in two places. The metal plate was too weak so that the beam itself moved. Due to thermal stress, slip occurs at the contact surface of the concrete structure. We found that the shock wave was generated by this stick-slip phenomenon.

3.3 Property of the sources

We have observed the stick-slip phenomenon even in buildings with steel frame structure and found similar wave forms. The wave form gradually decreases as it travels over distances. Finally, the shock wave is amplified by the space of the walls and ceiling and is then emitted into the room.

4 CONSIDERATIONS

4.1 Contact surface of an object

If we could see from the microscopic point of view, the plane contact is not smooth at all. The two rough surfaces overlap and assist each other at contact points called "Area of real contact". Each of the real contact points were moved by the shear stress of the thermal stress and static friction force turns into kinetic friction force[2].

4.2 Temperature Variations

The coefficient of thermal expansion of steel and concrete is approximately equal (about 1×10^{-5} / K)[3]. Therefore a 6 meter precast concrete beam will move about 1 millimeter with a 17°C shift. Fig. 11 shows the rapid change in temperature due to sunshine on the verandah.

5 CONTROL OF GENERATION

5.1 How to Repair

There are two ways to prevent stick-slip phenomenon.

1. Sliding joint.
2. Fixedly beam joint.

In a technical study we bonded the beam joint with a liquid epoxy resin injection and we filled the gap in the beam with grout. This procedure was repeated in more than 100 locations.

5.2 Effect of the treatments

As a result, the joints were fully integrated and the impact sound has not re-occurred since then. Even after the Great East Japan Earthquake last March there has been no report of the re-occurrence of impact sound, we are convinced of the effectiveness of this repair method.

6 CONCLUSION

This is a rare case of sound trouble of the building. But we can say that the stick-slip phenomenon occurred in many areas of building. In particular a) the verandah railing b) the joints in the curtain wall and c) the bolt and nut connections in the steel structure.

7 REFERENCES

1. Yasuaki Hayashi and Hidemaro Shimoda, "Generation and the measures of impact sound by stick-slip phenomenon at beam joint in buildings (the first report)", *Meeting of the Acoustical Society of America,* Hilton Salt Lake City Center, Salt Lake City, Utah, (2007)

2. F.P. Bowdent and D. Tabor, "The Friction and Lubrication of Solids", PP.19-110, Clarendon Press, Oxford, (2001)

3. "Chronological Scientific Tables", PP.397-398, Natural Institutes of Nature Sciences, (Japan) (2004)

Table 1 – Table of measurement data.

Data No.	Date	Time	Temp. ℃	First Obs point	Vibration Acceleration Level (dB)								A weighted sound pressure level (dB)			
					V1	V2	V3	V4	V5	V6	V7	V8	S1	S2	S3	S4
01	3/25/05	5:00:37	6.4	V4	76.4	94.3	82.1	94.0	82.2	88.1	87.5	86.5	70.9	68.3	66.3	55.8
02	3/25/05	5:04:33	6.4	V3	91.7	78.2	91.5	80.7	88.0	78.5	89.5	74.3	74.1	66.5	67.1	57.9
06	3/25/05	20:21:52	5.8	V3	86.1	71.0	87.6	73.9	82.2	71.7	81.4	67.4	66.7	59.1	59.8	53.8
07	3/25/05	20:41:25	5.5	V4	79.9	96.1	85.7	95.7	85.7	91.8	90.3	89.6	74.2	72.0	70.2	62.2
08	3/25/05	21:42:30	5.5	V4	79.9	96.1	85.8	95.7	85.7	91.8	90.3	89.7	74.3	72.0	69.9	62.2
09	3/25/05	22:42:41	5	V4	79.3	95.7	85.1	95.7	85.1	91.4	89.9	89.1	73.9	71.7	69.7	62.0
09-2	3/25/05	23:05:53	5	V3	82.7	81.0	89.5	83.2	89.5	91.4	91.1	76.8	67.4	63.9	67.1	59.9
10	3/26/05	23:44:40	5.1	V4	78.9	95.8	84.6	95.5	84.7	91.1	89.8	88.7	73.6	71.5	69.5	61.9
10-2	3/26/05	0:07:09	5.1	V3	92.1	77.9	91.7	80.5	88.4	77.8	88.2	74.1	74.0	65.9	67.0	58.4
11	3/26/05	0:45:42	4.5	V4	78.5	95.6	84.2	95.2	84.2	90.6	89.1	88.2	73.2	71.1	68.9	61.6
12	3/26/05	1:52:41	4.6	V4	78.8	95.7	84.3	95.3	84.4	91.0	89.4	88.2	73.5	71.3	69.3	61.5
12-2	3/26/05	1:53:38	4.6	V3	91.6	77.6	91.2	80.1	87.9	77.3	88.0	73.6	73.3	65.7	65.8	58.1
13	3/26/05	2:54:47	4.1	V4	78.2	95.4	83.7	95.0	83.8	90.8	89.1	87.8	73.2	71.1	68.5	61.3
13-2	3/26/05	3:51:57	4	V3	90.2	76.6	90.0	78.7	86.6	76.1	87.2	72.5	72.0	64.8	65.8	57.9
14	3/26/05	4:04:34	4	V4	77.9	95.1	83.6	95.0	83.6	90.4	88.9	87.6	72.3	70.8	67.8	61.6
15	3/26/05	5:17:58	3.6	V4	77.7	94.9	83.3	95.0	83.6	90.1	88.5	87.5	72.3	70.3	68.0	60.4
15-2	3/26/05	8:37:00	20	V1	79.2	74.8	69.7	69.8	69.7	65.6	80.7	66.1	55.1	51.3	54.1	51.8
16	3/26/05	9:17:19	14.8	V4	77.0	94.1	82.1	94.8	83.2	88.8	89.8	88.1	70.8	70.2	67.5	61.3
17	3/26/05	11:55:21	10.5	V4	76.5	93.9	81.4	93.7	82.3	88.9	89.1	87.7	71.9	68.7	71.5	59.9
18	3/27/05	4:18:00	5.5	V4	77.5	94.9	83.1	94.3	83.3	89.3	88.4	86.8	72.0	70.1	67.7	60.6

Fig. 1 – Measurement points.

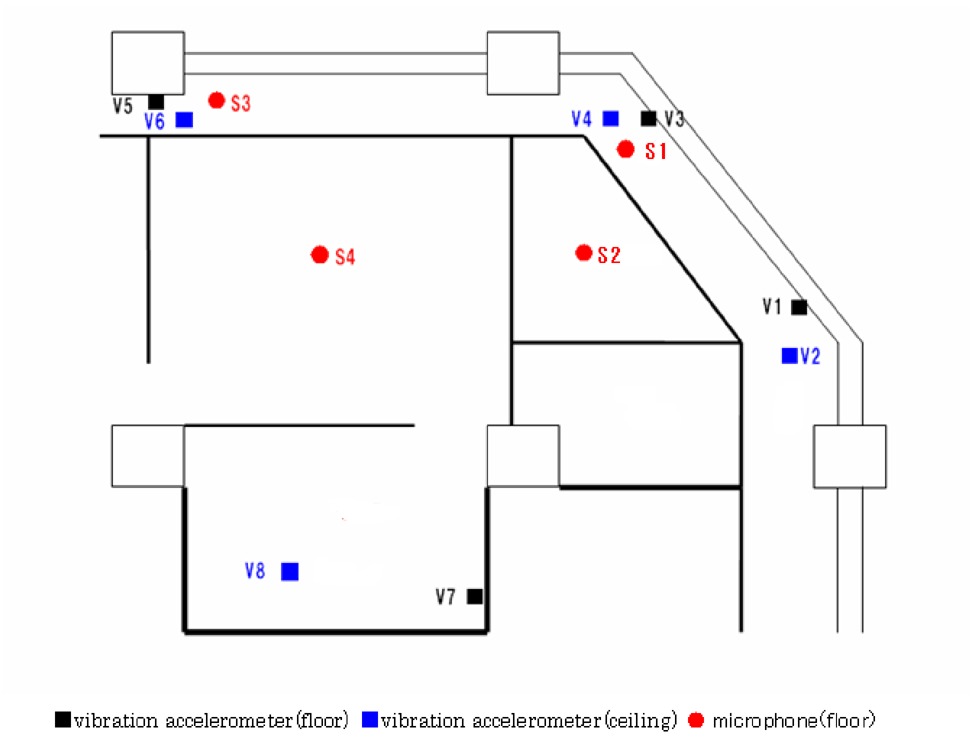

Fig. 2 – Observed vibration level.

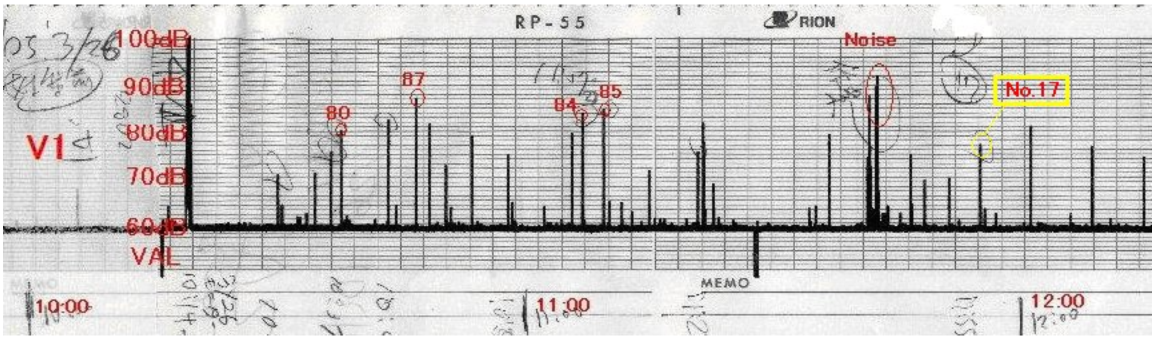

Fig. 3 – 1/3 oct-band spectrum of vibration.

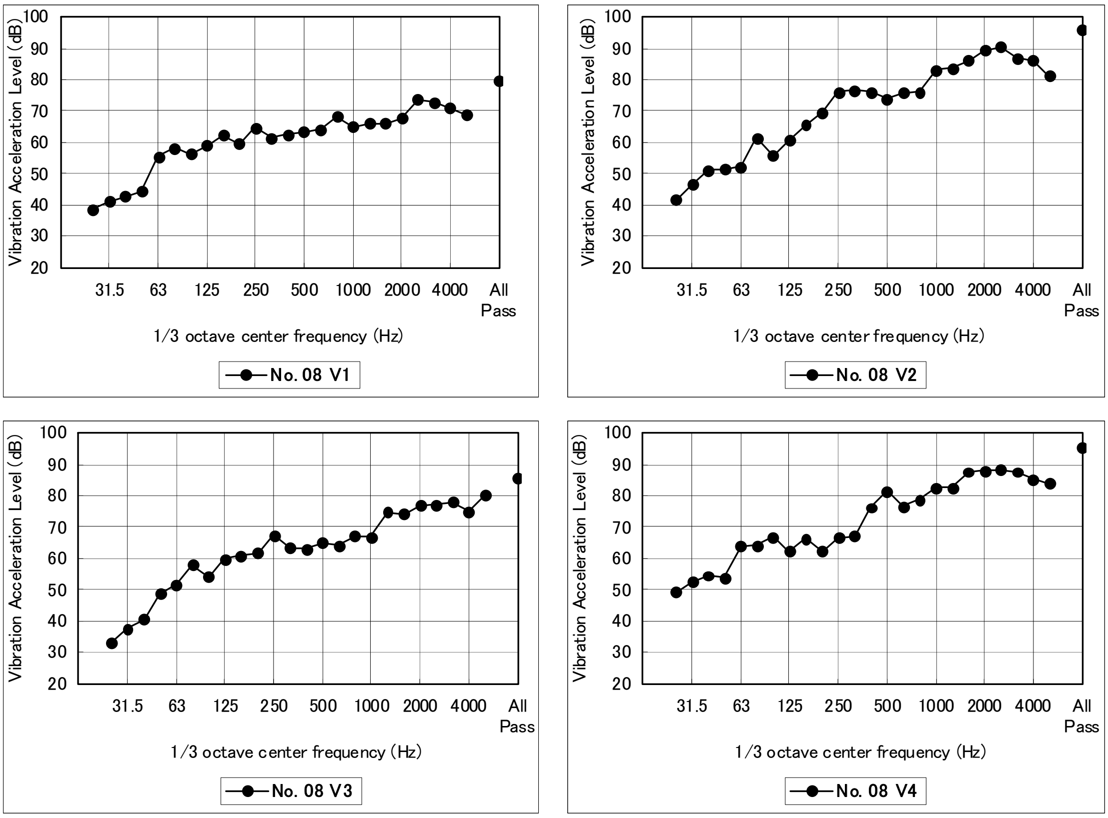

Fig. 4 – 1/3 oct-band spectrum of sound.

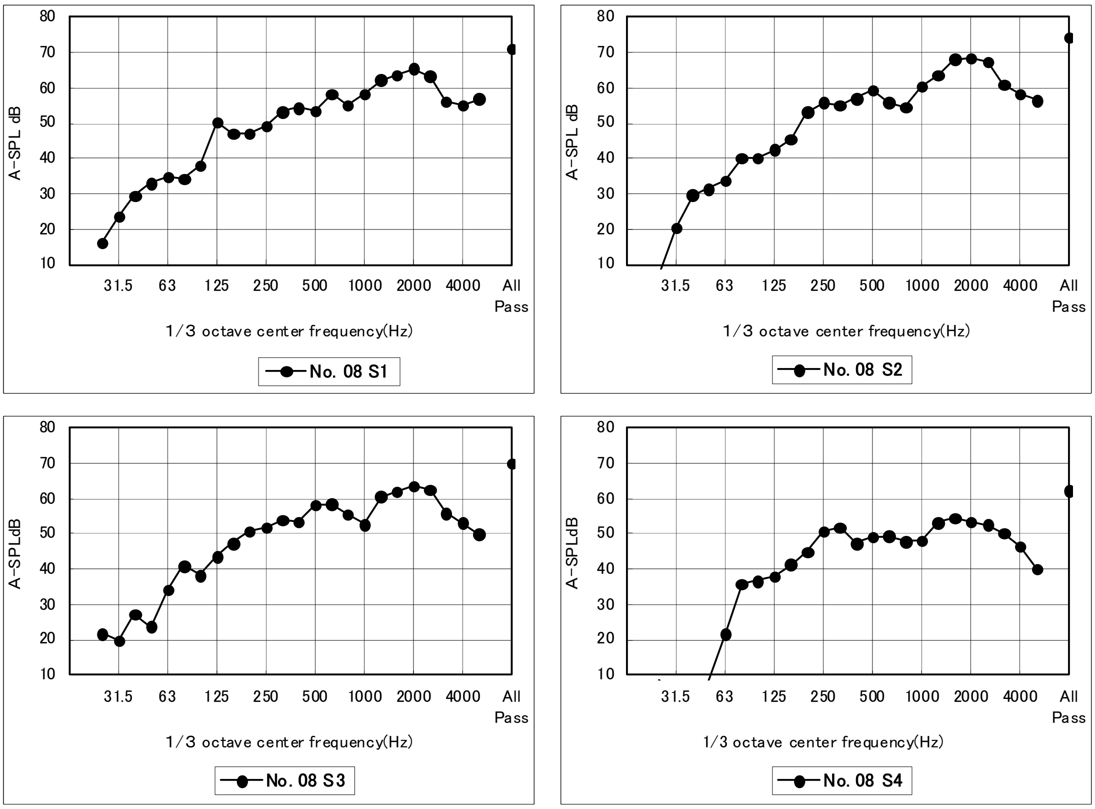

Fig. 5 – Example of observed phase difference in vibration-wave forms.

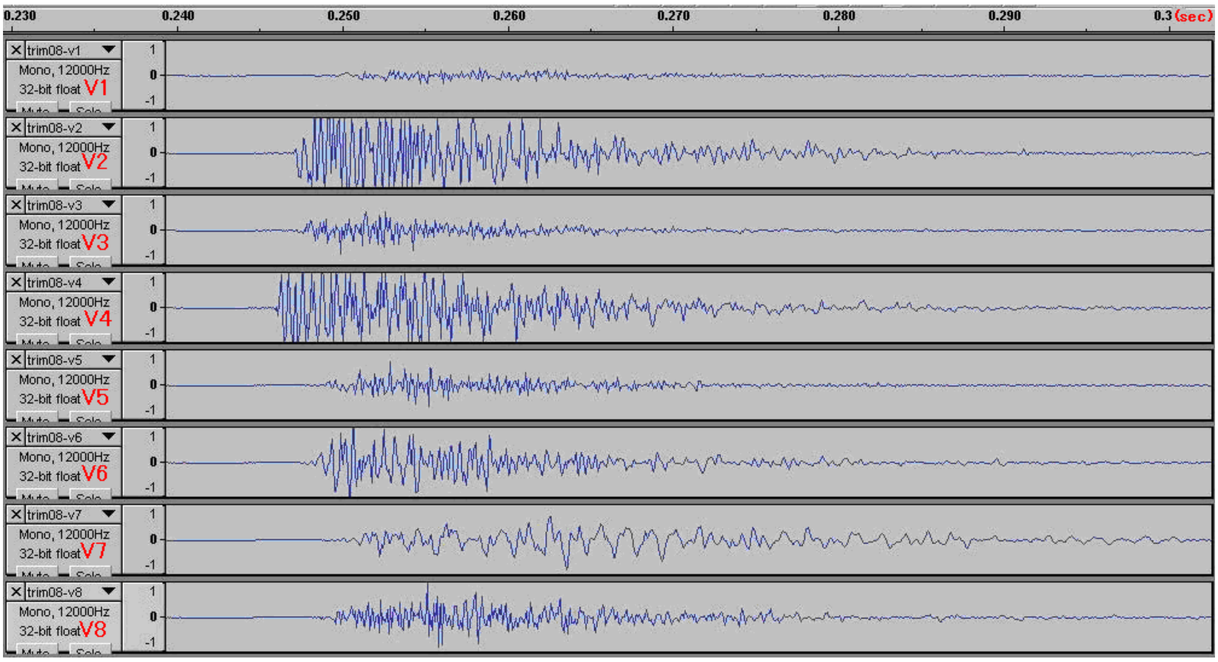

Fig. 6 – Estimated position of domain circle.

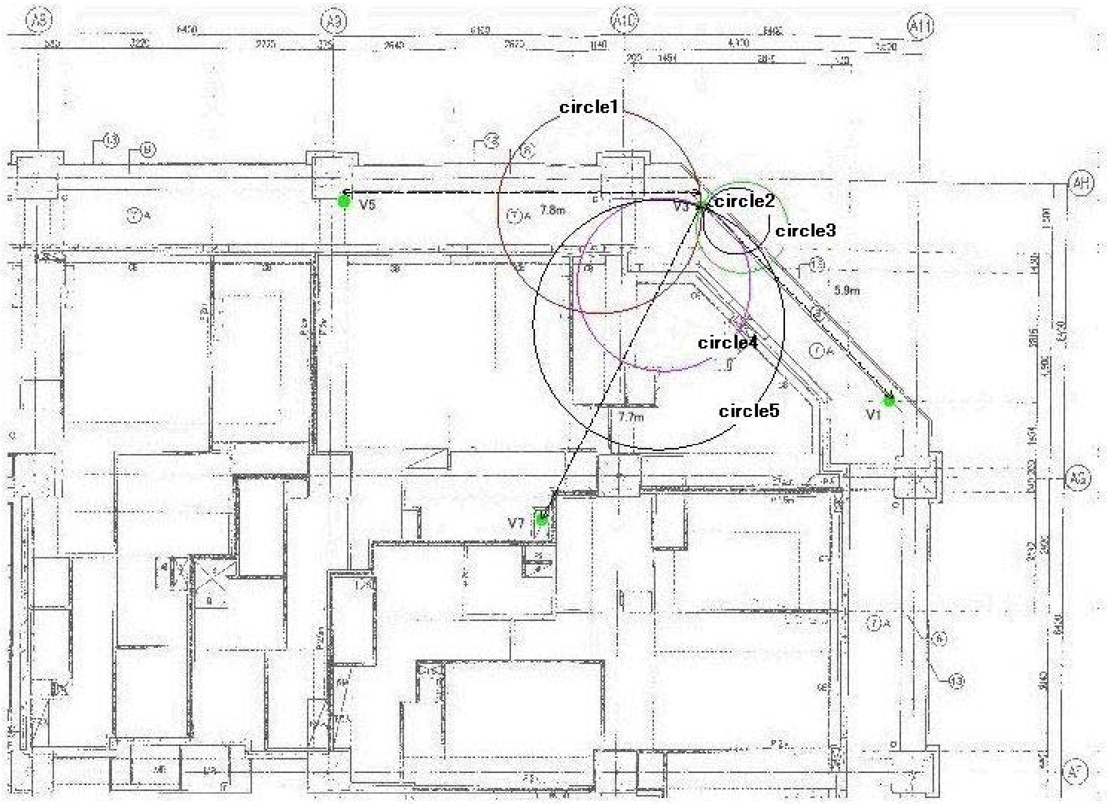

Fig. 7 – The joint area of the beam.

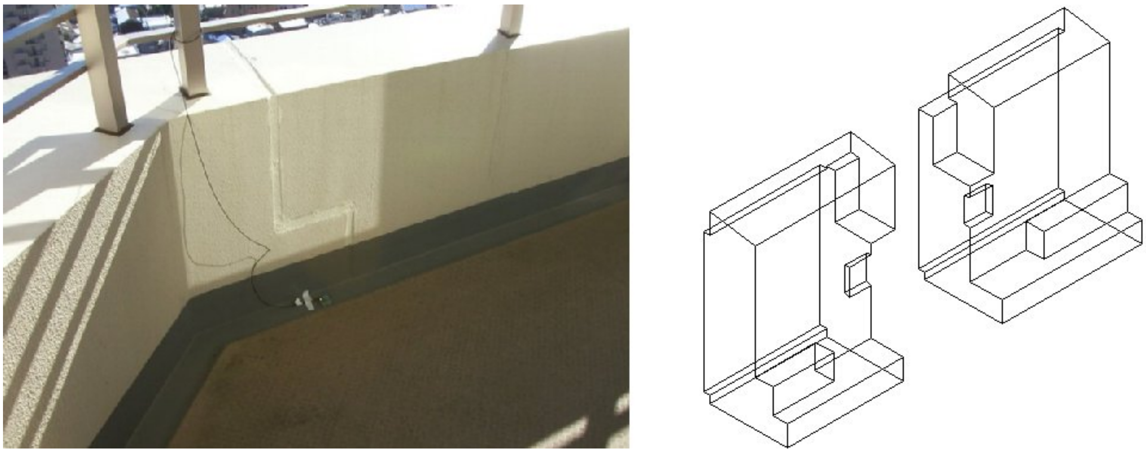

Fig. 8 – Impact sound-wave form.

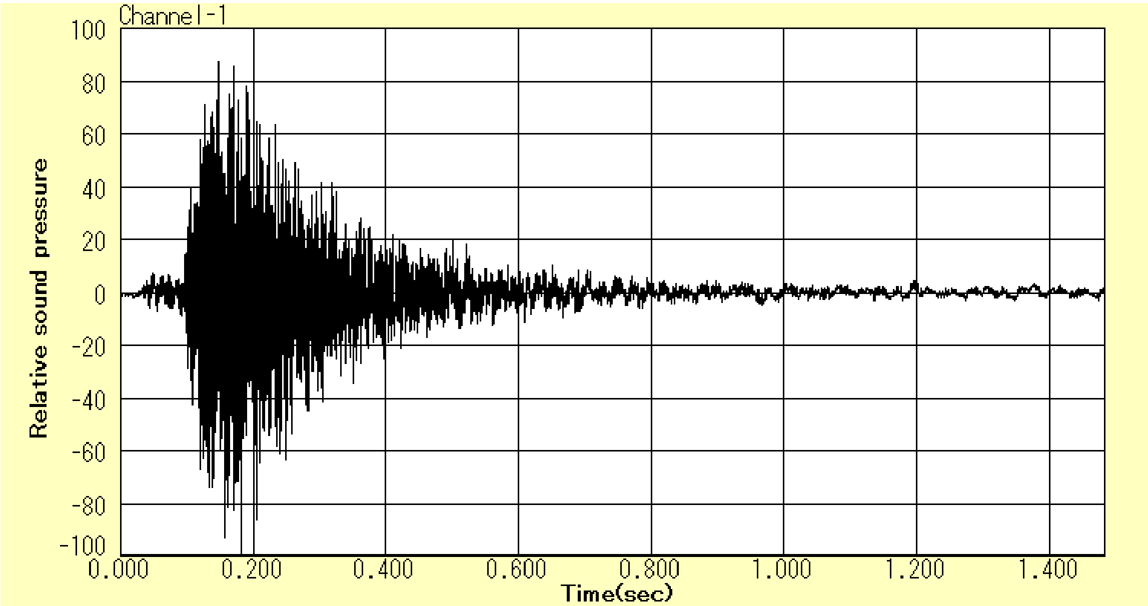

Fig. 9 – Power spectrum of sound.

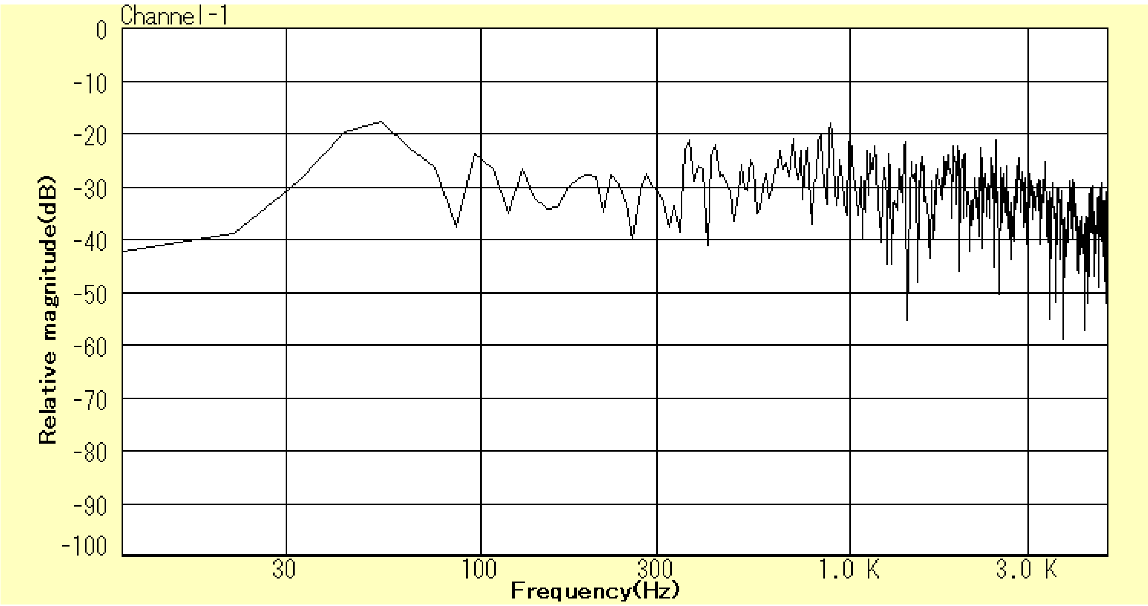

Fig. 10 – Concept of stick-slip phenomenon.

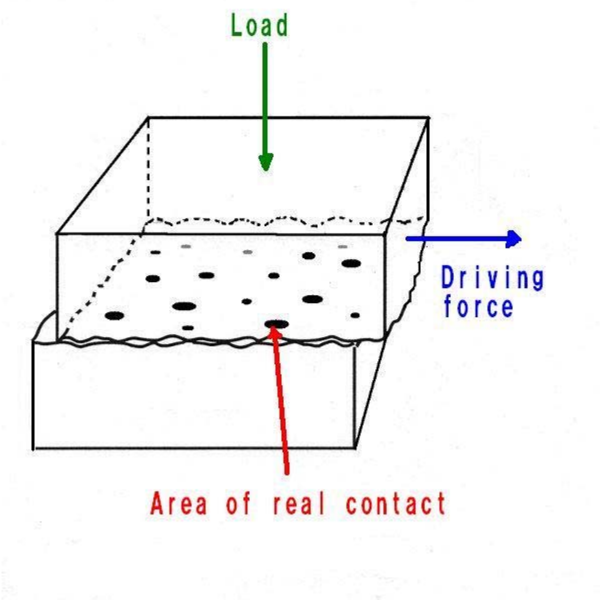

Fig. 11 – Temparatur of outside.

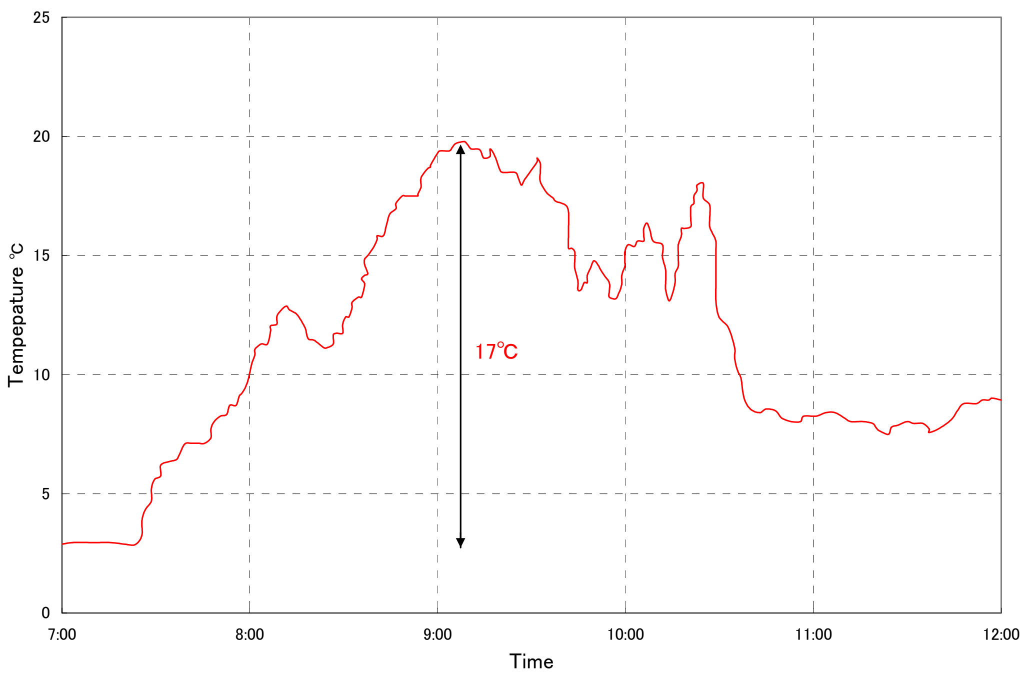

Fig. 12 – Viblation level chart. (after repairing)