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Mitigation Measures against Low-frequency Sound Caused by Discharging Water from Amagase Dam

N. Morinaga
Ministry of Land, Infrastructure and Transport, Kinki Regional Development Bureau,
Integrated Management Office of Yodo River Dam, Administraction Division
10-1,Yamadaikekitamachi, Hirakata-City, Osaka, 573-0166, Japan

ABSTRACT:
Amagase Dam was completed in 1964, which is a concrete arch dam on Uji River of Yodo River system that flows into the center of Kinki area. It is located in approximately 2km upstream from the center of the sightseeing spot in Uji City which has Byodo-in Temple registered as World's cultural heritage. It is also close to a residential area. There is the largest lake in Japan, called Lake Biwa, in the upper stream of Uji River. Along with the water-level control of Lake Biwa, the dam needs to be operated on large-scale discharged water comparable to the flow volume during times of flooding from the main sluice gate.
Because low-frequency sound caused by discharging water from the main sluice gate has drawn complaints from residents living in the vicinity of Amagase Dam in recent years, investigation of the low-frequency sound has been conducted since 2006.
This thesis reports the assumed mechanisms of low-frequency sound as the result of past investigations, and acknowledging this, informs an approach to mitigating the low-frequency sound by an alternative method of discharging waster.

Keywords: discharging water, low-frequency sound, mitigation measure

1. GENERAL INSTRUCTIONS

Amagase Dam was completed on Uji River of Yodo River system in 1964. It is a concrete arch dam whose height is 73m. It is also known as a multi-purpose dam whose purposes are flood control, supply of city water, and generation of electricity. There is a center of the sightseeing spot, such as Byodo-in Temple and Ujigami Shrine, in Uji City at approximately 2km downstream of the dam. Neighbourhood of the dam is dotted with the residential regions. (Fig. 1)

Normally, discharging water of Amagase Dam is operated through the power plant (maximum 186m^3/s) right under the dam. However, discharged water with large volume of flow is frequently conducted through the main sluice gate for a long time period (several weeks to about one month) when discharging water of Setagawa -Arai Weir is conducted to control the water level of Lake Biwa. Lake Biwa located in upper stream of Uji River is the largest lake in Japan. Amagase Dam is characterized by this operation that is a consecutive discharge for a long period. (Fig. 2)

It is identified that low-frequency sound is generated when water is discharged from the main sluice gate. Soon after the start of the management, complaints were made about the low-frequency sound from the left bank area. To respond those complaints, investigations of the low-frequency sound were conducted during 1974 to 1975. In recent years, complaints are made from the right bank area. To deal with this problem, investigation of the low-frequency sound has been conducted since 2006. Effects of the low-frequency sound that is identified in the local residential house are subtle because the effects, such as vibration of furniture inside the house, are detected or not detected depending on the different situations. Thus, investigation has been conducted under the various situations, such as different situation of discharging water. Moreover, mechanisms of generated low-frequency sound and possible mitigation measures have been considered.

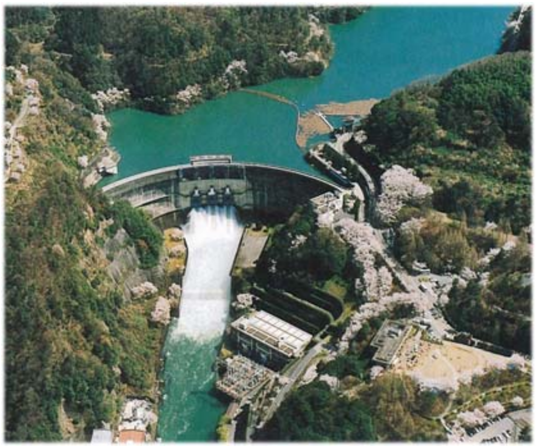

Figure 1. The whole view of Amagase Dam

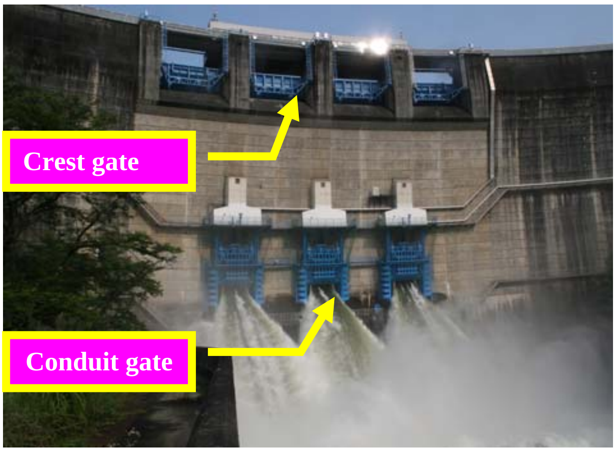

Figure 2. Discharge system of Amagase Dam

2. CONTENTS OF THE INVESTIGATION

Investigation of low-frequency sound was conducted at 4 spots close to the dam to reveal out the source and path of the low-frequency sound. In addition to 4 spots, the investigation was conducted at 12 spots of the right bank area and at 4 spots of the left bank area to assess the effects of the low-frequency sound on the residential areas. The farthest spot is more than 1 km from the dam. Wind speed was also measured since low-frequency sound is easily affected by the wind. (Fig. 3)

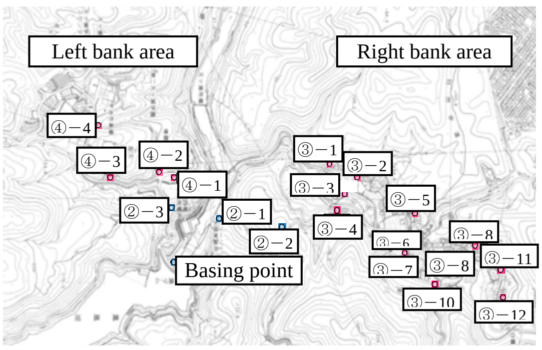

Figure 3. Investigation spot of low-frequency sound

Measurements were conducted by following "Manual about the methods to measure low-frequency sound (Ministry of the Environment, 2000)." The followings are the contents of the investigation at each study spot.

2.1. Investigation of the Relations with Water Volume Discharged by the Main Sluice Gate

To verify the relationship between discharged water volume and the level of the sound pressure, measurements of low-frequency sound under the various water volume discharged by the main sluice gate were conducted.

2.2. Investigation of the Relations with Patterns of Discharged Water by the Main Sluice Gate

There are 3 main sluice gates in Amagase Dam (from the left bank side, 1st built, 2nd built, and 3rd built). Under the normal circumstances, these 3 sluice gates discharge the same amount of water. Measurements of low-frequency sound about the following patterns were conducted so that it could be verified that how the sound pressure level changes depending on the number of the sluice gates used. (Fig. 4)

Pattern A: 3 sluice gates were used to discharge water (normally)
Pattern B: 2 sluice gates were used to discharge water (1st built+3rd built)
Pattern C: 2 sluice gates were used to discharge water (2nd built+3rd built)
Pattern D: 2 sluice gates were used to discharge water (1st built+2nd built)

Figure 4. Examples of patterns of discharge

Pattern A (Discharging water from 3 sluice gates)

Pattern B (Discharging water from 2 sluice gates of 1st built and 2nd built)

2.3. Investigation to Narrow down the Source of Low-frequency Sound

Multiple factors, such as main sluice gates, water film of discharged water from the main sluice gate, the part of stilling basin that discharged water falls into, resonance of space between water film and main body of the dam, and the overflow of water from stilling basin into the lower reaches, can be considered as the sources of low-frequency sound. To narrow down the sources of low-frequency sound, detailed measurements were conducted at the every single spot of stilling basin right under the dam. (Fig. 5)

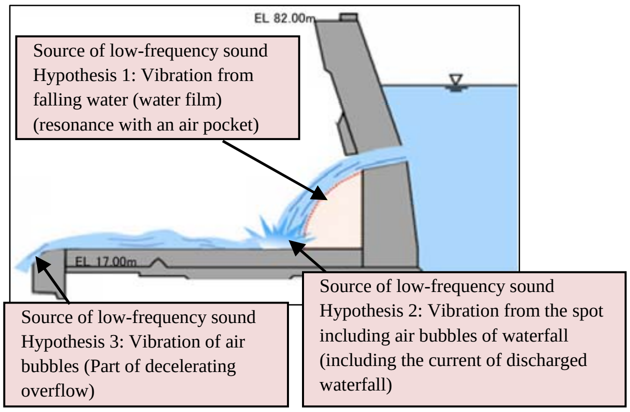

Figure 5. Assumption of the sources of low-frequency sound

3. RESULTS OF THE INVESTIGATION

Frequency analysis of sound pressure level and central frequency of 1/3 octave-band for measured data of low-frequency sound was conducted after processing the exclusion of cumbersome effects, such as noise. FFT analysis was applied to identify the characteristics of low-frequency sound in narrower area by using the part of the collected data so that it can be the useful reference to examine the occurrence factor.

3.1. Relationship between Discharged Water Volume and the Level of the Sound Pressure

Under the discharged water volume of approximately 400m^3/s (total discharged water volume, including the discharged water volume with generation of electricity, is 581m^3/s), the level of pressure of low-frequency sound increases as the discharged water volume increases. However, over the discharged water volume of 400m^3/s, the level of pressure of low-frequency sound remains on the same level. (Figs.6 and7)

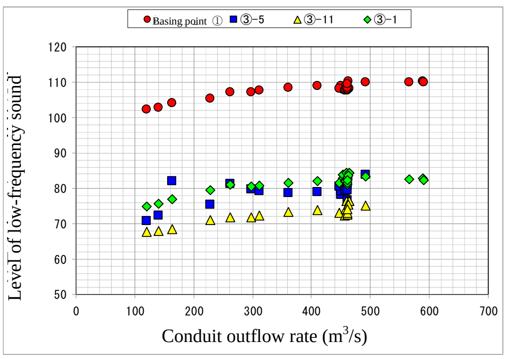

Figure 6. Relationship between discharged water volume and the level of the sound pressure (Basing point and right bank area)

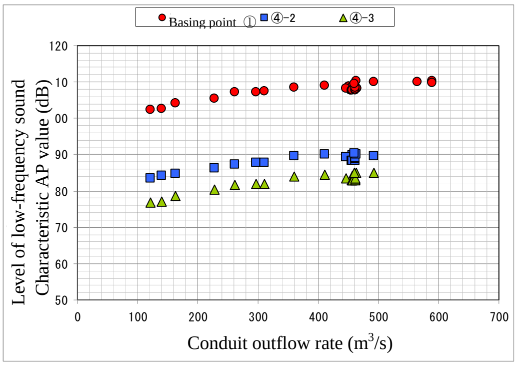

Figure 7. Relationship between discharged water volume and the level of the sound pressure (Basing point and left bank area)

3.2. Relationship between the Basing point and the Level of the Sound Pressure in the Neighbourhood Area

Compering it to the level of pressure of low-frequency sound at the basing point in the dam, the level of pressure of low-frequency sound in the right bank area decreases by approximately 20dB to 30dB regardless of discharged water volume. The pressure of low-frequency sound decreases by about 20dB in the left bank area as well.

3.3. Relationship between Frequency and the Level of the Sound Pressure

The frequency at the measured spots in each area will be largely different depending on the different discharged water volume if the band frequency is less than 20Hz. If the band frequency is over 20Hz, the sound pressure level will tend to decrease. The sound pressure level between 20Hz to 80Hz is nearly equal to background noise level in the absence of water volume discharged by the main sluice gate, especially in the right bank area. Moreover, at the band of 1.25Hz, the sound pressure level is in the same range regardless the discharged water volume. (Figs8and9)

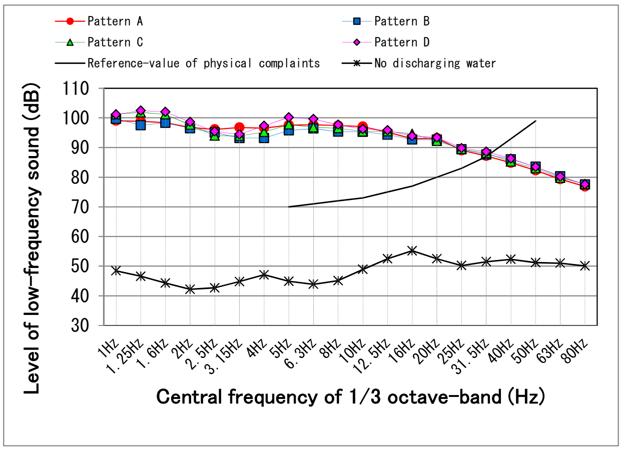

Figure 8. Relationship between frequency and the level of the sound pressure (Basing point)

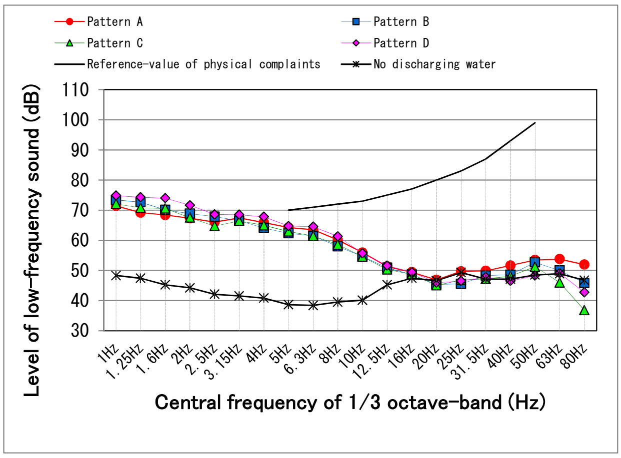

Figure 9. Relationship between frequency and the level of the sound pressure (Right bank area)

3.4. Relationship between Patterns of Discharged Water and the Level of the Sound Pressure

Figure 10 to Figure 12 show the difference in the sound pressure level caused by the different pattern of discharged water by the main sluice gates, which assumes that discharging water through 3 main sluice gates is the normal pattern (Pattern A). (Difference in the sound pressure level = Pattern A – Each pattern)

In each spot, discharging water through 2 main sluice gates (Pattern B) is most likely to decrease the level of low-frequency sound. Band 3.15Hz to 8Hz, especially, tends to decrease. At the basing point, the maximum decrease of about 4 dB was observed.

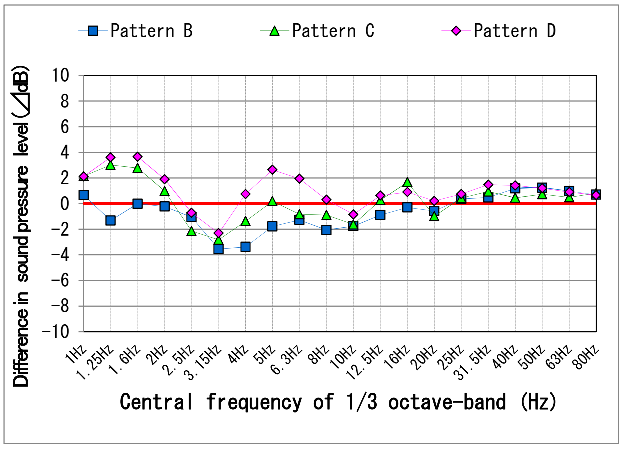

Figure 10. Relationship between patterns of discharged water and the level of the sound pressure (Basing point)

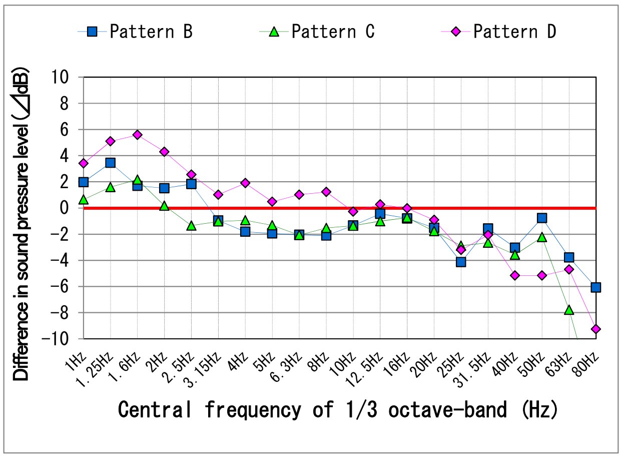

Figure 11. Relationship between patterns of discharged water and the level of the sound pressure (Right bank area)

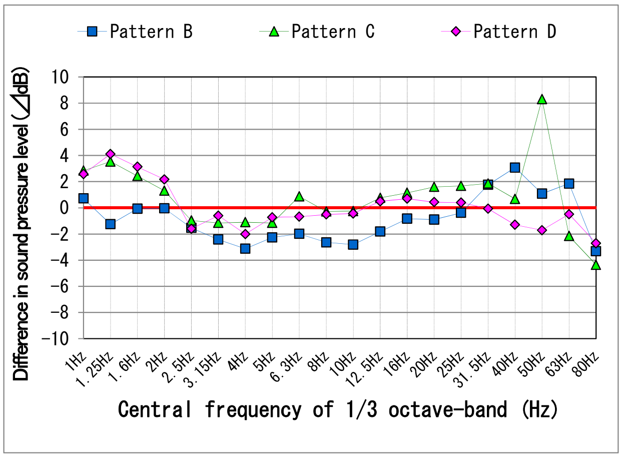

Figure 12. Relationship between patterns of discharged water and the level of the sound pressure (Left bank area)

3.5. Presumption of the Source of Low-frequency Sound

Figure 13 shows the contour of the sound pressure level based on the results of the measurement of low-frequency pressure near the stilling basin.

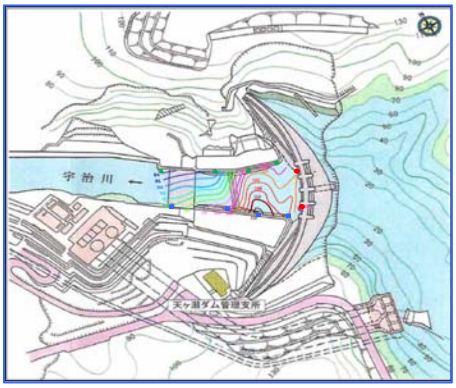

Figure 13. Contour map of the sound pressure level near the stilling basin

Since the highest sound pressure level was stilling basin, it can be cosidered that there is less possibility that the area from stilling basin to overflow section down the stream is the source of low-frequency sound.

Furthermore, as the result of the FFT analysis about the measurement result of basing point, several dominant frequencies were found. Figure 14 shows the result of FFT analysis and the dominant frequences. Higher amplitude was detected at 1Hz, 2.2Hz, 4.8Hz, and 6Hz. As Figure 15 shows, the time difference between the measured waveform in certain spots was analized. Table 1 shows its result. According to the result of the analysis, it was revealed that the source of low-frequency sound was probably different depending on the different frequences. Under 1 Hz, the sound travels from multidirections, including the lower reaches or the left bank side, so it can be considered that all-round stilling basin is the source of the low-frequency sound. Also, 2.2Hz reaches the spot A-3 faster, so it can be considered that low-frequency sound is generated from resonance with the space created by the arch dam. Moreover,4.8Hz and 6Hz is the fastest to reach the spot A-1, so it can be considered that the source of low-frequency sound is near the waterfall.

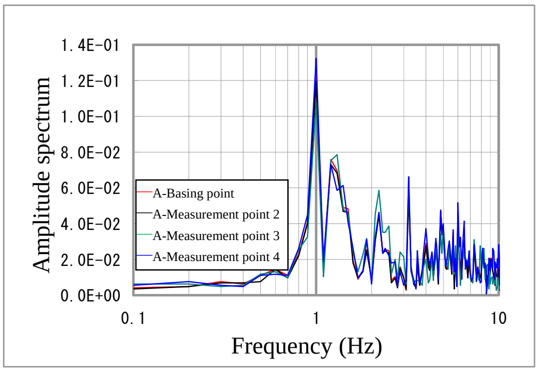

Figure 14. Results of FFT analysis

Investigation spot	Ground height	Horizontal distance based on spot A-1
	(m)	(m)
A-1	1.2	-
A-2	3.0	0
A-3	1.2	10
A-4	1.2	10

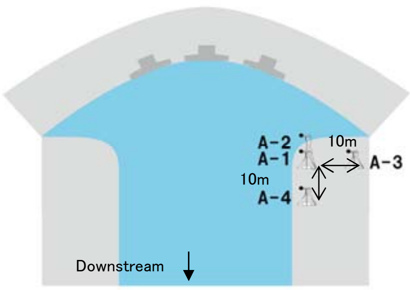

Figure 15. Investigation spot where the analysis of time difference was conducted

Table 1. Results of the analysis of time difference

Frequency	Time difference (sec.) ※Difference from A-1is written		
	A-2	A-3	A-4
1.0Hz	0.0127	-0.0422	-0.0444
2.2Hz	0.0072	-0.0047	0.0098
4.8Hz	0.0016	0.0153	0.0166
6.0Hz	0.0013	0.0281	0.0099

※Time difference is the difference from spot A-1

3.6. Estimation of the Travel Path of Low-frequency Sound

Figure 16 is the contour map prepared based on the results of the measurement, which contains the level of the sound pressure of low-frequency sound in the neighbourhood of the dam. As the contour map shows, the route along with the valley of the river joining on the lower reaches of the main river under the dam can be considered as a travel path of low-frequency sound in the right bank area. Additionally, the route crossing the mountain can be considered as a travel path of low-frequency sound in the left bank area.

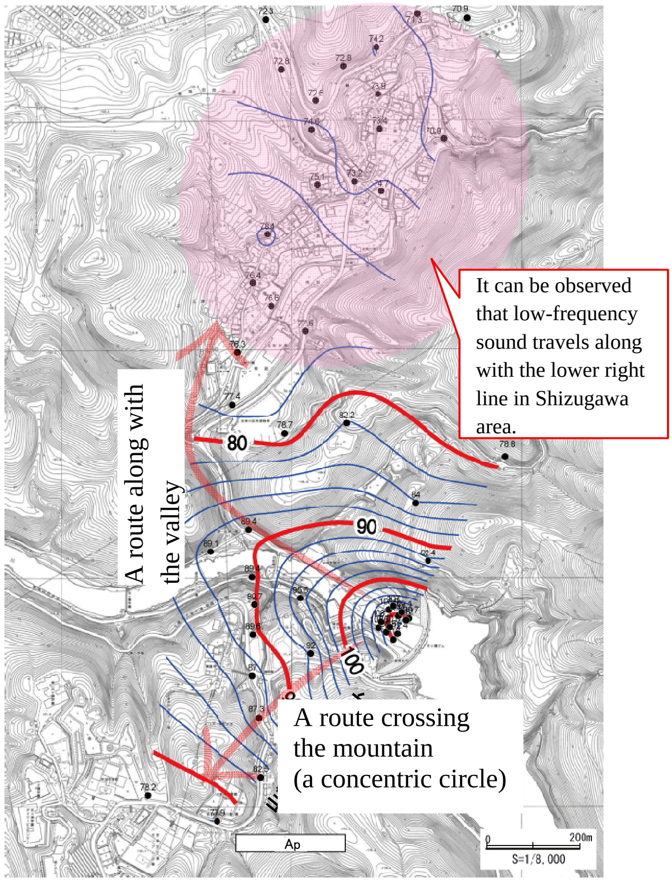

Figure 16. Contour map for the sound pressure of low-frequency sound in the neighbourhood of the dam

4. MITIGATIGATION MEASURES AGAINST LOW-FREQUENCY SOUND

Amagase Dam cannot be discharged water in the case of conducting flood control. It need to be discharged water through all main 3 sluice gates due to the limitation of the ability to discharge water under the circumstance of low reservoir level. However, when water is discharged for a long time periods along with controlling the water level of Lake Biwa, discharged water with generating electricity is conducted. In most cases, 2 main sluice gates can maintain the ability to discharge water due to the high reservoir level. Based on findings of investigations of low-frequency sound, discharging water by using 2 main outer sluice gates out of 3 main sluice gates has operated since May, 2011 on trial.

The reasons why using 2 outer sluice gate mitigate the low frequency sound can be phase shifting and change of resonance. The phase shifting is occurred when discharged water falls into the stilling basin. Change of resonance is caused by the space created between water film of discharged water and the body of arch dam under discharging water from 2 main outer sluice gates. The created space under discharging water from 2 main outer sluice gates is smaller than that under discharging water from 3 main sluice gates. Although those reasons are unspecified, mitigation of the low frequency sound is confirmed. It is difficult to operate an effective mitigation measure as long as using current method of reducing the flow of discharged water. Also, it is not easy to operate measures for sound path. Devising the management of the dam is only mitigation measures in the current situation. It was confirmed that sound pressure can be decreased by 2dB to3 dB according to the investigation conducted inside the building of maintenance facility of the dam that is most effected by low-frequency sound. This means that the loudness decreased by 50% to 60%. The vibration of the window obviously decreased inside the buildings in the maintenance facility.

On the other hand, some fittings are affected with vibration, and others are not in the houses that file complaints about low-frequency sound. Thus, investigation to know the starting point of vibration was conducted by using vibration exciter. As the result of the investigation, it was found that, in some cases, frequency from 5Hz to 20 Hz had similar level of vibration, which makes fittings start vibrating, to actual measured value of frequency under discharging water. Although there is no connection with the vibration from the investigation, some complaints were drawn. It can be considered that some conditions, such as humidity, air temperature, and opening and shutting windows, can make fittings vibrate.

5. CONCLUSION

A new discharging system of tunnel style will be constructed in the left bank side to enhance the ability of discharging of Amagase Dam. Redevelopment project of the dam is being gone forwarded. (Fig. 17) It is being examined whether there is possibility that the new discharging system of tunnel style generate low-frequency sound or not by conducting model experiment. The way of discharging water and reducing the flow of discharged water in the new system is different from that of current one. It is considered that low-frequency sound will be generated differently even if the new discharging system generates low-frequency sound. The affected area and distribution of the frequency will be very different. It is confirmed that generation of low-frequency sound from the main sluice gate can be mitigated under water volume of $4m^3/s$. After finishing the construction of the new tunnel discharging system, it will be possible to mitigate the generation of low-frequency sound by distributing appropriately the role of discharging water among two systems except for some occasions, such as the case of flooding that needs to be taken the full advantage of the both discharging systems

Until the new discharging system completed, 2 main sluice gates are used to mitigate the generation of low-frequency sound. Further investigation for characteristics of fittings affected with vibration will be conducted, and relationship between source of low-frequency sound and target of the conservation will be revealed out. Countermeasures against low-frequency sound will be discussed more so that its adverse effects can be minimized and mitigated.

Figure 17. Plan of reinforcement of discharging systems

REFERENCES

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Ministry of the Environment. (2004). Guidebook for treating the issue of low-frequency sound.