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THREE - DIMENSIONAL CHARACTERISTIC OF NAPPE OSCILLATION AND THE ESTIMATION OF SOUND PRESSURE LEVELS

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SYNOPSIS

The three-dimensional characteristics of nappe oscillations is outlined for the purpose of explaining the effects of using spoilers. The result of full-scale models indicates a common tendency for sound pressure levels (SPL) of low frequency air vibration experienced while increasing the overflow depth of weirs. Various combinations of openings for various weir nappes have confirmed the effects of spoilers in restricting oscillations to within narrow limits, as well as decreasing the peak sound pressure levels. A measure is proposed for estimating sound pressure levels using weir width, height, overflow depth and distance from the weir.

Keywords: Nappe Oscillation, Low Frequency Air Vibration, Sound Pressure Level, Overflow Weir, Spoiler

INTRODUCTION

On overflow gates and Sabo dams, intensive nappe oscillations which give rise to gate vibration and low frequency air vibration occur at specific overflow depths. Since a nappe oscillation can often be complicated by combinations of the nappe itself, an air cavity behind the nappe, gate shape and fall height, it is often difficult to distinguish one vibration source from an amplifying mechanism.

Although some studies (4) and (6) have previously focused on a flow-induced vibration condition when a gate, such as a flap gate, is suspended elastically, and the same phenomena are also observed on fixed weirs such as a Sabo dam. Accordingly, it is considered that nappe characteristics should be studied in detail. Previous works on the study of nappe oscillations (1), (2), (3), (5), (7) and (8) have shown that dynamic instability in a falling sheet of water results from the decrease of velocity and the attenuation of sheet thickness. These factors are closely related to the occurrence of oscillations. Here an air cavity or air column behind the nappe, work only as an amplifier mechanism.

This paper investigates oscillation conditions and dominant frequencies using a three-dimensional laboratory weir of changeable width and confirms the existing oscillation mechanism.

LABORATORY INVESTIGATION

The laboratory fixed-weir was considered to be a full scale model having 6m width, with a sharp edge rising 40° from the horizontal plane, and a maximum fall height of 2.5m (see Fig. 1). The overflow nappe was narrowed or split by using spoiler plates as shown in Fig. 2, In the case where the spoiler plates are placed at one side, the nappe is considered to be "opened" from a side wall, i.e. aerated from the side. Using other model weirs, different fall heights (H = 1.5 - 3.1m) were also investigated to ensure the fall height effect as shown in Table 1.

Sound pressure levels caused by a low frequency air vibration (SPL), were measured using a low frequency sound pressure level meter (RION-NA17) at a fixed-point, 6m downstream from a nappe and the subsequent dominant frequencies were obtained with a FFT analyzer (YOKOGAWA-3655E)(Fig. 3). A typical nappe oscillation condition (B = 6.0m, H = 2.5m, h = 4.6cm, fr = 21.5Hz) is shown in photo 1 .

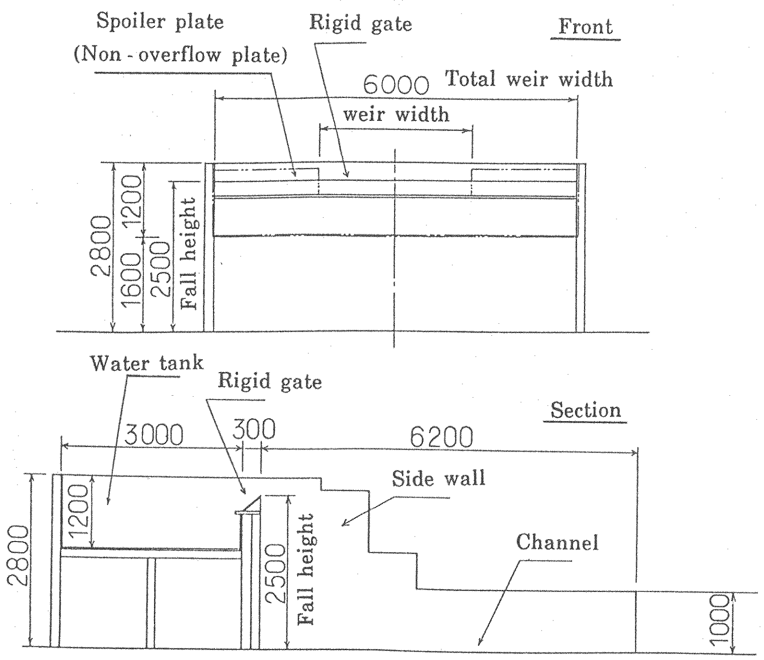

Fig.1 Experimental apparatus

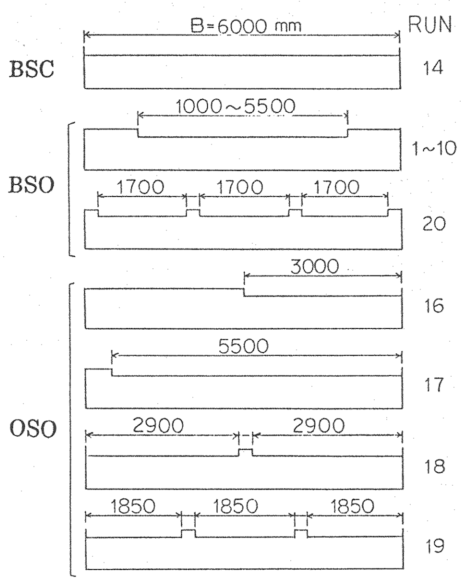

Fig.2 Spoiler plate combination

RUN	Aeration condition	Fall height H(m)	Weir width B(m)	Leaf rising angle α(°)	Over flow depth h(cm)
1	Both Sides Opening (BSO)	2.5	1.0	40	1~10 cm
2			1.5		
3			2.0		
4			2.5		
5			3.0		
6			3.5		
7			4.0		
8			4.5		
9			5.0		
10			5.5		
11		1.8	3.0		
12	Both Sides Closing (BSC)	1.5	0.9		
13		1.9			
14		2.5	6.0		
15		3.1	1.9		
16	One Side Opening (OSO)	2.5	3.0		
17			5.5		
18			2@2.9		
19			3@1.85		
20			3@1.7		

Table 1 Experimental condition

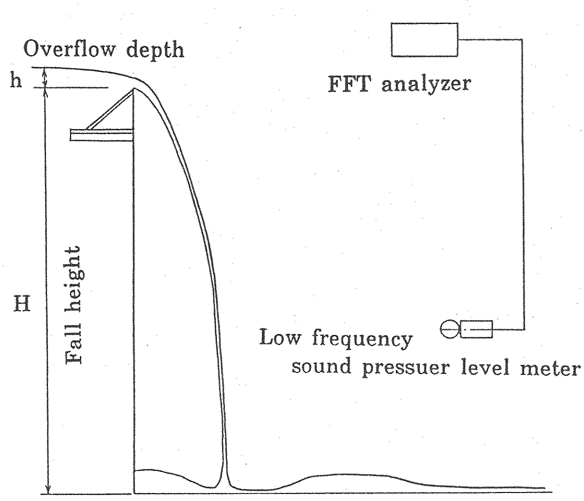

Fig.3 Measurring system

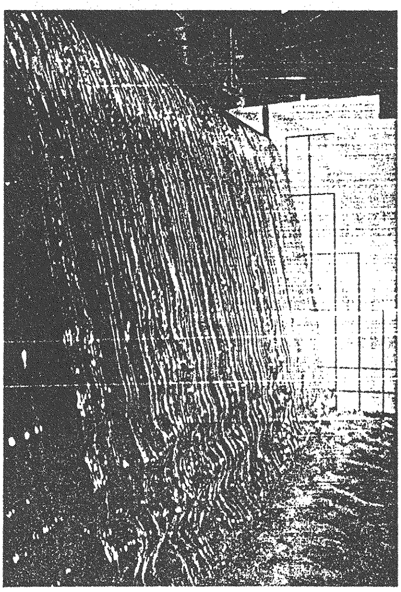

Photo 1 Nappe oscillation condition

EXAMPLE OF A LOW FREQUENCY AIR VIBRATION

The SPL which have obtained by a field measurement on a double leaf vertical gate of 4.2m height and 10.8m width, without spoilers are shows in Fig.4. These SPL had almost the same tendencies as that its maximum value occurred at about a height of 15-20cm. This field measurement was conducted to ensure the efficiency of the spoilers which attenuate the nappe oscillation.

Since the measured Noise Level (A-Type) shown in Fig. 4 had no characteristics concerning the nappe oscillation, a low frequency level measurement considered to be indispensable in determining the occurrence of the oscillation.

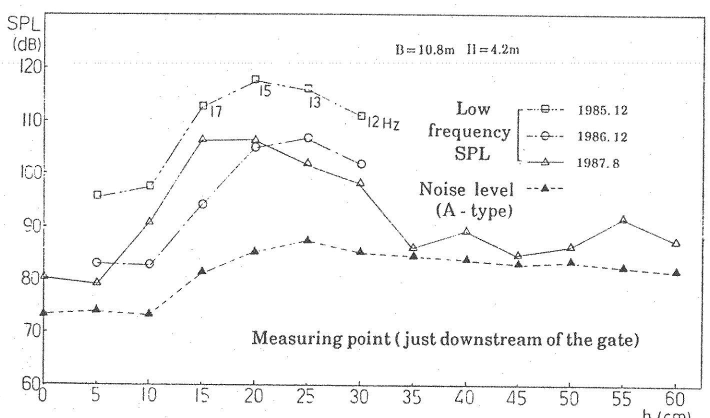

Fig.4 Example of low frequency air vibration
(Sound pressuer level on field measurement)

EXPERIMENTAL RESULT

Weir width effect

The relationship between SPL and weir width in the range from 1.0 to 5.5m under a constant fall height of 2.5m is shows in Fig. 5. Here the sound Power Level (PWL) defined in Eq. 1 is introduced to compare the magnitudes of air vibration,

$$PWL = SPL(r) + 20 \log r + 8 \text{ (dB)} \qquad (1)$$

where r = the distance from the nappe to measuring points (m) SPL(r) the SPL at that measuring point.

The tendencies of PWL for all veir widths are identical except for the specific over-flow depths (h_{max}) hich generate the maximum PWL (PWL_{max}) which increases in the wider weirs.

Previous study on noise levels from a falling nappe without oscillations (9) shows that PWL is a function of water fall energy, namely is dependent on weir width, fall height and mass of falling water. However, since oscillation amplitudes are presumed to change for different weir widths and the evaluated PWL_{max} per unit widths don't coincide with each other, we have to consider another formulation accordingly.

Nappe splitting effect

The difference in PWL_{max} between RUN5 (B=3.0m), and RUN 9 (B=5.0m) where the sides of nappe are separated from the both side walls, named "openeed" and RUN16, 17 where one of sides is attached to a side wall, named "closed" is shown in Fig.6 . Side openings are considered to decrease PWL_{max} about 10dB and only one side opening is insufficient to decrease PWL_{max} as seen in RUN17 which shows only 1dB lower than RUN14.

By splitting the center of the nappe, as seen in RUN18, 19 and 20 , number of splitting points are in creased, i.e. the width of each nappe, is narrowing the value at PWL_{max} is decreased effectively. It is very interesting that RUN18 which was split in the center was almost the same as RUN17, which was opened on one side and had the same width. The maximum difference in PWL_{max} was about 18dB between RUN14 and RUN20.

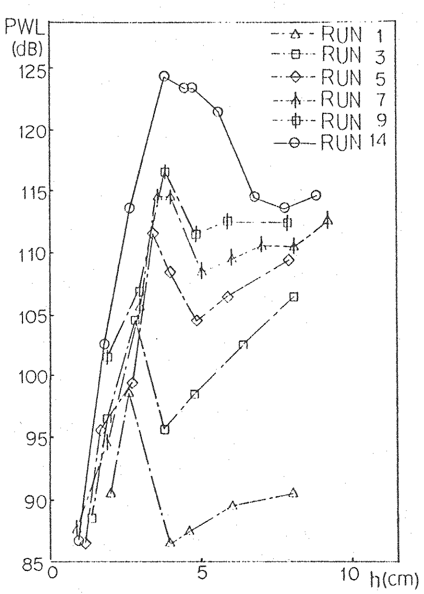

Fig.5 Weir width effect

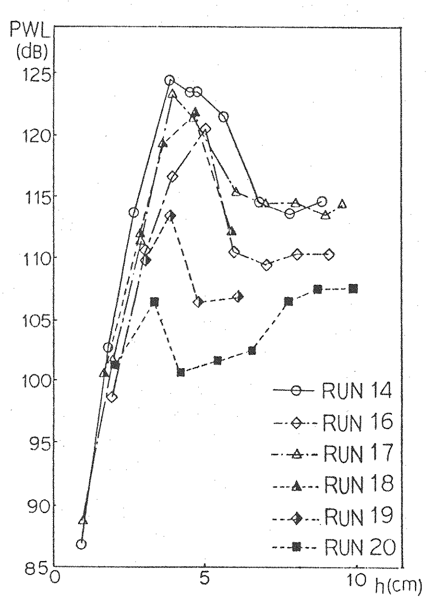

Fig.6 Nappe splitting effect

Fall height effect

PWL_{max} and h_{max} are increased according to the fall heights as shown in Fig. 7 and this fact is similar to the weir width effect in Fig. 5. We must pay careful attention to RUN12 and 13 which have the difference more than an estimated 6dB in the water fall energy PWL under the same weir width conditions. RUN15 gave the maximum h_{max}, out of all the experiments and proved that increasing fall heights and, consequently, an increase in fall velocities make thick nappes susceptible to oscillation, which has been encountered in former studies.

Certain trends in PWL without oscillation from RUN15 which is supposed to be equal to the water fall energy is also shown in Fig.7 and we can evaluate the added PWL caused by the oscillation was about 18dB in this case.

Dominant oscillation frequency under PWL_{max}

The dominant oscillation frequencies obtained by low frequency sound pressure level meter analysis were same for weir widths of 1.0 to 6.0m as shown in Fig. 8. At this time the nappe oscillation was considered to be two dimensional for frequencies. As for fall heights, the frequencies were 21 to 22 Hz for heights H = 1.8 to 2.5m except for H = 3.1m (27Hz) and H = 1.5m (20Hz).

The results coincide with " (k + 1/4) law " proposed by Schwartz (7) whereby wave numbers on a falling nappe are constant but are likely to increase with fall height.

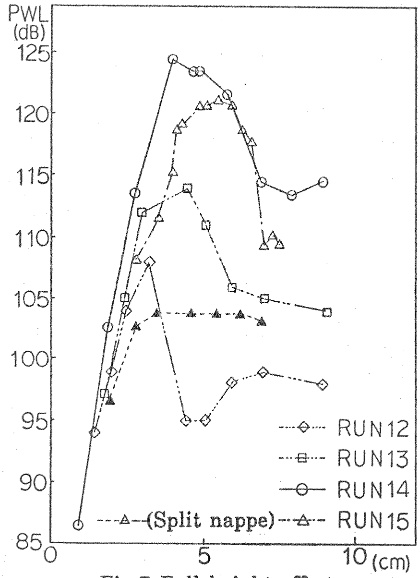

Fig.7 Fall height effect

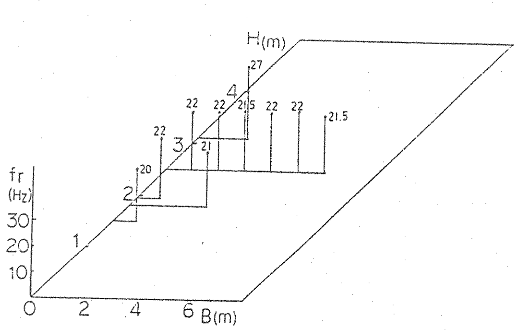

Fig.8 Dominant oscillation frequency under PWL_{max}

Sound pressure level

The SPL distribution along the center line of an oscillating nappe in RUN15 is shown in Fig.9. It is clear that low frequency air vibrations aren't caused by an area sound source but by a linear sound source. We can therefore assume that the propagation is isotropic, except for the bottom area which shows rather high levels, influenced by some sound reflection.

Therefore if we assume that the nappe provides a linear sound source of width B as shown in Fig. 10, then SPL(r) has a constant damping characteristic related to the non-dimensional distance of "r/B" from the nappe to the measuring point. The same characteristics with noise levels (9) are shown in Fig.10 and so the distribution can be assumed to be similar as an infinite-length line source (SPL(r) = PWL - 20 log r - 8) when $r/B \leqq 0.2$ and a finite-length line source (SPL(r) = PWL - 10 log r - 8) when $r/B > 1.0$. In Fig. 10, where the nappe is closed at one side, we modified the widths of the linear sound source using Eq. 2 below, i. e. lengthened weir widths, which takes into consideration the sound image effect of the side wall,

$$B' = aB \tag{2}$$

where B' = modified weir width ; "a" = the modification coefficient for weir width which equal to 1.5 for BSC, 1.25 for OSO and 1.0 for BSO.(See Fig.3)

Overflow depth on PWL_{max}

The relationship between weir width and h_{max} obtained from Fig. 5 to 7 is shown in Fig.11. Run number is shown near the maked paints Since h_{max} increased as the weir became wider in RUN 1 to 10 both sides were opened (BSO), we could establish the fact that long span weirs may cause nappe oscillations even in considerable high overflow depths. This may be attributed to contractions at the sides of a nappe which make a nappe depth thicker in the case of narrows weirs.

In RUN19 and 20 the nappes were split using spoilers and h_{max} values were almost the same for single nappe of the same width. Moreover Fig. 11 suggests that both increasing the height of a weir and closing off at one side, may increase h_{max}.

CONSIDERATION OF SOUND PRESSURE LEVEL

For SPL caused by a falling nappe, we consider sound energy to be directly proportional to the kinetic energy as in Eq. 3 below,

$$W = \alpha U \tag{3}$$

where W = sound energy ; U = kinetic energy ; α = fixed number.

Kinetic energy can be converted into pot ntial energy as in Eq. 4,

$$U = mgH \tag{4}$$

where m = mass of falling water ; g = gravity acceleration.
The mass of falling water is equal to the discharge described in Eq. 5 and this can be substituted into Eq. 4 to create Eq. 6,

$$m = \rho C B h^{3/2} \tag{5}$$

where ρ = density of water ; C = overflow discharge coefficient ; B = weir width ; h = overflow depth ,

$$U = \rho g C B h^{3/2} H \tag{6}$$

In the case of nappe oscillations, we should introduce the coefficient K, so as to modify the SPL by accounting for the effect of low frequency air vibrations. Therefore the kinetic energy would be modified to form Eq. 7 and we can finally replace Eq. 3 with Eq. 8,

$$U' = KU = K\rho g C B h^{3/2} H \tag{7}$$

where U' = the kinetic energy associated with the nappe oscillation,

$$W = \alpha K U = \alpha K \rho g C B h^{3/2} H = AKBh^{3/2} H \tag{8}$$

where A = a constant fixed number ($= \alpha\rho g C$).
Now we can obtain the PWL, by converting Eq. 8 into a logarithmic equation,

$$\begin{aligned} PWL &= 10 \log (AKBh^{3/2}H) \\ &= 10 \log A + 10 \log K + 10 \log B + 15 \log h + 10 \log H \\ &= \alpha_f + 10 \log B + 15 \log h + 10 \log H \end{aligned} \tag{9}$$

where α_f = a constant ($= 10 \log A + 10 \log K$).

A_f is calculated by using Eq. 9 which is proportional to a logarithmic expression of weir width for a nappe opened at both or one of the sides as shown in Fig. 12. We could find the same tendency for the runs using spoilers where weir widths were calculated from the split section.

On the other hand, α_f was about 60dB for all widths, in cases where the nappe was closed at both sides and, accordingly, we can obtain the following approximation,

$$\begin{aligned} \alpha_f &= 60 \text{ (BSC)} \\ &= 9 + 18 \log B, \quad B \leqq 6.0\text{m (OSO or BSO)} \end{aligned} \tag{10}$$

Finally, substituting Eqs. 9 and 10 into Eq. 1, we can obtain the following formulation and estimate the SPL of low frequency air vibrations,

$$SPL(r) = 10 \log B' + 15 \log h_{max} + 10 \log H - 20 \log r + 52 \quad \text{(BSC)}$$
$$= 10 \log B' + 15 \log h_{max} + 10 \log H - 20 \log r + 18 \log B + 1 \quad \text{(OSO or BSO)} \qquad (11)$$

where B = weir width (cm); B' = 1.5B(BSC), 1.25B(OSO), 1.0B(BSO) (cm); h_{max} = the overflow depth on PWL_{max} (Fig. 11) (cm); H = fall height (cm).

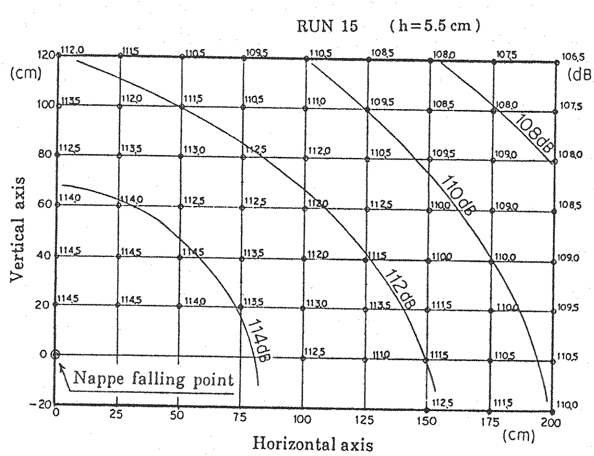

Fig.9 SPL distribution

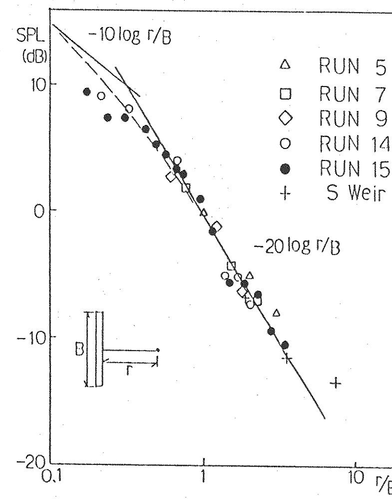

Fig.10 SPL damping trend

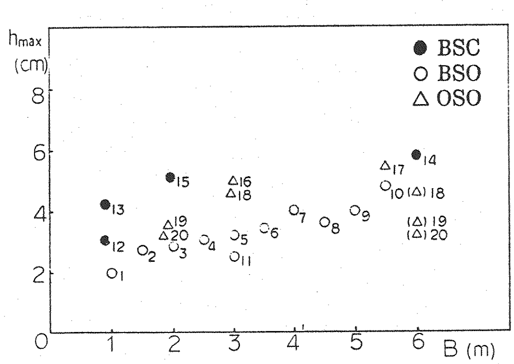

Fig.11 Overflow depth on PWL_{max}

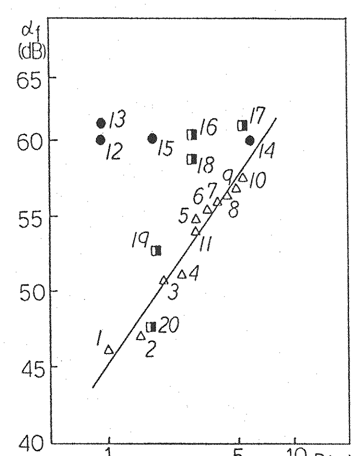

Fig.12 Constant value α_f

CONCLUSION

The experimental results indicate that weir width and splitting effects do not change the dominant frequencies and therefore the nappe oscillation have proved to be two-dimensional. The overflow depth of PWL_{max} and the SPL itself, however, were affected by the weir width and thus both splitting with spoilers and opening at the sides are considered to be effective in attenuating the oscillations and decreasing the SPL consequently.

We have obtained an oscillation condition under various weir widths and a formulation by which to estimate the SPL. It may be said that long span weirs have a greater possibility for causing oscillations during particularly high overflow depths. Thus, we ought to design a suitable interval for the spoiler spacing, which will effectively attenuate any oscillation.

Finally it is important to confirm the formulation presented here with field measurements, since low-frequency sound pressure levels are complicated and concerned with both the kinetic energy of falling water and the oscillating energy which may not be linearly proportional to the weir widths.

REFERENCES

1. Hagerty,W.W.and J.F.shea : A study of the stability of plane fluid sheets, Journal of Applied Mechanics, ASME, Dec. 1955.
2. Kolkman,P.A. : Instability of a vertical water-curtain closing an air-chamber, Flow-Induced Structural Vibrations, IUTAM / IAHR symposium, Aug. 1972.
3. Nakajima, Y. and T. Sumi : Oscillation characteristic of three dimensional nappe, Proceedings of the 44th Annual Conference of JSCE, Oct. 1989 .
4. Ogihara, K. : Self-excited oscillation of flap-gate and nappe, Proceedings of JSCE, No.357/II -3, May. 1985.
5. Okubo, S. and T. Sumi : Oscillation characteristic of vertically falling nappe, Proceedings of the 43th Annual Conference of JSCE, Oct. 1988.
6. Petricat, K. : Vibration tests on weirs and bottom gates, Water Power, February and march , 1958.
7. Schwartz, H.I. : Edgetones and nappe oscillation, Journal of the Acoustic Society of America, Vol.3, 1966.
8. Sumi,T. and S. Okubo : Oscillation characteristic of overflow nappe on flap-gate, Proceedings of the 43th Annual Conference of JSCE, Oct. 1989.
9. Taya, K. , H.Ogawa, and M. Yamashita, : Noise reduction of water fall, Journal of INCE of Japan, Vol.6, No.4, Aug. 1982.

APPENDIX - NOTATION

The following symbols are used in this paper:

A = constant as defined by Eq. 8;
a = modification coefficient as defined by Eq. 2;
B = weir width;
B' = modified weir width;
BSC = aeration condition of Both Sides Closing;
BSO = aeration condition of Both Sides Opening;
C = overflow coefficient;
fr = dominant oscillation frequency;
g = gravity acceleration;
h = overflow depth;
h_{max} = overflow depth on PWL_{max};
H = fall height;
K = coefficient associated with the nappe oscillation as defined by Eq. 7;
k = constant in "(k+1/4) law" by Schwartz (4);
m = mass of falling water;
OSO = aeration condition of One Side Opening;
PWL = sound Power Level;
PWL_{max} = maximum sound Power Level;
r = distance from a nappe to measuring points;
SPL = low frequency Sound Pressure Level;
SPL(r) = SPL at measuring points;
U = kinetic energy;
U' = kinetic energy associated with the nappe oscillation;
W = sound energy;
α = fixed number;
α_f = constant as defined by Eq. 9; and
ρ = density of water, respectively.

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