Discharge Coeffi cient of a Sluice Gate Placed at Sudden Expansion of Open Channel

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Synopsis

In this paper the discharge coefficient of a
sluice gate placed at the sudden expansion of an open
channel is investigated theoretically and experimentally.
Lateral and vertical expansions are treated in the study.
The coefficients obtained for channels with sudden expan-
sion are compared with those for the straight channel.
For free efflux,experimental results show that
the coeffcients for expanded channels are always larger
than those for a straight one,and that the coefficient
for a channel to be fully expanded to both lateral and
vertical directions takes about 1.2 times larger value
than that for a straight one.
For submerged efflux, the coefficient is obtained
theoretically by using the efflux model shown in this
study. The theoretical results explain the experimental
ones fairly well. The coefficient for lateral expansion
is always smaller than that for a straight channel. The
minimum downstream water depth required to submerged
efflux for the expanded channels becomes smaller than
that for a straight channel.

1. Introduction

There are many basic studies on the efflux from a sluice gate in
the open channel[1]. Almost all of them are about the gate placed in the
straight and horizontal channel. However,the channel geometry in prac-

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tice are very manifold. Then, in this paper as a first step of studying
on the characteristics of efflux mechanism with the channel geometry,
the discharge coefficients of the gate placed at channel expansions
shown in Fig.1.1 are investigated.

For the experiments the main channel (shown in Fig.1.2) that the
cross section is 0.3 m width X 0.4 m depth for upstream and 1.0 m X
0.7 m for downstream of the gate is used.

The discharge coefficient C in this paper is given by the follow-
ing equation under both free and submerged discharge conditions.

$$C = Q / (B_1 a \sqrt{2gh_1}) \qquad\qquad (1.1)$$

where, Q : discharge, B_1 : channel width upstream of the gate, a : gate
openning, h_1 : upstream water depth, and g : acceleration due to gravity.

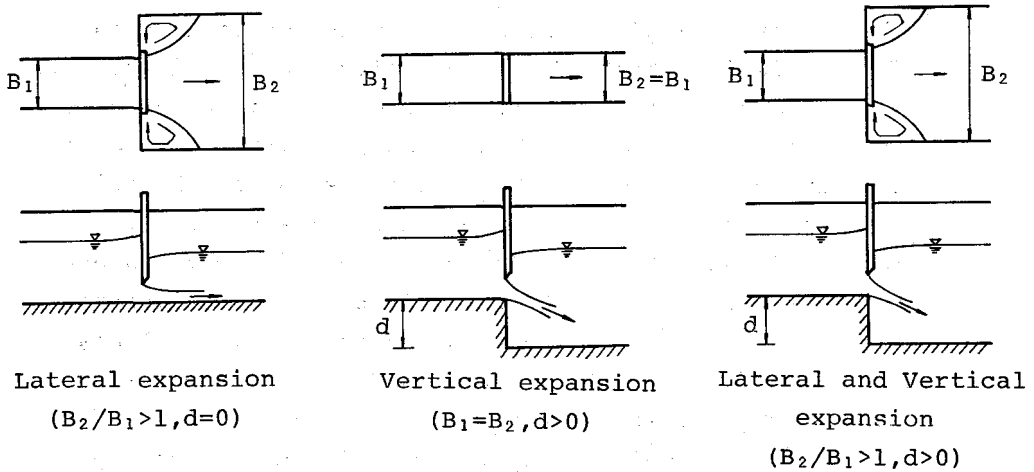Lateral expansion   Vertical expansion   Lateral and Vertical
   $(B_2/B_1>1,d=0)$ $(B_1=B_2,d>0)$ expansion
                                                         $(B_2/B_1>1,d>0)$
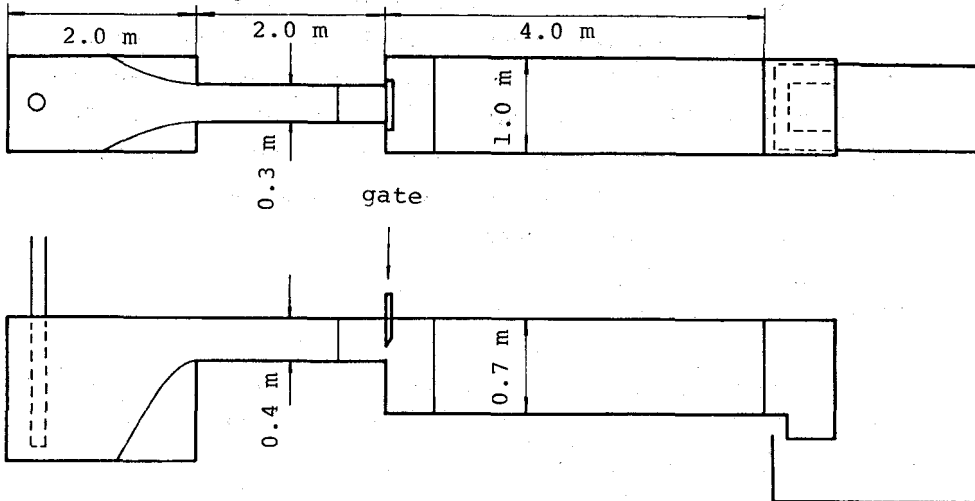
Fig.1.1 Several types of expansion

Fig.1.2 Experimental flume

2. Discharge Coefficient under Free Efflux Conditions

2.1 Influence of Lateral Expansion under d=0

In order to clarify the influence of the lateral expansion on the coefficient, horizontal channels (d=0) were used for the experiment. Several expansion ratios B_2/B_1 between 1 and 3.3 are adopted. The results are shown in Fig. 2.1, Fig. 2.2 and Fig. 2.3. The dotted line in these figures is Henry's experimental curve for a straight channel [2]. Fig. 2.4 shows the relation between B_2/B_1 and C/C_0, in which C_0 is the discharge coefficient for the channel with $B_2/B_1=1$ and d=0. These figures show that;

(1) For constant openning ratio a/h_1, the coefficient C increases rapidly with channel expansion and approaches to the constant value.

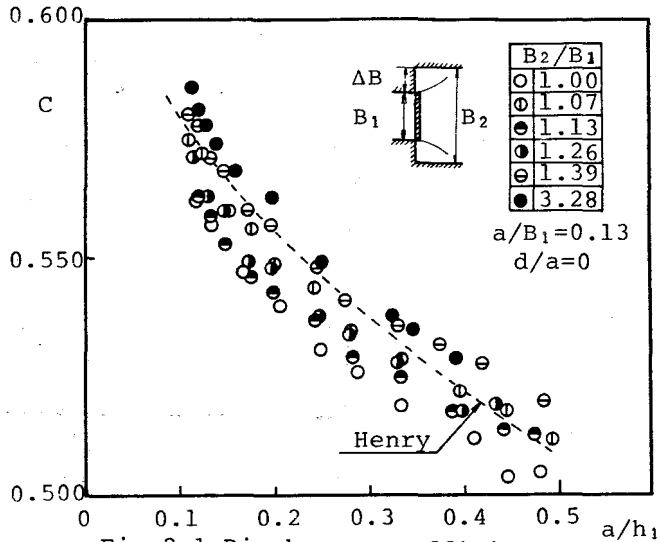(2) For constant expansion ratio B_2/B_1, the coefficient increases with a/B_1.
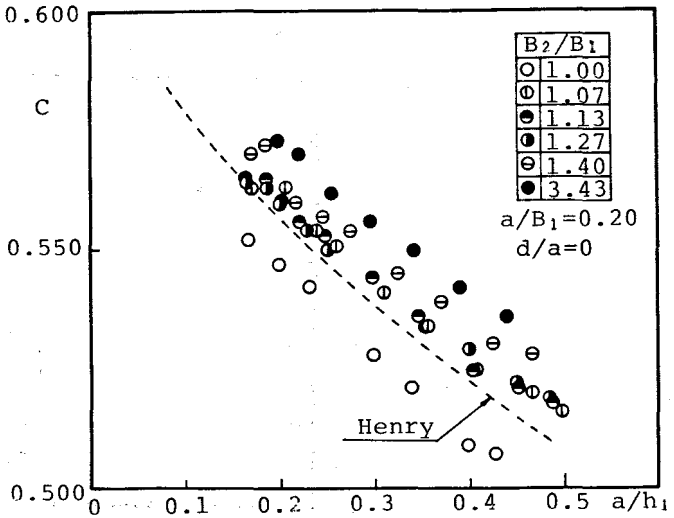

Fig.2.1 Discharge coefficient
(lateral expansion)

Fig.2.2 Discharge coefficient
(lateral expansion)

2.2 Influence of Vertical Expansion under $B_2/B_1=1$

In order to clarify the influence of vertical expansion, straight channels ($B_2=B_1$) were used for the experiment. The height of step down was varied from 0.8 to 30 cm. The results are shown in Fig.2.5. This figure shows that the influence of vertical expansion is more notable than that of lateral expansion. Fig.2.6 shows that the relation between
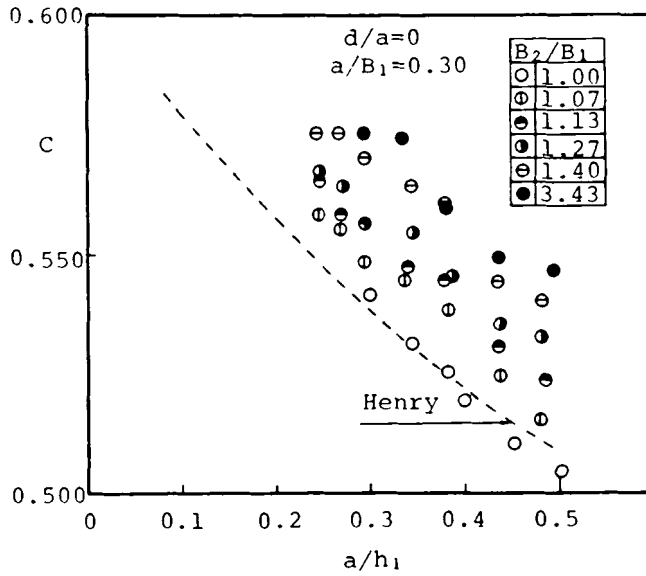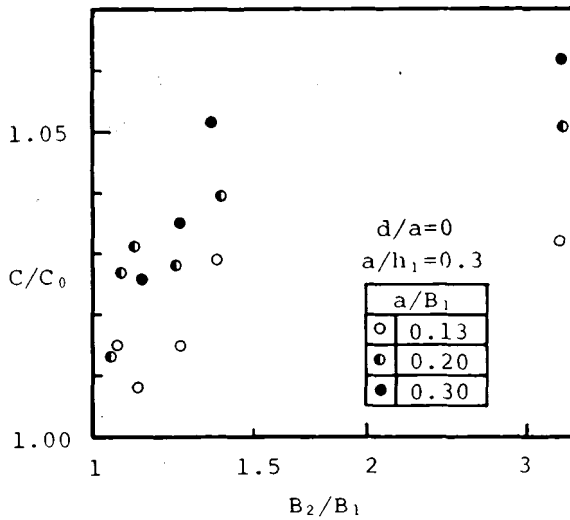
Fig.2.3 Discharge coefficient
(lateral expansion)

Fig.2.4 Discharge coefficient
(lateral expansion)

C/C_0 and d/a is similar to that between C/C_0 and B_2/B_1. That is, C/C_0 increases with d/a rapidly in the region where d/a is very small.
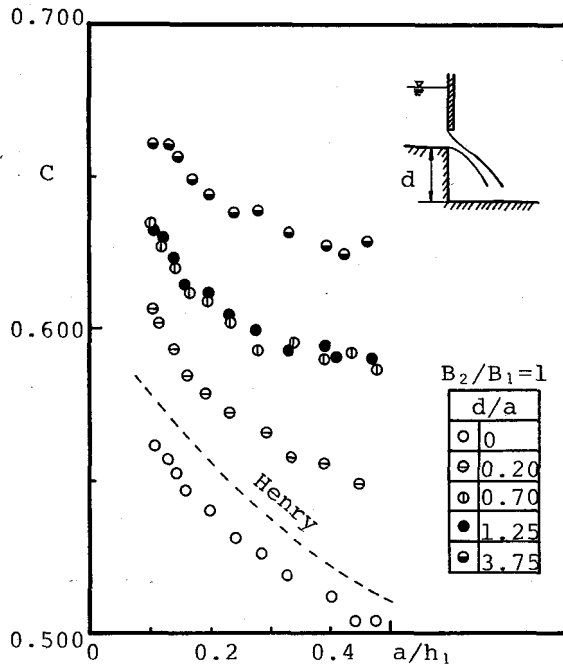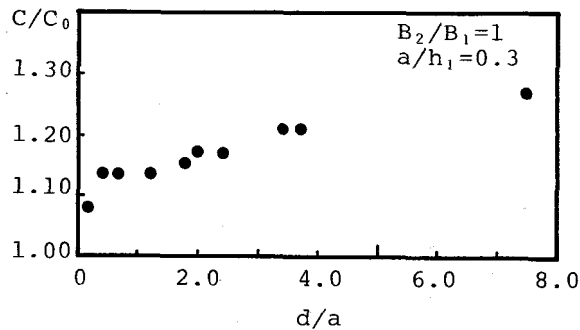
Fig.2.5 Discharge coefficient
(vertical expansion)

Fig.2.6 Discharge coefficient
(vertical expansion)

2.3 Discharge Coefficient under Both Expansions

Fig.2.7 shows the influence of vertical expansion under the conditions that the lateral expansion exist or not. Fig.2.8 shows the coefficients for two limited conditions, that is, one is for horizontal and straight channel, and the other is for fully expanded channel both to lateral and to vertical directions. Fig.2.8 shows that the coefficient for fully expanded channel is about 1.2 times larger than that for the channel without expansion.
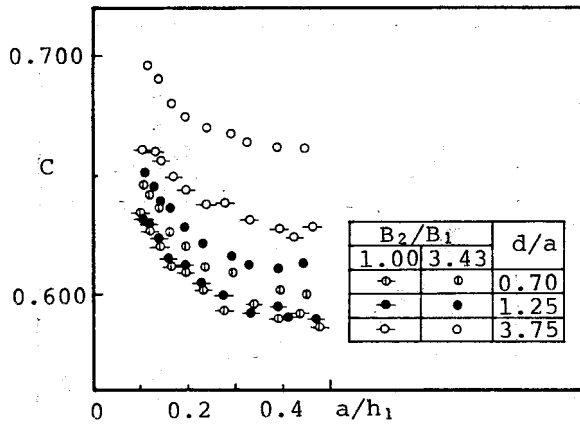
Fig.2.7 Discharge coefficient
(vertical expansion under
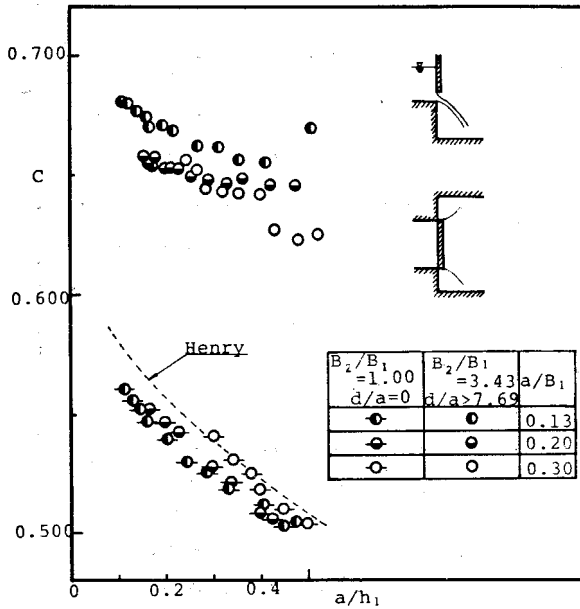large lateral expansion)

Fig.2.8 Discharge coefficient
(fully expanded to
both directions)

3. Discharge Coefficient under Submerged Efflux Conditions

3.1 Theoretical Investigation

The submerged efflux from a gate placed at the channel expansion

modelized as shown in Fig.3.1. By applicating the energy conservation's law between the section I and II ,and the momentum one between the section II and III ,the theoretical discharge coefficient C_T is obtained as follows.

$$C_T = C_c\sqrt{\{(d+h_1)/h_1-h_2/h_1\}/\{1-(C_c a/h_1)^2\}} \quad , \tag{3.1}$$

where,

$$h_2/h_1 = 1/2[D\pm\sqrt{D^2+4\{(h_3/h_1)^2-D(h_1+d)/h_1\}}] \quad ,$$

$$D=[4A/\{L(A^2-1)\}]\{Ah_1/(Lh_3)-\cos\alpha\},A=C_c a/h_1,L=B_2/B_1 . \tag{3.2}$$

As the assumed contraction coefficient Mueller's theoretical value is used for the case that the vertical expansion is not exist,and v.Mises' shown in table 3.1 is used for the case with vertical expansion [3],[4].
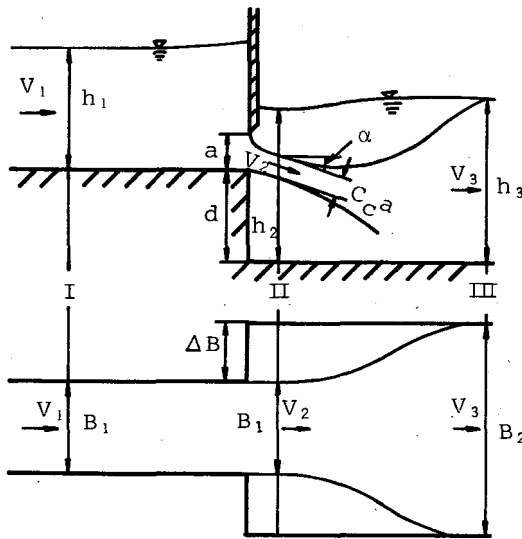
Table 3.1 Contraction coefficient by v.Mises

a/h_1=0.0	C_c=0.673	α=21°
0.1	0.676	20° 55'
0.2	0.680	20° 35'
0.3	0.686	20° 5'
0.4	0.693	19° 40'
0.5	0.702	19°
0.6	0.720	18°
0.7	0.740	16° 30'
0.8	0.782	14° 20'
0.9	0.842	11° 5'

Fig. 3.1 Schematic diagram of submerged efflux

3.1.1 Influence of Lateral Expansion (d=a)

Under the condition d=0,the coefficient C_T is calculated by using eq.(3.1) and eq.(3.2),and similarly C_{T_0} for the case without expansion

is obtained by providing d=0 and
$B_1=B_2$. The results are shown in
Fig.3.2 and Fig.3.3. In each figu-
re as B_2/B_1 increases,C_T/C_{T_0} fir-
st decreases suddenly from the va-
lue 1.0 and approaches gradually
to the constant value. It is also
evident that C_T/C_{T_0} decreases with
a/h_1 under the condition $(h_1-h_3)/$
a=constant,and with $(h_1-h_3)/a$ un-
der a/h_1=constant. C_T for $B_2/B_1=\infty$,
is shown in Fig.3.4 and Fig.3.5.
The boundary between a free dis-
charge and a submerged one shown
in these figures is calculated by
providing $h_2=C_c a$. These figures
show that as a/h_1 increases,the
change of C_T to the increment of
$(h_1-h_3)/a$ becomes large. In Fig.
3.6 the boundary is also shown in
the relation between h_3/h_1 and $a/$
h_1. This figure shows that as $B_2/$
B_1 increases,the minimum
downstream water depth
required to submerged eff-
lux becomes small under
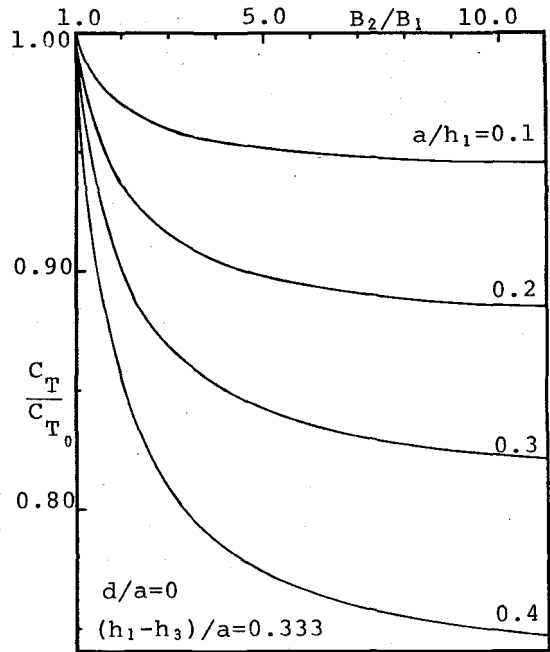a/h_1=constant.

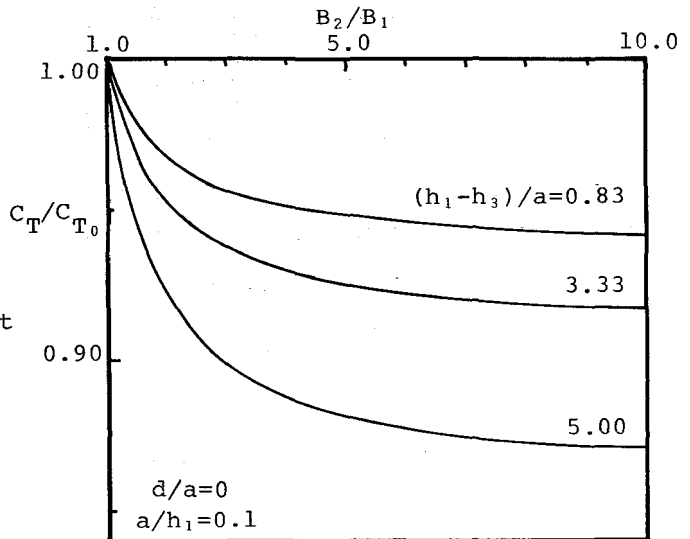Fig.3.2 Discharge coefficient
         (lateral expansion)

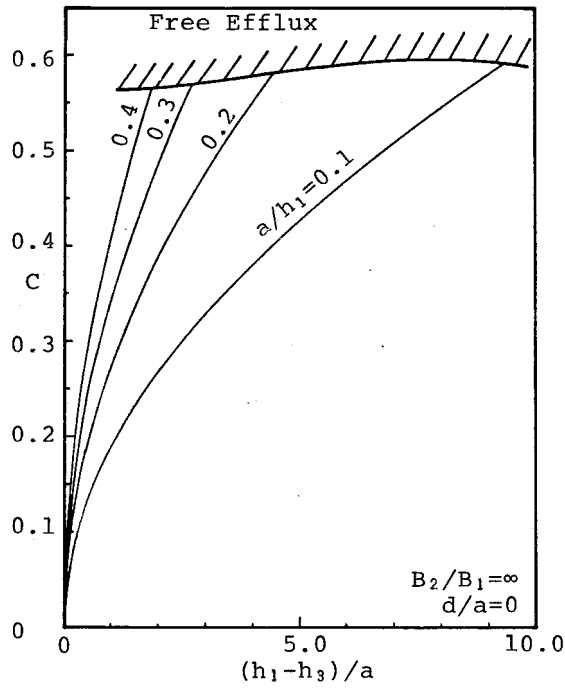Fig.3.3 Discharge coefficient
        (lateral expansion)

Fig.3.4 Discharge coefficient
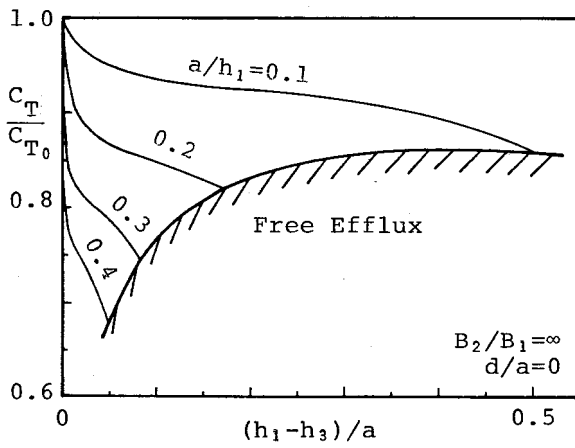(lateral expansion)
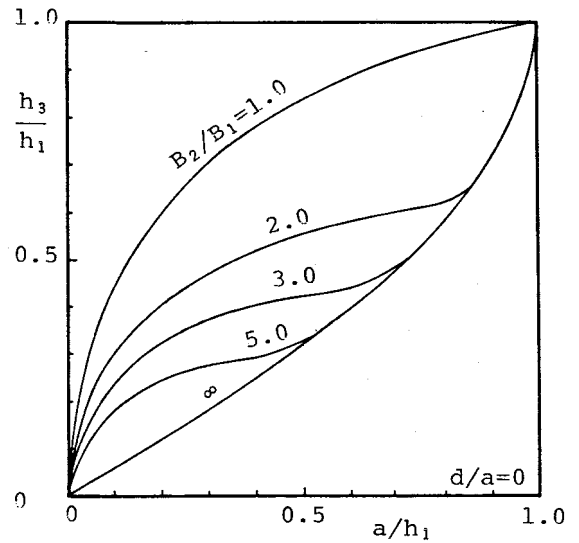
Fig.3.5 Discharge coefficient
(lateral expansion)

Fig.3.6 Boundary between free and
submerged(lateral expansion)

3.1.2 Influence of Vertical Expansion ($B_1=B_2$)

Under the condition $B_1=B_2$, C_T is similarly calculated by using eq.
(3.1) and eq.(3.2). The relation between C_T/C_{T_0} and d/a are shown in
Fig.3.7 and Fig.3.8. In each figure, though the decreasing tendency of
C_T/C_{T_0} with d/a is similer to one with B_2/B_1 mentioned above, it hap-
pens that C_T becomes larger than C_{T_0} for small d/a. The boundaries
calculated as shown in Fig.3.9. This figure shows that as the height
of vertical expansion increases, the minimum downstream water depth
required to submerged efflux becomes small in the same manner as that
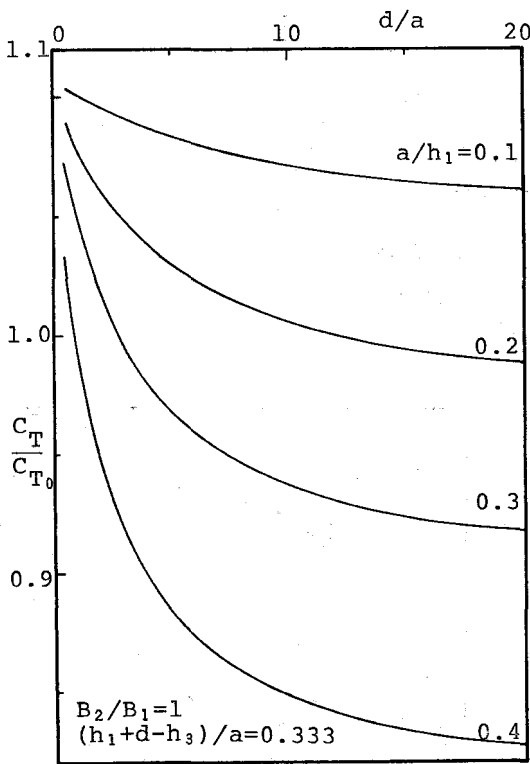for lateral expansion.

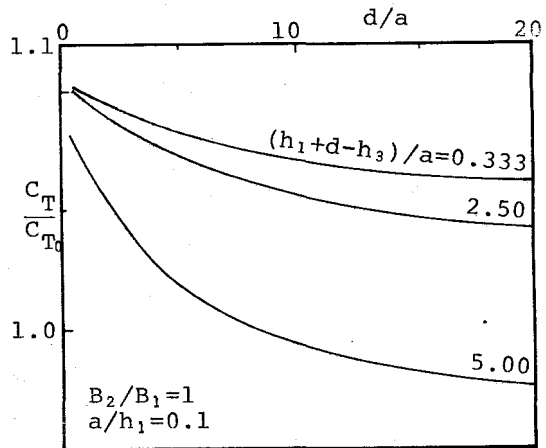Fig.3.7 Discharge coefficient
(vertical expansion)

Fig.3.8 Discharge coefficient
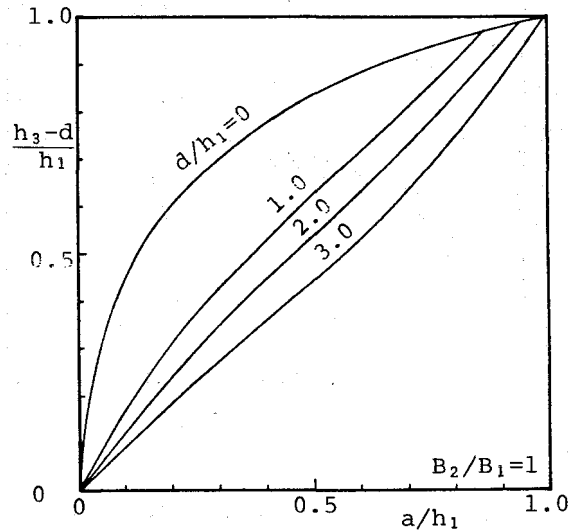(vertical expansion)

Fig.3.9 Boundary between free and
submerged(vertical expansion)

3.2 Experimental Verifications

In the experiment the gate openning a was fixed at 4.0 cm. This value gives the model scale to be able to nearly neglect the scale effects. Experimental results are shown in Fig.3.10,Fig.3.11 and Fig.3.12. In each figure the experimental values C_E are compared with the theoretical ones C_T. These figures show that experimental values are always several percent smaller than theoretical ones,even if the values of B_2/B_1 and d/a varies. But it seems that the method of analysis in this paper is fairly well applicable to estimate the discharge coefficients of the sluice gate placed at the channel expansions.
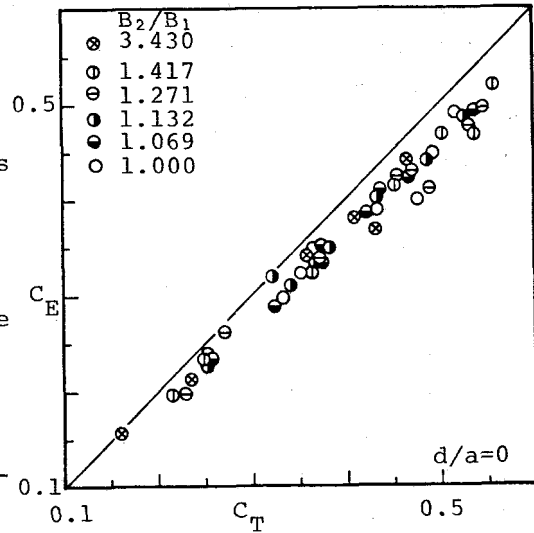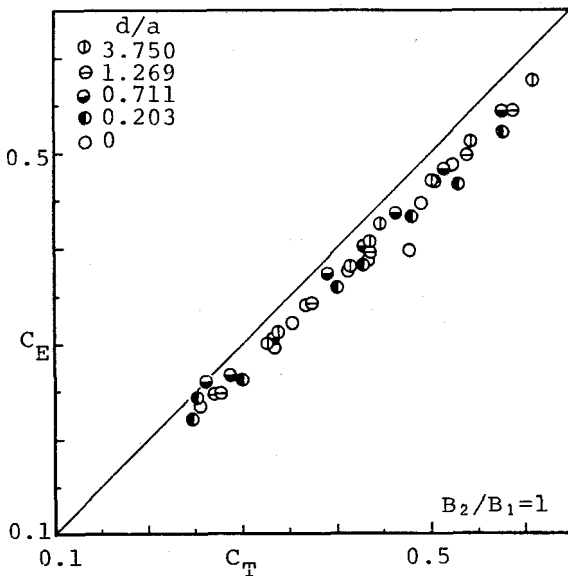
Fig.3.10 Discharge coefficient
(lateral expansion)

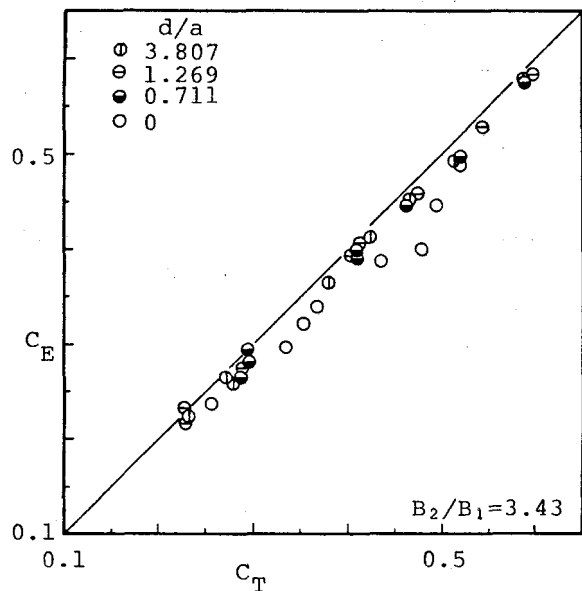Fig.3.11 Discharge coefficient
(vertical expansion)

Fig.3.12 Discharge coefficient
(vertical expansion under
large lateral expansion)

4. Conclusions

    In this study the discharge coefficients of a sluice gate placed
at channel expansions have been investigated experimentally and theo-
retically comparing with those of a horizontal and straight channel.
The main results obtained in this study as follows.
(1) Under free discharge conditions,it is clarified experimentally that
the influence of vertical expansion is more dominant than that of late-
ral one,and that as the degree of expansions increase,the coefficients
first become large suddenly and then approach gradually to the constant
values. The coefficient for the channel to be fully expanded to both
directions is about 1.2 times larger than that for a horizontal and
straight channel.
(2) Under submerged discharge conditions,it is verified by experiments
that the theoretical analysis to be developed in this study is appli-
cable to estimate the discharge coefficient. The coefficient for late-
ral expansion is always smaller than that for a straight channel. The
minimum downstream water depth required to submerged efflux for the
expanded channels becomes smaller than that for a horizontal and strai-
ght channel.

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References

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[4] R.v.Mises : V.D.I.(1917)