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Experimental Study on the Discharge Coefficient for Side Weir with Pressurized Flow in Circular Channel

Dongwoo KO[(1)], Hajime NAKAGAWA , Kenji KAWAIKE ,
and Hao ZHANG

(1) Graduate School of Engineering, Kyoto University

Synopsis

Urban inundations are caused by natural climate change and torrential rainfall during a short-time. As wide permeable areas go through the process of urbanization, the most of the storm water dose not infiltrate into the ground and total amount of storm water runoff has increased. Likewise, insufficient drainage capacity and pump station, water retention system in metropolitan areas can also result in urban flooding. So, the researches for the mitigation the amount of storm water are essential. Due to this, underground storage systems are installed to mitigate damage of urban flooding. Estimation of overflowing discharge into those storage systems is significant for evaluation of their mitigation effects. Such overflow happens between pressurized sewer pipe and storage system over a side weir. The equation proposed by De Marchi to estimate overflow discharge over a side weir has been verified through several experimental researches only for open channel flow. Therefore in this study, overflow discharge coefficient is evaluated for pressurized flow of circular pipe through experiments with different side weir length. The discharge coefficient derived from experimental results implies applicability of constant value to estimate overflow discharge if mean value of integrated water head along the side weir is used, which should be verified through numerical simulation in the future.

Keywords: Underground storage system, Side weir, Discharge coefficient

1. Introduction

Even though a large number of researches related to reduction of the urban inundation damage have been conducted, the damage is still serious problems every year. Urban inundation has caused immense property damage and personal injury due to local heavy rainfall during a short-time and extreme climate in worldwide. To mitigate this problem, underground storage systems as an effective countermeasure have been implemented especially in highly urbanized area. However, there are no criteria how much mitigation effect can be expected from installation of such underground storage systems. In many cases, those storage systems are attached to sewerage systems, and some part of stormwater within a sewerage pipe is diverted over the side weir into the storage system. Therefore, evaluation of mitigation effect of storage system requires appropriate estimation of overflow discharge from sewerage system over the side weir. So, the researches in terms of overflow discharge over the side weir related to underground storage

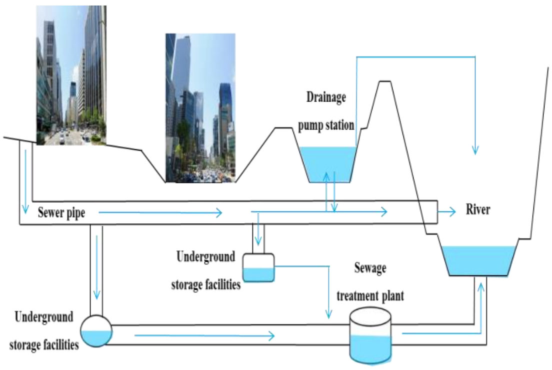

Photo 1 Underground storage system

systems are essential. Photo 1 shows the structure of underground storage system briefly.

Side weirs are hydraulic structures that are usually used as flow dividers in urban drainage

Table 1 Side weir discharge coefficient equations

Researcher	Equation
Subramanya et al. (1972)	$C_d = 0.611\sqrt{1-(\frac{3F^2}{F^2+2})} = 0.864(\frac{1-F^2}{2+F^2})^{0.5}$
Yu-Tech (1972)	$C_d = 0.623 - 0.222F$
Hager (1987)	$C_d = 0.485(\frac{2+F^2}{2+3F^2})^2$
Cheong (1991)	$C_d = 0.45 - 0.221F^2$
Borghei et al. (1999)	$C_d = 0.7 - 0.48F - 0.3\left(\frac{p}{h}\right) + 0.06\frac{L}{D}$

systems, irrigation channels and flood protection works (Granata et. al. 2013). A lot of researches suggested the discharge coefficient regarding the side weir with subcritical flow and supercritical flow in several channel conditions.

Nandesamoorthy et al. , Subramanya et al. , Yu-tech, Ranga Raju et al. , Hager, Cheong, Singh et al. , Jalili et al. , and Borghei et al. obtain the equations for discharge coefficients for rectangular, sharp-crested side weirs based on experimental results. Swamee et al. used an elementary analysis method to estimate the discharge coefficient in smooth side weirs through an elementary strip along the side weirs.

Ghodsian studied behavior in the rectangular side weir in supercritical flow. Khorchani et al. studied the overtopping discharge through the side weirs with a full-scale experiment using digital cameras.

Muslu, Yüksel and Muslu et al. used numerical evaluation to analyze the flow over a rectangular side weir(M. Emin Emiroglu et al. 2011).

The main contributor to the understanding of hydraulic behavior of side weir is De Marchi(1934). He presented theory based on the assumption of constant energy head along the side weir and the overflow discharge being calculated by classical weir formula which overlooks the effect of lateral outflow direction, local velocity and type of flow (pressurized or non-pressurized) in the system. The equation is as follows,

$$q = \frac{dQ_{out}}{dL} = \frac{2}{3}C_d\sqrt{2g}(h-p)^{\frac{3}{2}} \quad (1)$$

where q is discharge per unit length of side weir, Q_{out} is overflow discharge, L is distance along the side weir measured from upstream end of side weir, g is the acceleration of gravity, p is the height of the side weir, h is the flow depth at the section L, C_d is the discharge coefficient of side weir. The discharge coefficient is influenced by the following parameters,

$$C_d = f(v, D, g, h, p, L, S \cdots) \quad (2)$$

where D is diameter of main pipe, S is slope of main channel.

Some previous theoretical analyses and experimental researches have been reported in terms of flow over rectangular side weirs in circular open channel (Allen, 1957 ; Uyumaz and Muslu, 1985 ; Vatankhah, 2012 ; Granata, 2013). Generally, The method assumes one-dimensional flow conditions, thus neglecting the variations of overflow direction and the velocity distribution(Willi H. Hager 1987). Besides, as seen in Table 1, a lot of researches obtain the equations for discharge coefficients for rectangular side weirs based on experimental results, where F is Froude number for the upstream end of the side weir on the main channel. Those side weir discharge coefficients are determined by varying experimental conditions, such as flow state, weir length and height.

All of the above researches have been conducted under open channel flow conditions, and the De Marchi’s approach seems appropriate for the open channel flow condition. However, there are not researches that identify its suitability in the pressurized flow condition. Thinking of overflow from sewerage system during urban flooding, pressurized flow condition would often happen and

De March equation's applicability must be verified also in that condition. Hence in this research, the experimental set up is proposed with pressurized circular channel with different side weir length so that the effectiveness of the use of the above equation can be discussed.

The aim of this experiment is to determine the discharge coefficient for pressurized flow in circular channel with different side weir length so that effective conclusions can be made regarding suitability of the De Marchi equations also for this case and such experimental data can be extensively used to validate future numerical model estimating effects of underground storage systems.

2. Experimental Setup

The experiments were carried out in the Ujigawa Open Laboratory of the Disaster Prevention Research Institute (DPRI), Kyoto University. Experimental setup, side weir and sectional view of a rectangular side weir are shown in Photo 2, Photo 3 and Photo 4.

Experimental setup consisting of side weir with the two circular acrylic pipes of 4m long and 0.05m internal diameter. There are upstream supply tank with the recirculation pump system and downstream collecting tank with a movable gate to adjust the downstream water level. The recirculation system can be controlled by the RPM controller. A flowmeter was used to measure the upstream input discharge. The flow heads have been measured by total seventeen piezometer tubes placed along the bottom of pipe, as shown in Photo 5. All of the experiments were carried out by the zero slope. As seen in Photo 6, the three different lengths of side weir, 10cm, 15cm and 20cm, have been investigated. Experiments were conducted for steady flow condition. The weir height was set as 4cm in all the cases. The length and height of side weir model were determined according to real size of the pipe diameter and the side weir in Moriguchi city, which can be regarded as a typical overflow system of side weir.

Photo 2 Experimental setup

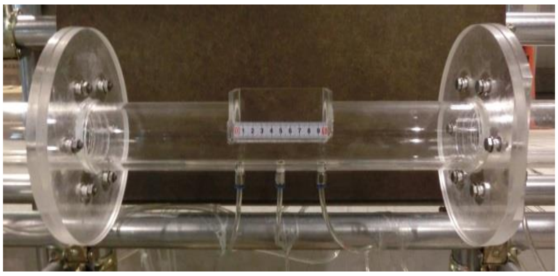

Photo 3 Side weir

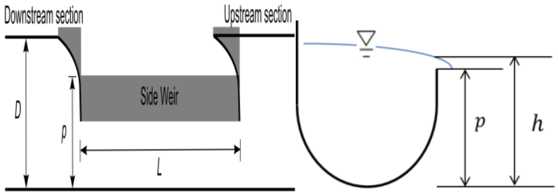

Photo 4 Sketch of the rectangular side weir in a circular pipe

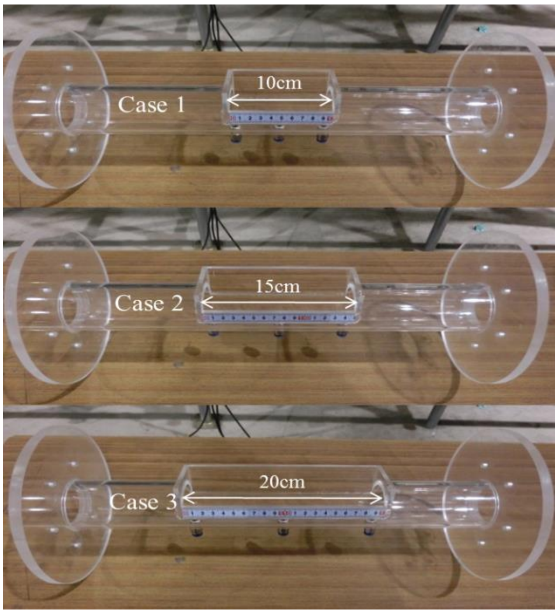

Photo 6 The three different length of side weir

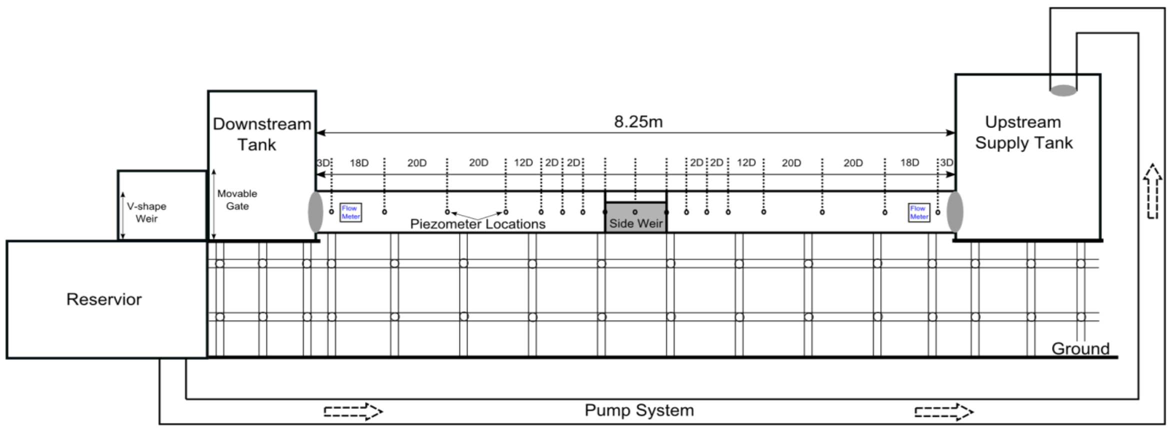

Photo 5 Experimental arrangement

Table 2 Experimental conditions (10cm,15cm.20cm)

Weir length(cm)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
Upstream discharge(ℓ/s)											
10, 15, 20	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
Froude number											
10, 15, 20	0.36	0.44	0.51	0.58	0.65	0.73	0.80	0.87	0.95	1.02	1.09
Water level at the downstream tank(cm)											
10	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.8
15	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7
20	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.4	1.5	1.6	1.7

3. Experimental Conditions

The experiments of 33 cases in total were conducted to determine overflow discharge coefficient keeping steady-state condition with different side weir length. Each side weir length has 11cases, and supplied discharge at upstream tank differs from 0.5 ℓ/s to 1.5 ℓ/s with fixed downstream movable gate level equivalent to the bottom of main channel pipe. The detailed hydraulic conditions were summarized in table 2, which contains the observed water level at the downstream tank. Each case of experiment was repeated three times to consider consistency of overflow discharge rate.

4. Experimental Results

4.1 Water Head Profile

The water surface profiles of whole pipe system of the case with 10cm weir length and those around the side weir of all the cases are described in Fig. 1. On the whole, the water head at the upstream end of the side weir is lower than that at the downstream end of the side weir, as shown in Fig. 1. The same situation was observed in all previous experimental studies. The water head slightly decreases at the middle of side weir for small upstream discharges. This situation is influenced by entrance effect at the upstream end of the side weir and lateral flow on the side weir. As the upstream discharge increases, the water head profile on the side weir becomes steeper in comparison with smaller discharges. The high water head at the downstream end of the side weir have an effect on

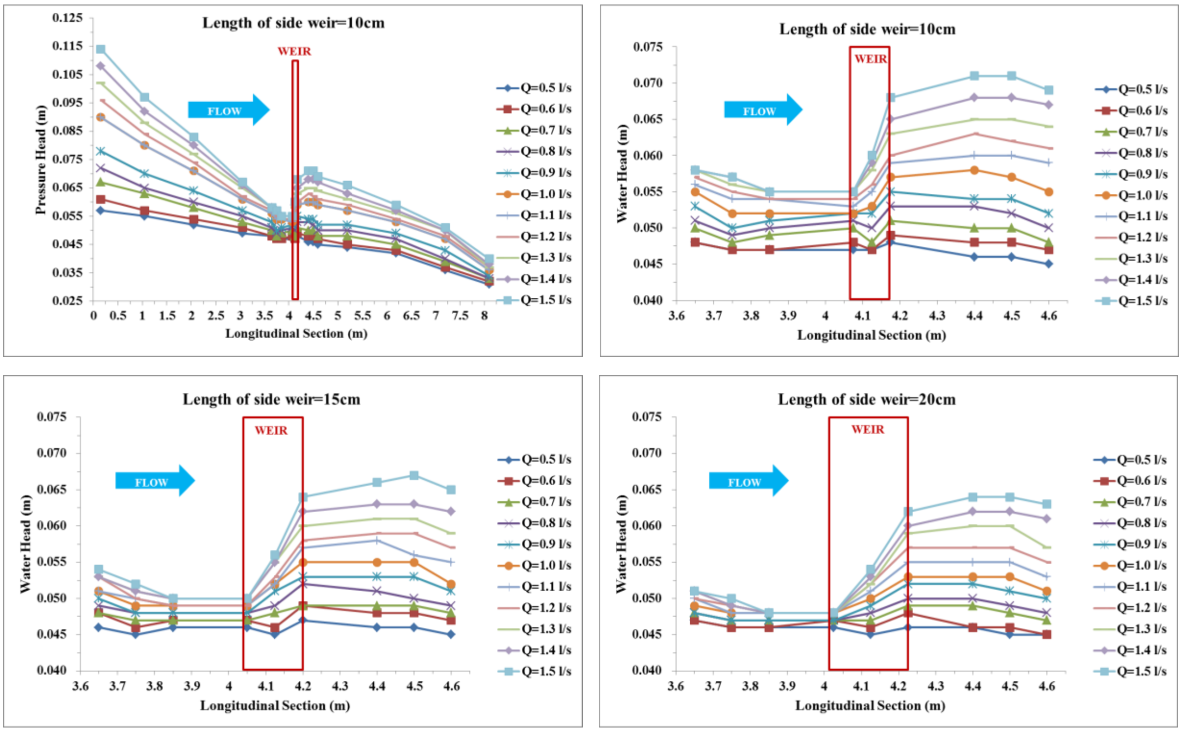

Fig. 1 The water surface profile

water heads of the downstream pipe.

4.2 Discharge coefficient

The discharge coefficient was calculated by De Marchi's equation as follows,

$$C_d = \frac{\frac{3}{2}Q_{out}}{\sqrt{2g}(h-p)^{\frac{3}{2}}} \qquad (3)$$

This discharge coefficient depends on the hydraulic conditions that are weir length, weir height, water head on the side weir and overflow discharge. According to some previous studies, water head at the upstream end of the side weir is used for parameter of discharge coefficient. However, as seen in the surface profile of Fig. 1, there is wide deviation in water heads on the side weir excessively compared with those of previous studies. With this point of view, the mean value of integral heads along the side weir was adopted.

Uyumaz (1985) also reported that water head was not constant on the side weir. Using the mean of upstream and downstream water heads on the side weir did not produce satisfactory solutions. Calculating the mean of several intermediate heads proved more satisfactory results. Fig. 2 shows, the coefficient value increases gradually if the water head at the upstream end of the side weir was used.

On the other hand, the discharge coefficient remains almost constant if the mean value of integral heads was adopted instead of water head at the upstream end of the side weir. In particular, this coefficient value becomes close to constant value as upstream discharge increases, which implies applicability of constant coefficient value. Table 3 shows the experimental results of overflow discharge rate and calculated mean of integral heads on the side weir. The discharge coefficients for each case are also shown in Table 3, which are derived from experimental data. As weir length increases, the coefficient values decreases.

In application to actual estimation of overflow discharge, the constant coefficient value would be easy to handle. Therefore, as the next step, applicability of constant value derived from these experiments will be investigated by using numerical model.

5. Summary

The present study has investigated the variation of discharge coefficient for pressurized flow in circular channel with different side weir length. A detailed work is also presented for flow in circular channel with different side weir length.

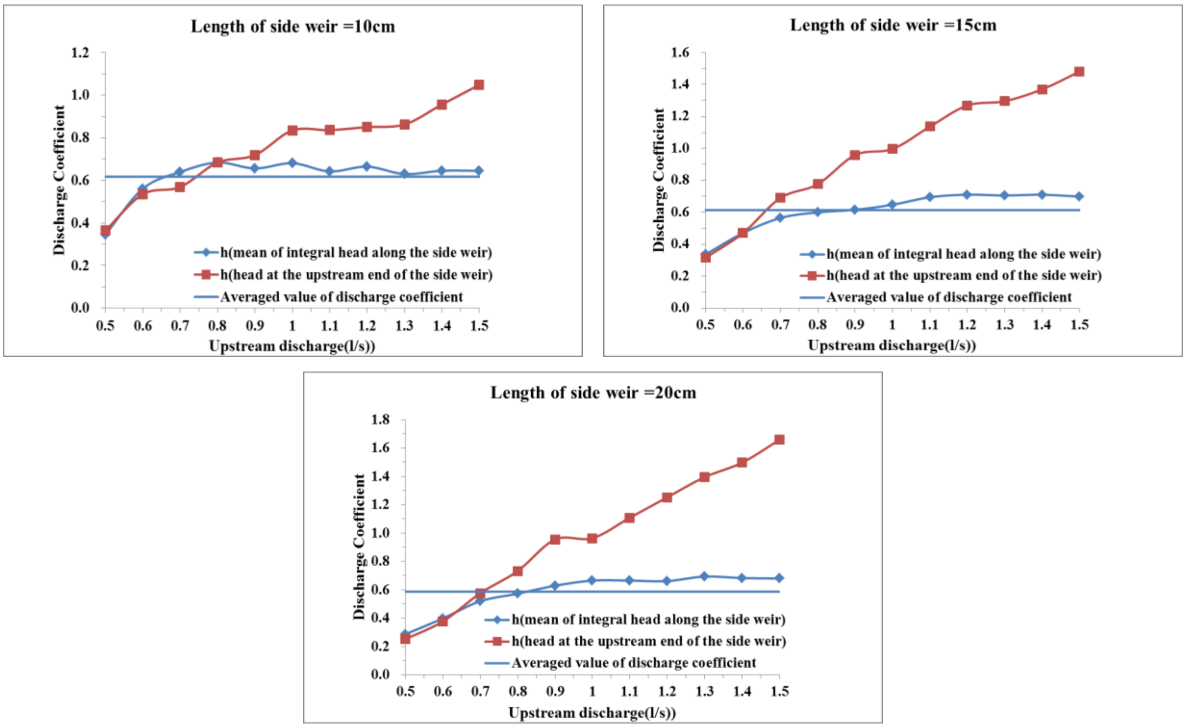

Fig. 2 The discharge coefficient distribution along the different water head on the side weir

Table 2 Experimental results (10cm, 15cm, 20cm)

Overflow discharge(ℓ/s)											
Weir length(cm)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
10	0.063	0.113	0.168	0.233	0.279	0.324	0.366	0.416	0.468	0.519	0.569
15	0.065	0.122	0.179	0.246	0.304	0.377	0.430	0.480	0.574	0.607	0.656
20	0.069	0.130	0.199	0.253	0.330	0.407	0.468	0.529	0.589	0.632	0.700
Mean of integral heads on the side weir(cm)											
Weir length(cm)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
10	4.73	4.78	4.93	5.10	5.28	5.38	5.55	5.65	5.85	5.95	6.08
15	4.58	4.7	4.80	4.95	5.08	5.20	5.25	5.33	5.50	5.55	5.65
20	4.55	4.68	4.75	4.82	4.93	5.03	5.13	5.23	5.28	5.35	5.45

Discharge coefficient												
Weir length(cm)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Average value of C_d
10	0.346	0.561	0.639	0.684	0.656	0.681	0.642	0.665	0.630	0.645	0.645	0.618
15	0.337	0.470	0.565	0.600	0.616	0.647	0.695	0.711	0.705	0.710	0.699	0.614
20	0.286	0.397	0.519	0.572	0.628	0.664	0.664	0.661	0.693	0.682	0.679	0.586

A detailed work is also presented for flow surface profile along the side weir and the discharge coefficient of the side weir.

The suitable discharge coefficient is essential to estimate the model validation through the experimental data and the water head on the side weir.

Finally, the next step will be to find out the suitable discharge coefficient within the limit of above experimental results for each weir length and experimental condition and to reproduce the overflow discharge obtained from experiment by using numerical model. That numerical model verified in that way would enable to estimate overflow discharge from sewerage to storage system and mitigation effect of those storage systems.

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References

Allen, J.W.(1957). “The discharge of water over side weir in circular pipes.” ICE Proc, Vol.6, No.2, pp. 270-287

Borghei, M., Jalili, M.R., Ghodsian, M.(1999). “Discharge coefficient for sharp-crested side weir in subcritical flow. ASCE Journal of Hydraulic Engineering Vol. 125, No.10, pp. 1051-1056

Cheong, H.F.(1991). “Discharge coefficient of lateral diversion from trapezoidal channel.” ASCE Journal of Irrigation and Drainage Engineering. Vol.117, No.4, pp. 321-333

De Marchi, G.(1934). “Saggio di teoria del funzionamento degli stramazzi laterali.” L’Energia Elettrica, Vol.11, No.11, pp. 849–860 (in Italian)

Ghodsian, M.(2003). “Supercritical flow over rectangular side weir.” Canadian Journal of Civil Engineering. Vol. 30, No. 3, pp. 596–600.

Granata, F., Marinis, G.D., Gargano, R., Tricarico, C.(2013). "Novel approach for side weir in supercritical Flow" J. Irrigation and Dranage Eng. Vol. 139, No.8, pp. 672-679

Hager, W.H.(1987). "Lateral outflow over side weirs." J. Hydraulic Eng. Vol. 113, No.4.

Khorchani, M., Blanpain, O.(2004) “Free surface measurement of flow over side weirs the video monitoring concept.” Flow Measurement and Instrumentation. Vol. 15, No. 2, pp. 111–117.

Muslu, Y.(2002). “Lateral weir flow model using a curve fitting analysis.” ASCE Journal of Hydraulic Engineering. Vol. 128, No. 7, pp. 712–715.

Nandesamoorthy, T., Thomson, A.(1972). “ Discussion of spatially varied flow over side weir. ASCE Journal of the Hydraulics Division. Vol. 98, No. 12, pp. 2234–2235.

Ranga Raju, K.G., Prasad, B., Grupta, S.K.(1979). “Side weir in rectangular channel. ASCE Journal of the Hydraulics Division. Vol. 105, No. 5, pp. 547–554.

Singh, R., Manivannan, D., Satyanarayana, T.(1994). “Discharge coefficient of rectangular side weirs.” ASCE Journal of Irrigation and Drainage Engineering. Vol. 120, No. 4, pp. 814–819.

Subramanya, K., Awasthy, S.C.(1972). “ Spatially varied flow over side weirs.” ASCE Journal of the Hydraulics Division. Vol. 98, No.1, pp. 1–10

Swamee, P.K., Santosh, K.P., Masoud, S.A.(1994). “Side weir analysis using elementary discharge coefficient.” ASCE Journal of Irrigation and Drainage Engineering. Vol. 120, No. 4, pp. 742–755.

Uyumaz, A., and Muslu, Y.(1985). "Flow over side weirs in circular channels." J. Hydraulic Eng. Vol. 111, No.1, pp. 144-160

Vatankhah, A.R.(2012) “New solution method for water surface profile along a side weir in a circle channel.” J. Irrigation and Drainage Eng.Vol.138, No.10, pp. 948-954

Yuksel, E.(2004). “Effect of specific variation on lateral overflows.” Flow Measurement and Instrumentation. Vol. 15, No. 5–6, pp. 259–269.

Yu-Tech, L.(1972). “Discussion of spatially varied flow over side weir.” ASCE Journal of the Hydraulics Division, Vol. 98, No.11, pp. 2046-2048

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