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Hydraulic Design of Side Weirs by Alternative Methods

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Abstract: Side weirs are widely employed to divert flows from rivers, channels, sewers and reservoirs or to divide flows between components of water treatment systems. However, the hydraulic behavior of this type of weir is complex and difficult to predict accurately by standard methods. Hydraulic design of side weirs presents a new design procedure from experimental studies on side weirs and results obtained from a calibrated numerical model. Presented in the form of graphs and simplified equations, this new design procedure enables the flow rate discharged by side weirs to be determined by direct calculation.

Key words: Side weirs, numerical model, Hydraulic design, Natural and artificial channels

INTRODUCTION

A side weir is a hydraulic control structure used to divert flow from a main (or parent) channel a side channel when the water level in the main channel exceeds a specified limit. As the name suggests, the structure is normally located in the side of the channel and water discharges over it freely under gravity in the same way as for conventional weirs.

The most common function of a side weir is to remove flow from a channel in order to prevent the downstream flow capacity of the channel being exceeded .It is a usual requirement that this function should be achievable without a large increase in the water level in the parent channel. Hence, the side weir is often considered as a means of limiting water level but, in fact, this is generally a secondary requirement of the structure.

The hydraulic design of a side weir is complicated because the flow conditions vary with distance along the weir and do not conform to simple weir theory. There are also practical design issues that could easily be overlooked if a designer is thinking just in terms of a conventional weir.

The diversity of applications of side weirs has the potential to complicate a guidance document such as this. This is because, although there are hydraulic similarities between, for example, a side weir in a river and one in a sewer, the practical differences make it inappropriate to attempt to cover these applications in one section.

Design Considrations:

The requirement for a side weir often comes about because of a need to discharge excess flow from a channel, without a large increase in water level in the channel. The side weir is ideal in this respect, because increases in water level can generate large flows, especially when the crest length is long.

The design of the parent channel is an integral part of the design of a bifurcation using a side weir. As well as influencing the head-discharge relationship, this will determine the velocity of the flow in the parent channel at different discharges. The velocity of the flow will, in turn, affect the hydraulic performance of the weir, as well as influencing practical aspects of the design, such as safety, sediment transport and the need for scour protection. If the velocity of the flow across the face of the weir is low then the determination of the head over the weir may be assessed with conventional weir theory.

The first consideration in the design of the side weir is to set the crest level so that the spill over the weir is initiated at the appropriate flow rate or level. The height of the crest above the invert level will correspond to a point on the head-discharge curve of the onward flow channel. In this way, the weir is set to start spilling at a defined flow in the parent channel, for which the water levels are assumed to be known.

In summary:

- The initiation of spill over the weir occurs when the water level in the parent channel reaches the weir crest level.
- Where the head-discharge relationship for the onward flow is fixed (i.e. it is not separately regulated and dose not due to changing conditions, such as vegetative growth), the overall head-discharge relationship of the structure can be defined.
- If there is provision to regulate the onward flow, the division of flow can be varied by the setting of the control structure.

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Desingning to Limit the Onward Flow:

A common requirement of a side weir installation is limitation of the onward flow in the parent channel. Limiting the onward flow to an absolute value is difficult, and cannot be achieved unless there is a control structure in the parent channel beyond the side weir. In the situation where is no control structure, the ratio between onward flow and diverted flow will vary throughout the operating range? The way in which the ratio varies will depend on a number of factors including the channel geometry, the length of the side weir and the crest level.

If the design requirement is to limit the onward flow to an absolute value, whatever the approach flow, then some form of automatically-controlled gate will be required in the downstream section of the parent channel.

In this situation, the side weir will take the balance of the flow, and the hydraulic design will focus, at least initially, on the control structure.

The hydraulic design of the side weir will be driven by any limitations set on the water level in the channel, in particular:

- The level at which weir flow is initiated, and
- The maximum acceptable water level.

Applictions of Side Weirs:

This paper gives examples of typical applications for side weirs:

- Complex weirs (such as the duck – bill and labyrinth types)
- Gated side weirs
- Side weirs with a sloping crest
- Side weirs in supercritical flow channels
- Side weirs operating under drowned (no modular) flow conditions.

Flow Charactristics of Weris:

Weirs are normally installed either as a means of controlling water levels in an upstream channel or as a means of accurately measuring the rate of flow. In the majority of cases, the weir is set transversely across the width of the channel so that the flow approaches at right angles to the line of the crest (unlike the case of side weirs considered elsewhere in this paper). Provided the weir is constructed with a horizontal crest and the upstream channel produces uniform approach conditions, the flow conditions at a transverse weir will be essentially two dimensional, with the vertical velocity profiles being similar at all points along the crest line of the weir.

For transverse weirs, the flow accelerates as it approaches the crest, leading to a fall in the level of the water surface. At some point, located at or very close to the weir crest, the flow passes through what is termed the critical flow depth and continues to accelerate for a certain distance beyond the crest depending on the cross-sectional geometry of the downstream channel and the depth of flow within it.

The critical values of flow area and surface width are, therefore, linked uniquely to the discharge by the equation (1):

$$\frac{A_C{}^3}{B_C} = \frac{Q^2}{g} \tag{1}$$

Knowing the cross-sectional shape of the channel and, therefore, the relationship between $A_C\,(m^2)$ and $B_C\,(m)$, it is possible to find the value of the critical flow depth, corresponding to a given flow rate.

Where g is the acceleration due to gravity

Many different equations for the flow capacity of transverse weirs have been developed but they all share the same fundamental form. If the flow passes though critical depth at, or very close to, the weir crest, it can be shown by applying the equations (3) that the discharge and the total head over the weir crest will be related by a equations (4).

$$Q = AV \tag{2}$$

$$Q = C_D \sqrt{g} L H^{\frac{3}{2}} \tag{3}$$

$$H = E - p \tag{4}$$

L is the length of the weir crest at right angels to the flow, and C_D is a non-dimensional coefficient of discharge.

An important factor that needs to be considered when designing weirs for level control or discharge measurement is the Froude number of the flow approach the weir. The equation (5) defining the Froude number, from which it can be seen that a flow has a value of $F = 1$ when the velocity of the water is equal to the corresponding value of critical velocity given :

$$F = \frac{V}{V_C} \tag{5}$$

$$V_C = \sqrt{\frac{gA_C}{B_C}} \tag{6}$$

- If $V < V_C$, sub critical flow
- If $V = V_C$,.critical flow
- If $V > V_C$,supercritical flow

Froude number can be calculated from:

$$F = \sqrt{\frac{BQ^2}{gA^3}} \tag{7}$$

Hydraulic Design of Side Weirs Methods:

Computational Fluid Dynamics (CFD) packages offer suitable capabilities but experience to date suggests that accurate CFD simulations of flows over side weirs can be difficult and need careful verification against experimental date. Also**,** results from CFD models are specific to the particular geometries considered and cannot easily be used to produce generalized results for routine application.

Data For Design:

- Average cross-sectional geometry of parent channel at side weir
- Flow conditions in parent channel at downstream end of side weir
- Mean width of parent channel
- Length of side weir
- Cross- sectional profile of the side weir

Calculation Methods:

a- Total Flow Rate Discharged by the Side Weir:

Having obtained the necessary data about the geometry of the side weir installation and the downstream flow conditions in the parent channel, as described in section data for design, the flow capacity of the side weir can be determined using equation(8):

$$Q_S = \eta\sqrt{g}Lh_O^{1.5}\left[J - K(\frac{L}{B})F_O\right] \tag{8}$$

$$h_O = Z_O - Z_W \tag{9}$$

$$Z_B = Z_W - p \tag{10}$$

$$p = \frac{A_W}{B_W} \tag{11}$$

Where:

Q_S = Total flow rate discharged by the side weir $(\frac{m^3}{s})$

$\eta =$ Factor allowing for effect of weir profile

$g = 9.81 \frac{m}{s^2}$

$L =$ Effective length of crest of side weir (m)

$h_O =$ Height of water surface above weir crest in parent channel at downstream end of weir (m)

J = Coefficient depending on the ratios $\frac{h_O}{L}, \frac{h_O}{p}$

$K =$ Coefficient depending on the ratios $\frac{h_O}{p}$

$p =$ Height of weir crest above channel (m)

$B =$ Mean width of parent channel at side weir (m)

$F_O =$ Froude number of flow in parent channel at downstream end of weir (m)

Z_O = Corresponding water level above datum at the downstream end of the weir (m)

$Z_W =$ Corresponding water level above datum of the weir crest (m)

$Z_B =$ Corresponding the average bed level above datum at the parent channel at the side weir (m)

$A_W =$ Flow area (m^2)

$B_W =$ Surface width of flow (m)

The values of the coefficient J and K can be determined graphically using the design graphs in Figures (1) and (2) respectively.

For sharp- crested weirs, the weir profile factor has a fixed value of ($\eta = 1$)

For rectangular broad-crested weirs, the weir profile factor can be estimated from:

$$\eta = 1 - 0.064(\frac{t}{h_O}) \text{ For } 0 < \frac{t}{h_O} < 2.5 \tag{12}$$

$$\eta = 0.84 \qquad \text{For } \frac{t}{h_O} \geq 2.5 \tag{13}$$

b- Flow Conditions at the Upstream End of a Side Weir:

The flow rate in the parent channel approaching the upstream end of the side weir is therefore:

$$Q_A = Q_O + Q_S \tag{14}$$

Where:

Q_O = Onward flow rate in the parent channel

The corresponding water level above datum at the upstream end of the side weir can be determined from the equation (15):

$$Z_A + \frac{1.15 Q_A{}^2}{2gA_A{}^2} = Z_O + \frac{1.75 Q_O{}^2}{2gA_O{}^2} \tag{15}$$

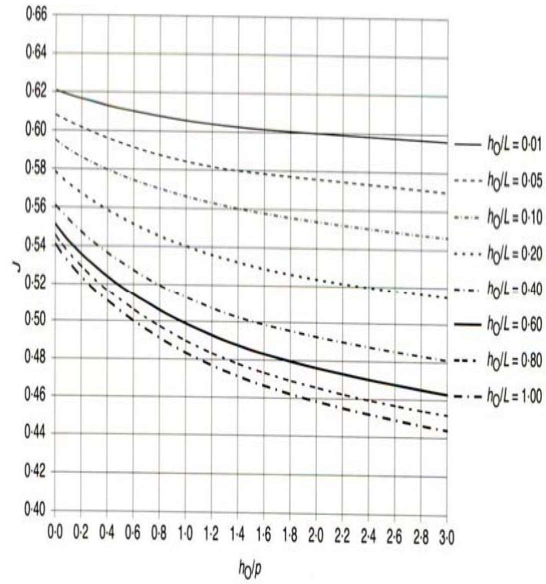

Fig. 1: Value of coefficient J **.**

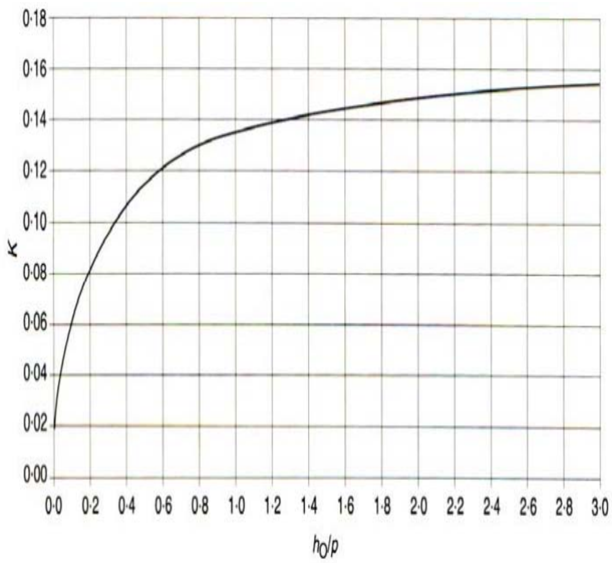

Fig. 2: Value of coefficient K **.**

Assuming that the flow rate approaching the weir is known, together with the values of at the downstream end of the weir, the following trail-and error method can be used to find.

- Value of the water level and calculated the corresponding flow area and surface width of flow using data on the cross-sectional geometry of the parent channel at the upstream end of the side weir.
- If the left-hand side of equation (15) dose not equals the right-hand side, repeat the calculations with revised estimates of until a satisfactory degree of agreement is achieved.
- In certain cases it may be found that the left-hand side of equation (15) is greater than the right-hand side whatever value of is assumed. This indicates that supercritical flow is likely to occur along the upstream part of the side weir, with the flow becoming sub critical further downstream through the formation of a hydraulic jump.

The value of the Froude number at the upstream end of the weir is given by equation (7).

Discussion and Conclusion:

I-Determining the Rating Curve of an Existing Side Weir:

This example illustrates the situation of an existing side weir for which it is necessary to establish a rating curve that will relate the flow rate over the weir to the rate of flow in the parent channel upstream of the weir. It is assumed that the geometry of the weir (e.g. the level of the weir crest, its effective length and the profile of the crest), together with the cross-sectional shape of the parent channel, have been determined from a site survey or from reliable drawings. It is also assumed that backwater calculations have been carried out to determine the relationship between the onward flow rate in the parent channel and the corresponding values of the water level at the downstream end of the side weir.

The following date for a side weir in a small river has been collected:

- Level of weir crest is $Z_W = 63.40m)$ datum
- Effective length of weir crest(allowing for support piers) is $L = 12.0m$.The line of the weir crest is parallel with that of the approaching flow
- Crest profile- broad crested rectangular with thickness perpendicular to crest line of $t = 0.60m$
- Average bed level of parent channel at side weir is $Z_B = 61.50m$
- Height of weir crest above average bed level is $p = Z_W - Z_B = 1.90m$
- When the onward flow rate in parent channel is $Q_O = 40\frac{m^3}{s}$, it is known from separate backwater calculations that the water level in the parent channel will be $Z_O = 64.40m$ above datum
- From cross-sectional data for the parent channel it is known that the water level, Z_O, corresponds to a flow area of $A_O = 32.0m^2$ and a surface flow width of $B_O = 16.80m$
- The surface width of flow along the length of the side weir is estimated using the water level. The value of surface width at the upstream end of the weir, the mid-point and the downstream end are 18.40m, 17.90m and 16.80m respectively, so the mean width to be used in the analysis is $B = 17.70m$.

From the above data, the following ratios and quantities can be determined:

- $\frac{L}{B} = 0.678, h_O = Z_O - Z_W = 1.0m, \frac{h_O}{p} = 0.526, \frac{h_O}{L} = 0.083$
- From Equation(7), the Froud number in the parent channel at downstream end of weir is $F_O = 0.289$ (since $F_O < 0.6$, the flow is sub critical and the conditions are within the range of validity of the design method)
- From Figure (1) and Figure (2), $J = 0.582$ and $K = 0.116$ respectively.
- From Equation (12), weir profile factor for rectangular broad-crested weir is $\eta = 0.962$.

Using these values, the spill discharge is calculated from Equation (8) as: $Q_S = 20.2\frac{m^3}{s}$

The flow rate in the parent channel upstream of the side weir is therefore: $Q_A = Q_O + Q_S = 60.2\frac{m^3}{s}$

The water level in the parent channel at the upstream end of the side weir is found using Equation(15).From the known values above, the right-hand side of the equation can be shown to have a value of 64.539m. Using data on the cross-sectional shape of the parent channel , a trial-and – error method of solution shows that the left-hand side of the equation has an equal value when:

- $Z_A = 64.356m$ above datum
- Which from the cross-sectional survey corresponds to $A_A = 34.0m^2$ and $B_A = 18.20m$.

The final step is to calculate the Froude number at the upstream end of the weir from Equation (7). This gives a value of $F_A = 0.414$, which confirms that the flow is sub critical at this point. The conditions are, therefore, within the range of validity of the design method.

Repeating the above procedure for a range of values of onward discharge enables sets of values of Q_O, Q_S, Q_A, Z_O and Z_A, to be established. Using these data, it is then possible to determine how the spill discharge varies with the water level, and the flow rate in the parent channel upstream of the side weir.

II-Designing a New Side Weir:

This example illustrates a case in which a side weir in water treatment plant is to be designed to divert a specified flow rate from an inlet channel to a set of new treatment tanks. The remainder of the flow is to continue to an existing set of tanks. Therefore, it is assumed that the onward flow rate in the channel and the corresponding water level at the downstream end of the side weir are already known.

Two main factors can be varied in the design to achieve the desired performance the level of the weir crest and its length. In addition, it may be possible to optimize the design by varying the profile of the crest. In general, lowering the crest level enables the length of the weir to be reduced. However, if the crest is set too low, there is danger that the flow may become supercritical along the side weir leading to the undesirable formation of a hydraulic jump. Also, there may be a requirement to prevent any water flowing over the side weir until the onward flow rate (and the corresponding downstream water level) exceeds a certain figure. In this example, it is therefore assumed that the weir level has been fixed and that the design problem is to determine the required length of the crest.

The following design data apply:

- Rectangular channel of constant width-therefore $B = B_O = B_A = 2.0m$
- Invert level of parent channel at side weir is $Z_B = 71.0m$ above datum
- Assumed level of weir crest is $Z_W = 72.25m$ above datum
- Height of weir crest above invert of channel is $p = Z_W - Z_B = 1.25m$
- Assumed sharp crested(e.g. adjustable metal weir plate)
- Onward flow rate in parent channel is $Q_O = 1.20\dfrac{m^3}{s}$
- Corresponding water level in parent channel at downstream end of side weir $Z_O = 72.50m$ above datum (determined from backwater analysis or sit measurements)
- Downstream water depth in channel is $Y_O = Z_O - Z_B = 1.50m$
- Since the channel is rectangular, the corresponding flow area is $A_O = BY_O = 3.0m^2$
- Downstream head over the weir is $h_O = Z_O - Z_W = 0.25m$
- Required spill discharge is $Q_S = 1.20\dfrac{m^3}{s}$
- Flow rate in parent channel upstream of weir is $Q_A = Q_O + Q_S = 2.40\dfrac{m^3}{s}$

A trial and error method of solution is necessary because the unknown length of the weir crest appears in the ratios $\dfrac{L}{B}$ and $\dfrac{h_O}{L}$, which affect the coefficients J and K in Equation (8) for the spill discharge. Therefore, make an initial assumption of $L = 7.50m$ and calculate the following values:

- $\dfrac{L}{B} = 3.75, \dfrac{h_O}{p} = 0.20, \dfrac{h_O}{L} = 0.033$
- From Equation(7), the Froud number in the parent channel at downstream end of weir is $F_O = 0.104$ (since $F_O < 0.6$, the flow is sub critical and the conditions are within the range of validity of the design method)
- From Figure (1) and Figure (2), $J = 0.607$ and $K = 0.0814$ respectively.
- Since the weir has a sharp crested profile, $\eta = 1.0$.

Using these values, calculate the spill discharge from Equation (8) as: $Q_S = 1.69\dfrac{m^3}{s}$

This value is more than the required figure of $1.20\dfrac{m^3}{s}$, so it is necessary to assume a smaller value for the weir length and repeat the above calculations.

In this way it can be shown that the side weir needs to have a crest length of $L = 5.30m$ in order to meet the design requirements. With this value of L, the ratios and quantities have the following final values:

- $\frac{L}{B} = 2.65, \frac{h_O}{p} = 0.20, \frac{h_O}{L} = 0.0472, J = 0.602, K = 0.0814, \eta = 1.0$

Therefore, from Equation (8): $Q_S = 1.20 \frac{m^3}{s}$

he water level in the parent channel at the upstream end of the side weir is found using from Equation (15). From the known value above, the right-hand side of the equation can be shown to have a value of 72.514m. For the rectangular channel, it can be found by a trail and error procedure that the left-hand side of the equation has an equal value when:

- Upstream water level is $Z_A = 72.475m$ above datum
- Corresponding to a water depth of $Y_A = 1.475m$ and a flow area of $A_A = 2.95m^2$.

Finally, it is necessary to check that the flow is sub critical at the upstream end of the weir. From Equation (7) it is found that $F_A = 0.214$, which confirms that the flow is sub critical at this point and that the conditions are within the range of validity of the design procedure.

III-Designing a Side Weir With Zero Onward Flow:

This example deals with the case in which all the flow approaching a side weir is discharged in to the spill channel with no onward flow occurring in the parent channel. The calculation procedure is illustrated using the side weir in section II. It is required to check a possible operational situation in which a penstock in the parent channel downstream of the side weir is closed so that all the flow entering the treatment works is diverted over the side weir .For this situation, the design problem is to determine what will be the water level in the parent channel upstream of the weir (since this may cause backing-up of flow in the piped system supplying the works).

The design conditions are therefore:

- Flow rate approaching the side weir is $Q_A = 2.40 \frac{m^3}{s}$
- Spill discharge is $Q_S = 2.40 \frac{m^3}{s}$
- Onward flow rate in parent channel is $Q_O = 0 \frac{m^3}{s}$
- Length of weir crest is $L = 5.30m$

Other details of the weir and the parent channel are as described in section II. The method of solution is to assume a value for the water level in the parent channel at the downstream end of the side weir, calculate the spill discharge over the weir, and repeat this procedure until the result is equal to the required value of $Q_S = 2.40 \frac{m^3}{s}$. The following calculation shows the results of the final iteration:

- Downstream water level in parent channel is $Z_O = 72.64m$
- Downstream head over the weir is $h_O = Z_O - Z_W = 0.39m$
- $\frac{h_O}{p} = 0.312, \frac{h_O}{L} = 0.0736, \eta = 1.0, J = 0.59.$
- Since there is zero onward flow, the value of the downstream Froud number in the parent channel is $F_O = 0$. Therefore, Equation (8) reduces to: $Q_S = \eta \sqrt{g} L h_O^{1.5} J$ and the value of K not need to be determined. Substituting in this equation gives $Q_S = 2.39 \frac{m^3}{s}$, which is close to the specified value of $2.40 \frac{m^3}{s}$ and can therefore be accepted as the solution.

The resulting water level in the parent channel at the upstream end of the side weir is found using Equation (15). From the above data, the right-hand side of the equation has a value of 72.64m (equal to Z_O since $Q_O = 0$). For the left-hand side of the equation has an equal value when:

- Upstream water level is $Z_A = 72.607m$ above datum
- Corresponding to a water depth of $Y_A = 1.607m$ and a flow area of $A_A = 3.21m^2$.

Finally, it is necessary to check that the flow is sub critical at the upstream end of the weir. From Equation (8) it is found that $F_A = 0.188$, which confirms that the flow is sub critical at this point and the condition are within the range of validity of the design procedure.

IV-Using a Control Structure to Improve Flow Conditions at a Side Weir:

This example illustrates a situation in which flow velocities in the parent channel are relatively high and there is a possibility of unsuitable flow conditions occurring at the side weir.
The following design data apply:

- Concrete-lined irrigation channel with trapezoidal cross-sectional profile
- Base width of channel is $B_B = 5.0m$
- Invert level of parent channel at side weir is $Z_I = 160.0m$ above datum
- When the approach flow rate is $Q_A = 15.0\frac{m^3}{s}$, the side weir is required to divert a flow rate of $Q_S = 5.0\frac{m^3}{s}$
- Uniform flow conditions apply in the parent channel downstream of the side weir for a Manning roughness of $n = 0.022$ and a longitudinal gradient of $S_O = \frac{1}{600}$, it is found that the flow depth in the channel downstream of the side weir is $Y_O = 1.0m$ when the flow rate is $10.0\frac{m^3}{s}$.

The initial design of the side weir is based on the following assumed geometry:

- Level of weir crest (horizontal) is $Z_W = 160.50m$ above datum
- Average bed level of parent channel, calculated by converting trapezoidal channel into equivalent rectangular channel using Equation (10), is $Z_B = 160.058m$ above datum
- Height of weir crest above average bed level of parent channel is $p = Z_W - Z_B = 0.442m$
- Rectangular broad-crested profile with thickness perpendicular to crest line of $t = 0.60m$
- Length of weir crest is $L = 10.0m$

The relevant parameters for the design flow conditions are therefore:

- Onward flow rate in parent channel is $Q_O = 10.0\frac{m^3}{s}$
- Corresponding water level in the parent channel at the downstream end of side weir is $Z_O = 161.0m$
- Downstream head over the weir is $h_O = Z_O - Z_W = 0.50m$
- Surface width of flow in parent channel at side weir is $B = 8.0m$
- From Equation (8) and the cross sectional shape of the channel, the value of the Froud number in the parent channel downstream of the weir is found to be $F_O = 0.544$ this is relatively high but within the limit of $F_O < 0.6$.

Using these values, the flow rate discharge by the side weir is $Q_S = 5.0\frac{m^3}{s}$, which matches the design requirements.

It is now necessary to determine the water level in the parent channel upstream of the side weir using Equation (15). From the known quantities Z_O, Q_O and A_O, it can be shown that the right-hand side of this equation has a value of 161.211m.

However, substituting the know approach flow rate of $Q_A = 15.0 \frac{m^3}{s}$ and assuming different values of the upstream water level it may be demonstrated that the left-hand of Equation (15) cannot have a value less than 161.30m.

No satisfactory solution of Equation (15) exists therefore. That supercritical flow is likely to occur along the upstream part of the side weir, with the flow becoming sub critical farther downstream through the formation of a hydraulic jump. This type of flow condition is not recommended and the value of spill discharge calculated above is not valid.

Owing to the relative steepness of the parent channel, the most suitable method of improving flow conditions at the side weir is to increase the water depth through installation of a flow control in the parent channel downstream of the weir. The increase in Y_O needs to exceed a certain minimum in order to produce satisfactory sub critical condition along the side weir but beyond that limit it is possible to consider various different combinations of weir length and crest level. The particular solution considered here involves raising both the downstream water depth and the crest level of the weir by 0.50m.

The new design flow conditions are therefore:

- Onward flow rate in parent channel is $Q_O = 10.0 \frac{m^3}{s}$
- Corresponding water level in the parent channel at the downstream end of side weir is $Z_O = 161.50m$ above datum
- Length of weir crest is $L = 10.0m$
- Level of weir crest (horizontal) is $Z_W = 161.0m$ above datum
- Average bed level of parent channel, calculated by converting trapezoidal channel into equivalent rectangular channel using Equation (10), is $Z_B = 160.187m$ above datum
- Height of weir crest above average bed level of parent channel is $p = Z_W - Z_B = 0.813m$
- Downstream head over the weir is $h_O = Z_O - Z_W = 0.50m$
- Surface width of flow in parent channel at side weir is $B = 9.50m$
- From Equation (8) and the cross – sectional shape of the channel, the value of the Froud number in the parent channel downstream of the weir is found to be $F_O = 0.274$ which satisfies the recommended limit of $F_O < 0.6$.

Using these values, the flow rate discharge by the side weir is $Q_S = 5.69 \frac{m^3}{s}$. The required discharge capacity is $Q_S = 5.0 \frac{m^3}{s}$, which indicates that the weir length should be reduced from $L = 10.0m$ to about $L = 8.80m$

The water level at the upstream end of the side weir is found as before from Equation (15). The right-hand side of the equation has a value of 161.575m, which is sufficiently large for a valid solution to exist. By trail-and-error substitution, it can be shown that the value of the left-hand side is equal to 161.575m when $Z_A = 161.45m$ above datum. The Corresponding value of the upstream Froud number is found from Equation (8) to be $F_A = 0.436$, which satisfies the recommended limit of $F_A < 0.6$ for reliable operation of the side weir.

The required increase in downstream water depth can be achieved by installing a suitable flow control in the parent channel downstream of the side weir.

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