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Effect of Variable Slopes on the Flow Conditions for Side Channel Spillway.

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***Abstract**: Spatially varied flow occurred in many hydraulic structures with the variable discharge including the main spillways designed for normal flood discharge and head above the sill at the crest, where hydraulic analysis of flow conditions have established through the research work carried at various laboratories, Efforts have been made here in this paper to assessment the flow in the receiving channel of a side channel spillway which is required to be provided to byepass the excess discharge above FRL during high floods. The present conditions particularly occur with earth dams where a conventional spillway cannot be used due to the settlement of the wall. The experimental studies were carried out for side channel spillway by using 3-D physical model to the scale of geometric similar scale (1/100). Experiments were carried out at Department of Civil engineering hydraulic laboratory, B.V.D.U.C.O.E, Pune. Side channel bottom was kept at the same level of spillway. Various experiments were carried out on the model of trapezoidal side channel spillway model, for different discharges varying from 1 lit/sec to 3 lit/sec for the different slopes from 0° to 20°. Coefficient of correlation varies from 0.80 to 0.98 which is fairly good. Maximum water depths for the higher discharge when channel is horizontal and depths decrease as slope of channel increases. Water surface profiles and discharge versus depths graphs were drawn from the hydraulic studies which may provide the guidelines related to flow conditions at side channel spillway.*

***Index Terms**: Keywords: Side channel spillway, Spatially varied flow, 3-D Physical model, Hydraulic studies, assessment of flow conditions.*

I. INTRODUCTION

Main function of spillway on dam is to control the excess discharge of upstream of dam. The design of dam is based on the need for the project and upon some factors such as the location of the spillway, the topography of the area where dam is to be constructed, purpose of the dam and the construction cost. Main function of spillway is to control excess discharge on upstream of dam and it provides a safe passage for the excess water at the downstream side. However, sometimes it may not be possible to locate regular spillway in a main dam portion and hence efforts are made to by-pass the excess discharges through various types of side channel spillway, Based on local topography and related back to river. The side channel spillway should be structurally safe and hydraulically adequate, which must be located in such a manner that the outfacing discharge back into the river does not undermine the downstream toe of the dam. There are various types of Spillway but in this present study the emphasis is given on the side channel spillway.

A. *Side Channel Spillway*

A spillway which is generally used to discharge excess water from the reservoir over full reservoir level and the control weir is placed parallel to the upper portion of the discharge channel. In hydraulic structures in large of variety spatially varied flow occurs in the direction of flow with the variable discharge. Increasing discharge is found an in effluent channels round sewage tanks, roof gutters, and side channel spillways. This paper is deal mainly with the flow conditions in the receiving channel of a side channel spillway. This type of structure is particularly useful with earth dams where a conventional spillway cannot be used because of the settlement of the wall. In order to be able to use a conventional free overfall spillway, the wall below the entire crest must be constructed in concrete. The side channel spillway which is a type of hydraulic structure, it has many applications, especially with earth dams. The difference is from other spillway is the spillway crests are usually perpendicular to the dam wall. Water flowing over the spillway crest and be collected in a channel running along its length which carries the water away. The depth of flow in this receiving channel cannot be calculated in the usual way as the flow is not constant along its length. Indeed, water is added continuously along its length.

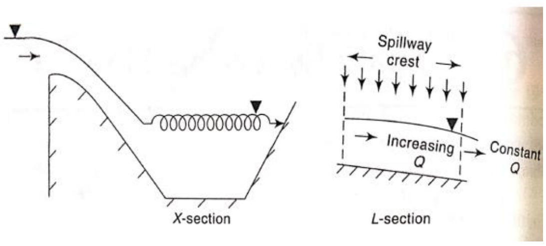

Fig. 1: Side Channel Spillway (flow from one side) (Source: Flow in open Channels reference book)

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B. *Spatially Varied Flow*

The discharge in a channel is a very important parameter within the flow characteristics study in a channel. Spatial variation in flow depth, bed slope, cross section shape and size have concerned varied flow situation. However, it assumed that the discharge remains same throughout the channel. In other words, the product of area and velocity remains constant at all sections.

- *SVF with increasing discharge –*

SVF with increasing discharge finds considerable practical applications. Flows in side channel spillway, wash-water troughs in filter plants, roof gutters, highway gutters are some of the typical instances. Fig.2 shows a typical side-channel spillway causing an SVF in the channel below it. The lateral flow enters the channel normal to the channel flow direction causing considerable turbulence. It is difficult to assess the net energy imparted to the flow and as such the energy equation of motion.

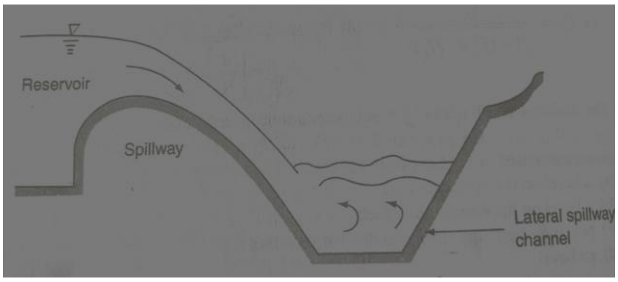


Fig.2: Spatially Varied flow in Spillway (Source: Flow in open Channels reference book)

II. LITERATURE REVIEW

Roger Breman [1] et al. "Experiments in side channel spillway", (1987). In this paper, author has presented. The calculations of the free surface profile in open channel flow with spatially increasing discharge and the results of experimental studies with rectangular side-channel spillways were presented, with particular attention to the effects of a non-prismatic cross section and the bottom slope on the free surface profile.

Arthur C.E. Knight [2] "Design of efficient side channel spillway", (1989). This paper described designing of an efficient side-channel spillway with a simplified method, with particular reference to an L-shaped weir. The method can be used for a straight weir or one U-shaped in plan with minor modifications. M. Pifster [3]et al., "Historical Development of Side Channel Spillway in Hydraulic engg."(2011). Author explained regarding historical development of facet channel spillway and importance of facet channel spillway in Hoover Dam. B. G. A. LUND [4] et al, "A Model Study of a Side-Channel Spillway with Deflector Bucket for Nuane Dam", (2011). Author describes the action of the bucket at high flow was to deflect the two-dimensional overspill jet across the body of water already in the trough, so reducing the tendency for the crest to be submerged. Marina Maradjeva [5] et al., "Hydraulic Research On Side-Channel Spillways Based On Physical Modeling And Optimization", (2012). The hydraulic operation of side-channel spillways had been studied. The most relevant hydraulic parameters are investigated by physical modeling and optimization analysis. Author proposed an effective measurement on the basis of variational principles and numerical modeling. T.D.Timm [6], "Design of Side Channel Spillway",(1977). Model tests were carried out on a side channel spillway of general typeas well as on the proposed dam spillway and the results were presented and discussed. J. J. Doland [7] et al. "Model Study of Spillway Characteristics", (2000). Authors worked on model study of spillway. This was west Frankfort reservoir spillway model. Three cooperating agencies was work for this spillway. R.Gab [8] et al., "Side-channel spillway – Hybrid modeling", (2011).In this paper, numerical and physical model were compared with one another. The most aim was to extend the discharge capability by considering limitations with regard to most permissible water levels within the reservoir. Jill Lucas [9] et.al, "Side channel flow: Physical model studies", J hydraulic. Eng. ASCE (2015). Authors studied Hydraulic investigations of three hydraulic model studies on side channels were presented. These include the side channels of the Tr¨angslet Dam, Sweden, the K´arahnjúkar Dam, Iceland, and the Lyssbach diversion tunnel, Switzerland, of which the former two have a trapezoidal cross section and the latter has a rectangular cross section. Puja Admane [10] et al. "Physical Model Study of Side-Channel Spillway", IJCIET (2018). In this paper authors studied aspect of side channel spillway was studied with three dimensional physical model experiments. Water surface profiles were plotted for different discharges and slopes. M. Mohammadi [11] et al. "Spatially Varied Flow Profiles In a V-shaped Side-Channel Spillway", Researchgate (2004).This paper terminated the presents the experimental data applying a practical equation of motion mathematically derived. Several series of experiments were carried out for v-shaped bottom channel.

III. METHODOLOGY AND EXPERIMENTAL SETUP

A. *Methodology*

In Literature survey different Literatures of Side channel Spillway is discussed about and the proposed model premise. In this section, the examination procedure clarifies how the proposed investigation will be satisfied. The water surface profile at various discharges and various slopes were estimated. Digital and vernier depth gauges were used to measure the depths and current meter for velocity. Depths which are experimentally observed were contrasted and analytical depth which was determined by using spatially varied flow equation and velocity for each depth was observed. Plot Water surface profiles for various discharges and slope.

I. Spillway -

3-D (Three dimensional) physical model of side channel spillway, which was designed previously and planned with the assistance of IS 5186:1994, and CECW-ED-D.

Engineer Manual 110-2-1603 (Department of armed force U.S armed force corps of Engineers), hydraulic design of the spillway. The scale of the model was 1:100. The spillway model had comprised of acrylic material and side channel made up of G.I sheet and both are painted with oil paint. The spillway height kept above the bed of the river and it was kept 50cm and 3 piers were given. The 1.5cm thickness of pier was given.

In the present study the existing model of spillway was used (scale 1: 100) and the side channel was redesigned. Side channel was designed for the highest discharge, so the dimensions of channel were different than previous channel. Channel bed was kept at the spillway bed; means the spillway bottom level and the channel bed levels were same.

II. Design of Side channel-

Model of side channel is geometrical similar scale model. From Froudian scale, dimensions of side channel were calculated as given below:

1. Top width of channel = 0.25 m
2. Bottom width channel = 0.18 m
3. Depth of channel = 0.12m
4. Area of channel = 258 m²

Table1: Dimensions of side channel

	Model dimensions	Prototype dimensions
Top width	0.25 m	25 m
Bottom width	0.18 m	18 m
Channel depth	0.12 m	12 m
Channel length	2.40 m	240 m

III. *Parameters of Study –*

The following parameters considered for model studies:

1. *Flow Discharge* -:
The flow discharge was vary from 1 lit/sec to 3 lit/sec. Model was run for different discharge with varying slope such as 1 lit/sec, 2 lit/sec, 3lit/sec for slope 0°, 10°, 20°.

2. *Flow Velocity* -:
The velocity of flow was measured at every section in downstream at every 30cm section. Approach velocity also measured. The velocity of flow at downstream varied between 0.36m/s to 0.65m/s for 0° slope of channel. Velocity varied from 0.61m/s to 3.3m/s for 10° channel slope and for slope 20° the velocities varied from 0.64 m/s to 8.77 m/s.

3. *Depth of flow-:*
Flow depths were measured at downstream of spillway in longitudinal channel section.

4. *Channel Slope* -:
Each flow discharge was measured for various slopes, 0°, 10°, and 20°.

5. *Froude no and Reynolds no* -:
Froude number and Reynolds number were calculated for different model runs.

Fig.3: Photograph of Side channel spillway model.

B. *Experimental set up*

The experiments were carried out in Post Graduate Hydraulic Laboratory of Bharati Vidyapeeth Deemed to be University college of Engineering, Pune. The recirculation flow system is served by 5Hp pump. UPVC pipe was used for recirculation flow system and pipe diameter was 40mm. One end of pipe was connected to water tank, and other end was connected to pump, and bypass valve was additionally provided to adjust required discharge. The depth gauge with vernier and digital depth gauge, preciseness of 0.1mm was accustomed to measure the water depths at different sections; channel was divided parts of 30cm each as chainage. To measure the point velocity current meter was used which was a propeller type. The volumetric tank was used to measure discharge at downstream of channel. The side channel was divided in to 9 sections at every 30 cm. The detailed sketch of experimental setup is shown in below Figure 4.

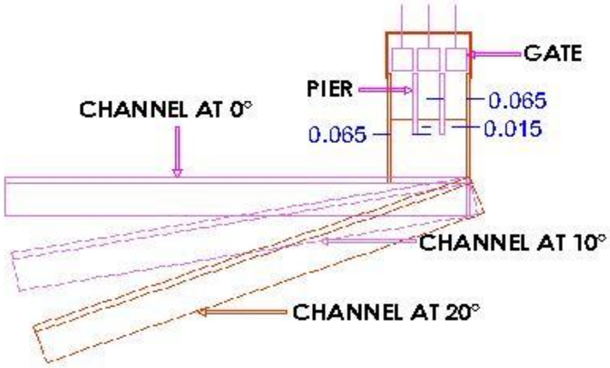


Fig.4: Schematic diagram of Side channel spillway model.

- *Froude model law*

It is the law in which the model is depend upon the Froude number which means the dynamic similarities between model and the prototype and the Froude number for model should be equal to the Froude number of prototype.

Let, (Fr.) model = (Fr.) prototype

- *Procedure of experiment*

As model design for maximum discharge was 3000 m³/sec for in prototype and the model discharge was 0.03m³/sec. Due to limitations, experiments were taken for the 3.5%, 7% and 10% discharge of model discharge and the slope. Discharge was 1lit/sec, 2lit/sec and 3 lit/sec and the different slopes 0°, 10° and 20° were kept for every set of discharge.

1. Discharge for 1lit/sec, 2lit/sec and 3lit/sec respectively set for 0 degree slope of channel, and the parameters are observed for 0 degree slope. Velocities at downstream of channel were measured by current meter and the flow depths were measured by the depth gauge. Channel is divided in 8 sections; every section was of 30 cm length. Approach velocity also measured near to the crest of spillway.
2. Channel slope change for next set of experiment, channel slope was kept 10 degree and discharge set for 1lit/sec, 2lit/sec and 3 lit/sec respectively and same procedure conducted as given in above for 0 degree. Parameters were observed for 10 degree.
3. For 20° slope carried same procedure which mentioned in above points. For every flow discharge and slope the study parameters were observed.

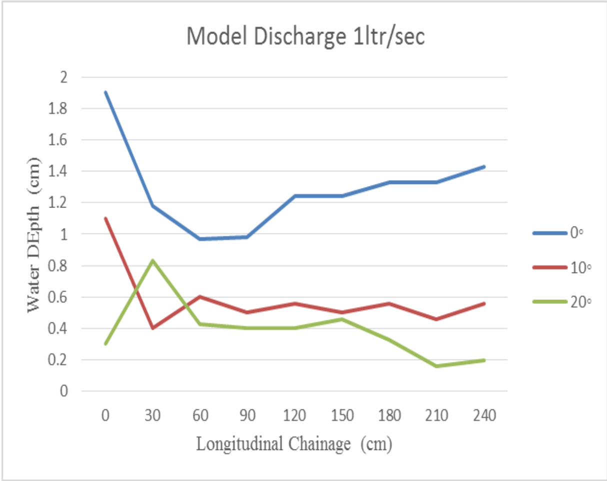
Hydraulic model results were analysed and the compared with theoretical results. SVF flow parameters were measured.

IV. HYDRAULIC ANALYSIS AND DISCUSSIONS

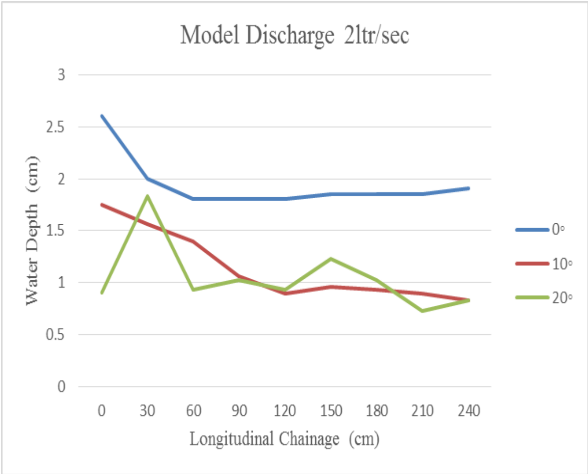
In this section the results of the study are given and mentioned with respect to the aim of the study. From the methodology different parameters like depth of flow, discharge, velocity of flow and others were observed. Methodology given in previous chapter is followed throughout the research work. These aspects were represented within the previous chapter that given the methodology employed in the study. In this chapter the analysis of results observed in experiments and analytical results are given below.

A. *Analysis of Longitudinal section of channel and water depths Graphs*

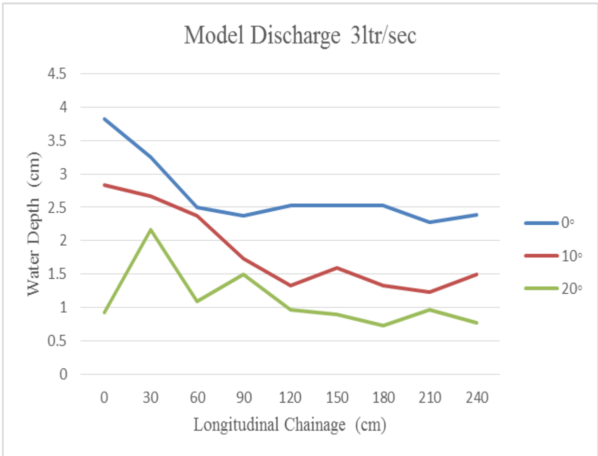
- Graphs were plotted from the observed results; Water depths were observed and measured at downstream side. Depths were observed and noted for Different discharge like 1lit/sec, 2lit/sec and 3lit/sec for various slopes as 0°, 10° and 20° in channel at every 30 cm.
- Those depths of flow of water and chainage considered for plot the graph. Graph of longitudinal section of channel and the depths were plotted.
- Water surface profile also plotted with respect to slope of channel bed.



Graph 1: Analysis of 1.0 lit/sec discharge for different slopes.



Graph 2: Analysis of 2.0 lit/sec discharges for different slopes.



Graph 3: Analysis of 3.0 lit/sec discharges for different slopes.

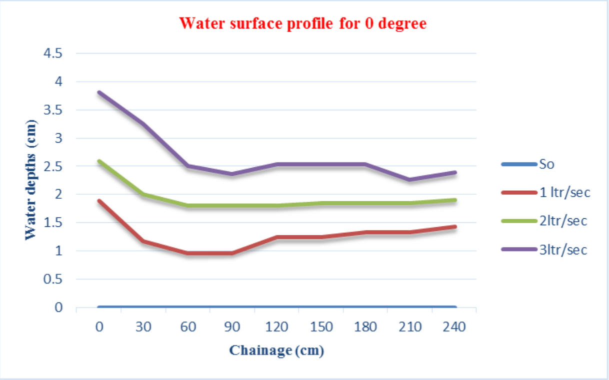
Graph number 1, 2 and 3 shows the observed depths of water in channel section with respect to the chainage. Graph 1 show the depths of 1 lit/sec, 2lit/sec and 3lit/sec for the 0° slope means channel at horizontal.

For 1lit/sec discharge depths were small as compared to 2lit/sec and 3lit/sec. Fluctuations high in 2 lit/sec and 3 lit/sec flows in first section which was in front of spillway bottom and in 0 – 30 cm chainage, therefore the flow was in that section was highly turbulent. For 0° slope water depths were vary uniformly in channel and velocity also. Water surface depths as increases velocity was decreases. As slope of channel changes, the depths were decreases at downstream side.

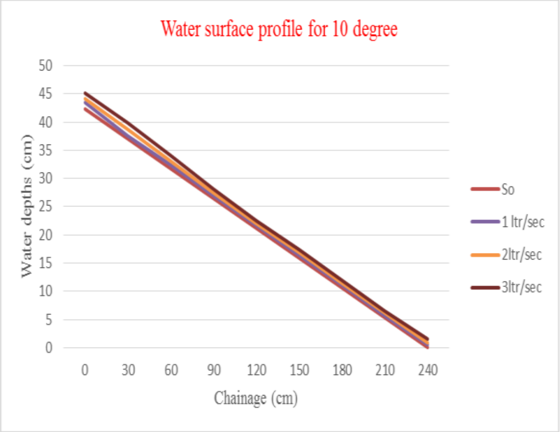
Graph shows that the for various discharge depth changes as slope changes, maximum depths for 3lit/sec discharge when channel is horizontal. As slope increases the flow depth decreases. For 1lit/sec discharge the depths varying upto 1.5 cm, for 2lit \sec discharge depths varying upto 1.9 cm and for 3lit/sec discharge the depth was varying upto 3.82 cm. From above graphs it is observed that if the discharge decreases the depth also decreases. Velocity for horizontal channel was uniform for all discharge, but for the sloping channel the velocity increased due to slope.

B. *Analysis of Water surface profile Graphs*

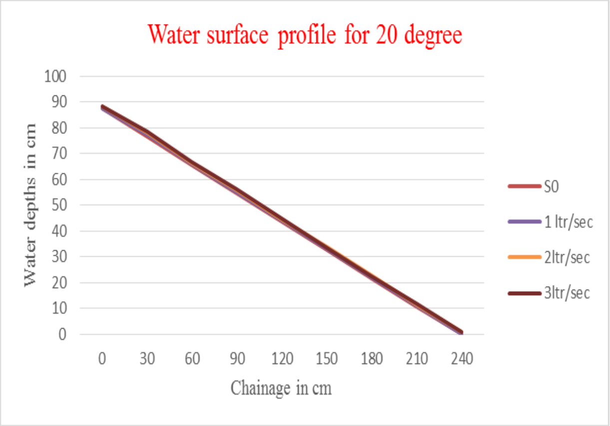
- Water surface profile plotted for each channel bed slope for 1litsec, 2lit/sec and 3lit/sec. Graph number 4, 5 and 6 shows the water surface profile for 0 degree, 10degree and 20 degree respectively for every discharge.
- Water surface profile of 0° slope is shown as in graph 4, it is approximate smooth curve. Turbulence was high in chainage section 0- 30cm due to the hydraulic jump for all set. In 0° slope, channel is horizontal and the jump is high for the maximum discharge and jump was strikes on the side channel wall. Channel bed was kept at level of the spillway bed therefore the jump was strikes first on outer side of side channel and then it returned towards the bottom of spillway. Hydraulic jump was formed higher for 3lit/sec discharge.
- For slope 10°, the flow was not uniform in 0 – 60 cm chainage, high hydraulic jump was formed so the flow was zigzag pattern so the erosion chances more. Flow strikes at 45cm right side of channel and then strikes at 135 cm chainage. 60- 90 cm Chainage flow is zigzag, but onwards 90 cm it was uniform.
- For slope 20°, the same flow pattern was observed like 10° slope channel. Turbulence was higher in section 0-30 cm due to hydraulic jump. More fluctuations formed due to higher slope and higher discharge. Jump was of 10cm, 8 cm and 5cm for discharge 3lit/sec, 2lit/sec and 1lit/sec respectively.



Graph 4: Water surface profiles of different discharge for 0-degree slope.



Graph 5: Water surface profiles of different discharge for 10-degree slope.



Graph 6: Water surface profiles of different discharge for 20-degree slope.

C. Analysis of Experimental and analytical depths plot

Scatter plot is plotted between experimental depth and analytical depth. Analytical depths were calculated by using SVF equation.
SVF equation as follows;

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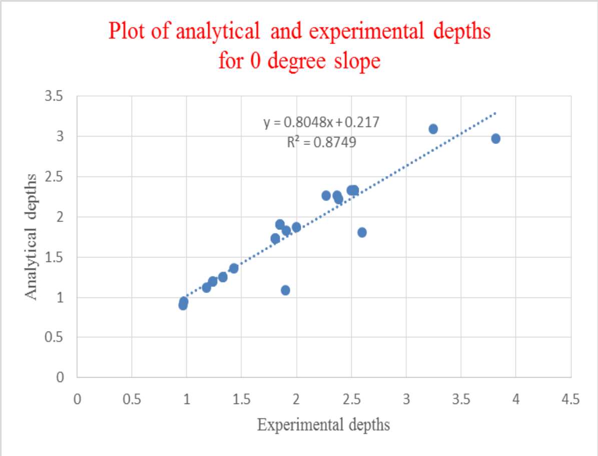
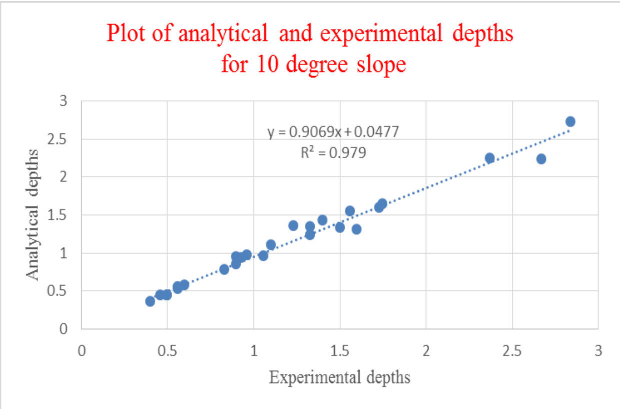
$$\frac{dy}{dx} = \frac{S_0 - S_f - \frac{2\beta Q q}{gA^2}}{1 - \frac{\beta Q^2 T}{gA^3}}$$

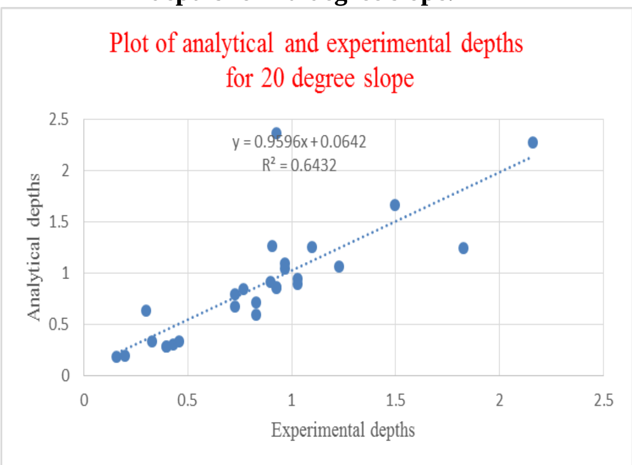
Experimental depths were observed and recorded for every section in side channel.



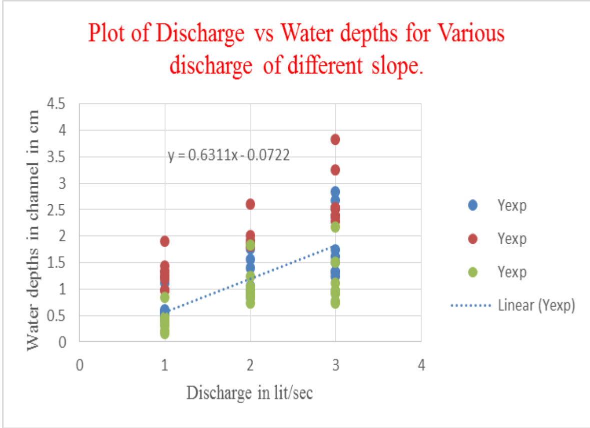
Graph 7: Scatter plot of Experimental and Analytical depths for 0-degree slope.



Graph 8: Scatter plot of Experimental and Analytical depths for 10-degree slope.



Graph 9: Scatter plot of Experimental and Analytical depths for 20-degree slope.



Graph 10: Scatter plot of Discharge versus water depths for different discharge and various slopes.

- *Classification of Hydraulic jump*

Table3: Sample calculations table

Slope	Discharge (lit/sec)	Froude no.	Type of jump
0°	1	1.361	Undular jump
	2	1.187	Undular jump
	3	1.001	Undular jump

Table4: Sample calculations table

Slope	Discharge (lit/sec)	Froude no.	Type of jump
10°	1	6.916	Steady jump
	2	2.081	weak jump
	3	12.97	Strong jump

Table5: Sample calculations table

Slope	Discharge (lit/sec)	Froude no.	Type of jump
20°	1	4.355	Oscillating jump
	2	3.438	Oscillating jump
	3	6.632	Steady jump

V. CONCLUSIONS

Following conclusions were withdrawn from the model study and observations based on experimentation. Therefore in order to analyze the characteristics of the spatially varied flow in a trapezoidal channel, a series of experiments has been carried out. Various flow discharges at different channel bed slopes were maintained. Using the experimental results the main conclusions were derived as follows;

1. Rapidly varied flow was observed at the downstream side of the channel. More the discharge, more the variations. The depth varied from 2 cm to 9 cm in the model for the discharge of 1 to 3 lit/sec and for various slopes.

2. As a slope increases, the depth decreases gradually towards downstream side of the lateral channel. The same trend can be observed from the graph 1, 2 and 3.

3. As a slope increases, the depth varies rapidly from the zero chainage to the 135 cm chainage for higher discharge, more fluctuations occurred in the depth. The typical flow profiles occurred which is shown in the graphs 4, 5 and 6.

4. For the more discharge, the flow tend to move with the super critical condition throughout the channel. Froude number varies from 1.001 to 12.97 for various discharges and channel slope.

5. The flow sometimes observed that tend to move from one bank to another bank for higher discharges forming the meandering pattern in the channel. This kind of flow may cause an erosion of the banks of canal in the prototype.

6. The experimental results were validated with the analytical results. Graph 7, 8 and 9 shows the relation between the analytical and experimental depths. The typical flow profiles occurred which is shown in the graph 4, 5 and 6.

7. Due to the limitations of the model, this present study has carried out for the scale of 1:100. For the detailed study, the large scale model can be prepared. This study is carried for the maximum discharge of 3lit/sec. In the model, the further study for higher discharges may be carried. The flow conditions may vary then these results for higher discharges.

Further scope of studies: The existing 1/100 Geometric Similar pilot model studies give clue for the prevailing flow conditions. However, hydraulic model studies on the larger scale of 1/50 Geometric Similar or so, with higher discharges, different slopes with different shapes of the side channel need to be carried out in future to confirm the trends indicated by the present studies.

A. Abbreviations

A: cross-sectional area of channel;
b: bed width of channel;
T: top width of the channel;
h: depth of channel;
y: flow depth in channel;
Fr.No.: Froude number;
g: gravitational acceleration or a constant;
n: Manninig's roughness coefficient;
Q: flow discharge;
V: velocity of flow in channel;
R: hydraulic radius (R=*A/P*);
s: side channel slope (1:s, vertical: horizontal);
S0: channel bed slope;
Sf: friction slope;
ρ : fluid density;
θ : angle between bottom of channel and Horizontal line;
S.V.F.; Sptially Varied Flow;
3-D: three dimensional;
β; momentum correction factor.

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Prof. Vilas B. Joshi. He has graduated in Civil Engineering. From University of Pune in 1970 and joined CWPRS in 1972. Since 1980 he joined the coastal group as Research officer. He has obtained Master of Science degree in Ocean Engineering from University of Hawaii at Honolulu USA during 1984-85 under UNDP fellowship program. He was working as Chief Research Director when he retired in 2007. His area of specialization is field data collection and analysis, Hydraulic modeling of river & coastal structures for feasibility of project layouts. He has published about 36 papers in National and international conference and journals. Since 2008 he has been delivering lectures at P.G. level at various engineering colleges in Pune in Hydraulic structures and Coastal Engineering. He is also working as project advisor for development o Port and Offshore project in private sector. He is life member of Indian Society of Hydraulics (ISH), Indian Society of Remote Sensing (MISRS) & Eastern Dredging Association (EADA).