Utilization of Reverse Slope to Increase Full Supply Level in Small Irrigation Channels

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Abstract- In this study optimal limit of the reverse slope, downstream of an irrigation outlet, where flow is supercritical was studied to create sufficient working head required to irrigate elevated fields in the command area of a watercourse. Three different types of outlets Adjustable Orifice Semi Modular (AOSM), Pipe and Open flume were designed and constructed in the lab. Various values of reverse slopes were incorporated in one-meter and two-meter length of the watercourse bed, downstream of the selected outlets, at a constant value Full Supply Level (FSL) of the canal. It was observed that FSL of watercourse increased with increase in reverse slope. Reverse slopes values of -0.10 and -0.15 incorporated in a length of one meter were found most suitable for an outlet of one-cusec discharge capacity. It was observed that FSL of watercourse increased with increase in reverse slope value up to -0.15 and then started decreasing gradually at -0.20. The outlet discharge decreased slightly (3%) for reverse slopes -0.10 to -0.15 and significantly (26%) at reverse slope -0.20, by submerging the outlets. Reverse slope incorporated in one-meter length of the channel bed was more useful than incorporated in the two-meter length of the channel bed. The results obtained for AOSM and pipe outlets were identical. Open Flume outlets found not to be fit for induction of reverse slope. The best hydraulic section for the reverse slope was with upstream width equal to the throat width (Bt) of the outlet, expanded in the direction of flow to join the designed width of the channel.

Keywords- Full Supply level, Outlet, Reverse Slope, Watercourse.

I. INTRODUCTION

Pakistan is gifted with numerous natural resources comprising land and water [1]. Useable water is deficit in the world these days. It holds the position of blood of our agriculture and life for economy [2]. The available water assets of Pakistan have been assessed up to 142 Million Acre Foot (MAF) [3]. Out of it about 42 MAF is offered for agriculture [4]. A considerable portion of this precious water is wasted in prevailing outdated irrigation system. Around 37 MAF of this water is lost only in tertiary irrigation system (watercourses) [5]. Pakistan possesses one of the best-integrated canal irrigation systems in the world. In terms of irrigated areas, Pakistan is at third position in Asia and at fifth position in the world [6]. The major goal of Pakistan's irrigation system was to save the region from the danger of food scarcity and at the same time to pave the way for establishing new zones to produce revenue for the colonial British regime by the sale of abundant lands [7-8].

The Irrigation network of Pakistan comprises of dams, barrages/headworks, core canals, branch canals, distributaries, minors, and watercourses [9]. This is mainly divided into three main units, primary (dams, barrages, and headworks), secondary (main canals, branch canals) and tertiary (watercourses). The tertiary component, the watercourse, starts from the downstream of the outlet. The water is delivered from the state owned section (canal/distributary/ minor) to farmer operated section (watercourse) through the outlets. Operation of the tertiary irrigation system depends upon the proper design of watercourses under the existing field conditions, so that equitable water distribution can be achieved efficiently. Performance of an irrigation scheme, to a significant level, depends upon better working of its water carrying and dissemination system.

In the irrigation system, the outlets are designed on the principle of gravity flow to irrigate the watercourse's command area [5]. When high elevated fields are to be irrigated than the existing Full Supply Level (FSL) of the watercourse, the outlets under these conditions get submerged. Sufficient outlet discharge decreases as a result of submergence. While irrigating high elevated fields the depth of water increases and the velocity of water decreases that causes siltation in the bed. To create sufficient working head to irrigate elevated fields and to avoid the bed from siltation, the field engineers often introduce a reverse slope in watercourse design, by introducing reverse slope downstream the outlet where the flow is supercritical. It helped in improving working head in the watercourse with considerable success to irrigate elevated fields than the normal fields.

The concept of reverse slope was introduced and was concluded that a load of water was reduced by using the reverse slope [10]. This study was performed at reverse slope values -0.015, -0.030 and -0.045 respectively. At the University Royale in France study was conducted to increase the water level to create the essential head to divert water into channels or other water delivery commitments and to reduce the load of water on aprons. Thus, responding to the uplift burden and therefore reducing the depth of the concrete apron essential in structures on the porous foundation [11].

Experiments were conducted to examine the length of the reverse slope, and water surface profiles downstream of the reverse slope. It was found that the length of the reverse slope increased with the increase in the Froude number [12]. Reverse slope was studied in trapezoidal and quadrilateral channels and found that the lengths of reverse slope in trapezoidal channels were longer than those in rectangular ones, especially when the side slopes of the trapezoidal channel are very flat [13]. Reverse slope was studied in horizontal conduits to avoid the conduit from siltation and decrease resultant roughness. Siltation reduced after reverse slope incorporation [14]. Reverse slope channels were studied to reduce flow velocity and energy loss of flow due to the reverse slope was observed [15].

Reverse slope in a horizontal and parabolic channel was studied by varying the Slope of the flume was kept from - 0.005 to -0.03. The ratio of sequent flow depth was well matched with the hypothetical values. The slope length was linked with the downstream flow depth and the difference of water surface level before and after the reverse slope [16]. Hydraulic jump formation was studied on the reverse slope and concluded that as the reverse slope increases more the energy is dissipated [17-18].

Several experiments were conducted on various reverse slope values of -0.25, -0.2 and -0.167 with approach Froude number values in the series of 9 to 13. Though, this series of Froude numbers was beyond the conventional design range for ordinary stilling basins. He concluded that reverse slope length increases with the increase in approach Froude numbers [19]. A study on the reverse slope in triangular channels was conducted. The experimental data of the sequent depth matched well with the theoretical predictions that the tail-water working head increases after the reverse slope adaptation [16].

Conjugate depth ratio was studied, relating upstream Froude number for different types of channels, e.g. rectangular, trapezoidal, triangular and parabolic in reverse sloping channels. The head loss ratio for all the sections was given in terms of the upstream Froude number. It was noted that milder the side slopes and narrower the bottom width, the longer was the length of the reverse slope [20].

Reverse slope was experimented to reduce the depth of the stilling basins. The author observed that in the chutes and pools regime of mobile bed flows, reverse slope occurs intermittently at the downstream face of a scour hole when the water was swept out of the stilling basins [21]. A reverse sloping transition section downstream of a spillway bucket could be used to stabilize flow at low Froude numbers in the range 2.5 to 4. They also used a scratched bed on the reverse slope to reduce more kinetic flow energy. The purpose of this study was to derive the design parameters for the reverse sloping prismatic rectangular channel. A set of dependent variables and the independent variables was: sequent depth & jump length and approach depth, approach Froude number, and bed reverse slope respectively [22].

Length of the reverse slope was studied numerous times to get a noteworthy mean value of depth of water downstream of the hydraulic jump [23]. Adverse slopes up to -0.025 were studied and was observed that adverse slopes (Reverse slope) steeper than S = -0.5 reduces more discharge of outlets [24]. The experiments on a reverse slope were made by studying the depth of water downstream of the channel before and after the utilization of reverse slope [25].

Relationship was determined before and after incorporation of the reverse slope to compare the different parameters i.e. length of the reverse slope, loss of energy and depth of tail water for parabolic, triangular and rectangular channels. The experiments were performed in a parabolic and triangular reverse sloping flume with bed slope varying from -0.0004 to -0.05 with an increment of -0.005. For each reverse slope value, experiments were performed for a wide range of discharge values at a sluice gate opening of 3.5 cm for the triangular and 2.3 cm for the parabolic channels. It was concluded that the trapezoidal channel was the best for the reverse slope [26].

Investigation was done on reverse slopes values - 0.10, -0.167, and -0.20, using a gate at the end of the basin for tail water control to increase the depth of water [23]. Adverse slopes up to -0.025 was studied and no analytical technique was explained to predict the sequent flow depth ratio. The study was conducted to monitor reduction in flow velocities [27]. In an upward sloping (Reverse sloping) channel the jump may either be unstable i.e. if the jump is slightly displaced from its equilibrium location or stable i.e., it returns to its original location. This study resulted that reverse slope length increases with an increase in Froude number [28].

Reverse slope on standard ogee weir was analyzed. The weir was utilized to produce supercritical flow at reverse slopes of -0.025, -0.050, -0.075, and -0.10. These values of reverse slope were produced at the downstream of the weir. Various parameters i.e. length of the reverse slope, and downstream depth of water were studied. Using momentum equation in the horizontal direction, the analysis of sequent depth ratio before and after the reverse slope was carried out. The obtained experimental data displayed that the reverse slope for the stilling basin decreases the sequent depths, whereas a positive slope rises the sequent depths [29]. A study was conducted upon four reverse slopes -0.00125, -0.0025, -0.00375 and -0.005 in two cases of rough and smooth bed. The results showed that the working head and the length of reverse slope upon smooth bed has been more than a rough bed for the same slopes and Froude numbers [30].

Hydraulic jumps were studied in adverse-slope stilling basins for stepped spillways. The results of model study showed that the method presented in this study can be used to adequately estimate the characteristics of F and B-F jumps for adverse-slope basins of the stepped chutes. This enables the investigation of a wide range of apron slopes with a single method, which was largely neglected in previous research [31].

Hydraulic jump was studied on reverse bed with porous screens. The results of the study revealed that use of screens on the reverse slope of − 0.025 dissipates more energy compared to reverse slope of − 0.015. While the distance of screens from the toe of the hydraulic jump, did not have a significant effect on the energy dissipation [32].

A common practice to utilize reverse slope in watercourse design to increase working head is that the same reverse slope value is provided in watercourses fed by different types of outlets. Without giving due considering to prevailing field conditions i.e. hydraulic section, FSL of canal and outlet discharge. The reverse slope is not incorporated in accordance with hydraulic properties of the outlet (Kinetic energy). The kinetic energy of outlet’s flow is not perfectly utilized in design. The considerable kinetic energy of the flow is also lost due to improper hydraulic section for reverse slope. Reverse slope holds a vital role in watercourse design and directly influences the hydraulic performance of outlets. An outlet is the most vital element of the watercourse. Hydraulic behavior of an outlet may vary towards high values of the reverse slope. The main objectives of this study were: to assess the optimal limit of reverse slope in watercourse design for the given outlet and FSL of the canal and to study the hydraulic performance (Discharge drawing capacity) of different types of outlets towards the provision of reverse slope.

This study would be the best guideline for the irrigation engineers and it would be helpful in better selection of suitable reverse slope while designing irrigation channels. The results obtained from the research will be useful for personnel working in the irrigation department, consultants dealing with irrigation projects and other national and international organizations working for the improvement of irrigation systems and management. It will also help the people working under different field conditions to compare their results with the results obtained under controlled conditions in the laboratory.

II. Material and Methods

Location of the Study

This study of reverse slope in watercourse was conducted by preparing and running physical models of three watercourses with three different types of outlets in the laboratory. Behavior of the constructed outlets was evaluated against the optimal limit of reverse slope. The study was conducted in Model Tray Hall at Centre of Excellence in Water Resources Engineering, Lahore. The Model Tray Hall is 46 m long and 16 m in width. The schematic layout of the experimental setup is given in Figure 1. A channel, rectangular in cross-section, 40 m long with a width of 1 meter and depth of 0.75 m having a discharge capacity of 3 cusecs was used as a distributary. Three watercourses were constructed. There was spacing of about12 meter among each watercourse. Three different types of outlets were constructed in the distributary to feed these three watercourses. The essential water level in the distributary was obtained with a sluice gate fitted at the tail end of the distributary channel.

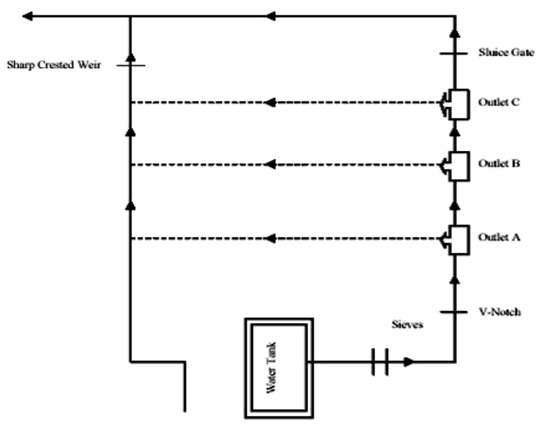

Fig. 1: Schematic layout of experimental setup.

Construction of Structures

The elements of the experiment, the outlets, the water channels and induction of reverse slope in the bed of watercourse were carried out with due care and workmanship according to the design principles. First of all, the outlets were designed having water drawing capacity of 28.32 lps (1-cusec). Three watercourses on three outlets were designed and constructed, each of length 10 m, width of 0.48 m and depth 0.44 m. The bed of watercourse was designed at the slope of 0.0003. The readings of FSL of watercourse were taken at the slope of 0.0003. Then induced the slope of -0.050 and readings of FSL of watercourse were taken. Similarly, reverse slopes of -

0.10, -0.150, -0.20 were construed and readings of FSL of watercourse were taken respectively. This procedure was repeated on each type of outlet. The sharp-crested rectangle weir was available at the drainage channel, at the downstream of the constructed watercourses to measure the discharge delivered by the outlet. This measured discharge was compared with the outlet computed discharge using standard formulae. The skilled labors were hired for model building.

Collection of Data

Data were collected by operation of the physical model constructed in the model tray hall. To remove the turbulence, the water was first released into the tank and then in the distributary channel. A sieve structures filled with pebbles was used to minimize the velocity of the water and flow of water under the effect of gravity was assured. The water flowing through the outlet was released in another channel where the sharp-crested weir was installed. The dumpy level was used to measure the head over the crest at the outlet, FSL of the canal and the watercourse. The FSL of the watercourse was raised by closing the tail portion of a watercourse by bricks so that the maximum FSL in the watercourse may be obtained till the outlet submerged. This practice was adopted on each reverse slope value. At each reverse slope, took the reading of watercourse FSL and also observed behavior of the outlet against those reverse slope values. Outlet wise adopted procedure is as under.

Adjustable Orifice Semi Module (AOSM)

Three combinations were used for this type of outlet:

i) For certain dimension of outlet, introducing various values of reverse slopes in 1-meter length downstream the outlet until submergence of the outlet. For this outlet Bt = 0.08 m, y = 0.16 m and FSL of the canal was 9.95 m. The reverse slope length was kept in 1 meter. The normal bed slope of the watercourse was 0.0003, the measured discharge was 27.64 LPS and FSL was at 9.70m.

ii) By changing the dimensions (Bt & y) of the outlet and introducing various values of reverse slopes in 1-meter length downstream the outlet until submergence of the outlet. The dimensions of the outlet were changed, Bt = 0.07 m, y = 0.14 m and FSL of the canal was 9.95 m. The reverse slope length was kept 1 meter. The normal bed slope of the watercourse was 0.0003, the measured discharge was 22 LPS and FSL was at 9.70 m.

iii) For the same dimensions of the outlet as in i but introducing various values of reverse slope in 2-meter length downstream the outlet until submergence of the outlet. FSL of the canal was 9.95 m. The normal bed slope of the watercourse was 0.0003, the measured discharge was 27.64 LPS and FSL was at 9.70m.

Open Flume

For the open flume outlet, reverse slope length was kept 1 meter, the FSL of the canal was 9.95 m and Bt of the outlet was 0.06 m. The normal bed slope of the watercourse was 0.0003, the measured discharge was 28 LPS and FSL was at 9.70 m.

Pipe Outlet

For pipe outlets, two diameters of the pipe were used:

i) The diameter of the pipe was 0.15 m and FSL of the canal was 9.95 m. The reverse slope length was kept 1 meter. The normal bed slope of the watercourse was 0.0003, the measured discharge was 28.394 LPS and FSL in the watercourse was at 9.70 m.

ii) This time diameter of the pipe was 0.125 m and FSL of the canal was 9.95 m. The reverse slope length was kept 1 meter. The normal bed slope of the watercourse was 0.0003, the measured discharge was 24.38 LPS and FSL in the watercourse was at 9.70 m.

Flow Data

i) Outlets discharge was calculated by using following formulas:

(a) AOSM

$$Q = 4030\, B_t\, y (H_s)^{1/2} \tag{1}$$

Where:
Q = Discharge (LPS)
B_t = Throat width (m)
Y = Distance between lower tip of roof block and crest
H_s = FSL of canal – Lower tip of roof block

(b) Pipe outlet

$$Q = cd\, A\, (2gh)^{1/2} \tag{2}$$

Where:
Q = Discharge (cumec)
Cd = coefficient of discharge
A = Cross-sectional area of the outlet pipe (sq-m)
h = Difference in FSLs of canal and watercourse
g = Acceleration due to gravity

(c) Open flume

$$Q = K\, B_t\, (G)^{3/2} \tag{3}$$

Where:

Q = Discharge (LPS)
B_t = Width of flume (m)
K = constant based on Bt
G = Depth of water above the crest

ii) Following equation was used to compute discharge delivered by the outlets using sharp-crested rectangle weir which was fixed at some distance downstream of outlet:

$$Q = C\,(L - 0.1\,I\,H)\,H^{3/2} \tag{4}$$

Where:
Q = Discharge in cumec
C = weir coefficient (1.84)
L = weir opening width
I = number of end constructions (I =1, 02)
H = Head above the opening (m)

III. Results and Discussion

An increase in FSL of the watercourse by introducing reverse slope in the watercourse, downstream of the outlet, where flow is supercritical and corresponding reduction in discharge drawing capacity of the outlet due to submergence, was studied in most commonly used types of outlets. The used outlets were Adjustable Orifice Semi Module (AOSM), Pipe and Open flume.

Adjustable Orifice Semi Module (AOSM)

Variation in FSL of watercourse and discharge drawing capacity of AOSM (i) outlet is shown in Figure 2. With the provision of the reverse slope (-0.05) FSL of the watercourse was observed at 9.74 m an increase of 0.04m and no reduction in drawn discharge was observed. For the reverse slope value of -0.10, the FSL value of 9.781m was observed in the watercourse without submerging the outlet. Though the outlet discharge was reduced by 1.2 percent (27.30 LPs) measured with sharp-crested weir. For the reverse slope of -0.15, FSL of the watercourse was observed at 9.81m an increase of 0.11 m without submerging the outlet. The outlet discharge (26.20 LPs) measured with the sharp-crested weir, reduced by 2.27 percent. FSL of the watercourse at the reverse slope of -0.20 was observed at 9.80m, increased by 0.10m.

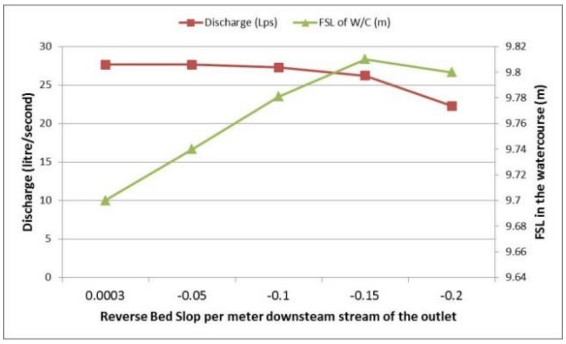

Fig. 2: Variations in FSL of the watercourse and discharge drawing capacity of the AOSM outlet (case- i).

This time the outlet was submerged and the outlet discharge decreased by about 26 percent and was 22.30 LPs. It was observed that FSL of watercourse increased with increase in values of reverse slope up to -0.15 and then started decreasing at reverse slope value of -0.20. Moreover, discharge of the outlet decreased from reverse slope values of -0.070 to -0.15 gradually and at a rapid rate on the reverse slope value of -0.20. Maximum FSL of the watercourse was obtained at -0.15 with a little decrease in discharge (1.2%), so the optimum limit of reverse slope value under this condition was found to be -0.15.

For second case of AOSM (ii), dimensions (Bt & y) of the outlet were reduced and reverse slope was incorporated in one meter length as in case (i). Variation in FSL of watercourse and discharge drawing capacity of this AOSM outlet is shown in Figure 3. FSL of the watercourse at the reverse slope of -0.05 was observed 9.72 m an increase of 0.02 m with drawn discharge of 21.89 LPS (0.5% reduced) without submerging the outlet. FSL of watercourse obtained at the reverse bed slope of -0.10 was 9.768m, an increase of 0.068 m and drawn discharge was 21.42 LPS (2.63% reduced) without submerging the outlet. FSL of watercourse obtained at the reverse bed slope of -0.15 was 9.74 m an increase of 0.04 m but caused submergence of the outlet that resulted in decrease (17%) in discharge. Drawn discharge measured by sharp-crested was 18.30 LPS.

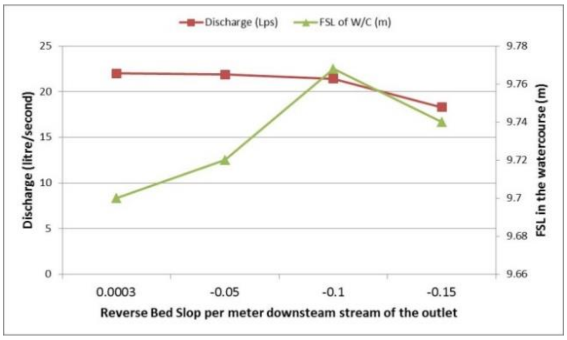

Fig. 3: Variations in FSL of the watercourse and discharge drawing capacity of the AOSM outlet (case- ii).

It was found that in this set of conditions maximum FSL of the watercourse was obtained at reverse slope value -0.10 and then FSL decreased at reverse slope value of -0.15. While the discharge started decreasing at reverse slope value -0.1 and rapidly decreased at the reverse slope of -0.15. With these dimensions of the outlet, the optimum reverse slope value was -0.10 with a little decrease in discharge (0.58 LPS).

For the third case of AOSM dimensions (Bt & Y) of the outlet were the same as in case (i) but the reverse slope was incorporated in 2-meter length instead of 1 meter. Variation in FSL of watercourse and discharge drawing capacity of AOSM (iii) is shown in Figure 4. FSL of watercourse obtained at the reverse bed slope of -0.25 was 9.722 m. FSL of the watercourse increased by 0.022 m by incorporating this reverse slope without submerging the outlet. The discharge measured by sharp-crested was 27.64 LPs. FSL of watercourse obtained at reverse bed slope of -0.5 was 9.74m and discharge measured by sharp-crested weir under this condition was 27.40 LPs. The FSL of watercourse increased 0.04 m by incorporating a reverse slope without submerging the outlet. FSL of watercourse obtained at the reverse bed slope of -0.75 was 9.74 m. The FSL of the watercourse was increased by 0.04 m but the outlet was submerged withdrawn discharge of 22.60 LPs.

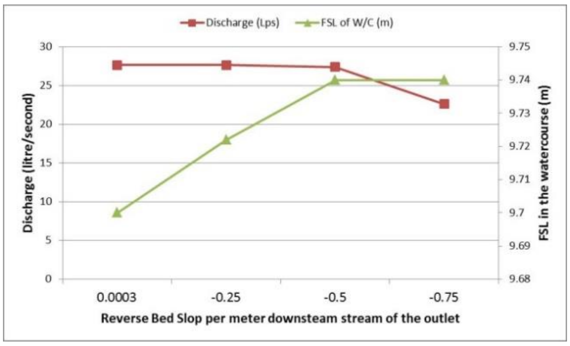

Fig. 4: Variations in FSL of the watercourse and discharge drawing capacity of the AOSM outlet (case- iii).

It was observed that maximum FSL of the watercourse was obtained at -0.50 and -0.75 reverse slope values, while the decrease in discharge at the reverse slope of -0.5 and -0.75was 0.87 percent and 18 percent respectively. It was also noted that the results obtained on reverse slope length in 2 meters were less significant than 1-meter length.

In AOSM types of outlets, hydraulic jump is formed downstream of the outlet. That is why it is said that discharge drawing capacity of this type of outlet is not dependent on water level in the watercourse. However, water level in the watercourse should be at such a level that hydraulic jump formation is admissible. The theme of this study was to use this energy of supercritical flow increase the bed level by introducing reverse slope at the downstream of the outlet. From the results of the study it was observed that the energy of supercritical flow was utilized more efficiently when reverse slope was incorporated in one meter length instead of two meter. It was also noted that for larger size of AOSM outlet with higher values of discharges, kinetic energy of supercritical flow was higher. So greater values of reverse slopes can be integrated in such outlets without submerging the outlets.

Open Flume

The open flume outlets are installed usually at the tail portion of the minor/canal. Variation in FSL of watercourse and discharge drawing capacity of this open flume outlet is shown in Figure 5. FSL of watercourse obtained at reverse bed slope of -0.025 was 9.752 m an increase of 0.052 m without submerging the outlet. The discharge measured by sharp-crested weir was 27.65 LPS under this condition. FSL of watercourse obtained with a reverse bed slope of -0.05 was 9.77 m. increased by 0.07 m with some submergence of outlet and discharge of the outlet was decreased by 11 percent. The discharge measured by the sharp-crested weir was 24.85 LPS. FSL of watercourse observed at reverse bed slope of -0.075 was 9.80m increased by 0.10 m. The outlet was found submerged and discharge decreased to 21.20 LPs.

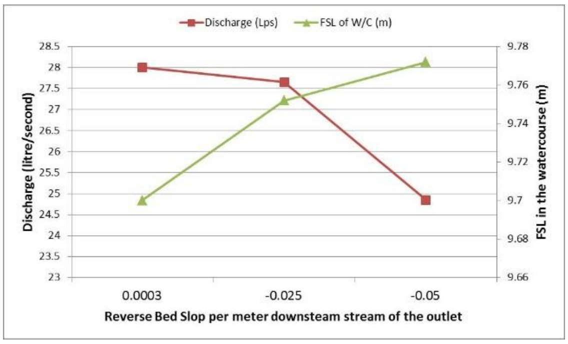

Fig. 5: Variations in FSL of a watercourse and discharge drawing capacity of open flume outlet.

It was observed that FSL of watercourse increased with an increase in reverse slope value but the discharge starts decreasing at reverse slope value of -0.05 and discharge decreased by 24 percent at –0.075 reverse slopes. The optimum limit for the reverse slope value for this kind of outlet is -0.025. The results concluded that open flume outlets are not fit for reverse slope. So be careful while designing reverse slope in open flume outlets. In open flume outlets, hydraulic jump is formed downstream of the outlet like that of AOSM. The same supercritical flow energy was used to induce the reverse slope in the bed of watercourse downstream the outlet.

Pipe Outlet

For two pipe outlets (i & ii), diameters of the pipe were 0.150 m and 0.125 m respectively. For pipe outlet (i) FSL of watercourse observed at the reverse slope of -0.05 was 9.771 m. Variation in FSL of watercourse and discharge drawing capacity of this type of pipe outlet is shown in Figure 6. The FSL of the watercourse was increased 0.061 m by incorporating reverse slope without submerging the outlet. The discharge measured by the sharp-crested weir at this slope was 28.39 LPS. For reverse slope value of -0.10 FSL of the watercourse was observed at 9.814 m increased by 0.114 m without submerging the outlet. The discharge measured by the sharp-crested weir at this reverse slope was 28.00 LPs (no reduction). For reverse slope value of -0.15, FSL of watercourse obtained was at 9.835 m increased by 0.125 m without submerging the outlet. The maximum FSL of watercourse was found at this reverse slope. The discharge measured by the sharp-crested weir at this reverse slope was 26.90 LPS. For the reverse slope value of -0.20, FSL of watercourse obtained was 9.82 m increased by 0.11 m. It was found that FSL of watercourse increased with the increase in reverse slope value up to -0.15 and started decreasing at -0.20 reverse slope value with the submergence of the outlet. The measured discharge by sharp-crested weir was 23.44 LPs.

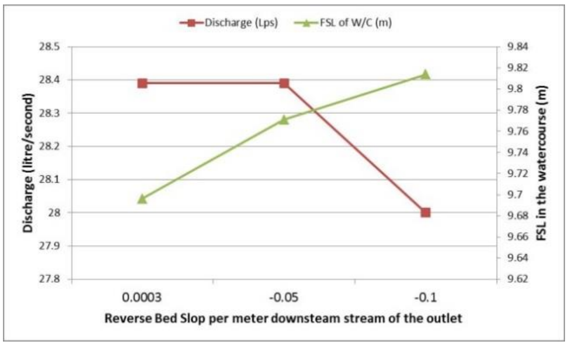

Fig 6: Variations in FSL of watercourse and discharge drawing capacity of pipe outlet (dia.0.15m).

For pipe outlet of diameter 0.15 m, it was observed that FSL of watercourse increased up to reverse slope value of - 0.15 and decreased at reverse slope value of -0.20. The discharge drawing capacity of the outlet also decreased considerably (15%) at the reverse slope value of -0.20. The discharge of outlet decreases up to 23.44 LPS, which is very low. The result showed that -0.15 reverse slope was optimal.

For the pipe outlet (ii) variation in FSL of watercourse and discharge drawing capacity the outlet is shown in Figure 7. For reverse slope value of -0.05 FSL of watercourse was at 9.74 m increased by 0.05 m without submerging the outlet. Discharge measured by sharp-crested weir was 24.38 LPs (no change). For the reverse slope value of -0.10, FSL of watercourse obtained was 9.78 m increased by 0.09 m without submerging the outlet. The discharge measured by sharp-crested weir was 24.00 LPS.

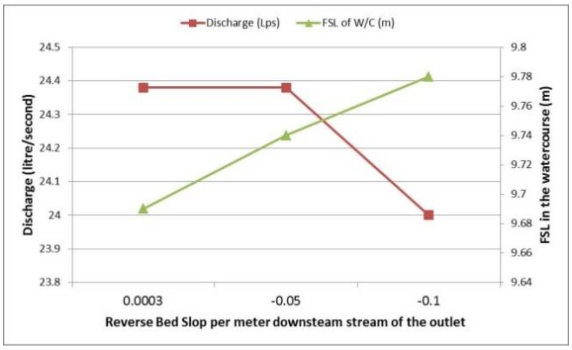

Fig 7: Variations in FSL of watercourse and discharge drawing capacity of pipe outlet (dia.0.125m).

For reverse slope value of -0.15, FSL of watercourse obtained was 9.82m increased 0.13m by without submerging the outlet. The maximum FSL of the watercourse was found -0.15. Drawn discharge (5.66% reduced) of 23 LPs was measured by the sharp-crested weir. For reverse slope value of -0.20, FSL of watercourse obtained was 9.81m, increased by 0.12m. The outlet was observed to be submerged and the discharge of outlet reduced (18%) to 20 LPs. It was found that FSL of watercourse increased up to reverse slopes of -0.15 and then decreased at the reverse slope of -0.2. For this diameter of the pipe outlet, it was observed that FSL of watercourse increased up to reverse slope of -0.15 with increase in reverse slope and started decreasing at reverse slope value of -0.20. Discharge drawn by the outlet started decreasing gradually (1.5 %) at -0.10 and abruptly (18 %) at -0.20 reverse slope. Therefore, reverse slope of -0.15 was optimal under such conditions.

Pipe outlets are provided where significant difference is available between the FSL of canal and outlet so that outlet can discharge freely in to air. Therefore, it is highly efficient. Due to availability of adequate head, kinetic energy was sufficient so it was possible to raise the bed of the watercourse by introducing the reverse slope.

IV. CONCLUSIONS

In this study experimental investigations were carried out in the laboratory to investigate optimal limits of reverse slope downstream of an irrigation outlet where flow is supercritical. Three different types of outlets (AOSM, Pipe and Open flume) were designed and constructed in the lab. The outlet discharges were computed using authorized formulas and also measured by the sharp-crested weir installed at the downstream end of channels. Several ranges of reverse slope and length of channel bed to incorporate these reverse slope downstream the outlet were studied for a possible rise in FSL of small irrigation channels usually termed as watercourses. Working of the used outlets was evaluated with reference to possible increase in the FSL of the watercourse due to the induction of reverse slope and resultant decrease in the discharge drawing capacity of the outlet due to possible submergence. The results of this study will be very useful for the field engineers of the irrigation departments to create sufficient working head required to irrigate elevated fields in the command area of a watercourse. From the results of the study following conclusions has been drawn:

- The optimal limit of the reverse slope was found to be in the range of -0.10 to -0.15 for AOSM and pipe type of outlets having a discharge capacity of about 28 LPS (one cusec).
- Reverse slope incorporated in 1 m length was found more useful as compared to incorporated

in 2m length.

- Identical behaviors of AOSM and pipe outlets were observed against reverse slope induction and reverse slope can be utilized downstream of these outlets to increase FSL in the watercourse.
- The reverse slope was not recommended where open flume outlet was used due to significant reduction in the discharge drawing capacity of the outlet against reverse slope induction.

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