Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan *Vol. 26 No. 2-2021*
ISSN:1813-1786 (Print) 2313-7770 (Online)

Validation of Selected Roughness Coefficient in a Lined Distributary and its Effect on Water Equity

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Abstract- In the present study design value of the roughness coefficient for a lined distributary (Chena distributary district Kasur) was validated and its effect on the water drawing capacity of outlets was assessed. Chena distributary, off takes from the left bank of Depalpur canal, at RD 359020. The total length of the distributary is 25.46 km. More than 50 percent of its length has been lined. In this study, a reach from RD 0.00 to 7590 having a trapezoidal lined section was used. The total numbers of outlets being fed by the distributary were 62. The first 17 outlets were included in the study. A comparison was made between design and field measurements of the hydraulic parameters of the canal and the outlets. Simulations of canal and outlet flows were made using the (Simulation Irrigation Canal) SIC model. A considerable difference was observed between the design and the prevailing water surface profiles and resultantly water drawing capacity of the outlets. The results showed that the prevailing value of the roughness coefficient was 0.02 instead of 0.016, the design value. Because of increased roughness coefficient value, due to sedimentation or due to some tempering, the depth of flow increased in the head reaches. Therefore outlets at the head were drawing more than allocated share. In the tail reaches due to reduced discharges, tail-enders were deprived of their due share. Not only cleaning and maintenance of lined portion of canal at regular intervals but also strict regulations to avoid tampering are required for sustainable operation of an irrigation system as per design.

Keywords- Validation, Roughness Coefficient, Lined Distributry, Water Equality.

I. INTRODUCTION

The canal irrigation system of Pakistan is the largest integrated irrigation network in the world [1-2]. It ranks fifth in the world and third in Asia in terms of irrigated area [3-4]. It covers an area of about 7.11 million hectares [5-6]. The irrigation system serves as the lifeline for sustaining agriculture in our arid to semiarid climate [7-8]. More than 90% of agriculture production is from irrigated land, accounting for about 25% of GDP, 80% of the country's export revenue and employment for over 50% of the labor force [9-12]. In order to sustain agricultural development, the need for proper maintenance of the existing irrigation canal network has become unavoidable.

The average annual flow in the country river system amount to about 139 MAF, of this about 104 MAF is diverted to integrated canal network meant to irrigate 34 million acres of land. About 44 MAF of groundwater is used in conjunction with canal water available at the farm gate. Out of 104 MAF, diverted to the canal system, 78 MAF (75%) is available at the head of distributaries. 26 MAF (25%) lost in conveyance losses in the canal system. Out of 78 MAF, 43 MAF (55%) available at the field outlets/Nakkas and the remaining 35 MAF (45%) lost in conveyance losses of distributaries. Out of 43 MAF, only 31MAF (72%) is available for crop and the remaining 28% lost in the field applications. 31 MAF water is available for the crop out of 104 MAF. So 73 MAF water is lost through seepage losses and contributes to the groundwater [12-13].

Many researchers studied canal designs and reported that improper design and deferred maintenance of irrigation canals leads to water losses and unequal water distribution problems [14-22]. The outlet is an important hydraulic structure connecting canals with watercourses. Different types of outlets have been used in subcontinent such as open flume, adjustable orifice semi-modular outlet and Adjustable Proportional Modules (APM) etc. Various researchers have studied the behavior of outlets [23-25].

The canal carrying capacity is disturbed due to sediment deposits, erosion, vegetation, and change of roughness co-efficient. Changes in equilibrium conditions for sediment transport result in periods of deposition or erosion and siltation of the canal system results in the reduction of conveyance capacity, overtopping, unequal water distribution through outlets, less reliable operation of flow control structures etc. [26-28]. With the passage of time the value of roughness co-efficient changes due to silting, vegetation and other factors and thus water surface profile and design discharge capacity of the cannel changes [29-30]. Resultantly water drawing capacity of non-modular and semi-modular outlets also changes [30-31]. Different researchers have tried to explain the resistance to flow by assuming a single type of bed, from the development on the channel bottom [32-36].

SIC model has been used extensively nationally and internationally to study irrigation requirement indents and releases of selected canal command based on operational and distributional constraints of irrigation canals and resultant variation in discharge drawing characteristics of canal outlets along the canal from head to tail [36-45].

In the present study effect of variation in roughness coefficient value selected at the design stage of a lined distributary on water drawing capacity (water equality) of outlets was studied using SIC model. Specific objectives of the study were: Estimation of water surface profiles for varied roughness coefficients, determination of prevailing roughness coefficient for the selected canal and determination of the effect of roughness co-efficient on equitable distribution of water through the outlets. The result obtained from this study will be useful for the irrigation department, concerned consultants and other national and international organizations working for the improvement and management of irrigation system. It will be helpful for future research studies in the operation of irrigation canal and outlets.

II. MATERIAL AND METHODS

Study Area

The study was conducted on Chena distributary off taking form left bank of Depalpur Canal at RD 359020. The total length of the Chena Distributary is 25.46 km. The design discharge available at the head of the distributary is 3.81m^3/s. More than 50% of its length is lined. The total numbers of outlets being fed by the distributary are 62 and first 17 were selected for the study. In this study, the reach from RD 0.00m to RD 7590 a trapezoidal lined section, was considered. The schematic diagram of Chena Distributary with the line diagram is shown in figure 1.

Data Collection

The study was based on design as well as the measured data. The following data were collected for the Chena Distributary.

1. Design data of selected reaches and outlets from the provincial irrigation department.
2. Measurement of dimensions of the concerned outlets and discharge measurement in the distributary & outlets.
3. Measurement of water surface levels in the canal.

Measurement of canal Discharge

The canal flows at selected RDs were measured with the help of flow meter using the velocity area method. The canal section was divided into four segments. Three points method was used to measure the velocity of water in each segment. The metering rod was placed at the center of each segment at appropriate depth (0.2d, 0.6d and 0.8d) from the top water surface, and the velocity of water flowing through the canal was noted from the screen of the control panel of the flow meter. The segmental discharge of each sub-section was calculated by multiplying the segmental area with the segmental velocity. The total discharge flowing through the canal was calculated by adding the segmental discharges. This methodology was used to measure the discharge of all the selected sections of the canal.

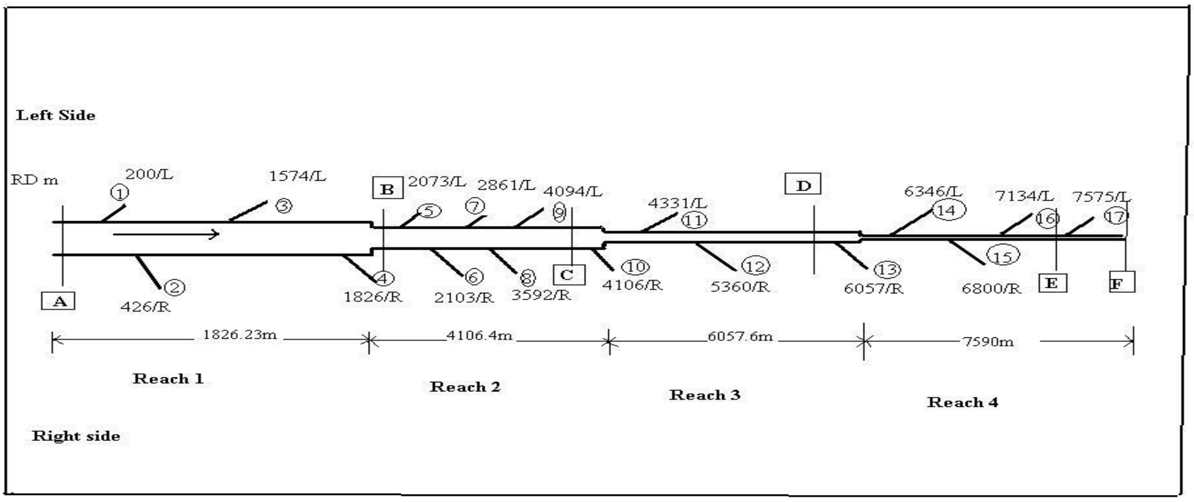

Fig. 1: Schematic layout of the study area

Measurement of canal dimensions

Dimensions of selected reaches of the canal were measured during the annual canal closure period. At site width, depth of the canal and watermarks, indicating water surface profile position at desired locations were measured. The water surface profile of the selected reach of the canal was noted with the help of a staff rod. Staff rod was placed vertically in the canal upstream and downstream of each outlet and watermarks were noted.

Measurement of flow in watercourses

Flows in watercourses were measured using the velocity area method. At a suitable location along the watercourse, the top width was measured by using steel tap. Then the cross-section was divided into the appropriate number of sub-section (normally 3, for 50 cm top width and 4 for 60 cm top width). The flow depths were measured at the center of each sub-section by using the meter rod. Following precautions were employed while using the current meter for discharge measurements:

- The water surface was stable and free from floating debris or tree-leaves at the discharge measuring site.
- The velocity was carefully recorded.
- The cross-sections of the segment were accurately measured.

Segmental discharge of each sub-section of the watercourse was calculated by multiplying the segmental area with the segmental velocity. The total discharge flowing through the watercourse was calculated by adding the segmental discharges. This methodology was used to measure the discharge of all selected outlets.

Measurements of outlet geometric parameters

The outlet geometry was measured in terms of width (B) for open flume type outlets and both, width (B) and height (Y) of the outlet opening for APM type outlets. The exact and accurate measurement of outlet geometry was very difficult job under canal flowing conditions. In this study, outlet geometry was measured at the time of annual canal closure. Steel tape was used to measure the height of opening for both APM and Open Flume (OF) type outlets. A large difference was observed among the design and at site geometry of the outlets.

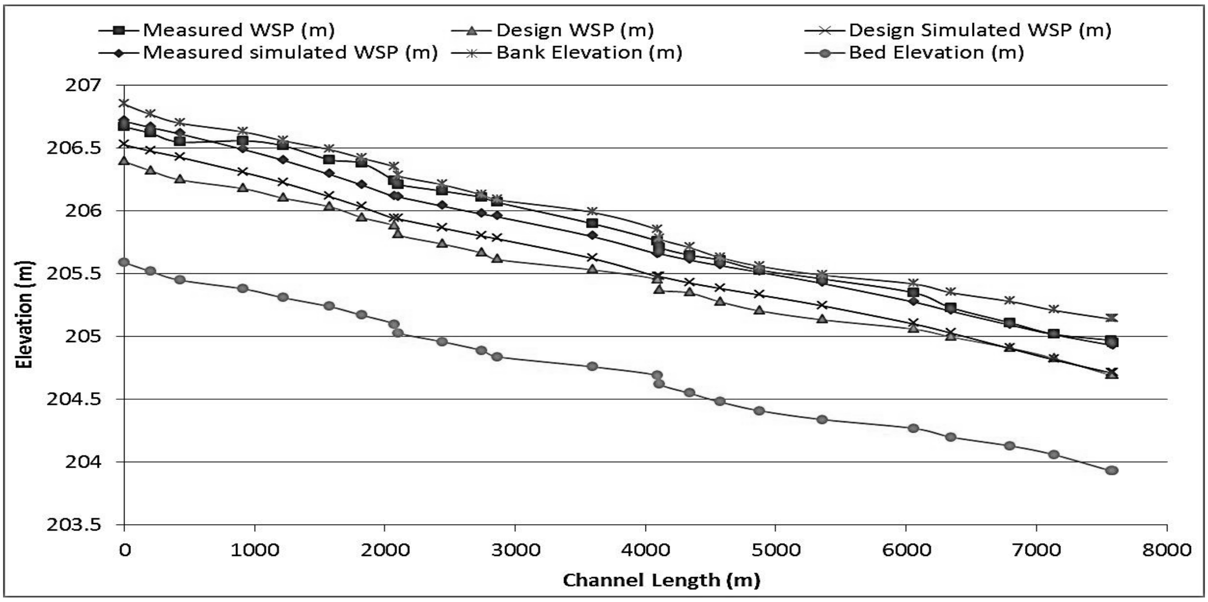

Fig. 2: Design and Measured water surface profiles (actual and model-simulated) with bank and bed elevation of Canal

Model Formulation.

Hydraulic simulation model “Simulation of Irrigation Canals (SIC)” developed by a French Institute, CEMAGREF, Montpellier, was used in this study [43a]. The model could provide answers to major problems that confront the canal manager, by:

1. Simulating the steady and unsteady state hydraulic and operational conditions in an irrigation canal.
2. Comparing and testing physical modifications in that canal topography or control structures.
3. Evaluating new management rules once defined and formulated.

First of all, the topology and geometry data was inputted. The geometric description of a cross-section of the reach was entered, i.e., bed width, bed elevation, bank elevation, side slop, calculation step and location of the cross-section. When the topology and the geometry were entirely described, the “coherence” option in the network menu was selected. Unit II computes the water surface profile in a canal under steady flow conditions.

This unit consists of three main options, data editor, steady flow computation and results. In this study, there were seventeen outlets in the selected reach, in which fifteen were APM and two were OF outlets. By double-clicking the branch, I option "Node or off take type" window appeared, here outlet data was entered. In the design option and Manning's co-efficient option, entered the Manning's co-efficient value from RD 0.00 to 7590. In downstream boundary conditions, the rating curve values were given and validated. In this way the canal was simulated using the model at different Roughness value. Checked the results on the graphs and determined the prevailing value of roughness coefficient.

III. RESULTS AND DISCUSSION

General

Two types of data sets were used in the study: Design data and measured data. Both these data sets were also simulated initially using the SIC model. Model output using design data was termed design simulated and model output using measured data was termed as measured simulated. First of all, an inter comparison was made between design data, measured in field values, design simulated and measured simulated water surface profiles was done as shown in figure 2. The design value of the roughness coefficient was 0.016. The significant difference was observed between the design water surface profile and measured water surface profile conditions. There can be two reasons for this difference: the discharge measured at the head of the canal was more than the design discharge, and secondly, the Manning's n value could be more than the design value. Some depressions in measured water surface profile at some locations (at 0 m and 100 m) were due to transition flow conditions produced by canal falls.

The water surface profile plotted by the model using design data was almost smooth and matched with department design water surface profile at 6000 m to 7590 m. Design data water surface profile deviates at 2000 m and 4000 m, due to falls at these locations. These falls were due to a change in bed slope and reduced width of the canal owing to the reduction in discharge dawn by the outlets. The measured water surface profile and the model simulated water surface profile using field measured data revealed that model simulated water surface profile was smooth and parallel with the measured water surface profile. Some contrast was observed at canal falls due to transitional flow conditions. Another cause of contrast between manually measured and model simulated water surface profile might be uneven roughness co-efficient values at different locations along the canal reaches. Because in model simulated design value of roughness coefficient (n = 0.016) was used.

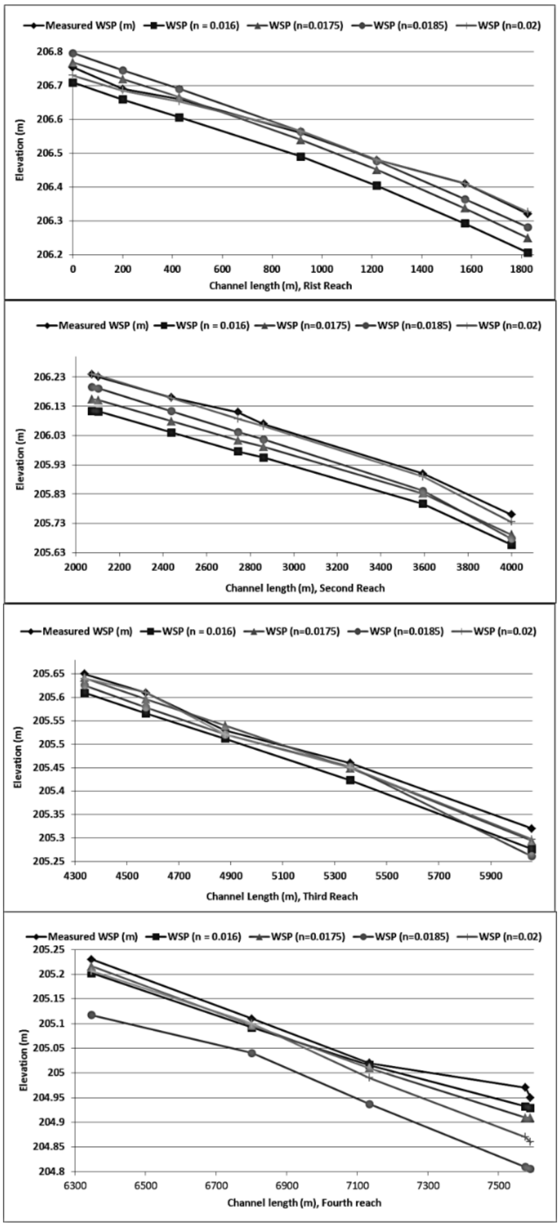

Fig. 3: Water surface profile elevations for different values of roughness coefficient by dividing the canal in to four reaches

Water Surface Profile at Different Roughness Coefficient Values

As the canal runs for a long time, the roughness coefficient value of the canal deviates from the designed value of 'n' due to change in roughness of bed and sides. Due to these changes, the water surface profile changes and thus, discharge of outlets also deviates from the targeted discharge. To have an understanding of this situation, the canal was simulated using measured canal data for different values of roughness coefficient (n) using the SIC model as shown in figure3.

For this purpose, the canal reach was divided into four sub reaches lengthwise. The model was run for multiple values of the roughness coefficient (0.016, 0.0175, 0.0185, and 0.02). Comparison among water surface profiles produced by model at different ‘n’ values and the measured water surface profile of the canal revealed that the water surface profile against ‘n’ value of 0.020 was very close to the measured water surface profile except in the tail end reach at location 7100m and 7500m. Therefore, roughness value of 0.020 was found prevailing value of the roughness coefficient (n) for this canal.

Outlet Discharge, design vs. measured

A survey was carried out for the performance evaluation of canal irrigation outlets at Chena distributary. The discharge drawn by APM and Open flume were measured at the site.

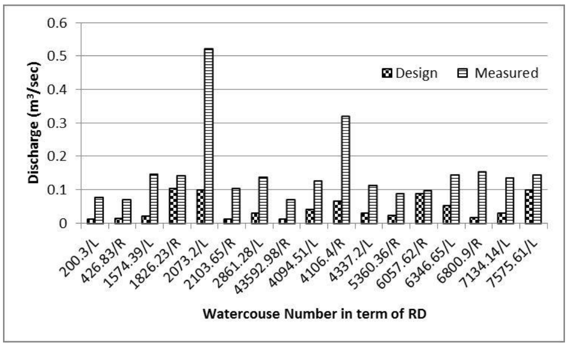

Fig. 4: Design and measured discharges of the outlets in the study area

A comparison was made between design discharges of outlets and the discharge drawn by outlets (measured in the field), as shown in figure 4. A significant difference was observed between measured discharge in the field and design discharge of the outlets. The outlet no 5 (2073.2/L) and 14 (4106.4/R) are open flume. These two outlets drew excess water while the outlet no.10 was tempered, that’s why it was drawing more amount of water. There could be more than one reason for these variations, such as the greater value of discharge in the canal than the design discharge, deviated value of roughness coefficient than the design value resultantly higher water surface profile than the design and tempering of outlets.

Outlet design and measured discharges simulated by the model

The outlet design data width, height, coefficient of discharge of outlet and targeted discharge was used as input data in the SIC model and results obtained from the model were compared with outlet design discharge calculated by the department with the help of APM and open flume formulas as shown in figure 5. It was found that the discharge given by the model at design data was more than the design discharge of outlets calculated by the department. At outlet no.5 (2103.65/R) discharge given by the model was more because it was an Open Flume outlet. While in other outlets, slight variations in discharges were observed. This variation was due to a change in the coefficient of discharge of outlet and change in water surface profile of the canal. Outlet discharge obtained from model using (canal, outlet dimensions) measured data at the value of roughness coefficient (n = 0.016) were compared with measured discharges drawn by outlets. It was found that the outlet discharge measured in the field were more than the model simulated discharges using measured data for most of the outlets. However, measured discharge in the field for outlets 5, 11, 14 and 15 were less than the model simulated discharge. This deviation was due to variation in discharge coefficient values of outlets and roughness coefficient values along bed and sides of the feeding canal at various locations. In reaches where the higher value of roughness coefficient prevails, water surface profile became higher, and resultantly outlets in such reaches drew more share of water and vice versa.

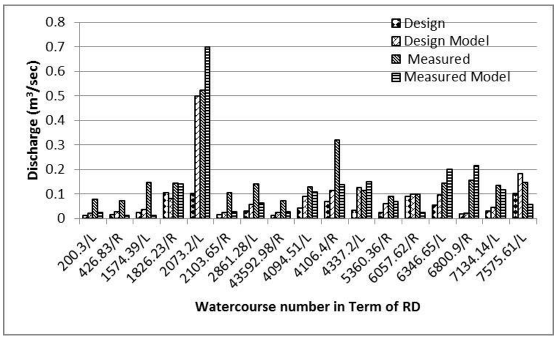

Fig. 5: Design and measured (actual and model simulated) discharges drawn by the outlets.

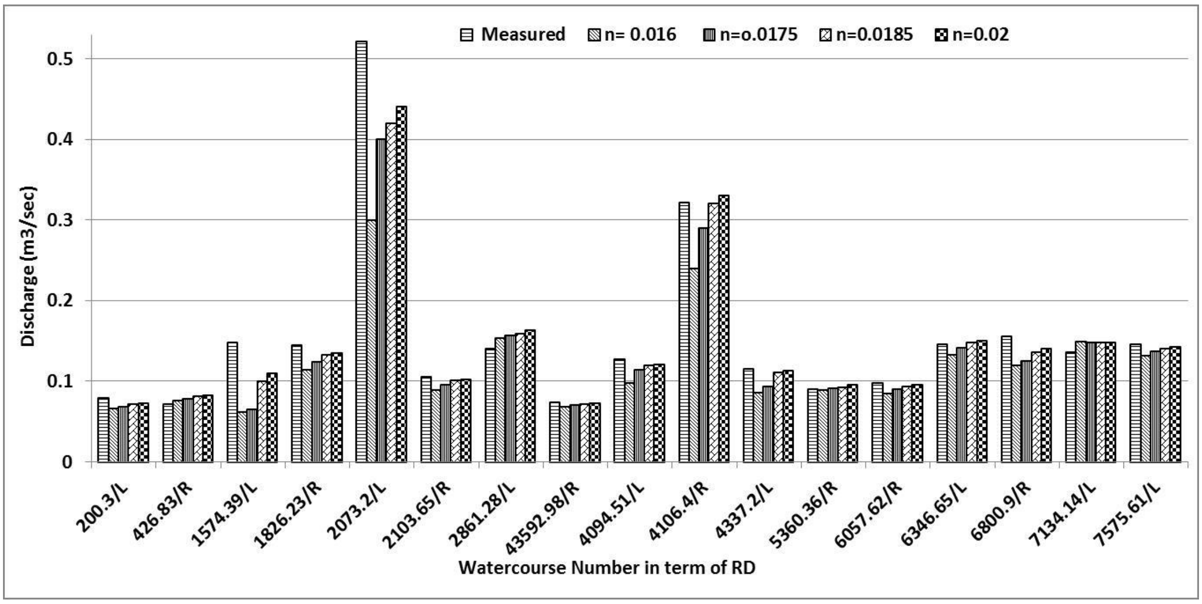

Fig. 6: Design and measured (actual and model simulated) discharges drawn by the outlets with different n values.

Outlet discharge at different Manning’s n value values

The canal was run on the SIC model using different values of Manning’s coefficient (0.016, 0.0175, 0.0185 and 0.02). For these values, varied elevations of water surface profiles were observed in the canal. Water surface elevation for roughness value of 0.02 matched well with the field observed water surface profile value. Resultantly the discharge drawn by the outlets changed due to change in water surface profile level in the canal.

Therefore, for different used values of roughness coefficient in the canal the resultant effect on discharge drawing capacity of outlets were studied as shown in figure 6. It was observed that for canal roughness value of 0.02 when the water surface profile was closer to the field measured water surface profile in the canal, model-simulated discharge drawn by the outlets were closest to the field measured outlet discharges.

IV. CONCLUSIONS

In this study, the roughness coefficient for a lined distributary (Chena distributary district Kasur) was verified, and its effect on the water drawing capacity of outlets was determined. Specific objectives of the study were: Estimation of water surface profiles for varied roughness coefficients, determination of roughness coefficient appropriate for the selected canal and determination of the effect of roughness co-efficient on equitable distribution of water through the outlets. A deviation in the design roughness co-efficient of the selected canal was observed that may be due to sedimentation or due to some tempering. Resultantly a considerable difference was observed between the design and the prevailing water surface profiles in the canal. The targeted discharge of outlets was not according to the design because of the change in water surface profile in the canal. Therefore outlets at the head were drawing more than allocated share of water and in the tail reaches due to reduced discharges, tail-enders were deprived of their due share. Furthermore, it was also observed that the majorities of outlets were tempered, and at some places farmer were also drawing water with siphon pipes. At some locations in the lined canal farmer has made a little concrete wall d/s of the outlet pipe

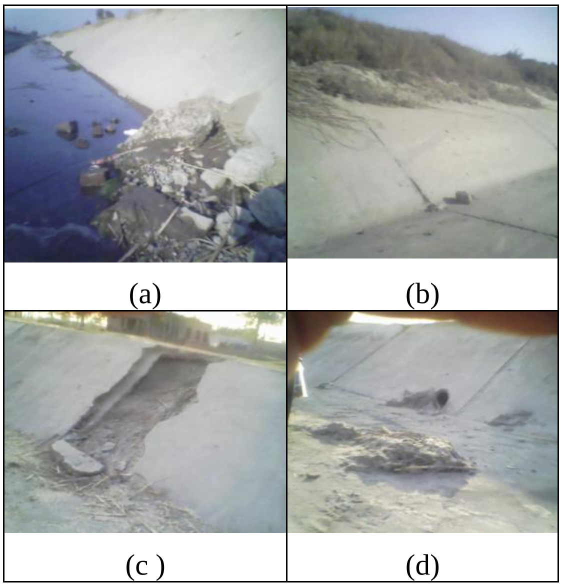
(a) (b)
(c) (d)

Fig. 7: (a) Debris accumulation at the bed (b) Vegetation growth at the bank (c) Bank fracture of canal (d) Outlet pipe and debris at the bed.

to draw more water. The variation of discharge between the designed and observed was considerably high; therefore, the annual calibration of the outlets should be carried out. Change in the water surface profile of the distributary, as well as the discharge rate entering into the watercourse, should be measured by using two-stage recorders, one on the upstream of the outlet and one on the downstream of the outlet. It has been observed that major issues were with maintenance and operation of the irrigation system rather than the design issues. It has been suggested that not only cleaning and maintenance of lined portion of canal at regular intervals is needed but also strict regulations to avoid tampering are necessary for sustainable operation of a canal irrigation system as per true design.

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