EXPERIMENTAL INVESTIGATION OF INFILTRATION ON SEDIMENT TRANSPORT IN CHANNELS

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ABSTRACT

Experiments have been carried out to study sediment transport in channels which are in unsaturated conditions emphasizing on effect of infiltration using the concept that as water infiltrates, flow rate decreases fairly linearly with distance along the channel thus the capacity of flow to transport the accumulated sediment decreases and net deposition occurs. Data obtained from experiments which were carried out in a laboratory flume was used to calculate sediment transport rate, flow discharge at the outlet of the flume and bed profiles measured with and without sediment injection leads to study the effect of infiltration and aggradation with non-uniform flow conditions. Experiments were also conducted for the saturated sand and comparison of data obtained from experiments which were carried out on unsaturated sand was done and observations and analysis was done.

Keywords:Infiltration, Sediment Transport, Aggradation, Unsaturated Sand

INTRODUCTION

Irrigation channel present an excellent opportunity to study sediment transport process in field soil. Due to infiltration water flow rate decreases at a linear rate with the distance along the channel and the flow capability to carry sediment decreases and thus deposition of accumulated sediment occurs. Consequently, the relationship between flow rate and sediment load can be determined. Irrigation channel sediment load field data were used to evaluate the concept of sediment transport capacity. Flow rates decrease in the downstream direction as water infiltrates. Fertilizer and nutrient necessary for the growth of crops are attached to the surface of soil and carried along the channels by the irrigation flow. So determination of sediment transport capacity, water discharge rate and prediction of bed forms is of prime significance.

GOVERNING EQUATIONS

The governing equations for flow and sediment transport explaining unsteady flow in irrigation channels and the equation of continuity for water flow and sediment flow for the conservation of sediment mass are solved numerically. These two governing equation are coupled due to the sink term in the Saint Venant equation. The figure 1 below depicts the flow in an irrigation channel.

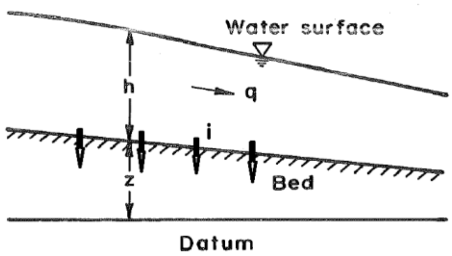

FIGURE 1. Definition sketch of flow in an irrigation channel

GOVERNING EQUATIONS FOR SURFACE FLOW

The partial differential equations governing overland in an irrigated channel in Cartesian co-ordinates are

:**Continuity equation for water:**

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} + i = 0 \qquad (1)$$

Momentum equation for water:

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q^2}{h} + \frac{gh^2}{2}\right) + gh\frac{\partial z}{\partial x} + gh S_f = 0 \qquad (2)$$

SEDIMENT TRANSPORT EQUATION

Continuity equation for sediment can be represented as:

$$\frac{\partial}{\partial t}\left[(1-p)z + \frac{q_s h}{q}\right] + \frac{\partial q_s}{\partial x} = 0 \qquad (3)$$

EXPERIMENTAL SETUP

The experiments were conducted in a 46cm wide, 58cm deep and 12m long tilting flume located in the hydraulics laboratory of IIT Roorkee, which can be shown by the figure 2. The flume was provided with glass side wall on both sides. The system consisted of a rectangular tank having sloping bottom to collect the sediment laden flow from the downstream end of the flume. A collector is placed below the downstream end of the flume to collect the sediment water mixture. A rectangular weir is located at the outlet of the flume to measure the water flow discharge with the help of vertical pipe fixed adjacent to the weir. A floating wooden suppressor situated at the entrance of the flume for resisting the disturbances at the free surface. A schematic diagram of experimental setup is shown in figure 2 below. The working length of flume is 8m, 3.5m length of the flume at upstream is filled with gravel and boulders to stabilize the flow and 0.5m length of the flume at downstream end is provided for easy flow of sediment water mixture into the collector. A movable carriage with a pointer gauge having a least count of 0.01 cm was mounted on a carriage which could move on the rails which are made from metallic tubes and were provided on the top of side walls. A pointer gauge was used for recording water surface and bed elevations. An adjustable gate at the downstream end of the flume was used to control the depth of flow in flume. The specifications of flume dimensions and sand used are summarized in a table 1; figure 1and figure 2 shows the schematic diagram of the experimental setup.

FIGURE 2. Experimental flume used in the study

TABLE 1. Specification of flume dimensions and sand used

Flume dimensions	
Length (m)	12
Working length(sand filled length) (cm)	8
Width (cm)	46
Depth (cm)	58
Sand filled depth (cm)	35
Dry density (gm/cm^3)	1.486
Specific Gravity	2.65
Median sieve diameter (mm)	0.32
Porosity	0.43
Initial moisture Content (%)	4.4
Dry density (gm/cm^3)	1.486
Specific Gravity	2.65

The sand was filled in the 8m length of the flume upto a depth of 35cm and levelled parallel to the rails. The sand forming the bed and injected material have a median sieve diameter of 0.32mm. The specific gravity of the sand is 2.65 and dry density of the sand used is 1486 kg/m^3. The grain size distribution curve of the sand used is shown in figure 3.

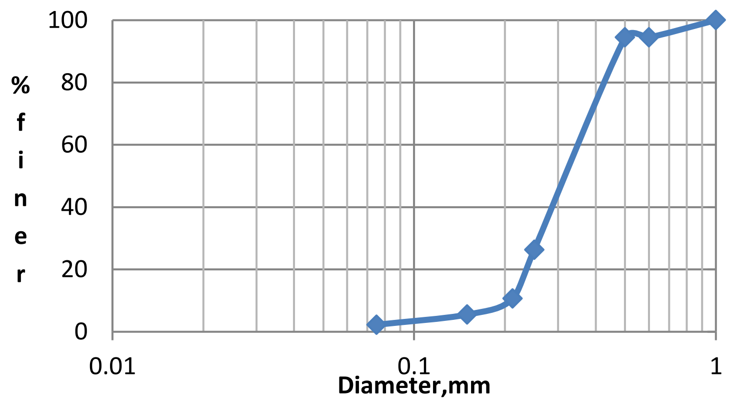

FIGURE 3. Grain size distribution of sand used for bed material as well as for injection

Moisture content

For each run, after ten minutes samples were taken at three different depths viz. 5cm, 10cm and 15 cm at three distances 2.3 m apart along the channel. The wet weight and dry weight of nine samples were measured and moisture content at different depths and at different distance along the channel was determined using the relation and samples taken and methodology adopted for the measurement of moisture content is shown below in figure 4.

FIGURE 4. Samples collected for the calculation of moisture content

TABLE 2. Measurement of water discharge for different depth of flow.

Depth of flow (cm)		h_1 (cm)	h_2 (cm)	H (cm)	C_d	Q (l/s)
5	Without sediment injection	51.1	49.8	1.3	0.614	1.746
	With sediment injection	51.2	53.2	2	0.615	1.955

FIGURE 5. Sand trap/collector used to collect sediment water mixture for each run

TABLE 3. Measurement of sediment transport rate for h=5cm without sediment injection

Wet weight of sample (kg),w_w	2.202
Dry weight of sample (kg),w_d	1.704
Water content (liter),w_o	0.498
Sediment concentration (mg/l) ($\times 10^6$)	3.421
Sediment discharge rate (kg/s),q_s ($\times 10^{-3}$)	2.84
Sediment transport rate (m^3/s),Q_s($\times 10^{-7}$)	8.3

TABLE 4. Measurement of sediment transport rate for h=5cm with sediment injection

Wet weight of sample (kg) w_w	4.918
Dry weight of sample (kg) w_d	3.75
Water content (liter) w_o	1.168
Sediment concentration (mg/l) ($\times 10^6$)	3.210
Sediment discharge rate (kg/s) q_s ($\times 10^{-3}$)	6.25
Sediment transport rate (m^3/s) Q_s($\times 10^{-7}$)	19.46

Bed elevation calculations

For each run the bed surface profiles were recorded at sixteen sections 0.5m apart along the 8m long flume with the help of a pointer gauge having least count of 0.01cm.

FIGURE 6. Bed profiles after experiments

TABLE 5. Bed profiles measurements for h=5cm with and without sediment injection

Distance along the channel(m)	Z (Without sediment injection)(cm)	Z (With sediment injection)(cm)
0	20.5	18.5
0.5	21	20
1	22	21
1.5	22.2	21.5
2	22.5	21.4

TABLE 6. Bed profiles measurements for h=7.5cm with and without sediment injection

Distance along the channel	Z (Without sediment injection)(cm)	Z (With sediment injection)(cm)
0	20.7	20.1
0.5	21.2	20.5
1	22.1	21.1

TABLE 7. Measurements of water discharge at different depth of flow in saturated sand

Depth of flow (cm)		h_1 (cm)	h_2 (cm)	H (cm)	C_d	Q (l/s)
5	Without sediment injection	50.2	51.8	1.6	0.615	2.38
	With sediment injection	51.1	52.8	1.7	0.615	2.61
7.5	Without sediment injection	50.9	53.6	2.7	0.618	5.23
	With sediment injection	50.8	53.6	2.8	0.618	5.55

Sediment transport: Same procedure is adopted as mentioned earlier for unsaturated sand experiments and sediment transport rate for different depth of flows & summarized in a table below(for h=5cm).

TABLE 8. Measurement of sediment transport rate for h=5cm without sediment injection

Wet weight of sample (kg) w_w	2.801
Dry weight of sample (kg) w_d	2.2
Water content (liter) w_o	0.6
Sediment concentration (mg/l) $(\times 10^6)$	3.667
Sediment discharge rate (kg/s) q_s $(\times 10^{-3})$	3.66
Sediment transport rate (m^3/s) $Q_s(\times 10^{-7})$	9.981

TABLE 9. Measurement of sediment transport rate for h=5cm with sediment injection

Wet weight of sample (kg) w_w	5.832
Dry weight of sample (kg) w_d	4.55
Water content (liter) w_o	1.282
Sediment concentration (mg/l) $(\times 10^6)$	3.549
Sediment discharge rate (kg/s) q_s $(\times 10^{-3})$	7.58
Sediment transport rate (m^3/s) $Q_s(\times 10^{-7})$	21.35

Moisture content: Same procedure is adopted as mentioned earlier for dry sand experiment and measured moisture content at different depth of flow can be summarized in table 3.25

TABLE 10. Moisture content calculation at different depths of flow with and without sediment injection

Distance along channel(m)	Depth (cm)	5cm		7.5cm		9.0cm	
		Without sediment injection	With sediment injection	Without sediment injection	With sediment injection	Without sediment injection	With sediment injection
2.3	5	41.5	41.12	42.34	40.4	42.9	41.7
	10	41.91	42.2	42.22	42.78	40.1	41.6
	15	42.7	42.24	42.45	42.56	42.66	42.36

DETAILED ANALYSIS

Data measured for the calculation of moisture content, sediment transport and bed profiles for dry and saturated sand with and without sediment injection of sand are compared for the detailed analysis of measured data.

TABLE 11. Moisture content calculations for different depths of flow

Distance along channel (m)	Depth (cm)	5cm		7.5cm		9.0cm	
		Without sediment injection	With sediment injection	Without sediment injection	With sediment injection	Without sediment injection	With sediment injection
2.3	5	26.31	23.68	32.8	31.4	31.50	40
	10	24.48	25.52	34.28	34.78	34	34.5
	15	28	29.66	29.72	30	31.20	35.71

RESULTS AND DISCUSSION

The main conclusions drawn from the experimental investigation are summarized below.

1. For same depth of flow water flow discharge measured at outlet of the flume in saturated sand is more than that of measured in unsaturated sand due to the unsaturated condition of sand, considerable amount of water infiltrates due to which flow rates decrease fairly linearly with distance along the channel.
2. For same depth of flow sediment transport capacity measured for unsaturated sand is less than that of measured for saturated sand because due to infiltration sediment carrying capacity of water decreases and sediment concentration measured at outlet of the flume decreases.
3. For same depth of flow sediment transport capacity with injection of sediment is more than that of without injection of sediment because due to the imbalance between sediment and water flow as sediment overloading causes more amount of sediment to flow.
4. Bed slope increases with time and with increase in depth of flow due to aggradation which occurs because sediment transport capacity of water decreases due to excess sediment load dropped on the bed.
5. Rate of infiltration is more in unsaturated sand than that of saturated sand because rate of infiltration decreases as moisture content of the sand increases.

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