CHAPTER 3

METHODOLOGY OF LABORATORY EXPERIMENT

3.1 General

This chapter incorporates the detailed description of the experimental set-up as well as measuring devices and measuring techniques. The experimental procedure and data collection techniques are also described in the following articles.

3.2 Experimental Set-up

The experimental model described herein was constructed in the Physical Modeling Facility of the Department of Water Resources Engineering, BUET, Dhaka. Figure 3.1 shows the physical appearance of channel model.

Figure 3.1: Experimental set-up at Physical Modeling Facility, DWRE, BUET

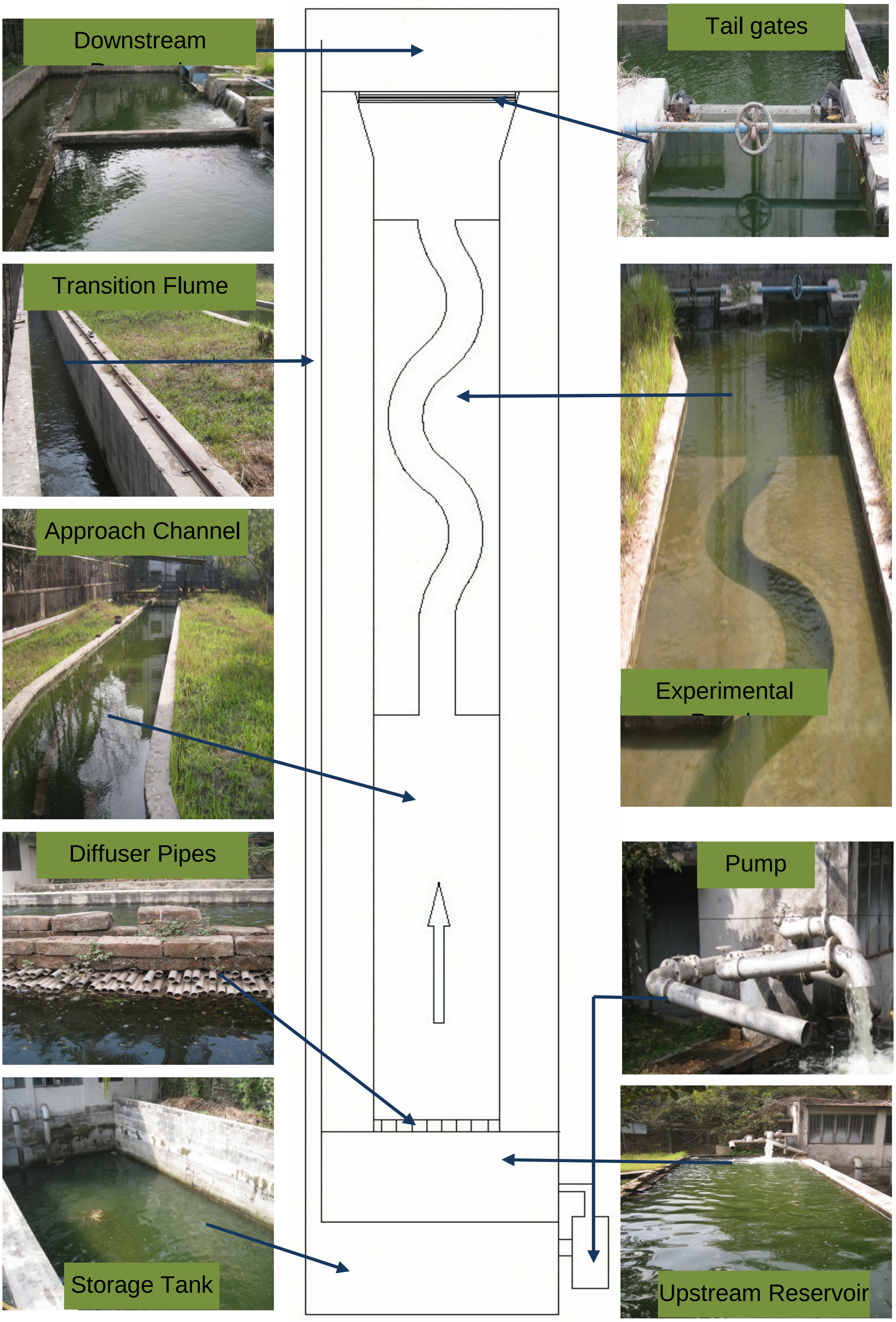


Figure 3.2: Plan View of Model Setup

The experimental set-up consists of two separate parts, the experimental reach and experimental facilities. The experimental facilities are necessary for the storage and regulation of the water circulating through the model and act as the guidance part. The experimental reach contains the actual experimental model of a river. It is possible to change its configuration as and when needed for carrying out further research, using the experimental facilities of the model without any drastic constructive changes. The experimental reach and the experimental facilities of the model are shown in Figure 3.2.

3.2.1 The Experimental Reach

The model is built in the experimental reach of the set-up. It is a rigid-bed model with fixed banks made of brick, sand and cement. The experimental setup for compound meandering channel will consist of a fixed floodplain on both sides of main channel. The total length of the channel is 975 cm of which 670 cm is meander channel. The main channel width is 46 cm and the variable floodplain width is 55 cm to 144 cm. The experimental meandering channel is symmetric and of regular pattern. The channel has rigid boundary walls and the floodplain walls are also fixed. The experimental reach has wavelength λ_m =366 cm, amplitude α_m = 136 cm, giving sinuosity of 1.117. It is very important to consider the meander parameters during the design of a meandering channel in the laboratory.

A detail drawing of the experimental reach is shown in Figure 3.3. In the following sections all elements of the experimental reach are described in detail.

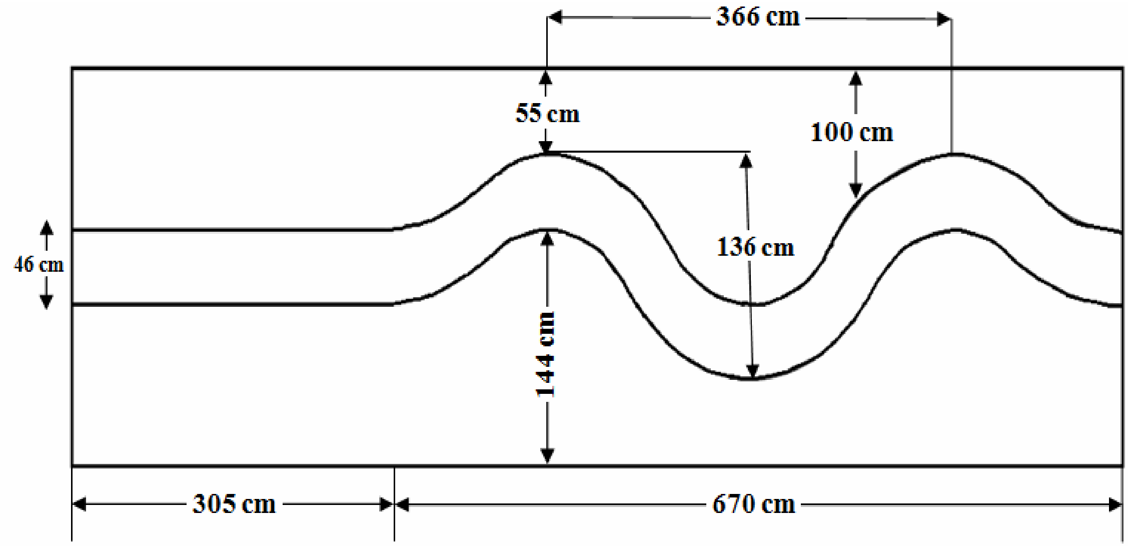


Figure 3.3: Dimensions of experimental reach

3.2.2 The Experimental Facilities

The experimental facilities are usually the permanent part of the set-up. It acts as a facility to conduct all different types of experiment in the channel reach. The components of the experimental facilities are given below:

1) Storage Reservoir
2) Pump
3) Upstream Reservoir
4) Approach Channel
5) Downstream Reservoir
6) The regulating and Measuring System

The components of the experimental facilities are described below in brief.

Storage Reservoir

The total capacity of reservoir is about 1152 m^3. From the storage reservoir water is withdrawn by the pump and discharged to the upstream reservoir. The valve attached to the reservoir is used to empty the reservoir for cleaning or repairing purpose (Figure 3.4).

Figure 3.4: Storage reservoir

Pump

The centrifugal pump near the pump house draws water from the storage reservoir and supplies to the upstream reservoir (Figure 3.5). The pump has a maximum delivery of up to 80 l/sec.

Figure 3.5: Centrifugal pump

Upstream Reservoir

The pump draws water from the storage reservoir and discharges into the upstream reservoir (Figure 3.6). The volume of the upstream reservoir is 100 m^3. The maximum water depth in the upstream reservoir can be 2 m. The upstream reservoir is near the pump house, located between the storage reservoir and the approach channel, where water is storage from direct supply of the pump. Water from the upstream reservoir passes through a wall made up PVC pipes into the approach channel. This is done to ensure undisturbed and uniform flow in the experimental reach.

Figure 3.6: Upstream reservoir

Approach Channel

The approach channel is at right angle to upstream reservoir and which conveys water to the experimental channel, it is 246 cm in width and length is 30 m (Figure 3.7). The walls of the channel are made of bricks, sand and cement. This approach channel carries water as a uniform flow. The sharp-crested weir is located in the upstream of the channel.

Figure 3.7: Approach channel

Downstream Reservoir

The downstream reservoir (Figure 3.8) serves as transition reservoir. The maximum water level can be at 0.77 m elevation with respect to reservoir bottom. There is tail gate at the entrance of the reservoir and a spillway at the end of the downstream reservoir for excess water to spill out.

Figure 3.8: Downstream reservoir

The Regulating and Measuring System

The regulating and measuring system of the model consists of the following:

- The Tail Gates
- The Stilling Basin and Transition Flumes
- The Guiding Vanes and Tubes

The Tail Gate

At the downstream end of channels the tail gate is placed to maintain desired water level in the experimental reach (Figure. 3.9). It is made of cast iron and encircled with rubber flaps, so that water flows only over the gates. It also has steel plates on both sides for guidance of flow. The downstream regulation is performed by the tailgates.

Figure 3.9: Tail gate and flow over tail gate

The tail gate has two functions –

a) To regulate the water level in the channel, and
b) To prevent the channel from running dry if a power failure occurs during experimentation or when it becomes necessary to stop the run for some reason.

The Stilling Basin and Transition Flumes

Behind the tail gate the water falls into a stilling basin there is a transition flume, which allows water for recirculation (Figure 3.10). Besides transporting water to the measuring part of the permanent facility, the stilling basin as well as the transition flumes helps destroy turbulence.

Figure 3.10: Stilling basin and transition flumes

The Guiding Vanes and Tubes

To ensure a more smooth flow towards the approach channels guiding vanes are placed between the upstream reservoir and the approach channels which are at right angle to each other. These vanes guide the water around the corner. In order to prevent creation of extra unwanted turbulence in the approach channels, PVC tubes (diffuser pipes) are used on the upstream side of the guiding vanes (Figure 3.11).

Figure 3.11: Guiding vanes and tubes

3.3 Water Circulation System

The water supply and re-circulation system is the most essential part of the experimental facilities. It supplies water to the reach during experimentation. Usually before each experiment water is stored within the storage tank. The pump draws water from the storage reservoir and discharges into the upstream reservoir. Before water enters into main channel it passes through the plastic pipes to remove the turbulence. After that water flows through the experimental reach back into the downstream reservoir. The figure (3.12) shows all the components which are responsible to flow the water in a proper way. These components have been described earlier.

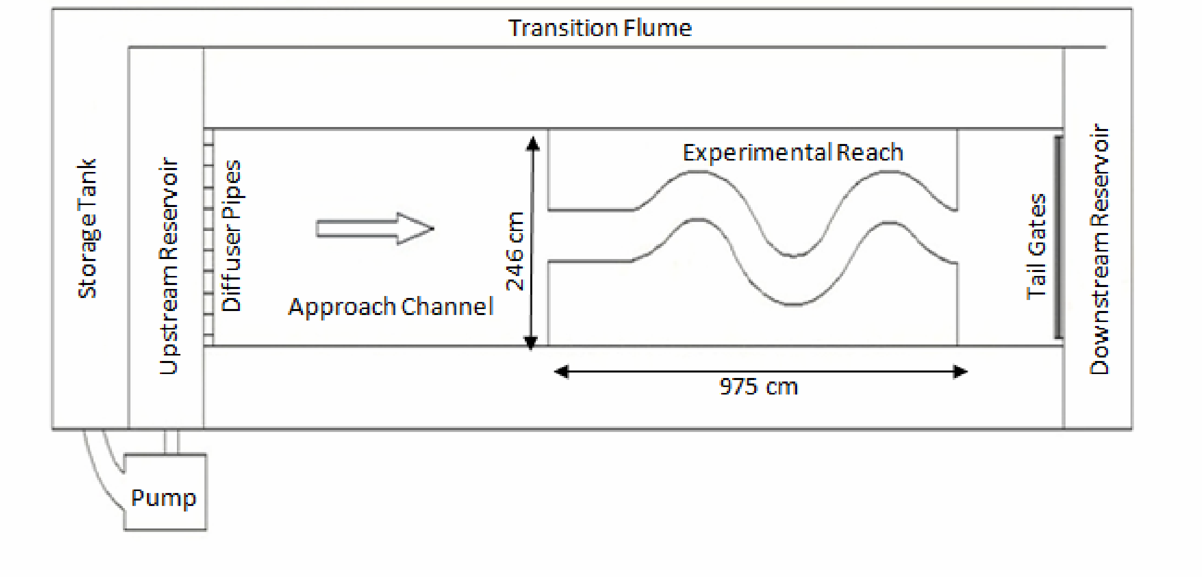


Figure 3.12: Water supply system with various components

3.4 Measuring Equipments and Devices

3.4.1 The Acoustic Doppler Velocity-Meter

10-MHz Micro ADV (Acoustic Doppler Velocity meter) from the original Son-Tek is the most significant breakthrough in 3-axis (3D) Velocity-Meter technology (Figure 3.13). This is single-point current meter that accurately measures the three components of water velocity in both high and extremely low flow conditions. After setup of the ADV with the software package it is used for taking high-quality three dimensional Velocity data at different points of the flow area are received to the ADV-processor. Computer shows the raw data after compiling the software package of the processor. At every point the instrument is recording a number of velocity data for a minute. With the statistical analysis using the installed software, the mean value of the point velocities (three dimensional) were recorded for each flow depths. The Micro-ADV uses the Doppler shift principle to measure the velocity of small particles, assuming to be moving at velocities similar to the fluid. Velocity is resolved into three orthogonal components(Tangential, radial and vertical), and measured in a volume 5 cm below the sensor head, minimizing interference of the flow field, and allowing measurements to be made close to the bed.

The Micro ADV has the feature like:

- Three-axis velocity measurement
- Sampling rate – up to 25 Hz
- Sampling volume – 0.25 cm^3
- High accuracy: 1% of measured range
- Large velocity range: 1 mm/s to 250 cm/s

Figure 3.13: The probe and control unit

3.4.2 Current Meter

A small current meter (Figure 3.14) is used for measurement of flow velocity at low water levels, e.g. in laboratories, river models, small canals etc. The highly precise, reinforced spindle bearing as well as a non-contact signaling system give the possibility for measuring flow velocities as of 0.025 m/s. Minimum depth of water for this device is approx 4 cm.

Figure 3.14: Current meter and counter unit

3.4.3 Point gage and Reference point

The point gage is used to measure water level in the channel. This point gage and the probe of ADV have been installed in a measuring bridge in different locations of channel. At the beginning of every setup, first the elevation of the reference point was measured and water level was measured with respect to this reference elevation.

3.4.4 Measuring line and Measuring Bridge

To indicate the co-ordinate system and the location of various measurements, both side walls are equipped with parallel measuring lines (Fig. 3.15), indicating the X direction. As the experimental reach is a meandering channel, so actual X direction for main channel is taken as the flow direction and by using a set-squire, the perpendicular direction is determined. During data collection, the measuring bridge is to be moved to the pre defined location along the channel manually. A small wooden trolley is fitted on the bridge and is operated manually. A base plate is fitted on this trolley which can be adjusted at any distance across the channel. The measuring instrument is kept fixed on this plate.

Figure 3.15: Measuring line on the side wall and measuring bridge across the channel

3.4.5 Plastic container

Since the image collection is very important to calculation the mass exchange coefficient. At the time of image collection, the uniformity of dye distribution in the selected groin area is more important. Steel box is used to spray dye uniformly in the groin field. Plastic container is used to collect the sample for calibration procedure.

3.5 Experimental Program

3.5.1 Determination of Bed Slope

The average channel bottom slope and floodplain slope were determined by measuring the elevations of bed levels at different intervals by a level and staff. By dividing the difference in bed level elevation to the length difference the bed slope of main channel for each segment is obtained and then averaging all the values, the channel bed slope S_{0mc} is obtained. Similarly by dividing the difference in elevation to the length difference of floodplain bed and then averaging all the values, the floodplain bed slope S_{0fc} is obtained. Table 3.1 is the calculation for bed slope.

Table 3 1: Determination of bed slope

Location	Distance (cm)	Elevation (cm)	Slope	Average slope
Right Floodplain	0	388.76	-	0.001821
	96.74	388.76	0	
	193.48	389.01	0.002584	
	290.22	389.132	0.001261	
	386.96	389.402	0.002791	
	483.7	389.694	0.003052	
	580.44	389.945	0.001561	
	677.18	390.101	0.001613	
Main Channel	0	421.978		0.001826
	96.74	421.978	0	
	193.48	422.152	0.001799	
	290.22	422.418	0.00275	
	386.96	422.443	0.000258	
	483.7	422.827	0.003969	
	580.44	422.961	0.001385	
	677.18	423.198	0.00245	
Left floodplain	0	388.76		0.001823
	96.74	388.76	0	
	193.48	389.01	0.002584	
	290.22	389.132	0.001261	
	386.96	389.402	0.002791	
	483.7	389.714	0.003059	
	580.44	389.945	0.001561	
	677.18	390.101	0.001613	

3.5.2 Set-Up Installation

To investigate the distribution of flow in the compound meandering channel with various encroachments conditions and different depths were used in the experiment (Figure 3.16). The locations of the encroachment were changed at floodplain for each setup. Thus the encroachment will cover the floodplain by 4 (four) different setup.

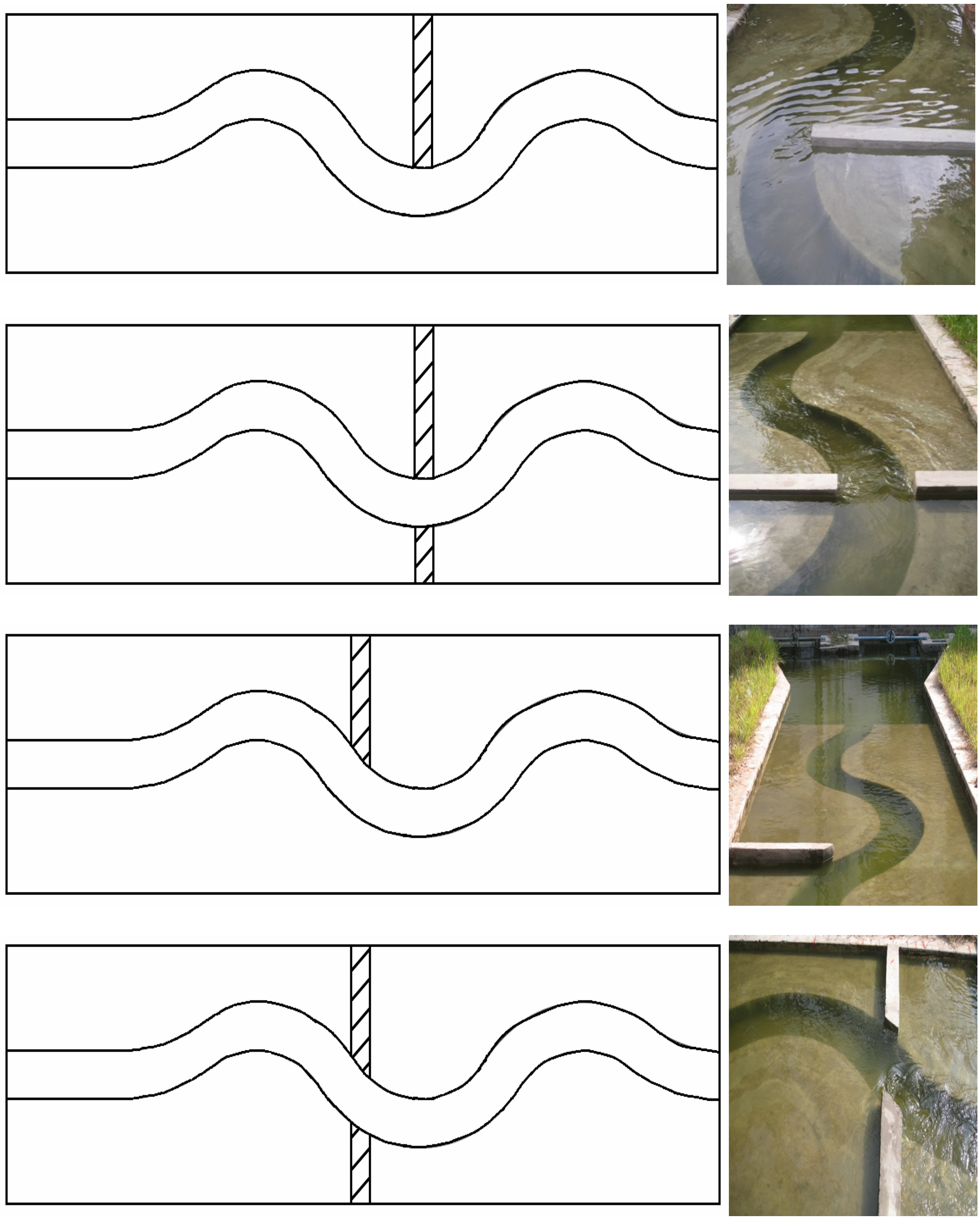


Figure 3.16: Various Encroachment condition at floodplain

Table 3.2 Placement of encroachment

Case	Floodplain condition
1	Without Encroachment
2	Encroachment on left side of floodplain at bend (at cross section 3)
3	Encroachment on both side of floodplain at bend (at cross section 3)
4	Encroachment on left side of floodplain at crossover (at cross section 2)
5	Encroachment on both side of floodplain at crossover (at cross section 2)

3.5.3 Coordinate system

The X-direction was defined lengthwise of the channel and positive in flow direction. The zero position started just upstream face of the compound meandering channel. The Y-direction corresponded to the perpendicular of X-direction, where Y = 0 was situated at the right bank of the channel. The direction from bed level to the water surface was defined as the positive Z-direction. Figure 3.17 gives an overview of the coordinate system.

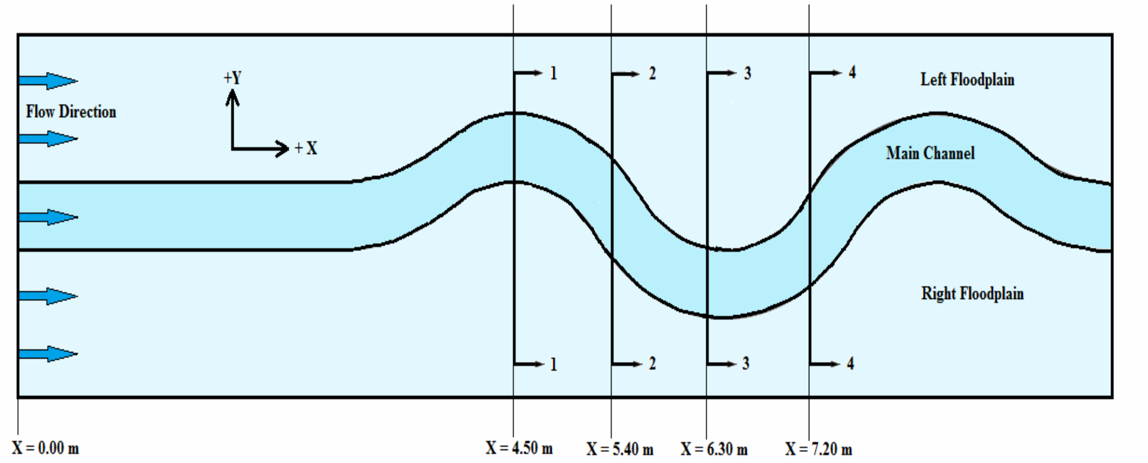


Figure 3.17: Coordinate system of the experimental channel

3.6 Experimental Procedure

3.6.1 Channel Preparation

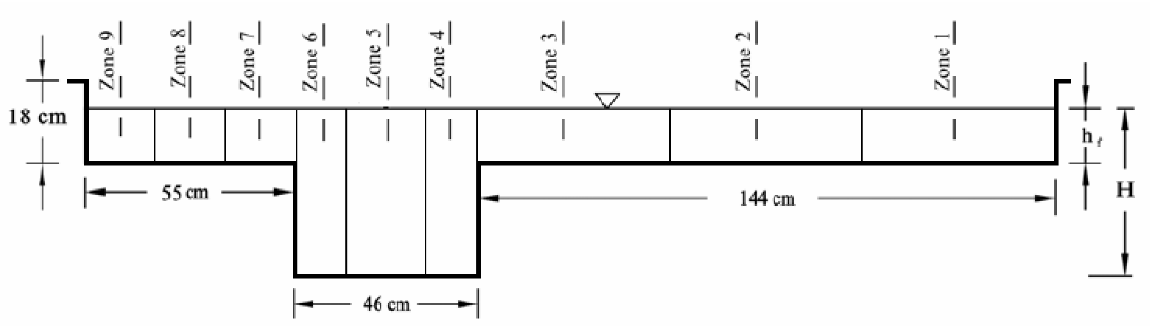
Since the model was made of CC work, so it is necessary to clean the whole set up before starting the experiment but it was not possible to clean the whole model thoroughly due to lack of time. Before the start of an experiment, the channel bed was cleaned from any dirt and the water from the reservoir was changed in order to maintain the uniformity of approaching flow and to get the proper value of velocity. The other components of the model were cleaned frequently after several runs.

3.6.2 Velocity Measurement

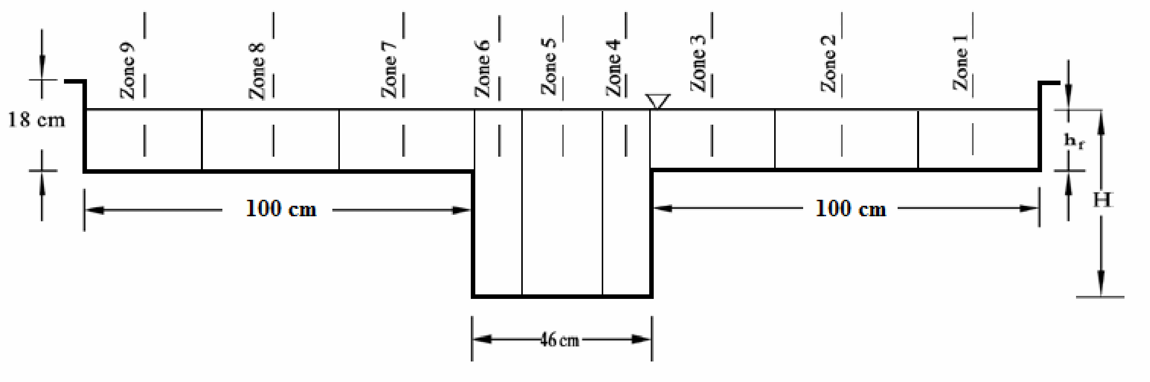
An Acoustic Doppler Velocity-Meter (ADV) is used to determine the three-dimensional velocities (V_x, V_y, V_z) at any point in the water channel. Each flow velocity measurement was measured during a period of 60 sec. The time was found optimal enough for a reliable reproduction of the mean value. The measured flow velocities were transported for display from the point to the control unit. This control unit displayed the flow velocities in both X, Y and Z direction. The point gauge and the ADV attached to the traveling steel bridge and can be moved in both the longitudinal and the transverse direction of the experimental channel at the bridge position. To control the accuracy, the probe needs to clean regularly. Before starting data collection it is necessary to load the correct probe configuration and run the Beam-Check diagnostics module. To run Beam-Check at the start and end of a data collection, this can assist in locating any problems should occurred by ADV. As the ADV is unable to read the upper layer velocity i.e. up to 5 cm from free surface, so a current meter is also used for the measurement of point velocity readings at some specified location for the upper 5 cm region from free surface across the channel.

To visualize the flow velocity pattern, the flow velocity were measured across the channel at four location which was (i) first meandering bend (at cross section 1) (ii) first crossover section (at cross section 2) (iii) second meandering bend (at cross section 3) and (iv) second crossover section (at cross section 4). The plan view for data collection is shown in figure 3.19 and the cross sections 1, 2 and 3 are shown in the figures 3.20 (a), (b) and (c) respectively. Cross section 2 and Cross section 4 are similar.

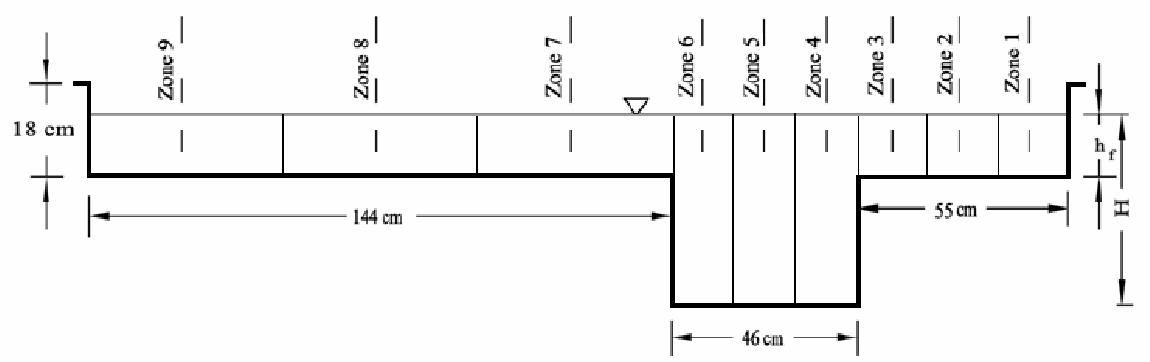
Each cross section is divided into nine zones (zone1 to zone 9), starting from the right floodplain to the left floodplain. The right floodplain, main channel and the left floodplain each are equally divided into three zones. Velocity data are collected in the middle of each zone at four pre-defined vertical points for different runs.



(a)



(b)



(c)

Figure 3.18: Layout of a) cross section 1, b) cross section 2 and (c) cross section 3

For every set-up there are two different run for two different depth ratios D=0.285 and 0.375. Where, $D = h_f/H$;

Here, h_f is floodplain water depth and H is the total water depth in the channel.

Velocity measurements for each set-up have been given in Table 3.3

Table 3.3: The experimental set-up

Run No.	Identification	Floodplain condition	Depth ratio(D)	Location of reading (distance from the surface water)
1	E1	Without Encroachment	0.285	Velocity readings at the 0.2h, 0.4h, 0.6h, 0.8h of the total depth
2	E2	Encroachment at one side of floodplain at its bend		
3	E3	Encroachment at both side of floodplain at its bend		
4	E4	Encroachment at one side of floodplain at crossover		
5	E5	Encroachment at both side of floodplain at crossover		
6	E6	Without Encroachment	0.375	
7	E7	Encroachment at one side of floodplain at its bend		
8	E8	Encroachment at both side of floodplain at its bend		
9	E9	Encroachment at one side of floodplain at crossover		
10	E10	Encroachment at both side of floodplain at crossover		

3.7 Processing of Data

3.7.1 Velocity Distribution

Flows in compound meandering channels with over bank flow consist of, in principle, the main channel flow and the floodplain flow. There exists some flow interaction between the main channel and the floodplains at the bank full level for over bank flow and the behavior of flow changes with the change of flow depth over the floodplain. At the over bank flow condition the total flow depth is divided in to two layers, the lower layer and the upper layer. The lower layer is below the bank full level and the upper layer is above. Most flow directions in the lower layer follow along the meandering channel and most flow directions in the upper layer in the main channel does not follow along the meandering channel, but are parallel to the direction of the floodplain bank. Though flow in a meandering channel is characterized by relatively strong secondary circulation due to centrifugal forces around each bend. However, when a meandering stream spills over onto the adjacent floodplain, interaction between the predominantly down valley floodplain flow and the meandering channel significantly modifies flow distribution and secondary circulation.

3.7.2 Depth Average Velocity

The velocity distribution in a stream across a vertical section is logarithmic in nature (Chow, V.T., 1959; French, R.H., 1985). In rough turbulent flow the velocity distribution is given by

$$v = 5.75\, v_* \log_{10}\left(\frac{30y}{k_S}\right) \tag{3.1}$$

Where, v = velocity at a point y above the bed level, v_* = shear velocity and k_s = equivalent sand-grain roughness. To accurately determine the average velocity in a vertical section, one has to measure the velocity at a large number of points on the vertical. As it is time consuming, certain simplified procedures have been developed:

- In shallow streams of depth up to about 3.0 m, the velocity measured at 0.6 times the depth of flow below the water surface is taken as the average velocity v in the vertical, $v = v_{0.6}$. This procedure is known as the single point observation method.
- In moderately deep streams the velocity is observed at two points;
    (i) at 0.2 times the depth of flow below the free surface ($v_{0.2}$) and
    (ii) at 0.8 times the depth of flow below the free surface ($v_{0.8}$).

  The average velocity in the vertical $\bar{v}$ is taken as

$$\bar{v} = \frac{v_{0.2}+v_{0.8}}{2} \tag{3.2}$$

- In this method (strip method), the profile is divided into a number of strips. Then the velocity at the midpoint of each strip (v_i) is determined from the graph. The average velocity,

$$\bar{v} = \frac{\sum v_i d_i}{d} \tag{3.3}$$

Where, d_i = width of strip and v_i = velocity of strip.

3.7.3 Discharge Measurement

There are different methods for measurement of discharge in open channel flow and of them area velocity method is the familiar one. In this method a channel section is subdivided into a number of segments by a number of successive intervals. Then by using the depth mean velocity determined according to the previous article, the discharge of the segment is calculated as follows

$$Q_i = \Delta A_i V_i \tag{3.4}$$

Where ΔA_i is the area of the segment.
The sum of the discharges through all the strips is the total discharge, i.e.

$$Q=\Sigma Q_i \tag{3.5}$$

Cross sectional mean velocity of the stream, $V_{mean} = \frac{Q}{\sum \Delta A}$ (3.6)

3.7.4 Estimation of Bed Shear Stress

It is often necessary to find the bed shear stress to calculate the velocities and flow rate, possible erosion of the bed as well as the rate of sediment transport. A simple method is to use the Preston Tube, in which the dynamic pressure Δp measured by a total head tube located on the boundary facing the flow, is correlated with the boundary shear stress using the law of the wall. For smooth boundaries, the calibration curve provided by Patel (1965) is generally used whereas for uniformly rough boundaries, the calibration curves developed by Hollingshead and Rajaratnam (1980) may be used.

Velocity Profile Method

It is well established that for a regular prismatic channel under uniform flow conditions the sum of retarding boundary shear forces acting on the wetted perimeter must be equal to the resolved weight force along the direction of flow. Assuming the wall shear stress τ_0 to be constant over the entire boundary of the channel we can express τ_0 as

$$\tau_0 = \rho g R S_0 \tag{3.7}$$

Where,
g = gravitational acceleration,
ρ= density of flowing fluid,
S = slope of the energy line,
R = hydraulic radius of the channel cross section (A/P)
A = area of channel cross section, and
P = wetted perimeter of the channel section.

The Log Law Method

The logarithmic profile method is used widely due to the easily available data although the covariance and kinetic energy method may give unbiased and less sensitive results when reliable data are available. Latter methods need measurement precision or techniques that are not generally used under typical field conditions.

The probe was used to measure the local velocity at different depths. The fundamental premise of the work is that velocity profiles can be used to determine, through statistical analysis, the characteristics velocity scale of the local flow (U^*), the local roughness parameter (Z_0) and the local displacement of the origin (D). The well known logarithmic relation expressed by the von Karman-Prandtl equation:

$$\frac{U}{U^*} = \frac{1}{\kappa}\ln\frac{Z}{Z_0} \tag{3.8}$$

Where Using Prandtl-von Karman universal velocity distribution law,

Where v is the mean velocity, v* is the friction velocity ($\sqrt{\frac{\tau_b}{\rho}}$), τ_b is the bed shear stress, ρ is the density of water, Z is vertical position above the bed and κ is von Karman’s constant (κ ≈ 0.40).

The above equation applies within a near bed region that is both well below the free surface and above the local influence of individual bed roughness elements. For steady uniform sub critical flow in a wide straight channel with roughness dominated by grains on the bed surface, a log profile is found to closely approximate velocity throughout the flow depth.

3.7.5 Velocity Distribution Coefficients

As a result of non uniform distribution of velocities over a channel section, the velocity head of an open channel flow is generally greater than the value computed according to mean velocity formula. When the energy principal is used in computation, the true velocity head may be expressed as $\alpha V^2/2g$, where α is known as the energy coefficient or Coriolis coefficient. From the experimental results the value of α varies from 1.03 to 1.36 for fairly straight prismatic channel. The values are generally higher for small channels and other parameters such that meander parameters and roughness criteria of the channel also affect the value.

$$\alpha = \frac{\int v^3 \, dA}{V^3 A} \approx \frac{\sum v^3 \Delta A}{V^3 A} \tag{3.10}$$

The non uniform distribution of velocities also affects the computation of momentum distribution in open channel flow. So a momentum distribution coefficient is introduced known as Boussinesq Coefficients β. From the experimental results the value of β varies from 1.01 to 1.12 for fairly straight prismatic channel, but it changes due to many factors such as meander parameters and roughness criteria of the channel.

$$\beta = \frac{\int v^2 \, dA}{V^2 A} \approx \frac{\sum v^2 \Delta A}{V^2 A} \tag{3.11}$$

3.8 Observation of Flow Pattern with Dye

Dye-concentration has been performed to determine the mass flux between the dead-water zone and the main stream, which is driven by large, horizontal, coherent motions in the mixing layer. Because these motions are mainly two-dimensional, a depth averaged approach has been chosen. The idea of the measurements is to determine the horizontally and vertically averaged concentration decay in the dead-water zone, while the concentration in the main stream is always zero. Therefore, the tracer has to be injected instantaneously and homogeneously distributed in the horizontal plane into the dead-water zone.