Empirical Assessment of Local Scour at the Head of Groynes

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Abstract

The main functions of groynes are bank protection as well as land reclamation and provision of navigable depth leading to river training. The design of a groyne is the determination of its shape, angle of inclination with the bank, length, spacing, and depth of scour. This paper presents an experimental study on the use of groynes in bank protection. The study is conducted in a physical model involving scour around groynes, in a mobile bed of a rectangular channel with fixed walls. Scour relations were formulated using dimensional analysis to relate local scour to other hydraulic variables. They were experimentally verified and empirical formulae were developed using regression analysis. The formulae revealed that scour is uniquely related to Froude number of the approaching flow, and the Shields parameter. The obtained results were compared with the previous research work as well as field measurements. Both results reasonably agreed to one another.

Key words: Groynes, bank protection, scour, Froude Number.

1. INTRODUCTION

Groynes are hydraulic structures constructed at an angle to the channel flow direction, extending from the outer bank of the channel into the main flow. Figure (1) shows a sketch illustrating a groyne system angle of inclination, length, spacing, and flow pattern. Groynes are usually built of stones, gravels, piles, or wood. Groynes are also known as spurs, spur dykes, transverse dikes or jetties. They are built to orient and adjust the channel flows in the desired direction, in order to reduce or eliminate flood damages. Consequently significant changes in depth, width alignment and stability of the channel are produced. The production of these changes results in the creation of local scour at some locations and deposition. This is usually associated with changes in the flow pattern and formation of eddies. The objective of this study is to investigate the effectiveness of groynes in protecting the banks. The study, also, aims at establishing empirical formulae to assist engineers in designing river training structures.

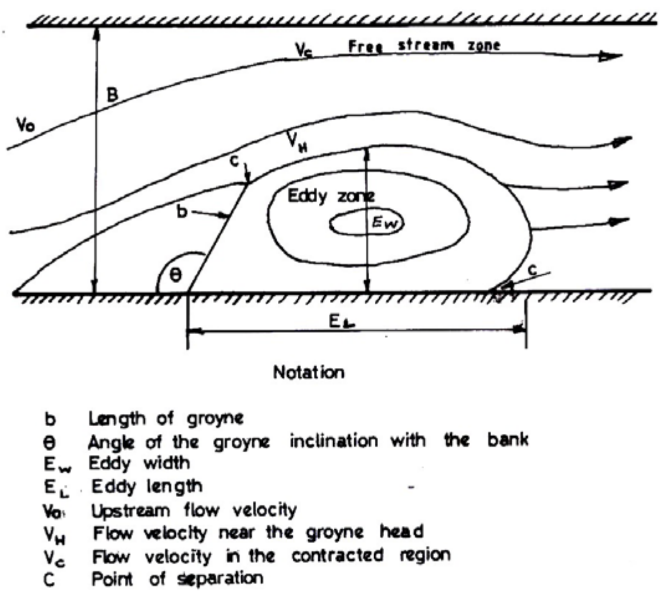

Figure 1 Sketch showing flow pattern around a groin

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2. GROYNES

The main function of a groyne is river training which may include bank protection, land reclamation and provision of navigable depth. The basic design problem of a groyne is to determine its shape, angle of inclination to the bank,length, depth of scour and resulting flow pattern(1,2,6,9,12,17,19).The common different shapes used are the straight groyne with or without round head-T-head groyne-L-head groyne, birds mouth groyne, and hokey stick groyne(2,6,8,9,10,12).The angle of inclination of the groyne to the upstream bank ranges from 30 to 120 degrees. A groyne with such an angle greater than 90 degrees is termed attracting groyne, that with an angle less than 90 degrees is termed repelling, while that with 90 degrees is termed reflecting (6,12,14). The length of the groyne is determined by the width and depth of the channel. Spacing of groynes is usually made in a certain proportion to their lengths. Type of construction (solid or permeable) depth of channel and height of the groyne (submerged or emerged), also affect spacing (1, 2, 4, 6, 7, and 8) in case of using a system of groynes.

3. LOCAL SCOUR

When river training problems are to be solved, consideration of erosion is vitally important. Local scour depth determination is important in the design of many hydraulic structures, the neglection of which leads, undoubtedly, to the destruction of valuable lands. The empirical formulae developed to determine maximum scour could possibly be categorized into three groups based on different experimental procedures. They are listed in the following section.

3.1 Formulae Following the Regime Concept

The formulae following the regime concept (1, 2,12,13,14, 15, 22) can be presented by Lacey's (14) approximate formula for maximum depth of scour. Also, Ahmed (1,2) conducted experiments to study the effect of discharge, sand grade, and angle of spur dyke to flow on scour depth. Ahmed obtained the equation

$$\frac{D_{t_0}}{D_{t_\infty}} = 1 - be^{-\alpha t} \tag{1}$$

in which:

D_{to}: scour depth below water level at any time t in meters

$D_{t\infty}$: maximum depth of scour at the end of the experiment in meters

α , b : Dimensionless constants depending on sand size

Ahmed`s equations, relating the maximum scour and discharge, is similar to that of Lacey`s. For a specific θ, Ahmed equation takes the form:-

$$D_{\max.} = Kq^{\frac{2}{3}} \tag{2}$$

Mohamed et al. (17) conducted similar experiments, and obtained similar results to that of Ahmed (1,2).

3.2 Formulae Following the Dimensionless Function Concept

These can be presented by Garde et al. (9) experimental results on spur dikes which revealed that the influence of flow, spur dike, and sediment characteristics on the maximum scour depth can be represented by the Froude number of the normal channel, the opening ratio, the angle of inclination of the spur dike and the average drag coefficient C_D of the sediment particle. Garde et al. (9) developed the equation

$$\frac{D + d_s}{D} = f\left(f, \theta \frac{V}{\sqrt{gD}} C_D\right) \tag{3}$$

in which: D = Depth of approaching flow in meters.

d_s =Depth of scour below bed level in meters.

V =Velocity of approaching flow in m/sec.

C_D =Dimensionless drag coefficient of sediment.

θ =Angle of inclination in degrees.

Garde et al.(9) used four sand sizes, four opening ratios α, and a constant angle of inclination of $\frac{\pi}{2}$,and developed the equation

$$\frac{D+d_s}{D}=f\left(\alpha,\frac{V}{\sqrt{gD}},C_D\right) \tag{4}$$

Hence they obtained the equation in the form

$$\frac{D+d_s}{D}=\frac{K}{\alpha}F^n \tag{5}$$

Where
K,n. =Dimensionless Functions of sand grade, opening ratio, and Froude number F.

Rajaratnam and Nwachukwu(19,20) developed their experimental equation

$$\frac{U_{.0}}{\sqrt{g\theta_{m\infty}}}=f\left(\alpha,\frac{U_{.0}}{\sqrt{gD}}\right) \tag{6}$$

in which
U_0 =Shear velocity of approaching flow in m/sec.
$\theta_{m\infty}$ = Maximum scour at the end of the experiment below bed level in meters.
D = Grain size of bed material in mm.
α = Dimensionless contraction ratio = $\frac{B-b}{B}$.

3.3 Formulae Following the Long Contraction Concept

This type can be presented by Straub (22), who has conducted experiments in Missouri River. Laursen (15) using several laboratory data obtained the equations:

For an abutment

$$\frac{d_s}{y_0}=0.8\frac{1}{y_0}\left(\frac{\tau_0}{\tau_c}\right)^{\frac{2}{3}} \tag{7}$$

For a pier of width b

$$\frac{d_s}{y_0}=0.4\frac{b}{y_0}\left(\frac{\tau_0}{\tau_c}\right)^{\frac{2}{3}} \tag{8}$$

in which
d_s = limiting depth of scour in contraction or at pier or abutment in meters.
y_0 =Depth of approaching flow to pier or abutment in meters.
τ_0 =Shear stress at boundary associated with the sediment particle $\frac{N}{m^2}$
τ_c = Critical tractive shear stress $\frac{N}{m^2}$.

Kumora (13), developed the following two equations. The first, using the regime theory and in the second using the tractive force theory.

$$\frac{d_2}{d_1}=\frac{y_s}{d_1}+1=C_dF_1^{\frac{1}{5}}\left(\frac{B_1}{B_2}\right)^{\frac{2}{3}}\sigma_\varphi^{\frac{-1}{5}} \tag{9}$$

$$\frac{d_2}{d_1}=\frac{y_s}{d_1}+1=C_sF_1^{\frac{1}{5}}\left(\frac{B_1}{B_2}\right)^{\frac{2}{3}}\sigma_\varphi^{\frac{-1}{5}} \tag{10}$$

in which
y_s = Equilibrium depth of scour in meters.
F_1 = Froude number in the section which is not contracted
d_1 = Depth of flow in the section which is not contracted in meters
d_2 = Depth of flow in contracted section in meters.

B_1 = Width of the section which is not contracted in meters
B_2 = Width of contracted section in meters.
σ_φ = Standard deviation.
C_d and C_s = Dimensionless coefficients.

Gill (10) obtained the equation from his experimental work as follows

$$\frac{d_2}{d_1} = 8.375\left(\frac{D}{d_1}\right)^{\frac{1}{4}}\left(\frac{B_1}{B_2}\right)^{\frac{5}{7}} \quad (11)$$

4. APPARATUS AND EXPERIMENTS

In practice, the designer of a groyne might not be interested in a certain shape, specific orientation, length, and prescribed spacing of groynes. His primary concern is to achieve his objectives, regardless to the shape, angle of inclination, length, and spacing. He only considers the case that achieves the most successful and economical condition that can solve the existing problem.

4.1 Model Study Flume

A flume was constructed in the laboratory of the Hydraulics Research Station of the Ministry of Irrigation at Wad Medani,(Sudan). The general layout plan and other details of the flume are shown on figure (2).The water level in the flume was adjusted by adjusting a vertical tail gate at the downstream end of the flume. The water was then discharged through the tail gate and returned to the sump where it was again pumped to the tank. The sediment materials used for these experiments consisted of three types of sand; each being used separately. The mechanical properties of these sands were determined by sieve analysis. Table (1) shows the properties of the three sand sizes.

Table 1 Properties of the used sand

Sand Type No	d_{16} mm	d_{50} mm	d_{65} mm	d_{84} mm	σ
(1)	0.310	0.475	0.560	0.900	1.739
(2)	0.270	0.520	0.600	0.820	1.655
(3)	0.185	0.300	0.340	0.425	1.542

The used models that simulated the groynes were made of steel metal plates of 3 mm thickness. These model groynes were fixed at different angles. Groynes, were symmetrically fixed with respect to the centre of the channel, with the first groyne located 7.0 m. downstream the fore bay baffles. The bed surface and water surface readings were measured by a standard point gauge. The velocity profiles were measured by a current meter. The velocity measurements were taken at the nodes of a grid.

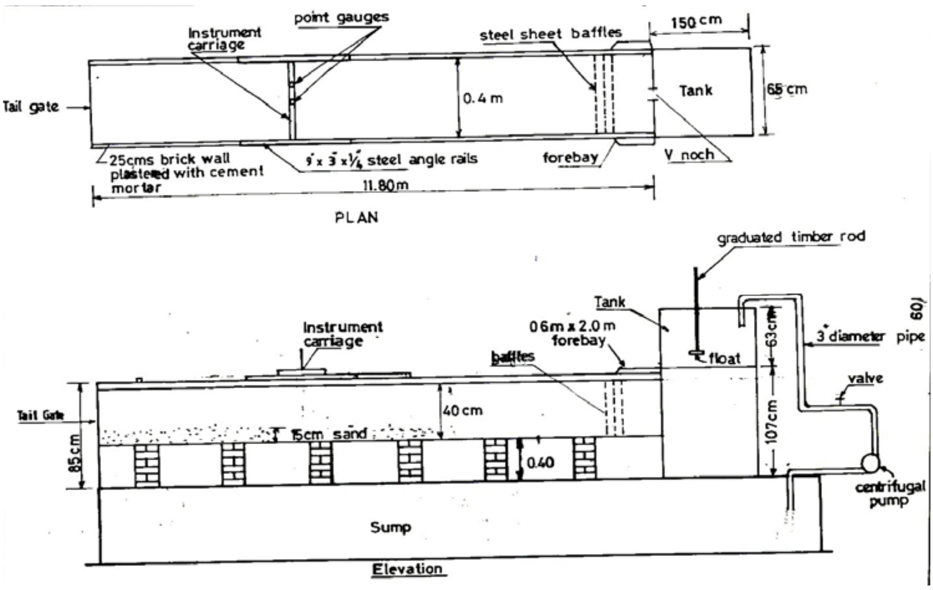

Figure 2 General layout of flume

Sand was placed in the channel bed at a predetermined flat slope and a definite water discharge was allowed to pass through the channel. This discharge was controlled by a valve in the inlet pipe and measured by a calibrated constant head tank with a V-notch weir located at the upstream end of the flume. A uniform flow was then established with the help of the tail gate located at the downstream end of the flume. The tail gate was so adjusted that the water depth remained the same along the channel length. The flow lasted for about half an hour to ensure equilibrium and uniform flow conditions. The flow was then stopped by closing the valve in the inlet pipe slowly without disturbing the bed materials. The steel model groynes of different lengths and different angles of inclination to the flow direction were carefully sung in the sand bed. The flow was then continued by slowly opening the valve until the previously uniform flow conditions were attained. The flow lasted for 3.5 hours, after which it was closed slowly, and the channel was carefully drained. The water surface readings, bed surface readings, velocity measurements, eddy length and width measurements, were taken at the observation stations shown on figure (3). Upon completion of the required test program for one size of sand (using different discharges) the sand was replaced by another sand size, and a new test series of experiments was performed.

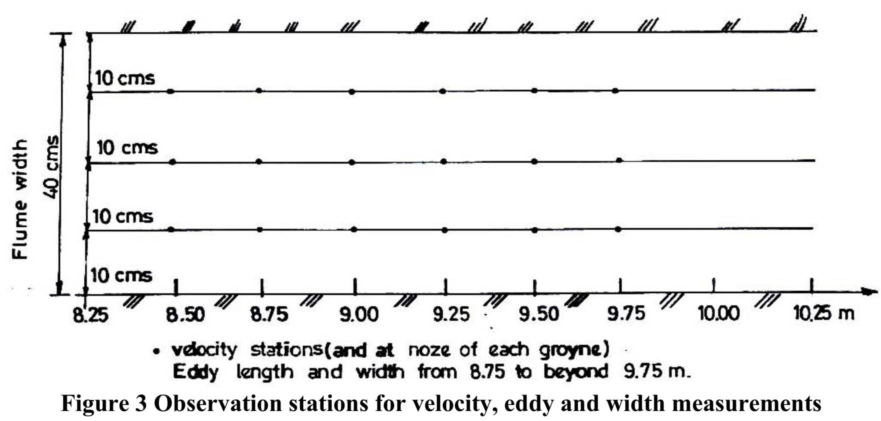

Figure 3 Observation stations for velocity, eddy and width measurements

4.2 Experimental Limitations

The model study of groynes in river training was investigated using clear water. The used bed materials properties are given in table (1).The used groynes were straight without round head. The used groynes were 7.5, 10, and 12.5 cm long. The angle of inclination with the bank was 60, 90, and 120 degrees.

The flow discharges in the runs ranged between 10.04 and 18.35 liter/second (1.004×10^{-2} to 1.853×10^{-2}) m^3/sec, and the flow depth varied from 0.12 to 0.15 m.

When the flow is obstructed by a groyne, figure (1), the main flow separates at the head of the groyne and reattaches to the bank downstream. An eddy zone of recirculation water is enclosed between the head of the groyne and the reattachment point. The flow within the eddy zone is essentially three dimensional pattern and the boundaries of the eddy zone oscillate irregularly about a certain mean (7, 8).The parameters involved are namely, geometrical, those of flow and those of sediment. The geometrical parameters are the channel width (B) and slope (i), the groyne length (b.) its shape (SH), and its angle of inclination to the bank (θ). The flow parameters are, the upstream velocity (V_o), and depth (D), eddy length (E_L), eddy width (E_W), density of water (ρ), its viscosity (μ), gravitational acceleration (g), and scour depth (d_s). The sediment parameters are median grain size of sediment (d_{50}), its standard deviation (σ), and its submerged weight (γ_{sub}).

To obtain dimensionless groups from these parameters their dimensions in terms of (M, L, T), can be displayed in a function interrelating all of the parameters. The resulting function could be in the form

$$\pi_0 = f\left(\frac{d_s}{D}, \frac{V_0}{\sqrt{gD}}, \frac{b}{B}, \frac{B}{D}, \frac{d_{50}}{D}, \frac{\gamma_{sub} D}{\tau}, \frac{E_L}{D}, \frac{E_W}{D}, {}_s \frac{W}{\sqrt{gD}}, \theta, i, SH, \sigma\right) \tag{12}$$

The above is a set of dimensionless groups of the previously defined parameters. The above equation (12) can be written in the form

$$\frac{d_s}{D} = f\left(\frac{V_0}{\sqrt{gD}}, \frac{W}{\sqrt{gD}}, \frac{E_L}{b}, \frac{B}{D}, \frac{E_W}{D}, \frac{d_{50}}{D}, \frac{\gamma_{sub} D}{\tau}, \theta, i, SH, \sigma\right) \tag{13}$$

The above equation (13), can also be written in the form

$$\frac{E_L}{b} = f\left(\frac{V_0}{\sqrt{gD}}, \frac{W_s}{V_0}, \frac{\tau}{\gamma_{sub} d_{50}}, \ldots\right) \tag{14}$$

$$\frac{E_W}{B} = f\left(\frac{V_0}{\sqrt{gD}}, \frac{W_s}{V_0}, \frac{\tau}{\gamma_{sub} d_{50}}, \ldots\right) \tag{15}$$

Equations of the form (12 to 15), show the relationship among dependent and independent dimensionless groups, and offer a guide to fit experimental data to reveal the inner mechanism of the phenomenon. This procedure will make it possible to single out, control and vary one dimensionless group at a time, while keeping the others constant. Proceeding with this technique and considering equation (13). According to the objectives and the experimental limitations, the shape SH, of the groyne is the straight type, therefore SH = constant. The range of the three sand types d_{50} is 0.3 mm to 0.52 mm has approximately equal standard deviation σ. The advantage of making tests with constant depth (D), makes $\left(\frac{d_{50}}{D}\right)$ insignificant as argued by Yalin (25), when sediment transport takes place near a plain bed. Furthermore for a small range of depth variation (D =0.12 m to 0.15 m), as outlined in the experimental limitations, $\left(\frac{B}{D}\right)$ term could be also considered to be constant within the experimental range of slope (i).Hence equation (13), is reduced to be as follows

$$\frac{d_s}{D} = f\left(\frac{E_L}{b}, \frac{E_W}{B}, F_r, \frac{\tau}{\gamma_{sud} d_{50}}, \frac{W_s}{V_0}, \theta, \frac{b}{B}\right) \tag{16}$$

Equation (16), is the basis of experimental program. It governs the relation among the scour depth ratio $\frac{d_s}{D}$, flow pattern spacing $\left(\frac{E_L}{b} \text{ and } \frac{E_W}{B}\right)$,groyne size $\left(\frac{b}{B}\right)$,angle of inclination θ, sand size d_{50}, and discharge. For any discharge value $F_r, \frac{\tau}{\gamma_{sub} d_{50}}, \frac{W_s}{V_0}$ can be computed. Hence any one of these three parameters could represent the discharge. Therefore equation (16), can be rewritten as follows

$$\frac{d_s}{D} = f\left(\frac{E_L}{b}, \frac{E_W}{B}, F_r, \theta, \frac{b}{B}\right) \tag{17}$$

According to the experimental limitation, three groyne sizes (b) and three angles of inclination are investigated. The effect of $\left(\frac{b}{B}\right)$, is included in $\left(\frac{E_L}{b}\ and\ \frac{E_W}{B}\right)$.When the discharge F_r, is varied, then for the same orientation, equation (16), becomes

$$\frac{d_s}{D}=f\left(\frac{E_L}{b},\frac{E_W}{B},F_r\right)(\theta_1\theta_2\theta_3) \tag{18}$$

Proceeding with the same technique varying the discharge, the value $\left(\frac{\tau}{\gamma_{sub}d_{50}}\right)$,can be substituted for F_r. The advantage of using $\left(\frac{\tau}{\gamma_{sub}d_{50}}\right)$,is that it includes shear stress τ, which could not be ignored in the study of scour and flow patterns. Its use has another advantage as it contains explicitly the medium diameter of sand d_{50}. Equation (16) can thus be rewritten as

$$\frac{d_s}{D}=f\left(\frac{E_L}{b},\frac{E_W}{B},\frac{\tau}{\gamma_{sub}d_{50}}\right)(\theta_1\theta_2\theta_3) \tag{19}$$

Similarly to express the relation between the scour and flow pattern, equation (16) becomes as follows, for the same type of sand

$$\frac{d_s}{D}=f\left(\frac{E_L}{b},\frac{E_W}{B},\frac{\tau}{\gamma_{sub}d_{50}}\right)(Sand-1,2,3) \tag{20}$$

Equations (18, 19, 20), jointly produce relations among scour, flow patterns, spacing, contraction ratio, angle of inclination, medium diameter of bed material and discharge. These relations are the main objectives of this research. The equations are three with four dimensionless parameters. However, usually one of the parameters is known thus the three equations could be solved simultaneously. Furthermore, proceeding with the same technique, and considering equations (14 and 15) relationships with $\left(\frac{E_L}{b}\ and\ \frac{E_W}{B}\right)$, and the other parameters could be obtained.

Assuming rigid boundary $\left(\frac{d_{50}}{D}\right)$, $\left(\frac{\tau}{\gamma_{sub}d_{50}}\right)$, σ becomes insignificant. Hence to reveal the relation between the flow pattern $\left(\frac{E_L}{b}\ and\ \frac{E_W}{B}\right)$, and the opening ratio $\left(\frac{b}{B}\right)$, for variable discharge (F_r) and for the same groyne orientation, equations 14 and 15 become

$$\frac{E_L}{b}=f\left(\frac{b}{B},F_r\right)(\theta_1\theta_2\theta_3) \tag{21}$$

$$\frac{E_W}{B}=f\left(\frac{b}{B},F_r\right)(\theta_1\theta_2\theta_3) \tag{22}$$

4.3 Test Program

A great number of runs have to be conducted in order to accomplish a comprehensive study that could illustrate the effects of the groynes on the flow pattern and the localized scour. However, using dimensional analysis reduced the number of runs. The runs were grouped in series. Each group tested one size of sand. 27 runs were executed for each sand size.

4.4 Determination of Scour

The produced scour attained its final equilibrium after about 3.5 hours. The discharge measurement was conducted by a calibrated constant head tank at the upstream side of the flume, figure (2). It was checked by passing a known discharge at the downstream end of the flume over a sharp crested weir. The velocity was measured by a calibrated current meter at 0.6 of the depth of flow at all the stations given in figure (2). The eddy length and width was observed by using, a dye of a distinguished color thin wire painted in red and equal sized floats and a point gauge were used to carry out the measurements. The floats are of equal weight and size. They are of circular section and are made of a light material. They were used to locate the stagnation and the reattachment points upstream and downstream the groyne. This was done by carefully putting the float adjacent to the wall at a distance upstream the model groyne. The float rolls and slides on the wall in the direction of flow. At the stagnation point, the float oscillates in both upstream and downstream directions. At this point a red wire arrow is carefully sunk adjacent to the wall. The same float is then used downstream to locate the reattachment point in a similar manner, and another arrow is sunk adjacent to the wall. The concentrated die is poured upstream and downstream between the arrows and the groyne. The boundaries of the dye shows clearly the boundaries of the eddies that are formed upstream and downstream the groyne. Red wire arrows are carefully sunk in these clearly defined boundaries. The area bounded by the arrows near the wall and away from the wall, gives the total eddy area. Hence the width and length of the eddy are obtained .The flow is then stopped, and the boundaries demarcated by the red arrows are measured with the help of the point gauge. The point gauge is moved until it touches the head of each arrow, and the distances along and transverse to the wall are measured. These measured distances for all the arrows are plotted on a graph paper showing the boundaries of the eddies with respect to the location of the groyne. Figure (4) shows a typical measured eddy area.

4.5 Bed and Water Levels Measurements

The bed and water levels were measured by a point gauge. The point gauge reads to the nearest 0.1 mm. At the beginning of each run, the sand bed is well screeded to an adjusted level in order to obtain a flat slope (i.e. the reading of the point gauge at any point is identical). The water levels at all the stations, figure (3), are read by the point gauge. At the end of each run, the flume is completely drained. The depths along the different cross sections were determined by a point gauge. Plate (1) shows the bed scour after one of the runs.

5. EXPERIMENTAL RESULTS AND ANALYSIS

The measurements were taken and were analyzed. This section displays the experimental results and their analysis.

5.1 Experimental Results

The flow pattern data consisted of velocity data as well as eddy zone areas and boundaries. The measurements were conducted at the locations given on figure (3). The measured and computed velocity readings for each run were plotted in a graph paper together with the eddy zone boundaries indicating the stagnation and reattachment points, figure (4) .The scour data were likewise plotted on graph papers. The results are listed in table (2) where the locations, indicating the maximum scour depths, are given, with respect to the location of the groyne

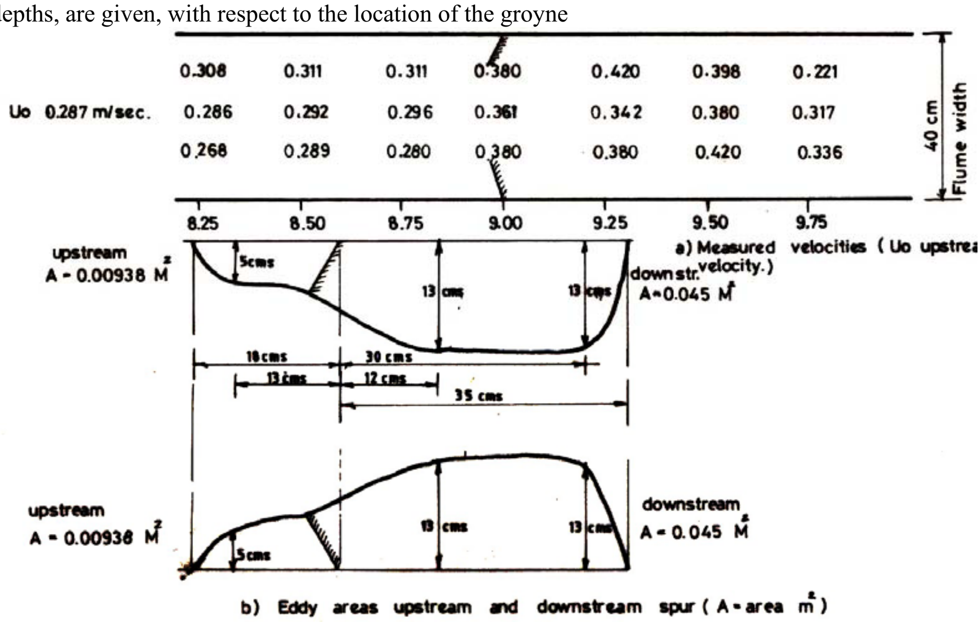

Figure 4 A Typical measured eddy area

Plate I Bed scour after run 64

The original bed level together with the drop of water level at the nose is also indicated. The velocity data were expressed in a dimensionless manner, by dividing each velocity by the upstream approaching velocity. These were presented diagrammatically on graph papers. Examination of these velocity diagrams indicated that the flow upstream the groyne is affected by the groyne to a certain extent. There is always a sudden increase in the velocity at the groyne location. Further increase was observed towards the downstream at the opposite side of the groyne and at the middle of the channel. A sudden decrease in the velocity in the same cross section passing through the middle of the channel on the side housing the groyne was also observed. Further downstream, the condition is reversed, where an increase in the velocity was observed at the side opposite to the groyne and at the middle of the channel and an increase in the velocity was observed at the side of the groyne. This further occurs along the downstream direction until the flow resumes the upstream approach flow velocity.

Table 2 Scour data

Run No 102

34.4	34.4	34.4	34.4	33.8	32.2	33.0	33.1	33.2	36.3	35.4	35.7	34.4
34.4	34.4	34.4	32.7	33.5	33.4	33.3	34.7	35.3	36.0	33.7	34.7	34.4
34.4	32.8	33.3	32.7	33.2	34.2	35.3	35.2	36.7	36.2	34.7		
34.4	32.7	31.8	32.2	33.1	35.7	36.8	36.5	35.6	35.4	34.7	34.7	34.4
34.4	30.8	29.3	32.2	37.2	37.6	37.4	36.3	36.4	34.7	34.9		
34.0	30.8	**29.2**	34.4	35.9	35.2	35.3	35.0	34.4	34.4	34.4	34.4	34.4
34.4	33.5	31.5	36.2	37.3	35.5	34.4	34.4	34.4	34.4	34.4		
34.4	34.4	34.4	35.2	35.6	34.8	34.2	34.4	34.4	34.4	34.4	34.4	34.4
8.9		9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0

40cm Flume width

Fig.(38) Original bed level 34.4cm. Drop of water level at the nose 4.0 mm
Scoured volume 2840 cm^3 – Deposited volume 3830 cm^3
In box is min level which corresponds to max. scour [$d_o = 34.4 - 29.2 = 5.2$ cm]

5.2 Determination of the Dimensionless Parameters

The values of the dimensionless parameters were formulated after equations 15 to 17. These values were composed of the measured and computed data .These was arranged in tables, with the calculated values of the dimensionless parameters, for each run. A sample is given here, table (3).

Table 3 Dimensionless parameters For all runs

Run No.	θ Radian	$\frac{b}{B}$	$\frac{d_s}{D}$	F_r	$\frac{W_s}{V_0}$	$\frac{\tau}{\gamma_{sub} d_{50}}$	$\frac{d_{50}}{D} \times 10^3$	$\frac{B}{D}$	$\frac{E_L}{b}$	$\frac{E_W}{B}$	$i \times 10^{-3}$
1- 81	1.0471 1.5707 2.0943	0.163, 0.188, 0.250	1.21 - 1.75	0.170 - 0.249	0.147 - 0.421	0.117 - 0.466	1.97 - 0.403	2.58 - 3.84	3.09 - 12.93	0.150 - 0.550	1.279 - 2.884

Using Statistical Package for Social Sciences (SPSS), a multiple regression analysis was conducted. The output of the regression gave a correlation coefficient (r), with the constants and exponents, with their standard errors. Statistical tests results, namely Student –t Test of the coefficients and excellence of fit F–value are also given by the computer. Equations, with 95 % confidence, with correlation coefficient c lose to (±1), with F- value and t value greater than the statistical values of the table were accepted. This was achieved for the similar run series with groynes having the same location and angles of inclination but with different bed material diameters d_{50}.The data values of the dimensionless parameters of table (3) were fed to the computer as indicated by equations (18, 19,20, 21, and 22).
An equation was obtained, corresponding to equation (18), for $\left(\theta = \frac{\pi}{2}\right)$:

$$\frac{d_s}{D} = 4.821\left(\frac{E_L}{b}\right)^{-0.094}\left(\frac{E_W}{B}\right)^{0.289} F_r^{0.455}\left(\theta = \frac{\pi}{2}\right) \tag{23}$$

A similar equation, to equation (19), is obtained for $\left(\theta = \frac{\pi}{2}\right)$:

$$\frac{d_s}{D} = 2.639\left(\frac{E_L}{b}\right)^{-0.092}\left(\frac{E_W}{B}\right)^{0.248}\left(\frac{\tau}{\gamma_{sub} d_{50}}\right)^{0.106}\left(\theta = \frac{\pi}{2}\right) \qquad \left(d_{50} = 0.475 mm.sand 1\right) \tag{24}$$

Similarly an equation corresponding to equation (20) was obtained for:

$$\frac{d_s}{D} = 2.389\left(\frac{E_L}{b}\right)^{-0.086}\left(\frac{\tau}{\gamma_{sub} d_{50}}\right)^{0.190} \qquad \left(d_{50} = 0.475 mm\, sand 1\right) \tag{25}$$

The data values of the dimensionless parameters of table (3), were fed to the computer as indicated by equations (21, and 22).An equation, corresponding to equation (21), was obtained, for $\left(\theta = \frac{\pi}{2}\right)$:

$$\frac{E_L}{b} = 0.089\left(\frac{b}{B}\right)^{-1.995} F_r^{-0.899}\left(\theta = \frac{\pi}{2}\right) \tag{26}$$

Similarly for equation (22), for $\left(\theta = \frac{\pi}{2}\right)$

$$\frac{E_W}{B} = 0.736\left(\frac{b}{B}\right)^{0.604} F_r^{-0.135}\left(\theta = \frac{\pi}{2}\right) \tag{27}$$

6. DISCUSSION OF RESULTS AND CONCLUSION

Data of previous investigators of the same kind as those given in table (3), were substituted in the above equations (23 to 27), to compare excellence of fit of calculated values of, $\frac{d_s}{D}$, $\left(\frac{E_L}{b} \, and \, \frac{E_W}{B}\right)$ and those obtained by the previous investigators. It was clear that solving equations (23 to27) could assist the designer to design safe groyne characteristics. Application of these equations to the obtained data indicated that, in the majority, they fit admirably well with the empirical equations. Ahmed results for example gave a value for $\frac{d_s}{D}$ = 1.98, while the value obtained by equation (23) is 1.94. Ahmed also obtained a value of $\frac{E_L}{b}$ = 4.29 while the value obtained by equation (26) is 4.24.

On the other hand, some of the data do not fit well with the equations, mainly due to the great difference in the contraction ratio or the size of the sand or both. Furthermore the explicit appearance of

d_{50} in the equations and the sensitivity of the dimensionless parameter $\left(\frac{\tau}{\gamma_{sub} d_{50}}\right)$, involving shear stress, also justify the weakness of fit. In spite of this, these empirical equations gave fairly acceptable results. However further future work is recommended to carry out some other experiments with several groynes in a row together with longer range of contraction ratios and larger range of sand size.

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