CHAPTER-1

INTRODUCTION

1.1. GENERAL

India is a part of Indian subcontinent composed of large number of rivers originating from the Himalayas (Aravalli range, sahyadri) as well as non-Himalayan region (Western Ghats). Rivers are of either alluvial or non-alluvial type. In India, most of the rivers are of alluvial type rivers. Alluvial rivers are those rivers that carries high amount of sediments with the flow. The main aim of this study is to estimate the depth of scouring which relates to the sediments in the flow so this study most commonly related to alluvial rivers. When stream flows from upstream areas towards the downstream side then stream attain required flow velocity that can disengage the particles from their original place. The minimum velocity required to detach the particles from the surface is termed as critical velocity. Eddies generated in swirl motion on the slope and flow velocity exerts shear force on the elements of river bed and banks. Shear force exerted by the flow over the particles have two components in horizontal and vertical direction. Mechanism is more understandable from Figure 1. When the vertical component (lift component) of shear force exceeds the submerged unit weight of the particles then particles detach from its original place. This lift force tries to lift, roll and slide the particles over the surface. Shear stress develop in between the particles due to their relative motion and flow can be computed using the shear velocity given by shield's equation. This non-dimensional equation proposed by shield's (1936) which show the shear velocity required to initiate the motion of sediment in a fluid flow.

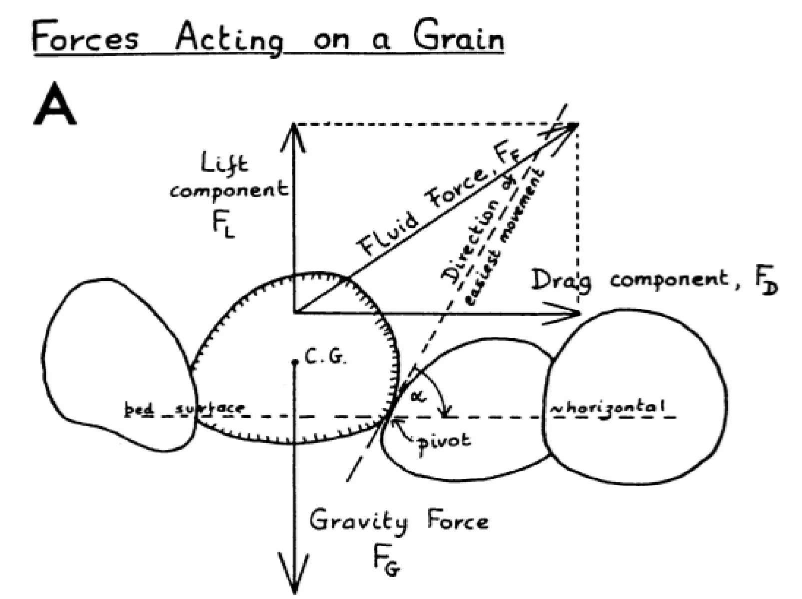


Figure 1.1: Mechanism of Detachment of elements from Bed of stream (Source: Middleton and Southard 1984).

The shield's equation given as:

$$\theta = \frac{\tau}{(\rho_S - \rho) g D} \tag{1.1}$$

Where,

θ=Non-Dimensional Shear stress or Shields's Parameter.

τ = dimensional shear stress.

ρ = density of the fluid.

ρ_S = density of sediment used.

g = acceleration due to gravity.

D = the characteristics particle size of the sediment.

When particles changes its state of rest to motion state due to action of shear stresses exerted by the flow is termed as incipient motion. Incipient motion include the very first moment when the particle raised by the uplift of flow. These particles when detached from the bed/banks of the river makes up the sediment load. These eroded particles of bed and banks of river carried away with the flow is called alluvium. Alluvium is a term given to the loose unconsolidated particle carried away with the flow due to action of tractive force exerted by the flow on the particles of bed/bank of the river. This mechanism of sediment erosion/detachment from the bed/banks of the river come in full force in the monsoon season. During monsoon season the flow becomes many times than the flow remain rest of the year so during that period the concentration of loose particles or alluvium is more and necessary work have to be done to avoid the risk of failure of hydraulic structures. Risk is not only confined to the hydraulic structures but also affect the structures constructed to protect the hydraulic structure. We are concerned with inorganic alluvium carried by the flowing water generated through weathering action (physical and chemical forces acted on the surface due to environmental action), construction mining activities along the reach of the river.

These particles of the bed/bank of the river is termed as sediment load.

1.2. Sediment load:

Sediment load is the term given to the particles of the river bed/bank of the river which are eroded due to the force exerted by flow of water. Force exerted by the flow tries the particle to roll, slide or lift the particle from its surface. These particles either rolled down with the flow over the bed of river, remain in suspension or move with the flow further in the downstream direction depend on the magnitude of force exerted by the flow. When this sediment is transported to a large distance in the downstream direction it is termed as sediment transport otherwise remain to its location termed as residual sediment.

1.2.1. Types of Sediment load:

Different types of sediment load in river can be classified as follows:

a) Dissolved load:

These are the tiny (very small) particles particularly in the ionic form. The particle size of these sediments is very small such that they exist in dissolved form. The muddy color or the false color of the water is due to presence of these dissolved ions. These particles may harm the structure in terms of durability/deterioration (outer/surface covering of the structure damaged due to chemical/physical action of water) consideration but these particles will not harm in terms of capacity reduction of reservoir. As these particles are of such small size which do not allow them to settle down even in still water so there is no effect on reservoir capacity.

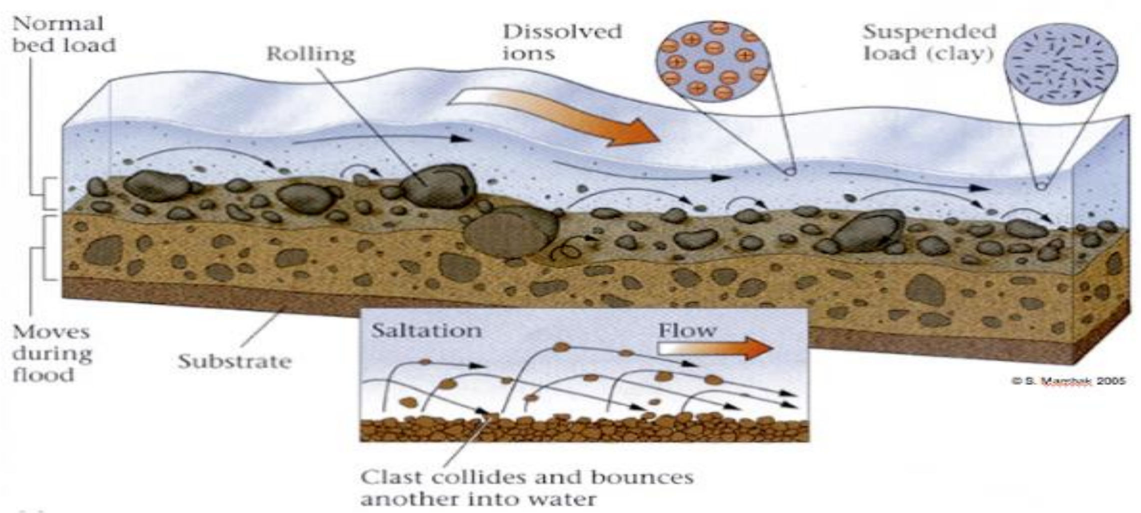


Figure 1.2: Different types of sediment Load. (Source: Essentials of geology by Stephan Marshak, 2005)

b) Suspended load:

These are the particles when detached from the bed/bank surface of the river remain in suspension with the flow. The size of these particles is more than the size of dissolved load. These particles make most of the bulk of sediment load. Concentration of these particles depend on the particle size as if uplift force balances the gravitational force of the particles these particles remain in suspension. These particles will settled down when they experience some obstruction or reduction in velocity in their path otherwise these particles will remain in suspension throughout the flow. The settling velocity of the particles can be calculated on the basis of stokes law which states that “The force which retards the motion of the particles through the viscous medium is directly proportional to the velocity of the flow”, this law can be used to calculate the approximate concentration of the sediment that may reduce the capacity of the reservoir. The calculation of sediment load becomes necessary to determine the design capacity (dead storage) of the reservoir, height of the bridge from bed level of river and for some other engineering activities. Another part of suspended load is washed load. Washed load composed of the particles which is not found in the bed material of river.

c) Bed load:

These are the particles which are large in size (gravels) and require high amount of flow velocity to displace from their original positions. Flow velocity is sufficient to retain them in the rolling condition but gravitational forces dominate the upward acting uplift forces so particles remain attached with the bed. Some particles rise to some height but ultimately settled down to the surface due to their submerged weight. High drag force is required to detach these particles from the bed surface of the river. Biggest particle of the bed which a stream can carry is termed as competence and the total amount of sediment that can be carried with the flow is termed as stream capacity.

The generation of the sediments depend on the topography of the area which includes presence/absence of vegetation over the surface and slope of the river. Presence of vegetation create obstruction to the flow and bind the particles with each other due to which more drag force is required to detach particles from the surface. The slope of the river also influence the erosion of particles. More slope develop more flow velocity that enhances the mechanism of detachment of bed particles.

(a) (b)

Figure 1.3: (a) Field area with vegetation cover and (b) Field area without vegetation cover.

The main aim of this study is to gather information about the scouring around hydraulic structures. To start with the scouring, this is important to discuss the mechanism of sediment transport because ultimately we want to entrap these sediments and protect banks of the river. Sediment initiates more scouring action due to development of more relative motion between the particles. This transport of sediment load with flow make up the dynamic behavior of river. Dynamic mechanism refers to the nature/tendency of the river that forces it to retain high amount of sediment load with flow even when sediment load settled down somewhere along the reach of the river. To maintain its dynamic behavior more scouring can be observed after the obstruction in the downstream direction. Effect of more scouring towards the downstream side to maintain its dynamic behavior is termed as retrogression.

1.3. Scouring:

The scouring is a natural phenomenon of exclusion of bed particles nearby to the foundation of any structure which obstructed the flow of the river. Generally, scouring occur in the main channel as well as near to the hydraulic structure depending on the geometry of the hydraulic structure and topography of the area. We are concern with the scouring develops in the neighborhood of hydraulic structure due to obstruction created to the flow.

1.3.1. Types of scouring:

There are different types of scouring depending on the situation. Scouring initiated due to the regular slope of the channel or due to obstruction created by the construction of hydraulic structure.

Types of scour are as follows:

a) General scour:

This is the scouring process which occur without the influence of any structure. As the name suggests, the scour that occur generally due to flow velocity in main channel of the river. To be more precise this scour occur due to the slope under which flow moves from upstream to downstream areas. More will be the slope of river bed more will be the general scour. Capacity i.e. discharge capacity of the channel increased due to scouring of the bed particles along the reach of the river by increase in the depth of flow. This flow capacity can be decreased with increase in depth of flow where these scoured sediments settled down and make up the bed of river. More idea of general scour can be observed from the figure 1.4.

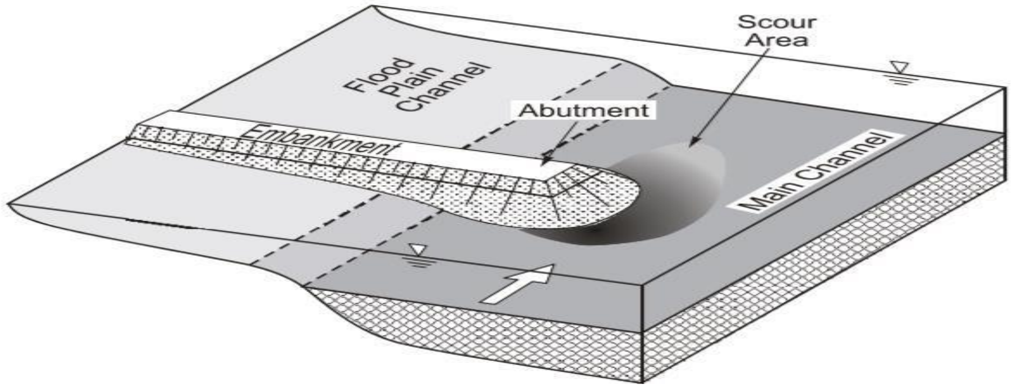


Figure 1.4: Shows General scour around abutment. (Source: Padmini Khwairakpam, 2009)

b) Contraction scour:-

This is also cleared from the name itself, the scour which initiates due to the contraction created to the flow through construction of hydraulic structures. Due to contraction in width of the channel the flow velocity increases in the neighborhood of hydraulic structure and decreases after striking with the surface of structure. This change of velocity around the structure initiate the process of contraction scouring. This includes the combination of both scour in main channel as well as near to the foundation. We are dealing with this contraction ratio along with local scour in our experimental study. For the experimental study, contraction ratio is varied which is defined as the ratio of width of hydraulic structure in the transverse direction to the width of the channel. In experimental study the width of channel refers to width of straight tilting flume.

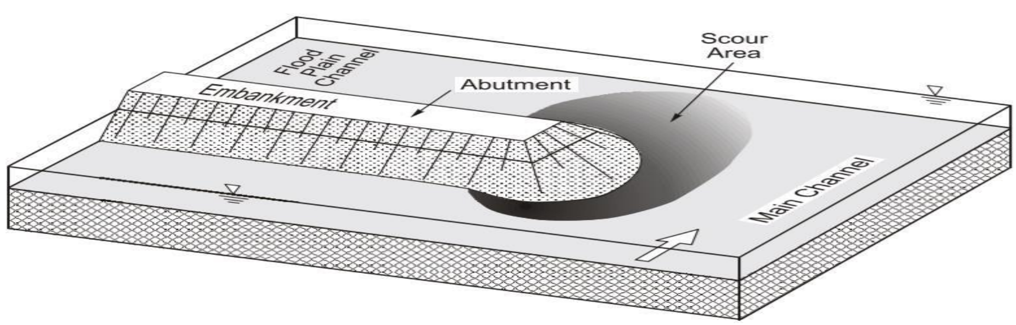


Figure 1.5: Contraction scour around abutment. (Source: Padmini Khwairakpam, 2009)

c) Local scour:

The scour which formed only due to the effect of construction of hydraulic structures is termed as local scour. This scour formed around the head/tip, nearby to the direct contact surface of the hydraulic structure with the main channel due to restriction in width of channel. We are mainly concerned with this type of scour that affects the hydraulic structures as well as structures constructed to protect other hydraulic structures. This is the scour for which empirical equations and laboratory investigations are going on. From the investigation, it is observed that scouring is more in the initial phase and then continues to decrease in the development phase as the flow attain equilibrium condition. This scour directly attack the foundation of the structure that may leads to failure of hydraulic structure, so study of local scouring become necessary to investigate the maximum depth of scour around hydraulic structures.

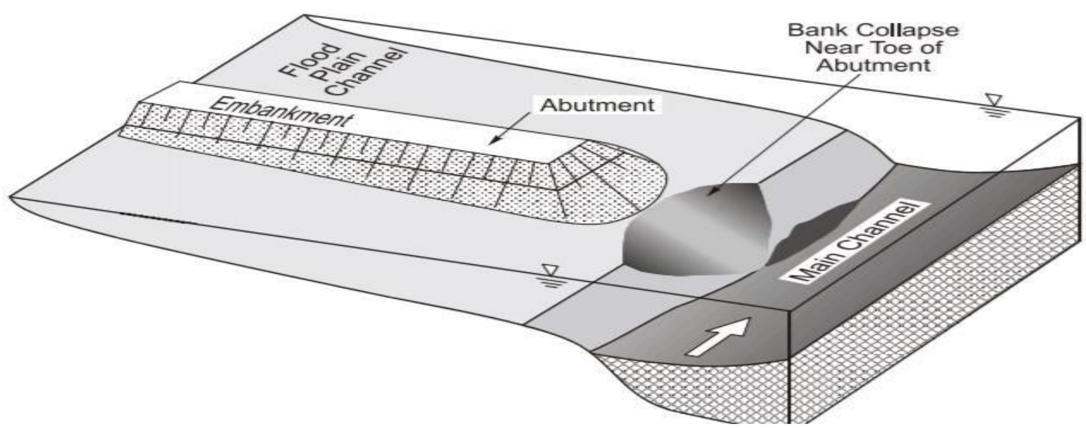


Figure 1.6: Local scour around abutment. (Source: Padmini Khwairakpam, 2009)

d) Confluence scour:-

This scour occur when the flow of two openings meet together having different flow rates, sediment concentration, different geometry so produce complex instability at the meeting point and develop secondary flow pattern which initiates the confluence scour.

This study of local scour become important because hydraulic structure which is formed for the safety of valuable agricultural land, protection of the banks of river, irrigation purpose, hydro-electric development and other purposes of usefulness will become disastrous for us instead of the benefits that is concerned during construction. This local scour around hydraulic structures attack directly to the foundation of the hydraulic structure and exposed it to the atmosphere with the period of time. When foundation of the structure exposed to the atmosphere then deterioration process is increased which reduces its life cycle as well as make it unstable i.e. it can tilt with the water pressure, sediment load and wave pressure which proves to be uneconomical with great loss of life and property so this study becomes of prime importance.

1.3.2. Mechanism of scouring:

Mechanism of scouring consists of two phase:

1) Initiation Phase:

In this phase, scouring initiates when incoming flow approaches the structure. Particles remain intact to their positions until the flow reaches to a certain minimum velocity. Condition of incipient motion discussed above comes under this phase.

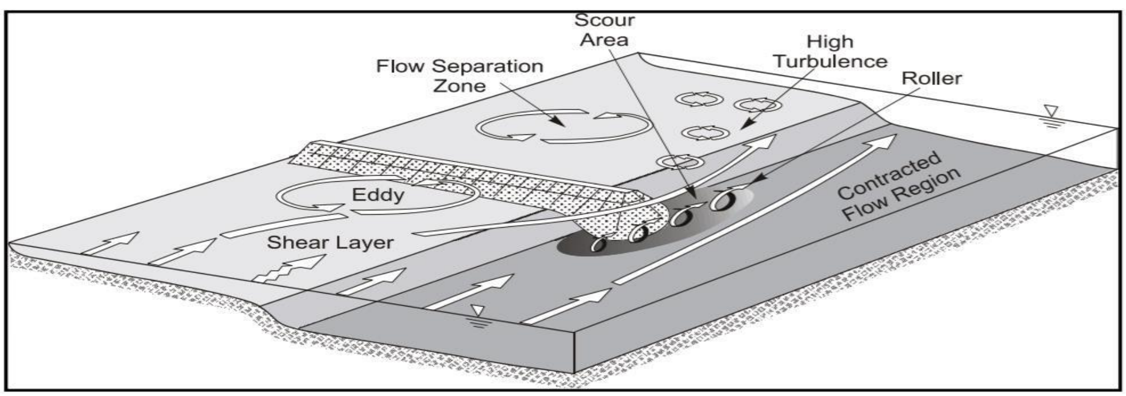


Figure 1.7: Mechanism of scouring around abutment. (Source: Padmini Khwairakpam, 2009)

2) Development phase:

In this phase, there is formation of circulatory vortices around the nose/tip surface of the hydraulic structure. Eddies generated on the banks and near the front end of the hydraulic structure along with formation of wake vortices and surface rollers. Wake vortices are formed due to the vertically downward movement of the water after striking with the face of structure. Surface rollers are formed around the tip/head of surface of the hydraulic structure. When flow approaches the hydraulic structure boundary layer will be formed due to frictional forces acting between the flow and structure. As the boundary layer detaches from the structure then it leads to formation of horse shoe vortex. When flow pattern is observed from top view horse shoe vortex refer to the total shape of the mechanism in the form of horse shoe form around the structure. These all forces combined to form a pressure gradient (negative) in the downward direction which initiates the process of scouring around the hydraulic structures. The intensity of this pressure gradient directly dependent on the flow velocity as well as the shape of the hydraulic structure. The pressure gradient formed in the downward direction because of the vortices and constrict width of the river. A region of flow separation is also formed behind the structure. Flow separation occur when the velocity become very low and due to less velocity behind the structure deposition of scoured sediment can be observed. These vortices form due to interaction of flow with structure is similar around bridge pier, abutments and groynes.

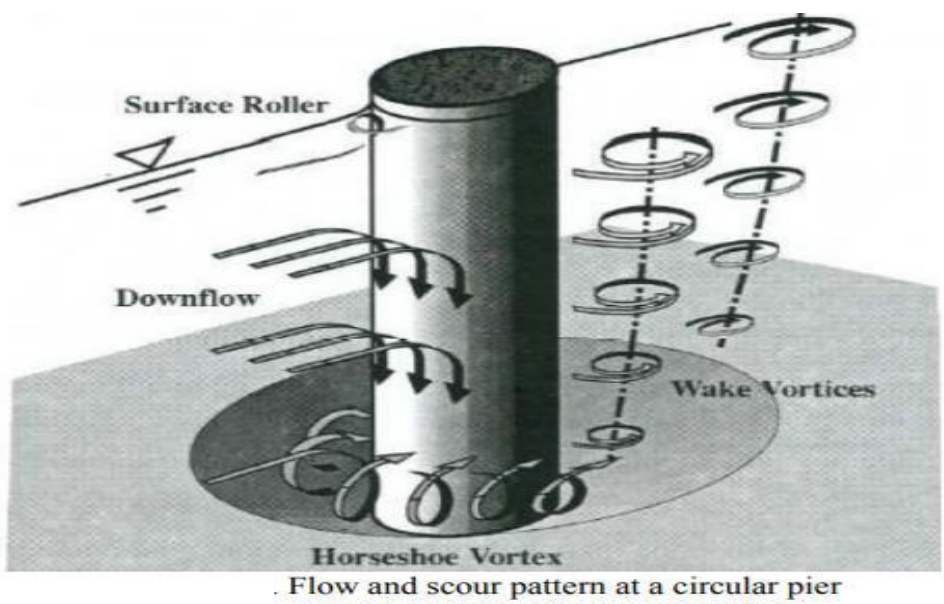


Figure 1.8: Mechanism of scouring around pier. (Source: Melville & Coleman, 2000)

According to the silting and scouring there are two condition arises that differentiates the behavior of river flow i.e. aggradation and degradation of the river. When sediment or bed material is scoured from bank/bed of the river then the depth of river is increased and termed as degradation condition whereas the degraded material from the upstream side settled down somewhere leads to decrease in the depth of flow along with storage capacity of the reservoirs termed as aggradation stage.

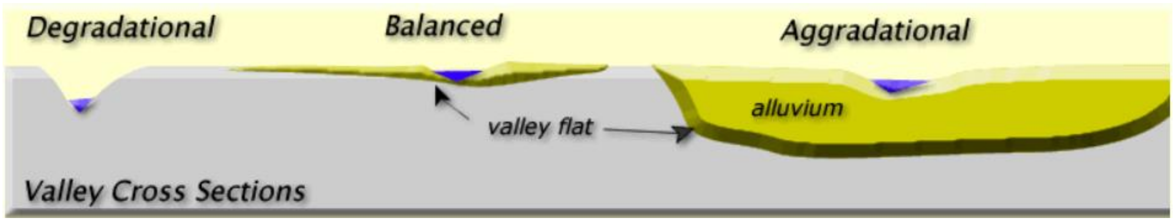


Figure 1.9: Behavior of river flow (aggradation and degradation).

1.3.3. Problems associated with scouring:

The scouring on the bed and banks of the river both will cause problem as:

a) Scouring of the river of any type discussed above especially local scour cause instability to the hydraulic structures. The spalling of the concrete members and foundation of the hydraulic structures inside the flow exposed it to the atmosphere due to which severe scouring around them can be experienced that may be leads to its collapse. As the spalling of the concrete results in exposure of reinforcement to the flow leads to formation of corrosion which weakens the structure.

b) Scouring reduces the ground support provided to the foundation. We can define it through the term of under-mining which is removal of the bed material through persistence of high flow velocity of the river. Mostly those hydraulic structures are affected which have shallow depth of foundation. To find out minimum depth of foundation based on scouring this study become of prime importance. Maximum depth of scouring should be find out around the hydraulic structures either through the empirical equations or through laboratory investigation. Maximum depth of scouring determine the minimum depth of foundation that have to be provided for safe working.

c) Scouring increased the amount of sediments in the river. These scoured sediments settled down at the location of low velocity or in still water behind the obstruction which reduces the depth of reservoir. The decrease in depth of reservoir leads to decrease in the storage capacity of the reservoir which is a serious problem. Dead storage is provided for the accumulation of the sediments but when the amount of sediments is more in the flow then it reduces the design life of the reservoir. Reservoir which is constructed to serve for various purposes for 50 years (approx.) now after high amount of sediments in the flow can serve only for 25-30 years. This is huge loss to land and property.

d) It is a well-known fact that the scouring of the banks cause meandering of the river. Meandering is the process due to which the straight course of the river changed to zigzag pattern/sinusoidal shape. With increase in meandering process finally an 'S' shape is achieved by the river ultimately results in the change of course of the river. Change of course of river is change of its path i.e. changes in morphological behavior of river. Morphological changes are the changes in geometrical features such as width, shape etc. for example, a bridge was constructed to cross the river become useless if the path of river is changed which leads to huge loss of money and time undertakes to construct that bridge. With increase in meandering process there is a stage achieved leads to formation of cutoff.

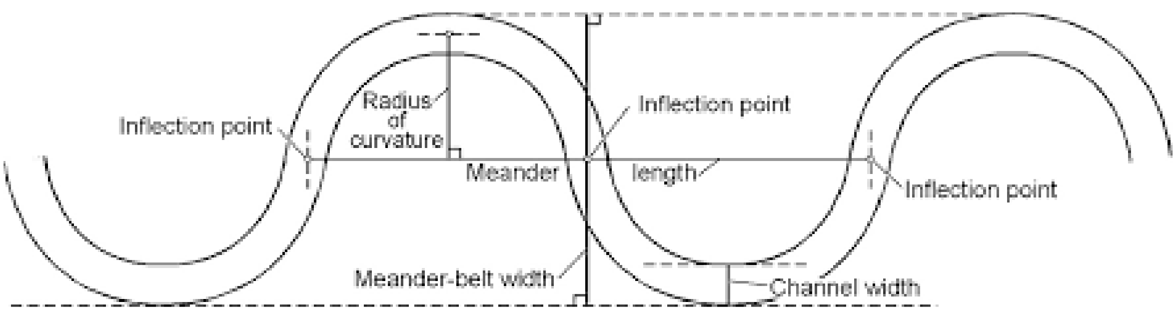


Figure 1.10: Shows specifications of meandering process.

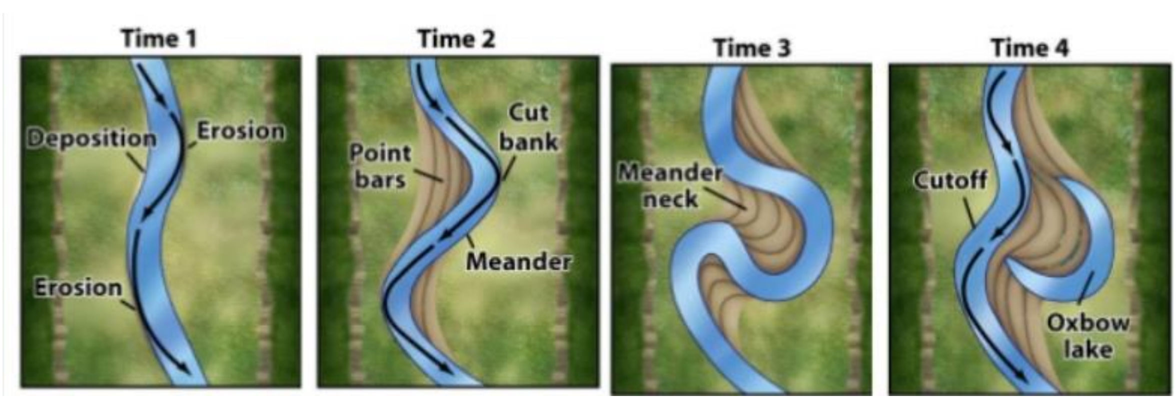


Figure 1.11: Process of meandering and cutoff formation with time.

Cutoff: - Cutoff is the development of shortest path formed by joining two inflexion points of meandering curve. Joining of the two curves of ‘S’ shape which means a totally change of path into straight channel. This initiates disturbances in regime conditions in upstream and downstream along the reach of river.

e) The sediments accumulated behind the reservoirs increase the load on hydraulic structure due to which design capacity have to be increased. Increase of design capacity leads to uneconomical design.

f) Scoured sediments in the flow also affects the hydroelectric power plants. When sediments flow inside the turbines with the flow excessive wear and tear can be observed on the blades, buckets of the turbines. This reduces the design life of the turbines.

Change of course through meandering or cutoff made our hydraulic structure useless and cost to benefit ratio comes out to be very less. To protect the scouring around the banks of river training structures can be used.

1.4. River training structures:

These are the structures which are constructed to trained the river. These structures allow the river to flow in a determined direction that reduces the chances of meandering and increase the efficiency of hydraulic structure. Basically, meandering is a process in which scouring increases on the concave side and deposited on the convex side which goes on increasing with time. So river training structures are constructed to reduce scouring on concave side and corresponding deposition on convex side. Ultimately, our aim is to minimize the problems of scouring i.e. to protect the banks and excessive turbulence generated to the flow through these structures.

1.4.1. Purpose of River training works:

a) Discharge of high intensity can pass safely through the river. This accounts for the average flow that have to pass maximum of the time through river but the structure should be sufficiently strong enough to handle or subsidize the flood flow whenever required.

b) Main problem of sediment load can be countered through river training structures. The sediment load either pass safely through the cross-section without disturbing the morphology of the river or the sediment should be entrapped behind the river training structures so that we have the clear water in the downstream of the river and maximum design life of the reservoir can be maintained.

c) Navigation purpose should be fulfilled. This is related to depth of flow maintained in the river for waterways. Based on the depth the river training works is further classified as:-

High water training: - This is done to provide the passage to high flood flow without disturbing the geometrical features of the river.

Low water training: - This is done to maintain the minimum depth in the river required for the navigation purposes of ships and boats. The minimum depth of flow can be maintained with the help of groynes by reducing the width of flow.

Mean water training: - This is the most important consideration of river training work which involves the structures used to reduce the high amount of sediment load, sediment transport, reduction in flow intensity otherwise that can leads to change in the course of river through meandering, cutting of the banks, wear/tear of turbines, reduction in reservoir capacity, under-mining and much more problems.

1.4.2. Types of river training works:

There are various river training structures which can be constructed according to the requirement or situation to be maintained in the river. There is brief discussion of various river training structure as:-

These are classified as transverse as well as longitudinal river training structures:-

i) Transverse river training structures:-

These are the structures constructed in the transverse direction to the flow of river i.e. in the lateral direction. Generally, these are constructed to the perpendicular direction but may be to the other orientation depend on the requirement and purpose. These are constructed to reduce the flow velocity of the river. To reduce this flow velocity or sometime to control the power of turbulence, intensity of flash floods these structures are constructed. Transverse river training structure are:-

a) Check dams:

These are the small barriers which are constructed in small streams/ rivers to retain the water behind it. They can be made of concrete, logs, bamboos, masonry and other nearby available material which increase the cost to benefit ratio. These small dams reduce the flow intensity by increasing the time of flow and reduce the amount of sediments in the flow by capturing them.

Figure 1.12: Check dam at Kudumboor across Chandragiri River.

b) Sills:

These are also part of transverse river training structures which are constructed in the transverse direction to the banks of river with a low gradient. The height of the sills are less than that of the check dams which are used to reduce the sediment load as well as the intensity of flow. These can be made with wood, concrete gabion and other material which is available nearby to reduce the cost of the structure.

Figure 1.13: Low height bed sills.

c) Screen and beam dams:

These are employed for screening of the material in the flow which either block the narrow section in between the piers or constrict the width midway between the stretches of the river. These are mostly constructed at the head of cross section where steep flow meets the flatter gradient. When the steep flow meets the flatter gradient then there is formation of alluvial fans and mountain torrents. Alluvial fans refers to large amount of the sediment load which settled down in the form of fan shape when two more streams meet at one point. These are either in the form of vertical bars used to capture the vegetated material (trees, shrubs, organic material) and horizontal bars constructed mainly from concrete and steel used to capture the high amount of sediments.

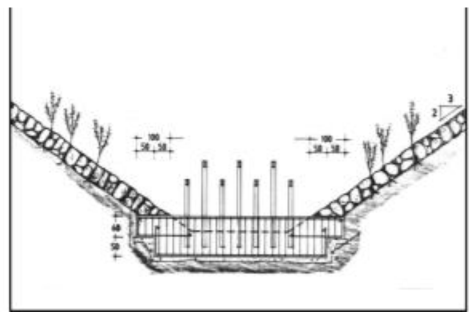


Figure 1.14: Screen dam and vertical bars for retention of mainly vegetative materials.

d) Porcupines:-

These are the structure constructed to reduce the flow velocity and sediments. Purpose is same as that of others to reduce the flow intensity and capture the sediment load but the structure is different and more economical than others. These are of tetrahedral shape joined with the help of iron nuts. These are employed in the river Brahmaputra. These are used in shallow depth of water flow of 3m to 4m.

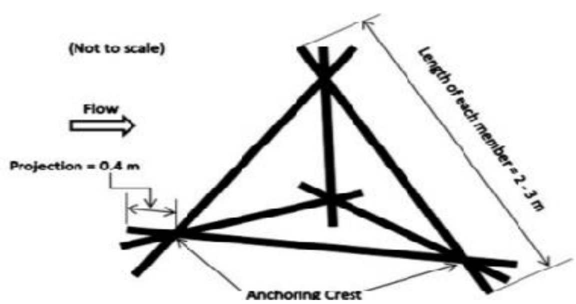


Figure 1.15: Porcupine structure.

e) Spurs dykes/groynes:-

These are the structures most commonly used for the river training works. These are the structures constructed in the lateral direction to the bank of the river just like that of cantilever beam. One end of the groin is fixed to the bank of river and other one is open to the current flow in the river. In this present study, we are going to discuss scouring around these groynes so more will be discussed about these in this section at the end of classification.

Figure 1.16: Transverse groynes laid in Kerala beach by IIT-Madras (2007).

Figure 1.17: Wing dikes in Mississippi river (source: Prairie rivers network).

ii) Longitudinal river training works:-

These are the structure which are constructed in the longitudinal direction of the flow i.e. in the parallel direction of the flow. These are constructed to protect the adjoining areas around the flow. They cover a length of stretch with the flow. Sometime spur dykes are also constructed with these so as to protect these structure from high wave flows.

Some of the longitudinal structures described as:-

a) Levees and earth fill embankments:-

These are the structures which are similar to the earth dams constructed to obstruct the flow to store water behind them but the difference here is that these are constructed parallel to the flow of river. These are made more flat in gradient so as to reduce the shear stress exerted by flow on the slopes and have more stability. They have section similar to earth dam so they carry the limitations of dam as well like they can fail when overtopping of the flow and have disastrous results. Flood plain is formed in the adjoining areas of the embankment to counter the flood flow in these areas after overtopping from embankment.

Figure 1.18: Embankment made near DEE River in North wales, England.

b) Guide bunds:-

These come into operation when we want to construct the bridge, weir across the river. The flood plain of the river consists of large width which is uneconomical in terms of bridge structure so guide bunds are constructed to limit the water way width and enhance the oncoming or outgoing flow through the cross section. Banks are more prone to the direct attack of approaching flow so high pitching or protection is required for them. Guide bunds consists of four parts as, curved portion in upstream and downstream of flow with a shank i.e. straight portion in between the curved section.

Now, we are in a position to understand why study of sediment transport and scouring is necessary around the hydraulic structures. Several studies are available from the past research still there are some areas which have to be more explained. Scouring leads to breakdown of the structure and includes complex mechanism formed around the groynes so it attracts most of the researchers to work in this field.

From all of the river training works, this present study is confined to the study of groynes/spur dikes.

1.5 Spur dykes/Groynes:

These are the part of transverse river training structures which are constructed in the lateral direction to the flow of the river. These are constructed in such a way that one end of groyne is fixed to the bank of river and other end remain open to the current flow of the river to restrict the width of flow.

1.5.1. Purpose of the groynes:

Functions to be served by groynes:

a) Basic purpose of the groynes is to reduce scouring of the banks by deflection the flow away from the banks. To protect the banks/coastline of the banks from further scouring.

b) To capture the sediments flowing in the river so that we have clear water in the downstream direction and the problems associated with sediments (undermining, meandering) can be minimized.

c) To form the slack/false object in between the groynes. When the length of protection is more than the groynes are installed in number depending on the area of protection so the sediment flowing in the flow gathered in the spaces in between the groynes that form artificial bank which can be used for other purposes. The artificial banks formed in between the groynes is productive and can be used for cultivation purpose.

d) In southern India nearby coastal area these are used for maintaining the aquatic environment inside the flow by the fisherman. The flow is concentrated in between the groynes that boost the growth of aquatic environment inside the flow.

e) These structures also maintain the navigability by increasing the depth inside the flow which was discussed earlier in the low water training condition. The water way is constricted due to the construction and depth of flow is increased which is useful for the navigability of ships, boats and other waterways.

Now, there are various types of groynes that can be used according to the situation and requirement. Based on that these are classified as:-

1.5.2. Classification of the groynes:-

a) On the basis of material:

On the basis of material the groynes can be classified as permeable or impermeable groyne.

Permeable groynes: - These are the groynes which allows the water to pass through it. These groyne do not provide direct obstruction to the flow instead slow down the intensity of flow and trapped the amount of sediments in between them. These groynes are used more when sediments are more in suspension which have to be settled down by reduction in velocity.

Impermeable groynes: - These are the one which provide direct obstruction to the flow. Direct obstruction to the flow create more instability. These are constructed when the purpose of deflecting the flow from the banks is more superior to capture the sediments.

Permeable groynes are more flexible than impermeable groynes and provided more when rivers have deep and shallow type of cross section. The geometry of permeable groynes can be changed in near future whenever required but this is not the condition with the impermeable groynes. Impermeable groynes develop complex mechanism due to direct obstruction in the flow than permeable groynes which leads to collapse of the structure in near future. Permeable structures are more cost effective than that of impermeable structures due to which these are used more these days and demand more investigation according to the situation (BIS, June 2005).

b) On the basis of material:

This consists of material by which groynes can be constructed. Impermeable groynes mostly constructed from cement concrete or stack of boulder stone that don't allow the water to pass through it. Timber groynes can be used to reduce the amount of sediment and flow velocity. Formation of timber groynes, a log of wood is used in the transverse direction. The life of timber groyne is not more than 8-10 years. Other permeable groynes can be made with rip-rap, timber arranged in the vertical direction having space in between them which are just capable to reduce the flow and entrap sediments.

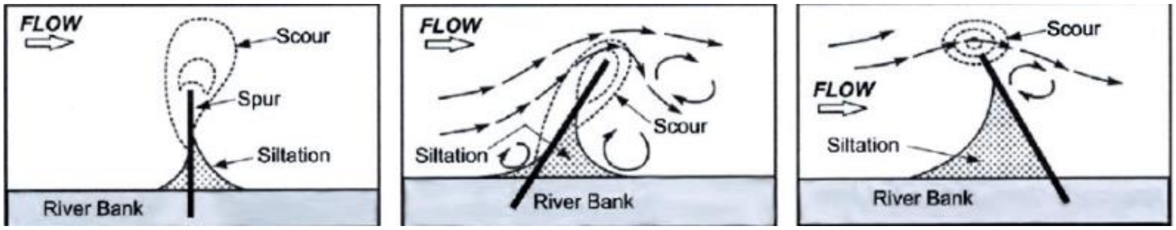
a) Rubble mound b) Timber groyne c) Rock groyne

d) Wooden groyne.

Figure 1.19: Different types of groynes based on construction material.

c) On the basis of orientation:-

Orientation refers to the alignment of the groynes or the angle made by the groyne with the horizontal i.e. with the bank. According to the angle with the horizontal it can be categorized as:



a) Straight groyne b) Attracting groyne c) Repelling groyne

Figure 1.20: Different types of groynes based on the orientation with bank.

Upstream groyne: - This is the groyne which is aligned in the upstream direction when the angle is less than 90 degrees with the horizontal. Upstream groyne mostly used to repel the flow from the bank of the river which is to be protected and also termed as repelling groynes.

Straight groynes: - This is the groyne which is constructed at 90 degree exactly perpendicular to the bank of river. These groynes experience direct obstruction to the flow than groynes of the other shapes due to which shows more scouring. This groyne is also termed as deflecting groyne.

Downstream groynes: - These are the groynes which are aligned in the downstream direction when the angle made by the groyne with the horizontal is more than 90 degrees. These are used when we want to attract the flow towards the bank and also termed as attracting groyne. This is done when the bank of other side should be protected from scouring.

These groynes can be arranged in group i.e. in series or individually depending on the area to be protected. When the area to be protected is more than groynes are arranged in series otherwise they can be employed individually. When the groynes are arranged in series then the factors length of groyne, spacing in between the groynes, contraction ratio have more influence on scouring.

d) On the basis of height of water:-

This is not the classification instead this is the situation based on the flow depth. When the depth of flow is more than the groyne height then it is termed as submerged groyne otherwise partially/non- submerged groyne.

Submerged groyne: - when depth of flow overtops the groyne then groyne is termed as submerged groyne. The study of submerged groynes is more complex than partially submerged groyne as the mechanism involve in this is difficult to observe. The sediment collection is less in this submerged groyne than partially submerged groyne. Flow above the groyne directly pass through the groyne and have more contact with the bank due to which more scouring is observed than partially submerged groyne so submerged groyne used less than partially submerged groynes. Study of mechanism of submerged groynes require 3D simulation.

Partially/non- submerged groyne: - when depth of flow is less than the height of the groyne. The mechanism involve in this type can be observed which is relatively easy than submerged groynes. The mechanism to be observed involve recirculation vortex as well as separation zone behind the groynes. The sediments collected is more in partially submerged than submerged groynes.

Generally, it is conventional process to construct submerged groynes as permeable and partially submerged as impermeable groynes as overtopping of submerged groynes cause excessive scouring along the banks.

d) On the basis of shape:-

Groynes can be made of different shapes as:-

i) Straight I shape.

ii) T shape/Denehey groynes

iii) L shape.

iv) Hockey shape.

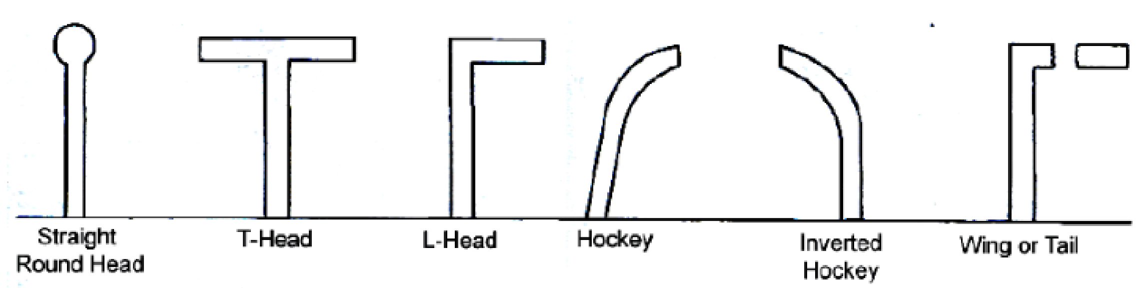


Figure 1.21: Schematic view of different types of groynes (Przedwojski et al, 1995).

From all of the river training structures discussed above, present study is concerned with the local scouring around groynes. Groynes are used to protect the banks of river from scouring and suspended sediments efficiently but after construction of groynes flow disturbs the foundation of the groynes. The banks are protected by the groynes but what about the scouring develop around the foundation of groynes. This is similar to sacrificing of the groynes itself for the protection of banks. Scouring around the groynes exposed the foundation to atmosphere and leads to failure/collapse of the groynes structure. The groynes which are constructed for the protection can becomes dangerous after failure through destruction of valuable land, property and human-life. So discussion becomes of prime importance to study the scouring around groynes to increase their design life and efficiency. Scour depth measurements are also necessary to determine the depth of foundation that have to be provided. The overestimation of the scour depth due to which deep foundation will be designed leads to uneconomical design. The under-estimation of the scour depth leads to shallow foundation that may be subjected to structural collapse and loss of valuable land and life. For the general information, when the depth of foundation is less than or equal to width then this is shallow foundation otherwise it is deep foundation.

Impermeable groynes were constructed in Brahmaputra River named as bentil and enayetpur completed in 2002. After the construction they were under repair many times which shows there is lack of design or river morphology was not considered during design. The permeable and impermeable groynes both were constructed in Kizu River in Japan, which were constructed in 2004. After their construction these groynes have to rebuilt and redesigned but after redesign their stability yet to be unknown.

CHAPTER 2

PAST RESEARCH

2.1 Introduction

In this chapter, we have a review of the past research work related to the present objective of this study. The main aim of this study is to estimate the depth of scouring around permeable and impermeable groynes and their comparison, so that effective among permeable and impermeable groynes may be identified. Hundreds of research work is available regarding scouring, flow pattern around impermeable groynes but less work has been done for permeable groynes which inspire the researchers for more investigation.

2.2 Earlier Researches

Some earlier research work that has been done through experimental observation as well as numerical modeling are as follows:

Emad ELAWADY et al (2000) carried out work on "Experimental Study of Flow Behavior around submerged Spur Dike on Rigid Bed". Experiments were carried out to study the flow behavior around impermeable straight and (fully submerged and just submerged condition) along with different orientation of spur dikes with horizontal wall categorized as deflecting, repelling and attracting groynes. Flume was used with white spray paint on the bed of flume to make it smooth rigid bed. Discharge was calculated with the triangular weir installed in the downstream direction of the flume. ADV refers to acoustic Doppler velocity meter was used to measure the velocity around the spur dike in vertical and transverse direction. Mesh wire is used to locate the points where measurements were taken. Total 750 readings were taken at a point to calculate the average velocity and velocity field pattern around spur dikes. In full submerged condition, water surface slope have no change in the upstream direction and a drop in water surface slope is observed in the downstream direction whereas in just submerged condition, water surface slope is increased in upstream direction and drop in the downstream direction but difference in both condition arises in the downstream direction. The drop in just submerged condition is far distance away from the spur dike as compare to fully submerged condition. Velocity field vectors was also observed in the full submerged and just submerged condition, flow separation zone and eddied were generated behind the spur dike within the dike height zone. With the inclusion of spur dike orientation change in velocity pattern was observed as the velocity which was increasing from the bed to surface in previous cases now there is opposite effect was observed. In the downstream direction, the velocity near the bed region was more than the velocity at the surface.

Roger A. Kuhnle et al (2002) carried out work on "Local scour associated with angled spur dykes". The main aim of this paper was to show the local scouring around the groynes sloping at an angle of 45, 90 and 135 degree with the horizontal and comparison of experimental results with the equation proposed by the **Melville (1992)**. Flow rate was measured through pressure transducer connected to a venture flume in the return pipe. These pressure transducers calculate pressure difference in the pipe and then velocity can be calculated using the Bernoulli's equation. The model of the spur dykes was made of concrete. Velocity profiles were collected with a 2 mm diameter total head tube mounted on a point gauge. Bed/water surface profiles was measured with RMU which operates in air and SedBed monitor which operates under water. Shear velocity can be calculated by the equation proposed by the **Coleman and Alonso (1983)**:

$$u_* = \frac{d\bar{u}}{Ad(log_{10}y)} \quad (2.1)$$

Where, A is constant have value of 5.75 for uniform flows over rough, flat surfaces. Volume of scour hole was determined from the surfer of golden software. Volume of scour hole increases with time and can be expressed with equation as:

$$\frac{V_i}{V_{30}} = .980(\frac{t_i}{t_{30}})^{0.653} \quad (2.2)$$

The width and downstream length of the scour hole were generally greater for the 135 and 45 degree spur as compare to the 90 degree angles spur.

The length of the scour hole from the left channel wall was less for 45 degree than that of other angles. This means that the near bank bed erosion was more for 45 degree spur and can cause more insecurity conditions than that of other spurs as this can cause the scouring of side banks and create more uncertain condition. Experimental results were compared with the results of **Melville and Coleman (2000)**. Abutments were classified as short, intermediate and long depend on the ratio length of groyne to depth of flow. Groynes used by Melville were long but in this paper groynes were of short type so results were not matched. The intermediate spur dykes shows similar trend with that of large structures. The short spur dyke show large scouring for 45 and 135 degrees angle.

The equation proposed by **Melville (1992)** was used to calculate the maximum depth of scour hole as:-

$$\frac{d_s}{y_\infty} = 2K_M\eta^{(1-\delta)} \tag{2.3}$$

This equation overestimate the maximum depth of scour when compared with the results of this experiments due to overtopping of flows in this experiment.

An equation was also presented at the end for the volume of scour prediction as:-

$$\frac{V_{30}}{(d_{s30})^3} = C \tag{2.4}$$

The value of constant suggested as 12.11 after calculating from all the ratios of volume and maximum depth of scour hole. The perfection of results obtained from this equation is still unknown because of presence of limit amount of data.

TOMASZ MIODUSZEWSKI et al (2006) carried out work on “Influence of the spur dike permeability on flow and scouring during a surge pass”. They carried out the experiment to study the effect of permeable spur dike on flow behavior and phenomenon of local scouring along with consideration of factors like excess pore water pressure, seepage force, and liquefaction. Impermeable groynes were made from Plexiglas and permeable groynes were made from mesh steel cross- section filled with stones. Twenty pressure transducers were used installed at different locations of upstream side wall, downstream side wall and head wall. These were installed in the flow as well inside the sand also. As flow behavior has to be seen with effect of surge pass so surge was created from the downstream direction. Pressure difference measured with the help of pressure transducers show pressure varies with the water depth. Sudden change in pressure difference was observed in impermeable spur dike whereas constant decrease was observed in permeable spur dike. Excess pore water pressure was measured with the pressure transducers installed in the flow and inside the sand. Excess pore water pressure is significant for permeable groyne than impermeable groyne due to presence of hydrodynamic pressure with the wall. Effect of liquefaction also observed during the experiment as liquefaction directly related to the scour depth. No liquefaction was observed on the upstream side but effect was considerable in downstream direction. Areas where liquefaction reside for longest time shows more scouring than other areas. Pressure readings shows impermeable structure initiate scouring process more rapidly than permeable structures. Seepage force was also observed which shows the pattern of water flow inside the sand. Water flows in horizontal direction and coming outward when moving from upstream to downstream direction. From the various literature review it was seen that, scouring process become weak with the time but this was not the case during experiment with surge pass.

A. Melih YANMAZ et al (2007) carried out work on "Surface characteristics of scouring at Bridge Abutments". The objective of this paper is to investigate the time-based deviation in the scouring around the bridge abutments and vertical wall abutments. Both the experiments were done in different flumes and duration of test run was kept at 6 hour. Experiments were run for a particular duration and then readings were taken so as to plot them with respect to time. The maximum scouring formed at the mid-section of bridge abutment and at the front vertical corner of vertical wall abutment. The deposition is similar in both the cases at the back side of the structures. Scouring contours were plotted in both cases, scouring contours were more uniform in the case of bridge pier whereas the vertical wall have non-uniform/asymmetrical type of contours because corners of wall create more flow separation than bridge pier. This shows the variation of shape on scouring. The shape of the scour hole was similar to inverted cone. Surface area and volume of the scour hole was also calculated with the software based on triangularization system. Only volume values were considered as surface area values were independent of scour depth. There was lack of equations and theory regarding this technique so two equations were selected from regression analysis and values were verified with the research paper by **Oliveto and Hager (2005).**

$$V_{cp}^{*} = 1.738T_{s}^{0.299} \quad (2.5)$$

$$V_{va}^{*} = 0.681T_{s}^{0.265} \quad (2.6)$$

The experimentally calculated volume was compared with the volume calculated from the equations. The experimentally calculated volume is less than the volume calculated from the equations. These equations shows the value of volume which was decreased with the value of T_s which is more pronounced in vertical wall then bridge abutment. As these equations were verified these can be used in the field conditions also so as to find out the maximum depth of scouring.

Manish Pandey et al (2007) carried out work on “Experimental Study of Temporal Scour around Spur Dikes”. The main aim of this study is to calculate the scour and maximum discharge by using ADV. Three dimensional flow velocity was calculated in x, y and z direction which shows the flow pattern around spur dikes. Groyne of partially submerged impermeable type was used and discharge was collected with the help of sharp crested weir. Twelve experiments were done in total with both single spur dyke (six) and multiple spur dikes (six) at three discharges Q_1, Q_2, and Q_3. All the experiments were done under clear water scour conditions (approaching velocity is less than critical velocity). The experimental results were validated with the simulated results of **Kothyari et al (2007)** and result agree with the equations proposed by **kothyari et al (2007)** with an error of (±0.25). The maximum scouring was observed around the head and at the wall spur joint. Scouring was decreasing along the length of the flume i.e. maximum around first groyne and then decreases towards second and third groyne. Maximum scour depth increase with increase in discharge and transverse length of spur dyke.

A. Shafaie et. al. (2008) carried out work on “The effect of minor spur dyke on scouring at the first spur dyke in the gravel bed”. The main aim of the study was to investigate the effect of length and orientation of the minor spur dyke on scouring of head spur dyke. In any case, the maximum scour can be seen on the first main dyke so the maximum possibility to get damaged from the scouring is first one so as to prevent it from the scouring a Minor spur dyke was used at the upstream of the head spur dyke to reduce the scouring on the head spur. Experiments were conducted with different lengths (L`) of minor spur dyke along with different distance(X) from the head spur dyke. Length would be varied by L`= 0.33, 0.5, 0.66 times of L and distance from head spur equal to 1.5, 2, 2.5 times the length of main spur dyke. The sand and gravel used in flume for the experiment having density 2650 kg/m3, d_{50} of 1mm – 3mm and standard deviation of 1.25mm.

Total 27 experiments were conducted and the results concluded were as follows:-

1.) Shape of the scouring hole is like reverse cone.

2.) Observation showed that the upstream slope of the hole (55-60) degrees is steeper than downstream slope (27-35) degrees.

3.) First spur dyke has maximum scouring and fourth have minimum scouring.

4.) Minor spur dyke has insignificant scouring.

Minor spur dyke was effective on the group of spur dykes compared to unprotected spur dykes. It reduced the scour rate at the head of spur dyke by 10-33%. Minor spur dyke have better efficiency when located at X/L = 2 upstream of group spur dyke with L`/L = 0.5 i.e. when the minor spur dyke was located at a spacing of twice the length of main spur dyke and half the length of main spur dyke.

Jennifer G. Duan et al (2009) carried out work on “Mean flow and turbulence around experimental spur dyke”. This paper presents the comparison of mean velocity, turbulent intensities and Reynold’s stresses in flat and erodible bed. Mean flow and turbulent properties both were important for the valuation and observation of sediment suspension, transportation and deposition which was done by the use of ADV. ADV was used in the experiment to carry out the measurement for velocity and turbulent in particular flow field. Research found near-bed turbulence structure played a significant role in transporting sediment through a combination of micro ADV, LDV, PIV and high-speed motion picture photography measurements. It was observed that sediment increases with increase of mean velocity due to which sediment flux also increased even when the bed stress decreases. Sontek micro ADV of 16 MHz time averaged flow study, turbulent, primary flow on the downstream and upstream of the spur dyke. Metal plate was used to behave as spur dyke. Two experiments were done one in flat bed when the sand bed was fixed and other one in the erodible bed. As in the flatbed the bed was fixed and in erodible bed sand bed was formed of the median size 1.59mm. The shear velocity in the flat bed was much less than that of erodible bed. The values of turbulence velocity and Reynold's stresses at the solid wall are zero because of maximum values at the nose tip of the groyne. The duration of the experiment was 48 hours so as to count the local scour.

When the turbulence intensity and shear stresses were measured then it was seen that the Reynold's number goes above 10000 that shows the distribution of turbulence and bed shear stress were independent of the approaching flow and there was no evidence till now that shows about the dependency of turbulence intensity, shear stress on the approaching flow after the increase of Reynold's number after 10000. Flow separation begins at the dyke tip in both runs and shifts towards the right bank. The mean velocity calculated at the downstream section was almost similar to the approaching flow but the velocity showed some variation in the lateral and transverse direction.

The velocity at the constriction section was 20% more than the oncoming velocity while in the flat bed it is 30% more than the approaching velocity. Negative velocity has been shown in the recirculation zone behind the groynes. For the scoured bed, the mean downstream velocity was reduced primarily due to the enlarged cross sections. On the other hand, the mean transverse velocity has increased near the bed surface in the scour hole, and the mean vertical velocity reverses its direction towards the flow surface in the scour hole. The length of recirculation zone was larger in case of flatbed than that in the scoured bed because the scoured bed dissipates more energy by the transportation of the sediments. For both non-erodible and erodible case the bed shear stress was 6 to 8 times to that of the approaching flow. In scoured bed the turbulent stress were more than that of Reynold's stress where as in the flat bed Reynold's stress dominate over the turbulent stresses.

Hao ZHANG et al (2009) carried out work on "Characteristics of Local flow and Bed Deformation at Permeable and Impermeable Spur Dykes". They carried out both numerical and experimental study to find out the difference in hydraulic and morphological changes after the installation of groynes. The sediment bed made up of sewage sludge ashes. The sediment used have mean size d=0.145cm and specific gravity= 1.9 which shows it is devoid of cohesive particles. Single spur dyke of both type (permeable and impermeable) was installed in the flume. The permeability of permeable groyne was kept at 50%. Experiment was allowed to run for 2 hour but the flow was stabilized after 1 hour. More scouring was seen during the initial stages and then the scouring was relatively less than initial stages. PVC material was distributed inside the flume for PIV analysis and three velocity components of velocity was measured with the help of electromagnetic velocity meters. Numerical model was established and RANS (Reynold's averaged Navier stokes) equations was used with k-ε model. Wall function was used near the walls of the flume and transport rate is based on Ashida-michiue's formula. Two cases were considered for both permeable and impermeable groynes one in movable bed condition and other one in fixed scoured bed condition. Triangles and hexahedra shapes were formed for the computations. Results were concluded as:

i. The wake flow behind a spur dyke is important as in the case of impermeable spur the flow attain fan shaped structure whereas permeable spur was not much different as flow can pass through the structure.
ii. Comparing the PIV and simulation results, simulation results were more accurate. PIV results were more 2D whereas simulation results were 3D type and can be analyzed easily.
iii. Transverse flow velocity was analyzed which show about the horse shoe vortex formed behind the spur dyke. The horse shoe vortex formed near the head of the groyne and moved away from the groyne. There is other vortex formed was wake vortex in the opposite direction of horse shoe vortex gives rise to fan shaped structure behind the groynes which was more pronounced in impermeable case than permeable case.

iv. Longitudinal flow velocities also shows the formation of horse vortex around the spurs and moved to the downstream side. Both transverse and longitudinal velocity shows horse shoe vortex plays an important role in scour geometry.
v. The simulated scour holes were smaller than the scour holes observed during the experiment due to insufficiency in interlinking between bed material and flow field.
vi. Scour holes were more in impermeable case than permeable case due to the flow separation in the impermeable spurs.

Mechanism was almost same in both types of the structure but there was difference in separation angle in both cases. Sediment deposited in downstream side of spur in either case.

G. K. Mojtaba et al (2009) carried out work on “Effect of groynes opening percentage on river outer bank protection”. This paper examines the scouring process in a flume having bend of 45°, 90°, 135° and 180° through experiments with different types of permeability. Iron bar and blades chosen as permeable structure to find out the scouring around permeable structures. Iron bars and blades were free to move to induce different degree of permeability during experimental run. Tilting flume of different bends formed in an area. A canal section was prepared with placement of cement inside it and then permeable structures were installed with different permeability. Overall 21 experiments were done at 63%, 66% and 70% permeability. Triangular weir was constructed at end to find out the discharge in flume and sand surface meter WH-406 made in japan used for measurement of scouring depths. First experiment was done with single bar of 70% permeability and then with two bars of 63% permeability by placing it on 45 degree bend. Experiment was run for duration of 3 hour even 2.5 hour seems to be stabilized regime condition. Results were concluded as scouring move in the downstream direction. Placement of permeable groyne reduce the scouring at outer bank with less length of bank covered for protection but with reduction in the cross section the number of structures have to be increased to protect the bank from scouring which is uneconomical. So structure with either variable permeability in series or mixed structures of permeable and impermeable can be introduced.

Padmini khwairakpam et al (2009) carried out work on “Local scour around Hydraulic structures”. The basic aim of this paper was to review the available literature on mechanism, prediction and reduction of scour around the hydraulic structures. The basic mechanism involve was the down flow creates due to striking of flow and fall to the bed in the form of vertical jet. Flow velocity decelerates near structure and reduced to zero just behind the structure. This reduction in the velocity increase the pressure at that point with flow separation zone behind the structure. Since the decreasing velocity going down from surface to bed creates pressure gradient in the downward direction. This downward negative pressure gradient form the scour hole due to formation of hard vortex. Combination of different types of vortices near the structure form a specific shape which resemble to the shape of horse shoe due to which it was named as horse shoe vortex. Intensity of this horse shoe vortex reduce flowing in the downstream direction due to which formation of scour hole reduce with time which is termed as stabilization stage of scouring. This vortex develops the characteristics of tornado and carry out the sediments with it. These wake vortices move from one side of the structure to the other side of the structure by creating the scour hole. Intensity of scour hole was increased after combination of wake and horse shoe vortex. As surface rollers were created after striking the pier surface behind the pier and wake vortices by the downward flow after striking with the pier. These vortices will grow up in size hand form the hard vortex when mix with the high intensity incoming flow. This will initiate the scouring phenomenon under the pier and expose the foundation of the pier structure. In the practical situation, the empirical equations formed and experimental investigations directly can’t be applied as the whole flow of actual river can’t be studied. Only the small portion of the river can be steady so only some equations can be applied directly to the real problem with some possibility of the error. There were some methods given for the reduction of the scour by using water splitter plates, threaded pile and pier collar. The scour around pier can be reduce by 50 to 60%. Using pier collar. By the use of splitter plates and threaded pile reduced the scour depth by 61.6% and 51.1% respectively.

Gh. Saeidifar et. al (2011) carried out work on “Investigation of scour depth at Bridge piers using Bri-Stars Model in Iran”. In this study, scour depth around bridge piers was calculated through a software termed as Bri-Stars. Software was calibrated with the help of available field data and then scour depth was computed using software.

Bri-Stars refers to Bridge Stream Tube Model for Alluvial River Simulation. There is 3 step stages for the predication of scour depth or any result through software as calibration, verification and prediction. The first step of calibration was done through the available American field data and second step of verification was done with the available field data of Fars province. Verification was done by finding out the result with the available data of Fars province and then compare that result with the accurate result. If there is difference between the software result and accurate result then value of error had to be calculated so that correction can be applied to the further results. This calibration and verification of the field date will show the quality or validation of model selected for the prediction of scour depth. After calibration and verification was completed then the prediction of the scour depth can be done. For this study, the bridge piers of Fars and Isfahan was selected for the prediction of scour depth. Model capabilities were enhanced with the inclusion of new sediment transport equations and graphical user interface. Both momentum and energy functions were used in the software of Bri-Stars so that the scour depth can be predicted in the sub-critical as well as in super-critical flows.

Equations used in the Bri-Stars computer program:-

a) Colorado state university (CSU) equation (1975) for equilibrium scour depth:-

$$\frac{d_s}{b} = 2.0K_1K_2\left(\frac{b}{y}\right)^{0.65} Fr^{0.43} \tag{2.7}$$

b) The laursen relationship (1960):-

$$\frac{b}{y} = 5.5\frac{d_s}{y}\left\{\left[\left(\frac{d_s}{11.5y}+1\right)\right]^{1.7} - 1\right\} \tag{2.8}$$

c) Froelich (1987) :-

$$\frac{d_s}{b} = 0.32\emptyset\left(\frac{b`}{b}\right)^{0.62}\left(\frac{y}{b}\right)^{0.46} Fr^{0.2}\left(\frac{b}{D}\right)^{0.08} + 1 \tag{2.9}$$

d) Jain (1981):-

$$(Fr - Fc) \geq 0.15 \tag{2.10}$$

$$\frac{d_s}{b} = 1.86\left(\frac{y}{b}\right)^{0.5}(Fr - Fc)^{0.25} \tag{2.11}$$

These are the equations developed by using the previous data of the past studies and data computed through experimental observations.

Calibration was done which is divided into three stages. The stages based on the material lying nearly to the bed of the pier. The first stage consists of material containing silt and clay whereas second and third stage consist of material sandy and gravel stratum. Graph was plotted between computed and measured scour depth. To find out the constants linear regression can be used or not. The graph comes out to be linear that shows linear regression can be used and SPSS software was used. After finding out the values of correlation for all the three stages it was seen that the software computations overestimate the measured results as experiments was done in the laboratory on the limited pier width and the equations were applied in field having more pier width this shows the effect of pier width on scour depth. The verification was done by finding out the error in computation and measured scour depth. Prediction was done for Iranian bridges without considering the debris effect. Debris effect increase the scour effect. Third stage i.e. clay stratum around pier shows less scour than other stages due to cohesive force of particles. Best results were shows by the CSU equation. For voluminous pier, scour depth cannot be estimated using Bri-Stars. Bridge Pier Prediction model can be used.

Kedar sharma and Pranab K. Mohapatra (2012) carried out work on "Separation zone in flow past a spur dyke on rigid bed meandering channel". The objective of this study is to present the mean velocity field and separation zone behind the 90 degree spur dyke in rigid bed meandering channel. Huge amount of research data was available regarding the separation zone around spur dyke in straight channel but rare data was available regarding the separation zone around spur dykes in meandering channel. Total 24 Experimental runs were carried out in rigid bed meandering channel to know about the mean velocity, length and velocity of separation zone behind the spur dyke. The flume chosen for the experiment followed the sinusoidal curve. Calm entrance had to be ensured inside the flume otherwise formation of wave and turbulence interfere with the actual data of scouring Separation zone can be observed both on the upstream as well as on the downstream portion of the flume **Ettema and Muste (2004)**. All velocity measurements was taken from Nortek ADV and win ADV software was used to plot the mean velocity variation at different location of the flume. Variation in mean velocity was observed from upstream to downstream direction. Upstream direction shows variation in velocity similar to standard process of maximum velocity at a depth lower than surface velocity but in the downstream direction mean velocity is maximum at surface. From the observations it was seen that the separation zone was increased as when the spur dyke moved towards the downstream side with change in direction of spur from right bank to left bank. Separation zone was less for spur dyke located on left bank as compare to when spur dyke was located on the right bank. Velocity is maximum when spur dyke was located at the inner bank of the curve and separation zone varies with the contraction ratio. Small effect on separation zone was observed with change in Froude's number.

USMAN GHANI et al (2013) carried out work on "Influence of spur dike on flow patterns in open channel". In this paper, numerical work has been done to know about the flow behavior around spur dike. FLUENT 12.0 solver was used with GAMBIT 6.3 to create geometry of the problem. Fluent solver was calibrated with the past studies available regarding the problem. **Zhang et al (2009)** did experimental work on spur dike used for validation purpose. The calibration of the solver was necessary to know about the ability of the software and its efficiency. K-E model was used with SIMPLE algorithm. Boundary condition was setup at the wall, at the entrance and exit of the flume and near the spur dikes. Velocity vectors was analyzed and it was observed that velocity was of increasing trend up to spur dike but velocity shows decreased value near the spur dike.

Velocity shows negative value behind the spur dike which means there was region of flow separation. Flow separation initiates the scouring process near spur dike. Velocity was increased when moving towards the downstream direction away from the spur dike. Stream line were plotted in the transverse direction of spur dike which shows reversal zone near to the spur dike having length equivalent to five times the length of the groyne. Turbulent kinetic energy was also measured which shows the intensity of turbulence in the flow. Intensity of turbulence is minimum in the flow until flow approaches the spur dike and distributed in the downstream direction having distribution equivalent to three times the depth of flow behind the dike.

Prof. Dr. Saleh I. Khassaf (2013) et al carried out work on "Development of a new scour formula for a clear water scour around groynes". This paper studied the effect on local scour formed around groyne after setting up of groyne at definite site. This paper also presents the formula to calculate the depth of scour around groynes. Complicated vortices were formed in flow after placement of the groynes which initiates the process of scouring. Scouring around groynes depend on various flow parameters, sediment characteristics and fluid parameters. These parameters were calculated through different run of experiments. The duration of each run of experiment was 4-hr. The computer package STATISTICA was used to make the non-linear regression analysis data collected through the experiment.

Equation developed through the computer package:-

$$\frac{d_s}{y} = C_1 \times \{\left(\frac{v}{vc}\right)^{c2} \times (Fr)^{c3} \times (b)^{c4}\} \tag{2.12}$$

Where, C_1, C_2, C_3, C_4 were the constants of the equation which was calculated through the non-regression analysis of the STATISTICA computer model.

And the constants are:-

C_1=7.51, C_2=0.751151, C_3=0.764262, C_4=0.178201.

The results from the experiments regarding scouring are:-

1.) Maximum depth of scouring was observed at the head/nose tip of the groyne.

2.) The scour depth increases with increase in the Froude's number, flow depth and flow velocity.

3.) The scour depth was increased about 20% by increasing the spacing between the groynes about 0.5 from the length.

Hamid Shamloo et al (2014) carried out work on "Numerical simulation of the angle of the groyne installation on the separation zone length behind it". This paper compares the numerical results of the researcher work with the experimental data proposed by **yeo et al (2005)**. **Yeo et al (2005)** performs 69 experiments in total to examine the separation zone in the downstream side of the groynes by varying groyne length, installation angle and degree of permeability. The flow in the main water way along the reach is divided into three areas. First section of the velocity separation or the velocity variation i.e. on the upstream side of the first main groyne. Second region is of the vortices formed behind the groyne and reverse flow due to the obstruction of the second spur. Third region is of the reattachment zone in the downstream direction. There is formation of eddies in the neighborhood of the groyne due to the incoming flow. The smallest eddy formed have its center at a distance equal to length of groyne and the largest eddies formed in the downstream direction of the smallest eddy have its center at a distance of approximately six times the length of the groyne. The channel slope and bed roughness was considered zero. Fluent software was used to carry out the numerical simulation. Flow parameters were calculated using the Navier-stokes equation using the finite volume method and turbulent flow field was calculated using the Reynold's stress turbulent model. One order implicit equation was used for the temporal discretization and second order differential equation was used for the space discretization. Very fine mesh was created near the groyne tip and wall boundary so as to carry out the accurate results. Inlet and outlet boundary conditions were defined along with the velocity set up equivalent to the mean velocity at the inlet of the flow. The boundary conditions were satisfied at the wall of the flume so as to satisfy the no slip condition at the boundary. The first grid point was formed near the wall. The data collected from the numerical simulation for the separation zone behind the groyne confirms the accuracy with the experimental data of the **yeo et al. (2005)**. The results will show the effect on the turbulence flow field in the presence of the groyne. The results also provide that the velocity variation will increase along with increase in the groyne installation angle and its value also confirms the accuracy with experimental values in the paper of yeo et al. also the angle of incidence confirms the results as the incidence angle was calculated from the equation:-

$$\text{Incidence angle} = -1.662\ (\text{groyne length} / \text{channel width}) + 5.031 \tag{2.13}$$

And comes out to be 4.78 degrees for the groyne of length 30cm and confirms with the numerical data. The separation zone for the impermeable groyne was 12 times the groyne length of 0.3m.

S. Amini et al (2015) carried out work on "Experimental study of scour depth in attracting groyne series". Total 27 experimental runs were done with the arrangement of three groynes in series made from stone grains. Discharge was varied during the experiment three times. At a particular discharge scouring values were observed with variation in the ratio of S/L (where S is the distance in between the groynes and L is the length of groyne in transverse direction.). Groynes were arranged in series at different orientation of 90, 120 and 135 degrees with the horizontal. After experimental run it was observed that maximum scour was at the nose tip of first groyne and bed formation extend up to the second groyne. Using the data of 27 experimental runs an equation was given through linear regression having $R^2 = 0.85$ to calculate the scour depth empirically:

$$\frac{z}{g} = 1.2\left(\frac{S}{L}\right)^{0.16}\left(\frac{90\theta}{180}\right)^{-3}(Fr)^{-0.047} \tag{2.14}$$

Aminuddin Ab. Ghani et. al (2016) carried out work on "Temporal variation of clear-water scour at compound Abutments". They studied the temporal variation of local scour at compound abutment experimentally under clear water conditions. Another objective of the study was to determine the similarity and difference temporal variation of scour depth at compound abutment and pier. Uniform as well as compound abutments were selected for the experiment. Compound abutment is the abutment made up of two cross sections. These abutments were short abutments. Melville (1997) statement was used to characterize them as short abutment (abutment with ratio of length to flow depth less than one considered as short abutment ($L/y < 1$)). Velocity measurements were done with the help of current meter that can measure the velocity up to 5cm/sec. Verification of the flow measurements done with the help of weir located at the downstream of the flume. Duration of the experiment was large as development of the scour hole never stops so the duration goes up to 50 hr. to 84 hr. the scour formation stabilized after duration of 42 hr. and only scour of 1mm was observed for every 7hr interval. Three cases were discussed as in case 1, the foundation is below the scour depth. In case 2, the level of foundation just touches the scour depth and in third case, the depth of foundation is exposed to the atmosphere due to scouring. It was seen that the local scour near to compound abutment was time dependent.

S. A. Salamatian et al (2016) carried out work on “Flow pattern and stress distribution around three spur dyke in ninety degree bend”. This paper presents the 2D flow pattern around 3 spur dykes in curved channel using 2D velocity meter. There were many researchers who studied the flow pattern around spur dyke in straight as well as in meandering channel but rare investigation was available about the flow in 90 degree bend so this paper add some information to that analysis. The spur dykes was made of Plexiglas. The flow imagining was carried out by releasing the potassium permanganate and then photography to trace the flow of the material. Some experiments were run for the 114 hours but the stability stage was considered 25 hour for all experiments and the velocity was almost constant after the 18 hour of the run. The maximum scour was observed in the 75 degree of the bend.

When the spur dykes located at 30, 35 and 40 degrees. There was velocity separation detected before the first groyne and that was approximately comes out to be 0.78 times of the groyne length. There were two types of flow exist in between the controlled area of the spur dykes. One is the down flow formed after striking with the surface of the groyne and move towards the downstream side along with the reverse flow formed from second dike to first dike. The combination of these two types of flow cause vortices around the nose tip of the groynes which initiates the process of scouring. Spur dykes were located at other angles with the interval of 5 degrees up to 70 degrees and it was observed that length of separation zone was increased with increasing angle of installation along with increase in the reverse flow. The value of shear stress was more in third spur dyke than that of other spur dykes because in other spur dykes there is more dissipation of energy through movement of sediment transport. From these conditions it can be concluded that the length of separation zone decreases but width remains constant.

Akash Pasher, N. K. Tiwari and Subodh Ranjan (Mtech Scholar) carried out work on “Local Scour associated with angle spur dyke”. The main aim of this study was to study the effect of scouring around groynes and relation between the scour hole and flow parameters. The experiment was conducted in the lab of NIT, Kurukshetra. Total 24 models of groynes was prepared in five different groups (30, 45, 60, 75, and 90). The sand bed have d_{50} equal to 0.18mm. The duration of the run of each experiment was 180 minutes. The results of the experiment can be concluded that:-

1.) The scour hole is steep on the upstream side and extended on the downstream side (due to higher flow energy and turbulence in the upstream than downstream).

2.) Shape of scour hole was similar to reversed frustum cone with its vertex downward shows the depth of maximum scour near nose tip of the groyne.

3.) Downstream length of scour hole is more than that of upstream length by factor of 2 and 4 times of scour hole depth respectively. Similar relation was observed with the length of groyne in the transverse direction in place of depth of scour hole.

4.) Length and depth of scour hole increase with increase in the contraction ratio.

5.) The angle 30 degree have good performance than that of other groynes (scouring is less as compared to other groynes).

6.) The Froude no. does not have any relative relation with the shape of the scour hole.

Giglou et al (2017) carried out work on “Numerical study on the effects of Spur Dikes on Sedimentation pattern”. Numerical modelling was done to know about the effects of spur dikes on sedimentation pattern with variation of distance and orientation of groynes. Numerical model had to be calibrated for further studies so experimental results of Heltz’s. Flow 3D software was used for the numerical simulation which solves the three dimensional equations of Navier-Stokes equation. There is interface between the air and fluid at free surface flow so to analyze that VOF method was used. Fine meshing was done near to spur dike and broad structure was formed away from the groynes with triangular mesh. Spur dikes were installed with different orientation and spacing in between the groynes to study the effect on sedimentation pattern. Two dimensionless ratio was also involve in the study to show length and width of return flow. With different orientation of the groynes, it was observed that width of vortex was more with more angle of groyne with the flow. Change in vortex pattern is more for 45 degree, 75 degree than 105 degree and 120 degrees. Length of return flow was increases with increase in the distance between the groynes for attracting type of groynes whereas decreases for the deflecting types of the groynes. Two dimensionless parameters D/L and W_v/L was used to determine the length and width of return flow. When D/L ratio is between 1 and 1.5 then length of return flow is more for deflecting type and when it lies between 2 to 3 then it was more for attracting type of groynes. Sedimentation area was increased with increase in angle of groynes with the flow. For angle of 45 degrees to 75 degrees the sedimentation area increased from 71% width and 92% length. When distances between the groynes was increased with constant length of the groyne then length of vortex increases with increase in the sedimentation area and it was concluded that when ratio between the length of spur dike to distance between spur dikes was less than 2 then flow perfectly enters with complete formation of vortices.

2.3 Objective of the study:

There has been a lot of data available on scouring around straight partially submerged impermeable groyne experimental as well as numerical modelling but rare data is available regarding permeable groynes. From the literature review, it is found that permeable groynes are more cost effective than the impermeable groynes and they can be employed in place of impermeable groynes. So aim of this study is to experimentally investigate:

1) Estimate depth of scouring at the head/nose tip of permeable as well as impermeable groyne with variation in contraction ratio.

2) Comparison in between permeable and impermeable results so as to find out the best one at same flow parameters.

CHAPTER 3

EXPERIMENTAL SETUP AND MATERIALS USED

3.1 Introduction

This chapter includes the detailed information about the experimental setup and materials used to achieve the objective of the study. Most of the instruments were provided by the Advance Hydraulics Laboratory of Delhi Technological University, Delhi.

3.2 Instruments used for Experimental work

3.2.1 Tilting flume:

Tilting flume is a man-made open channel which is used to develop a relation between discharge, flow depth and other flow parameters. This is just like a model of open channel flow of river in which free flow flows under gravity made to small scale ratio. Flume framed in confined dimensions to make a fixed hydraulic structure to use it in laboratory so that critical depth, critical velocity and other flow properties can be analyzed. There are various types of flume available in the market. Tilting flume having bend at 90 degree, 180 degree and having sinusoidal shape to study the effect of structures in meandering channel. Here, according to the requirement flow measurement flume having straight cross section was used.

Figure 3.1: Straight Tilting flume used in experiment.

The Tilting flume used for the study of this experiment is of dimensions of length 8m, width 0.3m and depth 0.4m. These dimensions taken from center to center of the flume frame. Flume is supported by steel frame along with acrylic glass plates on the wall of the flume so as to maintain the transparency of flow in the flume. Transparency help in imagining of moving sediment during experiments. Recirculation tank was fixed on the downstream end of the flume from where the fluid was recirculated in the flume.

Figure 3.2: Recirculation tank attached to the tilting flume.

Centrifugal pump is fixed at one downstream end of the flume near to the recirculation tank to maintain the discharge in the flume with the help of inlet valve. Small motor is fixed at the bottom of upstream end to adjust the slope of the flume.

There are two gates fixed in the flume, one on the upstream side i.e. head gate and other one on the downstream side of the flume i.e. tail gate used for maintaining the depth/head of flow in the flume. Initially the flume have to be checked for any leakage otherwise there may be error in the result.

3.2.2. Velocity measurement: Flow probe FP111:

Velocity measurements was done with the help of flow probe digital velocity meter (Model FP111). Flow probe is digital device based on the principle of propeller movement just like propeller used in current meter. Mechanism is similar to conventional current meter but this is the advanced version and allow the procedure of velocity measurements to complete with more speed and accuracy. The flow probe consists of longitudinal stick type arrangement made up of anodized aluminum light weight material due to which it is easy to hold during the experiments. The height of the flow probe that can extend from 1m to 1.7m approx. which make it clear that it can be used in both field and laboratory.

Figure 3.3: Flow probe velocity meter used for measurement of velocity (source: Global water solutions).

The propeller unit is housed at end of the flow probe in the circle of 2inch diameter which is sand or mud proof and other end i.e. at top there is large LCD display unit that shows the velocity of flow with the accuracy of 0.1 FPS. The LCD display is the detachable automatic unit which is connected to the propeller stick by pivot joint. LCD display run with the help of non-replaceable battery housed in it and have battery backup of around 5 years (approx.). There are four button on Digital display through which we can have the minimum, maximum and average values of the experimental run. It can store about 30 reading for future use. The reading is displayed in both FPS and MPS unit. Velocity measurements were done at the heap/nose tip of the groynes as well as in between the groynes so as to determine the velocity with more accuracy. More readings were taken to show the variation in incoming velocity of flow and the velocity vary along the length of the flume due to engagement of groynes.

3.2.3. Groynes/spur dykes

As we know these are the most important part of this study, groynes are the hydraulic structures which are constructed to protect the bank in such way that one end of it is fixed to the bank of river and other one remain open in the current flow of river. To study the flow parameters and effect of scouring, models of groynes was prepared with the wooden board. The study is based on maximum depth of local scouring in permeable and impermeable groyne along with their comparison. Each type of groyne model was prepared 5 in number i.e. total 20 in number. 10 groynes (permeable and impermeable) are of full length and 10 with different contraction ratio. These were termed as short length and full length groyne according to the criteria defined by **Melville (1997)**. These models were prepared with the suitable wooden board that cannot swell during experiment. Drilling machine was used to make holes in wooden groynes so as to make them permeable. All groynes are of straight profile. It should be kept in mind that groyne will remain dry before running of the experiment.

3.2.4 Point gauge

Point gauge is an instrument to measure the depth of flow, depth of scouring i.e. instrument which is used to measure the longitudinal (vertical) readings. This consists of a graduated ruler fitted to a movable trolley mounted on the rails of the flume so that readings can be taken with accuracy along the length of the flume. Zero error should be checked of the point gauge before using it in the measurements. Longitudinal length of the graduated point gauge was 1.5m used for this experiment. Ruler is movable with the help of screw available on the graduated ruler.

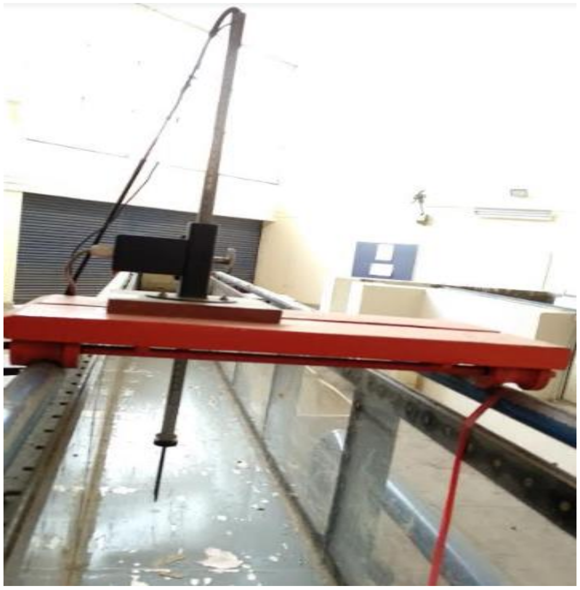


Figure 3.4: Shows graduated point gauge for the vertical (depth) measurements.

3.2.5. Scouring material:

Scouring material chosen is a type of non-cohesive matrix. Non-cohesive matrix is a material which is formed by mixing different proportions of the soil material. Soil material consists of cohesive as well as cohesion less material. Cohesive material is not used during the experiment because of its cohesive property. Cohesive ness of material increase its shear strength due to which it becomes difficult to dissipate the particles from their original position. More flow velocity is required to detach the soil particles from their position as more force is required to overcome the cohesive ness of material along with its submerged unit weigh that’s why sand is used as scouring material. According to IS code the soil classification includes:

Boulder: - 80mm – 300mm, Gravel: - 4.25mm – 80mm

Sand: - 0.075mm – 4.25mm, Silt: - 0.002mm - 0.075mm

Clay: - <0.002mm

The material used in the experiment have mean diameter (d_{50}) of 0.2143mm which is characterize as sand and found out with the help of sieve analysis. Sand used should be devoid of any impurity and bigger size particles that can produce erroneous results. The thickness of sand bed formed in the flume is calculated using the equations recommended IS code and sieve analysis was done to calculate the mean diameter of the cohesive matrix used.

3.2.6 Trowel/Scraper/Blade

Trowel/scraper/blade any one is required to make the uniform flat sand bed. Levelling of sand bed is necessary to reduce the error in depth of scour measurements and geometrical features of the scour hole can be analyzed. A small scraper blade was used in front of the flow to reduce the effect of turbulence of the flow. The turbulence created in the flow can enhance the scour measurements and disturbs the mechanism of scouring which are not comparable to the natural measurements. After every experimental run sand bed made uniform so that depth of scouring can be compared between different experiments.

3.2.7. Meshing wire and sack bag

Meshing wire and sack bags are used to retain the scoured sand of flow to accumulate inside the recirculation tank. As the water is recirculated from the same tank again and again through the centrifugal pump so it is necessary to avoid the setting of sand inside the tank that may damage the functioning of pump. Meshing wire and sack bag are fixed at the downstream end of the flume that entrapped the scoured sand otherwise tank have to be cleaned before running of each experiment. The other option to prevent settling of sand inside the recirculation tank is to provide two sources: one is to circulate the flow inside the flume and other one is to drain the water of flume i.e. same water is not recirculated inside the flume but this method leads to a lot wastage of water.

3.2.8 Sieve shaker and weighing scales

Sieve shake is a device which is used to shake the different sieves arranged in the decreasing order. This is used during the particle size analysis of sand material. Sieve shaker used is mechanical mixer type connected with the electrical motor having a time knob on it. The shaker used for 10 minutes. Weighing scale also used to measure the amount of sand retained over the different sieves. Initially the sand sample is weighed. 1kg of sample was taken over the first sieve and then the material retained over the different sieves are measured after completion of shaking to plot the graph. Graph plotted used for determining the median particle size of sand.

No.	Sieve size
1	10.0mm
2	6.3mm
3	4.75mm
4	3.35mm
5	2.36mm
6	1.7mm
7	1.18mm
8	825µm
9	600µm
10	425µm
11	300µm
12	212µm
13	150µm
14	63µm

Figure 3.5: Arrangement of sieves in decreasing order (Source: Slide share uploaded by John G. Luwalaga)

Figure 3.6: Procedure for weighing of sand (Source: Slide share uploaded by John G. Luwalaga).

CHAPTER 4

EXPERIMENTAL METHODOLOGY

4.1 Introduction

In this chapter we are going to discuss the detailed description of:-

i. Design of groynes adopted for the estimation of scouring depth during the experiment.
ii. The experimental procedure adopted i.e. work done for the experimental run.

4.2. Design of groynes

Design of groynes include the dimensions of the groynes used for the experiment. Groyne used in the experiment installed in series of 5 at one time. When groynes installed in series then the importance of Dimensions (length, width and height), spacing of the groynes increased. Design used in the experiments belongs to the specifications given in the IS code 8408-1994 (design of groynes).

4.2.1. Design specifications of Groynes

Design specifications given by the IS code for stable functioning of the groynes to minimize the depth of scouring around the groynes. These specifications increase the design life of the groynes by reducing the effect of flow over structures. The specifications given by IS code by considering the available previous data for specific recurrence interval (recurrence interval is the time period for the maximum rainfall/flood that have to be experienced by the structure in future). These factors come into action only when groynes are arranged in series.

i. Length of groynes:

Length of the groyne is the lateral distance measured normally from the bank of the river to the head/nose tip of the groyne. The length of the groyne should be kept in such a way that the scour hole made is away from both banks of the river. If the length of groyne is short then there is less effect of the groyne and scour hole formed affect the bank of the river. The long length of the groyne constrict more width of the river and concentrate more discharge in less area which increase the effect of scouring mechanism on opposite bank so the length of the groyne should be kept in permissible limits. To define the limits of length of groyne, it should be kept more than $2.5D_s$. Normally, the length of the groyne provided as 20% of the width of the river but if the river is wide, shallow, braided then it should not exceed 20% of the width of river. For site specific conditions, experimental work should be done to find out the length of the groynes. More length of the groyne can lead to adverse effect in the downstream reach of the river by entrapping most of the sediments in between the groynes and development of retrogression effect.

In this present study, groynes are used with different length as to measure the variation of scouring with contraction ratio (contraction ratio can be defined as ratio of width of the groynes to the width of the river) in both permeable and impermeable groynes. The length of the groynes kept as 12 cm and 7cm termed as full length and short length groyne respectively, to show variation in depth of scouring. Short and long length groyne is described by Melville (1997) on the basis of length of structure and depth of flow in channel. Here, ratio of length of groyne to depth of flow comes out to be less than 1 for short groyne otherwise long length groyne.

ii. Spacing of the groynes:

Spacing of the groynes also affect the occurrence of scouring around the groynes. To understand the effect of spacing on scouring we have to know about the mechanism of scouring which is discussed as above in the introduction part. The mechanism include generation of wake vortex due to downward movement of flow after striking the groynes, hard vortex formed due to reduction in velocity after striking the groynes and conversion of that velocity to potential energy when boundary layer detaches from the surface of groynes and horse shoe shape formed in between the space of two groynes. Wake vortex and hard vortex combined form the negative pressure gradient at the nose tip of the groyne which is the reason for formation of scour hole. So this process of scouring affected by varying the spacing of the groynes. The spacing given in the IS code as 2 to 2.5 times of the length of the groynes. we can see, the spacing is linked to the length of the groynes and length of the groynes linked to the depth of scouring so there is direct relation can be maintained between spacing and depth of scouring. The spacing can be kept more than 5 times to 6.25 times of D_S. The spacing of the groynes kept at 30cm to 35cm which is almost similar to the spacing mentioned in the IS code.

iii. Top level of the groyne:

Top level of the groyne is the distance between the top surfaces of flow and groyne. This top level or the space left is termed as free board while designing the structure. This is provided to compensate the high flood level in the river that prevents it from overtopping. After overtopping of the structure mechanism become complex and difficult to analyze movement of vortices formed around the structure. If structure is designed as partially submerged and flow overflows the structure then it will be dangerous for the neighborhood. This free board provided depend on the type of groynes as it is partially submerged or fully submerged. Generally, the free board is kept as 1m to 1.5m. The spacing left in the experiment is around 2.5cm to 3cm as experimental study is based on partially submerged groynes.

iv. Top width of the groyne:

Top width of the groynes is the thickness of the top. Normally, it should be 3m to 6m. Top width of groyne in experiment is the thickness of the wooden board used that is 2.5 cm. Top width of the groynes can be used for some natural scenic beauty depend on the area where they are employed.

v. Other specifications of the IS code include:

Provision for the side slopes, pitching, size and thickness of pitching. These provisions were not considered here as groyne is of straight type that eliminate the use of side slopes whereas pitching is a remedial measure provided to the structure against scouring which totally contradicts with our experimental study. Slope is provided on the sides of groynes also act as remedial measures for the groynes as side slope reduce the direct attack of water on the structures.

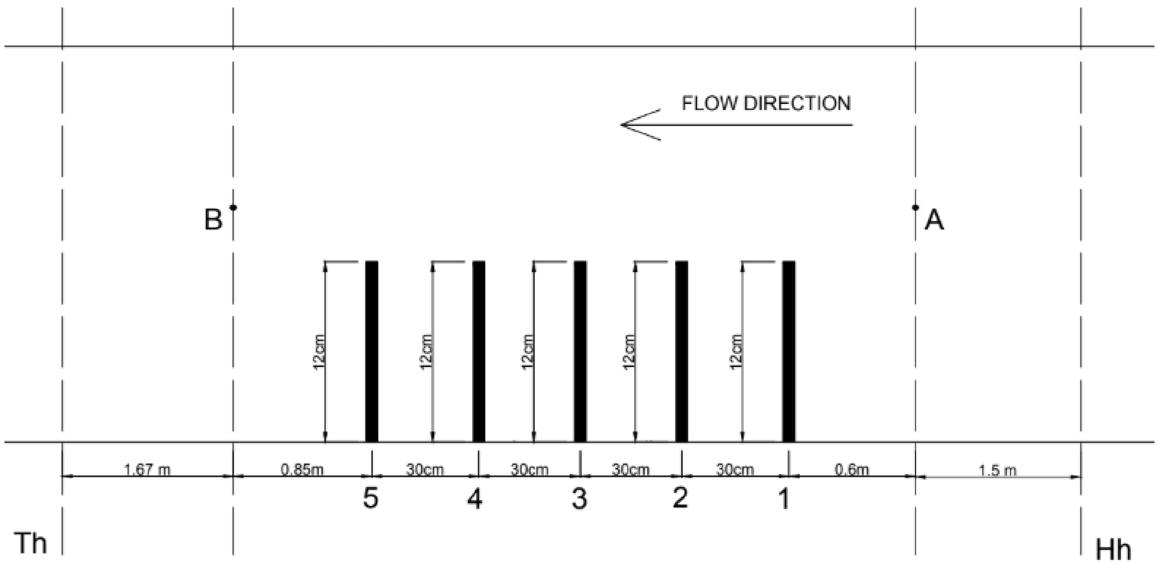


Figure 4.1: Overview of arrangements of straight groynes.

20 groynes model was made in total with the help of wooden board. 10 are of impermeable groyne and 10 are of permeable groynes out of which 5 of each type are of different contraction ratio. So there are 4 groups of 5 groynes. The permeability was introduced in the groynes with the help of drilling machine. Holes are made in the impermeable groyne to make it permeable.

4.3 Configuration of the groynes

Here are some images taken during experimental work that shows arrangement of the groyne in the flume:

i) Impermeable short groynes:

These are the impermeable groynes which cannot allow water to pass through it. Two types of groynes were analyzed in impermeable groyne with different contraction ratio. Full length impermeable groyne of length 12 cm and short length impermeable groyne of length

7cm to know the variation of scouring with contraction ratio. Short and long length groyne categorized depend on the ratio of length of the groyne to depth of flow (Melville 1997). If ratio comes out to be less than one then it is short length otherwise long length groyne.

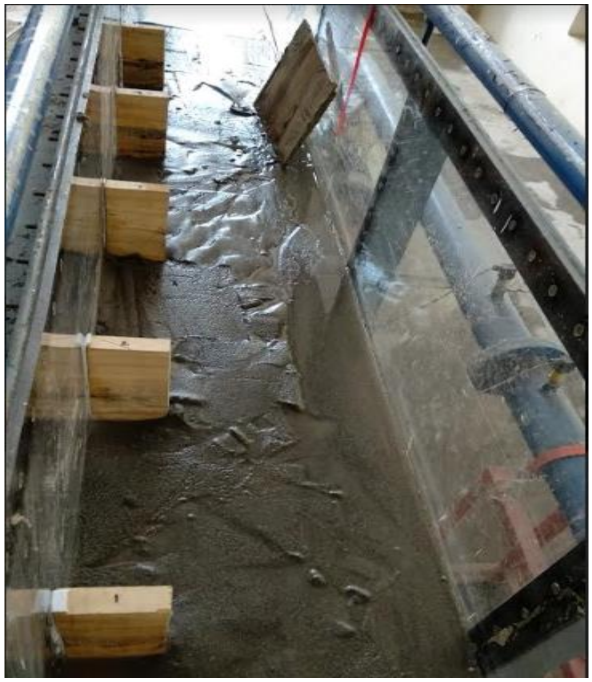


Figure 4.2: Placement of Short Impermeable groynes.

ii) Arrangement of permeable groynes:

Permeable groynes were formed with similar cross section as that of impermeable ones. Holes are made to induce permeability in the cross section with the help of drilling machine. Permeability can be find out by deducting the area of holes drilled in the total cross section of the impermeable groynes. These groyne are similar to timber, blade, vertical bars arranged in permeable structure provided with spaces in between them like a screen in the field. Permeability provided is sufficient to slow down the flow velocity and entrapped sediments in between them. These groynes are analyzed at the same discharge as maintained in the impermeable groynes. In this case also full length and short length permeable groynes were formed depending on the contraction ratio.

a) Straight Short length permeable groynes:

Cross section is similar to the short length impermeable groyne but permeability is induced in this case. Permeability induced is order of 23% with the help of holes made by drilling machine. Length of groynes is 7cm in the transverse direction.

(1) (2)

Figure 4.3.1: Placement of Permeable Short groynes.

Figure 4.3.2: Placement of full length Permeable groynes.

ii) Straight Full length permeable groynes:

This is similar to full length impermeable groynes with difference of permeability in the cross section. Permeability induces is of order 40% with holes drilled in the cross section with the help of drilling machine. Length of these groynes kept 12cm in the transverse direction from the wall of the flume.

4.4 Experimental Methodology

Experiments are carried out in the Advanced Hydraulics Laboratory of Delhi Technological University, Delhi to measure the depth of scouring around both (permeable and impermeable) groynes. In the present study, the main aim is to find out depth of scouring around permeable and impermeable groyne keeping discharge constant in each run. Discharge is kept constant in each run so that we can compare their independent results and build a satisfied relation between them. Results of two different parameters can only be compared when one element is variable and other elements remain constant throughout the process that's why almost all other elements remain fixed during experimental run. Straight tilting flow measurement flume is selected to carry out the experiment of dimensions length 8m, width 0.3m and height 0.4m. Slope of the flume fixed to 1/2000 throughout the whole procedure. Water tank is fixed at one end of the flume along with the centrifugal pump attached to it to recirculate the same water again and again in the flume. Sand bed of uniform depth 7cm approx. is made inside the flume and levelled with the help of scraper blade. The uniformity of sand bed is checked with the help of graduated point gauge along the length of the flume. Before filling the sand in flume the leakage in the flume should be checked along with the leakage from the discharge inlet valve. Discharge is checked initially before initiating the experiment and after that discharge is kept constant for whole experimental runs. After making up of sand bed inside the flume arrangements were made to install the groyne at suitable places. Markings are done on the glass plates of the flume according to the design consideration used for the study. Markings should remain same for all other experiments also so that positions of the groynes remain same for each experiment. Groynes are installed with the help of double tape which act as adhesive and keep them at a fixed position during the run. After installation of the groynes, flat sand bed readings are taken at the head/tip of each groyne where major scour hole expected to be formed. Extra reading were taken at two points fixed at 'A' upstream of the first groyne and 'B' point at the downstream end of the flume located at a distance of 1.5m from head gate and 1.67m from tail gate respectively. First groyne is installed at a distance of 2.1m from the head gate. Huge gap is taken from the head gate to first groyne to reduce the effect of turbulence in readings. These two points A and B are chosen to analyze the scouring in the beginning and deposition at the end. Now, the problem arises in the working due to accumulation of scoured sand inside the recirculation tank because the tank is connected to the pump and if pump sucked out the scoured sand then pump can be chocked. To overcome this problem arrangements are made by using the sack bag/mesh wire of suitable size at the downstream mouth of the flume that entraps the scoured sand Otherwise clean the tank after every run to protect the centrifugal pump from damage or arrange two different source of flow. One for the incoming of flow inside flume and other one for draining water from the flume. After all the necessary arrangements made then pump will be switched on.

Figure 4.4: Partially submerged condition in flume during experiment.

Water is allowed to flow inside the flume at constant discharge for time until scouring is stabilized in the flow. Each experiment is allowed to run for more than 60 minutes till the flow is stabilized. Stabilization refers to the condition when scouring around the structure become very less. During the experiment excessive scouring is observed in the initial 20 minutes then scouring is less but can be observed. After the experimental run of 45 minutes the flow is stabilized such that lifting of sediments is very less and cannot be observed from the transparent glass of the flume. Scouring is more in initial stage and reduces with time due to reduction in intensity of vortices formed around the groynes with time in the downstream direction. The depth of flow inside the flume is made constant with the help of head gate and tail gate located in the upstream and downstream side of flume. Head gate open slowly to drain the bed initially. The sand is like loose material on the surface so water is allowed to flow slowly over it in the initial stages otherwise it will scoured the surface more than usual readings. Depth of flow was maintained according to partially submerged case by closing the tail gate and opening of the head gate. System is allowed to stabilize for some time till flow attains its dynamic mechanism before measurements of velocity. Each experiment was run for a duration of more than 45 minutes depending on the stabilization condition achieved by the flow. Velocity is measured with the help of flow probe velocity meter (FP111). Velocity measurements are taken after stabilization of the flow (after 30 minute) at each tip of the groyne, spacing between the groynes and at two fixed points (A and B). Coordinates of the points where velocity measurements are taken kept same in all the experimental run. Velocity is measured at coordinates of (14.5, 11.8) in long length groynes where as it is (9.5, 11.8) in short length groynes. Velocity reading measure with one point method i.e. the velocity reading were taken at average depth of flow. The average depths include 0.6 times of depth of flow from the top surface of the flow. Velocity readings were taken at different points to show the variation in velocity along the flume due to placement of groynes and to determine the average velocity with more accuracy. Average comes out to be more near to the true value when values taken were more. After measurement of velocity, flow was allowed to flow till stable scouring conditions achieved in the flume. Pump was switched off and water is allowed to drain off from the flume. Measurements of formed scour hole was taken with the graduated ruler mounted over the rails of the flume. Depth of scouring can be measured by deducting the initial and final readings of sand bed. The shape of the scour hole can be drawn on the paper for future reference which shows the shape of the scour hole. After all the readings, the groynes were taken away from the flume so that other groynes can be placed at same location for further experiments. Again the surface of sand bed made of uniform depth and fill more sand if required. Other group of groynes were installed and repeat the same procedure as above.

CHAPTER 5

RESULTS AND DISCUSSION

5.1. Introduction

In this chapter, we are going to discuss detailed analysis of observations calculated from experiments presented in the form of tables and graphs.

In the beginning of this experiment, depth of sand bed inside the flume is unknown which is just sufficient to show the maximum depth of scouring. If sand bed provided is of less depth then maximum depth of scour still remain unknown due to exposure of flume bed. To find out about the depth of sand bed formula given by lacey's recommended by IS code 8408-1994 is used.

According to Lacey's maximum depth of scour given by:

$$D = 0.473[Q/f]^{1/3} \tag{5.1}$$

Where, Q is the discharge in cumec.

f is the silt factor given by:

$$f = 1.76\sqrt{d_{mm}} \tag{5.2}$$

Where d_{mm} is the mean diameter of the material used for making the sand bed. Mean diameter of sand particles usually taken as D_{50}.

To use this equation for maximum depth of scour we need mean diameter (D_{50}) of sand particle. Mean diameter of particle is d_{50} which means 50% of the particles are finer than this size.

To know about the mean diameter of sand sieve analysis was done in three stages. First sample was analyzed of the sample collected from the sand collected to make up the bed. Second and third sample based on the sand collected from the middle section flume and sand accumulated in the recirculation tank. Second and third sample was taken after completion of the experiments.

5.1.2. Sieve analysis for initial sand sample

Sieve analysis for initial sample refers to the sample which is collected from the fill used to make up the bed inside the flume. To make up the sufficient depth of sand bed particle size is analyzed. In this particle size analysis, sieve of different sizes arranged in the decreasing order and then sample is poured over the first sieve. Initially 1kg of sample is weighed to carry out the sieve analysis. Shaking is done with the help of mechanical shaker for 10 minutes approx. After shaking the sample retained weight on each sieve is weighed and noted down in the tabular form as follows:-

Table 5.1: Sieve analysis for Initial sample filled in flume.

Sieve Size	Wt. Retained	Wt. Retained (gm)	Retained %age	Cumulative Wt. Retained	Cumulative %age Retained	% finer
2.36	0.005	5	0.5	5	0.5	99.5
1.4	0.007	7	0.7	12	1.2	98.8
1.18	0.015	15	1.5	27	2.7	97.3
1	0.012	12	1.2	39	3.9	96.1
0.5	0	0	0	39	3.9	96.1
0.425	0.015	15	1.5	54	5.4	94.6
0.3	0.23	230	23	284	28.4	71.6
0.212	0.229	229	22.9	513	51.3	48.7
0.18	0.245	245	24.5	758	75.8	24.2
0.15	0.077	77	7.7	835	83.5	16.5
0.075	0.048	48	4.8	883	88.3	11.7
0.063	0.01	10	1	893	89.3	11.7
0.05	0	0	0	893	89.3	11.7

Initially 1 kg of sample was taken to carry out the sieve analysis and then different weight of material retained on each sieve is note down. We need median particle size i.e. d_{50}. D_{50} means that 50% of the particles are finer than this size. To find out the median size graph to be plotted between sieve size on X-axis and percentage finer on Y-axis as:

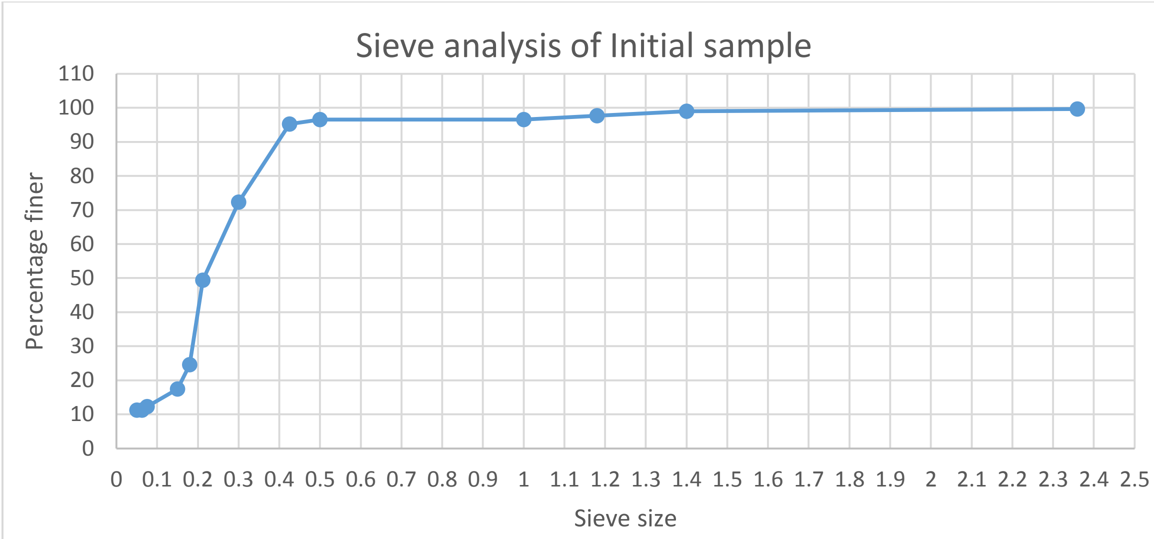


Figure 5.1: Graph plotted between sieve size and percentage finer for initial sample.

From the graph median size comes out to be 0.2143mm.

This median size used to measure the depth of sand bed which comes out to be 5cm. Sand bed made uniform in the flume of depth 7cm throughout the flume.

Now, the groynes were installed in the flume to carry out the experiment.

5.2. Impermeable groynes

Impermeable groynes are the structures which provide direct obstruction to the flow. Due to direct obstruction provided to the flow there is generation of complex and different types of vortices around the groynes. These vortices enhances the depth of scouring around the groynes and may leads to collapse/failure of the structure by exposing foundation to the atmosphere. So investigation becomes necessary to find out the maximum depth of scouring which further defines the maximum depth of foundation that have to be provided for the stability of the structure.

In this experiment, 10 models were made of impermeable straight groynes and maximum depth of scouring is calculated in partially submerged condition. Scouring is calculated with different contraction ratio of groynes. One is full length impermeable groyne (SFLIG) of 12 cm in the transverse direction and other one is short length impermeable groyne (SSLIG) of length 7cm.

5.2.1. Straight Full length impermeable groyne (SFLIG)

Full length impermeable groyne is made up with length of 12cm in the transverse direction having 40% contraction ratio. This length is more than the length defined by the IS code 8408-1994. Length kept more than the length specified by IS code 8408-1994 because we want to analyze the scouring depth in short cross section.

Velocity is measured around the head/nose tip of the groyne and spaces between the groynes.

Table 5.2: Experimental observation of velocity for SFLIG.

S. No.	Velocity (V) (m/s)	Water depth (y in cm)	Discharge (liter/sec)	Froude's Number
A Point	0.51	5.2	8.5	0.72
SFLIG-1	0.53	5.7	7.0	0.71
SFLIG-2	0.52	5.7	9.4	0.69
SFLIG-3	0.523	5.3	8.7	0.71
SFLIG-4	0.519	4.3	7.2	0.8
SFLIG-5	0.51	6.6	11.0	0.64
B Point	0.508	6.7	11.35	0.65
Average	0.517	5.64	9.08	0.7

Table shows the values of velocity calculated around the head of the groynes.

$$Discharge = Area \times velocity$$

Where,

$$Area = width \times depth$$

$$Area = 0.3 \ \times y$$

Discharge is collected by multiplying the velocity with the depth of water as width of the flume is constant throughout the flume. Discharge comes out to be 0.009cumec. Average discharge can also be calculated from the manning's formula by calculating the manning's roughness coefficient with median particle size of sand.

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{5.3}$$

where,

Q = Discharge in cumec.

n = Manning's roughness coefficient.

A = Area of the cross-section (width and depth of the flow).

R = Hydraulic mean depth which is given by (wetted area by wetted perimeter).

S = Slope of the channel.

Manning's roughness coefficient can be calculated from the relation given by **(chow 1959)** with median particle size of sand as:

$$n = 0.0342 {d_{50}}^{1/6} \tag{5.4}$$

Discharge calculated from these relations comes out to be 6 liter per second somewhat less than the discharge from impermeable case but similar to the conditions of other three cases. Velocity was taken at more than 7 points along the flume so that the discharge can be calculated with more accuracy. Two points are selected, one point 'A' at a distance of 1.5m from the head gate of the flume and other point taken after placement of last groyne at a distance of 1.67m from tail gate. These points will determine about the velocity of incoming and outgoing flow. Incoming and outgoing flow shows variation when flow comes in contact with the groynes. Main (front) groyne placed after sufficient distance of 2.1m to reduce the effect of turbulence on depth of scouring around groynes.

Froude's number can be calculated using the relation:

$$Fr = \frac{V}{\sqrt{gy}} \tag{5.5}$$

Froude's number comes out to be less than 1 so behavior of flow is subcritical in the flume. Subcritical flow means depth of flow is more than the critical depth and flow velocity is less due to more roughness/friction experienced from the wall of the flume.

Flume is allowed to run for 60 minutes in total. Velocity is measured when flow attain its dynamic equilibrium at the head tip and spacing in between the groynes. Condition of dynamic equilibrium is noticed through manual visualization which is attained after 20 minutes of operation.

Velocity variation at the head/tip of each groyne varies from upstream to downstream due to constriction in width of flow and formation of different types of vortices which is clearer from the graph as:

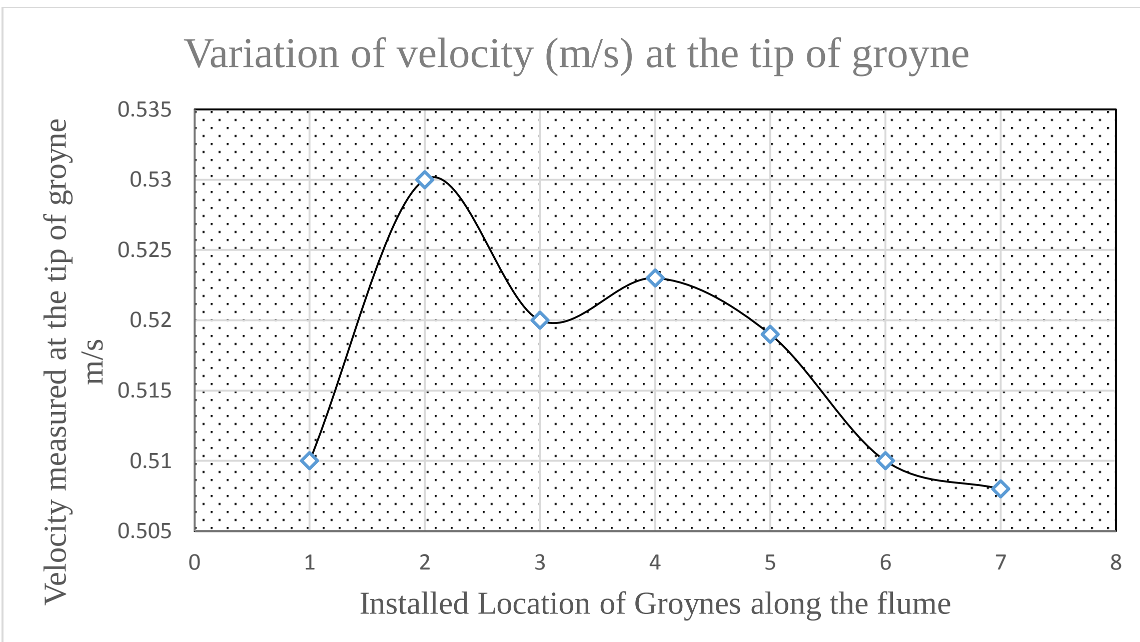


Figure 5.2: Graph plotted between positions of groynes in flume with velocity at their tip for SFLIG.

From the collected data and graph plotted it can be observed that, velocity is increased when flow strikes to the first groynes and then decreases towards the downstream direction of the flume but there is some increase in velocity at the location of third groyne. Velocity is decreased along the length of flume due to losses in the direction of flow and frictional forces that affect the flow velocity. The increase in velocity at third groyne is may be due to formation of hard vortices between the groynes and erosive forces that act at the nose tip of the groynes. Velocity is increased till main groyne and then its intensity is reduced around groyne.

Depth of scour is measured after velocity measurements. It takes around 5 minutes to observe the velocity measurement around the groynes and then flow is allowed to run till scouring around groynes reduces to the minimum value. It is observed that scouring is maximum in initial stages of flow and then diminishes as the flow flows from upstream to downstream side. It takes around 45 minutes to attain equilibrium condition i.e. scouring continues to grow around groynes but the intensity of scouring reduced with time.

Depth of scouring is observed as:

Table 5.3: Experimental observation of scour depth measured at nose tip of SFLIG

S. No.	Sand depth at Nose tip (S_D) (cm)	Depth of scour at nose tip (D_S) (cm)
A Point	4.5	0.4
SFLIG-1	4.3	3.1
SFLIG-2	4.3	0.5
SFLIG-3	4.2	1.1
SFLIG-4	4.1	0.8
SFLIG-5	3.6	1.0
B Point	4.5	-0.6

From the observations in the table, it is observed that maximum scouring is at the tip of first groyne and it keeps on decreasing along the flume towards the downstream direction. First groyne provide direct obstruction to the incoming flow which develop hard vortices near bed of the structure that keeps on reducing in the downstream direction. This can be concluded from the data that, more protection to be provided to the first groyne than other spur dykes. The change in the velocity variation along the length of flume also govern the data of scouring depth. Velocity is increased at the tip of first groyne that have maximum scouring, then decrease at the location of second groyne due to which there is less scouring but at the location of third groyne there is increase in velocity as well as increase in scouring depth. From this we can say that, with increase in velocity depth of scouring is increased.

From the graph plotted between depths of scouring along the length of flume around each groyne it is clear that there is definite relation between the velocity and depth of scouring as when velocity is increased then depth of scouring also increased. Depth of scouring is more at first groyne and keeps on decreasing towards the downstream direction. This shows vortices formed around the groynes keep on reducing towards the downstream direction. Scouring at the head tip of fourth groyne is more than the second, third and fifth groyne. The 'B' point located after the last groyne show some deposition of the scoured sand.

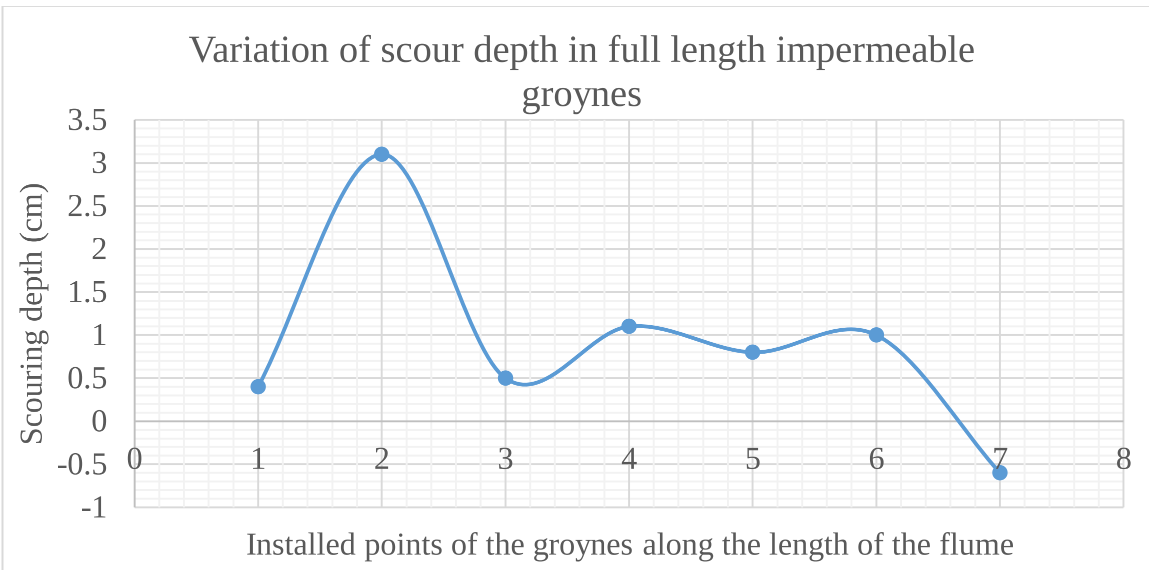


Figure 5.3: Graph shows variation in depth of scour with installed points of groynes along the flume in SFLIG.

Relation between Froude's number and depth of scour can be established which comes out to be more or less same as that of velocity variation with scour depth as:

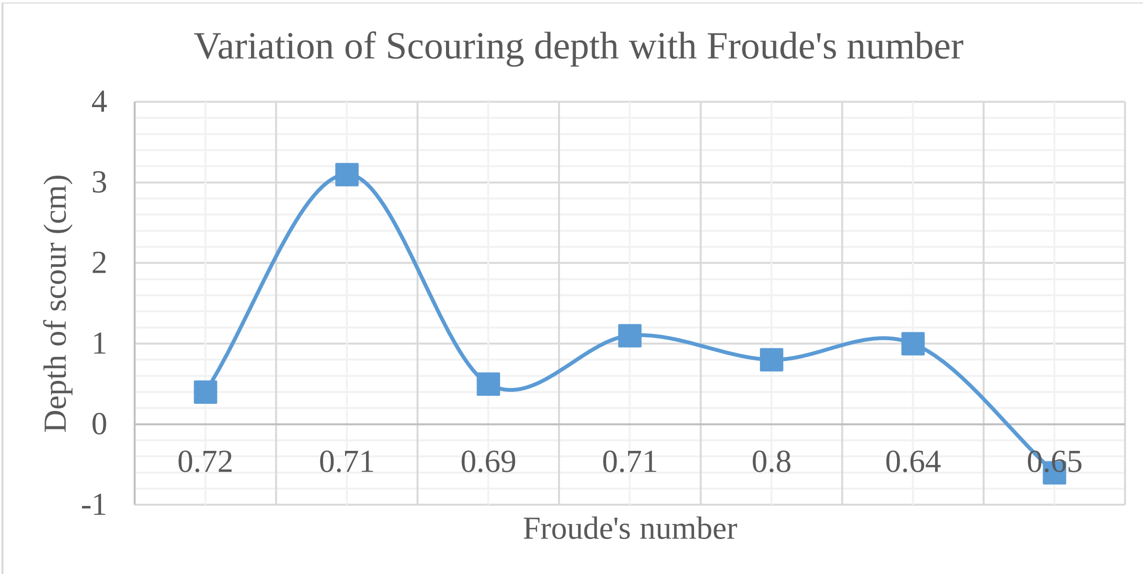


Figure 5.4: Variation in Depth of scour with Froude's number in SFLIG.

Depth of scouring can be seen through the figures captured during experiment as:-

Figure 5.5.1: Scouring around first full length impermeable groyne.

In this figure of scouring around first groyne, scouring almost exposed the foundation of the groyne. It remain fixed to its position to wall of the flume due to the support provided with the double sided tape. This means lateral foundation of the structure of bearing capacity of the bank of river should be high enough to retain the structure. Scour hole formed around first groyne is of cone shaped whose vertex is towards the downstream side. Special attention should be given to the first groyne. Pitching/heavy stones, particle size more than the scoured size can be provided to protect the scouring around groyne.

Figure 5.5.2: Scouring around second full length impermeable Groyne.

From this figure of scouring around second groyne, the scouring is in similar shape to that of first groyne with less depth of scour hole but enlarged in the downstream direction. The reason behind the scouring of less intensity is less flow velocity at this location. Scouring is more concentrated in the vicinity of the groyne which shows flow directly attacked to the foundation of the structure. Foundation is that part due to which provide support to groyne and if scouring weakens that part then it leads to its failure/collpase of the structure.

Figure 5.5.3: Scouring around third full length impermeable groyne.

In the third groyne, scouring is less than that in first and second case. Scouring is enlarged in first and second case in the downstream direction but in this case scouring is less in the downstream direction with less radius of circular shape around nose tip of the groyne. This shows the effect of vortices which created in the front section of the groynes now diminishes as the flow approaches towards the downstream direction but shear stresses are more due to less dissipation of the sand particles.

Figure 5.5.4: Scouring around fourth full length impermeable groyne.

In this case, scouring is less than other groynes due to decrease in the velocity of flow towards the downstream direction.

Figure 5.5.5: Scouring around fifth full length impermeable groyne.

In the fifth case there is negligible scouring around the groyne and at the B point which was set up after the last groyne show some deposition in that area. Deposition also can be seen in between the spaces of the groynes.

As we discussed or mention in the beginning that, length of the groyne in the transverse direction kept more than the normal length specified by the IS code to create the condition that supports formation of more scour around structures so it becomes relatively easy to compare the results of full length groyne with that of small length groyne at same discharge condition. Length of groyne kept more than normal because we want to discuss the scouring in short cross section of flume.

5.2.2. Straight Short length impermeable groyne (SSLIG):

In this, the length of the groyne is cut down to 7cm from 12 cm that makes the contraction ratio of 23%. Contraction ratio can be defined as the ratio of width of groyne to the width of the flume. Scouring is calculated at the head of the groyne in the similar way as that of full length impermeable groyne of 12cm. This is due to the fact that parameters can only be compared when the flow parameters are same. Discharge keeps to be constant in both the experimental run so that results can be compared. Two factors can only be compared when all other parameters are fixed so discharge maintain constant. Velocity measured at the head/nose tip of each groyne which can be observed in tabulated form as:

Table 5.4: Experimental observation of velocity measurements for SSLIG.

S. No.	Velocity (m/s)	water depth (cm)	Froude's number
A	0.2	7.0	0.243
SSLIG	0.43	7.0	0.518
SSLIG	0.38	7.0	0.458
SSLIG	0.33	7.0	0.4
SSLIG	0.27	7.0	0.326
SSLIG	0.3	7.0	0.362
B	0.2	7.0	0.243
Average	0.30	7.0	0.364

Experimental data of velocity varies along the length of the flume and shows a decreasing trend as usual. Froude’s number is calculated in the same way and shows subcritical flow inside the flume. Values of flow depth may be different from the values in full length impermeable groyne but this value does not affect the values of velocity and depth of scouring. Depth of flow is noted down as 7cm at all the points because variation in depth of flow is small so approx. value as 7 is noted down. Discharge is calculated with average velocity and depth of flow come out to be 0.0063 cumec.

Velocity variation at the site of groyne is clearly observed through the graph:

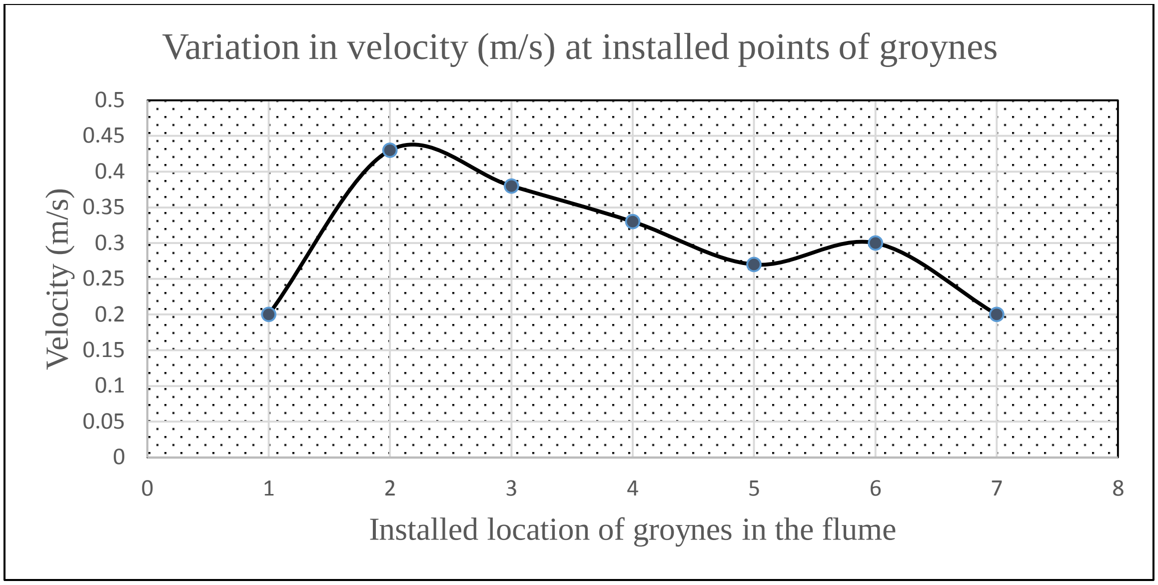


Figure 5.6: Graph shows variation of velocity at the head tip of short length impermeable groynes.

Graph is plotted between installed points of groyne in the flume on X-Axis and Velocity on Y-axis. Graph shows variation of velocity along the length of flume and have decreasing trend. There is increase in the incoming velocity when flow is obstructed by the front main groyne. The increase in velocity is due to decrease in flow width of the flume but after main spur dike flow velocity was keep on decreasing along the length due to obstruction created by the series of the groynes. Now, the question may arises width is decreased with each groyne along the length of the flume but velocity is increased with only main groyne. It is because of the fact that flow experience decrease in area at the site of first groyne from full channel width to constrict width but after that the flow width almost become constant up to the last groyne and that is the purpose for which groyne are employed to increase its effective area of influence. If velocity is reduced then purpose of the groynes will be served which also leads to capturing of suspended sediments in the flow and protection of the banks.

Table 5.5: Experimental observation of scour depth measured at nose tip of SSLIG.

S. No.	Sand depth at Nose tip (cm) S_D	Depth of sand bed at nose tip (cm)	Scouring depth (D_s) (cm)
A Point	10.4	9.5	0.9

SSLIG-1	10.4	6.5	3.9
SSLIG-2	9.5	7.5	2
SSLIG-3	10.2	10	0.2
SSLIG-4	9.7	8	1.7
SSLIG-5	10.3	7.5	2.8
B Point	10.4	12	-1.6

Depth of scouring is calculated by deduction of sand depth calculated before and after the experiment. Negative value in the table shows deposition of scoured sand.

Graph plotted between depths of scouring at location of groynes:

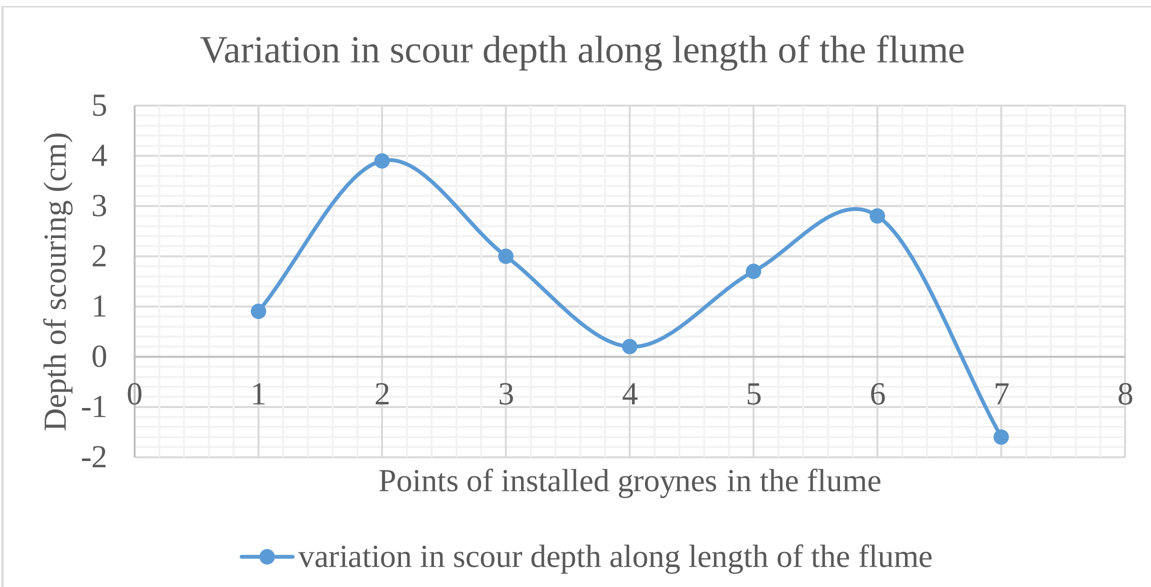


Figure 5.7: Graph shows variation in scour depth at installed points of short length impermeable groynes.

Graph is plotted based on the observed data collected from the experimental runs. In the graph, X-axis shows the points where groyne were installed and Y-axis shows the depth of scouring measured through point gauge at the head/nose tip of the groyne. From the graph it can be observed that, little bit of scouring is observed at the point chosen near to the head gate i.e. ‘A’ point. Maximum scouring is observed nearer to the main spur dike due to more velocity variation at that location. More will be the velocity more will be the scouring. As velocity is reduced along the length of scouring then scouring depth will also reduce along the length of the flume but there is sudden increase in scouring can be seen around the fourth and fifth groyne along with deposition of sediment after the fifth groyne. This may be due to increase in the reverse flow and turbulence created around these groynes. Flow travel from upstream direction after striking the groynes create turbulence after striking the wall of the opposite side due to which velocity is increased at these locations. Scouring is less around the third groyne due to which shear stresses developed are more as shear trying to displace the particles from their position but unable to do that so to counteract that vortices will be generated between third and fourth groyne due to which scouring depth is increase in the downstream direction. Fifth groyne shows more scouring due to increase in velocity.

Scouring around groyne can be seen after the experiment from figures as:

Figure 5.8.1: Scouring around first short length impermeable groyne.

In this figure, scouring around first short length impermeable groyne can be seen. Maximum of the scouring can be seen along the first groyne as compare to that of other groynes.

Figure 5.8.2: Scouring around second short length impermeable groyne.

Scouring around second groyne is less than first groyne due to decrease in the velocity and pressure gradient formed around first groyne. The scour hole formed around first groyne is circular in shape having more radius than scour hole formed around second groyne having circular shape but less radius than that of first one.

Figure 5.8.3: Scouring around third short length impermeable groyne.

Third groyne show almost negligible scouring. The recirculation and other vortices formed around the first and second groyne reduced in this case and there is no scouring around this groyne.

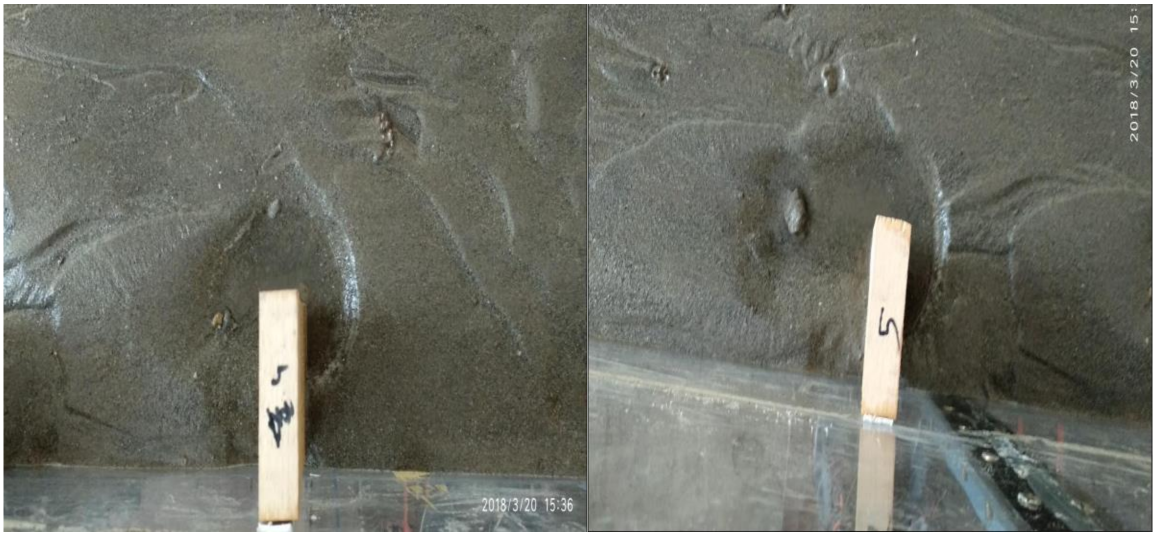


Figure 5.8.4: Scouring around fourth and fifth short length impermeable groyne.

Scouring can be seen around fourth and fifth groyne. Depth of scouring is less than the scouring in first and second groyne but more than that in the third groyne. Depth of scouring is less in fifth groyne than in fourth groyne. Scour hole formed is concentrated near the nose tip of the groyne which shows this scour hole will not affect the bank of the river that means by providing the sufficient measures around the head of the groyne the bank of the river can be protected.

5.2.3. Comparison of velocity and scour variation in impermeable groynes:

We discussed above variation of scour and velocity around the impermeable groynes with different contraction ratio. These groynes were analyzed with two contraction ratio because we want to observe how scour and velocity varies with decreasing the length of the groynes in transverse direction. As decrease in the length of groyne directly affect the construction cost of the groyne. The extra cost of the material can be used for further strengthening of the head and foundation of the groynes as per requirement.

From the graph variation can be observed as:

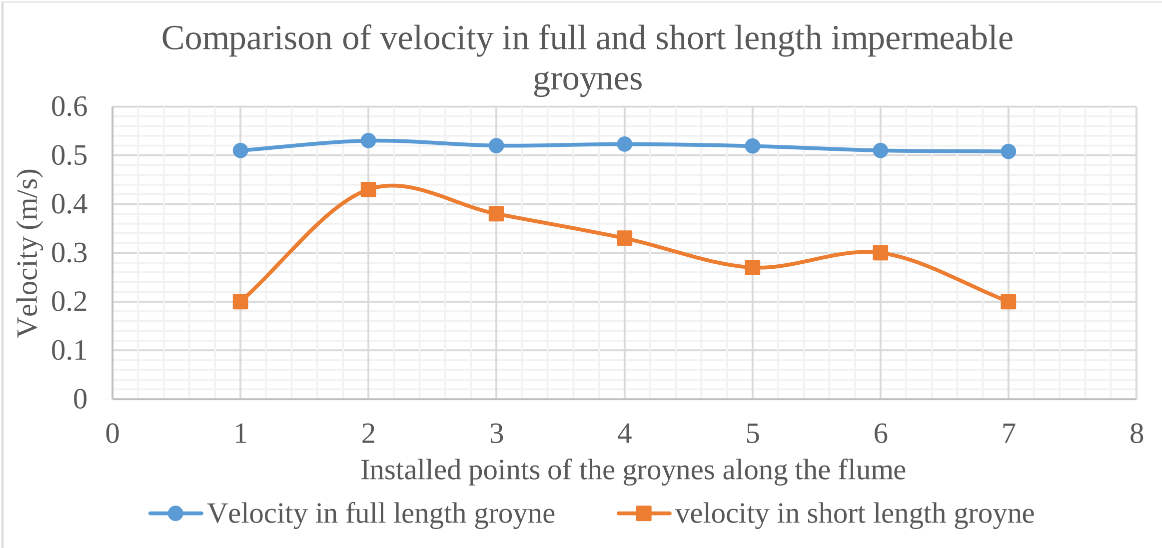


Figure 5.9: Graph shows comparison of velocity variation in full length and short length groynes.

From the graph it can be observed that velocity is decreasing in both the case along the length of the flume but the deviations of velocity values from the mean value is more in the case of short groyne than that in the full length groyne.

In both cases starting and end values of velocity at A and B point respectively are same. Around first groyne velocity is increased due to obstruction created to the flow. But the velocity more deviated from the approaching velocity in short groyne than full length groyne. More deviation of the values means more uncertainty or more instability of the situation. In engineering construction experimental values of that case is more preferred that in which more values lies in the average range i.e. which is less deviated from the mean values. Full length groyne is less deviated from the mean values but the main criteria of selection is maximum depth of scour around structure.

Variation of scour in both cases as:

From the graph, scour variation in both case almost follows the same trend along the length of the flume. First groyne shows maximum depth of scour in both the cases. Second groyne follows the decreasing trend. But there is change in the scouring depth at the location of third groyne. In full length groyne scouring is more in third case but less in short length groyne. In fourth groyne the scouring is more in short length than full length groyne.

Deposition is seen in both the case after last groyne but more in the case of short length groyne.

After all it can be concluded that variation of depth of scour in similar in both the cases. Now cost to benefit ratio decide which is to be installed according to the purpose and situation. Cost of short length will be less than full length due to less cost of construction.

From the shape of scour hole formed around the groynes, scour hole is of less intensity in short length impermeable groyne. Scour hole is enlarged in full length groyne in the downstream direction but the scour hole is concentrated to nose tip of the short groyne. This shows with decrease in the length of groyne the pattern of velocity and scouring is same but intensity of parameters are reduced. Short groynes are more beneficial according to scouring point of view. But there may be the case when the protection length provided with the short groynes is less than the length provided with the full length groynes. It can be countered by providing the short groynes more in number.

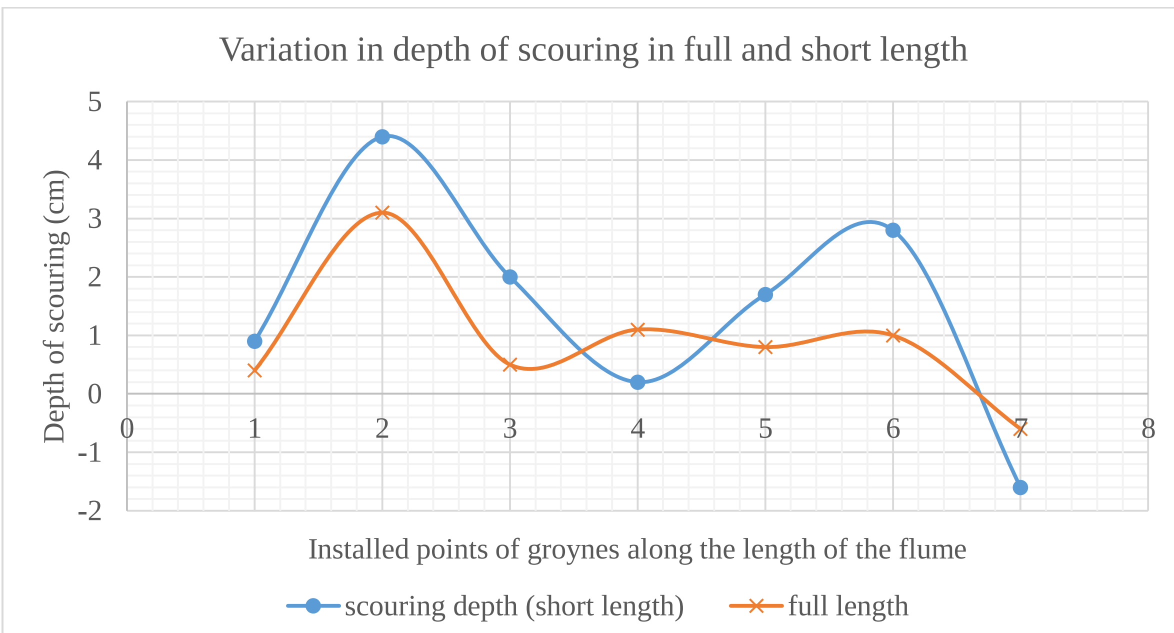


Figure 5.10: Graph shows comparison of variation in scour depth around full length and short length impermeable groynes.

After completion of experimental run with impermeable groyne, experiment is carried out with permeable groyne with same experimental setup. Before starting the experiment, sand bed made uniform similar to that of beginning condition.

5.3. Permeable groynes:

Permeable groynes are those having voids/spaces in between the structure such that flow can pass easily through the cross section. These groynes are used in the areas having maximum concentration of suspended particles in the flow. These are used when primary concern is to capture the suspended sediments instead of deflecting the flow away from the banks. Several past studies are there regarding the scouring around the straight groyne especially in impermeable groynes but rare data is available for the scouring around permeable groynes. Permeable groynes are more cost effective then impermeable groynes so it becomes necessary to observe the scouring in permeable groynes and comparison with the impermeable groynes at same flow parameters that make it easy to choose which one deals best against protection of banks and at the same time acts as cost effective structure.

All the parameters keep constant as that of the impermeable groyne i.e. procedure, instruments for measurements and geometrical features so that later on results can be compared. The points where impermeable groynes were installed permeable groyne are located at the same place and velocity measurements with flow probe (FP111), depth of scour measurements was done in similar way with the help of point gauge.

According to the length of the permeable groynes in the transverse direction they are also categorized as short and full length groynes to check variation of scouring with contraction ratio depending on the statement given by (Melville 1997).

5.3.1. Straight Full length permeable groynes (SFLPG):

In these permeable groynes permeability is induced with the help of drilling machine. Drilled holes are sufficient to reduce the velocity of flow and entrap the sediments of flow. Velocity measurements are done around the head/nose tip of each groyne with the flow probe at different points. Observed data of experimental run is arranged in the tabular form as:

Table 5.6: Experimental observation of velocity for SFLPG.

S. No.	Velocity (m/s)	water depth (cm)	Froude's number
A	0.1	9.0	0.11
SSLPG	0.2	9.0	0.213
SSLPG	0.2	9.0	0.213
SSLPG	0.3	9.0	0.32
SSLPG	0.4	9.0	0.425
SSLPG	0.3	9.0	0.32
B	0.1	9.0	0.11
Average	0.23	9.0	0.244

Variation of water depth along the flume around the groynes have very small drop/rise so approximately it is noted down as uniform depth of 9cm. this water depth is maintained above the sand bed. Froude's number shows flow is sub-critical in the flume which directly link to less velocity and more depth of flow inside the flume. Discharge is calculated through average velocity comes out to be 0.00621 cumec.

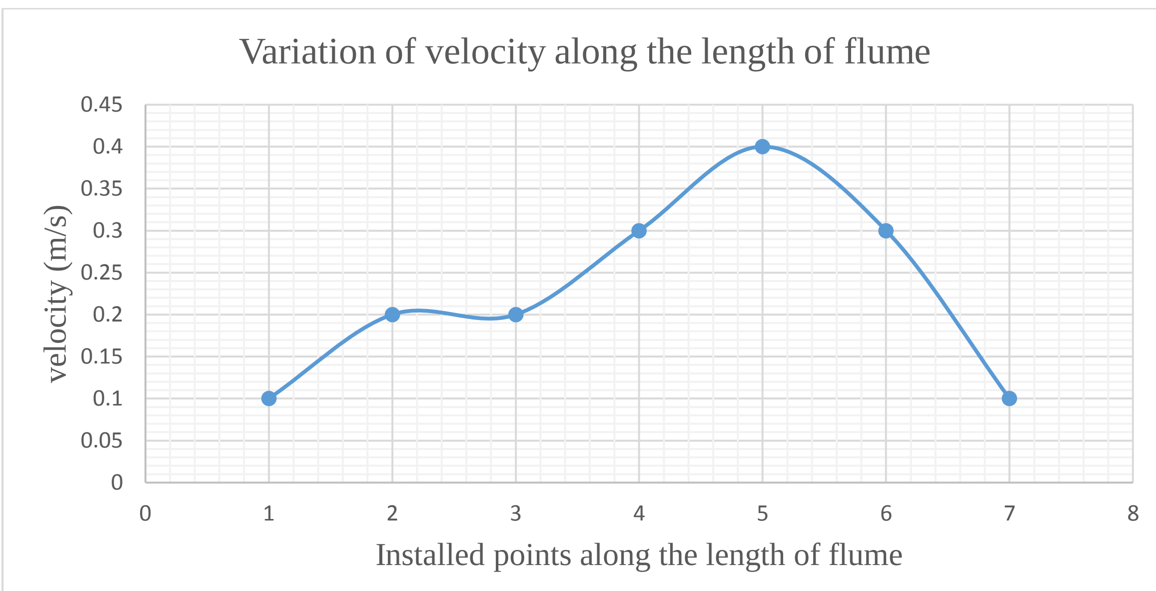


Figure 5.11: Graph showing velocity variation along the length of the flume for full length permeable groynes.

Graph is plotted on the basis of collected data from experiments. X-axis shows the installed points of the groynes along the length of flume and Y-axis shows the velocity of flow around head/tip of each groyne. Graph consists of one peak at fourth groyne. The nature of velocity is first increasing up to optimum point then decreasing. Optimum point is observed at the head/tip of fourth groyne. Velocity is increased at the first groyne due to constriction in width of flow but the velocity is increased along the length of flume and maximum velocity variation can be seen in the fourth groyne and at last it decrease near to fifth groyne. The velocity increase observed along the length of flume due to effect of erosion of bed particles and permeability induced in the groynes. After measurements of flow velocity flume is allowed to run for more 40 minutes till the flow come in equilibrium condition. Equilibrium condition refers to the condition when lifting of bed particles come into stabilized state i.e. when erosion of bed particles around groyne stop or concentration become very low such that with time there is very less increase in scouring depth. Depth of scouring is measured at the head of each groyne after draining the bed.

Table 5.7: Experimental observation of scour depth for SFLPG.

S. No.	Sand depth Before at nose tip (cm)	Sand depth (after) run at nose tip (cm)	Depth of scour at nose tip
A Point	10.3	10	0.3
SFLPG-1	10.4	9	1.4
SFLPG-2	9.8	8.9	0.9
SFLPG-3	9.7	9.1	0.6
SFLPG-4	10.3	8.3	2
SFLPG-5	10	9.1	0.9
B Point	9.5	9.2	0.3

From the data collected during the experiments presented in the tabular form. From the data it can be observed that, depth of scouring is more at the location of fourth groyne which is also satisfied with the graph of velocity variation. If we compare the velocity variation along the length of flume with the depth of scouring then velocity is more at the fourth position that shows the reason behind the more depth of scouring at fourth position. Other groynes show less scouring than the fourth one. Second and third groyne show minimum scouring. During the experiment, visually it is observed that, there is deposition of sediment in space between the first and second groyne. Total deposition is more than the deposition observed in impermeable groynes. The space opposite to the last groyne show scouring which means that the flow circle formed after striking the groyne can affect the opposite bank which is may be due to long length of the groynes in the transverse direction. The increase in velocity supports the increase in depth of scouring around groynes. Increase at the site of fourth groyne is due to erosive action of particles and turbulence created after striking the flow with the wall of opposite side. Opposite side may be harmed due to construction of these structures but this problem is solved by verification with groyne of less length in the transverse direction.

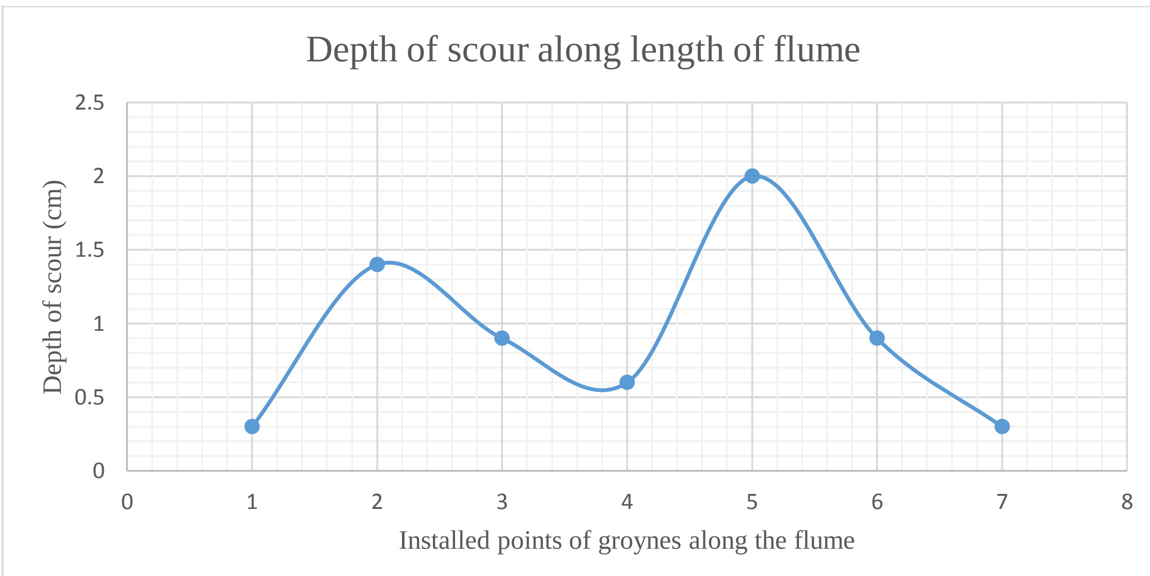


Figure 5.12: Graph shows scour depth variation along the length of flume for full length permeable groynes.

Images of the scouring around full length permeable groynes (SFLPG) as:

Figure 5.13.1: Scouring around first full length permeable groyne.

From the figure it can be observed that depth of scour hole formed around the first groyne is less but enlarged in the outward direction from the head of the groyne. The radius of the scour hole is more than its depth.

Figure 5.13.2: Scouring around second full length permeable groyne.

Scour hole of less intensity is observed around the second groyne. Scour hole develops towards the upstream direction and less deposition on the downstream side of nose tip of the groyne. Scouring is less as compare to first groyne.

Figure 5.13.3: Scouring around third full length permeable groyne.

There is almost negligible scouring around the third groyne as compare to first and second groyne.

Figure 5.13.4: Scouring around fourth full length permeable groyne.

In this experiment of full length permeable groyne maximum scouring is seen in this case which is also justified by the data observed of velocity variation around groynes. Maximum peak of the velocity graph is at fourth groyne and same is observed with the case of scouring.

Figure 5.13.5: Scouring around fifth full length permeable groyne.

Scour hole is not formed around this groyne. Only small amount of scouring can be seen around the length of groyne in the upstream direction extending from the wall which affects the foundation of the structure but negligible scouring at the head tip of the groyne. Another experiment with short length permeable groyne become necessary when full length permeable groynes affect the opposite banks of stream.

5.3.2. Straight Short length permeable groynes (SSLPG):

In this case, the length of the groyne is cut down to 7cm. This is similar to the case of short length impermeable groynes with induced permeability of 23%. Procedure of the experimental run, instruments, time of calculation and geometrical features remain same as that of other experimental run.

Velocity variation along the length of the flume as measured through Flow probe FP111:-

Table 5.8: Experimental observation of velocity for SSLPG.

S. No.	Velocity (V) (m/s)	Water depth (y) (cm)	Froude's number (Fr)
A	0.1	9.0	0.11
SSLPG	0.2	9.0	0.213
SSLPG	0.2	9.0	0.213
SSLPG	0.2	9.0	0.213
SSLPG	0.1	9.0	0.11
SSLPG	0.2	9.0	0.213
B	0.1	9.0	0.11
Average	0.157	9.0	0.168

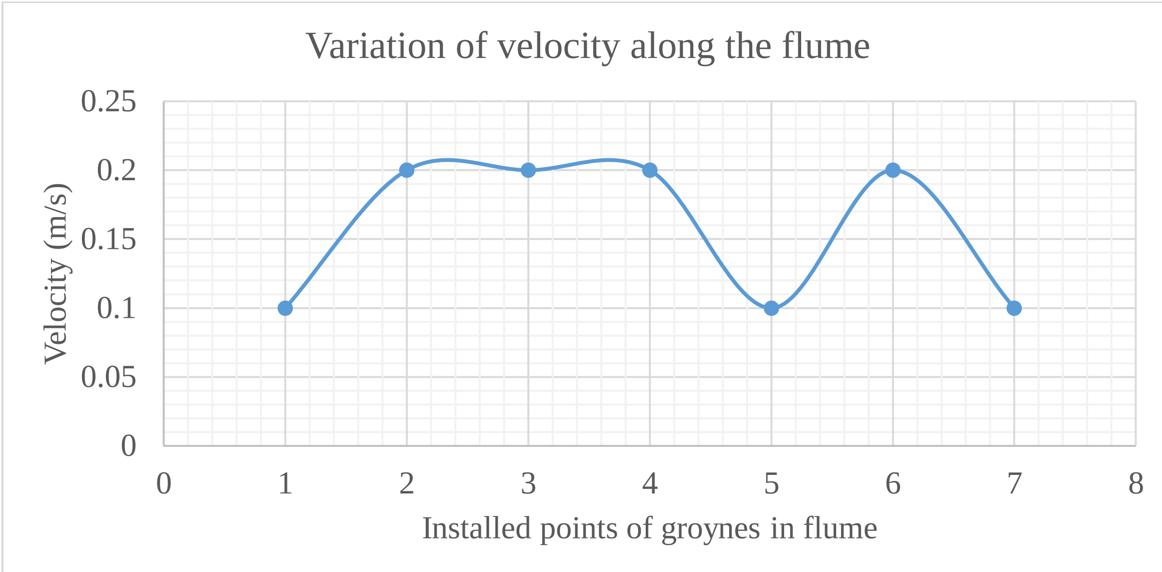


Figure 5.14: Variation of velocity along the installed points of groynes in flume.

Measurement of velocity after 20 minutes of running the flow at head point of each groyne. After velocity measurements flow is allowed to stabilize for more 15 minutes till displacement of sediment particles reduce to minimum. This stabilization condition is visualized manually from the transparent glass plates of the flume. More time is provided for the measurement of scouring depth because displacement of particles is maximum in the beginning of the experiment when the sand particles are loosely bound to the surface. After sometime of activity displacement of sediment particles reduces. A stage occur after approx. 40-45 minutes when displacement of sand particles reduces to minimum or show very less value if it is allowed to run for more time. Discharge comes out to be 0.0045 cumec. Scouring measurements are taken with the help of graduated point gauge mounted over the rails of the flume as:

Table 5.9: Experimental observation of scour depth for SSLPG.

S. No.	Sand depth Before run at Nose tip (cm)	Sand depth (after) run at Nose tip (cm)	Depth of scour at nose tip
A Point	9.7	9.6	0.1
SSLPG-1	10.2	7.2	3

SSLPG-2	9.6	9.3	0.3
SSLPG-3	9.4	9.4	0
SSLPG-4	9.5	9.7	-0.2
SSLPG-5	9.6	8.6	1
B Point	9	8.8	0.2

Figure 5.13: Graph shows velocity variation along the length of the flume for short length permeable groynes.

The values of velocity and scouring measure along the flume is plotted on the graph as X-axis denotes the installed points of groynes and Y-axis denotes the velocity and scouring depth respectively.

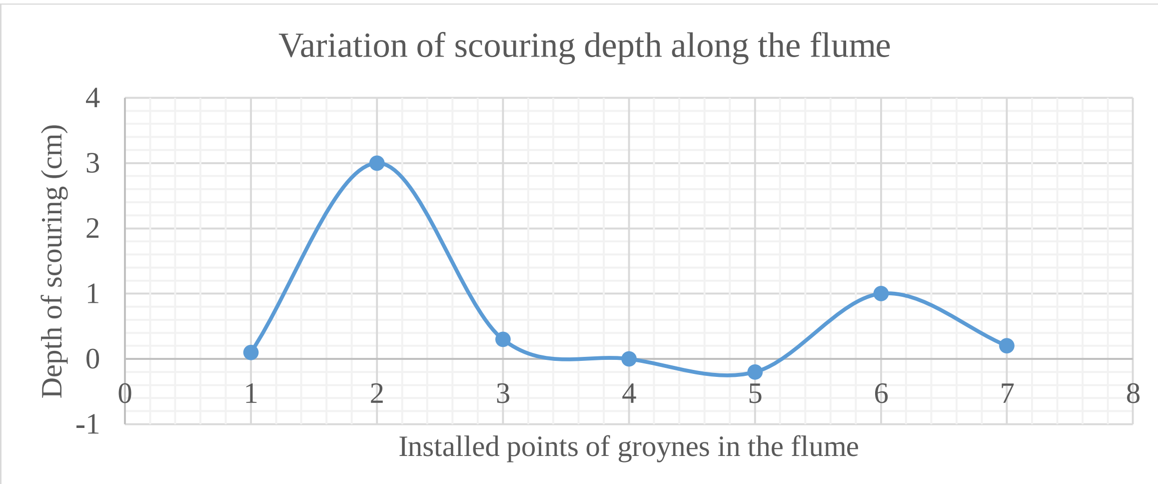


Figure 5.15: Graph showing variation of scour depth along length of flume for short length permeable groynes.

From the graphs of scour and velocity variation it is observed that, maximum scouring is seen at the first groyne due to direct obstruction to the flow but with almost same velocity the scouring is less or we can say very less around second and third groyne this is due to the formation of hard vortices around the first groyne along with more velocity. Around second and third groyne the effect of vortices diminishes due to more drainage path covered by the flow. The pressure gradient develop in the negative direction in downward direction is responsible for the formation of scouring at the very first groyne which is not dominant in the second and third case. Velocity is reduce at the location of fourth groyne which is satisfied by the relation of scour depth calculated. The fourth groyne shows deposition instead of scouring. This is the only case which shows deposition around the groyne otherwise deposition only seen either in the downstream direction after last groyne or midway in between two groynes. Deposition is formed due to flow separation zone formed behind the groynes. Flow separation zone is formed when flow velocity reduces to zero or attain negative velocity behind the groynes.

The practical observation can be analyzed through the pictures of experiment as:

Figure 5.16.1: Scouring around first short length permeable groyne.

This figure shows scouring around first groyne. Maximum velocity is around the first groyne that enhances the scouring around this groyne. The pattern of scouring shows there is circulatory motion around the nose tip of the groyne only which is not extending in the downward direction because the sediment scoured from the nose tip is deposited just near to the groyne in the downstream direction.

Figure 5.16.2: Scouring around second and third short length permeable groyne.

From the figures it can be seen that scouring is very less around the groynes. Some scouring can be observed at the nose tip of second groyne but no scouring is observed in third groyne. We can observed the deposition in main channel in constricted width of the flow.

Figure 5.16.3: Scouring around fourth and fifth short length permeable groyne.

All other groynes of this case except the first groyne shows negligible scouring whereas fourth groyne shows deposition around the groyne. Among all the test runs of permeable and impermeable groynes very less scouring is shown by this test run with more deposition around the groynes.

5.3.3. Comparison of velocity and scouring between SSLPG and SFLPG:

Comparison is done between short length and full length permeable groyne with respect to velocity and scouring measured at head tip of each groyne. Both groynes vary with different contraction ratio so this comparison makes it easy to find out opposite bank is harmed with length of groyne or not. Contraction ratio vary with length of groyne in the transverse direction.

From the Figure 5.17 and Figure 5.18, it is observed that velocity follows almost same trend in both the groynes but velocity shows sudden change around the fourth groyne which make placement of long length groyne uneconomical for the opposite bank. Velocity suddenly boost up at the location of fourth groyne due to turbulence created in the flow after striking/interaction with the opposite bank. Development of turbulence around groynes results in more scouring around the groynes along with scouring at the opposite bank which is not the case in short length permeable groynes. This make it clear that with change in length of groynes in transverse direction the effect of scouring on opposite bank as well as around the groynes can be minimized. Short length shows more deposition around the groynes and will be beneficial if slack object is required in between the groynes.

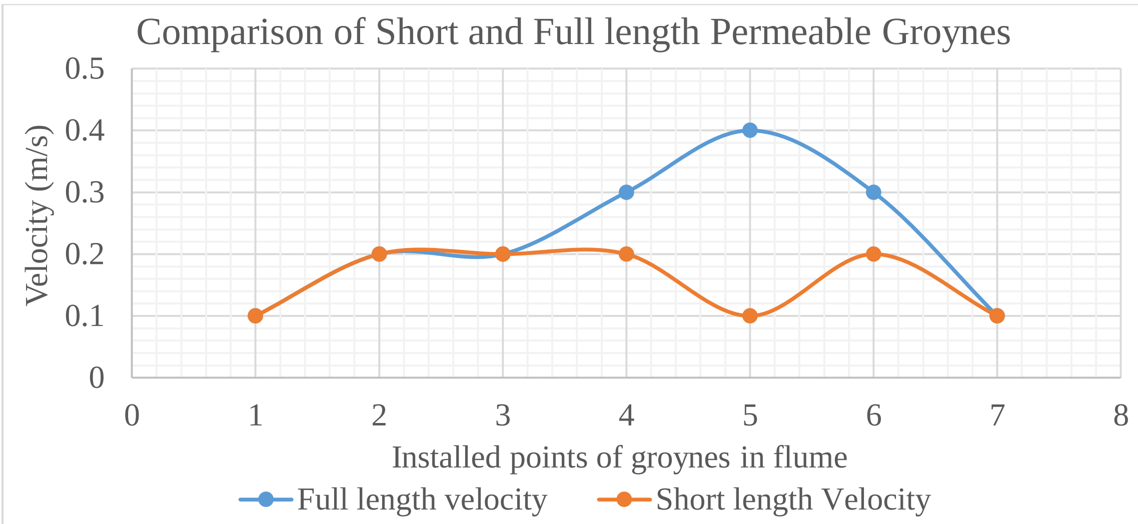


Figure 5.17: Comparison of velocity variation around groynes in Permeable groynes.

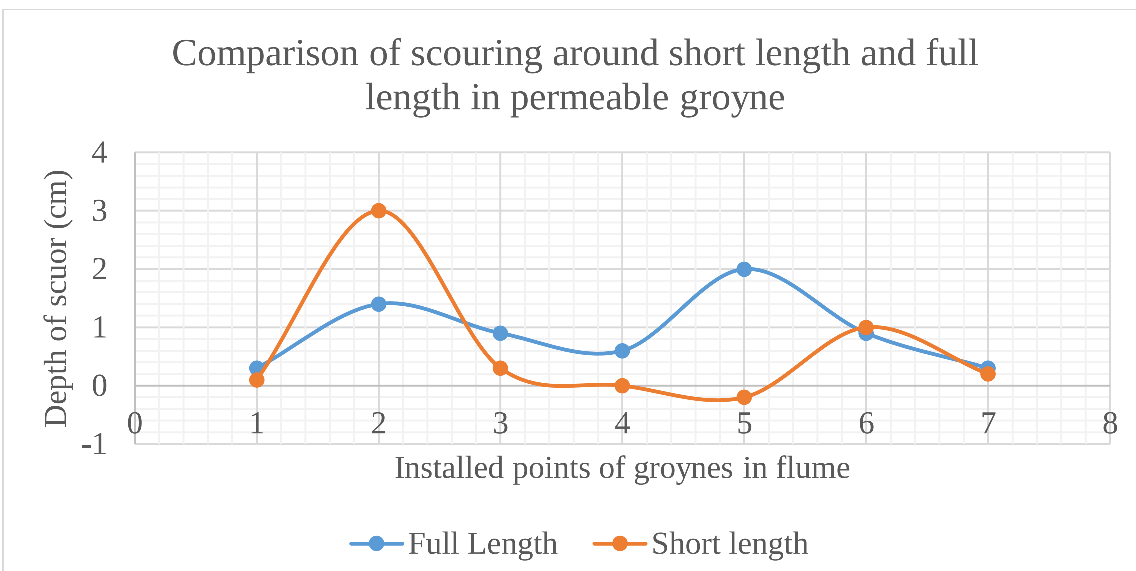


Figure 5.18: Comparison of scouring variation around groynes in Permeable groynes.

5.4. Comparison between impermeable and permeable groyne:

This is the point of primary concern to find out the efficiency of the groyne as which of the groyne have minimum depth of scouring. Groynes having minimum depth of scouring should be employed as they require less depth of foundation which is directly link to cost of construction. Either full length have or small length groyne have more efficiency which provide limit on the construction cost and require less protection measures around the groynes. Comparison is done with varying the contraction ratio to find out, groyne should not affect the opposite bank of the streams.

5.4.1. Comparison with respect to velocity between Permeable and Impermeable groyne:

A graph is plotted by combining the values of velocity of each experimental run to know about the maximum and minimum velocity variation. Analysis of velocity variation become necessary because velocity directly linked up with the variation of scouring depth around the groynes:

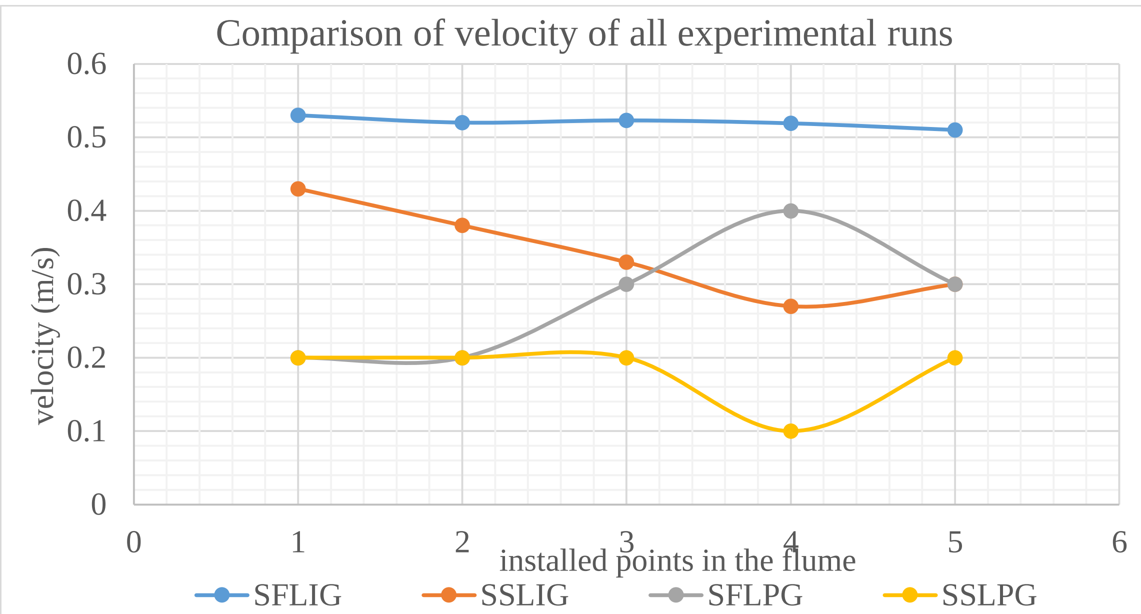


Figure 5.19: Graph compare velocity of all four experimental runs (permeable and impermeable groynes).

In the graph, X-axis show installed points of the groyne in the flume and on Y-axis velocity observed at the head of groyne. From the graph it can be perceived that, long length impermeable groyne have decreasing trend of velocity along the length of the flume whereas all other cases have fluctuating velocity. Impermeable groynes have more velocity than that observed in permeable cases due to flow can pass through the cross section but direct obstruction is provided by the impermeable structure. The fourth groyne have more variation than other groynes in either of the cases. In full length permeable groyne there is maximum velocity around the fourth groyne but in other cases deposition is observed around the fourth groyne. From all cases straight short length permeable groyne have stabilized condition compared to that of other cases.

5.4.2. Comparison with respect to scouring between permeable and impermeable groyne:

In this observation of scouring depth is combined of all the experiments. This is our main concern to find out the type of groyne which shows minimum scouring depth of scouring for which cost to benefit ratio is more. Depth of scour is linked up with the depth of foundation and amount of protection to be provided around the groynes.

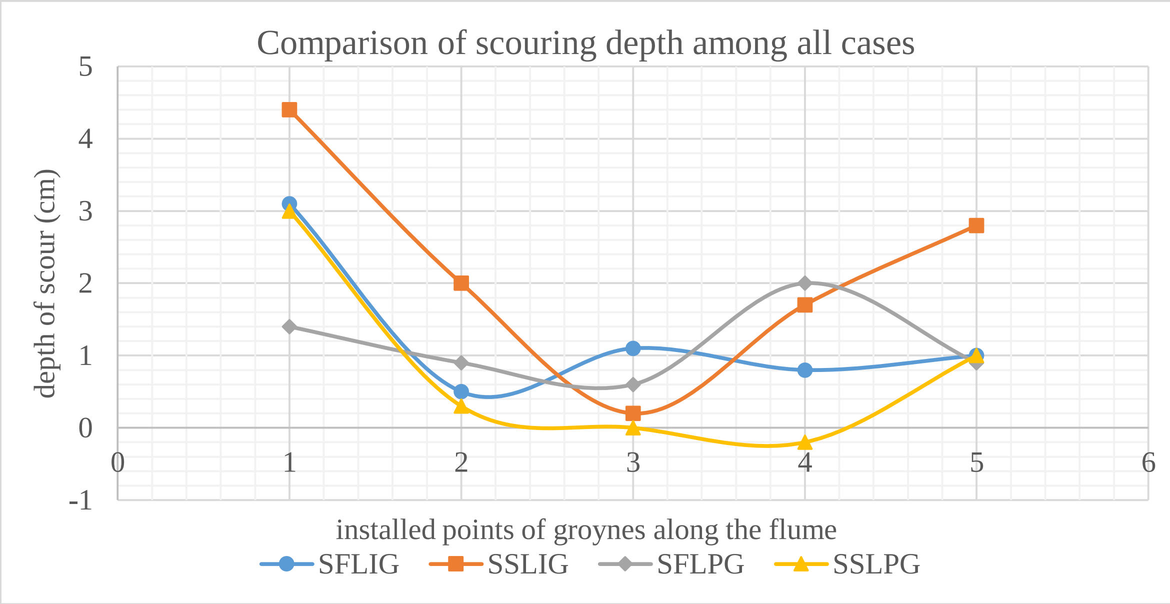


Figure 5.20: Graph compare depth of scour around groynes in both permeable and impermeable groynes.

From the graph it is observed that, maximum scouring is around the first groyne in all the cases. Scouring shows decreasing trend after first main groyne and reduced to almost negligible value up to third or fourth groyne. After minimum value, depth of scouring shows increasing trend. Depth of scouring meets at one point around fifth groyne except short length impermeable groyne. Scouring after first groyne shows different variation in all cases. Short length permeable groyne is the only one that shows minimum depth of scouring in all the groyne with deposition around the groynes. Deposition shows groyne play their role of entrapping the sediments in between the cross section.

Now, after performing the experiment sample of sand is collected from the mid-section of the flume and sand accumulated in the recirculation tank. These samples of sand behave as a remedial measures for scouring around the groynes. The sample which remain in flume is the one that can tolerate the flow velocity of that particular discharge. So when we provide that remain sand of flume around the groynes then scouring may be minimized to some extent.

5.5. Sieve analysis

5.5.1. Sand sample collected from the mid-section of the flume after experiment

This refers to the sample which is not scoured by the running flow. This sample of sand require more flow velocity to dissipate from their original position.

Particle size analysis is done through sieves as:

Table 5.10: Sieve analysis for sample remain after experiments inside the flume.

sieve size	Weight Retained	Weight Retained (gm)	Retained %age	cum Weight retained	Cumulative %age	% finer
2.36	0.013	13	1.3	13	1.3	98.7
1.4	0.007	7	0.7	23	2.3	97.7
1.18	0.001	1	0.1	24	2.4	97.6
1	0.001	1	0.1	25	2.5	97.5
0.5	0.011	11	1.1	36	3.6	96.4
0.425	0.018	18	1.8	52	5.2	94.8
0.3	0.80	800	80	852	75.2	24.8
0.212	0.037	30	3	882	88.2	11.2
0.18	0.058	58	5.8	940	94	6
0.15	0.020	20	2.0	960	96.0	4
0.075	0.016	16	1.6	976	97.6	2.4
0.063	0.006	6	0.6	979	97.9	2.1

0.05	0.001	1	0.1	980	98	2

From the observed data through sieve analysis graph is plotted to know about the median size of sample.

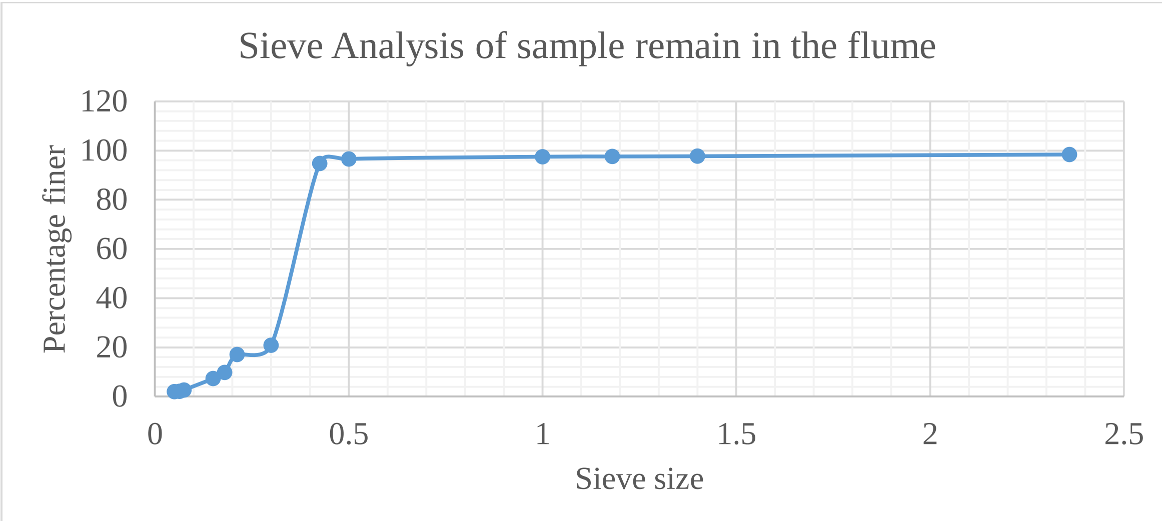


Figure 5.21: Sieve analysis for sample remain in the flume i.e. sand which is not scoured by the flow.

Median size calculate from this data is 0.35 mm which is more than the median size of initial sample analyzed in the beginning of the experiment. This will provide idea about the sediment size which can't be eroded from the running flow and act as a measure to reduce depth of scour. When this size of particles provided near the foundation/head of the groynes then the scour will be minimum from the values collected above and also increase the design life of the structure.

5.5.2. Sample collected from recirculation tank

This sample refers to the sand accumulated from the several experiments inside the recirculation tank. This is the sand which have more prone to scouring. To know about the median size of the sand which is eroded more sieve analysis is done in similar as done earlier with other samples.

Table 5.11: Sieve analysis for sand accumulates in recirculation tank inside the flume.

sieve size	Weight Retained	Weight Retained (gm)	Retained %age	cumulative Weight retained	Cumulative %age	% finer
2.36	0.02	20	2	20	2	98
1.4	0.006	6	0.6	26	2.6	97.4
1.18	0.001	1	0.1	27	2.7	97.3
1	0.01	10	1	37	3.7	96.3
0.5	0.01	10	1	47	4.7	95.3
0.425	0.011	11	1.1	58	5.8	94.2
0.3	0.578	578	57.8	636	63.6	36.4
0.212	0.073	73	7.3	709	70.9	29.1
0.18	0.185	185	18.5	894	89.4	10.6
0.15	0.007	7	0.7	901	90.1	9.9
0.075	0.08	80	8	981	98.1	1.9
0.063	0.005	5	0.5	986	98.6	1.4
0.05	0	0	0	986	98.6	1.4

To find out the particle size graph is to be plotted as:

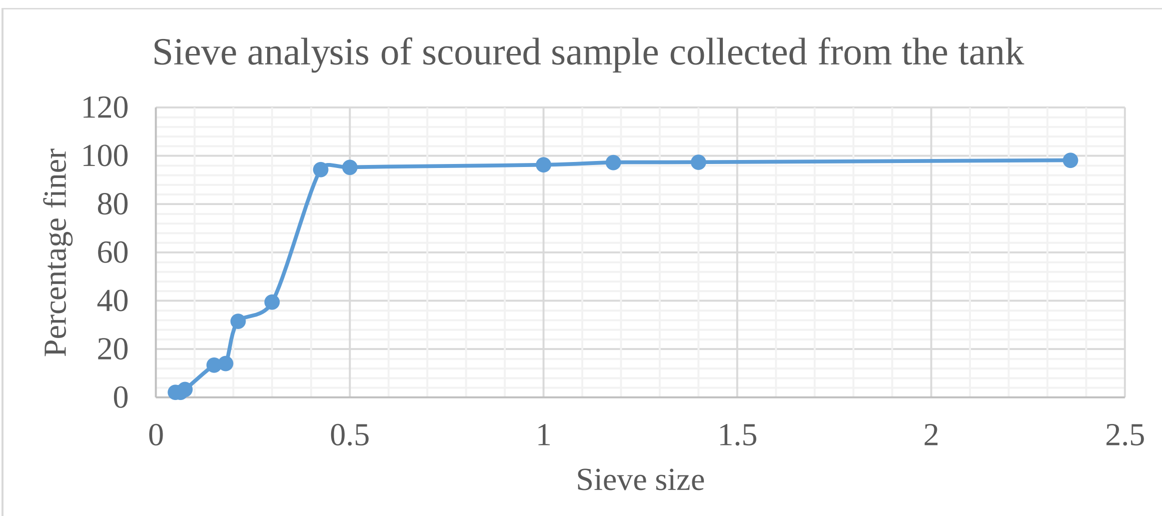


Figure 5.22: Sieve analysis for sample accumulated inside the recirculation tank.

Median size collected from this sample is 0.289 mm which is less than the sample collected from the flume after the experiments. This shows when this size of the sediment grains are present more near the groyne structure then severe scouring can be observed that can leads to failure/collapse of the structure.

The sample of sand remain in the flume and the one collected from the recirculation tank is the mixture of the sample from all the experimental runs.

CHAPTER 6

CONCLUSION

This chapter includes the final verdict of this present work that relates the aim of the present work and the outcome of the experiments. In this chapter, we are going to conclude the things based on the results discussed above.

Important points that we can conclude from the above discussion as:

a) Experiments are done on impermeable and permeable groynes with variation in contraction ratio at constant flow parameters so that their results can be compared later on. Groynes are categorized as long length and short length groyne based on the ratio given by Melville (1997). If ratio of length of groyne to depth of flow is less than one then it is named as short length otherwise it is long length groyne. Here, full length groyne have 12cm length and short length have 7cm length in the transverse direction from the wall of the flume in both permeable as well as impermeable.

b) Initially sand depth is measured with scour depth formula given by Gerald Lacey's recommended by IS code 8408:1994 (design of groynes). Lacey's scour depth required median size of sand i.e. d_{50} which is find out with the help of sieve analysis and come out to be 0.2143mm median size is used further to calculate the depth of sand bed maintained inside the flume during the experiments.

c) Each experiments is run for duration of 60 minutes with manual imagining of the flow from to know about the time when flow attain equilibrium condition. Flow attain its dynamic mechanism after 20 minutes of running and velocity measurements are observed. Scouring mechanism observed manually and it attain stable condition after 30-35 minutes. Scouring is more in the beginning of the experiment and then reduced with the passage of time. Initially scouring is more because of presence of loose material over the surface and dissipate easily with the flow of low intensity.

d) When the approaching flow comes in direct contact with the structures then there are formation of different vortices around the groynes. Wake vortices form in downward direction after striking the wall of the main groyne. Boundary layer form when flow flows from the head surface of the structure due to action of frictional forces and leads to formation of flow separation zone. Recirculation vortices formed behind the structure when boundary layer detaches from the structure along with flow separation zone just behind the groyne. Basically, this recirculation resembles to the reverse flow formed after striking second groyne and move towards the first groyne. Flow separation zone shows velocity reduces to minimum value and water move only in that particular area behind the groyne. Different vortices formed around the groynes initiate the hard vortex and negative pressure gradient in the downward direction that further initiate the formation of scour hole.

e) As different types of vortices are involved in the formation of scour hole so scour hole formed at the head of different groynes depending on the intensity of these vortices formed around groynes. Velocity increase up to first groyne and reduces when flow comes in contact with groyne which ultimately leads to minimum value behind the groyne. Minimum value of velocity behind the groyne and reverse flow create pressure gradient in the downward direction near to bed surface named as negative pressure gradient due to which scouring process initiates around groynes.

f) In straight full length impermeable groyne (SFLIG), velocity varies around the groynes from the incoming velocity. Velocity shows decreasing trend along the length of the flume with maximum value at first main groyne because of direct obstruction provided by the main spur dike to the flow. Similar trend as that of velocity variation seems to be followed by the depth of scour around the groynes. Maximum value of scour depth is observed at first groyne than other groynes with deposition in between the groynes and after the last groyne i.e. around ‘B’ point. This shows risk of failure is maximum to first groyne than other groynes. So protection provided to first groyne can reduce the risk of failure. Velocity variation around groyne govern the process of scouring around groynes and relation can be established as with increase in velocity depth of scouring also increases.

g) Scour hole shape is conical shape with vertex in downstream direction around the SSLIG groynes and more enlarged in the downstream direction. Scour hole reduces as move towards the downstream direction. The main purpose of groyne installation is to protect the banks from scouring so this is checked by measuring the horizontal values from the wall of the flume. Scour hole formed is much away from the wall of the flume.

h) As we know velocity have direct proportion with scouring so by decreasing the value of velocity around groynes depth of scour around groynes can also be minimized. Increase in velocity is experienced due to change in constriction width of flow if we can reduce the effect of constriction width by decreasing the length of groyne without compromising the protection of banks. To check this, experiments are carried out on short length impermeable groyne of 7cm.

i) In impermeable short groyne, velocity follows a decreasing trend along the length of flume around groynes. Maximum velocity is observed at the head tip of first groyne with decreasing trend up to fourth groyne but velocity increases at the head tip of fifth groyne with small value due to changes in the erosive forces. Scour depth shows decreasing variation up to third groyne with maximum value at around first groyne. After third groyne depth of scour hole increases till fifth groyne which is satisfied from the values of velocity calculated at the head tip of the groynes. Deposition observed in short length impermeable is more than the deposition observed in full length impermeable groynes. Trend followed by both groynes are same but magnitude of variation is less in short length groyne.

j) Scour hole formed is circular in shape extending from thick tip of the groyne but in full length groyne scour hole is circular of more radius with enlarged scour hole in downstream direction. Scour hole formed in short length groynes is less and concentrated in small area than scour at full length groynes. Third groyne shows negligible scouring in this case which shows increase in shear stress. When flow tries to displace the particles from the bed but unable to do so then shear stresses are stress which apply more force on the particle to move it from its location.

k) This same study is also applied to permeable groynes. Permeable groynes are more cost effective than impermeable ones so similar experiments are done to calculate the velocity and depth of scour hole so that best from them can be separate out for field conditions.

l) Permeability is induced in the impermeable cross sections with the help of drilling machine. Holes are drilled in cross section of impermeable groynes which are sufficiently enough to slow down the velocity and allow the flow to pass through it.

m) Full length permeable groynes show totally different structure as compare to other impermeable groynes. Impermeable groynes shows decreasing trend towards the downstream direction whereas in permeable full length groynes shows increase in velocity towards the length of the flume having maximum value at the fourth groyne. This change may be due to erosive effect and permeability induced in the cross section of impermeable groynes. Vortices formed around the groynes with less intensity than impermeable groynes because flow can pass through the cross section instead flow is deflected in the impermeable groynes which develop the reverse flows more around the groynes.

n) Variation in scouring around groynes follows exactly similar trend of velocity variation having maximum value of scouring around fourth groyne. The magnitude of scour depth is less in permeable groyne than impermeable groynes which shows there is less scouring in permeable groynes in similar condition than impermeable groynes. There is no enlargement of scour hole in permeable groynes even deposition can be observed around the groynes. Process of scouring in full length permeable groynes shows presence of turbulence effect created after interaction of flow with opposite bank. Opposite bank experiences scouring effect due to installation of these groynes so this problem is solved by verification with short length permeable groynes.

o) In short length permeable groynes, stabilized conditions are observed in both velocity and depth of scouring. Variation of velocity is almost uniform with maximum value of velocity observed at last groyne whereas maximum value of scouring observed at first one. Deposition observed is more in short permeable groynes due to reducing the flow velocity in between the groynes and after the last groyne. The main aim of installation of the groynes is to protect the banks from scouring and capture most of the suspended sediments from the flow which is fulfilled by these groynes.

p) To know about the more efficient groyne from permeable and impermeable experiments are carried out and from all the observations and results finally it can be concluded that short length permeable groyne will perform much better than other groynes. While choosing short groyne as compare to full length groynes, the length of protection or deflected flow from the banks is less than the length provided by full length groynes but this issue can be covered up by using short permeable groynes more in number keeping cross section of the member same.

q) After all the experiments, two sample are taken from the sand remaining in the flume and sand accumulates inside the recirculation tank due to scouring. This is carried out to determine the size of sand which is more prone to scouring. After particle size analysis the size of sand remaining in the flume comes out to be 0.35mm which is more than the size of initial sample 0.2143mm. If we provide this size of sand left inside the flume around groynes then the scouring is less than observed in the experiments. This provide economical remedial measure which can be adopted during construction.

CHAPTER 7

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