Scouring pattern at downstream of different types of energy dissipators on flat bed and inclined bed using two different size of aggregate.

A Thesis submitted in partial fulfillment of the requirements

for the award of the degree

of

MASTER OF TECHNOLOGY

in

HYDRAULICS AND WATER RESOURCES ENGINEERING

By

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DELHI

CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled **Scouring pattern at downstream of energy dissipators on flat bed and inclined bed using two different size of aggregate** in the partial fulfillment of the requirements for the award of the degree of "Master of Technology" in Hydraulics & water resources engineering submitted in the Department of Civil Engineering, Delhi Technological University, Delhi, is an authentic record of my own work carried out from **January 2016 to July 2016** under the supervision of Mr. T. Vijay Kumar, Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date:

Bharat kumar

2K13/HFE/13

Dedicated to

My father

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ABSTRACT

Dams and barrages play a very vital role in the economy of a country by providing essential benefits like irrigation, hydropower, flood control, drinking water, recreation, etc. However, when these fail in rare conditions, these may cause catastrophic flooding in the downstream area resulting in huge loss to human life and property. The spillway is among the most important structures of a dam project. It provides the project with the ability to release excess or flood water in a controlled or uncontrolled manner to downstream to ensure the safety of the project. The surface of the spillway should also be such that it is able to withstand erosion or scouring due to the very high velocities generated during the passage of a flood through the spillway. So the safety of spillway against the scouring at downstream is also important. To prevent the scouring of the riverbed and failure of the hydraulic structure, energy dissipators are commonly used for the purpose of dissipating the excessive kinetic energy of flowing water downstream of hydraulic structures.

An experimental study was conducted to understand the scouring pattern below downstream of the spillway. A rectangular flume of dimensions 6.0m(length)X0.30m(width)X0.60m(depth), four spillway models(ogee spillway, ski jump bucket, ogee spillway with subsidiary dam, ogee spillway with baffle wall) and locally available material to prepare bed were used in this study. A pitot tube was used to measure the flow velocity and discharge. To measure the pre-jump and post-jump for the calculation of energy loss point gauge was used. In this experimental study total 40 tests were conducted using same run time. The scour pattern (depth and length) were measured after each test run.

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Y_1	Pre jump depth of hydraulic jump
Y_2	Post jump depth of hydraulic jump
Ø	Ski jump Bucket lip angle
R	Ski jump Bucket radius
V_{th}	Theoretical velocity of flow in flume
V_{ac}	Actual velocity of flow in flume
h	Head difference between manometer limbs
C_v	Co-efficient of velocity of pitot tube
D_m	Maximum scour depth at downstream of spillway
L_m	Maximum scour length at downstream of spillway
E_L	Energy loss
T.W.L	Tail water level
G.L	Ground level
$osD_{mf2.36}$	Ogee spillway maximum scour depth for flat bed when particles size 2.36mm
$osD_{mi2.36}$	Ogee spillway maximum scour depth for inclined(slope 1/300) bed when particles size 2.36mm
$osD_{mf4.75}$	Ogee spillway maximum scour depth for flat bed when particles size 4.75mm
$osD_{mi4.75}$	Ogee spillway maximum scour depth for inclined(slope 1/300) bed when particles size 4.75mm
$osL_{mf2.36}$	Ogee spillway maximum scour length for flat bed when particles size 2.36mm
$osL_{mi2.36}$	Ogee spillway maximum scour length for inclined(slope 1/300) bed when particles size 2.36mm
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$sjbD_{mf2.36}$	Ski jump bucket maximum scour depth for flat bed when particles size 2.36mm

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$sjbEL_{i2.36}$	Ski jump bucket Energy loss for inclined(slope 1/300) bed when particles size 2.36mm
$sjbEL_{f4.75}$	Ski jump bucket Energy loss for flat bed when particles size 4.75mm
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Chapter 1 Introduction

1.1 General

Dams and barrages play a very vital role in the economy of a country by providing essential benefits like irrigation, hydropower, flood control, drinking water, recreation, etc. However, when these fail in rare conditions, these may cause catastrophic flooding in the downstream area resulting in huge loss to human life and property. This loss to life and property would vary with extent of inundation area, size of population at risk, and the amount of warning time available.

Scour has occurred upstream and downstream from essentially every navigation dam constructed. The severity of the scour varies greatly from project to project. Periodic inspections have been used in the past to assess the need for repair. Often these inspections do not provide enough information to adequately assess the extent of scour and the repair and/or rehabilitation requirements.

1.2 SPILLWAY

The spillway is among the most important structures of a dam project. It provides the project with the ability to release excess or flood water in a controlled or uncontrolled manner to downstream to ensure the safety of the project. In cases where safety of the inhabitants downstream is a key consideration during development of the project, the spillway should be designed to accommodate the probable maximum flood. The surface of the spillway should also be such that it is able to withstand erosion or scouring due to the very high velocities generated during the passage of a flood through the spillway.

The flood water discharging through the spillway has to flow down from a higher elevation at the reservoir surface level to a lower elevation at the natural river level on the downstream through a passage, which is also considered a part of the spillway. The water flowing down from the spillways possess a large amount of kinetic energy that is generated by virtue of its losing the potential head from the reservoir level to the level of the river on the downstream of the spillway. At the bottom of the channel, where the water rushes out to meet the natural river, is usually provided with an energy dissipation device that kills most of the energy of the flowing water. If this energy is not reduced, there is a danger of scour to the riverbed which may threaten the stability of the dam or the neighboring river valley slopes. These devices, commonly called as Energy Dissipators, are required to prevent the river surface from getting dangerously scoured by the impact of the out falling water. In some cases, the water from the spillway may be allowed to drop over a free over fall. Basic considerations affecting the design of spillways include design flood, crest control (gates), control system, structural stability, and adequate dissipation of energy. The capacity of a spillway must be sufficient to accommodate the maximum discharge without allowing the reservoir surface to rise above a predetermined (maximum reservoir elevation).Determination of the maximum flood to be used as a basis for spillway design results from hydrological studies and available flood peak data.

In general, spillways comprise five distinct components namely:

i) an entrance channel
ii) a control structure
iii) a discharge carrier
iv) an energy dissipator
v) an outlet channel.

The crest of the spillway is usually provided at F.R.L (Full Reservoir Level). However, in order to control floods the gates could be provided at the top and the The entrance channel transfers water from the reservoir to the control structure, which regulates the discharge from the reservoir. Water is then conveyed from reservoir to the low-level energy dissipater on the riverbed by the discharge conveyor. An energy dissipator is required to reduce the high velocity of the flow to anon scouring magnitude.

Most common types of spillway-control system used are roller, tainter, vertical-lift, and drum gates. In view of the varying conditions, the choice of suitable gate is bound by the cost, the head on the crest, the height of dam, and the hydraulic behavior of the gate.

Piers are located on the spillway crest for the purpose of supporting the control gates, the gate-operating mechanisms or a roadway. Their size and shape will vary accordingly with their function. The element which introduces the energy-reducing action is generally known as **"stillingbasin**." One of the most common methods out of several methods of dissipating the flow at the toe of a spillway is the hydraulic jump. Other types used in conjunction with spillways are roller and trajectory buckets. Spillway outlets means the combination of structures and equipment required for the safe operation and control of the water released for different purposes for which the dam is planned. These structures may be river outlets, penstocks, canal outlets. If the outlets are located in the overflow portion, the conduits should be aligned downwards to minimize disturbance to the flow over spillway. The discharge from an outlet, (gates, valves, or free-flow conduits) has a relatively high velocity. Flow must expend the energy in order to prevent scour of the bed and banks of the river channel. This may be accomplished by constructing a stilling basin immediately downstream from the outlet.

Water level could be increased up to maximum water level. The height between F.R.L and M.W.L is called the "Flood lift". Reservoir level should not cross MWL.

1.2.1 TYPES OF SPILLWAY

1. Free over fall (Straight Drop) Spillway
2. Overflow (Ogee) Spillway
3. Chute (Open Channel/Trough) Spillway
4. Side Channel Spillway
5. Shaft (Drop Inlet/Morning Glory) spillway
6. Tunnel (Conduit) spillway
7. Siphon spillway

1.2.2 OVERFLOW SPILLWAY OR OGEE SPILLWAY

The overflow type spillway has a crest shaped in the form of an ogee or S-shape. The upper curve of the ogee is made to conform closely to the profile of the lower nappe of a ventilated sheet of water falling from a sharp crested weir. Flow over the crest of an overflow spillway is made to adhere to the face of the profile by preventing access of air to the underside of the sheet of flowing water. Naturally, the shape of the overflow spillway is designed according to the shape of the lower nappe of a free flowing weir conveying the discharge flood. Hence, any discharge higher than the design flood passing through the overflow spillway would try to shoot forward and get detached from the spillway surface, which reduces the efficiency of the spillway due to the presence of negative pressure between the sheet of water and spillway surface. For discharges at designed head, the spillway attains near-maximum efficiency. The profile of the spillway surface is continued in a tangent along a slope to support the sheet of flow on the face of the overflow. A reverse curve at the bottom of the slope turns the flow in to the apron of a sliding basis or in to the spillway discharge channel. An ogee crest apron may comprise an entire spillway such as the overflow of a concrete gravity dam, or the ogee crest may only be the control structure for some other type of spillway. The ogee-crested spillway, because of its superb hydraulic characteristics, has been one of the most studied hydraulic structures. Its ability to pass flows efficiently and safely, when properly designed, with relatively good flow measuring capabilities, has enabled engineers to use it in a wide variety of situations.

Although much is understood about the general ogee shape and its flow characteristics, it is also understood that a deviation from the standard design parameters such as a change in upstream flow conditions, slightly modified crest shape, or construction variances can change the flow properties.

The figure 1.1 shows shape of an ogee spillway.

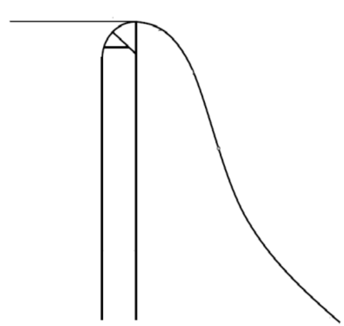


Figure 1.1: Shape of an ogee spillway

The discharge over an uncontrolled ogee crest is influenced by a number of factors:

i) Actual crest shape with respect to ideal nappe shape
ii) Ratio of actual head to design head
iii) Height of crest apex above the entrance channel invert
iv) Approaching flow velocity
v) Downstream apron interference or tail water submergence
vi) Upstream face slope

1.3 SCOURING

Scouring is a natural phenomenon caused by the flow of water in rivers and streams. It occurs as part of the morphologic changes of rivers and as result of manmade structures. The scour process involves turbulence with its great complexity and variability and sediment transport with its strong dependence on the complex interactions with turbulence flows.

According to Annandale (2006), scour, another name for extreme erosion, is a term generally used to describe severe localized erosion of earth material that occurs when the erosive power of water exceeds the ability of earth material to withstand it. The extent of the resulting scour depends upon whether the bed consists of cohesive, non-cohesive or rock material. If the bed material consists of rock material, scour will depend on rock type, weathering, the presence of fissures etc.

The scour which may occur at a structure can be divided into two different categories namely; type of scour and scour in different conditions of transport. The latter is subsequently subdivided into separate groups

Excessive scour can be caused by the following conditions:

1.) Flow concentration in the exit channel:

i) Exit channel geometry may confine flows.
ii) Composition of exit channel material may permit localized scouring.
iii) A depressed roadway in the exit channel may be susceptible to scour by concentrated flow.

iv) Flow passing through a culvert may concentrate flow.
v) A laterally sloping spillway apron tends to concentrate flow in the center of an exit channel.
vi) Scour material may deposit in the exit channel, forming a debris dam that can concentrate flow.

2.) Excessive velocities and turbulence at the downstream end of a spillway chute.

3.) Inadequate energy dissipation at the downstream end of a spillway chute.

4.) Head cutting in the exit channel:

i) Composition of exit channel material may permit localized scouring and thereby initiate head cutting.
ii) Change in exit channel grade may permit flow to change from sub–critical to super–critical and thereby promote head cutting.
iii) Excessive velocities and turbulence in the exit channel may initiate head cutting.

5.) Standing waves caused by flow at critical depths.

6.) Inadequate downstream protection.

7.) Flow duration greater than 30 days.

Scouring can have three major effects:

i) Undermining the stability of the structure itself by structural failure or increased seepage
ii) Undermining the stability of downstream riverbed or side slopes
iii) The formation of the deposition of eroded material which can raise the tail water level at the dam.

The scour which may occur at a structure can be divided into two different categories namely; type of scour and scour in different conditions of transport. The latter is subsequently subdivided into separate group.

1.3.1 TYPES OF SCOUR

1.3.1.1 GENERAL SCOUR

General scour occurs in a river or stream as the result of natural processes, irrespective of whether a structure is there or not. General scour can be broken down into four sub-categories:

i. Overall degradation

This occurs as a river adjusts to changes in the water or sediment flow. The changes may be natural or as a result of human interference. Changes could be: flow-rate variation, construction of weirs or dams, inter-basin water transfers, etc.

ii. Constriction scour

This is a special, localized case of overall degradation and occurs if a structure causes the narrowing of a water course or the rechanneling of berm or flood plain flow. As a result, the lowering of the bed level and the increased flow velocity are noticed in the constricted section.

iii. Bend scour

This is induced by the large coherent flow structure/secondary currents that are set up whenever the flow is forced to follow a curved path. These secondary currents result in increased local velocities in the vicinity of the bed on the outside of the bend and can cause scour with local depths up to twice the average flow depth (Armitage, 2002).

iv. Confluence scour

This occurs when two branches of a river meet. Differences between the two branches in terms of the flow rates, slopes, sediment transport and angle of approach relative to the downstream channel result in complicated secondary flow patterns with associated scour and deposition downstream of the confluence.

1.3.1.2 LOCAL SCOUR

Local Scour is directly caused by the impact of a structure on the flow. This scour, which is a function of the type of structure, is superimposed on the general scour.

Scour can be classified according to the way bed material is transported by the flow and therefore they described two different categories of scour which are explained in the following subsections

i. Clear-water Scour

Clear-water scour occurs if the bed material in the natural flow upstream of the scour area is at rest. The shear stresses on the bed some distance away from the structure are thus not greater than the critical or threshold shear stress for the initiation of particle movement.

ii. Live-bed Scour

Live-bed scour also known as scour with bed material sediment transport, occurs when the flow induces a general movement of the bed material. The shear stresses on the bed, therefore, are generally greater than the critical one. Equilibrium scour depths are reached when the amount of material removed from the scour hole by the flow equals the amount of material supplied to the scour hole from upstream.

1.3.3 PHASES OF SCOUR DEVELOPMENT

The evolution of a scour hole can be divided into four different phases namely; the initiation phase, the development phase, the stabilization phase and equilibrium phase.

1. The Initiation Phase

In the initiation phase, the transport capacity of the flow leading to sediment transport along the original bed entails gradual erosion downstream of the bed protection. The duration of this phase is generally short.

2. The Development Phase

Due to the enlargement of the scour hole, flow separation starts in this phase. As a result, a circulation flow takes place and near-bed velocities inside the eddy are directed towards the structure, whereas they are in the direction of the main flow outside the eddy. Thus, the stabilization of the upper slope of the scour hole is reached. This development phase generally lasts much longer than the initiation phase.

3. The Stabilization Phase

The depth of the scour hole in this phase becomes so large that the decreasing near-bed velocities almost reach either the critical value of initial motion and transport of sediment or a value corresponding to the upstream sediment transport. Therefore, the scour development in the stabilization phase stops or proceeds very slowly.

4. Equilibrium Phase

The near-bed velocity or shear stress is equal to the critical value in the case of clear-water scour and equal to the upstream value of the undisturbed under live-bed condition. At this stage, the local flow is not able to carry sediment out of the scour hole, against its downstream slope. As a result, the maximum depth of the scour hole is reached and defined as equilibrium depth.

Failure of downstream stone protection below a stilling basin is an example of a condition that may require special operation. If the failure is localized below a limited section of spillway, reducing the opening of the spillway gates in that section or complete closing may be required until repair can be effected. Raising the tail water elevation by operation of a downstream dam also may be effective in reducing the turbulence in the damaged areas. A combination may be required. Decreasing the flow in one part of a spillway will increase the unit discharge in other sections of a run-of-river project without storage available to adjust the spillway discharge. This can cause increased stress to undamaged sections of the stone protection.

1.4 ENERGY DISSIPATORS

Energy dissipaters are any device designed to protect downstream areas from erosion by reducing the velocity of flow to acceptable limits. Stilling basins and energy dissipaters are usually provided in conjunction with development of spillways, outlet works, and canal structures. It is often necessary to perform hydraulic model studies of individual structures to be certain that these energy dissipating devices will operate as anticipated. A relatively large volume of data is available from different types of energy dissipaters may be used along with a spillway, alone or in combination of more than one, depending upon the energy to be dissipated and erosion control required downstream of a dam. Broadly, the energy dissipaters are classified under two categories – Stilling basins or Bucket Type. Each of these are further sub-categorize

1.4.1 Stilling basin type energy dissipaters

They may fundamentally be divided into two types.

a) Hydraulic jump type stilling basins

1. Horizontal apron type
2. Sloping apron type

b) Jet diffusion type stilling basins

1. Jet diffusion stilling basins
2. Interacting jet dissipaters
3. Free jet stilling basins
4. Hump stilling basins
5. Impact stilling basins

1.4.2 Bucket type energy dissipaters

This type of energy dissipaters includes the following:

1. Solid roller bucket
2. Slotted roller bucket
3. Ski jump (Flip/Trajectory) bucket

1.4.3 HYDRAULIC JUMP TYPE ENERGY DISSIPATERS

A hydraulic jump is the sudden turbulent transition of supercritical flow to subcritical. This phenomena, which involves a loss of energy, is utilized at the bottom of a spillway as an energy dissipater by providing a floor for the hydraulic jump to take place. The amount of energy dissipated in a jump increases with the rise in Froude number of the supercritical flow.

The length of the jump is an important parameter affecting the size of a stilling basin in which the jump is used. There have been many definitions of the length of the jump, but it is usual to take the length to be the horizontal distance between the toe of the jump upto a section where the water surface becomes quite level after reaching a maximum level. Because the water surface profile is very flat towards the end of the jump, large personal errors are introduced in the determination of the jump length.

A hydraulic jump type-stilling basin may be defined as a dissipater in which whole or part of a hydraulic jump is confined. In this type of basins, the energy is dissipated by formation of hydraulic jump within the basin. These basins are further subdivided as under.

1. HORIZONTAL APRON TYPE

A rectangular cistern with its floor either at or below the riverbed creates conditions for the formation of a well-defined hydraulic jump. A shallow jet of water moving at a super-critical velocity strikes the water in the basin having conjugate depth and moving at a sub-critical velocity. There, part of kinetic energy of water is converted to pressure energy and the remaining into turbulent energy which ultimately gets converted into heat energy. Water level gradually rises so that no velocity at the basin end is reduced to the normal velocity of flow in the river. The length of basin required depends primarily upon the pre-jump Froude number (Fr1) and the discharge intensity. The conjugate depth required for the jump depends on the pre-jump.

Commonly used U.S.B.R. stilling basins are of type-I, II, III and IV depending upon the pre-jump Froude’s number and incoming velocity of flow before the jump. The basins are provided with dentate sills, baffle blocks, Chute blocks and end sills, depending upon pre-jump Froude number and pre-jump velocity.

2. SLOPING APRON TYPE

By using sloping aprons; it is possible to produce efficient jump at all discharges especially in situation when tail water depth available is more than sequent depth required for jump. It is generally agreed that a hydraulic jump with strong turbulence and excellent energy dissipating characteristics will form in channels with sloping apron downstream with an inclination no steeper than three horizontal to one vertical. When slope is too steep, the high velocity jet dips under the surface of the pool with little dissipation of energy and resulting in erosion of the streambed and sides downstream. This basin is; however, very costly due to excessive thickness of apron required.

3. WATER CUSHION (PLUNG POOL TYPE DISSPATOR)

In this type, the nappe impinges into the stilling water cushion below. There is no clear standing wave formation and the energy is dissipated by the turbulent diffusion as the high velocity jet enters the deep pool on the downstream. The water cushion offers easy solution but actually the design of suitable water cushion is difficult. Also, since this requires a huge depression just at or beyond the toe of the dam, and damage occurring to the basin may endanger the safety of the structure which is subjected to vibration due to impact and separation of free falling jet from the structure.

4. SOLD ROLLER BUCKET TYPE ENERGY DISSIPATOR

An upturn sold bucket is used when tail water depth is much in excess of sequent depth and in which dissipation of considerable portion of energy occurs as a result of formation of two complementary elliptical rollers, one in the bucket proper, called bucket roller, which is anti-clockwise (if the flow is to the right) and the other downstream of the bucket, called ground roller, which is clockwise. Bucket roller is effective within a design range of tail water variation. If the tail water is lower than the permissible lower limit, the incoming high velocity jet will sweep out and form a sky jump. When the tail water level exceeds the uppermost limit, the incoming jet will not form rollers but moves to the surface causing little dissipation of energy.

5. SLOTTED ROLLER BUCKET TYPE ENERGY DISSIPATOR

An upturn bucket with teeth in it is used when the tail water depth is much in excess of sequent depth and in which the dissipation of energy occurs by lateral spreading of jet passing through bucket slots in addition to the formation of two rollers as in solid roller bucket.

1.4.4 SKI-JUMP (FLIP OR TRAJECTORY BUCKET) TYPE ENERGYDISSIPATOR

An upturn solid bucket is used when the tail water depth is insufficient for formation of hydraulic jump and the bed of the channel downstream comprises of sound rock which is capable of withstanding (without excessive scour), the impact of high velocity jet. The flow coming down the spillway is thrown away from toe of the discharging upturned bucket and it falls into the channel directly, thereby avoiding excessive scour immediately downstream of the spillway. There is hardly any energy dissipation within the bucket itself. The device is used mainly to increase the distance from the structure to the place where high velocity jet hits the channel bed, thus avoiding the danger of excessive scour immediately downstream of the spillway. Due to the throw of the jet in the shape of trajectory, energy dissipation takes place by:

i) Internal friction within the jet

ii) The interaction between the jet and surrounding air

iii) The diffusion of the jet in the tail water pool in the crater formed due to scouring action of the jet.

iv) The impact on the channel bed.

The figure1.2 shows ski jump bucket in operation

Figure 1.2: Ski jump bucket in operation

Flip buckets or ski jumps are known as the most economical design for energy dissipation at high dams. The dissipation of energy does not take place in the bucket itself (except at low flows) but in the air and in the river bed where severe erosion can be expected. Scouring process downstream of flip buckets or ski jumps, consist of several stages which can be simplified as follows: free trajectory jet behavior in the air and aerated jet impingement, plunging jet behavior and turbulent flow in the plunge pool and other processes which finally lead to displacement of the scoured materials by sediment transport.

One of the most important measures affect on limiting the scour hole extent and its deepening is forced aeration and splitting of jet leaving spillway structures. In order to increase turbulent intensity, split and aerate the jets leaving flip buckets and crest lips, they are often equipped with splitters and deflector teeth in the form of dentate buckets. A free trajectory jet in air is affected by turbulence and shearing action. If the jet trajectory is long and the discharge small, the two effects may cause the jet to disintegrate almost completely before striking the water surface in the tail water. If a jet is only partially disintegrated, it causes a larger amount of scour in the impact area.

The figure1.3 shows scouring action through ski jump bucket.

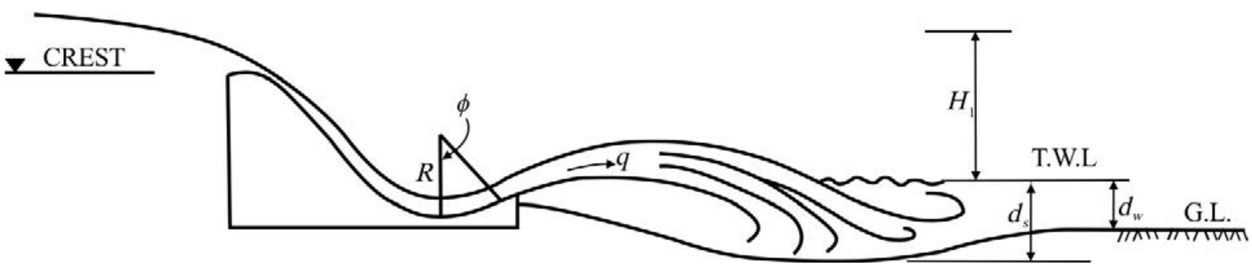


Figure 1.3: Scouring action through Ski jump bucket

1.4.5 STILLING BASINS

The basins are usually provided with special appurtenances including chute blocks, sills and baffles piers.

Chute blocks: are used to form a serrated device at the entrance to the stilling basin. Their function is to furrow the incoming jet and lift a portion of it from the floor producing a shorter length of jump than would be possible without them.

The sill: is usually provided at the end of stilling basin. Its function is to reduce further the length of the jump and to control scour. The sill has additional function of diffusing the residual portion of high velocity jet that may reach the end of the basin.

Baffle piers: are blocks placed in the intermediate position across the basin floor. Their function is to dissipate energy mostly by impact action. They are useful in small structures with low incoming velocities. They are unsuitable where high velocities make cavitation possible.

1.4.5.1 Classification of Stilling Basins

Stilling basins can be classified into:

1. Stilling basins in which$F1<4.5$. This is generally encountered on weirs and barrages.
2. Stilling basins in which$F1>4.5$. This is a general feature for medium and high dams.

1.4.5.2 Stilling Basin Design for Low Froude Numbers $F1<4.5$

i. R.S. Varshney

ii. Indian Standard Stilling Basin

iii. U.S.B.R. Stilling Basin IV

iv. S.A.F. (Saint Anthony Falls) Stilling Basin.

1.4.5.3 Stilling Basin Design for Froude Numbers $F1>4.5$

i. S.A.F. Stilling Basin.

ii. Indian Standard Stilling Basin II.

iii. U.S.B.R Stilling Basin II. This design is recommended for large and medium spillways and large canal structures. The length of basin is 33% reduced with the use of appurtenances. The basin contains chute locks and dentated sill. No baffle piers are used because high velocities might cause cavitation on piers.

1.4.6 SUBSIDIARY DAM

It is constructed below main dam. It increases the tail water dam and causes a jump to form at the toe of main dam. . This type of work is done for protection work of condition II where jump height curve lies lower than tail water curve at low discharges and higher at higher discharges .A low secondary weir (or dam) is constructed downstream of toe to raise the tail water. A low secondary dam (or a sill) is provided to increase the depth at high discharges. However, at low discharges, this arrangement will further increase the tail water depth, which is already quite high. Therefore, at low discharges, the jump will be more drowned and consequently, there will be less dissipation of energy. If this arrangement is not likely to cause much scour, it may be acceptable.

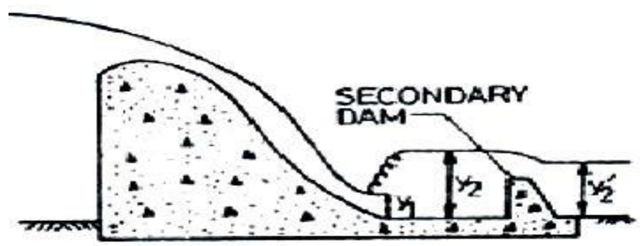


Figure 1.4: Subsidiary dam downstream of spillway

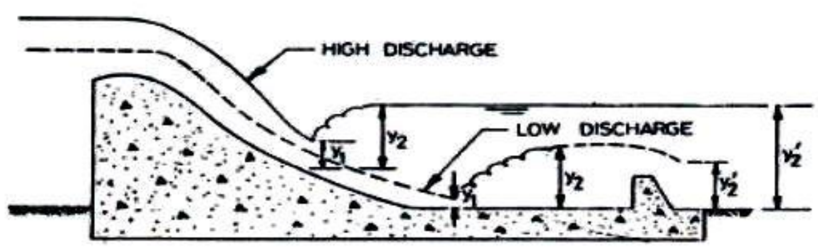


Figure 1.5: Effect of subsidiary dam downstream of spillway

1.4.7 BAFFLE WALL

When tail water deficiency is small, a baffle wall is provided at downstream of spillway. It dissipates the residual energy. Baffle wall are suitable only for low spillway or weirs. It generally gives way under high velocity jet due to their cavitation effects. It should be sufficiently strong to withstand ice and floating debris. The location, shape, spacing and size is best determined by modal studies. The energy dissipation is by impact and friction. This type of work is done for protection work of condition II where jump height curve lies lower than tail water curve at all discharges. In other words, the available tail water depth is greater than required for hydraulic jump. The jump in such a case will be completely submerged an no standing wave would occur

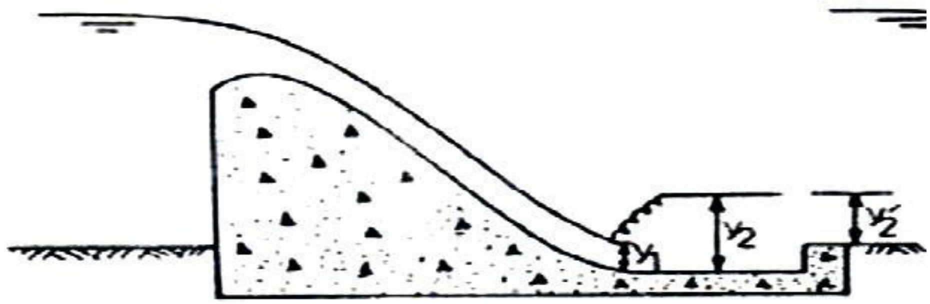


Figure 1.6: Baffle wall downstream of ogee spillway

Chapter 2 Literature review

2.1 General

Our main aim is to study scouring pattern in the downstream of spillway using different types of energy dissipaters with two different downstream aggregate size on flat bed and inclined bed (slope 1/300), that can help in study of pattern of scouring. For this we have used locally available sand for two different particles size one is retained over 2.36 mm sieve and passing from 4.75 mm sieve and second is retained over 600 µm sieve and passing from 2.36 mm sieve, ski-jump bucket, baffle wall and subsidiary dam to study the relative effect.

2.2 EARLIER RESEARCHES

Some earlier research work has been done on scouring pattern using neural network, vector regression, geotechnical aspect of scour, etc.

By systematic research on a number of models including Slapy dam & Orlik dam (Czech Republic), Cabelka & Horsky in 1961 concluded that take-offs with deflectors are always more effective than conventional type ski jumps (Cabelka & Horsky 1961).

They used velocity coefficient φ, to express the energy loss at the point of jet entry into the downstream pool in different configurations of terminal structure of spillways. They prepared a graph which, compares φ, for different specific discharges q, in a relatively low spillway of a classical type, equipped with take-off edge (ski jump) without baffles and with baffles.

Auroy (1965), reported that in order to obtain maximum energy dissipation and minimum scour simultaneously in Chastang dam (France), the perimeter of the jet was increased by positioning tooth-type elements at the take-off location. As a result, the rectangular approach jet becomes U-shaped shortly upstream of the impact area (Vischer & Hager 1995).

S. L. Yang (1994), applied a dispersive type of energy dissipator for Shanzi dam in China, which combines features of slotted bucket and ski jump energy dissipators. Tests showed that downstream scouring depths can be reduced by 40% to 90%, compared with the conventional ski jump dissipators (Yang 1994).

Khatsuria (1994), has mentioned to successful using of dentate bucket in Magat dam in Philippines. Using a special design of dentate bucket (Serrated bucket) in this project gave two advantages: considerably larger cross sectional distribution of jet impact on the plunge pool and air entrainment to the point of separation from the solid boundary thus reducing possible cavitation problems (Khatsuria 1994).

Flip buckets or ski jumps in some of large dam projects constructed around the world are equipped successfully with deflector teeth such as: Karakaya dam and Keban dam (Turkey), Pishin dam and Agh-Chai dam (Iran), Picote dam (Portugal), Oroville dam and Celevland dam (USA), Slapy dam and Orlik dam (Czech), Chastang dam (France), Magat dam (Philippines), Stiegler's gorge dam (Norway) and Gutianxi dam (China). In all of the above projects, physical modeling was used to optimize the geometric design and configuration of dentate buckets.

Khalil I. Othman (2007), conducted an experimental study to know the local scour at downstream of Ogee spillway by using to non-cohesive bed material. They explain the effect of hydraulic conditions of flow and sediment characteristics on depth and the length of scour. The results show that the depth and extent of scour affect very much by the rate of the discharge and the depth of tail water. The size and shape of bed material particles plays an vital role in characteristics of the occurred scour. The size and shape of particles of bed material plays an important role in the characteristics of scour. The scour characteristics in fine particle bed materials affect extensively by the variation of flow rate than coarse angular particles.

Azamuthalla H. Md. et al.(2007), studied scouring downstream using genetic programming on ski-jump bucket Actual field measurements were used to develop the GP model. The GP based estimations were found to be equally and more accurate than the ANN based ones, especially, when the underlying cause-effect relationship became more uncertain to model.

Arun Goel (2008), estimated scour downstream using SVM modeling. Prediction of the scour hole parameters like maximum depth, width and length downstream of a spillway using ski jump bucket type arrangement with linear regression and RBF & polynomial kernel based SVM technique have been attempted. The performance of different schemes was compared using two error criteria such as correlation coefficient and root mean square error. The study showed that RBF kernel based SVM scheme has emerged as the most satisfactory on the present data set as compared to the polynomial kernel based SVM model and the linear regression modeling.

S. H. Musavi Jahromi et al.(2010), preform an experimental study about effect of tailwater depth on the characteristics of local scour at downstream of falling jets. A flume with 5m length, 25cm height and 10cm width had been established. Jets with three shapes including; circular, square and rectangular were connected to the end of the flume. A Siliceous bed with d50=1.27mm, three drop heights including; 35cm, 65cm and 95cm and three tailwater depth; 6cm, 12cm and 18cm have been applied downstream of the jet. Different analysis of the observed data showed that the characteristics of scour-hole depend on erosion parameter and tailwater parameter. Also it was considered that increasing the tailwater depth from 6cm to 12cm and then to 18cm, at first causes increasing the depth, width and length of scour-hole and also the length of sediments mound on the average of 104, 42, 39 and 83%, respectively, then causes decreasing these characteristics on the average of 23, 24, 18 and 16%, respectively. In this case the height of sediments mound at downstream of scour-hole will increase on the average of 52%.

Ted M. Champahne et al.(2011), perform an experiment to know the scouring pattern at the downstream of stilling basin and they found that the primary scour hole was formed due to concentrated flow exiting the stilling basin and impacting the channel bed. Scour geometry was affected by the primary downward roller in combination with the counter rotating vortices. To a lesser extent, numerous eddies caused by flow separation in the plan-view also contributed to the scour geometry.

Tiwari H.L et al.(2013) conducted an experimental study in the laboratory to study the stilling basin performance with end sill for rectangular shaped pipe outlets. For that, experimental investigations were carried out in a recirculating flume of dimensions 0.95 meter wide, 1 meter deep and 25 meter long in the hydraulics laboratory. The width of flume was reduced to 58.8 cm. by constructing a brick wall along the length for suiting the requirement of width of flume according to the stilling basin design considerations as suggested by Bradely and Peterka3. A rectangular pipe of 10.8 cm x 6.3 cm was used to represent the outlet pipe. This pipe was connected with feeding pipe of diameter of 10.26 cm connected with centrifugal pump. The exit of outlet pipe was kept above stilling basin by one equivalent diameter (d = 9.3 cm). A wooden floor of size 58.8cm wide and 78.6 cm long was provided, downstream of the exit of the pipe outlet for fixing the appurtenances inside the basin. Three inflow Froude numbers namely Fr = 1.85, 2.85 and 3.85 were used as per discharge consideration in the flume. A manual tail gate was used at the end of the flume to control the tail water depth in the flume for experimentation. Bed Materials: to observe the scour, after the end sill of stilling basin, an erodible bed, consisting of coarse sand of specific gravity as 2.76, and passing through IS sieve opening size 2.36 mm. and retained on IS sieve opening size 1.18mm was used. For all testing same bed material was used to compare the basin performance. End Sills: During the experimentation to study the scour pattern for a stilling basin models, rectangular, square, and triangular of varying slope from 1V:0.5H to 1V:2H and trapezoidal end sills were used. Impact wall of dimension 1d x 2.2d was employed to facilitate the dissipation of energy in the basin. On the basis of experimental study, it is concluded that the shape of end sill affects the scour pattern downstream of the stilling basin significantly due to change in the flow conditions. The sloping vertical end sill(slope 1V:1H) dissipates more energy of flow as it gives the minimum value of scour depth and found to perform better for all flow conditions as compared to other end sills tested for rectangular pipe outlet basin. The variation of scour parameters is due to the variation in flow geometry because of varying the shape of end sill and discharge rate.

There has been a lot of work done using genetic programming, neural network. Most of the work is on ski-jump. Not work could be found on baffle dam and subsidiary dam, so the experimental program undertaken aimed:

1. Determine scour length and maximum scour depth for different type of energy dissipater and aggregate material downstream of spillway for flat bed and inclined bed.
2. Determine velocity of flow from the pitot tube and using it to calculate the discharge of flow in the flume.
3. Determine net energy dissipation for flat bed and inclined bed.
4. Comparison of scour depth, scour length and energy dissipation for flat bed and tilted bed.

Chapter 3 Experimental setup and methodology

3.1 General

Experiments were performed in hydraulic laboratory of department of civil engineering Delhi Technological University, Delhi. In this chapter detailed discussion about the experimental set up, procedure and methodology used is explained.

3.2 Experimental setup

3.2.1 Flume

Flume is a device which is basically used to determine the definite relationship between depth of flow and discharge of flow. They are designed to achieve critical depth within the structure. For present study the flume and other apparatus is provided by Delhi technological university, Delhi. The flume used in the experimental study is rectangular geometry whose dimensions are 6m × 0.30m × 0.60m. The flume was supported by a steel frame and contained sectioned acrylic glass. Discharge in the flumes was controlled by an inlet valve. Upstream and downstream depth was controlled by adjusting respective gate of flume. In the present study flume (figure 3.1) was used to determine the length of scouring and depth of scouring below the energy dissipaters.

Figure 3.1: flume used in the experimental work

3.2.2 Pitot tube

Pitot tube is a device which is basically used to measure the local velocity of flow. In present study the velocity of flow is determined by using pitot tube which in turn connected with a inverted U-tube manometer. Here in this experiment study stagnated pitot tube is used to measure the velocity of flow. The Pitot tube which is used during the present study is a L shaped metallic tube of external diameter 3.3 mm. An inverted U-tube manometer which consists of two identical glass tube clamped to a wooden stand was used. The wooden stand was fitted with measuring scale for the facility of measuring and taking the readings easily. The top end of the inverted glass tube is open to atmosphere and the two bottom ends are connected to the pitot tube with the help of two 2m long hard nylon tubes. There are two type of velocity named theoretical velocity and actual velocity of flow.

$$V_{th} = \sqrt{2gh}$$

$$V_{ac} = C_v \sqrt{2gh}$$

Where,

V_{th} = theoretical velocity of flow

V_{ac} = actual velocity of flow

h = head difference between the manometer readings

C_v = coefficient of velocity of Pitot tube

$C_v \in [0.98\ 0.99]$

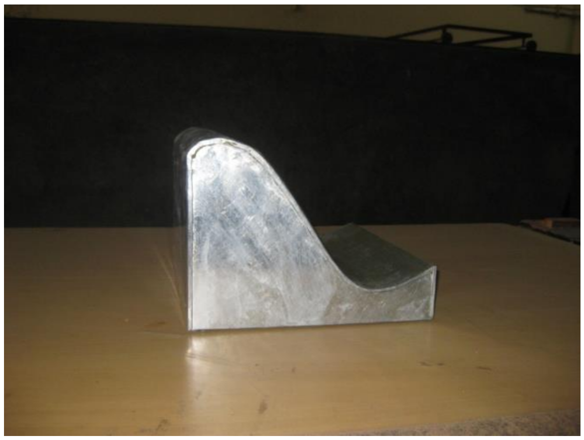
The detailed working of Pitot tube is given in the section. See in figure 3.3

Figure 3.2: Pitot tube with u-tube manometer

3.2.3 Spillway models

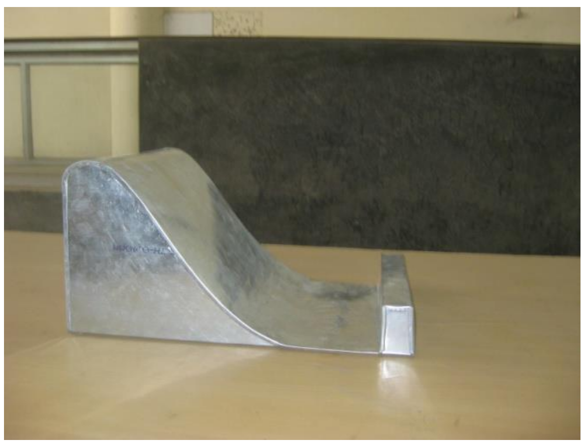
The spillway is among the most important structures of a dam project. It provides the project with the ability to release excess or flood water in a controlled or uncontrolled manner to downstream to ensure the safety of the project. To study the scouring pattern downstream of spillway using different energy dissipaters and two different sizes of downstream aggregate materials were required. For this, two different sizes (2.36mm and 4.75mm) of downstream aggregate materials, ogee spillway, ski-jump bucket, baffle wall and subsidiary dam were used to study the relative effect.

(a) Ogee spillway



(b) Ski jump bucket

(c) Ogee spillway with subsidiary dam



(d) Ogee spillway with baffle wall

Figure 3.3: Models used in experimental study

3.2.4 Pump

A close couple centrifugal pump assembled with the flume was used for water flow in flume. Speed of the pump could be regulated manually by using revolving wheel controller.

Figure 3.4: Pump attached with rectangular flume

3.2.5 Point gauge

It is a device which is basically used to measure the depth of flow, depth of scouring within the channel. It is mounted on the upper rails of the channel over which it slides easily from one point to another point. Length of point gauge 1.50 m used for this experimental study.

Figure 3.5: Point gauge used in experiment

3.3 Material used

Sand is granular form of silica. Sand used for mixed design is standard sand. In India standard sand is ennore sand. The standard sand shall be of quartz, light grey or whitish variety and shall be free from silt. The sand grains shall be angular, the shape of the grains approximating to the spherical form, elongated and flattened grains being present only in very small or negligible quantities. The standard sand shall be free from organic impurities. The loss of mass on extraction with hot hydrochloric acid of rd 1.16 (conforming to IS 265: 1987) shall not be more than 0.250 percent when tested. Melting point of sand is 1723^{0}C and specific gravity of sand is 2.65.

In this experimental study two type of fine aggregate are used.

Particle size passing from 2.36mm and retained over 600 μm sieve

Particle size passing from 4.75mm and retained over 2.36 mm sieve

Figure 3.6: Material used in experiment

3.4 Experimental Procedure

The experimental set up is located at hydraulics laboratory of department of Civil Engineering, Delhi Technological University, Delhi. Present study is carried out on a rectangular channel of dimensions 6m long, 0.30m wide and 0.60m deep. All the other appropriate instrumentations which are used for flow measurement profile are designed and installed. There is a pump which regulate the water from outlet to inlet. A tail gate is installed at the outlet of the channel.

To know the scouring profile below the energy dissipaters, first ensure that the flume has zero inclination or flume is purely horizontal after that fix the spillway model in the rectangular flume with the help of clay. Model is fixed in such a manner so that it should prevent the leakage of water over it. And then prepare sand bed at the downstream of model. Fill the collecting tank with clean water. And then switch on the pump. After 30 minutes of starting the pump(when the flow is stable), take the readings with the help of pitot tube to calculate the local velocity then discharge and with the help of point gauge take the reading of secant depths to calculate the loss of energy and then Switch off pump. After switching of the pump take the readings of maximum depth of scouring with point gauge and maximum length of scouring with the help of metallic tape.

Repeat the whole process by changing the opening of inlet valve that means take the readings at different-different discharges. And then tilt the flume with the help of jacking mechanism, installed in rectangular flume. Adopt same procedure for taking readings on inclined bed also. Some figures of experiment are given below

Figure 3.7: Scouring profile at downstream of ski jump bucket spillway with particle size 2.36mm on flat bed

Figure 3.8: scouring profile at downstream of ogee spillway with subsidiary dam with particle size 2.36mm on tilted bed (slope 1/300)

Figure 3.9: Scouring profile at downstream of ogee spillway with subsidiary dam with particle size 2.36mm on flat bed

Figure 3.10: Scouring profile at downstream of ogee spillway with baffle wall with particle size 2.36mm on flat bed

Figure 3.11: Scouring profile at downstream of ogee spillway with baffle wall with particle size 4.75mm on flat bed

Figure 3.12: Scouring profile at downstream of ogee spillway with baffle wall with particle size 4.75mm on tilted bed (slope 1/300)

Figure 3.13: Scouring profile at downstream of ogee spillway with subsidiary dam with particle size 4.75mm on flat bed

Figure 3.14: Scouring profile at downstream of ogee spillway with subsidiary dam with particle size 4.75mm on tilted bed (slope 1/300)

Figure 3.15: Scouring profile at downstream of ski jump bucket spillway with particle size 4.75mm on tilted bed (slope 1/300)

Chapter 4 Result and discussion

4.1 General

In this chapter the findings of the present study is presented in the forms of tables and graphs.

Table 4.1: Head difference of manometer for velocity and discharge calculation

S.NO	Difference of manometer readings x (cm)	Velocity of flow using pitot tube (m/sec.)	Discharge (m^3/sec.)
1	0.5	0.307	0.055
2	2.10	0.629	0.113
3	2.20	0.640	0.116
4	2.40	0.672	0.121
5	3.40	0.800	0.144

4.2 Ogee spillway

4.2.1 Scour depth.

Table 4.2: Maximum scouring length for ogee spillway

S.No.	Discharge (m^3/sec)	Maximum Scour depth D_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	5.64	5.31	4.91	5.07
2	0.113	8.17	7.95	6.67	7.86
3	0.116	8.86	8.57	7.23	8.09
4	0.121	9.57	9.49	8.07	8.67
5	0.144	10	10	9.37	9.41

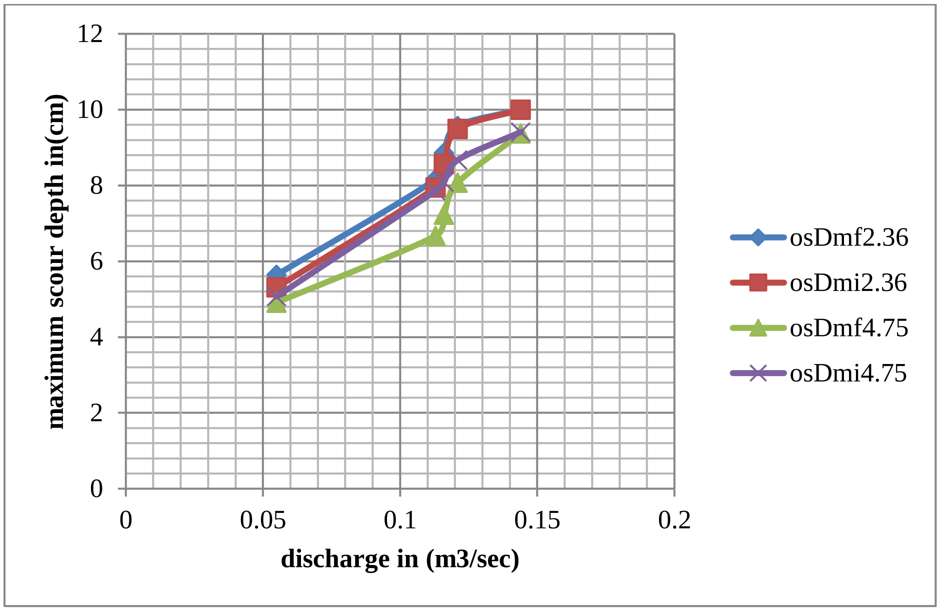


Figure 4.1: Comparison of maximum depth of scouring on flat bed and inclined bed for ogee spillway with discharge.

In the present experimental study for ogee spillway, it is clearly seen from graph (figure 4.1), that the minimum scouring depth below ogee spillway obtained from larger particles (size 4.75mm) over flat bed and maximum scouring depth was obtained from smaller particles(size 2.36mm) on flat bed. As in the case of inclined bed (slope 1/300) minimum scouring occurs for larger (4.75mm) particle and maximum smaller size (2.36mm) of particle.

4.2.2 Scour length

Table 4.3: Maximum scouring length for ogee spillway

S.No.	Discharge (m^3/sec)	Maximum Scour length L_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	63	40	53	38
2	0.113	80.65	53	76.5	50.5
3	0.116	123.6	98	117	91
4	0.121	155.6	118	148	109
5	0.144	176	164.3	169	149

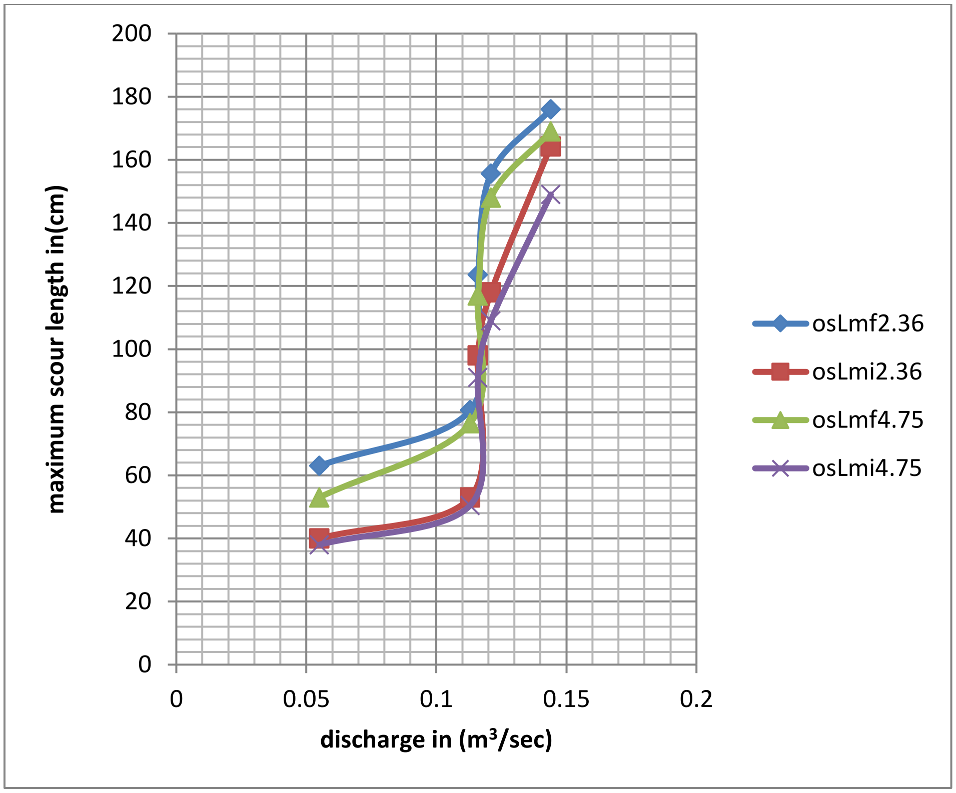


Figure 4.2: Comparison of maximum length of scouring on flat bed and inclined bed for ogee spillway with discharge.

From graph (figure 4.2), It is seen that minimum scouring length occur when bed in inclined position (slope 1/300) for larger size (4.75mm) of particle and followed by smaller size (2.36mm) of particle. As in the case of flatbed, minimum scour length for larger size (4.75mm) of particle and maximum for smaller size (2.36mm) of particle.

4.3 Ski jump bucket spillway

4.3.1 Scour depth

Table 4.4: Maximum scouring depth for ski jump bucket spillway

S.No.	Discharge (m^3/sec)	Maximum Scour depth D_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	5.88	5.09	3.72	3.31
2	0.113	6.03	6.22	4.49	4.34
3	0.116	7.56	8.05	5.39	5.31
4	0.121	8.01	8.14	6.17	6.93
5	0.144	10	9.85	8.73	8.64

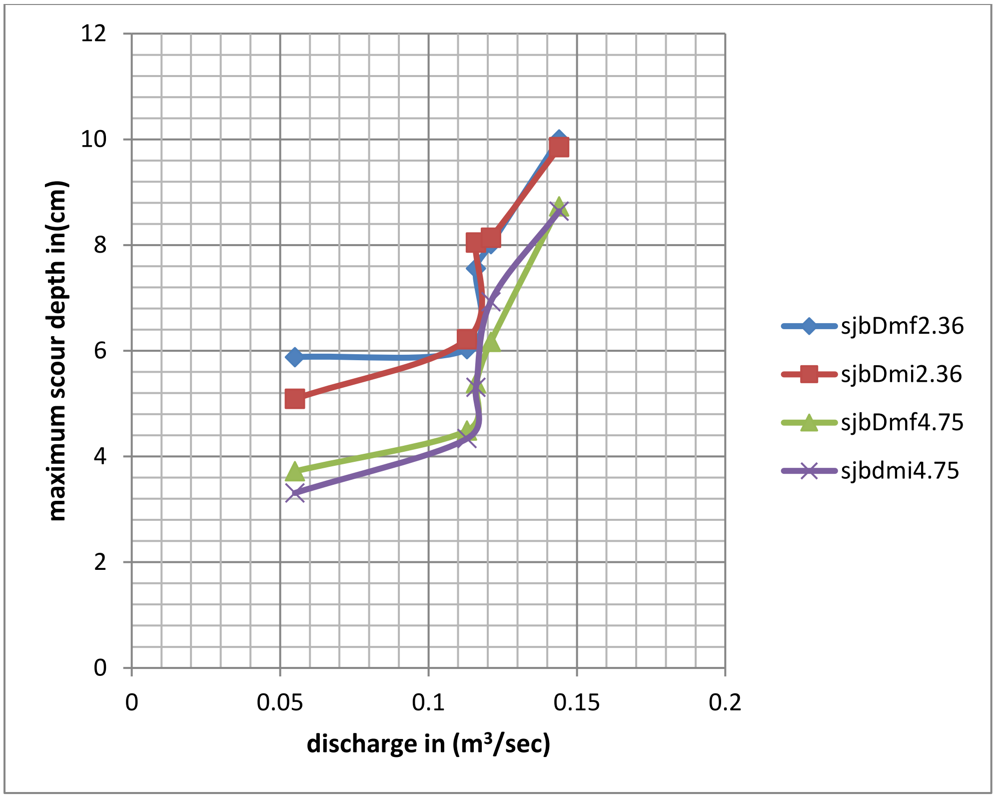


Figure 4.3: Comparison of maximum depth of scouring on flat bed and inclined bed for ski jump bucket spillway with discharge.

From graph (figure 4.3), It is clearly seen that in case of ski jump bucket spillway maximum scour depth obtained over flat bed and minimum in the case of inclined bed (slope 1/300). Scour depth is minimum for larger size (4.75mm) of particle and minimum for smaller size (2.36mm) of particle.

4.3.2 Scour Length

Table 4.5: Maximum scouring length for ski jump bucket spillway

S.No.	Discharge (m^3/sec)	Maximum Scour length L_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	63.5	41	53	37
2	0.113	75	58	67	47
3	0.116	94.5	85	97	73.5
4	0.121	115	93	102	87
5	0.144	135	103	117	101

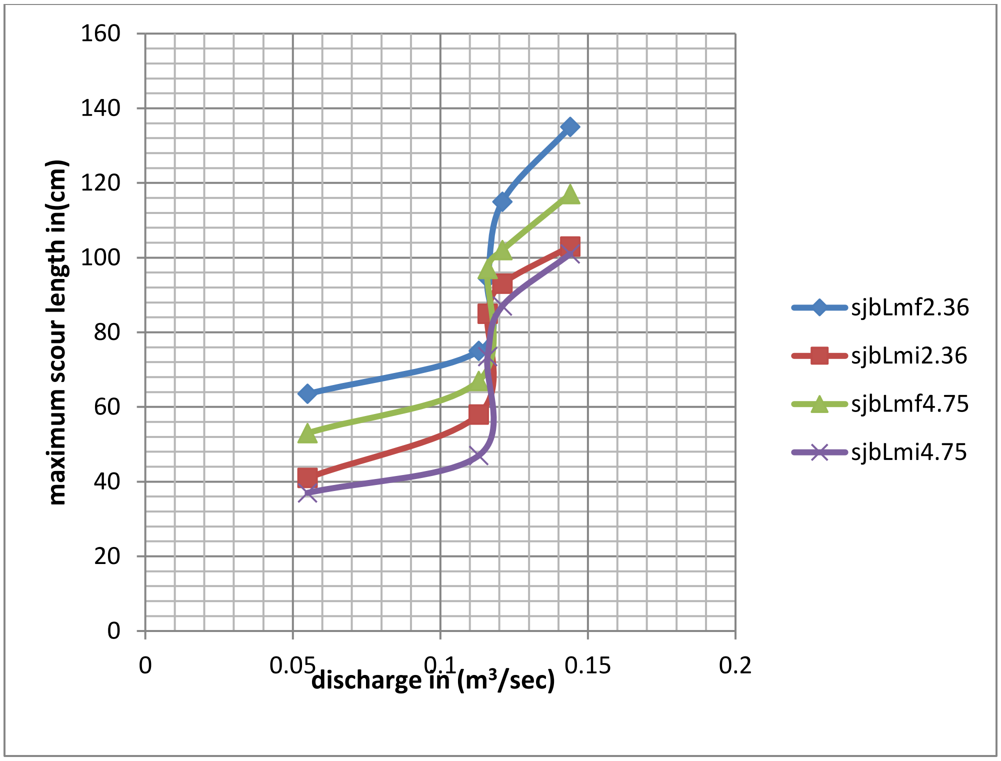


Figure 4.4: Comparison of maximum length of scouring on flat bed and inclined bed for ski jump bucket spillway with discharge.

From graph (figure 4.4), Minimum length of scouring take place when size of particles is large (4.75mm) and bed slope 1/300. Maximum scour length occur when the size of particles is small (2.36mm) for zero bed slope. But overall minimum scour length occur for larger size of particles and maximum for smaller size of particle.

4.3.3 Energy loss

Table 4.6: Energy loss for ski jump bucket spillway

S.No.	Discharge (m^3/sec)	Energy loss E_L(m)			
		Particle size 2.36mm-600μm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	0.02989	0.04121	0.04094	0.17046
2	0.113	0.04428	0.0818	0.11228	0.22841
3	0.116	0.04942	0.0969	0.13032	0.24564
4	0.121	0.05189	0.10925	0.16852	0.27952
5	0.144	0.06236	0.14127	0.22091	0.36312

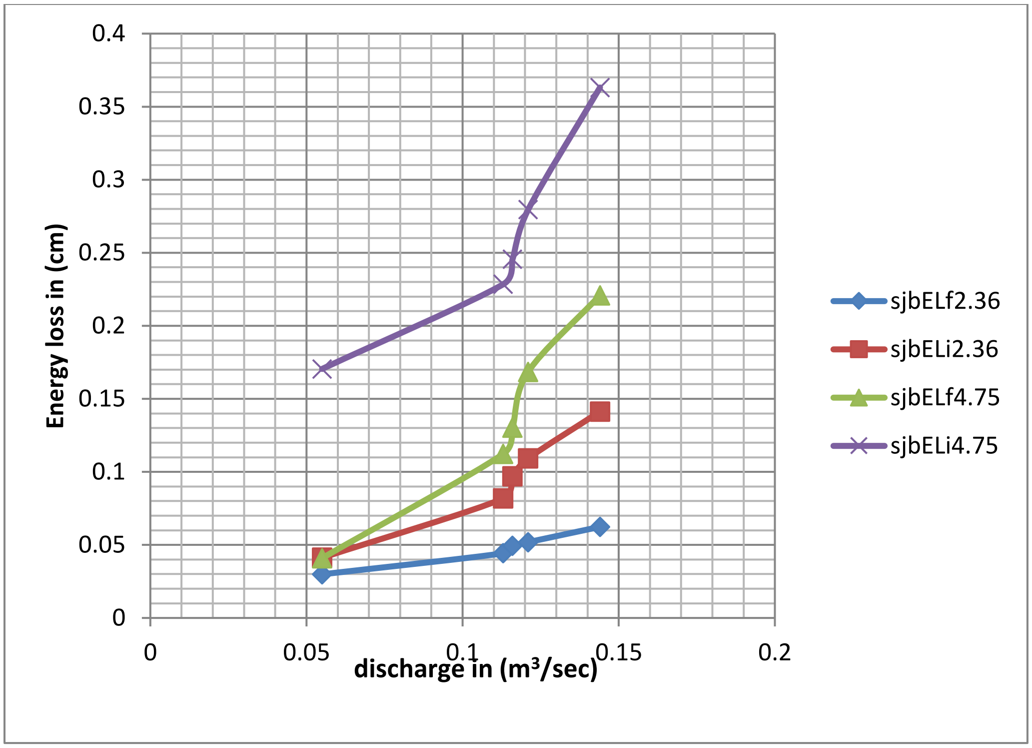


Figure 4.5: Comparison of energy loss on flat bed and inclined bed for ski jump bucket spillway with discharge.

It is clearly seen in the graph (figure 4.5) that by increasing the discharge, Loss of energy in the case of inclined bed(slope 1/300) is maximum for larger size (4.75mm) of particles and minimum in the case of flatbed for smaller size (2.36mm) of particles.

4.4 Ogee spillway with subsiddery dam

4.4.1 Scour depth

Table 4.7: Maximum scouring depth for Ogee spillway with subsiddery dam

S.No.	Discharge (m^3/sec)	Maximum Scour depth D_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	6.77	5.91	2.64	2.09
2	0.113	6.86	6.31	4.19	3.17
3	0.116	7.31	7.19	4.75	5
4	0.121	8.03	7.63	5.28	6.1
5	0.144	9.13	8.14	6.39	7.3

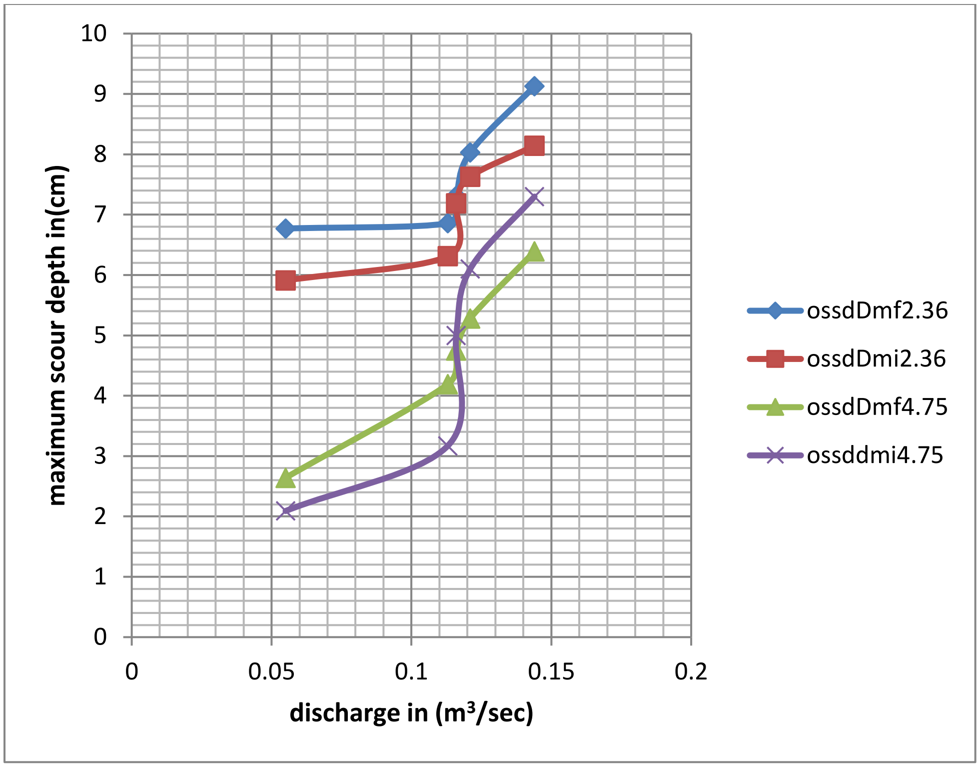


Figure 4.6: Comparison of maximum depth of scouring on flat bed and inclined bed for Ogee spillway with subsiddery dam with discharge.

By increasing discharge, scour depth also increased. Here it is clearly seen in the graph (figure 4.6) that the maximum depth of scour is occur in the case when the size of particles is small (2.36mm) for zero bed slope and minimum for larger size (4.75mm) of particles.

4.4.2 Scour length

Table 4.8: Maximum scouring length for Ogee spillway with subsiddery dam

S.No.	Discharge (m^3/sec)	Maximum Scour length L_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	16.5	15.5	14	13.5
2	0.113	59.5	56	42	39
3	0.116	72	63	66	59
4	0.121	82.5	79	77	74
5	0.144	97	89	91	85

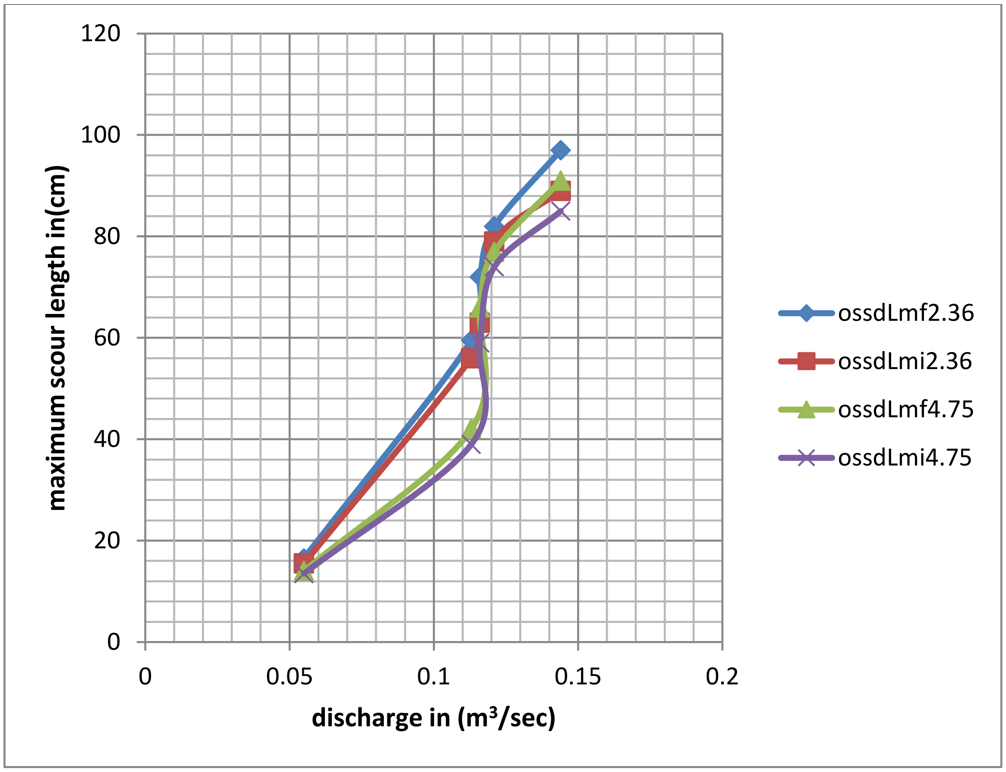


Figure 4.7: Comparison of maximum length of scouring on flat bed and inclined bed for Ogee spillway with subsiddery dam with discharge.

It is clearly seen from the graph (figure 4.7) that by increasing the discharge in all four case, scour length increased. Minimum length of scouring occurred in the case of larger size (4.75mm) of particles and maximum in smaller size (2.36mm) of particles.

4.4.3 Energy loss

Table 4.9: Energy loss for Ogee spillway with subsiddery dam

S.No.	Discharge (m^3/sec)	Energy loss E_L(m)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	0.002658	0.000476	0.002825	0.000403
2	0.113	0.012106	0.013281	0.012636	0.0141
3	0.116	0.015759	0.020283	0.01604	0.021847
4	0.121	0.01933	0.034298	0.018105	0.035752
5	0.144	0.023612	0.058478	0.022688	0.055802

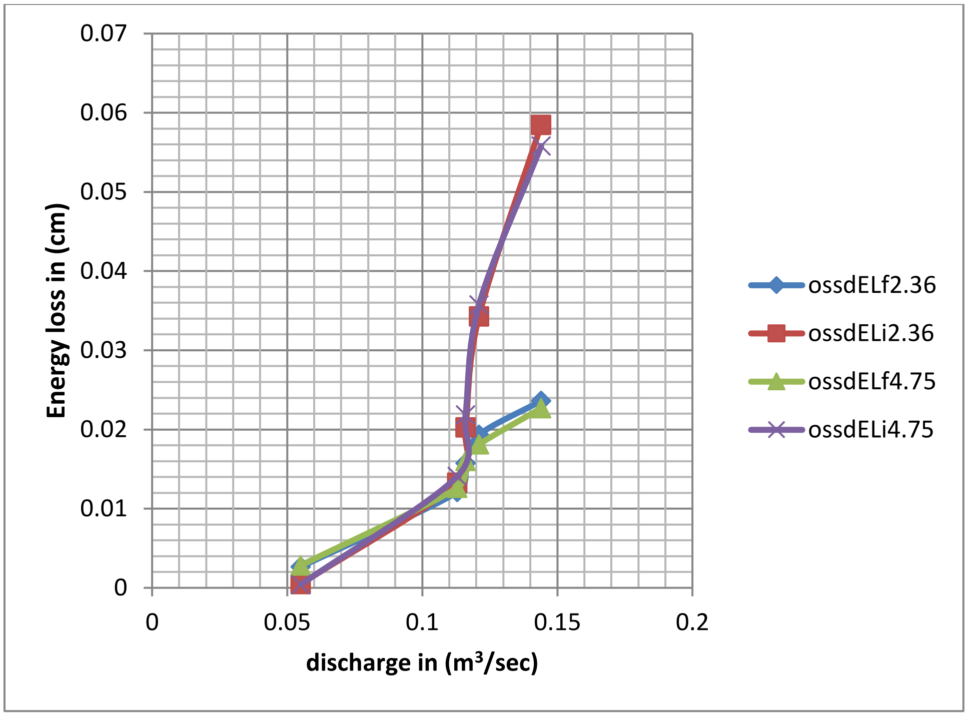


Figure 4.8: Comparison of energy loss on flat bed and inclined bed for Ogee spillway with subsiddery dam with discharge.

From the graph (figure 4.8) it is seen that the maximum loss of energy take place when bed slop is 1/300 for both case, smaller (2.36mm) size of particles and as well as for larger size (4.75mm) of particles. It is also seen from the graph that minimum loss of energy take place when slope of bed is zero.

4.5 Ogee spillway with baffle wall

4.5.1 Scour depth

Table 4.10: Maximum scouring depth for Ogee spillway with baffle wall

S.No.	Discharge (m^3/sec)	Maximum Scour depth D_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	2.59	2.64	2.93	2
2	0.113	4.56	4.15	4.41	4.45
3	0.116	5.89	6.01	5.26	5.71
4	0.121	6.47	7.29	5.41	6.03
5	0.144	7.43	8.12	6.69	7.01

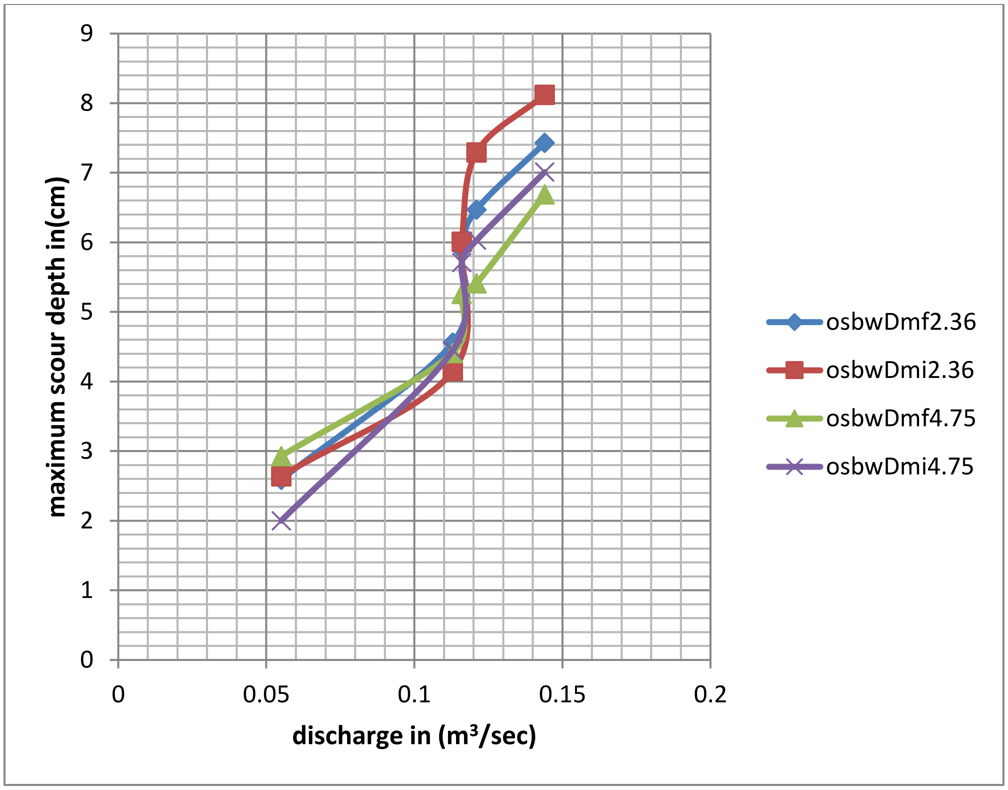


Figure 4.9: Comparison of maximum depth of scouring on flat bed and inclined bed for Ogee spillway with baffle wall with discharge.

From graph (figure 4.9), maximum scour depth occur for smaller size (2.36mm) of particles when bed is in tilted (slope 1/300) position and minimum scouring take place for larger size (4.75) of particles on flat bed.

4.5.2 Scour length

Table 4.11: Maximum scouring length for Ogee spillway with baffle wall

S.No.	Discharge (m^3/sec)	Maximum Scour length L_m (cm)			
		Particle size 2.36mm-600µm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	16	15.35	14.5	13
2	0.113	51	50	33	48
3	0.116	92	91	78	86
4	0.121	109	117	102	98
5	0.144	128	142	123	110

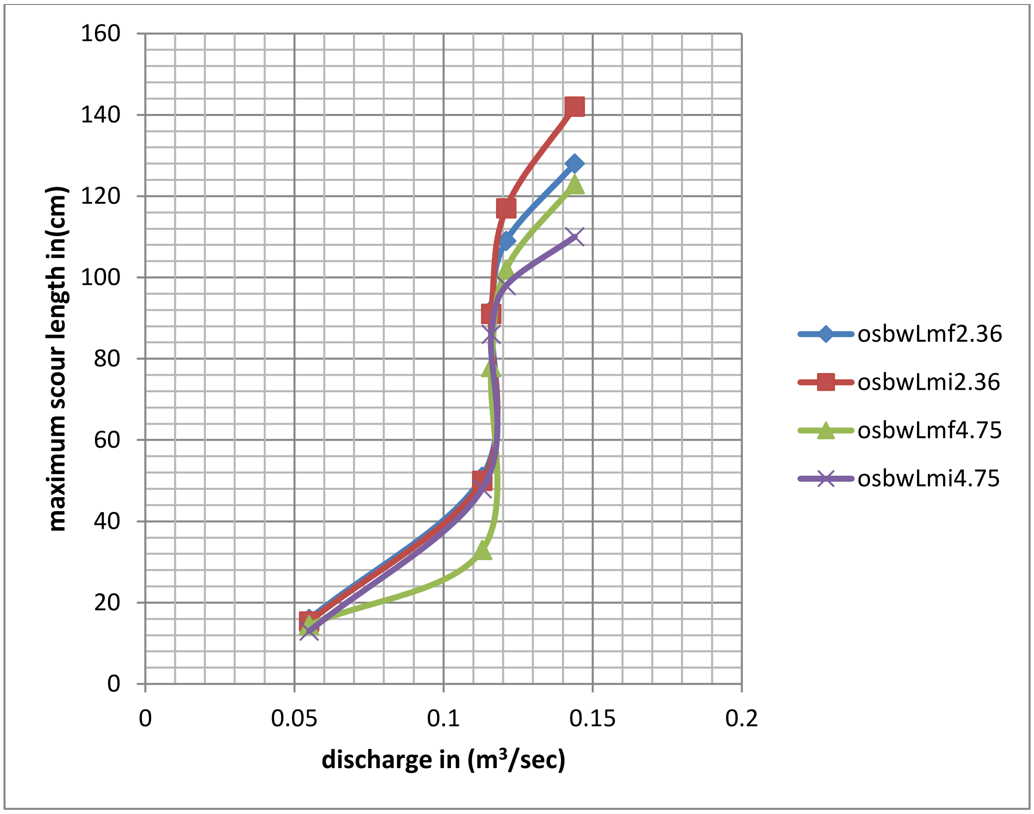


Figure 4.10: Comparison of maximum length of scouring on flat bed and inclined bed for Ogee spillway with baffle wall with discharge.

It is clearly seen from the graph (figure 4.10) that the maximum scour length obtained on flat bed when size of bed material is small (2.36mm). Minimum scour length take place on tilted bed (slope 1/300) for larger size (4.75) of particles.

4.5.3 Energy loss

Table 4.12: Energy loss for Ogee spillway with baffle wall

S.No.	Discharge (m^3/sec)	Energy loss E_L(m)			
		Particle size 2.36mm-600μm		Particle size 4.75mm-2.36mm	
		Flat bed	Inclined bed	Flat bed	Inclined bed
1	0.055	0.0011	0.00099	0.00074	0.00108
2	0.113	0.01334	0.00319	0.0113	0.00389
3	0.116	0.01703	0.00521	0.01423	0.00748
4	0.121	0.02211	0.0059	0.01793	0.00891
5	0.144	0.03	0.00651	0.02574	0.00944

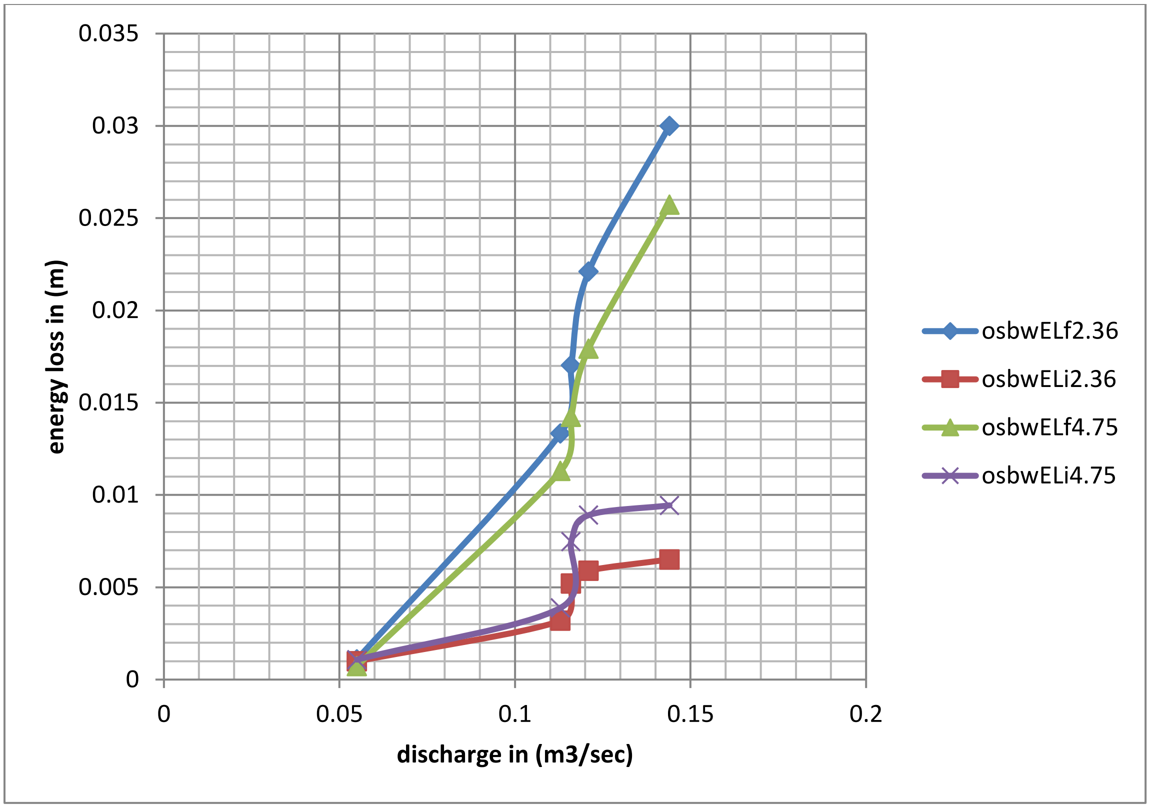


Figure 4.11: Comparison of energy loss on flat bed and inclined bed for Ogee spillway with baffle wall with discharge.

It can be seen from the graph (figure 4.11), maximum loss of energy occur when bed slope is zero for both size of particles but minimum energy loss occur in case of inclined bed (slope 1/300).

4.6 discharge vs scour length

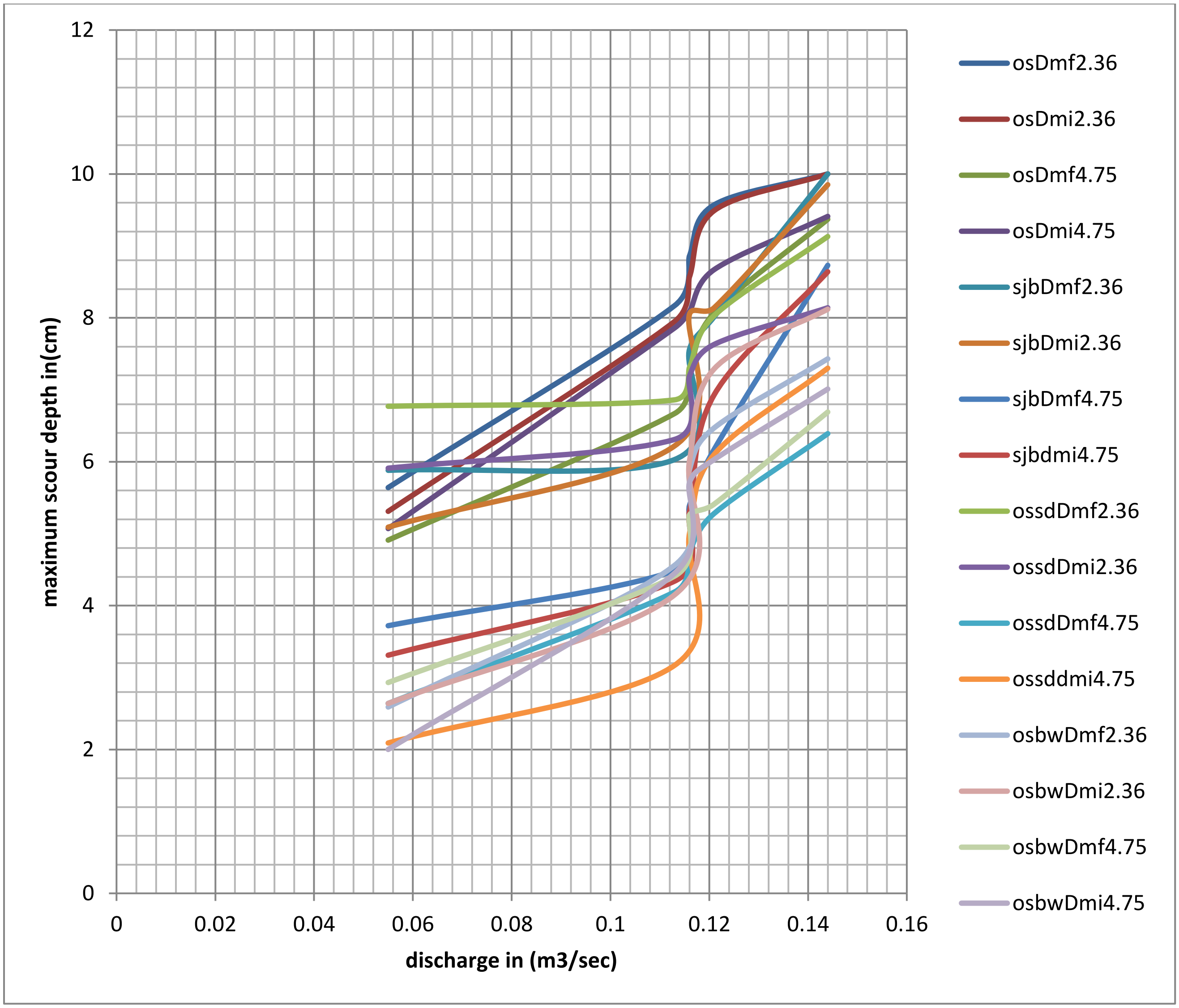


Figure 4.12: Comparison of maximum scour depth on flat bed and inclined bed for all types of models used in the experimental study with discharge.

From graph (figure 4.12), scouring is more for smaller size (2.36mm) of particle and lesser for larger size (4.75mm) of particles. Maximum depth of scour took place when ogee spillway used. Minimum scour depth obtained in case of ogee spillway with baffle wall. If a comparison is done in scour depth of ogee spillway with baffle wall and ogee spillway with subsidiary dam than scour depth less in ogee spillway with baffle wall than ogee spillway with subsidiary dam.

4.7 Discharge vs scour length

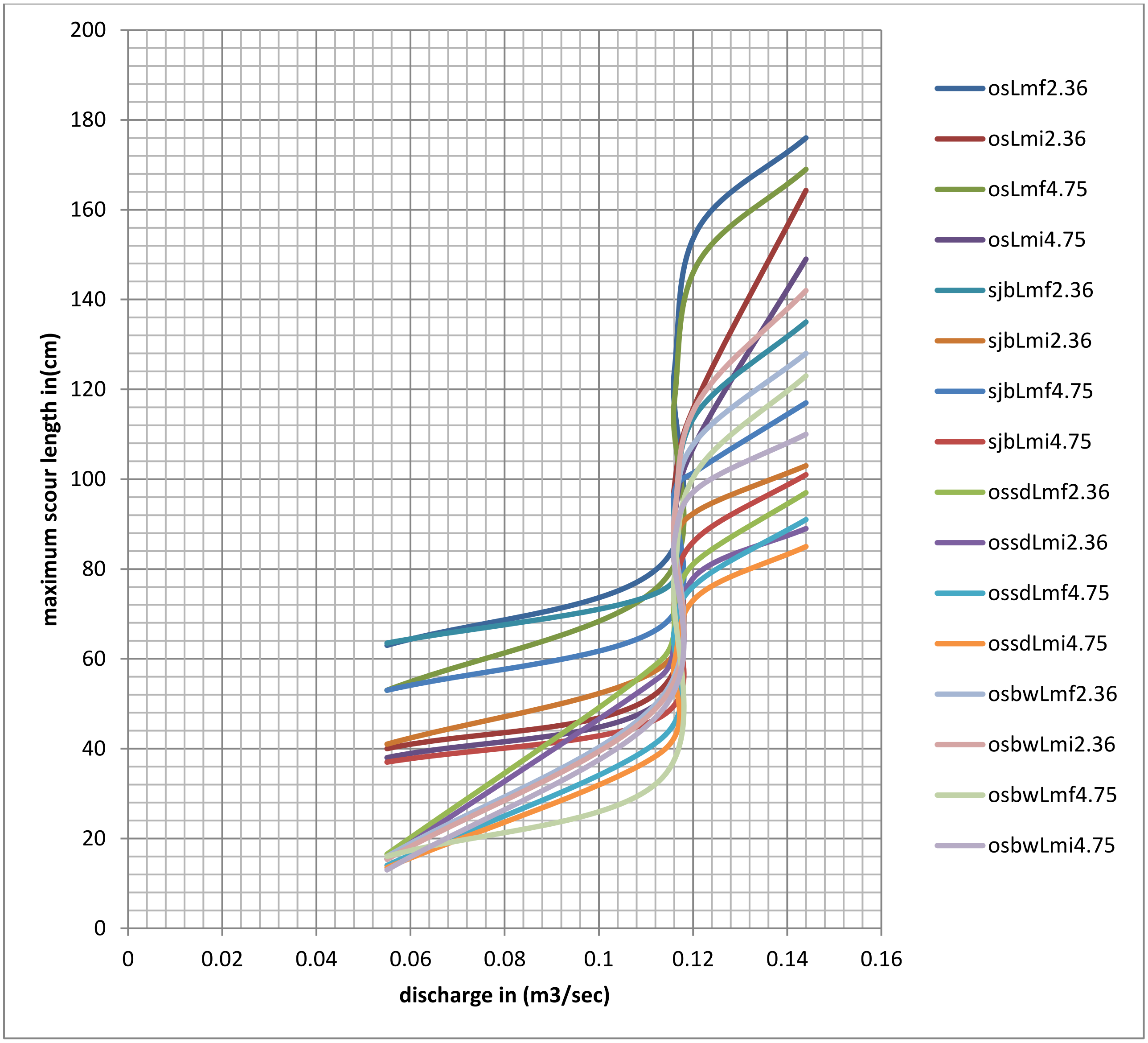


Figure 4.13: Comparison of maximum scour length on flat bed and inclined bed for all types of models used in the experimental study with discharge.

From graph (figure 4.13), Maximum scour length was obtained from ogee spillway and minimum from ogee spillway with subsidiary dam. Scour length was less for spillway with baffle wall than ski-jump bucket type spillway.

4.8 Discharge vs energy loss

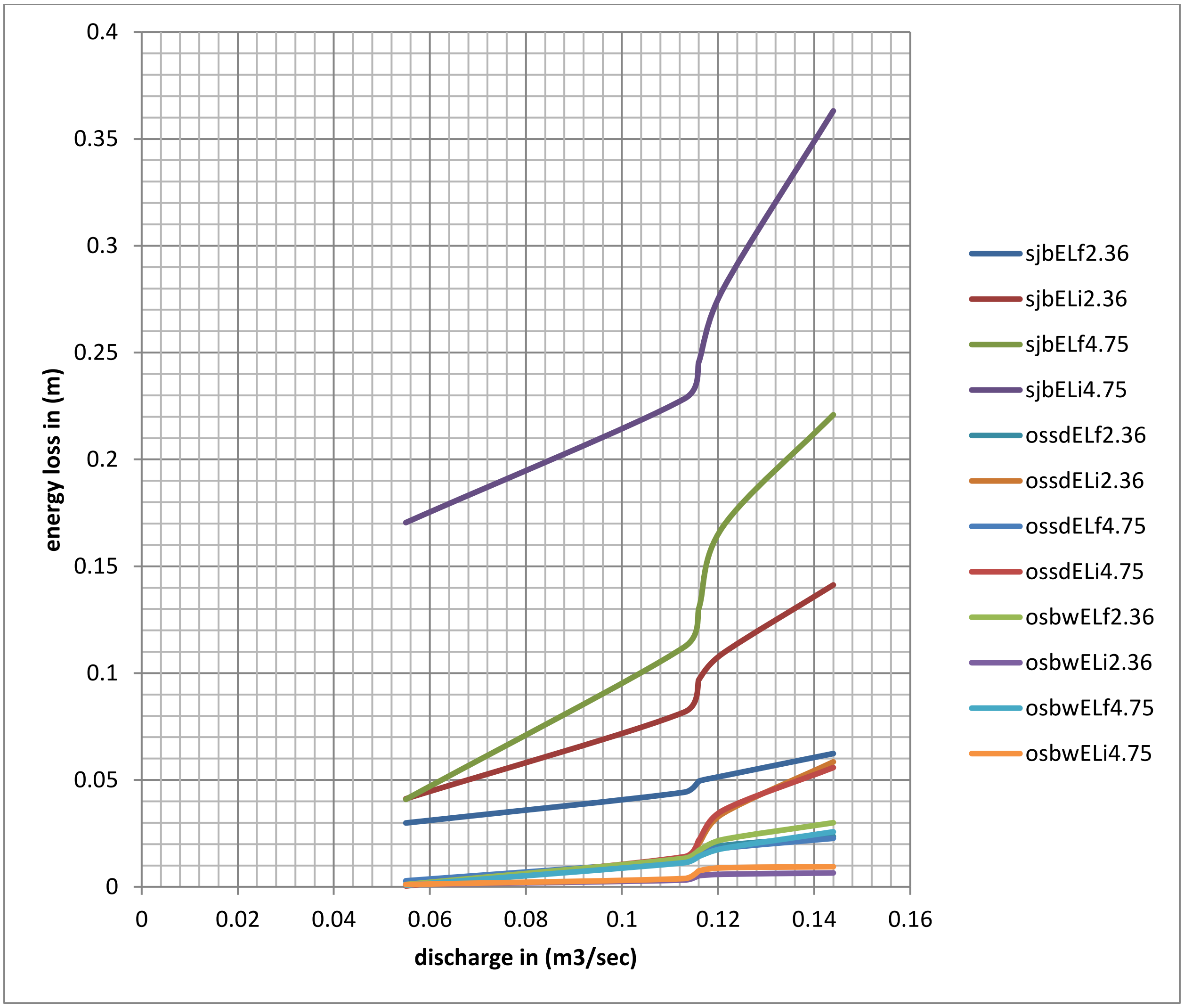


Figure 4.14: Comparison of energy loss on flat bed and inclined bed for all types of models used in the experimental study with discharge.

It can be seen from the graph (figure 4.14), maximum loss of energy obtained from ski-jump bucket type spillway and minimum loss of energy obtained from ogee spillway with baffle wall. If a comparison is done for loss of energy between ogee spillway with baffle wall and ogee spillway with subsidiary dam than energy dissipation is more in spillway with subsidiary dam than spillway with baffle wall.

Chapter 5 Conclusion

Conclusion

Main aim of this present experimental study is to know the scouring pattern at downstream of different type of energy dissipators on flat bed(zero slope) and inclined bed (1/300 slope) using two different sizes of fine aggregate (2.36mm and 4.75mm). Experiments were conducted on four spillway models named ogee spillway, ski jump bucket, ogee spillway with baffle wall and ogee spillway with subsidiary dam in flume of rectangular geometry whose dimensions are 6m (length) × 0.30m (width) × 0.60m (height).

Scouring is more for the smaller sizes (2.36mm) of particles and lesser for larger sizes (4.75mm) of particles. So to prevent the failure of hydraulic structure due to scouring at downstream, grater size of downstream material must be used. Larger sizes of particles beneath at downstream of spillway will lead the safety of hydraulic structure.

Scouring depth is proportional to increase in discharge. For higher discharge, scour depth is more. Maximum depth of scour took place when ogee spillway used. Scour depth was more for ogee spillway than ski-jump bucket type spillway. Scour depth found to be more for ski-jump bucket type spillway than ogee spillway with baffle wall and ogee spillway with subsidiary dam. Minimum scour depth took place when ogee spillway with baffle wall used. Minimum scour depth took place when ogee spillway with baffle wall used. If a comparison is done between scour depth of ogee spillway with baffle wall and ogee spillway with subsidiary dam, scour depth was less in ogee spillway with baffle wall than ogee spillway with subsidiary dam for smaller size of particles but for larger size of particles scour depth was more for spillway with baffle wall than spillway with subsidiary dam.

Maximum scour length took place when ogee spillway used. It was obtained that maximum scour length occur in case of flatbed than inclined bed for ogee spillway. High scouring length was obtained in case of ogee spillway whereas in case of ski-jump bucket type spillway maximum scouring length for same discharge was relatively less. Scour length was less for spillway with baffle wall than ski-jump bucket type spillway. Minimum scour length occurred when ogee spillway with subsidiary dam was used. It was obtained that more scour length occur in case of flatbed than inclined bed for all models used in these experiments.

The energy dissipation increases with increase in discharge. Maximum loss of energy obtained from ski-jump bucket type spillway and for this of spillways more energy dissipated for larger size of particles than smaller size of particles. Energy dissipation is more in ogee spillway with subsidiary dam than spillway with baffle wall. For ogee spillway with subsidiary dam, energy loss found to be less for zero bed slope. Minimum loss of energy obtained from ogee spillway with baffle wall and for this type of energy dissipators minimum loss of energy obtained when bed slope was zero. If a comparison is done for loss of energy in between ogee spillway with baffle wall and ogee spillway with subsidiary dam than energy dissipation is more in spillway with subsidiary dam than spillway with baffle wall.

Ogee spillways with baffle wall is suitable option to prevent the scouring depth at downstream of spillways. Ogee spillways with subsidiary dam may be used to overcome the problem of scouring length at the downstream of spillways. Ski-jump bucket type energy dissipators may be used to dissipate more energy.

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