

# Design of Energy Dissipator for Khadakwasla Dam to Control the Velocity of Flow

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**Abstract** - When the water is dispatched through the spillway the static energy gets converted in kinetic energy. This energy proves costly because of the force which destroys the nearby area by flooding. This breaks the kinetic energy to reduce it to acceptable limits. This was been observed at Khadakwasla Dam this year with flooding occurring with intensity of 14000 cusecs. This destroyed the surrounding area and caused damage to canal. The dissipation of energy is done through internal friction and turbulence or impact and diffusion of the high velocity flow in the mass of water.

So, we are going to use Ski-jump energy dissipator to reduce the kinetic energy of Khadakwasla dam. Ski jump is a trajectory bucket type dissipator which throws the water through bucket in mid-air which impacts the plunge pool resulting in breakage of momentum causing reduction in velocity of flow by considerable amount. This causes diffusion of energy thus reducing the velocity of flow and water pressure on hydraulic structure. This study proposes a design of ski jump energy dissipator which is to be installed on Ogee spillway on Khadakwasla Dam with Guidelines as per IS Code. A complete overview of hydraulic uplift and other hydrodynamic forces has been improved.

**Keywords:** Dissipation of energy, Ski-jump dissipator, Hydraulic uplift, Hydrodynamic force, Ogee spillway, IS Code.

## 1. INTRODUCTION

Controlling the velocity of flow in large dams is a serious concern. This is where energy dissipator comes into action. These are the devices and structures which are used to control and reduce the velocity of flow according to the required and acceptable limits, so that downstream side of channel is protected from action of erosion, damage to the structure by abrasion, flooding and damage to population and their assets. There are numerous types of energy dissipators which are used in action, and their main purpose is to break kinetic energy and the turbulence of water into

potential reach at downstream. This project is concerned with designing a ski jump energy dissipator for Khadakwasla dam in Nanded city.

Khadakwasla dam is built on the River Mutha which is 21 kms away from Pune city. This dam was built in 1879, as a result the flow techniques used in it are outdated. By designing new energy dissipator, we can enhance the control over velocity rather using old techniques. Flooding situation in this region can be minimized to great extent, if new designs are implemented. If the energy of water is not reduced, there are dangers of scour to the riverbed which may threaten the stability of this dam or neighboring valley slopes.

## 1.1 SKI JUMP ENERGY DISSIPATOR

One of the most effective & economical methods for dissipation of hydraulic energy from flood waters is to project the flow in free trajectories jet from to a location where impact creates a plunge pool in downstream side of riverbed. This type of energy dissipation can be done by ski-jump energy dissipator which is increasingly popular form of hydraulic dissipation for large dams.

Ski jump dissipators are provided where there is deficiency in tail water to produce a hydraulic jump situation which arises in hilly terrain with a steep sloping river bed made of hard and sound rock. The jet impact is transmitted through cracks and fissures of the rock in the form of hydrodynamic pressure fluctuations which might give rise to hydraulic jacking action and which get further intensified because of air locking.

An upturn solid bucket (see Fig. 1C) is used when the tailwater depth is insufficient for the formation of the hydraulic jump, the bed of the river channel

downstream comprises sound rock and is capable of withstanding, without excessive scour, the impact of the high velocity jet. The flow coming down the spillway is thrown away from toe of the dam to a considerable distance downstream as a free discharging upturned jet which 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.

### 1.2 COMPONENTS OF SKI JUMP ENERGY DISSIPATOR

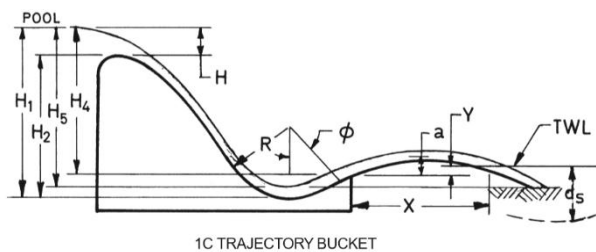


Figure 1 Components of Ski Jump Trajectory Bucket

Where,

$H$  = depth of overflow over spillway, in m;

$H_1$  = reservoir pool elevation minus bucket invert elevation, in m;

$H_2$  = spillway crest elevation minus bucket invert elevation, in m;

$H_3$  = reservoir pool elevation minus tail water elevation, in m;

$H_4$  = reservoir pool elevation minus bucket lip elevation, in m;

$H_5$  = reservoir pool elevation minus jet surface elevation on bucket, in m;

$R$  = radius of bucket, in m;

$X$  = horizontal throw distance from bucket lip to the center point of impact with tail water, in m;

$Y$  = difference between the lip level and tail water, sign taken as positive for tail water below the lip level and negative for tail water above the lip level, in m;

$d_s$  = depth of scour below tail water level, in m;

$a$  = vertical distance from the lip level to the highest point of the center of jet, in m;  $d_c$  = critical depth, in m;

$TWL$  = Tail Water Level = 3 m

$\phi$  = bucket lip angle (exit angle) with horizontal, in degree =  $30^\circ$

### 2. STATEMENT OF PROBLEM

On 18<sup>th</sup> of August, 2018 roads along Mutha River submerged due of excess of 14000 cusecs of water released from Khadakwasla dam into the river. This caused major disturbance in locality along Mutha River. Second incident was around 27<sup>th</sup> September, 2018 where the canal was breached due to excess velocity. This caused flooding in low lying areas. Both of these incidents were due to improper dissipation of energy. Thus, the solution was to break this energy by installation of Energy Dissipator.

### 3. LITERATURE REVIEW

(Utkarsh Nigam, S. Das, M. R. Choudhary, 2015) had dealt with energy dissipation of spillway through hydraulic jump type stilling basin. They had also given a complete overview of hydraulic uplift. Study of Energy dissipation with other hydrodynamic forces is also studied. (Valentin Haller, Willi Hager and Hans Erwin Minor 2005) this paper studies that ski jump energy dissipator is a major part of dam spillway. Several hydraulic problems related to ski jump no yet been solved. 1. Problem such as pressure head and pressure distribution along circular shaped bucket. 2. Impact characteristics in tail water with shock waves formations and height of recirculation. 3. Difficulties in flow condition by trajectory bucket. All such problems are correctly accounted by Froude's number. Hence by using Froude's number successfully design of ski jump in hydraulic structure is possible. (S.K. Mazumder, 2001) research conducted by them

was to test a scale model in ratio of 1:100 scale of ski jump energy dissipator on mobile sand bed for applicability of design guide lines design in I S:7365(1985) code for rocky type river bed. Throw length, throw height and submerged of jet web measured and compared with code provision. Other certain aspects such as scour depth and size of plunge pool with consideration of discharge and tail water depths compared with theoretical value.

(IS Code 11527: 1985) This code has guidelines on criteria of selection of energy dissipator for spillway. (IS Code 7365: 2010) This code has guidelines for designing the bucket type energy dissipator.

#### 4. METHODOLOGY

- The hydraulic jump type energy dissipator is designed by referring IS Code Proposed 7365: 2010.
- However, the amount of energy dissipator on type of jump formed which in turn depends upon the amount of flow entering spillway.
- The sub-critical depth of flow and bucket lip elevation.
- The jump formed will be stored with the help of training wall and divide wall.
- The lip level should be higher than tail water level. This will cause ski jump rather than roller action which is achieved in this case.
- This ski jump would help in dissipation through impact.

Proposed solution as per IS Code 7365: 2010

#### 4.1 DESIGN CONSIDERATION

Hydraulic design of trajectory bucket consists of determining the following: -

1. Bucket shape
2. Bucket invert elevation
3. Radius or principle geometrical parameter of bucket
4. Lip elevation and lip angle
5. Trajectory length
6. Estimation of scour downstream

##### 4.1.1 BUCKET SHAPE

The performance of trajectory bucket is judged by trajectory height and length of throw in flip action. Generally, a circular shape is preferred.

##### 4.1.2 Bucket Invert Elevation

Bucket invert elevation = 1.5 + Tail Water Depth

Tail Water Depth = 3 m

Bucket Invert Elevation = 1.5 + 3 = 4.5 m

- Trajectory Bucket Pressure

$$P = \left[ \frac{V_a^2}{gR} + 1 \right] \gamma d_1$$

Where,

P = Bucket Pressure, in  $t/m^2$

$\gamma$  = Weight of Water,  $t/m^3$

$V_a$  = Actual Velocity of Flow entering in bucket, in  $m/s$

g = Acceleration due to gravity, in  $m/s^2$

R = Radius of Bucket, in m

$d_1$  = depth of flow entering bucket, in m

$$P = \left( \frac{5.19^2}{9.81 \times 4} + 1 \right) 1 \times 0.76$$

$$P = 1.282 t/m^2$$

##### 4.1.3 Radius of Bucket

$$R = 0.8 \sqrt{H \cdot H_3}$$

Where,

R = Radius of Bucket

H = Depth of flow over spillway

$H_3$  = Reservoir Pool Elevation – Jet Surface Elevation =  
32.79 – 0.343 = 32.447 m

$$\text{Jet Surface Elevation} = \frac{V_a^2}{2g} * (\sin \theta)^2$$

Where,

$V_a$  = Actual Velocity of Flow entering in bucket, in  $m/s$

g = acceleration due to gravity, in  $m/s^2$

$\emptyset$  = Lip angle (30°-40°)

$$\text{Jet surface elevation} = \frac{5.19^2}{2 \times 9.81} (\sin 30) ^2 = 0.343 \text{ m}$$

$$R = 0.8 \sqrt{0.76 * 32.447}$$

$$R = 3.97 \cong 4 \text{ m}$$

#### 4.1.4 Lip Angle and Lip Elevation

$$\text{Lip Angle} = 30^\circ$$

$$\text{Lip Elevation} = 5.14 \text{ m}$$

#### 4.1.5 Trajectory Length

##### 4.1.5.1 Horizontal Throw Distance

$$\frac{X}{H_v} = \sin 2\emptyset + 2 \cos \emptyset \sqrt{(\sin \emptyset)^2 + \frac{Y}{H_v}}$$

Where,

X = Horizontal throw distance from bucket lip to the center point of impact with tailwater, in m

Y = Difference between tailwater level and lip level, sign taken as positive for tailwater below lip level and negative for tailwater above lip level, in m

$$Y = 5.14 - 3 = 2.14 \text{ m}$$

$H_v$  = Velocity head of jet at bucket lip, in m

$$H_v = \frac{V_a^2}{2g}$$

$V_a$  = Actual velocity of flow entering bucket, in  $m/s$

g = acceleration due to gravity, in  $m/s^2$

$$g = \frac{5.19^2}{2 \times 9.81} = 1.373 \text{ m/s}$$

$\emptyset$  = bucket lip angle (with the horizontal) in degree

$$\frac{X}{1.373} = (\sin 30)^2 + 2 \cos 30 \sqrt{(\sin 30)^2 + \frac{2.14}{1.373}}$$

$$X = 4.387 \text{ m}$$

##### 4.1.5.2 Vertical Throw Distance

$$a = \frac{V_a^2 (\sin \emptyset)^2}{2g}$$

Where,

a = Vertical distance from the lip level to highest point of centre of jet, in m

$V_a$  = Actual velocity of flow entering the bucket, in  $m/s$

$\emptyset$  = Bucket lip angle with the horizontal, in degrees

g = acceleration due to gravity, in  $m/s^2$

$$a = \frac{5.19^2 (\sin 30)^2}{2 \times 9.81} = 0.343 \text{ m}$$

##### 4.1.6 Estimation of Erosion at the Point of Impact

$$d_s = m (H_4 q)^{0.5}$$

Where,

$d_s$  = depth of scour in m below tailwater level

m = constant (0.36 for minimum expected scour and 0.54 for probable scour under sustained spillway operation and 0.65 for ultimate scour)

q = discharge intensity  $\frac{m^3/s}{m}$

$H_4$  = reservoir pool elevation - bucket lip elevation, in m

$$d_s = 0.65 [53.477(5.14 - 0.76)]^{0.5}$$

$$d_s = 9.9 \cong 10 \text{ m}$$

Another formula to work out the probable scour is also given below

$$d_s = 1.9 H_3^{0.225} q^{0.54}$$

Where,

$d_s$  = depth of scour, in m

$H_3$  = Reservoir pool elevation - Tail water elevation, in m  
= 32.79 - 3 = 29.79 m

$$d_s = 1.9 (5.14 - 0.76)^{0.225} 53.447^{0.54}$$

$$d_s = 19.37 \text{ m}$$

#### 4.1.7 Training and Divide Walls

##### 4.1.7.1 Height of Training Wall ( $h_t$ )

$$h_t = h_s + 1.5 \text{ m}$$

Where,

$h_t$  = Height of Training Wall

$h_s$  = Maximum Surge Height

$$h_t = \text{Lip level of bucket} + \text{Vertical throw distance} = 5.19 + 0.343 = 5.483 \cong 6 \text{ m}$$

##### 4.1.7.2 Length of Training Wall

The wall should be extended downstream beyond the surge portion by about 3 m.

We take 4 m.

$$\therefore \text{Length of Training Wall} = 6 + 4 = 10 \text{ m}$$

##### 4.1.7.3 Foundation of Training Walls

Foundation of Training Walls is below 2 m depth of scour

Depth of scour = 10 m

$$\therefore \text{Depth of Foundation} = 2 + 10 = 12 \text{ m.}$$

## 5. Result

Since the pressure developed =  $\rho gh = 1000 * 9.81 * 32.73$

$$= 32.11 \text{ t/m}^2$$

From IS Code 7365: 2010

$$P = \left\{ \frac{v^2}{gR} + 1 \right\} \gamma d$$

$$32.11 = \left\{ \frac{v^2}{9.81 * 4} + 1 \right\} * 1 * 0.76$$

$$\therefore V = 40.23 \text{ m/s}$$

Achieved Velocity per gate after installation of energy

$$\text{dissipator} = \frac{40.23^2}{11} = 3.66 \text{ m/s}$$

$$\text{Actual Velocity} = 5.19 \text{ m/s} > 3.66 \text{ m/s}$$

Thus, the achieved velocity by installation of ski jump energy dissipator is reduced than the actual velocity available at the dam.

## 6. CONCLUSIONS

- Ski Jump dissipator is found to be the most suitable energy dissipator because it has it proves beneficial in removing the sediments from the bucket.
- By choosing this type of dissipator, it has resulted economical due to the short dimensions of the bucket.
- The provision of divide wall up to the bucket lip completely leads to the possibility of soil erosion being wiped out.

## 7. REFERENCES

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