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Indian National Committee on Large Dams

INTERNATIONAL
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Dam Rehabilitation & Improvement Project

Central Water Commission

REPAIR & REHABILITATION OF SPILLWAY GLACIS USING STEEL LINER - CASE STUDIES OF DHAULIGANGA & TEESTA STAGE-V DAM

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CONTENTS

1. INTRODUCTION

- The Low Level Orifice Spillways are preferred in the Dam for ambitious purpose of **Flood disposal, Sediment flushing & maintaining Live Storage** in the reservoir.
- During reservoir flushing, the high Impact load by large sized Sediment particles, Stone & Rolling Boulders causes **Crushing & Erosion** of HPC.
- Erosion once started lead to **Progressive Erosion** and **deep Scouring** on the spillway glacis.

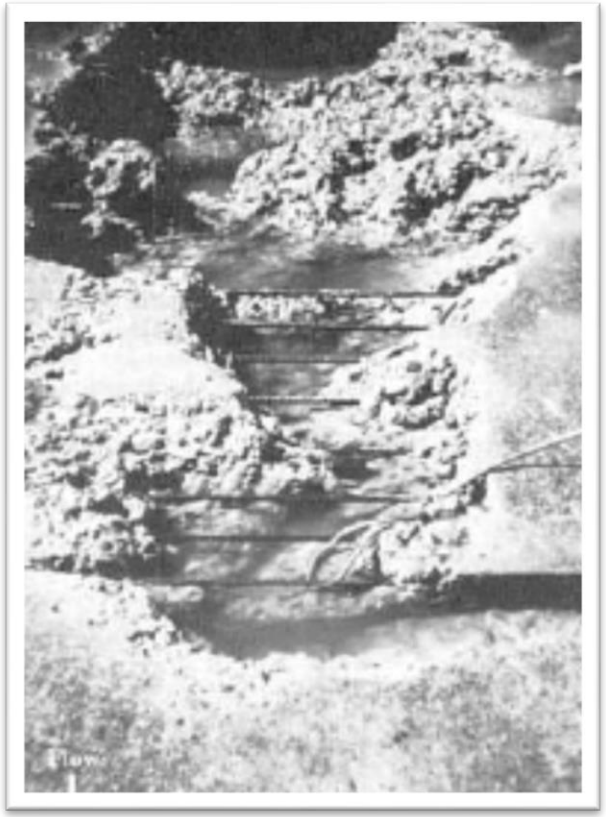
In this presentation our focus is on Restoration & Protection of Low level Orifice Spillway of **Existing Dams**.

2. CAUSES OF DAMAGE

ABRASION: It is gradual wearing away of concrete surface due to sediment flushing. The damage is relatively **Uniform** over large surface. The rate of abrasion depends on **Sediments load, Flow Velocity & Concrete Grade.**

Erosion in the bucket area of Crest Spillway - Salal Dam

CAVITATION: Formation & Bursting of water bubble causes tensile stresses at concrete surface. The **high stress in small area causing Pitting** on the surface.



Cavitation damage

IMPACT: Impact forces are caused by **Stones & rolling Boulders** during flood disposal. **Severe damages due to impact forces** are observed in the low-level Orifice Spillways.

Passing of boulders upto ±2.5m size are observed in the orifice spillways

WATER JET CUTTING:

Impinging water jets from small opening of gates or leakage through gate seal causes **Concrete cutting**.

Water jet cutting near radial gate

Once Abrasion, Cavitation, Impact force & Water jet have **substantially altered Spillway surface Profile**, the high velocity of water during flood strikes irregular surfaces and it further accelerates the damage.

Spillway discharge: view from Dhauliganga Dam top

3. DAMAGE CATEGORIZATION

The extent of Erosion depends on three major factors;

1. **Water Head over the Spillway Crest.**
2. **Annual Sediment load.**
3. **Size & hardness of sediment particle, Stone & Boulder.**

The Severity of Erosion has been categorized into three major categories [Ref. ICOLD paper 2021 by Team NHPC].

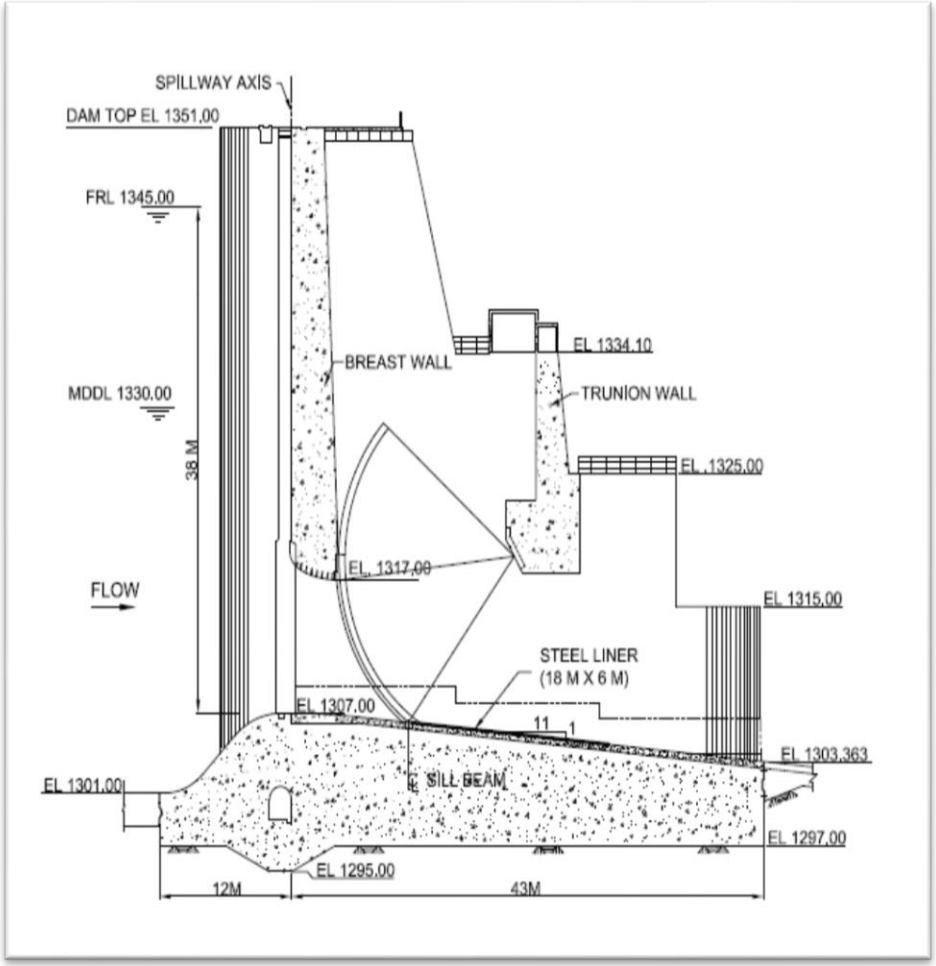
Erosion Condition	Water Head over crest (m)	Annual sediment (MCM)	Size of sediment/ boulder	Repair Material
Mild	0-15	0-30	No Boulder Rolling, Only silt/sand	**Standard Concrete** (M25 to M30)
Moderate	10-30	0-30	No Boulder Rolling, only silt/sand/gravel	**HPC (M65 to M80)** on the Spillway glacis & bucket, **Cementitious mortar (R4)** on the Piers
Severe	10-60	1-40	Boulder Rolling, along with silt/sand/gravel	**Steel Liners** on the upper glacis, **HPC** at the lower glacis, bucket, **Steel Liner**/ **Cementitious mortar (R4)** on the Piers

[Source. ICOLD paper 2021 by Team NHPC]

DHAULIGANGA DAM SPILLWAY

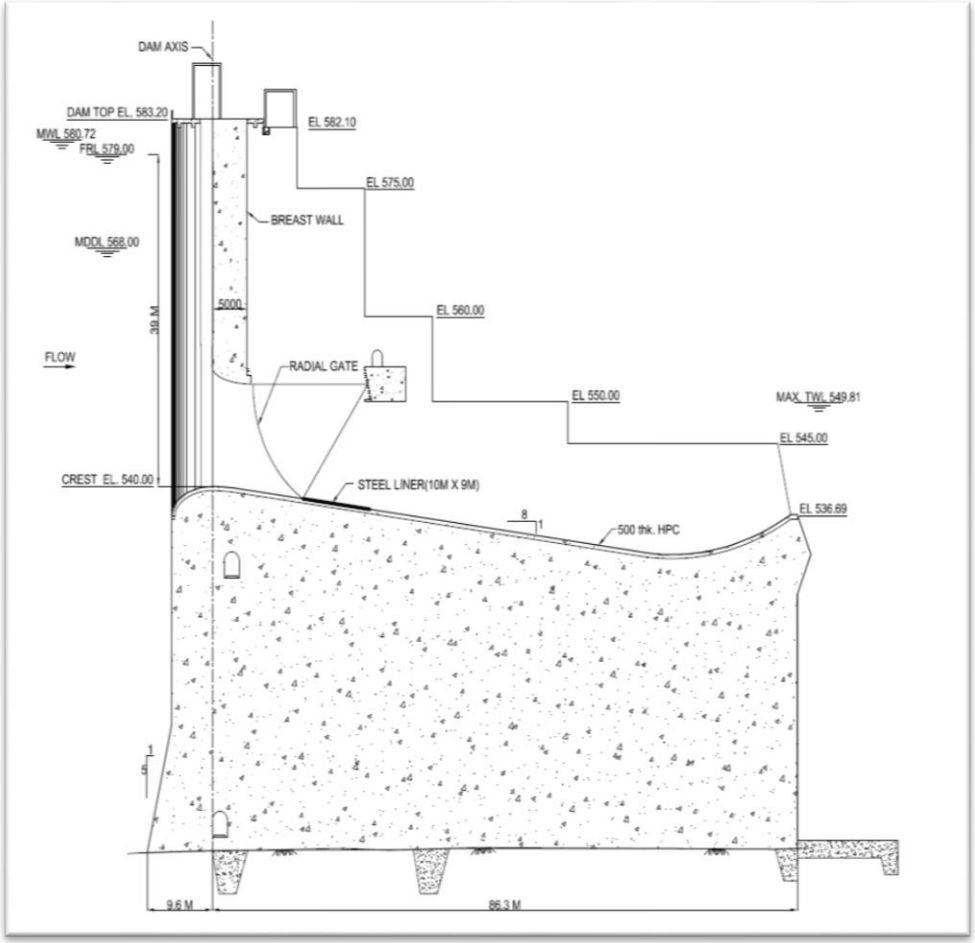
Damages on Spillway Glacis

DHAULIGANGA DAM SPILLWAY



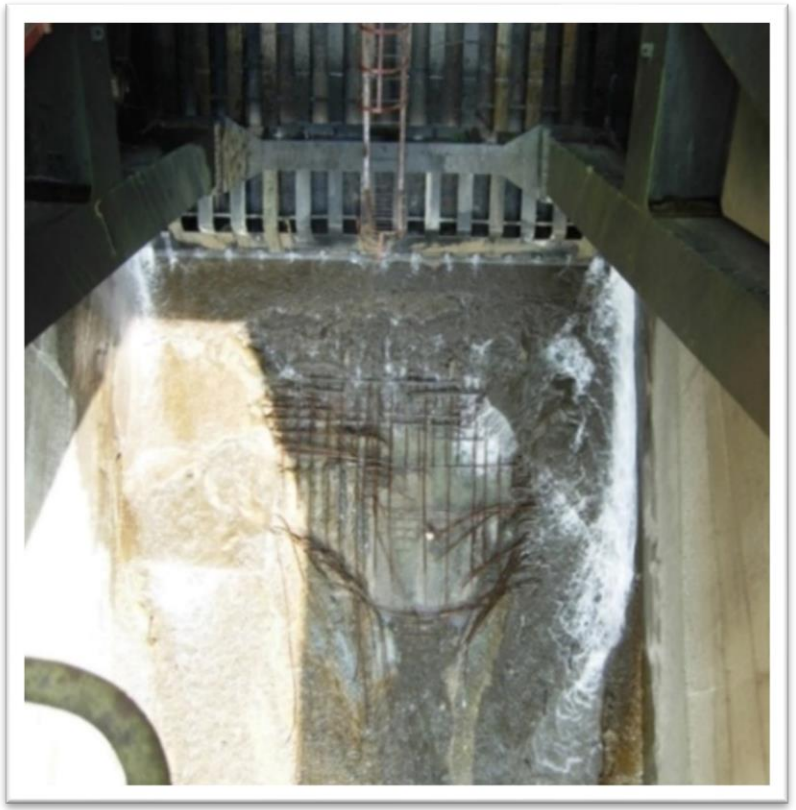
Spillway	
Dam Type	CFRD
Head over crest	**38 m**
Avg. annual sedimentation load	**3 MCM**
Avg. Velocity	22-25 m/s
Boulder rolling	**Yes**
Gate size (B x H)	6m x 10m
Design Flood	**3210 m^3/s**

TEESTA STAGE –V DAM SPILLWAY



Brief of Spillway	
Dam Type	Concrete Gravity
Head over crest	**39 m**
Avg. annual sedimentation load	**10 MCM**
Avg. Velocity	22.5 to 25 m/s
Boulder rolling	**Yes**
Gate size (B x H)	9m x 12m
Design Flood	**9500 m^3/s**

TEESTA STAGE –V DAM SPILLWAY



Damages on Spillway Glacis

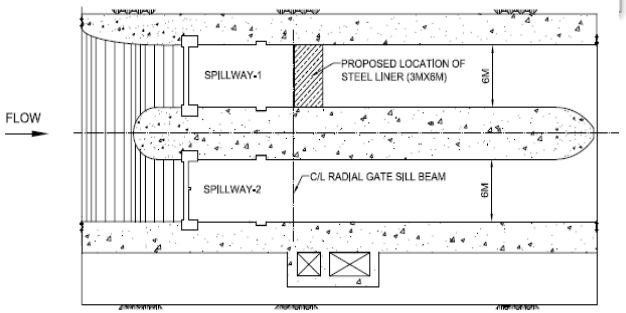
4. CONVENTIONAL REPAIR METHODOLOGIES

- Repair of Spillway Glacis & Piers with **High Performance Concrete (HPC)** of M60 /M70/M80 grade.
- Annual repair after monsoon with **Ready Mix Concrete (RMC)** for restoration of the glacis profile.

Over the period of time it has been experienced that performance of HPC & RMC was not found satisfactory in the low level orifice spillway that falls in severe erosion condition. **The repair frequency is once in 1 to 2 years**.

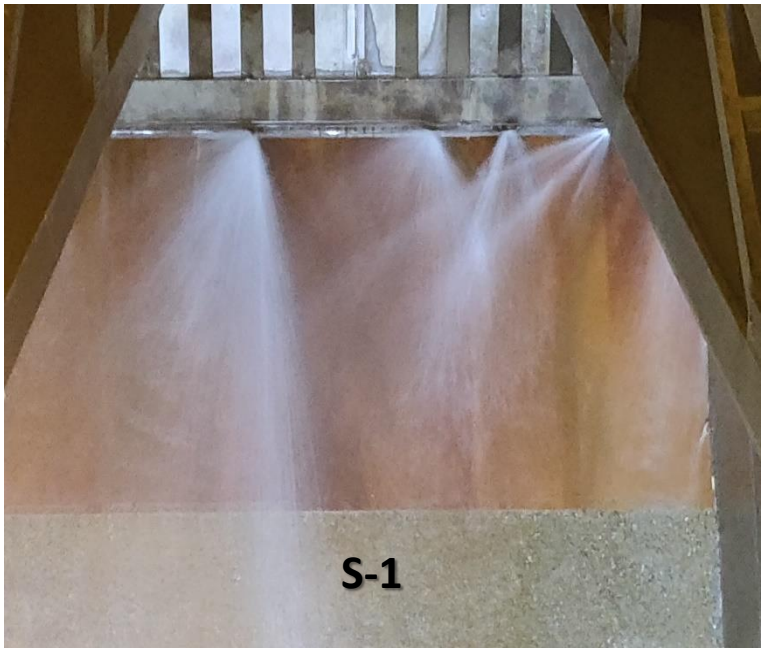
5. PURPOSE & NEED OF PROVIDING STEEL LINER

- In order to reduce frequent repair of glacis, Steel Liner plate has been installed in few reaches near radial gate sill beam area of two dams namely Dhauliganga (280 MW) & Teesta Stage-V (510MW) on **Experimental basis**.
- Abrasion resistant **Steel Liner Plate** (**E410 grade** or above) has been found effective in resisting impact load generated & water jet concrete cutting.



Steel Liner (3mx6m) at Spillway no 1 (Feb 2017)

DHAULIGANGA DAM SPILLWAY



Condition of Spillway # 1 & 2 in October 2018

The Dam Safety Inspection committee (Oct. 2018) reported that **Performance of Steel Liner is Satisfactory**.

Depending upon the Severity of Erosion, Water head & grade of Substrate Concrete the Steel Liner plate shall be installed by following mechanism;

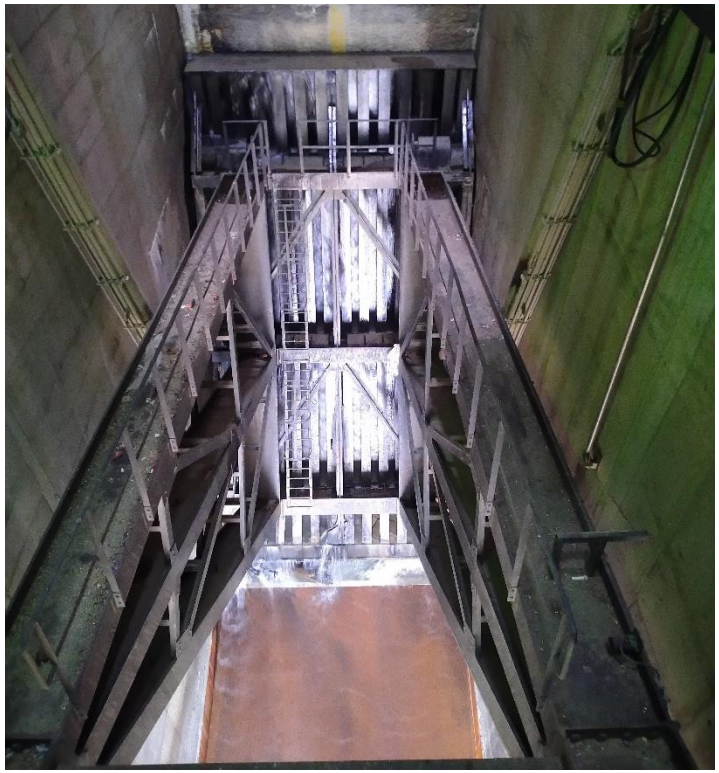
- Torque controlled Counter sunk anchor (**Mechanical anchor**)
- Epoxy grouted anchor (**Chemical anchor**)
- Conventional Method (**Stiffener plate)**
- Combination of above methods as per site requirement.

6. CASE STUDY I : DHAULIGANAGA DAM SPILLWAY

- The damage profile of spillway has been assessed and eroded portion of glacis has been restored to its original profile using HPC (M60) or Epoxy mortar based on extent of damage.
- The old concrete and HPC have been bonded by the provision of 25Φ Fe500 grade, L-shaped grouted anchors @ 1m c/c.
- The damaged reinforcement has been repaired with new reinforcement by providing requisite overlapping or welding as per the site suitability.
- The substrate surface has been prepared to the desired level and Steel liner plate of 32mm thick, E 410 grade has been placed in position.

- The Steel plate has been fixed by Torque controlled counter sunk anchor (Mechanical anchor).
- Epoxy Mortar conforming to ASTM C-881 Type-IV, Class B & C was used to fill the space between Steel liner and Pier.
- Epoxy Grout conforming to ASTM C-881 of Type-IV, Grade 1, Class B & C of bond strength >10MPa at 14 days was used for contact grouting between steel plate and HPC.
- The pressure for contact grouting was of order of 1-2 kg/ cm^2

DHAULIGANGA DAM SPILLWAY



Dam Safety Inspection Photographs April 2022

6. CASE STUDY II : TEESTA STAGE-V DAM SPILLWAY

The Steel liner on Spillway # 1, 4 & 5 has been installed by combination of **Mechanical anchors & Chemical anchors** (Similar to Dhauliganga Dam).

In Spillway # 2 & 3, due to high damages near radial gate the Steel liner has been installed by **Conventional method** (using stiffener).

Stiffener under Steel liner

Methodology for **Conventional Method** is as follows;

- 32mm thick Steel liner of E-410 grade has been used. The structural steel for stiffener was of grade E-250.
- The non-shrinkable self-compacting concrete of grade M35A20 was filled below the steel liner in damaged area.
- Non-shrinkable Cement grout was used for filling the gap between Steel liner and Concrete surface.
- Epoxy mortar conforming to ASTM C881 of Type-IV, Class C have been used to fill the recess between Steel liner and Pier.
- The lower portion of the spillway glacis has been repaired by HPC of grade M70A20.

TEESTA STAGE –V DAM SPILLWAY

Dam Safety
Inspection Photographs
December 2021

7. CONCLUSION & RECOMMENDATION

- The Low Level Orifice Spillways of existing dams witnesses limitation of HPC as wearing surface due to **high Sediment load, Stone and Boulder rolling** in the Himalayan river.
- Erosion once started near radial gate sill beam leads to **Progressive Erosion and deep Scouring** during reservoir flushing.
- It has been evolved that provision of Steel Liner from **Radial gate sill beam to 10-15m d/s** has been found very effective in low level spillway of Teesta Stage-V & Dhauliganga dam.

- The damages in the Lower Glacis and Spillway bucket area have also reduced as progressive erosion did not take place in the upper glacis.
- The Steel liner has been found **Cost effective** in comparison to 1-2 year repair frequency by conventional repair method using HPC/RMC.
- The performance of steel liner has been found **Satisfactory & Encouraging.**
- The use of steel liner is recommended for **Low-level Existing dam spillways & for New dam spillways** that comes under Severe Erosion condition.

8. REFERENCES

- ACI 210R-93: Erosion of Concrete in Hydraulic Structures.
- ACI 210.1R-94: Compendium of Case Histories on Repair of Erosion-Damaged Concrete in Hydraulic Structures.
- ACI 546R: Concrete Repair Guide
- EM 1110-2-2002: Evaluation and Repair of Concrete Structures.
- EN 1504(part-3)-2005: Products and Systems for the protection and repair of concrete structures - Structural & non-structural repair.
- Evolving Repair Methodologies for Spillways and Stilling Basins in Himalayan Region by Balraj Joshi, Keshav Deshmukh, Ajay Mittal, Shrish Dubey, ICOLD, 2021

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