EVOLVING REPAIR METHODOLOGIES FOR SPILLWAYS & STILLING BASIN IN HIMALAYAN REGION

by

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INTRODUCTION

- The Himalayas are young mountains with fragile geology. These rivers carry large amount of sediments.
- Landslides, flash floods, cloud burst and seismic events also generate sediment load.
- During monsoon these rivers carry large quantity of sediments at high velocities which accelerate the damages on spillway & its components (crest, glacis, bucket, piers, sluices, stilling basins) requiring frequent repair due to erosion.
- Provision of low level spillway crest to maintain the live storage capacity have further stressed the system due to high velocities at the crest.

MECHANISM OF EROSION IN SPILLWAYS

- Erosion takes place due to progressive disintegration of solids by Cavitation, Abrasion and Impact forces generated due to high velocity flow along with sediments.

- Cavitation occurs due to generation of extremely high pressures of implosion of water vapour bubbles at surface in small areas causing pitting.
- Abrasion results from abrasive effects of water borne silt, sand and gravels. Rate of abrasion is dependent on size, shape, quantity and hardness of sediments.
- Impact is caused by large boulders travelling in high gradient rivers causing crushing of the concrete surface due to high momentum.

- Once above forces substantially alter the spillway profile, high water velocities striking irregular surfaces accelerates the damages.

EROSION CONDITIONS & REPAIR MATERIAL

Erosion Condition	Major Characteristics			Material for Construction / Repair of the component
	Hydraulic Head over component (m)	Annual sediment load (MCM)	Max size of sediment / boulder	
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 glacis/bucket/stilling basin, Cementitious mortar (R4) on the Piers
Severe	10-60	1-40	Boulder Rolling along with Silt/Sand/ Gravel	Steel Liners on the upper glacis/crest, HPC at the lower glacis, bucket/stilling basin, Steel Liner /Cementitious mortar (R4) on the Piers

CATEGORISATION OF EROSION CONDITIONS

- **Mild Erosion** conditions are observed in the low head spillways with silt / sand as sediment particles.
- Erosion conditions at the Barrages located in the alluvial reach and the crest spillways of high dams with large reservoirs, can be categorized as mild conditions.
- Minor cavitation and abrasion forces exist at such locations.
- At **Moderate erosion** conditions, due to increase in velocity the cavitation & abrasion forces are prominently visible however impact forces are either minor or absent.
- **Severe erosion** conditions are observed in high head spillways with high sediment yield along with boulder rolling.
- Damages due to all forms of erosion i.e. cavitation, abrasion and impact are prominent at such locations.
- Impact load causes crushing/cracking of the concrete and formation of pits/craters

REPAIR MATERIAL (HPC)

- HPC possesses high strength (generally>65MPa) and high durability when compared to conventional concrete.
- HPC provides high erosion resistance in moderate erosion conditions for all the components of spillway.
- For severe erosion conditions HPC can be used for lower glacis, bucket, stilling basin and other components except crest and upper glacis portions.
- In design mix of HPC, cementitious material (silica fume + cement) may vary from 450-500kg per cum having a water cement ratio of 0.3 with a compatible PCE based super-plasticizer for required workability.
- It is desirable that Los Angeles Value, Crushing Value and Impact Value of the aggregate used shall be less than 25%.
- Mechanical bonding can be provided with epoxy grouted 25mm diameter ‘L shaped’ steel anchors between old and new concrete.

REPAIR MATERIAL (CEMENTITIOUS MORTAR-R4)

- Cementitious mortar complying with EN1504-3(R4) are used for structural repair of concrete structures to restore the damaged concrete.
- As per EN1504-3 minimum adhesive bond strength of 2MPa has been specified for cementitious mortars of R4 category.
- In lab test, abrasion resistance (as per ASTM-C-1138) of these cementitious mortars was found similar to M65 to M80 grade concrete.
- Layer thickness from 12.5mm to 50mm with cavities upto 100mm has been repaired and performance is found satisfactory at the piers of high head spillways.
- The erosion forces at piers are significantly lower in comparison to glacis. However, these mortars can also work in glacis with mild erosion conditions.
- The performance of this product has been found satisfactory at low level spillway piers at Dhauliganga and Teesta-V Dam.

REPAIR MATERIAL (STEEL LINER)

- The resistance of steel plates against cavitation, abrasion and impact loads is well established.
- Thick steel plates can resist impact load generated by big boulders during high flood conditions.
- Anchoring of new plates with existing concrete surface was being considered difficult because of vibrations leading to fracturing and eventual failure.
- At Dhauliganga spillway with severe erosion condition 32mm thick steel liner was installed with countersunk bolt @ 250mm c/c.
- The top of the countersunk bolt was placed 10mm below the finished surface which was flushed with compatible welding material after installation.
- At the end of steel plates, steel cutoff was also provided.
- The performance has been found satisfactory inspite of heavy boulder rolling at high velocities.

GENERAL VIEW DHAULIGANGA SPILLWAY

Erosion in Glacis after one year operation, before installation of steel liners

Erosion of Glacis after two years of operations with Steel Liner installed

REPAIR MATERIAL (EPOXY ASTM-C-881)

- Epoxy compounds have excellent adhesion, high compressive and tensile strength, rapid hardening and abrasion resistance.
- ASTM-C-881 provides standard specifications for epoxy system. ‘Type-IV’ epoxies recommended for structural repair works, can be used for spillway repair.
- Epoxy mortars have limitations regarding application thickness from 5mm to 15mm for the repair works.
- The cementitious mortar possess similar engineering properties as parent material and can be applied upto 50mm thickness are preferred at many locations.
- Epoxy mortars due to its excellent adhesive properties to steel as well as concrete may be found suitable at some of the locations.
- Performance evaluation need to be carried out at the prototype before large scale application.

RECOMMENDATIONS AND CONCLUSION

The frequency of repair can be optimized by study of causes of erosion and adopting suitable repair methodology as follows:

- Categorization of the various components of spillway as mild, moderate or severe based on three major characteristics i.e. hydraulic head, annual sediment load and maximum size of sediment/boulder.
- HPC is a versatile repair material for spillways however steel liners may be more suitable in severe conditions for the crest of the spillway along with near by pier area.
- Structural repair of the piers of spillway and other structures may be carried out with Cementitious Mortar (R4) complying with EN1504-3. The mortar have abrasion resistance of M80/M65 concrete.
- Epoxy materials complying with ASTM-C-881 have excellent bonding strength with concrete as well as steel however it has some limitations regarding thickness, etc.

RECOMMENDATIONS AND CONCLUSION

There is need to standardize the repair guidelines including technical specification for repair material and methodologies for proper execution of the repair work of spillways.

For the upcoming projects, major characteristics mentioned in the paper may be studied, for suitable erosion classification of the spillway components, to adopt appropriate material during construction stage to minimize damages during O&M stage.

Use of appropriate material with standardize performance characteristics can optimize the cost and frequency of repair and enhance the safety aspects of dam.
