EVOLVING REPAIR METHODOLOGIES FOR SPILLWAYS AND STILLING BASIN IN HIMALAYAN REGION

BALRAJ JOSHI, KESHAV DESHMUKH, AJAY MITTAL AND SHRISH DUBEY
NHPC Ltd., Faridabad, Haryana, India

ABSTRACT

Hydraulic structures like spillway glacis, piers and stilling basins on Himalayan Rivers require frequent repairs due to erosion. These rivers carry large quantity of sediments during monsoon at high velocities which accelerates damages. Erosion takes place due to progressive disintegration of solid by cavitation, abrasion and impact. Cavitation generates extremely high pressures in small areas causing pitting. Abrasion results from the abrasive effects of water borne silt, sand and gravels. Impact is caused by large boulders travelling in high gradient rivers. These forces become extremely high in case of low level spillways which substantially alter the spillway profile. In this paper it is suggested to categorize the 'Erosion conditions' at various components of the spillways as 'Mild, Moderate or Severe' based on three major characteristics i.e. hydraulic head over the component, annual sediment load and maximum size of sediment/boulder.

Repair materials and methodologies need to be adopted depending upon identified 'Erosion conditions' of the spillway component. Performance of materials such as High Performance Concrete, Cementitious mortars(R4), Epoxy compounds and Steel-liners etc. was evaluated for various erosion conditions, on numerous dams on Himalayan rivers, to identify the best suited material. Based on the past performance, a correlation has been established between erosion conditions and appropriate repair material. The repair materials should have engineering properties to withstand the erosion forces. There is a need to standardize guidelines including technical specifications for repair material and methodologies for proper execution of the work. This paper also provides standardize performance characteristics of various repair material, based on international guidelines/codes, to optimize the cost and frequency of repair and enhance the safety aspects.

1. INTRODUCTION

The catchment area of the Himalayan Rivers covers thousands of square kilometer from Brahmaputra in the East to Indus in the west. These rivers are perennial in nature replenished with water from rainfall, melting of snow & glaciers and their discharges become significantly high during monsoon. The Himalayas are young mountains with fragile geology. The Himalayan rivers flow with steep gradients having a serpentine course with numerous rapids and waterfalls and carry large amount of sediments. Landslides, flash floods, cloud burst and seismic events also generate sediment load. As such they carry large amount of sediment including silt, sand, pebbles and boulders which causes tremendous erosion.

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) and flushing galleries thus requiring frequent repairs due to erosion. The problem has become more severe due to ambitious layout having aim of efficient sediment management by significantly lowering the spillway crest to maintain the live storage capacity of the reservoir.

2. MECHANISM OF DAMAGES

Discharges at high velocities with high concentration of sediments have capability to erode large quantity of concrete causing damages to various components of spillways. Erosion is further increased during the reservoir flushing operations wherein huge quantity of river bed material is transported over these surfaces. Erosion takes place due to progressive disintegration of solid by cavitation, abrasion and impact.

2.1 Cavitation

Whenever the pressure in the flowing water is reduced to its vapour pressure, bubbles are formed. These bubbles grow and travel with flowing water to an area where pressure field will cause them implode causing tensile stresses at surface. This phenomenon is called Cavitation. Cavitation generates extremely high pressure in very small area causing pitting.

It can be recognized from the irregular shapes or pits formed. On the spillways, local pressure drop is caused by the surface irregularities which cause local high velocities and curved streamlines causing cavitation. Once erosion has begun, the rate of erosion increases as protruding pieces of aggregate become new generators of vapour cavities.

However the cavitation phenomenon is not well documented in concrete as it is in metal. It is also believed that micro-fissures at the surface and between the mortar and coarse aggregate contribute to cavitation damage. Studies have shown that cavitation erosion may be reduced if air-water ratio in the layers of water near the boundary is about 8% by volume by providing aerators at spillway surface. In NHPC projects, aeration grooves have been provided in Chamera-I dam and are proposed in Subansiri dam.

2.2 Abrasion

Abrasion erosion results from the abrasive effects of waterborne silt, sand and gravel impinging on the concrete surface during operation of hydraulic structure. Abrasion erosion is readily recognized by smooth, worn-appearing concrete surface. Spillway crest & glacis, apron, stilling basin, sluiceway, silt flushing tunnel and tunnel spillway lining are particularly susceptible to abrasion erosion. Rate of abrasion erosion is dependent on size, shape, quantity & hardness of sediments being transported, the velocity of water and quality of concrete. Sediment transportation during flushing of reservoir is one of the major causes of abrasion erosion.

2.3 Impact

Impact forces caused by large boulders at high velocities during large floods crush the concrete surface of spillways due to high momentum in rivers with steep gradients. The severe damages due to impact forces are clearly visible in many low level sluice spillways where craters are formed just below the crest due to repetitive impact of boulders. Impinging water jets due to small opening of gates or leakages through seals also cause such damages in low level spillways. Formations of 1m to 2m deep channels from the crest towards the glacis have been observed at some of the projects after large floods.

Once abrasion, cavitation and impact forces have substantially altered the spillway profile, high water velocities striking the irregular surfaces and mechanical failure due to vibrating reinforcing steel accelerates the damage.

3. CATEGORIZATION OF EROSION CONDITIONS

Erosion condition depends on various characteristics of the river such as annual sediment load, maximum size of sediment, annual water yield, hardness of the particles, river gradient, etc. It also depends on layout of the dam including depth of the crest, intensity of discharge, size of the reservoir, etc. However, for categorization of erosion conditions three major characteristics i.e. hydraulic head over the component, annual sediment load, maximum size of sediment/ boulder may be used. Erosion conditions can be categorized into three major categories i.e. mild, moderate and severe based on the causes of erosion as detailed in Table 1.

3.1 Mild Erosion Conditions

These conditions are observed in the low head spillways with silt/sand as sediment particles. Minor cavitations and abrasion forces exist at the locations however no impact erosion is observed. The barrages located in the alluvial reach of the river with hydraulic head over crest from 10m - 15m face 'Mild erosion condition' in many Himalayan rivers. The high crest spillway with similar hydraulic heads located on the dams with large reservoir capacity, also, fall in this category as the reservoirs trap all the sediments in the upstream. The erosion conditions at the crest spillways of high dams like Bhakra and Tehri Dams are also mild due to large reservoirs. Past experience at such locations indicates that standard concrete of the range of M25 to M30 grade is sufficient for such locations.

Table 1 : Categorization of Erosion conditions.

Erosion Condition	Hydraulic Head over component (m)	Annual sediment load (MCM)	Max size of sediment / boulder	Material for Construction / Repair of the component
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 sand/ silt/gravel	High Performance Concrete (M65 to M80) on the glacis/bucket/stilling basin, Cementitious mortar (R4) on the Piers
Severe	10-60	1-40	Boulder Rolling, along with sand/ silt/gravel	Steel Liners on the upper glacis/crest, HPC at the lower glacis, bucket/stilling basin, Steel Liner/Cementitious mortar (R4) on the Piers

Note: 1. Component implies Crest, Glacis, Bucket, Stilling Basin, Piers, etc.

2. Use of epoxies have been discussed at para no – 4.3

3. Annual Sediment Load and Max size of sediment/boulder passing over the component should only be considered for the categorization

3.2 Moderate Erosion Conditions

These conditions generally lie between mild and severe erosion conditions. At these locations the cavitation and abrasion forces are prominently visible however impact forces are either mild or absent. These locations have moderate hydraulic head (10-30m) however no boulder rolling should exist during monsoon. The annual sediment load with silt/sand/gravel, at such locations may be in millions of cubicmetre. At such locations the HPC provided over the glacis, stilling basins and piers have frequency of repair of 5 to 10years. This type of frequency can be managed with well planned repair strategies. Judicious delay in the repair helps to allow the wearing surface to a sufficient depth (100mm to 500mm) so that the cost and frequency of repair is optimized.

3.3 Severe Erosion Conditions

These conditions are observed in low level spillways with high sediment yield along with boulder rolling during high floods. Damages due to all the forms of erosion i.e. cavitation, abrasion and impact are prominent at such locations. These days low level spillways are being preferred to maintain the live capacity of the reservoir so that peaking power requirement are fulfilled as per electricity demand. However, the low level spillways generate tremendous forces on the hydro-mechanical components and concrete structures requiring frequent repairs. These forces causes serious damages as the momentum of the large size sediment particles/boulders generates very high impact loads causing crushing/cracking of the concrete and formation of pits/craters. Such uneven surfaces become more vulnerable to progressive erosion.

High Performance Concrete was used for the construction of Dhauliganaga & Teesta V spillways. The crest of these spillways are located 38m and 30m respectively below the FRL. The annual sediment load at these locations is 3MCM and 10MCM respectively. The boulder rolling was observed at both the locations during high floods and reservoir flushing events. Channel formation (1m-2m depth) has been observed in the concrete spillways at Dhauliganaga and large craters are formed at Teesta V spillways after monsoon. The frequency of repair at these spillways with HPC was of the order of 2-3 years only. To optimize the frequency of repair it was decided to provide steel liners at Dhauliganaga Dam two years ago. The steel liner (32mm) was fixed with counter sunk bolts @250mm c/c in the initial 18m reach from the crest. The performance has been found satisfactory with no damages in the steel liner. The damages in the lower glacis and bucket have also reduced as channel formation did not take place. Based on this experience steel liner is also being provided on Teesta V spillway surface also.

With such a categorization, various components of the spillway (i.e. Crest, Glacis, Bucket, Stilling Basin, Piers, etc.) may fall in different 'Erosion conditions' as the variation in the head takes place from the crest to glacis, bucket/stilling basin. In most of the high crest spillways, the crest may lie in mild conditions however the lower glacis/bucket/stilling basin may fall under moderate/severe erosion conditions. The Spillways Dams like Bhakra, Tehri, Salal, etc. are some of the examples of such cases.

Figure 1 : Erosion in Glacis of Dhauliganga Dam Spillway before providing steel liners

Figure 2 : Erosion in Pier of Dhauliganga Spillway before repair with cementitious mortar(R4)

At locations where there is no boulder rolling, the crest may fall under moderate condition however the lower component of the spillway and energy dissipation arrangement may lie in moderate/severe condition due to increase in hydraulic head. HPC in such cases can provide a frequency of repair of the order of 5-10years for all the components of spillway. In NHPC most of the project like Chamera I, II & III, Uri I & II, Parbati III, Nimoo-Bazgo, Baira Suil, Rangit, Sewa II, etc. falls under this category.

4. REPAIR MATERIALS & THEIR SUITABILITY

Suitability of the repair material is of utmost importance as per the existing erosion conditions. The technical specifications of the material used should be generic in nature complying with various international guidelines/codes. Based on experience on various projects in Himalayan rivers following repair materials have been identified:

4.1 High Performance Concrete

High performance concrete (HPC) possess high strength (generally>65MPA) and high durability when compared to conventional concrete. HPC does not require any special ingredients or special equipments except Silica fume & super plasticizers. The optimal mix design, production and execution also enhances resistance to erosion & workability.

HPC can be designed to provide high erosion resistance in the construction/ repair of various hydraulic concrete structures like spillway crest, glacis, bucket, stilling basin, silt excluder tunnels, tunnel spillways, etc. Abrasion resistance of these structures can be significantly improved by using High Performance Concrete consisting of dense cementitious paste and well graded hard coarse & fine aggregate. In order to develop high strength paste, the cementitious material may vary from 450-500 kg/cum comprising of cement (53grade) & silica fume (8-10%) having a w/c ratio of the order of 0.3 with a compatible super-plasticizer (PCE based) for obtaining required slump and workability. It is desirable that Los Angeles abrasion value, Crushing value and Impact value of the aggregate shall be less than 25%. Methodical curing is essential to minimize micro cracking. Generally repair work is conducted during lean season and due to limited working time, identification of suitable construction materials, aggregate sampling, testing and concrete mix design needs to be adequately carried out by Project authorities to save the time.

It is recommended that for moderate to severe erosion conditions, 500mm wearing layer should be provided in spillway glacis & bucket over the structural concrete base during construction so that no structural damage take place during initial erosion. The frequency of repair of this wearing surface may vary depending upon various parameters causing erosion. For repair purpose HPC with 20mm aggregate size is generally applied with a minimum thickness of 100mm. To create a mechanical bonding between old and new concrete, epoxy grouted 25mm diameter L-shaped steel anchor should be used. The projected L portion should be aligned along the flow direction. The epoxy bonding may also be used (complying with ASTM C-881, Type-2) as per manufacturer's directions, however improper application may create debonding. Judicious decision needs to be taken to delay the repair of wearing surface at the spillway glacis so that the frequency of repair is reduced and simultaneously the structural concrete beneath is not affected. Reinforcement should not be provided in the wearing surface of HPC as it accelerates the erosion when it gets exposed due to vibration and turbulence.

The performance of glacis, bucket & stilling basin, tunnel spillways, silt flushing tunnels repaired with HPC has been found satisfactory with repair interval of more than 5 years in moderate erosion conditions of the spillways. However at dams with severe erosion conditions the crest of spillway, Piers and Sill beam area becomes vulnerable. Further, the repair becomes difficult due to leakage of water and a higher frequency of repair is observed. Steel liner appears to be the only solution to optimize the frequency of repair, cost and enhance the safety aspect.

4.2 Cementitious mortar(R4) [complying with EN 1504-3 (R4)]

EN 1504 is a European Standard titled as "Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity". It consists of 10 parts. Out of these, part no3 i.e. *EN 1504-3 [Structural and non-structural repair (mortars)]* specifies requirements for the identification, performance (including durability) and safety of products and systems to be used for the structural and non-structural repair of concrete structures to restore and/or to replace defective/damaged concrete and to protect reinforcement, necessary to extend the service life of a concrete structure exhibiting deterioration.

Spillway piers of low level spillways are subjected to erosions mainly in lower reaches which varies from few to several 'centimeters' causing reduction in the concrete cover or exposure of reinforcement at places. Piers are structural members transferring the loads of gates and water head to the foundation therefore such damages require prompt repair. Cementitious mortars(R4) are preferred to repair such damages because the physical & mechanical properties of these mortars are similar to the parent concrete. In such repair, bonding of cementitious mortar with the old concrete is very much important. As per EN:1504-3(R4), minimum adhesive bond strength of 2 MPa has been specified. Due to this property, the repaired layer becomes integral part of the structure and the failure would not take place at the joint.

Layer thickness from 12.5mm to 50mm with cavities upto 100mm has been repaired and performance is found satisfactory at the piers of various dams even with low level spillways. Cementitious mortar(R4) could not perform for low level spillways on the glacis probably due to limitations related thickness and resistance against impact loads. The erosion forces at the piers are significantly lower in comparison to glacis, this is the main reason for its satisfactory performance on the piers of various spillways. However, it can work on the glacis for the head upto 10m with repair thickness upto 50mm in barrages and upper layer of crest spillway. In NHPC the performance of this product has been found satisfactory at low level spillway piers at Dhauliganga and Teesta V Dams. The repair cycle may vary from 3 to 10years depending upon erosion conditions. If the severity of erosion is beyond it, the steel liner is the only solution for piers also at such locations.

The repair mortar shall be CE certified for critical repair work meeting EN 1504-3 Class R4 categories for restoration work as per method principles 3.1, 3.3, 4.4, 7.1 & 7.2 defined in EN 1504-9. The cementitious mortar complying with these properties are prepared using crystalline technology or polymer based additives in the cement. Following initial performance tests on repair products in accordance with EN 1504-3 need to be complied for structural repair mortar class R4.

Table 2 : Properties/performance characteristics of cementitious mortar.

Item No.	Performance Characteristic	Reference substrate (EN 1766)	Test Method	Requirement based on EN:1504-3 (R4)
1	Compressive strength	None	EN:12190	≥ 45 MPa
2	Chloride ion content	None	EN:1015-17	≤ 0.05%
3	Adhesive bond	MC(0,40)	EN:1542	≥ 2.0 MPa
4	Carbonation resistance	None	EN:13295	d_k ≤ control concrete MC(0,45)
5	Elastic modulus	None	EN:13412	≥ 20 GPa

Abrasion resistance (underwater method) of these cementitious mortars, for various 'CE certified' brands available in the market, was tested as per ASTM C1138-2012 at NCB Ballabgarh under an R&D project of NHPC Ltd. and it was observed that its performance was similar to M65 to M80 grade concrete. Technical specifications may be prepared to use this cementitious repair mortar (R4) in repair of spillway piers, face slab of CFRD, freezing & thawing related damages, silt flushing tunnels, etc. The 'CE certification' would ensure uniformity of the product being used in critical conditions related with safety aspects.

4.3 Epoxy compounds (Complying with ASTM C881)

Epoxy compounds are used in repair of concrete structures due to various performance characteristics such as excellent adhesion, high compressive & tensile strengths, rapid hardening and abrasion resistance. Due to these qualities, epoxy compounds have found vide variety of uses such as sealants, grouts, binders in mortars, bonding agents, patching materials & crack filling. Epoxies having desired performance characteristics are considered as one of the alternatives for the repair of concrete and steel liners for damages upto 5-15mm thickness.

ASTM C881 provides standard specification for "Epoxy-Resin-Base Bonding Systems for Concrete". It provides technical specifications for use of various epoxies in load bearing and non-load bearing applications as a grout and binder for filler in epoxy mortar. This specification provides the classification by type, grade & class. For spillway repair works Type-IV epoxies are recommended as it is a structural repair work. Class 'C' signifies that the materials should be tested at 15°C. The physical & mechanical properties for epoxy resin bonding system as per ASTM C881 Type-IV Class C are as below:

Table 3 : Physical & Mechanical properties of epoxy resin bonding system.

Sl. No.	Performance Characteristic	Test Method	Requirement
1.	Viscosity of Neat Resin System	ASTM D1084	< 20 Poise (2.0 Pa.s)
2.	Compressive strength (7days)	ASTM D695	≥ 70 Mpa
3	Tensile strength (7days)	ASTM D638	≥ 50 Mpa
4.	Bond strength (14days)	ASTM C882	≥ 10 Mpa

The epoxy mortar comprises of epoxy binders (Resin & Hardener) and filler/fine aggregate. Quartz sand is used as filler material in preparation of mortar as per manufacturer's recommendation. The quantity of quartz sand/ filler materials is generally kept as 5-6 times of epoxy binder (Resin + hardener) system. The epoxy mortar is suitable for concrete repair in damp condition.

Epoxy can withstand severe abrasion & cavitation. However, there is difference in coefficient of thermal expansion of epoxy and concrete, so fillers such as silica are used to reduce the difference. Thermal stresses at the interface between concrete & epoxy mortar may generate causing peeling off the repaired layer from surface. However due to their excellent adhesive properties to steel & concrete, high compressive and tensile strength the durability of repair have been found satisfactory especially at locations where required thickness is less than 15mm.

Epoxies have also been used for repair of spillways piers, glacis and silt flushing tunnel. The epoxies has the advantage of having excellent adhesive properties with the concrete as well as steel liner hence it is preferred to repair the area where both of these materials are present. However, epoxies have limitation regarding thickness of application upto 15mm whereas the cementitious mortar can be used upto 50mm with cavities upto 100mm. The cementitious mortars possess similar physical properties as parent material, are cost effective solutions and have ease of applications.

4.4 Steel liner

The resistance of steel plates against cavitation and abrasion erosion is well established. Steel liner can be installed properly during construction stage with stiffeners and anchors to resist erosion forces effectively and grouting behind the plates can prevent vibration. Thick steel plates have the engineering properties to resist impact load generated by big rolling boulders during high flood conditions. The durability of steel plates against impact forces makes it most suitable material for severe erosion conditions in low level spillways. Steel Liner plate installed during construction at NHPC in Dul Dam spillway has performed satisfactorily for more than last 20 years. Steel liner has also been installed in Mangdechhu dam in Bhutan and is proposed in various upcoming projects like Teesta-IV dam in Sikkim, Kiru & Kwar dam in J&K of Himalayan region.

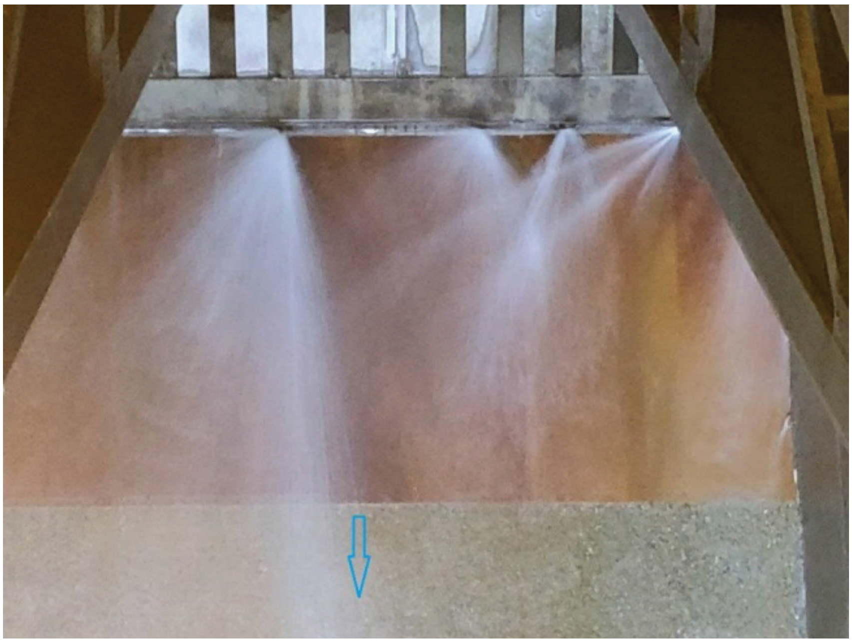

Figure 3 : Steel Liner installed at the crest of Dhauliganga Spillway on the existing base concrete

However anchoring of new plates with existing concrete structure was being considered difficult because of vibration of the liner plate leading to fracturing and eventual failure. Spillway crest and glacis of Dhauliganga Dam was getting damaged every year due to high head, high silt content and rolling boulders causing severe erosion conditions. Therefore, it was decided to provide 32mm thick steel liner with counter sunk bolt @250mm c/c. The space between the plate and concrete was grouted with epoxy. The liner has been provided in initial reach of 18m near gate. No damages have been observed in the first two years and the performance is found satisfactory.

The counter sunk bolt used for anchoring are being especially manufactured by a reputed company for dynamic load transfer to the foundation. The spacing of the counter sunk bolt was decided to reduce the vibration and effective transfer of the loads to the concrete of glacis/piers. The top of the counter sunk bolt was placed 10mm below the top surface of steel plate and the hole was filled with compatible welding material and flushed with the top surface. At the end of the steel plates a steel cut-off was provided so that the concrete beneath the steel plate is not eroded. The design and installation of steel liner need to be executed carefully as it is very difficult to repair the damaged liner once installed. If significant damage at the crest and upper glacis has already taken place during monsoon, steel liners can be installed with stiffeners by pouring concrete through holes in liner during O&M stage also.

In view of encouraging results from Dhauliganga Dam, it was decided to provide steel liners in the glacis and piers of Teesta V Dam also. Steel liners have performed satisfactorily at many other locations in various components such as silt flushing tunnels, tunnel spillways, upstream and downstream area of gate sill beam etc. to provide protection against severe erosion.

4.5 Fibre reinforced concrete (FRC)

Typically steel fibre reinforced concrete has less coarse aggregates and contains more paste and mortar to accommodate fibres. This lowers resistance to erosion compared to conventional concrete. HPC blended with steel fibres was used for repair of Glacis and bucket of one of the NHPC project Salal Dam during 1996-97. Later on, only HPC has been adopted for repair in Salal dam instead of FRC due to various observations like low workability, no significant increase in abrasion resistance and high cost.

4.6 Polymer concrete and coatings

Polymer modified concrete is developed by mixing polymer material to conventional concrete to enhance the concrete durability and bond strength. Acrylic latex based polymer concretes are reported to improve adhesion, abrasion, impact resistance. However, there are difficulties in application as these systems can be hazardous and requires care in handling and should be applied by skilled workmen experienced in their use. In addition to above, these materials are quite costly and their performance is yet to be proved in Himalayan Rivers. Some coatings such neoprene, polyurethane, polyurea, epoxies can reduce cavitation erosion damage but once there is tear or chip in the coating, the entire coating is soon peeled off due to weakness of the base concrete.

5. RECOMMENDATIONS AND CONCLUSION

Due to various erosive forces, damages take place at various components of spillways. The frequency of damages can be optimized by detailed studies of causes of erosion and by adopting suitable repair material and methodologies. The following is suggested for repair works of various components of spillways:

- Categorization of various components of the spillway should be carried out after a detailed study of various causes of erosion and analyzing the past behavior and frequency of the repair carried out. It is suggested to categorize the 'Erosion conditions' at various components of the spillways as 'Mild, Moderate or Severe' based on three major characteristics i.e. hydraulic head over the component, annual sediment load and maximum size of sediment/ boulder
- HPC is a versatile material to be used for repair of Spillway Glacis, bucket, apron, stilling basin, tunnel spillway, etc. However, steel liners may be more suitable in severe conditions for the crest of the spillway along with nearby pier area.
- Structural repair of the piers of the spillway and other structures may be carried out with Cementitious mortar (R4) complying with EN 1504-3(R4) materials having adhesive bond strength greater than 2 MPa.
- Lab tests carried out confirms that the abrasion resistance of cementitious mortars (R4) is of the order of M65 to M80 grade of HPC which provides desired strength, durability and reduction in frequency of repair.
- All the epoxy materials shall comply with ASTM C-881. Epoxies have additional advantages of having excellent bonding strength with concrete as well as steel. It can be applied on wet surfaces. However there is a limitation regarding the maximum thickness of the order of 15mm.
- For the upcoming projects detailed river inflow and sedimentation studies may be carried out for the suitable classification of the spillway based on the category of erosion condition to decide suitable methodology to mitigate and resist damages during O&M stage.

There is need to standardize the repair guidelines including technical specifications for repair material & methodologies for proper execution of the work. Use of appropriate material with standardized performance characteristics can optimize the cost and frequency of repair and enhance the safety aspects of the dam.

REFERENCES

ACI 210R-93: Erosion of Concrete in Hydraulic Structures.

ACI 546R: Concrete Repair Guide

ASTM C881/C881M-10: Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete.

EM 1110-2-2002: Evaluation and Repair of Concrete Structures.

EN 1504-3: Products and Systems for the protection and repair of concrete structures - Structural & non-structural repair.

Manual for Rehabilitation of Large Dams –Jan'2018, DRIP & CWC, India.

K Deshmukh, A Mittal, M Kumar 2018. "Dam repair materials & their generic perforformance characteristics"- International Dam Safety Conference