IMPACT OF SOFT WATER ATTACK ON DAM CONCRETE OF HYDRO POWER STRUCTURES IN THE HIMALAYAN REGION – CASE STUDIES

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ABSTRACT

To full fill country's irrigation and power requirements various large capacity dams have been constructed on major rivers in last 70 years. The long term sustainability of these structures is largely dependent on hydro-environment and the capacity of these structures to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The concrete deterioration is directly influenced by various geographical, climatic and ecological conditions. These are therefore the major factors to be considered during the designing and construction of the projects for enhancing their sustainability. Quality of water plays an important role in the production of concrete. The chemical reactions between cement and water enable the setting and hardening of cement, resulting in a binding medium for the aggregates and development of strength. Concrete can be made which will perform satisfactorily when exposed to various atmospheric conditions, to most waters and soils containing chemicals, and to many other kinds of chemicals. There are, however, some chemical environments under which the useful life of even the best concrete will be short. To make concrete durable, it is a must to understand the mechanisms of various factors affecting the durability of concrete to come to the remedial measures in an economic way. Understanding these conditions permit measures to be taken to prevent or reduce deterioration. The aggressiveness of a water is dependent on the pH value, the total dissolved salts , the degree of hardness, soluble chlorides, sulphates, carbonation, temperature and alkalinity etc. Aggressive water may deteriorate concrete structures to a great extent if proper precautions are not taken at the time of construction and/or during the life span of structure . A number of hydroelectric projects around the world are suffering due to attack of aggressive water on concrete / metallic equipment and a lot of economy in involved in the process of repairs and rehabilitation of such project. The review paper present the typical aggressive water quality issues encountered during our investigations. Central soil and materials research station involved in the water quality investigations of the various projects of the Himalayan regions and found the common issues related to soft water attack on concrete structures. Presence of low salt content in glaciers flow makes Himalayan river water soft in nature which in turn not good for concrete structures. Some outcomes of our studies related to Tehri dam H.E. project (THDC), Uttarakhand, Nathpa Jhakri Hydro power station, NJHPS (SJVN) Project, H.P and Baglihar H.E. Project, J & K are presented here for reference.

***Keywords** : Soft Water Attack, Aggressivity; Durability, Leaching of lime; Seepage; Hydro-environment.*

INTRODUCTION

During the last fifty years, many major developments have taken place in the establishment of water resources structures to full fill irrigation and power requirement. During the development of these mega structures the extensive investigations were carried out on surrounding geology and construction materials, however the importance of water quality criteria on concrete structures was some how ignored. As a results of this major dams built in Himalayan region and north east are facing severe problem of deterioration of structures and hydro mechanical equipment. Even with the perfect concrete mix design, it is important that the durability/performance of concrete get adversely affected under certain aggressive site conditions. The less travelled Himalayan Rivers generally have soft water i.e. water deficient of dissolved salts. To maintain the chemical equilibrium, it tends to leach out the salts, mainly calcium and magnesium salts from the concrete. Soft water or water deficient in dissolved salts of calcium and magnesium also causes corrosion of concrete by dissolving and subsequent leaching of free $Ca(OH)_2$ of concrete and transportation of calcium out of the matrix. The penetrability or water permeability of concrete turns out to be the only property, which can be directly related to long term durability. Many other physical and chemical causes such as quality of ingredients & quality control during construction, corrosion of embedded reinforcing or pre stressing steel, chemical attack by the external agents, physical chemical effects from internal phenomenon and leaching of lime etc. are responsible for deterioration of concrete. A number of case histories are there to show that impermeable concrete when exposed to aggressive environment perform much better than the high strength permeable concrete during the intended service life. Durable concrete will retain its original form, quality and serviceability when exposed to aggressive environment over the designed period. Deterioration of concrete is directly related to its durability that depends on the extent of efforts taken to ensure proper design of concrete mix, degree of quality control exercised during construction and guidelines followed to protect the concrete from harmful effects during hardening process. Some case studies related to some peculiar problems encountered during the pre and post construction investigations with special reference to deterioration of concrete due to poor water quality, problem of leaching of lime in seepage galleries faced at Tehri Dam, Uttarakhand, Nathapa Jhakri Hydroelectric power project, Himachal Pradesh, and Baglihar Dam J &K. represented in this paper.

1. TEHRI HYDRO POWER COMPLEX, TEHRI DAM PROJECT, UTTARAKHAND

The Project at a glance

It comprises of a 260.5m high earth & rockfill dam on river Bhagirathi at 1.5km downstream of its confluence with river Bhilangana. Dam is located in a narrow S-shaped valley with steep side slopes.

THPC is a multipurpose scheme on river Bhagirathi, a tributary of river Ganges. It is designed for storing surplus water of river Bhagirathi during monsoon and releasing the stored water to fulfil the irrigation and drinking water needs of the population in the Gangetic plains of Uttarakhand and Uttar Pradesh during non-monsoon period while generating 2400MW of peaking power. Tehri HPC consists of the following:

1. Tehri Hydro Power Plant (Tehri HPP) - 1000 MW (4x250MW)
2. Koteshwar Hydro Electric Project (Koteshwar HEP) - 400 MW (4x100MW)
3. Tehri Pumped Storage Plant (Tehri PSP) - 1000 MW (4x250MW)

The concrete spillway of Tehri dam was constructed to take care of inflow Probable Maximum Flood (PMF) of 5380 m^3/s. The underground power house, inspection galleries and drainage gallery of the dam have been constructed using concrete linings of different grades.

Encountered Problem

The inspection gallery (Grouting Gallery Riverbed Right (GRBR) , Grouting Gallery Riverbed Left (GRBL)), AGRBR and AGRBL has concrete lining. Leaching of lime has been observed at many locations in these galleries (Figure 1-4). In the present case the problem apprehended is possible deterioration of concrete due to softness of water. This necessitates the adoption of suitable remedial measures. Before deciding on remedial measures, it is important to establish the degree of aggressivity of water with respect to various parameters. Once this is established, reference to categorize aggressiveness can be made to various codes and practices. Investigation to determine the cause and mineralogy of the leached material was carried out.

Fig. 1

Fig. 2

Fig. 3

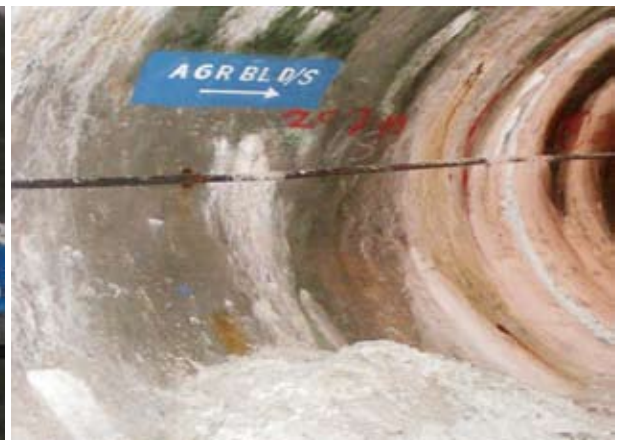

Fig. 4

Fig. 1-4 : White, Black and Brown Leachate deposit in the inspection galleries

Behaviour of concrete under chemical exposure

In the present case the problem apprehended is possible deterioration of concrete due to softness of water. This necessitates the adoption of suitable remedial measures. Before deciding on remedial measures, it is important to establish the degree of aggressivity of water with respect to various parameters. Once this is established, reference to categorize aggressiveness can be made to various codes and practices.

Field and Laboratory Investigations

Seepage water samples and leachate material were collected from galleries, reservoir and D/S at TRT respectively. were analysed as per analytical procedure laid down in IS 3025-1986 "Methods of Sampling and Test (Physical and Chemical) for Water used in the Industry". Some of the insitu parameters viz. pH, Ammonium and Sulphide were determined at site.

Further detailed chemical analysis of the samples was carried out at CSMRS laboratory for determining Suspended Solids, Total Dissolved Solids, Sulphates, Calcium, Magnesium, Acidity and Alkalinity as equivalent Calcium Carbonate. Leachate material samples collected from GRBR and GRBL gallery were analysed using X-Ray Diffrcatometer for determining their mineralogy.

In-situ observations

- The pH of water samples is alkaline and falls in the range of 7.48 to 9.23 at different locations. thus all the samples fall in the alkaline region.
- The conductivity value of the seepage water samples varied between 438 to 730 µmhos/cm thus indicating moderate soluble salt content. A lower conductivity values i.e. 208 µmhos/cm and 125 µmhos/cm are observed for the samples collected from the reservoir and D/S at TRT respectively.

- Calcium carbonate saturated pH values for all the samples were found to be in the range of 8.01 to 9.51.

Laboratory observations

- All the collected water samples showed low acidity values. The alkalinity values for five seepage water samples ranged between 110 to 130 expressed as $CaCO_3$ mg/l. For the samples collected from reservoir and D/S at TRT the vales were 80 and 40 expressed as $CaCO_3$ mg/l respectively.
- The TDS values for four seepage water samples ranged between 311 to 491 ppm (Inorganic solids) and 5 to 8 ppm (Organic solids). For the samples collected from reservoir and D/S at TRT the vales were much less and were found to be only 81 and 71 ppm respectively with no organic solid.
- The calcium, magnesium, chloride and sulphates ions present in all the water samples were observed to be very low in concentration.

International Commission on Large Dams (ICOLD) Bulletin No. 71 has recommended the calculation of Saturation of Langelier Index (LI) as a means of evaluating potential soft water attack. The details are given in Table 1. The Langelier Index (LI) of the three seepage water samples ranged between - 0.13 to 1.60 while for reservoir water sample and the sample collected from D/S at TRT the Langelier Index (LI) was found to be - 0.77 and – 1.43.

The water collected from reservoir and TRT has been classified as moderately aggressive and aggressive respectively (as the LI values are negative in nature) which may cause corrosion/leaching of calcium carbonate from the concrete mass directly in contact with such water for a prolonged period.

Table 1 : Classification of Degree of Aggressiveness based on Langelier Index *
(International Commission on Large Dams (ICOLD) bulletin No. 71- " Exposure of dam concrete to special aggressive waters – Guidelines and recommendations, 1989"

Sample No.	Langelier Index Values	Aggressiveness	Indication
1.	1.32	Non aggressive	Deposition of Calcium
2.	- 0.02	Non aggressive	May deposit Calcium
3.	0.30	Non aggressive	Deposition of Calcium
4.	- 0.13	Non aggressive	May deposit Calcium
5.	1.60	Non aggressive	Deposition of Calcium
6.	- 0.77	Moderately aggressive	Leaching of Lime
7.	- 1.43	Aggressive	Leaching of Lime

Analysis of leachate samples

Leachate material samples collected from galleries were analysed using X-Ray Diffractometer (Figure 5 and 6) for determining their mineralogy.

- In the X-Ray Diffraction analysis, the phase identification with ICDD database and AMCSD database for all the leachate samples indicates presence of Calcite as the predominant mineral.

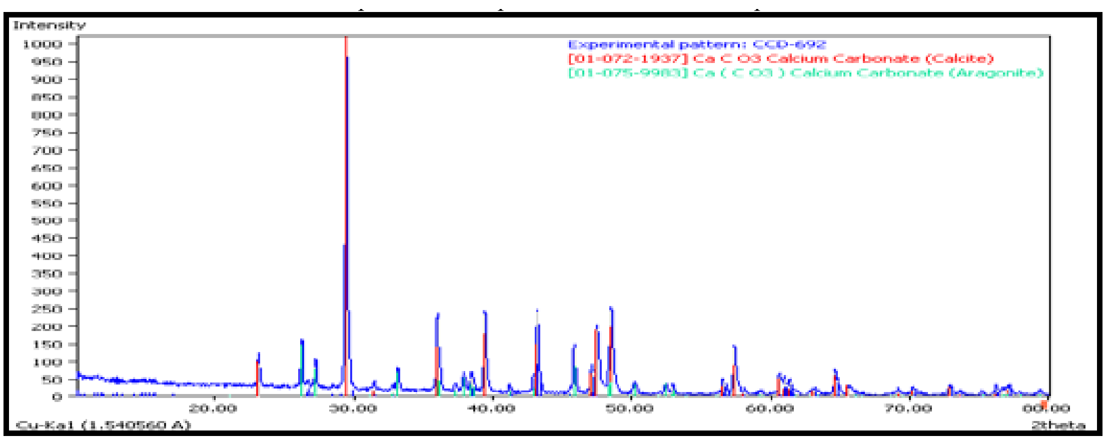

Fig. 5 : X-ray Diffractogram of White Leachate material

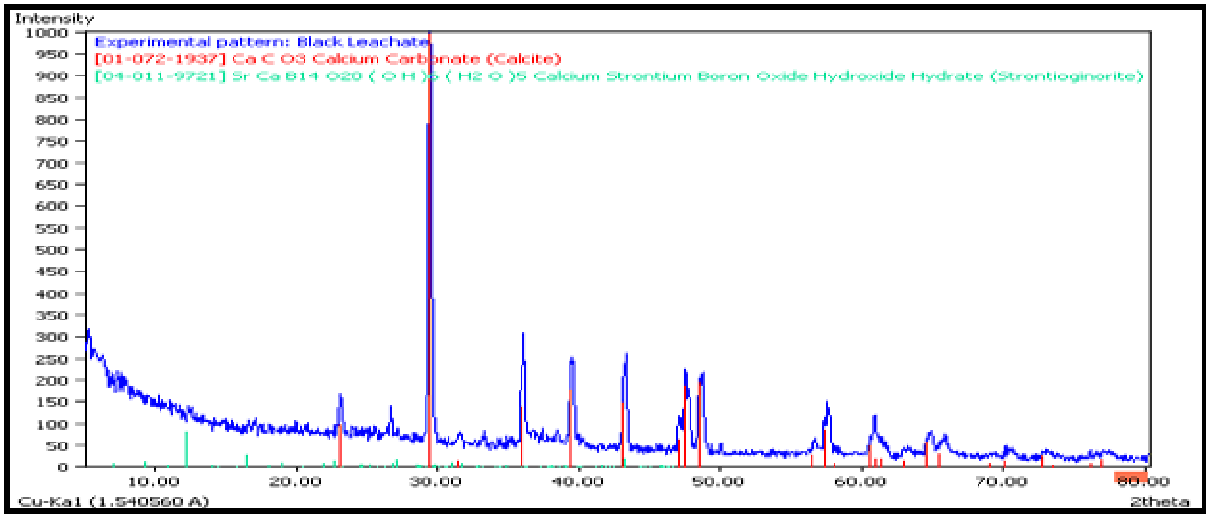

Fig. 6 : X-ray Diffractogram of Black Leachate material

Interpretation of test data with reference to codes and practices

- Water samples are moderately aggressive as per values calculated by Langilier index
- The mineralogical composition of the white as well as black leachate samples indicates presence of Calcite as the main mineral.
- Leaching of lime from concrete structures facing aggressive water has been observed.

2. NATHPA JHAKRI HYDRO POWER STATION (NJHPS) , H.E. PROJECT ,SJVN, HIMACHAL PRADESH.

The project at a glance

The project presently is being managed by Satluj Jal Vidyut Nigam limited (SJVN), a joint venture of Government of India and Government of Himachal Pradesh. The 1500 MW power generation capacity Nathpa Jhakri Hydro Power Station, HP has a concrete gravity dam at Nathpa, constructed on the River Sutlej in the district of Kinnaur (Himachal Pradesh), India. It is a run of the river project. This project consists of a 60.5m height dam, underground de-silting complex, 27.4 Km long Head Race Tunnel and an underground power house at Jhakri. During pre-construction investigations project was facing challenge posed by high temperature and hot water ingress throughout the entire length of HRT. Various remedial measures suggested after carried out systematic water quality analysis during its pre construction stages by central soil and materials research station.

Just after commissioning of the project in 2004, problem of seepage water and deposition of leaching material both started in dam galleries, power house complex and adits of HRT. CSMRS is monitoring the seepage water quality and leached materials of dam galleries, power house complex and adits.

Field and Laboratory Investigations

Various locations in the galleries at power house site and the foundation gallery at dam site where seepage of water and leaching of materials was observed were inspected. Seepage water samples and leached material samples from these locations were collected and analysed

In-situ observations

- The pH of the collected water samples from different locations ranges between 7.01 to 12.02. The pH of all the water samples fall in the alkaline region.
- The conductivity value of the seepage water samples varied between 331 to 4460 µmhos/cm. Except for one sample the result of conductivity test indicate low soluble salt content. Only one sample with high conductivity values i.e. 4460 µmhos/cm indicate very high soluble salt content.
- Calcium carbonate saturated pH values for all the samples were found to be between 7.60 – 12.17.

Laboratory observations

- The collected water samples showed acidity values in the range 0 to 3.20. Similarly the alkalinity values ranged between 8.75 to 140 expressed as $CaCO_3$ mg/l.
- The TDS values ranged between 201 to 1115 ppm (Inorganic solids) and 0 to 154 ppm (Organic solids).
- The Calcium concentration ranged between 32 to 300 mg/l.
- The Magnesium concentration for the all the water samples 4.8 to 24.0 mg/l.
- The Chloride concentration for the all the water samples ranged between 2.5 to 32.5 mg/l.
- The Sulphate concentration for the all the water samples ranged between 21.14 to 105.48 mg/l.

Soft-Water Attack

International Commission on Large Dams (ICOLD) Bulletin No. 71 has recommended the calculation of Saturation of Langelier Index (LI) as a means of evaluating potential soft water attack. The Langelier Index (LI) of the seepage water samples ranged between – 1.07 to 0.42 presented in Table 2.

Table 2 : Classification of Degree of Aggressiveness based on Langelier Index *

(International Commission on Large Dams (ICOLD) bulletin No. 71- " Exposure of dam concrete to special aggressive waters – Guidelines andrecommendations, 1989"

Sample No.	Langelier Index Values	Aggressi-veness	Indication
1.	5.73	Non aggressive	Deposition of Calcium
2.	-0.11	Non aggressive	-
3.	-0.49	Slightly aggressive	-
4.	0.03	Non aggressive	-
5.	0.42	Non aggressive	-
6.	-0.06	Slightly aggressive	-
7.	-1.07	Moderately aggressive	-
8.	-0.63	Moderately aggressive	-
9.	0.01	Non aggressive	-

3. ANALYSIS OF LEACHATE SAMPLES

Leachate material samples collected from these locations were analysed using X-Ray Diffrcatometer for determining their mineralogy.

- In the X-Ray Diffraction analysis, the phase identification with ICDD database using Cement Materials and Minerals sub-files indicates that the main mineral in all the leachate samples was Calcite. (Fig. 7)

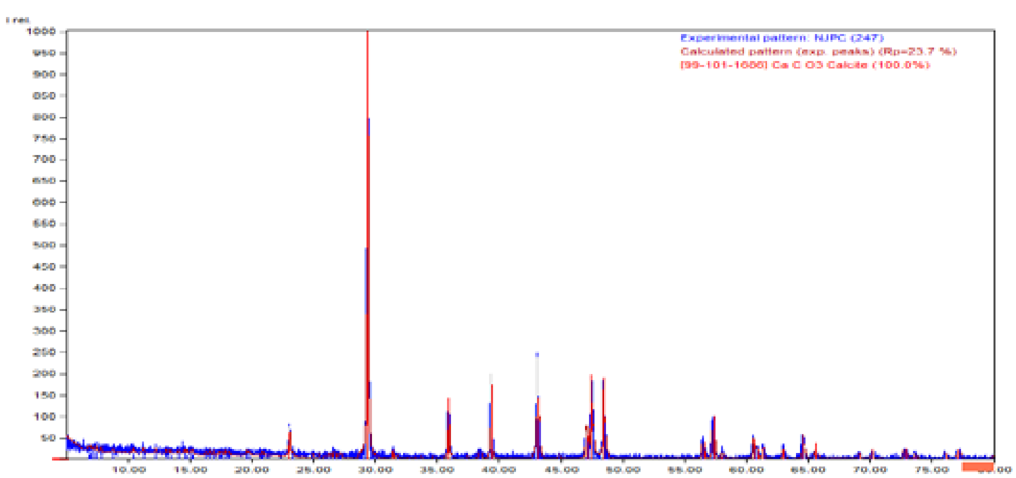

Fig. 7 : X-Ray Diffractogram of Leached material

Interpretation of test data with reference to codes and practices

- Water samples are generally non aggressive by nature as per IS : 456-2000 and the French National Code. However as per the value of Langilier index samples are found to be non aggressive to moderately aggressive.
- The mineralogy of the leached material samples indicates presence of Calcite as the main mineral.

4. BAGLIHAR H.E. PROJECT J & K

Baglihar Dam is built on Chenab River in the Doda district of Jammu & Kashmir. The hydro power project 'Baglihar Hydroelectric Power Project', is a run-of-the-river power project on the Chenab River. This project was conceived in 1992, approved in 1996 and construction began in 1999 and was commissioned in year 2009. It is 450 (3 X 150 mw) MW project. The Problem started surfacing soon after first filling of the reservoir with heavy seepage in the inspection galleries followed by deposition of leachate material on the roof and walls of galleries was observed.(Fig.8)

Fig. 8 : Leaching of Lime

Present investigation work aims to cover the following aspects:

- Chemical analysis of seepage water samples to assess its effect on the long term durability of concrete.
- Characterization of leachate samples.

In- situ testing of seepage water samples was done at site itself and seepage, reservoir water samples and leachate samples were collected and preserved for detailed laboratory analysis. The water samples were analyzed for various parameters as per analytical procedure laid down in IS 3025-1986. Wherever needed reference was also drawn from the procedure laid down by the American Public Health Association and Water Pollution Control Federation, USA. Leachate samples were collected from AGRBR and AGRBL gallery of the foundation gallery. Different approaches viz. chemical analysis, XRD, FTIR etc. were followed to investigate the composition of leachate materials.

5. DISCUSSIONS OF RESULTS

- The pH of all the water samples is alkaline and falls in the range of 7.65 to 9.17.
- The saturated pH is in the range 8.67 to 10.01. The delta pH for all the water samples is in negative value. The negative value of delta pH indicates that water has a tendency to dissolve cementitious material.
- International Commission on Large Dams (ICOLD) Bulletin No.71 has recommended the calculation of Saturation of Langelier Index (LI) as a means of evaluating potential soft water attack.
- Out of 7 water samples 4 water samples have – ve Langelier Index values respectively]. The negative values for LI indicate that the water samples are still unsaturated with respect to calcium carbonate content and more negative than the LI value for reservoir water. These water samples fall under moderately aggressive category and there is possibility of soft water leaching attack on concrete. In these circumstances, there is a possibility of concrete corrosion. For three water samples LI values were positive depict the possibility of deposition of lime .

6. CONCLUSION

- Post construction exposure of hydro power structures to various aggressive conditions including soft water attack leads to deterioration of concrete.
- Due to the soft nature of seepage waters and further categorization on other parameters, majority of the water samples fall under moderate to severe aggressive category. Hence, there is a strong possibility of leaching of lime from the concrete.

- Water quality, which is generally being ignored by the people involved in the construction, which plays a very important role towards the long term durability of concrete structures.
- In the Himalayan region where the temperature is low and the fresh mountain waters are often relatively free from dissolved ions, leaching and freeze-thaw are the most common degradation problems for concrete.
- Other degradation mechanisms may also become more and more effective in case of leaching of concrete since strength giving calcium is removed from the concrete during the process and concrete becomes more porous .In such situations, long term durability aspects needs serious attention to be addressed on priority.
- The case histories discussed above is the alarming indication towards deteriorating health of project in the Himalayan region. Further exposure of concrete to the aggressive conditions will lead to worsening of conditions. It is thus important that the durability/performance of concrete should be constantly monitored so that the cause of deterioration can be ascertained and effective remedial measures be explored.

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