Impact of Soft Water Attack on DAM Concrete

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Abstract—Concrete deterioration is directly influenced by various geographical, climatic and ecological conditions. Long term sustainability of concrete in hydro structures is largely dependent on quality of its hydro-environment and its capacity to resist weathering action, chemical attack, abrasion or any other process of deterioration. There are certain aggressive conditions under which the useful life of even the best concrete will be short. In India most of the hydro structures are established on major perennial rivers flowing through 2,400-km long Himalayan arc. Since independence various large/small capacity dams have been constructed on these rivers to full fill country’s irrigation and power requirements. Some of these structures have already started showing the signs of deterioration. Understanding these conditions permit measures to be adopted to prevent or reduce deterioration. Unusual problems like deterioration of concrete due to aggressive water, problem of leaching of lime in seepage galleries etc. have been encountered at various projects. In the present paper investigations in respect of one of the projects in this region where such problem is observed is discussed.

Keywords—Aggregates, Soft water attack on concrete, leaching of lime, Seepage, Aggressivity of water, Hydro-environment.

I. INTRODUCTION

During the last fifty years, many major developments have taken place in concrete industries both materials and construction practices. The dual focus of these developments has been to achieve strength and durability of concrete. Even with the perfect concrete mix design, it is important that the durability/performance of concrete get adversely affected under certain aggressive site conditions. Many 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. The penetrability or water permeability of concrete turns out to be the only property, which can be directly related to long term durability. 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. The present study focuses on investigations in respect of one of the projects in Himalayan region where problem of extensive leaching is observed. Leaching involves the complete process of dissolving and transporting the substances out of concrete.

II. ENCOUNTERED PROBLEM

The project was commissioned in year 2006. Problems started surfacing soon after first filling of the reservoir. Initially heavy seepage started in the inspection galleries followed by deposition of leachate material on the roof and walls of galleries was observed.

III. TARGETED AREA OF INVESTIGATION

Monitoring of the quality of reservoir water and seepage water samples has been done for quite some time so that the assessment of degree of aggressiveness of water can be done. As it is evident that quality of water affects the durability of concrete, the overall impact of the water on the long term durability aspects of dam has also been carried out. Mineral identification of leachate samples has also been done to assess the nature and degree of damage happening to the concrete. Following important aspects were taken into consideration during the investigation:

➢ During the field visit CSMRS field party inspected the foundation gallery and collected seepage water from various locations in the Grouting Gallery
➢ Water samples from Riverbed Right (AGRBR), river bed left (AGRBL), reservoir water sample and D/s water sample at TRT
➢ Leachate samples from both AGRBR and AGRBL locations.
IV. TEST METHODS AND SAMPLING LOCATIONS

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 details of the sampling locations along with samples’ designation are given in Table 1.

The water samples were analyzed for various parameters as per analytical procedure laid down in IS 3025-1986 [4]. Wherever needed reference was also drawn from the procedure laid down by the American Public Health Association and Water Pollution Control Federation, USA, [5].

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. The chemical constituents and loss on ignition were determined by standard test methods.

The mineralogical identification of leachate materials done with FTIR Spectroscopy (Thermo Nicolet IR 200 model instrument with KBr pallet) in the range 450 –4000 cm⁻¹ and X-Ray Diffraction patterns of leachate materials were obtained on a powder XRD model (GBC Emma with CuKα1 radiation (1.54 A₀)) with scanning speed of 40/minute. The results obtained were analyzed with the help of ICDD and AMCS database. [6]

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Sample No.</th>
<th>Nature of sample</th>
<th>Sampling location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WS 1</td>
<td>Seepage water</td>
<td>GRBL – 1,</td>
</tr>
<tr>
<td>2</td>
<td>WS 2</td>
<td>Seepage water</td>
<td>GRBL – 1,</td>
</tr>
<tr>
<td>3</td>
<td>WS 3</td>
<td>Seepage water</td>
<td>Ch 40, GRBL – 3,</td>
</tr>
<tr>
<td>4</td>
<td>WS 4</td>
<td>Seepage water</td>
<td>Ch 42, GRBL – 5,</td>
</tr>
<tr>
<td>5</td>
<td>WS 5</td>
<td>Reservoir</td>
<td>U / S</td>
</tr>
<tr>
<td>6</td>
<td>WS 6</td>
<td>Reservoir</td>
<td>D / S</td>
</tr>
<tr>
<td>7</td>
<td>WS 7</td>
<td>Seepage Water</td>
<td>D/S , CH-116, AGRBL</td>
</tr>
<tr>
<td>8</td>
<td>WS 8</td>
<td>Seepage water</td>
<td>D/S , CH-96, AGRBL</td>
</tr>
<tr>
<td>9</td>
<td>WS 9</td>
<td>Seepage water</td>
<td>U/S , CH-73, AGRBL</td>
</tr>
<tr>
<td>10</td>
<td>WS 10</td>
<td>Seepage water</td>
<td>U/S , CH-61, AGRBL</td>
</tr>
<tr>
<td>11</td>
<td>WS 11</td>
<td>Seepage water</td>
<td>D/S , CH-41, AGRBL</td>
</tr>
<tr>
<td>12</td>
<td>WS 12</td>
<td>Seepage water</td>
<td>D/S , CH-42, AGRBL</td>
</tr>
</tbody>
</table>

V. INVESTIGATIONS

A. Field Investigation

In-situ parameters viz: temperature, conductivity, pH, CaCO₃ saturated pH, ammonium and sulphide of representative water samples were determined at site itself.

B. Laboratory Investigations

The water samples were analyzed with state of the art equipment like, Atomic Absorption Spectrophotometer, microprocessor based flame photometer, UV-Visible Spectrophotometer. Wherever needed gravimetric methods were also followed. All water samples were subjected for determination for parameters such as Suspended solids, Total solids, Acidity, Alkalinity, Chloride, Sulphate, Carbonate, Bicarbonate, Calcium, Magnesium, Sodium, Potassium, etc. in laboratory.

Leachate samples were subjected to chemical analysis, XRD and FTIR for their chemical composition and mineral identification.

VI. OBSERVATIONS

Since leaching of material was happening there from the roof and walls of inspection galleries therefore possibility of deterioration of concrete due to soft water attack was apprehended. It is of paramount importance to establish the degree of aggressivity of water samples with respect to various parameters. After finding out the degree of aggressiveness the water samples can be categorized on the basis of various codes and practices before coming to the remedial measures.
VII. AGRSSIVITY OF CHEMICAL ENVIRONMENT WITH REFERENCE TO CODES AND PRACTICES

In order to classify the aggressive environment the Dam is facing, water samples from various locations as described were subjected to above mentioned parameters. In the present paper the test results of water samples of collected from various locations are discussed for parameters done in accordance to various national and International Codes and Practices viz."IS 456:2000 Code of Practice for Plain and Reinforced Concrete"[7], “United States Bureau of Reclamation(USBR) Standard for sulphateaggressivity”[8], “French National Standardp18-011, May 1985 for assessing aggressivity due to pH, Ammonium, Magnesium and Sulphate ions”[9]and “International Commission on Large Dams, ICOLD Bulletin No. 71[10]: Exposure of Dam Concrete to Special Aggressive Waters –Guidelines.

VIII. DISCUSSIONS OF RESULTS

A. Water Samples

1) pH Value: pH of the water samples is alkaline and falls in the range of 6.51 to 12.02 at different locations. The pH of water is affected by many factors both natural and man-made. Most natural changes occur due to interactions with surrounding rock (particularly carbonate forms) and other materials. pH can also fluctuate with precipitation (especially acid rain) and wastewater or mining discharges. In addition, CO2 concentrations can also influence pH of water bodies. If the pH of water is too high or too low, the aquatic organisms living within it will die. The aquatic life faces more severe challenges as the mobility and toxicity of chemicals and heavy metals increases in case of extreme pH levels.

2) Temperature: Temperature of all the water samples falls in the range of 17.8°C to 24.7°C. The consequences of hot water discharges into the reservoir can be studied on the basis of two fold points of views: (i) the rate of reaction increases with increase in temperature and hence the rate of reaction of deleterious ions on concrete may become faster with the rise in temperature of reservoir water. (ii) The rise in reservoir temperature has consequences on the ecology of the reservoir, particularly on the aquatic ecosystem.

The pictorial presentation of various parameters viz. temperature, pH, CaCO3 saturated pH, suspended solids, total dissolved solids, calcium, magnesium, bicarbonate has been presented in Figures 1-6.

3) Soft-Water Attack: The dam in subject is very valuable due to the involvement of heavy national economy and expenditure in it. It is made to fulfil the needs of ever-growing population of India to meet the requirements of irrigation, drinking water and electricity along with development of fishery and wild life conservation. During the recent floods of Uttarakhand in 2013, Tehri dam accommodated large amount of water in it and effectively controlled the menace of furious flood and in a way saved the regions below Rishikesh and Haridwar to a greater extent. The durability aspects of such structures are very important since they are built for the betterment of mankind for ages.

Soft water is aggressive to concrete structures because of its ability to dissolve substances in it. It is observed worldwide that structures made by taking utmost care and precaution can also be damaged due to soft water attack and consequent leaching. In Himalayan region where the temperature in 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. Soft waters are aggressive to concrete structures as they are short of dissolved ions and have a great tendency to dissolve ions from nearby materials. Leaching is the name of the whole process of dissolving and transporting substances out of the concrete. Other degradation mechanisms also become more and more effective in case of leaching of concrete since strength giving calcium is removed from the concrete during the process. Also as the pH value inside the concrete may decrease from 12-13 to 8-9, corrosion of reinforcement may also take place. A number of factors such as permeability of concrete, amount of total Ca and Ca(OH)2 in concrete, carbonation, hardness of water, amount of carbonic acid which is free to attack the concrete etc. may influence the leaching of lime from concrete.

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 all water samples ranged between –2.54 to 4.53. Negative values of LI indicate the aggressiveness of water whereas the positive values imply the likelihood of calcium deposition. It is seen from the data that there is possibility of soft water leaching attack since out of 18 water samples 9 water samples have –ve values for Langelier Index. In these circumstances there is a possibility of corrosion of concrete. The water samples collected from reservoir and TRT have been classified as moderately aggressive and aggressive respectively.
These may cause corrosion/leaching of calcium carbonate from the concrete mass if the exposure of concrete to such waters is prolonged. [11-13]

**B. Leachate Samples**

1) **Chemical Analysis:** The chemical analysis data of leachate materials is summarized in Table 2. The data shows the presence of calcium oxide in predominance. High values of Loss on ignition (LOI) indicate the presence of carbonaceous material in all the leachate samples.

**IX. MINERALOGY OF LEACHATE MATERIALS**

A. **X–Ray Diffraction Studies:** The result of XRD studies are presented in Figures 7-9. White leachate material has the presence of calcium carbonate as Calcite and Aragonite minerals whereas the black leachate material shows calcium carbonate as calcite and strontioginorite as major minerals. The comparison of the XRD of leachate materials was done with that of XRD of pure calcium carbonate which also showed both calcite as well as aragonite phases.[14]. Phase analysis of leachate materials with Siroquant software showed the presence of calcite 64.1% and Aragonite 35.9%.

**Table II: Chemical Analysis Of Leachate Material**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter % by wt.</th>
<th>White Leachate</th>
<th>Black/Brown Leachate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LOI</td>
<td>44.12</td>
<td>37.89</td>
</tr>
<tr>
<td>2</td>
<td>SiO₂</td>
<td>1.36</td>
<td>3.98</td>
</tr>
<tr>
<td>3</td>
<td>Al₂O₃</td>
<td>0.36</td>
<td>1.71</td>
</tr>
<tr>
<td>4</td>
<td>Fe₂O₃</td>
<td>0.21</td>
<td>3.73</td>
</tr>
<tr>
<td>5</td>
<td>CaO</td>
<td>54.24</td>
<td>51.45</td>
</tr>
<tr>
<td>6</td>
<td>MgO</td>
<td>0.18</td>
<td>1.23</td>
</tr>
</tbody>
</table>

**B. FTIR Studies:** The typical IR spectra of leachate materials with FTIR measurements observed in mid infrared region i.e. in the range 450 –4000 cm⁻¹ are shown in Figures 10-12. The spectra of all white/black/brown leachate materials show the presence of CaO in predominance which is again corroborated by chemical analysis as well comparison of spectra of leachate materials with that of the IR spectrum of pure calcium carbonate.

The quantitative determination of CaCO₃ content by FTIR was done on TQ Analyst software. The comparative data of CaCO₃ by chemical analysis as well as by FTIR has been given in Table 3.

**Table III: Calcium Carbonate Content In Leachate Material**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Leachate Material</th>
<th>CaCO₃ %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Chemical Analysis</td>
</tr>
<tr>
<td>1</td>
<td>White leachate</td>
<td>97.11</td>
</tr>
<tr>
<td>2</td>
<td>Black/Brown leachate</td>
<td>91.02</td>
</tr>
</tbody>
</table>

**X. CONCLUSIONS**

Based on the studies carried out on the water and leachate materials the following conclusion can be drawn:

- All the Water samples are generally non aggressive by nature as per IS : 456-2000, USBR and the French National Code. However, Langillier index value for majority of the water samples fall into the moderately aggressive category and few are categorized as aggressive. A positive shift in LI values for seepage water as compared to reservoir water indicates the soft water of reservoir has started leaching phenomena in concrete at various locations, which is present in the form of deposition of lime on concrete surface. The level of aggressiveness and its probable impact on the concrete is given in Table 4

- The result obtained by chemical analysis, XRD and FTIR analysis show that the presence of calcium carbonate is predominant in leachate materials. The high values of LOI also indicate the presence of high carbonaceous matter. XRD study shows the presence of calcium carbonate in the form of calcite as well as aragonite phases along with aluminum silicates.

- The analysis of leachate material done chemically is corroborated by XRD and FTIR. The results of quantification of Calcium carbonate content by FTIR method were very close to the gravimetric results.

- Moderate to heavy leaching of lime from concrete structures facing aggressive water has been observed. Photographs of the foundation galleries taken during the investigation clearly show leaching and deposition of lime from the concrete of roof and walls. Figure 1.
**Table IV:**

<table>
<thead>
<tr>
<th>WS No.</th>
<th>LI Value</th>
<th>WS No.</th>
<th>LI Value</th>
<th>WS No.</th>
<th>LI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS 1</td>
<td>-0.11**</td>
<td>WS 7</td>
<td>-2.54***</td>
<td>WS 13</td>
<td>-0.55**</td>
</tr>
<tr>
<td>WS 2</td>
<td>0.12*</td>
<td>WS 8</td>
<td>-1.14**</td>
<td>WS 14</td>
<td>0.07*</td>
</tr>
<tr>
<td>WS 3</td>
<td>-1.39**</td>
<td>WS 9</td>
<td>-0.77**</td>
<td>WS 15</td>
<td>1.63*</td>
</tr>
<tr>
<td>WS 4</td>
<td>1.22*</td>
<td>WS 10</td>
<td>4.53*</td>
<td>WS 16</td>
<td>1.08*</td>
</tr>
<tr>
<td>WS 5</td>
<td>0.52*</td>
<td>WS 11</td>
<td>0.22*</td>
<td>WS 17</td>
<td>-0.57**</td>
</tr>
<tr>
<td>WS 6</td>
<td>0.21*</td>
<td>WS 12</td>
<td>-0.17**</td>
<td>WS 18</td>
<td>-1.10**</td>
</tr>
</tbody>
</table>

* Non-Aggressive: Deposition of lime on concrete surface may take place

** Moderately Aggressive: May leach lime from concrete

*** Very Aggressive: May leach lime from concrete

**XI. RECOMMENDATION**

It has been seen from the past observations that leaching of lime from the roof sand walls of foundation galleries is taking place in substantial quantity and is continued. There is also a possibility of soft water attack on concrete as indicated by LI values. The mineralogy of leachate materials shows the predominance of calcite. Although presently the degree of leaching may not be alarming but continuous leaching of calcite, the important binding phase of concrete, will definitely affect adversely the long term durability of concrete. The in-depth investigation of seepage water, regular monitoring of foundation galleries and the physical observation of leaching of lime is recommended during the different stages of reservoir levels for a considerable period of time. Since the leaching process may also reduce the alkalinity of concrete, its impact on rebar corrosion and assessment of the strength of concrete should be carried out regularly on a periodic basis.

**Acknowledgement**

The authors extend their sincere gratitude to the Director, Central Soil and materials Research Station New Delhi for being a constant source of inspiration. We extend sincere thanks to all officers and staff of the Concrete Chemistry Division of CSMRS and authorities of Tehri Dam Project, Uttarakhand for extending timely help during laboratory and field investigations. We also extend our sincere gratitude to the authors whose publications provided us directional information from time to time.

**REFERENCES**


Figures 1-6 showing graphical presentation of chemical analysis’ data of water samples

Figure 7: X-Ray Diffractogram of White Leachate Material

Figure 8: X-Ray Diffractogram of Black Leachate Material

Figure 9: X-Ray Diffractogram of Pure calcium carbonate

Figure 7-9 Showing the Comparison of X-Ray Diffractograms of Leachate Materials with Pure Calcium Carbonate.
Figures 10-12 Showing the Comparison of IR Spectra of Leachate Materials with Pure Calcium Carbonate.

Plate 1: Photographs of Foundation galleries of Tehri Dam Showing the leaching of lime