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ROLE OF DURABILITY OF CONCRETE TOWARDS THE ECONOMIC GROWTH AND SUSTAINABLE DEVELOPMENT OF NATIONS

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Abstract: The regeneration of infrastructure is the fourth security (after food, water and energy) required by the developing world including India for the poverty eradication and providing a decent quality of life to its people. Hence, it is the pressing need to build the durable structures which withstand test of time and environment they are designed for in an economic and environment friendly manner without requiring much repairs and maintenances.

World over a lot of resources and in turn national economy is diverted for the repair / rehabilitation / total demolition and building of new structures in place of deteriorated / damaged structures. Also the cement / concrete manufacturing process impacts the environment in adverse manner by depleting resources and consuming energy or creation of waste. A considerable amount of emissions of greenhouse and acidifying gasses from cement manufacturing is contributing towards the global warming too.

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. Present paper discusses the severe damage of hydro structures by soft water attack, its thorough investigation, both in-situ as well as detailed laboratory analysis of seepage water and leachate materials and mechanisms involved in the process of deterioration of concrete and further the remedial measures suggested to the project authorities by the Central soil and Materials Research Station, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. The paper has far reaching impact on developing nations all over globe.

Keywords: Soft water attack on concrete, leaching of lime, aggressivity of water, hydro-environment, concrete corrosion.

1.0 INTRODUCTION

Even with the perfect concrete mix design, it is important that the durability/performance of concrete gets 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 [1]. The penetrability or water permeability of concrete turns out to be

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the only property, which can be directly related to long term durability. A number of case histories are there to show that less permeable concrete when exposed to aggressive environment perform much better than the high strength permeable concrete during the intended service life. 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 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. Leaching involves the complete process of dissolving and transporting the substances out of concrete [2]. Since the calcium salts in concrete are the strength giving components, hence leaching out of calcium salts may affect the strength and durability of concrete. Dams and other concrete hydro-structures in Himalayan region face dual possibility of deterioration from freeze-thaw as well as leaching of lime due to soft water attack along with other reasons which affect the durability of concrete to a great extent. Due to leaching of lime, concrete turns more porous, exposing it further for the ingress of more water, may pave the way for other types of deterioration mechanisms also.

In India, a number of hydro projectslocated in the Himalayan region are facing the problem of leaching of lime to a great extent. The Baglihar Dam in J & K, India isone of them suffering due to the soft water attack and leaching of lime. Just after the commissioning of the dam and the filling of reservoir, seepage of water in the inspection galleries started. During the course of time, materialsof white, yellow, brown and black colour also started coming out from the roofs and walls of the galleries. Present paper discusses about the impact of soft seepage water on the concrete of the Baglihar Dam along with the chemical identification of leachate material with the overall assessment of the health of the dam and also to suggest the ways and means to overcome the problems.

2.0 PROBLEM ENCOUNTERED

Baglihar Dam is a run-of-the-river power project on the Chenab River in the Ramban district of Jammu & Kashmirhaving an installed capacity of 450 MW, was commissioned in year 2009. The Problemstarted 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. 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

3.0 TARGETED AREA OF INVESTIGATION

Since the quality of water affects the durability of concrete, hence, the overall impact of the water on the long term durability aspects of dam has been carried out. Characterization 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:

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

4.0 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 [3]. Wherever needed reference was also drawn from the procedure laid down by the American Public Health Association and Water Pollution Control Federation, USA, [4].

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.

5.0 INVESTIGATIONS

A. Field Investigation

In-situ parameters viz: temperature, conductivity, pH, $CaCO_3$ 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.

The leachate samples were analysed for their chemical composition and mineralogy. For chemical composition wet analysis (WA) was followed while for characterization of mineralogy, XRD technique was followed. X –Ray Diffraction patterns of leachate material were obtained on a powder XRD model GBC Emma with CuKα1 radiation (1.54 A0) having a scanning speed of 40/minute.

6.0 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.

7.0 AGGRESSIVITY 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. 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"[5], "United States Bureau of Reclamation(USBR) Standard for sulphate aggressivity"[6], "French National Standardp18-011, May 1985 for assessing aggressivity due to pH, Ammonium, Magnesium and Sulphate ions[7]and "International Commission on Large Dams, ICOLD Bulletin No. 71: Exposure of Dam Concrete to Special Aggressive Waters –Guidelines [8].

8.0 DISCUSSIONS OF RESULTS

- The pH of all the water samples is alkaline and falls in the range of 7.65 to 9.17. 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, CO_2 concentrations can also influence pH of water bodies.

- 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. [Figure 1]
- 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 aggressiveness of water increases with the increase in negative value of LI. The Langelier Index value of river water can change with the change in water quality of river due to various factors depending on perennial precipitation pattern, flow of water, temperature, change in season etc.
- Out of 7 water samples 4 water samples viz. WS 1, WS 3, WS 4 and WS 5 have –veLangelier Index values [-0.17, -0.28, -0.059 and -0.023 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.
- Water samples WS 2, WS 6 and WS 7 depict the possibility of deposition of lime as the LI values for these samples are positive. These may cause corrosion/ leaching of calcium carbonate from the concrete mass if the exposure of concrete to such waters is prolonged [9-10]. [Figure 2]
- Chemical analysis data of leachate materials is summarized in Table 1. 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.The mineralogy of all the leachate samples indicates the predominance of Calcite mineral. [Figure 3]

SOFT WATER ATTACK AND LEACHING OF CONCRETE

Corrosion of concrete can be caused not only by waters containing aggressive chemical substances but also by entirely pure, salt-free, distilled water.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. When Portland cement-based concrete is in contact with soft water, the $Ca(OH)_2$ in the hardened cement paste is leached out as the water tries to establish an ion balance. Corrosion due to soft water initiates by dissolving and subsequent leaching of free

$Ca(OH)_2$. Leaching is the complete process of dissolving and transporting calcium out of concrete. The aggressiveness of soft water depends on a number of factors such as pH, degree of hardness of water, concentration of free carbon dioxide present in water, temperature, alkalinity etc. The pH of such water can be as low as 3-4 making the water highly aggressive to concrete. Water causes both chemical and physical processes of degradation of concrete.

3.0 MECHANISM OF LEACHING OF CONCRETE

The aggressiveness of soft water is measured by the rate at which $Ca(OH)_2$ is leached away from the cement paste. The aggressiveness is considerably increased if the water contains dissolved carbon dioxide (CO_2). CO_2 dissolves in water to form carbonic acid (H_2CO_3):

$$H_2O + CO_2 \rightarrow H_2CO_3$$

CO_2 first converts the $Ca(OH)_2$ to poorly soluble calcium carbonate (carbonation reaction) and then to soluble calcium bicarbonate which is easily removed by the water. These reactions are represented as below:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (1)$$

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2 \qquad (2)$$

Carbon dioxide exists in water mainly in the dissolved form with a small proportion combining to form carbonic acid resulting in the lowering of pH of water.

4.0 IMPACT OF LEACHING ON CONCRETE

Leaching process starts when water dissolves CH inside of concrete. In such process dissolution and diffusion both actions act simultaneously where:

- Water molecules diffuse to the reaction place in the pore walls,
- Water molecules dissolve solid compounds; and
- The dissolved compounds are transported away from the reaction site.

The presence of free CO_2 increases the solubility of $Ca(OH)_2$ and Ca-hydrates, which in turn increases the formation of calcium carbonate. In order to maintain chemical equilibrium, fresh hydrolysis of calcium silicates takes place and lime is released. pH of the concrete may drop from 12-13 to 8-9 due to excessive dissolution and removal of $Ca(OH)_2$ and the process of corrosion of reinforcement may also start if the favourable conditions are met. Further, since the hydration products of cement are stable at higher pH, decomposition of these salts starts as pH of concrete drops and concrete starts losing its strength.Very porous and pervious concrete may be attacked by other aggressive mechanisms simultaneously with sustained permeation of water across the concrete section.

9.0 CONCLUSION

- A serious concern is 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.
- 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. In 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 situation, long term durability aspects needs serious attention to be addressed on priority. Post construction exposure of these structures to various aggressive conditions such chemical attack by the external agents, physical chemical effects from internal phenomenon and leaching of lime etc. are responsible for deterioration of concrete.
- The case history 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.

9.0 SUGGESTION

- The phenomenon of leaching of lime should critically be evaluated periodically in terms of quality and quantity both for different seasons.
- Immediate protection to structures is required to stop the flow/seepage/ of water and leaching from any part of the concretes.
- To gauge the level of detrimental impact of soft water leaching impact on the health and present condition of the concrete structures, some necessary non-destructive tests (NDT) using PUNDIT, corrosion monitoring Half Cell Surveyor & Rapid Chloride Tests have become essential. [11,12].
- Leaching corrosion of concrete is termed as Diabetes of Concrete by the scholars. As the doctors suggest routine monitoring of blood sugar levels in humans, similar is the case

with concrete. Continuous monitoring of seepage/leachate/reservoir water as per national and international guidelines and codal provisions to evaluate its nature periodically at least twice in a year i.e., for lean season and monsoon season to assess its detrimental impacts and accordingly to get insight from the input analytical data is necessary for taking the pre-emptive measures to protect the structures from further deterioration.

- Since the CO_2 emission from the concrete production is directly proportional to the cement content used in the concrete mix; 900 kg of CO_2 are emitted for the fabrication of every ton of cement, accounting for 88% of the emissions associated with the average concrete mix, hence durability aspect of concrete must be given proper importance at the time of design and construction of the structures so that structures don't require much repairs and maintenances.
- The concrete structures irrespective of small or large involve huge wealth and drain out major national economy in their erection. Therefore, it is imperative to take all necessary measures to produce a durable concrete which should live its designed life without much maintenance and repair for the Economic Growth and Sustainable Development of Nations.

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Conflict of Interest - None.

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TABLE1: SAMPLE DESIGNATION AND SAMPLING LOCATIONS& CHEMICAL COMPOSITION OF LEACHATE MATERIAL

Sl. No	Sample No.	Type of sample	Sampling Location	Sl. No.	Sample No.	Type of sample	Sampling Location	Chemical Analysis of Leachate Material	
								Calcium Carbonate %	Loss on Ignition %
1	WS 1	Water	Transverse gallery Block 9, EL 714 m, LB, D/s face	8	L 1	Leachate	Transverse gallery, Block 9, EL 714 m, near SP-4, White in colour	98	44.89
2	WS 2	Water	Longitudinal Rock Gallery, Block 14, EL 714.5m, RB/ Us	9	L 2	Leachate	Longitudinal gallery, Block 14, EL 714 m, RB, U/s, Black in colour	88	33.95
3	WS 3	Water	Longitudinal Gallery, Block 10, EL 736 m, Us	10	L 3	Leachate	Longitudinal rock gallery, Block 9, EL 714 m, RB, Red in colour	98	46.83
4	WS 4	Water	Reservoir Water	11	L 4	Leachate	Longitudinal gallery 2, Block 11, EL 736 m, U/s	97	39.03
5	WS 5	Water	Longitudinal Gallery, Block 16, EL 766 m, Us RB, near J23 Triaxal Joint meter	12	L 5	Leachate	Transverse gallery, Block 9, EL 736 m, near pump operation room	99	30.83
6	WS 6	Water	Longitudinal Gallery, Block 3, EL 795 m, Us, LB	13	L 6	Leachate	Longitudinal gallery, Block 8, EL 766 m, U/s, White in colour	98	51.80
7	WS 7	Water	Overall seepage water sample, EL 714 m Block 9	14	L 7	Leachate	Longitudinal gallery, Block 12, EL 766 m, U/s, White in colour	96	45.89
				15	L 8	Leachate	Longitudinal gallery, Block 10, EL 795 m, U/s, White in colour	99	35.95
				16	L 9	Leachate	Longitudinal gallery, Block 13, EL 795 m, U/s, White in colour	97	58.60
				17	L 10	Leachate	longitudinal gallery, Block 3/4, EL 714 m, near U/s, orange-red in colour	81	40.03

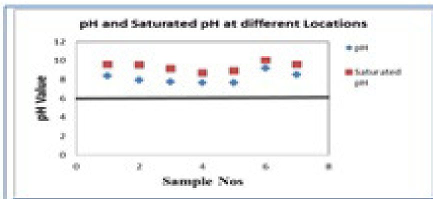

Figure 1: pH and Saturated pH of water samples at different locations in the Foundation Galleries.

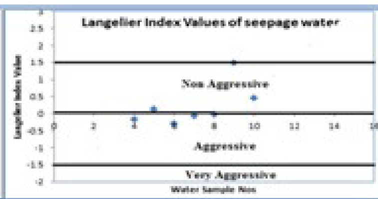

Figure 2: Langelier Index Values of Water Samples at different locations in the Foundation Galleries.

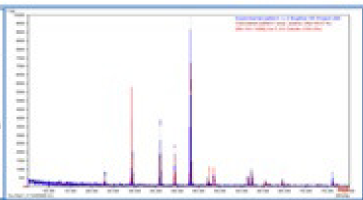

Figure 3: X-Ray Diffractogram of leachate sample showing presence of 100% calcite mineral [sample L-10 (CD 17/137)]

Figures [1-3]: Test Results and interpretation of data of water and leachate samples' analysis, Baglihar HE Project, J&K, India

Plate 1: Photographs of Foundation galleries of Baglihar HEP showing the leaching of lime