

**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH  
TECHNOLOGY****DURABILITY CONSIDERATIONS FOR DAM CONCRETE IN ACIDIC HYDRO  
ENVIRONMENT – A CASE STUDY****Kachhal Prabhakar\*, RP Pathak, N Sivakumar**\* Scientist C Central Soil & Materials Research Station, MoWR, RD &GR,  
Olof Palme Marg, Hauz Khas, New Delhi 110016Scientist C Central Soil & Materials Research Station, MoWR, RD &GR,  
Olof Palme Marg, Hauz Khas, New Delhi 110016Scientist E Central Soil & Materials Research Station, MoWR, RD &GR,  
Olof Palme Marg, Hauz Khas, New Delhi 110016

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**ABSTRACT**

Concrete can be made which will perform satisfactorily when exposed to various atmospheric conditions, to most waters and soils containing chemicals etc. There are, however, certain aggressive conditions under which the useful life of even the best concrete will be short. Understanding these conditions permit measures to be taken to prevent or reduce deterioration. Peculiar problems like deterioration of concrete due to poor water quality, problem of leaching of lime in seepage galleries, high temperature of water springs inside head race tunnels, acidic hydro environment etc. have been encountered during the pre and post construction investigations at various projects. In addition, the concrete deterioration is directly influenced by various geographical, climatic and ecological conditions. In these conditions, the designing and construction pose challenges for making long term durable concrete. Water plays an important role as the chemical reactions between cement and water for setting and hardening of cement. The long term sustainability of these structures is largely dependent on hydro-environment. Most of the regions in Assam State, Coal mines are wide spread. The autonomy gives freedom to the people to mine at their own will. Mining operations has led to extensive environment degradation and imparts acidic character in natural waters flowing around it. The present paper highlights the study of field and laboratory investigations of river Kopili and its tributaries and also discusses remedial measures for dam concrete for upcoming hydro power project in North East region of India.

**KEYWORDS:** Soft water attack on concrete, Coal, leaching, aggressivity of water, Acidic hydro-environment**INTRODUCTION**

Even with the perfect concrete mix design, it is important that the durability/performance of concrete get adversely affected under certain aggressive site conditions especially acidic hydro environment. 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. A number of case histories are there to show that nearly 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 pre-construction stage water quality investigations for Lower Kopili HE Project, Assam, which faces acidic hydro environment. The water quality of river Kopili evaluated in pre-monsoon, monsoon & post-monsoon seasons to explore its acidic character and finally suggested concrete mix design which can withstand the acidic hydro environment.

[Prabhakar\* *et al.*, 6(4): April, 2017]  
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**THE PROJECT AT A GLANCE**

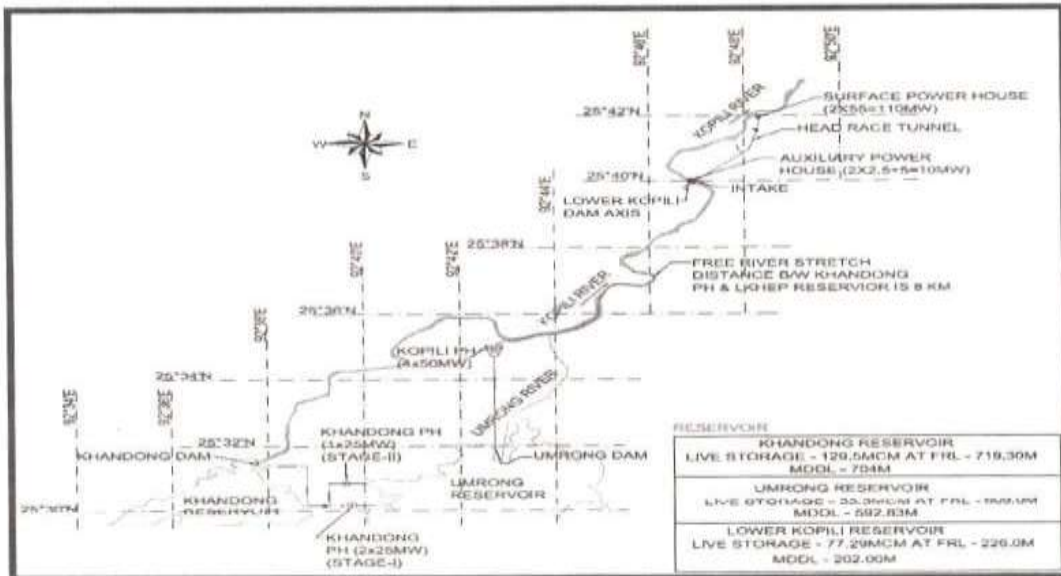
The proposed Lower Kopili HEP is coming up in Boro Longku village in Dima Hasao district. The project is situated on river Kopili which is a south bank tributary of Brahmaputra which originates in the Borail Range Mountains in Meghalaya at an altitude of about 1600 m and has a total length of 290 km up to its confluence with Brahmaputra. Its basin is bound by the Jaintia Hills in the west and the South Cachar and Mikir Hills in the east. Kharkor, Myntriang, Dinar, Longsom, Amring, Umrong, Longku and Langkri are its major tributaries in its upper reaches. After entering Assam the Kopili separates the Karbi Anglong district from the Dima Hasao North Cachar Hills district up to its confluence with Diyung River on its right at 135 km. The total catchment of Kopili River is about 16,421km<sup>2</sup>.

The project is developed by Assam Power Generation Corporation Limited (APGCL). The Lower Kopili dam will be a concrete gravity dam with 70.13 m high dam wall. This project will also have two power houses and the first power house, or the main power house will have an installed capacity of 110 MW (2X55MW). An auxiliary Power House with an installed capacity of 10 MW (2x2.5 MW+1x5 MW) has been planned at the toe of the dam for utilizing the mandatory releases for ecological purposes, making the total installed capacity 120 MW. The Head Race Tunnel (HRT) of the project will be 7.25 m in diameter and 3.6 km long. The free flowing river stretch between Full Reservoir Level (FRL) of Lower Kopili HEP and Tail Water Level (TWL) of upstream Kopili HEP is about 6 km.<sup>[1]</sup>

**SCOPE OF WORK**

The thrust area of in situ & laboratory water quality studies of river Kopili & its tributaries are:

- The work of assessing the water quality to ascertain its long term effect on durability of dam concrete structures.
- To investigate acidity problem of river Kopili at Dam axis, powerhouse site and adjoining Nallahs & possible remedial measures thereof.



*Sketch : 1 Lower Kopili HE Project Location map Curtesy : SANDRP*

**SITE INVESTIGATION PROGRAMME**

CSMRS team visited the LKHEP project site in February 2015, June 2016 & October 2016 & recoded water quality data for Pre-monsoon, monsoon & post-monsoon seasons respectively. Important water sampling locations covered are represented in Table 1.

*Table 1 : Location of Water Sampling Points*

Sample Nos.	Water Samples Locations
1.	Dam Axis , L/B

2.	2.5 Km U/S of Dam Axis, L/B
3.	Langsomapi Nallah, 3.5 Km U/S, L/B
4.	River water after confluence of Langsomapi Nallah, L/B
5.	Dangikpi Nallah, 3 Km U/S, L/B
6.	Longku Nallah, 500m U/S of Dam Axis, R/B
7.	River water near Powerhouse
8.	Kala Nallah, 1 Km D/S of Powerhouse
9.	Dam Axis, R/B
10.	Soho Nallah, 1 Km U/S of Dam Axis, L/B

Water samples were analyzed as per analytical procedure laid down in IS 3025-1986 "Methods of Sampling and Test (Physical and Chemical) for Water used in the Industry". Wherever necessary, reference was also made to the procedure laid down in "Standard Methods for the Examination of Water and Waste Water" published by American Public Health Association and Water Pollution Control Federation, USA, 1985. [2][3]

## ANALYSIS OF RESULTS

### In situ data (Temperature, pH & Conductivity)

#### Dam site river locations (Sample No. 1, 2, 4, 7 and 9)

Out of three season's pH observations, the pH values of river locations are noticed in highly acidic range in pre-monsoon (February 2015); marginally increases in monsoon (June 2016) in the range of 6.68 to 7.85. While in post monsoon season (October 2016), pH values become again slightly acidic in the range of 5.49 to 6.15. (FIG. 1)

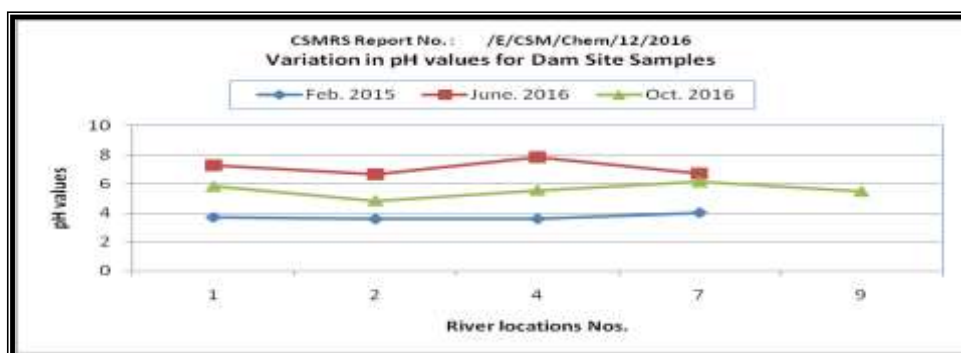


Fig 1 : Variation of pH values for river water locations

The conductivity values of post monsoon season are noticed in the range 76.7 to 151.2 micromhos/cm. (FIG. 2). The temperature (°C) values of the collected water samples are above 25°C (about 30°C) in monsoon and post monsoon seasons. While in pre-monsoon season (Feb. 2015), the temperature values are found in the range of (20.3°C - 22.9°C).

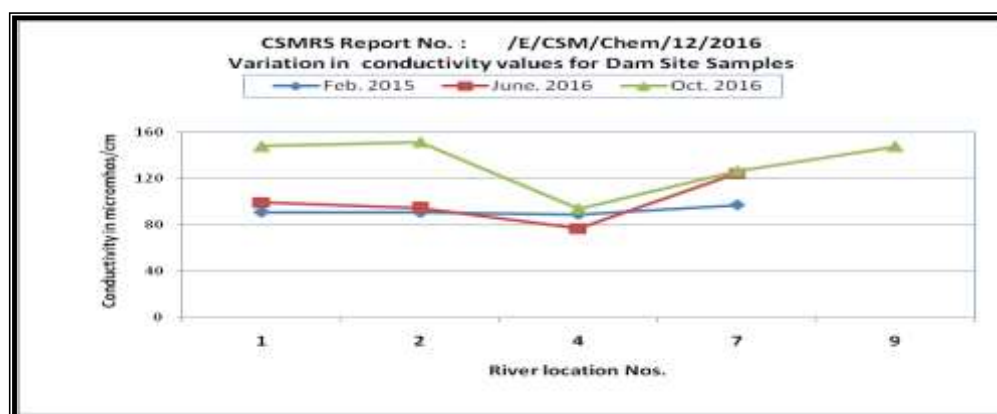


Fig 2 : Variation in conductivity values for river water locations

RIVER LOCATIONS



PHOTO 1 : Kopili river near Power house site



PHOTO 3 : Dam axis, R/B



PHOTO 2 : Dam axis, 2.5 km U/S, L/B



PHOTO 4 : River after confluence of Langsomapi Nallah, L/B

Nallah water samples (Sample Nos. 3,5,6,8 and 10)

The pH values of the collected water samples are found to be in the range 5.76 – 8.02. Pre-monsoon season (Feb. 2015) values are the lowest out of three seasons in the range of (5.76 to 6.21). (Fig. 3).

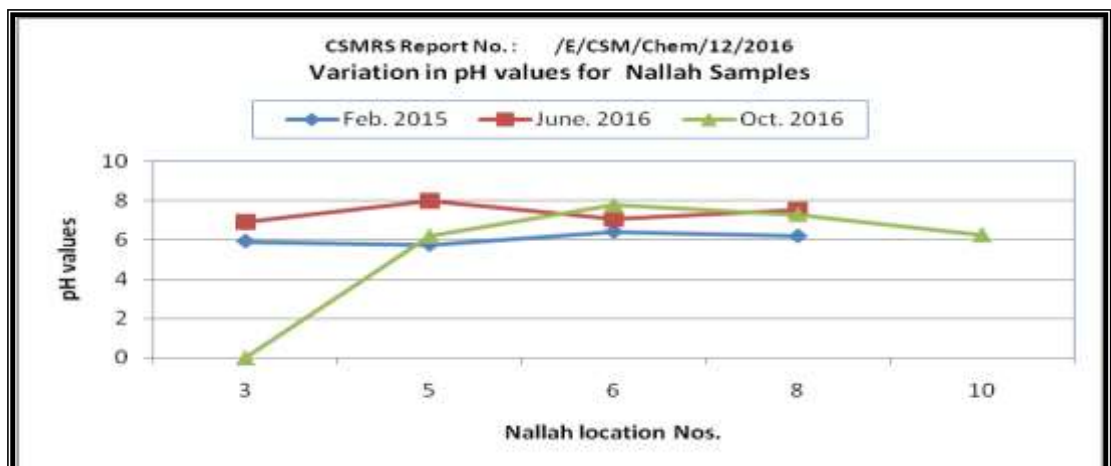


Fig 3 : Variation in pH values for Nallah water locations

The conductivity values of the collected water samples are found to be in the range 36.9 – 283  $\mu$ mhos/cm. Longku Nallah has observed conductivity slightly higher in the range (119.2 to 283)  $\mu$ mhos/cm. (Fig 4).

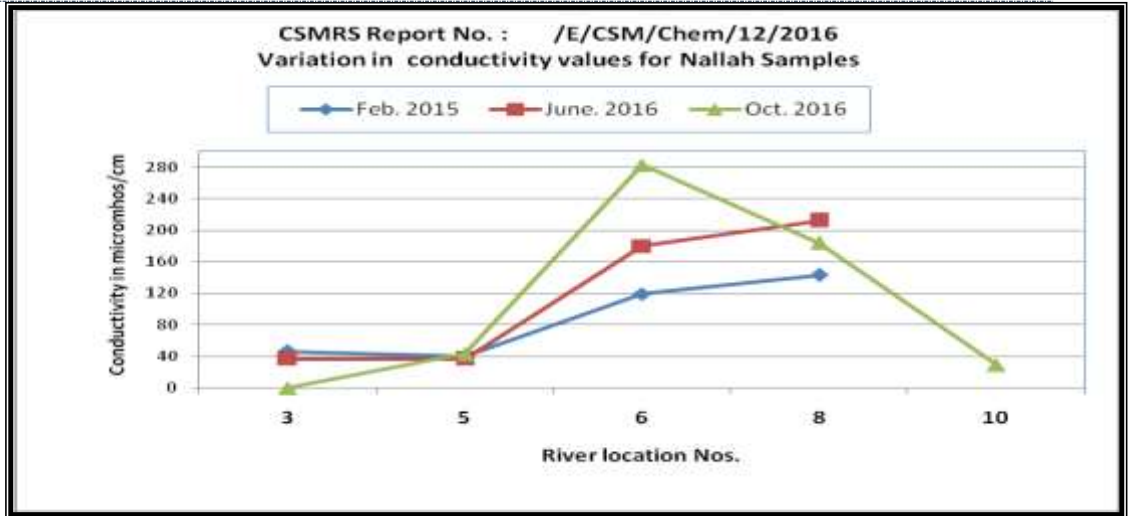


Fig 4 : Variation in conductivity in Nallah water locations

- The temperature (°C) values of the collected water samples are higher in post-monsoon observation (Oct. 2016) compared to other seasons. (around 30°C).

**NALLAH LOCATIONS**



PHOTO 5 : Dangikpi Nallah, 3 Km U/S L/B



PHOTO 7 : Kala Nallah, 1 km D/S, powerhouse, R/B



PHOTO 6 : Longku Nallah, 500m U/S Dam axis R/B



PHOTO 8 : Impact of acidic water on boulders

### Laboratory investigations

The water samples were tested for major cations and anions which are present in lower magnitude throughout the period of observations.

### SOFT WATER ATTACK

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. 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, acidic hydro environment, carbonation, hardness of water, amount of carbonic acid which is free to attack the concrete etc. may influence the leaching of lime from concrete. [4][6]

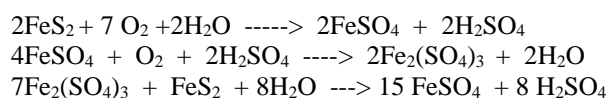
### Langelier Index (LI) for Soft Water Attack

Aggressiveness of pure water is dependent on the pH value, the degree of hardness and an amount of alkalinity & temperature. Due to soft water attack, the free lime in the set cement mortar/concrete paste is leached out. To maintain the chemical balance, fresh hydrolysis of calcium silicates occur and lime is released. An index to assess soft water attack has been developed by ICOLD Bulletin No. 71, 1989 as Langelier Index (LI). Negative values of LI indicate that the water is aggressive. The LI values more negative than -1.5 indicates the water is very aggressive and concrete structure can be corroded. LI values calculated during pre-monsoon study are highly negative and hence the water quality for that period is extremely aggressive (A4 Category). [7]

### ACIDIC NATURE OF THE RIVER

Majority of Kopili river and Nallah locations recorded low pH values during pre-monsoon and post monsoon seasons. The inflow of water in the river is predominantly comprised of rain water. During the field survey, it was observed that unscientific way coal mining activity might be undertaken in the catchment area probably using Rat Hole Technology. In this method, after excavation of coal, the holes and pits are generally left open and unattended. During monsoon, these get filled with rain water and the acidic water finds its way into the river. The interaction of water with coal mine lowers the pH of the water, when the river water becomes stagnant. CSMRS has performed the study to observe the pH variation of water after interacting coal with water in the laboratory. The study revealed that the reduction in pH of water is a function of time of interaction. Higher the contact time, lesser the resultant pH of the water. The chemical reactions are explained below:

The coal contains iron pyrite material (iron sulphide) which is ultimately oxidized with the atmospheric oxygen and produces sulphate in the presence of moisture. The sulphates further use oxygen and water to form sulphuric acid which tends to leach into the surface and sub-surface flow. This material mixes with river making the hydro-environment acidic. The impact of this phenomenon, however, reduced in monsoon season due to the flow conditions of incoming water.



During non-monsoon periods, stagnant water finds significant time to react with the pyrite prone material and tends to show much lower pH value. While in the case of running water, for want of time of contact, show much improvised pH values i.e. neutral to slightly alkaline range. Monsoon observation conforms this phenomenon wherein the pH values of most of the locations are near or above 7 (Fig. 1 & 3). Other contributory factor is related to non-availability of fresh water into the river in pre-monsoon and post monsoon seasons. In this condition, the water becomes stagnant and consumes more time with the pyrite-based minerals thereby showing acidic character. [8]

**OBSERVATIONS & RECOMMENDATIONS**

The type of the water under reference is “soft” in nature as the conductivity and anions and cations concentrations recorded lower side throughout the period of observations. However, due to discharge conditions, the pH values improve in river and Nallah locations in monsoon season.

**Environmental Exposure Conditions:** After the evaluation of water quality data for three seasons, the overall water quality of the various sites of the project may be classified as “severe” category as far as its attack on concrete is concerned. <sup>[4]</sup>

**Table 2 : Exposure conditions**

Sl. No.	Environment	Exposure Conditions
i)	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
ii)	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet concrete exposed to condensation and rain ; concrete continuously under water; concrete in contact or buried under non aggressive soil/ground water concrete surfaces sheltered from saturated salt air in coastal area.
iii)	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation. Concrete completely immersed in sea water Concrete exposed to coastal environment
iv)	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions while wet Concrete in contact with or buried under aggressive sub-soil/ground water
v)	Extreme	Surface of members in tidal zone Members in direct contact with liquid/solid aggressive chemicals

**Concrete Mix Design** – Minimum cement content, maximum water-cement ratio and minimum grade of concrete for different exposure conditions with normal weight aggregates of 20 mm nominal maximum size. The following combination for concrete mix design is suggested for concrete work for powerhouse and dam sites. <sup>[4]</sup>

**Applicable Mix design**

	Plain concrete	Reinforced concrete
Minimum cement content, Kg/M <sup>3</sup>	250	320
Maximum free water-cement ratio	0.50	0.45
Minimum grade of concrete	M20	M30

**Concrete cover:** The criteria for application of concrete cover shall conform in accordance with <sup>[4]</sup>

**Table 3 : Application of concrete cover**

Exposure	Nominal Concrete Cover in mm not Less than
Mild	20
Moderate	30
<b>Severe</b>	<b>45</b>
Very severe	50
Extreme	75

**Notes**

- For main reinforcement up to 12 mm diameter bar for mild exposure the nominal cover may be reduced by 5 mm.
- Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by +10 0 mm.
- For exposure condition ‘severe’ and ‘very severe’ reduction of 5 mm may be made, where concrete grade is M 35 and above.

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**CONCLUSIONS**

Water quality is soft in nature and has low pH values in general and its impact on concrete may be termed under “severe” range of aggressiveness for dam site, power house site and HRT region. Application of non-corrosive steels or coatings or chemical inhibitors or cathodic protection is some of the techniques for protecting the reinforcement. Use of blended cements namely Portland Pozzolana Cement (with flyash content of minimum 25%) or Portland Slag Cement (with slag constituent is minimum 50%) or silica-fume OPC concrete is recommended.

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**REFERENCES**

- [1] An article published in September, 2013 on “Lower Kopili HE Project, Assam “by SANDRP
- [2] "Methods of Sampling and Test (Physical and Chemical) for Water used in the Industry- IS 3025, 1986.
- [3] “Standard Methods for the Examination of Water and Waste Water”, published by American Public Health Association and Water Pollution Control Federation, USA, 1985.
- [4] BIS Code, “IS - 456 for sulphate attack and other durability considerations and curing & mixing purposes”, 2000.
- [5] United States Bureau of Reclamation (USBR) Standard for sulphate Aggressivity.
- [6] Classification of Degree of Aggressiveness based on  $\text{SO}_4^-$ ,  $\text{Mg}_2^+$ ,  $\text{NH}_4^+$  and pH, French National Code p8-011, May, 1985
- [7] International Commission on Large Dams, ICOLD Bulletin No. 71 —Exposure of Dam Concrete to Special Aggressive Waters – Guidelines and Recommendations for assessing aggressivity of soft water, 1989
- [8] CSMRS Report on chemical analysis of water samples of Loer Kopili HE Project, Assam, Report No. 26/E/CSM/Chem/12/2016, 2016.