# Effect of Geothermal Water on Strength and Durability of Concrete Structures – A Case Study

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## ABSTRACT

Even with the perfect concrete mix design, it is possible that the durability/performance of concrete get adversely affected under certain hostile environment like lying of fresh concrete in hot water zone. 1500 MW Nathpa Jhakri HE Project is a major hydroelectric power project on river Satluj situated near Rampur Tehsil in Himachal Ptradesh comprises of construction of 60.5m high concrete dam, an underground desilting complex and powerhouse including 27.4Km long Head Race Tunnel. During excavation for HRT at Wadhal adit, hot water springs having a temperature ranging 57- 65º centigrade were observed at several locations inside the Head Race Tunnel. This poses a great challenge in laying fresh concrete mix for lining work and special measures had to be taken in formulating concrete mix design for concrete lining work. CSMRS evaluated the water quality of the hot water at regular intervals. After assessing the quality of the hot water under reference, an attempt was made to classify the aggressiveness of water using JJ Basson and BJ Addis approach which quantify the aggressiveness due to temperature as corrosion indices like Leaching/Spalling/Overall corrosion indices to identify the class of concrete. Finally, remedial measures suggested to the project authorities for minimizing the adverse effects of hot water springs on the concrete lining inside HRT. This paper covers the above aspects in brief.

## INTRODUCTION

Concrete can be made which will perform satisfactory when exposed to various atmospheric conditions like chmical attack; soils containing chemicals and polluted environments. There are some chemical environments in which the useful life of even the best concrete will be reduced. Understanding these environments would help us to prevent or reduce deterioration. While analyzing the above factors, it is seen that combination of higher temperature, and adverse water quality does not find much mention in the literature thus calling for additional care while suggesting remedial measures. The Nathpa Jhakri H.E. Project built across at the Sutlej river generates 1500 MW electricity. It consists of 60.5 m high concrete Dam and a 27.40 Km long Head Race Tunnel (HRT) terminating in a 301m deep surge shaft. The excavation of tunnel was carried out through seven adits viz. Nathpa, Sholding, Nugalsari, Wadhal, Manglasd, Rattanpur and Valve Chambers U/S. During excavation of HRT about 1 km down stream of Wadhal adit, sudden inflow of hot water having temp. 57-65ºC was encountered. CSMRS investigated the problem by collecting hot water samples from the HRT and analysing them at the project site. The present Paper focuses on the method published by JJ Basson and BJ Addis in their approach Paper "A Holistic Approach to Corrosion of Concrete in Aqueous Environments Using Indices of Aggressiveness" published in ACI materials journal, SP 131-2 which addresses the aggressiveness of water by developing a set of indices to quantify its impact to concrete. It also takes care of role of multiple parameters including temperature. Corrosion indices like Leaching Corrosion Index and Spalling Corrosion Index were calculated to classify the aggressivity of water and class of concrete.[2]

Leaching corrosion of a concrete can result either from the direct dissolution of one or more of the components of the concrete into the water or by conversion of any of such components into more soluble forms as a result of interactions with the solutes present in the water. It is manifested by etching, roughening and general loss of material, starting at the exposed surfaces and progressing inwards. (Fig 1 &2).

*Fig 1 : Example of flat piece of concrete having dislodged with corroded rebar underneath, Welland River bridge across Queen Elizabeth Way in Niagara Falls, Ontario.*

*Fig 2 : Example of secondary efflorescence in parking garage exposed to diluted road salt from vehicles entering the garage during winter.*

Spalling corrosion is the term used for the various destructive effects that occur as a result of expansive reactions between one or more of the components of the concrete with solutes present in the water. This progression usually weakens the matrix followed by cracking and eventually spalling. The remedial measures for different classes of aggressivity were suggested accordingly. (Fig 3 &4)

*Fig 3 : Spalling due to rusting rebar.*

*Fig 4 : A diagonal crack from expansion of rusting steel*

**CODES AND PRACTICES**

Codes and Practices for concrete work used in various parts of the world deal with the question of aggressiveness of water to concrete in some detail. There are different codes and practices are available for accessing the effect of water on concrete viz. BIS, USBR, French National Codes etc. These Codes generally take an account of individual ion effect without considering temperature and offer widely divergent permissible limits of ionic concentration. While the approach adopted by JJ Basson & BJ Addis highlights the effect of multiple parameters of water on concrete alongwith temperature.[2] Only relevant portion of the code is reproduced in this paper for want of space.

**ENVIRONMENTAL FACTORS**

1.1 Temperature: Chemical reaction rates are temperature dependent and generally double for every 10 degree rise in Kelvin temperature. Warm waters will therefore have higher corrosion rates than cold waters.
1.2 Dissolved salts: Dissolved salts concentration in terms of ionic spices; corrosion is a function of specific ion concentration.
1.3 Dissolved gases: Dissolved gas viz. carbon dioxide accelerates corrosion by making more soluble calcium bicarbonates from the relatively insoluble carbonates on concrete surface.
1.4 Movement of water: Corrosion rate becomes diffusion dependent and proceed much more slowly under stagnant conditions rather than in turbulent conditions. The motion imparted due to the water constantly replenishes the interface layer of concrete and accelerates the rate of corrosion.
1.5 Ionic species: The rate of corrosion depends on which ionic species are present in the water. Spalling is normally associated with the presence of sulphate ions. The rate of corrosion depends upon which cation is associated with sulphate ion. Ammonium ion enhances corrosion in a faster rate as it exchanges with calcium ions and converted into ammonium hydroxide which volatilizes as ammonia and formation of voids takes place. It also decreases the pH of concrete and corrosion initiates.[7]

## DERIVATION OF CORROWSION INDICES AND CORRECTION FACTORS

The method involves the derivation of a series of numerical sub-indexes related to the aqueous parameters that can be used to calculate a leaching corrosion index (LCI); a spalling corrosion index (SCI) and a overall corrosion index (OCI). These indexes are used to determine an anticorrosive measures needed to protect the concrete. Since the indexes apply at standard normal conditions, it is to be corrected to allow the environmental factor of stagnant or turbulent conditions and temperature correction according to JJ Basson and BJ Addis approach. To distinguish between incorrect and corrected indexes, the later have been prefixed with a letter C e.g. LCI, SCI and OCI become CLCI, CSCI and COCI respectively. Other corrections are temperature and flow conditions to be applied to CLCI and CSCI to finalise the corrected indexes. Aggressiveness of the water is classified based on the values of special parameters (Table 1) as well as on corrected overall corrosion index which is given in Table 2.

***Table 1 : Recommended limits for assessing aggressiveness***

| **Property of water** | **Degree of aggressiveness of water** | | | |
|---|---|---|---|---|
| | **Moderate** | **High** | **Very High** | **Excessive** |
| pH | 8.0 to 6.0 | 6.0 to 5.0 | 5.0 to 4.5 | < 4.5 |
| Delta pH (pH minus calcium carbonate saturated pH) | -0.2 to -0.3 | -0.3 to -0.4 | -0.4 to -0.5 | < -0.5 |
| Calcium ion, mg/lit. | 120 to 80 | 80 to 40 | 40 to 20 | < 20 |
| Total ammonium ion, mg/lit | 30 to 50 | 50 to 80 | 80 to 100 | >100 |
| Magnesium ion, mg/lit | 100 to 500 | 500 to 1000 | 1000 to 1500 | >1500 |

| | | | | |
|---|---|---|---|---|
| Total sulphate ion, mg/lit | 150 to 1000 | 1000 to 2000 | 2000 to 3000 | >3000 |
| Chloride ion, mg/lit | 500 to 1000 | 1000 to 2500 | 2500 to 5000 | >5000 |

*Table 2: Aggressiveness of the water according to COCI*

| **Overall Corrosion Index (OCI) corrected if necessary for environmental conditions** | **Aggressiveness** |
|---|---|
| < 350 | None to mild |
| 350 to 750 | Mild to fair |
| 750 to 1000 | High |
| >1000 | Very high |

Thereafter, based on CLCI and CSCI values, the dominant mode of attack (leaching or spalling) and corresponding class of concrete is determined (Table 3).

*Table 3: Counter measures against leaching corrosion*

| **Leaching Corrosion Index** | **Other applicable factors** | **Recommended Class of Concrete** | **Recommended type of coating (Table 3)** | **Remarks** |
|---|---|---|---|---|
| Below 350 | Spalling-Corrosion index less than 300 | **1** | **None or A** | |
| | | **2** | | |
| 350 to 750 | Spalling-Corrosion index 350 to 750 | **3 or 4** | | |
| 750 to 1000 | Spalling-Corrosion index greater than 500 | **3 or 4** | **B**<br>**C**<br>**D**<br>**E** | Obtain coating manufacturer's advice on best coating type for specific conditions of exposure |
| Above 1000 | | **3 or 4** | **B**<br>**D**<br>**E** | |

*Table 4 : Coating for concrete for aggressive waters*

| Type | Category | Some examples | Minimum coating thickness required | Remarks |
|---|---|---|---|---|
| A | Inorganic | Extra thickness of base concrete as sacrificial allowance. Plater coats | 20 to 50 mm | Use under mild to moderate leaching conditions only |
| B | Preformed polymeric liners | Polyethylene Polyvinyl Chloride Polychloroprene | 0.2 to 1 mm | Available in light, regular and heavy duty gauges |
| C | Emulsion based water bourne organics | Polyacrylics Polyacrylonitriles | $150\mu m$ | Tolerant or wet surfaces |
| D | Solvent based organics | Chlorinated rubbers, Vinyls, Vinylidenes | $150\mu m$ | Highbuild, thixotropic types available |
| E | Catalized organics | Epoxy tars solvent less and water-based epoxies, Polyurethanes | $150\ to\ 300\mu m$ | Accurate mixing and time-scheduling required |

A remedial measure for different classes of concrete is given in Table 5.

*Table 5: Concrete for aggressive waters*

| **Class** | **Cement code*** | **Minimum cement content Kg/M$^{3**}$** | **Maximum water-cement ratio** | **Remarks** |
|---|---|---|---|---|
| 1 | NPC | 340 | 0.55 | Minimum quality recommended for use under fresh water conditions |

| | | | | |
|---|---|---|---|---|
| | 50/50 NPC/SL 70/30 NPC/FA 90/10 NPC/CSF | | | |
| 2 | NPC<br>50/50 NPC/SL<br>70/30 NPC/FA<br>90/10 NPC/CSF | 420 | 0.45 | Minimum quality recommended for use under marine or saline conditions |
| 3 | 50/50 NPC/SL | 420 | 0.45 | Improved protection to steel under marine or saline comditions as a result of chloride-binding ability |
| 4 | 70/30 NPC/SL<br>90/10 NPC/CSF | 420 | 0.45 | Improved denseness and impermeability of concrete as well as improved resistance to leaching attack because of pozzolanic pore-refinement properties |
| 5 | SRPC<br>20/80 NPC/SL | 420 | 0.45 | Moderately resistant to some sulphates |

NPC =Normal Portland Cement (ASTM I); SL =Ground granulated blast furnace slag; FA=Flyash; CSF=Condensed silica fume; SRPC=Sulphate resisting portland cement (ASTM II); ** refers to total of all binders. Note: The cement types grouped together for any class of concrete do not necessarily produce concrete of the same strength.

**Corrosion of steel in concrete**

Under the influence of high pH conditions in pore water of concrete, reinforced concrete is passivated by a thin surface film around steel. Any alteration in this film depassivates the film and reinforcement corrodes. Chloride ion plays an important role in the disruption of the film and consequently, steel becomes vulnerable to corrosion. The degree of aggressiveness of water due to chloride ion attack is given in Table 6.

***Table 6: Degree of chloride ion aggressiveness***

| Sl No | Chloride ion, ppm | Degree of aggressiveness |
|---|---|---|
| 1 | <500 | Mild |
| 2 | 500 to 1000 | Moderate |
| 3 | 1000 to 2500 | High |
| 4 | 2500 to 5000 | Very High |
| 5 | >5000 | Excessive |

**A Case Study - NATHPA JHAKRI POWER CORPORATION LIMITED, JHAKRI, HP**

Nathpa Jhakri Power Corporation Limited consists of 60.5 m high concrete Dam and a 27.3 km long Head Race Tunnel. There are seven adits viz. Nathpa, Sholding, Nugalsari, Wadhal, Manglasd, Rattanpur and Valve Chambers U/S along the HRT were excavated[4]. The hot water was encountered at many places especially between Wadhal and Manglad adits. Even though the water quality analysis was undertaken for entire length of tunnel, the discussion of the results is restricted with only a section of the HRT i.e. 2.8 km stretch from Wadhal adit in upstream phase. During the investigation, it was found that seepage rate of hot water was quite appreciable at RD 18775 where the temperature of the hot water was 65ºC. Seasonal investigation was initiated to get the representative data. In situ tests for pH, conductivity, sulfide, ammonium and total dissolved solids were carried out. Detailed chemical analysis of these collected water samples were also got done at quality control laboratory of the project using advanced equipments of CSMRS. Chloride, calcium, magnesium and sulphate are the predominant parameters were tested each time.

**Chemical analysis data**

The average value of selected important parameters are shown in Table 7 and 8.

***Table 7 : In situ parameters***

| Location RD No. | pH value | $CaCO_3$ saturated pH value | Delta pH | Temper-ature ºC | Ammoni-um as $NH_4^+$, ppm | Sulphide as $S^{--}$, ppm |
|---|---|---|---|---|---|---|
| 16080 | 7.85 | 8.61 | -0.76 | 21.4 | 0.40 | N |
| 16100 | 7.93 | 8.68 | -0.75 | 18 | 0.47 | N |
| 16135 | 7.79 | 8.64 | -0.85 | 23.5 | 0.51 | N |

| | | | | | | |
|---|---|---|---|---|---|---|
| 16170 | 7.95 | 8.68 | -0.73 | 21.5 | 0.59 | N |
| 16180 | 8.11 | 8.72 | -0.61 | 22.3 | 0.47 | N |
| 17542 | 8.07 | 8.46 | -0.39 | 47.3 | 0.64 | N |
| 18775 | 6.80 | 7.08 | -0.28 | 61.4 | 0.82 | N |
| 19110 | 9.10 | 9.49 | -0.39 | 45 | 0.66 | N |
| 19240 | 9.36 | 9.52 | -0.16 | 44.7 | 0.63 | N |
| 19295 | 9.36 | 9.60 | -0.24 | 38 | 0.61 | N |
| 19540 | 9.16 | 9.31 | -0.15 | 48.3 | 0.47 | N |
| 19630 | 9.77 | 9.88 | -0.11 | 46 | 0.63 | N |
| 19747 | 11.89 | 12.01 | -0.12 | 36 | 0.32 | N |
| 19795 | 8.81 | 9.10 | -0.29 | 51.5 | 1.0 | N |

**N: Negligible. Flow conditions at all sites were gentle**

***Table 8 : Laboratory analysis data***

| Location RD No. | Calcium, ppm | Magnesium, ppm | Chloride, ppm | Sulphate, ppm |
|---|---|---|---|---|
| 16080 | 28.8 | 4.8 | 3.4 | 36.67 |
| 16100 | 26.0 | 3.6 | 3.0 | 35.25 |
| 16135 | 29.0 | 4.2 | 3.0 | 36.26 |
| 16170 | 27.0 | 5.9 | 4.5 | 35.01 |
| 16180 | 22.7 | 7.2 | 4.3 | 66.61 |
| 17542 | 32.6 | 11.0 | 7.7 | 77.92 |
| 18775 | 211.7 | 124.3 | 5017.1 | 428.65 |
| 19110 | 2.0 | 1.2 | 9.0 | 37.50 |
| 19240 | 3.3 | 1.1 | 11.0 | 44.55 |
| 19295 | 4.0 | 3.6 | 28.0 | 175.11 |
| 19540 | 10.0 | 3.2 | 74.3 | 111.93 |
| 19630 | 2.0 | 0.0 | 3.0 | 51.50 |
| 19747 | 86.0 | 26.4 | 320.0 | 421.08 |
| 19795 | 37.0 | 2.4 | 640.0 | 161.10 |

**N: Negligible. Flow conditions at all sites were gentle**

**Derived corrosion index values**

Based on the chemical analysis data, corrosion indices were also calculated and shown in Table 8.

***Table 8: Average corrosion indices***

| Location RD No. | Corrected Leaching Corrosion Index (CLCI) | Corrected Spalling Corrosion Index (CSCI) | Chloride Corrosion Sub-index |
|---|---|---|---|
| 16080 | 497.83 | 6.36 | 0.68 |
| 16100 | 415.65 | 5.23 | 0.60 |
| 16135 | 584.07 | 7.25 | 0.60 |
| 16170 | 487.60 | 7.36 | 0.90 |
| 16180 | 459.59 | 10.78 | 0.86 |
| 17542 | 783.09 | 26.68 | 1.54 |
| 18775 | 529.91 | 216.31 | 1003.4 |
| 19110 | 730.88 | 13.93 | 1.8 |
| 19240 | 533.64 | 15.14 | 2.2 |
| 19295 | 502.24 | 38.50 | 5.6 |
| 19540 | 568.73 | 32.36 | 14.86 |
| 19630 | 481.08 | 16.68 | 0.60 |
| 19747 | 116.70 | 87.22 | 64.0 |
| 19795 | 692.89 | 51.30 | 128.0 |

**Interpretation of data**

While calculating the corrosion index, temperature and flow conditions of the seepage water have been taken into account. The flow condition has been taken as stagnant in all cases. It is seen that from table 6 that average leaching corrosion index (CLCI) remains less than 750 in majority of locations. Average corrected spalling corrosion index (CSCI) remains below 350 in all cases. Therefore, leaching corrosion is a possibility and has to be given priority. Concrete is classified as class 3 or 4 for corrected leaching corrosion index. The chloride corrosion sub-index remains below 350 in all the locations except in RD 18775, hence the attack of chloride corrosion to embedded steel is mild in general.

**Recommendations**

Cementitious material

In the beginning, a blend of 30+70 (flyash+OPC) cementitious material content of 420 Kg/M$^3$ was arrived at based on the recommendations of this approach. However, both were modified to keep in the requirement of IS : 456-2000 " Plain and reinforced concrete – Code of practice (third revision)", revised recommendations were:

- 75+25 blend of OPC + flyash **or**
  50/50 blend of OPC + Granulated Blast Furnace Slag
  Conforming to IS :455-1989 **or**
  15+85 blend of silica fume + OPC
- Cement content : 380 Kg/M$^3$
- Maximum water cement ratio : 0.45
- Minimum concrete cover : 50 mm

## CONCLUSION

Predominance of corrected leaching corrosion index indicates the possibility of leaching corrosion. The degree of aggressivity of water on concrete was classified as class 3 or 4 for concrete lining. The approach Paper of JJ Basson and BJ Addis titled "A Holistic approach to the corrosion of concrete in aqueous environments using indices of aggressiveness" was very useful and provides useful guidelines for laying of concrete structures in aggressive environments. Suitable remedial measures in the form of cement type, cementitious content, maximum W/C ratio and concrete cover were suggested and implemented by NJPC project authorities.

## REFERENCES

[1] American Concrete Institute Manual – ACI, 201.2R-77, ***Guide to durable concrete, Concrete International Design and Construction***, 7(9), 26, 1985

[2] Basson JJ and Addis BJ, ***A Holistic approach to the corrosion of concrete in aqueous environments using indices of aggressiveness,*** published in American Concrete Institute Materials Journal, SP 131-2, March-April, 1994

[3] Biczoc I., ***Concrete corrosion, concrete protection***, Published by House of Hungarian Academy of Sciences, Budapest, 1964

[4] Ranjodh Singh ***Use of fly ash in production of concrete for tunnel in Nathpa Jhakri Project- A case study,*** published in the proceedings of National Seminar "Utilization of Flyash in Water Resources Sector, April 11-12, 2001, CSMRS, New Delhi pp 167-172

[5] Malhotra VM and Mehta PK ***Pozollanic abnd cementitious materials, Advances in Concrete Technology,*** Volume 1

[6] Lea FM, ***The chemistry of cement and concrete,*** published by Edward Arnold (Publishers) Limited, UK, 1980

[7] A.K. Dhawan et. Al., ***Remedial measures for construction of a head race tunnel in a hot water zone*** published proceedings of INCONTEST 2003, 10-12 September, 2003, Coimbatore-641006