

Study of Corrosive Soil and Interaction with buried Concrete Structure

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Abstract: -- The various corrosive soil elements immunising into the hardened concrete through pores cause premature deterioration of concrete & steel although it is structurally safe. Soils are made up of a large number of geological matter and chemical compounds. They contain salts, acids, alkalis and organic matter. They can be varying in their sizes, from extreme fineness to extreme coarseness. Their structure determines their permeability to moisture, water, air and other oxidants required to favour corrosion. Thus corrosive condition exists in many soils. In the absence of adequate knowledge about the corrosive environment, the structures may have catastrophic failures. Hence proper Chemical analysis needs to be carried out for determining the various corrosive soil.

Keywords: - Saline soils, corrosive soils, carbonation, Buried structures, Corrosive soil elements.

I. INTRODUCTION

Large scale multi-storeyed building foundations in the vicinity of saline soils and water of high mineral contents, buried structures of prime importance such as hydroelectric power stations, bridges, tunnels, sea harbours, jetties, docking facilities which are intended to serve for centuries necessitates adequate corrosion control measures. The growth of the chemical industries and other allied technologies utilizing manufacturing products, Large scale multi-storeyed building foundations in the vicinity of saline soils and water of high minerals are corrosive to steel and detrimental to concrete. Industrial sewage, effluents from factories, ground water & water leaching manure containing harmful salts like sodium chlorides, magnesium chloride is an important constituent of industrial sewage soil & soil adjacent to sea water. Magnesium sulphate is highly destructive to concrete when concrete is exposed to soil water of high sulphate content. In certain localities, where considerable quantities of soluble salts are contained in ground water and soil, Portland cement concrete, especially thin members or buried metals are subjected to deterioration and corrosion. In certain soils, corrosive action may arise from Industrial wastes that have been dumped on the site. The soluble salts are usually sulphates of calcium, magnesium and sodium. Water containing these salts gets into the concrete and reacts with the set cement or hydraulic lime. The reaction is accompanied by considerable expansion which leads to cracking of the concrete. The amount of soluble sulphates may be considered excessive

from the point of attack on concrete if it is more than 30 parts of SO₃ per 100 000 parts of subsoil water or in case of clays if more than 0.3% of SO₃ by weight of clay in air dry condition. The corrosive soil elements immunizing into the hardened concrete through pores cause premature deterioration of concrete & steel although it is structurally safe. Buried reinforced members in contact with soils saturated or cyclically wetted with salt waters causes harmful effects on concrete slabs in a railroad embankment revetment near a bridge over a drying water stream running through a saline soil area. The Chemical composition of ground waters depends on many factors, among which are rock composition and nature of soils, the chemistry of feed water (atmospheric, river, sea waters), water table and climate of the given area. The corrosive aggressiveness of the soil is affected by the presence of micro organisms. Microbiological factors may also have a marked bearing on the chemistry of the ground waters. The rate of deterioration of concrete depends on:

Soil texture and acidity,

- Amount of sodium or magnesium sulphate present in the soil in dissolved form.
- Amount of sodium chloride (NaCl) in the soil in dissolved form.

Hence, it is observed that many different factors influence the corrosiveness of the soil.

Fundamentals of corrosion of metals in Soils

Presence of chloride, sulphates and carbonates & PH of soil are the important factors present in soil water that causes induced corrosion of steel in concrete. Accelerated or unanticipated corrosion of the reinforcements could cause sudden and catastrophic failure of structures, generally along vertical plane of maximum tensile stresses in the reinforcements. This plane is located at a distance varying from 0 to 0.3H from the face where H is the height of the structure. The failures of this type have been documented in a few instances in the United States, Europe and South Africa. In general, the most corrosive soils contain large concentrations of soluble salts, especially in the form of sulfates, chlorides, and bicarbonates and may be characterized as very acidic (low pH) or highly alkaline (high pH).

Effect of Concentration

The corrosion is also affected by concentration.

In Na₂SO₄ solution, the corrosion of Portland cement concrete is intensified by increase of concentration. Sulphoaluminate corrosion occurs at 1000mg/lit concentration and beyond 1000mg/lit concentration gypsum corrosion occurs. In the MgSO₄ solutions, 3 different processes occur. Sulphate corrosion is observed at 4000mg/lit. concentration, Sulpho-aluminate gypsum corrosion occurs between 4000 to 7500mg/lit concentration, Magnesium corrosion starts beyond 7500mg/lit concentration. The phenomenon of corrosion due to bases (OH⁻ ions) is due to exchange as well as swelling corrosion. Whenever a basic solution of higher concentration is given chance to penetrate the pores of a concrete, the base is carbonated by atmospheric CO₂ and the concrete is destroyed due to the accumulation of carbonates. If a concrete is completely immersed in a highly basic solution, corrosion is due to the dissolution of the silicate and aluminate content of the cement. Deterioration of concrete is due to the extremely high crystallization pressures of the carbonates. Initially, concrete gains considerable strength after immersion. With time, this gain decreases and the concrete is destroyed by the bursting force of crystallization.

Solubility of Hardened Cement in soil water system

Hardened cement concrete is not a homogeneous body either by structure or by properties. The hardened cement concrete when comes in contact with soil water, concentrations of soluble compounds of calcium hydroxide are gradually established. Calcium hydroxide is the most soluble compound and is the chief monitor in the hardened cement-water system.

The level of Ca(OH)₂ in one month old hardened Portland cement is 9-11%; after three months it reaches 15% by weight of cement.

Calcium Bicarbonate

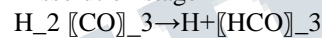
Calcium bicarbonate is corrosive, it destroys the concrete cover when comes in contact with concrete. In natural ground waters, it always contain in the form of carbonic acid.

Carbonic acid H₂CO₃

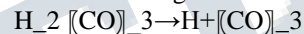
The principle sources of CO₂ in natural ground waters are geochemical processes occurring in the earth's crust. The actual content of carbon-di-oxide in ground water is normally higher, 10-100 mg/l.

Carbonic acid H₂CO₃, bicarbonate ion HCO₃⁻ and carbonate ion CO₃²⁻ exist in solution in certain equilibrium

Dissolution stage 1



Dissolution stage 2



The deterioration of concrete in case of buried structures embraces the exchange reactions between acids and salts of the environment, the hardened cement degrades within the surface layers of concrete.

New formations, which have no binding properties, nor sufficient density to resist the penetration of an aggressive compounds, are liable to get either dissolved or mechanically washed out, exposing the deeper layers of concrete due to the environmental influences. These deep layers deteriorate too and the destruction continues until the mass of concrete fails. However, the rate of deteriorative process varies.

Sulphates

Sulfates are always found in natural ground water and many industrial waste waters. Normally in ground waters it is high. The SO₄²⁻ ion content is found in the majority of rivers and fresh-water exceeding 60-100mg/L. The concrete, interacting with the sulphate, experience deterioration.

The attack on concrete of the SO₄²⁻ ion containing waters results in the formation in concrete of hydrosulfoaluminate and gypsum. Calcium hydrosulfoaluminate is the most harmful to resistance and durability.

Magnesium Salts

The content of the Mg²⁺ ion in natural ground waters varies greatly. In a number of regions, ground water may have up to 2500 mg/L of Mg²⁺. In most cases, however the amounts of Mg²⁺ in surface and ground water exceeds 200-300mg/lit. The concrete, interacting with magnesium undergoes deterioration. The magnesium attack is rapid and considerably destructive to concrete

Different types of corrosive soils

The Department of Agriculture, Govt. of India classify the following types of soils.

Black Cotton Soil:

The Black Cotton Soils cover about 20% of land area in India and are predominantly located in the Deccan trap covering the states of Maharashtra, Gujarat, Madhya Pradesh, Karnataka, Andhra Pradesh, Tamil Nadu, Uttar Pradesh and Rajasthan. The Black Cotton soils consist of clay minerals Montmorillonate, illite and Kaolinite. The soil varies in colour from grey to deep black due to small concentration of titanium oxide. It consist of free carbonates CaCO_3 , Sulphates (CaSO_4), CaO & MgO . Magnesium content is found to be high in many soil.

High pH ranging from 8.5 to 9.0,

Carbon 1%, Iron 10-13%

The reaction of surface soil ranges from slightly acid to alkaline. The Physical properties of Black cotton soil is that, it is a typical Expansive soil which loses its strength in presence of water causing swelling of the soil and in absence of water it shows multiple cracks due to shrinkage. The Montmorillonate mineral is responsible for swell-shrink behavior of the soil.

Alluvial Soil

It occurs in the plains (from Punjab to Assam) and also occur in the valleys of Narmada and Tapti in M.P. & Gujarat, Mahanadi in the MP and Orissa, Godawari in A.P and Cauvery in T.N. They are composed of sediments deposited by rivers and the waves. These soils are saline and alkaline in nature. It consist of salts of calcium, magnesium and sodium.

Red Soil

The term 'red soil' is due to the wide diffusion of iron oxides through the materials of the soil. It covers almost the whole of Tamil Nadu, Karnataka, Andhra Pradesh, South east Maharashtra, Chhatisgarh, parts of Orissa, Jharkhand and Bundelkhand. They are mainly formed due to the decomposition of ancient crystalline rocks like granites and gneisses and from rock types rich in minerals such as iron and magnesium.

It consist of usual soluble salts, free carbonates, silica & Alumina not exceeding 0.05%,

the pH ranges from 6 to 8.0,

the Lime (CaO) ranges from 0.1 to 0.8%,

the Nitrogen at 0.1%,

the Iron & Aluminaranges from 30-40%

High percentage of soluble acid Fe_2O_3 .

Laterite Soil

Found in parts of Western Ghats, Eastern Ghats, Raj Mahal hills, Maharashtra, Karnataka, Kerala, Orissa, West Bengal,

Assam, Tamil Nadu, etc. Found in typical monsoon conditions. under conditions of high temperature and heavy rainfall with alternate wet and dry periods.

The alterations of wet and dry season leads to the leaching away of siliceous matter and lime of the rocks and a soil rich in oxides of iron and aluminium compounds is left behind.

It consist of Oxides of Iron and Aluminium and the pH ranges from 3.5 to 4.0.

Saline and Alkaline Soils

These soils are alkaline in nature and are found in some parts of Bihar, UP, Haryana, Punjab, Rajasthan and Maharashtra.

Some of the salts are transported in solution by the rivers and canals, which percolates in the sub soils of the plains.

The accumulation of salts makes the soil corrosive in nature.

Peaty and Marshy Soils

Originate in the humid regions as a result of accumulation of large amounts of organic matter in the soil. They contain considerable amounts of soluble salts and 10–40%. Peaty soils are found in Kottayam and Alappuzha districts of Kerala.

Literature Review

Saravanan concludes that various metals and other materials corrode when they are on or in the soil, and some metals and materials corrode more rapidly when in contact with specific soils than when in contact with others.

VerBeck concludes that risk of corrosion on concrete pertains to the potential soil-induced chemical reaction between a base (the concrete) and a weak acid (the soil solution). Special cements and methods of manufacturing may be used to reduce the rate of deterioration in soils that have a high risk of corrosion. The rate of deterioration depends on (i) soil texture and acidity, (ii) the amount of sodium or magnesium sulphate present in the soil, singly or in combination, and (iii) the amount of sodium chloride (NaCl) in the soil. The presence of NaCl is one of the factors evaluated not because of its corrosivity of cement but because it is used to identify the presence of seawater. Seawater contains sulphates, which are one of the principal corrosive agents. A soil that has gypsum requires special cement. The calcium ions in gypsum react with the cement and concrete. Soil reaction (pH) correlates poorly with corrosion potential; however, a pH of 4.0 or less almost always indicates a high corrosion potential.

Escalante and Edward reveals that corrosion ratings, which are based on a single soil property or quality, that place soils in relative classes for corrosion potential must be tempered by knowledge of other properties and qualities

that affect corrosion. A study of soil properties in relation to local experiences with corrosion helps soil scientists and engineers to make soil interpretations. Special attention should be given to those soil properties that affect the access of oxygen and moisture to the metal, the electrolyte, the chemical reaction in the electrolyte, and the flow of current through the electrolyte. A constant watch should be maintained for the presence of sulphides or of minerals, such as pyrite, that can be weathered readily and thus cause a high degree of corrosion in metals.

V.M. Moskvina Russian Scientist has formulated the deterioration of concrete to assess the kinetics of corrosive process.

He carried out the assessment study of internal diffusion of an corrosive substance or external diffusion of carbon dioxide, crystallization of corrosive components and products of their interaction(CaCO₃)with hardened cement in the voids of concrete

He distinguished three principal forms of deterioration of concrete in the corrosive media.

Deterioration Form I : It Consist of decomposition of concrete due to the action of corrosive liquid which dissolved the ingredients of the hardened concrete.

Deterioration Form II: It embraces exchange reactions i.e. Chemical interaction between the hardened cement constituents and a Corrosive media by diffusion or percolation

Deterioration Form III: It involves Crystallization, accumulation and polymerization of reaction products due to the growth of crystals of calcium hydrosulfoaluminate in the structure in a salty media. Sulphate attack also refers to this form of deterioration.

***The Max.permissible limits of corrosive soils as per
Russian Scientist V.M. Moskvins's***

S.N.	Permissible Limits
Carbonic acid H ₂ CO ₃	<15 – 20 mg/ltr for sandy or gravely soils
pH	6.5 – 8.5 for most natural waters
Bicarbonates & Carbonates	< 44 mg/ltr
Sulphates	60-100mg/ltr for rivers & fresh waters 2500 -2700mg/ltr in sea waters.
Magnesium Salts	200 – 300 mg/ltr

Dilute CO ₂		< 20 mg/ltr			
Chlorides	pH	13.2	12.5	11.6	oxygen
	Cl-mg/L	8900	710	890	Nil
	Solution	NaOH	Ca(OH) ₂	Ca(OH) ₂	Nil

The Case Study carried out in Showaikh, Kuwait on failure of buried structure indicates that the Telecommunication training building constructed in 1972 showed deterioration of concrete and corrosion of steel in foundation at 4.0m below ground level which lead to intensive cracking in 10 years. The chemical analysis of soil samples revealed a very high concentration of 2-5% sulphate content just below ground level.

Lea has shown that the CaSO₄ and Na₂SO₄ solutions are corrosive to Portland cement upto 10% concentration. His findings concludes that higher C₃A content leads to the destruction of concrete in less than 3 years when it comes in contact with 3% Sodium sulphate solution.

Venkatesan has reported some of the common factors influencing the corrosion of buried structures. Soil is typically composed of sand, clay, chalk and humus in different combinations. The resistivity of soil depends on the soil wetness, dispersion of chemicals etc. These are further dependent on the permeability of the soil to air, and water. In general when the electrical resistivity of the soil is less, corrosion is more.

Palaniswamy has reported various types of underground corrosion. The difference in soil conditions may cause potential difference on pipelines resulting in corrosion due to dissimilar soil conditions. Physicochemical corrosion or swelling corrosion is the result of attack by certain salts. Its initial phase is accompanied by a hardening of the concrete, the pores and voids are filled by crystal formations which tend to increase the density of concrete. The crystals formed in the pores tend to grow and expand. The concrete is eventually destroyed by the swelling pressure. Swelling corrosion in concrete occurs due to sulphate ions, hydroxyl ions and due to alkali - aggregate reaction.

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Review of the literature presented above shows that many experimental investigations were carried out in finding the corrosivity of soil-water system. However, there is very limited information on soil-structure interaction of buried structures and many problems still await solutions. Research in this respect is therefore, necessary.

Experimental Investigation carried out in the laboratory:

The experimental studies for determining the Physical and Chemical studies were carried out on soil samples collected from various places stated above.

Laboratory Investigation carried out for Chemical properties :

1. pH Test
2. Chloride
3. Carbonates & Bicarbonates
4. Calcium Carbonate
5. Sulphates Determination
6. Conductivity Test.

The Soil samples were collected from the following different areas for laboratory investigations

1. Soil 1: collected from Coastal area of Sea shore which is highly saline in nature, Mumbai (west)
2. (Soil 2)Outskirts of East Surat,Gujrat
3. (Soil 3)Effluent Treatment Plant, Near Thermal Power Station.
4. (Soil 4)Black Cotton Soil,Nagpur
5. (Soil 5)Near Masara Dam , Ash Pond No.2, Thermal Power Station,Nagpur



The Prototype experimental models of R.C.C. Column shaft buried under different corrosive soil conditions were prepared & condition assessment of concrete and subjected to normal environmental conditions under the corrosive soils. The effect of soil elements on hardened concrete were

studied with Instrumentation and laboratory investigations of drilled hole concrete samples.



The Test Results of Chemical Analysis revealed the following;

S.N.	Chemical properties	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
1.	Chlorides mg/lit	13490	213	710	177.5	177.5
2.	Magnesium, mg Per 100 mg	298.9 3.0 %	106.75 1.0 %	77.83 0.78	12.20 1.22%	10.67 1.06%
3.	Carbonates,mg/l (Soluble Base)	240	180	1020		
4.	Bicarbonate, mg/l (Soluble form)	3359	2684	9699	1464	1708
5.	Sulphates mg/l	785	987	1435	439	326
6.	pH	9.01	8.40	6.29	7.75	6.90
7.	Conductivity mS/cm	33.3	0.53	4.31	0.37	0.22
8.	CaCO ₃	6.65 %	3.75%	23.19	1.79%	8.44%

Electrochemical Tests :

I - Half Cell Potential Measurement Test

Test Instrument : CORROSION ANALYSER

Technical reference : ASTM C – 876 –1999

Measured Potential difference (mV)				
Model No.1	Model No.2	Model No.3	Model No.4	Model No.5
-162 mV	-114 mV	-104 mV	-109 mV	-111 mV
-224 mV	-176 mV	-118 mV	-158 mV	-137 mV
-348 mV	-238 mV	-180 mV	-164 mV	-153 mV
-410 mV	-300 mV	-242 mV	-226 mV	-171 mV
-472 mV	-362 mV	-304 mV	-291 mV	-233 mV
-534 mV	-424 mV	-311 mV	-359 mV	-295 mV
-658 mV	347 mV	-321 mV	-366 mV	-301 mV

S.N.	Measured Potential Difference	Probability of corrosion
1.	More negative than (-) 350 mv	High probability of active corrosion
2.	Between (-) 200 mV to (-) 350mV	Uncertainty of Corrosion
3.	More positive than (-) 200 mV	High probability of No Corrosion

II- Resistivity Measurement Test

Test Instrument : RESISTIVITY METER

Technical reference : ASTM C 1202

Resistivity ρ, K Ω cm				
Model No.1	Model No.2	Model No.3	Model No.4	Model No.5
11.65	12.18	12.89	12.74	12.83
11.63	12.05	12.63	12.70	12.79
11.52	11.89	12.02	12.11	12.54
11.43	11.71	11.93	12.01	12.34
11.32	11.65	11.81	11.97	12.14
11.28	11.54	11.74	11.91	11.97
11.22	11.41	11.63	11.84	11.86
11.18	11.38	11.59	11.76	11.81
11.00	10.93	10.98	11.43	11.75
8.9	9.3	10.1	10.56	10.99
3.2	6.8	7.5	6.9	8.6
2.8	4.8	4.7	5.3	7.9

Threshold limit :

S.N.	Resistivity KΩ cm	Probability of corrosion w.r.t resistivity of concrete
1.	$\rho \geq 12$	Corrosion is improbable
2.	$\rho = 8$ to 12	Corrosion is possible
3.	$\rho < 12$	Corrosion is fairly certain

III - Dr. POURBAIX DIAGRAM FOR IRON FROM POURBAIX ATLAS, pH AND POTENTIAL

Test Instrument : Digital pH Meter

Technical reference : Dr. M. Pourbaix Diagram, ASTM 222

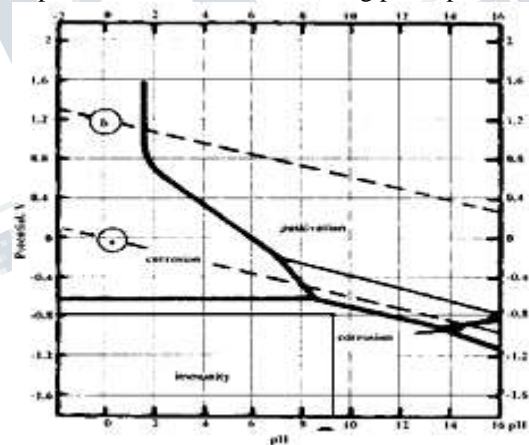
pH and Potential					
pH	Potential	pH	Potential	pH	Potential
12.86	-290	12.43	-284	12.76	-285
12.31	-285	11.58	-258	12.06	-280
12.04	-279	11.29	-247	11.77	-265
11.57	-258	10.91	-245	11.59	-261
10.74	-235	10.70	-232	10.98	-249

pH	Potential	pH	Potential
Model No.4		Model No.5	
12.55	-246	12.15	-247
11.12	-237	11.32	-239
10.94	-226	11.18	-236
10.63	-215	10.97	-226
10.29	-205	10.84	-240

Dr. M. Pourbaix Diagram describe three regions of corrosion:

1. Regions of corrosion.
2. Passivity.
3. Immunity.

The results of “pH” and “potential” of concrete were checked at certain durations and the results were compared with Dr. M. Pourbaix Diagram from Pourbaix Atlas for all the five models for analysing the stages of corrosion. Dr. M. Pourbaix developed potential of concrete against pH which indicates thermodynamically stable phase between metal & Concrete . These diagrams are based on NERSTH equation. Digital pH meter is used for measuring pH & potential



II. CONCLUSIONS

The Review of the literature and experimental investigations carried out in finding the corrosivity of soil-water system indicate that chemical analyses of soil samples and water as per IS: 1904-1986 should be carried out the aggressive salts present in the corrosive soil. The experimental investigation carried out on different models shows the soil structure interaction is complex phenomena and its interaction with corrosive soils concludes that cossosive soil elements present in the soil ingresses through pores of concrete and initiate destructive process in different ways.

The buried structures have considerable harmful effects when it comes in contact with aggressive salts present in soil through soil – structure interaction.

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