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DETERIORATION OF BORED CAST IN SITU PILES DUE TO AGGRESSIVE WATER

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ABSTRACT

Most of the data available from the cement industry and the literature exhibits performance of concrete cubes cured in normal water. Even the literature related to the durability of concrete deals mostly with concrete cured in normal water (closer to potable water in characteristics). However, the bored-cast-in-situ piles are cured in the ground water. The development of strength of concrete of bored cast-in-situ piles depends upon the quality of ground water.

The effect of sulphates and chloride is well established and most of the codes stipulate permissible limits of pH, sulphates and chlorides contents in the ground water. In the last 20 years, authors have come across a number of situations where inspite of water being certified as satisfactory, from chlorides-sulphate point of view the pile shafts have shown deterioration beyond the conceivable limits.

The authors have been working on the problem to establish the effect of quality of water with reference to Ryzner index and Marble test; a parameter that plays a significant role in deciding the quality of water and Marble test as proposed by DIN. The research work involves curing of cubes of same mix in a chemically analyzed ground water as well as normal water. The properties of the concrete like cube strength, elasticity, permeability and setting time are compared. Three types of cement in three grades of concrete are used. The cubes are tested for cube strength for 1, 7, 14, 28, 45 and 90. The findings of the research programme shall be presented into the paper

INTRODUCTION

All the foundations are always casted below the ground level. There is a possibility of ground water level above the founding level. It means that foundations are cured by the in situ ground water. In case the ground water is aggressive it's presence will be felt on the setting and hardening of concrete. For open foundation like raft foundations which are vibrated and side shutters are installed for a period so as to ensure the initial setting of concrete the matter is not so critical. However no such vibrations to densify the concrete are possible during concreting of cast in situ piles, and hence the piles are never vibrated. Similarly the casings are withdrawn giving hardly 15 minutes for setting of concrete. Even for initial setting ½ hour is required for the OPC cement and more for slag cement. It means that concrete while setting itself comes in contact with ground water and if aggressive water is encountered it may lead to complications.

The testing procedure of water plays a vital role. The engineer or designer can ensure a durable pile shaft if the water testing procedure gives him complete information of water quality. The precautionary measure or change of site can be suggested only if full information is available. At present in general the testing procedure includes tests like pH, chloride, sulphate and organic contents. Such test procedure is good enough for 70 % of the cases. But it has been observed in number of cases that inspite of the quality of water is reported to be non-aggressive as the conventional testing when piles are exposed they are found to be in bad shape. Unfortunately if the piles are not exposed or there is problem below the exposed level the performance of piles becomes doubtful, at best a guesswork. In the last 15 years numbers of such deteriorated piles were observed in and around Mumbai. Some of the typical case histories are narrated below to emphasize the gravity of the problem.

CASE HISTORIES

A) Site was located about 70 km from Mumbai in premises of working petrochemical industry. The existing structures were supported on bored-cast-in situ piles. The proposed expansion comprising of storage tanks pipe racks etc

was proposed. The consulting engineering firm a very well known at that for their professional standing proposed bored-cast in situ piles as foundations system for the expansion scheme. The decision to deploy the bored cast in situ piles was based on water analysis data from the soil investigation work carried out specifically for the expansion scheme. The parameters like pH chloride and sulphate clearly confirmed the non – aggressive nature of the ground water.

About 600 piles were installed. The cement used for the work was OPC. Couple of routine static tests by conventional methods were conducted to confirm the design capacity of piles. The results were satisfactory and hence pile capping was undertaken for the pipe rack supports. The excavated pits for the pile caps were extended up to the cut-off level of piles which was about 60 cm below the ground water level. The number of white floats were observed on surface of the water. The field engineer did not pay serious attention to the particular phenomenon and continued the capping activity being confident about the pile capacity because of satisfactory results of the pile load test. After completing pile capping work of pipe rack supports the pit for the ring beam of storage tank was excavated up to the pile cap bottom level, here not only floats whitish in colour but after dewatering the pit, the pile shafts below the ground water table were exhibiting snow white colour. The eroded shafts were looking like fruit bitten by the bird. Some of the shafts were extremely hot suggesting some chemical action was continuing even after 28 days after casting. The situation was very serious and three samples of pit water were sent to three different testing houses. All of them confirmed that water is non-aggressive. In fact one of them, very leading one added in the report that water is potable.

All sorts of doubts about quality of material and workmanship were expressed. The quality of materials used was confirmed and found to be very satisfactory. To remove or confirm the workmanship doubt fresh piles were casted under the supervision of the consultants. These piles were exposed and observed to be equally bad. The concrete cubes on deshuttering the mould after one day and concrete balls in pan a were kept for curing in the same ground water. The results confirmed that there concrete was not setting fully, the colour of the cubes and balls on the surface was whitish. It meant that the neither the workmanship nor he materials are responsible for the mishap.

Simultaneously the tests, on water sample on water sample were carried out in the petro-chemical laboratory. The procedure of test in this particular laboratory was according to test procedure for flow of fluid though pipes in the chemical industry. Test reports along with the conventional testing included a test called ‘Ryzner Index’ with a comment that water is corrosive as RI is 7.8 and is unsaturated in calcium carbonate ($CaCO_3$). This helped in finding out the cause of damage. The details are discussed later. All the piles were rejected and new foundations system was provided (Dec.1989). (chloride 150 ppm, sulphate 400 ppm, pH 7.8, RI 7.8).

B) A year before the above reported case history, similar phenomenon was observed while constructing a large residential complex at Kalyan near Mumbai. On completion of about 300 piles using OPC the load test on one of pile was conducted the pile could not take even 10 % of designed load. The nature of load settlement curve indicated brittle failure, more like concrete rather than ‘Rock’. To find out the cause, cubes were casted and kept along with the mould in the ground water. Even after 3 days concrete could not set, their was a layer with whitish material on the surface of cubes. It may please be noted that out of the six sides of the cube only one side i.e. top was in contact with water. To verify further concrete balls were made and kept in ground water for curing. The findings were similar to the cubes. At that length of time the cause could not be established. The pre-cast prebored piles were constructed and the problem was sorted out. To verify the performance for precast piles two piles were installed and grouted with 1:2 and 1:3 cement sand grout respectively and then pulled out after seven days. The observation reveled that pile with 1:2 grout was pulled out very easily and the surface of the shaft was absolutely clean without the trace of grout. While pile with 1:3 grout could not be pulled out easily and surface of the pile shaft clearly exhibited the grout contact.

The precast prebored piles with 1:3 cement-sand grout were adopted. On learning the significance of Ryzner index from the earlier case the ground water samples of Kalyan site were analyzed. The findings confirmed that the water has corrosive tendencies as confirmed by Ryzner index (RI = 10) inference table. On probing further it was noted that site is closer to Kalyan Railway platform serving as loading and unloading yard for the raw material as well as finished products of the chemical industries in the proximity of Kalyan. The heavy rains and near by Nalls flowing towards site, from the platform, must have contaminated the ground water (1988). (chloride 250 ppm, sulphate 550 ppm, pH 7.6, RI 7.7)

C) Similar experience was noticed at site in Pune located in the Bund Garden area. The bored-cast-in-situ piles casted using OPC on exposing for pile caps were found to be in a extremely deteriorated condition. Casing of cubes and curing them in the ground water clearly showed non–setting cubes and very white layer on the surface of cubes. The Ryzner Index test was carried out which confirmed the behavior of cubes and piles were exactly similar to the site of petrochemical industry an unexpected phenomenon in a posh area like Bund garden, Pune. On enquiry it was found that few years back a goods train carrying Wagon containing diesel met with an accident spreading the diesel which sipped through the ground water though ‘runoff (1994, August).

D) Similar incidences were taking place all over the world. This is the classical example which came into limelight in 1999 and a news item was published in the well known journal ‘Ground engineering’ under the heading of ‘concrete-eating bugs’. This happened in U.S. east coast. A fifteen year old building supported on precast driven piles made up off sulphate resistance cement was demolished because it was tilted on one side by 200 mm Dr. Emani from forensic Eng.

(U.S.A) analyzed the problem. The piles were eaten by bugs virtually disintegrating the piles not because of sulphate as sulphate levels were moderate. The attack was confined to areas where piles passed through anoxic silts with very high organic content. The detailed analysis revealed that there was a high level of sulphate reducing bacteria's. The free iron levels were very low due to absence of oxygen; Bacteria's were more likely to use iron than sulphate to complete the oxidization of organic matter with low iron levels in silts. The bacteria used the iron in the concrete piles matrix. It is known that increase in sulphate resistance in cement paste is due to the increase the ratio between the iron and aluminates content. If iron content is reduced significantly, the rate of sulphate attack increase dramatically Dr. Emani reported in her observations that a distinct 'Iron Front' i.e. very thin iron rock layer between corroded and sound concrete wherever the piles passed through silt which were contaminated. Dr. Emani further observed that piles passing through a layer contaminated by sewage, diesel fuel spilling similar results are expected.

SATURATION INDICES (RYZNER AND LANGLLER INDEX)

Though the deterioration of piles reported in the case histories is shocking to the foundation engineers the literature on quality of water for drinking purpose, spells in length the chemical phenomenon involved due to unsaturated calcium carbonate in water. Similarly oxygen demand in ground water may be because of bacteria's or because of chemical demand of oxygen by the inorganic matter when dissolved oxygen in water is not depleted is dealt by treatment method of sewage. Both these Characteristics of water play a very significant role in deterioration of piles particularly when concrete is fresh following paragraphs bring out theoretical aspect of both these chemical reaction.

The experimental method of detering the saturation indices in the manual of water testing of American Water Works Association

Corrosion occurs when a galvanic cell is set up between metal surfaces. This often happens in buried-pipe systems that pass through soils of different characteristics.

Whether a water will be scale-forming (encrustive) or corrosive can be predicted with the use of the Langerlier index (LI) and the Ryzner Index (RI).

LI = pH measured – pH sat, RI = 2pH sat – pH measured
Where,
pH measured = actual pH value measured in water.
pH sat = pH of the water equilibrium with the solid $CaCO_3$

The Interpretation of these Indexes is as follows:
For the Langerlier Index:
LI o Water is scale – forming (that is, supersaturated with respect to $CaCO_3$)
LI = O Water is neutral, LI = O Water is corrosive (that is, undersaturated with respect to $CaCO_3$

For the Ryzner Index :

	RI	5.5	Heavy scale with form
5.5	RI	6.2	Scale will form
6.2	RI	6.8	No difficulties
6.8	RI	8.5	Water is corrosive
	RI		Water is very corrosive

The difference between these indexes is that Langerlier derived his index from an analysis of chemical equilibrium, whereas Ryzner correlated the computed values of the index to field observations.

The value of pH sat can be determined by equation.

pH sat = -10 g

$$\frac{K_2\, Yca^{*2}\,[\,Ca^{*2}\,]\;YHCO_3 - [\,HCO_3\text{-}]}{K_{SP}} \qquad (1)$$

Calculating the pH sat value as given above requires knowledge of the activity coefficients for HCO_3 – and $Ca^{*}(rHCO_3 - rCA^{*2})$. In design, these values should be determined accurately. A close approximation of the activity coefficients can be made using the following relationship proposed by Langerlier.

$$(2.4 \times 10^{-5}) \times TDS\ g/m^3 \qquad (2)$$

INDEX PARAMETERS

From the study of the equation for pH sat it can be seen that the value of pH sat is a function of disassociation constant K_2 (as chemical identity) activity coefficient of HCO_3 Ca and Ksp solubility product constant (also as chemical identity)
In dilute solutions the icons that are present behave independently of each other. However, as the concentration of icons in solution increases the activity of the ions deceases because of ion interactions. The ionic strength of solution can be determined by following equation:

$$u = \tfrac{1}{2}\,(Ci \times Zi) \qquad (3)$$

Where,
Ci = Concentration of ionic species i, M
Zi = Charge of ionic species i

For most compounds 'Z' is equal to number of replaceable hydrogen atoms or their equivalent)

When concentrations are above 10^{-4} M, activity coefficients must be considered. The activity of dissolved ions is affected by other ions in solution, and this is accounted for through use of an activity coefficient Yi. In most field calculations Yi can be approximated as 1.0 but when more precision is necessary, the Guntelberg equation as stated earlier can be used to estimate rI.

$$\log Yi = \frac{0.5 (zi)^2 u1/2}{1 + u ½} (u\ 10^{-1}) \quad (4)$$

Where,
Yi = activity coefficient for ionic species i
zi = charge of ionic species i
u = ionic strength of solution

Water data required for working out Langelier and Ryzner Indices is stated below.

TDS (g/m^3) Ca^{*2} (g/m^3 mol/L) HCQ (g/m^3 mol/L) Conductivity us/cm, pH

On availing the data the following steps should be followed while determining the indices.

Procedure

1) From TDS and conductivity work out ionic strength (u)

2) Determine activity coefficients for HCO_2 and Ca using equation (4)

3) Determine pH sat using equation (1) and then work out Langerlier index and Ryzner Index.

4) As per the index group the water for its corrosiveness on the basis of recommendation of Langelier and Ryzner index.

BOD & COD TESTS REFERRED IN SEWAGE ANALYSIS

The term "Biological Oxygen Demand" chemical Oxygen demand of water are used by the professionals associated with waste water treatment management. Both these terms respectively spell out the demand of oxygen by bacteria's and inorganic acids respectively.

The bacteria's consume the dissolved oxygen in water to decompose organic matter which purifies the water. The water when in contact with atmosphere supply of oxygen is available. However when overburdened depth is more water table is quiet below the ground level, the degree of dissolved oxygen is in depleted stage, at times the oxygen may be absent. In such cases construction of bore- cast- in-situ piles shall provide the living bacteria's the oxygen. The BOD test is if carried out shall give us the indication of such oxygen demand suitable precautionary measures can only be taken if the complete information is available.

The high levels of sulfate reducing bacteria's at greater depth below the ground level lead to a complete deterioration of not only fresh concrete but even hardened concrete. The soils particularly silts do have low free iron levels and in the absence of oxygen the bacteria's may use iron than sulfate from concrete to complete the oxidation. The species called "Thiobacillus – Ferrooxidans "which are autotrophic i e their are able to obtain the energy for their growth and proliferation by the oxidation of inorganic compounds in the presence of Oxygen. The use of iron from the concrete pile matrix by bacteria's on account of low iron levels in the surroundings soil matrix may change the ratio between iron and alumina content. Such change in the iron contain creates a favorable environment for sulphate attacks. These features of underground water necessitates through probing of oxygen demand by bacteria's or in organic matter. The bacterial analysis is beyond reach of the common laboratories but C.O. D & B.O.D tests are commonly done which will enable the engineer to decide the need and nature of the precautionary measure to be undertaken

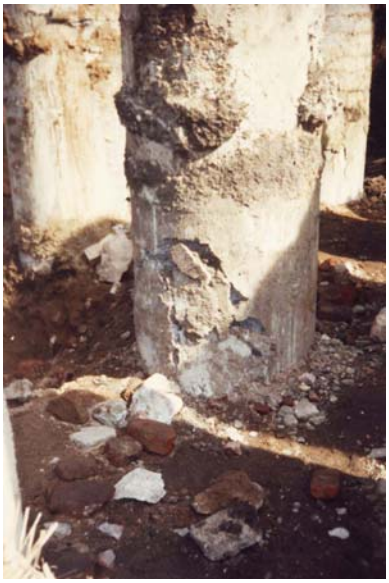
EXPERIMENTAL WORK

In order to study the problem in more depth a series of experiments of curing the cubes in water of known chemical characteristic & comparing the engineering parameters like strength, elasticity, Permeability with the cubes of same grade, and age cured in normal water were carried out in different water samples of cement in three different grades of water cements ratio was used.

Piling on dumping ground at Worli, Mumbai.

Site 2 Bund Garden, Pune
Diesel spillage site

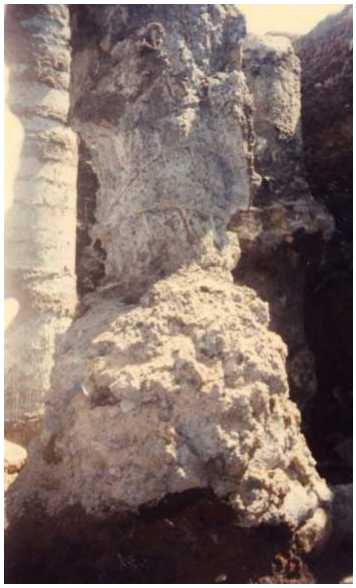
Site 3 Bund Garden, Pune
Diesel spillage site



Site –Worli, Mumbai
Piling on dumping ground

Site 1 Patalganga Petrochemical Industry

Site 1 Patalganga Petrochemical Industry



Site –Worli, Mumbai - Piling on dumping ground

Site 1 Patalganga Petrochemical Ind.

Concrete cubes – Experimental work

Procedure

In order to study quantitavely the effect RI on concrete strength the following experimental procedure was followed.

I. The experimental set up comprises of pouring concrete in the cube molds with the help of funnel to stimulate tremie concrete activity. The empty cubes were kept in the ground water and then concreted so as to ensure similar conditions to bored cast in situ piles.

II. The set of 18 cubes were cased as above and marked with identification mark. On completing 24 hours curing the cube molds were removed and curing in the ground water for scheduled period was continued. The 18 no. of cubes were also cast and cured in the normal water as per the procedure outlined. The cubes were tested for compression and results are presented in the table no. 2

The chemical analysis water samples was carried in 'Enlab Services' laboratories, Mumbai and results of the analysis are presented in the table no.1 and results of the analysis are presented in the table no. 1.

Table 1. The other parameters of the ground water summery of water parameter strength

Sr.	Site	Ryzner Index	Active Oxygen	Organic Matter
1	Grant Road	10.70	---	---
2	Worli Naka	8.50	6.90	840
3	Suncity Powai	6.20	6.50	90
4	Lokhandwala Juhu	5.58	4.50	100
5	Wadala Imax	8.07	5.82	230
6	*Dahisar	*4.02	---	---

Sr.	Site	Conductivity	pH	Chloride	Sulphate
1	Grant Road	'---	9.70	2000	1250
2	Worli Naka	55160	7.30	22400	7250
3	Suncity Powai	826.80	9.60	260	80
4	Lokhandwala, Juhu	286	7.38	380	120
5	Wadala Imax	26240	7.53	11800	4100
6	*Dahisar	---	7.03	108	2500

Table 2. % Loss of compressive strength of cubes cured in ground water compared with normal water strength.

Sr.	Site	Ryzner Index	Cube 1 Day		Cube 3 Day	
			PPC	OPC	PPC	OPC
1	Grant Road M20	10.70	16.27	22.22	6.32	17.67
2	Worli Naka M20	8.50	2.7	3.44	5.19	21.10
3	Suncity Powai M20	6.20	2.85	31.31	20.16	31.85
4	Lokhandwala Juhu – M20	5.58	14.28	36.47	61.58	56.00
5	Wadala Imax M20	8.07	4.42	46.55	7.79	60.55
6	*Dahisar M25	*4.02	5.17	10.00	*8.1	15

Sr.	Site	Ryzner Index	Cube 7 Day		Cube 14 Day	
			PPC	OPC	PPC	OPC
1	Grant Road M20	10.70	16.66	26.92	15.02	26.45
2	Worli Naka M20	8.50	-6.74	26.41	11.42	24.58
3	Suncity Powai M20	6.20	14.58	20.88	6.29	15.21
4	Lokhandwala Juhu – M20	5.58	16.49	35.38	6.34	25.78
5	Wadala Imax M20	8.07	17.97	63.52	13.14	58.65
6	*Dahisar M25	*4.02	*8.57	18.96	--	--

Sr.	Site	Ryzner Index	Cube 28 Day	
			PPC	OPC
1	Grant Road M20	10.70	7.33	16.59
2	Worli Naka M20	8.50	2.35	24.66
3	Suncity Powai M20	6.20	4.5	11.07

4	Lokhandwala Juhu – M20	5.58	0.68	2.76
5	Wadala Imax M20	8.07	7.76	48.45
6	*Dahisar M25	4.02	14.8	28.26

* Slag

OBSERVATIONAL INFERENCES

From the results of the experimental work summarized in the tables the following points are noted.

1) The water with Ryzner Index between 5.5 to 6.2 is not aggressive but the Ryzner Index more than 6.2 and less than 5.5 does indicate aggressive water.

2) From the table it can be easily observed that compressive strength is a function Ryzner Index but a complicated one. The law of proportionality can not established. The Ryzner Index test is a necessary test of assessing the aggressive nature of water but it is not sufficient as other chemical component present in water have a influence.

3) The study on M 25 and M 30 grade concrete is in progress the results of which are not presented in the paper. But the degree of deterioration reflected by loss of strength is much more in M 20 grade. It is an indication that for all under water works the concrete grade should be atleast M 25.

4) From the table it can also be seen that Portland pozzolona cement and slag cement have better resistance than the OPC. As such it is desirable to use PPC / slag cement. For under water concrete work like bored cast in situ piles.

5) The Ryzner Index is represented in pH form and hence it gives approximate information. There is a possibility of error in border line cases.

6) The denser the concrete the depth affected decreases improving the durability of concrete. The water cement ratio variation proved the observation. It is desirable to limit the water cement ratio in bored cast in situ piles to 0.45.

7) The marble test recommended in the DIN 4030 is more convenient test.

8) The other test like BOD shall also be very helpful in estimating the aggressive nature of the water.

9) The recommendation of the DIN 4030 appears to be cover most of the parameters affecting the quality of water for concrete from setting point of view.

10) The relation between fall in strength, depth of penetration of deterioration with reference to grade of concrete type of cement curing period and ground water quality has to be studied without which is a complete testing schedule for water can not be outlined.

11) As a precautionary measure the observation of performance of cubes cured in the ground water for 7 days atleast where bored cast in situ piles are proposed shall help in identifying the durability aspect atleast in ground water table near the ground level.

PRECAUTIONARY MEASURES

For the project site showing aggressive water or soil it is necessary to ensure that fresh concrete of the bored cast situ piles does not come in contact with the aggressive water before complete setting and hardening of concrete. Such separation can be achieved by introducing a Polyethylene liner jacketed around reinforcement cage. The liner shall have the circumference that of pile and the length will be as per requirement. When the concrete column is built inside the cage the hydro static pressure of concrete pushes the liner to take the shape of pile without developing strain in the liner fabric. The introduction of liner reduces appreciably or eliminates the contribution of frictional resistance. Such liner piles when exposed after six months were found to be sound and unaffected.

The liner is cost friendly.

Alternatively precast prebored piles can be resorted. In this situation also the frictional resistance can not be considered.

CONCLUSION

a. The water testing procedure as followed today for the underground construction requires modification.

b. The marble test (DIN 4050) and Ryzner or Langller Index test shall be included in the testing programme.

c. In water testing procedure in a area contaminated in the sewage water the tests like BOD and COD shall be carried out for determination the aggressive nature of water.

d. More research work is required so as to understand the behavour of bore cast in situ piles constructed in underground water.

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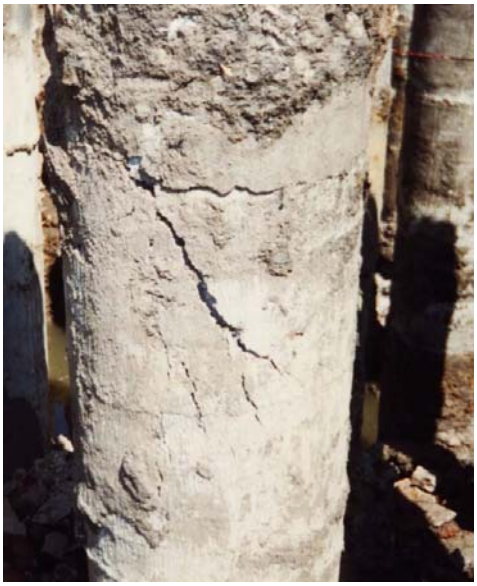
DIN 4030 Part 1 – Assessment of water, soil and gases for their aggressiveness to concrete, Principles and limiting values. (UDC 691.32: 620.193.2/.5:620.193.92)

DIN 4030 Part 2 – Assessment of water, soil and gases for their aggressiveness to concrete, Collection and examination of water and soil samples (UDC 691.32: 620.193.2/.5:620.193.92:620.113)

Site –Worli, Mumbai

Site –Worli, Mumbai



Site –Worli, Mumbai