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Research Paper

Effect of Environment with Heavy Industrial Pollution on the Selection of Concrete Mix for Building Structures

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ABSTRACT

This study proposes durable concrete mix design suitable for use in superstructures of an industrial plant of a cement company located in an area marked by heavy industrial pollution. Concentration of pollutants in the environment was recorded by undertaking ambient air quality monitoring along with an assessment of corrosivity of soil and ground water present at the site. Type of reinforcement, concreting procedures and protection methods were determined for reinforced concrete that was intended to be used in conjunction with steel structures. Experimental results indicated that soil and groundwater constituted no risk for the substructure. However, air was highly polluted and deemed to be severely corrosive due to the presence of chloride and sulfate salts, SO₂ and CO₂ in concentrations recorded several times higher than at a comparable industrial area. A concrete mix design suitable for observed conditions was recommended. Additionally, it was suggested that concrete reinforced with black steel bars should be completely coated while that using FBE coated steel bars should be coated up to a height of 1.5m from the grade level for protection against ingress of salt and water.

1 Introduction

Three main forms of environmental deterioration of reinforced concrete structures are caused by carbonation of concrete due to CO₂ ingress [1-2], thaumasite or ettringite formation caused by sulfidation, and reinforcement corrosion by chloride ions [3-4]. Porosity within concrete appears to be the most important parameter that promotes the detrimental effect of these agents [5]. Carbonation of concrete and reinforcement corrosion, are also promoted with increasing relative humidity beyond 50% and ambient temperature [6].

A statistical study showed that the presence of an admixture and the type of aggregate had the most significant effect on porosity [5]. Cement and its interactions with the concrete constituents also influenced porosity and the carbonation rate. It

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is known that carbonation of concrete containing Portland cement increases with humidity and temperature, and becomes the highest when the ambient Relative Humidity (RH) is between 50 to 70% [6].

The research showed that detrimental effect of environment increased when the reinforced concrete structures were exposed to more than one corrosive agent. It has been shown that the chloride penetration is more pronounced when the carbonation process is combined with the chloride ingress [7]. Further, it was also shown that the ratio of water-soluble chloride to the acid-soluble chloride content was higher for the case of the carbonated concrete.

In the presence of moisture, sodium sulfate and magnesium sulfate migrate into concrete and react with calcium hydroxide to form gypsum [8, 9]. Gypsum reduces the strength and increases the volume of cementitious mixture [10]. Gypsum then reacts with hydrated calcium aluminate, monosulfate or unhydrated tricalcium aluminate to produce secondary ettringite. Ettringite is responsible for expansion, cracking and spalling of concrete. Gypsum produced from classical sulfate attack also contributes to expansion and softening of concrete [11].

Thaumasite sulfate attack (TSA) takes place in the presence of carbonates and/or bicarbonates in the cementitious matrix with accompanying moisture at low temperature. This type of attack transforms concrete into a non-cohesive mass without any binding or load carrying capacity. The degree of TSA depends on the type and concentration of sulfate, temperature and relative humidity, location of structure relative to grade level, type of cement, limestone materials, and type/dosage of supplementary cementitious materials [12].

The effect of chlorides on the TSA of limestone cement concrete containing mineral admixtures at low temperatures was investigated [13]. The results showed that partial replacement of limestone cement with mineral admixtures retards and inhibits concrete's deterioration. In case of limestone cement concrete without mineral admixtures, chlorides mitigate the corrosive effect of sulfates. Regarding concrete containing mineral admixtures, the concomitant presence of chlorides amplifies the detrimental effect of sulfates and leads to augmented damage.

Shi et al. [14] reviewed thaumasite sulfate attack on cement mortar and concrete and pointed out to the fact that the presence of sulfates, carbonates, and moisture are amongst the primary factors that affect the formation of thaumasite.

This paper reports the formulation of a durable concrete mix with long service lifetime and minimal maintenance, which is also suitable for a heavily polluted industrial environment. The reinforced concrete was designed to function as part of a steel superstructure of an industrial plant of a cement company. The objective of this study was to determine the type of reinforcement, concreting procedures and protection methods that results in concrete constitution whose lifespan is comparable to that of concurrent steel superstructures. Since the concrete structure was meant to be erected at heavily polluted area, it was decided to assess the corrosivity of environment including evaluation of air, water and soil. Such analytical information would help to formulate optimum specifications for reinforced concrete including ways to provide latter with long-term protection against corrosive surroundings.

Experimental results indicated that soil and groundwater did not constitute an appreciable risk for the substructure. However, air was found to be laden with high concentrations of chloride and sulfate salts, SO₂ and CO₂. The pollution was estimated to be several times higher than that for a comparable industrial environment. High pollution at the site was attributed to neighboring industry, intense construction activity and heavy equipment operation at the location. Based on environmental conditions, a concrete mix design suitable for high corrosivity measurements was recommended. Moreover, it was suggested that concrete reinforced with black steel bars should be completely coated while that using Fusion Bonded Epoxy (FBE) coated steel bars should be coated up to a height of 1.5m from the grade for protection against ingress of salt and water.

2 Materials and Methods

Detailed geotechnical investigation exploring subsurface strata and groundwater conditions at the factory site was carried out in order to develop engineering recommendations for the design and construction of foundations for concrete superstructures. In summary, this investigation constituted the following major tasks [15-16].

1. Thirty-six boreholes were drilled to explore subsurface strata and groundwater conditions. Samples of subsurface material were obtained and analyzed in the laboratory.

2. Electrical resistivity was measured at 10 separate locations to obtain data to aid the design of grounding systems for steel structures.
3. Three cross-hole seismic tests were performed to evaluate dynamic soil properties.
4. Soil and rock samples recovered from the boreholes were tested in the laboratory to determine engineering and chemical properties.
5. The laboratory and field data were analyzed to develop recommendations for foundation design, construction, and protection.

2.1 Carbonation test

Phenolphthalein is a colorless solution and is used as an indicator for calcium hydroxide. It turns into pink color after reacting with calcium hydroxide $[Ca(OH)_2]$. Therefore, to test for carbonation, phenolphthalein solution was applied on the surface of the concrete cores. The normal concrete where no carbonation took place due to environmental carbon dioxide changed color and became pink. The carbonated locations of the concrete cores, on the other hand, showed no color change. Depths of carbonated zones were then measured at several locations, and average depth of carbonation from the surface of the cores was calculated [15, 17].

Ambient air sampling was carried out at two locations using high volume air sampler in GF/A Whatman® filter media/paper at low rate of 1.1 cu.m/min. Total suspended particulates, sodium chloride and sulfate concentrations were measured over a period of 24 hours. Different absorbent was used for the measurement of sulfur dioxide, hydrogen sulfide and chlorine concentrations with 2 liters per minute (LPM) for 8 hours. Air sample for carbon dioxide (CO_2) measurement was collected in Tedlar® bag [16, 18].

3 Experimental Results

3.1 Depth of Groundwater Table

Groundwater was not encountered in any of the boreholes drilled during this geotechnical investigation. It is believed that the groundwater level at the factory site is below the maximum drilled depth of 20 meter. However, it may vary because of seasonal variation in rainfall and surface evaporation rates.

3.2 Chemical Analysis of Soil and Groundwater

The subsurface stratigraphy at the site consisted of silty sand or sandy silt (SM or ML) from the existing grade to about 0.7 to 3 meters depth. Underneath was limestone rock to the maximum drilled depth of 20 meters. The soil encountered in the boreholes was generally medium dense in condition. The limestone rock encountered in the boreholes was moderately strong and weathered with closely to widely spaced joints.

Table 1 shows water soluble chloride content in the soil at 9 locations of borehole numbers 04, 09, 15, 17, 19, 25, 28, 33, and 35. The same table also summarizes rock type, percentages of CO_3^{2-} and SO_4^{2-} , pH, and electrical resistivity at these locations. The water-soluble chloride content of the soil varies from 0.011% to 0.286% at the depth of 1.07 to 3 meters, although in majority of the boreholes investigated, the water soluble chloride is less than 0.1%. SO_4^{2-} content of soil ranges from 0.013% to 0.908 % at the same depth range as the chloride content. The pH of soil changes from 7.88 to 10.77 at the same depth range. The results indicate that chloride content of the soil is 'negligible' [19], whereas sulfate (SO_4^{2-}) content ranges between 'negligible' to 'severe' according to standards [20-22]. Sulfate content of soil is negligible in most of the boreholes, moderate in two of the boreholes (Nos. 17 and 33), and severe only in one borehole (No. 04), where the soil is sandy silt to a depth of 3 meter (Table 1).

The carbonate (CO_3^{2-}) content in soil, according to the borehole results, varies in the range of 1% to 93% due to limestone rich stratigraphic formation of the site. This is reflected in high pH values indicating non-corrosive characteristic of soil at the installation site.

Table 1 - Chemical Analyses of Soil and Ground Properties at Cement Plant Site.

Bore Hole #	Rock type	CO ₃ , %	Cl, %	SO ₄ , % ACI318-05 Evaluation	pH	Electrical Resistivity, ohm-m
04	0.0–3.0 m Sandy silt 3.0 – 20.0 m Limestone	1	At 1.2 m 0.286	At 1.2 m 0.908 (Severe)	At 1.2 m 7.88	0. –45 m 40.5/41.7– 8.5/12.6
09	0.0–20.0 m Limestone	-	At 1.5 m 0.011	At 1.5 m 0.034 (Negligible)	At 1.5 m 10.6	0.5–45 m 0.1/4.5– 12.9/0.3
15	0.0–20.0 m Limestone	-	At 1.5 m 0.015	At 1.5 m 0.071 (Negligible)	At 1.5 m 9.93	NA
17	1.0–1.35 m Silty gravel with sand 1.35–12.0 m Limestone	93	At 1.0 m 0.113	At 1.0 m 0.108 (Negligible)	At 1.0 m 9.63	NA
19	0.0– 15.0 m Limestone	-	At 3.0 m 0.012	At 3.0 m 0.035 (Negligible)	At 3.0 m 8.44	NA
25	0.0– 15 m Limestone	-	At 1.5 m 0.084	At 1.5 m 0.035 (Negligible)	At 1.5 m 10.17	NA
28	0.0–1.5 m Silty gravel/sand 1.5 – 15.0 m Limestone	83	At 1.1 m 0.015	At 1.1 m 0.013 (Negligible)	At 1.1 m 8.5	NA
33	0.20–1.2 m Silty gravel/sand 1.5 – 15.0 m Limestone	92	At 1.07 m 0.122	At 1.07 m 0.183 (Moderate)	At 1.07 m 8.8	NA
35	0.0–1.5 m Carbonate silty sand with limestone 1.5–15.0 m Limestone	93	At 1.17 m 0.011	At 1.17 m 0.022 (Negligible)	At 1.17 m 8.75	NA

3.3 Electrical Resistivity

Table 2 summarizes resistivity measurements at 10 locations from 0.5 to 45 meters depth along NE-SW and NW-SE directions. The electrical resistivity results vary in the range of 0.0 to 69.10 ohm-m. The majority of resistivity results were in the range of 15 to 45 ohm-m. Low resistivity soils ($< 20 \Omega\text{-m}$) were considered corrosive. In addition, soils with more than 20% moisture are considered aggressive [23]. During rainy seasons, soil resistivity at the site will get lower than $20 \Omega\text{-m}$, and thus the corrosivity is expected to increase. However, the low salt and high carbonate contents are expected to reduce the corrosive activities in soil at the site even during rainy season. As shown in Table 2, the electrical resistivity data generally

indicates moderately corrosive soil at the factory site. However, resistivity values in borehole Nos. 8 and 9 indicate severely corrosive soil and in borehole Nos. 2, 3, 4, and 5, the soil becomes severely corrosive with depth as expected.

Table 2 - In-Situ Electrical Resistivity of Soil at Cement Plant Site.

Bore Hole #	Depth (m)	Resistivity, Ohm-m		Remarks
01	0.5 - 45	26.7 – 51.9	NE-SW	Non-corrosive
		23.7 – 18.9	NW-SE	Moderate
02	10	20.4	NE-SW	Moderate
	20	18.9	NE-SW	Moderate
	0.5 – 45	5.6 – 0.0	NE-SW	Severely corrosive
	10	18.9	NW-SE	Moderate
	20	62.8	NW-SE	Non –Corrosive
03	0.5 - 45	12.9 – 15.1	NW-SE	Corrosive
		69.1 – 0.0	NE-SW	Non-corrosive to
04	0.5 - 45	61.6 – 9.4	NW-SE	Severely corrosive
		40.5 – 8.5	NE-SW	Non-corrosive to
05	0.5 - 45	41.7 – 12.6	NW-SE	Severely corrosive
		45.3 – 19.8	NE-SW	Non-corrosive to
06	0.5 - 45	43.7 – 21.4	NW-SE	Moderate
		26.1 – 11.3	NE-SW	Non-corrosive to
07	0.5 - 45	22.1 – 14.5	NW-SE	Corrosive
		20.3 – 0.0	NE-SW	Non-corrosive to
08	0.5 - 45	22.1 – 21.7	NW-SE	Severely corrosive
		10.4 – 0.0	NE-SW	Severely corrosive
09	0.5 - 45	10.7 – 0.0	NW-SE	Severely corrosive
		4.5 – 0.3	NE-SW	Severely corrosive
10	0.5 - 45	0.1 – 12.9	NW-SE	Severely corrosive
		14.4 – 27.6	NE-SW	Corrosive to
		19.2 – 25.0	NW-SE	Non-corrosive

3.4 Carbonation Test

Three core specimens for carbonation test were obtained from outside surface of 3 old structures and another batch of 3 core specimens was taken from the inside surface of 3 old structures at factory test site as listed in Table 3.

As shown in Table 3, carbonation of concrete in two structures is zero even though the construction has existed for 40 years. Carbonation in electrical sub-station is significant at the inside surface of the structure i.e., 7.5 mm average. These results indicate that the electrical sub-station is the main source of CO₂ generation in the environment. If this power station remains operational in the years to come, then precautions should be taken to control the harmful emission from this plant. The core specimen #3 (Table 3), taken from the outside surface of Raw Meal Silo-II, has 3.125 mm carbonation, which is very low when the age of the structure is taken into consideration. Based on the carbonation results of old concrete structures, it can be concluded that carbonation is not a serious problem for concrete structures at this site.

Table 3 - Carbonation Test Results of Concrete Core Specimens of Cement Plant Structures.

Sr. #	Batch No.	Coring Specimen Detail	Age of Structure (Years)	Carbonation Depth (mm)	Average Carbonation Depth (mm)
1	1 (Outside Surface)	Existing Silo #1	40	0	0
2	1 (Outside Surface)	Raw Meal Silo-I	40	0	0
3	1 (Outside Surface)	Raw Meal Silo-II	40	4, 6, 2, 2, 5, 4, 2, 0	3.15
4	2 (Inside Surface)	Existing Silo #1, Line 5, Kiln-II	40	0	0
5	2 (Inside Surface)	Compound system Line-6, Fan	20	0	0
6	2 (Inside Surface)	Electrical Sub-Station	40	8, 7, 7, 8, 7, 8	7.5

3.5 Environmental Climate Data (T, RH, Rainfall, SO₂, CO₂, and NaCl; Pollution in air)

Ambient air quality monitoring was conducted to assess the existing status of pollutant concentrations during diverse operation conditions such as construction, digging, excavation, etc., and to ascertain adverse impacts during and after construction of the plant and surrounding environment. Table 4 shows the results of air quality analysis at two different locations (East and West zones) at the plant site.

3.6 Atmospheric Pollution Tests Results

As shown in Table 4, air at the work site was extremely polluted. This could partially be attributed to the activity of earth moving heavy equipment at a large scale in the area. To appreciate the severity of air pollution at the test site, the atmospheric analysis results were compared with data from an industrial and coastal area (Jubail, Saudi Arabia) and with a typical urban area (Riyadh) pollution data (Table 5).

Table 4 - Monitoring of Ambient Air Quality at Yamama Cement Plant Site.

Sr. #	Parameters	Unit	Location 1 (West Zone)	Location 2 (East Zone)
1	Total suspended particulate matter (TSP)	g/m ³	473.48	227.27
2	Suspended particulate matter (as NaCl)	g/m ³	14.68	3.35
3	Sulfate (SO ₄)	g/m ³	46.48	8.65
4	Sulfur Dioxide (SO ₂)	ppm	318	568
5	Hydrogen Sulfide (H ₂ S)	ppm	0.01 (LT)	0.01 (LT)
6	Chlorine (Cl ₂)	ppm	0.1 (LT)	0.1 (LT)
7	Carbon Dioxide (CO ₂)	ppm	1702	29748

Table 5 - Comparison of Atmospheric Pollution at three different areas.

City/Area	TSP (µg/m ³)	Chloride-NaCl (µg/m ³)	Sulfate-SO ₄ ²⁻ (µg/m ³)	SO ₂ (ppm)
Riyadh, Cement Factory Site	227.27-473.48	3.35-14.68	8.65-46.48	318-568
Jubail (Marine & Industrial)	30.91-1126.13	0.1-8.94	8.42-49.65	0.029
Riyadh, Urban Area	20-224	1-3	14	0.012

Conversion Factor for SO₂ gas: 1 ppb = 2.62 µg/m³, ppb = parts per billion

3.6.1 Total Suspended Particulate Matter (TSP)

Total suspended particulate (TSP) matter varied between 227.27 and 473.48 $\mu\text{g}/\text{m}^3$ in the site area (Table 4). This indicates presence of high air pollution at the test site. Measurements at another industrial and coastal area (Jubail) show TSP measurements between 70 to 224 $\mu\text{g}/\text{m}^3$, which is significantly lower than the measurements obtained from the site studied [16].

3.6.2 Suspended Particulate Matter as NaCl

Suspended NaCl in the atmosphere varied between 3.35 and 14.68 $\mu\text{g}/\text{m}^3$, which, again is higher than that (1-3 $\mu\text{g}/\text{m}^3$) measured at the other industrial coastal site (Jubail) used for comparison. The test site being an inland location, NaCl concentration is considered very high.

3.6.3 Sulfate (SO_4^{2-})

Sulfate concentration varied from 8.65 to 46.48 $\mu\text{g}/\text{m}^3$ at the plant test site as compared to the values of 8.42 to 49.65 $\mu\text{g}/\text{m}^3$ for the coastal site in Jubail, and 14 $\mu\text{g}/\text{m}^3$ for urban area in Riyadh, used for comparison purposes.

3.6.4 Sulfur Dioxide (SO_2)

Sulfur dioxide concentration varied from 318 to 568 ppm at the test site [16], which is very high compared to normal allowable air pollution data, where sulfur dioxide maximum concentration limit is about 0.28 ppm (730 $\mu\text{g}/\text{m}^3$) [24]. For Riyadh (KSU) urban area, the SO_2 value was 0.012 ppm [25], while it was 0.029 ppm in Jubail industrial area [24]. The high concentration of sulfur dioxide (SO_2) gas at project site was encountered due to excessive emission from heavy earth moving equipment and other machinery present owing to enormous construction activities being underway during the testing and evaluation period.

3.6.5 Hydrogen Sulfide (H_2S) and Chlorine (Cl_2)

Hydrogen sulfide and chlorine concentrations at the test site were low. They were in the order of 0.01 ppm.

3.6.6 Carbon Dioxide (CO_2)

Carbon dioxide concentration varied from 1,702 to 29,748 ppm (Table 4) at the test site, which is high compared to air pollution data in an urban area where carbon dioxide typically varies between 300 to 1000 ppm [18]. The high ambient pollution at the test site may be attributed to the construction activity that took place there during air quality monitoring.

3.7 Other Atmospheric Parameters

Relative humidity, rainfall, and temperature fluctuation are the most important parameters that have significant effect on concrete durability during service lifetime.

3.7.1 Relative Humidity (RH)

Relative Humidity (RH) increases corrosion of metals and carbonation of concrete when it is above 60 % [6]. The relative humidity at the test site reached 60% and above during six months of the year, namely January, February, March, April, November and December. Average RH values recorded for the previous 20 years also followed similar trend. During the months from November to April, corrosion of metallic structures and carbonation reactions in concrete are expected to increase if prior precautions are not taken.

3.7.2 Rainfall

Data for the last 20 years [16] show that the average rainfall was high from December to May. The rainfall varied between 4.5 to 22.5 mm per month during this period. During the high rainfall seasons, which coincide with high humidity

months, precautionary measures are necessary to reduce damage due to the potential of flash floods in the area. Floods will increase wetting of the structures at grade level mostly, and increase corrosion of reinforcing steel in concrete at these locations up to a height of about 1.5 m from the grade. Therefore, the structures should be provided with proper slopes, drainage systems and protective coatings to avoid corrosive effect of rainfall and floods.

3.7.3 Ambient temperature (T)

Maximum temperature variation at the test site occurred during the months from May to October. The monthly minimum temperature in that year varied from 9.0 °C in January to 30.2 °C in August. Monthly maximum temperatures, on the other hand, varied from 20.9 °C in January to 44.6 °C in August during the same year. The monthly temperature difference between minimum and maximum values varied between 13 °C to 14 °C during the months from May to October. As per records spanning over a period of 20 years, the difference between hourly minimum and maximum temperatures at the test site was above 28 °C throughout the year [16].

The available data shows large temperature fluctuation throughout the year in the test site area. Temperature fluctuation and high ambient temperatures experienced during summer months make the structures vulnerable to detrimental effects of expansion and contraction. It will cause formation of cracks in the concrete as well as within the coating applied on concrete and thus expose the structures to corrosive pollutants, humidity and rainwater present in the environment. The concrete mix should be designed to tolerate such adverse environmental conditions. Furthermore, the surface coatings selected should have expansion properties comparable to concrete substrate in order to accommodate the effect of temperature variations with minimum damage.

4 Discussion

Groundwater is deeper than 20 meters at the factory site. Possibility of the foundations to be affected from groundwater is quite remote and minimal at this site. Only temporary flooding in case of heavy rains may have some effect on the foundations during rainy seasons.

Soil pH varies from neutral to alkaline (7.88 - 10.77, Table 1) in the boreholes investigated. Water-soluble chloride and sulfate contents of soil are very low and vary from 0.011% to 0.286 %, and from 0.013% to 0.908 %, respectively. The electrical resistivity of soil (0.0 – 69.10 ohm-m, Table 2) is usually high at shallow depths and decreases with increasing depth. It may further decrease during rainy seasons. The low chloride and sulfate contents, high pH, and the high carbonate content (1 – 93% CO_3^{2-}) of soil makes it non-corrosive in dry season or slightly corrosive in wet season.

According to the ambient pollution test results (Tables 4 and 5), the test site has highly polluted environment when compared with similar industrial and urban atmospheres. Most of the measured pollution parameters such as TSP, NaCl, sulfate, SO_2 , and CO_2 are several times higher than that in other industrial sites. This maybe is due to the ongoing construction activities and heavy equipment operation prevailing at the site during the time of present investigation.

The ambient RH, temperature and rainfall data show that during the rainy months, RH increases beyond 60%. The detrimental effect of the ambient atmospheric and pollution parameters stated above should be taken into consideration when recommending mix design for a durable concrete and a protective coating for use in such industrially polluted locations. Existence of the above pollution parameters at very high levels coupled with high and fluctuating ambient temperature and RH, is expected to increase the detrimental effects of these parameters, due to their synergistic effect, on the reinforced concrete structures as also pointed out by several authors [5-9].

5 Conclusions

Following conclusions can be drawn from this study:

- The possibility of the substructures and foundations to be affected from groundwater is minimal at this site. Only temporary flooding in case of heavy rains may have some effect on the foundations during rainy seasons.
- The superstructure (metallic or reinforced concrete), on the other hand, should be well protected against atmospheric corrosion that will mainly be caused by chloride and sulfate salts, sulfur dioxide, and carbon dioxide, in the presence of moisture or relative humidity above 60% and fluctuating high temperature.

6 Recommendations

Based on the experimental results of this study, following recommendations can be put forward for concrete mix design, concreting and protection procedures for maintenance-free durable concrete for extended service lifetime.

6.1 Substructure

Soil and groundwater do not constitute corrosive environment except only during rainy seasons when the soil may become moderately corrosive for a short period. Therefore, usual concrete mix design with Type-V sulfate resistant Portland cement and coal tar epoxy coating on concrete surfaces can be used for structures in contact with soil to avoid sulfate attack.

6.2 Superstructure

The ambient pollution data showed high concentrations of carbon dioxide, sulfur dioxide, and sodium chloride content in the atmosphere. In addition, the seasonal variation in the relative humidity, rainfall, and temperature, and maximum temperature reached during summer months was high. Consequently, for superstructures the following concrete mix design is recommended:

Cement Type:	General Purpose Type - I Cement
Cement Content:	380 kg/m ³
Water/Cement (W/C):	0.45 (minimum)
Compressive Strength:	35 MPa (minimum)
Steel Bar:	Deformed Mild Steel Bar

Specifications for Type-I cement can be found in literature (ASTM C 150). Concrete should be cast during cool hours of the day and precautions should be taken by using cold or iced water for mixing to prevent excessive heating. After casting, the concrete should be wet-cured for 7 days followed by additional 21-day air curing before de-molding.

6.3 Surface Protection

The reinforced concrete structures should be protected against ingress of carbon dioxide, sodium chloride, water, and oxygen from environment during service. It is recommended that the surfaces of reinforced concrete elements be completely coated for protection. The performance of polyurethane and epoxy coatings is superior to that of other coatings in carbonation environments. Selection can be made depending on the ease of application, availability and cost.

Alternatively, it is recommended that FBE coated steel bars for reinforcement in concrete can be used. In this case, the surfaces of concrete structures need not be completely coated with the recommended coating. In case FBE coated steel bars are employed, the concrete structures should be coated only at their surfaces up to 1.5 m height from the grade, mainly for protection against ingress of water and salt.

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