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CRI TECHNOLOGY DIGEST

CEMENT RESEARCH INSTITUTE OF INDIA

GUIDELINES FOR FOUNDATIONS UNDER AGGRESSIVE ENVIRONMENTS

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INTRODUCTION

Concrete has excellent resistance to weathering. Therefore, concrete foundations and structures built with proper controls on material and workmanship have resulted in durable structures under normal environments, requiring practically very little maintenance for several decades. However, corrosion of concrete and reinforcement is likely to occur when such structures are constantly exposed to aggressive surroundings, such as obtaining in aggressive ground waters and soils, in chemical industries, marine environments, etc if special attention is not paid. This Technology Digest lays down guidelines for foundations under such aggressive environments. The selection criteria on the type of foundations to be employed and also the structural engineering considerations are important but do not fall within the scope of this Digest.

AGGRESSIVITY OF SOIL AND SUB-SOIL WATERS AND ITS EFFECTS ON CONCRETE FOUNDATIONS

Aggressivity of soil and sub-soil waters originates from a variety of sources. The geological formation of soil strata, weathering of rocks, nature and composition of minerals present in the soils, presence of certain salts in sub-soil water, fluctuations in water table, percolation of aggressive agents from the surface to the soil are some of the main factors. The intensity of aggressiveness depends both on the nature and quantity of the deleterious constituents present. The commonly occurring deleterious constituents in water, soil and sub-soil water, and sea water are sulphates, chlorides, nitrates, acids, magnesium salts, etc. The deterioration of concrete in such aggressive environments can be due to leaching of lime from the pores in concrete, exchange corrosion of the readily soluble substances in which case reaction products either leach or remain in place in non-binding form, and formation of reaction products having higher volume thereby causing corrosion by expansion.

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Corrosion inducing agents such as chlorides, oxygen, carbon dioxide are harmful to reinforcements. Chlorides in particular penetrate fast into concrete and destroy the passive protective layer around the reinforcements leading to serious corrosion. The higher is the *p*H of concete the greater is the tolerable limit of chloride. At *p*H 11 and below there is practically no protection offered by concrete to steel reinforcements.

CLASSIFICATION OF FOUNDATION CONDITIONS

Depending on the concentration of sulphates, chlorides, acids etc, in the soil and ground water, the foundation conditions can be classified in their order of aggressivity. In so far as sulphates are concerned such a classification is available in the British Standard CP-110 Part I 1972. Another classification as given by F M Lea in 'The Chemistry of Cement and Concrete' is in Table 1. As is seen sulphate content as low as 0.1 percent in soil and 0.015 percent in water can cause positive sulphate attack.

TABLE I : GRADATION OF SULPHATE ATTACK ON CONCRETE WITH RESPECT TO SULPHATE CONCENTRATION ON SOILS AND WATER

	Sulphate $SO_4^{=}$, percent	
Degree of sulphate attack	Soil*	Water
Negligible	0·00 to 0·10	0 to 0·015
Positive	0·10 to 0·20	0·015 to 0·100
Considerable	0·20 to 1·50	0·100 to 0·200
Severe	Over 0·50	Over 0·200

*Water soluble

In so far as chlorides are concerned, a similar classification is not available. However, a 50-year survey of foundation of certain concrete structures made elsewhere has shown that the expected life of unprotected concrete foundations generally decreases with increase in environmental chlorides, ie, from soils and ground water, and chlorides of the order of 5000 to 10000 ppm should be positively aggressive to concrete and reinforcements.

Simultaneous presence of deleterious salts such as sulphates and chlorides in the soils and ground waters in quantities harmful for the concrete foundations, their possible interaction and the periodic fluctuation of the ground water table can further aggrevate the situation arising out of such type of salinity attack. For example, presence of chlorides will reduce the sulphate resistance of concrete corresponding to certain amount of sulphates present, and periodic fluctuations of water table will enhance the degree of sulphate attack compared to another situation where such movements of water table are absent.

A *p*H in the range 6-10 is considered harmless to concrete and reinforcements. Magnesium ions in soil mainly originate from dolomitic rocks. Surface waters rarely contain more than 25 mg/litre M_g^{++} ions whereas the ground waters may contain as much as 300 mg/litres.

Classification on the aggressivity of nitrates is also not available. However the action of nitrates and chlorides on concrete being similar, the limits of chlorides may be the limits for nitrates too.

SITE INVESTIGATIONS

The site under consideration must be thoroughly investigated both for engineering properties of the soil, such as bearing capacity and settlement, and also for the presence of any deleterious constituents in the soil or sub-soil water. While it is neither desirable nor practicable to formulate the exact scheme for carrying out site investigations applicable to all cases, following are the broad steps which would be applicable in most cases involving site investigations:

a) Collection and analysis of complete geological data and information on the nature of the site.

b) Collection and analysis of complete data on engineering aspects of the soil and sub-soil conditions including water table fluctuations, etc.

c) Analysis of soil and ground water samples at different depths to establish the concentration of aggressive agents, such as sulphates, chlorides, nitrates, acids, magnesium salts.

d) Mineralogical investigation on the soil samples at different depths by X-ray diffraction, thermal, microscopic and spectroscopic analysis to ascertain the possible source of aggressive agents.

e) Study of performance of neighbouring structures.

f) Analysis of results to establish the origin (localised or uniform; perennial or of limited extent), nature and extent of the aggressive agents for arriving at viable solution to protect the foundations.

GUIDELINES FOR DURABLE FOUNDATIONS

Taking into account the degree of aggressivity of soil and ground water conditions, the type of foundations proposed, nature of super structure to be built etc a viable solution to protect the foundations from the aggressive environments can be arrived at. The general approach to the foundations under aggressive environment could be to remove the source of the deleterious constituents, or to neutralise by addition of chemicals or by minerals etc and also by providing extra mud mats, cover over foundations, barriers etc of suitable types. Proper choice of materials, concrete mix design, over dimensioning, good workmanship, protective coatings and barriers, etc are of utmost importance for making durable foundations.

Cement: The type, chemical composition and physical characteristics of cement greatly influence the resistance of plain and reinforced concrete in the presence of sulphates and chlorides. In so far as the sulphates are concerned, calcium hydroxide in concrete and calcium aluminate phase in cement are susceptible to sulphate attack and as such use of a sulphate resisting cement is the obvious solution. From this point of view cements in decreasing order of preference are high alumina cement, super sulphated cement, sulphate resisting portland cement, portland pozzolana cement, portland slag cement or ordinary portland cement. However, high alumina cement is not suitable for use under tropical conditions and super sulphated cements are not to be used above 40°C and also not available in India at present.

Sulphate resisting portland cement has been recommended for countering the attack of sea waters which contain both sulphates and chlorides in amounts ranging up to 3·65 g/litre and 19·00 g/litre respectively. As such this type of cement, conforming to the specification for ASTM Type V (ASTM C-150-1974) will be preferable. Accordingly the portland cement should contain C_3A not more than 5 percent and $2C_3A+C_4AF$ or solid solution (C_4AF+C_2F) not more than 20 percent. Such cements also conforming to IS : 269-1976 are available in India and may be considered for use. In the absence of this type of cement the choice may fall respectively on such portland slag cement (IS : 455-1976) and portland pozzolana cement (IS : 1489-1976) which are known to possess sulphate resistance greater than that of ordinary portland cement.

In so far as corrosion of reinforcement due to chlorides is concerned the choice of cement shall be for a cement having higher percentage of C_3A than the sulphate resistant cement as C_3A is known to immobilize certain proportion of the chlorides in concrete. However when chlorides and sulphates occur simultaneously, protection of concrete against sulphate attack assumes priority and the choice of cement may be governed by the consideration of sulphate resistance with due care on mix proportions. Requirements for concrete exposed to sulphate attack are tabulated in IS : 456-1978.

Aggregates: Coarse and fine aggregates from natural sources conforming to IS : 383-1970 shall be used in mortars and concretes. The shape, size and grading of aggregates shall be as per relevant standards and codes of practices so as to produce workable concrete which can be placed without segregation and will result in dense and uniform concrete. The aggregates should not contain any deleterious constituents. More specifically, the total acid soluble chlorides (as NaCl) in coarse and fine aggregates should not exceed 0·05 percent and 0·10 percent by weight respectively and soluble sulphates (as SO_2) should not exceed 0·40 percent by weight for use in aggressive environments.

Water: Water used for mixing and curing concrete should not contain harmful amounts of dissolved salts. It should conform to the requirements of IS : 456-1978. Sea water shall not be used for mixing or curing of reinforced or prestressed concrete.

Limits of Sulphates and Chlorides in Concrete: The total sulphates and chlorides in concrete at the time of placing should be limited. Such limits, however, should be related to the cement content of the concrete mix and therefore the limits are expressed as percentage of cement by weight. In so far as sulphates are concerned it is felt that total SO_3 upto twice the amount contributed by cement is tolerable and based on this a conservative 4 percent has been recommended in IS : 456-1978. The opinion is not unanimous as far as chlorides are concerned. However, it is considered that the total amount of chlorides in the concrete at the time of placing may be limited to 0·15 percent by weight of cement for reinforced concrete and 0·06 percent for prestressed concrete.

Mix Proportions, Workmanship and Quality Control: The concrete mix proportions should be such as to yield a fresh concrete capable of being placed around the reinforcements under specific situations and also result in low permeability in hardened state. The cement content is so chosen that the amount of cement paste is sufficient to overfill the voids in the aggregates mass and that the resulting water content of the mix gives a workability which corresponds to the situation of placing and desired cover thickness. This being largely dependent on the aggregates, the water-cement ratio and cement content should be chosen for the type of aggregates and the situation at hand and as per guidelines given in IS : 456-1978.

Adequate cement content, proper selection of well graded and dense aggregates, employing low water-cement ratio and strict controls on mixing and transportation and placing as well as proper curing of concrete are expected to result in highly durable concrete.

Protective Coatings and Barriers: Durability of concrete foundations under aggressive soil and sub-soil conditions is also ensured by protecting the concretes from the aggressive agents. This could be achieved by providing impermeable and resistant coatings and membranes, plasters, linings, wallings etc. A variety of protective paints and coatings etc are available commercially and specialised literature, opinion and advise need to be sought in dealing with such problems.

CRI EXPERTISE

Over the years CRI has successfully completed several R&D projects on durability on concretes and foundation problems under diverse

environmental conditions, some of the projects being of far-reaching importance to the country. CRI possesses the expertise to render necessary technical and technological assistance in the area of concrete foundations and durability of concrete under aggressive environments.

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