National Council for Cement and Building Materials

GUIDELINES FOR DURABLE CONCRETE CONSTRUCTIONS IN AGGRESSIVE ENVIRONMENTS

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NCB TECHNOLOGY DIGEST

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INTRODUCTION

Concrete is by far the most widely used construction material. Under normal usage and circumstances, concrete is sufficiently durable and provides trouble-free service for many years. However, with the growing variety of application of concrete in different types of constructions, under normal or aggressive environments, its successful performance has become dependent largely on its durability rather than on its strength properties alone. While there are large number of instances of the successful performance of concrete structures in various environments, instances of distress to certain concrete structures, although in minority, cannot be overlooked. This technology digest lays down the guidelines for making durable concretes for structures in aggressive environments.

SYSTEMS APPROACH TO DURABILITY OF CONCRETE

There are a number of agencies—chemical, physical, mechanical and biological—which may cause deterioration of concrete under a certain situation. The problem becomes more complex when these agencies act simultaneously or one paves the way for the attack of concrete by another. Therefore, there is a growing realization that the problem of durability of concrete structure should be tackled on a 'systems' approach involving a number of disciplines. The solution to the problem is to be sought in proper site selection and assessment of the environments, efficient structural design, choice of proper concreting materials and mix proportioning including protective coatings wherever necessary, proper construction technologies and workmanship, and finally, timely and adequate maintenance and repairs.

THE BASIC STEPS

A complete solution in each individual case should be arrived at only after proper analysis of the situation. The following basic steps, which are applicable in majority of situations, can be advantageously adopted for making durable concrete structures.

*Reprint.

Selection and Assessment of Site

The site chosen for construction must be thoroughly investigated, both for the 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, seasonal fluctuations of the water table, possibility of adequate drainage around the site or blocking of the source of harmful salts, if any, etc. The aggressiveness depends both on the nature and quantity of the deleterious constituents present. The common chemical agents present in water, soil and sub-soil water, which are deleterious to concrete include sulphates, chlorides, H_2S, CO_2, ozone, ammonia and acids. The concentration of sulphates in soil or in ground water corresponding to different degrees of aggressiveness are listed in Table 20 of IS : 456-1978. Environmental chlorides (from soil and ground water) of the order of 5000 to 10000 ppm are considered aggressive.

Assessment of Environments

Many of the chemical and other industries give rise to wastes, effluents, fuel gases or vapours, which may attack concrete. For example, the combustion products of many fuels contain sulphurous gases which combine with moisture to form acids which attack concrete. Water draining from some mines and some industrial waters may contain or form acids. Farm sillage, animal wastes, and organic acids from manufacturing or processing industries (eg breweries, dairies and wood pulp mills) are also aggressive to concrete.

Such man-made aggressive environments and their effects on concrete should be identified and adequate measures of safeguard be planned well in advance.

Design Considerations

To ensure durable constructions, proper structural systems and structural design should include choice of appropriate foundation, adoption of prefabrication where possible in order to ensure better quality control or prestressing to control cracking, adequate cover to reinforcement to prevent the ingress of aggressive agents, etc. IS : 456-1978 recommends that increased cover thickness may be provided when surfaces of concrete members are exposed to the action of harmful chemicals (as in the case of concrete in contact with earth faces contaminated with such chemical), acid, vapour, saline atmosphere, sulphurous smoke (as in the case of steam-operated railways), etc., and such increase of cover may be between 15 mm and 40 mm over and above than otherwise. For concrete of grade M 25 and above, the additional thickness of cover may be reduced to half.

Cracking of concrete under working stressess influences its long-term durability as it facilitates the ingress of harmful chemicals into the concrete and often leads to corrosion of reinforcements. From the point of durability of concrete, limit states are expressed in terms of the crack-width (0·1, 0·2 or 0·3 mm) depending upon the extent of exposure. Recent researches point that the first part of the life of a structure designed for durability, ie, up to the onset of corrosion cells and destroying the alkaline passivity provided by concrete to the reinforcing steel, is affected by the presence or absence of cracks. The remaining major part of the designed life, ie, from the time of depassivation to the time of unacceptable corrosion damage is independent of the width of cracks, once the cracks are wider than a 'threshold' value (of about 0·15 mm). Moreover cracks in concrete parallel to the reinforcements are more critical from the point of view of reinforcement corrosion than those perpendicular to the plane containing reinforcement. Therefore, it is necessary to control the width and number of cracks in concrete structures by proper detailing of the reinforcement as per the codes of practice.

Choice of Materials

Cement—The type, chemical composition and physical characteristics of the cement are known to greatly influence the resistance of concrete to the presence of sulphates and chlorides and the cements recommended for use under sulphate bearing environments are high alumina cement, sulphate resisting portland cement, supersulphated cement, portland pozzolana and portland slag cements. However, use of high alumina cement under tropical conditions is not recommended. The choice of cement in India is further limited because supersulphated cement is not being manufactured. Also its use at temperature above 40°C is not recommended.

For sulphate-resistance portland cement conforming to ASTM specification for type V (ASTM C-150-1974) or ordinary portland cement conforming to IS : 269-1976 with additional stipulation that C_3A not to be more than 5 percent and $2C_3A + C_4AF$ or solid solutions ($4CaO.Al_2O_3.\ Fe_2O_3 + 2\ CaO.\ Fe_2O_3$) not to be more than 20 percent is recommended for countering the attack of sea waters which generally contain both sulphates and chlorides in harmful amounts. In the absence of such a cement, portland slag cement conforming to IS : 455-1976 and portland pozzolana cement conforming to IS : 1489-1976 which are known to possess sulphate resistance greater than of ordinary portland cement, may be used.

In so far as the corrosion of reinforcement due to chlorides is concerned, ordinary portland cement containing greater amount of C_3A, than stipulated for sulphate-resistance, is perhaps desirable. In many cases, sulphates and chlorides occur together, as in sea water. In such situations, protection of the outside concrete around the reinforcement against sulphate attack would assume priority. Under such situations, the choice of cement may perhaps be governed by the consideration of sulphate resistance with due care on the mix proportions.

Aggregates—Coarse and fine aggregates from natural sources conforming to IS : 383-1970 shall be used. The shape, size and grading of aggregates should be as per the relevant standards and codes of practice so as to produce workable concretes which can be placed without segregation and which will result in dense, impermeable and uniform concrete. The total acid soluble chlorides (as NaCl) in coarse and fine aggregates should not exceed 0·05% and 0·10% by weight respectively and soluble sulphates (as SO_3) should not exceed 0·40% by weight.

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.

Limiting Deleterious Constituents—Though limits of deleterious constituents, mainly sulphates and chlorides, have been specified separately for aggregates, water and admixture, yet the total chloride and/or sulphate content in the concrete mix incorporating these constituent materials and supplemented by further diffusion from the environments, should not be beyond permissible limits. The total chlorides and sulphates in fresh concrete at the time of placing should be limited in relation to the cement content of the concrete mix. In so far as the sulphates are concerned, views have been expressed that total SO_3 up to twice the amount contributed by cement is perhaps tolerable (which amounts to a maximum of 5·5 percent by weight of cement). A conservative limit of 4 percent by mass of cement of the total soluble sulphate content in concrete has been recommended in IS : 456-1978. The opinion is divided on chlorides, specially in regard to safe limit of calcium chloride as an admixture. As chlorides-free concrete is not practicable, 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

The concrete mix composition should be so chosen as to result in fresh concrete which is satisfactory for placing, particularly around the reinforcement steel, where dense concrete is essential but adequate compaction by vibration or other means may not be possible. It should also result in low permeability of hardened concrete so as to minimise penetration of oxygen, moisture and salt from the external environments.

Towards this, limitations are expressed in terms of minimum cement content and maximum water-cement ratio that can be allowed for different type of exposure and when different types of cement are used. Basically the water-cement ratio is so chosen as to result in minimum permeability. Since permeability of cement paste increases drastically with water-cement ratio above 0·5 or so, the water cement ratio is to be restricted around this.

The cement content is to be chosen from two considerations; the amount of cement paste (ie, cement plus water) should be sufficient to overfill the voids in the aggregate mass and secondly, the resulting water content of the mix should give sufficient workability corresponding to the situation of placing and cover thickness provided. It is obvious that the desired volume of cement paste to overfill the aggregate voids as well as the workability that can be considered adequate largely depends upon the aggregates—its size, grading and proportion of course to fine fractions. From these considerations, the water cement ratio and cement content should be chosen for the type of aggregates and the situation at hand. General guidelines for different types of exposure and different concentration of sulphates in the soil and ground water are given in Tables 19 and 20 of IS : 456-1978.

Compressive strength of concrete, *per se* is not important. However, being taken as an index of overall quality of concrete, it is a useful consideration. Because of importance of cracking in problems associated with durability, perhaps tensile strength of concrete is more relevant. The bond strength at the interface between mortar and aggregate as well as between concrete and steel are important and to a first order of approximation both tensile and bond strengths are related to the compressive strength of concrete. Stipulations of minimum cement content and maximum water cement ratio made in IS : 456-1978 will suffice such requirements in most of the cases.

Protection and Protective Treatments—Durability of concrete, particularly in strongly aggressive environments, should also be ensured by protecting the concrete against intense contact with the aggressive agents. Protection of concrete surfaces can be obtained by impregnation and chemical treatment by concrete surfaces, impermeable and resistant coatings and membranes, plasters, linings, wallings etc. For details of various types of protective coatings/barriers suitable for different types of environments, specialist literature should be consulted or expert advice obtained from agencies dealing in such problems.

Proper Workmanship and Quality Control

Concrete of good quality, in a broad sense means dense, well compacted, impermeable, homogeneous and uniform concrete. This can be achieved by having strong, dense and well-graded aggregates, by employing sufficiently low water-cement ratio and adequate cement content and backed up by proper placing, thorough compaction and adequate curing of concrete. Since there is not one attribute to measure the quality of concrete, proper care in all aspects of mixing, transportation, placing, compacting and curing of concrete must be taken.

Proper Maintenance and Timely Repairs

Proper maintenance and timely repairs are of vital importance as these can stop the progress of deterioration and restore the structure to a satisfactory condition. Whenever a concrete structure suffers distress during its service life, any repair work must be preceded by proper assessment of the cause and extent of the damage. The actual remedial measures to be adopted in a given situation would depend upon a number of parameters. The steps generally consist of removal of deteriorated concrete and steel reinforcement, washing away aggressive chemicals, sealing of cracks, repair of damaged concrete, strengthening of the structural units, restoration of protective coatings and joints, and load reduction. A number of specialised materials and techniques are available for these purposes.

NCB EXPERTISE

NCB, as a pioneer industrial support organisation in the field of cement and building materials, possesses the requisite expertise and is in a position to take up investigational work and suggest viable solution to problems related to concrete constructions in aggressive environments. In fact, NCB has already successfully handled a number of such projects, both in the public and private sectors.

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