BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

DETERIORATION OF CONCRETE IN SULPHATE AND SOFT WATERS

Concrete is very widely used in the construction of harbours, docks, breakwaters and other structures exposed to the action of sea water. It may suffer attack on account of chemical action of the dissolved salts, crystallization of salts within the concrete under conditions of alternate wetting and drying and corrosion of reinforcement embedded in it. Deterioration may also take place when placing concrete for footings or piles in sub-soil waters containing harmful salts or when concrete is exposed to the action of soft acidic waters, for example in dams and waterworks handling spring waters.

Aggressive chemical attack on concrete caused indirectly by bacterial action is occasionally experienced and concrete may also deteriorate when used as a material of construction in the chemical industry. However, the attack of concrete by sulphate and soft waters is more widespread and this digest deals specifically with these types of deterioration.

Sulphate attack

Deterioration of concrete is caused more often by the action of aggressive agencies on the set cement which forms the cementing matrix. Sulphates of calcium, sodium and potassium react both with the free calcium hydroxide in set cement to form calcium sulphate and with the hydrated calcium aluminate to form insoluble calcium sulpho-aluminates. The reactions are accompanied by a marked swelling of the solid phase which disrupts the concrete mass, opening up the interior to further penetration of sulphate solutions and exposing the reinforcing steel. The action of magnesium sulphate is more severe because, in addition to reacting with the aluminates and calcium hydroxide, it results in the decomposition of the calcium silicate hydrate phase (the cementing solids in concrete).

Thus the sulphate attack takes different forms according to the type of sulphate present. The different factors influencing the attack are :

1. Amount and nature of salts present,
2. Water level and its variation,
3. Type and quality of concrete,
4. Type of cement used.

(1) *Amount and nature of salts present*

On an average, sea water contains dissolved salts in the following proportions :

Salts	*g/litre*
Sodium chloride	27.2
Magnesium chloride	3.8
Magnesium sulphate	1.7
Calcium sulphate	1.2
Potassium sulphate	0.9
Calcium carbonate	0.1
Magnesium bromide	0.1
Total	35.0

Chlorides are not deleterious to plain concrete. In reinforced concrete, the corrosion in steel is prevented by lime liberated during hydration of cement by maintaining high pH. If concrete is porous or if its protective cover is insufficient, the inhibitive action of lime surrounding the concrete is reduced due to leaching or carbonation of lime. Thus corrosion may start and the process may be accelerated by chlorides present in sea water.

The rate of attack on mortars and concretes by sulphate solutions depends on the strength of the solutions. It increases rapidly up to about 0.5 per cent concentration for magnesium sulphate and 1.0 per cent for potassium sulphate, but beyond these limits only at a diminishing rate. Magnesium salts are more destructive to concrete because of exchange of magnesium ions with calcium ions. Calcium silicate hydrate gets converted to magnesia and silica or to magnesium silicates which are not cementive. This is one of the mechanism whereby sea water attacks concrete.

Calcium sulphate, being soluble only to the extent of 0.2 percent has a much slower action on dense mortars and concretes than the stronger solutions that can be obtained with the more soluble salts. Carbonates and bromides present in very small quantities in sea water have no deleterious effect on concrete.

Data regarding sulphate content of sub-soil water in different regions of India is not precisely known. For any major construction project it is therefore desirable to find out sub-soil water conditions and the amount and nature of salts present which are liable to attack concrete. SO_3 content of less than 300 .ppm. in ground water is a safe limit for normal dense concrete for foundations.

(2) *Water level and its variation*

The attack of sea water on concrete structures is more severe just above the high water level. The sea water tends rise in the concrete by capillary action and by evaporation at its upper surface and draws more water continuously through the mass. The crystallisation of salts in the concrete tends to have a disruptive action. Portions between low and high water marks are affected by alternate wetting and drying and crystallisation of salts which cause disintegration. Portions of the structure below the low-water level which always remain immersed in water are rarely damaged.

The rate of attack of sub-soil water on concrete is increased by movements in the water caused by drainage or by fluctuations of the water table.

(3) *Type and quality of concrete*

Dense concrete of low permeablity is considerably more resistant to deterioration than one which is porous or otherwise of low quality. Concrete which is subjected to water pressure on one side is much more vulnerable since the sulphate-bearing water tends to be forced through the concrete.

To ensure low permeability of concrete, the cement content should not be less than 300 kg per cu. metre and normal 1 : 2 : 4 concrete satisfies this requirement. Aggregates should be dense and well graded. For water retaining structures coarse sand containing not less than 5 percent and not more than 25 percent of particles passing I.S. 30 sieve should be used. The water content should be kept reasonably low but should be above the minimum required for adequate workability. For normal concrete, w/c ratio should be kept below 0.6. In hydraulic structures, for example in the external faces of large dams, a water cement ratio of about 0.5 should be maintained.

Water to be used for mixing concrete should not contain dissolved substances which affect the setting time unduly or retard hardening. Water with sulphur trioxide upto 1000 p.p.m. or chlorine upto 500 p.p.m. is not objectionable. Sea water should not be used in reinforced concrete for it increases the risk of corrosion of the reinforcement. Care should be taken that the sand and coarse aggregate used in construction are free from sulphates and chlorides. Sea sand is not suitable aggregate for making reinforced concrete on account of the presence of chloride which may cause corrosion of reinforcement. This can, however, be used after washing it free from soluble salts.

(4) *Type of cement used*

The most vulnerable constituent of Portland cement is tricalcium aluminate and it is known that cements with 5 percent or less of tricalcium aluminate are resistant to the sulphate attack. Ordinary Portland cement generally contains 10 percent or more of this constituent. However, it has been observed that rich concrete mixes containing 375 kg. per cubic metre (1:1½: 3 mix) are fairly resistant to sulphate attack.

Some special cements are known to possess greater resistance to sulphate attack than ordinary portland cement and should be used under severe conditions of sulphate attack. Sulphate resistant portland cement (Portland cement containing less than 5% of tricalcium aluminate), Supersulphate cement (ground mixtures of 75% granulated slag, 20% anhydrous gypsum and 5% cement clinker), Portland blast furnace cement (ground mixture of 35% granulated slag and 65% of cement clinkar with 4% of gypsum) and portland pozzolanic cement (Portland cement mixed with 20-25 percent of fly ashes) are commonly recommended for this purpose in order of priority. The use of high alumina cement (fused product of limestone and bauxite) for construction, though recommended in cold climates, is not suitable in hot humid conditions on account of the possible conversion of monocalcium aluminate hydrate to tricalcium aluminate hydrate with consequent loss in strength and poor sulphate resistance.

Attack by soft waters

Spring waters and mountain waters generally contain low dissolved calcium bicarbonate and are termed soft waters. They may be acidic in nature due to dissolution of carbon dioxide from the atmosphere. Calcium bicarbonate is in equilibrium in the presence of free carbon dioxide.

When concrete is exposed to water containing free carbon dioxide, the calcium hydroxide liberated by hydration of the paste reacts with carbon dioxide precipitating calcium carbonate. However. if the water contains an excess of free carbon dioxide, this may react with calcium carbonate present in the set cement forming calcium bicarbonate, which being soluble, may be carried with the water. Partial decomposition of the cement binder takes place when all the free lime is thus removed. Therefore, by successive leachings, practically whole of the hardened cement can be decomposed.

Under normal conditions, provided concrete is dense, the action is only superficial and does not penetrate into the mass of the structure. On the other hand, lean and pervious concrete is very susceptible to destruction by this action and deterioration to considerable depth can take place.

Attack of this nature can be serious where thin sections such as concrete conduits, canal linings, flumes and low quality concrete or mortar pipe linings are concerned.

The aggressiveness of a natural acidic soft water is dependent not only on its pH but also on the temporary hardness (bicarbonate content) and the free carbon dioxide content. Amount of free carbon dioxide which can make the soft water aggressive to concrete is indicated below as a guide :

Temporary hardness	*Free Co_2*
ppm $CaCo_3$	ppm
40-50	more than 50
20-30	more than 30
10-20	more than 10
5	more than 5
2.5	more than 2

The pH value is not a safe guide, but in general, waters may be aggressive at pH value upto 7 or even 7.5, if the temporary hardness is below about 2.5 ppm and at pH value upto 6.0 or 6.5 for higher values of temporary hardness. The rate of deterioration due to attack by water containing both sulphates and carbonic acid appears to be considerably more rapid than if the deleterious constituents of the water consist only of sulphate or only of carbonic acid.

Precautionary Measures

Dense concrete of low porosity is most important for all sea-water concrete. The use of too wet a mix is dangerous, but mixes that are so dry that they cannot be adequately compacted must also be avoided. Vibration permits the use of lower water content and hence is recommended. Continued moist curing increases watertightness of the structure.

For concrete permanently under water a minimum cement content 300 kg per cu. metre (1:2:4 mix) is desirable. Portland cement would normally give satisfactory performance but sulphate resisting cements are to be preferred for work in tropics. For concrete immediately above high water level, a minimum cement content of 370 kg per cu. metre (1:1½:3 mix) is necessary.

Reinforced concrete above low tide level is much more vulnerable than plain concrete owing to the additional risk of corrosion of reinforcement. The cover of concrete over the reinforcement should be more than 5 cm. Mixes should not be leaner than 1:1¾:3½ by weight.

In case piles have to be used, injury to these piles during driving should be avoided. Prestressed piles are preferable when mechanical driving is choosen. If piles are damaged, the damaged upper end of each pile should be carefully embedded in the concrete cast in situ.

Precautionary measures to be observed when building concrete foundations which will be exposed to sulphate attack will depend almost entirely on the precise conditions existing at a particular site.

Broadly speaking, if SO_3 present in ground water is less than 300 ppm, portland cement concrete mixes not leaner than 1:2:4 are desired for concrete surrounded by clay. In case concrete is exposed to water pressure on one side or if it is of thin section, richer concrete, 1:1½:3 with w/c ratio less than 0.6, or the use of sulphate resisting cement is recommended. For SO3 content of 300 to 1000 ppm, rich dense Portland cement concrete (1:1½:3) placed in situ is unlikely to suffer seriously. The use of sulphate resisting cement is, however, desirable. For SO_3 content higher than 1000 ppm it is essential to use sulphate resisting cement with a low water cement ratio mix.

Precast Portland cement concrete products of high quality made with a rich mix (1:1½:3) and of low permeability are unlikely to suffer serious attack due to sulphates. Precast concrete pipes made with ordinary portland cement are not likely to suffer serious deterioration within 10 to 20 years in contact with ground water containing sulphates in concentration equivalent to 1000 ppm. Increased life can be obtained with sulphate resisting portland cement or other special cements.

One of the most effective methods of reducing the aggressiveness of soft waters is to allow the water to flow over or through beds of crushed limestone or to pack a layer of limestone, 30 to 45 cm around the exposed face of the component. In hydraulic structures, footings or piles in contact with acidic ground waters, the rate of deterioration can be reduced by the use of crushed, hard lime stone or dolomite aggregate in the concrete. An extra thickness of concrete can also be provided to ensure protection.

Conclusion

The first line of defence against sulphate attack on concrete lies in ensuring that the concrete is dense and impervious. In reinforced concrete for coastal area a minimum concrete cover of 5 cm to the reinforcement is necessary to prevent corrosion due to soluble salts.

Before any assessment can be made of the possible aggressiveness of sub-soil waters to concrete, exploration of ground water conditions and accurate chemical analysis of field samples, specially the contents of sulphate, bicarbonate, free carbon bioxide and pH value are essential.

There is a demand for short notes, summarising available information on selected building topics for the use of Engineers and Architects in India. To meet the need this institute is bringing out a series of Building Digests from time to time and the present one is the 36th in the series.

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