Concrete in sulphate environments

Swenson, E. G.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000872
Canadian Building Digest, 1971-04

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 136

Concrete in Sulphate Environments

Originally published April 1971

E.G. Swenson

Please note

Portland cement concrete is vulnerable to attack by aqueous solutions of sulphate salts that occur in some soils and groundwaters. The rate and degree of attack depend upon the amount of available (soluble) sulphate, the presence of water, the composition of the cement and certain characteristics of the concrete such as permeability. As the action progresses there is a gradual loss of strength in the hardened cement paste component so that the concrete will ultimately crumble.

Concrete elements that may be exposed to attack by sulphates in certain soils and groundwaters include footings, foundation walls, retaining walls, piers, piles, culverts, pipes and surface slabs. The severest attack occurs on elements where one side is exposed to sulphate solutions and evaporation can take place on the other, for example, retaining walls.

Some 50 years of research have been carried out on this reaction, much of the pioneer work in Western Canada where the problem has long been recognized and is under continuing study. Although the primary mechanism of attack was established many years ago, two important problems remain: known preventive measures have not yet been fully utilized in practice, and there is considerable evidence of a second reaction in failures that have occurred where all precautions were taken.

This Digest will discuss concreting in sulphate-bearing soils and groundwaters as it relates to Canadian environments and practice.

Occurrence of Available Sulphates

Soluble sulphates are frequently present in very high concentrations in soils and groundwaters on the Canadian Prairies. They are believed to be associated with the relatively dry climate and its action in "wicking up" the soluble sulphates from lower salt-bearing strata. Surface deposits of such salts, often mainly sodium sulphate, occur in many areas, and magnesium sulphate may also be present in high concentrations, particularly on the eastern Prairies. Although not normally high enough to interfere with the growth of crops and other vegetation, sulphate concentrations at or near the soil surface may be high enough to damage concrete.

In other parts of Canada higher precipitation maintains low sulphate concentrations at normal construction depths, with some exceptions. Where gypsum deposits are present, concentrations may be high, though localized. Naturally-occurring calcium sulphates such as gypsum have low solubility and do not by themselves produce a reaction of significant rate. Over a period of time, however, they may be converted to the more soluble salts such as sodium and magnesium sulphates.

High concentrations of soluble sulphates may be found at sites where coal has been stored over some years. Marshy ground also is sometimes high in such salts. Where sulphide-containing ores are present, for example, the pyrites occurring in certain shale deposits, oxidation to the sulphate may occur even through bacteriological action. Sewage and other waste materials sometimes give off sulphur-containing gases that are readily oxidized to the sulphate.

Sea-water attack on concrete has traditionally been treated as a problem quite distinct from the type of sulphate attack that occurs in soils and groundwaters. The sulphate concentration in sea water (in soluble, available form) is extremely high and is of the order of concentration that has proved to be damaging to concrete in groundwater. The fact that much concrete in sea water is only partly immersed and therefore subject to high moisture intake is certain to pose a sulphate threat. The problem has, however, been complicated by frost action, erosion, corrosion of reinforcing steel, and by physical damage due to ice and other impact and abrasion factors. Such complicating factors may also occur at soil surfaces where the threat of sulphate attack derives from soils or groundwaters.

Mechanism Of The Reaction

It has been demonstrated that sulphate attack on concrete results from a chemical reaction between the sulphate ion and hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste in the presence of water. The products resulting from these reactions are calcium sulphoaluminate hydrate, commonly referred to as ettringite, and calcium sulphate hydrate, known better as gypsum. These solids have a very much higher volume than the solid reactants and, as a consequence, stresses are produced that may result in breakdown of the paste and ultimately in breakdown of the concrete.

The destructive action of this mechanism has been proved experimentally many times with mortars and concretes. Preventive measures, verified in the laboratory and in the field, are based on reducing or eliminating one or more of the four reactants in the above reaction, for it is a well established principle that only one need be neutralized in order to stop the reaction.

Although preventive measures based on the specific sulphate reaction described above have proved effective in most instances, there have been cases where they were unsuccessful. It has been demonstrated that magnesium sulphate is more aggressive than sodium sulphate, and this has led to speculation that the magnesium ion operates in some separate reaction that can be destructive. This possible second reaction may account for cases of deterioration where a sulphate-resistant cement (low in calcium aluminate) has been used and the quality of concrete has not been in question.

Basic Preventive Measures

Because the sulphate reaction can be reduced or stopped by reducing or eliminating one or more of the four reactants considered earlier, preventive measures can be readily recognized.

The sulphate ion, if present in dangerous amounts (concentration values given later) and in soluble form, can be denied entry to the concrete by methods involving waterproof coatings or cut-off drainage. Bituminous coatings have been used with some success, for example, in special installations such as water pipes buried underground. The newer coating materials have apparently not yet had sufficient field use to demonstrate their effectiveness.

Water is not only a necessary reactant in sulphate attack in concrete but also the vehicle that carries the sulphate ion. Water enters concrete readily through capillary action. Again, waterproof coatings or drainage constitute the preventive measures. Design of foundation structures should recognize the need to reduce or eliminate entry of water into the concrete.

The calcium aluminate hydrate reactant derives from cement. In the manufacture of portland cement the normal amount of calcium aluminate present can be reduced to values that are effective in providing resistance to sulphate attack on concrete. These cements, called "sulphate-resisting cement" by Canadian Standards Association (CSA) Specifications and Type V by ASTM, have been manufactured and used in Western Canada for many years. These cements may have slightly lower strength gain properties than normal port- land cements. They are inherently low heat cements also, and have this benefit where concrete elements are massive. Present CSA specifications place a maximum limit of 5 per cent on C_3A (the calcium aluminate component) for sulphate-resisting cement.

The fourth reactant, the calcium ion, is present in the form of calcium hydroxide and is an inescapable product of cement hydration. In special processes, however, even this reactant can be controlled; for example, in high pressure steam curing of concrete pipes or in the use of an active pozzolanic admixture in concrete.

Sampling And Testing Of Soils And Groundwaters

Groundwater samples can be taken from boreholes and from seepage during excavation. Care must be taken to avoid dilution with surface water. Soil samples may be obtained from the test boreholes normally made for site studies and should be taken on a grid basis, with extra sampling where changes in strata occur.

Sulphate contents of groundwaters can be determined by one of several standard analytical methods that can be carried out in any chemical laboratory. Soils should be analysed for total sulphate by extraction with hot, dilute hydrochloric acid, and for water-soluble sulphate by extraction based on a weight of water equal to the weight of the soil sample. This is necessary to distinguish highly soluble sodium and magnesium sulphates from calcium sulphate (usually gypsum), which has a low solubility.

Groundwater concentrations are expressed as parts per million (ppm) of SO_4 or SO_3. Concentrations in soil samples may be expressed in per cent by weight or in grams per litre (of extract as per above method) of SO_4 or SO_3. Sea water will have a relatively fixed concentration of sulphate. More specific guidance is provided in the Canadian Standards Association Standards CSA A23.1 and CSA A23.2.

Testing of the resistance of cement or concrete to sulphate attack will not be considered here. A simple test method for cement is to be found in ASTM C452-68. Standard tests for concrete, as such, have not been developed, but outside exposure and laboratory tests have been and can be carried out for evaluation purposes. Specific information and advice are available from the Division of Building Research and other agencies.

Significance Of Sulphate Concentrations

Sulphate concentrations determined by the above sampling and testing procedures normally form the basis of a first approximation in assigning degree of severity of attack expected. The Canadian Standards Association CSA Standard A23.1, Concrete Materials and Methods of Concrete Construction, recognizes the following categories:

- "negligible" attack up to 150 ppm sulphate (SO_4) in groundwaters or up to 0.10 per cent sulphate (SO_4) in soil;
- "mild but positive" where the corresponding values are 150 to 1000 ppm and 0.10 to 0.20 per cent;
- "considerable" attack at 1000 to 2000 ppm and 0.20 to 0.50 per cent;
- "severe" over 2000 ppm and over 0.50 per cent.

On the Prairies, test samples of groundwaters yielding 5000 to 15,000 ppm in sulphates have been obtained in many areas, and in southeastern Ontario isolated sites have yielded over 4000 ppm. In sea water the average concentration of sulphate ion is about 2750 ppm. These ratings of severity, based on sulphate concentrations in samples, may require considerable modification, depending on certain influencing factors. Salt concentrations may vary seasonally with amount of rainfall and fluctuations in water table, the concentration increasing in dry periods. Where structures are only partially immersed or where only one side of a concrete element is in contact with sulphated water or soil the continuing capillary action through evaporation on the air side may build up much higher concentrations of sulphate within the concrete than would occur where no such driving force or pumping action exists. Thus, severe attack may occur even when sulphate contents of test samples are relatively low. For example, cases classified as "mild but positive" on the basis of concentrations of sulphates in test samples might, under continuous wicking action, be potentially much more severe and require correspondingly greater precautions.

On the other hand, concrete elements completely immersed in highly sulphated soils or waters will not normally be subjected to movement through the concrete. In such cases the attack will be initially rapid at the surface but will decrease very significantly so that the degree of severity may be somewhat less than that predicted by concentration criteria. To some extent this is also true of partly immersed concretes where the surface exposed is small compared with the total volume of the element. Where the exposed surface is subjected to a relatively low-drying environment (very high relative humidity) attack by sulphates may also be slower than would be predicted by concentration. Flowing water and groundwater under hydraulic head may increase severity of attack.

It is clear that each job site where tests indicate potential sulphate attack should be considered as an individual problem requiring individual preventive measures. Again detailed reference may be obtained from CSA A23.1 and CSA A23.2.

General Recommended Practice

For a given category of severity, judged on sulphate concentrations and modifying influences, distinction should be made between non-structural elements and structural reinforced concrete. The latter should, for obvious reasons, receive stricter precautionary treatment.

Where mild attack is anticipated normal portland cement may be used, but water-cement ratio should not exceed 0.50 and a minimum cement content should be specified, e.g., 550 lb per cu yd for structural concrete. If a sulphate-resisting cement is used, the minimum cement content may be lower, e.g., 475 lb per cu yd.

Where a considerable degree of attack is expected a sulphate-resisting cement should be used, with a maximum water-cement ratio of 0.50 and a minimum cement content of the order of 550 lb per cu yd.

For severe conditions a sulphate-resisting cement should be mandatory. Water-cement ratio should not exceed 0.45 and cement contents should be of the order of 600 to 625 lb per cu yd.

Placing and compaction techniques should ensure the lowest possible porosity or permeability. These can include the use of an air-entraining agent, which is generally a mandatory requirement for all concretes placed in highly sulphated soils. No admixture, however, will provide specific resistance to sulphate attack although it may improve workability and thereby density.

It is accepted that cements other than portland cement possess sulphate-resisting properties comparable or superior to a sulphate-resisting portland cement. The best known in Canada, and perhaps the only one now readily available, is high alumina cement. The relative advantages and disadvantages will not be considered in this discussion.

Metal reinforcement, when used, should be embedded not less than 3 inches from the surface, and not less than 4 inches at corners. Thin concrete sections are more affected by a given set of conditions than massive elements.

Impermeable coatings are recommended where conditions are particularly severe or where other precautionary measures are limited, although performance of such coatings applied many years ago indicates a rather limited lifetime. Present day bitumens, epoxies, and other organic coatings may show better performance. In any case, they can provide important protection, for example, where the water table is expected to fall during and after construction. They can also protect the concrete until it has matured and become more dense and less permeable. The latter consideration can be a very important one for such elements as culverts and buried conduits.

Concrete elements and structures that are to be exposed to possible sulphate attack should incorporate design features that provide intercepter drainage. Replacement of highly sulphated soils with well-drained granular fill should be general practice.

Structural elements already affected to a significant degree by sulphate attack can often be given extended performance by one or both of two methods. In some cases where sulphates are fed to the concrete by groundwaters, it may be possible to provide drainage systems and thus stop or reduce the reaction. It is often practicable, as for partly embedded supporting piers, to expose the affected concrete, clean away the deteriorated material, and rebuild with shotcrete concrete or other methods. This should be followed by waterproof coating.

Summary Statement

The rate and degree of sulphate attack depend on the concentration of sulphate present, the type and availability of the sulphate ion, the accessibility of water, and the type of cement and quality of concrete. Preventive measures include the following: use of sulphate-resisting cement, low water-cement ratio, minimum cement content, air-entrainment, waterproof coatings, drainage features, and special attention to reinforcing cover.