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Durability of Foundation Concrete in an Aggressive Environment

Durabilité du béton de fondation dans un environnement agressif

Dauerhaftigkeit von Betonfundationen unter aggressiven Bedingungen

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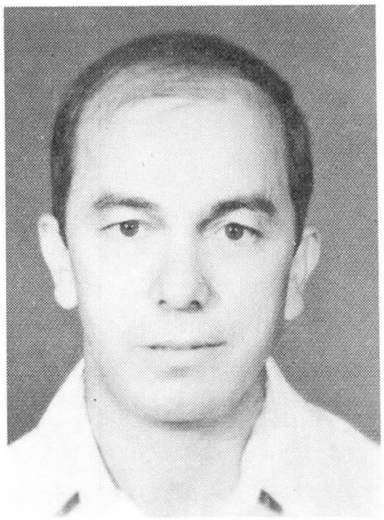

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SUMMARY

A case study assessing the durability of foundation concrete in the vicinity of the sea where a number of aggressive conditions exist is presented. The use of OPC compared to SRC is preferred when sulphates and chlorides coexist due to its high resistance to chloride diffusion. Durability of foundation concrete can be enhanced by a sacrificial layer all around and applying a waterproof coating.

RÉSUMÉ

L'étude évalue la durabilité d'un béton de fondation dans des conditions extrêmes d'agressivité dues à la proximité de la mer. L'utilisation de l'OPC est préférée à celle du SRC due à sa haute résistance à la diffusion chlorique lorsque des sulphates et chlorides co-existent. La durabilité du béton de fondation peut être augmentée par une "couche de sacrifice", ainsi que par un agent imperméable appliqué sur la fondation.

ZUSAMMENFASSUNG

Vorgestellt wird eine Fallstudie zur Dauerhaftigkeit von Betonfundationen in einer Region mit aggressiven Bedingungen in Meeresnähe. Die Verwendung von OPC ist dem SRC vorzuziehen, wenn Sulfate und Chloride gleichzeitig vorkommen, da Ersterer zu einem dichteren und weniger durchlässigen Beton führt. Die Dauerhaftigkeit der Fundamente kann durch eine "Opferschicht" von mindestens 50 mm Beton und durch einen wasserdichten Anstrich verbessert werden.

1. INTRODUCTION

This study is devoted to the assessment of durability of concrete foundations of overhead transmission line towers constructed in a number of aggressive conditions commonly met in Sebkha region. Environmental aggression to foundation concrete occurs due to: (a) Aggressive compounds in the sub-soil or ground water surrounding the concrete, and (b) Effect of wetting and drying.

For foundation concrete, the effects of aggressive compounds in sub-soil and ground water are more predominant. It is well known that chemicals in the dry state will not attack concrete; this applies particularly to sulphates as these are often found in the form of lenses in soil strata. The tolerable level of sulphate concentration in relatively dry, well drained soils is about four times the acceptable limit when the sulphates are in the form of a solution in ground water. In most soils, it is the concentration of aggressive chemicals in the ground water which decides the type of cement and the quality of concrete to be used.

All portland cement concrete is prone to acid attack. Some of the chemical compounds which may be encountered in ground water of Sebkha region and which are aggressive to ordinary portland cement are described below. Further, their effects on the durability of the concrete are also presented.

2. AGGRESSIVE CHEMICAL COMPOUNDS IN SEBKHA

2.1 Sebkha

The soil in Sebkha in the vicinity of sea is generally aggressive and is very little compacted. The ground water level is very near the surface and contains aggressive chemical compounds like sulphates and chloride in solution, and acids in various proportions. In winter the lowest parts of Sebkha form shallow lakes and in summer the ground dries out and hardens. Aggressive compounds in the subsoil and ground water surrounding the foundation concrete attack it by reacting with hardened cement paste. Attack on cement can thus take place, sulphates reacting with $Ca(OH)2$ and with calcium aluminate hydrate. The products of the chemicals reactions gypsum and calcium sulpho aluminate, have considerable large volume than the compounds they replace, so that the reaction with the sulphate leads to expansion causing tensile stresses which finally leads to cracking of concrete.

2.2 Sulphates in Solution in Ground Water

The most commonly found sulphates in Sebkha ground water are those of calcium, magnesium and sodium. Calcium sulphate is less soluble at normal temperatures than the other sulphates mentioned above; and the solution is saturated at about 2000 mg/litre of $SO3$.

Sodium and Magnesium sulphates are very soluble in water and therefore their concentration can be much higher than calcium sulphate. Magnesium sulphate is more aggressive to portland cement concrete than the sulphates of sodium, calcium and pottassium, when in equal concentration. Magnesium sulphate attacks calcium silicate hydrate as well as $Ca(OH)2$ and calcium aluminate hydrate and, decomposes the hydrated calcium silicates.

The rate of sulphate attack increases with an increase in the strength of the solution, but beyond a concentration of about 0.5% of Mg SO4 the rate of increase in the intensity of the attack slows down. If the w/c ratio is low, the deteriorating effect of sulphate takes much longer time.

The concentration of the sulphates is expressed as the number of parts by weight of SO3 per million (ppm). Conversion of SO4 to SO3 can be made as follows:

$$SO_3 = 0.83\ SO_4$$

A concentration of 1000 ppm of SO3 is considered moderately severe and 2000 ppm are severe especially if Mg SO4 is the predominant constituent.

In addition to the concentration of sulphate, the speed with which the concrete is attacked depends also on the rate at which the sulphate removed by the reaction with cement can be replenished. Thus in assessing the danger of the sulphate attack the movement of ground water has to be known. Alternating saturation and drying in Sebkha leads to rapid deterioration of concrete.

2.3 Chlorides in Solution in Ground Water

Chloride is generally present in ground water as a solution of sodium chloride (common salt). The chloride solution of high concentration can attack the cement paste. Chlorides in solution react with the calcium aluminate phase in the cement to form calcium chloro aluminate, and although there is a debate as to the precise mechanism involved, it is well known that in certain circumstances where there are high concentrations of chloride expansive disruption of the concrete can occur. However, the chloride salts are highly soluble and can be leacked from the concrete preventing their concentration.

2.4 Sulphates and Chlorides in Ground Water

It is however known that in the case of sulphates co-existing with chlorides in ground water, the latter inhibits the expansion of concrete [1, 2] and the question of sulphate attack is then considered less critical and the chloride attack becomes more alarming. Chlorides in ground water of Sebkha near the sea have a tendency to combine with a part of the C3A forming a "more or less insoluble chloro aluminate" [3].

It has been a common practice and is even today to use cement with low C3A content to overcome sulphate attack in concrete exposed to sulphates either soluble in ground water or present in marine environment. Among these cements are the sulphate resisting cement (SRC) where the C3A content is limited to a maximum of 3.5% by B.S. 4627 and the ASTM Cement V in which C3A is limited to a maximum of 5%. Recent research, however, indicates that concrete made with SRC has less resistance to chloride ingress (or migration).

2.5 Acids in Ground Water

When the pH of subsoil and/or ground water is below the neutral point of 7.0 the water is then acidic and is liable to attack concrete made with any type of portland cement. The severity of the attack depends upon a number of factors. The pH value is a measure of the intensity of the acidity, and by itself does not give any indication of the type or the amount of acid present.

3. DETERIORATION OF FOUNDATION CONCRETE IN SEBKHA

Solid salts do not attack concrete, but when present in a solution they react with hardened cement paste. Disruption of concrete mass may occur by the expansive reaction of voluminous crystalline salt formations, normally caused by the ingression of chloride and sulphate solutions. Erosion of materials by dissolution of the cement mainly due to the action of acids, if present, can take place. Chemical reactions can lead to the type of damage generally known as 'Concrete Corrosion'.

Foundation concrete below or near the ground water table are affected by chemical effects accompanied with alternative cycles of drying and wetting. When the water table is high the concrete becomes saturated and when it goes down, part of the water evaporates from concrete causing salts to crystallize. A subsequent rise in water level causes the concrete to saturate again with water containing higher concentration of salts. The recurrence of such a process in course of time causes crystal growth within the pores, if the concrete is permeable, resulting in swelling action leading to cracking of concrete. There is a limit to the size of cracks allowable for various types of exposure; these limits range from 0.1 mm for very severe environment to 0.4 mm for mild environment.

Maximum precautions must be taken to ensure crack free concrete in order to stop ingression of chlorides. Steel reinforcement is protected from corrosion by the surrounding concrete provided this concrete is dense and of adequate thickness. The corrosion potential of steel due to the presence of soluble chlorides in the ground water is increased in porous concrete which in turn can result from inadequate compaction, high w/c ratio and low cement content. In case of reinforced concrete, the migration of chloride ions from the ground water establishes anodic and cathodic areas, the resulting electrolytic action leads to an accumulation of the corrosion products on the steel which causes its expansion with a consequent rupture of concrete.

As mentioned earlier, the chloride solution of high concentration can attack the cement paste and expansive disruption of the concrete can occur. Fortunately, the chloride salts are highly soluble and can be leacked from cement preventing their concentration.

When sulphates co-exist with chlorides in ground water of Sebkha, the latter inhibits the expansion of concrete and the question of sulphate attack is then considered less critical and the chloride attack then becomes more predominant. The rate of diffusion of chlorides in SRC is more than in OPC. In the circumstances where chlorides coexist with sulphates and are in higher quality, the effect of chloride attack and subsequent corrosion of reinforcement is relatively increased by the use of SRC.

4. MEASURES TO ENHANCE DURABILITY OF FOUNDATION CONCRETE IN SEBKHA

In the light of chemical expansive reactions which are responsible for the deterioration of concrete in Sebkha containing aggressive water soluble salts in ground water as mentioned above, it is necessary to take some special precautions to protect the foundation concrete from cracking and corroding.

Protection against subsoil chemical action has to be preventive in nature because the affected areas of concrete in contact with the soil and the ground water are practically impossible to inspect after construction. The protective measures should obviate the need for maintenance and repairs and should serve as water proofing. Some of the preventive measures recommended are as follows:

- Use of cement low in C3A. In practice, it has been found that a C3A content of 7% provides an approximate border line between cements of good and poor performance.
- Where chloride and sulphates co-exist with a large quantity of chlorides, use of OPC should be preferred over SRC.
- Use of a dense, impervious and high strength concrete.

5. CASE HISTORY

A doubt regarding the durability of concrete consisting of OPC of overhead transmission towers foundation in Sebkha area necessitated an investigation into chemical aggressiveness of Sebkha. Results of the chemical analysis of a water samples conducted by Raymond International of Deleware Inc. (Tripoli branch) in April 1978 are presented below:

Sample No. 1/W/3.0; Site: Misurata Sebkha.

Chemical Analysis

pH	=	7.3
Chlorides	=	80250 mg/l
Hardness as $CaCO_3$	=	23600 mg/l
Calcium	=	900 mg/l
Magnesium	=	5200 mg/l
Sulphates	=	9200 mg/l

A proper chemical analysis demonstrated that first $CaSO_4$ will be formed consuming 1500 mg/l of sulphates necessary for a saturated solution of calcium sulphate. The remaining sulphate (9200 - 1500 = 7700 mg/l) will react with (7700 x 0.253) 1948.1 mg/l of magnesium forming maximum possible amount of $MgSO_4$. The balance magnesium will either react with the chloride or will remain in the ground water in the form of hardness. Hence, all magnesium available will not react to form $MgSO_4$ which is more aggressive to portland cement concrete than the sulphates of sodium, calcium and pottassium when in equal concentration.

It is well known that in addition to the concentration of sulphates, the speed at which foundation concrete is attacked depends upon the rate at which sulphates removed by reaction with cement can be replenished. Thus the movement of ground water plays a key role since alternating saturation and drying leads to rapid deterioration of concrete. Most of the tower foundations were either in the submerged state or in a dry state, hence the effect of ground water movement with less variation was considered less serious.

Normally, SRC should be used when sulphates in higher concentration are present. But this recommendation is not obligatory when sulphates and chlorides co-exist in the ground water since the later inhibit the expansion of concrete and the question of sulphate attack is then less critical. Recent research [4] has indicated that SRC has poor resistance to chloride ingression as compared to OPC. Therefore the use of OPC in the present circumstances was considered more acceptable than SRC provided other precautions for concrete in Sebkha are also taken into design consideration.

6. CONCLUSIONS AND RECOMMENDATIONS

- Durability of concrete foundations in Sebkha can be ensured with the following precautions:

  a) Adequate concrete cover to the reinforcement. 50 to 75 mm concrete cover is recommended.

  b) Provision of a sacrificial concrete layer (minimum thickness 50 mm) all around the foundation concrete.

  c) Use of a dense, impermeable and high strength concrete is made.

- Although SRC is generally recommended for use in foundation concrete in Sebkha; but when sulphates and chlorides co-exist, in ground water, the use of OPC can be preferred over SRC due to its higher resistance to chloride ingression.

- A coating of a water proofing material around the foundation concrete will enhance the durability.

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