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Longtime Studies and Field Experiences with Sulfate Attack

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Synopsis: Sulfate attack on concrete has long been studied and measures taken to combat sulfate attack. Therefore, damage due to sulfate attack is not prevalent today. Illustrations are given to show damage which results when preventive measures are not taken. Tests results are reviewed which led to preventive measures being taken, such as low C_3A cements, use of pozzolans, and low water to cement ratio concrete.

Keywords: aggregates; asbestos-cement products; concrete durability; concrete pipe; fly ash; long-time study; pozzolans; sulfate attack; sulfate resisting cements; tests; water cement ratio.

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INTRODUCTION

Sulfate attack on concrete has been studied almost as long as we have known portland cement. About 60 years ago, we learned that cements low in tricalcium aluminate resisted sulfate attack, and as a result in about 1940, ASTM developed a specification for sulfate resisting cement known as Type V. About the same time, we also learned that many pozzolans were beneficial in making concrete resistant to sulfate attack.

DETERIORATION OF STRUCTURES CAUSED BY SULFATE ATTACK

When I am asked to show someone a structure that has deteriorated due to sulfate attack, I am hard pressed to find good examples for them to see. For 40 years, we have been building our structures to resist sulfate attack, and the older structures that did deteriorate have now been replaced. When you add this to the fact that probably well over 90 percent of the concrete in the United States is not exposed to sulfate attack, it is not hard to understand why most people today have never seen sulfate attack. It is becoming very hard to convince people who have never seen sulfate attack that it is necessary to use premium-price, hard-to-get Type V cement. It is hard to justify why a particular pozzolan, which must be shipped 1,000 miles, should be used instead of a similar pozzolan available at a 50-mile distance.

A few examples from past years may serve to illustrate that sulfate attack on concrete is real and show what can happen when preventive measures are not taken because they cost a little more.

Figure 1 shows total loss of concrete from sulfate attack on White Wood Creek Bridge columns on our Belle Fourche Project in South Dakota. On this project, water samples have shown sulfate concentrations as high as 9,900 p/m.

Figure 2 shows a concrete-lined irrigation ditch on our San Luis Unit of the Central Valley Project in California. The concrete is in an extreme state of deterioration due to sulfate attack. The concrete was made with Type I cement and was 5 years old when the photograph was taken.

Figure 3 shows a test plot on our Uncompahgre Project in Colorado. Data are not available on this test plot, but the effect of sulfate on the concrete pipe specimens is quite obvious. The concrete was 20 years old at the time of photograph.

Figure 4 shows a slab on grade near our Coachella Project in southern California. Distress in the concrete caused by expansion due to sulfate attack caused abandonment of the project after about 3 years.

Figure 5 is a concrete drop structure on our Riverton project in Wyoming. In this location, the ground water is high so that seepage runs over the top of the concrete. The structure was 14 years old at the time of the photograph.

I hope these figures have served to illustrate that sulfate attack can be very severe and is also widespread throughout the western United States.

One difficulty in protecting against sulfate attack is locating the potential problem areas. Sulfates may be general over an area but more frequently appear as localized severe concentrations. Intermittent samples along the alinement of a pipeline, canal, or transmission line may not reveal localized areas of high concentrations of sulfates. Three choices are presented: (1) very extensive testing for sulfates; (2) construct the entire canal, pipeline, or all transmission tower footings of sulfate resistant concrete; or (3) construct for moderate resistance and take a calculated risk that isolated sections may have to be replaced at some future time.

TYPES OF STRUCTURES SUBJECT TO ATTACK

It is usually structures such as canals, pipelines, transmission tower footings, and highway pavements that are subjected to sulfate attack. One major structure of a different type that serves as an example is Alcova Dam (fig. 6). Alcova Dam is a 265-ft-high earthfill dam on the North Platte River in Wyoming. Construction of the dam was started in 1935 and completed in 1938. This dam has a concrete-lined open channel spillway in the left abutment. Over the years, progressive deterioration of the concrete in the spillway floor resulted in severe spalling and erosion. In 1967, steps were taken to repair the spillway. Because of the extent of the deterioration, cores were taken from the spillway for examination as to possible causes (1). The compressive strength of the concrete was still quite good with an average of 5,890 lb/in^2. However, the tensile strength was only 2.2 percent of the compressive strength and the modulus of elasticity (2.53 million lb/in^2), only about one-half of the expected modulus. Under petrographic examination, the concrete showed alteration products of sulfate attack. White deposits of calcium sulfoaluminate (ettringite) were present in moderate amounts scattered throughout the broken surfaces of the samples and in some of the pebble sockets. Some deposits of silica gel were also visible but generally concentrated around only a few pebbles. In contrast, concrete from the spillway walls was sound and showed no evidence of sulfate attack. A spring originates from the hillside left of the spillway and flows toward the downstream end of the structure for a short distance and disappears into the ground. Chemical analysis of the spring water showed a soluble sulfate content of 1,370 p/m. Other ground water in the area had high enough soluble sulfates to exert a positive attack. It was concluded that the deterioration could be primarily attributed to sulfate attack.

CONCRETES RESISTANT TO SULFATE ATTACK

A test program conducted in the 1950's (2) evaluating the effect of sulfate exposure on the mechanical properties of concrete developed the same basic conclusion of previous investigations; namely, that the lower the percentage of tricalcium aluminate (C_3A) in the cement, the better would be the concrete resistance to sulfate attack (fig. 7). The exposure condition for the test data shown in figure 7 was a laboratory accelerated test in which concrete specimens were alternately soaked 16 hours in a 2.1 percent solution of sodium sulfate at approximately 73 °F and dried 8 hours in air, under forced draft, at 130 °F. This program also reflected that an increase in cement content increased the sulfate resistance of the concrete for all types of cements. This is perhaps better illustrated by these curves (fig. 8) from a different test program (3). Concretes with water to cement ratios of 0.45 require about twice the time to produce failure as comparable concretes at 0.65 water to cement ratios.

There is one limiting factor in the use of figures 7 and 8. Cements with zero C_3A have not shown greater resistance to sulfate attack than cements having around 3 percent C_3A. Therefore, any extrapolation of these curves below 3 percent C_3A is not valid.

Calcium chloride is frequently added to concrete during cold weather concreting to accelerate early strength. However, our test data indicate that calcium chloride added to concretes containing Types II and V cements reduces their ability to resist sulfate attack (4). Our specifications at the present time do not permit the use of calcium chloride with Type V cement.

Many pozzolans have been found that can effectively double the service life of a concrete when exposed to sulfate attack (fig. 9) (5). The composition of the pozzolan that causes it to increase or decrease the resistance of the concrete to sulfate attack is not fully understood, but in general terms it appears that low calcium pozzolans perform best in sulfate environments. Most natural pozzolans meeting the requirements of ASTM specification C 618 for class N pozzolans are effective in resisting sulfate attack as are most fly ashes meeting ASTM C 618 class F requirements. Fly ashes meeting class C requirements should be individually evaluated if subjected to sulfate exposures.

SULFATE RESISTANCE OF ASBESTOS-CEMENT PIPE

The failure of an asbestos-cement pipeline near Ordway, Colorado, due to sulfate attack after only 13 years of service led to studies of asbestos-cement pipe products. It was found that asbestos-cement pipe which had been water cured followed the same resistance pattern of other concretes. However, asbestos-cement pipe which had been autoclave cured (high-pressure steam cured) showed good resistance to sulfate attack regardless of the type of cement used in the pipe. Therefore, a specification requirement that the pipe shall have less than 1 percent uncombined calcium hydroxide will assure an autoclave cure and a sulfate resistant pipe. Tests on specimens from asbestos-cement pipe are difficult to conduct and evaluate. Sawed specimens tend to delaminate when placed in sulfate solutions. Expansion measurements, therefore, reflect any expansion due to delamination as well as the expansion that results from sulfate attack.

EFFECT OF AGGREGATES CONTAINING SULFATES

Occasionally aggregates are proposed for use that contain significant quantities of sulfate in various forms. Some of these produce a self-contained type of sulfate attack when the concrete is exposed to moisture. Mortar bar tests using the mineral alunite (a hydrous potassium aluminum sulfate) as aggregate suffered extensively from sulfate attack when kept moist (6). On the other hand, a jarositic (potassium iron sulfate hydrate) sandstone did not show significant expansion during 24 months of moist sealed storage at 100 °F. At this time, we have no criteria for acceptance of sulfate bearing aggregates. When they occur, each one must be evaluated individually in moist storage for self-induced sulfate expansion.

TESTS OF CONCRETE PIPE

Perhaps our biggest disappointment in sulfate testing occurred in a joint testing program with the American Concrete Pipe Association. The test pipes were made at a pipe production plant and specimens sawed or drilled from the pipe were shipped to our laboratory in Denver for testing and evaluation. Test variables included 5- and 7-bag cement contents; 0 and 20 percent pozzolan using both a fly ash and a natural pozzolan; concrete of low, medium, and high absorption, and pipe made by packerhead and spinning processes. All of the pipe tested showed poor resistance to sulfate attack, regardless of the method of manufacture or combination of cementitious materials used. Instead of having all the answers as to how to make concrete pipe that will withstand sulfate attack, we were left with the conclusion that no matter how we made it or what materials were used, we could not make a concrete pipe with any degree of resistance to sulfate attack. We were not willing to accept this conclusi and since any explanation was purely speculative, a report was never published.

TYPE OF SULFATE EXPOSURE

Soil samples taken from areas around our convention site here in Las Vegas show very high soluble sulfate contents. Therefore, our construction specifications in this area require not only a Type V cement but also a good sulfate resistant pozzolan. There is some question as to whether this degree of protection is necessary because the sulfates encountered in this area are calcium sulfates. The calcium sulfates have a solubility of only 2,000 and 3,000 p/m. Even though the total sulfates available from soil samples are very high, will the low solubility of these calcium sulfates ever expose the concre to the same severity level as the more soluble sodium sulfates? Until we have a more conclusive answer, we will probably continue to specify a Type V cement plus a sulfate resistant pozzolan.

LABORATORY RESULTS CONFIRMED BY FIELD EXPOSURE

From 1951 to 1971, Interpace Corporation maintained a fiel exposure test plot near Fort Collins, Colorado (7). This site was selected because of severe sulfate attack on a concrete pipeline in this area. We had a great interest in this test plot and, since it was convenient to our laboratory and remote from Interpace's laboratory, it was to our mutual benefit that we participate in all the evaluations. Figure 10 shows the beginning of excavation to retrieve test specimens. The ground water in this area is high so that at all times there was enough moisture present to sustain sulfate attack. Figure 11 shows some of the test specimens removed from the pit after they were washed and brushed. Test specimens included cast cylinders, concrete pipe sections, irregular pieces of larger diameter concrete pipe, and even a few pieces of metal pipe. Figure 12 shows mortar lining and coating specimens from the test plot.

I believe it is significant that results from this test plot tend to verify our laboratory tests. Concretes made with Type I cements and concretes with very high absorptions are reduced to rubble in the same length of time in actual field exposure as in laboratory tests. It is also noted that nearly all specimens in the plot showed some signs of attack. On this basis our present requirements for sulfate resistant concrete are not considered to be excessively conservative. A disturbing result is the degree of attack shown by the mortar coating samples. The cement content of mortar coatings was expected to make them more resistant than indicated in these tests.

SUMMARY

I hope these illustrations show that sulfate attack is real. However, procedures have been developed and used that make concrete resistant to sulfate attack. Primarily these procedures are the use of cements with low tricalcium aluminate content, concrete made with low water to cement ratio, and the addition of certain pozzolans to the concrete. Much of this testing was being performed during the same time period George Verbeck was conducting investigations into the sulfate resistance of concrete and these data support the conclusions set forth by him (8).

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Fig. 1--Sulfate attack on bridge columns. White Wood Creek, Belle Fourche Project, South Dakota

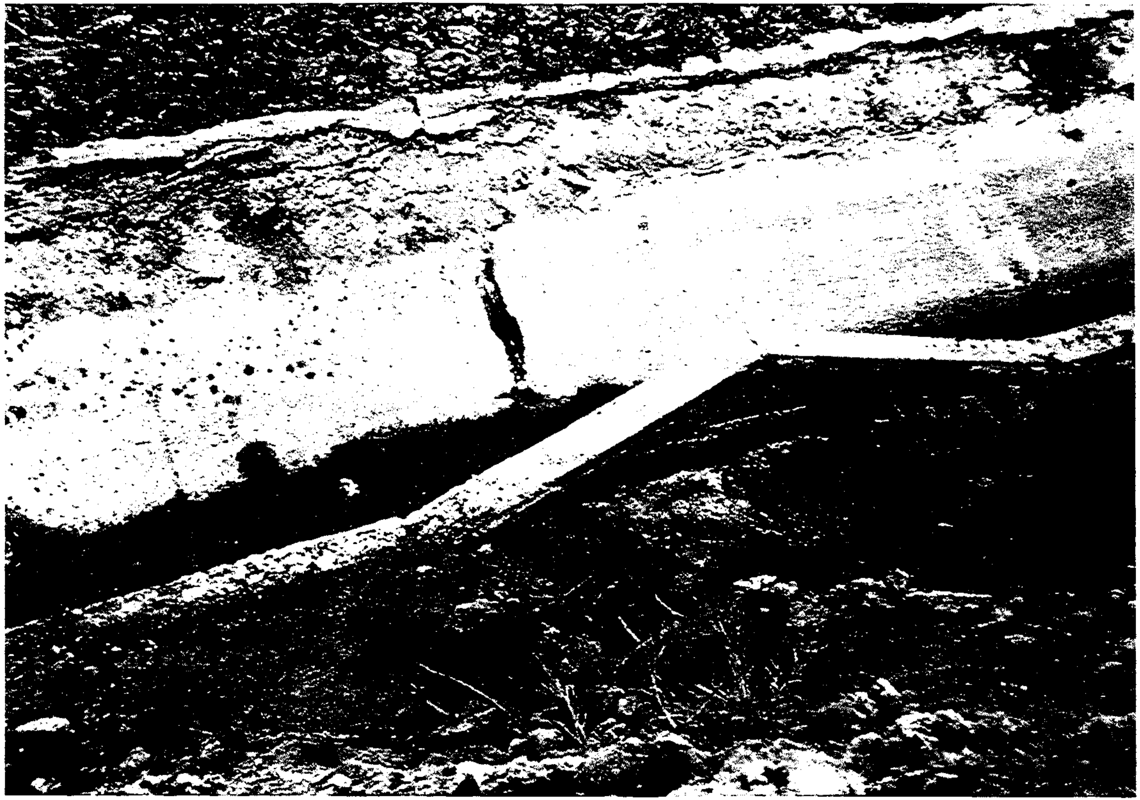

Fig. 2--Sulfate attack on concrete canal lining. San Luis Unit, Central Valley Project, California