SP 64-1

The Future of Expansive Cement

By Bryant Mather

Synopsis: The future of expansive cement depends on a realization by cement users that there are circumstances where the best cement to use is one that expands. If there is an awareness that it is the optimum product for certain uses then it will be made available and its future will be assured.

Keywords: cracking (fracturing); economics; expansive cement concretes; expansive cements; marketing; research.

Honorary ACI member Bryant Mather is Chief, Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. He served as president of ACI in 1964, and received the Henry C. Turner Medal from ACI in 1973. He is currently chairman of ACI Committee 308, Curing Concrete.

INTRODUCTION

I had the honor of knowing--and to some extent at least--working with both Alex Klein and Cedric Willson--from as far back as before either one of them was involved with expansive cement. I was selected to prepare this paper because I previously prepared and presented a luncheon address at the Expansive Cement Symposium at Berkeley in 1972.(1) Anyone who has been bold enough--or fool enough--to stand up at a cement symposium and preach a sermon on expansive cement was presumably regarded as bold enough--or fool enough--to speak on "The Future of Expansive Cement".

On one previous occasion--the 1970 ASTM Marburg Lecture (2)--I made predictions about the future of cement; I said:

> I believe that the next two major areas for development, innovation, and improvement in specifications for portland cement will be to provide assurance (1) of greater uniformity of behavior and (2) that the cement will perform more uniformly in concrete with the selected kinds of admixtures with which it is used.

That was 7 years ago. You can each judge for yourself the probability that any part of that prediction has been or will be realized and perhaps then weigh accordingly the rest of these remarks.

USES OF EXPANSIVE CEMENT

I submit that expansive cement is a product that should be used when it is an advantage to the user of the cement to have a cement that expands. The problem the maker and marketer of expansive cement faces is how to convince the cement user that it is to his advantage to have a cement that expands. He can read ACI SP-38 (3) or any of a lot of other literature--but will he?

This problem is compounded in two ways. First: For many years in the past, in the present, and in the future, one criterion of acceptability of cement and hence one basis of its rejection as unsuitable for use has been, is, and will be a test for expansion--

if, when so tested, it expands appreciably it is, by definition "unsound" and unfit for use. Second: The phenomena that make expansive cement expansive are phenomena that are well known to be evil--and have been so recognized for a long time. This is why in my 1972 remarks in Berkeley (1) I took as one of my texts the words of the prophet Isaiah in Chapter 5, verse 20, of his prophesy: "Woe unto them that call evil good and good evil".

However it has also been recognized that there is a problem of cracking of concrete after hardening and that this problem is contributed to by many different factors--cooling, drying, and bending, among them. Cooling causes contraction; drying causes shrinkage; contraction, shrinkage, and bending all cause tension, which if in excess of the tensile strength, causes cracking. If the contraction on cooling, the shrinkage on drying, and the tension on bending can be compensated for by a prior expansion then we have a potentially powerful tool to fight cracking. It is however not the only available tool. For many purposes for which concrete is used, the members are of such dimensions and produced in such ways, that problems of cooling contraction and drying shrinkage do not arise. In somewhat different situations only relatively simple and economical measures to maintain a satisfactory moisture and temperature regime (called curing) suffice to prevent problems of cracking due to cooling and drying. In still other cases mechanical prestressing provides a satisfactory and economical solution.

Thus the question of "uses of expansive cement" devolves not merely on what it can do but on when can it do what it can do more economically than alternative methods of achieving the same goals. This is where the engineering skills come into play. The bidder who, by using expansive cement, comes up with a more economical means of accomplishing a concrete construction, will be the low bidder and hence the contractor and reap such profit as results from the job.

The foregoing scenario assumes that there has been a realization of the primary facts. First that more is needed in construction than mere absence of failure, and second that success involves locating and using a solution that rather closely approaches optimum. To do this it is essential that the concrete to be provided for use in a construction be considered from the standpoint of the desired performance of the system of which the construction is a part, the performance of the construction of which the concrete *is a part and,* finally, the performance of the concrete itself in the environment of service. If concrete fails to give satisfactory service it is either because the specifications were defective or they were not complied with. (4)

The role of expansive cement is to provide under appropriate circumstances a concrete that has appropriate levels of relevant properties so that when it interacts with the environment of service the concrete performance contributes desirably to the performance of of the system of which the concrete is a part (Fig. 1).

AVAILABILITY OF EXPANSIVE CEMENT

The forces that act upon a manufacturer of hydraulic cement that ultimately determine which products are produced at a given manufacturing plant are myriad in number, complex in nature, and ever-changing in importance. Air pollution, energy costs, raw material costs, market demands, are merely the more obvious. Few are the cement manufacturers who are prepared today to come to the market with a new or different product. Few indeed are the cement producers who are willing aggressively to promote a product even if they are convinced of its usefulness. In the USSR last fall, at each laboratory I visited I kept being asked about regulated-set cement, a product invented in the United States, which once was being produced by a number of companies, but which, so the Soviet scientists had heard, is not produced widely any longer. Why not, what is wrong with it? If, in reply, one speaks of market demand, they look blank. If it's a good product it should be made and used for those purposes for which it is good. But a producer will not make regulated-set cement available, nor will he make expansive cement available, unless he is satisfied there is a market for the product.

FUTURE OF EXPANSIVE CEMENT

Having spoken in a general way of uses and availability; I now turn to the future--and the conclusion is obvious. If the awareness of the uses permeates the users, the users will create the demand, which will, in turn, cause the producers to make the product available; or so the principles of capitalism say. But who is it that causes the awareness of the uses to permeate the users? Do designers get taught in engineering schools about the benefits of using expansive cements? Do the building codes provide for differences in design when it is used? If not, why not? If expansive cement is truly the better mousetrap why isn't the path to the cement plants that make it a path to every cement plant in the world? In the USSR I formed the opinion that expansive cement was not as widely used as one might expect in view of the longer period during which it has been under development there. It seemed to me that everybody else was sort of waiting for Professor Mikhailov to do it all. This is not, I believe, the sort of problem we have. I believe our problem is merely one of inertia. Not only are there few cement producers who are willing to promote a product other than the most ordinary, but there are few specifiers who are willing to permit use of products other than the most ordinary. I believe that this will change and it <u>must</u> change. As we move, throughout the world, to a period of materials and energy shortages we must learn to use energy and materials more efficiently. When we begin more aggressively to seek more efficient solutions to engineering design problems we will, of necessity, find that special products have their roles to play in specific situations where they can do the job that needs to be done with maximum efficiency--which means minimum cost. Then where the user needs a cement that will expand, he'll know that's what he needs, he'll demand it, he'll get it, and he'll be happy--and the future of expansive cement will be assured.

REFERENCES

1. Mather, Bryant, 1972, "Some Reflections on Expansive Cement Concrete", Proceedings, Symposium on Expansive Cement Concrete, University of California, Berkeley, 22-23 June 1972, 5 pp.

2. Mather, Bryant, 1970, "Portland Cement Concrete - Research, Testing, and Performance", ASTM Journal of Materials, V. 5, No. 4. pp. 832-841.

3. Test, C. Taylor, Symposium Chairman, 1973, "Klein Symposium on Expansive Cement Concretes", ACI SP-38, 491 pp., Detroit, Michigan.

4. Mather, Bryant, 1972, "Relating Materials Quality to Materials Performance to Structural Performance of Concrete", Proceedings of the Joint RILEM-ASTM-CIB Symposium on the Performance Concept in Buildings, National Bureau of Standards, Special Publication 361, V. 1, pp. 719-724.

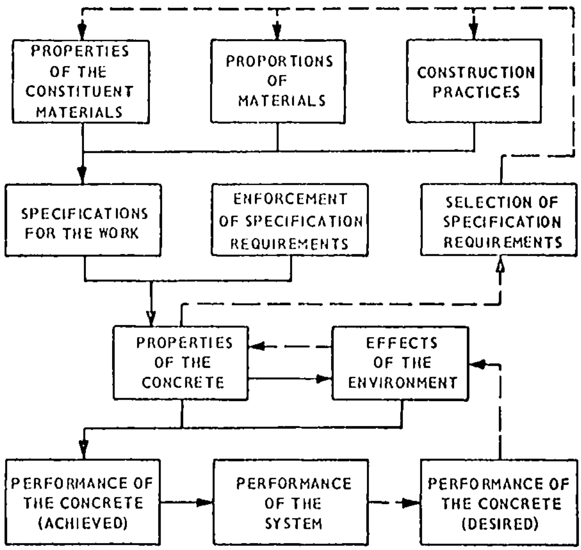
PROPERTIES OF THE CONSTITUENT MATERIALS
PROPORTIONS OF MATERIALS
CONSTRUCTION PRACTICES
SPECIFICATIONS FOR THE WORK
ENFORCEMENT OF SPECIFICATION REQUIREMENTS
SELECTION OF SPECIFICATION REQUIREMENTS
PROPERTIES OF THE CONCRETE
EFFECTS OF THE ENVIRONMENT
PERFORMANCE OF THE CONCRETE (ACHIEVED)
PERFORMANCE OF THE SYSTEM
PERFORMANCE OF THE CONCRETE (DESIRED)

Fig. 1

SP 64-2

Hydraulic Structures Designed with Shrinkage-Compensating Concrete

By Joe V. Williams, Jr.

Synopsis: A brief description of the scope of shrinkage-compensating usage in various types of hydraulic structures is given. Effects of shrinkage-compensating concrete on reduction of drying shrinkage stresses, cracking, and water stops as potential points of leakage are discussed. Design considerations by some engineering firms with respect to shrinkage reduction, particularly in circular tanks, are outlined. Construction advantages, such as higher slumps, ease of placement, reduced honeycombing, and larger placement areas are covered. Durability factors such as freezing and thawing, deicer scaling, abrasion, and sulfate exposure are compared with portland cement concretes.

Keywords: concrete construction; cracking (fracturing); drying shrinkage; expansive cement concretes; freeze-thaw durability; hydraulic structures; seepage; shrinkage-compensating concretes; sulfate resistance.

ACI member Joe V. Williams, Jr. is presently Architectural Marketing Manager, Cement Division, Texas Industries, Inc., Arlington, Tex. He holds a BSCE degree from Southern Methodist University and is a member of ACI Committee 223, Expansive Cement Concretes and 350, Sanitary Structures. He is a registered engineer in Texas and a member of ASCE and ACI.

INTRODUCTION

The first known use of shrinkage-compensating concrete in hydraulic structures was an addition to a water treatment plant in Atlanta, Georgia in 1968, followed closely by a new water treatment plant in Midland, Tex. Since then several hundred similar structures have been completed with an ever-increasing number under construction or in the design stage.

Most all types of hydraulic structures have been constructed with shrinkage-compensating concrete. They include cooling tower basins, swimming pools, water storage tanks, walls and foundations for digesters, clarifiers, stilling basins, pump stations, outlet works, spillways, and some experimental work on a lock and dam by the U.S. Army Corps of Engineers.

LEAKAGE

Hydraulic structures are usually constructed to last for an indefinite period time, and as a result, a certain amount of conservation is exercised in the design. However, in addition to a long service life, the most important function of a hydraulic structure is its ability to contain the fluids for which they are intended without leaking.

Barring a structural failure, the primary sources of leaks are at waterstops, usually due to faulty construction, and from cracks caused when the tensile strength of the concrete is exceeded by excessive drying shrinkage in the concrete. Leakage at waterstops can be prevented by proper attention to detail in design and closer inspection during construction. Drying shrinkage cracks, however, are more difficult to control and add further cost to the structure when a more conservative design approach is used.

Some engineers are rather philosophical about cracks in concrete, believing that some will always occur no matter what precautions are taken. Others are more concerned and take extra care in their design in an effort to reduce cracking and subsequent leaking. In any case, leakage in hydraulic structures presents an unsightly appearance and tends to cast doubt on the structural integrity of the element where it occurs. The engineer must explain the cause of the leakage, and the contractor will usually have to bear the cost of repairs satisfactory to the owner.

EFFECT OF SHRINKAGE COMPENSATING CONCRETE

Research work at the Portland Cement Association laboratories on walls and slabs, the main components of hydraulic structures, demonstrate the advantage of shrinkage-compensating concrete over portland cement concrete. Pfeifer (1) concludes that "when companion walls were compared, the flexural cracking strength of the expansive cement specimen was always greater than the comparable Type I specimen. These flexural tests illustrate the advantageous effect of induced concrete compressive stresses caused by restrained expansion which minimize concrete tensile stresses caused by restrained drying shrinkage". Russell (2) states in his research on slabs that "some of the problems associated with the cracking or excessive deformation of reinforced concrete structures can be attributed to strains caused by shrinkage of concrete. Performance can be improved by either reducing shrinkage to a more acceptable level or eliminating its effects completely. A properly used shrinkage-compensating concrete achieves this. In this type of concrete, expansion takes place during the early hardening period and offsets subsequent shrinkage strains".

Thus the use of shrinkage-compensating concrete has enabled engineers to increase concrete placement sizes and thereby reduce the number of water stops as potential leakage sources. At the same time, the size and frequency of cracks have been reduced, or in many cases completely eliminated. The growing acceptance of shrinkage-compensating concrete in hydraulic structures in the United States would indicate that less leakage occurs when it is used.

DURABILITY

Still another consideration in hydraulic structures is the durability of the concrete. As stated before, length of service under extreme weather conditions and other outside influence is most important. Such durability can and is being obtained with shrinkage-compensating concrete. Recommendations of ACI Committee 223 (3) state that shrinkage-compensating concretes made with expansive cements are equally resistant to freezing and thawing, and deicer scaling and abrasion as portland cement concretes of the same water-cement ratio, when properly designed and adequately cured.

In many instances, hydraulic structures are subjected to sulfate exposure, and either Type II or Type V portland cement concrete is then used. When shrinkage-compensating concrete is used under sulfate exposure conditions, a check of the chemical properties should be determined. Some shrinkage-compensating cements made with Type I portland cement may be undersulfated with respect to the aluminate available. As a result, the concrete could be susceptible to further expansion and deterioration after hardening when exposed to an external source of additional sulfates. Shrinkage-compensating cements made with a Type II or Type V portland cement clinker, however, when adequately sulfated, produce concretes having sulfate resistance equal to, or greater than, concrete made of the same type portland cement (4).

DESIGN CONSIDERATIONS

An increasing number of engineers are also utilizing the advantages of shrinkage-compensating concrete in their design procedure. For example, circular concrete tanks are most often designed by methods recommended by the Portland Cement Association. (5) The concrete stress due to ring tension is determined from the equation

$$f_c = \frac{CE_sA_s + T}{A_c + nA_s}$$

where C is the coefficient for shrinkage with an assumed value of 0.0003. When using shrinkage-compensating concrete, some engineers are reducing this coefficient in varying amounts to as much as zero. Depending on the configuration of the structure involved, a reduction in wall thickness can sometimes be achieved.

Other design advantages with shrinkage-compensating concrete are larger placement areas and fewer joints, as mentioned previously, and a possible reduction in reinforcement for drying shrinkage purposes.

A Dallas-based firm has another approach. When using portland cement concrete in circular structures, the allowable tensile stress due to ring tension is limited to 250 psi. When shrinkage-compensating concrete is used, the allowable tensile stress is increased to 350 psi.

CONSTRUCTION

This same firm currently has under construction a large waste water treatment facility near Dallas for the Trinity River Authority. When completed, the plant will have a capacity of 100 mgd with 96% removal of influent impurities. It will be capable of 250 mgd with a removal of 70% of the impurities, about the national average.

The project is actually an enlargement of an existing outmoded facility using open lagoons. Construction was scheduled in three phases: Interim, Phase I, and Phase II.