MISCELLANEOUS PAPER NO. 6-796

SYMPOSIUM ON CRACKING OF CONCRETES, CRACKING INDUCED BY ENVIRONMENTAL EFFECTS

by

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March 1966

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FOREWORD

The 62nd Annual Convention of the American Concrete Institute (ACI) to be held in Philadelphia, Pennsylvania, 7-11 March 1966, will feature a Symposium on Cracking of Concrete arranged by a committee chaired by Mr. Robert E. Philleo, Office, Chief of Engineers. One of the ten presentations will be based on the attached manuscript.

This manuscript was submitted to the Office, Chief of Engineers and approved for presentation and publication. It will be submitted to the ACI for publication in the Proceedings of the Symposium. The paper was prepared under the direction of Mr. Thomas B. Kennedy, Chief, Concrete Division.

Colonel John R. Oswalt, Jr., CE, was Director of the Waterways Experiment Station during the preparation of this paper. Mr. J. B. Tiffany was Technical Director.

Symposium on Cracking of Concretes

Cracking Induced by Environmental Effects

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SYNOPSIS

When concrete cracks as a result of its interaction with its environment and the cracking is an undesirable feature of the history of the concrete, the occurrence represents the consequences of an imperfect choice in selecting the particular concrete that was produced for service in the environment in which it was used. Six phenomena that bring about environmentally induced cracking are mentioned: expansion due to the use of unsound cement, the alkali-silica reaction, sulfate attack, corrosion of embedded metal, freezing and thawing, and plastic shrinkage. In all of these phenomena, environmentally induced moisture movements are primary participants in the phenomena that may cause cracking. In each case the environmentally induced cracking that these phenomena may produce can be avoided by giving appropriate attention to the properties of the environment and their anticipated interaction with the properties of the concrete and thus including in the specifications for the work appropriate requirements for materials properties, proportions of the materials, and construction practices, and by insuring strict enforcement of the specification requirements selected.

Symposium on Cracking of Concrete

Cracking Induced by Environmental Effects*

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From a review of the titles of the papers being presented by the other contributors to this symposium, it is possible to form a fairly good idea of what my paper is not about. It should not concern itself with the difficult problem of definition of what is a crack; with microcracks; with cracks in reinforced concrete due to external loads; with prevention of temperature cracks in mass concrete; with the general questions of control of cracking in reinforced concrete or pavements; or with the use of random fibers to prevent or control cracking. We are, therefore, at this point in the program concerned with cracks larger than microcracks, which I will assume to be cracks that can be seen with the naked eye, that somehow form in concrete because of conditions that might not be as they are if the concrete that cracked had been somewhere else.

I will further assume that the cracks with which we are here concerned are not desirable or beneficial and hence are manifestations of some sort of interaction of the concrete with its environment that we would be happier about if it had not taken place to the degree that it did. Our concern, therefore, is with discovering why the interaction that induced the crack took place, in part so that we may be able to modify either the concrete or

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*Prepared at the request of Mr. Robert E. Philleo, Chairman, ACI Ad Hoc Committee on Cracking of Concrete, for presentation at the Symposium on Cracking, American Concrete Institute Convention, Philadelphia, Pa., March 1965, and for inclusion in the Proceedings of that Symposium.
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its environment or both in ways that will tend to avoid the interaction that induced the crack. In fig. 1 a diagram is shown that is intended to indicate that the tendency of concrete to undergo environmentally induced cracking results from an interaction between the properties of the concrete and the properties of the environment. It is also intended to indicate that the properties that the concrete actually possesses when it interacts with its environment are the result of an interaction between the specifications under which the concrete was produced and the mechanisms that were provided for enforcing these specifications. The principal relevant aspects of what was specified are indicated to be the properties of the materials used, the proportions of these materials, and the construction practices employed. It is finally indicated that the selection of what to specify in respect to materials, proportions, and construction practices is properly based on due consideration of the properties of the environment in which the concrete to be made must render the service to be expected of it.

I suggest that every environmentally induced crack as here defined represents the consequences of an imperfect choice in matching the concrete selected for use in a given environment with the characteristics of that environment. In many cases the fact that the choice was imperfect was known to those who were required to make the choice and the selection was made in spite of such knowledge due to compelling considerations of cost or by the assumed practical unavailability of concretes better matched to the environment. In other cases, no such awareness existed; those who selected the particular concrete did not appreciate that it was likely to crack when it interacted with the environment in which it was to be used.

In these considerations it is also desirable to differentiate between normal environmental effects and abnormal effects, in much the same way that design or service loads are distinguished from abnormal loads such as might be induced by catastrophic occurrences. Most environments in which concrete is normally used do not involve exposures to extremely low or extremely high temperatures, and it will seldom be practical to provide concrete that will resist the tendency to crack under normal environmental conditions and also be assured of not cracking when subjected to extremely severe abnormal conditions.

There are a number of environmentally induced mechanisms that cause cracking in concrete that have been sufficiently thoroughly studied so that not only is the mechanism rather well understood but also the means of avoiding the consequences of the mechanism are readily available. When cracking does occur from such mechanisms, it merely indicates failure to specify what should have been specified or failure to obtain what was specified. Such mechanisms include those to be discussed in the following subparagraphs.

a. Concrete may crack due to internal expansion caused by reaction of moisture with unhydrated calcium oxide or magnesium oxide that was introduced into the concrete as a part of the cement. This will not happen if the cement used is sampled, tested, and inspected to insure compliance with current specifications which limit the allowable autoclave expansion of cement.

b. Concrete may crack due to internal expansion caused by freezing of freezable water in the capillary cavities in hardened cement paste. This will not happen if the cement paste is provided with a system of entrained air voids so that the bubble spacing factor of paste is 0.008 in. or less.(1)(7)

c. Concrete may crack due to internal expansion caused by reaction of alkalies in solution in the concrete with soluble silica in the aggregates. If the environment in which the concrete is to serve is moist and includes sources of abundant alkalies external to the concrete, this can only be confidently avoided by not using aggregates containing deleterious amounts of soluble silica. If the environment does not include ~~moisture and~~ external sources of alkalies, this kind of cracking can be avoided by requiring that the cement not contain more than 0.60 percent of alkalies ($Na_2O\% + 0.658\ K_2O\%$), as is provided as an optional requirement of current specifications. If the environment does not include moisture, no special precautions will be required.

d. Concrete may crack due to rapid evaporation of moisture during the early stages of hardening; so called "plastic shrinkage cracking." This will not occur if the surface is prevented from drying during the critical period. When the evaporation rate from a concrete surface exceeds 0.1 lb of water per square foot per hour, such cracking can be induced; if the evaporation rate is much greater, such cracking will almost certainly occur unless precautions are taken.[2][3]

e. Concrete may crack due to internal expansion resulting from corrosion of embedded corrodible metal. This will not occur if agents that promote corrosion are prevented from reaching the corrodible metal as will be the case if no such agents are present in the concrete or in the environment. If the concrete is to be exposed in an environment such that chlorides are present, metal items that can corrode should be embedded to a sufficient depth depending on the impermeability of the concrete to preclude access to the metal by the corrosive agents. It has been recommended[4] that for marine exposures all steel, including stirrups and chairs, should be at least 3 in. from exposed faces and 4 in. from corners. It has been reported[5] that chloride corrosion has been observed at distances up to 10 miles inland from the seacoast.

f. Concrete may crack due to internal expansion resulting from reaction of sulfates in solution with aluminate hydrates of the cement. This will not occur if the quantity of such aluminate hydrates that can form in the cement is sufficiently low or if the amount of available soluble or dissolved sulfates is sufficiently low. If the amount of aluminate hydrate is large, such cracking may take place due only to interaction with moisture from the environment if the source of the sulfates were the cement or the aggregate; this, however, is not the normal condition. When the sulfate comes from the environment, the cracking can be avoided by the use of cements of degrees of sulfate resistance appropriate to the degree of environmental attack that needs to be withstood. The Corps of Engineers in its Civil Works construction program requires[6] that, where sulfate concentrations exceed 0.20% as water-soluble SO_4 in soil that will be in contact with the concrete or exceed 1000 ppm as SO_4 in water which will be in contact with the concrete, type V (sulfate-resisting) cement will be used; where concentrations are in the range 0.10 to 0.20% in soil or 150 to 1000 ppm in water, type II portland cement ~~of~~ or type IS (MS) portland blast-furnace slag cement will be used. Where the concentrations are lower than 0.10% in soil or 150 ppm in water, no special precautions are required.

Having reviewed very briefly a few specific kinds of interaction between concrete properties and the environment, it is possible to construct a tabulation of the interacting properties that are involved (table 1). This list is far from complete; there are many other interactions that can cause environmentally induced cracking that are just as well known as these, and there are others that are less well known. All such interactions can and should be considered in essentially the way that has been discussed here. When they are so considered; when the properties of environment in which a concrete structure is to be put are properly considered in selecting the provisions governing selection of materials, proportions, and construction practices to be stipulated in the specifications for the work and these specifications are enforced, then, and only then, will the resulting concrete, when called on to serve in the environment in which it is situated, have properties such that, as they interact with the properties of that environment, no one will wish either that the concrete were different or that it were somewhere else because of environmentally induced cracking.

References

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5. Halstead, S., and Woodworth, L. A., "The deterioration of reinforced concrete structures under coastal conditions." Transactions of the South African Institution of Civil Engineers, vol 5, April 1955.

6. Office, Chief of Engineers, Standard Practice for Concrete, Engineer Manual 1110-2-2000, 15 Dec 63, pp 24-25.

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Table 1

Property of Concrete	Property of Environment
Unsound Cement	
Excessive amounts of unhydrated CaO or MgO	Moisture
Alkali-Silica Reaction	
Excessive amounts of soluble silica in aggregates and of alkalies in cement	Moisture
Excessive amounts of soluble silica in aggregates	Moisture and excessive amounts of alkalies
Sulfate Attack	
Excessive amounts of hydrated calcium aluminates	Excessive amounts of sulfates
Corrosion of Metal	
Corrodible metal and corrosion inducing agents	Moisture
Corrodible metal and inadequate concrete cover	Moisture and excessive amounts of corrosion inducing agents
Freezing-and-Thawing	
Saturated capillary cavities in hardened cement paste, inadequate air-void system	Moisture and freezing-and-thawing
Plastic Shrinkage Cracking	
Premature surface drying	High evaporation rate

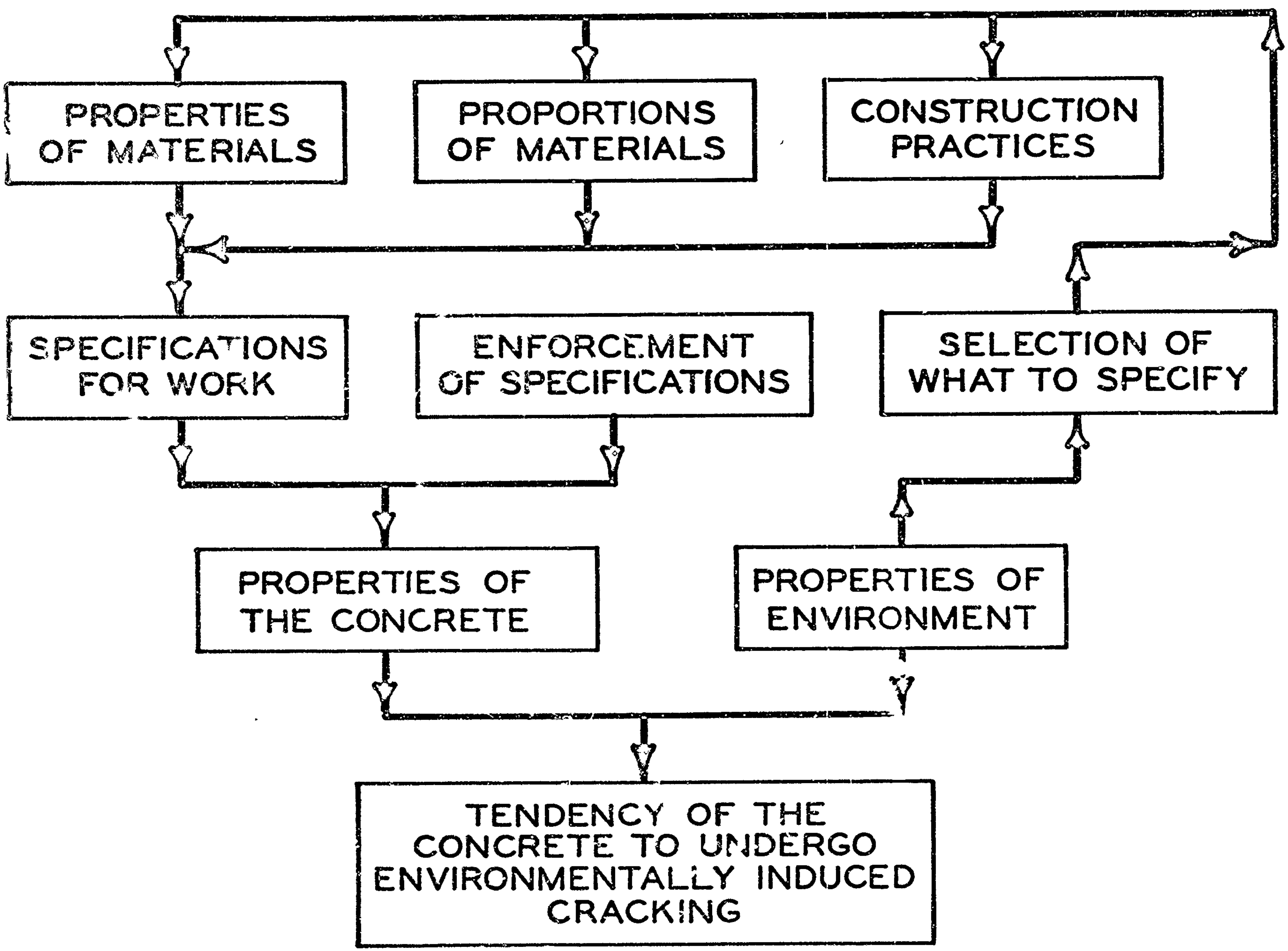
PROPERTIES OF MATERIALS
PROPORTIONS OF MATERIALS
CONSTRUCTION PRACTICES
SPECIFICATIONS FOR WORK
ENFORCEMENT OF SPECIFICATIONS
SELECTION OF WHAT TO SPECIFY
PROPERTIES OF THE CONCRETE
PROPERTIES OF ENVIRONMENT
TENDENCY OF THE CONCRETE TO UNDERGO ENVIRONMENTALLY INDUCED CRACKING

FIG 1