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Project Summary

Effects of Acid Deposition on the Properties of Portland Cement Concrete State-of-Knowledge

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Presented are the results of a program conducted to determine the state-of-the-art knowledge pertaining to the effects of acid deposition on the properties of portland cement concrete structures. Information was collected from a computerized literature survey, interviews, and replies to mail and telephone inquiries addressed to cement and concrete researchers and to governmental agencies and private firms active in the maintenance and restoration of concrete structures. In general, the study revealed very little qualitative or quantitative information on the effects of acid deposition on portland cement concrete structures. The rate of deterioration of reinforced portland cement concrete structures in polluted areas, however, appears to be increasing, and available information makes it readily apparent that acids and acid waters significantly affect the durability of concrete, and that SO_2, NO_x, and HCl accelerate the corrosion of reinforcing steel.

This Project Summary was developed by EPA's Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

As part of the National Acid Precipitation Assessment Program (NAPAP) Task Force project G3-1.05, sponsored by the U.S. Environmental Protection Agency/ Atmospheric Sciences Research Laboratory (EPA/ASRL), Brookhaven National Laboratory (BNL) conducted a program entitled "Effects of Acid Deposition on the Properties of Reinforced Portland Cement Concrete Structures." The objectives of the program were (a) to determine the state-of-the-art knowledge pertaining to the effects of acid deposition on the properties of portland cement concrete (PCC), and (b) if the results indicated a need for quantitative data, to develop recommendations for an experimental test program to be submitted for Task Group G approval and implementation.

Information for the state-of-the-art review was obtained from a computerized literature survey, interviews, and replies to mail and telephone inquiries addressed to cement and concrete researchers and to governmental agencies and private firms active in the maintenance and restoration of concrete structures.

Results of Survey

In general, the computerized literature survey indicated that an abundance of literature on acid precipitation is available, but most of it deals with the chemistry of acid precipitation and its effects on the natural environment. Literature dealing with the effects of acid deposition on buildings and building materials does exist; however, very little of it pertains to cement or concrete. The information that was found regarding the effects of acid deposition on buildings and building materials indicates that the increasing acidity of precipitation enhances normal weathering and corrosion processes. In addition, private communi-

cations indicated that a rapidly increasing number of reinforced concrete structures in cities are showing deterioration which the respondents attributed to SO_2, NO_x, and HCl.

Because the literature on the effects of acid deposition on PCC is limited, the large amount of literature dealing with the corrosive effects of acids, acid waters, and sulfates on concrete was reviewed in an attempt to estimate the effects of acid deposition on PCC. This review indicated that acid solutions generally attack concrete in a combination of four ways: (a) by dissolving both hydrated and unhydrated cement compounds present in the cement paste; (b) by dissolving calcareous aggregates present in the composite; (c) through physical stresses induced by sulfate and nitrate salts crystallized within the pore structure; and (d) by salt-induced corrosion of the reinforced steel.

The first two forms of attack involve the same mechanism: the leaching away of water-soluble salts formed by reaction of the acid with the calcium compounds present in the cement paste and aggregate. This is one of the major mechanisms of the deterioration of many ancient statues, monuments, and buildings made with calcareous building stone in and near industrialized areas of Europe.

The latter two forms of attack involve the development of stresses within the pores of the cement paste or aggregate which eventually cause the concrete to crack or spall. These stresses result from the crystallization of salts that have accumulated beneath the surface of the concrete or from salt-induced corrosion of the reinforcing steel.

In addition to the forms of deterioration identified above, the cracking and spalling of concrete due to acid-induced corrosion can also lead to and accelerate other forms of deterioration, most notably freeze-thaw deterioration.

The literature review concentrated on the effects of three specific pollutants, carbon dioxide, sulfur dioxide, and nitrogen oxides.

Carbon dioxide was found to affect concrete in two ways, through carbonation of the concrete surface and carbonic acid attack. The carbonation of the concrete surface results in a decrease of the pH value of the cement paste, which eventually leads to the corrosion of the reinforcing steel near the surface. Carbonic acid attack primarily results in the leaching of calcium hydroxide from the surface and interior of the concrete.

Sulfur dioxide, when dry, has little or no effect on dry concrete. It does, however, combine with water and oxygen to form sulfurous and sulfuric acid, both of which will attack concrete. Sulfuric acid attacks concrete (a) by converting calcium carbonate to gypsum, which is subsequently leached away; and (b) by reacting with calcium compounds to form salts which crystallize; the crystallization produces enormous stresses within the pores of the cement paste, which eventually lead to spalling and cracking. The latter form of attack is commonly known as sulfate attack.

Very little information was available regarding the effects of nitrogen oxides on concrete. They do, however, react with water or, as ammonia, with oxygen to form nitrous and nitric acid. Nitric acid is not as strong as sulfuric acid; however, it is destructive enough to bring about extensive deterioration, even in highly diluted solutions, primarily through the transformation of calcium hydroxide into highly soluble calcium nitrate.

None of the individuals and organizations responding to the mail and telephone inquiries was aware of any documented information dealing specifically with the effects of acid deposition on PCC structures, or of any research that had been or was being done in this area. Comments on the need for such research were varied: some respondents thought it was needed because the large volume of concrete structures in the United States could present a potentially large problem; others thought the need for such research was open to question because they considered other mechanisms of deterioration to be more important.

Conclusions

The study revealed very little qualitative or quantitative information on the effects of acid deposition on PCC structures. The rate of deterioration of reinforced PCC structures in polluted areas, however, appears to be increasing, and available information makes it readily apparent that acids and acid waters significantly affect the durability of concrete, and that SO_2, NO_x, and HCl accelerate the corrosion of reinforcing steel.

On the basis of this evidence, it is recommended that an experimental test program, consisting of both laboratory and field tests, be developed and implemented to quantitatively measure the effects of acid deposition on PCC structures. It is, however, recommended that a preliminary series of accelerated laboratory tests be carried out before a full-scale field evaluation program is instituted. The objectives of the laboratory test progra should be to identify the magnitude of th problem and to attempt to differentia between the effects of wet deposition, d deposition, and normal weathering.

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The complete report, entitled "Effects of Acid Deposition on the Properties of Portland Cement Concrete. State-of-Knowledge," (Order No. PB 85-171 452/AS; Cost: $8.50, subject to change) will be available only from:
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