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RESEARCH SUMMARY

INVESTIGATION OF ETTRINGITE IN MARYLAND BRIDGE STRUCTURES

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The objectives of this study, sponsored by the Maryland State Highway Administration, were to do a preliminary survey of Maryland bridges for potential delayed ettringite formation (DEF) damage; and to conduct tests on Maryland fine aggregates to determine any association with DEF.

Preliminary Survey of Maryland Bridges for DEF

The objective of the study included investigating the possible presence of DEF in cast-in-place concrete. Two nondestructive test (NDT) methods, potassium autoradiography and impact-echo, were utilized in the study. In addition, cores were taken for analysis with a scanning electron microscope and energy dispersive analysis x-ray, which identify DEF by crystal morphology and elemental composition. The focus of this study was on bridges exhibiting wet map cracking on the surface, which is regarded as a surrogate for DEF. The PONTIS® Bridge Management System database provided a means for selecting a sampling population A representative number of bridges from this set were selected from each district based on the percentage of total bridges in that district.

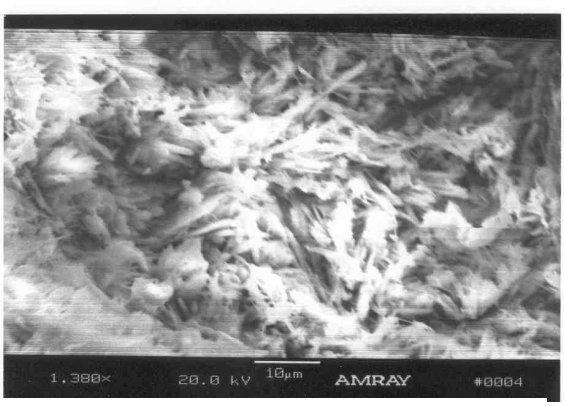

Figure 1: Scanning electron micrograph of ettringite crystals in concrete from a bridge

The study found DEF throughout the sampled Maryland bridges indicating that DEF is not simply a regional problem that affects only a few states like Texas. Of the twenty-nine cores taken, twenty-six exhibited DEF and two bridges without visible map cracking also contained DEF. A sample result from a scanning electron microscope is shown in Figure 1. Alkali-silica reaction (ASR) gel, which is commonly said to be associated with map cracking, was observed in only a limited number of bridges with map cracking. Therefore, map cracking is not necessarily a definitive indicator of ASR. The study also showed cases of coexistence of DEF and ASR in six of the ten bridges cored, with this sample population showing a correlation between a distinct map cracking pattern on the exterior surface and DEF / ASR within the concrete. This suggests a possible link between DEF and ASR. Also, in the bridges that were studied, DEF was found in cast in place bridge elements. This therefore refutes the theory that DEF happens only as a result of high temperature curing.

The potassium autoradiography NDT method measures the radiation emitted from 40K, a radioactive isotope of potassium. The test determines the actual levels of potassium present in the concrete. However establishing a correlation between DEF and potassium level proved to be difficult since all the seven sampled bridges exhibited DEF. A larger sample size and more advanced image processing of the autoradiographs may reveal a correlation. The impact-echo NDT method uses

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attenuation of ultrasound to characterize the degree of damage. The method provided useful data in undamaged concrete, but the existing signal processing algorithm was difficult to use in damaged concrete. Preliminary research into a more sophisticated algorithm suggests the method could be successfully applied to damaged concrete as well.

The Phase I study also discovered that different morphologies of ettringite crystals appear to be associated with different patterns of map cracking and the presence of ASR. Additional samples are needed to confirm these relationships. If these are verified, then it could be the basis for a more definitive crack classification system for visual inspection.

Influence of Maryland Fine Aggregate Lithology on DEF

The main variable in this part of the study was ASR reactivity of the fine aggregates. The scope of the study was limited to three fine aggregates currently being used in Maryland State Highway projects: Millville, Brandywine, and Silver Hill. The fine aggregates vary in geographic place of origin, Alkali – Silica Reactivity (ASR), method of production, and petrographic makeup. Only one coarse aggregate was used throughout the study and all other concrete mix factors were kept constant. Two replicate sets of prisms were involved; one set stored under water, the other in 100% RH. Also, as a control, a third set of Millville specimens was stored under dry, i.e. ambient RH, conditions. The Duggan test as modified by UMD/FHWA, SEM with EDXRD, and Computed Tomography X-ray were used to investigate DEF as the possible damage mechanism. In addition, compressive strength was measured at 28 days and 270 days.

This study concludes that fine aggregate type can significantly predispose a concrete sample to DEF and associated damaging expansion, while the exposure condition may exacerbate the effect. For example, the samples made from the sand with the highest ASR reactivity, Silver Hill, and stored under water exhibited the highest concentration of ettringite and most severe expansion in terms of rate, duration, and amount. Additionally, water exposure seemed to enable DEF. For example, concrete samples made with Millville sand and stored under water were commonly found with various forms of ettringite, while dry samples of the same type had little or no ettringite.

The expansions observed in this research program agreed with the ranking obtained in the MDSHA test: Silver Hill was the highest, Brandywine intermediate and Millville, the crushed limestone, the lowest. However, for the two siliceous aggregate types the expansion measurements did not predict the correct rank order of damage as measured by compressive strength at 270 days. The kinetics of the expansion varied among the aggregates. It is important to examine the expansion rate curve, i.e. the time derivative of expansion, to characterize the process rather than relying solely on the measured expansion at some fixed point in time. The various aggregates showed different responses to fog vs. submerged conditions. This suggests that the effect of each type of aggregate on the microstructure and hence the absorptivity of the cement paste needs to be considered in addition to its potential for ASR in evaluating expansion test data.

Ettringite was observed in most of the specimens. The morphology of the crystals may be an indication of the progress of damage. However, there is no quantitative way of correlating DEF with expansion measurements at the present time. Finally, the results show that the measured expansions come from a combination of moisture absorption, DEF and ASR. Consequently, expansion tests do not measure ASR effects only.

For a copy of the 2-volume report, contact the Research Division at badkins@sha.statemd.us or 410-545-2921. For information about the project, contact Dr. Amde at AMDE@UMD.EDU or 301 405 1946