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DEVELOPMENT OF MDOT'S FREEZE-THAW TESTING OF COARSE AGGREGATES IN CONCRETE

Many Michigan concrete pavements and structures constructed in the 1940s and early 50s exhibited a deterioration attributable to freeze-thaw action of aggregate particles. Much of this deterioration was in the form of popouts caused by particles known or suspected as being of poor quality (deleterious). Pavements made with aggregates from some sources provided noticeably better performance than pavements with aggregates from other sources, not specifically related to deleterious particle content. While an aggregate source could be evaluated based on its performance in pavements after 10 to 20 years of use, there was no reliable method for evaluating the performance potential of new sources, or new strata in existing sources.

Testing

MDOT started laboratory freeze-thaw testing of coarse aggregate in concrete in February 1954. The basic procedure used was ASTM C291, "Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water" (now ASTM C666, Procedure B). The freeze-in-air procedure was adopted over the freeze-in-water procedure because the latter tends to saturate the mortar fraction and deterioration takes place in the mortar instead of the coarse aggregate. The C291 (and the C666) procedure does not describe the concrete, so the provisions of ASTM C233, "Test for Air Entraining Admixtures for Concrete," was used to describe the mix parameters. Based on studies current at that time, a decision was made to test the aggregate in a vacuum-saturated condition to increase its vulnerability to freezing, thus obtaining definitive results in a shorter time. The laboratory testing was intended to indicate relative durability of aggregate from different sources or under different methods of production, not specifically indicate years of service before failure of a pavement due to freeze-thaw action, since field conditions vary from location to location. It is recognized that in the absence of water, there is no freezing and thawing. Likewise, when there is ample free space, the expansion of water on freezing is accommodated without harm. When stone or gravel aggregate receives a 24-hour soak, there are still approximately 18 to 26 percent unfilled voids to accommodate the 10-percent expansion as water freezes, and thus little damage is likely to be done to the concrete. Freeze-thaw testing of aggregate in concrete under such conditions will only measure the time necessary for water to permeate the mortar until the coarse aggregate is critically saturated (pores more than 91 percent filled with water).

A study by MDOT in 1982 indicated that gravel and stone aggregates as produced typically contain more water than can be induced by the vacuum saturation procedure used by MDOT. This agreed with a Pennsylvania DOT study which reported that the bottom of a pavement slab typically has a moisture content greater than can be achieved by vacuum saturation.

Early testing indicated a need to increase the number of specimens per test from six to nine, and this was done in 1956 to improve reliability of the results. Other minor refinements in testing procedures have been made over the years, without significant effect on freeze-thaw results. The detailed test procedures are presently given in Michigan Test Methods (MTM) 113, 114, and 115.

Slag Coarse Aggregate

Slag coarse aggregate testing was an exception to the procedure used for other aggregates. Slag was first tested in 1972. It was soon evident that some slags performed poorly when tested in the vacuum-saturated condition. A decision was made in 1976 to exempt slag from vacuum saturation since when used in concrete it was fresh from blast furnaces and not saturated, unlike stone and gravel which was saturated by ground water for thousands of years. Subsequent studies indicated that slag as used in concrete has a moisture content significantly less than vacuum saturated, usually closer to the 24-hour soak moisture content (40 to 60 percent of vacuum saturation). No information is available concerning the moisture condition ultimately attained by slag aggregate at the bottom of a concrete pavement.

As a result of the decision in 1976 to moisture condition slag by 24-hour soak, all freeze-thaw tests have resulted in Durability Factors (DF) of 95 to 100 (dilation of 0.002 percent per 100 cycles or less), and the freeze-thaw test is ineffective because the aggregate is not critically saturated.

Specifications

The MDOT aggregate specifications first mentioned freeze-thaw durability in 1960, requiring that coarse aggregate for concrete "...demonstrate, to the satisfaction of the Engineer, adequate freeze-thaw resistance for the particular use, either by means of extended field record in similar concrete, similarly exposed, or by accelerated laboratory freeze-thaw tests, or both."

The 1976 Standard Specifications contained the first numerical requirements, with a minimum freeze-thaw Durability Factor of 20. This value is reported to have been selected since there seemed to be an absence in results near 20 DF or less for sources tested to that time, and most large suppliers had test results exceeding 20 DF. (Review of freeze-thaw results from 1970 through 1977 indicates 8 of 92 tests had test results of 15 to 25 DF representing seven sources; for three of those sources the result was 20 DF or above, and three other sources had subsequent tests with results of 35 DF or above. Thus, the concept of setting the limit so that no major supplier would be eliminated seems more likely.) Setting the minimum limit at 20 DF did serve to at least eliminate the truly poor durability aggregates.

When the numerical value for Durability Factor was inserted in the specifications, the requirement for sulfate soundness was deleted. It has been noted that the imprecise soundness test was eliminating a number of crushed stone sources that had significantly better freeze-thaw durability than most gravel sources.

The Research Laboratory's study of selected pavements constructed in the 1960s indicated that some built with aggregates from sources only marginally exceeding 20 DF required essentially 100 percent joint replacement due to

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freeze-thaw action, while adjacent pavement constructed with aggregate from sources with high durability (70 to 100 DF) aggregate had almost no freeze-thaw damage after 20 years. Based on the high cost of repair and the disruption of traffic, the MDOT Engineering Operations Committee decided, in the early 1980s, that concrete pavements constructed for freeways and other major traffic arteries carrying more than 5000 ADT (average daily traffic) per lane should contain coarse aggregate of higher durability. The limit was set at 40 DF minimum (now 0.040 percent per 100 cycles dilation maximum, equivalent to 36 DF).

After a number of years of comparison testing for Durability Factor and dilation (expansion) of the freeze-thaw specimens, a correlation relating the two was developed. Starting in 1987, the method of expressing freeze-thaw test results was changed to "dilation, percent per 100 cycles. The specification limiting value of 20 DF minimum became 0.067 percent per 100 cycles maximum dilation."

Correlation with Field Performance

A number of studies have been performed over the years by units of the Materials and Technology Division to specifically correlate pavement performance to freeze-thaw durability. The first was conducted in the latter 1950s, and attempted to correlate the number and area of popouts per square yard to durability, but was inconclusive because of the extreme variation with aggregate from the same source used on different projects. These differences were attributed to different environments, micro-climate, bases, contractors, and change in aggregate characteristics at different points in time of production. Subsequent attempts to correlate precisely pavement performance and durability have likewise been unsuccessful for those reasons and because freeze-thaw deterioration may manifest itself in different forms. In spite of the inability to make a precise correlation, there is indisputable evidence that pavements constructed with aggregates having superior freeze-thaw durability perform well over many years, while pavements constructed with aggregates of poor durability indicate joint deterioration problems starting at relatively early ages. The conclusion that cannot be stated with certainty is the exact numerical values separating poor, mediocre, good, and excellent durability. Until such a line can be drawn, it is the recommendation of the Materials and Technology Division that the durability requirements be set high enough to assure good pavement performance. The slight increase in cost for more durable aggregate should be more than offset by longer pavement life.

-Ralph Vogler

TECHADVISORIES

The brief information items that follow here are intended to aid MDOT technologists by advising or clarifying, for them, current technical developments, changes or other activities that may affect their technical duties or responsibilities.

MDOT RESEARCH PUBLICATIONS

Evaluation of United Salt's Corrosion Inhibitor Intended For Use With Sodium Chloride Deicing Salt, Research Report No. R-1313, by Ronnie L. McCrum and John V. Heffernan. Because of the high cost of the damage done by highway deicing salt, MDOT continues to search for alternate deicing agents and corrosion inhibitors for salt that might lower the effective long-term cost of using salt as a deicer. United Salt Corporation's corrosion inhibitor, composed primarily of a buffered organic fertilizer, is intended to deposit a barrier coating on steel surfaces. The corrosion inhibitor/salt mixtures were judged by their subjectively rated performance as viewed by maintenance personnel, their effect on the rate of corrosion of reinforcing steel specimens placed in a concrete pavement in a real highway environment, and their effect on on the scaling rate of concrete specimens exposed to controlled freeze-thaw cycles in the laboratory. It was found that the inhibitor-treated salt functioned about as well as untreated salt, but tended to plug the application equipment. Little difference was found in the weight loss of the steel specimens in the concrete pavement. The concrete freeze-thaw specimens exposed to the corrosion inhibitor had as much or more weight loss due to scaling than those exposed to untreated NaCl. In view of the negative test results and application problems, United Salt Corporation's corrosion inhibitor, as tested in this study, does not appear to merit either current usage or further testing at this time.

Corrosion and Alternate Deicers - Interim Report, Research Report No. R-1315, by Ronnie L. McCrum. The report (R-1313) abstracted above is but one phase of a larger, ongoing project. This interim report brings us up to date on the comprehensive project. The report summarizes the previous laboratory work (available in its entirety in Research Report No. R-1295) which involved accelerated weathering of typical highway metals in a corrosive environment. Because of the high cost of the most effective alternative deicier (calcium magnesium acetate, or CMA) various mixtures of CMA and some other alternative deicers, were combined with rock salt in various proportions. It has been noted that although the accelerated laboratory weathering tests provide some indication as to which deicers are the least corrosive, 'real world' conditions introduce variables that cannot be replicated in the laboratory. Thus, a three-phase field evaluation has been undertaken and its current results are presented here. Research Report No. R-1313 (above) covers the completed Phase I of the field evaluation, which is briefly described in this interim report. Phase II is only partially completed, and is discussed herein. Racks were fabricated to hold the same sorts of samples used in the laboratory testing under selected highway bridges to be subjected to salt spray from traffic. It was found from the initial evaluation that the positioning of the racks posed some problems and that in the future the materials will be subjected to more uniform amounts of salt spray. The early results of this phase are discussed. Phase III involves a number of simulated bridge deck slabs, wired to a trailer-housed computer data acquisition system. The macrocell corrosion current between the top and bottom reinforcement mats is monitored by the computer system both before and after a slab is exposed to an alternate deicer. Unfortunately, problems with a data acquisition board giving results that fluctuated more with board temperature than the actual macrocell corrosion current have invalidated our first year's data. Data will, however, be available in the future. Differences between the field results and reported laboratory results necessitated a detailed discussion of some of the factors that can make the real world vastly different from a laboratory environment and stresses the need for more widespread use of realistic field testing of the corrosion performance of alternate deicers.

This document is disseminated as an element of MDOT's technical transfer program. It is intended primarily as a means for timely transfer of technical information to those MDOT technologists engaged in transportation design, construction, maintenance, operation, and program development. Suggestions or questions from district or central office technologists concerning MATES subjects are invited and should be directed to M&T's Technology Transfer Unit.

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