Office of Innovation, Partnerships & Energy

Innovation, Research & Implementation Section

Executive Summary Report

Forensic Investigation of AC and PCC Pavements with Extended Service Life: Volume 2: Petrographic Examination of PCC Core Samples at Lankard Materials Laboratory

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Problem

The overall purpose of this research project as described in the Executive Summary Report for Volume 1 (FHWA/OH-2010/04A) is to identify flexible, rigid and composite pavements that have not received any structural maintenance since construction and are considered to be performing in either an excellent or an average manner, and to determine the reasons why excellent pavements perform better than average pavements. By identifying these reasons and implementing them into standard practice, the overall performance of pavements in Ohio can be improved in the future.

The present report describes the methodology used and the results obtained in the petrographic examination of cores taken from twenty Portland cement concrete (PCC) pavement projects in the ODOT system. The criteria of selection of the twenty PCC pavements are described in the Volume 1 Report.

Objectives

Using the findings of the study it was intended to (1) identify material differences in the concretes that could account for the distinction between "excellent" performance and "average" performance, and to (2) identify material features of the excellent/average pavements that could distinguish them from ODOT PCC pavements that could historically be categorized as having shown marginal or poor performance.

It was intended to identify those material and/or design features of the excellent/average performance pavements which could be put into more widespread practice to provide improved performance in future ODOT PCC pavement projects.

Description

The age of the PCC pavements rated as "excellent" ranges from 1946 to 1997. The age of the pavements rated as "average" ranges from 1958 to 1996.

The pavement cores were examined petrographically and using other tests. Characterization data were obtained on (1) the concrete constituents, (2) microstructural features of the concretes, and (3) distress features and mechanisms. These data were supplemented with (1) historical information on the pavement projects, and with (2) pavement and base design information.

Two 4-in (10 cm) diameter, full-depth cores were taken from each of the twenty PCC pavement projects; one through a transverse control joint and one through a mid-slab crack. All of the cores were taken at a location on the pavement slabs that showed no distress in the wearing surface at the time of coring. In our examination we learned that most of the cores had some level of sub-surface distress within the joint fracture plane or within the mid-slab crack fracture plane. Efforts were made to relate these distress features to the material and pavement design characterization data.

Conclusions & Recommendations

On the basis of the properties and microstructural features that were evaluated in the study, there is no single variable that clearly stands out as explaining the difference between "excellent" and "average" performance.

For the purpose of further analyses of the data, all twenty of the Research Study concretes were figuratively placed within the category of "satisfactory" performance.

Within the context of the "satisfactory performance" category it became clear that for a given material variable, substantial between-concrete differences could be tolerated. For example, for the ten "excellent" concretes the average compressive strength was 6180 psi (43 MPa), with a range of 4880 to 8410 psi (34 – 58 MPa). For the ten "average" concretes the average compressive strength was 6310 psi (44 MPa), with a range of 3760 to 8720 psi (26 – 60 MPa).

From a materials point of view the major factors contributing to a "satisfactory" level of performance of the twenty study pavements are (1) the presence of intentional air entrainment, (2) the excellent freeze/thaw resistance of the coarse aggregate phase of the concrete, and (3) a low value of water-cement ratio (ca. 0.45) in the cementitious phase of the concrete.

For the twenty study pavements the only significant distress is in the concrete that forms and is immediately adjacent to the transverse control joint and the mid-slab crack if it is present. There is no mid-slab cracking on six of the twenty study concretes. Factors influencing this outcome are discussed in the report. Distress associated with the transverse control joints and the mid-slab crack begins as sub-surface cracking, which in most cases is the result of freeze/thaw cycling of the concrete while in a state of critical water saturation. Water passing into the pavement from the wearing surface side, as well as water ponding along the bottom of the slab are both involved in the creation of the condition of critical moisture saturation in the concrete. Even air entrained concretes containing aggregates with a good freeze/thaw record are vulnerable in the long run to freeze/thaw distress if they are critically saturated.

Implementation Potential

The findings of this research project confirm that the construction of PCC pavements with a service life of 50 to 100 years is a realistic goal. One of the pavements in the study, with a joint spacing of 40 feet (12 m), has been in service for 64 years, and many of the original transverse joints are still in place. A second pavement, with a joint spacing of 60 feet (18 m), has been in service for 52 years, and the original joints were not replaced for 40 years.

Lessons learned from the Research Study include insights into material and design factors that affect long term PCC pavement performance. Items recommended for consideration for implementation are focused on steps that appear to have the potential to (1) better assure proper functioning of control joints, (2) eliminate or minimize mid-slab cracking, and (3) provide concretes with even further improvements in freeze/thaw durability. In making the recommendations, the unique requirements of high volume versus low volume pavements have been taken into account. The steps offered for consideration to achieve the desired ends include,

- Encourage, or even mandate the use of supplementary cementitious materials, such as fly ash or slag cement. Their use has a favorable environmental and economic benefit, and will result in improved long term strength and durability in the concretes.

- Consider a reduction in the cement content of the pavement concretes, concomitant with an increase in the maximum size of the coarse aggregate. In addition to an economic benefit, a reduced cement content can provide for improved volume stability of the concretes. The cement content of the 64 year old pavement evaluated in this study has an estimated cement content of 430 lb/yd^3 (255 kg/m^3)

- Increase the maximum size of the coarse aggregate to 2 in (5 cm) or even higher. The larger aggregate size can provide (1) improved volume stability, (2) an improved aggregate interlock function, for the reduction of faulting. The aggregate sources considered for these concretes must have a good service record, with a low proneness to D-cracking.

- Where deemed desirable, require the use of carbonate coarse aggregates to minimize the potential for mid-slab cracking. All six of the study concretes that have no mid-slab cracking issues have limestone coarse aggregates. Historically, the coefficient of thermal expansion of carbonate aggregate concretes is significantly lower than that of concretes containing siliceous aggregates.

- The use of air entrainment is essential for insuring the freeze/thaw resistance of the cementitious phase of the concretes. This practice should be continued. However, a rationale is given in the report for a reduction in the maximum required air content for ODOT pavement concretes, with no sacrifice in the freeze/thaw resistance. A lower air content requirement should lead to more consistent levels of strength and a higher average strength for the pavement concretes.

- Three of the study pavements that show no mid-slab cracking have free-draining bases. None of the fourteen study pavements that have mid-slab cracking have a free draining base. Future thinking could look deeper into this aspect of base design as it affects the formation of transverse slab cracking.

- It is reasonable to assume that dowel bar misalignments can contribute to the failure of control joints to function as intended (and hence increase the probability of mid-slab crack formation).

Consideration can be given to the use of load-transfer dowels that are more flexible than the 1¼ in (3.2 cm) diameter steel bars in use today. Providing some "give" in the dowels could mitigate this problem. For the 64 year old study pavement this was achieved through the use of ¾ in (1.9 cm) diameter dowels. The use of small diameter steel dowels or composite material dowels could be considered for low volume pavements.

- The effectiveness of the joint sealant material system was quite variable in the twenty study pavements. Poor sealing led to increased freeze/thaw damage in most instances. A renewed emphasis on providing an effective long-term durable joint sealing system is recommended. Some of the hot mix, poured-in-place bituminous joint sealant used for the 64 years old study pavement is still in place today and is functional.

- Current ODOT guidelines for PCC pavements for high volume projects call for unreinforced concrete with 15 feet (4.6 m) joint spacings. Of the three study concretes that have 15 ft (4.6 m) joint spacings, two have a mid-slab crack, one of which shows the initiation of sub-surface freeze/thaw damage. Long term durability of the cracked concrete could be improved through the use of an effective and durable crack sealant material. Currently, neither the transverse control joints, nor any transverse cracks are sealed in these pavements.

- Five of the six study pavements with no mid-slab cracking have a joint spacing of 21 ft (6.4 m). Some sections of the 64 year old study pavement with a joint spacing of 40 ft (12.2 m) are currently crack-free. With the potential economic benefits that fewer joints offer (initial construction and maintenance), consideration can be given to expanding the current 15 ft. (4.6 m) joint spacing for low volume pavements.