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Pervious Concrete Overlay Design, Construction and Performance

Vernon R. Schaefer[1], John T. Kevern[2], and Kejin Wang[2]

[1]*Professor of Civil Engineering, Iowa State University, 488 Town Engineering Building, Ames, Iowa 50011-32323 USA E-mail: <vern@iastate.edu>, <kejinw@iastate.edu>.*

[2]*Assistant Professor of Civil Engineering, University of Missouri-Kansas City, 370H Flarsheim Hall, Kansas City, MO 64110-2499 USA. E-mail:<kevernj@umkc.edu>.*

ABSTRACT

This paper presents the results of studies conducted to develop a self-consolidating Portland Cement Pervious Concrete (PCPC) for overlay applications to reduce roadway noise, reduce splash and spray, and to improve friction as a surface wearing course. A variety of mixture variables were characterized for workability to develop a mixture for mechanized placement. During the fall of 2008, a 100 mm thick pervious concrete overlay on traditional concrete was constructed at a test facility. Construction is described as well as results of field tests to characterize the condition of the pavement seven months following construction. Performance testing of the overlay section included bond strength, permeability, skid resistance, and noise generation. The results of these studies show that effective PCPC overlays can be designed for wearing course applications. (126 words)

INTRODUCTION

Portland Cement Pervious Concrete (PCPC) contains the same material components as conventional concrete, namely, cementitious binder, aggregate, water, and chemical admixtures, but through specific mixture proportioning maintains around 20% porosity for water percolation. PCPC is a technology which has been tried in all parts of the U.S. for stormwater management and is relatively common in certain areas. However in the U.S., the use of pervious concrete in applications other than parking areas for stormwater management is limited. Areas in Europe, Japan, and Australia have successfully used pervious concrete as roadway material. The motivation for employing pervious concrete as a road surface includes noise reduction in urban areas, and reduced splash and spray and hydroplaning potential for safer pavement [Vorobieff and Habair 2005, Beeldens 2001; Olek et al. 2003].

Pervious concrete is designed to transport stormwater through a series of interconnected voids while providing the designed load-carrying capacity and meeting other required design criteria. In overlay applications, the water must travel laterally as well as vertically. The interconnected voids are produced by balancing between aggregate gradation and binder volume. There is a direct relationship between voids and compressive strength, where lower void contents produce more intraparticle contact and consequently higher load-carrying capacities [Schaefer et al. 2006]. Design considerations include adequate strength for long-term durability using highly durable aggregate for resistance to polishing and freeze-thaw issues, sufficient porosity (around 20 to 25%) to maximize noise reduction and minimize permeability maintenance, uniform surface porosity for consistent durability and noise production, high workability for ease of placement facilitating uniform porosity across the pavement thickness and, an ability to maintain voids when compaction is applied by the paver for uniform surface porosity.

This paper details the development and testing of PCPC designed for use as an overlay for noise reduction and improved skid resistance and the construction and performance of a pervious concrete overlay placed on a low volume road test section at the Minnesota Department of Transportation MnROAD facility.

OVERLAY DESIGN PROCEDURES AND DEVELOPMENT

The strength and freeze-thaw durability of pervious concrete mixtures have been addressed in recently completed studies by Kevern *et al.* [2008a] and Schaefer *et al.* [2006]. The research shows that strong, durable pervious concrete mixtures can withstand hard, wet -freeze environments. The strength and durability is achieved through the use of a small amount of fine aggregate (i.e. concrete sand) and/or latex admixture to enhance the particle-to-particle bond in the mixture.

Areas evaluated during this mixture development phase include: aggregate type, aggregate gradation, fine aggregate content, binder content, cementitious components, water content, fiber type, fiber dosage rate, and admixtures. Concrete mixtures have been evaluated for workability, strength development with time, porosity, permeability, freeze-thaw durability, surface durability, deicer resistance, and overlay bond strength. Kevern *et al.* [2008b] provides additional details of the mixture development for overlays.

The testing program evaluated a wide-variety of potential mixture combinations to achieve the stated objectives. Both angular and round locally-available aggregate were evaluated. The locally-available aggregate was a highly durable granite. As some sand-sized particles were already in the coarse aggregate (CA) gradation, the experimental combined gradation was investigated up to 15% additional fine aggregate (FA). Total cementitious content was varied to achieve the proper paste thickness around the aggregate for workability, strength, and durability. Supplementary Cementitious Materials (SCMs) were investigated in both binary and ternary combinations up to 50% replacement for Portland Cement. Water-to-cement ratio was varied across typical values for PCPC. Various fiber lengths and types were investigated at three addition rates up to 3.0 kg/m^3 of concrete. Two lengths of polypropylene fibers were investigated as well as cellulose microfibers. Admixtures were investigated individually and in combinations at typical and increased dosages. The standard baseline mixture contained a polycarboxylate high-range water-reducer (HRWR), vinsol resin air-entraining agent (AEA), and hydration stabilizing admixture (HS). Additional admixtures included a viscosity modifier (VMA) and a latex additive. Since traditional concrete overlays have been successful with and without a latex bonding agent, two versions of the selected mixture proportions were studied, one with a latex polymer additive and one without.

MIXTURE DESIGN RESULTS AND DISCUSSIONS

The following results and discussion include a summary of the testing information. The full final report detailing the entire testing program will be available upon conclusion of the project at www.cptechcenter.org. During the initial testing it was determined that more paste was required for an angular aggregate to produce a similar paste thickness and therefore similar workability than a mixture containing like-sized rounded aggregate. However, using similar aggregate types and at similar densities and void contents, the angular mixtures had higher tensile strengths. Therefore angular coarse aggregate material was selected. The granite coarse aggregate had 18% passing the 4.75 mm (No. 4 sieve), specific gravity of 2.65, absorption of 0.59%, and compacted voids of 45%.

Workability and Strength Performance

Pervious Concrete mixtures that have excellent performance in the lab may stiffen during transport, resulting in poor compaction or requiring additional water in the field. Addition of water at the job site increases water-to-cementitious binder ratio (w/c), impacting concrete strength and durability. To date, determining the workability of pervious concrete has been considered an art form since the conventional slump test does not provide useful information for such stiff concrete. A more scientific method of workability determination was required to develop the surface overlays.

A Superpave Gyratory Compactor (SGC) was modified to develop a test method to characterize the workability of pervious concrete simulating various field compaction conditions and is further described in Kevern *et al.* [2009]. Values are presented for acceptable ranges in Table 1. The new test method is able to distinguish the changes in mixture workability from a variety of factors, including aggregate gradation, binder volume and type, fibers, admixtures, and working time.

Table 1. Ranges of Pervious Concrete Workability Values

Workability (WEI) Behavior	**Range**
Highly Workable	> 640
Acceptable Workability	640>WEI>600
Poor Workability	WEI<600
Compactibility (CDI) Explanation	**Range**
Self-Consolidating	CDI<50
Normal Compaction Effort Required	50<CDI<450
Considerable Additional Compaction Effort Required	CDI>450

The effect of binder content on the workability and material properties is shown in Figure 1 for a pre-selected baseline mixture containing 10% fine aggregate (FA) to coarse aggregate (CA), straight cement, and a water-to-cement (w/c) ratio of 0.29. The range of binder-to-aggregate (B/A) combinations selected represented common cement contents that had been previously successful. In the past is has been observed that B/A values less than 21% (by mass of straight cement using aggregate with specific gravity values around 2.62) had high porosity but low strength. It was also observed that B/A above 24% had good strength but low permeability [Kevern *et al.* 2008c; Kevern *et al.* 2009]. Increasing B/A the initial workability (WEI) slightly increased while the resistance to compaction significantly decreased (CDI). For these particular mixtures, porosity was not impacted by the additional binder, although more binder did improve strength. B/A of 24% was selected due to the highest strength and workability and lowest resistance to additional compaction.

Previous research has shown that at w/c less than 0.27, typical pervious concrete using standard admixture types and dosages, the paste is not sufficiently wetted and has poor strength and durability. Again, for typical pervious concrete mixtures, w/c above 0.33 causes the excess paste to drain from the aggregate [Kevern *et al*. 2009]. Consequently, a range of w/c from 0.27 to 0.33 was studied for this application. Additional water slightly improved workability and caused a significant reduction in porosity at w/c of 0.33. However, strength was highest of 21.2 MPa at w/c of 0.29, which was selected.

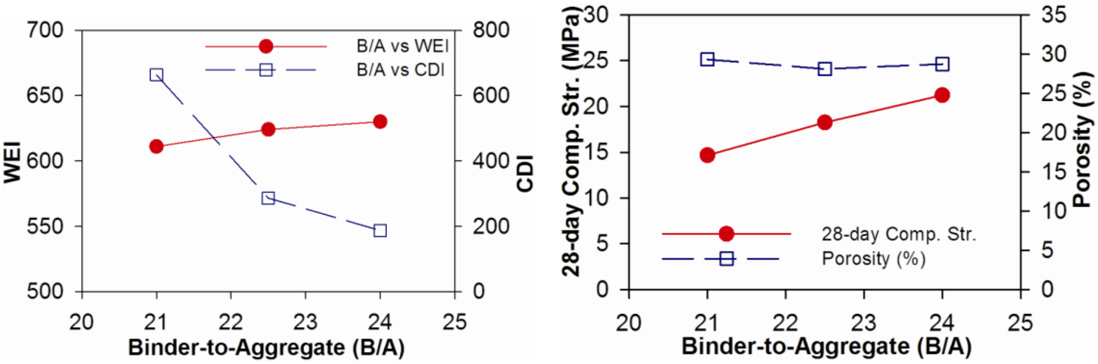


Fig.1. B/A vs. Workability and Strength and Porosity

The effect of gradation on workability is shown in Figure 2 for mixtures containing B/A of 24% and w/c of 0.29. Workability (WEI) increased with increased sand content. At FA/CA less than 7.5% there was no difference in resistance to compaction. However, above FA/CA greater than 7.5% the FA increased the paste/mortar thickness around the aggregate and reduced resistance to further compaction. Porosity decreased with increased workability up FA/CA of 12.5%. At the 15% level the amount of sand stiffened the mortar and held the CA particles apart. While porosity decreased to the 12.5% level, 7-day compressive strength peaked at the 7.5% level at 27.9 MPa. Due to the decrease in resistance to compaction between the 7.5% and 10% rate and only a slight decrease in compressive strength, FA/CA of 10% was selected for this application.

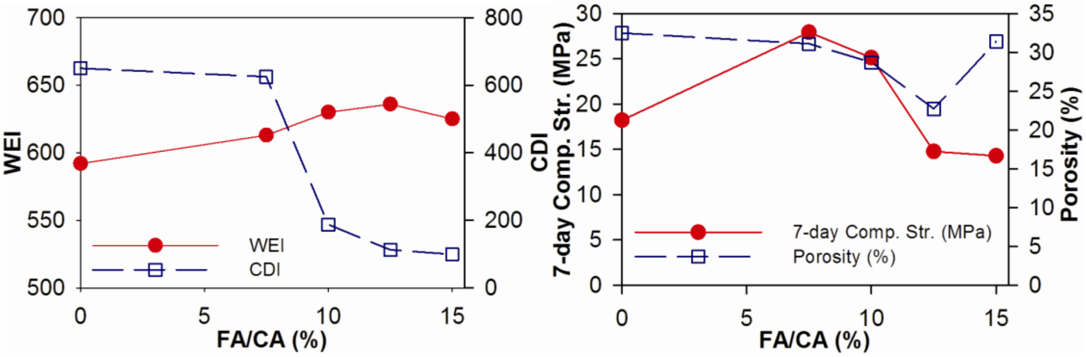


Fig. 2. Effect of Fine Aggregate on Workability, Strength, and Porosity

The effects of different types of fibers on the workability of a mixture were tested for both polypropylene and cellulose fibers. General trends were the same for both fiber types. Additional fibers decreased workability and increased the resistance to additional compaction. For mixtures containing polypropylene fibers a significant increase to additional compaction was observed at the 3.0 kg/m^3 rate. Visually there was not enough paste for the amount of fibers. The fibers prevented aggregate particle contact and the behavior was similar to 15% FA/CA. All mixtures had similar increases in tensile and compressive strengths at the 0.9 kg/m^3 and 1.8 kg/m^3 and a decrease in compressive strength at the 3.0 kg/m^3 rate. The selected design contained both types of fibers each at 0.9 kg/m^3 rate.

Once the primary components of aggregate type, binder content, w/c, and sand content were selected a range of binary and ternary cementitious material combinations were investigated up to 50% replacement for Portland cement. The SCMs included class C fly ash and grade 120 ground granulated blast furnace slag. Mixture iterations were based on 7-day strengths due to the opening criteria of pervious concrete being cured for 7-days before removal of the plastic. All SCM combinations were more workable and required less additional compaction than the 100% Portland cement mixture. Also, all SCM combinations had higher 7-day tensile strengths and similar compressive strength values as the 100% Portland cement mixture. The highest 7-day compressive and tensile strengths were achieved by the mixture containing 50% slag of 23.7 MPa and 2.7 MPa, respectively. The mixture containing 35% slag and 15% fly ash had lower 7-day compressive strength of 17.6 MPa, however similar tensile strength of 2.6 MPa. Due to the potential for greater long term strength gain from the fly ash, a ternary blend of 35% slag and 15% fly ash was selected.

Overlay Bond Strength

An important aspect of a bonded overlay is the bond strength between the substrate and the overlay. Pervious concretes have been placed wet-on-wet, which produces very high bond strength [Beeldens 2001]. However traditional pervious concrete does not lend itself to high bond strength over existing pavement due to the dry nature of the mixture and the reduced contact area. Fortunately pavement modeling of pervious concrete wearing course indicates a relatively low strength is required of 1 MPa [Bax *et al.* 2007].

Overlay bond strength was tested according to Iowa DOT test method 406C which calls for applying a constant load at 2.8 to 3.4 MPa/minute) to a 100 mm diameter specimen [IDOT 2000] Traditional concrete samples were placed at approximately 100mm height. After curing for 28-days, an additional 100 mm of pervious concrete was placed on the hardened concrete. The surface of the PCPC was leveled using a flat plate without applying any pressure. The reported bond strength is the peak value.

Fresh PCPC samples placed over hardened concrete without any vibration or compaction represented the lowest probable bond strength. Four different surface preparation techniques were used on both of the selected mixtures 1) clean and dry concrete surface, 2) polymer additive applied as a tack coat and topped with fresh pervious concrete when sticky, 3) standard mortar surface grout, and 4) polymer mortar surface grout. Bond strength values were highly variable indicating more samples are required for any determination. The grouted samples had the highest bond strengths with an average of 1.8 MPA. The combination of non-latex polymer concrete with non-latex grout had highest strength of 2.2MPa. The latex polymer had better bond strength on the clean and dry concrete than the mixture without the latex polymer, 0.8 MPa and 0.2 MPa respectively. The polymer tack coat did the opposite as expected and prevented bonding of either PCPC mixture.

Final Design

The final mixture proportions are shown in Table 2. The selected aggregate was a crushed granite coarse aggregate containing 18% passing the 4.75mm (No. 4) sieve. The selected mixture contained B/A of 24%, w/c of 0.29, additional FA-to-CA of 10%, 0.9 kg/m^3 each of short graded polypropylene and cellulose micro fibers, and had 35% slag and 15% fly ash replacing Portland cement. The non-latex additive mixture had HRWR, AEA, HS, and VMA, while the latex mixture contained a latex concrete block additive, HRWR, AEA, and HS. Due to construction schedule and timing, the final design was the latex polymer-modified concrete mixture overlayed on a clean and dry concrete surface. The concrete was self-consolidating, porosity was uniform across the section profile, and had good edge-holding ability.

Table 2. Concrete Mixture Proportions for Pervious Concrete Overlay

Material	Amount
Coarse Aggregate (3/8" granite, oven dry)	1330 kg/m^3
Fine Aggregate (concrete sand, oven dry)	130 kg/m^3
Portland Cement	180 kg/m^3
Class C Fly Ash	50 kg/m^3
Blast Furnace Slag	120 kg/m^3
Water-to-cement (0.29)	100 kg/m^3
Cellulose Fibers	1 kg/m^3
Polypropylene Fibers	1 kg/m^3
Polycarboxylate HRWR	3 mL/kg cement
Air entraining agent	1 mL/kg cement
Hydration Stabilizer	8 mL/kg cement
Latex-polymer Additive	8 mL/kg cement

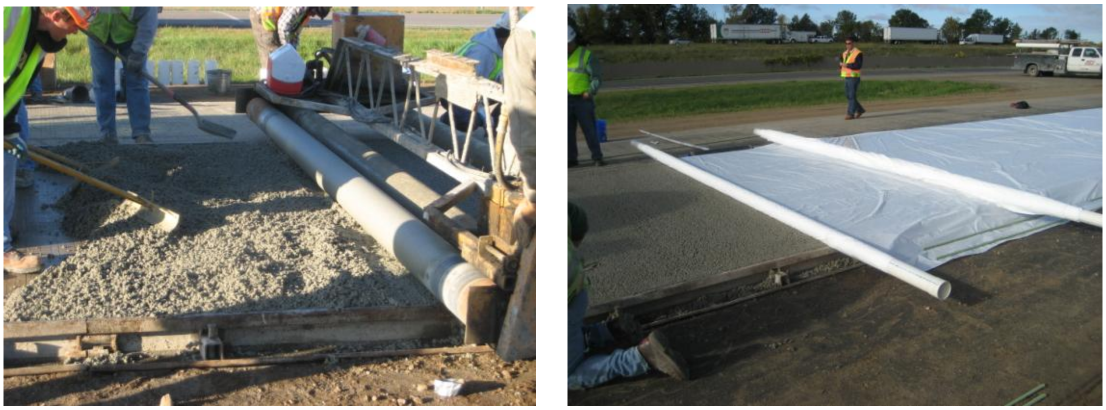
CONSTRUCTION

Pervious Concrete Overlay Project Site Information

The pervious concrete overlay was constructed on cell 39 of the Low Volume Road (LVR) of the Minnesota Road Research Project (MnROAD). The LVR is a closed 4 km loop with two lanes, one tested with a 36,300 kg controlled 18-wheel, 5-axle tractor/trailer (inside lane), and the second environmental lane with no traffic load (outside lane). Cell 39 of the LVR, constructed originally in 1993, is approximately 152 m in length and consists of concrete pavement is nominally 165 mm thick with transverse tining, skewed joints, and 6 m x 3.7 m panels. Load transfer is achieved with 25 mm dowels. The subbase is 125 mm Class 5 well-graded aggregate base and subgrade is clay. The PCPC overlay is nominally 100 mm thick with formed joints. The pervious concrete overlay was placed on an existing concrete pavement section in Cell 39. Thus preparation for placement of the overlay was relatively minor, necessitating only cleaning of the existing concrete surface. On September 29, 2008, the surface of cell 39 was sandblasted and swept clean. Forms were placed for the hand placement of the concrete. Notches were milled into the concrete on both ends of cell and bituminous tapers placed as transitions to the overlay. The cell was designed and built with a class 5 aggregate shoulder. Shortly after construction, it was noted that water draining to the pavement edge from the pervious overlay simply sat on the aggregate shoulder because the aggregate was, for all practical purposes, impervious. The MnROAD operations staff corrected the problem by building French drains along both shoulders. The drains were approximately 150 mm wide and 100 mm deep along the entire length of both sides of the cell. The drains were backfilled with an open graded concrete aggregate that would drain the water. Transverse outlet drains were placed approximately every 30 m along the shoulders.

Concrete Placement

The environmental lane (outside lane, south side) was constructed first, on Wednesday October 1. Delivered concrete temperature was maintained at 15°C. Placement air temperature ranged from 4°C to 12°C with 5 to 8 kph winds from the northwest, wind gusting to 18 kph. The traffic lane (inside lane, north side) was constructed on October 17. Placement air temperature ranged from 4°C to 11°C with 2 to 3 kph winds from the northwest, wind gusting to 8 kph. The batch facility was approximately 30 minutes from the site and the concrete was delivered to the site in six cubic meter batches. The mixture shown in Table 2 was used. The delivered concrete temperature was maintained at 16°C. Approximately 115 m^3 of concrete were used in each lane. An inverse slump test was not conducted and thus workability could not be assessed. The existing concrete surface was prewetted with water prior to placement of the pervious concrete material. In appearance the aggregates were well coated and fibers appeared to be well dispersed throughout the mix. The contractor used a triple tube powered roller-screed and finished the surface in 1.5 to 3 m sections with an initial pass, backed up 0.6 m to 0.9 m, fresh concrete added to the surface as needed, and finishing continued with the roller-screed. Placement of concrete and the initial pass of the roller-screed are shown in Figure 3a. Following the second pass, the finished surface was sprayed with a curing compound and the joints were aligned with the existing pavement joints, which were skewed. In creating the joints, multiple passes (two to four) were made using the jointing device. The surface was then covered with plastic sheets secured with rebar, as shown in Figure 3b. The plastic was removed after seven days.



(a) **(b)**

Fig. 3. (a) Placement of Pervious Concrete Overlay using Roller-screed. (b) Completed Surface of Overlay and Covering with Two Layers of Plastic

PERFORMANCE

On May 21, 2009, a site visit was conducted to review the condition of the pavement and perform field permeability tests on the pervious overlay. At the time of the site visit, the driving lane had been subjected to 67 days of loading by the tractor/trailer between December 16, 2008 and May 19, 2009, with 3092 passes of the 36,300 kg vehicle. The weather conditions following construction in October were typical of the winter/spring season in

Minnesota. Below freezing (0°C) temperatures began in mid-November. Below -18°C conditions occurred in mid-December and continued sporadically through February with occasional below -18°C in March also. Typical daytime temperatures from December through February were in the range of -12° to -1°C. In April and May daily temperatures climb to the 4° to 21°C range. There were two periods of temperatures above 27°C, one in late April and one in mid-May.

Field Condition Survey

A visual inspection of the surface was conducted during the site visit. The pavement distresses were grouped into four categories, three of which are shown in Figure 4 (joint deterioration, stretch marks, surface sealed). Detailed results of this survey are shown in Schaefer *et al.* [2010]. Joint deterioration is widening of the joint caused by raveling of aggregate pieces. Stretch marks are localized areas of visually-observed low density. Stretch marks may or may not accompany increased raveling and no deterioration was observed around stretch mark areas. Surface sealing is caused by excess mixture water allowing the paste to clog the surface voids. The fourth pavement distress of debonding is more difficult to identify with pervious concrete. It was observed that the corners of panels had visual movement when compressed. A sounding was performed across the entire cell indicating possible significant debonding. However, sounding performed on full-depth pervious concrete where no debonding was possible, indicated difficulty indentifying the appropriate baseline for pervious concrete. The suspected debonded areas will be monitored for any cracking or other deterioration.

(a) Joint Deterioration **(b) Stretch Marks** **(c) Surface Sealing**

Fig. 4. Observed Surface Distresses

Flow Characteristics

Flow of water through the surface pervious concrete was determined by conducting field permeability tests using a NCAT AP-1B Field Permeameter. Tests were conducted in five locations. One of the tests was conducted near the center of the cell, in the south (driving) lane. The other four tests were conducted in close proximity to the core samples (within one meter). The field permeability values reported in Table 3 are the average of five to seven trials. Testing locations were visually selected to represent one at a lower surface porosity, one at a higher surface porosity, and three at typical surface porosities. Results show that the permeability for the pervious concrete overlay varies from about 0.16 to 2.11 cm/s, a factor of over 10. The low end of the flow results shows that the pervious concrete contains sufficient flow capacity to remove storm waters from the pavement. All of the field permeability tests were conducted in the middle of panels and the time for water to flow from the test area to the edge of the pavement, generally a distance of about two meters, was two to three minutes for the north lanes of Panels 6 and 16 to 15 minutes for the south lane of Panel 6. These observations indicate that good lateral permeability exists in the overlay.

Core samples were taken back to the laboratory and tested in a falling head permeameter. Comparison to the field permeability results in proximity to the core locations show that the field values are much higher than the laboratory values, ranging from ratios of 2 to 3 up to 23 times higher. The difference is likely due to scale effects, a much larger volume of pervious concrete being tested in the field than in the laboratory. The highest difference occurred in the lowest permeable core sample, further indicating the scale effects on less porous samples. However, even at the low value of 0.007 cm/s determined in the laboratory, the pervious concrete overlay would possess sufficient flow capacity to move water under most storm events.

Table 3. Permeability of Pervious Concrete Overlay

Sample Location	Field Permeability cm/s	Core Sample Laboratory Permeability cm/s (in/hr)
Panel 12 South Lane (Env)	0.85	
Panel 6 South Lane (Env)	0.78	0.20
Panel 6 North Lane (Drive)	1.52	0.42
Panel 16 South Lane (Env)	0.16	0.007
Panel 16 North Lane (Drive)	2.11	1.13

Noise Studies

Noise reduction is one of the advantages of pervious concretes and a primary reason for developing a pervious concrete overlay. On-Board Sound Intensity (OBSI) provides average tire-pavement noise values. Recent studies show that various concrete textures provide tire-pavement noise values in the range of 100 dBA to over 111 dBA [Ferragut *et al*. 2007]. A 10 dBA change in noise can represent a doubling of perceived sound for the same sound. The pervious concrete overlay in cell 39 has been subject to noise studies by the Minnesota DOT using OBSI equipment. The equipment and the noise studies at MnROAD are further described by Izevbekhai [2008]. Three trials conducted in March 2009 on the driving (outside) lane of cell 39 resulted in an average OBSI reading of 98 for the pervious concrete overlay, among the quietest of concrete pavements. Recent test runs on the environmental lane (outside, south lane) and the traffic lane (inside, north lane) in July 2009 showed noise intensity in the low 90’s. The variation of intensity with frequency for July 22, 2009 test runs along cell 39 is shown in Figure 5. The peak intensity for the traffic lane is 96.0 dBA and for the environmental lane the peak intensity is 92.4.

SUMMARY AND CONCLUSIONS

The pervious concrete overlay has been in place at MnROAD's low volume road for approximately 12 months. Investigation of its condition reveals localized pavement distresses, but overall good performance and durability. The concrete mixture was designed for slipform mechanized placement and the observed distresses are related to the selected method of construction, which was hand placement using a roller-screed. A higher degree of construction consistency would have been expected using mechanized placement.

The flow characteristics of the pervious overlay were investigated using both field and laboratory permeability tests. Both vertical and lateral flow characteristics were investigated and showed that the pavement possesses more than adequate flow to handle storm events and prevent surface ponding. Operations during rain events indicate that the pervious overlay quickly removes rainwater from the pavement surface and that the water migrates laterally to the side of the pavement. These results indicated pervious concrete is a successful tool for mitigating splash and spray and reducing hydroplaning difficulties.

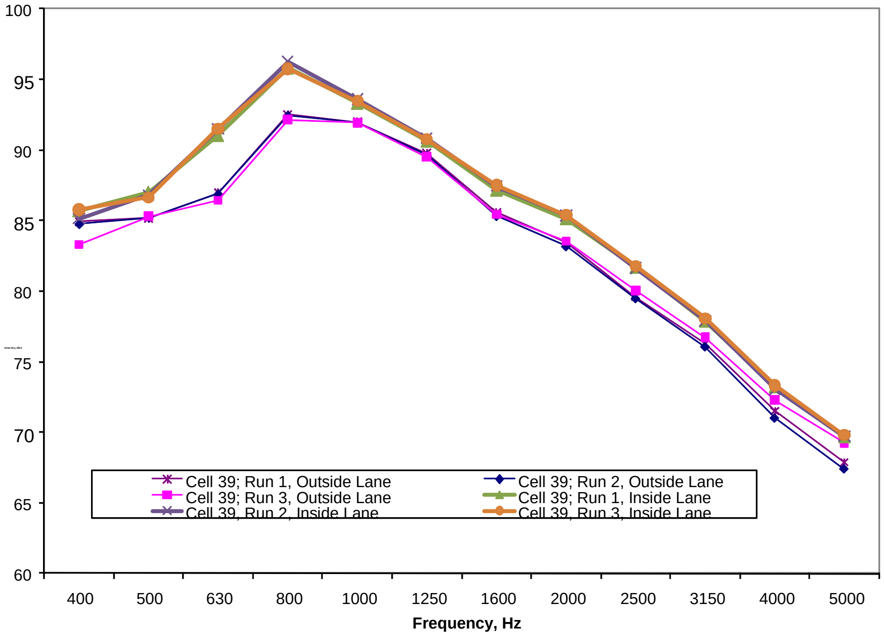


Fig. 5. Pervious Overlay Sound Intensity, 1/3 Octave Bands

The noise measurements conducted in March and July of 2009 reveal a remarkably quiet pavement with OBSI values in the 90 decibel range. The driving range showed OBSI values of 98 in March and 96 in July. There is about a 4dBA difference in intensity between the environmental lane and the traffic lane with the environmental lane quieter. The quieter environmental lane had generally a better surface condition and lower permeability than the concrete located in the drive lane. However, the low noise intensity values for both lanes bode well for the use of pervious concrete as an overlay in urban areas.

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