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Porous Asphat Design for Cold Climate Use

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Abstract

Porous asphalt pavements offer an alternative technology for stormwater management. A porous asphalt pavement differs from traditional asphalt pavement designs in that the structure permits fluids to pass freely through it, reducing or controlling the amount of run-off from the surrounding area. By allowing precipitation and run-off to flow through the structure, this pavement type functions as an additional stormwater management technique. The overall benefits of porous asphalt pavements may include both environmental and safety benefits including improved stormwater management, improved skid resistance, reduction of spray to drivers and pedestrians, as well as a potential for noise reduction. With increasing environmental awareness and an evolving paradigm shift in stormwater management techniques, this research aims to provide guidance for Indian engineers, contractors, and government agencies on the design of porous asphalt pavement structures. One of the keys to the success of this pavement type is in the design of the asphalt mix. The air void percentage, which is ultimately related to the effectiveness of the pavement to adequately control the runoff, is a critical component of the mix. However, special consideration is required in order to obtain higher air void percentages while maintaining strength and durability within a cold climate.

The objectives of this study were to evaluate several laboratory porous asphalt mix designs for durability and strength in cold climate conditions. The porous asphalt mixes consisted of a porous asphalt Superpave mix design method whereby the asphalt binder type was varied. Performance testing of the porous asphalt including draindown susceptibility, moisture-induced damage susceptibility, dynamic modulus, and permeability testing were completed. Based on the preliminary laboratory results, an optimal porous asphalt mix was recommended for use in a Indian climate. Initial design guidelines for porous asphalt were provided based on preliminary findings and hydrological analysis.

1. INTRODUCTION

In the late 1960's, research into a new type of pavement structure was commencing at The Franklin Institute Research Laboratories in the United States. With the support of the United States Environmental Protection Agency (EPA), a porous pavement program was developed. This new pavement structure was initially installed in parking lots [Thelen 1978].

A porous pavement is a distinct pavement type that permits fluids either from precipitation or elsewhere, to pass freely through the structure reducing or controlling the amount of run-off from the surrounding area. By allowing precipitation and run-off to flow through the structure, this pavement type can be applied as a stormwater management practice. These particular types of pavements may also result in a reduction in the amount of pollutants entering the ground water by filtering the runoff. They are generally designed for parking areas or roads with lighter traffic [EPA 1999]. The original proposed structure of a porous pavement consisted of an open-graded surface course placed over a filter course and an open-graded base course (or reservoir) all constructed on a permeable subgrade [Thelen 1978].

There are, however, some disadvantages of this pavement type. In general there is a lack of technical expertise in these types of pavements particularly in cold climates. Clogging potential is of concern due to the open structure of the pavement. There is a potential risk of groundwater contamination as well as a potential for toxic chemicals to leak into the system.

Porous pavements are not currently designed to treat pollutants. Finally, there is a potential for anaerobic conditions to develop in underlying soils if the systems is unable to dry out between storm events [EPA 1999].

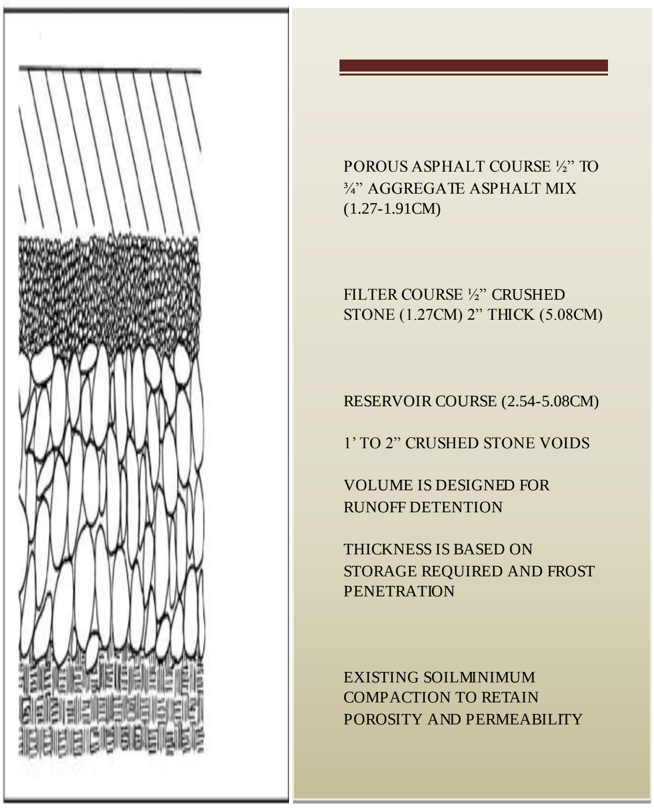

Fig.1.Porous Asphalt Paving Typical Section [Diniz 1980]

"Fig.1", presents an example of a typical porous section (for parking lots and light-weight vehicle pavements) that was provided in an Environmental Protection Agency study.

The EPA had identified two major types of porous pavements: porous asphalt and pervious concrete. Each type of porous pavement is a variation of the respective conventional or traditional impermeable pavement design. Porous asphalt consists of an inter-connected void system containing open-graded coarse aggregates bonded with asphalt cement and fibres, whereas the pervious concrete pavement consists of portland cement, uniformly open-grade coarse aggregates, and water combined using special porous mix designs [EPA 1999].

The literature indicates that porous pavement may also be referred to as pervious or permeable pavement. As indicated earlier, the term "porous" is often used when referring toasphalt mixes and the term "pervious" is used for cast in place concrete pavement structures. Both terms have, however, been used interchangeably [MDEQ 1992]

2. BACKGROUND

Three categories of pavement structures exist in modern pavement design. Flexible pavements composed of asphalt cement concrete, rigid pavement composed of portland cement concrete, and interlocking concrete pavers. In most paving applications dense graded mixes are used for roadway and parking lot surfaces. Porous pavements are an emerging technology constructed for low volume roads and parking lots as an alternative stormwater management technique or best management practice.

Traditionally pavements are designed to allow fluid to flow along the surface and drain towards catch basins and/or ditches along the side of the roads or parking lots. Porous pavements are distinct pavement types that actually permit fluids to flow through the structure. The objective of the system is to reduce or control the amount of run-off from the surrounding impermeable area as well as providing additional benefits such as noise reduction, improved safety measures for drivers and pedestrians due to reduced spray during rain, and reduced potential for black ice/ice due to improper drainage [Thelen 1978, EPA 1999, Ferguson 2005]. Disadvantages of this technology may include: lack of technical expertise (particularly in cold climates), clogging potential, potential risk of groundwater contamination, potential for toxic chemicals to leak into the system, and potential for anaerobic conditions to develop in underlying soils if unable to dry out between storm events [EPA 1999].To date there has not been extensive research into the performance of porous pavements in cold climate applications. Little research has been conducted on porous asphalt to investigate the actual performance of these mixes in colder climates.

3. PURPOSE/MOTIVATION

The purpose of this research was to investigate the potential use of an emerging stormwater management technology as it applies to the Indian climate. With increasing environmental awareness and an evolving paradigm shift in stormwater management techniques, this research aims to provide guidance for Indian engineers, contractors, and government agencies in dealing with porous asphalt as a stormwater management technique. The goal of the research is to be proactive by providing an initial framework for technical expertise for the porous asphalt mixes and performance measures. This research was established as a three way partnership between Golder Associates Ltd, the Natural Science and Engineering Research Council (NSERC) and the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo.

4. SCOPE AND OBJECTIVES

The purpose of this thesis is summarized as the following objectives:

1. Review literature on porous asphalt, pervious concrete, and permeable interlocking concrete pavers with respect to applications, design, construction, and maintenance.

2. Evaluate several laboratory porous asphalt mix designs for durability and strength in cold climate conditions.

3. Recommend an optimal mix design to be used in a Indian climate

4. Provide initial design guidelines for porous asphalt based on preliminary findings and hydrological analysis

5. MATERILAS

The following section describes the materials used to produce the porous asphalt samples for this research. The materials used for this research included two different types of aggregate, two different asphalt binder types, as well as cellulose fibres.

A.Aggregates

The aggregates used in the porous asphalt mixtures consisted of limestone coarse aggregate and a screenings fine aggregate. A small percentage of filler was also used in this particular mix design. Limestone was chosen as the coarse aggregate as it is a common higher quality aggregate available in Ontario. “Fig.2”, provides a photograph of the aggregates.

Fig.2. Coarse and Fine Aggregates

B. Asphalt

Two different types of asphalt binders were used in the design of the mixes. It has been recommended that high stiffness binders be used in porous asphalt mixes, specifically two grades higher then what is typically placed in a region. It is also recommended that polymer modified binders may be used to enhance stiffness. [NAPA 2003]. A PG 64-28 and a PG 70-28 polymer modified asphalt (PMA) binder were chosen to be used in the porous mixes.

Fig.3. Polymer modified asphalt

C. Fibres

Porous asphalt because of the nature of the mix design can be susceptible to draindown of the asphalt binder. Cellulose fibres were added to the mix in order to prevent draindown from occurring during mixing and placement. Fibres may assist with the mix's durability as the fibres may allow for the asphalt content to be increased allowing for an increased film thickness around the aggregates [Cooley 2000].

Fig.4. *Cellulose fibres*

6. MIXDESIGN BACKGROUND

There are three major methods for designing hot-mix asphalt. Between the 1940's and the mid 1990's the Marshall or Hveem methods were the most common mix design method used. More recently, there has been a shift to the Superpave mix design method [NCAT 1996]. The Asphalt Institute states that the objective of asphalt mix design is to "determine a cost-effective blend and gradation of aggregates and asphalt that yields a mix having [Asphalt Institute 1997]:

1. Sufficient asphalt cements binder to ensure a durable pavement.

2. Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.

3. Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of asphalt expansion due to temperature increases without flushing, bleeding, and loss of stability.

4. A maximum void content to limit the permeability of harmful air and moisture into the mix.

5. Sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance.

For surface mixes, proper aggregate texture and hardness to provide sufficient skid resistance in unfavourable weather conditions."

A. Marshall Mix Design Theory

The original concept for the Marshall Mix design was initiated by Bruce Marshall in 1943 with the Mississippi State Highway Department. Using these concepts the U.S Army Corps of Engineers developed the mix design criteria, and finally the American Society of Testing and Materials (ASTM) standardized the test procedures [Asphalt Institute 1997]. The Marshall method attempts to provide similar laboratory densities as those exhibited in the field due to the densification induced by traffic loading. A 4.54 kg (10 lbs) hammer with a 98.4 mm (3.875 in) foot plate was selected for compaction. A compacted effort of 50 blows per each specimen side has become standard practice [NCAT 1996].

B. Superpave Mix Design Theory

Superpave mix design is a newer system for specifying asphalt materials for asphalt concretes that was developed as part of the Strategic Highway Research Program (SHRP) in the late 1980's. The system provides a method for selecting and specifying asphalt binders and includes various aggregate requirements. According to the Asphalt Institute, the unique feature of the Superpave system is that it is considered a performance-based system. The theory is that the tests and analysis performed in the laboratory will have direct relationships to field performance of the asphalt mixtures. The Superpave system of designing mixes begins with the selection of asphalt and aggregates that meet Superpave specifications, and a volumetric analysis is conducted of the mix specimens that have been compacted with a Superpave gyratory compactor [Asphalt Institute 2001].

Fig.5. Rainhart Superpave Gyratory Compactor

TABLE I.POROUS ASPHALT TESTS

Test	*Standard*	*Purpose*
Draindown	ASTM D6390-99	To determine whether the asphalt draindown of the mixes were within acceptable limits.
Modified Lottman Test	AASHTO T-283	To examine the resistance of the asphalt mixtures to moisture-induced damage.
Permeability	Gilson Asphalt Permeameter and The Florida Department of Transportation Designation FM 5-565	To assess the effectiveness of the mixes to transport fluid through the structure.
Dynamic Modulus	AASHTO TP62-03	To determine dynamic modulus values for characterization of the asphalt for both pavement design and in-service performance purposes.

7. MIX DESIGN TESTS

The initial phase of the experimental matrix included the investigation of durability and strength in cold climate conditions. In addition to general mix design procedures, the draindown characteristics of the mixes were determined. The Modified Lottman Test was also performed on the mixes in order to evaluate their susceptibility to moisture induced damage.

A. Draindown Characteristics

The determination of the draindown characteristics was completed using the ASTM standard test method (ASTM D6390-99). The acceptable draindown for the porous asphalt has been recommended at less then 0.3% [NAPA, 2003]. A summarized method for determination of draindown involves preparing laboratory uncompacted samples. These samples were placed in a standard draindown basket and placed in the oven for one hour. The amount of asphalt draindown from each mix was then determined. The draindown test was completed on a PG 64-28 porous mix at 5.5%, 6.0%, and 6.5% asphalt content, as well as on a PG 70-28 polymer modified asphalt porous mix at 5.5%, 6.0%, and 6.5% asphalt content.

B. Modified Lottman Test (AASHTO T-283)

The Modified Lottman Test or AASHTO T-283 Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage was used to investigate the effects of saturation and accelerated water conditioning under freezing and thawing cycles [AASHTO 2004d]. The American Association of State Highway and Transportation Officials (AASHTO) summarizes the test method as the following: [AASHTO 2004d]

Each mixture condition specimen is divided into two subsets. The first subset is tested for indirect-tensile strength in a dry condition. The second subset is subjected to a vacuum saturation and a freeze cycle, followed by a warm-water soaking cycle, and then the indirect-tensile strength is determined. Once the test data is determined for both the dry and conditioned subsets, numerical indices of retained indirect-tensile strength properties are calculated, and the tensile strength ratio (TSR) is determined. As recommended due to the higher porosity, this test was completed at five freeze-thaw cycles [NAPA 2003]. Previous research at the National Centre for Asphalt Technology (NCAT) has indicated that for the higher air void percentages observed in both an open graded friction course as well as porous asphalt, the samples should be tested under more severe cases, therefore the number of cycles in the Modified Lottman Test should be increased [Mallick 2000].

8. PERFORMANCE TESTING

The second phase of the laboratory component of the research included the performance testing of the porous asphalt mixtures. This testing was carried out in the state of the art CPATT laboratory. Two performance tests were conducted on the specimens: dynamic modulus and permeability. These tests are particularly important for comparisons to other new and innovative asphalt pavement designs.

A. Dynamic Modulus

The dynamic modulus values determined in this research can assist in the characterization of the asphalt for both pavement design and in-service performance purposes. The test was performed in accordance with AASHTO TP 62-03. The dynamic modulus test was performed over a range of temperatures and frequencies of loading to simulate real world environmental and traffic loading conditions. The measurements observed can be further used for performance criteria [AASHTO 2003].

The AASHTO summary of method is as follows:a sinusoidal axial compressive stress is applied to a specimen of asphalt concrete at a given temperature and loading frequency. The applied stress and the resulting recoverable axial strain response of the specimen is measured and used to calculate the dynamic modulus and phase angle [AASHTO 2003]. The dynamic modulus is a fundamental property required for Level 1 of the Mechanistic Empirical Pavement Design Guide (MEPDG) design.

Fig.6. Interlaken Testing System

Fig.7. Sensor Configuration for Dynamic Modulus Testing

B. Permeability

One of the critical properties of the porous asphalt is the ability to properly drain the fluid (i.e.rainfall, etc) through the system. Permeability tests were performed on the porous asphalt samples using the Gilson Asphalt Field Permeameter and procedure. All of the samples tested for dynamic modulus were first tested using the permeameter in order to determine the coefficient of permeability.

Fig.8.Permeameter Apparatus

C. Air Void Confirmation

The air void percentages for the porous mixes were difficult to determine due to the open structure of the mix. Several methods were employed and finally the air voids were confirmed using a CoreLok® apparatus performed by DBA Engineering Ltd.

Fig.9.Corelok® Apparatus

D. Hydrological Analysis

The hydrological analysis for the porous pavement design was completed using an analysis program provided by the Portland Cement Association and the National Ready-Mixed Concrete Association (NRMCA) [PCA 2006].

CONCLUSIONS

Further performance testing should continue on porous asphalt including indirect tensile testing, resilient modulus, beam fatigue, and detailed freeze-thaw testing. Additional dynamic modulus testing could be conducted in attempt to determine the dynamic modulus values at the two higher temperatures. Field trials should be constructed to evaluate field performance of the porous asphalt mixes in all climates but especially in cold climates.

The high porosity of these pavements increases the clogging potential. If the pavements are completely clogged then the entire system cannot function properly and fluid may collect on the surface providing a hazardous situation for drivers and increasing the stormwater run-off. Further research needs to be conducted on the clogging potential especially in colder climates where the pavements are subjected to de-icing activities such as salt and sand.

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