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DEVELOPMENT OF EDUCATION TOOLS FOR INTERLOCKING CONCRETE PAVEMENTS

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ABSTRACT: Concrete pavers were developed in the late 1940's in the Netherlands as a replacement for clay brick streets. By the mid 70's automated production was introduced to North America. In 1980, the total consumption of concrete pavers in North America for all markets was estimated at 4 million m^2. For 2003, the total sale of pavers in North America is estimated at 65 million m^2. Commercial and municipal applications account for approximately 32% of the market.

The use of concrete pavers for municipal, commercial and heavy use applications is well accepted throughout the world. In North America, the process of institutionalization of interlocking concrete pavements began in the mid to late 80's (Smith 1992). While institutionalization among engineers is still in the development stages, concrete pavers are considered an orthodox solution in many applications, particularly heavy load applications. A significant component of institutionalization for any technology is exposure of theory, design, and practical application for civil engineering students within the university setting.

In 2003, a team of educators at the University of Waterloo, under the guidance of the Interlocking Concrete Pavement Institute, developed a curriculum for interlocking concrete pavements for integration into existing undergraduate and graduate civil engineering courses. The curriculum has already been tested at the University of Waterloo. In addition, a university professor's workshop was conducted in December 2004. The curriculum consists of nine instructional modules that cover material and standards, structural design for roads and parking lots, construction methods, maintenance and management, life-cycle cost analysis, airport pavement design, port and industrial pavement design, and permeable interlocking concrete pavements.

This paper will give an overview of the new curriculum and highlight the instructor's guide which includes teaching strategies for each module as well as suggested assignment questions.

1. INTRODUCTION

Concrete pavers were first developed in the 1950's in Western Europe as a low cost replacement for the traditional clay bricks. By the mid 70's automated production was introduced to North America. In 1980, the total consumption of concrete pavers in North America for all markets was estimated at 4 million m^2.

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2. CURRICULUM

The curriculum consists of nine instructional modules (1 through 9) that cover an introduction, material and standards, structural design for roads and parking lots, construction methods, maintenance and management, life-cycle cost analysis, airport pavement design, port and industrial pavement design, and permeable interlocking concrete pavements. Modules 1-4 can be easily integrated into existing civil engineering pavement courses at the undergraduate level. Modules 5-9, although more technically advanced, can be used as introductory material for undergraduate students or as independent study projects. They can, however, be presented in their entirety at the graduate level.

2.1 Module 1: Introduction

Module 1 includes an overview of the historical development of interlocking concrete pavement (ICP), a brief introduction to the major components of ICP’s (as shown in Figure 1), their range of applications, and the other teaching modules in the course. The teaching strategy for this module is to try and raise the level of interest and awareness of ICP to the students. An introductory video clip is available to be shown in the first lecture. If concrete pavers are installed around the university campus, a quick tour can be arranged to see the applications, or an exercise can be given to the students to locate the different concrete paver applications around the school campus.

There is a rich history behind segmental concrete pavement, much of it developed by Dutch and Germans since the 1950’s, and much of the construction technology can find its root in the Romans roads of antiquity. The Romans built an 80,500 km intra-state network of roads with segmental pavement and this 2000 year-old pavement sections are still with us today. A history of segmental concrete pavement in Europe and road building of Roman roads could be included as part of the introductory lecture, as many principles of design, materials, and construction transfer to interlocking concrete pavements and other pavement types.

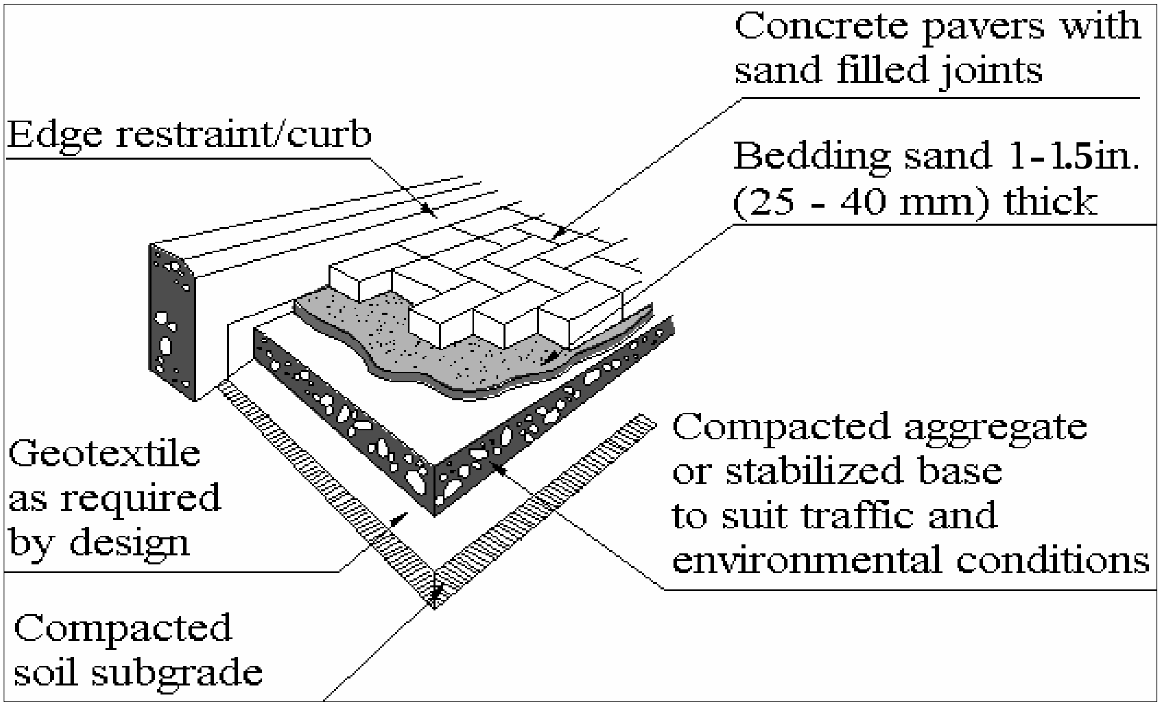

Figure 1. Typical components of interlocking concrete pavements.

2.2 Module 2: Materials and Standards

Module 2 covers construction materials and standards used in the interlocking concrete pavement industry, putting emphasis on the advantages of manufactured concrete pavers over field-prepared paving materials. Module 2 also includes test methods and criteria used to verify the strength and durability of the paver units, and material specifications for bedding sand, joint sand, and edge restraints. Two files are prepared for this module: one using CSA standards for Canadian universities and the other using ASTM standards for university programs in the United States.

The teaching strategy for this module is to use a laboratory demonstration/ exercise to reinforce material presented in class. The laboratory demonstration/ exercise could be to test the compressive strength of a concrete paver and compare results with the strength of a concrete cylinder (for rigid pavement). Also, sieve analysis for bedding sand and joint sand could be performed to illustrate the importance of particle size in the applications of the two sands. A visit to a local manufacturer of concrete pavers also provides excellent awareness for the student and insight to the material properties and manufacturing quality control process.

Some suggested assignment questions include; What are the two measures for durability used for concrete pavers? What are bedding sand and joint sands? Why joint sand should never be used for bedding sand, but the reverse is considered allowable? What are the main functions for edge restraints? Name three common types of restraints available in the markets.

2.3 Module 3: Structural Design for Roads and Parking Lots

Module 3 covers the principle of interlock and presents design methods for roads and parking lots with concrete pavers, with an emphasis on how AASHTO design process is applied to ICP structural design. Interlock is the inability of a paver to move independently of its neighbours and is the key to the load spreading and structural contribution of ICP's. The AASHTO pavement flexible pavement provides an adequate model for this contribution. It is important that students have previous exposure on AASHTO design method and if possible theory behind mechanistic analysis.

Design examples should be solved using unbound, cement- and asphalt-treated base materials so students can see the proportional differences depending on variations in soil strength/ stiffness and traffic (ESALs) and develop a feel for this engineering "intuition". Lockpave is a software program developed by the Interlocking Concrete Pavement Institute (ICPI) which performs thickness design using either the AASHTO design method or a mechanistic analysis, as shown in Figure 2. An interactive presentation of Lockpave with the class, on their computers, allows for demonstration of sensitivity analysis based on inputs and assumptions built into the software program.

Some suggested assignment questions include; Why is the design method for AASHTO flexible pavement adopted for ICP's, even though the pavement surface is made of concrete? How is the load-transfer mechanism in ICP's compared with that of typical flexible and rigid pavements?

The design example problem is described as follows: A two-lane urban collector is to be designed using interlocking concrete pavers. Laboratory tests indicate that the subgrade soil is of ML-CL soil type according to the USCS classification system. No field CBR or resilient modulus data are available. From available climate data and subgrade soil type, it is anticipated that the pavement will be exposed to moisture levels approaching saturation around 35% of the time. Drainage quality is poor, but frost is not a design consideration. Detailed traffic data are not available. Using the above information, provide a pavement design for the collector with an aggregate base, cement- and asphalt- treated base.

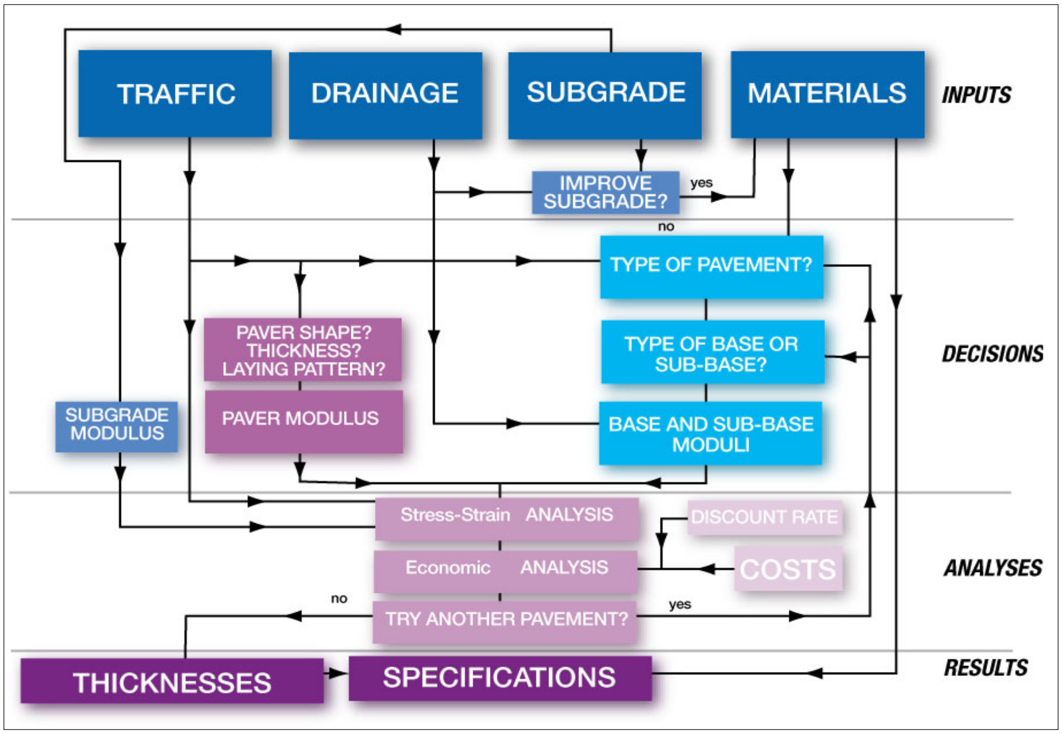

Figure 2. ICPI Lockpave Flowchart.

2.4 Module 4: Construction Methods

Module 4 presents typical construction methods for ICP's, as well as some failure mechanisms that can arise from inadequate design and detail or from improper construction methods. Construction specifications for manual and mechanical installation are also introduced. Module 4 is equipped with a video clip to illustrate how mechanical installation is used in paving. To make construction more than just specifications on paper, site visits by the class to projects or mechanized installation projects could be arranged with ICPI contractor members.

Some suggested assignment questions include; Outline the construction steps for ICP's. Describe three most common failure mechanisms for ICP. When should geotextile be installed between base and subgrade in ICP? Find a construction site with concrete pavers and provide a photographic documentation with notes of the project during the course of the semester. Present it to the class with projected images and describe the process.

2.5 Module 5: Maintenance and Management

Module 5 provides students with an understanding of typical distresses found in ICP's and the maintenance actions required. Conducting a field condition survey on a distressed ICP application could be used as a teaching strategy for this module. Students are given an opportunity to learn and develop survey skills on how to identify various distress types and determine proper severity levels. Students could be challenged to seek remedies to distresses found, based on knowledge developed from the construction module, and from talking with contractors. As the material in this module builds upon the construction module, students should be familiar with the pavement construction process and should have basic knowledge of typical pavement maintenance techniques for asphalt and cast-in-place concrete pavements. This enables the students to build comparisons among pavement types. Sealing and joint sand stabilization are application specific. Students should learn where and when these materials should be applied to various ICP's applications.

Some suggested assignment questions include; Why is sealer required for airport pavement applications? What are the advantages of using slurry mix/unshrinkable fill as base material in a utility repair? What are the advantages of interlocking concrete pavement compared with monolithic pavements in maintenance perspectives?

2.6 Module 6: Life-Cycle Cost Analysis

Module 6 covers basic cost estimating principles and methods to perform life-cycle cost analysis on ICP's. The purpose of the lifecycle analysis is to account for the time value of money. Most life-cycle cost analyses do not usually account for indirect costs from closing a pavement for maintenance or rehabilitation. The amount, value, and timing of indirect costs, however, can have a significant impact in determining the pavement type. In some traffic situations, ICP's may have an advantage over other pavement types by incurring lower indirect costs from reducing repair time and this message should be emphasized in this module.

The teaching strategy for this module can be to have students practice life-cycle cost analysis calculations, first by hand, to develop a thorough understanding of the relationship of the variables. ICPI Lockpave software can then be used to run a series of life-cycle cost scenarios on various designs. A sensitivity analysis of variables such as initial costs, maintenance costs, and discount rates can be conducted by iterating the software program. Students should be encouraged to compare life-cycle costs of flexible, rigid, and ICP's, and estimate the break even points based on various design lives, traffic loads, and pavement structure scenarios.

Some suggested assignment questions include; Compare and contrast typical maintenance routines for ICP, flexible and rigid pavements. Describe a situation when indirect costs can produce a significant difference in cost saving. After using the information provided in the design problem in Module 3 to perform a flexible pavement thickness design, perform life-cycle analyses on both the flexible pavement and ICP, based on the design thicknesses calculated. Unit costs can be obtained from up-to-date construction cost guides, local contractors, or from the Internet. Students should state all assumptions and perform the life-cycle cost routine using ICPI Lockpave software program.

2.7 Module 7: Airport Pavement Design

Module 7 emphasizes the selection criteria for ICP's in airports and provides students with basic understanding of FAA-approved design methods for airport pavements with concrete pavers. Case history studies could be used as a teaching strategy for this module. For example, the use of 500,000 m^2 of ICP's at the Hong Kong International Airport provides a state-of-the-art case study on design, construction, functional and safety requirements, and impacts on airport operation during maintenance for the class to explore.

Some suggested assignment questions include; Which areas in an airport are not recommended to use ICP's and why? What characteristics of concrete pavers make them a good surfacing material for airport pavement? Design an airport apron with concrete pavers for a design weight of 11 metric tons with subgrade CBR of 7% (Assume 1000 annual departures). Design a low-speed taxiway with concrete pavers for dual tandem gear aircraft of 181 metric tons, 15,000 annual departures, and subgrade CBR of 7% (the design pavement area can be considered critical).

2.8 Module 8: Port and Industrial Pavement Design

Module 8 covers the principle of heavy-duty pavement design and the design method for port and industrial pavements, including overlays with concrete pavers. Specifications for construction of heavy duty pavements for ports and industrial areas are included in this module. Case history studies can also be one of the teaching strategies for this module. For example, the largest ICP project in the western hemisphere is at the Port of Oakland, California, with 470,000 m^2 of concrete pavers. This state-of-the-art project provides the students an opportunity to explore different aspects of the port and industrial pavement designs with concrete pavers.

ICPI Lockpave software includes an option for industrial and port pavement design based on mechanistic analysis of pavement layers. In addition, ICPI provides a design manual, *Port and Industrial Pavement Design with Concrete Pavers*. This design method is derived from a similar publication by the British Ports Association that has been used to design all types of port pavements around the world including ICP's. The method is based on a finite element model and presented in a simplified design format.

Some suggested assignment questions include; using the same information from the design problem described in the ICPI design manual consider new conditions such as:

1. Straddle carrier wheel loads during braking and corner at the same time.
2. Straddle carriers running freely on a smooth surface.
3. Instead of using a straddle carrier, consider a typical front lift trucks operation during (1) braking (2) cornering and braking (3) acceleration.

Using the same information from the overlay problem described in this module, perform an overlay design with concrete pavers with no rutting in the existing granular base. What are the two main techniques to determine the remaining life of pavement and briefly describe how the two techniques work?

Design problem: A weakened PCC pavement has previously been strengthened by the application of an asphalt wearing course which is still intact. The port is, however, shortly to take delivery of heavier handling equipment (equivalent single wheel load is assumed to be 578 kN) and wishes to upgrade the pavement further. During the initial strengthening operations, it was observed that concrete was substantially cracked. Slight reflective cracking has occurred in the asphalt overlay. There is no rutting. Transform each course to an equivalent thickness of CTB and back-calculate the number of additional passes enabled by overlay with concrete pavers.

2.9 Module 9: Permeable Interlocking Concrete Pavement

Federal, state/provincial, and local stormwater regulations have encouraged the implementation of best management practices (BMPs) to reduce runoff and non-point sources of water pollution. Introduced by Germany to North America in the mid-1990s, Permeable Interlocking Concrete Pavements (PICP's) are a viable BMP for infiltrating and reducing pollutants in runoff. This module provides students with an understanding of the differences between typical pavers and permeable interlocking concrete pavers, and an overview of the design process. The ICPI manual, Permeable Interlocking Concrete Pavements, should be distributed to students exposed to this module. This manual provides detailed design information as well as information on construction and maintenance. Students should have previous exposure to soils test methods and theories such as soil classification, infiltration, CBR/R-value, and proctor density. Visiting sites with permeable pavement or those under construction with PICP's also serves as an excellent introduction to this module.

Some suggested assignment questions include; What are major types of permeable pavements? Give examples to their respective applications. What are three design options for permeable interlocking concrete pavements? Describe three benefits and three limitations of PICP's. Name three areas where PICP's are not recommended to be used.

2.10 Example Term Project

The layout of an area (e.g. parking lot) constructed with ICP is given to the students. This layout includes locations for storm drains, overhead utility lines, landscaped areas, etc. Traffic loads and weather conditions of the area are also given. Students are asked to provide a report with the following components:

1. A detailed design with concrete pavers
2. Material and pattern selection
3. Structural analysis (include calculations or printout from ICPI Lockpave software)
4. Edge restraints (provide drawings/ schematics)
5. Justification for design parameters (based on the weather and traffic information provided)
6. Life-cycle cost analysis
7. Maintenance schedule (include justification for any assumptions made)

Different parts of the report could be submitted at specified time during the course of the term (e.g. two weeks after the lectures covering the specific topics needed to complete the particular section of the report). This avoids students waiting until the last moment to do everything and provides students an opportunity to practice what they learned in class immediately. More importantly, such an involved project will not overwhelm the students when it is broken up into manageable pieces. Students (or groups of student) will be asked to make a presentation of their designs at the end of the term.

3. FINAL REMARKS

The nine modules in this new university curriculum contain enough material to create an entirely new university course on ICP's. Indeed, the curriculum could easily consist of some 40 hours of lectures, plus laboratory work, and field assignments. The curriculum, however, is also designed and intended for adoption and integration by university professors into existing civil engineering undergraduate and graduate pavement courses. In 2004, part of this new curriculum was tested at the University of Waterloo in the undergraduate and graduate Civil Engineering classes. Materials from Modules 1 to 5 were incorporated in the "test-drive" lectures and they were well received by the students. In addition, the first university professor's workshop was held in Toronto in December 2004. It was a great success and there was a common consensus that the information included in the new curriculum is very thorough and well documented, and all attendees would incorporate at least some of the information into their current curriculum. With the success of the first workshop, a second professor's workshop is being planned to be held in August 2005 and a third is planned as part of the 8th International Conference on Concrete Block Paving in November, 2006.

4. REFERENCES

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