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INTERLOCKUTOR

RESILIENCY IN GREEN INFRASTRUCTURE RENOVATION

Couldn’t Stand the Weather

Mark Twain said, “Everybody talks about the weather, but nobody does anything about it.”

Global climate change might be altering the implications of Mr. Twain’s saying because we are likely doing something to the climate and maybe something about it. While the causes and effects of climate change receive endless debate in scientific and political spheres, regional-scale rainfall patterns are changing for certain. The result has been wetter weather in some parts of North America, drier in others.

The weather changes have been so dramatic that rainfall statistics defining storm recurrences are seeing realignment. A hypothetical example explains this shift. Say there are 80 years of storm data and some indicates that very occasionally, a city receives five inches rainfall in 24 hours. Some statistics are run and they conclude that the city has 4% probability of that rainfall depth occurring in any given year. So it’s called a 25-year storm. But data gathered over the past two decades now indicate a 10% probability. So that rain event has shifted to a 10-year storm recurrence. The old 10-year storm with maybe three inches of rain is now five inches.

This shift directly affects cities because storm sewers back up and can’t immediately drain the additional water. When that happens, it can end up in someone’s basement. Besides property damage, the city can be liable for damages. Storm sewers originally designed to manage a 10-year storm are now obsolete as confirmed by revised rainfall statistics.

Hurricanes plague the East, tornadoes the Midwest and South, and earthquakes the West. Because of natural disasters like the earthquakes in Northridge and Loma Prieta, and Hurricanes Katrina, Irene and Sandy, governments at all levels are seeking resilient designs and technologies to resist excessive wind, rain and tectonic plate movements. Resilient infrastructure resists these onslaughts from nature by designs that minimize damage to private property and society’s productivity. As urban infrastructure is rebuilt, resilient technologies and designs are increasingly included.

One city implementing resilient infrastructure is Atlanta, GA. It recently completed the Southeast Atlanta Green Infrastructure Project. Infrastructure renovation involved replacing century-old water lines, storm and sanitary sewers in two neighborhoods. The ‘green’ portion reduced stormwater runoff, a fundamental goal in most GI projects, with permeable interlocking concrete pavement. Atlanta went beyond reducing runoff. It installed around 700,000 sf (65,000 m²) of permeable interlocking concrete pavement with enormous water storage capacity to reduce increasing flood events.

According to Todd Hill, P.E., Atlanta’s Director of Watershed Management, the pavement stores about 7 million gallons. That approaches one million cubic feet of water in over 10 Olympic-sized swimming pools. As an extra bonus, maybe a fourth of that water is infiltrated back into Atlanta’s clay soils. A portion of the $66 million invested will be returned in spared litigation costs, not to mention increased property values and resulting taxes.

In their present state, many urban drainage systems simply can’t stand the weather. In response, resilient urban infrastructure is an intentional public investment goal. As they rebuild, cities and neighborhoods can resist bad weather by providing permeable pavements that control flooding while remaining un-flooded and useable during the worst storms. Atlanta certainly magnifies and affirms the role of permeable interlocking concrete pavement in resilient infrastructure.
Clearing the Air

ICPI WORKS TO RAISE AWARENESS ABOUT RESPIRABLE SILICA

Repeated exposure to respirable silica poses long-term health risks, according to medical studies. How much exposure is considered safe? In 1971, OSHA established 250 micrograms per cubic meter of air (µg/m³) per 8-hour workday as the permissible exposure limit (PEL) to respirable silica dust for the construction industry. In March, OSHA published a final rule lowering the PEL to 50 µg/m³ averaged per 8-hour day effective June 23, 2016, with compliance required by June 23, 2017. The construction industry in general has rejected this rule on the basis of technological infeasibility plus the untenable costs related to reducing exposure by 80%.

In an effort to educate contractors, ICPI has approved new language for inclusion in its contractor courses and manuals (see sidebar). Though OSHA might rarely visit residential jobsites, an estimated 75% of all pavers and paver products see use in residential applications. Thus, raising awareness and providing knowledge on jobsite protection are important responsibilities for ICPI. A resource webpage on respirable silica is in the works for the new ICPI.org website. It will include links to research and reports on the issue.

Worker health and safety are universal priorities on which everyone can agree. Workers understand why protecting their eyes, backs, knees, elbows and hands are important because there is a fairly immediate cause and effect if they do not. However, effects from repeated exposure to respirable silica can become manifest over a long period of time. When risks are not immediately apparent, prevention may seem less imperative. That is why knowledge and awareness are so important, as well as safety training. A worker’s lungs need protection too.
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ASCE Permeable Pavement Standard in Final Stages

Under development for three years, the American Society of Civil Engineers Transportation and Development Institute will likely release a national standard guide on design, construction and maintenance of permeable interlocking concrete pavement (PICP) later this year. The 100+ page draft was written by a committee of consultants, government agency personnel, stormwater advocacy groups, contractors and industry suppliers. The group is chaired by David K. Hein, P. Eng. with Applied Research Associates, Inc. Final stages include balloting by his committee, comments from the public and resolution of persuasive public comments.
Titled Design, Construction and Maintenance of Permeable Interlocking Concrete Pavement, the document is divided into five chapters. The first chapter provides a table to assist users in determining if a particular site is suited for PICP. Then the material components of PICP are covered including system infiltration options; full, partial and none.

Structural and hydrologic analyses are provided. Structural analysis includes subbase thickness tables developed from mechanistic modeling and validation using full-scale accelerated load testing at the University of California Pavement Research Center (UCPRC) in Davis. These introduce a new design approach where the designer must estimate the number of days annually water will be in the subbase. This is conservatively estimated by determining the infiltration rate of the underlying soil subgrade and then, using daily rainfall data, determining the average number of days per year with rainfall greater than the 24-hour infiltration rate of the subgrade. This approach addresses the reality that some PICP projects have water standing in the base and soil, i.e., a saturated condition, for a number of days. This weakened state of the soil subgrade is factored into tables used to determine the subbase thickness.

The other influence on subbase thickness is the required water storage. The amount of storage and resulting base thickness are determined by the infiltration rate of the soil, given requirements from the local government on how much water should be managed. The standard provides equations for estimating subbase thicknesses that infiltrate all of the water into the

Continued on page 8

The emerging ASCE PICP standard guide lists ICPI's Permeable Design Pro among several software programs used for hydrologic calculations during the design process. The advantage of this program is its ability to calculate subbase thicknesses required for water storage plus the thickness required to support vehicular traffic. Besides pavement design, the program outputs CAD drawings of design solutions. To download a free 30-day trial version, visit www.permeabledesignpro.com.

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To address the number-one question by project owners and stormwater agencies, the standard covers maintenance surface cleaning methods and surface repairs. Specifically, the standard describes routine preventive maintenance to keep surface infiltration flowing and more concentrated remedial maintenance techniques should the surface become clogged and render very low infiltration. Like construction, the section on inspection deserves a checklist covering most aspects. A foundational inspection item is checking surface infiltration by observing ponding during or just after a rainstorm. Clogged areas should be checked using ASTM C1781 Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems.

After an extensive References section, the Appendixes include a design example for structural design that leads the user through the UCPRC subbase thickness design charts. Additional hydrologic design examples quantify water volume and flow through full, partial and no-infiltration configurations. Appendixes include a guide construction
specification with direction on using a lightweight deflectometer for deflection testing the compacted subbase and base. (See Engineer’s View in this issue for more information on this device.)

For comparison purposes, the Appendix also has subbase thickness design charts calculated from the flexible pavement design method (for non-permeable pavements) in the AASHTO 1993 Guide for Design of Pavement Structures. These yield conservatively thick subbase thicknesses. These are similar to those found in the UCPRC tables under the highest number days per year water stands in the subbase.

The ultimate purpose of this emerging ASCE standard is for provincial, state and local governments to reference it in their green infrastructure and low impact development manuals, as well as in stormwater management and road agency design guidelines. While the standard’s propagation and acceptance may take years, the expectation is less time will be required than an entirely new technology. PICP has been in use in parking lots, alleys and streets for over 15 years, representing well over 150 million sf (14 million m²).

In 2010, ASCE released ASCE 58-10 Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways. This design guide is for roadways experiencing up to 10 million lifetime 18,000 lb (80 kN) single axle loads or ESALs. The emerging ASCE standard guide for PICP will complement 58-10, covering designs up to 1 million ESALs. Additional research may see an increase in lifetime ESALs with hybrid systems that include other pervious materials. Finally, as the paving slab and plank market grows, a need may arise to develop an ASCE design, construction and maintenance standard for these segmental concrete paving products and systems. Looking ahead, the vision is using such standards to further institutionalize all of these paving systems among designers, owners and government agencies.
The morning after an overnight rainstorm, Tom Sweet, AECOM senior engineer, walks two blocks from the Downtown Berkeley BART station and puts on his yellow safety vest to inspect the Allston Way permeable paver street he helped design. “How’s the ride?” he asks a passing skateboarder, who gives a thumb’s up in response. Local residents approach from the adjacent park, ask if he’s involved with the new street and tell him how beautiful it is. When he explains the street can also infiltrate stormwater, filter pollutants, reduce runoff to San Francisco Bay and improve the health of the park’s trees, they ask, “Why aren’t all streets like this?”
Facing an aging infrastructure as are many cities today, the City of Berkeley sought a durable alternative to its existing asphalt road surfaces in need of replacement. Situated on a hill that slopes down to San Francisco Bay, mitigating stormwater runoff also ranked highly among its priorities. A public works commission began extensive research into green infrastructure redevelopment options and called in David Hein, P. Eng., Vice President of Transportation with Applied Research Associates, Inc. (ARA).

“The City had wanted to do this for a long time,” said Mr. Hein, referring to the City Council’s desire to construct a green roadway using a permeable paver system as a demonstration project. A 40-year life-cycle cost analysis showed permeable interlocking concrete pavement to be almost the same cost (less than 2% difference) as an impermeable flexible pavement. However, the analysis did not take into account the benefits from permeable pavements such as reducing stormwater runoff volume, peak flows and pollutant loads. If these cost factors were taken into account in the LCCA, the permeable pavement would have the lowest total present worth cost, according to Mr. Hein.

**SUITABILITY EVALUATION**

With numerous sites proposed by the City for the PICP demonstration street, an evaluation matrix created by ARA for this project determined the best choice. The suitability design matrix identifies key factors that may influence design and effectiveness for a specific project, categorizes those factors as primary or secondary considerations and assigns weighted values on a scale of 0-100 (see matrix on page 12). If the score totals less than 65, the project is not considered a good candidate for permeable pavement. Scores between 65 and 75

- **CROSS SECTION:**
  - 29,145 sf (2,700 m²)
  - 240 x 120 x 80 mm pavers
  - 2 in. No. 8 open-graded bedding course
  - 4 in. No. 57 open-graded base
  - 20 in. No. 2 open-graded subbase

An 8-in. plastic cellular confinement layer in the subbase provided the structural support for bus traffic while at the same time reducing the necessary excavation depth by a full foot from the initial design.
A project's suitability for permeable pavement depends on key factors specific to the site. By identifying the primary and secondary considerations and assigning weighted values to each from 0-100, the criteria is established for an evaluative decision matrix.

**PICP SUITABILITY DESIGN MATRIX FOR BERKELEY CANDIDATE SITES**

**Primary Considerations:**
- **20** Significant Longitudinal Grades
- **15** Geotechnical Risks
- **25** Presence of Utilities
- **20** Traffic Volume (ADT)
- **20** Presence of Bike Paths

**Secondary Considerations:**
- **20** Groundwater Contamination Risk
- **20** Potential for Sediment/Biomass Loading
- **20** Soil Infiltration Rates
- **20** Target Design Volumes and Runoff
- **20** Risk of Flooding

are worthy of consideration, but scores over 75 indicate a well-suited site. A section of Allston Way received a high evaluation with a score of 81.

However, there were a number of initial concerns expressed about the project. The cycling and skateboarding communities weren't sold on a segmental road surface for the heavily trafficked bike route of Allston Way. City engineers had concerns about the utilities below the street and the depth of excavation required for a properly installed PICP system as well as the suitability of Berkeley's clay soil for infiltration. City arborists made specific requests for care and caution in excavation around tree roots. And a small time window for construction to coincide with the adjacent high school's summer break added another challenge. To address these concerns and requirements, the initial design underwent some innovative refinement.

**REFINED DESIGN**

“We had a fairly deep section proposed,” explained Mr. Sweet. “Over the course of the design, as a cost-benefit, we looked into making the section thinner from a pragmatic approach.” And that’s when flexible HDPE cellular confinement for the aggregate base entered the picture. From an initially proposed depth of 41 in., the addition of an 8 in. cellular confinement layer provided enough structural stability and strength to reduce excavation to 29 in. It shaved a full foot off the excavation depth requirement, thus saving time, reducing the cost of off-haul as well as emissions and minimizing risk to the

[A Continued on page 14]
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underlying utilities.

A few more innovations addressed concerns about clay soil infiltration and the street’s nearly 3% longitudinal slope. Eleven check dams were specified, but the flexible design permitted non-uniform placement at the most logical locations, i.e., where the sections had been excavated to full depth and around the existing utilities. “We didn’t want all the water to go to one end and oversaturate the subsoils, so we were very careful in the detailing to segregate the water,” Mr. Sweet said.

Additionally, the underdrain was raised up 6 in. from the subbase to take advantage of some detention and infiltration over clay soil. “It’s an opportunity that most projects miss,” explained Mr. Sweet. “A lot of folks in the profession say, ‘It’s clay soil, we can’t infiltrate.’ In fact, you can infiltrate, you just need to be more careful with how you do it and where you do it.” The sizes of the openings in the underdrain were carefully considered. “We wanted to recover but we didn’t want it to act as a conveyance,” said Mr. Sweet. The underdrains buffer the rate of flow leaving each check dam. Though the water level might reach the holes in the perforated pipe, limiting the number and the opening size allows water to go higher. Designed for a 48-hour drawdown, the underdrain system is a water recovery mechanism, not an instantaneous outflow. “Personally, I am very excited about this system. I think it’s almost the highlight of the project,” said Mr. Sweet.

BREAKING NEW GROUND
Construction of the project took place during the summer of 2014. The curb-to-curb pavement surface area totaled 29,145 sf (2,700 m²). Don Irby, P.E., Associate Civil Engineer with the City of Berkeley Public Works Department, managed the construction from beginning to end. This was Mr. Irby’s first permeable paver project. “We had to close the road for almost three months because it’s just not really economical to do this type of installation in sections,” Mr. Irby said. “That played into our location selection because we had to look at driveway access. There are a lot of things you need to take into account when you
Continued on page 16

Ghilotti Construction Co. managed the road closure as the general contractor for the project and handled the careful excavation around utilities and tree roots.

European Paving Designs Inc. (EPD), an ICPI-certified installer, installed the pavers. "As soon as we saw the tight spec for this project, we were really motivated to get the job," said EPD CEO Randy Hays. "[The specification] referenced ICPI's PICP manual. We knew we had the expertise and experience to make it successful."

With a seven-man crew working in two phases, the blend of reddish orange-and-charcoal pavers was installed in a herringbone pattern before installing pavers for striping. "That seems to work the best," Mr. Hays said. "It allows for some give and take with the location of the stripes, so if we have to shift it an inch for alignment, as long as there are no small pieces, that's the right way to do it."

UNDERDRAIN SYSTEM DESIGN

- **Concrete curb**
- **Crushed open graded bedding course ASTM No. 8**
- **Crushed open graded base ASTM No. 57**
- **Crushed open graded subbase ASTM No. 2**
- **6" dia. solid HDPE**
- **12LF – 2” perforated HDPE pipe with ¼” holes @ 10” O.C. top**
- **Soil subgrade sloped to drain**

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Yellow-pigmented pavers provided contrast with the darker pavers, all supplied by Pavestone Company. The EPD crew laid out the pavers for the stripes, cut the sections out from the installed field and then inserted the yellow pavers. Mr. Hays said his foremen recall people first seeing the completed installation while they were doing cleanup work. “They were looking down as they crossed the street and said, ‘Wow, that’s unique.’”

MANUALS FOR LABOR
As part of their involvement on the project, ARA created two manuals for use by the City of Berkeley. One established a maintenance plan and the other specific maintenance procedures. Mr. Hein explained, “Ultimately, the purpose of ICPI is to provide guidance to people on the use of paver products. If you handle them, here’s how you do it right. I think the Utility Cut Manual and the Maintenance Guidelines are very important.” Each manual’s appendix includes ICPI Tech Spec 6 — Reinstallation of Interlocking Concrete Pavements.

RESULTS EXCEED EXPECTATIONS
In the year and a half since the Allston Way project’s completion, it has been routinely and closely monitored. “The system has exceeded expectations with regard to stormwater management,” said Mr. Irby. “The infiltration rate that we’re seeing is better than we had estimated. He added, “We haven’t published the data yet, but what we’ve gathered to date does show that the pollutant levels have been reduced.” “The most recent storm we monitored was 1.75 in. over 19 hours, a fairly large storm for California,” said Mr. Sweet. “And we attenuated 94% of the runoff. We did readings off the discharge pipe and it really shows the benefit of spreading the water out and letting it infiltrate at a comfortable rate, to the extent that it can.”

Additionally, the City Forestry Department is monitoring the health of trees in the adjacent park to see if there is noticeable improvement. The trees are photographed on a regular basis for analysis, but this study will require a good deal of time before results become apparent. “There was a lot of concern about the roughness of the surface from the cycling community, but I haven’t heard a word from them since it was installed,” said Mr. Irby. “And we see hundreds of bikes on the street every day, and skateboarders too. It’s an incredibly smooth surface.” That smooth surface is due to EPD’s expert installation of the ADA-compliant pavers specified, which feature a quarter-inch joint and interlocking spacer bars. In fact, the permeable paver surface is likely safer for cyclists to traverse in wet conditions because it prevents standing water from collecting of the pavement surface. “The coefficient of friction for a permeable paver surface is better than most asphalt roads,” Mr. Irby explained. “There are lots of benefits that people aren’t really aware of.”

THE INTANGIBLES
“The arc of this project was very gratifying,” Mr. Sweet said. Given the initial concerns expressed by the City and the community, “Everyone landed in the same place saying, ‘Wow, this project is worthwhile, it’s interesting, it’s the right thing, and it turned out great.’” “I’m happy I got to be a part of this project,” Mr. Irby said. “I have coworkers who go out of their way just to walk by that street because it’s really nice to look at.”

“The City of Berkeley is really committed to the environmental aspects of construction.” Mr. Hays said. “Sustainability in the construction industry, especially with regard to water conservation, is very important. Building streets that actually return water to an underground system is a pretty cool thing.” As for the question “Why aren’t all streets like this?” That answer may just be a matter of time.
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Permeable interlocking concrete pavements (PICP) require open-graded, crushed aggregate subbases and bases for water storage and infiltration into the soil subgrade. For vehicular areas, ICPI recommends using a subbase of ASTM No. 2, 3 or 4 aggregate sizes. This layer is topped with a 4 in. (100 mm) base of ASTM No. 57 or similar-sized aggregate. A 2 in. (50 mm) thick bedding layer of smaller aggregate (typically ASTM No. 8) and concrete pavers are placed on the base layer and compacted. The joints are filled with permeable aggregate and the pavers are compacted again.

As with all pavements, PICP subbase and base layers must be compacted. Lift thickness should be no thicker than 6 in. (150 mm). Maximum lift thickness can increase to 12 in. (300 mm) if a 10-ton roller compactor seats it (Figure 2). A large, reversible plate compactor can be used as well, and will be required to compact next to curbs, foundations and utility structures, as well in corners, i.e., places where roller compactors cannot reach. Large means 13,500 pound-force (60 kN) and equipped with a compaction indicator (Figure 1). These machines weigh around 900 lbs (~400 kg), so they require moving assistance with a forklift or forks attached to a Bobcat-type equipment.

A core question is determining the level of compaction. The compaction indicator on a plate compactor tells the operator when the machine is finished compacting. That is a good start. An effective way to determine compaction levels is by measuring deflection of the compacted stone. This is done with lightweight deflectometer or LWD. Figure 3 illustrates the device that uses a shaft-guided, 22 lb (10 kg) weight that when allowed to fall, hits a plate. The impact force simulates an instantaneous pressure from a car tire passing over the pavement. LWD instrumentation records the movement of the aggregate surface in millimeters, calculates the stiffness and provides GPS coordinates.

An LWD is useful for checking post-compaction deflection of compacted, open-graded aggregate subbase and base for PICP. An LWD can also be used to test deflection on compacted, dense-graded aggregate and subgrade soils. For these materials, LWDs are replacing nuclear density measurements.
Initial acceptance by the Indiana and Minnesota Departments of Transportation likely has initiated the start of acceptance by other DOTs in the near future. Indiana and Minnesota DOTs developed quality control/quality assurance test specifications after their research and by the National Cooperative Highway Research Council in their 2014 Synthesis 456, Non-nuclear Methods for Compaction Control of Unbound Materials.

Open-graded aggregates can be difficult to test for compacted density using a nuclear density gauge. ‘Nuke’ testing must be done in backscatter mode where the gauge probe is not inserted into the material. See Figure 4. Gamma rays are shot into the material and some bounce back to the bottom of the device and measured. This test method must be used because the probe cannot penetrate compacted, open-graded aggregates. The method can produce high variability measurements. Moreover, the nuclear gauge operator and device must be certified since the latter contains radioactive material. The LWD has none of these restrictions.

A draft national standard, ASCE PICP design, construction and maintenance guide, is in its final stages and will likely be approved and published later this year. It includes a guide construction specification with a test method using an LWD. Testing follows ASTM E2835 Standard Test Method for Measuring Deflections Using a Portable Impulse Plate Load Test Device. The specification provides guidance on the minimum number of tests including those close to adjacent curbs, pavements and buildings. The specification includes limits for variation

- Continued on page 20
in measured deflection as well as a maximum allowable deflection. These are currently drafted at 0.05 mm and 0.5 mm, respectively based on in-situ tests. The test objective is to have minimum variability in stiffness across the pavement subbase and base, thereby minimizing settlement and callbacks, as well as the rate of rutting from vehicle tires.

An existing ASTM test method with acceptance criteria to help contractors, engineers and project owners verify the level of compaction on a project through measuring deflection. The LWD can measure deflection in maximum 12 in. (300 mm) thick lifts, so that provides another reason (besides time and money savings) to use equipment that can compact 12 in. (300 mm) of subbase aggregate all once. The LWD costs about $8,000, about as much as a high-end nuclear density gauge without the extra user time for certifications.

As the permeable pavement market grows, the LWD will be the means for checking if open-graded base compaction achieved consistent results. As a tool for assessing compaction of soils and dense-graded bases, it can be immediately applied to regular interlocking concrete pavement construction as well as to other pavements and subgrade soils.

Figure 3. A lightweight deflectometer or LWD testing deflection of ASTM No. 2 aggregate subbase for permeable interlocking concrete pavement.

Figure 4. A nuclear density test gauge on compacted No. 57 aggregate is operated in backscatter mode with the probe (black vertical rod) in the up position because it cannot penetrate open-graded aggregates.
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