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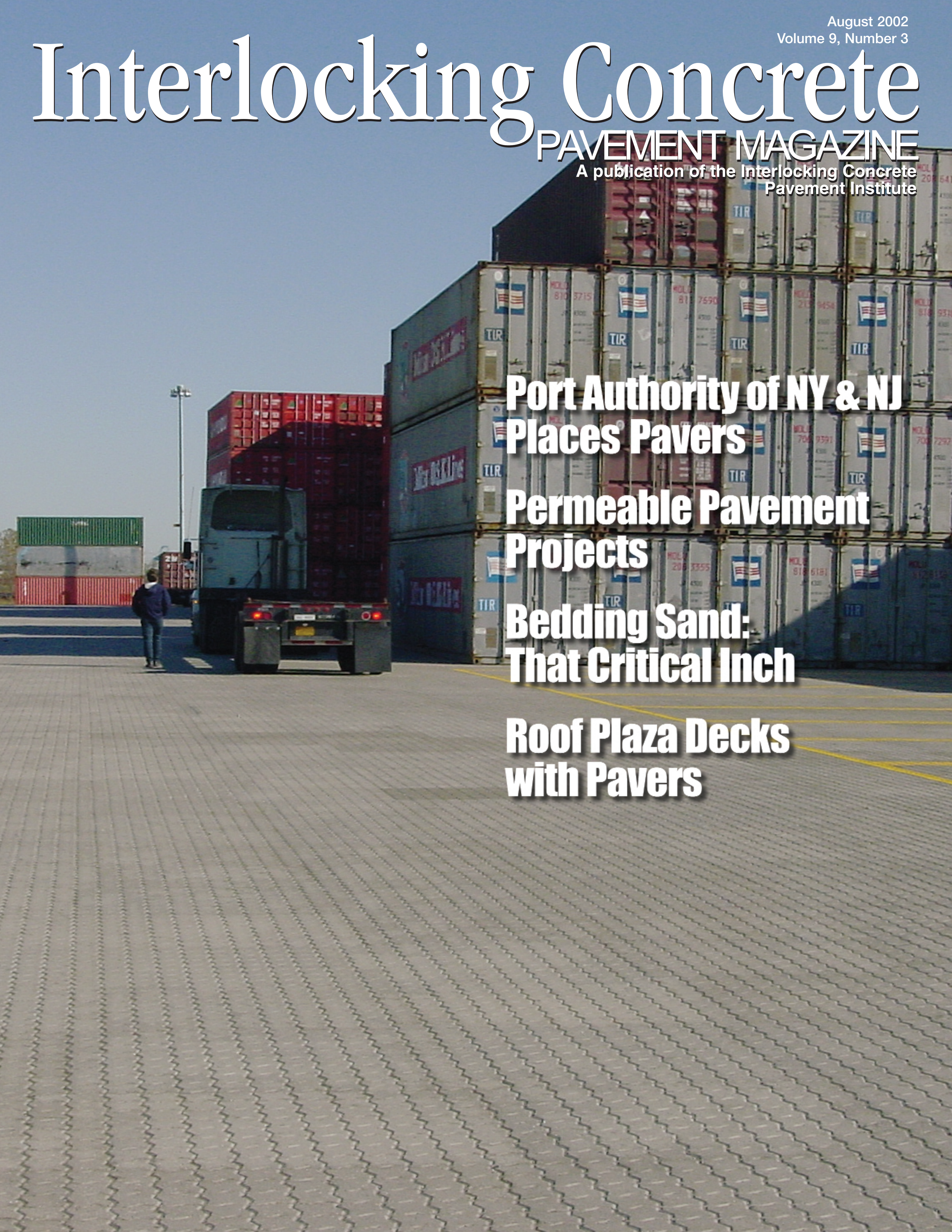

Port Authority of NY & NJ Places Pavers

Permeable Pavement Projects

Bedding Sand: That Critical Inch

Roof Plaza Decks with Pavers

Permeable Pavements Now in First Port Application

The Port Authority of New York and New Jersey has constructed the first port pavement in North America to combine solid *and* permeable interlocking concrete pavements for container handling equipment. Located on the northwest corner of Staten Island, New York, Howland Hook Marine Terminal, expanded an existing container terminal by 13 acres (5.3 ha). The Port Authority and several other American ports have used millions of square feet (meters) interlocking concrete pavements for container yards. While it is a standard pavement for overseas ports, it is becoming so for those in North America. The unique aspect at Howland Hook is a test area of 0.25 acres (0.1 ha) of permeable interlocking concrete pavement to verify structural, hydraulic and water quality improvement properties. The only other documented permeable port pavement in the western hemisphere is 1,320,000 (132,000 m^2) at Santos Container Port, Brazil.

Port Operations at Howland Hook

Container movement operations include Taylor top pick equipment, huge lift trucks that use a telescoping beam and clamp on one end to grasp the top of a steel shipping container. The trucks lift 40 ft (12 m) long containers and stacks them four high on the pavement. Each loaded container can weigh as much as 50,000 lbs. (22,700 kg), so a four high stack concentrates at least that amount weight on the pavement at each corner of the bottom container. When grabbed by top pick, a container and the vehicle together can result in a 215 kip (97,500 Kg) load on the dual wheel axle. The load on the front tires also increases substantially during braking and turning. Besides movement and stacking of containers with the heavy top picks, there are (highway and off-road) truck chassis that receive and transport containers to and from Howland Hook.

Engineered Pavement Design

The interlocking concrete pavement is designed to provide service for at least 200,000 passes of the top pick vehicles over an estimated 20 years of service. The resulting cross section taking these loads and winter environment consists of 3 1/8 in. (80 mm) thick concrete pavers over an inch (25 mm) of bedding sand. The base

The Port Authority of New York and New Jersey placed some 13 acres (5.3) hectares of interlocking concrete pavements and a 0.25 acre (0.1 ha) test section of permeable interlocking concrete pavements for container yards.

consisted of an 8 in. (200 mm) of New Jersey Interagency Engineering Committee (NJIEC) mix 1-2A Asphalt Concrete Bottom Course constructed in accordance with a Port Authority specification on an 18 in. (450 mm) thick recycled concrete aggregate base. This base was compacted to at least 95% modified Proctor density to achieve a CBR (California Bearing Ratio) of at least 60%. The base was placed over a sandy subgrade reinforced with geogrids and geotextile. This 24 in. (600 mm) layer is designed to spread loads over the decades-old fill containing gypsum. The geogrids are designed to span any voids that result when the gypsum is dissolved by water.

Structural design of the pavement was developed using the British Port Federation (now the British Ports Association) design method. In addition, engineers used two other computerized layered elastic models to characterize the loads and resulting stresses and strains in the pavement materials. The designers were ERES Consultants of Champaign, Illinois and Nigel Nixon and Partners of Plano, Texas. They examined various layer thicknesses and strengths using a 1 in. (25 mm) rutting failure criteria. They found the combination of material strengths to provide at least 20 years of pavement service while maintaining deformations below this criterion.

Mechanical Installation

Members of the Interlocking Concrete Pavement Institute (ICPI) supplied and installed the pavers and bedding course in both areas. Figure 5 shows the screeding of the bedding sand and Figure 6 shows one of two machines used to place the pavers. The pavers were compacted into the bedding sand, joints filled with sand and compacted again. The daily average installation using two machines machine was 15,000 sf (1,500 m²). This includes screeding, installation of pavers and joint sand and compaction.

An Innovative Experiment with Permeable Interlocking Concrete Pavement

The Engineering Department of the Port Authority took an innovative step by combining the features of pavement and infiltration trench in a test section of per-

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Figure 1. A top pick provides movement of the containers at Howland Hook while exerting wheel loads in excess of 50,000 lbs. (22,700 kg).

Figure 2. Unlike asphalt, concrete pavers can withstand loaded stacked containers that can exert over 50,000 lbs. (22,700 kg) at the corners without indentations that could interfere with container movement operations.

Permeable Pavements Now in First Port Application *Continued from p. 7*

Figure 3. Cut away construction view of the base: soil subgrade covered with geogrid, recycled concrete aggregate base, and asphalt ready (left) for bedding sand and concrete pavers.

meable interlocking concrete pavement. As part of the larger interlocking pavement construction, a 0.25-acre (0.1 ha) section of permeable pavement combines the structural load-bearing capacity with a surface that allows runoff to infiltrate. The designers enabled an increase in useable port pavement area by selecting a surface which functions as a pavement for container storage and as a retention pond.

The idea emerged from Principal Civil Engineer Walt Sieglen, Jr., P.E. with the Port Authority's "Green Ports" Task Group. According to Mr. Sieglen, "The experiment supports the Port Authority's objective to reduce water runoff and non-point source water pollution. If successful, we could see greater use of permeable interlocking concrete pavements for port paving in order to meet environmental conditions for new port facilities." Besides the heavy loads, port container operations are noted for their heavy loading of pollutants in runoff. Oils, rubber, steel, and brake compounds from the container lift trucks, plus occasional minor leaks from containers are washed into storm sewers and to the adjacent bay. Like all industrial facilities, port areas are subject to federal and state mandates to reduce stormwater runoff and non-point source pollution.

Pavement Surface as Retention Area

Permeable interlocking concrete pavements were of special interest to Mr. Sieglen because they capture the "first flush" or the first 30 to 60 minutes of rainfall, typically 0.5 to 1 inch (13 to 25 mm). The runoff from the initial portion of the rainstorm has the highest concentration of pollutants. This portion is subject to regulation by state environmental laws through the use of best management practices (BMPs) for control of runoff quantities and water quality. For New Jersey, BMP designs should capture and treat the first 1.25 inches of rainfall over two hours and for New York it is 0.5 inches. (Stormwater drainage design for New Jersey and New York is considered by the Port Authority as projects may be built in both states.) The permeability of the surface will well exceed these rainfall intensities even with some sediment in openings from years of use.

Permeable interlocking concrete pavement was selected because of its ability to infiltrate and reduce the concentration of pollutants by filtering and oxidizing. Since the soil subgrade (an old landfill containing gypsum) was moisture susceptible, the runoff flowing into the permeable base would be treated there, pass into perforated drain pipes, and then released into the Authur Kill channel. While total runoff from storms would not be substantially reduced from infiltration back into the soil, the treatment of runoff in the base was viewed as an advantage rather than collecting it in storm sewers and detention ponds. Ice and heaving of the pavement was not viewed as a problem due to the low risk of the permeable base becoming saturated.

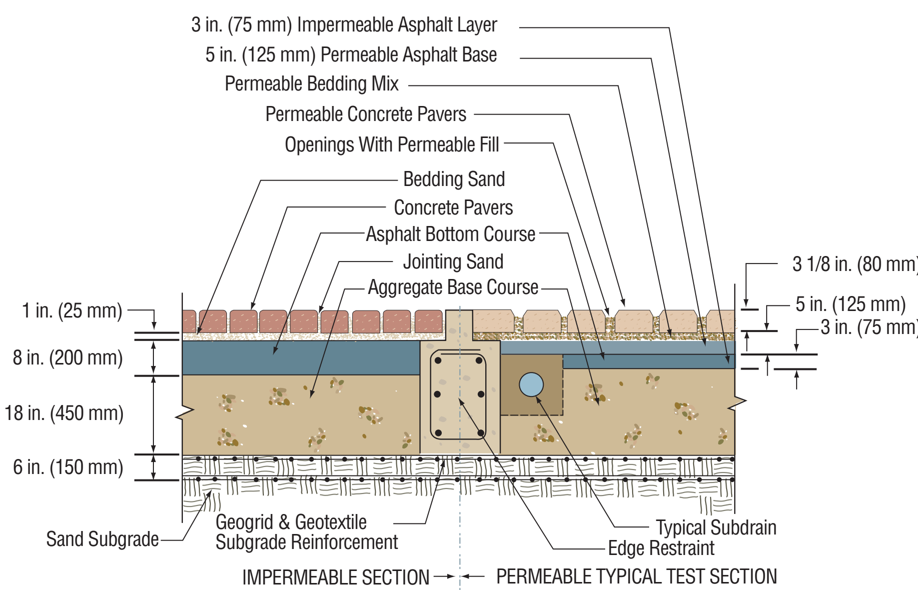

Figure 4. The pavements have a common base course of recycled concrete aggregate, one surface is impermeable and the other is permeable.

Figure 5. Powered screeding of the bedding sand accelerates its installation.

Figure 6. Mechanical equipment places the concrete pavers that are manufactured in the pavement laying pattern.

Figure 7. The two pavements are separated by a significant concrete edge restraint.

The typical construction for impervious port pavement includes a network of surface drain inlets and underground pipes often directed to retention ponds. The inlets, pipes, and ponds hold the water for a time, allowing the sediment to settle, and slowly releasing the remaining water. They take on sediment over time and have to be cleaned periodically by removing the sediment and disposing it in a landfill.

A full-scale installation of permeable interlocking concrete pavement would provide long-term spreading of sediment-filled runoff over a wider area. The sediment is spread by the runoff and collected in the first few inches of open-graded base in and under the pavers, and can be periodically removed from the surface with vacuum cleaning. However, the actual cycle for cleaning will be influenced by a realistic assessment of doing this work in busy container terminal.

The Howland Hook test area specified an ASTM No. 9 open-graded aggregate in the openings of the pavers and directly under them as a bedding material. The 1-inch (25 mm) thick bedding was placed directly on the 5 inch (125 mm) thick layer of permeable Plant Mix Macadam (NJIEC I-1). This layer directs water to subdrains at the perimeter of the area. A small well is located at the low end of the drains for monitoring water levels and sampling. The permeable layer of asphalt is placed over 3 inches (75 mm) of impermeable I-2A asphalt and 18 inches (450 mm) of recycled concrete aggregate base. The location of the test area exposes it to both stacked containers and top pick traffic.

Lower Maintenance Costs Expected to Offset Higher Initial Costs

Performance at Howland Hook will be evaluated by the Port Authority. These includes costs for regular vacuuming of the surface to remove dried sediment and repairs to damaged pavers. Costs will compared to those associated with a conventional pavement such as cleaning drop inlets, pipes, and detention ponds. The adjacent impervious concrete pavers with a conventional drainage system will provide a source of maintenance cost data from an impervious surface. It is anticipated that the savings by not building

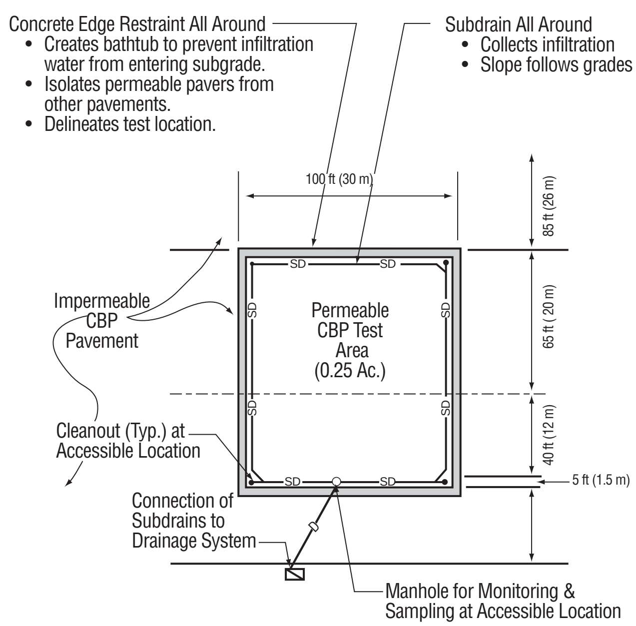

Figure 8. Plan of permeable interlocking concrete pavement test area.

Figure 9. The permeable pavement test area is surrounded by solid interlocking concrete pavement. The pavers against the curb haven't yet been cut to fit against it.

Figure 10. Essential to all permeable pavements, the Howland project included an observation well to monitor water levels, drainage rates, and sample water quality.

and maintaining a conventional drainage system and detention pond for water quality purposes will be greater than the additional periodic expense for vacuuming the surface and replacement of the aggregate in various places.

The test area could also be used to obtain water quality data to support permit applications for future projects to develop new, environmentally friendly port facilities. A successful test would demonstrate that permeable pavers area a cost-effective alternative to conventional impermeable pavements and stormwater treatment systems.

A New Application?

When placed on an open-graded base, and on soil subgrade for infiltration, permeable interlocking concrete pavements are typically for low traffic areas. ICPI has a design manual for such applications mentioned elsewhere in this issue. The unique aspect of the Howland Hook project is its test of permeable pavement for port and other heavy-duty loads. Economics dictated by limited land area and stormwater runoff laws will increasingly drive the decision to use permeable interlocking concrete pavements in a variety of applications.