Interlocking Concrete Block Pavements
At Howland Hook Marine Terminal

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Abstract

The Port Authority of New York and New Jersey has constructed the first port pavement in North America that includes both impermeable and permeable interlocking concrete block pavements for container handling equipment.

Located in the northwest corner of Staten Island in New York City, the Howland Hook Marine Terminal expanded the existing container yard by approximately 5 ha (12 acres) in an area with a subgrade that is subject to failure due the presence of gypsum. Interlocking concrete block pavement (ICBP) was selected for resistance to container loads, particularly damage at corner castings, and because of the potential subgrade problems. The Port Authority and several other American ports have constructed millions of square feet of pavement with ICBP. They are frequently used for overseas ports, and are now an established option for ports in North America[1].

The pavement design was for a 20-year service life of the current grounded container yard that uses chassis (highway and off-road) to move container between the yard and the ship, and top picks and lift trucks at the 4-high container stacks. The container handling equipment can result in dual wheel axle loads of 97,500 kg (215,000 lb) excluding dynamic forces. The stacked containers can result in point loads of up to 23,000 kg (50,000 lb) at each corner casting at the bottom container.

A unique aspect of this project was the inclusion of an installation of 0.1 ha (0.25 acres) of permeable interlocking concrete block pavement (PICBP) that can be utilized to demonstrate the structural, hydraulic and water quality enhancement properties of PICBP. Permeable pavement is one of several strategies that will be considered for meeting water quality requirements that are anticipated for many future major expansions of existing facilities or for new port facilities.

This paper presents information on the selection, design, and construction of the ICBP and PICBP and the experience during the initial container yard operations.

SITE CONDITIONS

Site History

The Howland Hook Marine Terminal was originally developed in the mid-1970s by New York City for a wheeled (container on chassis) operation. It consisted of asphalt concrete (AC) pavement sections designed for highway-type trucks. The Port Authority of New York and New Jersey (Authority) reconstructed the terminal in the early-1990s, and leased it to the operator, Howland Hook Container Terminal.

During the design of the reconstruction, large sinkholes were found in a 5 ha (12-acre) area at the northeast corner of the container yard. These holes were up to 3m (10 ft) across and 1m (3 ft) deep, and the cratered surface was dubbed the "Moonscape Area". A Geotechnical investigation concluded that the area had been used for disposal of gypsum waste from by a wallboard (dry wall) manufacturing operation that predated the Marine Terminal. It was concluded that tidal groundwater and/or rainfall infiltration was causing the gypsum to dissolve thereby creating large voids in the subgrade. As the unbound pavement base disappeared, the asphalt layer would span the void until it could no longer support its own weight or until a load was applied on the surface. A major safety concern was that a sudden collapse could result in a catastrophic tipping of stacked containers or container handling equipment. Since the area was not immediately needed, and to prevent any possibility of catastrophic collapses involving container operations, the operations in this area were restricted maintenance vehicles and other light traffic. As a further precaution, the asphalt pavement and several feet of subgrade were removed and replaced with clean fill and a surface course of approximately 0.3 m (1 ft) of recycled concrete aggregate base course (RCABC).

Development Of The 'Moonscape' Area

By 1998, it was clear that the Howland Hook Marine Terminal was in need of additional area for the container yard operation. The Civil (pavement design) and Geotechnical (subgrade design) staff of the Authority's Engineering/Architecture Design Division conducted preliminary design investigations for extending the container yard into the Moonscape area. The preliminary and final geotechnical design of the subgrade stabilization is beyond the scope of this paper.

The civil design included a site inspection that revealed further 'moonscaping', primarily along the site perimeter that abutted the tidal creek. However, the sinkholes were less than 1 m (3 ft) across and 0.3 m (1 ft) deep. In one case, the RCABC pavement appeared to have spanned a void until traversed by the wheel of what appeared to be a construction vehicle. Inspection of the adjacent container yard revealed no evidence of 'moonscaping'. However, the asphalt surface was experiencing damage after only approximately 3 years of service. In particular, there was substantial pavement damage within the container stacks due to corner casting indentations (Fig 6,8). Wheel load damage in the aisles (cracking and rutting) was also noted, but was not unanticipated for a pavement that was designed for highway loading.

INTERLOCKING CONCRETE BLOCK PAVEMENT

Preliminary Design Selection

ICBP was selected as the pavement type for the anticipated container yard traffic and unique subgrade conditions. ICBP has been used numerous times for container yards in North America and is a pavement standard in many other countries[1] (Fig 1, 4, 5, 18, 19). During the preliminary stages of the Port Authority gathered information from various sources including seminars by pavement engineer Professor Brian Shackle[2] a renowned ICBP researcher. The high-strength concrete pavers are resistant to the corner casting indentations such as those experienced in the AC surface at Howland Hook. Individual damaged units can be replaced with minimal interruption to operations by facility forces. ICBP is a flexible pavement that has a performance equal to or better than AC under heavy wheel loads associated with fully loaded container equipment. Surface rehabilitation over the 20-year service life is anticipated to be minimal. However, the mechanism of interlocking the units with unbound (sand) bedding and joint fill would provide advanced warning in the form of a dislodged section of pavers if voids should develop in the underlying base. In combination with the subgrade stabilization, this would minimize the risk of sudden, catastrophic collapse under wheel loads.

Other pavement types were considered and rejected during the preliminary pavement design. Both the operator and Port Commerce Department rejected unbound pavements in the container yard. AC pavement could be designed to support the wheel loads, but the problems at corner casting indentations would remain (Fig 6, 8). In addition, there was the prior experience that bound, flexible pavements would span voids, with the potential fail catastrophically with little or no warning. There was little information on the performance of thin “rigid” surfaces (whitetopping or AC filled with cementitious material) in container yards. Rigid pavements would provide an acceptable surface like ICBP. However, they also could fail without warning due to loss of the base material, and the potential cost and duration of repairs was considered unacceptable. Providing a rigid pavement with an independent support that did not rely on the gypsum-laden subgrade was cost prohibitive.

Final Design Of The Interlocking Concrete Block Pavement

Nigel Nixon and Partners, Inc., Plano, TX prepared the final structural design of the ICBP as a Sub-Consultant for the Authority’s “Call-In” pavement design consultant (ERES Consultants, Champaign, IL.). The final design included an operational analysis of the Howland Hook Container Yard and preparation of Construction Specifications. The ICBP section was designed for a specified Service Life of 20 years for a highly intensive container operation. The design analysis utilizing the British Ports Federation method[3] indicated that the equipment that is most damaging to the pavement (i.e. the design vehicle) is the Taylor TEC-950L container handler, and the other, less-damaging vehicles were incorporated as equivalent repetitions. Final design was for 200,000 repetitions of a 22,700 kg (50,000 lb) wheel load at 800 kPA (116 psi). Layered elastic analysis of the strains within various pavement sections was performed using a computer program from The Asphalt Institute[4]. Verification of the final pavement section and sensitivity analysis was performed with the Transport Research Laboratory computer program[5] so that a greater number of sub-layers could be included for the aggregate base (three) and subgrade (four).

The Authority's Geotechnical Engineers designed the geotextile and geogrid reinforced subgrade that would span up to 2 m (6 feet) if voids develop in the gypsum subgrade. This consisted of a geotextile and 150 mm (6 in.) of existing fill or RCABC sandwiched between geogrids. The reinforced concrete edge restraints at the perimeter of the ICBP were designed to anchor the geogrids.

Pavement Section

The ICBP section consists of: 80 mm (3.125 in.) thick interlocking concrete block pavers, 25 mm (1 in.) bedding sand, 200 mm (8 in.) AC base, and 450 mm (18 in.) aggregate base on the 150 mm (6 in.) subgrade reinforcement.

The interlocking concrete pavers suitable for machine installation were specified to conform to ASTM C936 for a compressive strength of 55 MPA (8000 psi), 5% maximum water absorption, tensile splitting strength of 5 MPA (720 psi) and coefficient of friction of 0.6. Mock joints were specified for a uniform "square" surface appearance. Interlocking pavers were specified in either a dentated rectangular or a dentated "L" shape[6]. The bedding was specified to be clean, naturally occurring sand conforming to the gradation of ASTM C33 except that zero percent passing Sieve Size 0.150 mm (No.100) and up to 1% passing 0.075 mm (No. 200) was acceptable.

The asphalt and aggregate base courses were furnished and installed in accordance with the Port Authority's Standard Specifications. The AC was "Asphalt Concrete Base Course" conforming to New Jersey Interagency Committee (NJIEC) Mix I-2A. The contractor stockpiled the existing recycled concrete aggregate base course (RCABC) pavement for use as the aggregate base course. Additional aggregate base material, as needed, was either new RCABC or NJIEC "Dense Graded Aggregate Base Course".

PERMEABLE CONCRETE BLOCK PAVEMENT TEST SECTION

Identification Of The Need For A Demonstration of PICBP

A 0.1 ha (0.25 acre) area of the PICBP was included in the Howland Hook project in order to demonstrate its performance in a container yard. The Port Authority's "Green Ports" Task Force identified porous (permeable) pavements for possible use in environmentally friendly port facilities. Future construction of new or expanded port facilities is expected to require compliance with State and Federal water pollution controls for Best Management Practice (BMP) of storm water runoff.

PICBP was selected for demonstration because it offers the advantages of a flexible pavement with a durable, hard surface plus the environmental benefits of reduced runoff and improved quality of the storm water discharge.

PICBP also provides port designers with the opportunity to improve the operation of container yards by reducing pavement slopes, minimizing ponding (birdbaths) at surface depressions, and increasing the spacing of storm water inlets. In the design of conventional port pavement and drainage systems, there is an inherent conflict between the operational and drainage requirements. Container yard operators want minimum slopes and fewer, more widely spaced inlets for maximum operating efficiency of their equipment and for safe stacking of containers. Steeper slopes and closer spaced inlets are generally needed to promote the overland flow of storm water runoff and to prevent icing. In addition, many ports are constructed on filled land that experiences settlement over the life of the facility. Conventional designs need to provide sufficient "fall" from the high points to the inlets to minimize the effects of differential settlement and the resulting "bird baths" (ponding) at depressions. This further increases the slopes beyond what would normally be required solely for drainage purposes. Permeable pavements can be designed at lesser slopes because the bulk of the storm water does not drain along the surface, and ponding is not anticipated at any depressions. Reduced runoff and the permeable surface should permit increased spacing of the storm water inlets and some reduction in the drainage system capacity.

It is also anticipated that PICBP will require less maintenance of the pavement than conventional pavement systems. ICBP surfaces resist damage due to corner castings and other heavy loads. As a "drainable" pavement system, a properly engineered PICBP is much less subject to water-related structural damage of the subgrade and base. The occasional maintenance to sweep/vacuum and replace the aggregate for restoration of permeability of the PICBP surface is anticipated to be less critical, less costly and less disruptive than the routine maintenance (crack and joint sealing, repair of surface damage, etc.) for asphalt or concrete.

Permeable Concrete Block Pavement Section

The Port Authority's Civil Engineering Design Group prepared the structural design of the PICBP section. The primary purpose of the PICBP demonstration section (Fig. 3) was to provide an apples-to–apples comparison to the surrounding (impermeable) ICBP and to the new AC pavement in the transition to existing grades of the container yard.

Since a comparison was desired to the ICBP structural performance, the PICBP section retained the same layer depths for the pavers, bedding, AC and RCABC. The modifications to the ICBP section replaced the AC with 75 mm (3 in.) of impermeable "Asphalt Concrete Bottom Course" followed by 125 mm (5 in.) of "Plant Mix Macadam" (PMM) (NJIEC Mix I-1). The Authority has successfully used PMM as a drainable base for both concrete and asphalt pavements. The permeable surface course was specified as an 80 mm (3.125 in.) L-shaped dentated interlocking concrete paver[7] on 25 mm (1 in.) drainable bedding (Fig 12). The replacement layers of permeable asphalt and PICPB were estimated conservatively to provide approximately the structural performance as ICBP.

Drainage Design

The Civil Engineering Design Group also prepared the design for the drainage of the PICBP. The impermeable nature of the RCABC base and moisture sensitivity of the subgrade (gypsum) precluded infiltration of the storm water (roof water). The design provided for vertical flow of roof water through the aggregate filled openings and joints of the permeable interlocking pavers[6] and through the drainable layers of bedding and plant mix macadam. Horizontal flow along the impermeable asphalt surface transmits the water to a piped collection system at the perimeter. The pipes connect to the storm water drainage system, and include access points for any future sampling or flow monitoring. The perimeter concrete edge restraints and the impermeable AC layer form a "bath tub" to prevent water from entering the adjacent pavement section (Fig 2, 3).

It is anticipated that future new or expanded port facilities will require measures for the control of storm water runoff for water quality purposes. State environmental regulations include the use of Best Management Practice (BMP) for water pollution control that require capture and treatment of the "first flush" runoff. The first flush is defined as the first 12 mm (0.5 in.) by State of New York and 30 mm (1.25 in.) uniformly over 2 hours by the State of New Jersey. Both requirements are well within the capacity of a properly designed and constructed PICBP. The actual design was based on achieving the highest permeability within the constraints imposed on the aggregates by the bedding depth and the size of the surface openings.

The design was generally based on the UNI-Group U.S.A. "Design Considerations For The UNI Eco-Stone Concrete Paver"[8] and on the Authority's previous investigations of drainable pavements[9]. A 10 mm (3/8 in.), ASTM No. 9 gravel was selected for the bedding and to fill the surface openings and joints. The contractor was permitted to use "bedding sand" if necessary to completely fill the joints, but this was not required. Filter Criteria of the PMM and gravel bedding, and of the gravel bedding and bedding sand met the recommendations of the U.S. Army Corps of Engineers. The bedding was therefore placed directly on the PMM with no geotextile. The PICBP with the specified gravel fill was estimated to provide a minimum flow rate in excess of 75 mm (3 in.) per hour, or approximately six times the rates that would be necessary to comply with the requirements for BMPs in New York and New Jersey. The authors estimate that the initial rate was probably substantially (two to three times) higher since only gravel was used to fill the joints.

PAVEMENT CONSTRUCTION AND PERFORMANCE

Construction Of The Moonscape Area

Port Authority Contract HH-334.008 "Open area Paving and Utilities" was publicly advertised, bid and awarded for $6.2 million (US) to the low bidder, Railroad Construction Co., Inc., Patterson, NJ at the end of 1999. The ICBP surface course was bid at a unit price of $43.60 per square meter ($4.05 per square foot) including bedding, and was installed by Syrstone, North Syracuse, NY. The PICBP area was constructed on a "Net Cost" basis at an additional cost of approximately $100,000 (US) primarily for the additional edge restraints, additional mobilizations, and due to the relatively small quantities of materials.

The Port Authority's Construction Management Engineering Division provided the construction management. Nigel Nixon Partners, Inc. provided technical assistance with regard to the construction of ICBP. The contract was completed in two

approximately equal phases. Upon completion of Phase 1 in 2000, the area was immediately put into service. Phase 2 was completed in the following year.
A detailed description of the construction is beyond the scope of this paper. Prior to construction of the pavement, the general sequence was to excavate to the subgrade and stockpile the existing RCABC, install the subsurface utilities and drainage, and construct the geogrid reinforcement and concrete edge restraints. The general contractor also completed the RCABC and AC base for each phase before the ICBP installer was mobilized. This installer placed the bedding directly on the AC base using rails and power screed equipment. The ICBP was installed at an average daily rate of 1500 sm (15,000 sf) using two machines (Fig. 11, 13), followed by compaction, sanding of the joints and another compaction. No significant problems were reported during the ICBP installation.
The PICBP area experienced several correctable problems during and immediately after construction. A hole in the vertical pipe of one monitoring well allowed erosion of the bedding resulting in a depressed area around the well. There was also settlement along the perimeter, and some breakage of pavers that were sitting part on and part off the shelf of the edge restraint. This may have been due to inadequate consolidation of the plant mix macadam base or, more likely, misjudgment of the amount that the gravel bedding would consolidate. In both cases, the recommendation was to correct the cause of the problem and reset the pavers (Fig 15). It was also noted that joint sand from the adjacent ICBP area was being blown onto the PICBP surface. In this case, the impact on permeability was not an issue, but removal by vacuuming was recommended.
One lesson learned was that permeable pavement sections require more care during construction. Better housekeeping is required to protect permeable surfaces including measures to minimize clogging by wind, water and vehicle borne sediments. Cutting of pavers and other operations that generate fine particles should not be performed on or near permeable surfaces (Fig 10). If construction is interrupted (or staged), the surfaces openings should be filled and all permeable surfaces should be covered.

Initial Pavement Performance

Civil Design Engineers inspected the pavements during construction and after they were placed in service. Based on one year in service, the performance of the PICBP and ICBP has been excellent (Fig 9, 14, 16, 17, 20). There was neither evidence of damage due to heavy wheel loads nor any serious damage beneath corner castings (Fig 9, 14). In contrast, damaging indentations from corner castings were already appearing in the surface of adjacent the AC top course that was constructed in the Contract (Fig 6, 8).

Impact On Future Projects

The Howland Hook paving project will demonstrate the long-term performance of ICBP under the severe load conditions in a major grounded container terminal in the Port of New York. The Port Authority of New York and New Jersey also acquired experience in the design and construction of ICBP. During the preparation of the Project, the Authority's Port Commerce Department requested a second demonstration installation at Port Newark. This included ICBP at a public berth (Berth 34) including the access road (Starboard Street) both of which had experienced the virtual destruction of the AC pavements by scrap metal operations. The ICBP surface was selected because it remains serviceable over a wide range of conditions, is resistant to the damaging effects of heavy wheel loads, tracked vehicles, etc., and is a flexible pavement that will accommodate settlements due to the surcharge effect of bulk cargo storage.

Conclusion

The PICBP test section at Howland Hook provides an opportunity for an apples-to-apples evaluation of structural performance compared to ICBP and AC pavements constructed at the same time and subject to the same surface loads. Water quality testing of the discharge can be undertaken when and if required for future projects. PICBP offer real promise for use in future port developments. Potential benefits include:

- ICBP is a low maintenance, high quality, flexible surface that can accommodate a wide range of operations, equipment, etc.
- A permeable pavement also fulfills requirements for Best Management Practice (BMP) to meet water quality requirements at approximately the same cost as traditional (impermeable) pavements.
- PICBP eliminates or reduces the costs to provide traditional BMPs that detain and/or treat runoff, and provides more flexibility to change the operational layout, equipment, etc. without concern for the load carrying capacity and access to the BMPs.
- Port operation can be improved by a reduction in pavement slopes and an increase in the spacing of drainage inlets without compromising surface drainage.
- Permeable pavements eliminate "birdbaths" at the inevitable depressions that develop due to differential settlements.
- Permeable pavements provide the advantages in structural performance of a "drainable" pavement section.

PICBP provides a cost effective, high quality pavement section that also meets environmental requirements for water quality, and should continue to attract the attention of the port community.

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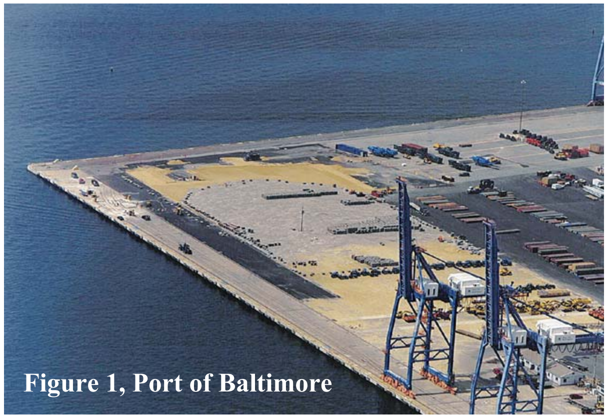

Figure 1, Port of Baltimore

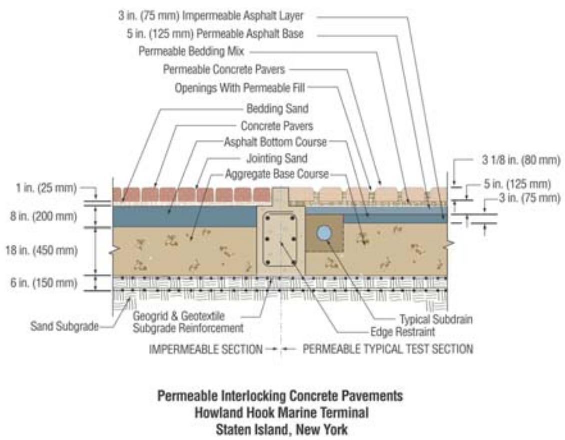

Figure 2, ICBP and PICBP cross-section

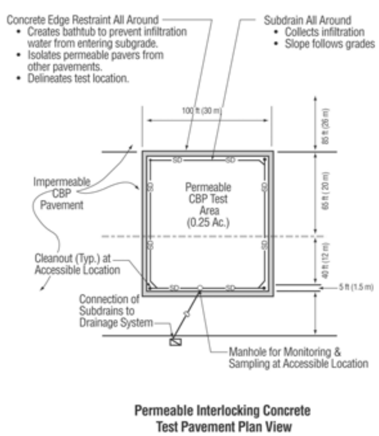

Figure 3, PICBP section

Figure 4, Borrows Shipyard, UK

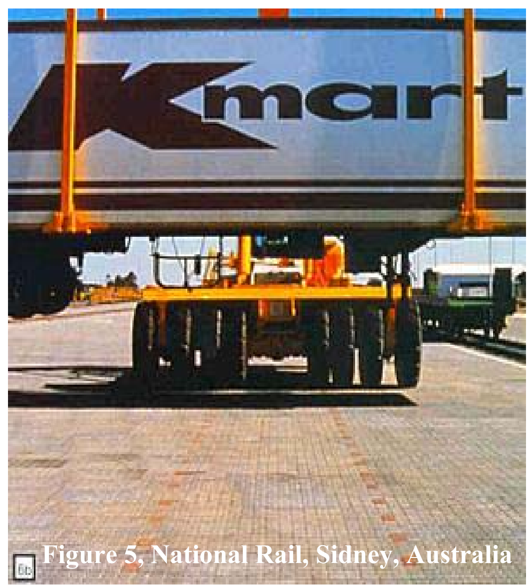

Figure 5, National Rail, Sidney, Australia

Figure 6

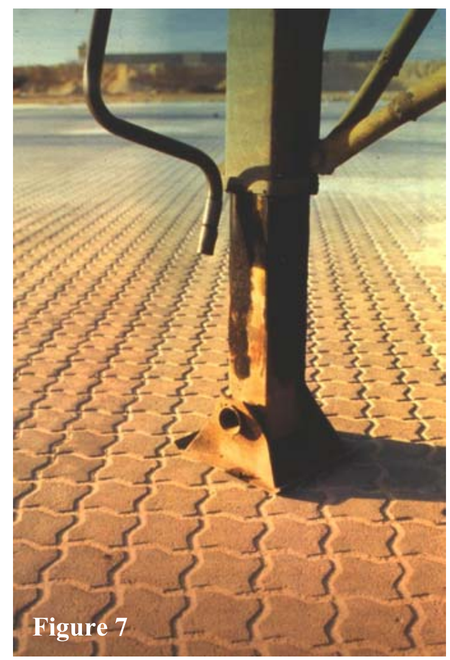

Figure 7


Figure 8


Figure 10


Figure 12


Figure 14


Figure 9


Figure 11

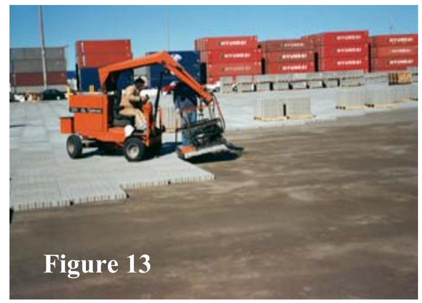
Figure 13


Figure 15


Figure 16


Figure 17


Figure 18, Port of Tampa

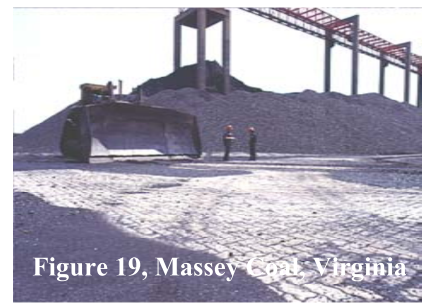
Figure 19, Massey Coal, Virginia

Figure 20, Panoramic view of PICBP (forefront) and ICBP