A CASE HISTORY OF CONCRETE BLOCK PAVERS AT DUNDALK AND SEAGIRT MARINE TERMINALS

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SUMMARY

Concrete paver blocks are an integral part of the paving solution at public terminals owned and operated by the Maryland Port Administration (MPA). The principal use of concrete block pavers (CBP) has been at the MPA's two main terminals, Dundalk Marine Terminal (DMT) and Seagirt Marine Terminal (SMT). While Dundalk is an existing terminal with the focus being on rehabilitation and reconstruction, Seagirt was a "greenfield site." A total of 179,472 m^2 of CBP paving have been installed to-date, spanning the period from 1988 to the present. Concrete paver blocks have been the preferred paving option for a variety of operational conditions. The areas where CBP pavements have been installed at Dundalk and Seagirt are shown in Figure 1. The implementation of this type of pavement has proven to be the right tool for the particular design application. There are, however, some lessons to be learned in regard to CBP pavement design when used in a grounded container operation with repetitive wheel paths.

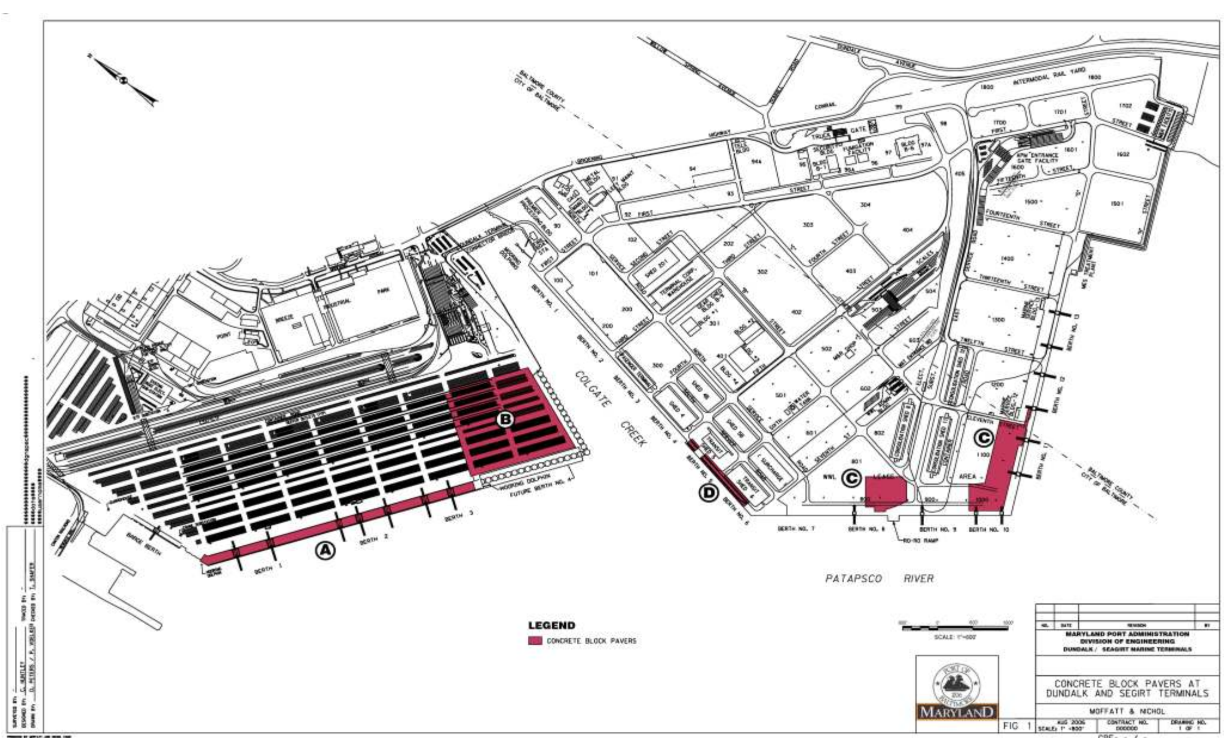

Figure 1. Concrete Paver Block Pavements at DMT and SMT

2. DUNDALK MARINE TERMINAL FACILITY OVERVIEW

Dundalk Marine Terminal is Baltimore's largest general cargo facility. The MPA acquired the 360 acre Harbor Field Municipal Airport in 1959. Through a series of land reclamations and property acquisitions, the terminal has grown to its present size of 230 ha. Its peninsula-like landmass is bounded on the west by Colgate Creek, on the south and east by the Patapsco River, and on the north by Broening Highway. An aerial photograph of Dundalk Marine Terminal is shown in Figure 2.

Figure 2. Aerial Photo of Dundalk Marine Terminal

The development of DMT has evolved in response to the types of cargoes handled. Among the earliest cargoes handled at DMT were automobiles, followed by break-bulk goods such as scrap, steel and lumber products. By the mid 1960's military shipments, construction equipment and liquid molasses had begun moving through the terminal. Starting in the late 1960's, MPA began an intensive capital campaign to develop facilities dedicated to the handling of containerized cargo. The last container berth, Berth 13, came on line in 1983. Since the early 1990's, MPA has directed its redevelopment efforts toward making Dundalk more operationally efficient, rehabilitating its older facilities and constructing new facilities to accommodate market demand. Today, the primary cargoes handled at Dundalk are automobiles, containers, forest products, project cargo, and RoRo equipment.

3. SEAGIRT MARINE TERMINAL FACILITY OVERVIEW

During the design phase of the interstate highway I-95 Fort McHenry Tunnel project in the late 1970's, several sites were evaluated as candidates to receive the spoil from the tunnel dredging. The Canton-Seagirt property located on the northern shore of the Patapsco River adjacent to Dundalk Marine Terminal was selected. Construction of 76 cellular steel cofferdams, which served as the retention structure, began in 1980, creating an impounded area of 60 ha. By the time dredging was completed in the spring of 1982, approximately 2.3 million m^3 of dredged material had been hydraulically deposited at the site.

A master plan for the phased development of a three berth state-of-the-art container terminal was prepared, which integrated the stabilization of the dredged slurry and underlying harbor bottom sediments with construction of terminal facilities. Site stabilization of Berth 1 was initiated in 1985 followed by the start of wharf construction in 1987. The Seagirt marginal wharf provides 1014 m of straight line berthing with a quayside depth of 12.8 m.

As construction of the marginal bulkhead and container yard progressed, several parcels adjoining Seagirt became available for purchase. The acquisition of these parcels expanded the terminal footprint to 39 ha. The master plan was revised to incorporate a 26.3 ha Intermodal Container Transfer Facility (ICTF), rehabilitation of the existing 9 ha SeaLand Terminal including a 213 m barge berth, and a state-of-the-art Entrance Gate Facility. The ICTF came on line in 1989, followed by the opening of the berths in 1990.

MPA began the phased development of the 1 ha Berth 4 backland area shortly thereafter. The Berth 4 area, which is surfaced with concrete paver blocks, was completed in 2002. An aerial photograph of Seagirt is shown in Figure 3.

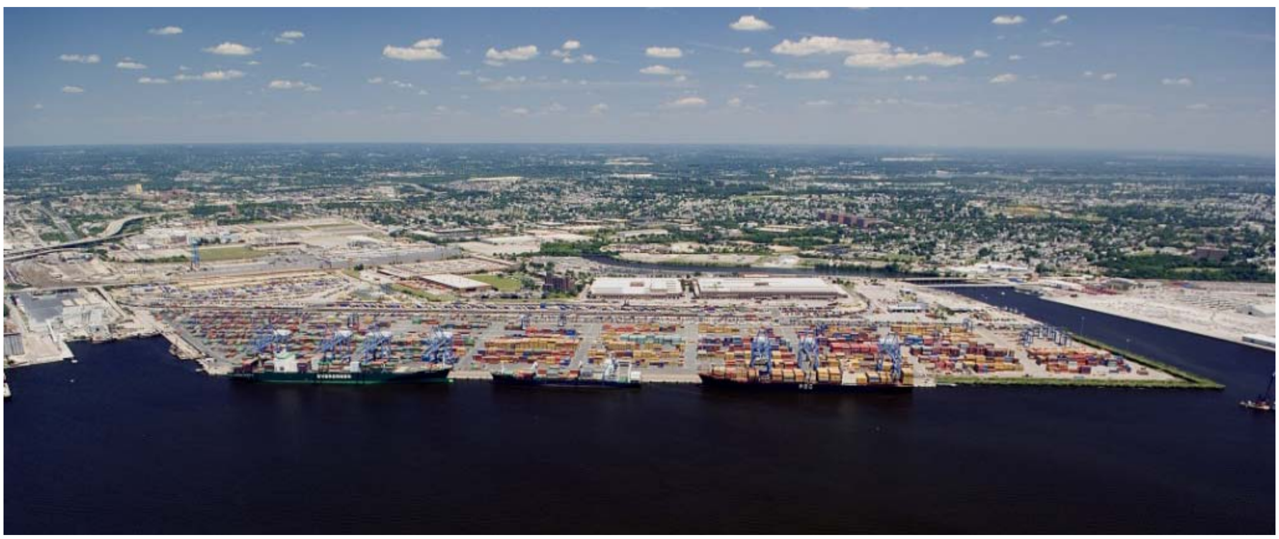

Figure 3. Aerial View of Seagirt Marine Terminal

4. SEAGIRT PAVEMENT DESIGN CONSIDERATIONS

The design and construction of pavement structures at Seagirt presented significant technical challenges. A strong, reliable, and durable pavement is required to accommodate the heavy wheel loads, high contact surface pressures and lock wheel turning conditions common to container terminals. Unfortunately, the subsoil conditions at the site are complex and highly variable. At the conclusion of the stabilization program, the bulk of the site consisted of a granular fill cap of varying thickness overlying the consolidated dredged slurry. While the stabilization program dramatically improved the shear strength of the dredged slurry, field and laboratory tests revealed that the dredged slurry had a CBR = 1.0%.

Container equipment wheel loads can range from 22,680 to 51,255 kg. Contact pressures on chassis landing gear can approach 2.75 to 3.4 MPa. The design criteria selected for the design of the Berth 1, 2, 3 pavements was 25,000 repetitions of a 21,215 kg wheel load. The ICTF design criteria was increased to 25,000 repetitions of a 45,360 kg wheel load, while the Berth 4 pavement design criteria was 50,000 repetitions of a 45,360 kg wheel load.

Based on these design considerations, the pavement design approach was predicated upon the following concepts:

1. Once constructed, frequent pavement rehabilitation would be both disruptive and costly. Accordingly, a relatively high degree of conservatism is built into the design methodology.
2. The small, but finite possibility of future differential settlements due to secondary consolidation led to the elimination of rigid pavement surfacing (PCC) or rigid base course (cement treated base).
3. The placement of a high modulus layer deep within the pavement structure is highly beneficial in attenuating the deep shear stresses imposed by the heavy wheel loads on weak subgrade soils. This "deep stiff" layer should decrease the likelihood of subgrade rutting.
4. To minimize the possibility of load induced fatigue cracking this "deep stiff layer", it should be placed deep in the pavement structure with an unbound granular layer above it. This granular layer will serve as a crack relief barrier.
5. A sufficient cover of borrow material is required between the dredged slurry and the bottom of the "deep stiff" layer to serve as a construction platform.
6. A high modulus surface layer is required to resist creep deformation under static loads.
7. It is necessary to install an effective subsurface drainage system to prevent weakening of the unbound granular layer and minimize potential frost heave.

The initial pavement cross sections were established using empirical CBR flexible pavement design procedures assuming both the surface and deep stiff layers were bituminous concrete. The final cross sections were derived through multi-layer elastic theory. In this approach, critical tensile strains were examined at the bottom of the asphalt layers (fatigue) and compressive strains were analyzed at the top of the dredged slurry subgrade (rutting).

Two alternate materials were considered for the high modulus surface course, bituminous concrete with a modifier and concrete paver blocks. The generalized design of the CBP pavement alternative for Seagirt is shown in Figure 4.

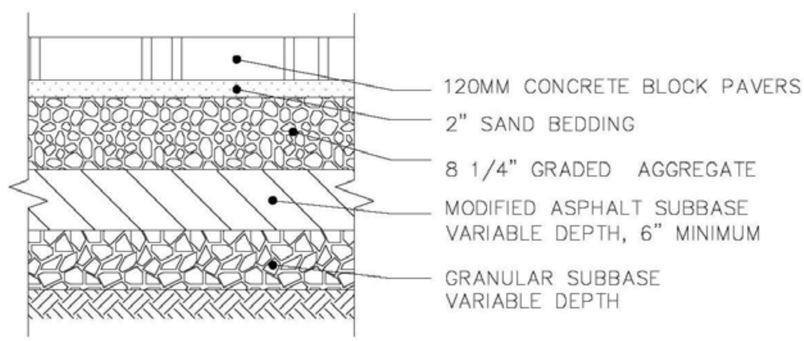

Figure 4. Seagirt Generalized Pavement Design (1" = 25 mm)

5. CONCRETE PAVER BLOCK SPECIFICATION

When the Seagirt pavements were being designed in the mid-1980's, there had been no large scale application of concrete paver blocks at U.S. ports, only a few trial sections. Consequently, the design was based on CBP installations at European ports, particularly European Container Terminus (ECT) in Rotterdam, and research papers prepared by Shackel, Knapton, and Rollings. Although 60 mm and 80 mm blocks were being used for some heavy load applications, the decision was made to go with 120 mm pavers that were being used at ECT. The main rationale for this decision was that thicker blocks would be more resistant to point loads and more resistant to damage caused by container impact or dropped loads. The concrete paver blocks were specified in accordance with ASTM 936, *Solid Concrete Interlocking Paving Units,* with a minimum compressive strength of 55 MPa.

6. CBP INSTALLATIONS

6.1 Seagirt Marginal Wharf

MPA made the decision to specify concrete paver blocks for the wharf pavement at Seagirt Berths 1, 2, 3, with the expectation that the container yard areas would also be CBP pavement. The Seagirt marginal wharf is designated as 'A' on Figure 1. Rectangular paving units were specified and the winning bidder, McLean Contracting Company, elected to use Holland Stone units (213 mm long x 105 mm wide). McLean quoted a unit price of $22 per square meter for the pavers and bedding sand, in-place. The pavers were placed on a 50 mm thick sand bedding directly over the compacted wharf ballast fill. A photo of the Seagirt Marginal Wharf is shown in Figure 5. The wharf CBP pavement is 27,517 m^2.

Figure 5. CBP Pavement at Seagirt Berths 1, 2, 3

The pavers were supplied locally by Balcon Industries. During production of the blocks, the quality control results showed that the pavers did not meet the 55 MPa compressive strength requirement when tested in accordance with ASTM C-140, *Sampling and Testing Concrete Masonry Units*. A correction factor was then implemented that adjusts the strength based on block thickness. This adjustment was then incorporated into all later CBP specifications. The pavers were placed by hand using labor hired directly by the Contactor in 1988 and 1989.

Figure 6. Seagirt Wharf Repairs

The wharf pavement has performed quite well over time. There is some settlement of the blocks adjacent to the pile-supported concrete beams of up to 25 mm. Some cracking and corner spalling of the blocks is also evident. Sinkholes have developed in several areas that are not underlain by the wharf relieving platforms and erosion of the underlying fill has occurred. In some instances, bituminous concrete patches have been installed to repair these areas instead of removing and relaying the pavers. Figure 6 shows the bituminous concrete spot repairs. MPA's annual maintenance contract includes line items for asphalt repair, but not CBP repair line items.

6.2 Seagirt Berth 4

The Berths 1, 2, 3 backland area were bid with two alternate surface courses, concrete block pavers and modified asphalt. A 25% allowance was included in the bid package for the CBP alternate to account for projected lower long-term maintenance costs. The winning bidder, P. Flanagan & Sons, came in with asphalt prices that were 50% lower than the CBP alternate, therefore, the modified asphalt section was constructed.

A problem that became evident as the container yard became active was the damage caused by the high point loads exerted by chassis landing gear and by the corner castings of grounded containers. While the modified asphalt surface course had a higher modulus than conventional asphalt, chassis landing gear and container corner castings were causing surface deformations and damage.

After evaluating the performance of the modified asphalt in the Berth 1, 2, 3 backland areas, the MPA made the decision to go with a CBP surface in the Berth 4 backland area. Berth 4 is designated as 'B' in Figure 1. The thickness of the sand bedding was reduced to 25 mm, while the thickness of the dense graded aggregate was increased to 235 mm. Since the number of design repetitions was increased, the thickness of the underlying modified asphalt subbase was also increased.

The Berth 4 backland area was constructed in two phases. The first phase was constructed in 1997 by IA Construction. The bid price for the pavers and bedding sand, in-place, was $26.30 per square meter. The second phase of the Berth 4 project was bid in 2000. The winning bidder, Haverhill Construction, submitted a unit price of $32.30 per square meter for the pavers and bedding sand, in-place. In both phases, Uni-Anchorlock units, manufactured by Oldcastle (Balcon), were placed by an Optimas laying machine over the 10.2 ha site.

Figure 7. Toploader Operation in Berth 4

When the Berth 4 yard was brought on-line in 2001, this area was used primarily for wheeled storage with some stacking of containers by toploader. To provide more yard capacity to accommodate the growth of container cargo, the Operator implemented an all grounded operation using rubber tired gantry cranes (RTG's) to handle loaded import boxes, and toploaders to handle loaded export boxes and empties. A toploader stacking area is shown in Figure 7.

While the CBP pavement has performed very well under the wheeled and toploader operation, the RTG's have caused rutting of the CBP pavement similar to that observed in the modified asphalt surfaced areas. A typical rut along an RTG travel path is shown in Figure 8.

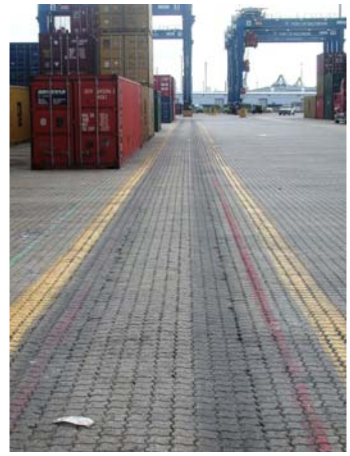

Figure 8. Rutting from RTG Operation

The MPA is in the process of removing the existing pavement and constructing 300 mm thick reinforced concrete runways along the RTG travel lanes in both the modified asphalt and CBP areas. The lesson learned is that in situations where the container handling equipment follows the same wheel path repetitively, a flexible pavement will invariably rut.

6.3 Dundalk – WWL Terminal

In 2001, Wallenius Wilhelmsen Lines (WWL) agreed to a long-term lease with the Maryland Port Administration with the understanding that a dedicated mini-terminal would be constructed behind Berth 7 thru 11 at Dundalk Marine Terminal. WWL handles a wide range of cargo from automobiles to containers to heavy construction equipment. A significant amount of the Roll on – Roll off (RoRo) cargo has steel tracks instead of wheels. The new mini-terminal was to be completely repaved, typically to a higher elevation than existing grade.

Recognizing the damage caused by tracked equipment on conventional asphalt pavement, it was recommended that specific areas be paved to handle tracked vehicles starting at the berth face and continuing into the yard. Concrete block pavers were selected as the most appropriate solution for this problem. Two specific areas were identified: one behind Berth 8 and one behind Berth 11, comprising an aggregate base of 45,727 m^2. These areas are designated as ‘C’ in Figure 1.

The loading criteria selected for design of the WWL pavement was 50,000 repetitions of a Taylor toploader. The pavement structure was designed using the procedures outlined in *Port and Industrial Pavement Design with Concrete Pavers*[1]. The WWL section is shown in Figure 9. The existing pavement is asphalt of varying thickness. Depending on the difference in grade between proposed and existing elevations, the existing asphalt section was incorporated into the pavement structure by varying the thickness of the bituminous concrete layer.

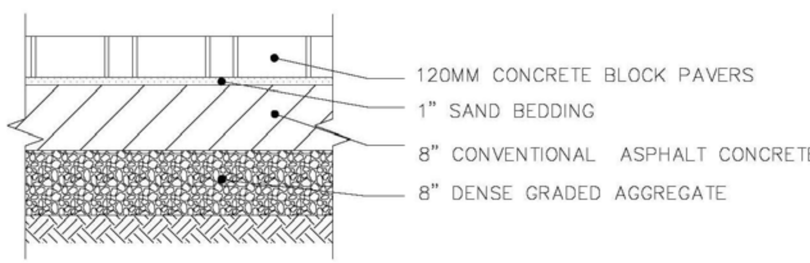

Figure 9. WWL Pavement Section (1” = 25 mm)

Figure 10 WW Yard Area Paved with CBP

The pavers were Uni-Anchorlock units supplied by Oldcastle (Balcon) and were mechanically placed by an Optimas laying machine. Construction was completed in 2002. A recent photo of the area behind Berth 8 (Figure 10) shows the wide range of cargoes handled at this facility.

The CBP pavement has performed well to-date; however, the wear caused by the turning movements of the tracked vehicles as they transit from the berth into the aisleways has caused some noticeable damage. The stress on the pavement is made worse by the facts that the tracked equipment makes locked track turns. This damage includes abrasion of the top surface and fracturing of the blocks. A distressed area behind Berth 8 is shown in Figure 11. A distressed area behind Berth 8 is shown in Figure 11.

Figure 11. Damage to CBP Pavement Caused by Tracked Equipment

<u>6.4 Dundalk Berths 5 – 6</u>

Berths 1-6 at DMT are being reconstructed in four phases beginning at Berths 5 - 6 and proceeding to Berth 1. The first phase, Berths 5-6, totaling 365 m of wharf has recently been completed. Berths 5 - 6 are designated as 'D' in Figure 1. The new wharf structure is a low level relieving platform supported on prestressed concrete piles.

Although Berths 5-6 are forecasted to handle primarily forest products, steel, and break-bulk commodities, MPA wanted to provide a pavement with the flexibility to handle any type of cargo, including tracked RoRo vehicles. Based on the positive performance of the Seagirt Marginal Wharf, MPA elected to go with a CBP pavement. The wharf pavement section consists of 120 mm thick pavers over 25 mm sand bedding over 200 mm dense-graded aggregate.

The pavers are interlocking rectangular blocks supplied by Pavestone and placed both mechanically and manually. The CBP pavement covers approximately 4,046 m^2. A view of the CBP pavement at the Berths 5-6 wharf is shown in Figure 12.

Figure 12. CBP Pavement at Berth 5-6, DMT

7. PERFORMANCE OVERVIEW

Staff from MPA Operations, MPA Engineering, and the terminal operators were contacted to obtain their input relative to the performance of the CBP pavement. The oldest CBP installation (Seagirt Marginal Wharf) has now been in service for 18 years. Their consensus was that the CBP pavements had performed well at both Dundalk and Seagirt. Their durability under high point loads in a container operation and to tracked vehicle wear in a RoRo operation are strong endorsements to their use in future applications of this nature. If asphalt prices continue to climb relative to concrete block paver prices, CBP pavement will become a more attractive option from a life cycle cost perspective.

Some rutting and failures have occurred, but these are due to inadequate base or subgrade support. For situations where there are a high number of repetitions by heavy container handling equipment along a well-defined wheel path, a rigid base, such as cement treated base, is required below the blocks. MPA does have to come up with line items within their annual pavement maintenance contracts to deal with repair and reinstallation of damaged CBP pavement.

8. REFERENCES

Knapton, John, “Heavy Duty Pavements for Industrial Areas, Bulk and Container Ports”, Port and Industrial Pavement Design With Concrete Pavers, A Comprehensive Guide (ed. D. R. Smith)