PORT OF OAKLAND - THE LARGEST BLOCK PAVING PROJECT IN THE WESTERN HEMISPHERE

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SUMMARY

While there is an extensive experience base on competing products such as asphalt, many design professionals in North America do not have experience with larger concrete paver projects. The Port of Oakland and their consultants have been using interlocking concrete pavers for larger pavement projects since the mid 1980's. That first project consisted of approximately 5,000 square meters of Rubber Tire Gantry runway. Since then there have been four major industrial installations totaling over 600,000 square meters. The similarities and differences between large paver projects and projects using more traditional materials are discussed. As a result of these projects and others, Port staff and their consultants have acquired useful experience in bringing paver projects to successful conclusions within the parameters of North American construction practices and contracting models. This paper discusses the history of pavers at the Port. In addition, the more important elements specific to the selection of pavers are discussed.

1. INTRODUCTION

The Port of Oakland is a modern container port, with over 500,000 m^2 (4.7 million sf) of concrete pavers. The Port of Oakland can accommodate the world's largest container ships. In many cases, the Port reflects the state of the art. In all cases, it shows an awareness of thoughtful design. One of the goals of the Port of Oakland is to promote economic development in the region. To do so, the Port provides facilities that are profitable for the various businesses that operate the shipping terminals. The decision to use pavers to support that goal was arrived at after careful consideration on the part of Port staff and consultants.

Concrete pavers have been used at the Port because they allow flexibility for arrangement and movement of shipping containers that asphalt does not. Moreover and in spite of expected differential settlement and loads from stacked containers, they provide support for containers and container handling equipment with wheel loads 5 to 8 times that of over-the-highway trucks.

Asphalt Concrete (AC) has satisfied operational needs for all equipment with minimal issues until the late 1980's. Since that time container handling equipment has changed requiring heavier pavements. Table 1 describes the projects utilizing interlocking concrete pavers at the Port of Oakland.

Year	Location	Paver Type	Cost
1987	Jack London Square 20,000 m^2 (5 ac)	100 mm key shaped paver 25 mm (1 in) sand, no stabilizer	$3.50/sq ft
1999	Berths 55/56 Phase 1A 51,000 m^2 (12.5ac)	100mm thick 100x200 rectangular, 25mm (1 in) sand + stabilizer	$3.80/sq ft
1999	Berths 55/56 Phase 1B 141,000m2 (34.9 ac)	100mm thick 100x200 rectangular, 25mm (1 in) sand + stabilizer	$3.29/sq ft
2001	Berths 57/59 189,000 m^2 (46.7) acres	100mm thick 100x200 rectangular, 25 mm (1 in) sand + stabilizer	$3.43/sq ft
2001	Berths 55/56 Phase 2 59,000 m^2 (14.5 ac)	100mm thick 100x200 rectangular, 25 mm (1 in) sand + stabilizer	$3.30/sq ft
2006	Berth 32 Reconstruction, 49,000 m^2 (12 ac)	100mm thick 100x200 rectangular, 25 mm (1 in) sand + stabilizer	$3.56/sq ft

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2. STRUCTURAL DESIGN

The pavers selected for use at the Port have been 100 mm rectangular, "4 x 8" (nominal 100mm x 200mm) units. These have provided good service. The range of thickness typically found in port applications is from 80mm to 120mm. All of those have provided good service in various locations. There was a great deal of discussion about what thickness to use. In the end it came down to an engineering decision by the engineer of record, Richard Woodman of JWD Group with a great deal of experience in container terminal design. He was an early proponent of the use of pavers for industrial applications. Based on his observations of pavers in use at marine terminals and airports around the world, he was convinced that the margin of safety provided by 100mm versus 80mm paver was worth any additional expense. (The authors are in complete agreement.)

The structural design at the first project was carried out by Peter Kaldveer and Associates, later merged into Harza Engineering. Design was based on the premise that pavers have the same structural capacity as an equal thickness of asphalt and could be treated in a similar fashion during the design phase. This model has been successful and is in continued use at the Port.

3. HISTORY OF PAVER AT THE PORT OF OAKLAND

3.1 Berth 25

The first paver installation at the Port occurred in the retrofit of Berth 25 for Rubber Tired Gantry crane runway relocations. Performance of the installation was below expectations. The existing pavement section was removed and replaced with 2 meter width of recompacted subgrade, an aggregate base (AB) section, sand, and four-inch shaped pavers. Ruts up to 15 cm developed in some areas. The worst areas were removed and replaced with an additional 50 mm thick AC layer installed under the pavers. Ruts between 1 and 5 cm still developed. However, the runways remained in service about ten years until the runways were replaced when new equipment was brought on site requiring a new terminal layout. Even in a deteriorated condition the pavers provided a workable surface. Lessons Learned – Upon investigation it was determined that the ruts were caused by the poor compaction of the underlying AB and the subgrade, not by the paver size**.** The bands were too narrow to allow compaction equipment of sufficient size.

3.2 Jack London Square

The second project occurred in 1987; the Port installed approximately 16,000 m^2 at Jack London Square. The Square is a public area serving pedestrians, autos, and trucks. At the time it was constructed, it was the largest application of pavers on the West Coast, at the time approximately five acres. The work was done by hand.

Lessons Learned – A special sized paver was selected. This has caused some minor difficulty for repairs. Detailing and installation around utility structures was not given sufficient attention causing minor dislocations of pavers. The contractor was not well versed in the quality control measures required for commercial projects. And the Port was not well versed in construction inspection knowledge. Though the Port had been told that the pavers would give flexibility in phasing, the installation of the pavers in improperly sized phases led to quality control problems. Over time the drip line at awnings developed erosion of the joint sand, in response a schedule for joint sand stabilization was established.

3.3 Berth 30

The third project was at the Berth 30, Trapac Terminal and included 25, 000 m^2. The tenant, TraPac, a company with roots in Japan wanted to maximize the flexibility of the container yard for equipment use. They anticipated changing equipment mix from chassis to top picks to RTGs. They did not want to shut down operations to install the heavier pavement as larger equipment was introduced.

Although Port personnel knew that pavers had been used successfully elsewhere, they had some reservations about the installation of interlocking concrete pavers over such a large area. Some staff, like engineers everywhere, was not eager to be the first to try the concept on a large scale on the West Coast.

TraPac had several successful experiences with pavers and expressed a preference for them. In the end, since TraPac was paying for the improvements and was responsible for maintenance, the Port raised no objection and the work went ahead.

The Berth 30 project was a breakthrough for the concrete paver industry being the first project of significant size on a West Coast port in North America. The interlocking concrete pavement at Berth 30 supports reach stacker operations and truck chassis storage.

The paving section for the heavy duty grounded storage portion of the project consisted of a compacted subgrade, 250mm (10 in.) of compacted aggregate base, 170mm (7 in.) of asphalt concrete, 25mm (1 in.) of bedding sand, and interlocking concrete pavers. The section for the balance of the project was the same minus the pavers. The subgrade consisted of a brown field site with reasonably good, if variable strength values.

The details and specifications, written in the early 1990s, used for the Berth 30 project represented the state of the art. They were prepared believing the project would be installed by hand. In the end the work was performed using a single installation machine which placed nearly a square meter of pavers at a time. The installation went relatively smoothly. There were some scheduling issues and the installer was financially stretched by the project, however a good work product was obtained.

Over the years there has been some breakage of pavers by the operating equipment. However, the surface has remained waterproof and in no case has this resulted in any loss of service to TraPac. The weight from stacked containers can total as much as 90,700 kg (200,000 lbs.), or 50,000 kg (22,700 lbs.) concentrated by the corner castings, each barely a square foot (0.10 m^2) in area. While there has been damage at Berth 30, (as there has been at all the installations) it has not resulted in loss of service.

Lessons Learned – The Berth 30 interlocking concrete paver project has been a success by any measure. All rationale for selection of the pavement mentioned elsewhere in the paper are applicable to this project. The reasons for selection of pavers for the grounded storage area were not limited to the strictly rational. During the design phase the client made it very clear that high architectural standards were expected throughout the facility. In large part the pavers were selected because of the visual impression they provided when viewed from the rather elegant fourth floor of the building. Indeed, the facility won an award from the American Institute of Architects Award for Architecture in Transportation in 1995.

Figure 1. Showing typical damage under corner castings. This type of damage has caused no loss of service.

3.4 Berths 55/56

The fourth project, Berths 55/56, was conceived as part of the Port of Oakland's Vision 2000 plan. An essential component was flexibility. During the planning of the project, no tenants had yet been secured for the facilities. Therefore, the layout for the container terminals required maximum flexibility since any tenant or tenants could lease all or a portion of the areas.

The paving section for the heavy duty grounded storage portions of the project consisted of a compacted subgrade, 500 mm (20 in.) of compacted aggregate base, 75mm (3 in.) of AC, 25mm (1 in.) of bedding sand, and 100mm interlocking concrete pavers. The subgrade consisted of a brown field site with reasonably highly variable strength values. The initial section had consisted of 24 inches of compacted AB, 25 mm of sand, and 100mm thick pavers. The layer of asphalt was substituted to provide a working surface for construction activities prior to the installation of the pavers and as part of a negotiated program to provide additional capping of potentially toxic unknown dredged material.

Structural design was a special consideration. The land had been a navy base constructed hurriedly in the early 1940s. Every source for fill imaginable was on the site. Rock, construction debris, furnace slag, organic material, and a host of other materials were buried there. Additionally, the numerous structures that were on site were all pile supported. The area was crisscrossed by railroad beds, old wharves and numerous utilities. To say the subgrade was variable is a gross understatement.

Additionally, the area had to be used for disposal of dredge material from improvement of the shipping channel and wharf site. Approximately 2.3 million cubic meters of dredged soils were stockpiled on the site and were eventually used in the grading. Monitoring for toxics was required during the fill process. Dredged soil fill was compacted and de-watered. Some areas required extensive surcharging.

Port personnel and the designers presented Hanjin Shipping (the tenant), who joined the project about a year into the planning process, with pavers as the preferred option for pavement at Berth 55/56. Pavers were selected primarily because they offered Hanjin the flexibility to operate toppicks and RTG container handling equipment in any configuration and at different times throughout the year.

The Port staff and their consultants both noted that an advantage of the interlocking concrete pavement was that they allowed the use of RTGs without expensive, cast-in-place concrete runways that are typically used to support them. Like many shippers, Hanjin uses different kinds of container handling equipment depending on demand, yard layout, and operating costs. Hanjin uses top pick lift trucks, 8-wheeled RTGs and chassis in the operation at Berth 55/56. The combined cost savings of not needing concrete RTG runways and a reduced base thickness, plus the increased structural and environmental benefits from the asphalt layer provided sufficient savings to justify the expense of interlocking concrete pavement.

Another advantage identified in the use of pavers was the reuse of material in design and maintenance. Pavers could be reused on the project or elsewhere on Port property when they were removed for other construction activities.

Based upon Hanjin's positive response to pavers, the amount planned was actually increased for the site. The result was 16 ha (39 acres) of pavers extending 275 m (900 ft) from the back of the wharf into the container yard.

Berths 55/56 and 57/59 are the largest ever mechanically installed interlocking concrete pavement in North America at the time they were constructed.

Lessons Learned – The Berth 55/56 project went reasonably well. There were apparent problems with one of the installers in their ability to handle a project of this size. Additionally, the general contractor had little experience with pavers. A number of coordination, and scheduling issues resulted. Changes addressing these issues were incorporated into the new specifications used on Berths 57/59 project. Major issues regarding dryness of joint sand and getting sand vibrated into the joints needed to be addressed.

Additionally, the joint sand stabilizer was installed incorrectly resulting in a surface that was shiny. When the sun was low it created difficulties seeing pavement markings. The problem has resolved itself with the weathering of the stabilizer.

Figure 2. A view of the completed Berth 55/57 project

<u>3.5 Berths 57/59</u>

The fifth project was Berth 57/59. The site has similar physical constraints as described for the Berth 55/56 project. The area of pavers consisted of 156,000 m^2 (46.7 ac), with an option for an additional 75,000 m^2 (22.5ac) after anticipated settlement in a portion of the yard. That area was not covered with pavers in recognition of the added cost to remove and reinstall following settlement.

While the Berth 55/56 project was under construction and the Berth 57/59 project was nearing completion of design, the Port identified the need to prepare a set of Specifications specifically for installation of pavers by machine. One of the authors (Wilbanks) was contracted to prepare the document for incorporation into the bid documents.

The new specifications incorporated some technical revisions that reflected newer industry standards. But the main component was the requirement for a Quality Control Plan and Method Statement.

Lessons Learned – The new specifications used at Berth 57/59 and the experience gained by the installers and the Port on the Berth 55/56 project, resulted in an installation that had fewer installation issues and operational issues.

Figure 3. Showing a view of the construction at the Berth 57/59 Project

4. RATIONAL FOR SELECTION OF INTERLOCKING CONCRETE PAVERS AT THE PORT OF OAKLAND

4.1 Flexibility of Use

Terminal operators need flexibility in the use of their facilities. As their clients change so do the nature and physical parameters of their operations. For example, the traffic path of the equipment may be changed or areas which are used for container storage on wheeled chassis may be converted to grounded storage. Container handling equipment improves over time and dimensions between wheels can change. Sometimes grounded storage areas are moved a meter or so to even out pavement wear over the facility. Traditional asphalt paving often requires special reinforcement or concrete elements in wheel paths. This limits making changes in the layout due to additional time and expense. A properly designed unit paver surface can support the imposed wheel loads at all points rather than just specific reinforced areas. Pavers permit modification of the terminal operation or the introduction of new equipment possible with minimal changes to the terminal.

4.2 Lower Initial Cost

The Berth 55/57 and 57/59 projects were designed to allow operation by RTGs, top picks and chassis. The choices for a paving section came to either an asphalt concrete pavement with reinforced concrete beams to support the RTGs, or an interlocking unit pavement. Both options were to be placed on a layer of engineered, compacted dredge soils and compacted aggregate. The asphalt surface with a reinforced concrete runway has been the most commonly used surface in North America. General wisdom said that in this market the pavers would be more expensive than asphalt. At the time of the design of this project that was true when comparing a unit area of pavers versus a unit area of asphalt. However, when the cost of the RTG runways required by the asphalt design was factored in the overall cost for the project, interlocking unit pavement was close to asphalt with concrete runways for the chosen pavement section. When the longer life cycle of unit paving over asphalt was considered it appeared to be a better choice. However, with recent information developed with respect to the cost of removal and replacement of the pavers, the life cycle cost of the paver has been negatively impacted.

4.3 Changes in Leasing and Operational Practices

Typically the terminal operator has leased the property from a landlord port for a period of 5 to 15 years and the responsibility for the improvements at the site varied with the operator over the life of the lease. Corporate decision making dictated purchase of pavements that were more or less equal to the term of the lease. With a short term planning horizon, asphalt usually appeared to be the best choice. For some time the nature of some of the leases have been changing. Terminal operators wish to have more flexibility to reduce or expand their facilities in response to changes in their markets. The intensity and density of use has increased as the land available for maritime use is being capped. The longer term leases, greater densities, and higher maintenance costs require consideration of a longer planning horizon. Design life periods are increasing beyond the traditional 10 to 20 years. Some facilities are looking at pavement life of up to 35 years. (At the time of this writing, there is a Public Utilities District specifying an 11,000 m^2 (125,000 SF) interlocking pavers facility with a 50 year design life.)

4.5 Resistance to Seismic Damage

The San Francisco Bay area is noted for earthquake activity. The Port has to take continuity of operations into account with any project. The soils under the pavement at the Port have a high potential to shift during an earthquake (liquefaction) and may settle unevenly, especially after differential compaction caused by repeated wheel loads from container handling equipment. Concrete pavers allow a serviceable pavement even with some degree of subgrade movement. Terminal operations are more likely to continue than with other types of pavements.

4.6 Reuse of Pavers

The reuse of pavers was not as cost effective as originally anticipated. In part this is due to scale of Port projects. These larger facilities tend to have larger repairs for items such as new utilities extensions, settlement or a repair spanning several thousand feet along the back of a wharf. These jobs are almost always reinstalled by machine. The cost effectiveness for pavers specifically molded into patterns intended to be installed by machine is very high. It is simply not worth the cost to properly repalletize the pavers by hand. Nor are contractors currently skilled at removal of the pavers by machine as a reversal of the installation process. While reuse maybe more practical for smaller projects, it is not likely to be useful on large projects until effective onsite mechanical repalletizing equipment is readily available. As noted previously, this removes a positive impact that had been taken into account in the life-cycle cost of the pavers

5. CONCLUSIONS

- Each of the paver projects at the Port had their unique set of challenges; each should be considered a success. The Port continues to use pavers for appropriate projects.
- Interlocking pavers are an appropriate wearing course for heavy wheel load environments. Standard rectangular unit paver installed in a herringbone pattern provides good service under heavy wheel loads.
- A Quality Control Plan and Method Statement, signed by all parties, is a useful way to ensure understanding and common mutual expectations by the responsible parties involved.
- Close construction monitoring of the work is required.
- Damage due to corner castings does not typically require replacement unless there is an associated subgrade failure.
- Reuse of pavers may not be practical for larger projects.
- The Port will continue to consider pavers for future projects.
- The cost effectiveness of pavers is heavily dependent upon pavement section design.