DEVELOPMENT OF PAVING STANDARDS FOR PORT AND LARGER PROJECTS IN NORTH AMERICA

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SUMMARY

The Port of Oakland and their consultants have been using interlocking concrete pavers for larger pavement projects since the mid 80's. That first project consisted of approximately 5,000 square meters of RTG Runway. Since then there have been four major industrial installations totaling over 600,000 square meters with 58,000 square meters currently under construction. As a result of these projects and others, Port staff and their consultants have acquired useful experience in bring a paver project to a successful conclusion within North American construction practices and contracting models. The challenges of larger paver projects are discussed. Crucial elements including a Quality control, specific technical issues, and suggested improvement to existing industry literature are included.

1. INTRODUCTION

In 1992 a concrete paver surface was constructed at Berth 30. It has performed well under reach stackers and top picks. At the time it was the largest paver project on the West Coast. The pavers were selected both for their aesthetic appeal and the operational flexibility they provided. The section consisted of 100 mm rectangular pavers on 25 mm thick bedding sand, on 175 mm of asphalt on 425 mm of compacted aggregate base. This was a typical overall thickness for various asphalt pavements at the Port.

The project was constructed using specifications prepared in part by one of the authors (Wilbanks) while employed at JWD Group. Mr. Mark Smallridge was a consultant. The specifications were state-of-the-art at the time they were created. They were primarily a hand installation specification. Berth 30 was a success. Those specifications were also use for the Berth 55/56 project in 2000/2001. While the Berth 55/56 project was ultimately a success, a number of problems were identified.

The industry had gone through some significant transitions between the Berth 30 and Berth 55/56 projects. Machine installation was more common. Some installers were trying to make the transition from residential projects to commercial and industrial ones. Management skills for projects in the commercial/industrial world were different that what they were used to. Many of the installation practices that produce acceptable results in low wheel load environments like residential driveways would fail in high wheel load locations. Some contractors had rarely, if ever, worked under a formal set of specifications. Adjusting to the more formal practices of a large public sector proved difficult for some installers.

Paver manufacturers had more dedicated paver manufacturing machines. These machines could produce very large clusters of pavers. While these large clusters potentially increased production rates, they also required a higher level of experience to install correctly.

1.1 Need for Practical and Complete Specifications

Port Staff and Consultants identified a need to produce specifications that were applicable major projects installed by machine. At the time there were no specifications available in the North American market that were sufficiently rigorous and complete to assure a quality construction. Contractor problems with the Berth 55/56 project had driven home the point that the North American market was primarily a residential market. Successful projects had been done at the Port of Oakland and other ports in the past. However, they were controlled by contract documents that were intended primarily for hand installed projects. A set of specifications and details specifically tailored for machine laid projects did not exist. The problems that needed to be addressed fell into two categories, technical issues and project management.

2. THE TECHNICAL ISSUES IDENTIFIED

2.1 Joint Width

Joint widths in previous specifications had followed an industry published standard of 2mm to 5mm. This range has provided good service where it was used. Areas that were installed where joints were too wide, suffered loss of joint sand and movement of the pavers occurred. Areas where the pavers were installed too tightly often had joints that were not completely filled with sand.

The issues related to joint width were compounded by “spacer bars.” The spacer bar is vertical lug that is in the side of the paver. To call this lug a spacer bar is a misnomer since they were not intended to set the actual joint width. They were intended to facilitate even spacing when pavers were installed from a machine that tightly compressed a cluster of pavers. Most lugs in North America are about 1 to 1.5mm thick, significantly tighter of the industry standard minimum joint width of 2 mm. When the lugs are placed in contact with an abutting paver, the direct paver to paver contact defeats the even transfer of load that a properly installed sand joint provides.

Fortunately, the pavers come out of the clamp in a shallow arc. This promotes spreading of the pavers so that the lugs do not generally contact the abutting paver. However, some installers have over tightened the units with a rubber mallet. This may be done as an attempt to fit one layer into the next.

2.2 Variation in Paver Sizes

Pavers must be placed in with pavers of the same general size. Over the life of a paver mold the dimensions of the mold cavities will grow due to mold wear. This is especially true for large fields of pavers. The tolerances for older specifications called out a dimensional tolerance for length and width that was actually a typical variation in paver size of 1.5mm due to mold wear. Since a group of larger pavers from the end of the life of the mold cannot be installed next to pavers from the beginning of the mold life, a new standard had to be devised. The specifications developed called out that no paver could be installed next to a paver that was from more that 500 mold pressings later or earlier. While this standard makes a certain amount of sense it is difficult to enforce on the job site.

A large variation in cluster size can reduce mechanized paving productivity, thereby increasing costs and lengthening production schedules. Extreme variations in cluster size can make mechanical installation impossible. Following certain procedures during manufacture will reduce the risk of areas of cluster sizes that will not fit easily against placed clusters. Such procedures include (1) consistent monitoring of mold cavity dimensions and mold rotation during manufacture, (2) consistent filling of the mold cavities, (3) using a water/cement ratio that does not cause the units to slump or produce "bellies" on their sides after the pavers are released from the mold, and (4) moderating the speed of production equipment such that pavers are not contorted or damaged. All of these factors are monitored by regular measurement of the cluster sizes by the manufacturer and the subcontractor. It is essential that at least two identical jigs be used to check cluster dimensions, one in the paver production plant and the second on the job site. The manufacturer should provide these two jigs. The jigs should check the overall length and width of assembled, ready to place clusters.

Projects the size of those at the Port usually require several molds to product enough pavers. One part of the solution was to have the paver manufacturer provide a mold rotation plan. Basically the molds are measured when they were delivered and as they are used. A mold that varies too much is removed from the rotation or run a little longer to keep the product from several molds be run with it at about the same size as those molds wear.

The typical dimensional tolerances of concrete pavers are governed by an ASTM standard. For length and width tolerances, ASTM C 936 allows ±1.6 mm. (± 1/16 in). This variation is actually the tolerance for the expansion allowed in a paver mold cavity. If the pavers intended for machine installations the tolerance should be reduced to ±1.0 mm (i.e., ±0.5 mm for each side of the paver) for mechanically installed projects, excluding spacer bars. Height should not exceed ±3 mm (±1/8 in) from specified dimensions. Dimensions should be checked with calipers.

Spacer bars are required for mechanical installation and are not included in the overall dimensions. Spacer bars should protrude from the side of the paver a distance equal to the minimum allowable joint width.

2.3 Variation in Cluster Size

One of the more significant issues was managing the placement of clusters during mechanical installation. Concrete paver installation contractors had the manufacturer number each package of pavers delivered to the site and, wherever possible, install them sequentially. This helped to some extent in reducing delays from force fitting layers together by grouping layers of similar widths.

In addition, the paver installation contractors also determined the average width of the layers. They then pulled string lines set at multiples of the average paver layer width. The string lines provided a framework for placing the layers while reducing shoehorning of layers to a minimum. This enabled an initially "loose" installation with wide joint widths. Layers were then adjusted and tightened together to the specified maximum joint width of 4 mm. Compaction of the pavers followed as described earlier.

2.4 Quality of Bedding Sand

Bedding sand gradation has been a topic of discussion The Port has specified bedding sand that conforms to ASTM C33. It has been successful. Sand degradation testing is of paramount importance. Sand that performs well under typical residential or even city street loads of 8,200 kg (18,000lbs.) may not perform well under the loads exerted by container handling equipment axles, 90,000 kg (200,000 lbs). Sand durability testing such as that called out by the Lilly-Dowson Test (4) can provide good guidance.

2.5 Joint Sand

Joint Sand must be of sufficient strength to support the loads and small enough to fill the joints at the low end of the 2-5 mm width tolerance. Additionally, during installation it must be dry enough so as to fill and bridge the joints during installation. Consolidation of the joint sand is essential to achieving interlock among the units. Consolidation also reduces infiltration of water into the sand and base. Traditionally joint sand was placed using a vibrating plate. Some contractors want to use a vibrating roller in lieu of a vibrating plate. Because the Port must be cautious about dictating the means and methods of the installer, the specifications do not directly prohibit use of a vibrating roller. However, the vibrating seems to provide only marginal results. A vibrating roller can be made to work under ideal conditions. All of the projects on which a vibrating roller was use required some recompaction of the joint sand. The joint must be checked to see if it is completely filled prior to installation of a sealer or stabilizer.



Figure 2. Typical vibrating plates compacting pavers.

2.6 Automated Application of Joint Sand Stabilizer

One issue that developed was poor application of joint sand stabilizer. Liquid penetrating was used by the Port. While the product is deemed to be worthwhile the application of it is critical. No automated methods have yet been shown to be effective. Manual application with a squeegee is required. Dry mix organic or polymer additives that must be combined with joint sand prior to placing it in the joints were not deemed appropriate for large scale projects.

2.7 Compressive Strength Testing

The typical requirement for compressive strength for concrete pavers is 55 MPa (8,000 psi), when tested according to ASTM C140. There has been some confusion about the way the test should be performed and what the value should be for thicker pavers, leading to some minor delays on one project and initial feelings of ill will. Upon investigation it was determined that if whole pavers are tested, an adjustment factor should be used. For thicker units the tested compressive strength is multiplied by the factor per the table below to compensate for the height of the unit (2). If cut, cube-shaped coupons are tested, use the 55 MPa and 50 MPa values regardless of the initial dimensions of the paver from which the coupon was cut. This fact need to be included in the specifications.

Table 2. Compressive Strength Adjustment Factors for Concrete Pavers

Nominal Thickness	Multiply Tested Compressive Strength by
3 1/8 in. (80 mm)	1.18
4 in. (100 mm)	1.24
4 3/4 in. (120 mm)	1.33

2.8 Preparation of the Work Area

Problems developed on several of the projects because the general contractor did not really understand the preparation needed for the installation of pavers. The elevations and surface tolerance of the base determine the final surface elevations of concrete pavers. The paver installation subcontractor cannot correct deficiencies in the base surface with additional bedding sand or by other means. Heavy-duty paving will often have high strength base material such as cement stabilized base, concrete slabs or asphalt. Asphalt crews often use different elevation control methods for base lifts than they do for top lifts. Even though these materials are being used as a base layer, the construction specification must require installation of the top layer of these base materials to be constructed to typical surface finish tolerances.



Figure 2. Paver installation machines.

2.9 Stack Test

One project had a serious problem with a paver installer due to the use of a “stack test’ to determine the usefulness of the pavers for installation by machine. In no case should the "stack test" be used as a means for determining dimensional consistency. This test consists of stacking 8 to 10 pavers on their sides to indicate square sides from a stable column of pavers, or leaning and instability due to bulging sides or "bellies." It is an early warning test to indicate the possibility of installation problems from bellied pavers (3). Investigation by Port consultants determined that the stack test is not in any way reliable and should not be substituted for actually measuring the pavers to see if they meet specified tolerances.

2.10 Incorrect Changing of the Pattern

The herringbone pattern in rectangular pavers has served the Port well. At the time of the Berth 55/56 construction, the pavers came from the manufacturer pavers came from the manufacturer in a herringbone pattern ready for installation by machine. There was some switching of direction of individual pavers required to stitch the clusters into an even pattern. One installer changed the way in which the pattern was finished out. The change added several millimeters to each cluster. The result was a lengthening of the pattern until layers no longer fit into the abutting row of pavers effectively stopping the installer’s progress.

2.11 Not Finishing the Work at the End of Each Day

The clusters are some times manufactured with half paver spaces missing on the sides. These

holes are filled with extra pavers after the cluster is placed. Normally this operation takes place as the clusters are installed and fairly loose. One of the installers insisted on waiting a day of two to complete this operation. The result was that inserting the filler paver became very difficult. Pavers had moves slightly to fill the void. Inserting the fill pavers required tightening the pattern all around.



Figure 3. Showing the stitching operation taking place after other operations was completed resulting in great difficulty in inserting the pavers.

2.12 Pre-Screeding Too Much Bedding Sand

Large projects lend themselves to several types of high-volume production methods. One of these it to pre-screed bedding sand ahead of the paver laying operation with an asphalt spreader. Large areas, several days worth of production, can be screeded with rapidly with few personnel. The technique works well and produces an adequate product. However, the bedding sand is vulnerable to the elements. On several occasions operations had to cease for two or three days until the pre-screeded bedding sand could dry. It is not likely that the advantage in screeding production was worth the lost time from rainy weather.

3 PROJECT MANAGEMENT ISSUES IDENTIFIED

3.1 Coordination

Any large civil project such as a marine terminal has a number of issues requiring coordination between the various trades. This is the responsibility of the general contractor (GC). While the available GCs who were qualified to bid on marine terminal projects were used to controlling most of the trades, they had little experience with interlocking paver mechanics. The GC did not understand the requirements for staging appropriate materials, how to identify quality materials, or preparing a base properly for accepting unit paving. The GC had no substantive experience

identifying problems with the installation or if, and how, far the work was behind schedule. The GC was typically unable to appraise the activities of the paver installed beyond measuring the area installed. The primary needed change was a method to assure that the GC, who typically had little experience with pavers, would become informed enough to provide practical staging and project control.

To address this, a requirement for a method statement was included in the specifications. The CG, the unit paver installer, paver manufacturer and an independent testing agency were required to prepare a document together for submittal to the Engineer. The Port of Oakland required method statement prepared jointly by the general contractor, installer and paver manufacturer. The objective of such an approach was to establish working procedures to ensure a smooth operation on the job site.

Spacer bars are required for mechanical installation and are not included in the overall paver dimensions. Spacer bars should protrude from the side of the paver a distance equal to the minimum allowable joint width. The Port's specification required that pavers be sampled and tested regularly to ensure conformance with ASTM C 936.

3.2 Submittals

As with any major project, submittals are required. These are required to be submitted by the GC to the Engineer for review and approval. Items such as pavers, manufacturer's catalog cut sheets and production mold drawings, the stitching pattern for joint clusters, bedding sand, joint filling sand, joint stabilization material, and the Quality Control Plan

3.3 Quality Control Plan

The Port identified that, typical project management methods did not seem to be working appropriately primarily due to inexperience of the GC with pavers. In the end the Port's contract was with the GC and it was imperative that the GC had control and responsibility for the with the paver installation. The new Specifications devised a way to promote that understanding by the GC.

The Quality Control Plan is a relatively new concept to the paver industry. It reflects the need of the Port to ensure that a GC unfamiliar with pavers was adequately informed by the installers of the needs of the work, and that installers moving from the residential market to industrial one, the requirements of a larger project.

Development and implementation of the Quality Control Plan is a joint effort by the GC, the paver installation subcontractor, material suppliers and testing laboratories. It includes:

1. Quality Control organization chart with the names, qualifications, and contact information of responsible personnel, and each individual's area of responsibility and authority.
2. A listing of outside testing laboratories employed by the GC and a description of the services provided and the tests performed by GC personnel.
3. Preparation and maintenance of a Testing Plan containing a listing of all tests to be performed by the GC and the frequency of testing.
4. Procedures for ensuring that tests are conducted according with the Plan including documentation and steps for taking corrective actions if materials do not meet criteria for

meeting the standards.
5. The paver installation subcontractor's method statement.

A detailed description of a quality control plan and method statement has been included in the Interlocking Concrete Pavement Institute's ICPI Tech Spec 15 (1).

It should be noted that when the concept of a quality control plan was introduced to the industry it was met with a wide range of responses. Many of the responses reflected the inexperience of installers with larger projects and the paperwork required. One indicator that the quality control plan was a useful and more or less fair approach was the similar responses from the various sides of the industry. Many manufacturers said they thought the requirement was about right for the installers but a bit heavy handed on the manufacturers, while many installers felt that the requirements were correct for the manufacturers but a bit difficult for the installers. The GCs did not like the paperwork but could see the value in getting a clear planning effort from the other parties.

3.4 Project Communication
Every project of any size has conflicts and scheduling issues. Written communication and record keeping is essential. Some of the installers were not used to the formal project control processes.

3.5 Protection and Clean Up
The GC should insure that no vehicles other than those from subcontractor's work are permitted on any pavers until completion of paving. This requires close coordination of vehicular traffic with other contractors working in the area. It acknowledges that the GC is ultimately in control of the project site and not the installer.

4. CONCLUSIONS

Establishing good practices and proper channels of communication through the Quality Control Plan and the specifications is important to a good project. When the Port started there was not a large pool of qualified installers to which to draw. Over time, that pool has increased. The Port is confident that the new specifications address appropriate issues. The Port will continue to improve standards as information become available. Additionally, the Port will continue to consider interlocking concrete pavers for future projects.

5. REFERENCES

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