PERFORMANCE OF BRICK PAVEMENTS SUBJECTED TO HEAVY VEHICULAR TRAFFIC

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ABSTRACT

Segmental pavements have grown in popularity over the last few decades, but very little research has been done on their performance. In order to obtain performance data of flexible brick pavements, the Brick Industry Association has periodically monitored brick paving installations at two brick plants in the United States. Information on traffic loads and volumes, soil properties, brick unit properties, base materials, and edge restraints were used to design the appropriate layer thicknesses and materials necessary for construction. Different paver thicknesses, edge restraints, bond patterns, and paver types were used to assess the effect of these variables on performance and to assess which parameters are most important to pavement performance.

Monitoring of the pavements has occurred periodically over a nine-year period. Initial monitoring included an evaluation of design and construction of the brick pavement section. Performance attributes measured include surface distress data, abrasion resistance, paver durability, pavement creep and edge restraint condition. The empirical information from this field study will be used to improve design guides and specifications for brick pavements.

Key words: brick, clay pavers, flexible pavements, pavements, traffic.

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INTRODUCTION

The use of flexible brick pavements has seen increased usage over the last decade. It is recognized as a durable and economical paving system. A flexible brick paving system is one in which no mortar is used. The brick pavers are set on a sand setting bed with sand between the units. Although any base could be used, a crushed aggregate base is favored for its flexibility and lower cost.

Brick paving was the material of choice at the end of the 19th century and beginning of the 20th century in the United States. Brick was one of the few materials that withstood the heavy steel wheels in use at the time. The production of brick pavers reached a peak around 1925. The use of brick as a road surfacing material decreased with increasing vehicle speeds and the improvement of concrete and asphalt paving materials and methods in the 1930's and 1940's.

Research on concrete pavers has been conducted around the globe, supported by cement, concrete and masonry associations. However, research on clay pavers has been considerably less. The Brick Industry Association (BIA), through its paving committee, proposed a series of tests on brick pavements at brick manufacturing facilities throughout the United States. The test pavements would result in a body of data and could be used to demonstrate that clay segmental pavements could resist heavy vehicular traffic. A number of paving applications were designed and installed, but only two pavements were monitored over a period of 9 years.

Although data from this research is limited, there are many other sites around the country that have used flexible brick paving in heavy vehicular applications. A few of these installations will be described.

DESCRIPTION OF THE TEST AREAS

Several brick manufacturing plants in various locations around the United States were chosen as test sites. Designs were prepared for nine locations. Of those, only four pavements were actually installed and only two were monitored over a long time period. These monitored locations were Sugarcreek, Ohio and Columbia, South Carolina. The locations provide a geographical and environmental mix so they provide broader results.

Each of the test sites was selected to include areas that received the heaviest truck traffic. Usually this was a plant entrance or a loading or unloading zone. At all the sites, existing roads were used. The existing asphalt wearing course was removed and the existing base was overlain with the new brick wearing course in all but one case. A sand setting bed and pavers comprised the wearing course and were placed on top of the aggregate base.

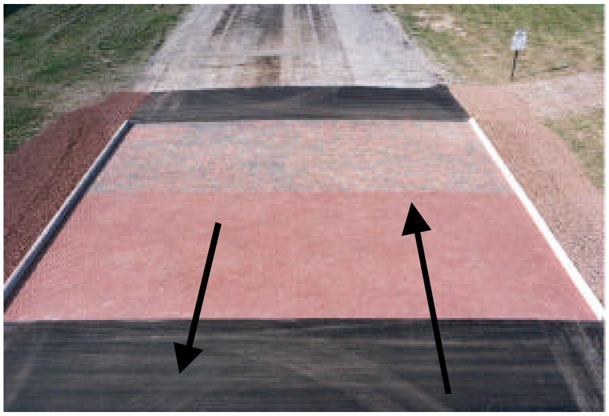
Table 1 provides the approximate sizes of the paved areas. Figs. 1 and 2 show the two monitored test sites and the typical traffic flow patterns. At the South Carolina site, two areas were installed: a truck loading and unloading area (Area #1) and a truck unloading area (Area

#2). Area #1 also had two different bond patterns: stack bond and herringbone. Area #2 used only a herringbone pattern, but a thicker unit was used. The Ohio location was a load tie-down area for all trucks leaving the plant. It used two different pavers within the same test section: a wirecut flashed paver and a smooth unflashed paver.

Table 1. Size of Test Areas

Location	Size, m (ft)
Columbia, SC Area #1	9.4 x 11 (31 x 36)
Area #2	9.1 x 12.2 (30 x 40)
Sugarcreek, OH	12.8 x 12.8 (42 x 42)

Columbia, SC Test Site, Area #1
Figure 1



Sugarcreek, OH
Figure 2

Various edge restraints were used. Area #1 in South Carolina had rigid plastic edge restraints along the sides of the paving area. A concrete grade beam was used on the leading edge on the pavement for each traffic direction. The trailing edge was asphalt concrete. Area #2 used concrete on three sides while the North side was asphalt concrete. The Ohio location used poured in-place concrete curbs along the sides of the pavement and a steel angle with steel reinforcing bar spiked into the ground at the ends. Asphalt was placed on top of the angle and against the brick.

Physical Properties of Clay Pavers

Table 2 shows the physical properties of the brick units used at the monitored test sites. The units were taken from typical production runs. All units were extruded brick. Brick used on the South Carolina test area had chamfers while the Ohio location did not. The test results were determined by the brick manufacturer according to ASTM C 67.

Table 2. Physical Properties of the Paving Units

Location	Columbia, SC		Sugarcreek, OH	
	Area #1	Area #2	Paver #1	Paver #2
Compressive Strength, Mpa (psi)	50.1 (11, 256)	not measured	89.1 (20,040)	102.9 (23,140)
24-hr Cold Water Absorption, %	4.7	“	2.6	2.1
5-hr Boiling Water Absorption, %	6.6	“	3.6	3.0
Saturation Coefficient	0.72	“	0.72	0.70
Abrasion Index	0.04	“	0.013	0.010
Size, w x h x l, mm (in.)	102 x 57 x 203 (4 x 2 ¼ x 8)	102 x 70 x 203 (4 x 2 ¾ x 8)	95 x 57 x 191 (3 ¾x2¼x7½)	95 x 57 x 191 (3 ¾x2¼x7½)

Each of the units passed the requirements of ASTM C 902, Class SX, Type I. At the time of the installations, ASTM C 1272 Specification for Heavy Vehicular Paving Brick had not been adopted yet. All units would meet the current requirements of C1272, Type R. However, only one would meet the requirements for ASTM C 1272, Type F since the minimum thickness is 66. 7 mm (2 5/8 in.).

Dimensional tolerances were not directly measured, but were reported to conform to ASTM C 902, Application PS. This allows the length to vary by +/- 6.4 mm (0.25 in.) and the width by +/- 4.7 mm (3/16 in.).

DESIGN AND INSTALLATION OF TEST SITES

Design of the flexible brick pavements was conducted using the AASHTO Methodolgy (AASHTO 1986) that is reiterated in BIA's Flexible Brick Pavements Design Guide (BIA 1991). Designs were verified using a computer program for concrete pavers since they behave similarly. Assumptions were made on soil type, traffic and drainage. In the end, the designs were not strictly followed. Instead, the existing base was felt to be adequate in most of the test areas and so the setting bed and pavers were laid directly on top.

South Carolina Test Area Installation.

Installation procedures were followed as prescribed in the BIA (1991). Area #1 used a 152 mm (6 in.) layer of compacted crushed stone. A fine silica sand was used for the setting bed in both Areas 1 and 2. The setting bed was 50 mm (2 in.) thick. Two bond patterns were used in Area #1: stack bond and herringbone. Stack bond was used to verify the recommendation of using a herringbone pattern in vehicular areas. Area #2 used a thicker paver which was laid in a herringbone pattern. After the pavers were laid in the appropriate pattern they were compacted into place with a plate vibrator. The vibrator did not have a rubber pad. Figs. 3 and 4 were taken during installation of the test areas.

Compaction of Base, Area #1
Figure 3

Vibration of Stack Bond, Area #1
Figure 4

Ohio Test Area Installation

This installation also followed BIA (1991). A concrete curb was poured along the sides of the test area. A 50 mm (2 in.) sand setting bed was used on top of the existing road. Two pavers, a smooth paver and a wirecut flashed paver were used. The pavers were compacted into place after laying. Figure 5 shows the thickness of the sand setting bed and weep holes in the concrete curb. The weep hole were thought necessary to drain water from the pavement.

Installation of Setting Bed
Figure 5

MONITORING OF TEST SITES

Monitoring of the pavements occurred on an unscheduled basis. A condition survey form was filled out for each monitoring period. Monitoring occurred on a somewhat yearly basis for the first three years and then not until the ninth year. Records of environmental conditions, traffic and pavement distress were taken. Photographs at the time of each inspection were also taken. Enough information was gleaned from the sparse data to make some basic conclusions.

Environmental Conditions and Traffic

Records of environmental conditions were taken including air temperature, humidity, rainfall, snowfall and frost depth. Traffic counts were also noted. Table 3 lists the typical vehicular traffic for the monitored pavements.

Table 3. Vehicle Loads

Type of Vehicles	South Carolina, Area #1	South Carolina, Area #2	Ohio
Passenger cars	50	25	30
Delivery truck	--	--	25
Trailer truck	54	54	261
Dump truck	--	--	15

Performance of the Clay Pavers

The performance of the units was directly related to the performance of the pavement as described in the following sections. Typical distress occurred in the pavement when the units were able to move out of position. Cracked or chipped pavers were the result. There was no freeze/thaw failures seen at either location.

A flexural failure occurred in some pavers along an edge as shown in Fig. 6. This is likely the result of a poorly compacted base directly beneath the edge units. Fig. 7 is an example of chippage due to loss if interlock and subsequent movement of the pavers. Notice the major movements of the units, even though the surface has stayed relatively flat.

Cracking along edge, South Carolina Area #1
March 2001
Figure 6

Edge Chippage, Ohio
August 2000
Figure 7

Performance of Pavements

All of the test areas performed adequately in most areas. Problems that were identified at the test sites included rutting, unit chippage, unit cracking, creep of the pavement and loss of joint and bedding sand. These will be discussed in context of the contributing factors.

Bond Pattern

In vehicular areas, especially in flexible pavements, a herringbone bond pattern is recommended. This bond pattern allows forces due to accelerating, braking and turning to be spread out to adjacent pavers more evenly. As seen in the South Carolina location a stack bond pattern was used as a variant. Creep or movement of the pavers occurred soon after the pavement was installed. There was not a catastrophic failure, but created uneven bond lines and opened up an area along the leading edge of the pavement as shown in Fig. 8. Creep also occurred in Ohio even though a herringbone pattern was used. This could be attributed to joint tolerances.

Creep of Bond Pattern, South Carolina, Area #1
March 2001
Figure 8

Edge Restraints

Edge restraints are necessary to contain the brick pavement. Edge restraints are also required to allow interlock to occur. Without proper edge restraints, the pavers are allowed to move around and chippage and cracking would occur.

In most of the test locations, an asphalt concrete was used as an edge restraint. This was an existing pavement or a newly installed pavement. After traffic used these pavements, the asphalt interface moved or softened. Horizontal interlock was lost and the pavers moved out of place. The condition was not severe enough to cause the units to crack but creep did occur.

In the Ohio location, weep holes were used in the concrete curb to allow water to be drained from the pavement. Unfortunately, the weep holes were large, 25 mm by 25 mm (1 in. by 1 in.), and they were located at the same level as the sand setting bed. This allowed the sand to flow out of the weep holes. Loss of sand allowed the pavers to shift out of place and undulate as shown in Fig. 9, resulting in loss of interlock. Removal or filling of the weep holes, or use of a geotextile in front of the curb would have kept the sand in place.

Loss of interlock due to sand loss through weep holes, Ohio
August 2000
Figure 9

Dimensional Tolerances

All pavement materials have some type of dimensional tolerance. Brick pavers are no different. Each run of paving brick will have different dimensional tolerances than others. In many cases this is due to the raw materials or manufacturing process. Flexible brick pavements require tighter dimensional tolerances because of installation and performance issues. Large dimensional tolerances will make the installation more difficult because there will be a greater need for realignment of the pavers. Large dimensional tolerances will also allow sand to be lost from the joints between the pavers over time. The pavers conformed to Application PS as noted earlier. ASTM C 1272, Type F (those used in a flexible pavement) requires all pavers to meet Application PX requirements. Application PX requirements are almost half that of Application PS. An example of movement is shown in Fig. 10.

Figure 10 Movement of Pavers, Ohio December 1992

PAVEMENT PERFORMANCE IN OTHER LOCATIONS

The test areas described in this paper are by no means the only pavement designed to resist heavy vehicular traffic. Many municipalities around the country have installed flexible brick pavements. Many installations have used brick pavers in a wide range of setting beds and bases. By far the most common is a bituminous setting bed over a concrete slab or asphalt base. Not as common, but nonetheless a strong system, is brick pavers over a sand setting bed. A noteworthy project using flexible brick paving is described below.

Gateway Center, Los Angeles, California

The flexible brick pavement is located at multi-node transportation center and was constructed in 1995. The brick pavement receives over 2,000 passes of bus traffic per day. The system is a concrete slab situated over a parking area with a waterproof membrane, a sand setting bed and brick pavers. Several trial areas were constructed to determine the performance under accelerated traffic of different pavers. A unit from the United Kingdom was chosen because of its close dimensional tolerances and chamfered edges. The paving uses three colors of pavers set in unique patterns. These patterns help define pedestrian and vehicular areas as shown in Fig. 11. The pavers are laid in a 45 degree herringbone pattern. Interlock is well developed and the pavement has retained a high level of serviceability.

Figure 11 Gateway Center, Los Angeles

SUMMARY AND RECOMMENDATIONS

The performance of heavy vehicular pavements depends largely on the base. However, other factors can cause serviceability problems if not addressed in design or construction. If the base is designed and constructed properly, then the flexible brick pavement usually performs adequately. The base in each of the test sites was already a well-compacted pavement. The brick pavers were placed on top of the base as a wearing course.

All pavements have remained serviceable throughout the monitoring periods. Although there were no catastrophic failures, several things affected performance. These included edge restraints, bond patterns, paver dimensional tolerances, and a stable sand setting bed. Each of these could allow the pavers to move relative to adjacent pavers. This loss of interlock will result in chippage and cracking of pavers. Pavements that develop interlock provide a rigid paving surface with lasting performance. Since the failure patterns found in these test areas were mostly serviceability issues and not total pavement failure, it is recommended that adherence to standard practices and guidelines be followed. This includes unit dimensional tolerances, use of herringbone patterns, adequate bases and base compaction and rigid edge restraints. ASTM standards for durability appear to provide for a durable unit.

Faith in flexible brick pavements should be increased due to this small amount of research. A version of flexible brick pavements used in the early 20th century can used again with great success. The result would be durable riding surfaces that have great aesthetic appeal.

REFERENCES

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