Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 7(1):69-76

Evaluating Sustainability of Face Bricks for Road and Airfield Pavements

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Abstract: The feasibility of using face bricks as an alternative to concrete or asphalt paving was evaluated for lightweight and heavyweight vehicle traffic. Paving materials and equipment can be scarce in expeditionary environments, so the use of bricks recycled from existing infrastructure may provide a local resource for constructing pavements suitable for meeting the military's mission requirements. The field testing documented in this paper follows a laboratory study in which a series of strength and characterization tests were conducted on selected face bricks and brick pavers. The success of the laboratory testing led to the full-scale field evaluation of the face and paver bricks trafficked with a commercial dump truck load of approximately 24.5 t and then trafficked with a 20.4 t single-wheel C-17 aircraft load cart. The field testing indicated brick-paved roads constructed with a moderately high-strength base are capable of sustaining more than 10 000 passes of truck traffic without failure. The same brick-paved roads were not capable of withstanding C-17 aircraft traffic. Further results from the evaluation are presented and include material characterization test data, rut depth measurements, wheel path and cross-section profile measurements, instrumentation response data, and forensic assessments.

DOI:10.6135/ijprt.org.tw/2014.7(1).69

Key words*: Aircraft traffic; Brick; Brick paving; Road; Truck traffic.*

Introduction

Background

Alternative resources for construction of infrastructure, particularly roads and airfields, are often desired, especially when increased sustainability can be achieved. In locations where paving materials and equipment are scarce, the use of recycled or recently manufactured face brick (e.g., house or building brick) may provide a local resource for constructing suitable pavements, particularly for meeting the military's mission requirements. Face bricks are among the most commonly reclaimed building materials; however, they are not generally used for road paving. Face bricks may provide a low-maintenance pavement surface with comparable structural characteristics to typical hot-mix asphalt (HMA) or portland cement concrete (PCC) pavements. Brick-paved roads are classified as a flexible pavement.

During 2010, an extensive literature review was conducted to identify various types of brick, brick composition, manufacturing processes, strength characteristics, previous uses of brick for roads, brick specifications, and common laboratory testing suitable for brick specimens. Following the literature review, a laboratory study was completed on five selected face brick types to evaluate their strength and durability [1]. A brick paver was also included to use as a control for the study. The results from the 2010 laboratory testing supported the need to evaluate, through full-scale field testing, the use of face bricks as a surface for low-volume roads and military aircraft parking ramps. The full results and analysis of the field testing described in this paper are presented in a published technical report [2].

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Note: Submitted March 13, 2013; Revised June 21, 2013; Accepted June 25, 2013.

Objective and Scope

The purpose of this research was to evaluate the use of face bricks for paving surfaces on low-volume roads (< 400 vehicles per day) and aircraft cargo areas with full-scale field testing and evaluation. Four types of face bricks and a brick paver were selected, based on the results of the laboratory testing, to be included in the field testing.

The full-scale field testing included six test items with the same subgrade and base course. Each item had a different brick surface and was instrumented with multiple earth pressure cells (EPC) in the base and subgrade. Channelized traffic was applied to the outside lanes of the test items with a loaded commercial dump truck of approximately 24.5 t with approximately 752 kPa tire pressure. Ruts occurred near the outsides of the test items where the truck traffic was applied. Traffic continued on each item until surface rutting reached an average depth of 80 mm (failure) or 10000 passes.

Channelized traffic with a single-wheel C-17 load cart of approximately 20.4 t and 979 kPa tire pressure was then applied to the center of each item. Traffic continued on each item until surface rutting reached an average depth of 80 mm or more (well beyond the approximately 25 mm rut depth considered as failure for aircraft traffic) or 1000 passes were achieved.

Literature Review

Brickwork has often been used because of the long-term durability and low-maintenance associated with it. The variety of bricks is extensive; several types of brick are manufactured, which offer a wide range of textures and performance characteristics [3]. Bricks are made from clay, shale, soft slate, calcium silicate, concrete, or shaped from quarried stone, with clay being the most common material [4].

Performance Measurements

Compressive strength (ASTM C 67) is the stated performance parameter for bricks. Literature has reported the minimum compressive strength for face or common bricks ranges from 10 to 99 MPa [4]. Compressive strength requirements of 55 MPa with concrete paving blocks have proven to be adequate for use in military airfield applications [5].

Water absorption (ASTM C 67) is another performance measurement that determines the porosity of bricks [4, 6]. Water absorption gives insight into bricks' resistance to rain penetration. Materials with very low porosity are generally extremely durable in most conditions. The water absorption commonly reported is 4.5 to 30 % [4].

The Los Angeles Abrasion (LAA) test provides a measure of aggregate hardness and is a good indicator for determining the general quality of brick pavers [7]. Concrete abrasion resistance is affected by a variety of factors such as aggregate quality, water-cement ratio, and curing techniques, but concrete compressive strength has been widely used as an abrasion criterion [5]. Mazumder et al. found that LAA values increase with increases in water absorption capacity of the aggregates [7]. Therefore, the more efficient water absorption test (ASTM C 67) can be used as an alternative to the LAA test (ASTM C 131 or C 535) in austere or contingency environments. There is little agreement on what represents an adequate abrasion test for concrete paving units [8].

Density or specific gravity (ASTM C 127) of bricks gives insight into the amount of void space within the specimen. DeVekey stated that the gross (bulk) density of clay brickwork ranges from about 1394 to 2403 kg/m^3 [4]. Bricks may have a low specific gravity and may be relatively porous because of a lack of proper quality control during manufacturing [9].

Skid resistance is related to tire/roadway friction, which is applicable to vehicular traffic, and is measured by the dynamic coefficient of friction [9, 10]. Trimble stated that the coefficient of friction for brick is approximately 0.75; however, most wet brick pavements have a coefficient of friction of approximately 0.5 [9]. Most new brick pavements have adequate skid resistance, but brick pavers will polish over time, eventually reaching an equilibrium position [10]. The skid resistance of bricks must be evaluated over time [6].

Case Studies

The following paragraphs highlight a few case studies involving the use of bricks as a paving material. When the authors did not specify the type of brick, it was assumed that they were most likely evaluating brick pavers. Pavers are generally stronger and more durable than regular bricks because they are fired at higher temperatures.

In 1981, Hammett and Smith performed a study where trial areas of clay paving, assumed to be brick pavers, were laid on an industrial road that handled approximately 300 commercial vehicles per day. After 11 years, the pavers were still performing adequately and showed no signs of deterioration [3].

In 1989, a concrete block pavement demonstration project was conducted at Aberdeen Proving Ground, MD. This project involved the use of concrete pavers rather than regular bricks. The site was an unsurfaced tank road intersection that brought four range roads together near a motor pool area for tracked vehicles. The traffic during this time consisted of ten M-88 (50.8 t) tank retrievers and ten M-578 (27.2 t) tracked vehicles per day. The area was completely reconstructed. A geotextile was placed on top of the compacted subgrade, and a select-fill subbase of unknown material was spread and compacted over the geotextile in several lifts for a total thickness of 480 mm. A 100 mm thick crushed stone base course was placed, and the concrete block pavers were laid in a herringbone pattern. After 3 years of traffic, no maintenance had been required, and there was no significant rutting or settling [11].

The streets of several cities in Iowa were originally constructed with brick pavements. The brick pavements consisted of two layers of bricks with sand used as filler between the two layers. The bottom layer of bricks was placed with its long dimension parallel to the line of travel, and the top layer of bricks was placed perpendicular to the bottom layer. The strength of the brick paving was determined to be inadequate for current and future traffic loadings. Therefore, in some cases, 80 mm thick HMA overlays were placed over the bricks as a rehabilitation technique. After an unknown period of use, the HMA cracked in some places, broke away in other places, and exposed the existing brick base. It was concluded that the combination of movement of the bricks and the flexibility of the HMA accentuated the original problems [12].

Materials Characterization

The test section consisted of a brick surface constructed over a bedding sand layer, geotextile material, base course, and subgrade. Each layer of the pavement structure was characterized through laboratory tests or visual inspection to ensure the desired in-place properties of each material were met.

Pavement Structure

High-plasticity clay material, classified by the Unified Soil Classification System (USCS) (ASTM D 2487-06) as CH, was used for the subgrade. This material was used because of the uniform conditions the clay provides over time and because of its ability to control strength by controlling moisture. The CH had an approximate California Bearing Ratio (CBR) of 6, as measured by traditional CBR testing.

Four soils were blended to obtain a silty gravel base course material, classified by the USCS as GM. The blend consisted of two types of crushed gravels (30% each), sand (35%), and silt (5%). The CBRs, measured using a dynamic cone penetrometer (DCP), for the base course material ranged from 55 to 100. More specifically, DCP results for Items 1, 2, and 3 measured CBRs ranging from 55 to 60, while the CBRs of Items 4, 5, and 6 ranged from 80 to 100. Items 1 through 6 refer to the six different brick surfaces that were evaluated within the test section. The DCP was used on each item directly before trafficking began by drilling a 25 mm diameter hole through the brick to get to the surface of the base layer. The base material strengthened with time, which may explain the increase in CBR values for Items 4, 5, and 6.

A nonwoven needle-punched geotextile composed of

Fig. 1. Brick Types Included in Test Section.

Table 1. Brick Dimensions and Weights.

Brick Type	Length (mm)	Width (mm)	Height (mm)	Weight (kg)
Queen	190	70	70	1.4
Utility	295	92	90	3.5
Reclaimed	210	95	60	2.0
Standard Modular	194	90	57	1.5
Paver	194	90	60	2.1

polypropylene fibers was used on top of the base course to support the bedding sand layer needed for the brick surface. The geotextile material weighed approximately 135 g/m^2 and was 1 mm thick. The geotextile material is capable of containing the bedding sand layer while still allowing water to penetrate through the pavement structure.

Based on the laboratory testing results, four types of bricks were selected for the field study. The bricks were obtained from a local manufacturer/distributor and included queen, standard modular, reclaimed, and utility types (Fig. 1). A brick paver was also selected as a control. Note that the names of bricks may differ depending on the region. The exact compositions of the bricks are unknown; however, the brick manufacturer/distributor noted they are made mostly of clay and shale. Table 1 presents the dimensions and weights of each brick type.

Brick Laboratory Test Results

The five brick types were tested in the laboratory for their various strength properties. Laboratory tests, including LAA, water absorption, specific gravity, and compressive strength, were previously conducted on the bricks during the initial brick study in 2010 [1]. Complete results are presented later in this paper.

The laboratory test results revealed that some of the selected face bricks had characteristics that were similar to, or better than, the brick pavers'. The LAA test results on the bricks were within the typical ranges for traditional aggregate material, indicating a strong possibility that bricks could prove satisfactory for use as a paved surface. Also, literature stated that concrete pavers with compressive strengths of 55 MPa have proven to be adequate for military road applications [5]. The compressive strengths of all brick types tested, with the exception of the queen and reclaimed brick types, exceeded 55 MPa. However, the measured specific gravities and water absorptions of the face bricks indicated there could be a problem with durability during freezing and thawing periods. The specific gravities of the bricks were lower than the standard values of natural aggregates (2.6-2.7). Maximum water absorption of 1% for aggregates is preferred in construction applications [13]; the water absorption for the bricks ranged from approximately 5-20%. Full details from the laboratory testing and results are documented in [1].

Test Section Construction

The full-scale test section was 24 m long by 11 m wide and was constructed in the U.S. Army Engineer Research and Development Center's (ERDC) Hangar 4 test facility. The test section was divided into six items, each 12 m long by 4 m wide. Fig. 2 shows the plan view of the test section.

Each item was constructed of the same subgrade and base materials and to the same thicknesses. The subgrade was constructed with approximately 610 mm of CH, and the base course was constructed with approximately 310 mm of GM. Approximately 30 mm of bedding sand was placed on top of the geotextile material. A 100 mm wide concrete edge restraint was added to the perimeter of the test section and between each lane to aid in keeping the bricks stable during construction and trafficking.

The bricks were laid by hand on top of the bedding sand in a herringbone pattern (45 degree angles to each other) between the concrete curbing. The bricks initially were tapped into place using a rubber mallet. After the bricks were in place, a vibrating plate compactor was used to compact the bricks into the bedding sand.

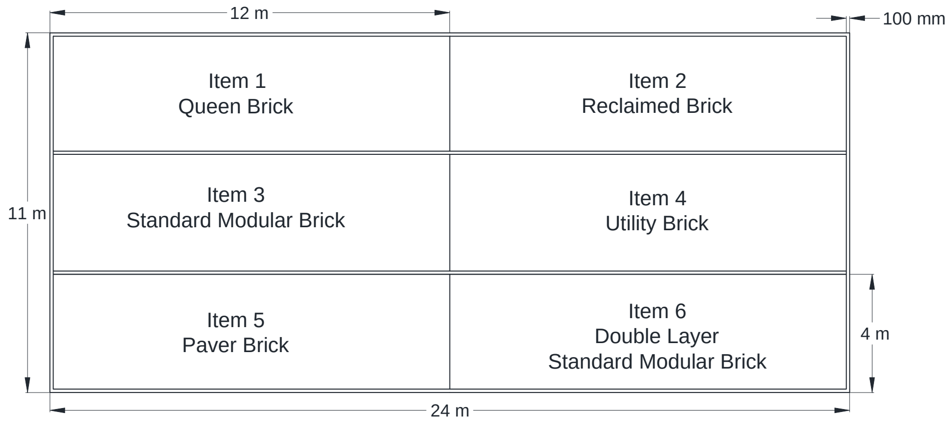

Fig. 2. Test Section Plan View.

Sand was then swept into the joints of the bricks for adhesion and stability. A vibrating plate compactor was used again to help compact the sand in the joints. The process was repeated until the joints were completely filled with compacted sand. Item 1 was paved with the queen bricks, while Item 2 was paved with the reclaimed bricks. Items 3, 4, and 5 were paved with the standard modular bricks, utility bricks, and brick pavers, respectively. Item 6 was constructed of two layers of the standard modular bricks.

Each item was instrumented with three 230 mm diameter EPCs to measure the in-situ pavement response to the truck loading. No instrumentation data were obtained with the C-17 load cart traffic. EPCs were installed 50 mm into the base and 50 mm into the subgrade to measure the vertical stress distribution throughout the pavement system caused by the wheel loads and tire pressures. Two EPCs were placed in the base to ensure that an accurate measurement was recorded, because little to no information exists on the stress distribution under a brick surface. Two EPCs were installed in the center of the wheel path of the front and rear tire path (one in the base and one in the subgrade), and one EPC was installed in the center of the axle of the dual rear tire paths (in the base).

Traffic and Evaluation Procedures

Trafficking took place during the months of May, June, and July 2011, where the maximum daily air temperatures ranged from 18 to 37^{o}C. The test section was free from environmental effects such as direct sunlight and rain, because it was constructed under a shelter.

The test section was initially trafficked in a channelized pattern using a commercial dump truck with a total gross vehicle weight of approximately 24.5 t. The commercial dump truck contained three axles including a front axle and a rear tandem axle. The front axle carried a load of approximately 6.4 t, and each rear axle carried a load of approximately 91 t. The tire pressure of each front and rear tire during trafficking was 827 and 751 kPa, respectively. Trafficking was to conclude after 10 000 passes or when the test item failed. Failure of a flexible road pavement with truck traffic occurs when the brick surface layer has an average surface rutting of 80 mm.

After completion of the dump truck traffic on each test item, the test section was trafficked with a single-wheel C-17 load cart to evaluate the brick surfaces for military aircraft parking. The C-17 load cart, with a load of approximately 19.1 t and a tire pressure of 979 kPa, was trafficked down the center of each item in a channelized pattern. Trafficking was to conclude at 1000 passes or shortly after the test item failed. The failure criterion for military aircraft traffic on flexible pavements is typically based on 25 mm of surface rutting.

Data Collection

At selected traffic intervals, the traffic was stopped, and the brick pavements were inspected for breakage and rutting. Data collection during the scheduled truck traffic breaks included (1) rod and level measurements of left wheel path profiles and cross sections at each quarter point and (2) permanent deformation (rut depth) measurements. Once traffic resumed, pressure cell measurements under dynamic loading were collected during the following 10 passes. Data collection for the C-17 traffic study included (1) rod and level measurements of the wheel path and cross sections at each quarter point and (2) permanent deformation measurements. With the exception of the instrumentation measurements, all data were collected at the same three quarter points (Stations 3, 6, and 9) each time. The instrumentation data were collected at Stations 4.5 and 9. The station numbers correspond to the distance from the beginning of the test item (north end; Station 0) in linear meters.

For all traffic, the maximum total rut was recorded. The maximum total rut is defined as the elevation between the peak of the upheaval and the bottom of the ruts.

Forensic Investigation

Upon completion of all trafficking, a 1 m wide trench was excavated across the center (Station 6) of each test item for forensic investigation. Each layer of the pavement structure was removed individually and assessed at the center of the C-17 wheel path and in areas outside of the rut. DCP, CBR, and oven moisture content tests were conducted at each location on each foundation layer. Furthermore, rod and level cross-section profile measurements (150 mm increments) were performed on the surface of each layer to aid in determining where failure occurred.

Brick Pavement Performance Results

It is important to consider during the performance analysis that the test section was constructed and trafficked in a sheltered environment without the harsh environmental effects of rain, direct sunlight, etc. Deterioration rates of the pavements will likely increase with precipitation or continued exposure to sunlight.

Truck Evaluation

All brick types were trafficked with the commercial dump truck to 10 010 passes without failure. Minimal breaking of all brick types occurred during trafficking. The edge conditions of the bricks after trafficking were similar to the edge conditions of the brick pavers; there was minimal damage.

The double layer of standard modular bricks (Item 6) had the least amount of rutting with an average depth of 7 mm, while the reclaimed bricks (Item 2) had the most rutting with an average depth of 24 mm. The remaining test items, including the brick pavers, had similar rut depth measurements of approximately 14 mm at 10 010 passes. Fig. 3 shows the rut depth progression of the right wheel path of the truck in Item 2 (reclaimed bricks). Although the reclaimed bricks had the most surface deformation, Fig. 3 illustrates the general rut depth trend of all brick types.

The longitudinal profiles showed immediate settlement of about 2.5 mm after the first 10 passes on each item. This was likely due to the bricks settling into the bedding sand. The longitudinal profiles showed a small but steady decrease in elevation with an increase in traffic. The cross section profiles showed a moderate amount of upheaval (approximately 13 mm) outside of the wheel paths for the queen and reclaimed bricks (Items 1 and 2) and slight upheaval (6 mm) outside the wheel paths for the standard modular, utility, and paver bricks (Items 3, 4, and 5). The double layer of standard modular bricks of Item 6 had approximately 4 mm of upheaval outside the wheel paths.

The EPCs in the subgrade of each item showed minimal changes in pressure with each increasing pass level. The measurements between each item ranged from approximately 69 to 103 kPa, with the lower pressure occurring in Item 6 (double layer of standard modular bricks). In general, the EPCs installed under the wheel path in the base recorded peak pressures approximately the same as the EPCs installed between the two tires in the base. The average peak pressures for each test item in the base course were around 310 kPa.

C-17 Evaluation

The brick surfaces were not capable of supporting channelized C-17 aircraft load cart traffic. Each brick type failed with 25 mm of surface rutting between 15 and 60 passes, with the reclaimed bricks being the weakest and the double layer of standard modular bricks being the strongest. Rutting of each test item began almost immediately when the C-17 load cart traffic was applied to the bricks. With the exception of the utility bricks, the majority of the bricks crushed under traffic, particularly the queen and reclaimed bricks. The crushed bricks have the potential to damage aircraft. The edge conditions of the brick pavers were similar to the edge conditions of the manufactured bricks after trafficking.

The cross-section profiles revealed that there was a large amount of increasing upheaval as traffic was applied. This indicates there was movement or consolidation in the surface and underlying layers. The centerline profile measurements also showed that the increase in rutting was somewhat consistent throughout trafficking. Fig. 4 shows the cross-section profile measurements of the brick surface of Item 4 (utility bricks) at Station 6 with increasing C-17 traffic.

Summary

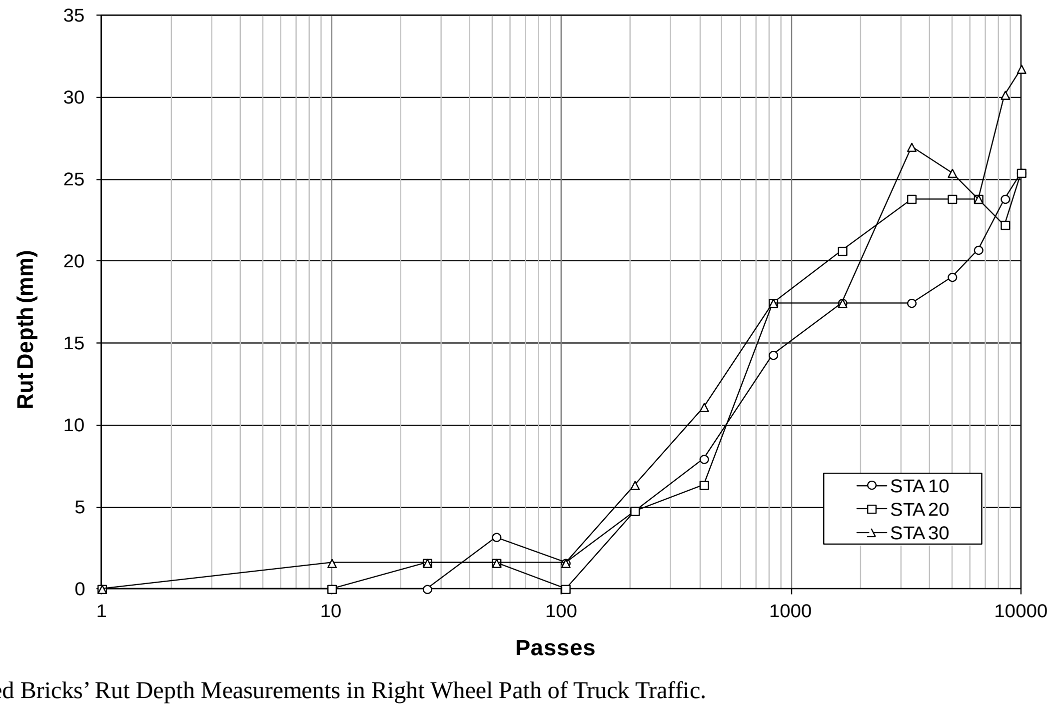

Fig. 3. Reclaimed Bricks' Rut Depth Measurements in Right Wheel Path of Truck Traffic.

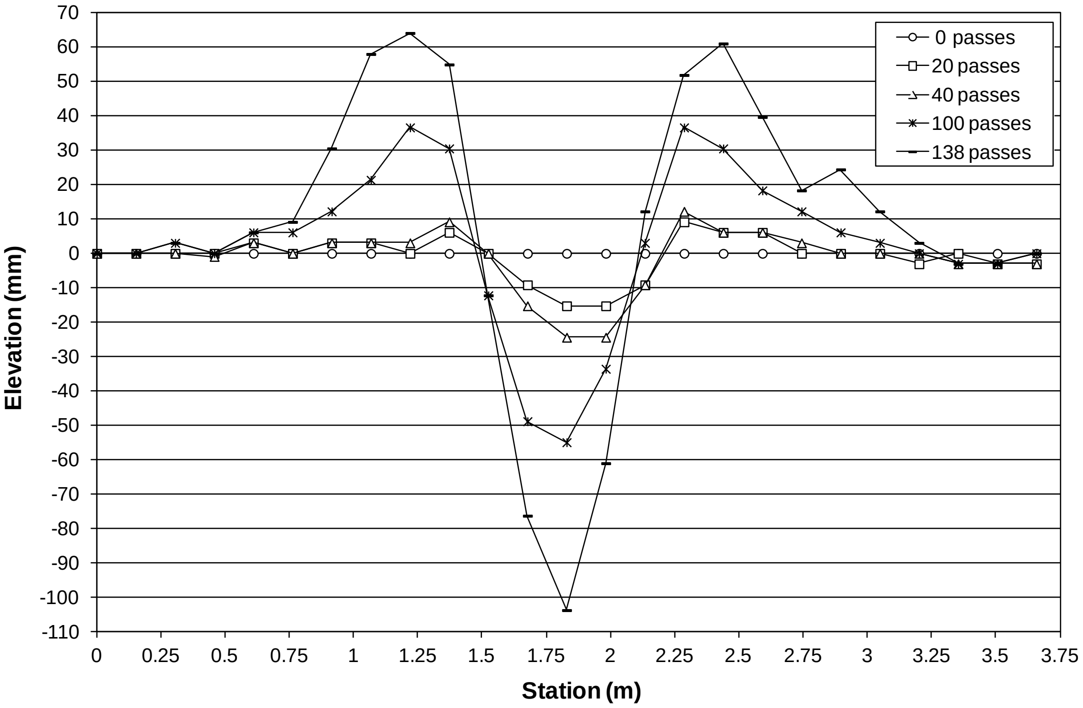

Fig. 4. Utility Bricks' Cross-Section Profile Measurements with C-17 Traffic.

Table 2. Laboratory and Field Performance Summary of Bricks.

Brick Type	Laboratory Performance										Field Performance			
	Compressive Strength (MPa)	Rank	LAA: % Loss	Rank	5-hr Boil Absorption (%)	Rank	24-hr Cold Absorption (%)	Rank	Specific Gravity	Rank	Truck Traffic		C-17 Traffic	
											Avg. Rut (mm)[a]	Rank	Failure Pass[b]	Rank
Queen (Item 1)	33	4	55.8	5	16.9	4	11.1	4	2.02	4	17	5	25	5
Reclaimed (Item 2)	25	5	44.0	4	17.2	5	23.4	5	2.02	5	24	6	15	6
Standard Modular (Item 3)	135	1	26.5	2	8.1	2	4.9	2	2.24	2	17	4	25	4
Utility (Item 4)	73	3	41.7	3	8.6	3	5.3	3	2.22	3	12	2	30	3
Paver (Item 5)	119	2	22.8	1	7.1	1	4.8	1	2.32	1	14	3	35	2
Double Layer Standard Modular (Item 6)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7	1	60	1

[a] Average surface rut measured at 10 010 passes of commercial dump truck traffic. Failure of flexible road pavements with truck traffic is 80 mm of surface rutting.

[b] Approximate failure pass; failure of flexible aircraft pavements is 25 mm of surface rutting.

Table 2 presents an overall view of the bricks' performance from the laboratory and field testing. The brick types were ranked after each test, with 1 being the best, to determine which brick type was the most durable, reliable, least susceptible to frost, etc. The best laboratory performers were not necessarily the best field performers.

The overall performances of the bricks for road surfaces, based on the overall laboratory test results and the measured rut depths in the field, are as follows.

- Queen bricks had undesirable performance in the laboratory but performed well in the field. They performed as well as the standard modular, utility, and paver bricks in the field.

- Reclaimed bricks had the least desirable performance in the laboratory and in the field.
- Standard modular and paver bricks had the most desirable performances in the laboratory, and they performed well in the field. They performed as well as the utility and queen bricks in the field.
- Utility bricks had average performance in the laboratory and performed well in the field. The field performance was similar to the queen, standard modular, and paver bricks.
- The double layer of standard modular bricks had the most desirable performance in the field.

The general performance evaluations listed above are relative comparisons. Based on the limited field testing conducted during this study, brick surfaces are not capable of handling aircraft loads.

Forensic Assessment

Overall, there was little permanent surface deformation after the completion of the truck traffic. The forensic investigation was conducted to evaluate the pavement structure after the completion of the aircraft load cart traffic when the most damage occurred. A 1 m wide trench was dug across the center of each test item for the forensic investigation. Cross-section profiles were measured from the surface of each underlying layer to determine the location(s) of failure. Fig. 5 shows Item 4's (utility bricks) cross-section profile measurements of the pavement structure after C-17 traffic, which is similar to the general condition of the other test items. The profiles indicated consolidation and shear movement occurred in the C-17 wheel path of both unbound layers of the pavement structure but mainly in the base layer of each item. The bound surface layer of bricks likely had shear movement.

Field CBR tests and/or DCP tests were performed on each layer at the conclusion of the truck trafficking and then at the conclusion of the C-17 load cart trafficking. The post-test DCP data from the truck traffic tests were used as the pre-test strength data for the C-17 load cart trafficking. DCP tests were conducted as an alternative strength measurement for the base layer (GM material). CBR tests were difficult to run accurately on the base material during construction and during the forensic evaluation because of the loose gravel. Overall, the post-test DCP results in the base material were much lower than the pre-test DCP results (80 – 100 CBR post-test truck/pre-test C-17 measurements compared to 35 – 80 CBR post-test C-17 measurements). This was likely due to base course movement caused by the C-17 traffic. There was a slight increase in the CBR (from 6 CBR pre-test to 8 CBR post-test) of the subgrade (CH) likely due to the moisture content of the material decreasing. Fig. 6 shows the test section before and after trafficking.

Conclusions

The ERDC was tasked to evaluate the use of face brick for road paving and aircraft parking in expeditionary environments. The face brick would most likely be recycled material from existing infrastructure. This paper presented the procedures, results, and analysis of the full-scale field testing and evaluation of face brick for use on roads and aircraft parking ramps in expeditionary environments.

The following conclusions were developed from the full-scale field testing and evaluation of the bricks.

- The bricks tested under controlled environmental conditions are capable of withstanding low-volume truck loads of approximately 24.5 t. Each brick type was trafficked to 10 010 passes and measured less than 25 mm of surface rutting. Failure of flexible road pavements subjected to truck traffic is

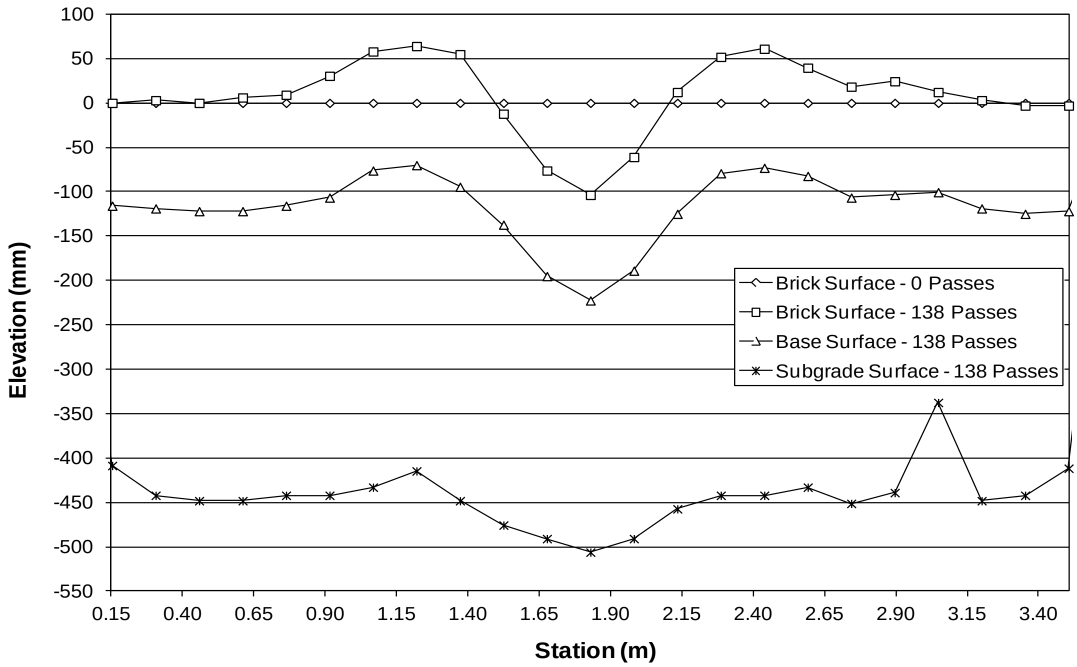

Fig. 5. Utility Bricks' Cross-Section Profile Measurements of Pavement Structure after C-17 Traffic.

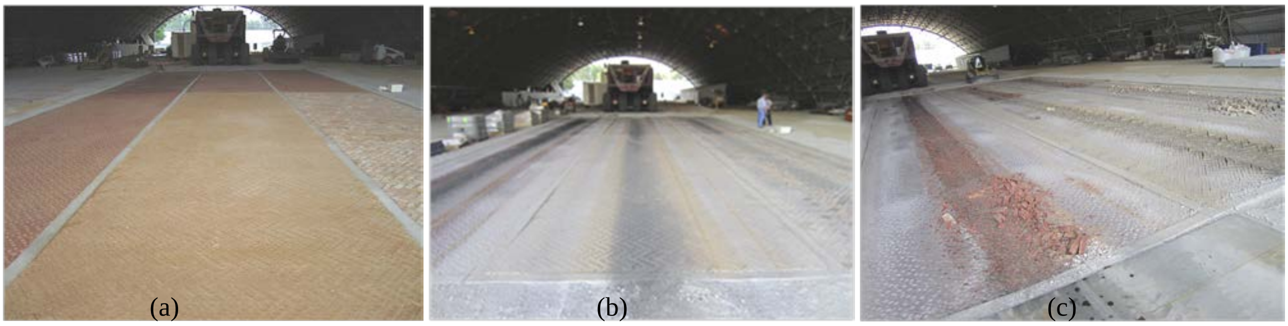

Fig. 6. Test Section: (a) before traffic, (b) after Truck Traffic, and (c) after C-17 Load Cart Traffic.

defined as 80 mm or more of surface rutting.

- The bricks tested under controlled environmental conditions are not capable of withstanding fully loaded C-17 load cart traffic. All brick types tested failed with approximately 25 mm of surface rutting between 15 and 60 passes of the load cart. The brick pavers failed at about 35 passes. Failure of flexible airfield pavements subjected to aircraft traffic is 25 mm of surface rutting.
- Although the laboratory results showed large differences in strength, the queen bricks and the standard modular bricks had similar field performances when subjected to both the truck and single-wheel C-17 traffic.
- The double-layered standard modular bricks performed significantly better than the other evaluated brick types for both types of traffic. In terms of rut depth, the double-layered standard modular bricks performed approximately 2.5 times better than the single layer of standard modular bricks subjected to both the truck traffic and the aircraft traffic.
- The reclaimed bricks performed considerably worse compared to the other brick types for both truck and aircraft traffic.
- The queen and standard modular brick types crushed under the aircraft traffic. The crushed brick could potentially damage aircraft.
- Literature stated that brick pavers with compressive strengths of 55 MPa have proven to be adequate for military road applications. The compressive strengths of all brick types tested, with the exception of the queen and reclaimed brick, exceeded 55 MPa. The reclaimed brick types were the worst performing bricks for both types of traffic. However, the queen bricks performed relatively well in the field.
- The forensic investigation revealed consolidation and shear movement of all unbound structure layers, particularly the base layer, after trafficking with the single-wheel C-17 load cart. Shear movement was observed in the brick surface layers.

Acknowledgements

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research sponsored by the U.S. Air Force Civil Engineer Center and performed by the U.S. Army ERDC. Permission was granted by the Director, Geotechnical and Structures Laboratory, to publish this information.

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