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Prediction of soil deformation beneath temporary airfield matting systems based on full-scale testing

Timothy W. Rushing[a,b,*], Isaac L. Howard[b]

[a] US Army ERDC, 3909 Halls Ferry Rd, Vicksburg, MS 39180-6199, USA
[b] Department of Civil and Environmental Engineering, 235 Walker Hall, Mississippi State, MS 39762-9546, USA

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Abstract

This paper presents results from full-scale evaluations of an aluminum structural mat system with regard to carrying heavy aircraft across graded, but unimproved, soil with California Bearing Ratios (CBRs) of 6, 10, 15, 25, and 100. The objective was to determine relationships among soil deformation rate, the mat's flexural modulus, the number of applied passes, and the underlying soil's CBR. Current prevailing performance prediction models for aluminum mat systems are based on full-scale tests using historic aircraft loads over soils having a CBR of 4 that were never validated for soils with higher CBR values. Full-scale test results presented herein demonstrated the inability of current models to accurately predict mat permanent deformation. Strong correlations were found between measured and predicted data across the entire spectrum of soil CBRs. These relationships can be used to noticeably improve the accuracy of performance prediction models. An empirical equation was developed to reasonably predict subgrade deformation for any number of passes and soil CBR for the loading and mat system tested.
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Keywords: Airfield mat; Full-scale test; Subgrade deformation; Aluminum mat; Mat; Structural mat; Temporary pavement

1. Introduction

Structural mat systems have been used to create temporary roads and aircraft operating surfaces for many years. Mat systems are typically individual structural panels that can be placed directly over soft soils and assembled in a continuous array using mechanical connectors to create vehicle operating surfaces. AM2 is an aluminum matting system that was designed by the U.S. Navy and is manufactured exclusively for the U.S. military. Fig. 1 shows an example of bundles of AM2 aluminum airfield mat panels, an AM2 cross section extrusion, and an aircraft operating on an AM2 mat surface. Most steel and aluminum systems used in the U.S. were developed for military applications; however, composite systems are commercially available for use by the petroleum, construction, and event industries for reusable roads, work platforms, and turf protection (Rushing and Howard, 2011).

The ability to predict the number of allowable passes across matting systems, especially for aircraft, presents formidable challenges because of their complex designs, unique material compositions, and the difficulty predicting soil behavior under confined stress states. Previous and current prediction models known to the authors were all based on full-scale test section data over soils with California Bearing Ratios (CBRs) ranging from 4 to 10. Until recently, no full-scale data was available to validate prediction models over the full spectrum of soil bearing capacities. Recently, testing has been conducted for CBR's of 6, 10,

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* Corresponding author at: US Army ERDC, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, USA. Tel.: +1 (601) 634 2858.
E-mail addresses: Timothy.W.Rushing@usace.army.mil (T.W. Rushing), ILHoward@cee.msstate.edu (I.L. Howard).

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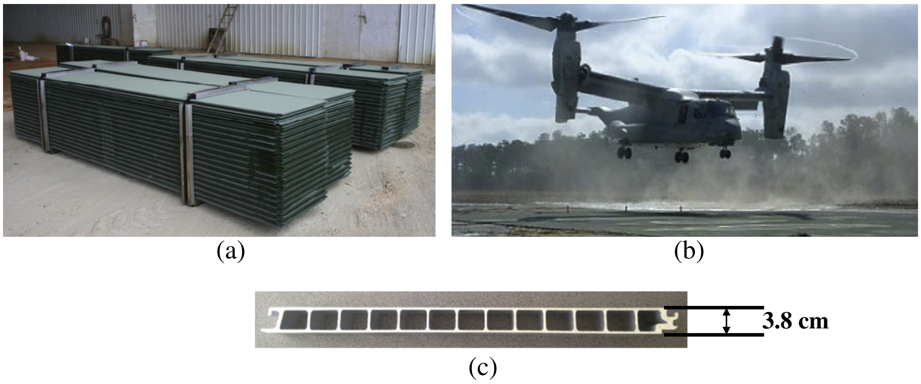

(a) (b) (c)

Fig. 1. (a) AM2 aluminum airfield mat panels prior to installation, (b) MV-22 aircraft operating on an AM2 mat surface, and (c) and AM2 extrusion cross section.

15, 25, and 100 in an attempt to gather enough data to develop and validate new prediction models.

The objective of this paper is to determine the relationship for the rate of subgrade deformation, the number of applied passes, and the subgrade CBR from measurements obtained from full-scale traffic testing of mat-surfaced subgrades with CBRs of 6, 10, 15, 25, and 100. The relationship described herein is specifically for AM2 matting systems, single-wheel gear military fighter aircraft traffic, and a normally distributed traffic pattern. The overall research objective is to advance the ability to predict mat behavior under various types of aircraft traffic. Successful achievement of this goal stands to be useful to a wider segment of the terramechanics community than just the military (e.g. using the data presented herein for AM2 for benchmarking other rapid construction approaches or commercially available matting systems). The full data set is fairly comprehensive for AM2 matting under simulated military fighter and cargo aircraft loads. Companion work intends to evaluate damage to the mat itself caused by fatigue. Future work also intends to characterize rutting and mat damage behaviors for other aircraft loads and multiple wheel gear configurations. As discussed in the next section, previous work on matting has been predominantly focused on testing with a much smaller focus on analysis and prediction model development. Narrowly focused data sets have been used for analysis/prediction efforts in many cases.

2. Background

Since the 1940s, millions of U.S. dollars have been spent testing matting systems, with a considerable portion of these efforts performed at the U. S. Army Waterways Experiment Station site in Vicksburg, MS. While they are not cited for brevity, a casual search found over 70 reports on matting systems. The overwhelming majority of these reports were tests reports, with only a few specifically addressing analysis, characterization, or prediction model development. The background presented herein focuses on the non-testing aspects of matting research, as this is the area of primary interest in this paper.

Throughout the four decades spanning the 1940s through 1970s, several steel and aluminum mat systems were tested using full-scale aircraft simulators. A review of ten test reports from aluminum systems revealed nearly all were conducted over a 60 cm (24 in.) deep soil test bed with a nominal CBR of 4 (White, 1971, 1972, 1973, 1974; Smith, 1972; Green and McCormick, 1971; Carr, 1972, 1973, 1974; Green, 1972). Applied loadings were 120 kN (27,000 lbf) on a single-wheel with a tire inflated to 2750 kPa (400 psi). Many of the tests were developmental or qualification experiments. Flexural properties of the mat systems were not documented.

Most past analysis has consisted of inputting data, representing a single failure point from one full-scale test, into Eq. (1) to determine the equivalent thickness of flexible pavement provided by the mat. The equivalent thickness is based on typical airfield asphalt failure criteria of about 25 mm (1 in.) of rutting or reaching some crack development limit.

$$t = (0.23\log C + 0.15)\sqrt{P\left(\frac{1}{8.1CBR} - \frac{1}{p\pi}\right)} \qquad (1)$$

In Eq. (1), t = total thickness (in.) of flexible pavement above the subgrade (for a standard airfield pavement design of asphalt over granular base), C = number of aircraft coverages (no units), P = single or equivalent single-wheel load (lbf), CBR = measure of subgrade strength, and p = tire contact pressure (lbf/in.^{2}). Eq. (1) was derived from the CBR design equation (Ahlvin, 1991) for flexible pavements in English units. The CBR design method is based on single-layer load/deflection theory with empirically derived factors from full-scale pavement test sections. The CBR method remains the predominant design procedure for flexible airfield pavements for the U.S. military.

Using inputs for C, P, CBR, and p from a full-scale mat test, an equivalent thickness of flexible pavement, t, was calculated using Eq. (1) that provided the same load support for the loading and subgrade condition found in the