Pavement Design Criteria for Heavy-Load Vehicles

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Extensive prototype tests were conducted at the U.S. Army Engineer Waterways Experiment Station to adapt Corps of Engineers (CE) flexible pavement design criteria to pavements to be used in the MX missile program. The initial shell game concept for dispersing the MX missiles required construction of approximately 8,000 miles of roads capable of sustaining numerous passes of a missile transporter weighing about 1,500,000 lb. This research resulted in increased knowledge of the performance of pavements subjected to heavy loads. Prototype test sections of bituminous surface-treated roads and gravel-surfaced roads were designed and constructed using current CE criteria. The test sections were trafficked to the design number of operations using a trafficking rig simulating the MX missile transporter. The trafficking rig was equipped with two load tires in line, each approximately 8 ft tall by 3 ft wide, inflated to 65 psi, and having a loaded weight of 62,500 lb. Test traffic was placed on the pavement and conditions were monitored for pavement distress. Analysis of the resulting test data led to the conclusion that existing CE criteria can be modified to provide a more economical pavement than was previously expected for very heavy loads. Most distress appeared in the form of deeper consolidation caused by the very heavy loads on the unusually large tires. Other load parameters such as contact area and contact pressure were in more typical ranges and, therefore, gave more typical results.

The U.S. Air Force Regional Civil Engineer for the MX missile program (AFRCE-MX) was charged with numerous aspects of the MX Program. The principal AFRCE objective was to select design criteria and methodology for construction management of the heavy-duty, low-volume road networks that would be the heart of the MX missile deployment scheme.

The shell game concept that generated this intensive research effort and resulted in a large amount of new data consisted of 200 MX missiles, each housed in a cluster of 23 horizontal shelters for a total of 4,600 shelters. The MX system was to be deployed according to the shell game concept wherein a single missile is moved among the 23 silos of a cluster as required for deception and concealment. The horizontal silos were to have a minimum spacing of approximately 1 mile and were to be connected by roads over which the MX missile would be moved as required. Roads also connected the 200 clusters to each other and to the service and storage areas.

The MX missile was to be carried on a transporter-erector-launcher (TEL) approximately 250 ft long with a loaded gross weight of approximately 1,500,000 lb. One definition of the vehicle support system included 24 single wheels on 12 axles (6 front and 6 rear), and the anticipated wheel load was to be 62,500 lb.

The resultant road requirement consisted of approximately 8,000 miles of all-weather roads to support the TEL for approximately 430 vehicle passes during its life of 15 years. Because first cost or installation cost of the entire system was a primary consideration, the objective was to develop a satisfactory road system at the lowest possible initial construction cost. After conducting preliminary studies and considering numerous alternatives, the AFRCE selected the U.S. Army Corps of Engineers (CE) road design methods as the basis for the MX road program. The U.S. Army Engineer Waterways Experiment Station (WES) Geotechnical Laboratory (GL) Pavement Systems Division (PSD) was designated as the prime consultant to the AFRCE and the lead agency in determining a suitable design, construction, and life-cycle management technology to the AFRCE for the MX road system. In response to this requirement the WES launched an extensive support program in 1979 designated as the MX Road Design Criteria Studies (RDCS).

Although the RDCS program was discontinued in October 1981 because of the Presidential decision to use more modest basing mode concepts, extensive prototype tests were conducted that resulted in a massive volume of performance data for very heavy vehicle operations on low-volume roads with various pavement constructions. As a result of these prototype tests and the analysis conducted before program discontinuance, significant findings have been generated to date, and further analysis of the available data should significantly advance the current state of the art in heavy-load, low-volume road life-cycle management from conception to termination.

OBJECTIVE

The objective of the RDCS was twofold. The first objective was to extend the validated range of current CE design criteria to include the characteristics of the MX TEL. The second objective was to determine the most economical road type that would meet these criteria keeping in mind the 15-year life cycle. Within this framework, the specific requirements included the following:

1. Extension of existing structural criteria to provide for MX road design in terms of layer strengths and thicknesses (1).
2. Determination of surface stability requirements to minimize functional deterioration or surface loss associated with environment and traffic.
3. Evaluation of overall functional performance and minimum serviceability criteria.
4. Evaluation of the applicability of nondestructive testing procedures for increased quality control and evaluation.
5. Determination of the amount of cover required for shallow-buried drainage structures.
6. Use of the Differential Analysis System (DAS) to optimize design with respect to minimum reliability requirements (2).

SCOPE

The conduct of the RDCS included an extensive prototype test designed to satisfy the stated objectives. The prototype test section was trafficked with representative wheel loads, results were observed, and data that would be useful in a comprehensive data analysis were recorded.

Although the RDCS ended in October 1981, some preliminary analyses were accomplished that could have a significant impact on the future design of heavy-load, low-volume roads. This paper includes the preliminary results of analyses that have been conducted to date on the data accumulated from prototype tests of the test pavements.

PROTOTYPE TESTING

The test philosophy of expanding existing criteria as well as developing specialized criteria for existing field conditions of the then likely Nevada-Utah Basin range required the selection of two categories of soils. The first category was similar to soils used to develop classic criteria. The second category was representative of field materials in the basin area and was used to make classic criteria more applicable to actual conditions. The test section consisted of three separate traffic lanes; each lane contained five test sections (referred to as items) to provide for a comprehensive spectrum of traffic-pavement-soil types.

Figure 1 shows a layout of the test section. The test items shown were designed to meet the stated objectives. Items 3, 4, and 5 in Lane 3 were designed in part to provide data for determining surface stability requirements. Although the combinations of test items, traffic lanes, and test parameters are manifold, the scope of this paper dictates that only the performance of these items be discussed to illustrate those findings of concern here. Figure 2 shows a profile view of those items used to determine surface requirements.

The test section was located at the WES, Vicksburg, Mississippi, in hangar 4. The soil in this area is a lean clay. The average water table was at a depth of approximately 9 ft. The hangar floor was leveled before excavation to facilitate uniform construction. A benchmark was used for all vertical control throughout construction and testing of the MX test section.

TESTING AND BEHAVIOR

Test Cart

Traffic tests were performed on all traffic lanes with a specially designed test vehicle (Figure 3). This vehicle was a modified prime mover built by Marathon LeTourneau, Inc. in Vicksburg, Mississippi. The vehicle was modified so that two test wheels could be installed in tandem to represent a portion of the TEL. Although the TEL experienced several design changes during the conduct of the program, one set of characteristics was used in these studies. The TEL simulated in these studies was supported on 24 tires, each having a total loaded ground weight of 62,500 lb. The total gross weight of the vehicle was expected to be approximately 1,500,000 lb and the vehicle was designed with 6 tires on each quadrant of the vehicle. The tires used had a smooth surface and were approximately 98 in. high and 39 in. wide. The tire designation was 37.5 x 39.

Operational Design

The operational scenario of the MX deployment concept called for the movement of the TEL, upon command, among 23 horizontal silos within a cluster. Because these moves were to be infrequent, a total of 430 TEL passes were anticipated during the 15-year life of the system. Because the vehicle design called for 6 wheels on each corner or 12 wheels in line on one side, the TEL-to-test vehicle trafficking ratio was 6 to 1. It would therefore require 2,600 passes of the test vehicle to represent 430 TEL passes.

All traffic was applied with the tandem-wheel configuration with a backward and forward movement along each traffic lane. The traffic was applied in a single line with no wander permitted across the traffic lane. Each pass of a wheel was defined as one coverage. Therefore one test cart pass was two coverages. Traffic was commenced and continued for 2,600 passes.

Test Items

Those test items that were monitored for purposes of evaluating surface requirements were items 3, 4, and 5 of Lane 3. A description of these items is as follows.

Item 3, Lane 3. This test item consisted of 6 ft of a blended cohesionless sand-gravel material (Blend II) considered representative of the material below the 2-ft depth in the prospective basing area. The top 6 in. of the Blend II was compacted at optimum moisture and surfaced with a double bituminous surface treatment. Surface deterioration of this item was minimal with a maximum rut depth of 1.1 in. as shown in Figure 4.

Item 4, Lane 3. This item consisted of 5 ft of Blend II material covered with 12 in. of a blended cohesionless sand-gravel material (Blend I), con-

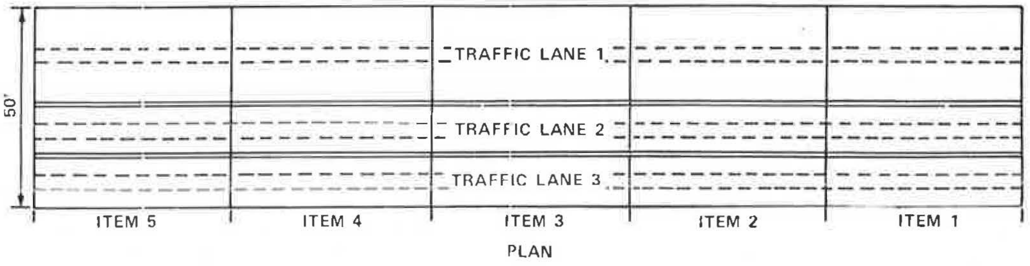

Figure 1. Plan view of test section.

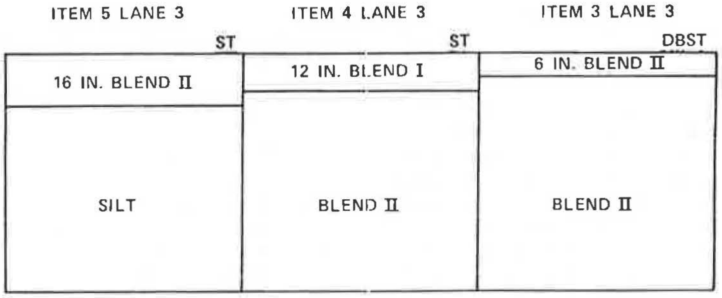

Figure 2. Profile view of Lane 3, items 3, 4, and 5.

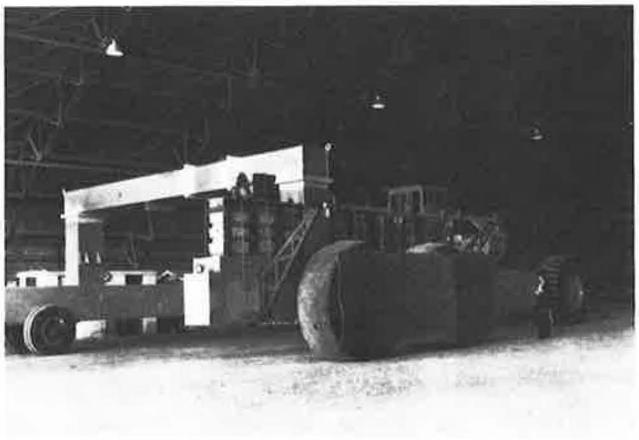

Figure 3. Test vehicle.

sidered representative of the material in the top 2 ft of the basing area, that was compacted at optimum moisture. The item was surfaced with a single surface treatment. Deterioration of the surface of this item was also minimal with a maximum rut depth of 1.0 in. as shown in Figure 4.

Item 5, Lane 3. This item consisted of 44 in. of a silt material overlaid with 16 in. of Blend II compacted at optimum moisture and surfaced with a single surface treatment. The maximum rut depth was 0.7 in. as shown in Figure 4.

Data Collection

Data were collected before and after trafficking as well as at predetermined intervals. Cross sections, profiles, photographs, instrumentation readings, nondestructive tests, and rut-depth measurements were among the data recorded as were the physical parameters of moisture, density, and strength. Rutting in the items is the primary parameter discussed here.

ANALYSIS OF SURFACE-TREATED TEST ITEMS

Performance

Soil strengths and rut depths for the surface-treated items are shown in Table 1. Each test item was subjected to 2,600 passes of the simulated MX load cart having a loading of 125,000 lb on two tires with an inflation pressure of 65 psi. This traffic produced 1.1 in. of rutting in item 3, 1.0 in. of rutting in item 4, and 0.7 in. of rutting in item 5. Figure 4 shows the development of rutting with increased numbers of passes for each test item.

Table 1. Comparison of rut depths and CBR values for unsurfaced and surface-treated items.

				Rated CBR	
Test Lane	Test Item	Top Soil Layer	Rut Depth (in.)	Top Soil Layer	Subgrade
Unsurfaced					
1	3	Blend II	1.93	19.5	NA
	4	Blend I	4.16	36	21
	5	Silt	1.3	67	NA
Bituminous Surface Treatments					
3	3	Blend II	1.1	100+	19.5
	4	Blend I	1.0	79	21
	5	Blend II	0.7	59	24

General failure criteria for a flexible pavement is considered by the CE to be the development of rutting equal to or greater than 1.0 in. This rutting may be due to shear deformation under traffic resulting from insufficient thickness or due to densification resulting from inadequate density. Investigation of the rutting produced in these test items indicated that it was caused primarily by initial densification under traffic, because there appeared to be no shear deformation in the soil layers of the test items.

To compare the performance of the test items with current CE thickness design criteria, the allowable traffic was computed for each test item. The number of passes predicted by the CE criteria to cause failure is given in Table 2. Items 3 and 4 reached the 1.0-in. rutting failure criteria at 2,600 passes, which was significantly more than the CE criteria would predict, indicating that the CE criteria for thickness design may be conservative in

Table 2. Predicted traffic passes before failure for bituminous surface treatments.

Test Lane	Test Item	Subgrade Soil Type	Before Traffic CBR	Thickness of Cover (in.)	Predicted Passes
3	3	Blend II	15	6	<10
	4	Blend II	12	12	20
	5	Silt	22	16	>10,000

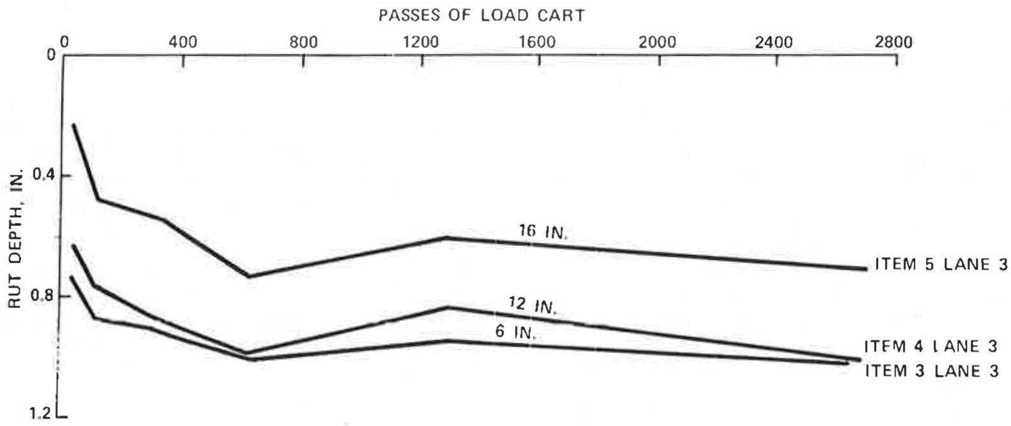

Figure 4. Rut depth measurements for surface-treated items.

the range of load, size of tire, and tire pressure tested.

Comparison

When the surface-treated items were compared to similar items having no surfacing, there was significant improvement in the performance of the surface-treated items. Data for unsurfaced items also trafficked by the simulated MX load cart are given in Table 1. As can be seen, item 3 of Lane 1 contained Blend II material at the surface and sustained 1.93 in. of rutting; whereas, item 3 in Lane 3 contained the double surface treatment on Blend II material and sustained only 1.1 in. of rutting. Also, item 4 of Lane 1 had Blend I at the surface and sustained 4.61 in. of rutting; whereas, item 4 of Lane 3 containing a single surface treatment sustained only 1.0 in. of rutting. There was also significant movement of the soil in items 3 and 4 of Lane 1 from underneath the tire to the sides of the traffic lane; this did not occur in the surface-treated items. The important implication of these results is that the application of a surface treatment on the in-place soils at the MX deployment area may be sufficient to carry the anticipated heavy loads and provide an adequately paved road.

CONCLUSIONS

The following conclusions resulted from this analysis:

1. Adequate compaction of soil layers is important to prevent densification.
2. Surface treatments performed satisfactorily under heavy loads.
3. Rutting of soil layers was reduced by the application of surface treatments.

REFERENCES

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2. V.C. Barber et al. The Deterioration and Reliability of Pavements. Technical Report S-78-8, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., July 1978.

Development of Rigid and Flexible Pavement Load Equivalency Factors for Various Widths of Single Tires

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An analytical study to compare the effects of axles with single and dual tires on pavement performance is presented. Both rigid and flexible pavements were analyzed using currently available finite-element and elastic-layer analysis programs. The stresses and strains obtained from these programs were used in fatigue failure models to develop equivalency relationships between dual tires and various widths of single tires. Equivalent wheel-load factors were developed for various widths of single tires on both rigid and flexible pavements. These factors can be used to evaluate regulations relating to tire and axle loadings. They also permit conversion of mixed traffic having axles with single tires to equivalent 18-kip dual-tire, single-axle load applications for use in pavement design and evaluation.

An increasing number of trucks are being observed with heavy loads on axles with single tires. Concern over whether current regulations properly consider the relative effects of axles with single tires resulted following observations of serious distress on a highway in northwestern Washington State. In 1979 as the result of a railroad abandonment, transportation of limestone between a quarry and cement plant near Bellingham, Washington, shifted to trucks. The trucking contractor elected to use tandem axles with single 12-in. wide tires on double trailer trucks. This tire and axle configuration was selected to permit the maximum load on the minimum number of tires and comply with tire and axle load regulations. Washington State Department of Transportation regulations permit a maximum tire load of 550 lb/in. of width for tires less than 12 in. wide and 660 lb/in. of width for tires 12 in. wide or wider. The maximum axle loads permitted are 20,000 lb for single axles and 34,000 lb for tandem axles.

It became apparent that the use of single tires in lieu of dual tires should be examined. Thus, the objective of this study was to determine the relationship between axles with single tires and axles with dual tires and pavement performance. The results of the study can be used to answer the question: If axles with single tires are a major contributor to pavement deterioration, what changes are needed in the regulations?

Various rigid and flexible pavement sections were analyzed by using existing finite-element and elastic-layer analysis programs. The maximum calculated stresses and strains resulting from various tire loads were used to determine the fatigue life of the pavement under these loads. Equivalency factors between single and dual tires were then determined based on relative fatigue lives. Dual tires with a width of 10 in. and center to center spacing of 15 in. and single tires with widths of 10, 12, 14, 16, and 18 in. were used in the analysis. The study approach is outlined in Figure 1.

ANALYSIS OF RIGID PAVEMENTS

In the analysis of portland cement concrete pave-