PAVEMENT TESTS TO PROVIDE FOR THE JUMBO JETS

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U. S. Army Engineer Waterways Experiment Station
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FOREWORD

This paper was prepared by Mr. R. G. Ahlvin, Chief of Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station (WES), for presentation at the Seventh Paving Conference, University of New Mexico, 11-12 December 1969. Before presentation, this paper was reviewed and approved by the Office, Chief of Engineers.

The Director of WES during the preparation of this paper was COL Levi A. Brown, CE. Technical Director was Mr. F. R. Brown.
Abstract

With the advent of jumbo-jet aircraft, as represented by the Lockheed C-5A Galaxy and the Boeing 747, we are faced with supporting three-quarter million pound and larger aircraft on pavement facilities. To provide information on pavement behavior, test sections of both flexible and rigid pavement have been constructed and are being tested to failure under the full prototype loading of one 12-wheel main landing gear of the C-5A aircraft. The testing program is a joint effort of the Army, Air Force, and Federal Aviation Administration and is being conducted at the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Each of the test sections incorporates items of different thicknesses planned to fail at various load repetition levels. The test subgrade was constructed to a carefully controlled strength to a full 12-ft depth. Both test sections incorporate stress, strain, and deflection measuring instruments at various depths within the structure. These instruments have been loaded not only with the full 12-wheel C-5A gear but with single-wheel gear and components of the C-5A and 747 gear at various loadings.

At this reporting, only very preliminary results are available, but general indications imply less severe pavement loadings than direct extrapolations from prior criteria would predict.
Development of a new giant jet transport aircraft by the U. S. Air Force (AF) has led to a significant increase in aircraft size and weight to be accommodated by existing and future airfields. This giant aircraft is the C-5A Galaxy (see photograph 1) built by Lockheed. In the design competition for this aircraft, Boeing, Lockheed, and Douglas Aircraft Companies were prime participants, and Boeing is now building the 747 aircraft, Lockheed the L-500 aircraft, and Douglas the DC-10 aircraft, all of which are in the general gross weight range of the C-5A. The C-5A will have a gross weight of over three-quarters of a million pounds with growth potential.

Since these aircraft will be twice as heavy as their predecessors, there is wide concern over requirements for pavements to support them. Because of this, three separate agencies (Army, AF, and Federal Aviation Administration (FAA)) are jointly supporting a study of the response of pavements to the loadings represented by these new giant aircraft and the requirements of pavements for their support. This study is being conducted for AF, FAA, and Army by the Corps of Engineers at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. Overall supervision of the tests and all details pertaining to the flexible pavement testing

1Engineer, Chief of Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
is being provided by WES. The rigid pavement testing is being directed by the U. S. Army Construction Engineering Research Laboratory, Champaign, Ill. This paper will attempt to present information on all aspects of the test program but will treat the flexible pavement portion of the study in more depth because of the author's more direct responsibility for this phase of the total program.

Increase in aircraft size and weight has been experienced repeatedly in the past, and following World War II the need to spread aircraft loads to more wheels became apparent and led to two- and four-wheel gear configurations. With the advent of the C-5A and equivalent large civil aircraft came the need for substantially more wheels beneath the aircraft. Fortunately, the problem of aircraft ground-flotation requirements had received some study (1,2,3),* and this study provided a basis for consideration of flotation in the design of the landing gear for the C-5A and apparently also for the above-mentioned 747, L-500, and DC-10 aircraft.

The C-5A was designed with flotation sufficient to permit its unrestricted use of medium-load AF airfields. A medium-load pavement, as defined for AF use, is one that is capable of supporting aircraft with 100-kip twin wheels spaced 37-in. c-c and having tire contact areas of 267 sq in. Such a pavement will also support KC-135 aircraft at 320-kip gross weight. The KC-135 aircraft is the military version of the Boeing 707 and has requirements about the same as those for an unstretched DC-8 aircraft. Medium-load pavement design requirements formed the

* Numbers in parentheses designate References at end of paper.
basis for design of the test pavements in the program reported herein. Landing-gear complexes of 20 to 28 wheels are the result of providing medium-load pavement flotation in the C-5A and flotation comparable to that of current commercial jet transports in forthcoming large civil aircraft. For flexible pavements, this puts new emphasis on the effect of wheel interaction and the broader deflection basin commensurate with the multiple-wheel landing-gear complexes. For rigid pavements, the distribution of wheel loadings over virtually all parts of a single pavement slab raises new questions of the adequacy of assumptions of center or edge loadings on slabs assumed to extend to infinity. Also, it raises questions in regard to conventional assumptions of degree of load transfer across joints. It is in the hope of providing better information on these problems that the reported study has been undertaken.

Test Section

A test section was constructed at the WES and full-scale traffic tests are being conducted on the pavement using one main gear of the C-5A aircraft. Photograph 1 shows the C-5A with gear extended. Since the greatest effect of combined loadings from a number of wheels is felt at greater depths, a fairly low-strength subgrade has been used, thereby requiring larger structure thicknesses. Accordingly, a subgrade having about a $\frac{1}{4}$ CBR and 100 $k^*$ strength was selected. Since the load from the many wheels would be effective to substantial depth, the subgrade strength

*"k" is the coefficient of the subgrade reaction expressed in pounds per cubic inch.
has been controlled to a 12-ft depth. The native lean clay was processed to suitable moisture and density in the lower extremes, and a 3-ft layer of heavy clay, which is much easier to maintain at known strength over extended periods, was placed directly below the structural pavement layers.

The AF medium-load pavement criteria dictated the use of plain (unreinforced) concrete for the rigid pavement and 3-in. hot-mix surfacing on a 6-in. dense graded, crushed-stone base for the flexible pavement. The rigid pavement has a keyed longitudinal joint and grooved transverse joints. Subbase strength in the flexible pavement was required to be no less than 50 CBR. The subbase material used was a cohesionless sand gravel.

The test loading was selected at 360,000 or 30,000 lb per wheel for each of the 12 wheels. The 12 wheels are one main gear of the C-5A aircraft. Dimensions of the gear are shown in fig. 1. For the test loading, six wheel elements of the gear are mounted under each of two load boxes. These boxes are held in alignment and moved along by a large U-shaped load cart supported and powered by four 98-in.-diam electric wheels. Photograph 2 shows the load cart in use.

The flexible pavement test section consists of five items each 60 ft long with suitable overruns at each end to accommodate the load cart. The main variable is structure thickness, which ranges from 15-in. total thickness over the 4-CBR subgrade in item 1 to 42-in. total thickness in item 5. Items 3 and 4 are identical to a depth of 21 in. below the top of the 4-CBR subgrade. Below this depth, item 4
has a 24-in. layer of 2-CBR subgrade placed to determine possible effects of a deep soft layer beneath very heavy multiple-wheel aircraft. A plan and cross section of the flexible pavement test section are shown in fig. 2.

All variations in thicknesses of pavement structure are provided in the subbase layer, except for the soft subgrade layer in item 4. In all cases, the pavement is 3 in. of high-quality bituminous hot mix, and the base is 6 in. of dense graded crushed stone. All elements of quality of materials, compaction, construction tolerances, etc., as set by current Corps of Engineers' criteria for AF medium-load pavements were required in the test pavements. Most of these requirements can be found in the manual for design of flexible pavements for AF airfields (4).

A prime purpose of the tests, of course, is to gain a direct indication of pavement requirements for support of the test load. Accordingly, the various test items are being trafficked to failure in order to determine the repetitions level each is capable of sustaining. Since it is only at failure that a definitive terminal point of pavement behavior is found, it is necessary to sustain failures. The flexible pavement test section items have been designed to fail under the selected test loading and planned traffic.

The rigid pavement test section was designed following the same philosophy as for the flexible pavement section. Four test items were used at thicknesses of 8, 10, 12, and 14 in.; these were unreinforced with simple keyed center joints and grooved transverse joints. Slabs were 25 by 25 ft with items 50 ft in length. Transition and end slabs were provided and heavily reinforced to avoid their failure and possible
consequent influence on the test slabs. A plan of the rigid pavement test section is shown in fig. 2. It was anticipated that the 8-in. pavement would fail very early under traffic and the 12-in. pavement would sustain a reasonable traffic life.

In addition to the results anticipated for rigid and flexible pavements, behavior information was desired on flexible overlays of rigid pavements. Since the 8-in. rigid pavement was expected to fail very early under traffic and the 10-in. pavement to have a limited life, plans were included for flexible overlays of these items. When the 8- and 10-in. items failed, they would be overlaid with 6 and 4 in., respectively, of bituminous hot mix. Both overlays would continue to be trafficked along with the 12- and 14-in. rigid pavement items and behavior observed.

Instrumentation

Because of the many questions involved with the widely distributed multiple-wheel loadings of such large magnitude, substantial instrumentation for measurement of stress, deflection, and strain was included. These measurements are expected to be of direct use in extending the findings for the test load to other loadings for the C-5A and to other similar aircraft. It is felt that these measurements will also be used in later developments of improved pavement design methods.

Instrumentation was placed in items 3 and 4 of the flexible pavement test section. Vertical stress and vertical deflection at various depths within the pavement structure were the primary measurements. Limited
horizontal strain measurements were attempted in the bottom of the bituminous surfacing. Because of experience with instrumentation failures, essentially all installations were made in duplicate.

Vertical stresses were measured with the WES earth pressure cell. This is a quite reliable cell proven in a number of previous installations. One of these is described in Reference 5, which also includes a description of the cell. In several cases, the duplicate installation was made using a commercially available soil pressure cell. This cell was selected for installation under the rigid pavement test section, and the several cells installed in the flexible pavement test section were included for comparison. Vertical pressures were measured beneath the base, the subbase, and at several depths within the subgrade. A layout of the instrument installation in the flexible pavement test section is shown in fig. 3. Only the duplicate installations for reliability were made at each depth. The pattern of stress with offset from the central axis of the load was determined by placing the load in various offset positions.

Vertical deflections were measured by LVDT transducers between reference flanges at the instrument depth and reference rods in cased holes extending to reference flanges at the 12-ft depth. The increment of deflection occurring below the 12-ft depth was determined by use of a reference rod in a cased hole to the 12-ft depth and extending to the surface. Thus, optical measurements could be made of the vertical movement of the 12-ft depth as the load was positioned or removed from a point immediately adjacent to the reference rod. Gage installations
were made at the surface, bottom of base, bottom of subbase, and two depths within the subgrade. Gage depths are shown in fig. 3. The pattern of deflection with offset was determined by positioning the load as indicated for pressure measurements.

Since some researchers are attempting to use horizontal strain at the bottom of the bituminous layer as a critical element in design, attempts were made to measure such strains. Direct embedment, resistance-type transducers were obtained and installed to measure longitudinal and lateral horizontal strain in duplicate installations in items 3 and 4. Time did not permit pretrial of these gages; and as a consequence, a very high casualty rate was experienced.

In the rigid pavement test section, primary measurements were of strains in the pavement slab and vertical deflections beneath the slab. Strains and deflections were measured in the 10-, 12-, and 14-in. items at midslab and on either side of the joint at the midpoint of the slab edge on both the center joint and the transverse joint. Strains were measured with resistance-type gages at top and bottom of slabs and deflections were measured with LVDT transducers installed similarly to those in the flexible pavement test section except that all measurements were between the pertinent depth and the bottom of the pavement slab. A layout of instrumentation in the rigid pavement test section is shown in fig. 4.

Deflections were measured at several points beneath the 8-in. pavement item, and pressures were measured at various locations beneath the 12-in. pavement item. As mentioned earlier, vertical stresses were measured
with soil pressure transducers. These transducers were installed at mid-slab and at both interior and exterior corners; at midpoint of slab edge on center joint, transverse joint, and free edge; and at the slab quarter points along center lines in each direction. Instruments were placed directly beneath the pavement at all locations and at two greater depths within the subgrade at midslab.

While traffic to failure on these test sections can be applied with only one loading in any one traffic lane; various loadings can be used to assess pavement response, as indicated by the instrumentation complexes. Accordingly, a number of loadings were applied to gain instrument measurements for various comparative conditions. The 12-wheel C-5A gear was applied at two load magnitudes. To provide direct comparison between one and many wheels, single-wheel loads were also applied at two magnitudes. Since interest extends to other very heavy aircraft, instruments were loaded with a twin-tandem component of the Boeing 747 and, for tie-in, with a six-wheel component of the C-5A aircraft.

**Vibratory Tests**

Measurements characterizing pavement response were made using vibratory loading equipment. These measurements are of two general types. One type is a stiffness measurement in which a vertically vibrating loading is applied to the pavement and the resulting deflection of the pavement is measured seismically. The other type is a wave-velocity measurement in which a vertically vibrating loading induces waves that
emanate from the source and the propagation velocity is determined through suitable time-distance relations again using seismic pickups.

Two types of equipment have been used for the stiffness measurements. One is a 6000-lb vibrator, which uses counterrotating eccentric masses to induce up to 6000-lb additional dynamic pulses. The other is the Dynaflect equipment, which weighs about 1600 lb and applies up to 1000-lb dynamic force to the pavement. With either equipment, a row of seismic pickups is placed along a line radiating from the center of loading. These pickups measure the deflection at various points along the radiating line and indicate not only the maximum deflection but the shape of the deflection basin created by the applied loading.

Stiffness measurements, both magnitude and basin shape, are being used, through accumulating correlations, to reflect relative pavement behavior. It is hoped that with sufficient correlation, these measurements will shortly provide a basis for predicting actual performance to be expected from a pavement. Stiffness measurements have also been used in rigid pavement computations in determining a volumetric coefficient-of-subgrade reaction for evaluation of load-carrying capability.

Velocity of wave propagation measurements are made using either a small electromagnetic vibrator or the 6000-lb vibrator described above. Either of these can be varied through a range of frequencies, the small vibrator providing higher frequencies and the large vibrator lower frequencies. By moving a seismic pickup away from the vibrating source, suitable time-distance determinations can be made that define velocity and wavelength. In a pavement structure, a number of discreet wavelength
signals can be identified and their velocity of propagation determined. It has been established that the emanating waves are predominately effective at depths within the pavement system of approximately one-half a wavelength. Thus, the velocity of waves carried in each layer of a pavement structure can be determined. From these, using suitable values of density and Poisson's ratio, the effective modulus of elasticity of each layer can be derived.

Direct correlations have been made between elastic moduli from wave-velocity determinations and measurements of material strengths, such as CBR values. These show promise of providing nondestructive means of determining material strengths in place in a pavement system for use in evaluating pavement strengths.

There is also a need to characterize the response of individual layers for applications of layered-system theory to the prediction of stresses and deflections in a pavement system. The velocity of wave measurements provides means of evaluating effective elastic moduli for use in computations involving this theory.

**Surface Deflection Basin Measurements**

Before the initiation of regular rolling traffic, measurements were made showing the shape and depth of the surface deflection basin produced by the full 360,000-lb assembly load. Measurements are made at points along both longitudinal and lateral axes. Measurements cannot, of course, be made directly under the wheels by external means.
Normal optical survey techniques are used for measurements on the flexible pavements, except that special short tripods and level rods are used to permit sitting beneath the load cart. Representative plots of the deflections measured before traffic in items 2, 3, and 5 are shown in fig. 5.

For the rigid pavement, the deflected slab shape is more critical because of the desire to infer strains within the slab. Because of this, somewhat more accuracy of measurement is desirable. Measurements were therefore made in three ways in an attempt to obtain suitable information. Direct optical measurements were made as for the flexible pavements, but special techniques were adopted to control the line of site at both ends, to prepare reference seating positions, and to get resolution of measurements to 0.001 in. In addition to this, slope of the deflected surface was determined at points along the same axes by use of a precise "tilt meter" or slope indicator seated on prepared control points. And finally, strain gages were cemented to the surface of the slab at points along the same axes.

Response of all these systems to the full 12-wheel, 360,000-lb load and the equivalent response to a single wheel identical with one of the 12 wheels were determined.

Traffic Tests

The primary testing effort involves the behavior of the various thicknesses of test items, both flexible and rigid, to traffic of the 360,000-lb, C-5A aircraft gear load. Traffic of the 12-wheel gear was
applied in lanes 16 ft wide with lateral distribution within this lane applied to simulate the distribution expected on prototype airfields. Pavement condition is carefully noted during all traffic application, and behavior is fully documented. Cross sections and profiles were measured periodically as well as deviations from a 20-ft straightedge to observe surface configuration change. Initiation and development of cracking were noted as indications of failure conditions. Deflection basin shape and magnitude measurements were made after substantial traffic application in some cases. Also, some vibratory tests, both stiffness and wave-velocity types, were made after application of some traffic and after failure in several instances.

The rigid pavement traffic lane was located so that about 25 percent of the traffic would be positioned with two wheels of the 12-wheel gear across the center line on the adjacent slab. For the remaining 75 percent of the traffic, all wheels were on one side of the center line but adjacent to it.

Except for setback from the edge of construction, lateral location on the flexible pavement was not critical. It was therefore possible to locate an additional traffic lane within the test section for single-wheel traffic. In this extra lane, traffic was applied over a 9-ft width, distributed to simulate prototype airfield distribution, using a single tire inflated to 100 psi with a 30,000-lb load. This was identical with the load and pressure of tires in the 12-wheel gear and thus gave a direct comparison of behavior. Since, however, this load was much less severe
than that of the 12-wheel gear, failure could only be developed in the thinnest item.

Repetitions, for behavior evaluation purposes, are counted in terms of coverages. One coverage is sufficient wheel passes in immediate adjacent wheel paths, with no overlap or gap, to just cover some width of concern. The controlled traffic pattern used on the test sections accumulates wheel passes from all 12 wheels along each of five (seven for the single wheel) traffic lanes spaced the width of one tire print. The coverages considered are the wheel passes accumulated in the central portion of the traffic lane.

Preliminary Results

At this time the reporting presented herein can only be preliminary. Final results must await completion of a thorough analysis, which is presently under way. Since the analysis is not final, any results presented can only be of a preliminary nature, subject to some modification as a result of further analysis. Accordingly, some first indications are presented, but it is cautioned that these must not be taken as final.

Indicated preliminary results are shown in the following tabulations:
### Behavior of Flexible Pavement

<table>
<thead>
<tr>
<th>Total Thickness Over Subgrade</th>
<th>Design Subgrade Strength, CBR</th>
<th>Nominal Coverages to Produce Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 in.</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>24 in.</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>33 in.</td>
<td>4/2*</td>
<td>1500</td>
</tr>
<tr>
<td>33/54*</td>
<td>4</td>
<td>1500</td>
</tr>
<tr>
<td>42 in.</td>
<td></td>
<td>3500 (without failure)</td>
</tr>
</tbody>
</table>

### Behavior of Rigid Pavement

<table>
<thead>
<tr>
<th>Slab Thickness in.</th>
<th>Subgrade Strength, k</th>
<th>Nominal Coverages to Produce Failure**</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 in.</td>
<td>75</td>
<td>180†</td>
</tr>
<tr>
<td>10 in.</td>
<td>75</td>
<td>200†</td>
</tr>
<tr>
<td>12 in.</td>
<td>75</td>
<td>Under Test</td>
</tr>
<tr>
<td>14 in.</td>
<td>75</td>
<td>Under Test</td>
</tr>
</tbody>
</table>

### Behavior of Bituminous Overlay of Rigid Pavement

<table>
<thead>
<tr>
<th>Overlay Thickness in.</th>
<th>Base Slab Thickness in.</th>
<th>Subgrade Strength, k</th>
<th>Nominal Coverages to Produce Failure**</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 in.</td>
<td>8 in.</td>
<td>75</td>
<td>Under Test</td>
</tr>
<tr>
<td>4 in.</td>
<td>10 in.</td>
<td>75</td>
<td>Under Test</td>
</tr>
</tbody>
</table>

* Section built with extra weak subgrade layer.

** Data will be added from tests now under way prior to preparation of final paper. Only nominal results will be included.

† Flexural strengths are above design values and greater in the 8-in. pavement.

The behavior of the 15-in.-thick item is reasonably consistent with direct extension of current criteria. Here effects of interaction of the many wheels is minimum. On the other hand, the 33-in.-thick items behaved...
much better than extension of current criteria would predict. At the
greater subgrade depths, effects of wheel interaction are greater. This
implies that current means of treating multiple-wheel loads is unduly con­
servative for low-strength subgrade.

Closure

Preliminary results have been obtained of the behavior of various
thicknesses of flexible and rigid pavement under actual traffic of a
landing gear of the C-5A aircraft. A complex of instrument measurements
have been obtained for each pavement type under loadings of the C-5A
aircraft landing gear, four-wheel components of the Boeing 747 aircraft
gear, and single-wheel components of both. It is intended that detailed
analyses will result in improved pavement design criteria suitable for
accommodation of the very-heavy multiple-wheel aircraft known to be
forthcoming.
REFERENCES

1. Ladd, D. M., "Ground-Flotation Requirements for Aircraft Landing Gear," Miscellaneous Paper No. 4-459, December 1961; Revised July 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.


5. U. S. Army Engineer Waterways Experiment Station, CE, "Investigation of Pressures and Deflections for Flexible Pavements; Homogeneous Sand Test Section." Technical Memoranda No. 3-323, Report 4, December 1954, Vicksburg, Miss.

Photograph 1. C-5A Galaxy
Photograph 2. Test load cart
WHEEL ARRANGEMENT
VERY HEAVY MANY-WHEELED
LANDING GEAR TEST

Fig. 1
PLAN VIEW

SECTION A-A
FLEXIBLE PAVEMENT TEST SECTION

SECTION B-B
RIGID PAVEMENT TEST SECTION

MULTIPLE-WHEEL HEAVY GEAR LOAD TEST SECTION

Fig. 2
In this image, the document appears to depict an instrument layout for a flexible pavement test section designed for very heavy many-wheeled aircraft. The layout includes various layers such as the asphaltic concrete base course, subbase, subgrade, and natural subgrade, each containing pressure and deflection gages. The diagram also shows the placement of strain gages and reference plates.

**Section:**
FLEXIBLE PAVEMENT TEST SECTION
FOR VERY HEAVY MANY-WHEELED AIRCRAFT

**Figure:** 3
LEGEND

O DEFLECTION GAGES
D PRESSURE CELLS
□ STRAIN GAGES

NOTE: NUMBER BY SYMBOL REFERS TO NUMBER OF CELLS OR GAGES IN GROUP.

PLAN SCALE

SECTION

HORIZONTAL SCALE

INSTRUMENT LAYOUT
RIGID PAVEMENT TEST SECTION
DEFLECTIONS UNDER 12-WHEEL ASSEMBLY
FLEXIBLE PAVEMENT TEST SECTION

Parallel to traffic

Distance from centroid of front assembly (ft)

Transverse to traffic

Distance from centroid of front assembly (ft)

Fig. 5