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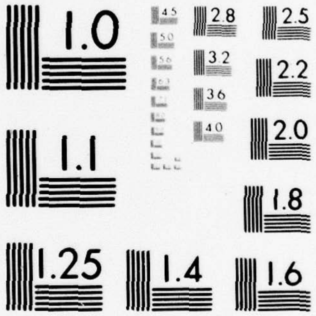
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T. R. GL-79-11 EVALUATION OF DRILLED & GROUTED-IN-PLACE DOWELS FOR LOAD TRANSFER OF PORTLAND CEMENT CONCRETE, TYNDALL AFB, FLORIDA AUG. 1979

TECHNICAL REPORT GL-79-11

# EVALUATION OF DRILLED AND GROUTED-IN-PLACE DOWELS FOR LOAD TRANSFER OF PORTLAND CEMENT CONCRETE, TYNDALL AIR FORCE BASE, FLORIDA

by

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Final Report

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This study utilizes the results of measured strains under static loadings and measured deflections under nondestructive vibratory loadings of the portland cement concrete at three instrumented test locations to determine the adequacy of dowels installed by the drill-and-grout method in longitudinal joints as load transfer devices. Two test procedures are used to evaluate the instrumented joints, and then the test results are compared. The computed load transfer of these joints determined from the strain measurements were compared

(Continued)

20. ABSTRACT (Continued).

with the results of the same type of testing performed in the 1950's on drilled and grouted-in-place doweled joints and with a theoretical analysis of this type of joint construction. Nondestructive test results performed on joints of different construction from the instrumented joints are also presented for comparison purposes.

# PREFACE

The investigation reported herein was sponsored by the Directorate of Military Construction, Office, Chief of Engineers, U. S. Army, and was conducted under Project/AMS Code 4K07812AQ61/728018.2, "Evaluation of Drilled and Grouted Dowels for Load Transfer of PCC." The responsibility for conducting the study was assigned to the Geotechnical Laboratory (GL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, with support from Tyndall Air Force Base (AFB), Florida. Field tests were conducted at Tyndall AFB during April 1978.

The investigation was conducted under the general direction of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, GL, respectively. The engineers who were actively engaged in the planning, testing, analyzing, and reporting phases of this study were Messrs. R. L. Hutchinson, Pavement Program Manager, J. W. Hall, Jr., Chief, Evaluation Branch of Pavement Investigations Division (PID), and R. W. Grau, PID. This report was prepared by Mr. Grau.

Acknowledgement is made to Mr. D. N. Brown and other personnel of the Air Force Civil Engineering Center, Tyndall AFB, Florida, for their assistance and cooperation.

Directors of the WES during the conduct of this study and the preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

## CONTENTS

## CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins* |
| feet | 0.3048 | metres |
| gallons (U. S. liquid) per minute | 3.785412 | cubic decimetres per minute |
| inches | 2.54 | centimetres |
| kips (force) | 4.448222 | kilonewtons |
| microns | 0.001 | millimetres |
| mils | 0.0254 | millimetres |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per square inch | 0.6894757 | newtons per square centimetre |
| pounds (mass) | 0.45359237 | kilograms |
| pounds (mass) per cubic inch | 27,679.9 | kilograms per cubic metre |
| square inches | 6.456 | square centimetres |

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

# EVALUATION OF DRILLED AND GROUTED-IN-PLACE DOWELS FOR LOAD TRANSFER OF PORTLAND CEMENT CONCRETE, TYNDALL AIR FORCE BASE, FLORIDA

## PART I: INTRODUCTION

### Background

1. There is concern as to the adequacy of dowels installed by grouting in drilled holes as load transfer devices in longitudinal joints in portland cement concrete (PCC) pavement formed by slip-form pavers. Tests conducted by the Corps of Engineers during the 1950's indicated that installation by the drill-and-grout method was unsatisfactory because of (a) inability to meet alignment requirements and (b) inability to consistently obtain complete filling of the drilled hole with grout, and thus resulted in looseness and lack of load transfer. The current guide specification, MCGS 02611,* permits only the drill-and-grout method of dowel installation for doweled longitudinal construction joints in concrete placed using slipform pavers. This method was recently used in construction of new runway pavement at Tyndall Air Force Base (AFB); therefore, to help resolve the questions regarding the adequacy of drilled-and-grouted dowels, tests were performed to evaluate the load transfer capability of these joints.

### Objectives

2. The objectives of this study were to:

a. Evaluate the load transfer capability and efficiency of drilled and grouted-in-place doweled longitudinal joints constructed in the PCC pavement at Tyndall AFB.

b. Evaluate the efficiency of other joints of different construction for comparison purposes.

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* Departments of the Army, Navy, and Air Force. 1975. "Concrete Pavement for Roads and Airfields," Military Construction Guide Specification 02611, Washington, D. C.

c. Compare the load transfer capability of the drilled and grouted-in-place doweled joints constructed at Tyndall AFB with the same type joint construction performed in the 1950's.

## Scope

3. The objectives of this investigation were accomplished by measuring the strains under static loading and deflections under nondestructive vibratory loadings of the PCC on either side of three doweled longitudinal construction joints. The efficiencies of these joints were computed by determining the load transfer of the joints from the strain measurements and the ratio of the deflections measured on either side of the joints.* The joint efficiency test (deflection method) is much easier to perform; therefore, the two methods were correlated at three locations and the joint efficiency method used for larger coverage or for testing joints of different construction. All of these tests were conducted on the new Drone runway at Tyndall AFB, Florida, during 26-30 April 1978. This report also presents for comparison purposes the results of joint efficiency tests conducted at other installations during the 1950's.

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* Percent load transfer is defined as the strain in the concrete on the unloaded slab divided by the sum of the strains on the loaded and unloaded sides multiplied by 100. Percent joint efficiency is defined as the deflection of the surface of the concrete at "X" distance from the applied load and "Y" distance from the joint on the unloaded side of the joint divided by the deflection of the surface of the concrete at "X" distance from the applied load and "Y" distance from the joint on the loaded side of the joint multiplied by 100.

## PART II: TESTS ON DRONE RUNWAY

### Description of Test Installation

#### Pavement description

4. The field tests described herein were conducted on the newly constructed PCC Drone runway at Tyndall AFB, which was designed for a 15,000-lb* single-wheel load. There was no distress observed in any of the test areas prior to or after testing. The runway pavement contained four longitudinal paving lanes, each 37.5 ft in width, making the overall width of the runway 150 ft. These paving lanes were joined together by the drill-and-grout method of dowel joint installation. The dowels were 1-in.-diam steel round bars, 16 in. in length and spaced 12 in. center-to-center. This design was in conformity with the criteria specified in TM 5-824-3/AFM 88-6, Chapter 3.** Transverse and longitudinal sawed contraction joints were spaced at 15.0- and 12.5-ft intervals, respectively. The length of the runway was 7000 ft. The pavement thickness for the center 5000 ft (sta 36+00 to 86+00) was uniform at 8 in. The thickness of the pavement at each end (sta 26+00 to 36+00 and sta 86+00 to 96+00) was uniform at 10 in. Based on construction control data, the average flexural strength of the pavement at 28 days was 719 psi.

#### Pavement construction

5. During construction of the runway, the placement sequence of the paving lanes was lanes 2, 3, 1, and 4. Figure 1 shows the location of the paving lanes. This resulted in the bonded portion of the dowels in the longitudinal joints between paving lanes 1 and 2, 2 and 3, and 3 and 4 being in paving lanes 2, 2, and 3, respectively. The method of installing the dowels was identical for all drilled and grouted-in-place doweled joints and was accomplished in the following manner:

<u>a</u>. The concrete was placed by slipforming with a vertical edge. Following placement and hardening of the concrete

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is given on page 3.

** Departments of the Army and Air Force. 1970. "Rigid Pavements for Airfields Other Than Army," Army Technical Manual 5-824-3, Air Force Manual 88-6, Chapter 3, Washington, D. C.

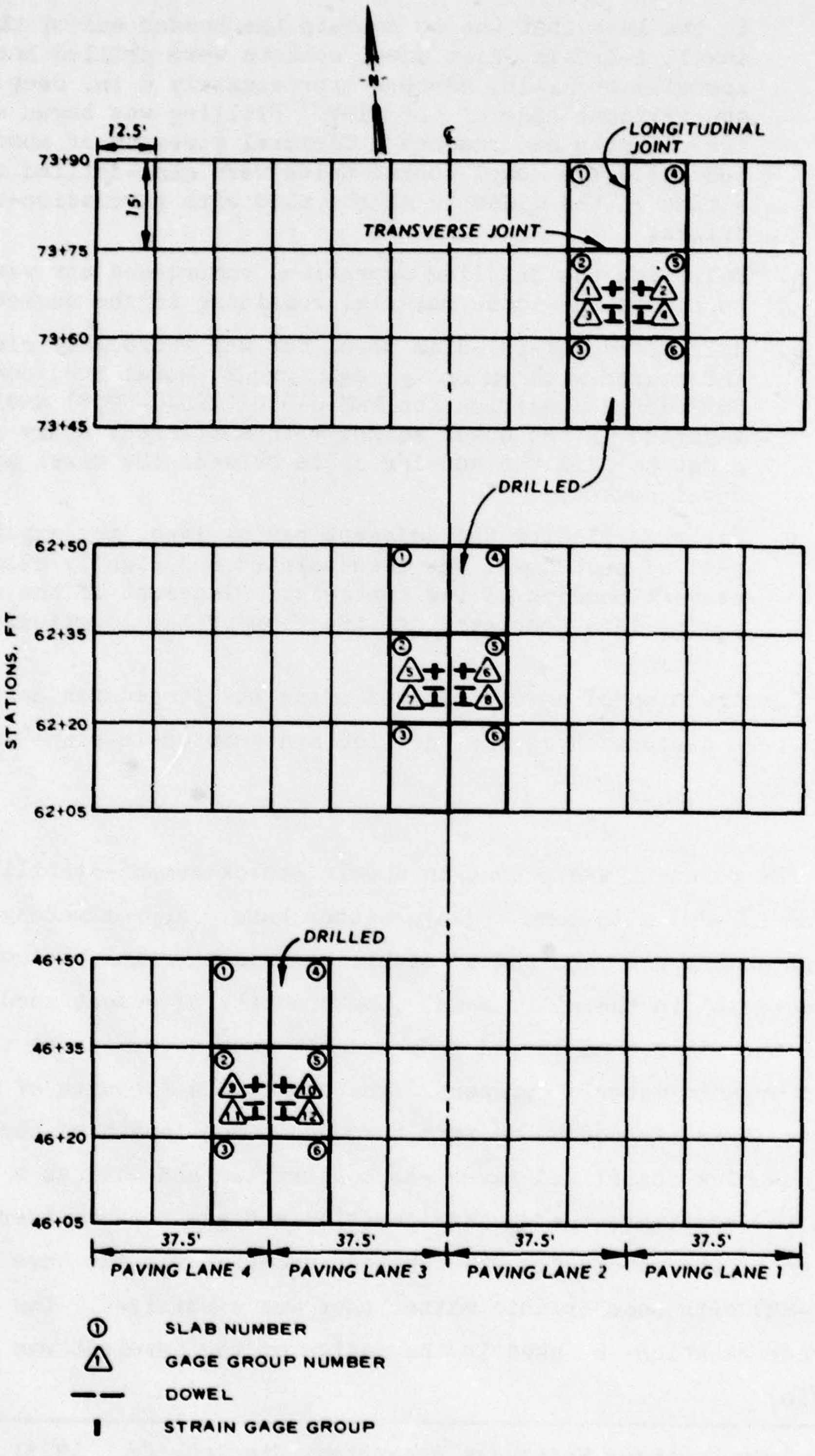

Figure 1. Layout of test areas

in the lane that was to contain the bonded end of the dowel, 1-1/8-in.-diam dowel sockets were drilled horizontally on 12-in. centers approximately 8 in. deep into the vertical edge of the slab. Drilling was begun after the concrete had reached a flexural strength of about 500 psi. The dowel socket holes were gang-drilled four at a time at the middepth of the slab with percussion-type drills.

b. Following the drilling operation, compressed air was used to remove the loose material remaining in the sockets.

c. Half of each 1-in.-diam dowel bar was thoroughly cleaned and coated with an epoxy resin grout, Dural 104, conforming to Federal Specification MMM-G-650 (CRD-C-590*) and then inserted in the dowel socket with sufficient epoxy resin grout to fill the annular space between the dowel and dowel socket.

d. Prior to placing the adjacent paving lane, the exposed half of each dowel was then painted and lightly oiled to prevent bonding to the concrete. Placement of the adjacent paving lane completed construction of the longitudinal joint.

6. Construction of doweled joints using the procedures described above had been designated as the "drilled and grouted-in-place" method of installation.

## Subgrade

7. The pavement was placed on a 6-in.-thick cement-stabilized silty sand (SP-SM) with some organic matter base. Approximately 13 to 16 percent cement was required to stabilize this material because of the organic material in the silty sand. The quantity of cement used to stabilize the silty sand varied from area to area according to the amount of organic material present. Therefore, the strength of the stabilized layer may not be uniform throughout the length of the runway. This 6-in.-thick stabilized layer was constructed and used as a working platform to facilitate the paving operation and was not considered in the design of the pavement. The subgrade material was the same silty sand (SP-SM) with some organic matter that was stabilized. The modulus of subgrade reaction k used in the design of the pavement was 160 psi/in.

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* U. S. Army Engineer Waterways Experiment Station, CE. 1973. "Specifications for Grout, Adhesive, Epoxy Resin, Flexible, Filled," Handbook for Concrete and Cement, CRD-C-590, Vicksburg, Miss.

### Test section

8. The static loading and strain measurement tests were made at three test areas on a doweled longitudinal construction joint. Deflection measurements were also recorded under vibratory loadings at these three test areas for comparison purposes. The test areas were located between sta 46+05 and 46+50, 62+05 and 62+50, and 73+45 and 73+90. Each test area, as shown in Figure 1, consisted of three alternate pairs of slabs on either side of a doweled longitudinal construction joint separating a paving lane.

9. During the test period and for several days preceding the tests, air temperatures at Tyndall AFB ranged from approximately 55° to 85°F. Based on visual inspection, the joints in the test areas were closed. An examination of the general condition of the pavement surface in the test area showed no defects. Shrinkage cracks were observed in several areas elsewhere in the pavement slabs.

### Other tests

10. The efficiency of additional joints was determined by the vibratory load and deflection measurement method. These additional joints consisted of longitudinal contraction, transverse contraction, doweled transverse construction, thickened edge, and special joints doweled T-1 and R-1. Figure 2 shows the details of these joints.

## Instrumentation

### Strain measurements

11. All strains were measured using Micro-Measurements (M-M) precision strain gages (gage type EA-06-20CBW-120), which in turn were cemented to the top surface of the pavement. These gages had an effective gage length of 2 in. These M-M gages were of open-faced construction with a 1-mil tough flexible polymide film backing. The gages were cemented to the pavement surface using a compatible M-M certified M-Bond, and then the open-faced gages were sealed with protective coatings to protect the gages from external moisture. The technique used in attaching the gages to the pavement was as follows:

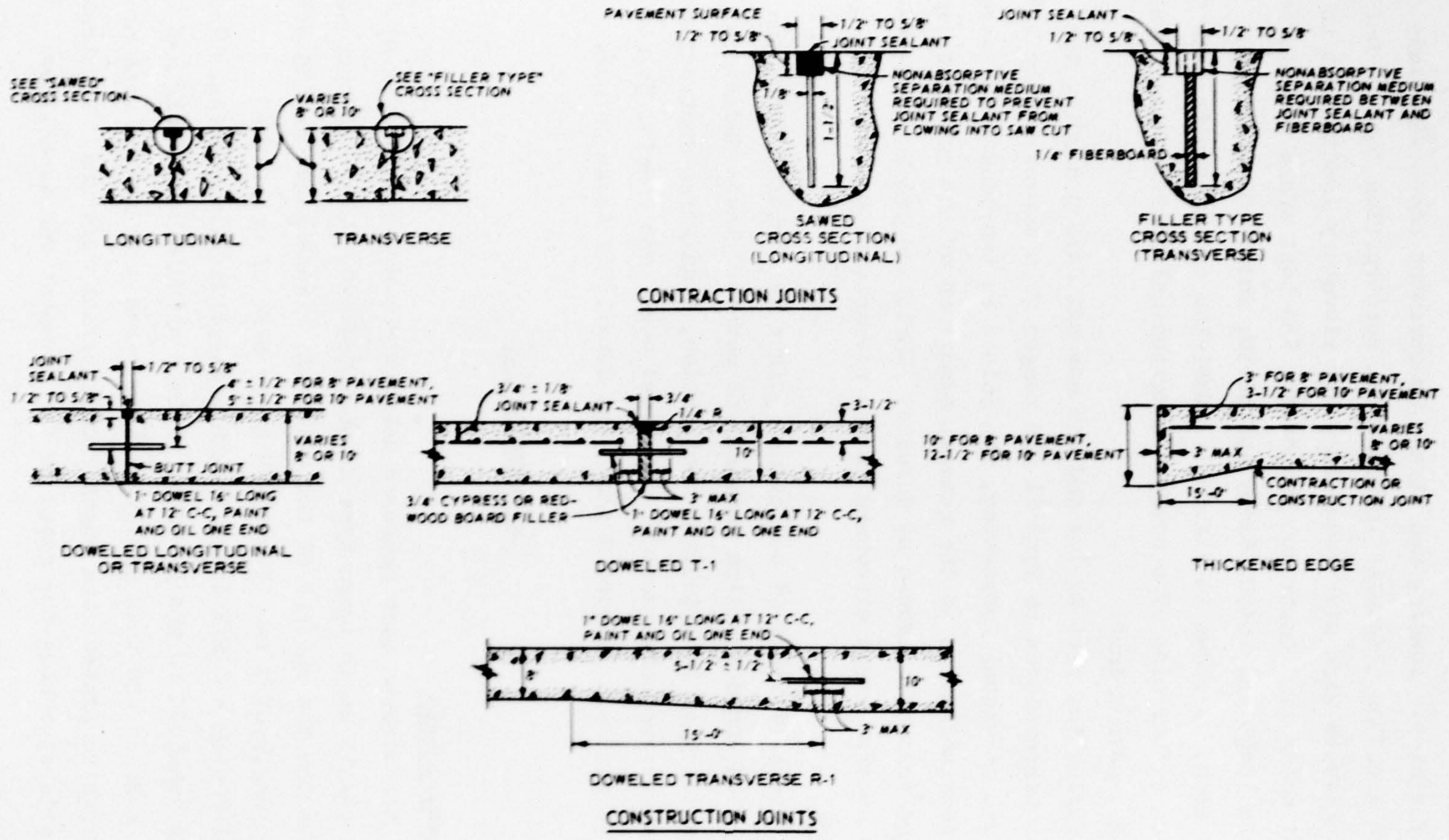

Figure 2. Details of joints tested

a. An initial coat of M-Bond AE-10/15 was applied to the rough and uneven surface and allowed to air-dry for about 15 hr.

b. After drying, the AE-10/15 was ground with an electric belt sander until the surface at each gage area was smooth and level as shown in Photo 1.

c. Using a second application of AE-10/15 bond, two pairs of gages (one parallel to the joint and another perpendicular to the joint) were bonded to the prepared surface and held in place during the drying period by steel and lead blocks, which produced a pressure of about 2 psi on each gage. A layer of tape and 1/4-in.-thick rubber padding was placed between the gages and weights.

d. After drying of the AE-10/15 bond, the weights, padding, and tape were removed, and the gages were waterproofed with an M-M strain gage protective coating. Photo 2 shows two gage locations after the gages had been bonded to the pavement, and Photo 3 shows four gage locations after the protective coating had been applied.

12. The M-M gages were installed on the pavement surface in pairs of groups of gages along each side of the longitudinal doweled joint. Each gage group consisted of four gages, two gages parallel and two gages perpendicular to the longitudinal doweled joint, as shown in Figure 3. One pair of gage groups after installation is shown in Photo 2. A total of six pairs of gage groups were installed along the longitudinal doweled joint. In order that the effect on load transfer due to relative positioning of the wheel load with respect to the dowels could be observed, three pairs of gage groups were placed directly over the dowels, and the remaining three pairs of gage groups were placed at points midway between dowels. A Jetco electronic metal-mineral detector, Model 0770, was used to locate the position of the dowels in the pavement.

13. The three pairs of pavement slabs that comprised the doweled joint test area were instrumented with one pair of a group of M-M gages directly over a dowel and one pair of a group of M-M gages midway between two adjacent dowels. The gages in each group were positioned such that the longitudinal axes of two gages were parallel to the joint and that the longitudinal axes of two other gages were perpendicular to the joint.

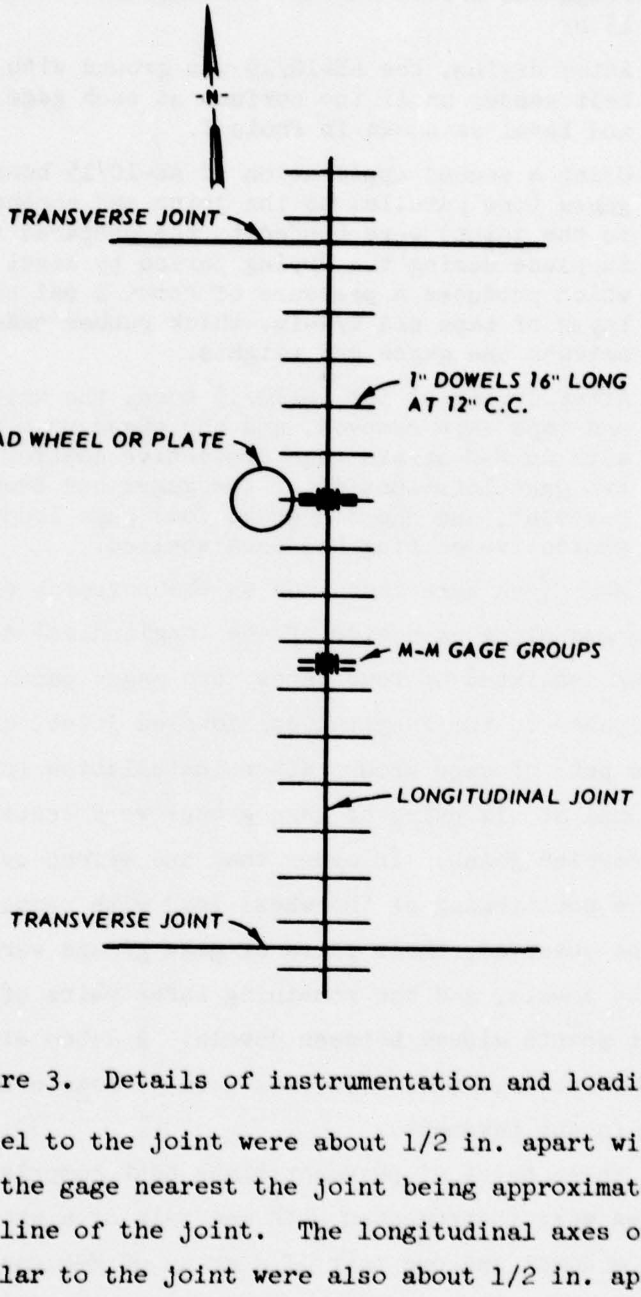

Figure 3. Details of instrumentation and loading

The gages parallel to the joint were about 1/2 in. apart with the longitudinal axis of the gage nearest the joint being approximately 1-1/2 in. from the center line of the joint. The longitudinal axes of the two gages perpendicular to the joint were also about 1/2 in. apart and symmetrical about either an underlying dowel or the space midway between two adjacent dowels. Each pair of gage groups was located a minimum of 5-1/2 ft from the nearest transverse joint.

14. All strains were measured using a direct-reading, transistorized Baldwin-Lima-Hamilton SR-4 strain indicator, Type BN. The indicated reliability of this strain indicator was approximately ±5 microns.

15. Figure 1 shows a plan view of the pavement test area showing a layout of gage groups and test slabs. Figure 2 presents details of the location and orientation of the strain gages with respect to the dowels shown in Figure 3.

### Deflection measurements

16. The WES 16-kip vibratory loading device (Photo 4) was used in the dynamic loading tests to determine the joint efficiencies by the deflection method. This vibrator operates electrohydraulically and is housed in a 36-ft semitrailer that contains supporting power supplies and automatic data recording systems. The vibrator mass assembly consists of an electrohydraulic actuator surrounded by a 16,000-lb lead-filled steel box. The actuator uses up to a 2-in. double-amplitude stroke to produce a vibratory (dynamic) load ranging from 0 to 15,000 lb with a frequency range of 5 to 100 Hz for each load setting. Electric power is supplied by a 25-kw diesel-drivel generator set. The hydraulic power unit is diesel-driven and has a pump that can deliver 38 gpm at 3000 psi.

17. Major items of electronic equipment are a set of three load cells mounted on the load plate, which measures the dynamic force; velocity transducers (pickups) located on the 18-in.-diam steel load plate and at points away from the plate, which are electronically integrated to give vertical deflection measured during vibratory loading; a servomechanism, which allows variation of frequency and load; an X-Y recorder, which produces load versus deflection and frequency versus deflection curves; and a printer, which provides data in digital form.

18. During the joint efficiency tests the load plate and pickups were oriented as shown in Figure 4 and Photo 5. Two pickups were placed on each side of the joint so as to be equidistant from the center of the load plate and the joint. An additional pickup was placed midway between

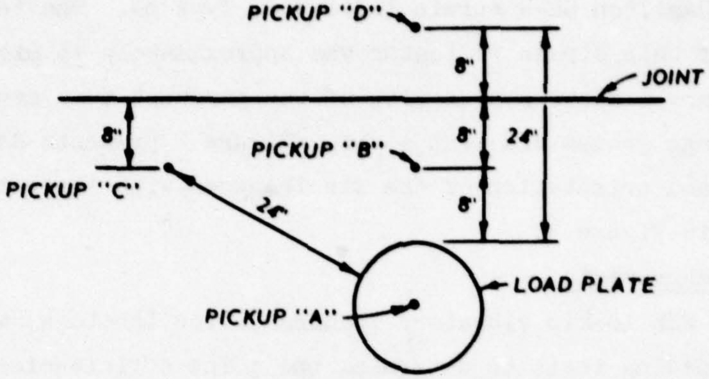

Figure 4. Location of load plate and deflection pickups for joint deflection tests

the joint and the edge of the load plate and the same distance from the joint as were the first two pickups.

Static loadings

19. A single-wheel test cart (Photo 6) loaded to 15,000 lb was used in the static load tests. It was equipped with an outrigger wheel to prevent overturning and was powered by the front half of a four-wheel-drive truck. The load cart was equipped with a 30 by 11.5 24-ply tire inflated to 225 psi.

Dynamic loadings

20. The WES 16-kip vibrator described in paragraph 16 was used to apply the dynamic loads. This device applies a static preload of 16,000 lb to the pavement through an 18-in.-diam steel plate and then applies a vibratory load. Deflection measurements were recorded at dynamic loadings of about 5000 and 7500 lb (peak values) at a constant 15-Hz frequency.

## Test Procedure

Static load tests

21. The static loading tests were repeated with the load cart positioned alternately on both sides of the joint so that the load

transfer from the bonded side of the dowel to the unbonded side could be compared with the load transfer from the unbonded side of the dowel to the bonded side. In making the strain measurements, the following procedure was followed:

a. Beginning with the load cart positioned approximately 20 ft away from the pair of group of gages to be read, the SR-4 strain box was connected to the group of gages on the unload side of the joint, and the M-M gages were balanced for the condition of "no load" and the readings recorded. The SR-4 strain box was then connected to the group of gages that were on the side of the joint to be loaded, and the M-M gages were balanced for the "no load" condition and the readings recorded.

b. The load cart was then backed to the position shown in Photo 3 such that the outside edge of the tire was approximately 5 in. from the joint and that the center of the load wheel was aligned with the center of the gages parallel to the joint and directly between the two gages placed perpendicular to the joint. The diagram in Figure 3 shows the position of the load wheel with respect to a pair of group of gages being read. Due to the maneuverability of the load cart, it was possible to obtain quite accurate positioning of the load wheel with respect to the strain gage groups and the joint.

c. As soon as the load cart was positioned correctly, the "load" readings were obtained from the strain box connected to the gages on the loaded side of the joint. Then, these gages were disconnected from the strain box, and the gages on the opposite side of the joint (unloaded side) were connected, read, and recorded.

d. The load cart was then moved forward about 20 ft to the "no load" position, and the rebound readings were obtained for the pair of group of gages.

e. With the load cart on the same side of the joint, the above procedure was repeated four times for both pairs of gage groups in the test area.

f. The load cart was then turned 180 deg and positioned on the opposite side of the joint from the previous measurements.

g. The test procedure outlined in a through e was then repeated for the two pairs of gage groups in the test area.

h. The test cart was then moved to the additional two test areas, and the test procedure outlined in a through g was repeated for the two pairs of gage groups in each test area.

22. During the static load tests, all four M-M gages in a gage group and then only the single M-M gage, which was placed parallel and adjacent to either side of the joint, were read. None of the gages were damaged during test operations with the load wheel positioned adjacent to the gages. However, following these tests the positioning of the load wheel on top of the gage groups resulted in several damaged gages.

Nondestructive tests

23. Nondestructive tests were repeated with the load plate positioned alternately on both sides of the joint at each gage group location so that the joint efficiency from the bonded side of the dowel to the unbonded side could be compared with the joint efficiency from the unbonded side of the dowel to the bonded side. Strain readings were not recorded during nondestructive testing. In making the deflection measurements, the following procedure was recommended:

a. The nondestructive test van was positioned at each pair of gage groups, as shown in Photo 5, such that the edge of the load plate was about 16 in. from the joint and the center of the plate was along a line running through the center of the pair of gage groups. Two pickups were placed, one on one side of the joint and the other on the opposite side, so as to be equidistant from the load plate and the joint. A third pickup was placed directly between the load plate and the joint so as to be equidistant from the load plate and the joint and the same distance from the joint as were the other two pickups.

b. As soon as the load plate and pickups were positioned correctly, deflection measurements were recorded at dynamic forces of 5000 and 7500 lb at a constant 15-Hz frequency.

c. The test van was then moved forward to the other pair of group of gages at the test location, and the test procedure outlined in a and b was repeated.

d. The test van was then turned 180 deg and positioned on the opposite side of the joint from the previous measurements.

e. The test procedure outlined in a through c above was then repeated at the two pairs of gage groups in the test area.

f. The test van was then moved to the other two test areas, which had been instrumented and then tested statically, and the test procedure outlined in a through e was repeated.

g. After testing the three instrumented areas, the test van was moved to other joints of different construction, and the test procedure outlined in steps a and b above was repeated at each of the joints.

# Theoretical Analysis

## Basic concepts of joint design

24. Design criteria for rigid pavements for military airfields are based on the premise that all types of joints transfer a minimum of 25 percent of the load from the loaded slab to the adjacent unloaded slab. As long as the stresses in the pavement and subgrade remain within their respective elastic limits, wheel load and pavement stress are directly proportional. Thus, the reduction in the critical edge stress becomes related directly to the degree of load transfer achieved through the joint. In current design criteria, as given in TM 5-824-3/AFM 88-6, Chapter 3, no differentiation is made as to the load transfer capacity of the various types of joints used in rigid pavements for airfields.

25. In the case of doweled joints, several factors affect the load transfer capacity of the joint. Probably the most important single factor involved is the amount of looseness that exists between the dowel and its socket in the pavement. Furthermore, it is quite probable that the magnitude of the initial looseness is related to the particular procedure* and/or the care used in the installation of the dowels. During the service life of the pavement, some additional looseness will develop as a result of the gradual enlarging of the dowel socket due to the effects of load repetition. Loss of load transfer capacity in a doweled joint also can result from a reduction in the effective cross-sectional area of the dowels due to the corrosion of the dowels. Previous experience, however, has indicated that dowels in airfield pavements seldom exhibit detrimental corrosion damage.

## Theoretical strains

26. The computed** maximum strains for the conditions of free edge loading and for loading along a joint having the capacity for

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* The current guide specification, MCGS 02611, permits only the drill-and-grout method of dowel installation for doweled longitudinal construction joints in concrete placed using slipform pavers.

** W. C. Kreger. 1967. "Computerized Aircraft Ground Flotation Analysis - Edge-Loaded Rigid Pavement," Report No. EPR-FW-572, General Dynamics, Fort Worth Division, Fort Worth, Texas.

25 percent load transfer are as follows for the pavement thickness, subgrade strength, and test cart load used in the tests at Tyndall AFB:

- a. Strain at a free edge = $95 \times 10^{-6}$ in./in.
- b. Strain on the loaded edge of the joint = $71 \times 10^{-6}$ in./in.
- c. Strain on the unloaded edge of the joint = $24 \times 10^{-6}$ in./in.

These strains are based on assumed values of $5 \times 10^{6}$ psi and 0.20 for the modulus of elasticity and Poisson's ratio for the concrete, respectively; a pavement thickness and modulus of subgrade reaction of 8 in. and 225 psi/in., respectively; and a 15,000-lb single-wheel load with a contact area of 75 sq in. The 225-psi/in. value was assigned for a $k$ based upon the subgrade classification and the thickness of the stabilized material above the subgrade.

27. Maximum strains were also computed for the conditions above (paragraph 26) after converting the existing composite pavement to an equivalent PCC slab thickness of 8.8 in. by the formula

$$h_e = \sqrt[1.4]{h^{1.4} + \left(\sqrt[3]{E_s/E_c} + t\right)^{1.4}}$$

where

$h_e$ = equivalent thickness of PCC
$h$ = thickness of existing PCC slab
$E_s$ = modulus of elasticity of stabilized layer
$E_c$ = modulus of elasticity of concrete
$t$ = thickness of stabilized layer

The equivalent thickness of PCC and computed strains are based on assumed values of $1.5 \times 10^{5}$ psi for $E_s$, $5 \times 10^{6}$ psi for $E_c$, 0.20 for Poisson's ratio for the concrete, and a modulus of subgrade reaction of 160 psi/in. The computed strains are as follows:

- a. Strain at a free edge = $113 \times 10^{-6}$ in./in.
- b. Strain at the loaded edge of the joint = $85 \times 10^{-6}$ in./in.
- c. Strain at the unloaded edge of the joint = $28 \times 10^{-6}$ in./in.

## Experimental Data

### Measured strains

28. A summary of the strain measurements obtained during the static loading tests made along the doweled longitudinal joints is given in Tables 1 and 2 for loadings on the bonded side of the joint and in Tables 3 and 4 for loadings on the unbonded side of the joint. The strain measurements summarized in Tables 1 and 3 are for loadings adjacent to the gage groups, and those summarized in Tables 2 and 4 are for loadings on top of the gage groups.

### Comparison of theoretical and measured strains

29. Table 5 compares the theoretical strains given previously in paragraph 26 and the average measured strains on the loaded and unloaded side of the joint and the total strain at the joint. The strains listed in columns labeled B/A and C/A are averages of the strains measured with only the gage in each gage group that was parallel to and adjacent to the joint. The average total strain at the joint measured with the wheel load adjacent to the gage groups was $51 \times 10^{-6}$ in./in., which was approximately 54 percent of the theoretical total strain. The fact that these measured strains were much less than the theoretical strains is probably due to the distance between the load wheel and the M-M gages measuring the principal strain or those gages parallel to the joint. When the load wheel was positioned adjacent to a gage group, the distances between the M-M gage or gages measuring the principal strain in the gage group and the center of the tire and the tire edge adjacent to the gage group were about 8 and 3.5 in., respectively. The average total strain at the joint, measured with the load wheel on top of the gage group, was the same as the theoretical total strain based on Westergaard's analysis. It should be noted that when the load wheel was positioned on top of a gage group, the edge of the tire was about 1.5 in. from the joint. This resulted in the edge of the load tire being about tangent to that gage in the loaded group, which was parallel to and closest to the joint, or about the similar load wheel/strain gage

relationship obtained by the Ohio River Division Laboratories during their field testing of various types of joint construction in the 1950's. The fact that the measured strains recorded with the load wheel on top of the gage groups were about the same as the theoretical strains was not in agreement with the major portion of previous Ohio River Division Laboratories' experience in the measurement of rigid pavement strains in full-scale test pavements. Such tests generally have shown measured strains to be 15 to 30 percent less than the theoretical strains.

## Measured deflections

30. Table 6 summarizes the joint deflection measurements obtained with the 5000- and 7000-lb dynamic load tests made at each of the strain gage group locations. The deflections shown in columns A, B, C, and D are at the center of the load plate, at a point midway between the edge of the load plate and the joint, at a point on the loaded side of the joint equidistant from the load plate and the joint as was D, and at a point on the unloaded side of the joint equidistant from the load plate and the joint as was C, respectively. Figure 4 shows the relationship between the load plate, the four velocity pickups, and the joint during a joint efficiency test.

# PART III: EVALUATION AND ANALYSIS

## Evaluation of Load Transfer for Doweled Joints

### Computation of load transfer

31. If it is assumed that both the wheel load and the dowels act on the pavement as point loads, the sum of the strains on the loaded and unloaded sides of a doweled joint is theoretically equal to the strain produced by a point loading at a free edge of the pavement. Although the wheel of the load cart represents a loaded area of finite dimensions rather than the idealized point loading, it is believed that use of the total strain as measured simultaneously on both sides of the joint is sufficiently valid to permit a reasonable determination of the load transfer characteristics of doweled joints. Tables 7 and 8 summarize the computed values of load transfer for loadings on the bonded and unbonded sides of the doweled joint, respectively.

### Analysis of load transfer

32. Based on (a) all test data in Tables 7 and 8 without regard to positioning of the load wheel relative to the dowels or gage groups, and (b) all test data in Tables 7 and 8 with the load positioned on top of the gage group and measured by the M-M gage parallel to and nearest to the joint (column 4 data only), the average load transfers for the doweled joint were 31.2 and 30.4 percent, respectively. Thus, the average of all indicated values of load transfer is comparable to the average of the load transfer values calculated using only the data that were recorded when the load wheel/strain gage relationship was similar to that obtained during field testing of joints in the 1950's. As can be determined from Tables 7 and 8, the indicated values of load transfer ranged from a minimum of 17.1 percent to a maximum of 46.8 percent. Theoretically, the load transfer should not exceed 50 percent.

33. If all values for load transfer as given in Table 7 are considered, the average value for load transfer is 30.8 percent for loadings on the bonded side of the dowel. Similarly, the average of all values of load transfer given in Table 8 is 31.6 percent for loadings on the

unbonded side of the dowel. The fact that less load transfer was achieved when the joint was loaded on the bonded side of the dowel is in agreement with results obtained from previous Ohio River Division Laboratories' tests on dowels installed by the "cast-in-place" technique and with results from field testing during the 1950's on various Air Force pavements of dowels installed by the "dummy-half-dowel," "grouted-in-place," "split dowel," and "cast-in-place" techniques. Table 9 summarizes the values for load transfer calculated for various types of doweled construction joints tested during the 1950's.

34. If all values for load transfer as given in Tables 7 and 8 are considered with respect only to test area, the average load transfers for the doweled joint at the test areas between sta 73+45 and 73+90, 62+05 and 62+50, and 46+05 and 46+50 are 24.8, 40.2, and 28.9 percent, respectively. Also, if the average of all values of load transfer for each of the three test areas are compared with respect to load position, load on the bonded side (Table 7) to load on the unbonded side (Table 8), the results would be: 19.1 to 29.0 percent, 41.4 to 38.7 percent, and 29.0 to 28.8 percent. The fact that the average load transfer for these three test areas with respect only to test area ranged between 24.8 and 40.2 percent and that inconsistency in load transfer calculated with respect to load position occurred between test areas could be indicative that, in some cases, the epoxy resin did not completely fill the annular space between the dowel and the drilled dowel socket, a function of joint opening and/or poor quality control during construction. The consistent small range in value for total strain measured at each test area with respect to load position and number of gages per gage group read (see Tables 1 through 4) tends also to indicate that the above inconsistencies were attributed to the doweled joint rather than the strain gages.

### Effect of the relative positions of wheel load and dowel

35. If the data presented in Tables 7 and 8 are analyzed on the basis of whether the wheel load was positioned directly over a dowel as compared with being positioned midway between two dowels, the indicated average values of load transfer are 32.7 and 29.4 percent, respectively.

The fact that greater load transfer was obtained with the wheel load positioned directly over a dowel is in accordance with the theory and is to be expected. The closer the wheel load is to a dowel, the greater the load imposed on the dowel becomes with the result that greater loads are transferred to the adjacent slab. Inasmuch as the load transfer with the wheel load positioned midway between the dowels averaged 29.4 percent, it is concluded that the dowel spacing was not excessive.

## Evaluation of Joint Efficiency for Doweled Joints

### Computation of joint efficiency

36. The deflections measured on the loaded and unloaded sides of the doweled joint resulting from a dynamic load were used to compute the "joint efficiency." Joint efficiency as used herein is the ratio, expressed as a percentage, of the deflection across the joint from the load plate (unloaded side) to the deflection on the side of the joint on which the load is applied (loaded side). This is illustrated in Figure 4 as the ratio of deflection of point C to the deflection of point D. Points C and D are located on opposite sides of the joint; however, they are equidistant from the center of the load plate and from the joint. In calculating "joint efficiency," it was assumed that the dynamic load produces a deflection basin symmetrical about the plate. Thus, any difference in deflection measured at point D as compared with point C reflects a loss in efficiency of the load transfer device in the joint. Table 6 summarizes the deflections measured at each gage group location and the calculated joint efficiency for each load plate position. Table 10 presents the computed joint efficiencies of the additional joints other than those at the strain gage locations.

### Analysis of joint efficiency

37. Based on all test data without regard to positioning of the load plate relative to the dowels or to the magnitude of the dynamic load, the average joint efficiency for the instrumented doweled joint was 94.2 percent. As can be determined from Table 6, the indicated values of joint efficiency ranged from 84.3 to 105.8 percent. Joint

efficiencies of more than 100 percent were calculated at plate positions 7 and 8. These joint efficiency values that exceed 100 percent may be due to some slight error in the very small deflection measurements. The joint efficiency should not exceed 100 percent.

38. If all values for joint efficiency except those greater than 100 percent are considered, the average value for joint efficiency is 93.3 percent for loadings on the bonded side of the dowel and 91.4 percent for loadings on the unbonded side of the dowel. This is also true for each of these three test areas. The average of all values of joint efficiencies for loadings on the bonded side of the dowel to the joint efficiencies for loadings on the unbonded side of the dowel for test areas 1, 2, and 3 are 88.3 to 86.9, 97.3 to 94.3, and 96.2 to 94.6 percent, respectively. The fact that the joint efficiency was higher when the joint was loaded on the bonded side is in disagreement with the load transfer or strain gage test results. No reason for this difference in the consistency of test data is readily apparent.

39. If all values for joint efficiency as given in Table 6 are considered with respect only to test area, the average joint efficiencies for the doweled joint at test areas 1, 2, and 3 are 87.6, 99.6, and 95.4 percent, respectively. These data indicating the relative strengths of the joint at each of the test areas are consistent with the load transfer data calculated for each test area.

### Effect of the relative positions of the load plate and dowel

40. If all joint efficiency data with the exception of that greater than 100 percent presented in Table 6 are analyzed according to whether the load plate was positioned directly over a dowel as compared with being positioned midway between two dowels, the indicated average values of joint efficiency are 92 and 91 percent, respectively. The fact that greater joint efficiency was obtained with the load plate positioned directly over a dowel is in accordance with the theory discussed previously and with the load transfer values shown in Tables 7 and 8.

## Load Transfer Versus Joint Efficiency

41. Figure 5 shows the relationship between load transfer and joint efficiency of the three instrumented test areas. An average of all load transfer data and joint efficiency values except those greater than 100 percent shown in Tables 6, 7, and 8, respectively, were used in calculating the points plotted in Figure 5. A straight-line relationship of load transfer versus joint efficiency determined by the least squares method is shown for load on the bonded side of the dowel, load on the unbonded side of the dowel, load over a dowel, load between two dowels, and all points plotted. These relationships indicate that less load is transferred by the doweled joint when the unbonded side is loaded than when the bonded side is loaded, and that for a joint to meet design criteria or to transfer a minimum of 25 percent of the load from the loaded slab to the adjacent unloaded slab, its efficiency should be at least about 91 percent. It would have been desirable to have collected data of this nature at additional locations in order to be more conclusive.

### Additional joint deflection test results

42. Calculated joint efficiencies are based on deflection measurements at each of the additional joints tested, other than the instrumented joints (Table 10). A minimum of three joints were tested for each type joint listed in Table 10. Table 11 summarizes the averages of the computed joint efficiencies for each type joint tested. It should be noted that calculated joint efficiencies of more than 100 percent were disregarded during the preparation of Table 11. If all values for joint efficiency, as given in Table 11 for the joints tested in both 8- and 10-in.-thick pavements, are considered with respect to pavement thickness, the average joint efficiency for the joints in the 8- and 10-in.-thick pavements are 91.7 and 92.7 percent, respectively. The fact that greater joint efficiency was calculated for the joints in the 10-in.-thick pavement than for the joints in the 8-in.-thick pavement is probably due to tightness of the joint resulting in more area for aggregate interlock.

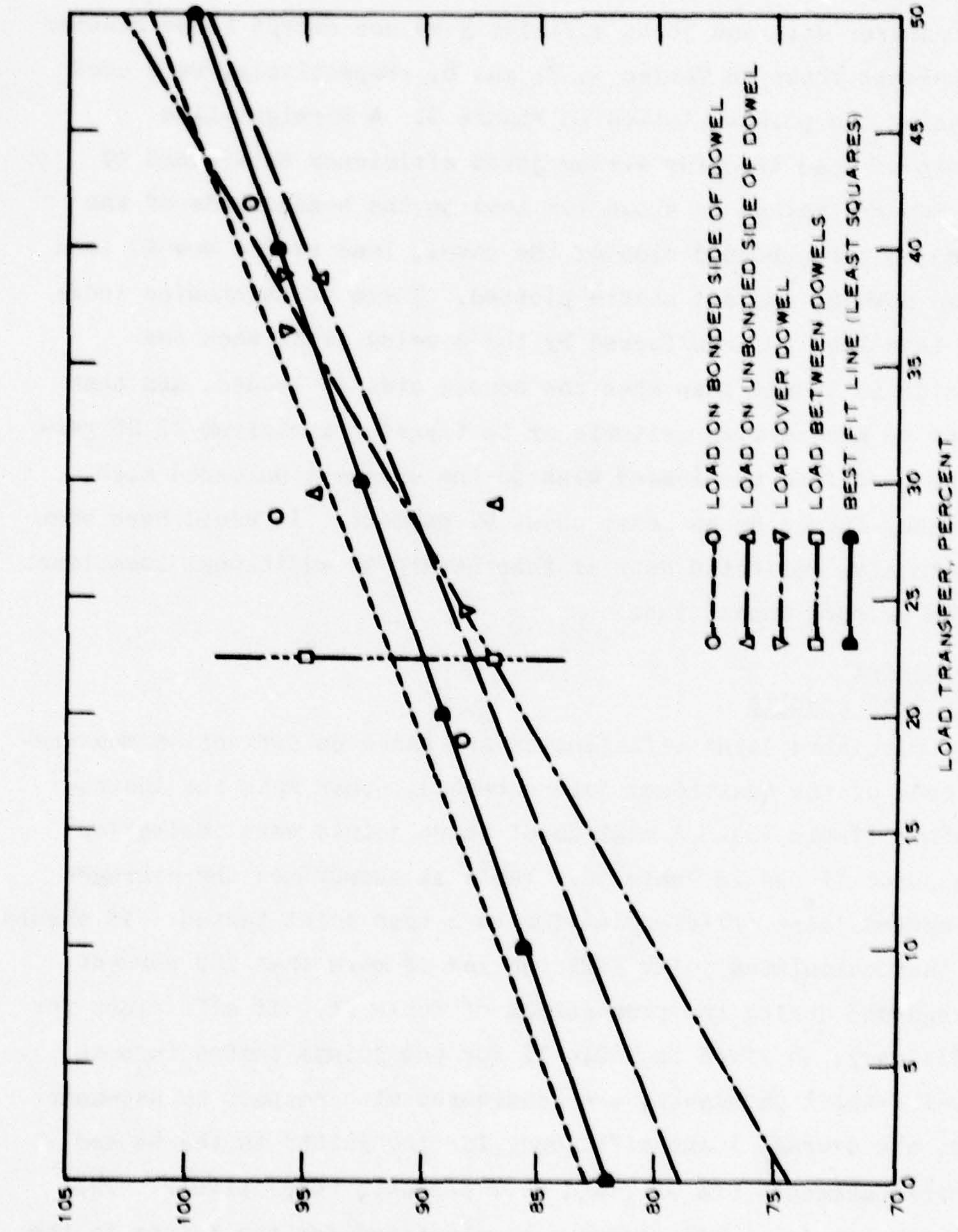

Figure 5. Load transfer versus joint efficiency effect of relative positions of load and side of dowel

43. If all values of joint efficiency, as given in Table 11, are considered with respect only to joint type, the most and least efficient joints would be the doweled transverse R-1 and thickened edge joints, respectively. It should be noted that although the thickened edge-type joint is not a load transfer device, in some instances (see TM 5-824-3/AFM 88-6, Chapter 3) it is permitted in lieu of load transfer-type joints. The average of all joint efficiency values excluding the thickened edge efficiency values was 92.9 percent; however, the efficiency of the doweled transverse R-1 joint was 97.6 percent, and the efficiency of the doweled transverse construction joint was 89.5 percent. No signs of distress were observed during the testing of these joints. It would have been desirable to have collected data of this nature at additional locations in order to be more conclusive.

### Effect of temperature

44. In evaluating the load transfer or joint efficiency characteristics of the joints studied in these tests, cognizance should be taken of the prevailing temperature during which the tests were conducted. During the field tests on the newly constructed PCC pavement at Tyndall AFB, and for several days preceding these tests, the temperature had ranged between 55° and 85°F. This was sufficiently warm so that all joints tested were reasonably tight. If the temperature had been significantly lower, such that contraction of the slab would have resulted in joint opening of 1/8 in. or more, it is possible that the observed values of load transfer and joint efficiency would have been less than the values reported herein.

45. If the average values of load transfer, as given in Table 9 and computed for the same type of dowel installation, are considered with respect only to air temperature, the average values for load transfer for dowels installed by the "split dowels" method and tested at air temperatures of 40° to 65°F and 65° to 90°F are 10.5 and 32.0 percent, respectively. Also, as can be determined from Table 9, a low average load transfer value of 16.7 percent is indicated for the doweled joint constructed by the "cast-in-place" method and tested when the air temperature was between -8° and 20°F.

## PART IV: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

46. Based on the results of the tests reported herein, the following conclusions are believed warranted:

a. The average total strain measured with one gage per gage group on both sides of the doweled joint and with the load wheel positioned on the gage group (the resulting load wheel/single gage position relationship was similar to that obtained during joint tests performed in the 1950's) was the same as the maximum theoretical strain for loading at a free edge of the pavement.

b. Total strain measurements for the same load wheel/gage relationship as in a on the unbonded side of the dowels exceeded total strain measurements for loadings on the bonded side of the dowels by 5 percent.

c. For all doweled joint tests, an average value of load transfer of 30.4 percent was obtained when the data were taken as in a above for the dowels installed by the "drilled and grout-in-place" procedure and for the condition of closed joints.

d. The average value of load transfer calculated using all test data (loadings adjacent to and on top of the gage groups and recording the strains from one gage per gage group) was essentially the same as that calculated from only the data that were recorded when the load wheel/gage position relationship was similar to that obtained during joint tests performed in the 1950's, 31.2 and 30.4 percent, respectively.

e. For tests with the load wheel on the bonded side of the dowel only, the average value of load transfer was 30.8 percent.

f. For tests with the load wheel on the unbonded side of the dowel only, the average value of load transfer was 31.6 percent.

g. For tests with the load wheel positioned directly over a dowel only, the average value of load transfer was 32.7 percent.

h. For tests with the load wheel positioned midway between adjacent dowels only, the average value of load transfer was 29.4 percent.

i. The average values of load transfer calculated for the three different test areas ranged from 24.8 to 40.2 percent.

j. The joint efficiencies calculated at the instrumented joints produced generally the same results qualitatively as did the load transfers calculated from the strain measurements; however, the joint efficiency number or ratings have little quantitative significance at this time and should be used for comparison only.

k. Use of the "drilled and grouted-in-place" procedure for the installation of doweled longitudinal construction joints in the pavement test areas described herein gave an average indicated value of load transfer somewhat greater than the minimum assumed in the design criteria.

l. The relatively high degree of inconsistency of average load transfer values for the three test areas was attributed to the epoxy resin not completely filling the annular space between the dowel and the drilled dowel and/or poor quality control during construction.

m. For pavements 8 in. thick, current doweled joint criteria regarding the required dowel diameter and dowel spacing appear adequate.

n. Based on the deflection tests performed on the additional joints tested and the load transfer versus joint efficiency relationship determined for the instrumented doweled longitudinal joints, all additional joint types tested except the thickened edge joint had an average indicated value of load transfer greater than the minimum assumed in the design criteria.

o. Generally, the average load transfer values of doweled joints tested at low pavement temperatures were less than those constructed in the same manner and tested at higher pavement temperatures.

## Recommendations

47. Based on the qualitative joint efficiency results obtained and the speed at which joints can be tested with the WES 16-kip vibrator, it is recommended that studies be initiated to determine the quantitative significance of "joint efficiency" and to develop a standard joint test procedure using the WES 16-kip vibrator.

48. Based on the findings of these tests, it is recommended that no changes in dowel joint design be made at this time; however, improved

techniques should be developed for bonding the dowel into the dowel socket.

49. Indications are that pavement temperature has a great effect on the load transfer capability of joints; therefore, it is recommended that tests be performed to determine the relationship between pavement temperature and joint efficiency.

Table 1

**Strain Measurements for Loading Adjacent to a Gage Group and on the Bonded Side of the Dowel**

| Load Position Gage Group No. | Strain Gage Group No. | Number of Gages Read | Gage Group Position OD/BD* | Measured Strain $\times 10^{-6}$ in./in. | Total Strain $\times 10^{-6}$ in./in. |
|---|---|---|---|---|---|
| 1 | 1 | 1 | OD | 28 | 36 |
| 1 | 2 | 1 | OD | 8 | |
| 3 | 3 | 1 | BD | 33 | 41 |
| 3 | 4 | 1 | BD | 8 | |
| 6 | 6 | 1 | OD | 38 | 66 |
| 6 | 5 | 1 | OD | 28 | |
| 8 | 8 | 1 | BD | 39 | 65 |
| 8 | 7 | 1 | BD | 26 | |
| 10 | 10 | 1 | OD | 31 | 49 |
| 10 | 9 | 1 | OD | 18 | |
| 12 | 12 | 1 | BD | 40 | 52 |
| 12 | 11 | 1 | BD | 12 | |
| | | | | | Average 52 |
| 1 | 1 | 4 | OD | 30 | 38 |
| 1 | 2 | 4 | OD | 8 | |
| 3 | 3 | 4 | BD | 47 | 58 |
| 3 | 4 | 4 | BD | 11 | |
| 6 | 6 | 4 | OD | -- | -- |
| 6 | 5 | 4 | OD | 13 | |
| 8 | 8 | 4 | BD | -- | -- |
| 8 | 7 | 4 | BD | 14 | |
| 10 | 10 | 4 | OD | 20 | 35 |
| 10 | 9 | 4 | OD | 15 | |
| 12 | 12 | 4 | BD | 39 | 53 |
| 12 | 11 | 4 | BD | 14 | |
| | | | | | Average 46 |

*OD - over dowel; BD - between dowels.

Table 2

Strain Measurements for Loading on Top of a Gage Group and on the Bonded Side of the Dowel

| Load Position Gage Group No. | Strain Gage Group No. | Number of Gages Read | Gage Group Position OD/BD* | Measured Strain x $10^{-6}$ in./in. | Total Strain x $10^{-6}$ in./in. |
|---|---|---|---|---|---|
| 1 | 1 | 1 | OD | 65 | 77 |
| 1 | 2 | 1 | OD | 12 | |
| 3 | 3 | 1 | BD | -- | -- |
| 3 | 4 | 1 | BD | 18 | |
| 6 | 6 | 1 | OD | 55 | 98 |
| 6 | 5 | 1 | OD | 43 | |
| 8 | 8 | 1 | BD | 59 | 97 |
| 8 | 7 | 1 | BD | 38 | |
| 10 | 10 | 1 | OD | 52 | 84 |
| 10 | 9 | 1 | OD | 32 | |
| 12 | 12 | 1 | BD | 86 | 105 |
| 12 | 11 | 1 | BD | 19 | |
| | | | | | Average 92 |
| 1 | 1 | 4 | OD | 97 | 114 |
| 1 | 2 | 4 | OD | 17 | |
| 3 | 3 | 4 | BD | 64 | 79 |
| 3 | 4 | 4 | BD | 15 | |
| 6 | 6 | 4 | OD | -- | -- |
| 6 | 5 | 4 | OD | 22 | |
| 8 | 8 | 4 | BD | 27 | 48 |
| 8 | 7 | 4 | BD | 21 | |
| 10 | 10 | 4 | OD | -- | -- |
| 10 | 9 | 4 | OD | -- | |
| 12 | 12 | 4 | BD | 111 | 129 |
| 12 | 11 | 4 | BD | 18 | |
| | | | | | Average 93 |

*OD - over dowel; BD - between dowels

Table 3

## Strain Measurements for Loading Adjacent to a Gage Group and on the Unbonded Side of the Dowel

| Load Position Gage Group No. | Strain Gage Group No. | Number of Gages Read | Gage Group Position OD/BD* | Measured Strain $\times 10^{-6}$ in./in. | Total Strain $\times 10^{-6}$ in./in. |
|---|---|---|---|---|---|
| 2 | 2 | 1 | OD | 29 | 40 |
| 2 | 1 | 1 | OD | 11 | |
| 4 | 4 | 1 | BD | 29 | 35 |
| 4 | 3 | 1 | BD | 6 | |
| 5 | 5 | 1 | OD | 32 | 60 |
| 5 | 6 | 1 | OD | 28 | |
| 7 | 7 | 1 | BD | 33 | 62 |
| 7 | 8 | 1 | BD | 29 | |
| 9 | 9 | 1 | OD | 37 | 54 |
| 9 | 10 | 1 | OD | 17 | |
| 11 | 11 | 1 | BD | 40 | 56 |
| 11 | 12 | 1 | BD | 16 | |
| | | | | | Average 51 |
| 2 | 2 | 4 | OD | 22 | 35 |
| 2 | 1 | 4 | OD | 13 | |
| 4 | 4 | 4 | BD | 26 | 33 |
| 4 | 3 | 4 | BD | 7 | |
| 5 | 5 | 4 | OD | -- | -- |
| 5 | 6 | 4 | OD | 12 | |
| 7 | 7 | 4 | BD | -- | -- |
| 7 | 8 | 4 | BD | 15 | |
| 9 | 9 | 4 | OD | 32 | 51 |
| 9 | 10 | 4 | OD | 19 | |
| 11 | 11 | 4 | BD | 52 | 69 |
| 11 | 12 | 4 | BD | 17 | |
| | | | | | Average 47 |

*OD - over dowel; BD - between dowels

Table 4

## Strain Measurements for Loading on Top of a Gage Group and on the Unbonded Side of the Dowel

| Load Position Gage Group No. | Strain Gage Group No. | Number of Gages Read | Gage Group Position OD/BD* | Measured Strain $\times 10^{-6}$ in./in. | Total Strain $\times 10^{-6}$ in./in. |
|---|---|---|---|---|---|
| 2 | 2 | 1 | OD | 49 | 73 |
| 2 | 1 | 1 | OD | 24 | |
| 4 | 4 | 1 | BD | 40 | 65 |
| 4 | 3 | 1 | BD | 25 | |
| 5 | 5 | 1 | OD | 137 | 177 |
| 5 | 6 | 1 | OD | 40 | |
| 7 | 7 | 1 | BD | -- | -- |
| 7 | 8 | 1 | BD | 43 | |
| 9 | 9 | 1 | OD | 52 | 77 |
| 9 | 10 | 1 | OD | 25 | |
| 11 | 11 | 1 | BD | 72 | 93 |
| 11 | 12 | 1 | BD | 21 | |
| | | | | | Average 97 |
| 2 | 2 | 4 | OD | -- | -- |
| 2 | 1 | 4 | OD | 19 | |
| 4 | 4 | 4 | BD | -- | -- |
| 4 | 3 | 4 | BD | 17 | |
| 5 | 5 | 4 | OD | -- | -- |
| 5 | 6 | 4 | OD | 17 | |
| 7 | 7 | 4 | BD | -- | -- |
| 7 | 8 | 4 | BD | 23 | |
| 9 | 9 | 4 | OD | -- | -- |
| 9 | 10 | 4 | OD | -- | |
| 11 | 11 | 4 | BD | -- | -- |
| 11 | 12 | 4 | BD | -- | |
| | | | | | Average -- |

*OD - over dowel; BD - between dowels

Table 5

Comparison of Theoretical and Experimental Single-Gage Strains

| | | Loading Adjacent to a Gage Group | | Loading on Top of a Gage Group | |
|---|---|---|---|---|---|
| Location | Theoretical Strain x $10^{-6}$ in./in. (A) | Measured Strain x $10^{-6}$ in./in. (B) | Percent Theoretical Strain (B/A) | Measured Strain x $10^{-6}$ in./in. (C) | Percent Theoretical Strain (C/A) |
| Loaded side to joint | 71 (75)* | 34 (67)* | 48 | 67 (71)* | 94 |
| Unloaded side of joint | 24 (25)* | 17 (33)* | 71 | 28 (29)* | 117 |
| Total strain of joint | 95 | 51 | 54 | 95 | 100 |

* The number in parentheses represents percent of total strain.

## Table 6

## Joint Deflection Test Results

| Load Plate Position Gage Group No. | Gage Group Position OD/BD* | Dynamic Load lb | Deflection, in. | | | | Joint Efficiency Percent (D/C) |
|---|---|---|---|---|---|---|---|
| | | | Center Of Plate (A) | 8-in. From Plate (B) | 24-in. From Plate (C) | 24-in. From Plate Opposite Side (D) | |
| 1** | OD | 5,172 | 0.001606 | 0.001260 | 0.000999 | 0.000864 | 86.5 |
| 1** | OD | 7,571 | 0.002293 | 0.001773 | 0.001399 | 0.001239 | 88.6 |
| 2† | OD | 5,071 | 0.001483 | 0.001253 | 0.000954 | 0.000864 | 90.6 |
| 2† | OD | 7,495 | 0.002177 | 0.001845 | 0.001424 | 0.001233 | 86.6 |
| 3** | BD | 5,142 | 0.001520 | 0.001296 | 0.000989 | 0.000873 | 88.3 |
| 3** | BD | 7,638 | 0.002163 | 0.001887 | 0.001429 | 0.001284 | 89.9 |
| 4† | BD | 5,146 | 0.001599 | 0.001319 | 0.001113 | 0.000955 | 85.8 |
| 4† | BD | 7,678 | 0.002333 | 0.001920 | 0.001590 | 0.001340 | 84.3 |
| | | | | | | Avg | 87.6 |
| 5† | OD | 5,287 | 0.002030 | 0.001792 | 0.001500 | 0.001410 | 94.0 |
| 5† | OD | 7,648 | 0.003032 | 0.002756 | 0.002280 | 0.002155 | 94.5 |
| 6** | OD | 5,260 | 0.001969 | 0.001799 | 0.001416 | 0.001390 | 98.2 |
| 6** | OD | 7,649 | 0.002884 | 0.002679 | 0.002137 | 0.002059 | 96.4 |
| 7† | BD | 5,146 | 0.002060 | 0.001824 | 0.001423 | 0.001487 | 104.5 |
| 7† | BD | 7,740 | 0.003170 | 0.002813 | 0.002186 | 0.002313 | 105.8 |
| 8** | BD | 5,114 | 0.001959 | 0.001749 | 0.001424 | 0.001439 | 101.1 |
| 8** | BD | 7,615 | 0.002969 | 0.002649 | 0.002129 | 0.002172 | 102.0 |
| | | | | | | Avg | 99.6 |
| 9† | OD | 5,185 | 0.001972 | 0.001756 | 0.001407 | 0.001320 | 93.8 |
| 9† | OD | 7,664 | 0.002957 | 0.002639 | 0.002156 | 0.001983 | 92.0 |
| 10** | OD | 5,139 | 0.001839 | 0.001406 | 0.001124 | 0.001124 | 100.0 |
| 10** | OD | 8,222 | 0.002920 | 0.002172 | 0.001789 | 0.001745 | 97.5 |
| 11† | BD | 5,220 | 0.002278 | 0.001910 | 0.001479 | 0.001425 | 96.3 |
| 11† | BD | 7,672 | 0.003500 | 0.002882 | 0.002239 | 0.002159 | 96.4 |
| 12** | BD | 5,207 | 0.001776 | 0.001515 | 0.002161 | 0.001189 | 94.3 |
| 12** | BD | 7,561 | 0.002526 | 0.002170 | 0.001851 | 0.001719 | 92.9 |
| | | | | | | Avg | 95.4 |

* OD - over dowel; BD - between dowels.

** Bonded side of dowel.

† Unbonded side of dowel.

## Table 7

### Load-Transfer for Load on Bonded Side of the Dowel

| Load Position Gage Group No. | Gage Group Position OD/BD* | Load-Transfer, % Loading Adjacent to a Gage Group 1** | Load-Transfer, % Loading on Top of a Gage Group 1** |
|---|---|---|---|
| 1 | OD | 22.2 | 15.6 |
| 3 | BD | 19.5 | -- |
| 6 | OD | 42.4 | 43.9 |
| 8 | BD | 40.0 | 39.2 |
| 10 | OD | 36.7 | 38.1 |
| 12 | BD | 23.1 | 18.1 |

* OD - over dowel; BD - between dowels.

** Number of gages per gage group read during testing.

## Table 8

## Load-Transfer for Load on Unbonded Side of the Dowel

| Load Position Gage Group No. | Gage Group Position OD/BD* | Load-Transfer, % | |
|---|---|---|---|
| | | Loading Adjacent to a Gage Group | Loading on Top of a Gage Group |
| | | 1** | 1** |
| 2 | OD | 27.5 | 32.9 |
| 4 | BD | 17.1 | 38.5 |
| 5 | OD | 46.7 | 22.6 |
| 7 | BD | 46.8 | -- |
| 9 | OD | 31.5 | 32.5 |
| 11 | BD | 28.6 | 22.6 |

* OD - over dowel; BD - between dowels.

** Number of gages per gage group read during testing.

Table 9

Summary of Load Transfer Data for Doweled Joints Tested in the 1950's

| Location (Temperature During) Testing, °F | Method of Dowel Installation | Modulus of Soil Reaction, k lb/cu in. | Flexural Strength psi | Slab Size ft | Pavement Thickness in. | Dowel Size Diameter x Length in. | Dowel Spacing C to C in. | Load Position Gage No. | Gage Position | Load Transfer % | Average Load Transfer of the Joint % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lockborne AFB, OH<br>(-8 to 20) | Cast in place | 75 | 680 | 25 x 25 | 12 | 1 x 20 | 15 | 1* | OD† | -- | 16.7 |
| | | | | | | | | 3* | BD† | 17.9 | |
| | | | | | | | | 5* | OD | 22.8 | |
| | | | | | | | | 7* | BD | 23.7 | |
| | | | | | | | | 9* | OD | -- | |
| | | | | | | | | 11* | BD | -- | |
| | | | | | | | | 13* | OD | 9.9 | |
| | | | | | | | | 15* | BD | 11.1 | |
| | | | | | | | | 2** | OD | 17.6 | |
| | | | | | | | | 4** | BD | 16.1 | |
| | | | | | | | | 6** | OD | 22.2 | |
| | | | | | | | | 8** | BD | -- | |
| | | | | | | | | 10** | OD | 16.2 | |
| | | | | | | | | 12** | BD | -- | |
| | | | | | | | | 14** | OD | 8.4 | |
| | | | | | | | | 16** | BD | 7.4 | |
| Lincoln AFB, NE<br>(60 to 80) | Cast in place | 65 | 675 | 25 x 22 to 25 | 21 | 1.5 x 20 | 10 | 2* | BD | 27.8 | 36.5 |
| | | | | | | | | 4* | OD | 50.0 | |
| | | | | | | | | 6* | BD | 31.3 | |
| | | | | | | | | 8* | OD | 35.0 | |
| | | | | | | | | 10* | BD | 27.8 | |
| | | | | | | | | 12* | OD | 29.4 | |
| | | | | | | | | 14* | BD | 42.8 | |
| | | | | | | | | 16* | OD | 28.6 | |
| | | | | | | | | 1** | BD | 37.5 | |
| | | | | | | | | 3** | OD | 40.0 | |
| | | | | | | | | 5** | BD | 42.9 | |
| | | | | | | | | 7** | OD | 42.8 | |
| | | | | | | | | 9** | BD | 31.3 | |
| | | | | | | | | 11** | OD | 35.0 | |
| | | | | | | | | 13** | BD | 37.4 | |
| | | | | | | | | 15** | OD | 44.4 | |
| Hunter AFB, GA<br>(60 to 80) | Remove and replace | 175 | 715 | 25 x 25 | 18 | 1.5 x 20 | 18 | 2* | BD | -- | 27.4 |
| | | | | | | | | 4* | OD | 42.1 | |
| | | | | | | | | 6* | BD | 33.3 | |
| | | | | | | | | 8* | OD | 27.8 | |
| | | | | | | | | 10* | BD | 24.0 | |
| | | | | | | | | 12* | OD | 35.3 | |
| | | | | | | | | 14* | BD | 18.2 | |
| | | | | | | | | 16* | OD | 24.0 | |
| | | | | | | | | 1** | BD | 23.5 | |
| | | | | | | | | 3** | OD | 26.3 | |
| | | | | | | | | 5** | BD | 25.0 | |
| | | | | | | | | 7** | OD | 20.0 | |
| | | | | | | | | 9** | BD | 22.2 | |
| | | | | | | | | 11** | OD | 20.0 | |
| | | | | | | | | 13** | BD | 26.7 | |
| | | | | | | | | 15** | OD | 42.9 | |
| McCoy AFB, FL<br>(65 to 85) | Remove and replace | 225 | 670 | 25 x 25 | 18 | 1.5 x 20 | 18 | 2* | BD | 20.0 | 24.4 |
| | | | | | | | | 4* | OD | -- | |
| | | | | | | | | 6* | BD | 30.8 | |
| | | | | | | | | 8* | OD | 35.7 | |
| | | | | | | | | 10* | BD | 25.0 | |
| | | | | | | | | 12* | OD | 21.4 | |
| | | | | | | | | 14* | BD | 23.5 | |
| | | | | | | | | 16* | OD | 23.1 | |
| | | | | | | | | 1** | BD | 14.3 | |
| | | | | | | | | 3** | OD | -- | |
| | | | | | | | | 5** | BD | 26.7 | |
| | | | | | | | | 7** | OD | 19.0 | |
| | | | | | | | | 9** | BD | 15.8 | |
| | | | | | | | | 11** | OD | 25.0 | |
| | | | | | | | | 13** | BD | 25.0 | |
| | | | | | | | | 15** | OD | 33.3 | |

(Continued)

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* Load on bonded side of dowel.

** Load on unbonded side of dowel.

† OD - over dowel; BD - between dowels.

Table 9 (Concluded)

| Location (Temperature During Testing, °F | Method of Dowel Installation | Modulus of Soil Reaction, k lb/cu in. | Flexural Strength psi | Slab Size ft | Pavement Thickness in. | Dowel Size Diameter x Length in. | Dowel Spacing C to C in. | Load Position Gage No. | Gage Position | Load Transfer % | Average Load Transfer of teh Joint % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ellsworth AFB, SD (35 to 65) | Dummy half dowel | 215 | 675 | 20 x 22 | 23 | 2 x 24 | 18 | 1* | BD† | 40.0 | 41.3 |
| | | | | | | | | 3* | OD† | 45.5 | |
| | | | | | | | | 5* | BD | 38.9 | |
| | | | | | | | | 7* | OD | 31.6 | |
| | | | | | | | | 9* | BD | 30.4 | |
| | | | | | | | | 11* | OD | 38.1 | |
| | | | | | | | | 13* | BD | 41.7 | |
| | | | | | | | | 15* | OD | 41.7 | |
| | | | | | | | | 2** | BD | 50.0 | |
| | | | | | | | | 4** | OD | 44.0 | |
| | | | | | | | | 6** | BD | 42.3 | |
| | | | | | | | | 8** | OD | 40.0 | |
| | | | | | | | | 10** | BD | 42.9 | |
| | | | | | | | | 12** | OD | 40.7 | |
| | | | | | | | | 14** | BD | 45.0 | |
| | | | | | | | | 16** | OD | 37.5 | |
| Beale AFB, CA (75 to 105) | Grouted in place | 150 | 642 | 25 x 25 | 25 | 2 x 24 | 17 | 1* | BD | 27.6 | 32.8 |
| | | | | | | | | 3* | OD | 36.9 | |
| | | | | | | | | 5* | BD | 16.7 | |
| | | | | | | | | 7* | OD | 17.4 | |
| | | | | | | | | 9* | BD | -- | |
| | | | | | | | | 11* | OD | 30.8 | |
| | | | | | | | | 13* | BD | 33.3 | |
| | | | | | | | | 15* | OD | 52.1 | |
| | | | | | | | | 2** | BD | 31.0 | |
| | | | | | | | | 4** | OD | 26.3 | |
| | | | | | | | | 6** | BD | 52.3 | |
| | | | | | | | | 8** | OD | 37.5 | |
| | | | | | | | | 10** | BD | 31.8 | |
| | | | | | | | | 12** | OD | 36.4 | |
| | | | | | | | | 14** | BD | 38.5 | |
| | | | | | | | | 16** | OD | 23.5 | |
| Dow AFB, ME (40 to 65) | Split dowels | 350 | 700 | 25 x 25 | 19 | 1.5 x 20 | 18 | 2* | BD | 7.4 | 10.5 |
| | | | | | | | | 4* | OD | 16.7 | |
| | | | | | | | | 6* | BD | 0.0 | |
| | | | | | | | | 8* | OD | 9.1 | |
| | | | | | | | | 10* | BD | 8.3 | |
| | | | | | | | | 12* | OD | 14.8 | |
| | | | | | | | | 14* | BD | 7.7 | |
| | | | | | | | | 16* | OD | 18.6 | |
| | | | | | | | | 1** | BD | 14.1 | |
| | | | | | | | | 3** | OD | 35.7 | |
| | | | | | | | | 5** | BD | 0.0 | |
| | | | | | | | | 7** | OD | 16.0 | |
| | | | | | | | | 9** | BD | 0.0 | |
| | | | | | | | | 11** | OD | 0.0 | |
| | | | | | | | | 13** | BD | 0.0 | |
| | | | | | | | | 15** | OD | 19.2 | |
| March AFB, CA (65 to 90) | Split dowels | 100 | 840 | 25 x 25 | 16 | 1.5 x 20 | 17 | 2* | BD | 42.9 | 32.0 |
| | | | | | | | | 4* | OD | 25.0 | |
| | | | | | | | | 6* | BD | 29.8 | |
| | | | | | | | | 8* | OD | 47.4 | |
| | | | | | | | | 10* | BD | 28.6 | |
| | | | | | | | | 12* | OD | 21.9 | |
| | | | | | | | | 14* | BD | 31.1 | |
| | | | | | | | | 16* | OD | 23.1 | |
| | | | | | | | | 1** | BD | 37.0 | |
| | | | | | | | | 3** | OD | -- | |
| | | | | | | | | 5** | BD | 35.4 | |
| | | | | | | | | 7** | OD | 20.0 | |
| | | | | | | | | 9** | BD | 36.8 | |
| | | | | | | | | 11** | OD | 38.5 | |
| | | | | | | | | 13** | BD | 29.9 | |
| | | | | | | | | 15** | OD | 33.3 | |

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* Load on bonded side of dowel.

** Load on unbonded side of dowel.

† OD - over dowel; BD - between dowels.

Table 10

Joint Deflection Test Results

| Station | Thickness in. | Type Joint | | | | | | | Efficiency % | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Longitudinal Contraction | Transverse Contraction | Doweled Longitudinal Construction | Doweled Transverse Construction | Doweled T-1 | Thickened Edge | Doweled Transverse R-1 | | |
| 75+85 | 8 | | x | | | | | | 90.9 | Paving Lane No. 4 |
| 75+85 | 8 | | x | | | | | | 90.7 | Paving Lane No. 3 |
| 75+85 | 8 | | x | | | | | | 95.9 | Paving Lane No. 2 |
| 75+85 | 8 | | x | | | | | | 88.9 | Paving Lane No. 1 |
| 75+47 | 8 | x | | | | | | | 87.4 | Paving Lane No. 4 |
| 75+62 | 8 | x | | | | | | | 87.2 | Paving Lane No. 4 |
| 75+77 | 8 | x | | | | | | | 86.1 | Paving Lane No. 4 |
| 75+92 | 8 | x | | | | | | | 86.5 | Paving Lane No. 4 |
| 63+75 | 10 | | | | | x | | | 94.9 | South Fillet of T/W & R/W |
| 63+75 | 10 | | | | | x | | | 91.3 | South Fillet of T/W & R/W |
| 63+50 | 10 | | | | | x | | | 94.4 | South Fillet of T/W & R/W |
| 63+81 | 8 | | | | | | x | | 62.8 | Juncture of R/W & T/W |
| 63+68 | 8 | | | | | | x | | 72.3 | Juncture of R/W & T/W |
| 63+43 | 8 | | | | | | x | | 86.2 | Juncture of R/W & T/W |
| 73+75 | 8 | | x | | | | | | 97.9 | Load on Slab No. 5 |
| 73+75 | 8 | | x | | | | | | 98.8 | Load on Slab No. 2 |
| 73+83 | 8 | x | | | | | | | 96.7 | Load on Slab No. 1 |
| 73+68 | 8 | x | | | | | | | 98.4 | Load on Slab No. 2 |
| 73+53 | 8 | x | | | | | | | 100.0 | Load on Slab No. 3 |
| 62+35 | 8 | | x | | | | | | 82.6 | Load on Slab No. 1 |
| 62+35 | 8 | | x | | | | | | 96.5 | Load on Slab No. 4 |
| 62+43 | 8 | x | | | | | | | 89.4 | Load on Slab No. 1 |
| 62+28 | 8 | x | | | | | | | 91.1 | Load on Slab No. 2 |
| 62+13 | 8 | x | | | | | | | 94.2 | Load on Slab No. 3 |
| 46+35 | 8 | | x | | | | | | 87.9 | Load on Slab No. 1 |
| 46+35 | 8 | | x | | | | | | 90.5 | Load on Slab No. 4 |
| 46+43 | 8 | x | | | | | | | 88.3 | Load on Slab No. 1 |
| 46+28 | 8 | x | | | | | | | 86.3 | Load on Slab No. 2 |
| 46+13 | 8 | x | | | | | | | 88.2 | Load on Slab No. 3 |
| 39+40 | 8 | | | | x | | | | 90.2 | Paving Lane No. 3 |
| 39+40 | 8 | | | | x | | | | 90.5 | Paving Lane No. 3 |
| 39+40 | 8 | | | | x | | | | 87.7 | Paving Lane No. 3 |
| 35+12.5 | 10 | | | | x | | | | 91.3 | Paving Lane No. 1 |
| 35+12.5 | 10 | | | | x | | | | 92.2 | Paving Lane No. 1 |
| 35+12.5 | 10 | | | | x | | | | 88.1 | Paving Lane No. 1 |
| 26+15 | 10 | | x | | | | | | 94.7 | Dowel Joint, Lane No. 1 |
| 26+15 | 10 | | x | | | | | | 97.1 | Dowel Joint, Lane No. 2 |
| 26+15 | 10 | | x | | | | | | 90.1 | Dowel Joint, Lane No. 3 |
| 26+15 | 10 | | x | | | | | | 90.4 | Dowel Joint, Lane No. 4 |
| 93+33 | 10 | | | x | | | | | 92.5 | Load on Unbonded Side |
| 88+19 | 10 | | | x | | | | | 97.6 | Load on Bonded Side |
| 83+57 | 8 | | | x | | | | | 97.3 | Load on Unbonded Side |
| 78+44 | 8 | | | x | | | | | 85.5 | Load on Bonded Side |
| 73+45 | 8 | | | x | | | | | 96.8 | Load on Unbonded Side |
| 68+47 | 8 | | | x | | | | | 92.3 | Load on Bonded Side |
| 63+50 | 8 | | | x | | | | | 98.4 | Load on Unbonded Side |
| 58+47 | 8 | | | x | | | | | 93.0 | Load on Bonded Side |
| 53+51 | 8 | | | x | | | | | 89.6 | Load on Unbonded Side |
| 48+42 | 8 | | | x | | | | | 93.0 | Load on Bonded Side |
| 43+45 | 8 | | | x | | | | | 100.0 | Load on Unbonded Side |
| 38+50 | 8 | | | x | | | | | 97.2 | Load on Bonded Side |
| 31+47 | 10 | | | x | | | | | 100.6 | Load on Unbonded Side |
| 28+49 | 10 | | | x | | | | | 82.9 | Load on Bonded Side |
| 86+98 | 10 | x | | | | | | | 91.9 | Paving Lane No. 2 |
| 86+83 | 10 | x | | | | | | | 92.4 | Paving Lane No. 2 |
| 86+68 | 10 | x | | | | | | | 94.3 | Paving Lane No. 2 |
| 86+53 | 10 | x | | | | | | | 93.6 | Paving Lane No. 2 |
| 86+60 | 10 | | x | | | | | | 95.7 | Paving Lane No. 4 |
| 86+60 | 10 | | x | | | | | | 94.4 | Paving Lane No. 3 |
| 86+60 | 10 | | x | | | | | | 90.8 | Paving Lane No. 2 |
| 86+60 | 10 | | x | | | | | | 98.8 | Paving Lane No. 1 |
| 86+00 | 10 | | | | | | | x | 100.0 | Paving Lane No. 1 |
| 86+00 | 10 | | | | | | | x | 100.6 | Paving Lane No. 2 |
| 86+00 | 10 | | | | | | | x | 103.5 | Paving Lane No. 3 |
| 86+00 | 10 | | | | | | | x | 98.4 | Paving Lane No. 4 |
| 86+00 | 10 | | | | | | | x | 102.2 | Paving Lane No. 4 |
| 86+00 | 10 | | | | | | | x | 102.6 | Paving Lane No. 3 |
| 86+00 | 10 | | | | | | | x | 94.4 | Paving Lane No. 2 |
| 86+00 | 10 | | | | | | | x | 104.8 | Paving Lane No. 1 |

## Table 11

## Summary of Joint Efficiency Test Results

| Joint Type | Pavement Thickness in. | Joint Efficiency % |
|---|---|---|
| Longitudinal contraction | 8 | 90.8 |
| | 10 | 93.1 |
| Transverse contraction | 8 | 92.1 |
| | 10 | 94.0 |
| Doweled longitudinal construction | 8 | 94.3 |
| | 10 | 93.3 |
| Doweled transverse construction | 8 | 89.5 |
| | 10 | 90.5 |
| Doweled T-1 | 8 | 93.5 |
| | 10 | -- |
| Thickened edge | 8 | 73.8 |
| | 10 | -- |
| Doweled transverse R-1 | 8 | -- |
| | 10 | 97.6 |

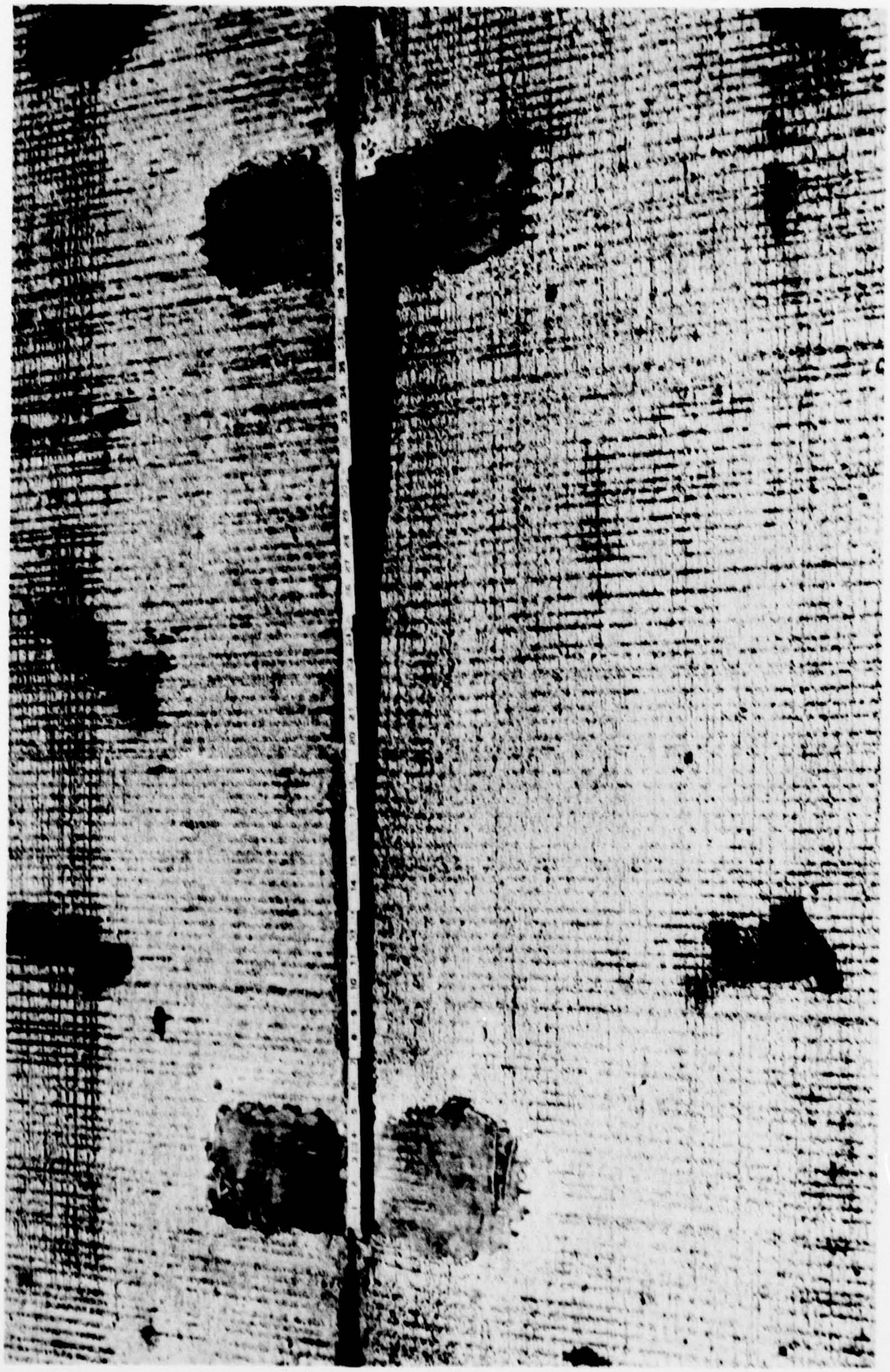

Photo 1. Four gage group locations prior to gage installation

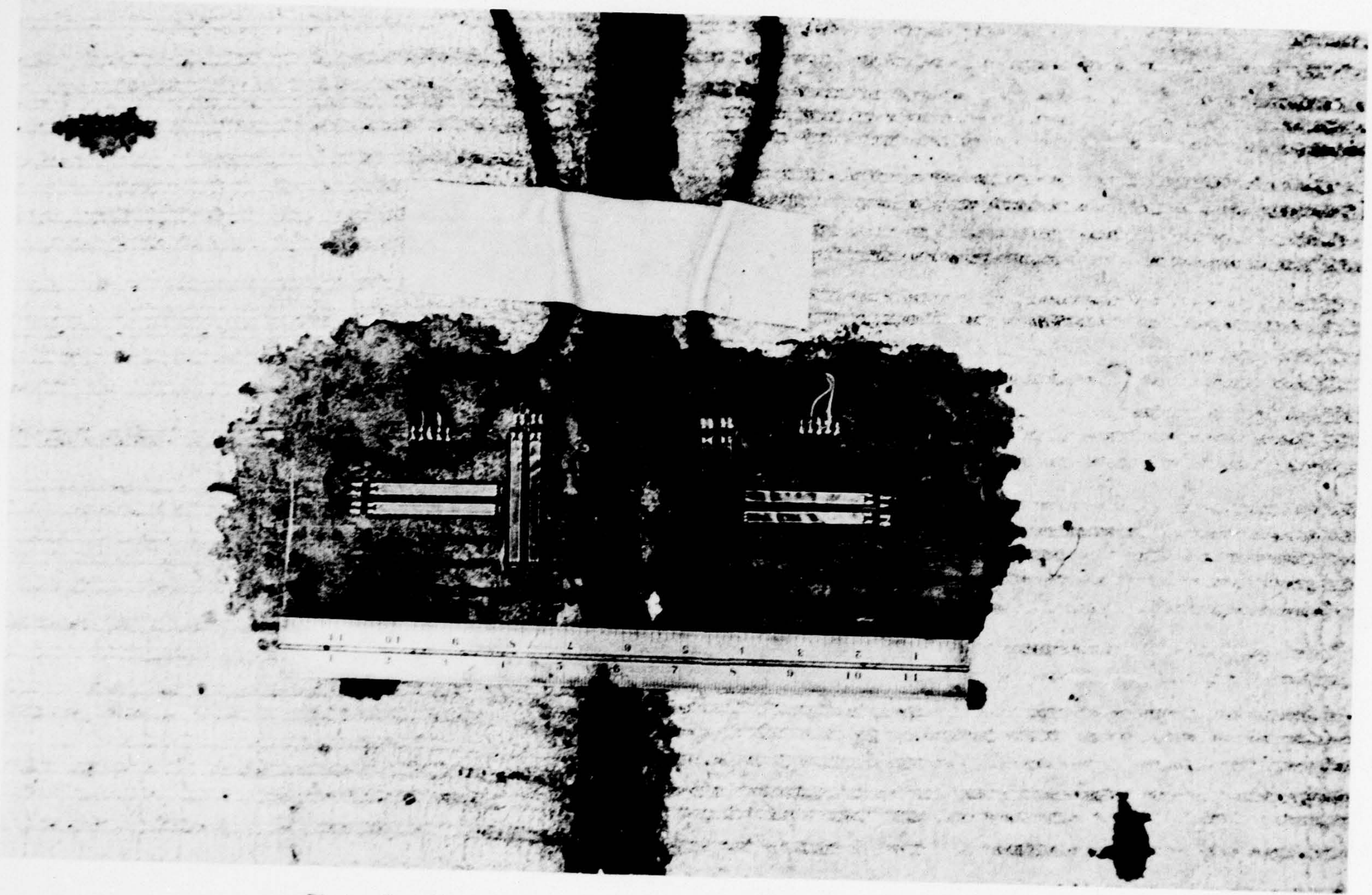

Photo 2. One pair of gage groups after gage installations

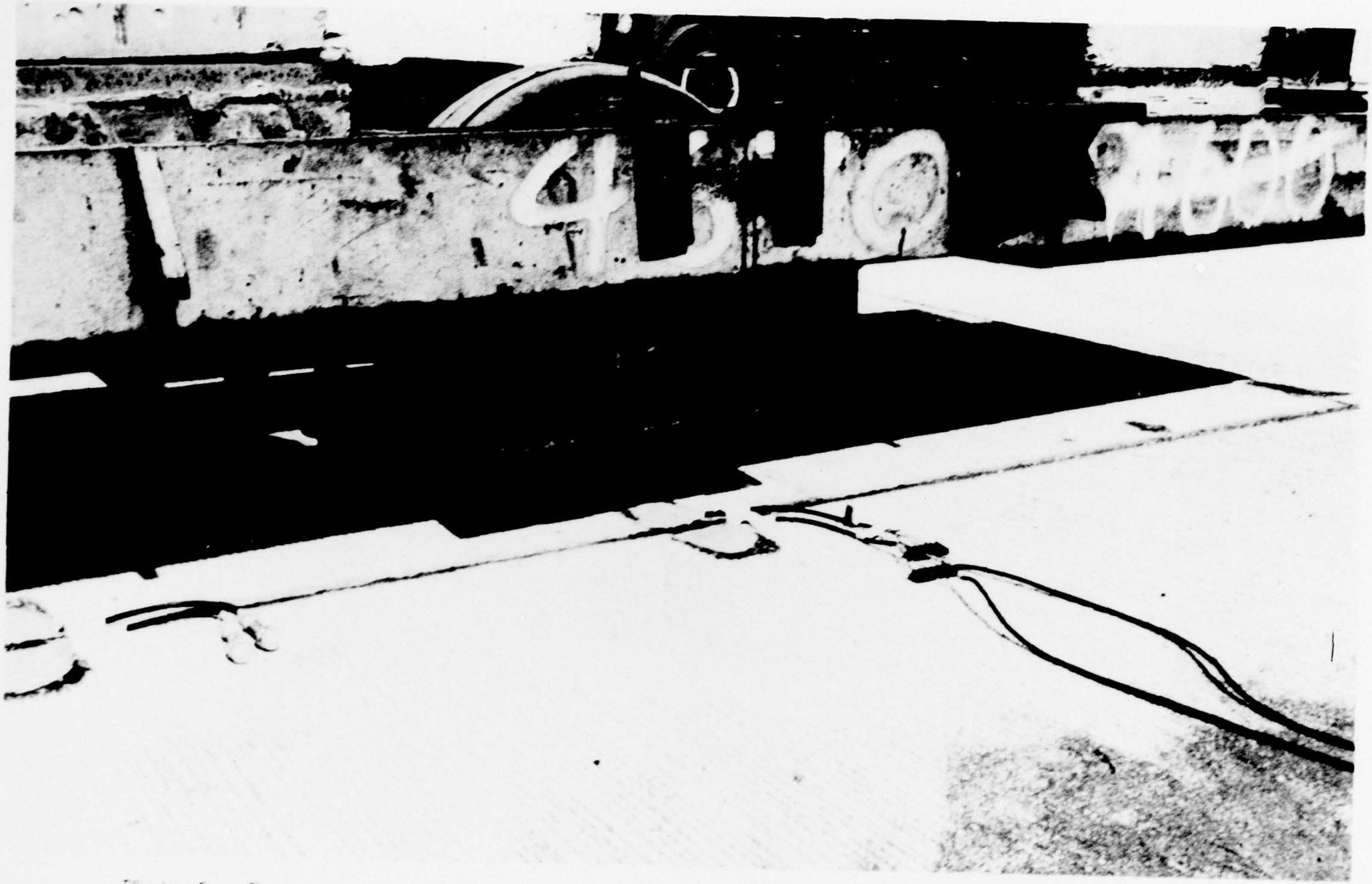

Photo 3. Four gage groups after a protective coating had been applied to the gages and with the load wheel adjacent to a gage group

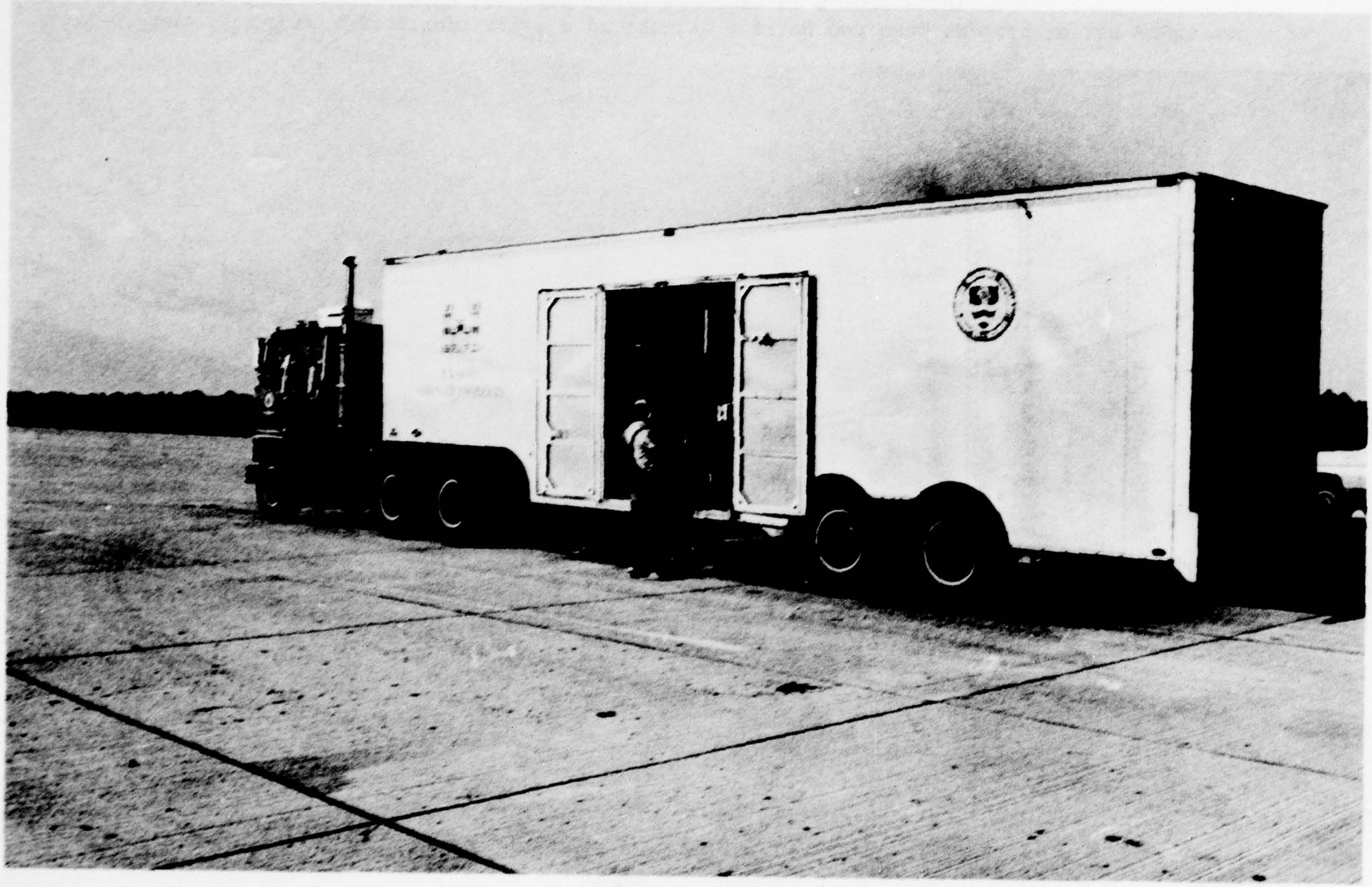

Photo 4. WES 16-kip vibrator

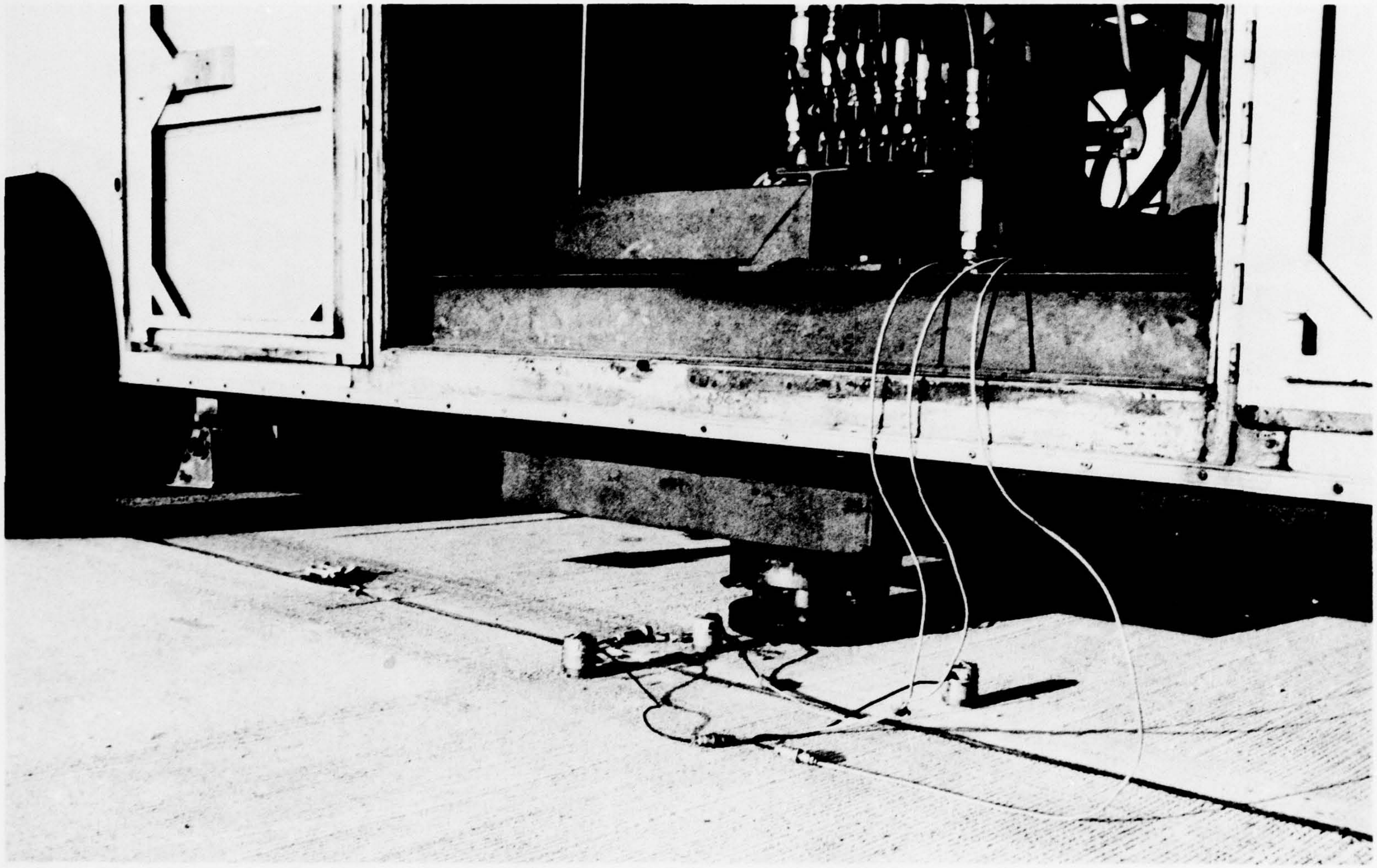

Photo 5. Load plate and deflection pickup orientation with joint during a joint deflection test with 16-kip vibrator

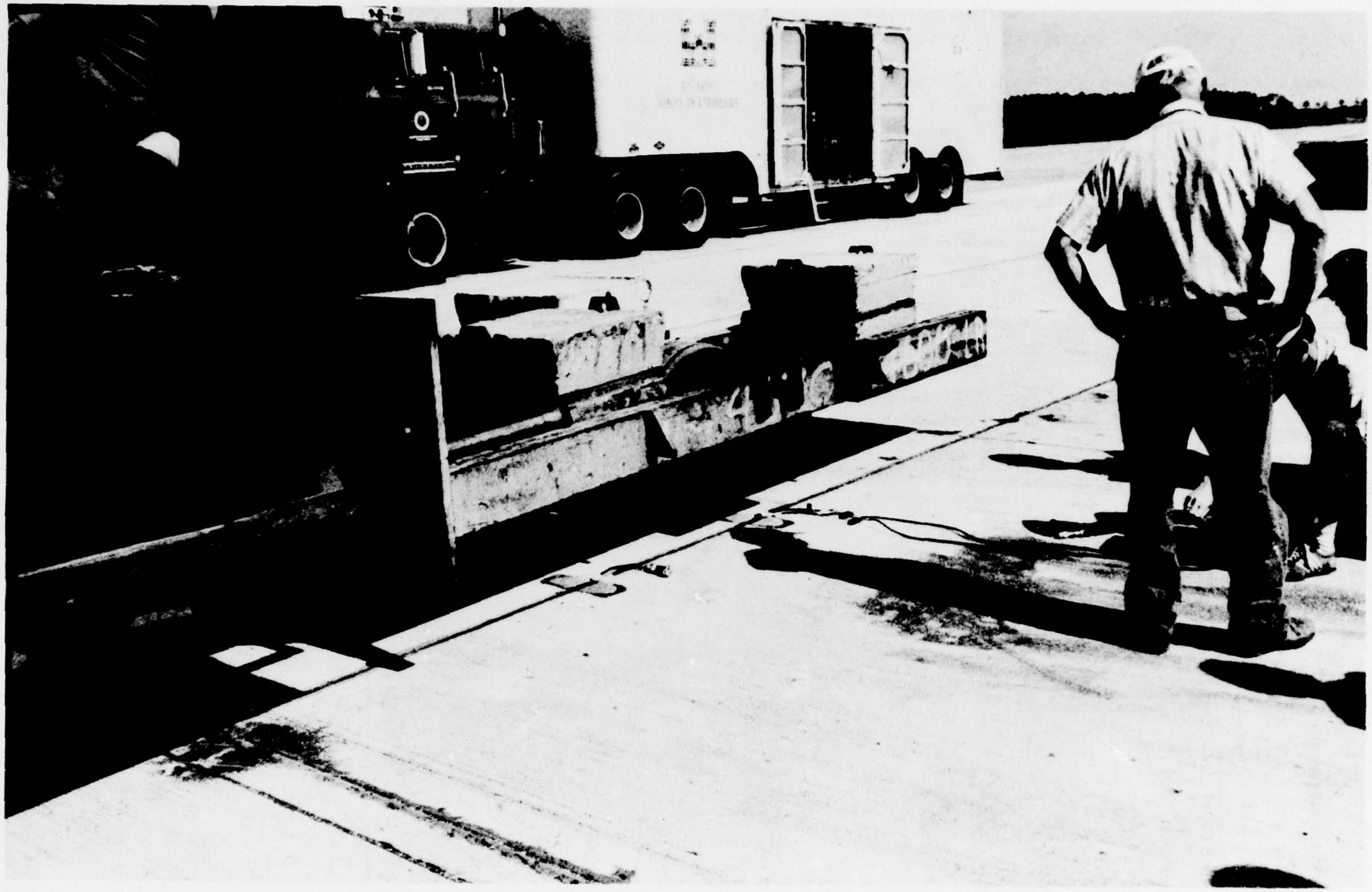

Photo 6. Single-wheel test cart loaded to 15,000 lb

**In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.**

Grau, Robert Walter
Evaluation of drilled and grouted-in-place dowels for
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Force Base, Florida / by Robert W. Grau. Vicksburg, Miss. :
U. S. Waterways Experiment Station ; Springfield, Va. :
available from National Technical Information Service, 1979.
30, [18] p. : ill. ; 27 cm. (Technical report - U. S.
Army Engineer Waterways Experiment Station ; GL-79-11)
Prepared for Office, Chief of Engineers, U. S. Army,
Washington, D. C., under Project/AMS Code 4K07812AQ61/728018.2.

1. Concretes. 2. Dowels. 3. Joints (Junctions). 4. Load
transfer. 5. Portland cements. 6. Tyndall Air Force Base,
Fla. I. United States. Army. Corps of Engineers. II. Series:
United States. Waterways Experiment Station, Vicksburg,
Miss. Technical report ; GL-79-11.
TA7.W34 no.GL-79-11