estimate can be made of the role played by excess depth in full-scale scour phenomena.

CONCLUSIONS

Although no specific shape can as yet be recommended, the general principles which will govern the design of piers for minimum scour are becoming evident. The primary criterion is that the pier should present the minimum flow obstruction. The minimum flow obstruction may be approached both by streamlining the shape and by using the smallest pier-size structurally reliable. This also implies the careful alignment of solid or webbed piers with the flow. The possibility of inhibiting scour with arrestors such as described is dependent on the designer's ability to predict the scour depth with considerable certainty. However, their use may be justified if only as a safety device. The course of future studies on shape will depend partly on the results of the other phases of the laboratory investigation and partly on information on the structural and constructional requirements of piers.

The laboratory investigation of the second phase of the program has revealed that for any pier in steady flow there is an equilibrium depth of scour which increases with increasing depth of flow but is not affected appreciably by a change in velocity. Under unsteady flow conditions, however, excess depths may be attained, because of an apparent lag in the establishment of transport equilibrium. This study is being repeated with an improved, recording version of the scour meter and a coarser sand. The range of the investigation of the second phase will thereby be extended and the study of the third phase, sediment characteristics, initiated. The recording feature of the scour meter will also be employed in exploratory investigations of unsteady flow conditions.

STRUCTURAL BEHAVIOR OF HEAVY-DUTY-CONCRETE AIRFIELD PAVEMENTS

R. R. Philippe, *Chief of the Soils and Cryology Branch Office, Chief of Engineers,* and F. M. Mellinger, *Technical Director, Ohio River Division Laboratories, Corps of Engineers, U. S. Army*

SYNOPSIS

The Corps of Engineers test program of full-scale concrete pavements, described initially in the 1944 Highway Research Board Proceedings (*4*), is brought up to date in this paper. Accelerated traffic tests have been completed on two full-scale test pavements. The traffic loadings applied were 150,000 lb. with a single wheel and with a four-wheel or twin-tandem-gear configuration. In the case of the single-wheel loading, the test pavement officially designated as Lockbourne No. 2 Experimental Mat is described in the referenced paper, and only limited results of these tests are given in this paper. A complete description of the test pavements for the multiple or twin-tandem-wheel loading is presented. The test results given include the crack-pattern development on these pavements, as well as strain and deflection measurements at selected intervals throughout the traffic loading. This latter is officially designated as Lockbourne No. 2 Modification, Multiple-Wheel Study. Comparative strains produced in a 20-in. thick pavement are given for the single and multiple loadings. Finally, results of all accelerated traffic tests obtained throughout the program are summarized on a chart showing tentatively the percent of design thickness required for a given number of load repetitions.

• The test program up to 1944 has been reviewed by Philippe (*4*). This review carries through the design and construction of the Lockbourne No. 2 Experimental Mat, which was completed in December 1944. The accelerated traffic tests of these test pavements under the 150,000-lb. single-wheel traffic were completed in January 1948. About the time these tests were well under way, in December 1945, the Air Force changed to a multiple-

wheel-gear configuration on their heaviest bomber, the B-36. This was a twin-tandem arrangement of four wheels on each main gear, where previously the 150,000-lb. loading on this gear had been carried by a single 110-in.-diameter tire and wheel (see Fig. 2b). Accordingly, at this time an investigation of the effect of multiple-wheel loading produced by heavy aircraft was initiated by the chief of engineers. The problem was to determine the effective reduction of stress provided by the better distribution of load on the pavement by the four wheels of the twin-tandem gear as compared to that of a single wheel carrying a similar load. This more advantageous distribution would naturally reduce to some degree the thickness of pavement required. Early results from the traffic tests with the single-wheel loading on the Lockbourne No. 2 Experimental Mat were used in selecting pavement designs for the multiple-wheel study. Plain concrete pavements 12, 15, and 20 in. thick on natural subgrade similar to slabs in the experimental mat were used. This new test section was designated Lockbourne No. 2 Modification and located adjacent to the experimental mat. Design and Construction of the modification was completed in October 1946, and the accelerated traffic tests with the multiple-wheel loading were run between February 1948 and May 1949.

TESTS AND TEST DESIGNS

Lockbourne No. 2 Modification. A layout of this test pavement is shown in Figure 1. The test pavement consists of three basic designs. The first, the 12-in. slabs are 12 in number located by the letter coördinates P, Q, R, and S and numbers 0, 1, and 2. The test slabs are 25 ft. square, separated longitudinally by a doweled construction joint and a keyed construction joint, and transversely by a plain dummy contraction joint, a doweled dummy joint, a plain dummy contraction joint and a final separation from the transition slabs by a doweled expansion joint. The transition slab effects the change in pavement thickness from 12 to 15 in. A similar pattern is followed for the twelve 15- and 20-in. thick pavement slabs.

The layout and details of the installations for the deflection gages are also shown in Figure 1. The deflection gages used were of the electric type with oscillograph circuits designed to record dynamic deflection under moving wheel loads. These gages were removable and placed in the pavements only at the time measurements were being made. A more complete description of these gages is given in the references (*2*, *3*).

A total of 38 Carlson strain meters (*1*) were installed in the pavements of the modification. These meters were installed in pairs at 1.5 in. from the top and bottom of the test slabs. These pairs were located at the interiors of the pavement slabs and along the edges or joints. During measurements, these meters were tied into recording oscillograph circuits and a complete recording of strain was made as the wheel load approached, passed over and left the meter.

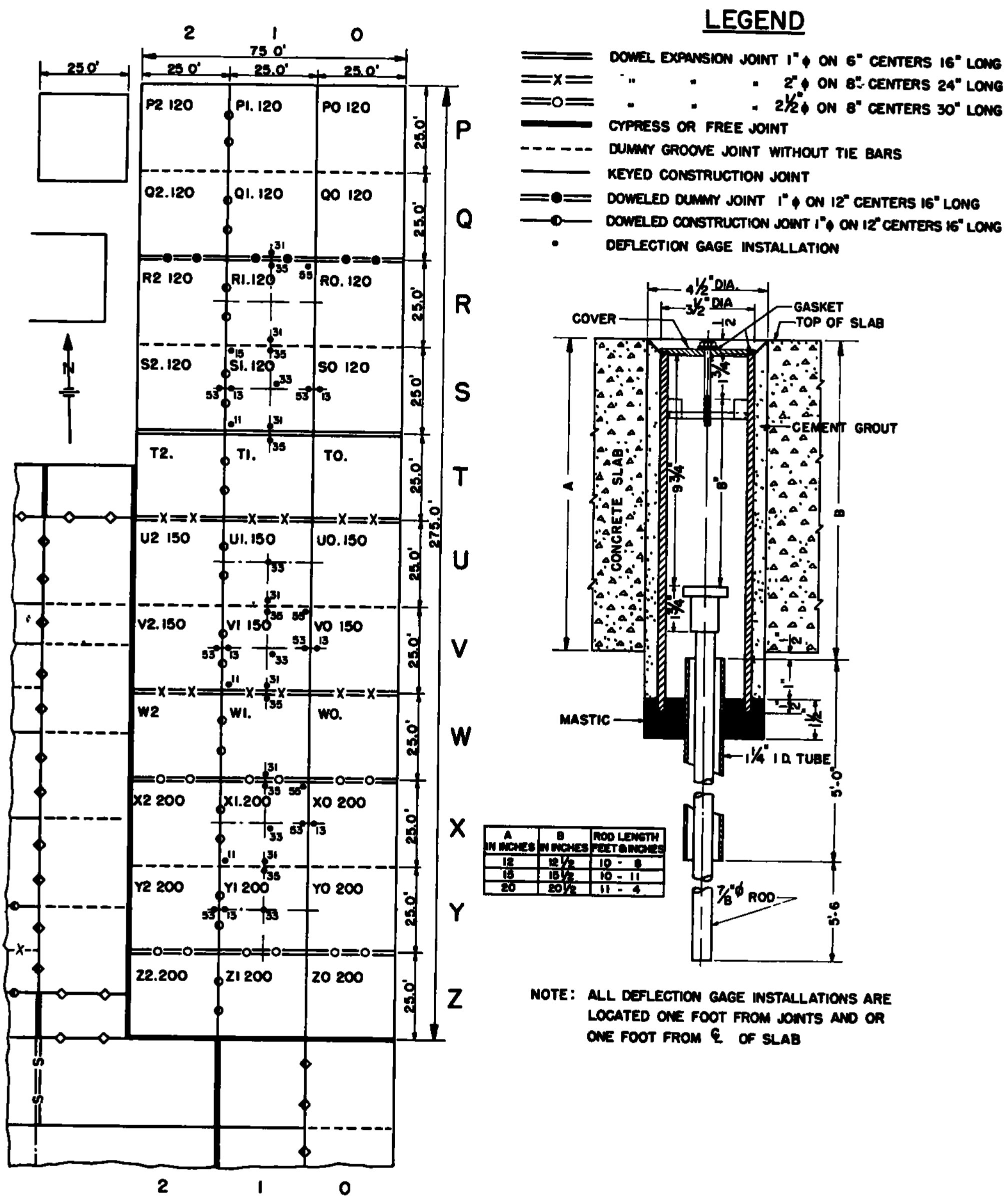
Traffic Loading. A picture of the 110-in. tire and wheel, and the twin-tandem assembly are shown in Figure 2b. The 150,000-lb. load box in which they were installed is shown in Figure 2a with the stabilizing yoke and power unit. The dimensional details of the pavement contact are given in Table 1.

The transverse spacing of the four-wheel assembly was 31.25 in. center to center, and the longitudinal spacing 62.75 in. center to center (see Fig. 3). The width of the 110-in. tire print was 35 in., and that of the 56-in. tire about 13 in. The shape of the individual tire prints was generally elliptical for both 110-in. and 56-in. tires.

Traffic Pattern. The traffic loading application was measured by converages, one coverage was obtained by moving the load rig forward and backward from one end of the test area to the other by trips. Each trip was controlled by guide lines on the pavement in such a manner that the surface of the test pavements was covered transversely by the widths of the tire prints. In the case of the single-wheel loading, 66 trips completed one coverage for the entire area of the mat, while for the twin-tandem loading, 18 trips completed one coverage. The forward speed of the load rig was about 2.8 mph. Figure 3 gives complete details of this coverage pattern for the modification (twin-tandem loading). A maximum of 2204 traffic coverages was applied to the experimental mat pavements, as their surface condition permitted, by the single-wheel loading. This application was made over a 30-month period from August 1945 to January 1948. Similarly, a maximum of 2204 coverages were

applied to the modification with the twin-tandem loading over a period of about 14 months, from March 1948 to May 1949. As traffic testing progressed a complete record of the crack-pattern development in the various designs was kept.

Prior to and during the traffic tests, measurements of horizontal joint movements, temperature gradients in the concrete and subgrade, and permanent subsidence of the slabs, were made in addition to the dynamic strain and deflection measurements (*2*, *3*).



A IN INCHES	B IN INCHES	ROD LENGTH FEET & INCHES
12	12½	10 - 8
15	15½	10 - 11
20	20½	11 - 4

Figure 1. Layout and details of deflection-gage installation, Lockbourne No. 2 Modification.

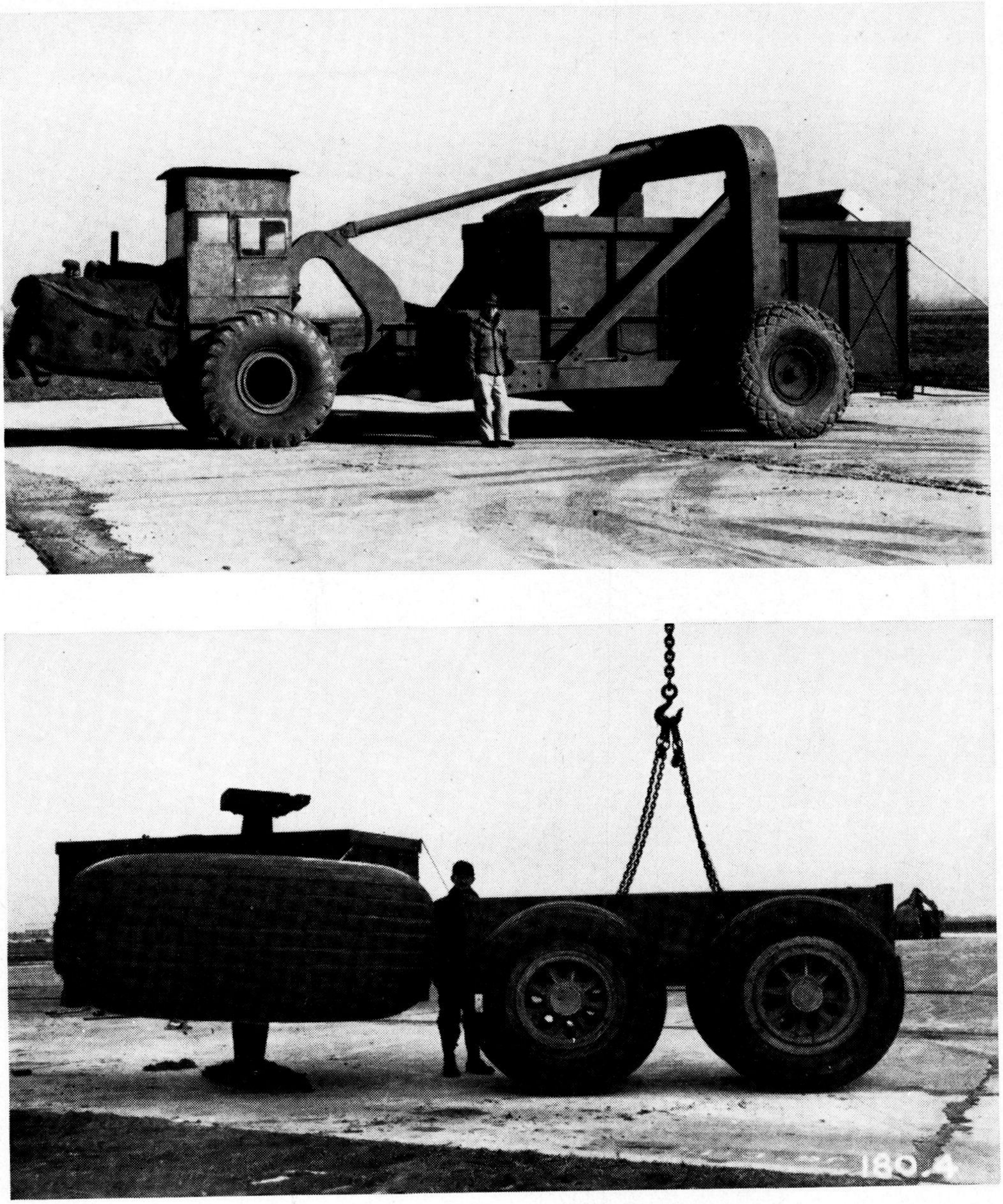


Figure 2. Photographs of traffic loading rig and twin-tandem assembly used for the Lockbourne No. 2 Modification tests At top: twin-tandem rig. Bottom: Comparison of 110-in. tire and twin-tandem assembly.

Pyysical Properties of Concrete and Subgrade. Measurements of these important properties were made during construction and at the conclusion of the traffic tests. From these measurements, average values of the concrete and the subgrade were ascertained which may be considered applicable in evaluating the results of the traffic tests. In both cases, the natural subgrade on which the major designs were placed was predominately a lean clay. The liquid and plastic limits of these soils averaged about 42 and 24 percent respectively. Natural

in-place water contents of the subgrade at the time of the traffic tests averaged about 23 percent of dry weight. The subgrade moduli of the natural subgrade for both the mat and modification varied from 75 to 100 lb. per cu. in. The average properties of the concrete

TABLE 1
DIMENSION DETAILS OF SINGLE- AND FOUR-WHEEL-TWIN-TANDEM 150,000-LB. LOADING

Type	Tire diameter	Inflation pressure	Contact Area
	in.	*psi.*	*sq. in.*
Single	110	107	1459
Twin-tandem	56	147	1080

TEST RESULTS

Only a few selected test results are presented to give an idea of scale and to demonstrate a basis for some of the discussion and conclusions. This is accomplished by presenting the final crack pattern for Lockbourne No. 2 (Fig. 4) after completion of the 150,000-lb. single-wheel-load traffic, a selected crack-pattern development (Fig. 5) for the 12-in. slabs of the modification under the 150,000-lb. twin-tandem-wheel-load traffic, and finally some strain and deflection measurements made under moving wheel loads for Lockbourne No. 2 and the modification (Table 2 and 3, Fig. 7).

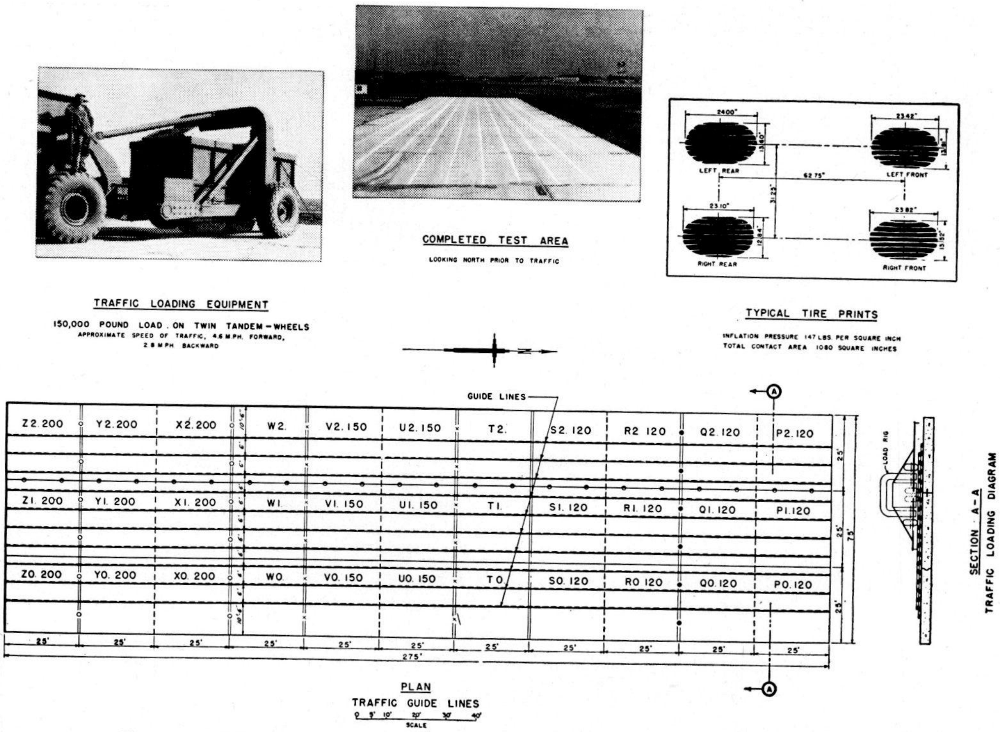


Figure 3. Details of coverage pattern for traffic-loading tests, Lockbourne No. 2 Modification.

at the time of the traffic tests may be summarized as follows:

Property	Experimental Mat	Modification
Flexural strength	781 psi.	725 psi.
Modulus of elasticity (flexure)	4.0×10^6 psi.	4.0×10^6 psi.
Poisson's ratio	0.20	0.20

Standard ASTM procedures were used for obtaining the above properties.

In Figure 4, the final crack pattern is superimposed on the basic layout of Lockbourne No. 2. The shaded slabs which have only their designations noted received the full 2,204 traffic coverages while the slabs without shading have a single additional figure, which is the number of coverages at which traffic was discontinued. For example, slab H5.150 is 15 in. thick on natural subgrade, and traffic on this slab was discontinued after 200 cover-

ages. Slabs H9.200 and H11.240 are 20 and 24 in. thick respectively on natural subgrade, and were subjected to the full 2,204 traffic coverages. The figure after the decimal point in the designation indicates the thickness of concrete, while the following number such as 0 and 15 indicate natural subgrade and a 15-in. base course respectively. Some of the results easily observed on Figure 4 are the weakness of the free expansion joints, the superior behavior of the longitudinal doweled construction joint as compared to that of the longitudinal keyed construction joint, and the adequacy of the 20- and 24-in. plain concrete slabs to carry the 150,000-lb. single-wheel-load traffic. Complete design details and test results for Lockbourne No. 2 are given (*2*).

Due to the fact that a single wheel carrying 150,000 lb. was discontinued on the B-36 almost before the tests of Lockbourne No. 2 were completed, the tests with the new twin-tandem gear, which replaced the single-wheel main gear for this aircraft, will be of greater interest. Three stages of the crack pattern development and the final crack pattern for the 12-in. pavements of Lane 1 in the modification are given on Figure 5. As may be seen from this figure, the maximum number of coverages for the 12-in. pavements in this lane varied from 800 to 1,359 under the 150,000-lb. loading on twin-tandem wheels. Of interest in this figure is the initial development of longitudinal cracks and their more rapid formation near the longitudinal keyed construction joint as compared to the formation along the longitudinal doweled construction joint. A better understanding of the character and extent of the final failure of the 12-in. slabs is illustrated by Figure 6. This is a photograph of Slab R1.120 after 1359 coverages of the 150,000-lb. twin-tandem-wheel-load traffic.

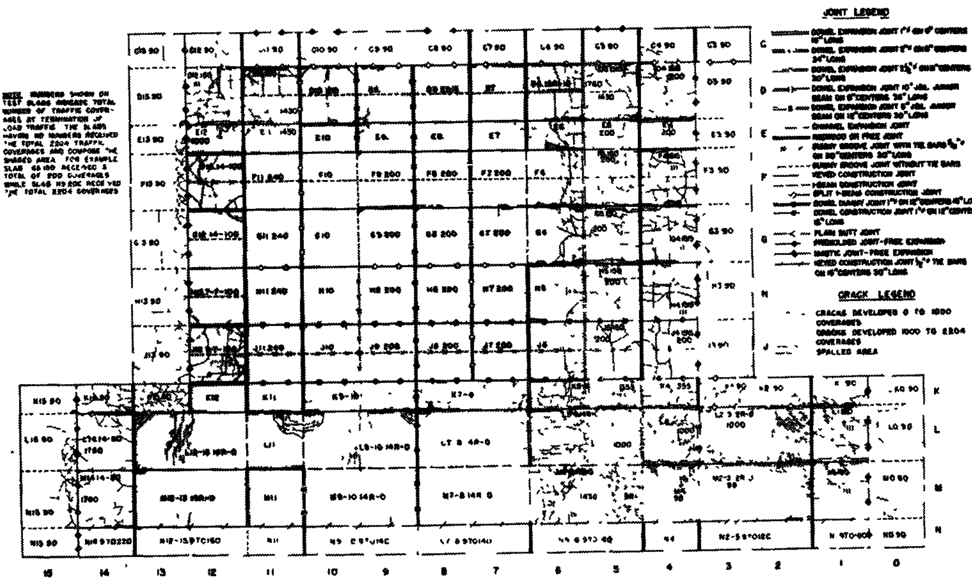


Figure 4. Final crack pattern, Lockbourne No. 2 Experimental Mat, after 2,204 coverages.

The 15- and 20-in. test slabs of the modification sustained 2,204 coverages of the 150,000-lb. twin-tandem-wheel-load traffic. Only one failure occurred in these slabs. This was a continuous longitudinal crack through the center of slab V1.150, which appeared on the surface at the transverse dummy contraction joint at about 1,500 coverages. At this time, it was about 12-in. long and developed for the full length of the slab, where it terminated visibly at the transverse doweled expansion joint at about 2,200 coverages.

In Table 2, a few deflection measurements are given. They are transient deflection meas-

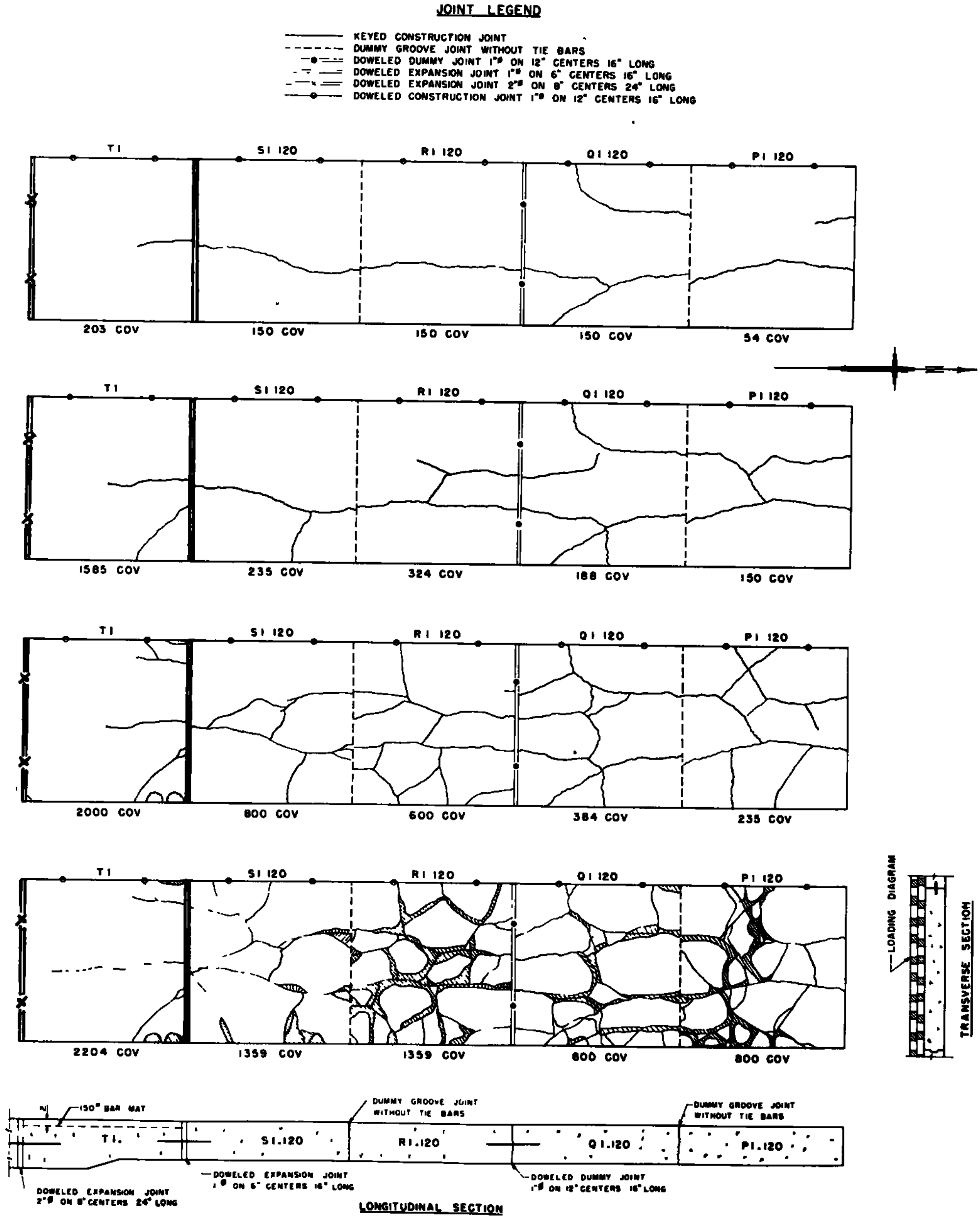


Figure 5. Rate of crack-pattern development in 12-in. pavement, Lockbourne No. 2 Modification.

ured under the moving 150,000-lb. twin-tandem-wheel loading. When the transient deflections are in the range of 0.1 in. at the corners and edges as in the case of the 12-in. slabs, eventual failure under traffic can be expected. Generally the magnitude of the deflections at the corners and edges for a jointed pavement are about the same for slabs

of similar thickness. Where the design is just adequate for the loading, transient interior deflections were about 0.05 in., as indicated by the 15-in. slabs. From the deflections shown, the transverse doweled expansion joint does not exhibit any marked advantage over the transverse dummy joint.

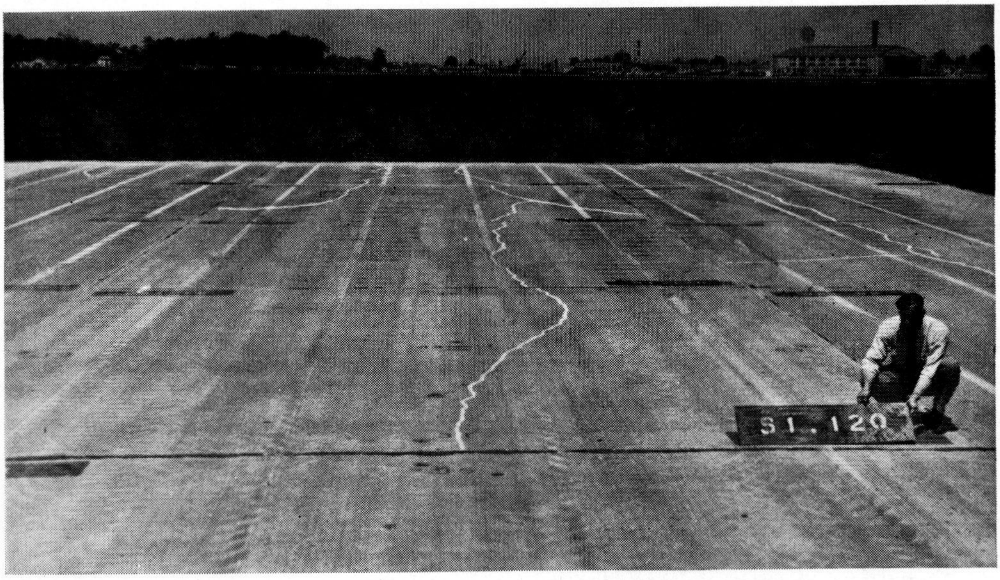


Figure 6. Photographs of failures in 12-in pavement, Lockbourne No. 2 Modification. Top: Slab R1.120 after 1,359 coverages Bottom: Slab S1.120 after 150 coverages.

The strain measurements listed in Table 3 are transient strains produced as the 150,000-lb. twin-tandem-wheel assembly passes over

a strain meter located 1.5 in. from the bottom surface of the concrete test pavements. The interior and longitudinal edge strains given in this table are measured parallel to the direction of wheel movement. At the transverse edges, the strains are measured normal to the direction of wheel movement. Thus the interior and longitudinal edge strains are comparable in so far as direction is concerned. joint, and second, the reduction in ratio of edge to interior strain for the 20-in. pavement, as compared to that of the 15-in. pavement, which proved just adequate for the loading.

The transverse edge strains are included in Table 3 because they were measured in conjunction with the single failure reported previously for one of the 15-in. slabs of the modification. In this case, the gage is located to

TABLE 2
150,000-LB. TWIN-TANDEM-WHEEL LOADING COMPARATIVE DEFLECTIONS

Slab thickness	Location	Feb. '48 0 Cover.	May '48 54 Cover.	May '48 150 Cover.	Dec. '48 1000 Cover.	May '49 2204 Cover.
in.		*in.*	*in.*	*in.*	*in.*	*in.*
12	Interior	0.075	0.063	—	—	—
15	Interior	0.048	0.056	0.052	0.062	0.042
20	Interior	0.034	0.036	0.032	0.032	0.031
12	Transverse	0.104	0.108	0.110	—	—
15	Doweled	0.054	0.043	0.062	0.048	0.060
20	Exp. joint	—	0.041	0.044	0.052	0.036
12	Transverse	0.097	0.091	—	—	—
15	Dummy joint	0.085	0.049	0.056	0.091	0.063
20	Dummy joint	0.050	0.041	0.043	0.060	0.060
12	Corner[a]	0.096	0.092	0.063	—	—
15	Corner[a]	0.079	0.064	0.070	0.087	0.031
20	Corner[b]	0.055	0.048	0.052	0.067	0.101

[a] Corner at intersection of a transverse doweled expansion joint and a longitudinal doweled construction joint.
[b] Corner at intersection of a dummy contraction joint and longitudinal doweled construction joint.

TABLE 3
150,000-LB. TWIN TANDEM-WHEEL LOADING COMPARATIVE STRAIN IN MILLIONTHS

Slab thickness	Location	Feb. '48 0 Cover.	May '48 54 Cover.	May '48 150 Cover.	Dec. '48 1000 Cover.	May '49 2204 Cover.
in.						
12	Interior	80	84	—	—	—
15	Interior	39	33	31	24	14
20	Interior	25	33	26	23	30
		Longitudinal Edge				
15	Long. key	72	72	76	50	60
20	Long. key	50	59	44	38	30
15	Long. dowel	62	46	54	61	49
20	Long. dowel	49	44	39	35	38
		Transverse Edge				
15	Dummy joint[a]	114	94	105	514	374
15	Doweled exp.[b]	71	31	34	27	24

[a] Pavement Failure at gage.
[b] Pavement Failure near gage.

For the 15-in. pavement, the ratio of the edge strains to interior strains averaged 2.6 with the longitudinal keyed construction joint, and 2.2 with the longitudinal doweled construction joint. Similarly, for the 20-in. pavement they average 1.6 and 1.5 respectively. Two points of significance are illustrated by the foregoing: first, the greater relief of longitudinal strain provided by the doweled construction measure strain in the bottom of the slab parallel to the transverse edge of the joint. Failure occurred almost immediately at the transverse dummy joint, probably at the first few coverages, as indicated by the very high strain. Later, at about 1,500 coverages, the crack appeared at the surface of the pavement indicating failure of the concrete at about the center of the gage. The remarkable part of

this is that the gage continued to function to the end of the tests, providing a record of the action of the crack under the traffic loading. Since the gage length is 10 in. movement or separation of the crack measured at 1,000 coverages would be 0.005 in., and 0.004 in. at 2,204 coverages. The strain recorded by the gage at the doweled expansion joint is less than would ordinarily be expected, since the crack developed to one side of the gage, relieving the strain in its vicinity.

In concluding this presentation of results, a comparison of recorded strains for the single and twin-tandem 150,000-lb. moving-wheel loadings is shown in Figure 7. These comparisons are given in the form of influence lines of strains, as they indicate the strain at one particular point in the 20-in. pavement slab as the moving load approaches, passes over, and leaves this point. These influence lines differ from conventional influence lines, since the strain is measured at a particular point on the structure (slab) as the total load moves across the slab; whereas, a true influence line would show the strain at a particular point as a unit load is placed at several successive points across the structure. In the latter case, a condition of equilibrium is assumed to exist as the unit load is applied to each point. In the case of the moving load, the shape of the influence line depends somewhat on the speed and direction of the loading as it moves over the structure (slab).

The influence lines of strain are shown for the two types of loadings at an interior point and a point near the edge of the slab or joint. These locations are shown by the sectional sketch at the top of the figure. All gages are located on the longitudinal centerline of the slab. Meters 8 and 20 measure strains parallel to the direction of traffic, while Meter 10 measures the strain normal to the direction of traffic. In general, all positions at which strains were recorded show a reduction of maximum strain for the twin-tandem loading. The least reduction is that shown for Meter 10, which measures the strain normal to the direction of traffic at the center of the slab. This particular comparison may be affected by the fact that the measurements were not taken at the same number of coverages. The reduction in maximum strain at the interior of the slab was reduced 12 per cent by the twin-tandem loading, while that near the joint or edge (Meter 20) was reduced by 49 percent. More complete information on comparative loadings and theoretical checks is given in the references (*3*, *4*).

COMMENTS

This paper, with its companion of similar title in the 1944 Highway Research Board PROCEEDINGS (*4*), brings up to date the reporting of the full scale tests of concrete pavements conducted by the Corps of Engineers. While detailed reports have been published covering these studies, the analysis and application of the data to design criteria will continue. This information is by no means sufficient in itself to yield the final answer to design problems, although it provides an excellent starting point. Continuing studies by the Corps of Engineers include keeping abreast of pavement requirements for present and future military aircraft, periodic condition surveys of existing pavements with regard to operational use, study of the properties of paving materials, and correlation studies by theoretical and small scale model analysis.

Correlation of the strain and deflection measurements described previously were made using Westergaards' analysis (*5*). It was generally found that:

Correlation of deflection measurements with theory was not very successful, due to the great variation in the measurements.

The average reduction in strain obtained by the twin-tandem gear over the single-wheel gear was very close to that predicted by theory.

The measured strains were less than the theory indicated for both the twin-tandem and single-wheel loading.

The shape of the influence curves produced by the strain meters was in good agreement with the theoretical for interior measurements.

One problem of particular importance is the effect of load repetition on the structural adequacy and life of airfield pavements. To illustrate this, two sets of points have been laid out graphically on the semilog plot of Figure 8. This plot was compiled by calculating the required design thickness of concrete pavement on the basis of the present design criteria of the Corps of Engineers compatible with the traffic loading and physical properties of the test pavements. Then a set of points was plotted showing the percent of design

thickness of the test pavement and the number of coverages at which the first failure occurred. These points are the solid circles or dots on Figure 8. Also shown on this figure are the open circles plotted for the same test items but at the number of coverages at which it was necessary to discontinue traffic because of extensive failure of the test item. Tentative curves averaging these points have been drawn on the graph. These curves indicate approxi-

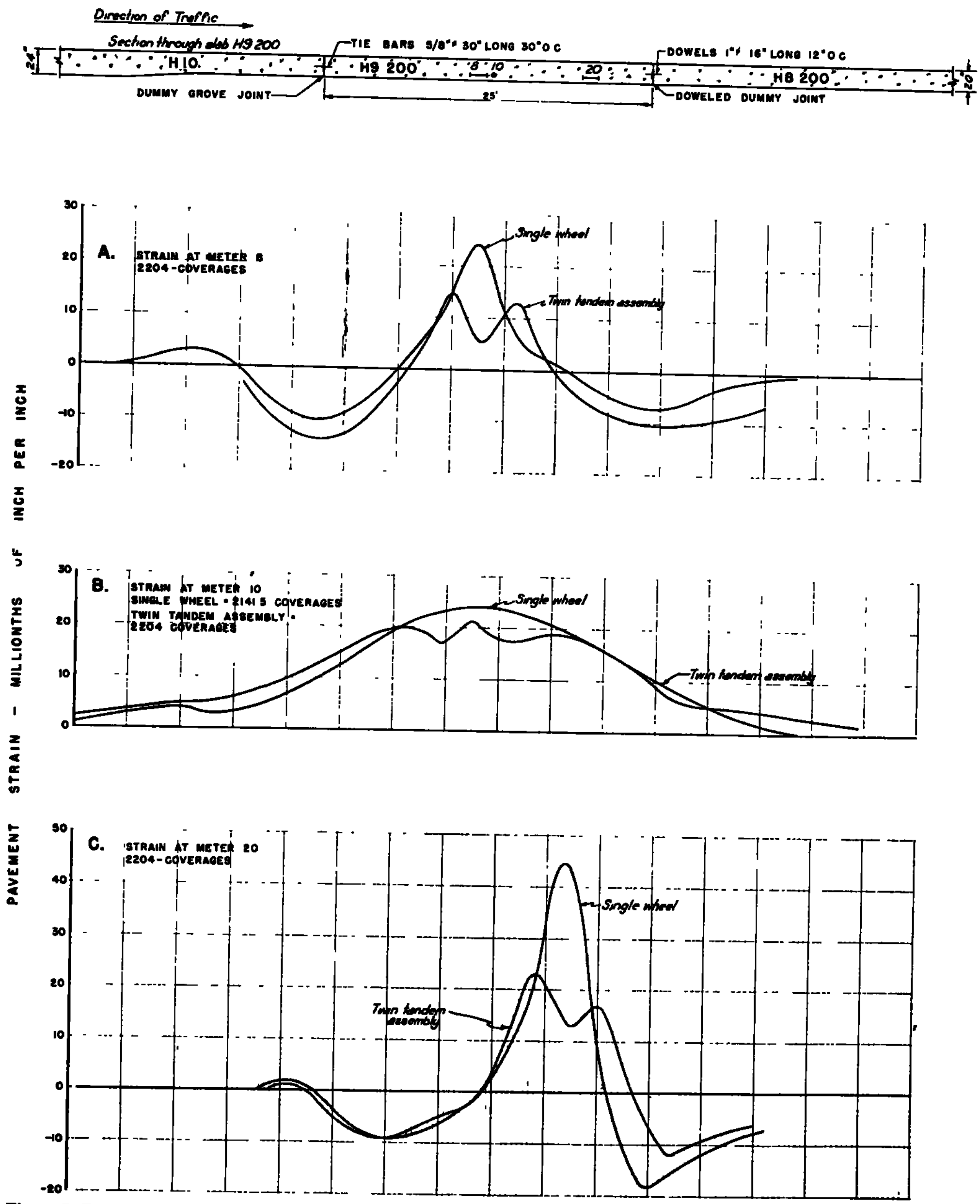


Figure 7. Recorded strains for single and twin-tandem 150,000-lb. moving-wheel loads, Lockbourne No. 2 Experimental Mat

mately the expected performance of taxiways, aprons, and runway ends for an airfield pavement under its design loading.

A further conversion of these results has been attempted in the columns listed below the graph, wherein coverages are converted to cycles of operation for a given type of aircraft. An example of the application of this chart would be the operation of a B-29 on a 6-in. taxiway pavement, under conditions where the actual design requirements would be a 10-in. pavement. Some of the points on this chart would indicate that as high as 60 operations of this aircraft could be accomplished on the taxiway before any indications of failure would appear. On some fields where the operation of heavy aircraft is infrequent, 60 cycles might correspond to a two to three year period, with no apparent damage to a 6-in. pavement. Present design criteria of the Corps

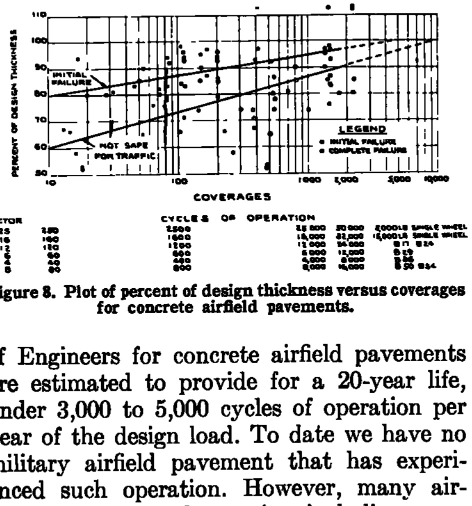


Figure 8. Plot of percent of design thickness versus coverages for concrete airfield pavements.

of Engineers for concrete airfield pavements are estimated to provide for a 20-year life, under 3,000 to 5,000 cycles of operation per year of the design load. To date we have no military airfield pavement that has experienced such operation. However, many airfields are under observation including some where aircraft loadings have exceeded the design load of the pavements for short periods. In some cases of excessive overload and high operational frequency, failure of the pavements has resulted, while in others where the frequency of operation is low, considerable overloading has resulted in little or no apparent evidence of structural failure on the pavements.

CONCLUSIONS

The conditions under which the two sets of tests were conducted were similar, the locations being immediately adjacent to one another, both test periods were lengthy, and the physical properties of the materials differed only to slight degrees.

The deflection under the two loadings for comparable thickness is of the same order of magnitude and roughly equal for center loading and only slightly less for loading at the joints and corners for the case of multiple wheels.

The substitution of multiple wheels produced an appreciable reduction in measured strains which is very close to that predictable by theory.

The measured strains were less than those predictable by theory for both loadings.

The substitution of multiple wheels for a single wheel reduces the measured strains in the center of the slab only mildly; 12 percent whereas at the edge the reduction is 49 percent.

The substitution of the multiple-wheel arrangement for the single-wheel load substantially reduced the thickness of pavement required to support a load of 150,000 lb. Based upon these tests it appears that slightly over 20 in. is required for the single-wheel-load arrangement, whereas 15 in. appears to be sufficient for the multiple wheel load arrangement.

The adequacy of a pavement must be measured in terms of its ultimate life. An inadequate pavement may carry design loads for substantial periods of time. This factor must be taken into account when observing pavement reaction.

ACKNOWLEDGMENT

The planning, supervision, and execution of the studies described in this paper was carried out by the staff of the Ohio River Division Laboratories in conjunction with members of the Airfields Branch, Engineering Division, for Military Construction, Office, Chief of Engineers. This work was done under and by the authority of the Office, Chief of Engineers, U. S. Army.

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DISCUSSION

Gordon K. Ray, *Engineer, Highways and Municipal Bureau, Portland Cement Association*—Figure 8 in the above paper is of particular interest. The Portland Cement Association has been making a continual survey of many airfields, civil and military, throughout the country. Just recently a detailed study of 20 civil airports was completed in Texas, Louisiana, Arkansas and Oklahoma All of these surveys verified the facts that the thin concrete pavements built during the war (usually 8-6-6-8 or 9-6-6-9 in cross section) could carry an almost infinite number of DC-3's and smaller planes without failure. These thin airfield pavements could also carry a limited number of much heavier planes. Many such fields with a few operations of Constellations or DC-6's show no structural defects. Also many fields which carried B-29's for only a few months near the end of World War II are still free from structural cracks. This is true in spite of the fact that pavement designed for these loads would be from 9 to 12 in. thick.

It was equally apparent that those fields with large numbers of heavy planes sometimes reached the breaking point. Thin pavements, 6 to 8 in. thick, which previously were structurally adequate, showed signs of extreme overload soon after airlines switched from DC-3's to DC-6's, Constellations, and Stratocruisers. The same was true of military fields which switched from fighter planes and B-17's to B-29's and B-36's.

In an effort to properly evaluate aircraft-loading frequency and pavement conditions, statistical methods were used for computing aircraft distribution on runways and taxiways. Figures A through D illustrate the results of this study.

Figure A shows a comparison between a normal frequency distribution curve for a 104-ft. runway and an actual observed distribution as determined from tire marks on the pavement. Note that the percent of all aircraft is shown for each 10-ft. lane in which they operate. A total of 271 observations were made of actual tire marks on this particular runway.

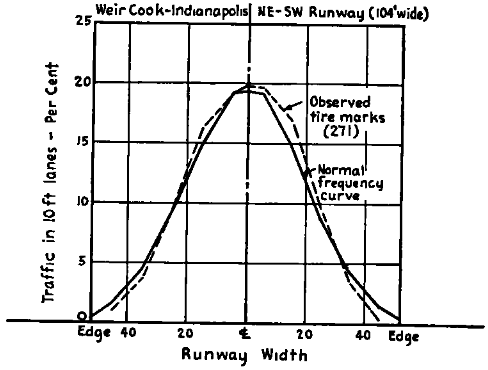

Figure A.

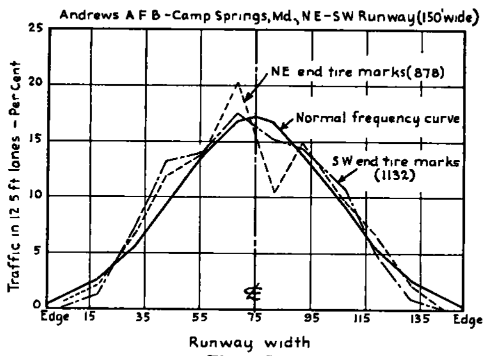

Figure B.

Figure B shows a comparison for a 150-ft. runway where 2,010 tire marks were found. Here the percent of total traffic in each 12½-ft. lane is plotted.

Figure C shows a comparison between a normal curve and actual observed tire prints for five military airfields where aircraft with 15,000-lb. wheel loads were operating on a 150-ft. runway. To make an accurate comparison, a normal distribution curve was computed for tire locations of a DC-3. This plane also has a wheel load of about 15,000 lb.

Figure D shows a similar comparison for 13 military airfields used by aircraft with a 30,000-lb. wheel load. In this case the normal curve was based on DC-4 traffic which has a wheel load of about 30,000 lb. and landing-gear spacing about the same as the military aircraft shown.

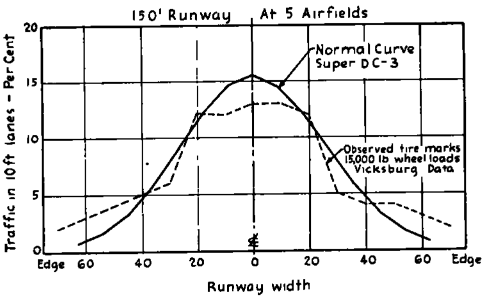

Figure C.

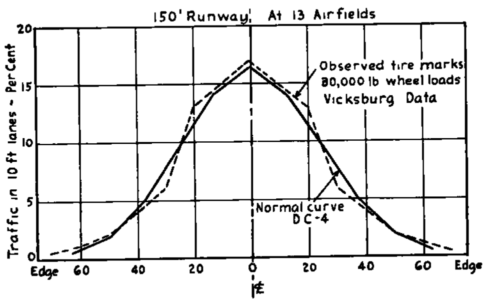

Figure D.

Once it was established that the normal distribution curves gave results closely paralleling actual operations, the transverse distribution of wheel loadings was computed on various widths of runways and taxiways for planes with various sizes and spacings of landing gears. Table A shows the number of stress repetitions which can be expected in any one spot for 100 aircraft operations.

Using these data and knowing the approximate number of aircraft operations for any airport facility, the necessary design safety factor for any aircraft can be determined.

Comparisons with actual airport condition surveys show this method to be reliable. This study confirms Philippe's and Mellinger's conclusion that airport pavements do not have to be designed for the heaviest occasional load. However, under actual operating conditions it is felt that their curve should be slightly modified. All of their points are based on accelerated traffic tests where load frequency is high. On actual airport pavement where this number of operations is spread over several years rather than several months, a much lower percent of design thickness should be adequate for the same load.

TABLE A

TRANSVERSE DISTRIBUTION OF WHEEL LOADINGS ON RUNWAYS AND TAXIWAYS ACCORDING TO THE NORMAL CURVE AT 1-PERCENT LEVEL

Type of Aircraft	Stress Repetitions Per 100 Operations			
	150-ft. Runway	200-ft. Runway	50-ft. Taxiway	75-ft. Taxiway
DC-3......	3.3	2.9	7.1	5.7
202 .	8.1	6.2	23.2	11.7
Convair ...	7.6	5.8	21.6	11.0
DC-4.	9.6	7.3	27.2	13.8
DC-6	10.4	7.9	29.8	15.1
Constellation	9.6	7.5	35.4	15.7
B-50. .	12.2	9.6	44.8	20.0
B-47	16.7	11.2	—	59.5
B-36.	15.4	14.9	—	26.5
F86	1.5	1.1	4.3	3.0
F90 . .	2.1	1.5	6.1	4.2
F89	1.9	1.4	4.8	2.9