

Accelerated Proof-Tests of Runway Pavement, Columbus Air Force Base, Mississippi

CHARLES R. FOSTER,* *Assistant Chief,
Soils Division, U.S. Army Engineer Waterways Experiment Station,
Vicksburg, Miss.; and*
J. P. SALE, *Engineer,
Airfields Branch, Military Construction Division, Chief of Engineers Office,
Washington, D. C.*

Accelerated traffic was applied to pavements at the Columbus (Miss.) Air Force Base to proof-test the Army Corps of Engineers' design for interior of runways under simulated B-52 aircraft traffic. A total of 5,000 coverages was applied with a cart equipped with four tires arranged in the same pattern as the tires on the rear gear of a B-52. The tires were inflated to 266 psi and the cart was loaded to 212,000 lb. The paper describes the pavements, the accelerated traffic test procedures, and the behavior of the pavements under traffic.

• IN FEBRUARY 1954, an initial series of hearings on the subject of air-strip paving materials was held by the Subcommittee for Special Investigations of the House of Representatives Committee on Armed Services. The Congressional inquiry was concerned primarily with an Air Force policy that required the use of portland cement concrete in certain areas of airfield pavements and permitted a 5 percent premium in favor of rigid pavement in the award of paving contracts for other areas.

The testimony of paving engineers from both government and industry established the following principal points regarding military airfield pavements:

1. As of 1954, no demonstrated difference had been observed in the structural capabilities of adequately designed rigid and flexible pavements to carry the traffic loadings of the heaviest military aircraft.

2. No demonstrated difference had been found in the maintenance requirements for the two pavement types, again considering only the effects of traffic loadings and weathering.

3. Investigational tests and actual pavement performance in the field had shown the resistant properties of portland cement concrete pavement to the effects of fuel spillage and the heat and blast of jet-engine exhaust to have a marked superiority over flexible pavements.

4. Parking, service, and maintenance aprons on military airfields were known to be subject to significant fuel spillage.

5. The isolated blast pads, where jet engines are periodically checked out by "running-up" to full military power over a considerable period of time, and runway ends, were considered to be the only paved areas where the heat and blast of exhaust gases caused a pavement problem. On the jet-engine blast pads, neither portland cement concrete nor asphaltic concrete could withstand the heat and blast generated, and special refractory materials were being developed as early as 1954 for these areas. On runway ends, the heat and blast were not sufficiently intense to affect the portland cement concrete pavements adversely, but caused scouring and raveling of asphaltic concrete.

* Now Coordinator of Research, Nat. Bituminous Concrete Assn., Vicksburg, Miss.

Based on the considerations outlined, in its May 1954 report the subcommittee concurred in the Air Force classification of all aprons and the 1,000-ft ends of runways as "critical" areas, and in the requirement that portland cement concrete pavements be used exclusively for these areas. The subcommittee felt that the evidence presented showed no need for portland cement concrete in "non-critical" areas, such as the interior portions of runways and the taxiways. It considered that the evidence indicated that these should be constructed of the paving type having the lowest first cost, without the existing 5 percent premium in favor of rigid pavement.

In August 1954, the Department of the Air Force integrated these concepts into its criteria for pavement type selection. In taking this action, the Air Force reiterated its stand that portland cement concrete pavement had a definite advantage over other paving materials for military airfield construction, but admitted it had been "unable to collect adequate engineering back-up reflected by maintenance costs to substantiate this view."

Between the late summer of 1954 and the winter of 1955, the peculiar traffic distribution patterns of the B-47 aircraft had begun to develop pavement distress on a significant number of Air Force bases throughout the country. This distress, which was confined primarily to taxiway pavements, could not be associated directly with either rigid or flexible pavement but tended to be more objectionable on flexible pavement because of the magnitude of surface roughness created.

In seeking the cause of this large-scale pavement distress condition, paving engineers found that the B-47 aircraft did not "wander" and distribute traffic over the taxiway as had been the case with earlier aircraft. Rather, the aircraft followed closely the centerline paint stripe. A study of these phenomena by the Corps of Engineers in 1955, using time-lapse photographic techniques, established the fact that 75 percent of all B-47 taxi traffic was channelized in a 7.5-ft width,

which produced about six times the stress repetitions in pavements as had been experienced with earlier propeller-driven aircraft.

In certain instances, B-47 operating conditions produced distress in the pavements. The type of distress differed in the rigid and flexible pavements. In the case of rigid pavements, cracking occurred along the centerline of the taxiways at a few airfields. The cracking was not due to overload, but to the great increase in stress repetitions over and above design assumptions, and accompanying fatigue. In the case of flexible pavements, the distress consisted of settlement and grooving of the pavements at a few airfields, in some cases reaching magnitudes of 1 to 3 in. In most instances the distress was due to compaction of the base and subgrade by the aircraft traffic.

The Corps of Engineers Rigid and Flexible Pavement Laboratories, under the direction of the Chief of Engineers, immediately took steps to formulate changes in design criteria for the two pavement types for this channelized traffic condition. In rigid pavements, the remedial action was fairly straightforward in that additional pavement thickness was all that was required for the increased number of loading repetitions. For flexible pavements, an improvement in quality, an increase in compaction of the upper layers, and a slight increase in thickness were necessary. The changes required in the design criteria were made by extrapolating the existing criteria to the new conditions. Certain features of the revised criteria were subsequently checked by accelerated traffic tests.

Faced with the conditions just discussed, the Department of the Air Force changed its criteria for pavement type selection in December 1955. It specified that all pavements on which aircraft are normally operated, parked, serviced, or maintained should be classed as "primary use" pavements and that all primary use pavements should be constructed of portland cement concrete. At the same time a proof-test program was planned to establish whether or not the changes made

by the Corps of Engineers in flexible and rigid pavement design would be adequate for the channelized traffic of B-47 aircraft. A second purpose of the proof-test program was to determine the ability of a contractor on a typical airfield paving project to meet the Corps of Engineers specification requirements.

Kelly Air Force Base was selected as the site for these tests. In early 1956, a section of taxiway was constructed utilizing the most recent design and construction procedures developed by the Corps of Engineers for both rigid and flexible pavement. The tests consisted of applying 30,000 hot-weather (defined as a pavement temperature of 90 F or higher) traffic coverages to two 200-ft long adjoining sections of rigid and flexible pavement using a duplication of a B-47 landing gear. This gear consisted of twin wheels spaced 37 in. center-to-center, with a load of 100,000 lb on the two wheels. The tires were inflated to produce a 267-sq in. contact area, which required an inflation pressure of approximately 200 psi.

The tests were made in the spring and early summer of 1956. From the results of these tests (1) it was considered that:

1. The rigid pavement design and construction procedures developed by the Corps of Engineers for channelized traffic of B-47 aircraft were validated.

2. The flexible pavement design and construction procedures for total thickness and compaction requirements for the channelized traffic of B-47 aircraft were validated.

3. The design and construction procedures for the asphaltic concrete portion of the flexible pavement did not produce pavements capable of withstanding the hot-weather traffic conditions imposed.

Within a month after completion of the Kelly tests, the Corps of Engineers Flexible Pavement Laboratory at the Waterways Experiment Station, Vicksburg, Miss., developed new asphaltic concrete mix designs that would satisfactorily withstand 30,000 coverages of the 100,000-lb twin-wheel loading as imposed at Kelly AFB. However, in June 1956,

the loading requirements were revised upward from the 100,000 lb on the twin-wheel gear of the B-47 to the 240,000 lb on the four-wheeled twin-twin landing gear assembly of the B-52 aircraft. The inflation pressure for this gear was approximately 260 psi.

Prompted by inquiries from representatives of the asphalt industry as to the "fairness" of the Kelly tests, the Subcommittee for Special Investigations again held hearings on the subject of airstrip paving materials in late June and July of 1957.

In this second series of hearings the asphalt industry contended that the requirement of 30,000 coverages of all hot-weather traffic was unnecessarily severe for testing the capabilities of flexible pavements. The Corps of Engineers had already discussed this feature with the Air Force and had adopted a ratio of approximately 1 to 3 for hot-weather *versus* "year-round" traffic. For example, 10,000 coverages of hot-weather traffic would be used to establish mix design requirements for 30,000 coverages of traffic applied at temperatures experienced throughout an entire year. Thickness and compaction criteria had been prepared for both channelized and nonchannelized B-52 traffic, but asphalt mix design criteria had not been developed for the channelized condition. The Corps contended that flexible pavements, including the asphalt mix, could be designed and constructed to perform satisfactorily under the less severe B-52 loadings that occur in the interior portions of runways. The subcommittee suggested that the Chief of Engineers and the Director of Installations, United States Air Force, jointly plan an accelerated traffic test to demonstrate the adequacy of flexible pavements for the interior portion of runways. The test location agreed upon was at Columbus Air Force Base, Miss.

Purpose

The primary purpose of the Columbus tests was to proof-test the Army Corps of Engineers flexible pavement design and construction methods for interiors

of runways to be used by B-52 planes. It was desired that the juncture between the flexible and rigid pavements be included in the tests. Consequently, a portion of the rigid pavement was also subjected to traffic.

TESTS

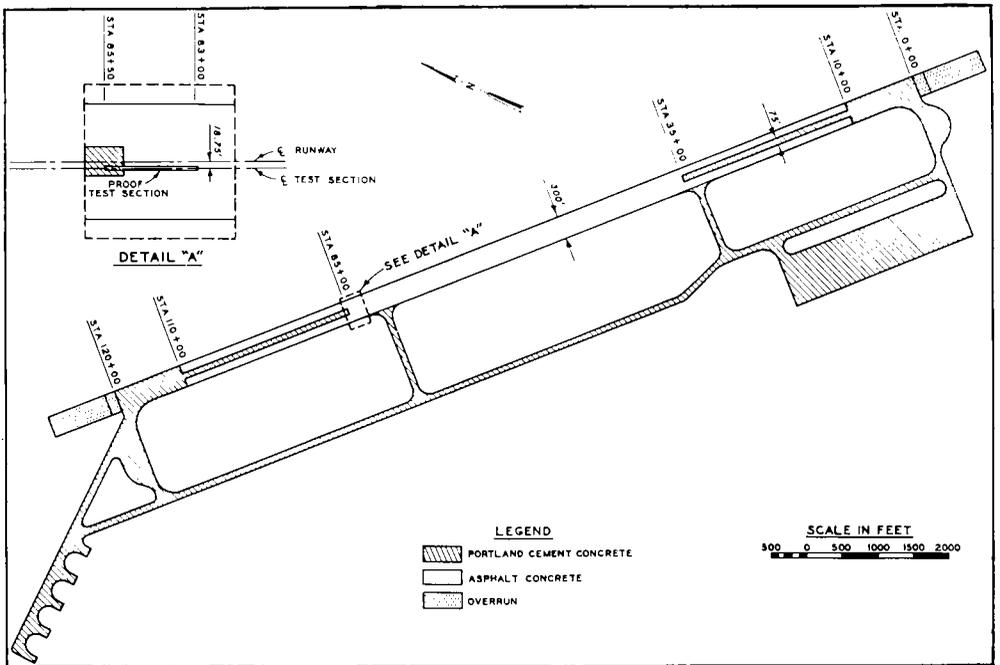
Runway Pavements

The terrain at the Columbus, Miss., airfield site consists of two terraces, with a difference in elevation of approximately 25 ft. The natural soil in the higher terrace is primarily sandy to clayey gravel, and that in the lower terrace is primarily fine-grained silty to sandy material. The southeastern part of the runway lies on the higher terrace, and construction operations were such that the runway in this area was in cut sections. The northwestern part of the runway lies on fill material. In the vicinity of the proof-test the fill is approximately 9 ft thick and is composed of sandy to clayey gravel taken from the upper terrace.

Drainage in the area is normally good.

Figure 1 shows a layout of the runway, which is 12,000 ft long by 300 ft wide and consists of both rigid- and flexible-type construction. The first 1000 ft on each end, and the center 75 ft of runway extending for an additional 2500 ft from each end, are of portland-cement concrete; the remainder of the runway is of flexible-type pavement. In planning for the tests, representatives of the Corps of Engineers and the Air Force agreed that the test section would be located within the central 75 ft of the runway at one of the two locations where the flexible and rigid pavements join. The specific location was to be selected by the Air Force after construction was completed.

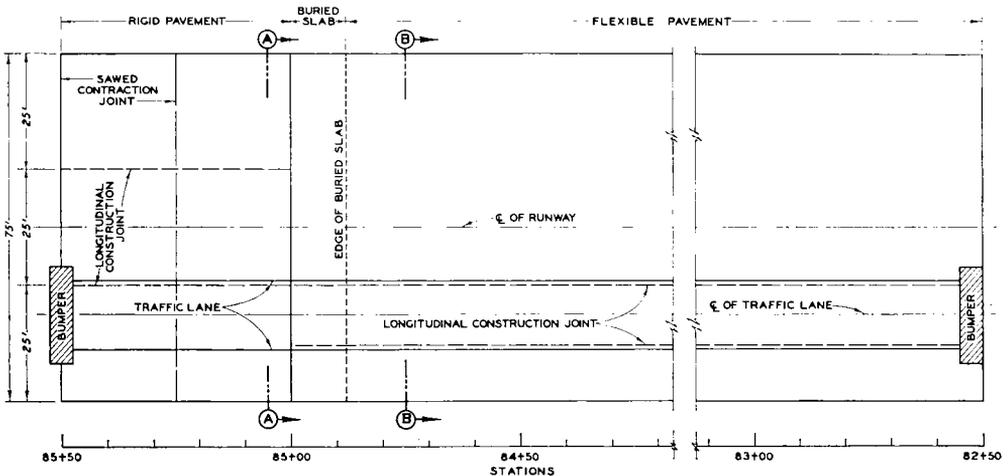
It was desired that these tests relate to the requirements for the latest model (B-52G) aircraft, which require pavements designed for a 265,000-lb gear load. The pavements at Columbus had been designed and were being constructed for earlier, lighter design loads; therefore, the areas in the vicinity of the juncture of the flexible and rigid pave-



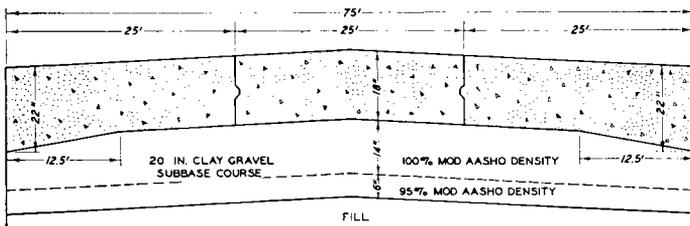
ments had to be redesigned for the 265,000-lb gear load. Design procedures specify a reduction in load to compensate for partial uplift of the wings; the reduction in this specific case was 20 percent. The portland cement concrete paving in the two possible test section areas was completed on November 11, 1957 and the flexible pavement was completed at these locations on August 25, 1958.

Test Section

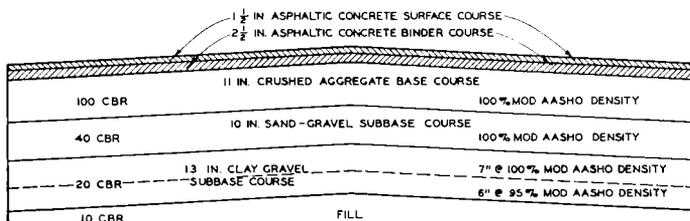
At the completion of construction of the runway pavements in the two possible test locations, the Air Force selected an area between Stations 83+00 and 85+50 (Fig. 1) as the test location. The Air Force requested that the centerline of the traffic lane be located 18.75 ft southwest of the center line of the runway. Figure 2 shows a plan of the center



PLAN



SECTION A-A



SECTION B-B

Figure 2. Layout of traffic lane and typical sections of proof-test section.

75 ft of runway and a layout of the traffic lane within the runway section and typical sections of the rigid and flexible pavements. Figure 3 presents a profile along the centerline of the traffic lane. The CBR and compaction requirements indicated in Figure 3 are the design requirements for the flexible pavement construction. It is pointed out that the original design for the center 75 ft of runway between the 1000-ft portland cement concrete ends was all flexible pavement, and that the construction was accomplished up to within 10 in. of the surface elevation in accordance with the original design. At this time the design was changed to require that the rigid pavement extend out to 3500 ft from the end of the runway. The clay-gravel subbase, which had been constructed under the earlier contract, was used directly for the foundation of the portland cement concrete. This clay-gravel subbase and the underlying fill had been constructed under a specification that required higher densities than would normally be specified for a rigid pavement design.

Fill. The fill material was obtained

from the southeast end of the runway, which was in a cut section, and consisted mostly of clayey gravel. The natural ground on which the fill was placed was wet and relatively soft at the time of placement; therefore, the first layers of fill were placed in thick lifts (2 to 3 ft). As the height of the fill increased, the thickness of the layers was decreased and the compaction effort increased as necessary to obtain the minimum density required. For this paper, the fill material is considered the subgrade for the pavements.

Clay-Gravel Subbase. The clay-gravel subbase was local pit-run material, about 1½-in. maximum size, with 10 to 25 percent finer than the No. 200 U. S. standard sieve, and having a plasticity index ranging from 0 to 15. The material was originally placed as a subbase (and the term was retained); however, when the pavement was redesigned the material was classed as select material. Specifications for select material contain no gradation requirement, but suggest that the maximum size aggregate be 3 in. and plasticity index be less than 12. The clay-

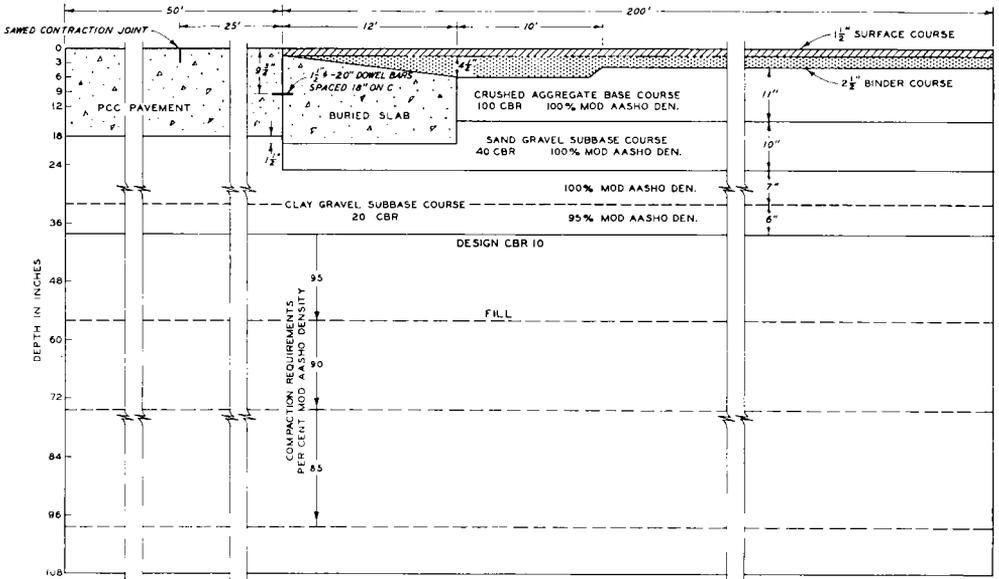


Figure 3. Profile of pavement along centerline of proof-test section.

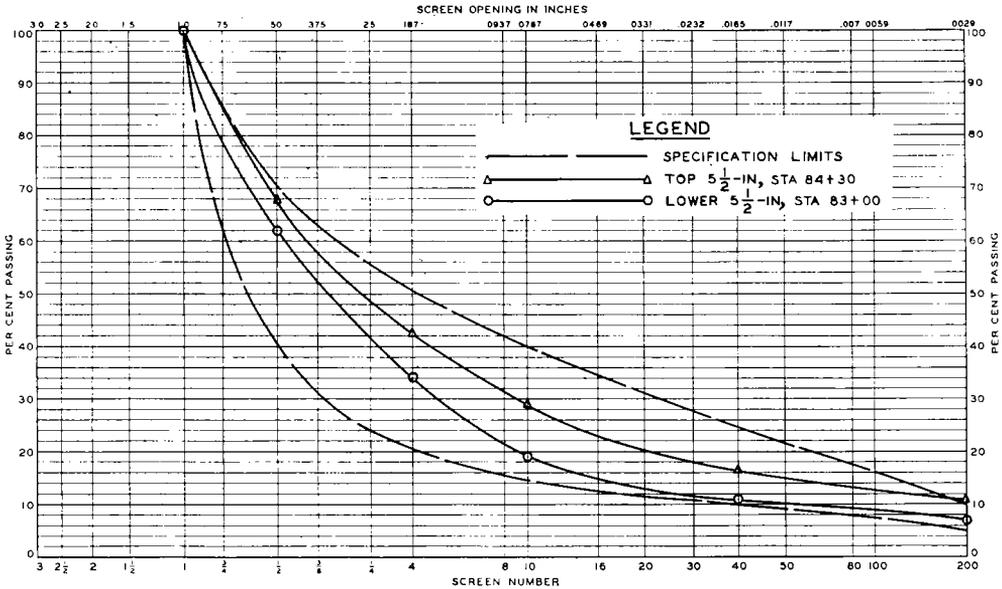


Figure 4. Grading curves for crushed aggregate base course.

gravel subbase extends under both the rigid and flexible pavements, as shown by the profile in Figure 3, and is 13 in. thick under the flexible pavement. In addition to the compaction requirements shown in Figure 3, the top of the clay-gravel subbase was subjected to 30 coverages of proof-rolling with a 60-ton, 150-psi, rubber-tired roller.

Sand-Gravel Subbase. The sand-gravel subbase consisted of 3/4-in. maximum size crushed chert gravel, sand, and limestone dust placed in two lifts. Crushed slag was blended with the lower lift. The gradation requirement as for 2-in. maximum size material with not more than 50 percent finer than the No. 10 sieve nor more than 15 percent finer than the No. 200 sieve. The specified plasticity index was less than 5. In addition to the compaction requirements shown in Figure 3, the top layer of subbase was subjected to 30 coverages of proof-rolling with a 60-ton, 150-psi, rubber-tired roller.

Crushed-Aggregate Base Course. The crushed-aggregate base used in the flexible pavement section consisted of a blend of slag, crushed chert gravel, sand, and a small amount of limestone dust. This

material was blended in a pugmill in proper proportions to meet the gradation requirements. The blended material was well graded and nonplastic. Grading curves of samples of the blended material are given in Figure 4. In addition to the compaction requirements given in Figure 3, each layer of the base course was to be subjected to 30 coverages of proof-rolling with the 60-ton rubber-tired roller.

Asphaltic Concrete. The asphaltic concrete consisted of a 2 1/2-in. thickness of binder course and a 1 1/2-in. thickness of surface course mix. The aggregates for the paving mixtures were a 1-in. maximum size crushed limestone, 3/4-in. maximum size crushed chert gravel, 1/4-in. maximum size limestone screenings, coarse washed sand, and fine bank sand.

A job-mix formula was prepared from plant-mixed, laboratory-compacted samples for both the binder and surface course mixes using the stockpile aggregates described and the 85- to 100-penetration asphalt supplied for use on the job. Test properties of the asphalt used are given in Table 1. The stockpile ag-

TABLE 1
TEST RESULTS ON ASPHALT USED IN PAVEMENT MIX

Test	Results	Spec. Limits ^a
Specific gravity	1.036	—
Flash point (F)	560	Not less than 347 F
Softening point (F)	117	104-140 F
Penetration at 77 F	90	85-100
Ductility at 77 F (cm)	150+	—
Percent loss, 5 hr at 325 F	0.01	Not more than 1%
Penetration, residue (% of orig.)	88.89	Not less than 60%
Percent soluble, CS ₂	99.9	Not less than 99.5%
Percent organic insoluble	0.0	Not more than 0.2%
Percent water	Trace	Zero
Spot	Negative	Negative
Thin film test: ^b		
Percent loss, 5 hr	0.06	Not more than 1%
Test on residue:		
Penetration	60	—
Penetration (% of orig.)	66.67	Not less than 50%
Ductility (cm)	150+	Not less than 100%
Softening point (F)	130	—

^a The material furnished under Federal Spec. SS-A-706b for a given contract, type, and grade shall be uniform in character and samples from deliveries shall neither vary more than ± 5 C (± 9 F) in softening point within the limit specified nor more than ± 0.010 in specific gravity from the results of tests on a representative sample furnished by the contractor prior to delivery.

^b Bureau of Public Roads test and suggested limits.

gregates were combined in the following proportions:

	Percent Used	
	Binder Course	Surface Course
Stockpile Aggregate		
1-in. max. limestone	24	—
3/4-in. max. crushed chert gravel	34	46
1/4-in. max. limestone screenings	26	34
Coarse washed sand	9	12
Fine bank sand	7	8

The combined grading curves for the binder and surface course mixes, along with the gradation specification limits, are shown in Figures 5 and 6, respectively. The design criteria for determining the satisfactoriness of the asphaltic concrete mixes at optimum asphalt content were as follows:

Test Property	Surface Course	Binder Course
Stability, Marshall (lb)	1,800 or higher	1,800 or higher
Flow, Marshall (0.01 in.)	16 or less	16 or less
Voids total mix (%)	3-5	5-7
Voids filled with bitumen (%)	70-80	50-70

The mix design properties for the binder and surface course mixes are shown in

Figures 7 and 8, respectively. From these tests the normal optimum asphalt content for the 75-blow Marshall compaction effort was established as 4.4 percent for the binder course and 5.6 percent for the surface course mix. During construction of surface and binder courses at optimum asphalt content, the previously listed specifications were met. The runway design required a 20 percent reduction in asphalt content for the center 75 ft of the runway. Therefore, for this portion of the runway the asphalt content was reduced to 3.5 percent for the binder course and 4.5 percent for the surface course mix. All of the binder course material for the center 75 ft of the runway was placed at an asphalt content of 3.5 percent. However, during placing of the surface course mixture, a decrease occurred in voids total mix, as indicated in Figure 8, caused by a slight change in the properties of the aggregate. This required a slight adjustment in the optimum asphalt content. The actual asphalt content used in the surface course mix of the proof-test section was 4.3 percent. Attention is directed to the fact that current practice for mixes placed at reduced asphalt contents calls for the mix to meet the specification requirements when prepared at optimum asphalt content. When the asphalt content is reduced, the test values (stability, voids,

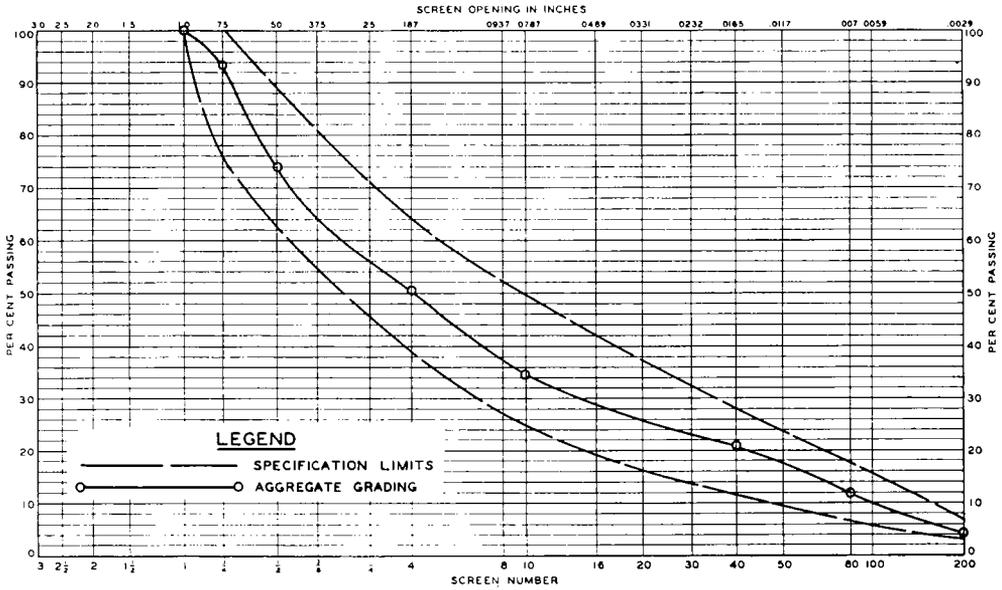


Figure 5. Grading curves for asphaltic concrete binder course.

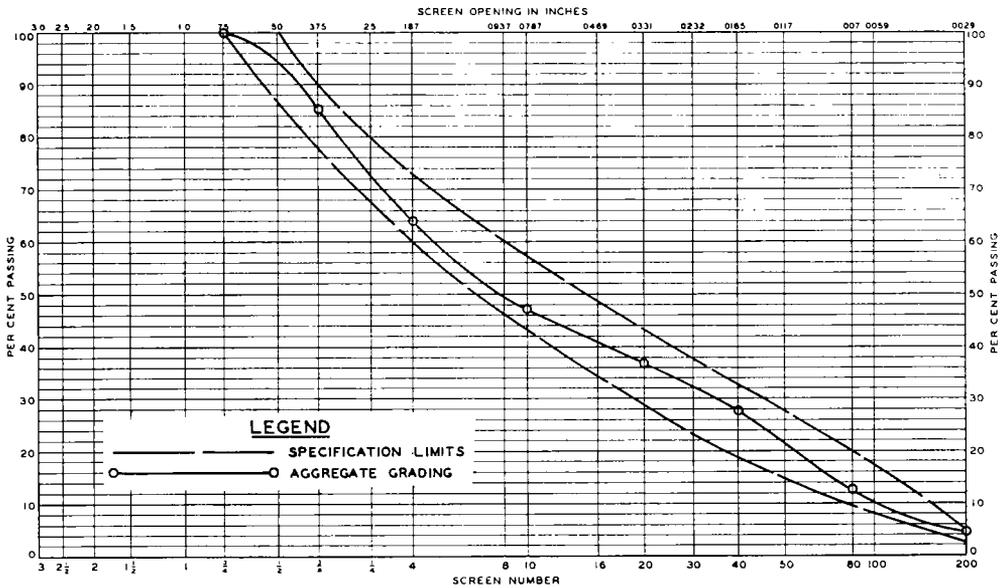
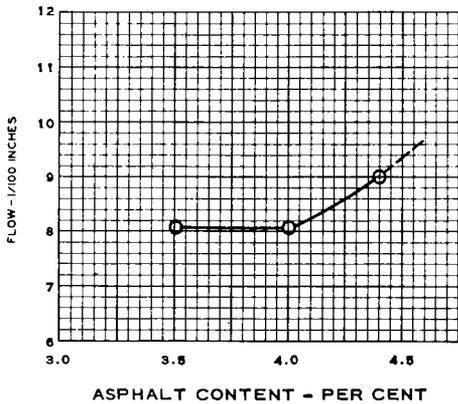
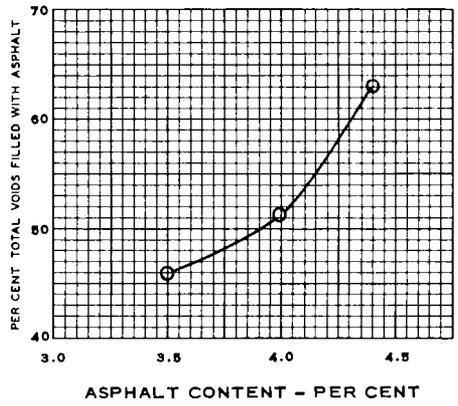
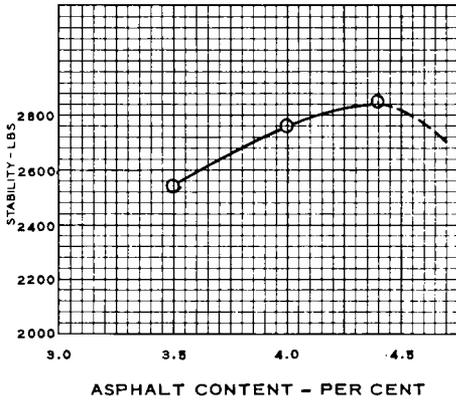
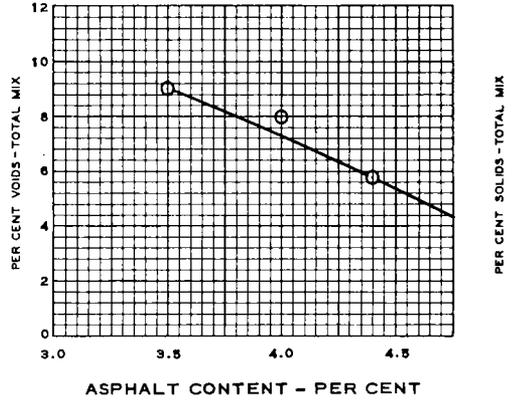
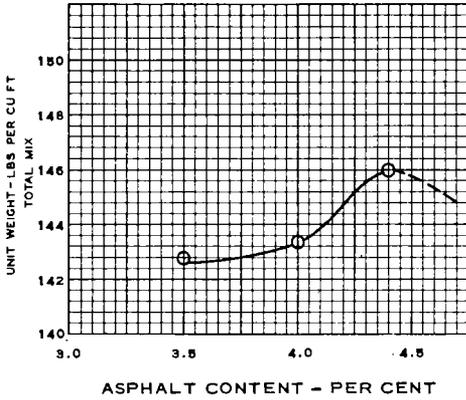
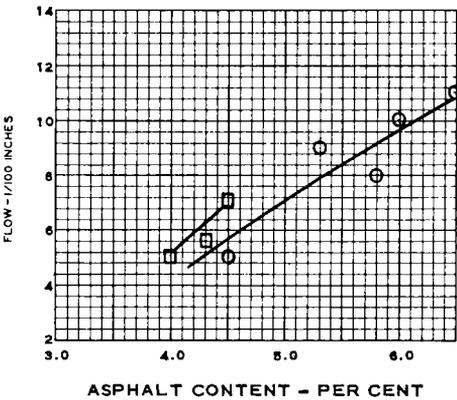
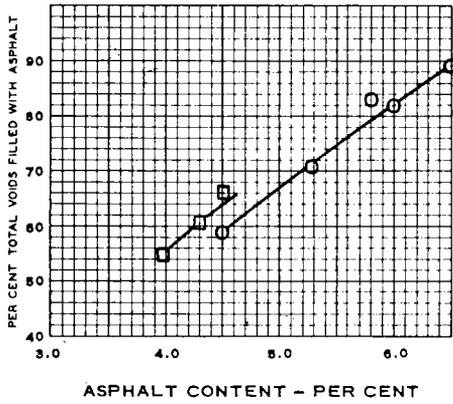
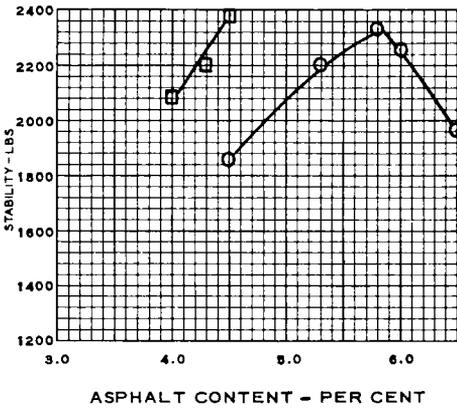
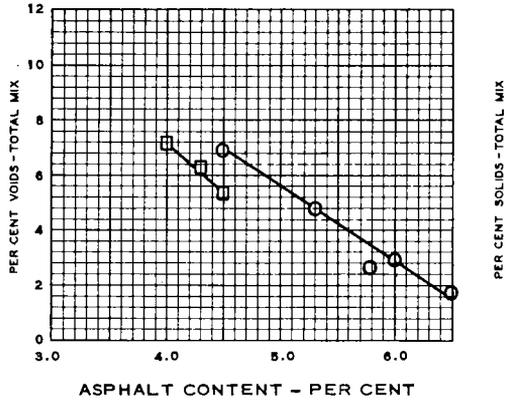
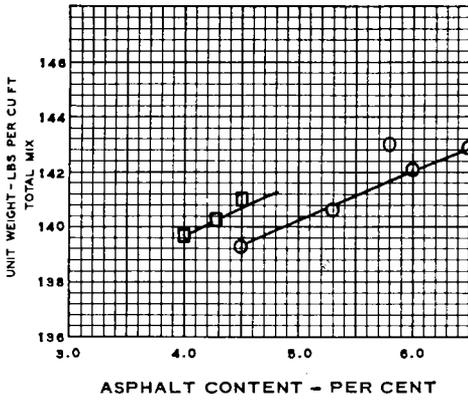


Figure 6. Grading curves for asphaltic concrete surface course.



OPTIMUM ASPHALT CONTENT 4.4 PER CENT,
REDUCED TO 3.5 PER CENT FOR CENTER
75 FT OF RUNWAY.

Figure 7. Mix design properties for plant-mixed laboratory-compacted samples of binder course.



LEGEND:

- PLANT-MIXED LABORATORY-COMPACTED CURVE DEVELOPED AT THE START OF SURFACE-COURSE PAVING. OPTIMUM ASPHALT CONTENT 5.6 PER CENT, REDUCED TO 4.5 PER CENT FOR CENTER 75 FT OF RUNWAY.
- PLANT-MIXED LABORATORY-COMPACTED CURVE DEVELOPED DURING PAVING NORTH-WEST TEST SECTION. OPTIMUM ASPHALT CONTENT 5.4 PER CENT, REDUCED TO 4.3 PER CENT FOR CENTER 75 FT OF RUNWAY.

Figure 8. Mix design properties for plant-mixed laboratory-compacted samples of surface course.

TABLE 2
SUMMARY OF FIELD TEST DATA, ASPHALTIC CONCRETE, PROOF-TEST SECTION

Coverages	Asphalt Content (%)		Stability (lb)		Flow (0.01 in.)		Density (lb/cu ft)		Voids (%)				Plant Laboratory Density (%)		
	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder	Total Mix	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder
	4.3	3.5	2200	2540	6	8	140.1	142.8	6.1	9.0	60.0	46.6			
	4.3	3.5	537	1410	11	12	137.3	140.0	8.3	10.7	52.3	41.5	98.0	98.0	98.0
180	4.3	3.5	1047	1687	10	14	139.6	141.5	6.7	9.8	58.1	44.1	99.6	99.6	99.1
1100	4.3	3.5	1345	1751	11	13	141.5	143.2	5.5	8.7	63.3	47.2	101.0	100.3	101.0
2129	4.3	3.5	1380	1955	13	14	141.5	142.6	5.5	9.1	63.4	46.1	101.0	99.9	101.0
3334	4.3	3.5	1470	2115	9	11	142.0	142.8	5.2	9.0	64.8	46.6	101.4	100.0	101.4
3761	4.3	3.5	1457	2300	9	13	141.5	143.6	5.4	8.4	63.4	48.1	101.0	100.6	101.0
5000	4.3	3.5	1751	2402	9	11	142.2	143.6	5.0	8.4	65.6	48.2	101.5	100.6	101.5

(b) FIELD CORES															
Coverages	Asphalt Content (%)		Stability (lb)		Flow (0.01 in.)		Density (lb/cu ft)		Voids (%)				Plant Laboratory Density (%)		
	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder	Total Mix	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder
	4.3	3.5	2200	2540	6	8	140.1	142.8	6.1	9.0	60.0	46.6			

(c) PLANT LABORATORY SAMPLES															
Coverages	Asphalt Content (%)		Stability (lb)		Flow (0.01 in.)		Density (lb/cu ft)		Voids (%)				Plant Laboratory Density (%)		
	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder	Total Mix	Sur-face	Binder	Sur-face	Binder	Sur-face	Binder
	4.3	3.5	2200	2540	6	8	140.1	142.8	6.1	9.0	60.0	46.6			

etc.) may not necessarily meet the specification requirements.

Marshall test properties of the plant-mixed laboratory-compacted samples are shown in Table 2(a). No difficulties were encountered in mixing or placing this pavement.

Portland Cement Concrete. The concrete aggregate consisted of local washed chert gravel and sand. The gradations of the coarse and fine aggregates are shown in Figure 9. In the area of the test section, the blend contained 66 percent coarse aggregate and 34 percent fine aggregate. Cement factor was 5.5 sacks per cu yd, and water-cement ratio was 5 gal per sack. The air content ranged from 3.1 to 3.6 percent and the slump was 1.5 in. The design flexural strength for the concrete was 700 psi. This value, together with the design modulus of subgrade reaction (*k*) value of 250 lb per sq in. per in. required a pavement thickness of 18 in. in the interior with 22-in. thick edges (section A-A, Fig. 2).

The portland cement concrete for the center 75 ft of the runway was placed in 25-ft wide longitudinal lanes. The longitudinal construction joints are keyed (section A-A, Fig. 2). The transverse contraction joints are sawed dummy-type joints spaced at 25-ft intervals. The center lane, the west edge of which was subjected to traffic, was placed on November 1, 1957. The southwest lane of portland cement concrete, which was in the traffic test lane, was placed on November 11, 1957.

Transition Joint. A detail of the buried-slab transition between the rigid and flexible pavements is shown on the profile in Figure 3. The base material was originally placed and compacted to final grade to the portland cement concrete juncture. The base was then cut out to a vertical face for a distance of 12 ft beyond the end of the portland cement concrete pavement and the concrete was placed against the face of the base course without the use of a form.

Test Conditions

The traffic tests were performed under conditions and procedures previously

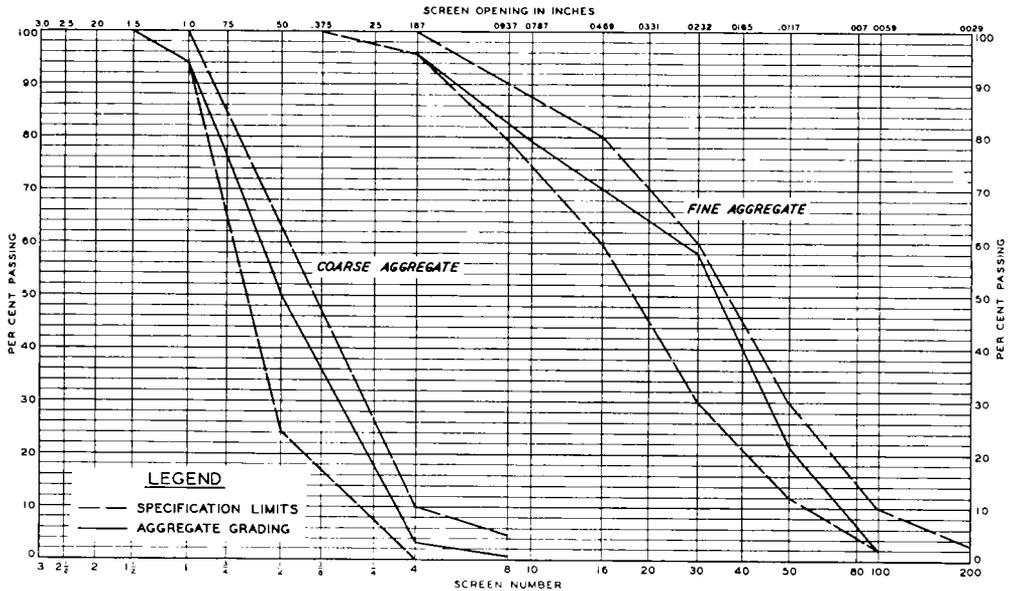


Figure 9. Grading curves for portland cement concrete aggregates.

agreed to by representatives of the Air Force and the Corps of Engineers. Establishment of loading and traffic conditions for an accelerated traffic test that duplicate actual traffic can be accomplished with a far greater degree of accuracy for a taxiway than for the interior portion of a runway. This does not mean that a reasonable duplication of taxiway traffic is a simple operation, but at least the speed of travel, the effective loading, the traffic distribution across the pavement, and the total number of stress repetitions used in the test more closely simulate prototype conditions than can feasibly be realized in duplicating runway operations.

When aircraft are operating on a runway interior pavement they are generally moving at a high rate of speed. There is certainly an effective reduction in static loading caused by the aircraft tending to become airborne. The distribution of loading on the forward and rear main landing gear of a bicycle-gear aircraft undergoes a change during acceleration and take-off. Because an accelerated traffic test must be conducted at relatively slow speeds with only one weight, certain assumptions must be

made relative to the correlation with prototype conditions.

Prior to 1957 the Corps of Engineers had established through investigational study a reasonable idea as to the lateral distribution of traffic on a runway. Additionally, the Department of Air Force had furnished data regarding the total number of B-52 operations that might be expected to occur in a 20-year period, the normal variation in the operational weight of the aircraft, the speed of the aircraft at various points in its take-off run, and data on the apparent reduction in gear load that occurs as the aircraft becomes airborne. By combining these data with experience records of runway interior pavement performance, the Corps of Engineers was able to formulate the plan of testing described subsequently, which it was agreed simulated as closely as possible the operations of a B-52 plane in a period approaching 20 years.

Test Cart. Traffic was applied to the test section with a test load cart (Fig. 10) consisting of a load box equipped with a twin-twin wheel assembly and towed by a Tournapull Super C tractor. The box was loaded to result in a net

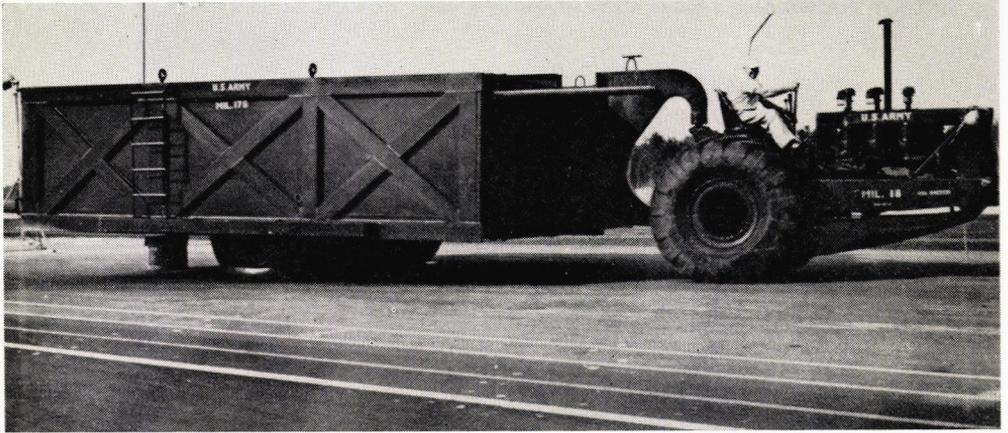


Figure 10. Test load cart.

weight of 212,000 lb on the four airplane-type wheels under the load box (Fig. 11). This represents a 265,000-lb load for the aft gear assembly of a B-52 aircraft (see Fig. 12) reduced by 20 percent to compensate partially for the wing lift that occurs on the runway. The tires are 56 x 16, 32-ply airplane tires mounted on axles with tire spacings as shown in Figure 12. The tires were inflated to 266 psi in accordance with Air Force practice for this load.

Test Lane. The traffic test lane was 250 ft long, which included 200 ft of flexible pavement and 50 ft (2 slabs) of

rigid pavement. As shown in Figure 2, the traffic lane included two longitudinal joints in the surface course of the flexible pavement and one longitudinal construction joint and one transverse contraction joint in the rigid pavement.

Traffic Pattern. The test load cart was operated back and forth in the traffic lane and was shifted laterally on each forward pass to obtain uniform coverages of traffic over the 14-ft-4-in. wide traffic lane. A coverage is defined as a single-wheel-load application over all points in a given area. The load cart was operated at a speed of about 4 mph. The pattern

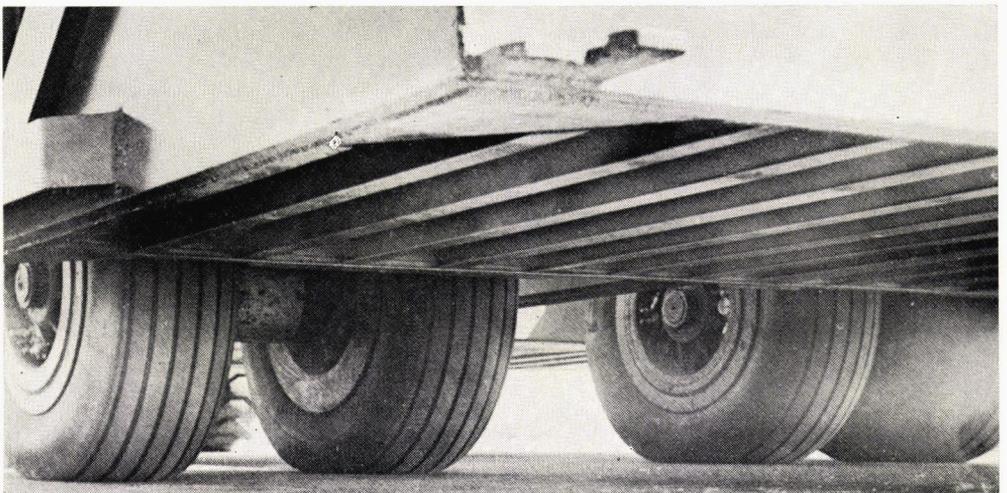


Figure 11. Close-up of gear wheel assembly.

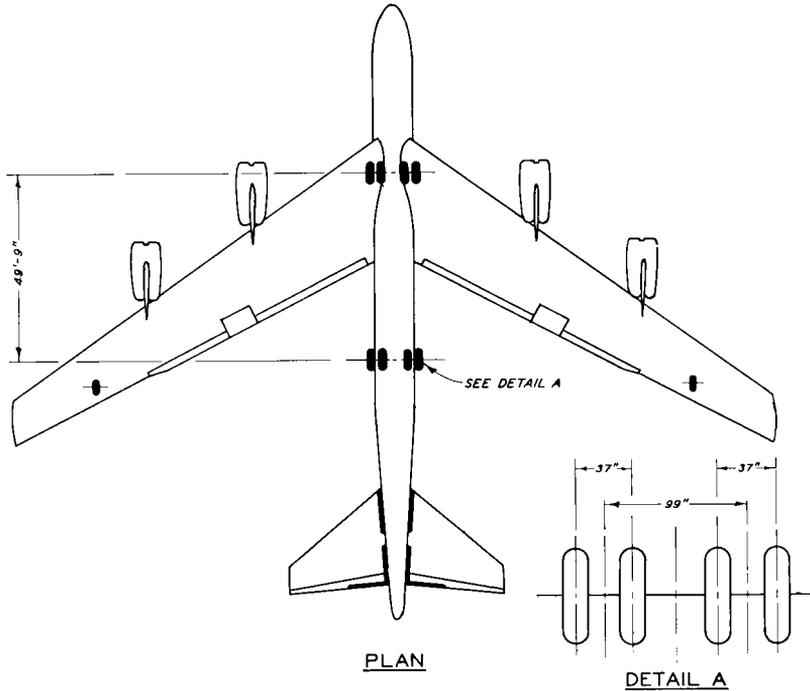


Figure 12. B-52 landing gear layout.

followed in applying the traffic is shown in Figure 13. From this pattern, it can be seen that in applying uniform coverages over the 14-ft-4-in. wide traffic lane, one wheel of the assembly ran in the area 1 to 2 ft outside the traffic lane, but a blank space about 1 ft wide on each edge of the traffic lane received no traffic. This width lane and traffic pattern were chosen for reasons of economy. After about 400 coverages of traffic, it was noted that settlement had occurred in the traffic lane and in the area outside the traffic lane where the outside wheel ran, which resulted in a ridge along the blank space that was receiving no traffic. Under normal operations of aircraft, traffic would be distributed over a wider area and would not be concentrated in 14 ft; therefore, for the remainder of traffic the cart was shifted occasionally to apply a small amount of traffic over this blank space. This resulted in nonuniform coverages of traffic over an area about $2\frac{1}{2}$ ft wide on each side of the uniform-coverage traffic lane. The amount of traffic applied

in the blank space was not sufficient to iron out the ridge and it continued to develop throughout the period of traffic.

Coverages and Temperature. A total of 5,004 coverages was applied during the period September 4-28, 1958. Table 3 is a daily log of traffic, which was applied as nearly as practicable for 24 hr a day, 7 days per week, until the 5,000-coverage level was reached. Pavement temperature controlled the rate of application of traffic to some extent, as it was required that the percentage of coverages *versus* temperature fall within 2 percent at 90 F of a predetermined pavement-temperature distribution curve. Curve 1 of Figure 14 shows the pavement temperature distribution curve obtained at Vicksburg, Miss., for the year from June 1, 1957 through May 31, 1958. It was agreed with the Air Force that this curve would be used to control traffic. Curve 2 of Figure 14 shows the actual traffic distribution with pavement temperature at Columbus, Miss. The pavement temperature was that measured at the surface

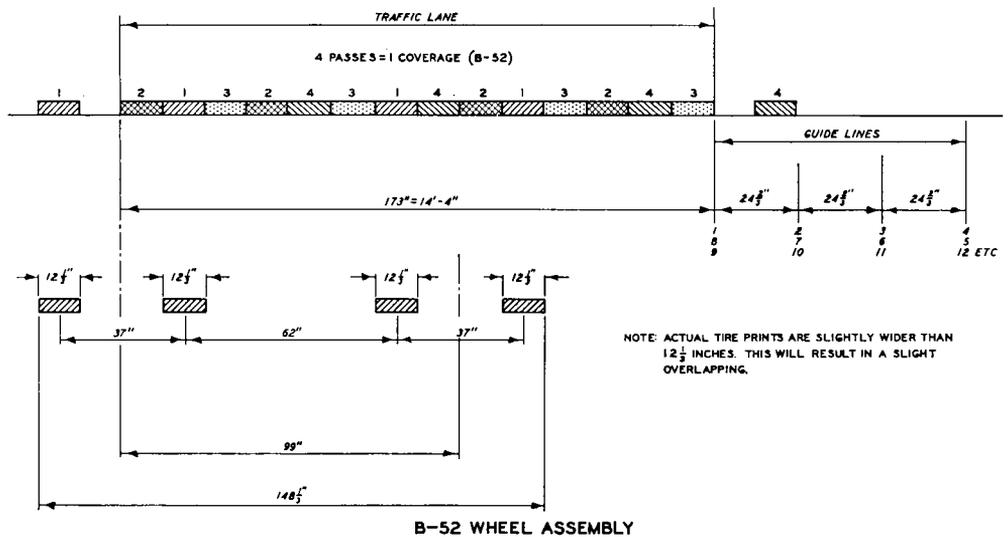


Figure 13. Traffic pattern for simulated B-52 traffic.

TABLE 3
DAILY LOG OF TRAFFIC TEST

Date	Weather	Coverages				Total	Behavior of Pavement
		Daily		Accum.			
		Above 90 F	Below 90 F	Above 90 F	Below 90 F		
Sept. 4	Clear, warm	91	15	91	15	106	
5	Clear, mild	112	117	203	132	335	
6	Clear, warm	29	136	232	268	500	
7	Clear, warm	102	133	334	401	735	
8	Clear, mild	128	156	462	557	1019	Hair cracks in asphaltic concrete opening and closing under traffic.
9	Clear, mild	100	132	572	689	1261	
10	Clear, mild	117	152	689	841	1530	Crack noted in rigid pavement near centerline of runway.
11	Cloudy, showers	—	301	689	1142	1831	Rate of deformation decreasing in flexible pavement structure.
12	Cloudy, showers	—	109	689	1351	2040	
13	Cloudy, cool	86	191	775	1542	2317	Closely spaced surface cracking noted in rigid pavement.
14	Clear, cool	68	205	843	1747	2590	
15	Cloudy, showers	31	187	874	1934	2808	
16	Clear, mild	121	128	995	2062	3057	
17	Cloudy, mild	33	143	1028	2205	3233	Magnitude of cracks previously noted in rigid pavement has increased.
18	Cloudy, mild	—	163	1028	2368	3396	
19	Clear, mild	13	125	1041	2493	3534	
20	Rain	—	68	1041	2561	3602	Very fine hairline cracking in asphaltic concrete.
21	Rain	—	79	1041	2640	3681	
22	Cloudy, mild	39	157	1078	2797	3875	Deformation in flexible pavement structure continues, but at a decreasing rate.
23	Clear, mild	—	189	1078	2986	4064	
24	Clear, mild	—	229	1078	3215	4293	
25	Clear, mild	29	285	1107	3450	4557	Most of the cracks in asphaltic concrete sealed under +90 F traffic.
26	Clear, mild	—	198	1107	3648	4755	Cracks in asphaltic concrete opening under traffic.
27	Clear, mild	110	119	1217	3767	4984	
28	Clear, mild	20	—	1237	3767	5004	Cracks in asphaltic concrete continue to open and close under traffic.

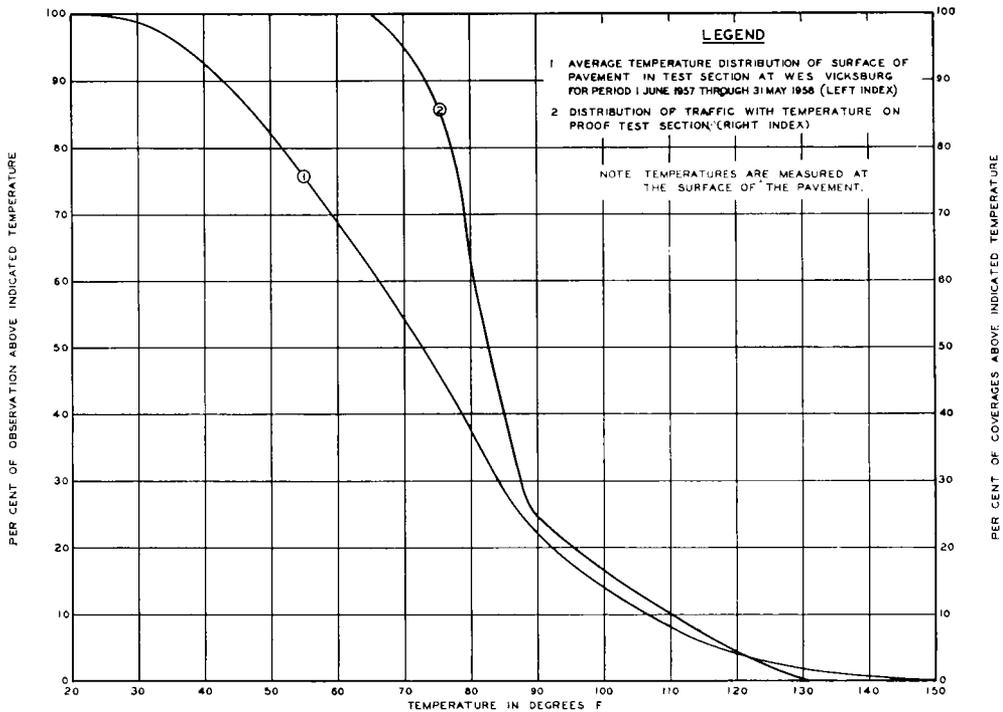


Figure 14. Traffic and pavement temperature distribution.

of the pavement. As can be noted from Figure 14, the traffic was applied over a range of pavement temperatures from 65 to slightly above 130 F. The hot-weather traffic (above 90 F) agrees very closely with the one-year temperature-distribution curve. However, the below-90 F pavement temperature traffic was applied at temperatures of from 65 to 90 F, as compared with 20 to 90 F for the annual curve. About 10 percent of the traffic coverages were applied during light rain or on wet pavement. The night traffic was performed under floodlights.

TEST RESULTS

Behavior Under Traffic

Visual observations of pavement behavior were recorded at various coverage intervals during traffic. These observations were supplemented by (a) level readings to establish the settlement (permanent downward movement), (b) deflection measurements (downward move-

ment under a given load application, which in this case is practically equal to the elastic deflection), (c) Marshall test properties determined from cores cut from the asphaltic concrete, and (d) photographs. Cracking that occurred during traffic is summarized in Table 3.

Asphaltic Concrete. Marshall test properties obtained in tests on core samples cut from the asphaltic concrete at various intervals of traffic are summarized in Table 2. These data show that the initial density of both the surface and binder course mixes was 98 percent of the laboratory design density (zero coverage data). The voids total mix corresponding to 98 percent density were 8.3 and 10.7 percent for the surface course and binder course, respectively. The stability values at zero coverages were 537 and 1,410 for the surface and binder courses, respectively. As traffic was applied, an increase in pavement density and a decrease in voids total mix occurred for the first 1,100 coverages, with little change in

density or voids thereafter. The stability of the pavement showed a continuous increase throughout the period of traffic.

The rate of densification of the asphaltic concrete is best illustrated by a plot of voids *versus* coverages (Fig. 15). From these data it can be seen that a rapid decrease in voids occurred during the first 200 coverages of traffic, gradually decreasing up to about 1,000 coverages, with little change occurring beyond 1,000 coverages. At the end of traffic, the voids total mix were 5.0 percent in the surface course and 8.4 percent in the binder course. These data, along with visual observations, show that the asphaltic concrete (both surface and binder courses) had sufficient strength and was sufficiently resistant to compaction to withstand the traffic in these tests without flushing or excessive reduction in voids.

Deflection. Surface deflection measurements were made at two locations on both the flexible and rigid pavements at zero coverages and at various intervals during traffic. These measurements were obtained with a level instrument by reading rods (engineer scales) placed in a

prearranged position on the pavement adjacent to and between the load wheels. The rods were read with the load on the pavement; then the load cart was moved forward, and a second reading taken with the load off. The difference in rod readings indicates the rebound of the pavement and, for practical purposes (checked in previous tests at WES with buried electronic deflection gages), the total downward movement of the pavement.

The deflection data are given in Table 4; Figure 16 is a schematic diagram indicating the locations where the readings were taken. These data show that the maximum deflection of the flexible pavement under load was about constant throughout the period of traffic and was in the order of 0.08 to 0.1 in. The pavement deflections did not increase with coverages, and even showed a slight decrease at 5,000 coverages as compared to the value at 3,500 coverages. This is evidence that the strength of the material under the asphaltic concrete increased with traffic. The deflection of the rigid pavement was in the order of 0.07 in. near the juncture with the flexible

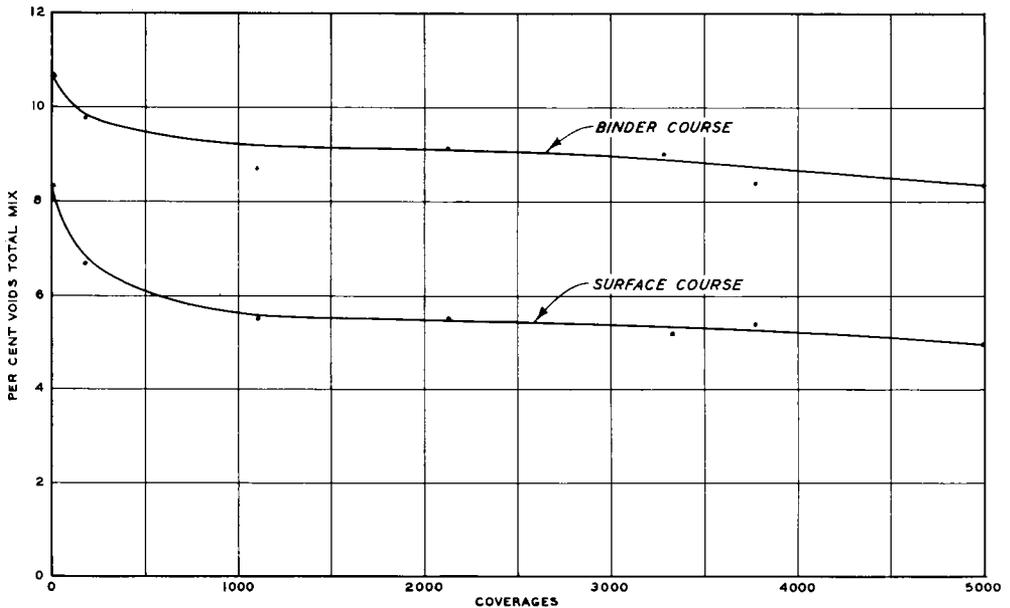


Figure 15. Voids total mix in bituminous pavement.

TABLE 4
DEFLECTION DATA *

Pavement Type	Station	Coverages	Deflection (in.)					
			Point 1	Point 2	Point 3	Point 4	Point 5	
Flexible	83+50	0	—	—	0.084	0.084	—	
		411	—	—	0.096	0.096	—	
		1239	0.094	0.100	0.092	0.102	0.108	
		1910	0.094	0.102	0.100	0.102	0.106	
		2877	0.092	0.100	0.090	0.082	0.090	
	84+50	3520	0.080	0.100	0.100	0.090	0.090	
		5000	0.080	0.088	0.084	0.098	0.100	
		0	—	—	0.084	0.084	—	
		411	—	—	0.084	0.084	—	
		1239	0.094	0.096	0.088	0.094	0.090	
	Rigid	85+00.5	1910	0.092	0.096	0.090	0.090	0.088
			2877	0.096	0.090	0.088	0.094	0.092
			3520	—	0.080	0.100	0.080	0.100
			5000	0.080	0.092	0.082	0.080	0.086
			0	0.056	—	0.054	—	—
85+27		411	0.053	—	0.055	—	—	
		1239	0.088	—	0.084	—	—	
		1910	0.074	0.068	0.074	—	—	
		2877	0.070	0.068	0.066	—	—	
		3520	0.060	0.080	0.060	—	—	
85+27		5000	0.068	0.080	0.070	—	—	
		0	0.046	—	0.042	—	—	
		3520	0.060	—	0.060	—	—	
		5000	0.050	0.050	0.050	—	—	

* See Figure 16 for location of deflection measurement points.

construction and 0.05 in. at the other location tested.

Settlement. Level readings were taken prior to traffic and at various intervals of traffic across the test lane at 25-ft sections on the flexible pavement and at one

location on the rigid pavement. Similar readings were taken along the centerline of the traffic lane. These observations were made to determine the rate and magnitude of settlement.

Figure 17 shows typical sections across the flexible pavement. The section at Sta 83+50 represents about the minimum settlement on the traffic lane. Sta 84+25 represents the average settlement and the section at Sta 84+75 indicates the maximum settlement. The settlement at Sta 84+75 averages about 1½ in. These data show that the settlement in the traffic lane where uniform coverages of traffic were applied is quite uniform. The average of all settlement readings at the end of 5,000 coverages was approximately 1¼ in. This settlement was primarily the result of densification of the underlying material, because no shear failure occurred as evidenced by the small and diminishing deflections under traffic. The grooves just inside the traffic lane are in the two longitudinal construction joints. As indicated by the zero-coverage cross-sections, these joints were low at the start of traffic and in some areas during traffic tended to settle a slightly greater amount than the rest of the pavement. The ridges noted just outside the traffic lane (at a coverage level of 411 and

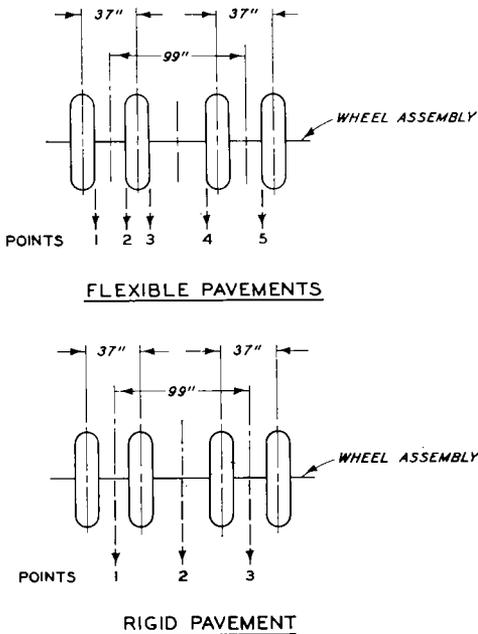


Figure 16. Location of measuring points for deflection data.

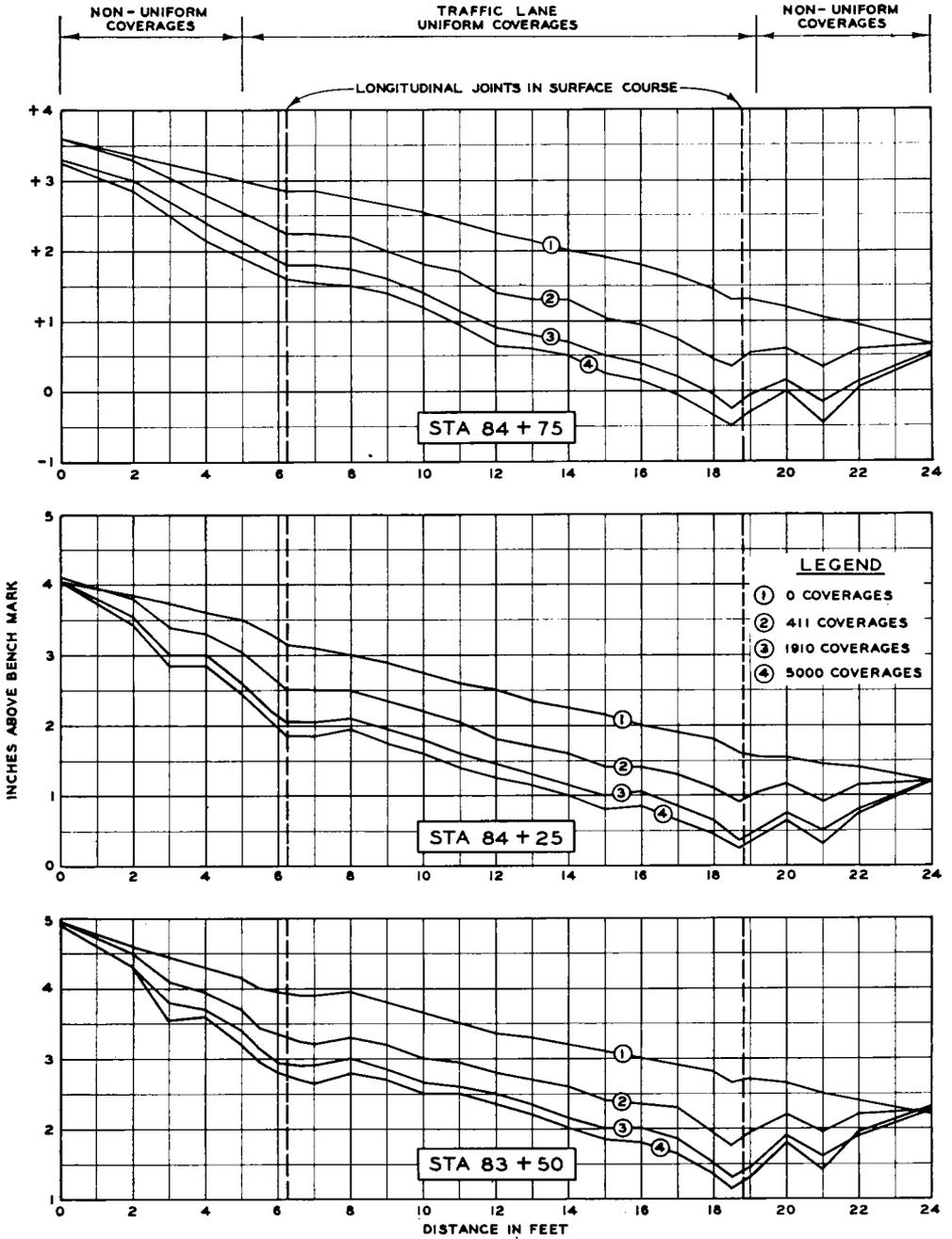


Figure 17. Typical flexible pavement surface cross-sections.

greater) are at the blank spaces indicated on the traffic pattern (Fig. 13) where only a small amount of traffic was applied.

Cross-sections across the portland cement concrete are shown in Figure 18. The data for Sta 85+00.5 were obtained on the portland cement concrete 6 in. from the buried-slab juncture. The data for Sta 85+30, were obtained 5 ft from the sawed contraction joint at the end of 5,000 coverages of traffic. The settlement averaged about 0.4 in. in this location. Level readings were not obtained at Sta 85+30 prior to traffic.

Level readings were taken at selected locations on both the flexible and rigid pavements at more frequent intervals than those made for the cross-sections to establish the rate of settlement. In Figure 19 data for four locations on the flexible pavement section plotted to logarithmic scale result generally in a straight-line relation of coverages *versus* settlement. A similar plot of coverages *versus* settlement for Sta 84+25 plotted to an arithmetic scale is shown in Figure 20, from which it can be seen that most of the

settlement occurred within the first 1,000 coverages. Similar data are shown in Figure 21 for a location on the rigid pavement.

A plan and a surface profile of the test section are shown in Figure 22. The profile shows the initial and final centerline grade of the test section. The initial profile was obtained on the flexible pavement at 25-ft intervals along the centerline of the runway and at one point on the rigid pavement at Sta 85+00.5. However, by 411 coverages it was noted that considerable settlement had occurred in the flexible pavement and that settlement was occurring in the rigid pavement at Sta 85+00.5. Therefore, at the end of 411 coverages level readings were taken at 1- to 5-ft intervals along the centerline of the traffic lane on the rigid pavement from Sta 85+00.5 to 85+25. These readings were used to establish the profile shown at 411 coverages. The final profile at the end of 5,000 coverages was established from level readings taken at 1-ft intervals along the entire length of the traffic lane. The settlement along the centerline of the traffic lane is of the same

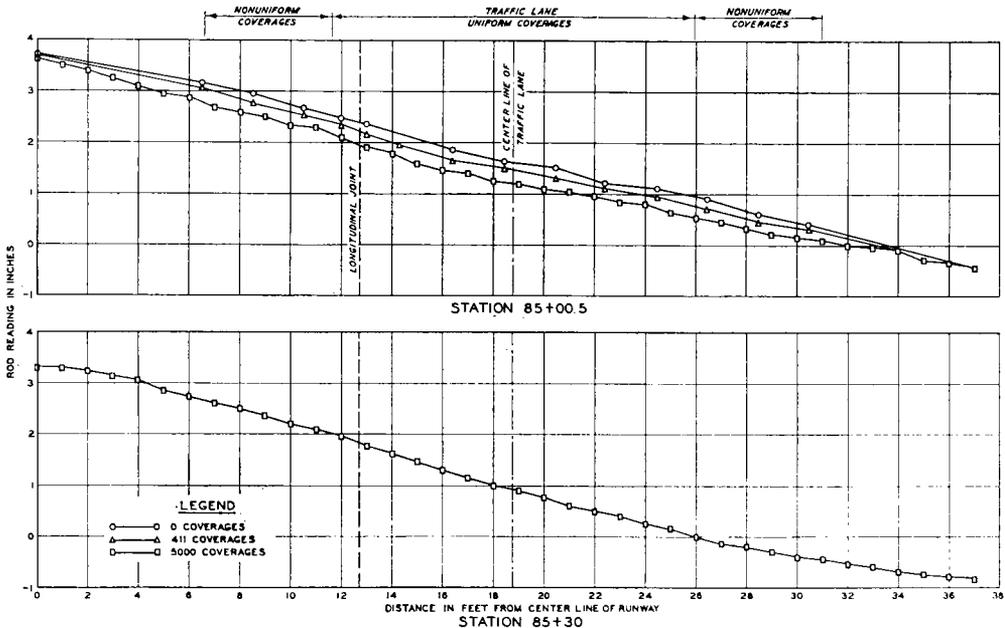


Figure 18. Rigid pavement surface cross-sections.

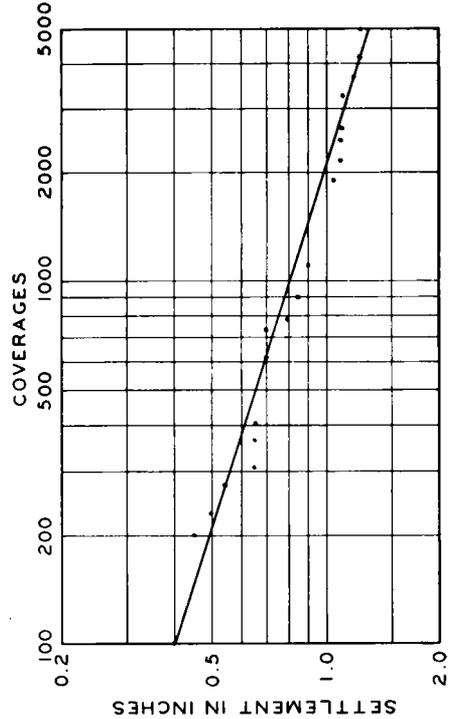
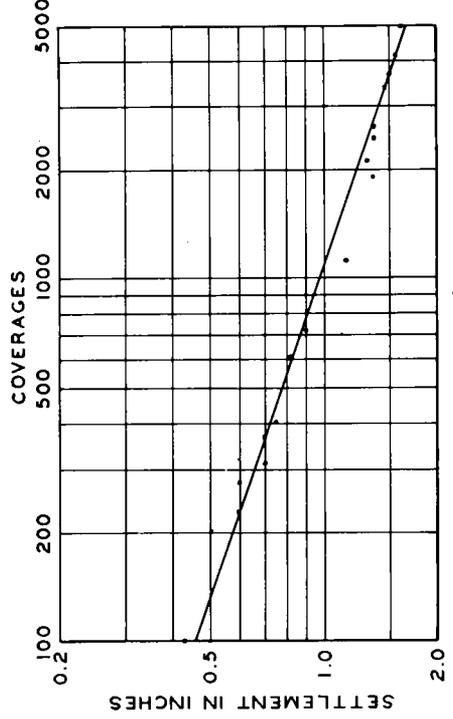
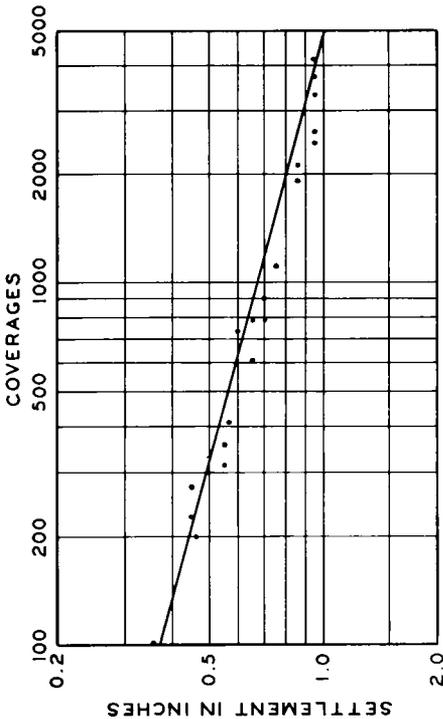
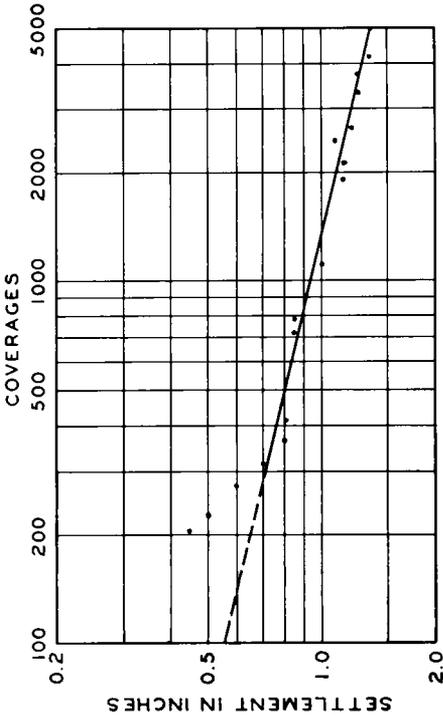


Figure 19. Settlement curves for flexible pavement. Distances refer to corresponding distances in Figure 17.

Figure 19. Settlement curves for flexible pavement. Distances refer to corresponding distances in Figure 17.

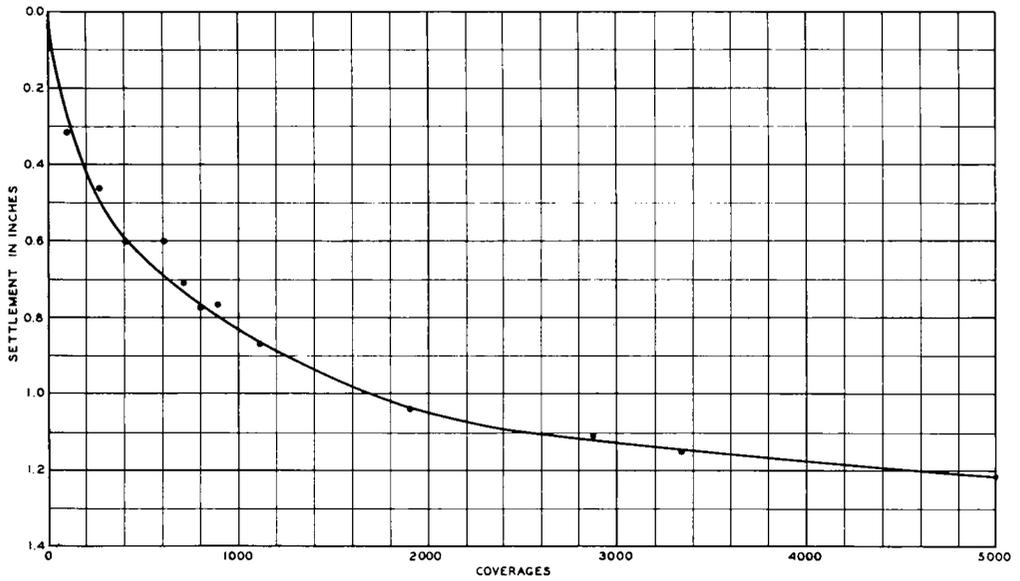


Figure 20. Average settlement curve on flexible pavement at Sta 84 + 25.

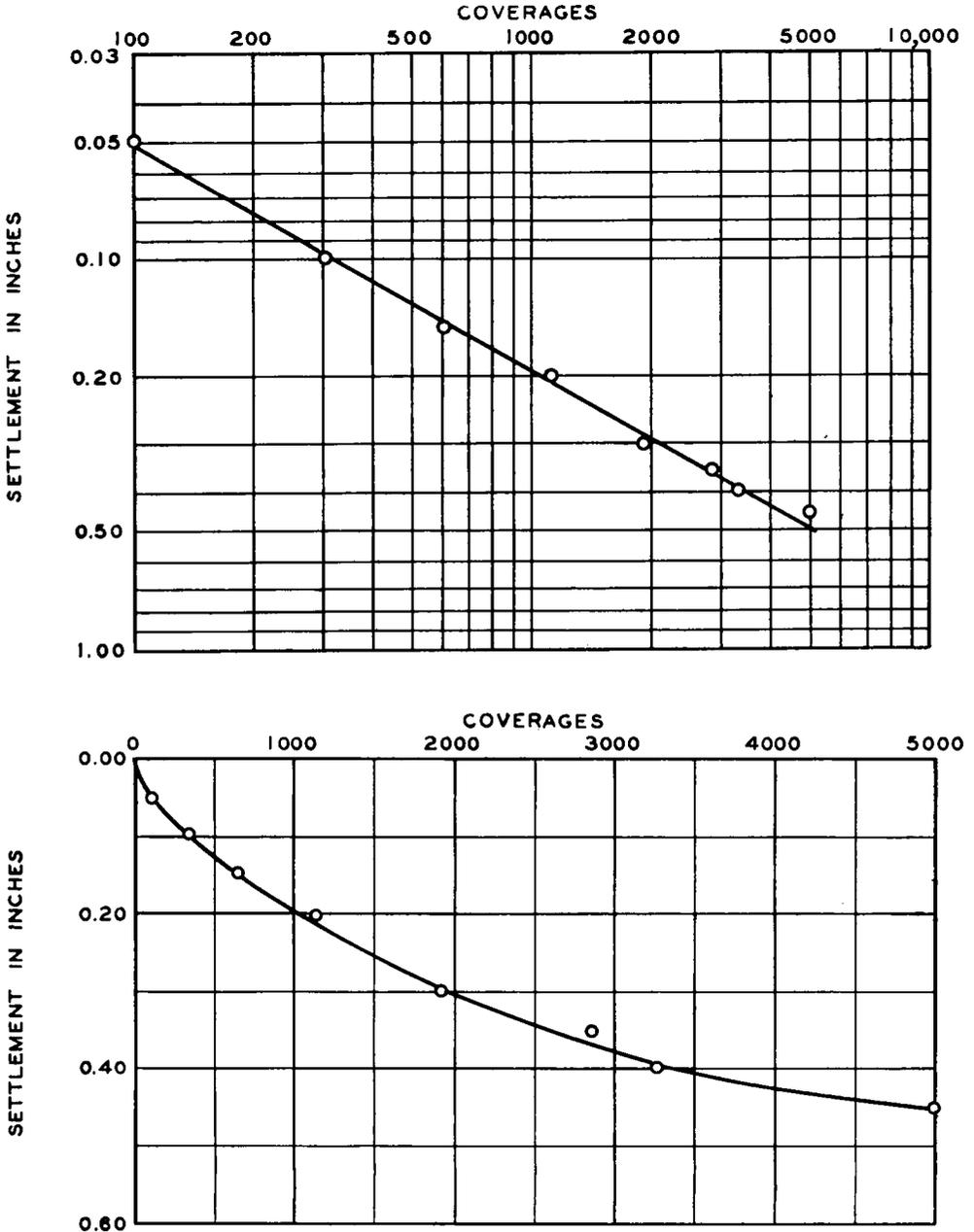
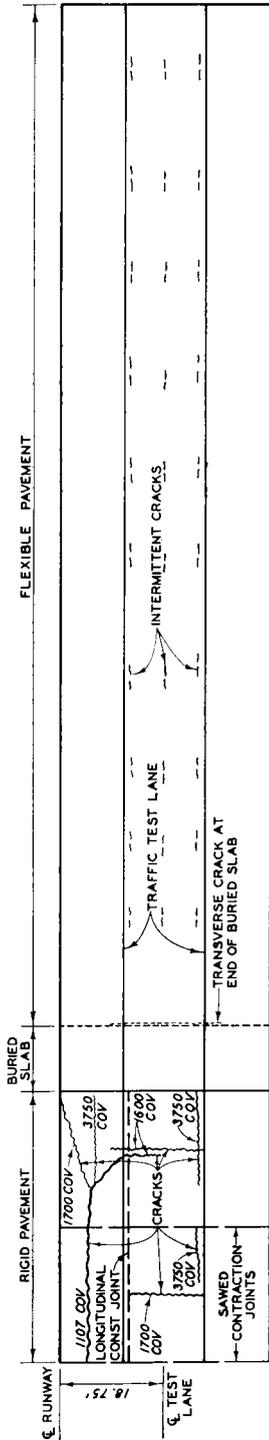
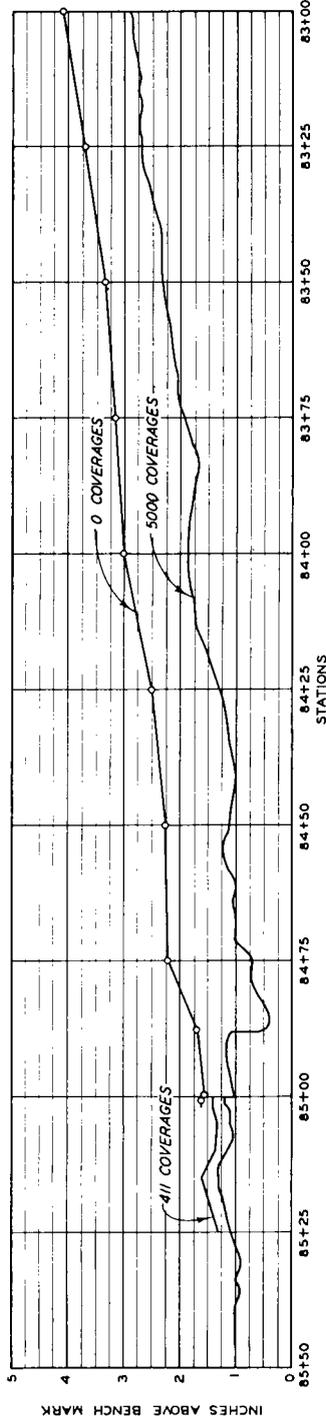


Figure 21. Settlement curves for rigid pavement at point 19 ft from centerline of runway at Sta 85+00.5.



PLAN

NOTE: NUMBERS BY CRACKS INDICATE COVERAGES AT WHICH CRACKS WERE FIRST NOTED.



SURFACE PROFILES ALONG CENTER LINE

Figure 22. Plan and surface profiles of proof-test section.

order of magnitude as the values indicated from the cross-sections measured at 25-ft intervals. The settlement was uniform, so that the surfaces of both the flexible and rigid pavement were relatively smooth at the end of traffic; however, a differential settlement of $\frac{1}{4}$ in. developed at the juncture between the rigid pavement and the asphaltic concrete. Also, a differential settlement of 0.6 in. developed at the end of the buried slab. Views of the test section at 3,334 and 5,000 coverages are shown in Figures 23 through 27.

Pavement Cracking. Some cracking occurred in both the flexible and rigid pavements. The first cracking in the asphaltic concrete was noted at about 1,000 coverages, when intermittent hairline cracks developed parallel to the direction of traffic near the centerline of the traffic lane and along the two construction joints (see plan, Fig. 22). Throughout the remainder of traffic these cracks tended to seal over during periods of hot-weather traffic and reopen during periods of cool-weather traffic. Figure 23 shows the surface texture of the asphaltic concrete and one of the cracks in the flexible pavement at 3,334 coverages. Pavement cores cut through one of the

most pronounced cracks at the end of 5,000 coverages indicated that the maximum depth of the cracks was in the order of 1 in. A transverse crack developed in the asphaltic concrete at the end of the buried slab at about 2,800 coverages and was visible throughout the remainder of traffic. In addition to these cracks, very fine hairline cracking occurred generally over the traffic lane at about 3,600 coverages. These cracks could be seen only as the pavement dried out after a rain when the cracks retained moisture. The cracks were so shallow that their depths could not be determined.

A number of small cracks occurred in all four rigid pavement slabs subjected to traffic (Figure 22). The most severe crack was first noted at 1,107 coverages and was located about 6 ft outside the traffic lane, running parallel with the traffic lane for a distance of 35 ft, then angling into the traffic lane and terminating at a longitudinal construction joint and later extending across the joint as shown in Figure 22. This crack opened slightly with a very light amount of raveling along its edges as traffic was continued to 5,000 coverages. This was the only crack that could be detected to

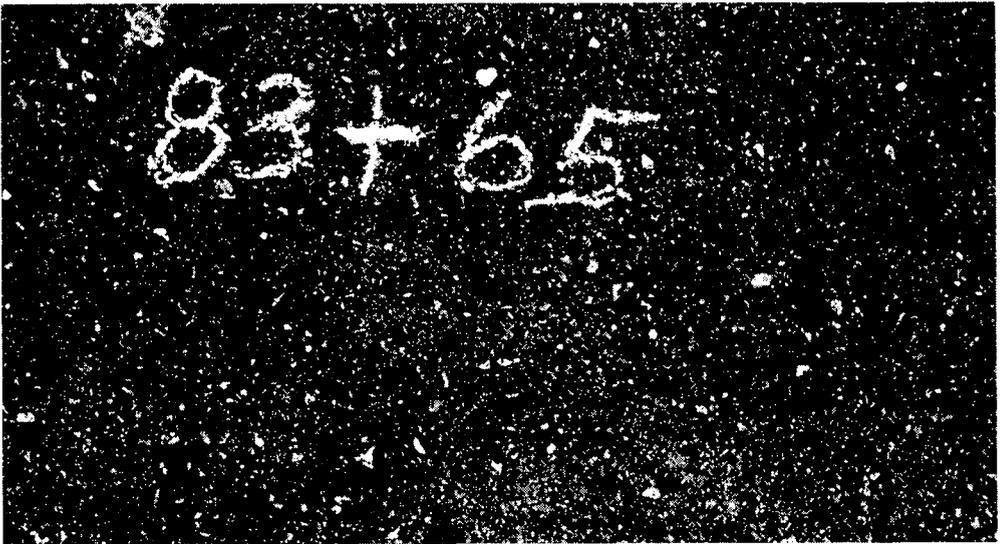


Figure 23. Close-up of asphaltic concrete surface texture and longitudinal cracks near centerline of test lane, 3,334 coverages.



Figure 24. Crack in portland cement concrete at 3,334 coverages.

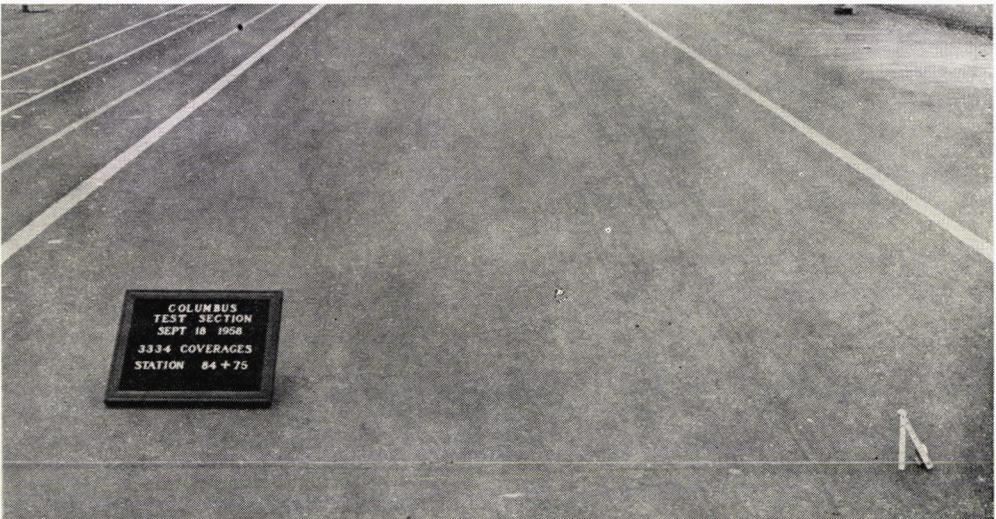


Figure 25. Deformation in flexible pavement structure at 3,334 coverages.

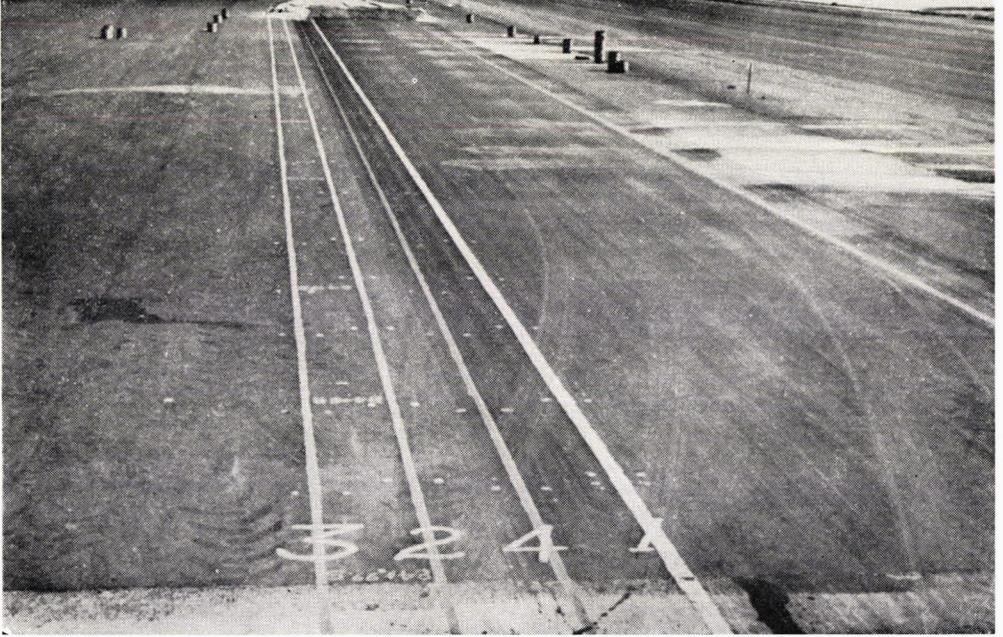


Figure 26. Test section at 5,000 coverages.

be working during traffic. Figure 24 shows a portion of this crack at the completion of 3,334 coverages. A few other fine hair-line, nonworking cracks were first observed at the coverage levels noted in Figure 22. When first noted, they were

from a few inches to 1 to 2 ft in length and progressed to the extent shown in Figure 22 at the end of traffic. In some instances the cracks were visible only as the pavement dried out after having been wet.

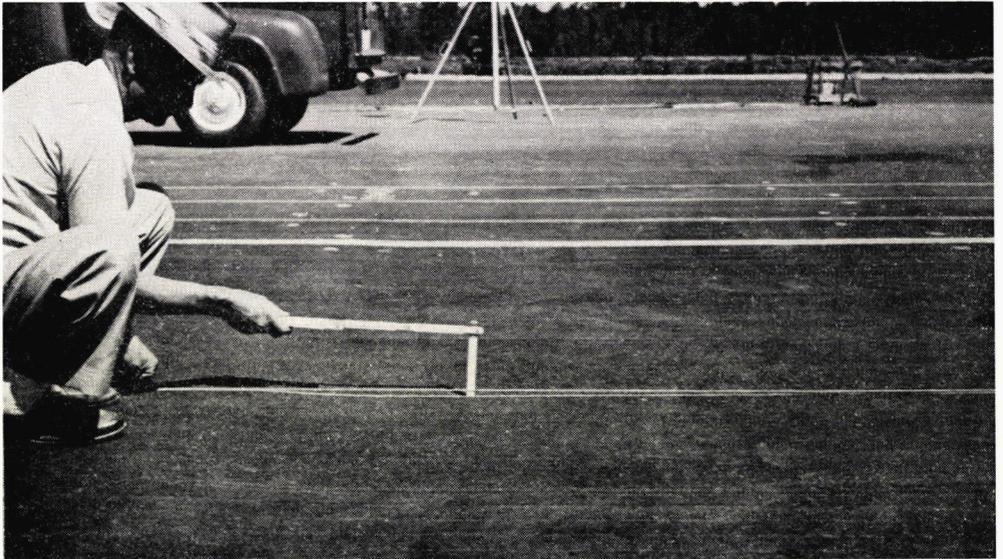


Figure 27. Differential settlement at end of buried slab.

Smoothness. The Waterways Experiment Station requested the resident engineer at Columbus AFB to make tests on the section to determine deviation of the surface from the construction tolerances for smoothness after completion of 5,000 coverages. The construction tolerances for surface smoothness are $\frac{1}{8}$ in. in 12 ft in the longitudinal direction and $\frac{3}{16}$ in. in the transverse direction. The tests were made on October 3, 1958, and were located within the limits of the uniform-coverage trafficked area. The results are given in the following.

After 5,000 coverages the surface of the flexible pavement conformed to the construction tolerances in a longitudinal direction except at the juncture between the rigid pavement and the asphaltic concrete and at the end of the buried slab (Sta 84+87).

In the transverse direction, the surface of the flexible pavement conformed to the construction tolerances except at the two longitudinal joints in the surface course which are just inside the traffic lane on each side. Grooves from 9 to 18 in. wide exist at the joints. The following tests made at 10-ft intervals show the deviation from the $\frac{3}{16}$ -in. tolerance in the lowest part of the grooves. "Right" and "left" refer to the groove on the right or left of the centerline of the traffic area when looking in the direction of increasing station numbers.

Station	Deviation (in.)		Station	Deviation (in.)	
	Right	Left		Right	Left
83+00	$\frac{1}{8}$	$\frac{3}{16}$	84+00	0	$\frac{1}{4}$
83+10	$\frac{1}{16}$	$\frac{3}{16}$	84+10	$\frac{1}{16}$	$\frac{5}{16}$
83+20	$\frac{1}{16}$	$\frac{1}{4}$	84+20	$\frac{1}{8}$	$\frac{1}{8}$
83+30	0	$\frac{1}{8}$	84+30	$\frac{1}{8}$	$\frac{1}{16}$
83+40	0	$\frac{3}{16}$	84+40	0	$\frac{1}{8}$
83+50	$\frac{1}{16}$	$\frac{1}{4}$	84+50	$\frac{1}{8}$	$\frac{1}{4}$
83+60	0	$\frac{1}{16}$	84+60	0	$\frac{1}{8}$
83+70	$\frac{1}{16}$	$\frac{1}{4}$	84+70	0	$\frac{1}{8}$
83+80	$\frac{1}{16}$	$\frac{1}{4}$	84+80	0	$\frac{1}{8}$
83+90	0	$\frac{1}{4}$	84+87	0	$\frac{1}{4}$

After 5,000 coverages the surface of the portland cement concrete pavement conformed to the construction tolerances

for smoothness in both the longitudinal and transverse directions except for a $\frac{1}{8}$ -in. deviation in the middle of the slab at Sta 85+12.5, which was present at the start of traffic.

SUMMARY OF FINDINGS

The findings of the proof-test are summarized in the following.

Flexible Pavement

Asphaltic Mix. Construction of the lean-mix pavement placed in the test areas presented no significant problems. The asphaltic concrete (both surface and binder courses) had sufficient strength and was sufficiently resistant to compaction to withstand the traffic in these tests without flushing or excessive reduction of voids.

Intermittent cracks, parallel to the direction of traffic, developed at about 1,000 coverages along the centerline of the traffic lane and along the two construction joints at each edge of the traffic lane. Throughout the remainder of traffic the cracks sealed during hot periods and reopened during cold periods. Maximum depth of crack was in the order of 1 in.

Very fine hairline cracking occurred generally over the trafficked area at about 3,600 coverages. The cracks were so fine that they could be seen only when they retained moisture. The depth was so shallow that it could not be determined.

Base, Subbase, and Subgrade. The materials below the asphaltic concrete were adequate from a strength standpoint to withstand more than 5,000 coverages of the accelerated traffic applied in these tests.

Densification occurred to the extent that settlement developed in the traffic lane, averaging about $1\frac{1}{4}$ in. and reaching a maximum of $1\frac{1}{2}$ in. The major part of the densification occurred in the first 1,000 coverages. The densification resulted in an over-all increase in strength of the flexible pavement structure.

Deflection. The maximum deflection of the flexible pavement was in the order

of 0.1 in. The deflection was practically constant throughout the majority of the traffic period with a slight tendency to decrease during the latter stages.

Surface Smoothness. Settlement in the traffic lane was quite uniform. The grooves and ridges along the outside edges of the traffic lane were the result of nonuniform traffic distribution. The grooves along the traffic lane on the inside of the lane were the result of slight deficiencies in the two construction joints at these points.

At 5,000 coverages the surface smoothness within the area where traffic was uniformly distributed was within the construction tolerances ($\frac{1}{8}$ in. longitudinal, $\frac{3}{16}$ in. transverse deviation in 12 ft), except at the two construction joints at each edge of the traffic lane.

Juncture

A crack developed in the asphaltic concrete at the end of the buried slab at 2,800 coverages and remained visible throughout the remainder of traffic. A differential settlement of $\frac{1}{4}$ in. developed at the juncture of the rigid pavement and the asphalt overlying the buried slab. A differential settlement of 0.6 in. developed in the flexible pavement adjacent to the buried slab.

Rigid Pavement

Deflection. The deflection of the portland cement concrete pavement was in the order of 0.07 in. near the juncture with the flexible pavement and 0.05 in. at the other location measured.

Slab Behavior. Settlement occurred in the portland cement concrete pavement. Immediately adjacent to the buried slab transition (the only location where initial readings were made), the settlement averaged about 0.4 in., reaching a maximum of 0.5 in.

Cracking occurred along the outside of the traffic lane at 1,100 coverages and inside the traffic lane at 1,600 coverages. Cracking continued to develop with traffic through 3,700 coverages.

Surface smoothness of the portland cement concrete slab at the end of 5,000

coverages was within construction tolerances, except for one deviation which was present at the start of traffic.

APPLICATION OF RESULTS TO PROTOTYPE CONDITIONS

The surface smoothness of the traffic lane after the completion of traffic essentially met the smoothness tolerances permitted during construction. The cracking that occurred in the traffic lane in the rigid pavement was not extensive enough to require maintenance, and that which occurred in the flexible pavement would have been minimized under normal conditions by the application of one or more seal coats throughout the 20-year period.

The average $1\frac{1}{4}$ -in. settlement, combined with the peculiarity of the pattern of traffic in the test, resulted in a differential elevation between the trafficked and nontrafficked area that would be objectionable if present in a runway. Under normal runway operations, this abrupt change in surface elevation would not develop because traffic would be distributed across the runway in a "bell-shaped" pattern, with the maximum accumulation of traffic in the central part of the runway and the amount of traffic tapering gradually to the edges of the trafficked area. In a few instances, runways have been subjected to incidental periods of taxi operations. Such periods have occurred during repairs to taxiways and extensions to the runways. If taxi operations extend over a period of six months or longer and are confined in the narrow channel normal to taxiway operations, the Columbus tests indicate that objectionable differential settlement could possibly develop.

The buried-slab transition between the rigid and flexible pavements did not provide satisfactory smoothness. Although an improved transition should be possible, adequate smoothness could have been restored to the transition at Columbus in less than one day for about \$200; and if this condition was projected to both ends of a typical runway, smoothness could be restored in one day for

about \$1,000. This minor maintenance work could be accomplished at the same time that the joints in the adjacent rigid pavements were being resealed.

The Columbus test does not provide an answer regarding the durability of the relatively lean asphalt concrete used in these tests. Admittedly, the mix design used at Columbus is potentially less durable than the somewhat richer paving mixtures used for pavements to support lighter aircraft in the past. However, it is believed that the reduction in durability is slight; that is, if the older mixes are durable for a period of 20 years, the newer mixes will be durable for 17 to 18 years by comparison. Unfortunately, there is no known accelerated weathering test that will prove or disprove this appraisal. Considering all available information, it is believed that the pavement design at Columbus will be satisfactory from the standpoint of durability.

CONCLUSIONS

Based on the results obtained at Columbus, observations of the conditions of the tests, and considering the requirements of the user, the Corps of Engineers has drawn the following conclusions:

1. The pavements were designed and constructed under normal contract conditions.
2. Considering normal B-52 operations only, the tests at Columbus Air Force

Base demonstrated the validity of the design and construction procedures developed by the Corps of Engineers for heavy-load flexible runway interior pavements.

3. The abrupt change in surface elevation between the trafficked area and the nontrafficked area to either side would not occur under normal B-52 operations, but would be a possibility under extended taxi operations.

4. Runway pavements may have to support incidental periods of B-52 taxi operations in addition to the normal landing and take-off traffic. The tests indicated that objectionable differential settlement can develop on runways where taxi operations are extended over a period of six months or longer. Therefore, as a general policy, the Corps of Engineers is in agreement with the Air Force that a center strip of rigid pavement in runway interiors is good insurance.

The Corps of Engineers presented these conclusions to the Subcommittee for Special Investigations on December 2, 1958. The Air Force concurred, generally, with the conclusions presented in this meeting.

REFERENCE

1. "Demonstration Test of Performance of Heavy-Load Airfield Pavements." Tech. Rep. 3-459, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. (June 1957).

DISCUSSION

ARVIN S. WELLBORN, *Chief Engineer, The Asphalt Institute, College Park, Md.* — The Asphalt Institute is in substantially complete agreement with the Corps of Engineers' findings from the accelerated proof-tests of runway pavement at Columbus Air Force Base, Mississippi. It is also in agreement with the conclusions made from the test with two qualifications, as follows:

1. An abrupt change in surface elevation due to extended taxi operations in

a narrow traffic channel need never occur. The one conspicuous lesson learned from the Columbus test project was that additional compaction in the base structures during construction will practically eliminate later consolidation under heavy wheeled traffic.

2. The use of a center strip of rigid pavement in runway interiors does not appear to be needed. Major General W. K. Wilson, Jr., Deputy Chief of Engineers, Department of the Army, in his

testimony before the Congressional committee on December 2, 1958, reported that it would require normal operational taxiway use of the runway pavement over a period of six months to produce a "slight grooving." Notwithstanding the results that can be obtained with additional compaction during construction as previously described, there is no reason to expect a runway to be used as a taxiway for such an extended period.

A significant point concerning the Columbus AFB test pavement was made by General Wilson in his Congressional testimony and confirmed by Brig. General E. A. Brown, Jr., Assistant Chief of Engineers, Department of the Army, as follows:

The pavement deflections did not increase with coverages and even showed a slight decrease at 3,000 coverages as compared with the value at 3,500 coverages. This is evidence that the strength of the material under the asphaltic concrete increased with traffic.

The 200-ft test section of asphaltic concrete pavement at Columbus Air Force Base has now received a simple and inexpensive sand-asphalt seal and is a stronger, smoother, more durable pavement than it was when testing began. Additional seals, applied over a span of years, not only will extend the service life of that pavement almost indefinitely, but also will keep the surface in more nearly new condition continuously.

It is not believed that the same can be said for those adjoining concrete slabs which developed cracking although not directly subjected to test traffic.

W. G. WESTALL, *Senior Airfield Engineer, Portland Cement Association, Chicago, Ill.*—This paper describing the construction and testing of a section of flexible pavement at Columbus Air Force Base, Miss., presents test results considered encouraging in view of the previous behavior record of flexible pavement under the heavy wheel loads of Air Force jet bombers. It is the purpose of this discussion to point out certain factors not emphasized in the paper which influ-

enced the results obtained. Also, exception will be taken to certain of the conclusions arrived at by the authors.

The natural conditions existing at Columbus Air Force Base, by their very nature, had a great bearing on the results obtained on the test strip. For example, the field is located in an area where commercial sand and gravel are produced.

The official Corps of Engineers report (2) of the test states that the test section lies on fill material which, in the vicinity of the proof-test section, is approximately 9 ft thick and is composed of sandy and clayey gravel. In addition to this excellent fill material, there are 38 in. of flexible pavement. This comes to a total of 12 ft of flexible surface, base, subbase and fill consisting essentially of gravelly material. It is extremely unlikely that natural fill materials of this excellent quality could be found on site at any other air base in the country.

The Navy Bureau of Yards and Docks, in commenting on the Corps of Engineers report covering the test, made the following statement relative to construction materials and subgrade (3):

The runway test strip at Columbus, Mississippi, is a flexible pavement constructed of excellent materials under optimum conditions. The materials used show very good hardness, abrasive resistance and other desirable aggregate properties. In addition, the native materials forming the subgrade are of excellent quality and provide site conditions considered better than the average encountered throughout the world. The quality of pavement developed therefore, may not be achieved economically at all locations.

The authors admit that the Columbus test did not provide an answer to the question of durability of the lean asphalt mix used in the test. Following this statement, they proceed to speculate on how durability might be affected by such a mixture. This seems to invite speculation and opinions from other sources.

A reduction of 20 percent below the optimum asphalt content was made in the pavement mix for this test conducted in a period of 24 days. In other words, laboratory tests were made to determine

the amount of bitumen that would provide the maximum stability and durability, then the bitumen was arbitrarily reduced by one-fifth that amount in order to provide favorable conditions for the short-term test.

For the warm weather conditions which existed during the test, where approximately 95 percent of the load applications were made at temperatures above 70 F, an asphalt mix with a reduced bitumen content is beneficial. For normal temperature ranges, such a mix would probably develop severe brittleness or lack of flexibility.

The many surface cracks that appeared after "cool-weather" (night time) testing indicates that the asphalt surface disintegration would be even more severe during the actual cool weather traffic common to a large percentage of Air Force bases. It is probable that the same test performed under winter conditions would have shown entirely different results.

Exception must be taken to the authors' conclusion that the test section was constructed under normal contract conditions. The Portland Cement Association had observers present during the construction of the test sections. It was observed that the supervision and inspection of the construction were performed by a group of the leading asphalt specialists in the Corps of Engineers. Such supervision and control could not be exercised on every contract construction job. It seems a fair statement to say that the flexible test sections were constructed under laboratory control conditions. The portland cement concrete used by the test vehicle was built several months before the asphalt and was inspected by the normal inspection force of the resident engineer.

Regarding the differential elevation of some $1\frac{1}{4}$ in. between the trafficked and non-trafficked areas, the authors employ the assumption that such abrupt changes in surface elevation would not occur in normal runway operations because there would be a relatively even distribution of traffic across the runway instead of a restriction to the narrow band involved

in the test area. A further assumption might be, since the test rig employed in the test did not duplicate the effect that a B-52 bomber would have on the pavement, that several things could happen to the surface under normal operations which would be quite different from what did happen under the test rolling. The aircraft would travel at 150 to 200 mph instead of the 4 mph of the test rig. The pavement would be subjected to differential load levels during acceleration and deceleration of the aircraft, particularly during crosswind conditions. High-speed braking would apply stresses to the pavement of a type which have been a source of serious damage to asphalt pavements in the past. Under these influences, common to normal operations, it can be assumed that consolidation and settlement would occur irregularly, resulting in a roughened pavement surface which would be hazardous to aircraft operation.

The statement is made in the paper that the test track, after traffic, met the specified transverse surface tolerances except at the longitudinal construction joints. It must be pointed out that these joints are integral to the construction of asphalt pavements and occur at from 10- to 12-ft intervals across the entire pavement width. The tendency of these joints to form ruts under traffic is a serious source of surface roughness and cannot be minimized in the evaluation of pavement performance.

The paper minimizes the differential settlement in the flexible pavement which occurred adjacent to the buried concrete transition slab, suggesting that it could be inexpensively repaired at some convenient time, such as when the joints of the concrete required resealing. Such a transverse depression, more than $\frac{1}{2}$ in. in depth, can become the source of extensive pavement damage resulting in a condition extremely hazardous to the operation of heavy jet bombers. The following is part of a statement given by an Air Force general officer in testimony before a Congressional subcommittee (4):

. . . The most important characteristic in a pavement, after the basic strength is assured, is surface smooth-

ness. Surface roughness results from . . . unequal settling at the junction between pavement of two different design standards or types.

Regardless of the source of the roughness, it produces an oscillating effect in an aircraft taking off which we call "porpoising" and is a completely unsatisfactory condition.

The life span of a "porpoise" runs something like this. The front gear passes over a hump or a hollow and, as a result, the fore-end of the aircraft is pushed slightly higher in the air than it should be. Just as the fore-end begins settling back toward the pavement, the rear gear crosses the same unevenness with the result that as the front is at the lowest point, the rear of the aircraft is at its highest point. These two events occur in periods of time measured in seconds or less. The springing action of the gear causes the fore-and-aft oscillation up and down of the aircraft to continue for a significant period of time, and on flexible runways, additional humps or hollows are developed by the aircraft bounding on the pavement. This condition continues to get worse as time goes on.

This statement, made by an officer experienced as both pilot and commander, is graphically descriptive of the chain of events which may be initiated by a depression across the surface of the runway.

Finally, it should be pointed out that this was a limited test made on a strip of asphalt pavement 200 ft long and 14 ft wide built under optimum conditions with laboratory controls. The test rig traveled at 4 mph in providing uniform load coverage across the test track. It did not subject the pavement to the violent dynamic loading of high-speed aircraft under normal and emergency conditions of operation. In spite of these favorable factors, the flexible pavement, early in the test, developed the typical surface defects which have made asphalt objectionable for runway pavements.

REFERENCES

2. "Proof-Test Section Columbus Air Force Base." Tech. Rep. 3-490, U.S. Army Engineer Waterway Experiment Station, Vicksburg, Miss. (Nov. 1958).
3. "Comments on Tech. Rep. 3-490." U.S. Navy, Bur. of Yards and Docks (Dec. 1958).
4. KNAPP, J. B. (Brig. Gen., Hdqtrs., Strategic Air Command). Statement before Subcommittee for Special Investigations, House Armed Services Comm., hearings on airstrip paving materials (Dec. 2, 1958).

CHARLES R. FOSTER and J. P. SALE, *Closure*. — The authors had the pleasure of hearing essentially the same comments by Messrs. Westall and Wellborn, but in more detail, at the December 1958 meeting of the Subcommittee for Special Investigation of the House Armed Services Committee.

In preparing this paper an attempt was made to present a true and descriptive picture of the purpose, planning, design, construction, traffic testing and behavior of the Columbus Air Force Base runway pavements subjected to the accelerated traffic proof-tests with simulated B-52 aircraft loadings. The authors also presented the conclusions drawn by the Chief of Engineers based on the results of the test. In formulating these conclusions the facets of the tests discussed and commented upon by Messrs. Westall and Wellborn were given detailed consideration. There is no desire to discuss further points of controversy regarding the Columbus tests except to comment briefly on some of the points already raised.

Mr. Westall states that ". . . the airfield is located in an area where commercial sand and gravel are produced." The authors do not consider this unusual, because it would be hard to find an area in the United States where commercial sand and gravel are not produced.

Attention is called to the 9 ft of fill and by adding this thickness to the 38 in. of subbase, base, and pavement, inferring that the total flexible pavement construction was 12 ft thick. All airfield and highway construction involves cut and fill to achieve desired grades and economy. The 9-ft fill at Columbus was dictated by the runway grade and not by the strength of the natural ground at this location.

Mr. Westall also describes the fill material as excellent; however, the pavement designer, based on explorations prior to construction, assigned a CBR value of 10 and a subgrade modulus of 250 lb per sq in. to the fill materials. The authors consider these values as representative of average rather than excellent subgrade materials.

It should further be pointed out that the laboratory adequacy of the pavements in question had been established prior to the Columbus tests in the Corps of Engineers investigational program at the Waterways Experiment Station and for a wide range of foundation conditions. No effort was made to be selective or to represent "average conditions" in assigning the proof-test program. Columbus Air Force Base was selected simply because it was the only active flexible heavy-load airfield pavement project available at the time the test was initiated.

Presentations made by the Navy at the subcommittee hearings are quoted regarding the excellent quality of the materials used in the flexible pavement. Resident engineer personnel at Columbus AFB would cite an entirely different aspect. The crushed chert gravel produced by the contractor at Columbus was marginal from the standpoint of gradation and percentage of fractured faces, and it was necessary for the contractor to blend other materials with the crushed gravel to meet the minimum specification requirements. The authors are confident that flexible pavement of equal or better quality could be achieved economically at most locations in the United States. The gravel was very porous, which presented a difficult drying problem. In addition, the blending of the gravel with other materials of widely varying specific gravities produced serious construction control problems.

Reference is made to the 20 percent reduction in bitumen content. The authors have no comment to add over and beyond the discussion on this subject which appears in the paper. It does appear pertinent to call attention to the fact that the 20 percent reduction was

not made for these specific tests, but represents normal practice in the Corps for B-52 runway pavements in the same climatic conditions. Also, if the same pavement had been placed farther north, a higher bitumen content would have been used because current practice in the Corps is to vary the bitumen content with climatic conditions.

Mr. Westall states that ". . . the supervision and inspection of the construction were performed by a group of the leading asphalt specialists in the Corps of Engineers" and that ". . . the test sections were constructed under laboratory control conditions."

It is true that the test at Columbus held great interest for pavement engineers not only in the Corps and other governmental agencies, but in all segments of the pavement industry. There was, as a matter of record, a continual flow of interested visitors present at the test site, both during construction and during the traffic test operation. If the construction of the pavement in the test area received more than what could be considered "normal" inspection, the situation could only stem from a natural attitude on the part of the resident engineer and his forces to do the best job possible in the face of so much public attention. The authors must take exception to any inference that construction control was exercised by any groups or individual other than the resident engineer forces.

The agreements for the test, made between the Corps and the Air Force, were that construction would be supervised by normal resident engineer personnel. The Flexible Pavement Laboratory was permitted one observer during construction, but he had no responsibilities regarding supervision of construction. The Flexible Pavement Laboratory provided assistance to the resident engineer on certain specific problems, primarily in connection with the difficulties caused by the use of the marginal crushed chert gravel and the blending of this material with other widely varying specific gravities. This assistance was provided as a part of the normal function of the Flexible Pavement

Laboratory to provide assistance where needed. The test agreements did not negate this normal procedure. Throughout the entire period of construction at Columbus, The Flexible Pavement Laboratory adhered to both the letter and the spirit of the test agreement. In the opinion of the authors, the supervision and inspection exercised at Columbus did not represent laboratory control conditions but did represent what can and should be achieved in all Corps of Engineers' airfield construction regardless of pavement type.

Mr. Westall states that under normal operations irregular settlement would occur, resulting in a roughened pavement surface. The tests showed that the conditions in the base, subbase, etc., were remarkably uniform, so that settlement would be proportional to the number of load repetitions. All of the unusual loadings that would be caused by features mentioned by Mr. Westall (differential loading during acceleration and deceleration, etc.) would be distributed rather than concentrated in a 14-ft lane. Also, there would be no sharp dividing line between the area where repetitive loadings occurred and where no loading occurred; instead, there would be a gradual transition. Even with the unusual loadings mentioned by Mr. Westall, they would be distributed in such a manner that abrupt changes in surface elevations would not occur.

Regarding Mr. Wellborn's qualification regarding compaction, test pits were excavated after traffic and it was determined that the majority of the settlement occurred in the base course. Specifications for the base course at Columbus called for compaction to 100 percent of modified AASHO maximum density plus 30 coverages of proof-rolling with a heavy rubber-tired roller. The specifications were based on a base course compaction test section conducted several

years ago at the Waterways Experiment Station which indicated this procedure should yield densities in the range of 103 to 105 percent of modified AASHO. These densities were not achieved at Columbus and a study of needed revisions to the specifications has been made. The study indicates that closer control than was called for in the Columbus specifications needs to be exercised relative to percentage of fractured faces in crushed aggregate base courses and moisture content during compaction. Revisions to Corps of Engineers' guide specifications and inspectors' manuals have been accomplished in an effort to improve base course structural quality and compaction in future work.

Regarding the discussion of the load-carrying capacity of the test pavements after the application of 5,000 coverages of test traffic, the authors agree that the densification undergone by all layers of the flexible pavement has rendered them stronger than initially constructed. However, any conclusion that the pavements could withstand an unlimited design traffic usage is hypothetical because of such factors as the decrease in air voids the asphaltic concrete pavements have undergone and the attendant potential for developing pore pressure in the bitumen with additional compaction under traffic.

In closing, the subcommittee report became available on March 27, 1959. This report recommends that the engineering conclusions presented by the Corps to the subcommittee on December 2, 1958 be accepted, adopted, and implemented by the Air Force, the Corps, and the Bureau of Yards and Docks. The subcommittee also recommended that all future bids for pavement construction in areas where both rigid and flexible pavements have proved satisfactory specify alternates for portland cement and asphaltic concrete.