Analysis of Flexible Pavement Deflection and Behavior Data

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In the WASHO Road Test there was a pronounced difference in the performance of the edge and center portions of the bituminous pavement, as well as a great difference in behavior of sections with 2 in. of surfacing and those with 4 in. of surfacing.

This paper presents a series of relations to indicate to what extent the over-all pavement structure thickness and the seasons of the year enter into the differences in behavior of the edge and center portions of the pavement, and into the difference in behavior of the sections with 2-in. and 4-in. surfacing.

● IT HAS LONG been a matter of common knowledge that the edges of a pavement of the flexible type are more likely to fail under traffic than the interior portions.

The WASHO Road Test served to provide numerical values as to the degree of difference that might be expected in the behavior of the edge and center areas of this type of pavement. For example, at the end of this test almost twice as much distress had developed along the edge as in the interior. In the three thicker sections of pavement in the test the distress that developed was practically all found to be along the edge.

The findings of the WASHO test in regard to this particular problem and what might be done about it in the design and construction of new pavement have received the attention of highway engineers in all sections of the country. One possible solution that was investigated to a limited extent at the project site in Idaho involves paving of the shoulders. Soon after test traffic was started failures began to develop along the edge of the pavement and it was decided to pave the shoulders of part of some of the sections and to observe if this would prove effective in retarding the rate of development of distress of the original edge of pavement. Before the end of the test it was concluded that to all intents and purposes the outer wheel path (OWP) with paved shoulders became the equivalent of the inner wheel path (IWP) of travel. In this connection it should be pointed out that the observed difference in behavior of the test pavement in the outer and inner wheel paths where the shoulders were not paved was more pronounced than that between two adjacent sections where the difference in over-all structure thickness was 4 in. This would seem to indicate that if the shoulders of such pavements are paved some reduction in the over-all thickness of the structure would be justified. However, this would require some positive means by which the movement of traffic could be controlled to prevent operation of heavy loads on the shoulders.

As shown in Figure 1, the WASHO pavement consisted of two identical test loops. One tangent of each of the loops included five 300-ft test sections having a 2-in. asphaltic concrete surface and a 4-in. base course; one of the sections was laid directly on the selected embankment subgrade soil, the other four on an intervening subbase course, 4, 8, 12, and 16 in. thick. The other tangent of each of the loops contained identical sections except that the surface course was 4 in. and the base course 2 in. thick. Single-axle loads (18,000 and 22,400 lb) operated on each 12-ft lane of one of the loops and tandem-axle loads (32,000 and 40,000 lb) operated on each lane of the other loop.

As stated in Part 2 of the WASHO Road Test report (HRB Special Report 22) the structural distress that developed in the test pavement was confined largely to two critical periods of traffic operation. Because this was the case, data were assembled in the report (Table 4-d-1) relative to the observed behavior and deflection of the pavement for certain designated periods of the year. These periods were as follows:

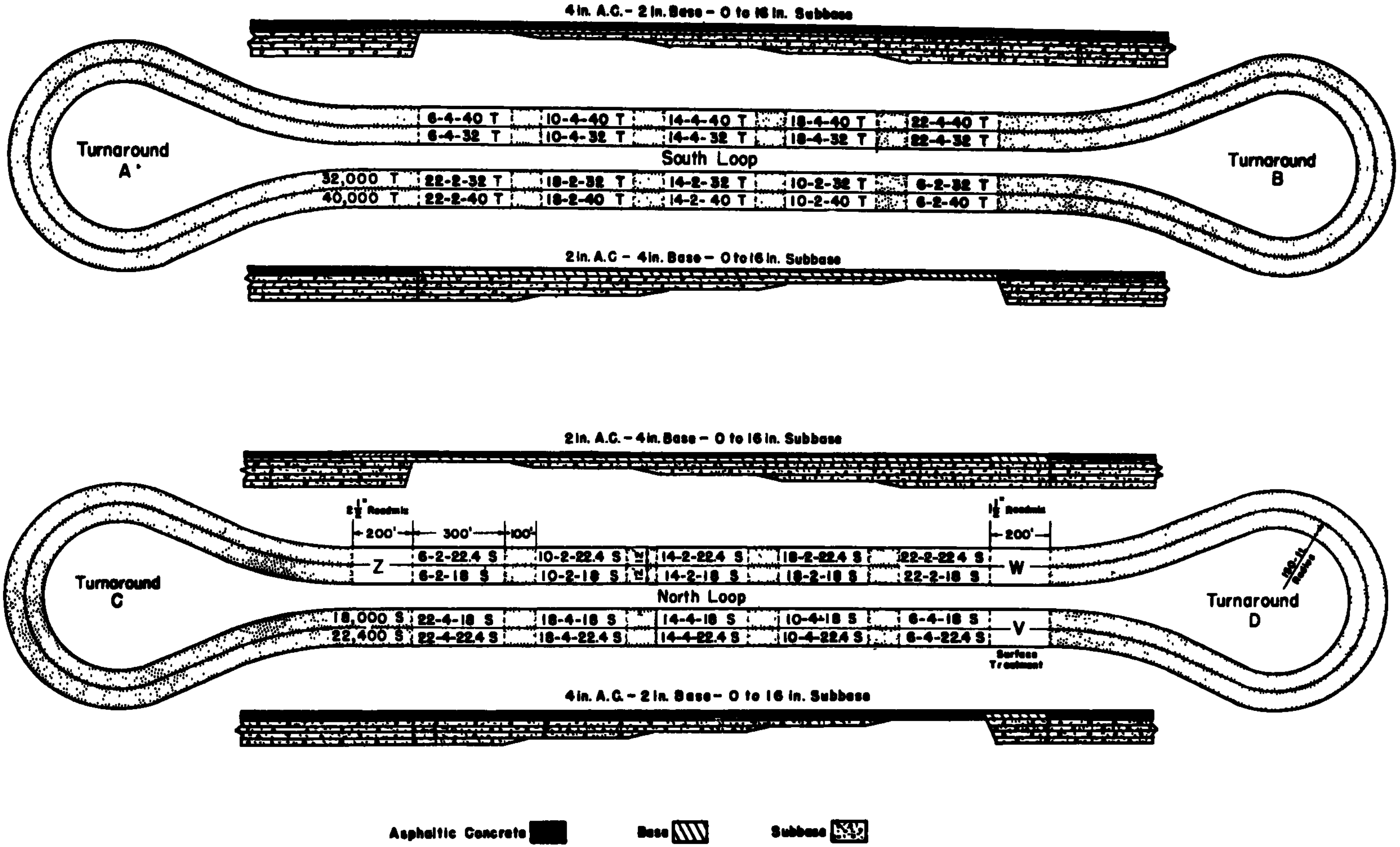

Figure 1. Schematic layout of test loops, WASHO Road Test.

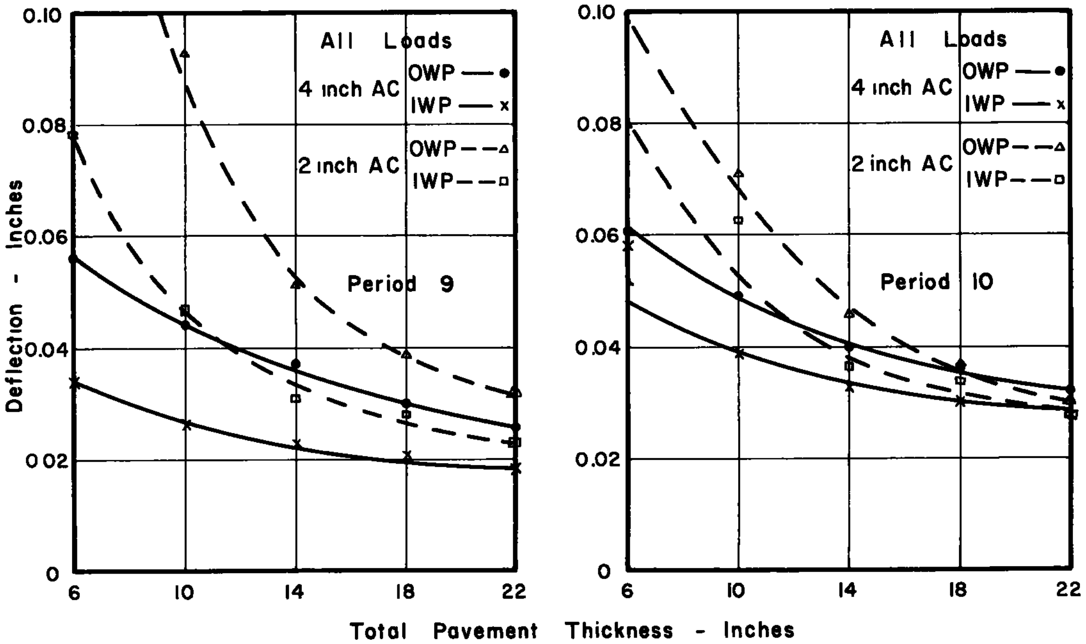

Figure 2. Pavement thickness-deflection relations.

Period	Date
3	June 10 - July 7, 1953
4	July 7 - July 24, 1953
5	July 24 - Nov. 21, 1953
6	Nov. 21 - Dec. 11, 1953
9	Feb. 23 - Apr. 7, 1954
10	Apr. 7 - May 29, 1954

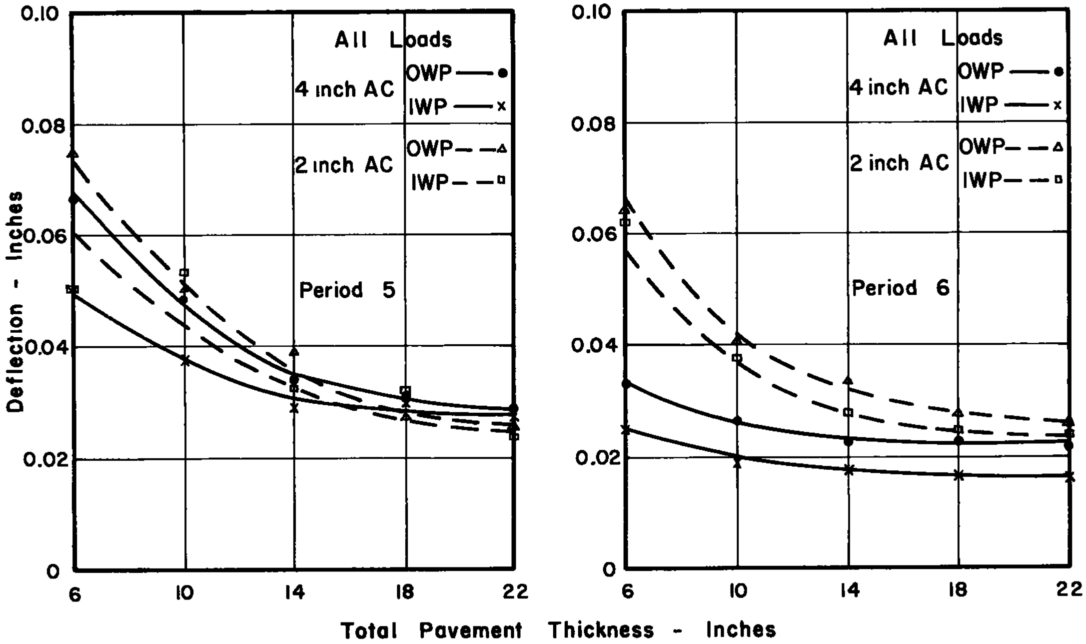

Figure 3. Pavement thickness-deflection relations.

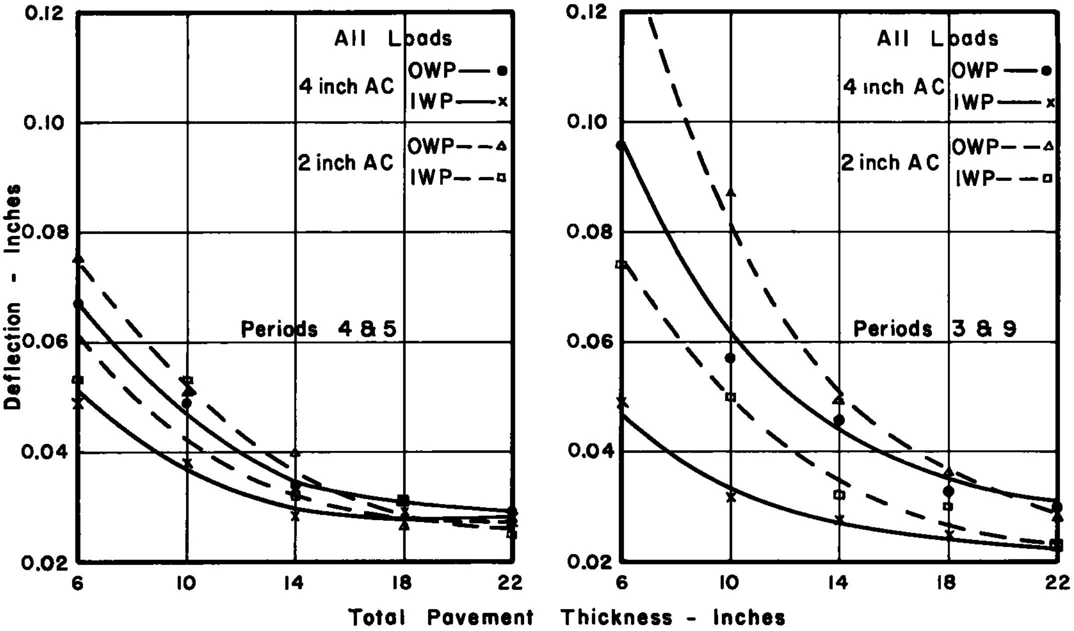

Figure 4. Pavement thickness-deflection relations.

SUPPLEMENTAL ANALYSIS OF THE ROAD TEST DEFLECTION DATA

In an effort to answer some of the questions raised by the WASHO test regarding the difference in behavior of the outer and inner wheel path areas of the pavement, a supplemental analysis of the deflection data was made. For example, it was attempted to determine from the analysis to what extent the thickness of the structure, the thickness of the bituminous surface, and the season of the year entered into the difference in behavior

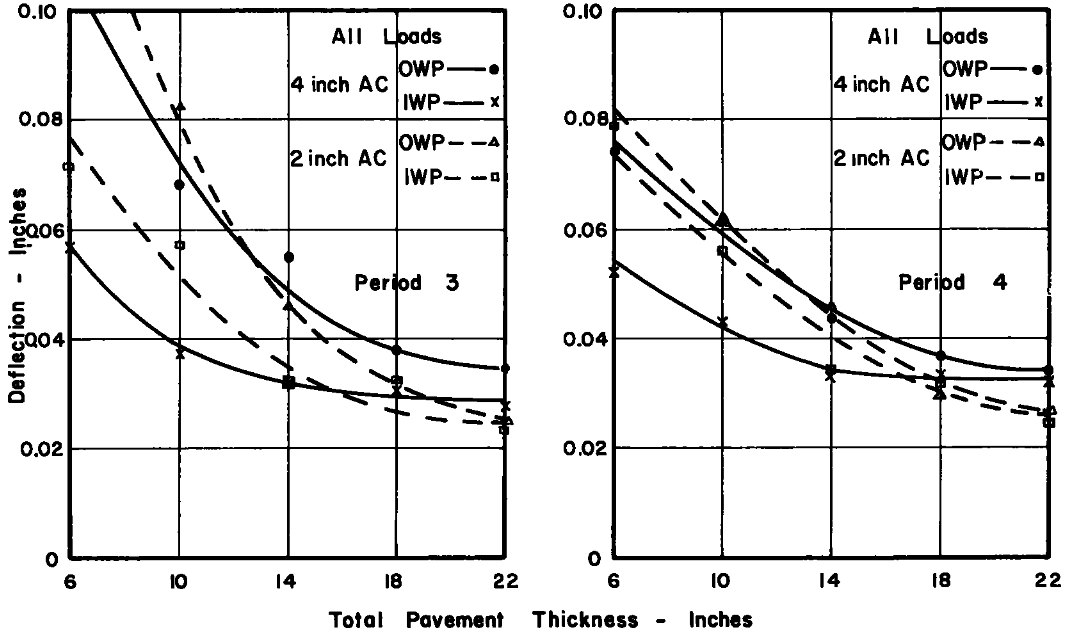

Figure 5. Pavement thickness-deflection relations.

TABLE 1

PAVEMENT DEFLECTION RATIO VALUES

		2 in. AC/4 in. AC						OWP/IWP				
		Pavement Thickness						Pavement Thickness				
Period	Wheel Path	22	18	14	10	6	Thickness AC Surface (in.)	22	18	14	10	6
3	Outer	0.77	0.87	0.94	1.11	1.25	2	1.08	1.18	1.31	1.54	1.77
	Inner	0.83	0.93	1.09	1.36	1.33	4	1.17	1.27	1.53	1.89	1.88
4	Outer	0.76	0.84	0.96	1.05	1.07	2	1.04	1.03	1.07	1.11	1.11
	Inner	0.76	0.91	1.20	1.37	1.33	4	1.03	1.12	1.35	1.40	1.42
5	Outer	0.90	0.91	1.03	1.06	1.09	2	1.04	1.03	1.09	1.16	1.23
	Inner	0.89	0.97	1.06	1.16	1.20	4	1.03	1.11	1.13	1.26	1.36
6	Outer	1.17	1.22	1.40	1.55	2.00	2	1.12	1.12	1.15	1.13	1.18
	Inner	1.41	1.47	1.55	1.85	2.24	4	1.35	1.35	1.28	1.35	1.32
9	Outer	1.23	1.30	1.47	2.02	2.46	2	1.39	1.44	1.60	1.94	1.80
	Inner	1.27	1.35	1.50	1.70	2.30	4	1.44	1.50	1.64	1.63	1.68
10	Outer	0.94	1.00	1.15	1.38	1.64	2	1.07	1.12	1.24	1.29	1.24
	Inner	1.00	1.06	1.15	1.36	1.65	4	1.14	1.20	1.24	1.25	1.25
3+9	Outer	0.97	1.06	1.16	1.31	1.41	2	1.20	1.37	1.50	1.64	1.80
	Inner	1.25	1.33	1.40	1.60	1.76	4	1.30	1.46	1.63	1.88	2.08
4+5	Outer	0.90	0.93	1.06	1.15	1.13	2	1.00	1.03	1.15	1.20	1.23
	Inner	0.93	1.00	1.06	1.13	1.17	4	1.03	1.10	1.16	1.24	1.30

Figures 2, 3, 4, and 5 show a series of pavement deflection-thickness relations for each of the foregoing periods and for each of two combined periods. These relations were developed by plotting the average of all the deflection tests made during the period on the pavement sections under all four test axle loads. In the majority of cases the values are the average of 150 or more individual tests, the average standard deviation of which varies with the magnitude of the deflection and is of the order of ⅕ to ⅓ of the mean.

As a general rule it appears that the relations are well supported by the test data. In several instances, however, the tests were made at locations where the pavement was partially distressed or was undergoing structural deterioration; in these cases some of the average values were erratic and considerable judgment had to be exercised in fitting the relations to the plotted points.

Table 1 lists values of the ratio of deflection of the 2- and 4-in. AC sections of pavement and the outer and inner wheel path portions of the pavement. These ratios were computed for the various thicknesses of pavement by using deflection values obtained from Figures 2, 3, 4, and 5.

Figure 6 is a plot of the outer and inner wheel path ratio values for each of the periods of traffic operation. From these data it is apparent that the values are greater generally for the thinner sections of pavement, particularly for major distress periods 3 and 9.

Figure 7 is a plot of the outer-inner wheel path ratio values as a function of the thickness of the pavement, both for periods 3 and 9 and periods 4 and 5 combined. According to the curves fitted to the plotted points there is a well-defined and consistent effect of thickness of the pavement structure (that is, the ratio values increase almost in linear fashion as the thickness decreases) and there is a pronounced difference in the values for the two designated periods. The fact that the ratio value is 1.00 for the 22-in. section in periods 4 and 5 suggests that the weakness of the

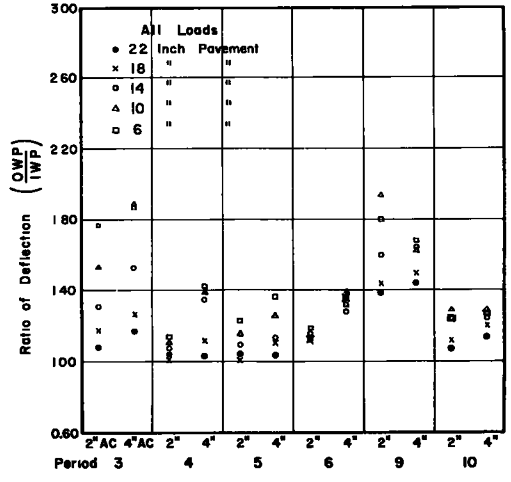

Figure 6. Pavement deflection-ratio values.

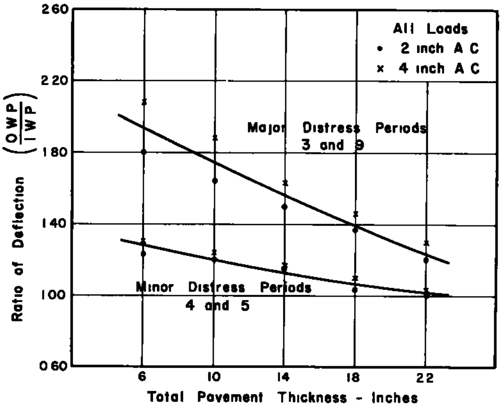

Figure 7. Deflection ratio relations.

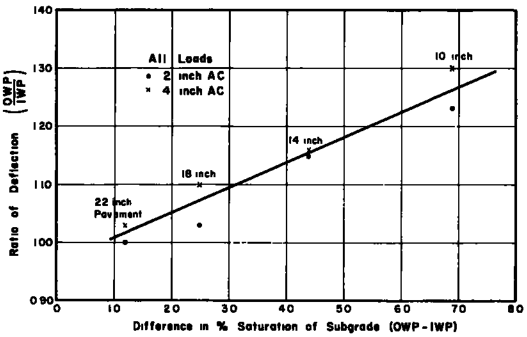

Figure 8. Effect of condition of subgrade soil on deflection of pavement.

edges of flexible pavements may under certain circumstances be overcome by increasing the thickness of the structure. Under other circumstances it may be greatly reduced by the use of increased thickness of pavement, but perhaps never eliminated.

CONDITION OF THE SUBGRADE SOIL

It is generally considered that the weakness of the edge of a flexible pavement is due to the more adverse condition of the supporting subgrade soil than may exist beneath the edge and/or to the discontinuity associated with the termination of the paved surface. Data concerning the condition of the subgrade soil of the test pavement during the summer months are given in Table 2. The values are the averages of determinations made beneath all the 22-, 18-, 14-, and 10-in. sections. The saturation values were computed from:

$$S = \frac{W}{1/d - 1/s} \qquad (1)$$

TABLE 2

CONDITION OF EMBANKMENT SUBGRADE SOIL DURING SUMMER MONTHS
(0- to 12-in. Depth)

Pavement Thickness (in.)	Wheel Path	Moist. Cont. (%)	Dry Density (pcf)	Saturation (%)	Diff. in % Saturation
22	Outer	26.0	90.2	86.7	1.2
	Inner	25.3	90.7	85.5	
18	Outer	24.5	93.3	88.4	2.5
	Inner	24.3	92.5	85.9	
14	Outer	25.0	91.5	86.2	4.4
	Inner	23.3	92.2	81.8	
10	Outer	26.0	91.3	89.0	6.9
	Inner	24.3	90.7	82.1	

in which

W = moisture content (wt of water/wt. of soil);
d = dry density, in g per cc; and
s = specific gravity (2.55).

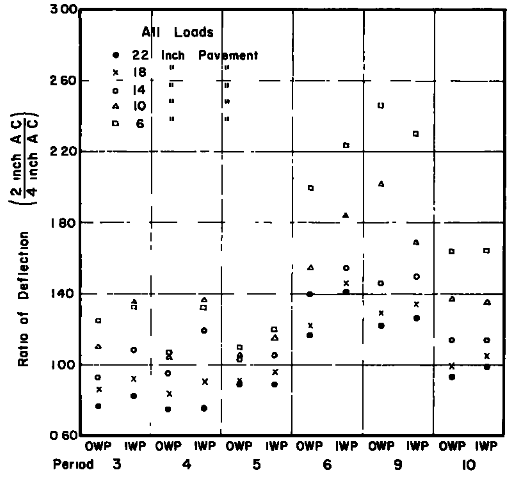

Figure 9. Pavement deflection-ratio values.

Figure 8 is a plot of the difference in the saturation values in the outer and inner wheel paths for each of the four thicknesses of pavement versus the ratio of deflection in the two wheel paths. The resulting curve serves to lend support to the supposition that the difference in deflection of the pavement in the outer and inner wheel paths during the summer months may have been due in large part to the difference in condition of the subgrade soil at the two locations. Why the deflection in the two wheel paths of the 22-in. section of pavement was about the same (ratio of 1.0) when there was a difference of 1.0 percent in the degree of saturation of the subgrade is not known.

From the data available on the condition of the subgrade soil during the spring months it was not possible to explain why the outer-inner wheel path deflection ratios for the spring period were so much greater than during the summer months.

PAVEMENT DEFLECTION AND BEHAVIOR

Data concerning the ratio of deflection of the 2- and 4-in. AC sections of pavement are shown in Figures 9 and 10. According to Figure 9 there is little difference in the ratios for the warm weather periods (3, 4, 5, and 10). The ratios for cold weather periods (6 and 9), however, are significantly greater than for the other periods, indicating that the thicker AC surface sections offered considerably more resistance to deflection at low than at moderate to high temperatures.

In Figure 10 these ratio values are plotted as a function of the total thickness of the pavement. The marked difference in the indicated resistance of the 2- and 4-in. asphaltic concrete pavement sections in the cold and in the warm weather periods is clearly shown by the curves fitted to the plotted points. Also they show the pronounced effect of pavement thickness for cold weather period 9 and to a lesser degree its effect for warm weather periods 4 and 5.

These data imply that in cold weather areas where adverse subsurface conditions

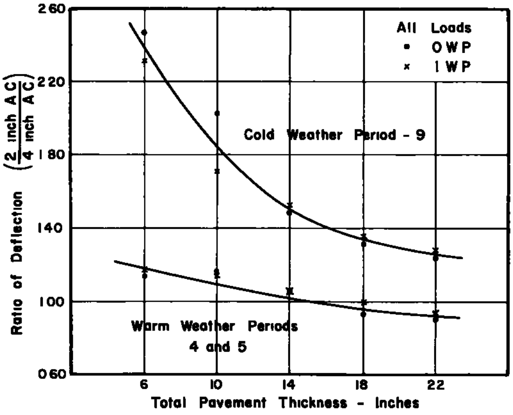

Figure 10. Deflection ratio relations.

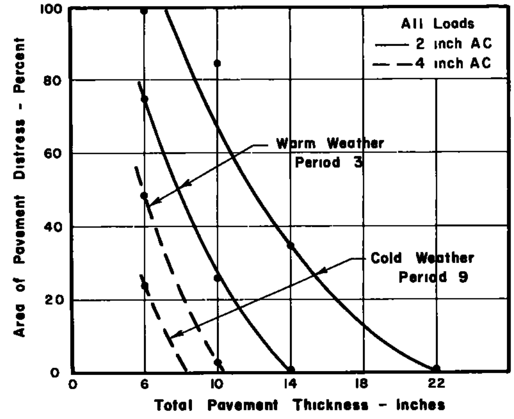

Figure 11. Pavement distress thickness relations.

due to frost action may reduce the ability of pavements to carry load, the use of relatively thick bituminous surfaces would be justified. Furthermore, that in warm weather areas the use of the thicker surface would be justified where there may be some question as to the ability of the basic pavement structure to support the prevailing or anticipated future traffic loadings.

Of significance in the foregoing connection are the data shown in Figure 11. Here the distress that developed in the 2- and 4- AC designs of pavement in the two periods in question is plotted as a function of the over-all thickness of the pavement. The resulting relations serve to demonstrate the marked difference in behavior of the two designs that occurred during the two critical periods of traffic operation.

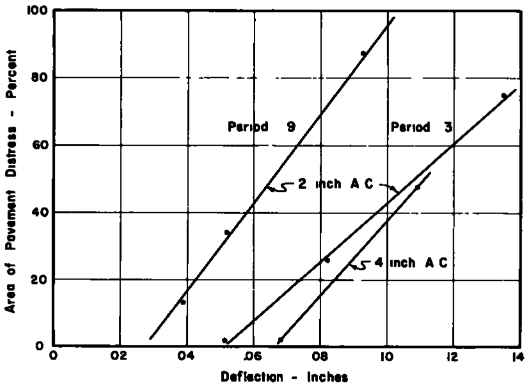

Figure 12. Pavement distress deflection relations—all loads.

As indicated in the statement of findings in the WASHO Test Road report, very little distress (551 sq ft, or 1. 6 percent of the total) occurred during period 5, when 45 percent of the total test loads were applied. This distress was about evenly distributed between the 2- and 4-in. AC sections, a development which serves to lend support to the relations shown in Figure 10 and the discussion pertaining thereto.

The report (p. 93) states:

> "The traffic tests demonstrated the importance of the factor of thickness of the pavement structure. With very few exceptions, the thin sections underwent structural deterioration first and damage progressed in an orderly manner to the next increment of pavement thickness."

Figures 2, 3, 4, and 5 show that as a general rule the deflection of the pavement increased in a consistent and orderly manner as the thickness of the structure decreased. This in itself would seem to indicate that there should be a reasonable degree of correlation between deflection, as measured in this test, and pavement behavior. Actually, this was indicated from the tests and observations made, and analysis of the data resulted in the selection of maximum values of deflection that were not considered to be associated with the development of structural distress in the pavement (that is, 0. 045 in. in warm weather and 0. 030 in. in cold weather).

The reexamination of the distress-deflection data resulted in the development of the curves shown in Figure 12. Here, as in Figure 11, distress is expressed as a percentage of the area of a particular section that was in good condition at the start of the period in question. The deflection values are the averages of all the tests made in the respective periods, the same values as those plotted in the previous graphs.

The curves drawn through the plotted points indicate that the distress varies as a linear function of the deflection. Although the three curves are practically parallel, the values for period 9 are significantly less than those for period 3. There are several possible explanations for this including the following:

1. The difference in the level of the temperature of the AC surface (period 3 being a warm and period 9 a cold weather period). As indicated previously, it was concluded in the initial analysis of the data that the pavement surface cracked or was distressed at lower deflections in cold weather than in warm weather.

2. Period 3 was the first extensive period of traffic operation and the pavement surface may have been more flexible than during period 9 after it had been subjected to almost uninterrupted traffic throughout the summer and fall months of 1953. During this time the density of the bituminous surface increased appreciably and this change

in the physical state of the material, together with a possible hardening of the asphalt cement, may have tended to reduce its flexibility.

SUMMARY

The information presented in this report serves to emphasize the importance of thickness of the pavement structure and the season of the year, both with regard to the difference in resistance to deflection of the edge and interior portions of the pavement and to the difference in resistance to deflection of the 2- and 4-in. AC surfaces.

During the major distress periods the data show that the deflection of the edges of the 6-, 14-, and 22-in. WASHO sections was 2. 0, 1. 6 and 1. 3 times that of the interior portions of the sections; during the minor distress periods these values are about 1. 3, 1. 2, and 1. 0. These values clearly indicate what might be accomplished in the way of balancing the load-carrying capacity of flexible pavements by increasing the thickness of the structure.

During the cold weather periods the deflection of the 2-in. AC surfaces of the 6-, 14-, and 22-in. sections was about 2. 40, 1. 50, and 1. 30 times that of the 4-in AC surfaces; during the warm weather periods these values are about 1. 2, 1. 0, and 0. 90. These values are considered an indication that the use of thick (4 in.) asphaltic concrete surfaces would be justified in areas where low temperatures are common. Also, that their use would be justified in warm weather areas where the basic pavement structure may be considered inadequate.

AASHO ROAD TEST STUDIES

One of the important decisions made during the planning stages of the AASHO Road Test was to construct a series of representative sections of flexible and rigid pavement to be used only for special observations and measurements. These sections form the smallest of the project's six test loops. Its tangents are 2,100 ft long, with flexible sections on one side and rigid sections on the other. In the 32 flexible sections, surface thicknesses include 1, 3, and 5 in. of AC; base thicknesses, 0 and 6 in. of crushed stone; subbase thicknesses, 0, 8 and 16 in. of sand-gravel. Eight of the flexible sections will be used for bi-weekly subsurface observations and tests and 24 for deflection measurements. These measurements will cover a wide range in temperature conditions of the AC surfaces and a variety of conditions of the subsurface components.

From this work it is anticipated that a great deal of additional information of the same general nature as that presented in this report will be obtained regarding the ability of flexible pavements of different thicknesses of surface, base, and subbase to support load in both the outer and inner wheel paths under different climatic conditions.

Discussion

W. H. CAMPEN, Manager, Omaha Testing Laboratories, Omaha, Nebraska — It may be that the larger deflection at the edge of the pavement is due to lack of lateral support. If this is the case, the lateral support could be provided to correct the situation, rather than increasing the edge thickness.

It is the writer's understanding that during the testing period at the WASHO project lateral support was provided on certain portions. Perhaps the author knows what was done and what results were obtained.

The writer happens to be consulting engineer for Douglas County, Nebraska. This county has had an extensive program for about 9 years and has constructed about 120 miles of pavement consisting of 4 to 6 in. of stabilized base plus a prime and double armor coat. For lateral support a 4-in. by 12-in. concrete header or curb has been used. The top of the curb is flush with the top of the base. This type of construction has eliminated distress along the edges and has prevented the usual progressive base disintegration from the edge toward the center. The roads are on the secondary road system and 20 ft in width. The curb costs about 17 percent of the entire cost of construction.

CLOSURE, A. C. Benkelman — Shortly after test traffic was started on the WASHO pavement, the shoulders of part of three of the test sections were paved. This proved highly effective in reducing the deflections and the rate of development of distress of the original pavement edge. However, it was not determined how much of this reduction was due to the additional lateral support afforded by the shoulder paving or how much was due to an improvement of the condition of the subsurface components underlying the shoulder.

The AASHO Road Test has been planned in such a way that a great deal of factual information should be obtained on the question raised by Mr. Campen.