Deflection Tests on Texas Highways

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This paper presents some of the experiences and results obtained from an investigation of pavement deflections in Texas. The data discussed were taken from measurements made by use of the Benkelman beam during annual deflection tests on 117 mi of flexible pavements. Results of laboratory and field tests are presented showing the reliability of the Benkelman beam. Factors which may affect the deflection data are discussed, including temperature of the pavement surface, length of the deflection "trough," friction in the Benkelman beam and Helmer recorder, and field techniques in the operation of the Benkelman beam. Methods are also given for correcting the deflection data for these factors.

●DEFLECTIONS in flexible pavements have received considerable attention from highway engineers in recent years. From a design standpoint, several methods have been advanced which are based on the limiting deformation or deflection of a pavement system under load. For the most part, these methods rely wholly on theoretical analysis or partly on theory and partly on experience. As a group, they suffer from the assumptions that the materials in the pavement system behave elastically at all times and that the applied loads are uniformly distributed. Considerable research must be undertaken in an effort to determine the effect of these assumptions on stresses and deflections in actual soil materials before the validity of the design methods can be accepted.

On the other hand, the use of deflections for evaluation purposes has shown more promise. Engineers visualize the application of deflections to the determination of useful pavement life, the selection of allowable wheel loads during both ordinary and critical climatic periods, the evaluation of assumptions made in pavement designs and other more specialized uses. The most obvious advantages of obtaining deflections directly on existing pavements are the speed of the determinations and the release of certain theoretical assumptions regarding the interaction of layers in pavement systems. Deflections have been successfully used in large-scale evaluations (1, 2, 3), but the deflection results have been supported by other information not normally available to the engineer who must evaluate several miles of pavement with a 1-mi budget.

Means for measuring pavement deflections include electronic methods (1), photogrammetric techniques (4), rigid beams equipped with a series of extensometers (3), and lever-type beams such as the Benkelman beam (1). At present, the Benkelman beam appears to be the most popular deflection measuring device.

In Texas, impetus in deflection measurements was provided in 1955 by a preliminary investigation of the Benkelman beam by the Texas Highway Department. In 1956, the Texas Highway Department authorized the Texas Transportation Institute to conduct an evaluation of selected flexible pavements using deflections obtained by the Benkelman beam. Within six months after the initiation of the test program, deflections had been obtained on nearly 500 mi of pavement. The ease of obtaining deflections with the Benkelman beam temporarily overshadowed studies concerning reliability of the deflection values. Not until several hundred test sites were analyzed was it realized that the accuracy of the deflection values was highly questionable.

Subsequent research into the equipment and field measuring technique disclosed methods of collecting reliable data. Of prime importance was the determination of various corrections to be applied to the Benkelman beam measurements. This report is concerned primarily with these corrections and the field techniques. At a later date it is anticipated that a more complete pavement evaluation process based on deflections can be reported.

DESCRIPTION OF EQUIPMENT AND METHODS

The primary equipment used in this study consisted of a load vehicle and two Benkelman beams. Equipment of secondary importance included a thermometer for measuring pavement temperature and a tire pressure gauge.

The Benkelman beam (Fig. 1) has been discussed adequately elsewhere (1, 5) and only a brief description is required here. The beam rests on one rear reference support and two front reference supports. The probe arm has an effective length of 12 ft and is suspended by a single bearing bracketed exactly 4 ft forward of the extensometer contact point. The forwardmost part of the probe arm, the toe, rests on the pavement exactly 8 ft from the bearing axis of rotation. Vertical movement of the pavement surface at the toe will indicate one-half of this movement on the extensometer.

To produce the desired load, a standard dump-truck was loaded with steel grader blades. The load was arranged such that the dual wheel loads were accurate to within 15 lb. Tire pressures on the load vehicle were maintained at 90 psi. The dual tires

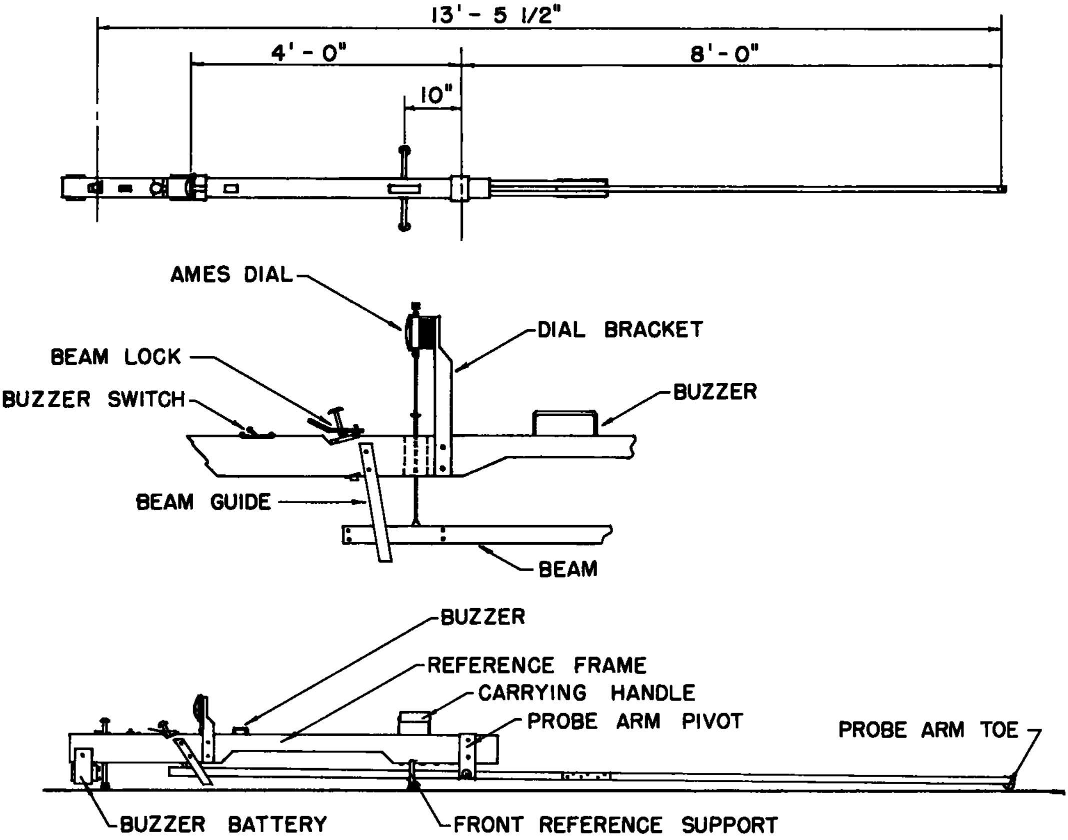

Figure 1. The Benkelman beam.

were spread apart an additional ½ in. with steel spacers to reduce the possibility of rub between the beam toes and the tires.

Deflection tests were performed by inserting the probe arms of the beams between the dual tires until the tires were equidistant from the front reference supports and the beam toe. With the load vehicle in this position an initial extensometer reading was recorded. The load vehicle then moved forward at creep speed (0.3 mph) to approximately 15 ft past the beam toe. Both the maximum and final readings of the extensometer were recorded during this movement.

In accordance with the accepted procedure, the difference between the initial and maximum extensometer readings was doubled and was termed the deflection. The difference between the initial and final readings was doubled and termed the residual (or permanent) deformation. Early in the testing program it was noted that the residual values were sometimes negative. These negative values resulted from pavement extrusion between the dual tires of the load vehicle and reveals that one of the inherent disadvantages of the Benkelman beam is that it measures deflection between and not underneath the tires. It was found, however, that extrusion occurred primarily on pavements of very high asphalt cement content or on pavements with very low load-carrying capacity.

Pavement temperatures were measured by inserting a thermometer into an oil-filled hole approximately 1 in. deep and ½ in. in diameter formed by driving a pointed steel rod into the surface. There is some indication that temperatures measured in this manner are about 10 F less than temperatures determined from thermocouples inserted in the interior of the pavement surface (6).

When the deflection testing program was initiated, one of the first correlations attempted was wheel loads versus deflections. Wheel loads of 7,000, 9,000 and 12,000 lb were selected for this study. Surprisingly, little correlation was found and in most instances deflections for the 12,000-lb wheel load were smaller than for the 9,000-lb wheel load. Examples of the results obtained on a typical test section are shown in Figure 2.

The residuals followed the expected pattern more closely than the deflections. For the 7,000-lb wheel load, residuals were almost non-existent, registering greater than 0.002 in. only 10 percent of the time; for the heavier loads they increased significantly as the load increased. Figure 3 shows the residual values corresponding to the deflections shown in Figure 2. The lack of correlation between wheel loads and deflections

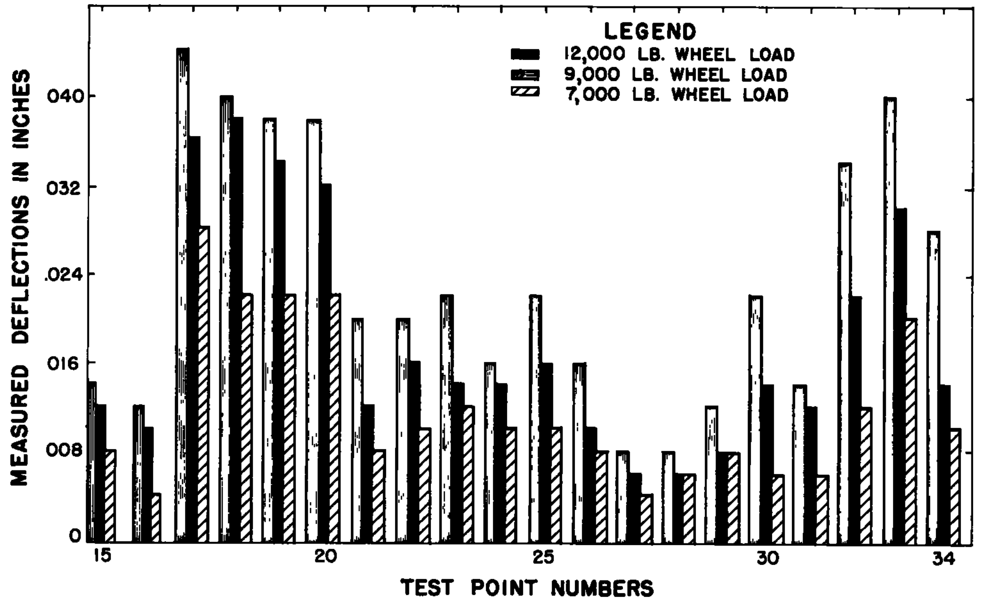

Figure 2. Relationship of wheel load to deflection on a typical test section.

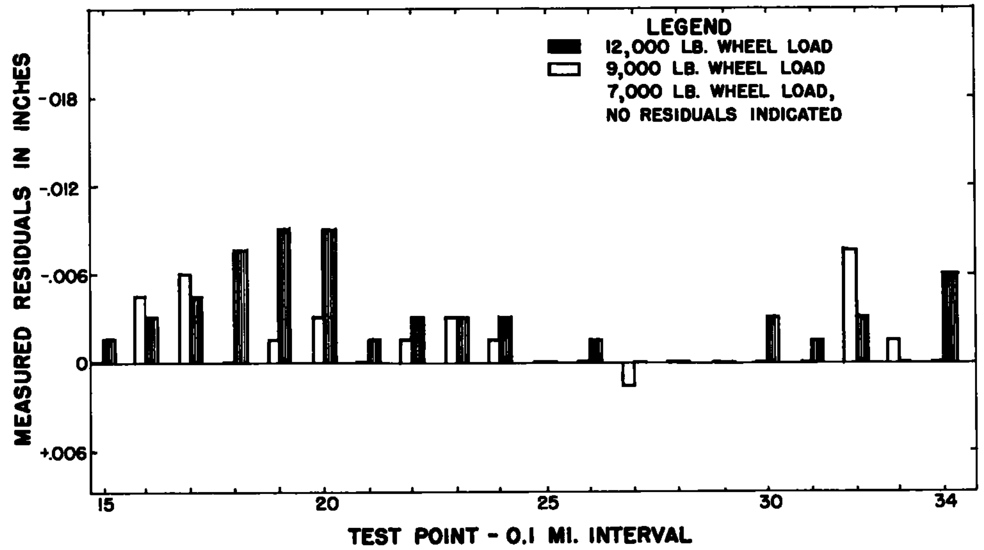

Figure 3. Relationship of wheel load to residual deformation for test section shown in Figure 2.

was very disappointing when considered in the light of the excellent correlations obtained in other investigations (1, 2).

After the original testing program was completed and the results tabulated, it was found that the data were too erratic to indicate any trends. Also, the data showed many factors which were extremely confusing. Several of the pavements which were rated as good showed higher residual values than those rated as poor. In addition, many researchers familiar with flexible pavement deflections felt the beams were indicating values much smaller than the actual road deflections.

HELMER GRAPHICAL RECORDER

In an effort to increase the accuracy of the results, Helmer graphical recorders were added to the Benkelman beams in 1957. The recorder, developed by R. A. Helmer of the Oklahoma Highway Department, operates from a lever actuated by the Benkelman beam probe arm. A pen mounted on the lever draws a graph of the beam toe deflection as the test vehicle is driven up to and beyond the beam toe. The vertical movement of the beam toe is magnified ten times on the graph. A friction drive motivated by a cord attached to the load vehicle provides horizontal movement of the graph paper at the

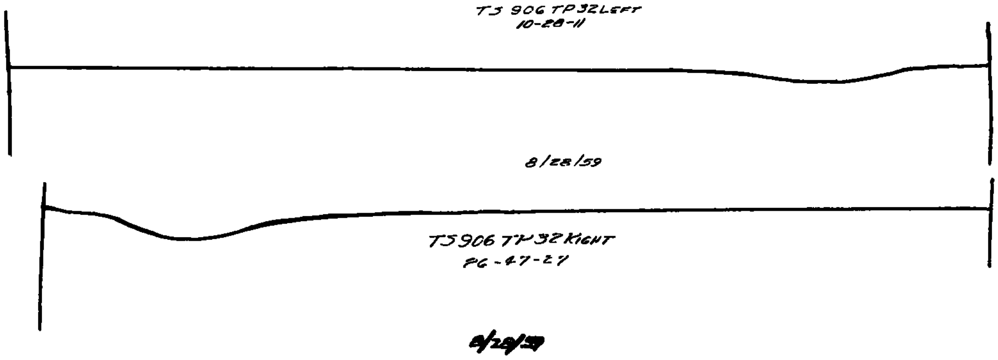

Figure 4. Deflection graphs made by Helmer graphical recorder.

rate of 1 in. = 1 ft. Examples of the graphs drawn by the recorder are shown in Figure 4.

After analyzing many deflections taken with the Helmer recorder, the data were still found to be erratic and inconclusive. Only in isolated instances were there any measurable correlations between pavement performance and deflections. Attempts were also made to correlate other data obtained from the Helmer recordings—such as slope of the deflection curves and minimum radius of curvature—with pavement performance, but these efforts proved fruitless.

INVESTIGATIONS OF ACCURACY OF DEFLECTION VALUES

Subsequent investigations into the causes of the erratic data led to a closer examination of the residual values. It was not at all uncommon for pavements rated as very good to have residual values as high as 0.010 in. On most of these good pavements the average of the ten heaviest daily wheel loads exceeded the test vehicle wheel load by 1,000 to 3,000 lb. Because these pavements had received thousands of the heavier load repetitions it was reasoned that either the residual values were in error or else they recovered after some unknown period of time. Otherwise many of the older pavements would have settled several feet under the action of the traffic.

Tests were then conducted to determine the extent to which the residuals actually existed. This was accomplished by varying the manner in which the load vehicle traveled over the beam toe. Three test cycles, designated as A, B and C in Figure 5, were used at several different test sites. With Test Cycle A, the usual manner of obtaining deflections, a real difference was found between the initial and final extensometer readings, thereby indicating a residual deformation. Test Cycle B was accomplished by driving the load vehicle forward in the normal manner to a distance of 15 ft past the beam toe and then returning the load vehicle to the original starting position. Normal values obtained on the forward pass indicated a residual deformation, but when the load vehicle returned to the starting position it was found that the original extensometer reading was unchanged even though two repetitions of the wheel load had passed over the beam toe. Several repetitions of the test cycle at each test point showed this relationship to be true in all cases except for those pavements classified as very poor. In these pavements, definite accumulative residual deformations were evident.

To check the trends noted in Test Cycle B another procedure—known as Test Cycle C—was developed. In this cycle, the load vehicle was started approximately 15 ft away from the beam toe, backed to a point slightly beyond the toe, and then returned to the starting position. Again residual deformation of the pavement surface was not evident even though 6 to 8 load cycles passed over the test points.

The only obvious reason for this discrepancy in residual deformations was that the usual placement of the load vehicle at the start of the test (Test Cycle A) caused sufficient downward movement of the front support and toe of the beam to bias the initial reading. It will be recalled that the Benkelman beam was designed on the basis that the deflected area of the pavement would not extend more than 4.5 ft from the center of the load wheel.

In the light of the results obtained from Test Cycles B and C, further tests were conducted to determine the length of pave-

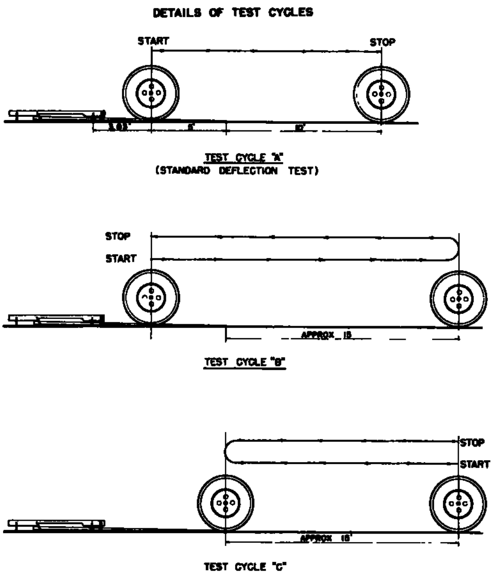

Figure 5. Plan of wheel movement for Test Cycles A, B, and C.

ment influenced by the load. In these tests the load vehicle was started approximately 20 ft away from the beam toe and backed slowly toward the beam. The position of the load wheel was marked at the first discernible movement of the beam extensometer and also when the extensometer indicated a movement of 0.002 in. at the beam toe (a movement of one division on the extensometer dial). Results for several test sites on four different test sections (Fig. 6) indicate much larger areas of influence than previously reported in literature (1, 2).

Although Test Cycles B and C eliminated most of the false residual values resulting from the long depressed areas, it was a difficult and time-consuming task to back the load vehicle over the probe arms of the beam. In addition, if a graphical recording was desired, a rather complicated pulley system would have been necessary to actuate the Helmer recorder on the back-up passes of Test Cycles B and C.

DATA CORRECTIONS

In order to use Test Cycle A and still use the results of the graphical recordings, a method was developed to correct the recordings based on measurements obtained from the recordings themselves. This method requires several assumptions which are discussed as follows:

1. The graph drawn by the recorder shows the deflection at the beam toe produced by a moving wheel load. If conditions of homogeneity can be assumed within the area influenced by the wheel load, the curve can also be considered as the deflection of the area produced by the wheel load at the instant it passes over the beam toe. From a

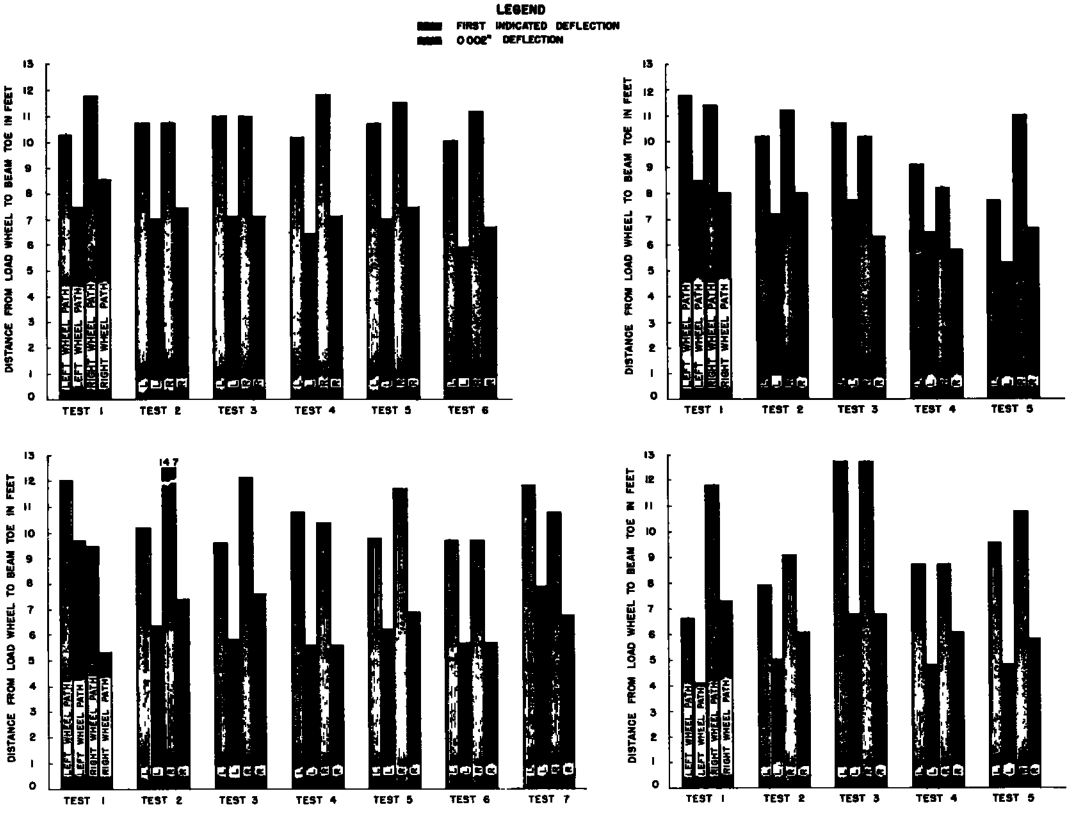

Figure 6. Average distances of load wheel from toe of beams at extensometer readings indicated.

practical standpoint the assumption of homogeneity appears reasonable for the small area in question.

2. Another assumption is that all points on the pavement deflect to their full value immediately upon application of the load and rebound almost immediately when the load is removed. Proof of this assumption has been determined as follows. At several points on the pavement during the performance of the standard deflection test (Test Cycle A) the load vehicle has been stopped and allowed to stand as long as 3 min. Each time the load vehicle came to a halt, the extensometer hand immediately stopped moving and remained constant until the load vehicle moved again. It has also been noted that the "stop" end of the recordings shows a level, straight line several inches long. This could not have occurred if the beam toe continued vertical movement as the load vehicle reached the end of the cycle.

3. A further assumption, somewhat related to that listed previously, is that no residual deformation occurs under the action of a single pass of the load vehicle. On the basis of the results obtained from Test Cycles B and C, it appears that this assumption is valid for most pavements. For those pavements that show a real and definite residual deformation, this method cannot be used.

4. The final assumption is that the deflection curve produced by a slowly moving wheel load is symmetrical on both sides of the wheel. It would at first appear from the deflection curves shown in Figure 4 that this assumption is incorrect, however these curves actually are asymmetrical because of the bias caused by downward movement of the front beam support. In other words, at the same time the load wheel is moving closer to the beam toe and causing it to deflect, the front beam support is rising. This interaction causes the graphical recording to be incorrect as long as the front support is within the deflected area. A further check on this assumption was made by limited tests using the Helmer recorder in Test Cycle C. A comparison of the back-up and forward graphs showed that regardless of the direction of travel of the test vehicle the graphs become symmetrical at the point where the front support was no longer in the deflected area.

On the basis of the foregoing assumptions, the deflections were corrected by measurements taken from the recordings made with Test Cycle A. The first step was construction of a base line from the "stop" end of the recording parallel to the top edge of the paper. The scaled distance from the "trough" of the deflection curve to the point where the deflection curve becomes level (or intersects the base line) represents one-half of the length of the deflected area. If this distance was less than the distance from the load wheel to the front supports or beam toe at the beginning of the test then neither the front supports nor the toe were in the deflected area at the beginning of the test. In these cases there are no residual deformations (except in the case of very poor pavements) and it is not necessary to correct the Helmer recordings.

If one-half of the deflected area was found to be greater than 3.83 ft but less than 8.9 ft then both the toe and front supports of the beam were in the deflected area at the beginning of the test. In this case the initial portion of the curve from the "start" point to the deflection trough was incorrect. It is possible to geometrically determine a correction for the initial reading in this case, but its use is not warranted inasmuch as the curve is correct at least from the "trough" to the "stop" end.

If one-half of the deflected area was greater than 8.9 ft, then not only was the initial reading in error, but the maximum reading also was in error. In this case it was necessary to correct the maximum Helmer recording value by a geometrical process. The first step in this process was to determine from the recording graph the distance that the front support was depressed at the time of the maximum reading. This was done by measuring 8.9 in. from the "trough" of the deflection curve along the base line. At this point (which corresponds to a distance of 8.9 ft away from the beam toe on the pavement) the measured vertical distance from the base line to the deflection curve represents the front support movement when the load wheels are at the beam toe.

The influence of downward front support movement on the maximum deflection was determined by rather simple geometrical means and the results are shown in Figure 7.

Front support movements of 0.013 in. have been recorded on Texas highways. This means that corrections as high as 0.038 in. have been required.

As an aid in extracting the dimensions from the recordings, the lucite template shown in Figure 8 was made. On the template, scaled dimensions of the Benkelman beam are etched on a horizontal base line. The vertical scales allow direct measurements of deflections and front support movements.

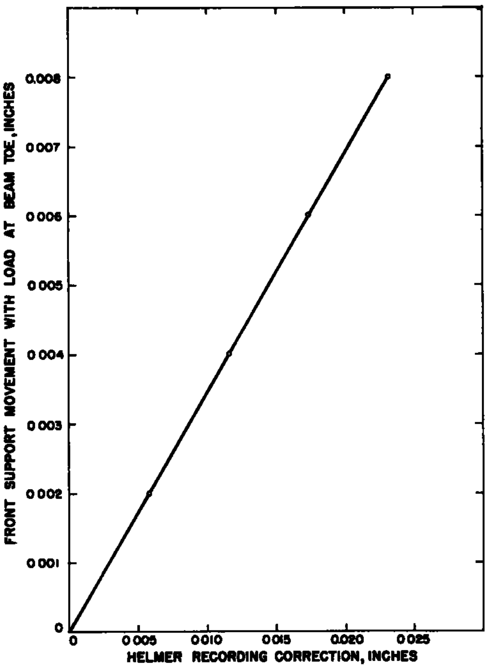

Figure 7. Correction to be added to deflections obtained from the Helmer graphical recorder when the front support is depressed at time of maximum deflection.

The use of the Helmer recorder with the Benkelman beams prompted another investigation to determine the reliability of recorders. Previous tests had been performed on the beams by placing gage blocks of known thicknesses under the beam toes. To check the recorders it was felt that the movement of the beam toes should duplicate that occurring during actual testing. This was satisfied by placing the beam toes on the lower platen head of a Universal testing machine (Fig. 9). As the recorder was actuated to reel out the graphing paper, the beam toe was lowered and raised again to the initial position. The testing machine operator was quickly able to reproduce curves like those obtained in the field. A comparison between the deflections measured from the recordings and the actual movements of the beam toes is shown in Figure 10 for both the right (outer wheel path) and left (inner wheel path) beams.

Because of wear, looseness of parts in the recorder or faulty adjustments, these corrections change often and it is necessary to periodically check the beams. This has been accomplished satisfactorily in the field by the use of the apparatus shown in Figure 11. The beam toe is placed on the hinged lever which may be moved up or down with a fine thread bolt. As the Helmer recorder is placed in

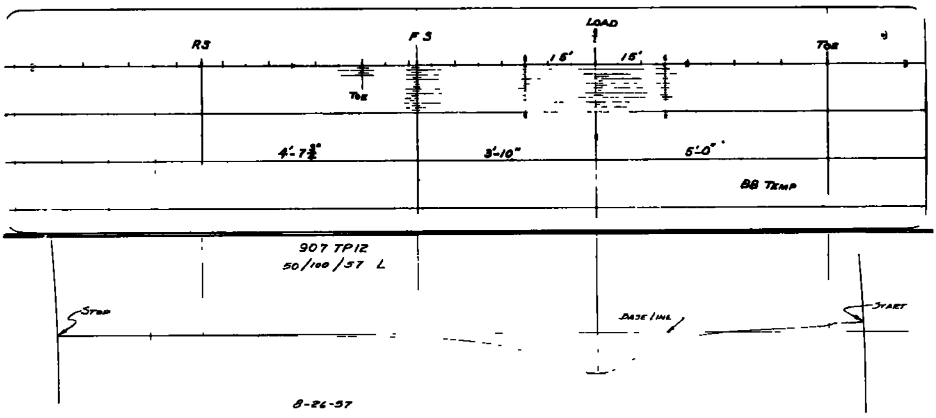

Figure 8. Template used to simplify measurements from graphical recordings.

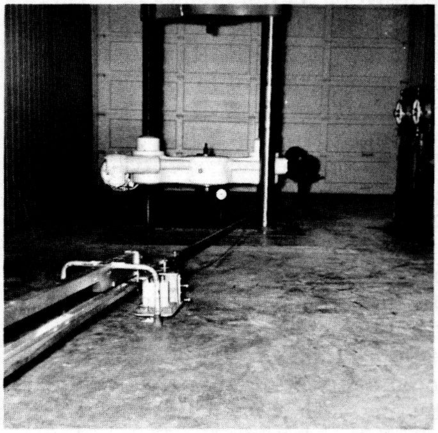

Figure 9. Laboratory set-up used to calibrate Benkelman beams and Helmer recorder.

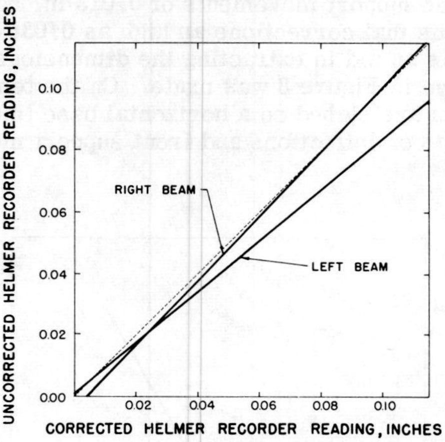

Figure 10. Corrections to be applied to Helmer recordings as a result of laboratory calibrations.

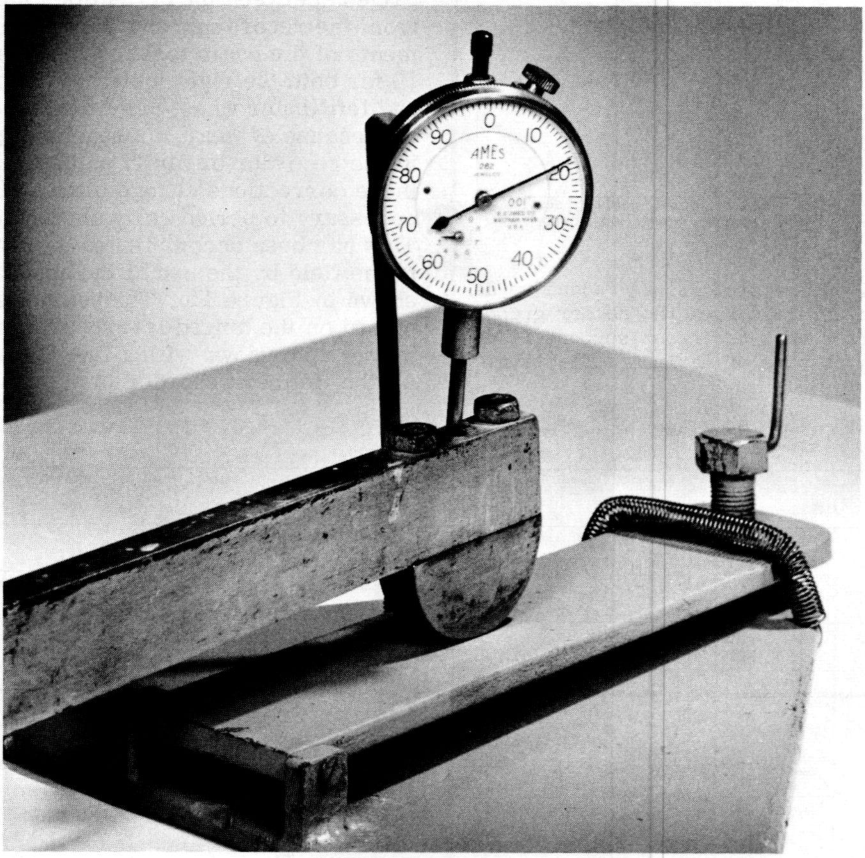

Figure 11. Apparatus for checking Benkelman beam calibration in the field.

motion, the lever is lowered and then raised to the initial position. The movement of the beam toe, as measured by the extensometer mounted on the stationary base plate, is compared to the deflection measured from the graphical recording. When this comparison shows a significant variation from the correction charts, the beams and recorders are examined for looseness of parts, etc. If necessary the beams are returned to the shop for cleaning and adjustment, which is then followed by another laboratory calibration. Experience has shown that the recorders easily get out of adjustment and field checks should be performed several times daily.

Another factor to be considered, although not directly associated with the accuracy of the Benkelman beam, is the effect of temperature on flexible pavement deflections. This could be particularly important when comparing deflections at a certain point during various times of the year or even at various times of the day. To check this effect, two pavement sections were selected. One section was surfaced with a single asphalt surface treatment and the other was surfaced with 4 in. of hot-mix asphaltic concrete. At several test points on each pavement at least 4 separate deflection and temperature tests were obtained between dawn and dusk. Temperatures varied between 75 F and 119 F which corresponded nicely to the over-all temperature variation of 70 F to 140 F noted during previous deflection tests. It was suspected that if any temperature effect was present it would be more noticeable in the asphaltic concrete section than in the surface treatment. The results given in Table 1 indicate a general but erratic tendency on both sections for the deflections to increase as the temperatures increase. The correlation is rather poor for this limited data and it appears that other unknown variables are affecting this data. As a matter of interest it is pointed out that pavement deflections at the WASHO Road Test were not significantly affected by temperatures above 70 F (5). This relationship may not hold true for other pavements, and it appears that more research must be undertaken on the temperature-deflection relationship for a wide range of pavement surfaces and thicknesses.

TEST RESULTS

After the deflection testing program was completed on the original 500 mi of highway, it became apparent that it would be extremely difficult and expensive to collect the information on all of the significant variables involved. As a result, several of the test sections were eliminated. The remaining sections (totaling approximately 117 mi) were selected to have a maximum variation in age, traffic characteristics, pavement cross-sections, and construction materials. Determination of the effect of each of these variables on surface deflections will still involve a major statistical analysis. Although it is too early at the present time to predict general trends or values, there are a few specific points considered worthy of mention.

Table 2 shows the results of deflected length measurements for 1,114 tests taken during the summer of 1959. The values were obtained for a 9,000-lb wheel load. It is seen that the deflected length was longer than 16 ft for about 50 percent of the test points. Also, about 82 percent of the test points had deflected lengths greater than 10 ft. In these instances the initial Benkelman beam readings were biased to the extent that erroneous residual deformations were indicated. Approximately 40 percent of the test points had deflected areas greater than 18 ft thereby indicating that the maximum deflection also required correction.

Attempts to correlate the deflected length with pavement behavior have been unsuccessful. This is probably a result of the many factors affecting this length. One such factor is given in Table 3 which presents the deflected lengths for 5 adjacent test sections. These 5 sections, each 250 ft long, were constructed for a soil stabilization study. The sections are alike in every manner except that the top 6 in. of the subgrade in each section is stabilized with a different type or amount of stabilizer.

Shortly after the test section was opened to traffic it was used as a haul road for a nearby construction project. Several hundred heavily-loaded gravel trucks traveled on the west-bound lane and returned empty on the east-bound lane. The high wheel loads caused a significant increase in the deflected length of the west-bound lane. This would indicate that an increase in density also increases the deflected length of the pavement.

TABLE 1

PAVEMENT TEMPERATURES AND CORRECTED DEFLECTIONS[1] FOR A SERIES OF FOUR TEST REPETITIONS

Test Point	Wheel Path							
	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
	(a) Test Section 903[2]							
27	77	77	88	88	102	102	108	108
	(11)	(14)	(16)	(14)	(15)	(11)	(14)	(15)
28	75	75	90	90	104	104	110	110
	(10)	(13)	(17)	(11)	(15)	(9)	(19)	(38)
29	76	76	87	87	105	105	113	113
	(22)	(10)	(22)	(18)	(22)	(14)	(23)	(35)
30	77	77	91	91	108	108	114	114
	(14)	(21)	(20)	(19)	(17)	(16)	(20)	(40)
32	76	76	90	90	109	109	114	114
	(19)	(13)	(24)	(14)	(19)	(8)	(21)	(23)
33	75	75	93	93	109	109	112	112
	(17)	(16)	(38)	(30)	(38)	(23)	(37)	(32)
34	76	76	95	95	111	111	111	111
	(12)	(12)	(24)	(7)	(20)	(10)	(18)	(18)
35	77	77	94	94	108	108	111	111
	(18)	(10)	(21)	(10)	(15)	(12)	(18)	(15)
38	77	77	96	96	113	113		
	(12)	(10)	(22)	(11)	(20)	(12)		
39	77	77	93	93	111	111	113	113
	(7)	(8)	(18)	(7)	(27)	(14)	(30)	(18)
40	79	79	96	96	119	119	116	116
	(25)	(18)	(31)	(8)	(25)	(35)	(27)	(10)
41	81	81	101	101	112	112	113	113
	(22)	(19)	(25)	(16)	(25)	(15)	(29)	(30)
42	81	81	98	98	107	107	112	112
	(16)	(8)	(17)	(9)	(23)	(20)	(22)	(26)
43	81	81	98	98	102	102	106	106
	(22)	(20)	(25)	(16)	(21)	(14)	(46)	(36)
44	80	80	97	97	106	106	107	107
	(24)	(28)	(33)	(27)	(35)	(27)	(34)	(32)
46	81	81	99	99	106	106		
	(24)	(16)	(24)	(14)	(29)	(14)	(26)	(32)
47	81	81	95	95	105	105	111	111
	(14)	(16)	(11)	(9)	(18)	(12)	(13)	(30)
	(b) Test Section 905[3]							
148	79	79	83	83			97	97
	(22)	(26)	(24)	(29)			(28)	(36)
149	79	79	85	85	100	100	97	97
	(30)	(42)	(32)	(36)	(35)	(45)	(39)	(52)
150	79	79	84	84	101	101	100	100
	(37)	(44)	(29)	(40)	(27)	(41)	(41)	(54)
151	78	78	86	86	98	98	101	101
	(32)	(32)	(22)	(19)	(53)	(43)	(41)	(40)
152	78	78	87	87	99	99	101	101
	(29)	(35)	(26)	(39)	(31)	(34)	(40)	(33)
153	78	78	86	86	102	102	102	102
	(27)	(30)	(16)	(32)	(28)	(34)	(27)	(29)
154	78	78	87	87	103	103	102	102
	(29)	(35)	(38)	(36)	(28)	(35)	(38)	(29)
155	78	78	87	87	102	102	99	99
	(24)	(18)	(22)	(26)	(30)	(24)	(26)	(31)
156	79	79	89	89	102	102	102	102
	(31)	(29)	(21)	(62)	(34)	(30)	(35)	(38)
157	79	79	89	89	98	98	107	107
	(34)	(41)	(25)	(40)	(33)	(44)	(43)	(49)
158	78	78	89	89	99	99	107	107
	(29)	(25)	(30)	(53)	(43)	(42)	(36)	(35)
159	79	79	93	93	97	97	103	103
	(26)	(17)	(28)	(39)	(29)	(30)	(15)	(19)
160	79	79	93	93	99	99	106	106
	(29)	(41)	(30)	(49)	(31)	(49)	(22)	(33)
161	79	79	93	93	99	99		
	(31)	(26)	(33)	(33)	(38)	(29)	(37)	(27)
162	79	79	95	95	98	98		
	(26)	(41)	(27)	(57)	(29)	(47)	(38)	(50)

[1] Values in parentheses are corrected deflections, in 10^{-3} in.

[2] Four-inch hot-mix asphaltic concrete surface.

[3] Single asphalt surface treatment.

TABLE 2

PERCENTAGE OF TESTS FALLING WITHIN VARIOUS INTERVALS OF DEFLECTED LENGTH OF PAVEMENTS

Test Section No.	Percentage of Tests Falling Within Deflected Lengths Shown															Total Test Points
	Deflected Length, ft															
	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	
201	0	0	0	11.5	11.5	19.3	19.3	3.8	3.8	15.4	3.8	7.8	3.8	0	0	26
204	0	5.0	5.7	9.3	14.3	14.3	12.8	10.0	11.4	9.3	3.6	2.9	1.4	0	0	140
205	0	3.0	9.0	13.4	13.4	11.9	10.4	4.5	6.0	7.5	11.9	7.5	1.5	0	0	67
207R	0	1.2	8.1	11.6	14.0	23.1	7.0	14.0	8.1	4.7	3.5	1.2	3.5	0	0	86
207L	0	3.8	11.5	7.8	3.8	15.4	19.4	3.8	7.8	11.5	3.8	11.5	0	0	0	26
901	1.6	0.8	0.8	3.2	7.2	9.6	16.0	17.6	12.8	11.2	10.4	7.2	1.6	0	0	125
902	0	0	1.1	1.1	4.4	5.5	7.7	12.1	9.9	19.7	8.8	16.5	11.0	1.1	1.1	91
903	14.1	9.1	8.1	16.2	16.2	10.1	6.1	2.0	4.0	3.0	5.1	4.0	1.0	0	1.0	99
905	0.6	7.8	9.1	14.5	13.0	12.3	5.8	5.2	2.6	5.8	7.8	5.8	3.9	5.2	0.6	154
906	0	2.4	3.6	5.4	4.8	5.4	9.0	15.3	13.9	12.0	7.8	7.2	6.0	5.4	1.8	166
907	0	0	0	4.1	2.7	4.1	4.1	12.2	13.2	12.2	16.2	12.2	12.2	6.8	0	74
908	1.7	0	5.0	3.3	13.3	13.3	8.3	16.7	11.7	5.0	10.0	5.0	1.7	5.0	0	60
All Sections	1.6	3.3	5.1	8.4	10.2	11.1	9.5	10.7	9.2	9.4	7.8	6.8	4.1	2.3	0.5	
Acc. Percent	1.6	4.9	10.0	18.4	28.6	39.7	49.2	59.9	69.1	78.5	86.3	93.1	97.2	99.5	100	

TABLE 3

DEFLECTED LENGTHS FOR BOTH LANES OR SPECIAL TEST SECTIONS

Test Section	Test Point	Deflected Length, ft			
		East-Bound Lane		West-Bound Lane	
		O.W.P.	I.W.P.	I.W.P.	O.W.P.
I	1	17.4	15.4	-	16.6
	2	15.5	16.0	15.4	16.4
	3	17.0	16.2	18.4	24.2
	4	15.5	17.5	23.8	17.6
	Avg	16.4	16.3	19.2	18.7
II	5	19.8	18.0	18.2	17.2
	6	16.2	16.0	26.2	22.4
	7	23.6	20.2	16.2	16.0
	8	19.4	14.1	26.6	17.6
	Avg	19.8	17.1	21.8	18.3
III	9	12.8	13.0	18.8	-
	10	12.4	13.6	Inc	23.4
	11	11.0	13.0	14.4	19.0
	12	14.5	12.4	24.4	19.8
	Avg	12.7	13.0	19.2	20.7
IV	13	17.0	-	27.0	18.8
	14	20.3	17.2	24.6	20.6
	15	-	18.8	22.0	17.4
	16	14.7	18.4	26.0	-
	Avg	17.3	18.1	24.9	18.9
V	17	20.0	18.0	29.2	23.8
	18	16.2	14.4	19.4	-
	19	17.0	18.8	31.4	17.2
	20	18.5	17.6	25.0	17.5
	Avg	17.9	17.2	26.3	19.5

TABLE 4

DEFLECTION DATA FOR TEST SECTION—9,000-LB WHEEL LOAD

Test Point	Corrected Deflection, 10^{-3} in.	½ Deflected Length, ft	Deflection ÷ ½ Deflected Length, $\frac{\text{in.}}{\text{ft}}$	Pedological Soil Type
1	19.0	11.1	0.0017	Irving clay
Avg.	19.0	11.1	0.0017	Irving clay
2	31.0	7.2	0.0043	Catalpa clay
Avg.	31.0	7.2	0.0043	Catalpa clay
3	45.0	12.8	0.0035	Houston clay
4	50.0	11.4	0.0044	Houston clay
Avg.	47.5	12.1	0.0039	Houston clay
5	29.5	6.3	0.0047	Wilson clay
6	17.0	7.5	0.0023	Wilson clay
7	36.0	12.4	0.0029	Wilson clay
8	18.0	7.2	0.0025	Wilson clay
9	23.0	9.9	0.0023	Wilson clay
10	32.0	8.1	0.0040	Wilson clay
11	30.0	8.3	0.0036	Wilson clay
12	32.0	-	-	Wilson clay
13	26.0	8.5	0.0031	Wilson clay
14	26.0	10.8	0.0024	Wilson clay
15	20.0	10.0	0.0020	Wilson clay
16	33.0	9.0	0.0037	Wilson clay
17	25.0	13.8	0.0018	Wilson clay
Avg.	26.7	9.3	0.0029	Wilson clay
18	31.0	12.7	0.0024	Irving clay
19	15.0	6.1	0.0025	Irving clay
20	34.0	10.4	0.0033	Irving clay
21	25.0	9.8	0.0026	Irving clay
22	29.0	12.3	0.0024	Irving clay
23	36.0	-	-	Irving clay
24	44.0	8.8	0.0050	Irving clay
25	28.0	10.3	0.0027	Irving clay
26	11.0	5.9	0.0019	Irving clay
27	31.0	12.5	0.0025	Irving clay
28	21.0	6.7	0.0031	Irving clay
Avg.	27.7	9.6	0.0028	Irving clay
29	29.0	12.1	0.0024	Bell clay
Avg.	29.0	12.1	0.0024	Bell clay
30	27.0	10.3	0.0026	Irving clay
31	32.0	10.6	0.0030	Irving clay
32	24.0	8.4	0.0029	Irving clay
Avg.	27.7	9.8	0.0028	Irving clay
33	21.0	6.2	0.0034	Lewisville clay
Avg.	21.0	6.2	0.0034	
34	53.0	11.0	0.0048	Houston clay
35	69.0	12.0	0.0058	Houston clay
36	53.5	-	-	Houston clay
37	39.0	10.3	0.0038	Houston clay
38	34.0	11.4	0.0030	Houston clay
Avg.	49.7	11.2	0.0044	Houston clay
39	39.0	12.9	0.0030	Wilson clay
40	30.0	11.7	0.0026	Wilson clay
41	25.0	7.1	0.0035	Wilson clay
42	30.0	9.0	0.0033	Wilson clay
43	30.0	10.4	0.0029	Wilson clay
Avg.	30.8	10.2	0.0030	Wilson clay
44	40.0	9.3	0.0043	Houston black clay
45	36.0	5.4	0.0067	Houston black clay
46	40.0	9.6	0.0042	Houston black clay
47	33.0	11.9	0.0028	Houston black clay
Avg.	37.3	9.1	0.0051	
Grand Avg.	31.5	9.8	0.0032	

The effect of subgrade soil type on both the deflected length and the corrected deflection is given in Table 4. The data were obtained from a pavement with a cross-section of 12 in. of crushed limestone base and a single asphalt surface treatment over the prepared native subgrade. It can be seen that there is a very close relationship between similar pedological soil types. This is best shown by a measure of the curvature of the surface similar to the "index ratio" used at the WASHO Road Test (1). In Table 4, curvature is expressed as a ratio of the deflection in inches to one-half of the deflected length in feet. For the Wilson clay between test points 5 and 17 this ratio is 0.0029 in. per foot and between test points 39 and 43 the ratio is 0.0030 in. per foot. Similar close relationships are noted for the Houston clay and Irving clay. Because of this relationship it should be possible to evaluate pavements on various subgrades by the use of the pedologic classification rather than the much more expensive method of sampling and testing the subgrade soil. This method will undoubtedly be limited to those areas of the pavement where the depth of fill is insignificant.

SUMMARY

The increased use of the Benkelman beam in pavement evaluations makes it necessary that the limitations and accuracy of the equipment be known. A significant and misleading error in deflection values occurs when the front beam supports are within the deflected length of the pavement during the test cycle. Test results are presented showing that the deflected lengths obtained on 117 mi of Texas highways were significant enough to require correction of the deflections for a large percentage of the tests. Means have been given for correcting the deflections when a recorder attachment is used on the Benkelman beam. Examples are also given which show the value of the deflected length measurements obtained from the recordings.

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