STRUCTURAL OVERLAYS FOR PAVEMENT REHABILITATION

Roy W. Bushey, Karl L. Baumeister, and James A. Matthews,
California Department of Transportation

Research in California on the use of deflection measurements for asphalt concrete overlay design resulted in a revision to the California overlay design method presented at the Western Summer Meeting of the Highway Research Board in August 1970. Deflection reduction characteristics and tolerable deflection levels of asphalt concrete were revised based on the performance of highway projects under study since 1960. A higher initial deflection level will result in a slightly greater percentage of reduction for a given overlay thickness. An evaluation of the design method compares predicted versus measured deflections on 69 reconstructed highways. The deflection level after reconstruction can be predicted within ±0.008 in. (±0.2 mm) with a 95 percent confidence limit by using the deflection reduction guide. Pavement deflections are measured by using the California traveling deflectometer, which provides a dynamic type of measurement while traveling along the roadway at ½ mph (0.8 km/h). An asphalt concrete overlay design guide was developed that simplifies the procedure for determining overlay thicknesses, but other factors such as the condition of the structural section and reflection cracking potential may alter the design. Since 1960, the overlay method has been used on approximately 450 different roadways.

•IN 1951, a comprehensive deflection research program was initiated in California to establish a reasonable relationship between the fatigue failure of asphalt concrete (AC) surfacing and the magnitude of pavement deflection. The results and conclusions of this study were published in 1955 (1). Evaluation of data from this study suggested maximum tolerable deflection levels for various pavement thicknesses. These values were an approximation of the highest levels of transient pavement deflection that a given pavement thickness could tolerate under specific traffic conditions during its design life without developing fatigue cracking.

The deflection criteria that were reported in 1955 provided the basis for further study since the roads that were investigated were major highways with relatively high traffic volumes designed for 10 million 5-kip (22-kN) equivalent wheel loads (EWL). These criteria were adjusted for variations in traffic volumes so that they would be more representative of different traffic situations. This was accomplished with fatigue tests in the laboratory on specimens cut from various AC pavements and was reported by Zube and Forsyth (2). They graphically presented an exponential relationship between strain and number of load applications to failure.

Using this relationship along with deflection attenuation data, the California Division of Highways developed Test Method Calif. 356-D (3) as its pavement overlay design method. The method has been used for overlay design on approximately 450 roadways since 1960. This report explains recent modifications made to the design method through further research and refinement.

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DEFLECTION MEASUREMENT BACKGROUND

Pavement deflection measuring experience by the California Division of Highways dates back to 1938 (1). Until 1954, deflection measurements were obtained with the General Electric travel gauge and the linear variable differential transformer.

In 1954 the California Division of Highways began using the Benkelman beam, which greatly simplified the task of measuring pavement deflections under wheel loads. An automatic deflection measuring device known as the California traveling deflectometer was later developed by the Materials and Research Department and put into operation in 1960. A newer version was introduced in 1967 and is shown in Figure 1.

The deflectometer is a truck-trailer unit that measures deflections based on the Benkelman beam principle. It carries an 18-kip (80-kN) single-axle load on the rear tires and a carriage to support probes for measuring pavement deflection under both wheels simultaneously. The electromechanical device measures pavement deflections at 20-ft (6.1-m) intervals while it moves steadily along the road at ½ mph (0.8 km/h). The deflections are measured to the nearest 0.001 in. (0.03 mm) by means of a probe arm resting on the pavement and are permanently recorded on chart paper. Between 1,500 and 2,000 individual deflection measurements are possible per day when the deflectometer is used; about 300 measurements are possible when the manually operated Benkelman beam is used

The deflectometer measurement has been adopted as a standard for use by the California Division of Highways. The Dynaflect, road rater, and Dehlen curvature meter have been related to this device (3, 4). Other states and agencies use the Canadian Good Roads Association (CGRA) Benkelman beam rebound procedure using an 18-kip (80-kN) single-axle dual wheel load. The traveling deflectometer produces a dynamic type of measurement that approximates the WASHO Benkelman beam method (5). This measurement is generally much lower than that produced by the rebound (CGRA) method (6).

The deflectometer deflection measurements are not corrected for temperature or structural section moisture content. It is doubtful whether a single temperature correction factor could be universally applied because of the varying thicknesses and types of materials placed in a structural section. Most of our deflection measurements are taken during the spring or early summer when the moisture content in the roadbed is high and the temperature moderate. Many roadways are constructed with a cement-treated base, and temperature changes should have little effect on the deflection measurements. Our experience indicates a correction should be applied to deflections measured during cold weather [say below 50 F (10 C)] on roadways with untreated bases. Further research work is planned in this area.

DATA ANALYSIS

California now has under way a research project (7, 8) to evaluate deflection criteria by relating pavement performance to tolerable deflection level, structural section, asphalt-hardening properties, and traffic loading. Deflection attenuation properties of various thicknesses of AC overlays are also being investigated on highway projects reconstructed by using our overlay design method.

Our studies indicate that slight modifications should be made to the previously published tolerable deflection curves shown in Figure 2, and to the deflection attenuation graph shown in Figure 3 (6).

Tolerable Deflection

The previously developed tolerable deflection values for AC thicknesses of 0.2 and 0.3 ft (0.06 and 0.09 m) are substantially verified by experience for California conditions as shown in Figure 4. Table 1 gives field data on pavements showing distress. However, thicker AC pavements of 0.4 and 0.5 ft (0.12 and 0.15 m) have been constructed

Figure 1. Traveling deflectometer.

Figure 2. Variation in tolerable deflection based on asphalt concrete fatigue tests.

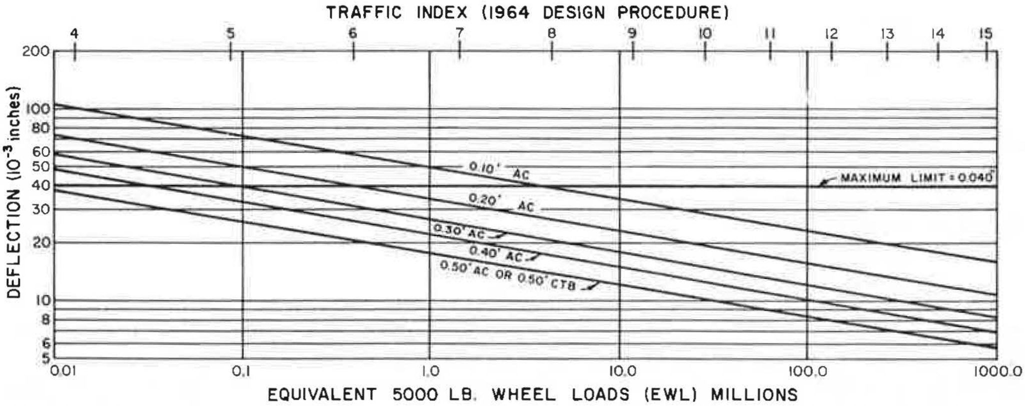
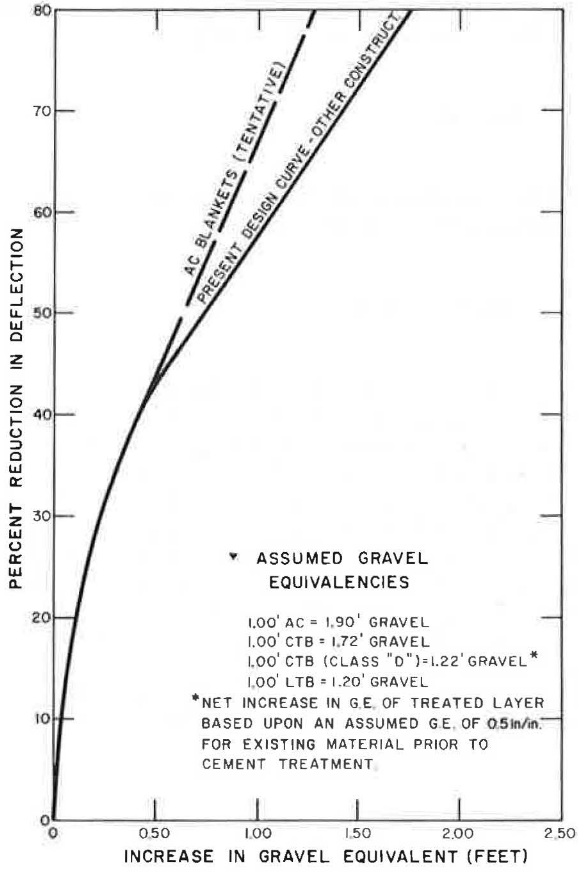


Figure 3. Reduction in deflection resulting from pavement reconstruction.



and are performing well even though the 80 th percentile evaluated deflection level (that deflection level where 80 percent of readings are lower and 20 percent are higher) exceeds the tolerable deflection. This is shown in Figure 5. Although our experience with 0.4 to 0.5-ft (0.12 to 0.15-m) overlays is somewhat limited, the deflection data collected thus far indicate that tolerable deflection levels for these thicker pavements should be adjusted upward.

Research performed by Monismith, Epps, Kasianchuk, and McLean (9) led to the development of an equation for the exponential relationship between initial flexural strain and number of stress applications to failure. Their work suggests that the fatigue behavior of asphalt concrete can be represented as follows:

$$N_f = K\left(\frac{1}{e}\right)^n \tag{1}$$

where

N_f = stress applications to failure,
K and n = constants,
e = initial bending strain, and
n = 2.81 for average California AC (9).

Equation 1 can be used to develop a relationship between the fatigue life for a 0.2-ft (0.06-m) AC pavement and a 0.5-ft (0.15-m) AC pavement where both pavements are assumed to have the same deflection and the same radius of curvature in the deflection basin. This assumption would provide a conservative result because the 0.5-ft (0.15-m) AC pavement should have a larger radius of curvature and therefore less strain.

The ratio of maximum bending strains for each pavement should be approximately equal to the ratio of the thicknesses of AC,

$$e_{0.5}/e_{0.2} = 0.5/0.2 = 2.5 \tag{2}$$

The ratio of EWL repetitions for the two pavements is inversely proportional to the ratio of AC thicknesses to the 2.81 power.

$$N_{0.2}/N_{0.5} = 2.5^{2.81} = 13.1 \tag{3}$$

Equation 3 shows the ratio of EWL repetitions to failure to be 13.1:1. Holding the established 0.2-ft (0.06-m) AC curve in its original position and adjusting the tolerable deflections for 0.5-ft (0.15-m) AC on the original chart (Figure 2) to reflect this relationship result in about a 20 percent increase in the tolerable deflection values for 0.5-ft (0.15-m) AC as shown in Figure 6. The tolerable deflection values for 0.3 and 0.4-ft (0.9 and 0.12-m) AC thicknesses are moved upward slightly as a result of interpolation and consideration of recent experience. Except for the value for 0.1-ft (0.03-m) AC, these modified tolerable deflection values check closely with the levels given by Hveem (1). The tolerable deflection curve for 0.1-ft (0.03-m) AC was lowered because our experience has demonstrated that thin AC overlays fail prematurely when placed on distressed roadways.

These deflection levels would seem appropriate for highways located in climates with moderate winter temperatures [30 to 50 F (-1.1 to 10 C)], but evaluation would be needed for colder climates. The modified tolerable deflection chart is shown in Figure 6.

Figure 4. Comparison of predicted and measured deflections in 0.25 and 0.3-ft (0.07 and 0.09-m) pavement showing distress.

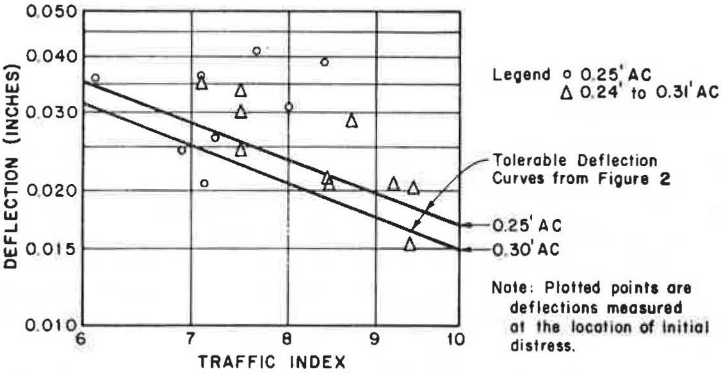
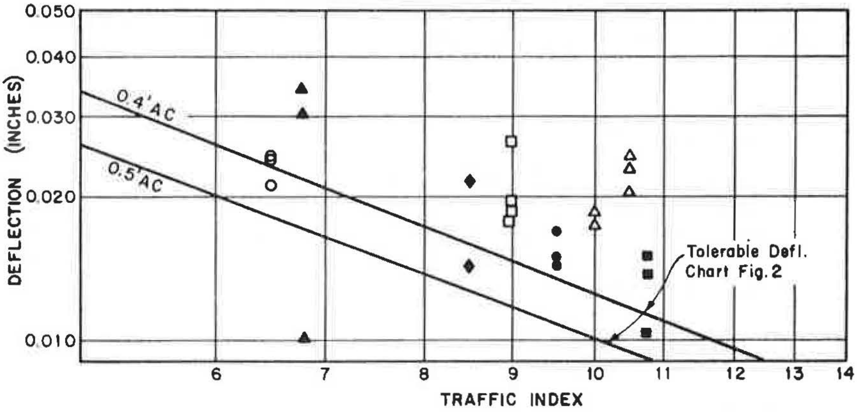


Table 1. Field data on pavements showing distress.

Project	Station	Measured Deflection at Location of Distress (in.)	Asphalt Concrete Thickness (ft)	Traffic Index
03-Col-88	145 + 00 - 155 + 00	0.036	0.25	7.1
	356 + 00 - 366 + 00	0.024	0.25	6.9
	310 + 00 - 300 + 00	0.026	0.25	7.3
03-Gle-162	748 + 00 - 767 + 00	0.021	0.25	7.2
03-Sac-232	352 + 00 - 342 + 00	0.024	0.30	9.4
	326 + 00 - 321 + 00	0.020	0.30	9.4
03-Yol-99	Webster St.	0.028	0.29	8.7
	Devon St.	0.022	0.29	8.5
	Alameda St.	0.020	0.29	8.5
05-SB-149	110 + 00 - 100 + 00	0.029	0.31	7.5
	33 + 00 - 43 + 00	0.024	0.31	7.5
	80 + 00 - 90 + 00	0.033	0.31	7.5
05-SBt-156	296 + 00 - 286 + 00	0.021	0.31	9.3
06-Ker-141	30 + 00 - 20 + 00	0.038	0.25	8.3
	50 + 00 - 60 + 00	0.041	0.25	7.7
	0 + 00 - 10 + 00	0.031	0.25	8.0
06-Fre-1329	536 + 00 - 526 + 00	0.035	0.25	6.2
06-Fre-33	502 + 00 - 492 + 00	0.034	0.29	7.1

Note: 1 in. = 25.4 mm. 1 ft = 0.3 m.

Figure 5. Comparison of predicted and measured deflections in 0.4 and 0.5-ft (0.12 and 0.15-m) pavements showing no distress.



Each point represents the evaluated deflection value for one test section.

○	Stan. Co. Howard Rd.	0.50' AC
△	05-Mon-101 (2C)	0.61' AC
□	03-Sac-99	0.55' AC
◆	04-SCI-156	0.50' AC
●	04-CC -800 WC	1.10' AC (Over native material)
▲	11-SD — Sweetwater Rd.	Variable AC
■	05-Mon-101 (2D)	0.59' AC

Deflection Attenuation

Our present deflection design method is based on the previously mentioned tolerable deflection curves and deflection attenuation data. Curves published by Kingham (10) and Lister (11) indicate that the percentage of reduction in deflection depends on the initial deflection before an overlay is placed. Our data also tend to support this theory as shown in Figure 7. Although the scatter is relatively wide because of the numerous variables, the general trend indicates that the percentage of reduction of deflection values depends to some extent on initial deflections. These findings have been incorporated into the deflection reduction guide shown in Figure 8.

The previous deflection attenuation graph (Figure 3), which was not based on the initial deflection level, provided satisfactory results. A comparison of predicted versus measured deflections was made on 69 projects where deflection measurements were taken before and after reconstruction. Figure 9 shows the correlation results that are good when consideration is given to the number of variables involved such as moisture content, temperature, repeatability of equipment, and test location. On the average, 2 to 3 years passed from the time initial measurements were taken, an overlay was placed, and final deflection measurements were made. As with most California deflection investigations, measurements were taken during the spring months to minimize the error caused by a change of moisture content in the roadbed.

Overlay Design

The revised tolerable deflection and deflection attenuation data are used with past experience to produce a design guide for AC overlays as shown in Figure 10. This guide is patterned after one developed by Lister (11). Lister's chart gives values that are generally more liberal than those obtained from this guide for the AC pavements having less than about 0.5-ft (0.15-m) thickness when the initial deflection is 0.03 in. (0.76 mm) or greater. British asphalt mixes are considered to be more fatigue resistant than those used in California (mainly because of their greater asphalt content); therefore, this comparison is as would be expected. Use of a design guide will greatly simplify California's overlay design method and not simply transpose values from two charts by trial and error. The intent of the design guide is to approximate overlay thicknesses. Considerable distress in the existing pavement would substantiate greater overlay thicknesses than indicated by the design guide.

Reflection Cracking

For some pavements, the magnitude of the existing deflection level is not a governing criterion for overlay design. Frequently the need to eliminate potential reflection cracking from the underlying pavement controls the AC pavement overlay thickness. At present, there is no verified method to determine this thickness, but a general rule used for prevention of reflection cracking is as follows:

1. The new blanket thickness should be at least one-half the thickness of the existing AC pavement over untreated bases.
2. For AC overlays on existing AC pavements with an underlying cement-treated base or portland cement concrete pavements, a minimum thickness of 0.3 ft (0.09 m) of AC should be used. A 0.5-ft (0.15-m) AC overlay has been used successfully on high-volume urban portland cement concrete freeways.

SUMMARY AND CONCLUSIONS

1. On 69 reconstructed highways, the design methods predicted deflection compared favorably with the measured deflection. The coefficient of correlation is 0.90,

Figure 6. Tolerable deflections.

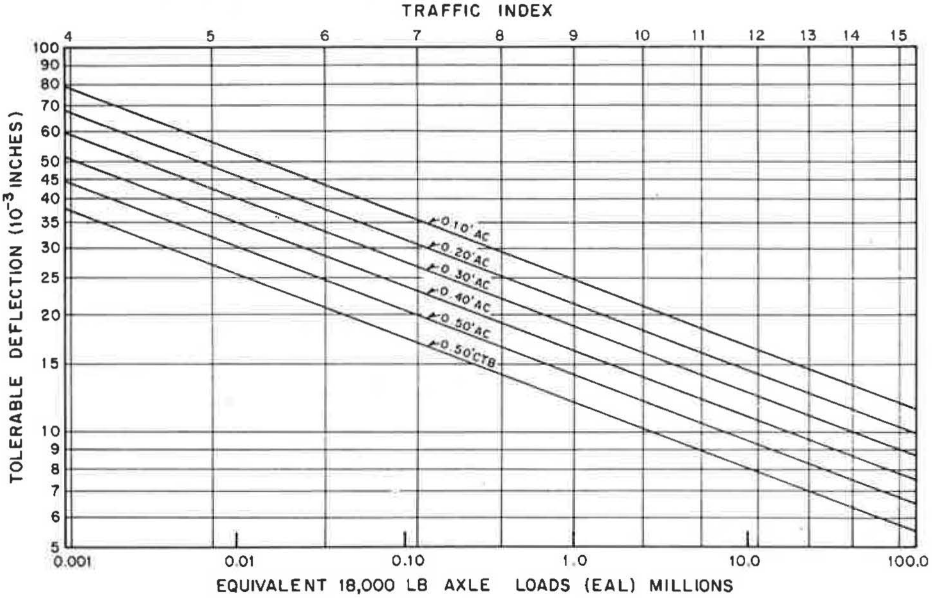


Figure 7. Initial deflection versus percentage of reduction.

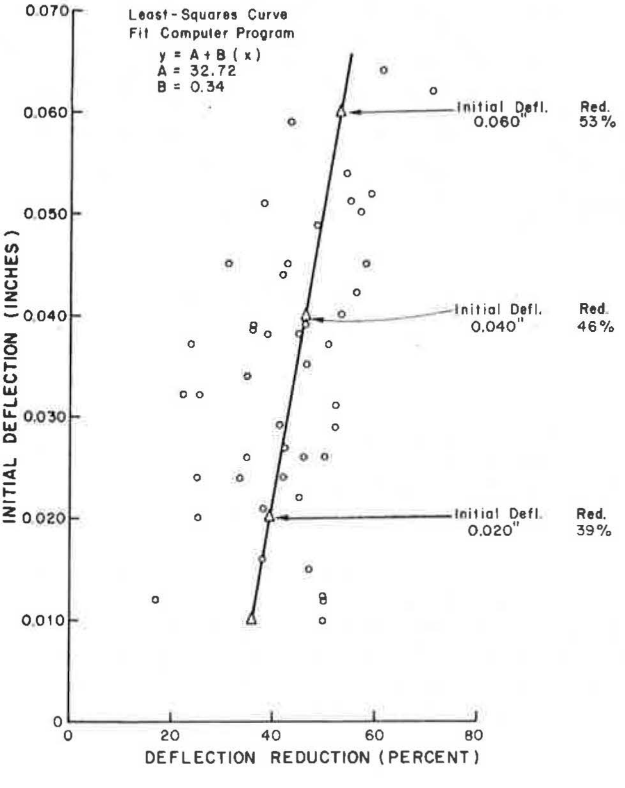


Figure 8. Deflection reduction guide.

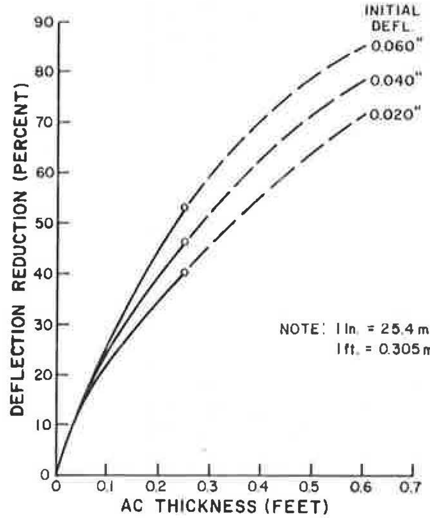


Figure 9. Predicted versus measured deflection taken before and after reconstruction.

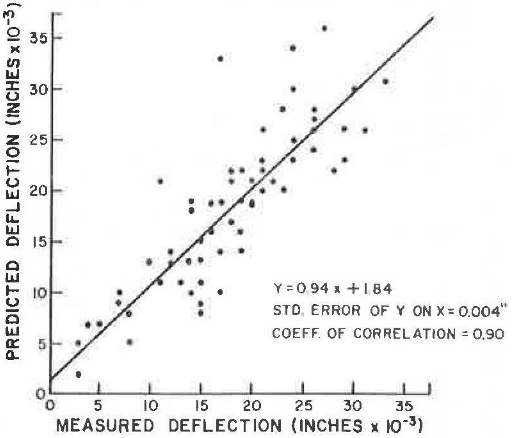
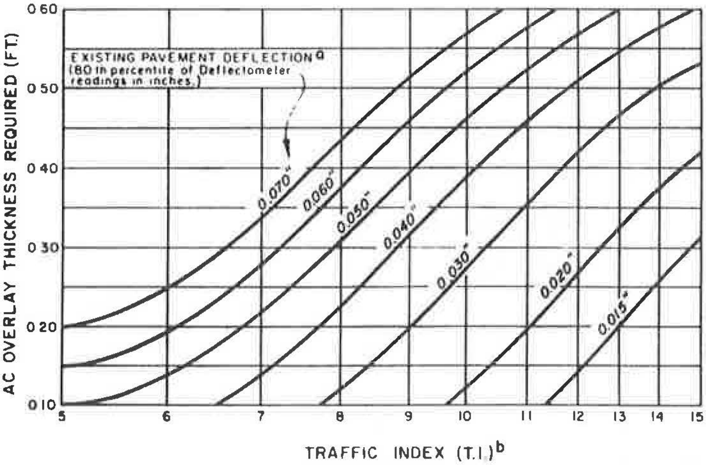


Figure 10. Asphalt concrete overlay design guide.



a. APPROXIMATES WASHO BENKELMAN BEAM METHOD.

b. $T.I. = 9.0 \left(\frac{\text{EQUIVALENT 18K AXLE LOADS}}{10^6}\right)^{0.119}$

and the standard error of y on x is 0.004 in. (0.1 mm).

2. Our previously developed tolerable deflection values for overlays between 0.2 and 0.3 ft (0.06 and 0.09 m) have been substantially verified by experience for California conditions, and about a 20 percent increase in tolerable deflection is justified for a 0.5-ft (0.15-m) AC overlay.

3. For a given AC overlay thickness, the percentage of reduction in deflection depends on the initial deflection before the overlay is placed.

4. The revised tolerable deflection curves and the deflection attenuation curves have been combined to produce a design guide for AC overlays. Use of this design guide rather than a trial and error process involving values picked from two charts greatly simplifies the method of selecting overlay thicknesses.

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REFERENCES

1. F. N. Hveem. Pavement Deflection and Fatigue Failures. HRB Bulletin 114, 1955, pp. 43-79.
2. E. Zube and R. A. Forsyth. Flexible Pavement Maintenance Requirements as Determined by Deflection Measurement. Highway Research Record 129, 1966, pp. 60-75.
3. Materials Manual—Testing and Control Procedures. California Division of Highways, Sacramento, Vol. 1.
4. E. Zube, D. O. Tueller, R. A. Forsyth, and J. B. Hannon. Evaluation of the Lane-Wells Dynaflect. Materials and Research Department, California Division of Highways, Sacramento, Research Rept. 633297, Oct. 1968.
5. Special Committee on Pavement Design and Evaluation, Canadian Good Roads Association. Pavement Evaluation Studies in Canada. Proc. 1st International Conference on the Structural Design of Asphalt Pavements, Univ. of Michigan, 1962.
6. G. B. Sherman and J. B. Hannon. Overlay Design Using Deflections. Materials and Research Department, California Division of Highways, Sacramento, Research Rept., April 1970.
7. E. Zube, R. A. Forsyth, and J. B. Hannon. An Interim Report on Statewide Follow-Up Deflection Study of Overlays and Roadway Reconstruction. Materials and Research Department, California Division of Highways, Sacramento, Aug. 1966.
8. E. Zube, D. O. Tueller, R. A. Forsyth, and J. B. Hannon. Statewide Flexible Pavement Performance and Deflection Study. Materials and Research Department, California Division of Highways, Research Interim Rept. 633128, Dec. 1968.
9. C. L. Monismith, J. A. Epps, D. A. Kasianchuk, and D. B. McLean. Asphalt Mixture Behavior in Repeated Flexure. Institute of Transportation and Traffic Engineering, Univ. of California at Berkeley, Research Rept. TE70-5, Dec. 1970.
10. R. I. Kingham. Development of the Asphalt Institute's Deflection Method for Designing Asphalt Concrete Overlays for Asphalt Pavements. Asphalt Institute, Research Rept. 69-3, June 1969.
11. N. W. Lister. Deflection Criteria for Flexible Pavements and the Design of Overlays. Proc., 3rd International Conference on the Structural Design of Asphalt Pavements, London, 1972.