General Discussion

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•THESE PAPERS are concerned with pavement rehabilitation, a problem that is becoming increasingly important. It essentially concerns determination of the additional thickness of overlay material needed to restore the riding qualities of pavements that have deteriorated due to environmental effects or the additional thickness needed to increase the structural capacity of distressed pavements to accommodate existing traffic or an estimated growth in traffic. At one time this was done solely on the basis of judgment and experience of the engineer. These papers demonstrate that an increasing amount of interest is currently being shown in the use of deflection data to arrive at the answers needed. To achieve an appreciable level of success, one must know, within reason, the tolerable deflections for different pavements, and the inherent ability of many different materials to reduce deflection when used as overlay.

The paper by Zube and Forsyth contains considerable information on these two items. By converting the values on the horizontal scale in Figure 2 in the report (Increase in gravel equivalent thickness) to inches of asphalt concrete using the equivalence cited (1 in. AC = 1. 9 in. gravel), it was possible to compute the percent of deflection reduction for each inch of material. The values range from 29 percent per inch of the material per inch of thickness to 14 percent for 3 in. and 9 percent for 6 in. These values, as indicated in the text, show that the degree of reduction or attenuation in deflection depends on the thickness of the AC layer, i. e., as stated, "The highest rate of deflection reduction occurs with relatively thin treatment."

Similar values, developed in Carneiro's paper, indicate that the deflection reduction for 1 in. of a typical grade of asphalt-concrete would amount to about 17 percent per inch for a 1-in. thickness, 14 percent for 3 in., and 10 percent for 6 in.

An attempt was made, without success, to develop a similar set of values from Huculak's paper. However, it is possible to obtain a picture of how Canada views the question by reference to a plot shown in a recent publication of the Canadian Good Roads Association, "A Guide to the Structural Design of Flexible and Rigid Pavements in Canada." According to the plot, the reduction of deflection per inch of thickness is dependent on the tolerable or design deflection. For a tolerable deflection of 0. 030 in. the reduction of deflection is about 6 percent per inch assuming the previously mentioned 1:1. 9 layer equivalency for asphalt-concrete to gravel. The reduction increases with increase in tolerable deflection to 12 percent for a deflection of 0. 050 in. As a greater tolerable deflection would demand less thickness, there again seems to be agreement that the highest rate of deflection occurs with relatively thin treatment. The magnitude of the reduction, however, appears less, according to Canadian experience.

At the AASHO Road Test, studies of 99 overlaid (3-in. -AC) sections of the test pavement showed that the deflection, on the average, was reduced 14 percent per inch of overlay, the same value as that cited previously for California.

From the work done in California, as reported by Zube and Forsyth, tolerable deflection limits have been developed. The values vary over wide limits depending on traffic and the makeup of the pavement. According to Figure 2, for pavement having a 6-in. AC surface and carrying heavy traffic the value amounts to about 0. 017 in., for light traffic about 0. 030 in. In contrast, for a 1-in. AC surface, these values are about 0. 040 in. for heavy and 0. 080 in. for light traffic.

At the AASHO Road Test, analysis of deflection data showed that a pavement having a spring deflection of 0. 020 in. would sustain over 6,000,000 applications of an 18,000-lb axle load before its condition dropped to a serviceability level of 2. 5. In contrast, a pavement having a deflection of 0. 060-in. at this time would support only about 200,000 applications before its serviceability dropped to the same level.

Huculak states: "Higher deflections are usually permissible on a lightly traveled highway as compared to a heavily traveled highway for the same magnitude of load." Also, "Some pavements are still in service with deflections as high as 0. 075 in. but carrying relatively low volume traffic." The influence of the temperature of AC surfaces is discussed in his report as follows: "Since the effect of lower temperatures is to render the bituminous surface more brittle, the pavement is more susceptible to detrimental cracking during the spring period when the surface layer cannot deform as readily without rupturing." On the overall question of permissible deflections, Huculak is of the opinion that those developed at the WASHO Road Test, 0. 035 in. for spring and 0. 050 in. for summer conditions, are realistic values for the environment in his areas (Alberta Province).

The problem is complicated because of the interrelated effects of temperature and thickness. It appears that as the temperature of an asphalt concrete decreases and its thickness increases, there would be an ever-decreasing attenuation in tolerable deflection. To a degree this viewpoint is supported by the California data (Zube and Forsyth), i. e., the tolerable deflection level of flexible pavements decreases as the thickness of the AC surfacing increases.

The report of the Canadian Good Roads Association comments on the subject of permissible deflections as follows:

> The performance and life of flexible pavements with rebound deflection values exceeding 0.05 in. is controlled largely by the wheel loads of the traffic. The life of such pavements which carry more than 1,000 vehicles per lane per day, including wheel loads ranging up to 9,000 lb, is drastically reduced as the rebound values exceed this critical value by relatively small amounts.

Also, it is recommended that flexible pavements which will have ADT volumes of 1,000 or more vehicles per lane, including 10 percent or more trucks and buses, within 10 yr after construction be designed for a maximum spring Benkelman beam rebound value of between 0. 030 and 0. 050 in. The choice of design rebound value within this range depends on the relative costs of initial construction and resurfacing.

Carneiro discusses the question of tolerable deflection in considerable detail, mentioning studies conducted by several investigations in Brazil and abroad, including those of the Road Research Laboratory in England; of D. A. Welsh, British Columbia, Canada; and those of Hveem in California before 1960. He cites the following values being used in Brazil at the present time—0. 020 in. for heavy, and 0. 028 in. for light traffic—and he implies that they are subject to revision as data are obtained from the extensive work program planned.

The paper of Schrivner, Swift, and Moore describes a unique device for producing and measuring dynamic deflections of a road surface. Since loads on pavements are essentially dynamic in character, it is more realistic to measure deflections under such loads than under standing or slowly moving loads. Certainly the device described is promising; and after more preliminary testing is done and more data are obtained, it should see considerable use in connection with problems of pavement design, performance, and rehabilitation.

This discussion has served to show that there is wide diversity of opinion existing at the present time on the question of tolerable deflection of flexible pavement and, to a lesser degree, on the ability of overlays to reduce deflection. For example, the Zube and Forsyth paper is the only one presenting evidence of the need for reducing the tolerable level of deflection with increase in thickness of overlay. The factor of temperature of the overlay material and its possible marked effect on tolerable deflection is mentioned only by Huculak.

To say that a pavement of the flexible type has a given level of tolerable deflection has little meaning unless its performance for this level is defined. This is emphasized in the findings of the AASHO Road Test, i.e., at a high level of deflection a given pavement section could sustain only a relatively limited number of repetitions of the deflection before its condition deteriorates to the extent of needing rehabilitation; at a lower level of deflection a much greater number of repetitions could be sustained. Data reported by Zube and Forsyth agree with this finding.

Without reference to performance, this writer lists some tentative values of tolerable deflection for different intensities of traffic. Obviously, as data are accumulated it may be possible to relate such values to performances; to put the method of pavement rehabilitation on a firm basis by the use of deflection data, this will be necessary.

There is reasonable agreement among investigators regarding the ability of asphalt concrete overlays to reduce deflection. Data in the California and Brazil papers and those of the AASHO Road Test indicate that 3 in. of the material would reduce the deflection about 14 percent per inch; data in the report of the Canadian Good Roads Association suggest a somewhat lesser contribution for this thickness, about 9 percent. More factual data are also needed on this item; the temperature of the material is obviously one of importance.

In light of this discussion, the following values are offered merely as guidelines for those who may be contemplating the use of deflection data in pavement rehabilitation work. For deflections under 18,000-lb axle load, a tolerable value for light traffic would be 0.060 in., for moderate traffic 0.045 in., and for heavy traffic, 0.030 in. deflection reduction afforded by AC overlay: for a thickness of 1 to 2 in., 20 percent per inch; for a thickness of 2 to 4 in., 15 percent per inch; for a thickness of 4 to 6 in., 10 percent per inch.

For those who expect to continue handling the problem of pavement rehabilitation on the basis of judgment and experience, the following material may prove of interest.

Existing Pavement Condition Category	Method of Treatment
Acceptable riding qualities; minor evidence of structural weakness; some perceptible rutting and some surface cracking.	Thin AC overlay
Acceptable riding qualities; marked evidence of structural weakness; excessive rutting and surface cracking.	3 to 5-in. AC overlay
Inferior riding qualities; minor evidence of structural weakness; some perceptible rutting and some surface cracking.	Leveling course, thin AC overlay
Inferior riding qualities; marked evidence of structural weakness; excessive rutting and surface cracking.	Leveling course, 3 to 5-in. AC overlay
Inferior riding qualities; no evidence of structural weakness.	Leveling course plus thin AC overlay

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•ONLY ONE paper mentioned the measurement of radius of curvature of the deflected surface. This may be measured with reasonable accuracy by means of a very simple and inexpensive device known as a curvature meter which originated in South Africa and is described in Highway Research News No. 19.

Measurements of both rebound deflection and curvature were recently made on 57 projects in Virginia. Correlation between the two indicates that rebound deflection could be estimated from curvature measurements with a standard error of approximately 0. 007 in. The uncertainty is greatest on the stiffer pavements of the black-base type where high deflections may be obtained even though curvature values are low. Correlation is much better on the 40 nonblack-base sections where a standard error of only 0. 005 in. was computed.

The paper by Scrivner, Swift, and Moore indicates correlation with a standard deviation of approximately 0. 007 in. between Dynaflect values and deflections on a variety of pavements. Accuracy might be improved by making separate analyses for specific base types such as untreated crushed stone, asphaltic-concrete, cement-treated aggregate. Although the Dynaflect is certainly a much more costly instrument than the curvature meter, it apparently is more rapid and does not require a heavily loaded truck. Its development should be watched with considerable interest by pavement evaluators.