EFFECT OF SURFACE IRREGULARITIES ON THE RIDING QUALITIES OF HIGH TYPE PAVEMENTS

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The ultimate purpose of any highway organization is to produce accessible routes by which motorists can travel from one point to another in their daily pursuits. From the early wagon trails, roads have developed to the modern high-speed highways, requiring a vast industry of technically trained people to design, construct, and maintain them. The average citizen does not always comprehend the problems confronted by the highway builders, nor does he always appreciate the "behind the scenes" work required to produce the highways. He is naturally limited to a few basic means of judging this work, and to about the same extent is able to judge the over-all qualities of a highway.

On the average, a motorist probably judges a road in this way:
First, the road is straight or crooked
Second, the road is wide or narrow
Third, the road is rough or smooth.

Beyond this he will have some definite impression as to whether he has ample and safe opportunities to pass; whether there are signs or other traffic control devices to mark the way; whether the road presents a pleasing appearance; and perhaps whether the road is generally congested. Certainly the structural soundness of the road, which has long been the main concern of the highway builders, will not register with him at all unless a failure has occurred. We all know what his reaction will be in that case.

As a result of years of effort and experience, the highways have advanced to the point where structural stability is largely assured within the limits of loading for which the roads were designed. Also, modern standards for width, grade and alignment have solved the problems of the crooked, narrow road with limited sight distances. Of course, all roads of this description have not been eliminated, but all of us, including the driving public, realize that we know how. Traffic control devices have been brought up to the level where a driver can be safe if he will. Roads have been given esthetic value by roadside
planting for erosion control, roadside parks, and even by graceful designs for bridges and other structures. Very recently emphasis has been placed on the problem of congestion with the resulting super highway, expressway, limited access way, or what have you.

The one thing which seems to have received the least specific attention is the roughness or riding quality of the road. Certainly it has received the least attention from the standpoint of reliable means for measuring roughness or evaluating riding qualities. Such means that are in existence are crude to say the least.

When it is said that a road is rough, it is generally implied that the passengers in a vehicle sense a high degree of discomfort resulting from up-and-down or side-to-side motion. This motion generally speaking, should have some relation to the amount of irregularity in the pavement; assuming, of course, that the car itself is not faulty. Even so, a large number of variables exist with regard to the vehicle concerned such as, the length of chassis; the type and size of tire; the weight of the vehicle, and the suspension. A certain amount of the roughness in a pavement can be essentially overcome by controlling the vehicle speed. Probably most of you have "smoothed out" the bumps in a very rough road by accelerating.

Unless you have had occasion to analyze it, you may not be aware of the fact that side-to-side motion is more objectionable to you than up-and-down motion. As a matter of fact, experiments conducted at Purdue University more than fifteen years ago showed that the average person feels about 13 times as much discomfort from transverse horizontal motion as he does from vertical motion of equal force and magnitude. Also, this side-to-side motion is about twice as discomforting as longitudinal horizontal motion. These experiments were conducted with several hundred individuals as samples and over a long period of time, so they were undoubtedly exhaustive in more than one sense.

Obviously road roughness has importance in ways other than riding comfort. Viewed from the standpoint of impact loads there must be some deterioration in a pavement itself resulting from irregularities and roughness. More important is the fact that irregularities can become progressively greater through displacements under impact loads. If the irregularities become great enough and occur in certain places, they do, as you know, become hazardous particularly to cars traveling at high speed. But despite all these, in the roads being built to today's

(*Jacklin, H. M. and Liddell, G. J., "Riding Comfort Analysis", Purdue University Engineering Experiment Station Bulletin No. 44, 1933.)
high standards, riding comfort should probably be the chief concern of the builder insofar as surface irregularities go.

Over a period of time specification tolerances for road surfaces have been developed with a view toward controlling irregularities. Presumably these were based as much on the requirements for good riding qualities as they were on requirements for the lasting qualities of the road itself.

However, the factual data by which the tolerances were established is not exactly clear and there is no concrete evidence that the tolerances themselves assure good riding qualities. As a matter of fact, there is evidence that they have not assured good riding qualities even though they are a necessary factor in providing good pavement surfaces. Nevertheless, we do have these provisions in our specifications and we do have or should have means for determining whether the specifications are being met.

In Figure 1, there is shown a type of straight edge with which many of you are familiar and one that has been applied to measurements on cement concrete pavement surfaces for a long period of time. The specification requirement here and in practically all states is such that the surface irregularity cannot be greater than \( \frac{1}{8} \) inch measured over distance of 10 feet longitudinally. The specification further provides that if the surface does exceed this tolerance the high spot shall be ground down either by rubbing with a carborundum brick if that is sufficient or by means of a grinding machine after the concrete has become 28 days old. Personally, I have never seen conclusive evidence that an irregularity greater than \( \frac{1}{8} \) inch in a 10-foot distance will produce unsatisfactory riding qualities, or for that matter, that satisfactory riding qualities can be obtained by keeping the irregularity at \( \frac{1}{8} \) inch or slightly less.

Figure 2 shows a type of straight edge that has found widespread use on high-type bituminous pavement construction in many sections of the country. Here the base plane from which the measurements are made is formed by the points of contact between the wheels and the pavement surface. Once again the irregularities are measured over a 10-foot distance. Taking the Class I construction as an example of Kentucky specification requirements that have been in use for a number of years (according to the 1945 Book of Standards), the tolerance was 1/16 inch per foot for base or binder courses, as measured from the nearest point of contact. For surface courses, the permissible variation was \( \frac{1}{8} \) inch per 10 foot distance. At best, the specifications were stated in such a way that they were ambiguous, and this largely accounted

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for a study of surface tolerances and resulting roughness factors by the Highway Materials Research Laboratory at the University during the past Fall.

The investigation was made at the suggestion of the Engineer of Specifications and the Division of Construction. The device which you see in this illustration is one of the type used for this study. In this instance the scratch bolts set at the quarter points were the means by which excessive irregularities in the pavement surfaces were located. These bolts could be adjusted for depth of setting to fit any tolerance, and wherever the bolts scratched, the pavement surface exceeded this tolerance. About 55 miles of bituminous pavement (mostly Class I) were measured with this device during that investigation.

In order to better evaluate the magnitude of the irregularities, a system of levers was devised to magnify the pavement surface irregularities on a graduated arc. This device was termed a Deviometer Attachment for the Roller Straightedge. The Straightedge with this attachment in place is shown in Figure 3. By the use of this device any irregularity on the surface was transmitted through the lever system and magnified to such an extent that the displacement on the arc scale was 7 times the actual displacement on the road. This, of course, facilitated the taking of more accurate measurements.

The whole intent of the investigation was to find out not only the number and extent of surface irregularities, but also to find out what these measurements meant in terms of roughness; or better still, riding qualities. Also, it was intended to show whether specification tolerances as they existed were reasonable; whether they could actually be followed to the smallest fraction of an inch during construction; and whether revision was necessary in order to make them practical. The over-all viewpoint was constantly directed toward riding qualities on the assumption that this is the primary reason for establishing limits on irregularities.

In Figure 4 there is shown a device for measuring pavement roughness which was developed some eight or ten years ago by the Bureau of Public Roads. Without going into detail it is sufficient to say that the recording mechanism on this device adds up the amount of vertical displacements of the wheel as it bounces over the pavement, and the final expression is given in terms of inches of roughness per mile of road. This apparatus, although of Public Roads design, was acquired from the Virginia Department of Highways on a temporary basis and was operated over almost 200 miles of pavements of all types and ages in Kentucky. Roughness values ranged from a low of 90 inches per
mile on a bituminous resurfaced concrete pavement to a high of 216 inches per mile on a road-mix project. Although Virginia and others have established general ratings for roads in accordance with recorded inches of roughness, it was necessary for us to analyze these results and determine what they meant in terms of riding qualities.

To do this the pavements were rated by passengers in vehicles passing over the roads. This was crude, of course, but nevertheless it had some logical foundation since riding qualities are factors of human evaluation. At any rate, it soon became apparent that single-wheeled equipment of this type passing over a pavement in one limited path could not possibly measure all of the factors that determine the roughness of a road as a persons senses it. The forces set up laterally as well as vertically enter into this – as illustrated by the Purdue experiments – and the single-wheeled roughometer measures only vertical displacements. To a person designing and building the road it becomes necessary to consider factors by which sway is created, and if it is created how to eliminate it. That again carries back to construction practices and specification requirements.

Beginning with the finished elevations on a grading project, or with the ultimate sub-grade as it were, there are logically three factors which controlled in combination would provide a smooth-riding road. First, all of the elements must be kept to the prescribed grade constantly, and in some types of construction this is done by setting forms or edge boards to grade by means of a level and rod. Even with the grade controlled at the edges, irregularities that produce side sway can enter unless the transverse section as designed is actually maintained. This means not only a uniform section, but also a section that is measured from an unchanging base or datum. Figure 5 illustrates base course construction for which there appears to be no reliable datum from which cross-sectioned control can be exercised. In contrast, Figure 6 shows the operation of a template resting on a firm foundation at subgrade elevation or some constant distance above it. Here the template is being used to determine the surface of a water-bound base course which will be topped with bituminous concrete.

With the base course established and controlled in this manner, and with modern methods of spreading the bituminous mix, there is only one remaining way in which the pavement can become rough – through local surface irregularities. That is where the Roller Straight-edge, or some other means of checking surface tolerance, comes into play. If the local irregularities become too great and they are detected early enough, added rolling would probably iron them out. In case
they are not detected early enough to be corrected by additional rolling, them obviously it will be necessary to resort to some other means for obtaining the desired surface characteristics.

Having controlled all these features, we theoretically have eliminated all of the principal factors of road roughness. Only such things as degree of curvature, super elevation and other features of geometric design in the road could introduce undesirable riding qualities. These, of course, constitute a problem within themselves. But even with all of these things controlled we still haven’t found a way of measuring riding qualities as a passenger senses them when he passes over a road in a car. That is one of the things which is now under investigation by the Research Laboratory. Only when we have a device that will measure in some way the amount of force set up in all of the three principal directions, and will measure all of them in combination, will we actually have authentic means for registering the passenger’s feelings. Theoretically this can be accomplished and we have confidence that it will be.

Viewed from the standpoint of all things that enter into the building of a road, good riding qualities appear unimportant. For years they have been just that, there being so many more pressing needs. Many of these needs are still with us and will continue to be for a long period of time. But the new roads will be with us for a long time too, and it is incumbent upon us to make them serviceable and satisfactory for the future as well as the present.

The future work, whether it be new construction, relocation or old roads, or resurfacing of existing pavements, should include a means of controlling these roughness features. The Research Laboratory will continue in its search for information and a way that will help those designing and building the roads to obtain better riding qualities.