Experience with a BPR-Type Roadometer In Illinois

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The Illinois Division of Highways in 1957 constructed a road roughness indicator ("roadometer") patterned after the device introduced by the Bureau of Public Roads in 1941. Numerous modifications were made in adapting the device for use in Illinois. After an extensive series of tests, the Illinois instrument was placed in regular service recording the smoothness of new and old pavements beginning in 1959. The recently developed use of road roughness indicators in furnishing measurements that assist in estimating the present serviceability of pavement under the concept originating at the AASHO Road Test has greatly enhanced the value of these devices. This paper describes the various modifications made by Illinois in constructing its "roadometer," tests to which it has been subjected, and its use in rating Illinois pavements under the present serviceability concept following correlation of the device with the AASHO Road Test profilometer.

• IT IS ONLY natural that the emphasis the traveling public places on the riding quality of pavements has caused the highway engineer to search diligently for a means for making objective measurements and evaluations of this riding quality. The search has led to the development of a considerable number of measuring devices, all directed at the same objective of determining the surface smoothness of pavements, but differing widely in principle and detail.

The prototype of what has come to be the most widely used device today was developed in 1940 by the Bureau of Public Roads. Various names have been applied to this piece of equipment including road roughness indicator, roughometer, and roadometer.

The BPR-type device is basically a single-wheel trailer that is towed along the highway. The wheel is linked to the trailer by two single-leaf springs. The frame of the device is constructed of standard steel channels and has a rectangular shape. The wheel is mounted centrally in the frame, and the frame is weighted so that, if it were suspended from the towing vehicle hitch as a pendulum, the center of percussion would be in the plane of the axle. Two damping units help control the movement of the wheel with respect to the frame.

All of the foregoing construction is subject to standardization so that measurements made by various agencies operating the devices can be correlated.

As the device is towed along the pavement, irregularities in the pavement surface cause a differential vertical movement of the wheel with respect to the frame. This movement is transmitted by a wire cable to a double-acting ball-clutch integrator which converts the upward vertical motion to unidirectional rotary motion. This rotary motion is what is recorded to determine riding quality. Accuracy of the integrator is all important in the successful operation of the roadometer.

The roadometer operates on the fundamental principle that vertical oscillations of the wheel with reference to the chassis are indicative of the riding quality of a pavement. The device has proven to be reasonably sturdy and not difficult to use. Experience with reproducibility characteristics has been varied, but on the whole reasonably good. An important feature of the device is the speed at which it is operated; 20 mph, as com-

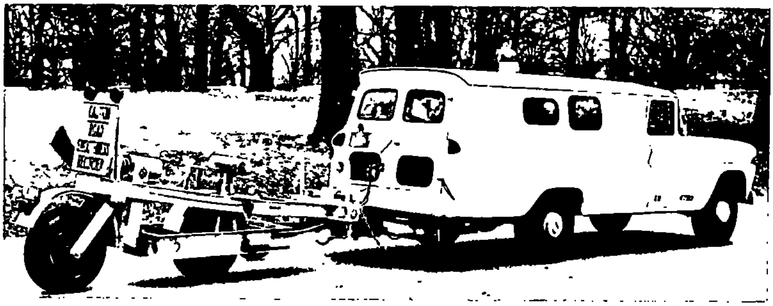

Figure 1. Over-all rear view of Illinois Division of Highways roadometer, outrigger trailer and van.

pared with the 3 to 5 mph of many other devices. This is believed advantageous for safety when operation in the regular traffic stream becomes necessary.

The Illinois Division of Highways operates two roadometers. Both have the basic features recorded in plans furnished by the Bureau of Public Roads. These features are those which were reported by J.A. Buchanan and A.L. Catudel in 1941. Although the basic details have been retained, numerous modifications have been made in both devices.

The first device placed in service by Illinois was constructed by the Division's personnel; the second, only recently acquired, was purchased already constructed. The following comments on construction and calibration details apply only to the device built by Illinois.

ILLINOIS MODIFICATIONS OF ROADOMETER

The device constructed by Illinois was built in 1956 and first placed in service in 1957. In constructing the Illinois device, advantage was taken of certain modifications developed by the highway departments in California, Minnesota, and Missouri. Among these were the addition of profile and cumulative potentiometers to the integration system so that the roughness profile and also the accumulated roughness could be recorded on an oscillograph tape. A two-channel oscillograph as proposed by California is used in making the recordings. A multi-tapped, low-voltage, high-current, dc-power supply having the vehicle battery as its source is used to operate the oscillograph in place of dry cells that have been used by others.

Printing counters are used on the Illinois device to record counts under conditions where the details furnished by the oscillograph records are not needed.

Stepping switches activated by the revolving roadometer wheel are used to actuate automatically the recording equipment on the Illinois device to record inches of roughness at the end of each mile of travel on long runs. These switches cause the oscillograph pens to reverse at the end of each mile of travel, with each of the two recording pens serving in alternate miles as cumulative recording pens and profile recording pens. The switches also cause the recording counters to print out the measured number of inches of roughness as each mile of travel is completed.

Minor modifications include the use of open-type ball bearings with grease cap and shield to replace the double-shielded bearings, and the use of universal joints instead of ball socket joints on the damper units as shown on the Bureau of Public Roads plans.

A major innovation developed by the Illinois Division of Highways is a single-wheel outrigger carrier trailer which eliminates the necessity for carrying the device in the towing vehicle when not in use.

The roadometer travels within the outrigger trailer, and is connected to the trailer by the standardized roadometer trailer hitch. The outrigger trailer is connected to the towing vehicle by a special hitch in which a transverse lead screw extending across a specially designed bumper on the vehicle allows the device to be moved to either wheelpath of the traffic lane by the turn of a crank.

Figure 2. Close-up view of Illinois Division of Highways roadometer and outrigger trailer and van.

The outrigger trailer has an over-all width of about 33 in. and does not interfere with other traffic while the device is recording in the wheelpath positions. A cable hitch is used to raise the roadometer free of the pavement for travel when not in use and for storage. Raising or lowering of the device can be done in a few seconds.

Figures 1, 2 and 3 show the Illinois Roadometer.

ACCURACY OF RESULTS

The Illinois device, from the beginning, has shown good reproducibility of results. Static calibrations, and field calibrations over measured lengths of pavement, have shown little deviation that could be attributed to changes in the recording characteristics of the equipment.

Static calibrations of the Illinois device made by the usually accepted procedures on an average of about once every six weeks while the roadometer is in service have shown no important changes in response of the device. Deviations from theoretical values have usually been less than 2 percent and in only one instance reached 10 percent.

The Illinois device is calibrated dynamically on a 1-mi section of rigid pavement constructed over 25 years ago. This pavement once served a high volume of traffic, but has been used only as a local road serving a few vehicles per day during the period in which it has been used for calibration purposes. During the four years of calibrating the Illinois device on an average of about once a month, roughness index values have been found to range between 106 and 116 in. per mi except in a few isolated instances. No permanent increase or decrease in readings during the four-year calibration period has been discernible.

Reading has also been repeated at less frequent intervals on other pavements of varying roughness, from very smooth to very rough, without important changes in the recorded values.

The reliability of the Illinois device is believed to be due to several factors. One of the most important is believed to be the protection that is given the equipment when not in actual operation. The outrigger carrier trailer system has been designed in such a way that the roadometer can be raised easily from the pavement and supported by the trailer when not in use. There is little reason for a careless operator to tow the recording device over rough pavements at high speeds, causing excessive wear and even damage to the relatively delicate mechanism.

Keeping the device suspended during periods of storage also removes the tendency toward the forming of flat spots on the tire. Several agencies have noted that flat spots will cause erratic readings.

Figure 3. Interior view showing instrumentation in Illinois Division of Highways roadometer van.

A frequent source of trouble recognized by users of the BPR-type roadometer is the mechanical integrator. Extreme care was used in the manufacture of the Illinois integrator, with all parts machined to the closest reasonable tolerances. Careful attention is given to ordinary maintenance of the integrator, and each winter it is completely disassembled, cleaned, and oiled. The behavior of the integrator is believed to be responsible in large measure for accuracy of results.

The entire roadometer is also cleaned and oiled each winter, the wiring is checked, and parts that show an indication of serious wear are replaced.

Breakdowns of the equipment have not been uncommon. These, however, do not cause concern as to the reliability of the results. The malfunctioning of the equipment is evident and false readings that would lead to erroneous analyses are not introduced. Components that have proved most troublesome have been the wheel revolution counters, the printing counters, and several of the relays in the system.

PRESENT SERVICEABILITY INDEX

The roadometer furnishes a record of the cumulative upward movement of a spring-mounted wheel and axle with respect to a frame, over a measured distance of travel. The vertical movement is measured in inches and the distance in miles. The resultant inches of vertical movement per mile of travel is termed the "roughness index." The roughness index, which is simply the inches of differential movement of a spring-mounted wheel with respect to its carrying frame, per mile of travel of the wheel, is an abstract number. In itself it tells nothing about the riding quality of a pavement. To be of value the roughness index must be related to highway user opinion of riding quality.

The problem of establishing a working relationship between the results of roadometer measurements and highway user opinion of pavement riding quality has been a difficult one, and a major reason for slow acceptance of the device. Fortunately, the need for developing a system of rating pavements of the AASHO Road Test led to what appears to be a significant step forward in the solution of this problem. This may prove to be one of the important by-products of the road test.

Under a pavement serviceability-performance concept developed on the AASHO Road Test project, a system was devised for rating any pavement's ability to serve the traveling public on a scale ranging from 0 to 5. The serviceability, as it is called, relates only to the time of rating. It is the average rating that would be applied to a pavement by highway users. It is the answer to the question of how well on this scale of 0 to 5 this pavement is able to serve high-speed, high-volume mixed passenger and truck traffic at this time.

Of primary significance in connection with the roadometer was a finding that the user rating of a pavement can be estimated closely from a series of physical measurements, including the measurement of wheelpath roughness. Other items found to influence rating significantly were cracking, patching, and rutting. Mathematical expressions involving these items have been developed to show the relationship between the ratings applied by rating items and the objective physical measurements. The estimate of the serviceability index obtained from the use of these mathematical expressions is called the "present serviceability index."

One such mathematical expression was developed for portland cement concrete pavements and another for bituminous concrete surfaces. Measured values of roughness, made with a BPR-type roadometer or other devices, together with measurements of cracking and patching, and of rutting in the case of bituminous surfaces, can be substituted in these equations to determine the serviceability index at any time.

The original mathematical expressions that were developed at the AASHO Road Test take into account the measurement of surface irregularities made by a profilometer which records variances in the longitudinal slope of pavements. A first step in using the Illinois roadometer in connection with determining the present serviceability index of pavements was its correlation with the AASHO device. This correlation furnished the following two equations for pavement serviceability based on the Illinois roadometer results:

Portland Cement Concrete (Rigid) Pavement

$$PSI = 12.0 - 4.27 \log RI - 0.09 \sqrt{C+P}$$

in which

PSI = present serviceability index;
RI = roughness index (by Illinois roadometer);
C = lineal feet of crack per 1,000 sq ft of pavement surface; and
P = square feet of bituminous patching per 1,000 sq ft of pavement surface.

Bituminous Concrete (Flexible) Pavement

$$PSI = 10.91 - 3.90 \log RI - 0.01\sqrt{C+P} - 1.38D^2$$

in which

PSI = present serviceability index,
RI = roughness index (by Illinois roadometer);
C = square feet of cracked area per 1,000 sq ft of pavement surface;
P = square feet of patching per 1,000 sq ft of pavement surface; and
D = average rut depth in inches at deepest part of rut.

The development of the present serviceability concept has enhanced greatly the value of the various devices used to determine the riding quality of pavements, including the BPR-type roadometer. As discussed later, it has provided a means for establishing a working relationship between roadometer measurements and highway user opinion.

The importance of the present serviceability concept should not be underestimated. This concept offers the engineer, for the first time, a good possibility for designing a pavement to be so constructed that it will carry a specified number of load applications until some predetermined terminal serviceability index is reached.

Also through the use of this concept, there is the possibility that the engineer can rate existing pavements presently in service and predict with reasonable accuracy the number of axle loadings that may be carried in the future before some predetermined terminal serviceability index is reached.

Knowledge of the serviceability level at which it is desirable to reconstruct or resurface pavements (terminal serviceability) is necessary for applying the present serviceability concept in design and in assessing the remaining useful life of pavements. To provide this information, the Illinois Division of Highways is currently engaged in making an intensive study of pavements scheduled for retirement. Roughness recordings are being made in all parts of the State on pavements scheduled for reconstruction or resurfacing because of structural inadequacies. Surveys of patching and cracking (and rutting of bituminous surfaces) are being made in conjunction with the roadometer studies to provide values for substitution in the terms of present serviceability equations.

Preliminary results of the roadometer and other measurements on pavement scheduled for retirement in Illinois because of structural inadequacies have been encouraging in that they have yielded reasonable values of the terminal serviceability index. Values thus far have ranged from about 2.5 to less than 1.0. The lower values of the terminal serviceability index have been found to be consistently associated with pavements carrying a relatively small volume of traffic. High-volume pavements are more frequently retired at the higher index values. This phase of the study is not complete and is continuing.

ADJECTIVE RATINGS OF PAVEMENT RIDING QUALITY

A second important application of the present serviceability concept has been the establishment of a working relation between roadometer measurements and highway user opinion. Heretofore, the usefulness of the roadometer has been somewhat limited because of the lack of knowledge concerning this relationship.

In the assessment of highway user opinion that led to the development of the mathematical expressions under the present serviceability concept, adjective descriptions of user opinion were applied to various ranges of the rating scale of 0 to 5. The removal of the terms of the present serviceability equation relating to cracking, patching, and rutting allows a determination of the influence of the roughness index alone on the present serviceability index. For the Illinois roadometer, this provided the following group descriptions:

AASHO Present Serviceability Rating		Illinois Roadometer Roughness Index		
Numerical	Adjective	Rigid Pavement (in./mi)	Flexible Pavement (in./mi)	Adjective Rating
5		45	35	-
	Very good			Very smooth
4		75	60	
	Good	90	75	Smooth
3		125	105	Slightly rough
	Fair	170	145	Rough
2		220	190	Very rough
	Poor			Unsatisfactory
1		375	330	
0	Very poor			-

The adjective ratings at the right of the preceding table are being applied tentatively by Illinois to further subdivide the groupings established by use of the present serviceability equations.

In the table, the response of the device to irregularities in portland cement concrete and bituminous concrete surfaces is apparently somewhat different.

Roughness indices have been determined in Illinois for many hundreds of miles of portland cement concrete pavements and bituminous concrete resurfacings. The roughness indices have covered a sufficient range to indicate beyond doubt that they are truly definitive of the riding quality of pavement surfaces. Of considerable significance from a correlative standpoint has been the fact that the isolated complaints that have been received about the riding condition of new pavements invariably have concerned pavements that recordings have shown to be rough. Fortunately, the mileage of such pavement has been small.