ROBERT HUMPHREYS
COMMISSIONER OF HIGHWAYS

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

November 27, 1956

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

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P. 4. 1.

MEMO TO: D. V. Terrell
Director of Research

For the past several years the Research Division has been actively engaged in the development and useful application of equipment for measuring and recording the riding qualities of pavements. From the beginning this effort has stood in contrast to the ordinary procedures for measuring and expressing pavement roughness, as typified by the suspended single-wheel device that has gradually achieved widespread use.

Not only is our approach realistic in that it involves a standard vehicle and the combined effects of four wheels in contact with the pavement simultaneously but also the elements of motion recorded are amenable to fundamental analysis of human comfort. This has been done on the premise that the real need in this respect is measurement and evaluation of the effect of road surface characteristics on the comfort of passengers, and not the measurement of localized irregularities in the surface itself. There are methods for measuring the localized irregularities, but it has been found that even when accurate measurements are made and control limits applied in construction (1/8-inch deviation from a plane surface over a 16-foot distance, for example), the riding quality of the pavement can still be poor.

When our last report on this subject was made in January, 1955, we recognized some deficiencies in the equipment and the cumbersome procedures for taking data from the charts. Since that time additions and revisions to the device, in the form of a so-called "jerk pickup", have improved the technique considerably. Still more improvement in the equipment, from the standpoint of accuracy and expediting the results, could be brought about by the addition of integrators to combine readings from the three principal directions into a single value of discomfort. The high cost of integrators has kept this matter in abeyance. Even so, I believe that now it will be possible to make very effective rating of relative riding qualities with confidence; consequently the equipment could be used in a standard way to evaluate the riding qualities of different types of pavement after each construction season, and changes in riding qualities with the passage of time after each pavement is in use. These more-or-less routine applications could be supplemented with studies for sufficiency ratings of pavements now in service, and similar applications of a research nature.

You will note that the data tabulated in the Appendix of the attached report, having been accummulated with the original instrumentation and method of analysis, are regarded as too much subject to human error to represent absolute ratings of the riding qualities of the several roads. However, they are valuable indicators of the wide differences in characteristics of the pavements, and suggest locations where attention to improved surface contour is highly desirable in case resurfacing or other operations are contemplated. For example, blade spreading of binder courses or other tried and verified methods of improvement may need consideration in some instances.

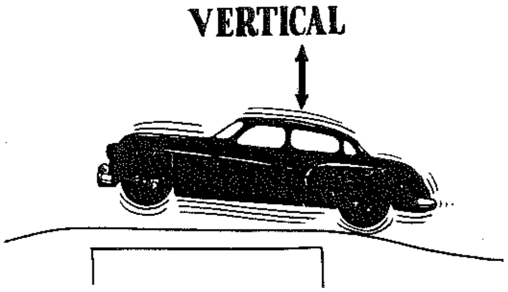
As a final feature of this report, we have included a brief account of tests comparing our equipment, the California profilograph, and the Missoui version of the BPR single wheel bumpometer on a construction project in Missouri. There is no direct basis for comparison among the three devices since they actually measure different things; nevertheless the comparison is interesting and undoubtedly it will have a bearing on further developments in this field. As a result of these tests and earlier correspondence, the California Division of Highways has built equipment for measuring riding qualities, modeled after the improved version of our device.

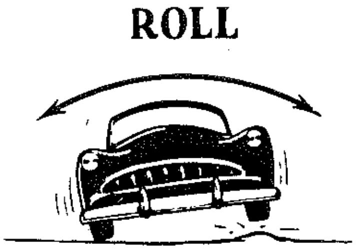
Respectfully submitted,

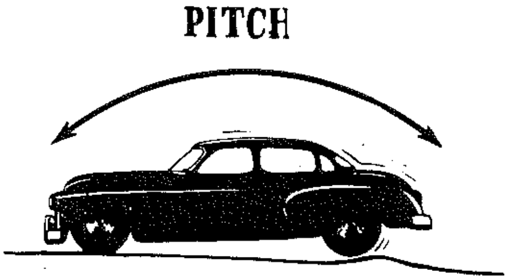
L. E. Gregg
Assistant Director of Research

LEG:dl
Enc.
Copies to: Research Committee
J. C. Cobb (3)

Commonwealth of Kentucky
Department of Highways







# ANALYSIS OF PAVEMENT RIDING QUALITY

## A Triaxial Evaluation of Pavement Roughness

By William S. Foy
Research Engineer

Highway Materials Research Laboratory
Lexington, Kentucky
November, 1956

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# INTRODUCTION

For the last twenty-five years considerable research has been directed toward developing reliable equipment for evaluating pavement roughness. Since roughness inhibits passenger riding comfort and safety, as well as inducing vehicle deterioration, the determination of the features that cause roughness would indicate possible improvements in pavement design, materials, construction practices and equipment. For example, certain types of base design might be found to produce smoother surfaces than others; and a construction practice such as a blade-spread leveling course might result in more uniform pavements. Then too, evaluation of pavement roughness would permit relative comparison of pavements as one of several factors in determining the most needed of possible improvements, with the normally limited finances available. This could appear in a tabulation of sufficiency ratings such as those used by the Kentucky Department of Highways.

It is also conceivable that the equipment, when fully developed and proven, would be used to evaluate newly constructed pavements as a means of detecting and verifying substandard construction. Should this happen, greater assurance of smoother pavements would be provided - either as the result of a spontaneous increase in effort or from a requirement governing roughness incorporated into the specifications.

With these considerations in mind, the Division of Research initiated a project to develop the necessary instruments for measuring pavement roughness with respect to riding quality. Extensive library research revealed some of the demands expected to be met by such equipment. First, it must be portable enough to be mounted and operated in a moving passenger vehicle while remaining sufficiently sensitive to measure and record accurately the riding vibrations experienced. Then it must be capable of measuring roughness completely - which means measurement of vibrations from all directions. The most feasible way of accomplishing this is to utilize instruments triaxially sensitive to vibratory motions. With such equipment a vibration sensitive element is mounted on each of three mutually perpendicular axes in order to record components of vibration in the transverse, vertical, and longitudinal directions - "bounce," "roll", and "pitch" respectively - enabling the evaluation of any and all vibratory motions.

The most common method of evaluating vibrations uses either displacement, velocity, acceleration, or jerk as a direct function of vibration. Although each of these characteristics is a different expression of vibratory motion, they are interrelated by the frequency of the vibration. Thus, if any one of these functions is measured, it is theoretically possible to calculate the others from the known value, the waveform, and the vibrational frequency. Jerk sensitive elements are feasible and desired but satisfactory ones have not yet been found. However, jerk may be obtained by recording acceleration and measuring the rate of change of acceleration with respect to time. This is the method in use at this time, although satisfactory jerk pickups may eventually be found.

The acceleration sensitive elements are attached to a passenger by suspending them from his neck, thereby measuring the vibratory motions of his body. This permits evaluation of the pavement by analyzing the motions of the passenger's body transmitted from the pavement by the vehicle.

The initial report (1)* on this study, describing the fundamental relationships of riding comfort and equipment used in acquiring data, was presented at the 34th annual meetisg of the Highway Research Board in January, 1955, and copies were distributed to the Research Committee of the Kentucky Department of Highways. The method of analysis developed at that time has since been revised and expanded, but certain characteristics inherent in the method require still further revisions.

Although the present equipment functions quite satisfactorily, additional instruments must be utilized in order to reliably perform the analysis. These instruments would automatically analyze riding quality as the vehicle is being driven down the pavement and the record being taken. As a result, human errors involved in the manual procedure used at present would be eliminated. Accuracy and reliability would be

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* Numbers in parentheses refer to the list of references at the back of this report.

improved and valid comparisons of pavements would be made possible. The discrepancies due to the human error involved at present are exceedingly large, preventing any significant comparisons among pavements, or even among groups of pavements.

Although it is recognized that the riding quality values determined by the present method of analysis may be quite incorrect, the tabulated results from analysis of 156 pavements in Kentucky are presented in the Appendix. These evaluations are included in this report to illustrate the ability of the existing equipment and the severe limitations inherent in the method of analysis. The data are not to be used for comparison of pavements or any features thereof; it is presented mainly as a record that is of future value, and as a means of demonstrating the type of information which will be available when complimentary instruments are added to allow accurate and reliable analysis. In addition, related research in the relative importance of motion in the three different directions is necessary before the method of analysis can be fully established.

## THE EVALUATION OF DISCOMFORT

In 1948, R. N. Janeway presented to the Society of Automotive Engineers an analysis (2) of data compiled in studies by several independent organizations. In this analysis Janeway derived comfort relationships between vibrational frequency and amplitude over a range of frequencies from one to 60 cycles per second. He found that this range should be divided into three groups, each with a unique means for evaluating discomfort. In the frequency range from 20 to 60 cycles per second, discomfort is directly proportional to the maximum vibrational velocity experienced. Thus within this range, discomfort or riding quality should be evaluated in terms of maximum velocity of the vibrations. In the range from six to 20 cycles per second, however, discomfort is best indicated by measurement of the maximum <u>acceleration</u> of the vibration, and from one to six cycles per second, in terms of the maximum <u>jerk</u> - jerk being the rate of change of acceleration, or the third derivative of displacement with respect to time, in a vibratory motion. Fig. 1 illustrates the three ranges as they appear in a plot of vibrational amplitude against frequency. The recommended limit is a segmented, calculated curve closely approximating the average results of the data represented by the systems of plotted points.

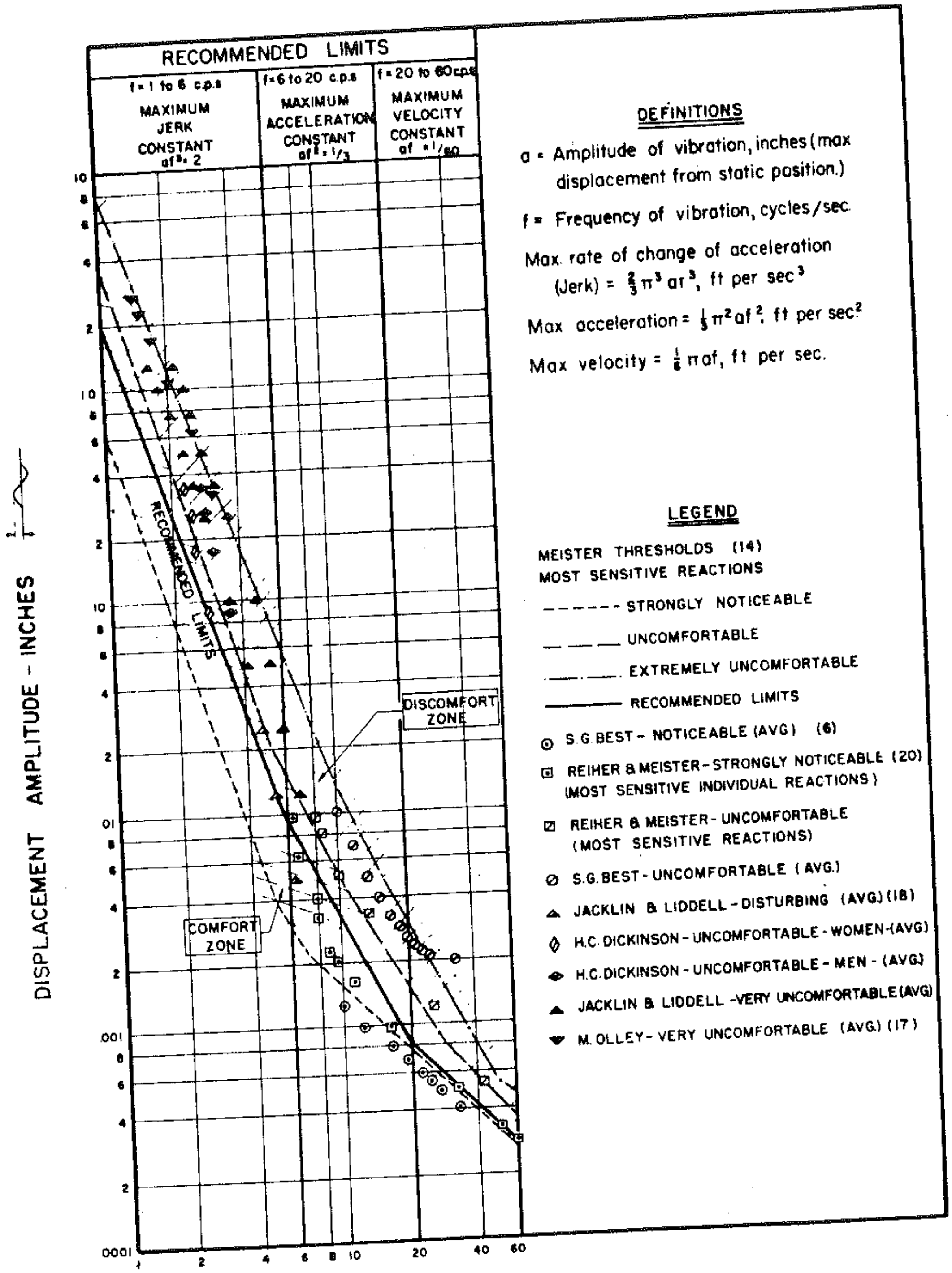


Fig. 1 - Human Reaction to Vertical Vibration
(From S.A.E.; "Ride and Vibration Data")

The necessity of calculating over three different ranges may be explained as the result of the damping of vibrations by the vehicle seat and the passenger himself. Uniform velocity can not be uncomfortable, as no unbalanced forces are present to cause vibration. And, under unvarying acceleration, the unbalanced force is constant and is not considered in this study as a factor producing discomfort. However, it may be fatiguing; as a passenger may not be able to withstand the continual added force. Finally, jerk, or change of acceleration, results in fluctuations of the unbalanced force and requires continual effort of the passenger to resist the vibrations. This occurs at the lowest frequencies, where very little of the vibration is damped. As the frequency increases a greater amount of energy is absorbed by the seat of the vehicle or by the passenger himself, altering the slope of the curve of Fig. 1. This necessitates other equations to correct for damping losses. Thus, in the low frequencies, measurement of jerk best indicates the severity of vibrations that produce discomfort; while at higher frequencies acceleration and velocity are the best mathematical evaluations of discomfort. It is fortunate that the riding vibrations resulting from pavement roughness occur at low frequencies within the jerk range, thus enabling a single method of evaluating pavement riding quality.

In addition to Janeway's report, taken from SAE Special Publication SP-6 (4), other studies have been considered. Fig. 2 compares the results of Janeway's data with those of E. F. Burton of the Douglas

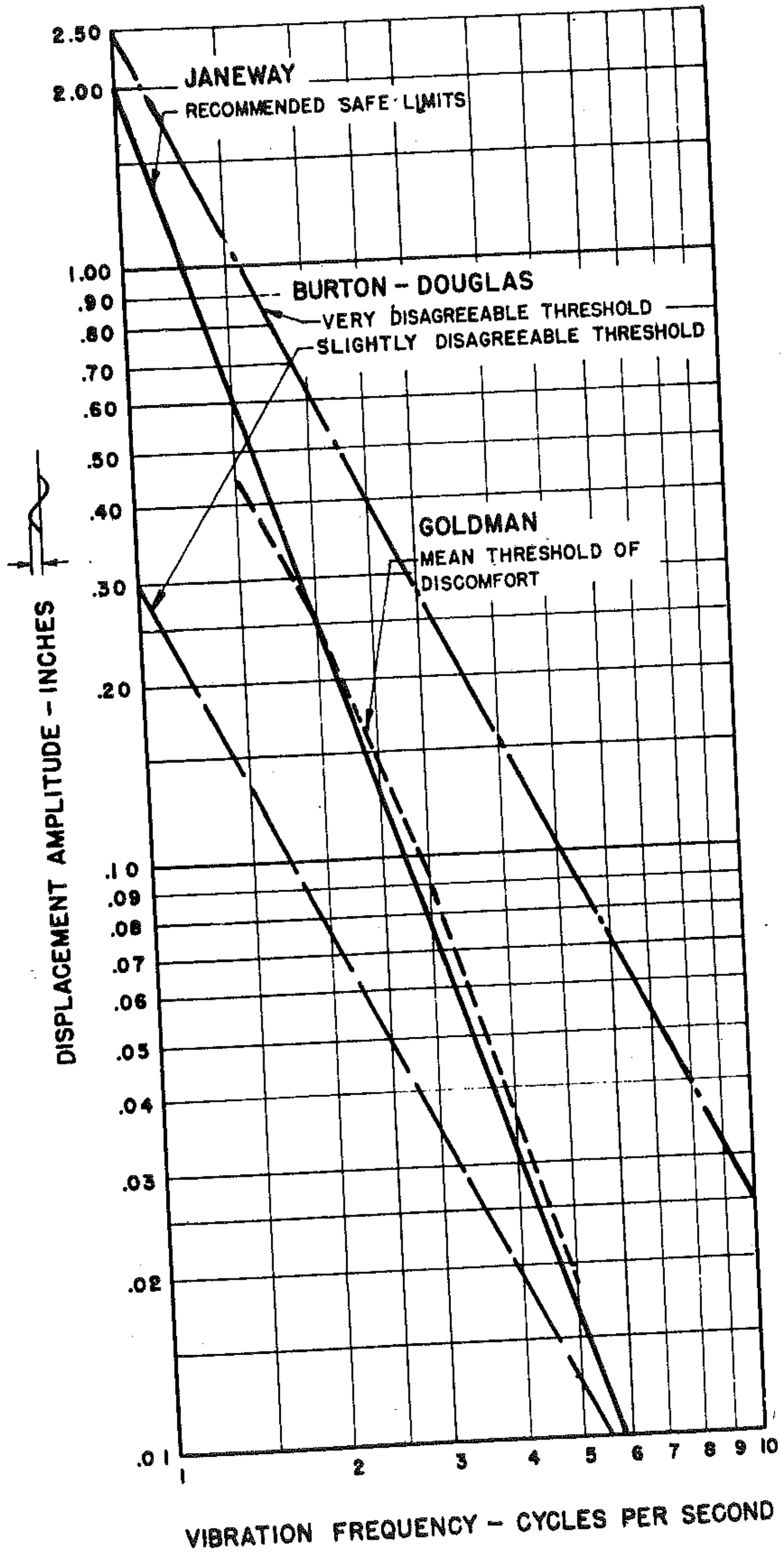


Fig. 2 - Comparison of Discomfort Thresholds at Low Frequencies (From S.A.E.; "Ride and Vibration Data")

Aircraft Co., and D. E. Goldman of the Naval Research Institute. Janeway's recommendations are devoted to automobile and railroad practices, while the Burton-Douglas limits concern aircraft. The broad biological basis in the matter is presented by Goldman. Note how closely Janeway's "Recommended Safe Limit" coincides with Goldman's "Mean Threshold of Discomfort". Note also that the frequency range of Fig. 2 is from one to ten cycles per second. Since most highway disturbances remain in this frequency range, this chart was particularly valuable in determining a method of analysis.

Janeway's Recommended Safe Limit represents a jerk of 41 ft. per sec.$^3$ as the point above which discomfort occurs. Since a certain portion of the vibratory motion is damped by the vehicle seat and the body of the passenger, for use in this study the comfortable limit has been reduced from Janeway's limit to one g per second, or 32.2 ft. per sec.$^3$ - one g being the acceleration due to gravity, 32.2 ft. per sec.$^2$.

As these limits are applicable to vibrations in the vertical directions only and no similar information is available for horizontal vibrations, the comfortable limits for the transverse and longitudinal components are estimated on the basis of inconclusive data. Jacklin and Liddell included some horizontal movement in their study (3) but not as extensively as the vertical. Their evidence indicates that a transverse or longitudinal disturbance may have to be only one-tenth that of a vertical one to cause equal discomfort. Experience, however, has shown that this ratio of ten-to-one is unsatisfactory for use in riding quality analysis and should be reduced to approximately five-to-one or less. This consideration is based on observations of the relative value of each vibratory direction on many sections of widely varying pavement conditions. As a result, the comfortable limit for the transverse and longitudinal directions has been, in this study, arbitrarily assigned a value of 0.5 g's per second; that is, of 16.1 ft. per $sec^3$.

## PROCEDURE OF ANALYSIS

As in the initial report, the vibratory disturbances are recorded by measuring the accelerations experienced. The type of record made is shown in Fig. 3, below.

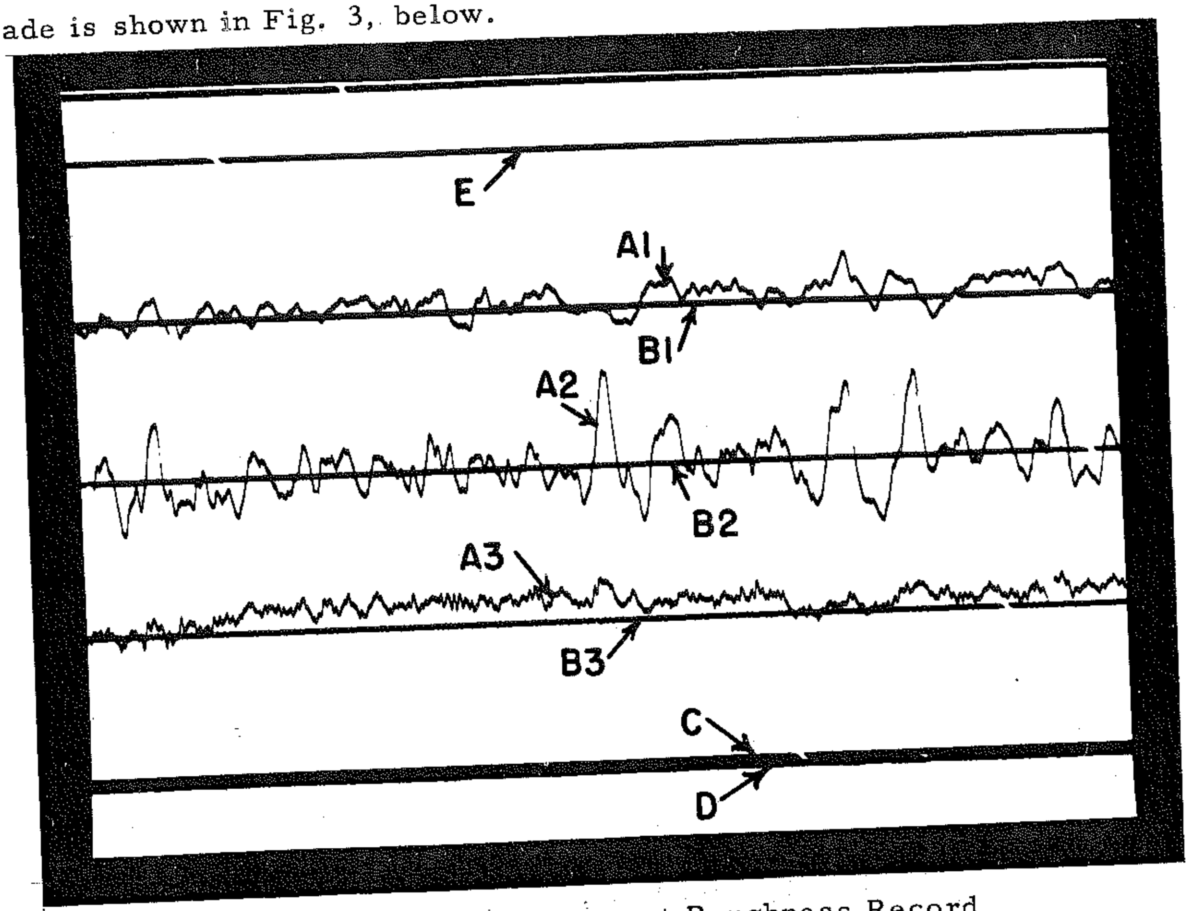


Fig. 3 - Typical Pavement Roughness Record

Code letters on the record indicate the following:

A. Acceleration traces
    1. Transverse
    2. Vertical
    3. Longitudinal

B. Zero acceleration traces
    1. Transverse
    2. Vertical
    3. Longitudinal

C. Tachometer trace for indicating vehicle speed

D. Battery voltage monitor to verify validity of records

E. Event marker to record beginning and end of test section and other pertinent events.

From these charts maximum jerk values must be obtained from the acceleration traces. Since jerk is the rate of change of acceleration, the maximum jerks are obtained from the maximum slopes of the acceleration traces. To accomplish this measurement the device shown in Fig. 4, below, was constructed.

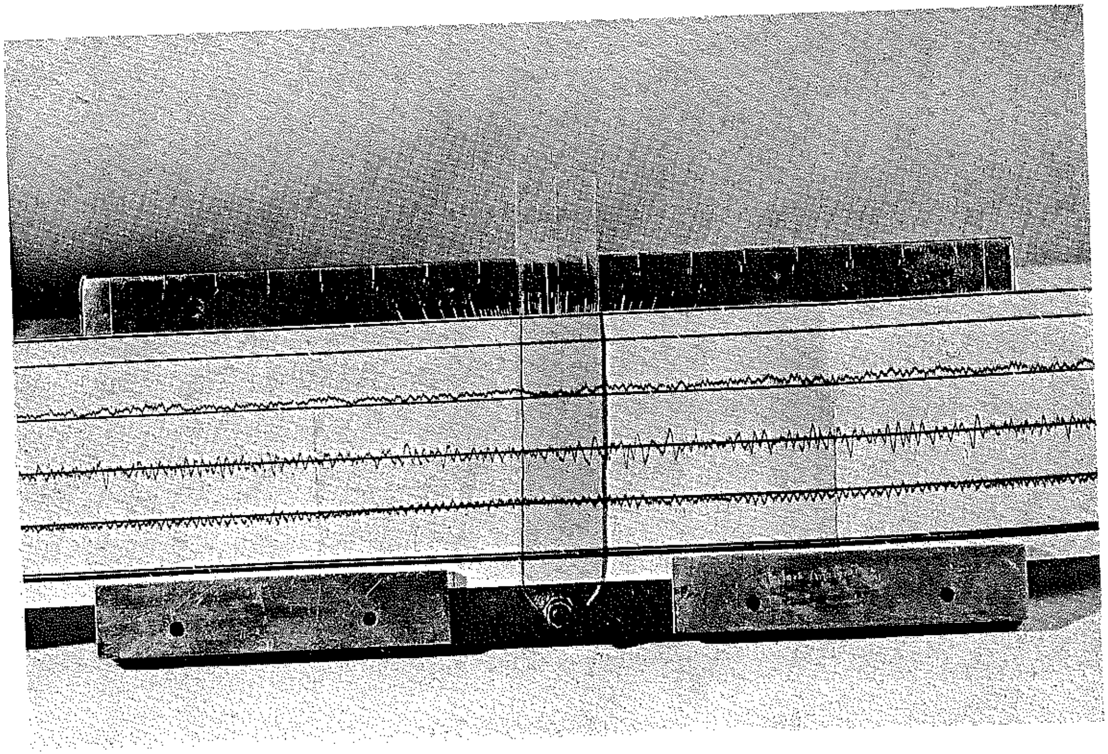


Fig. 4 - Device Used to Measure Individual Jerk Values

The operator superimposes the indicator line of the plastic pointer upon the steepest portion of each acceleration node, and the jerk value is read from the scale directly above the top of the chart and recorded in a paper-tape adding machine. The chart is then adjusted until the indicator line can be aligned with the steepest portion of the next vibratory node, and the next reading made. When all of the values for a minute of time are entered in the adding machine they are totaled and an average maximum jerk value is found.

The intent of this procedure is more clearly understood by using Fig. 5. The top curve represents an acceleration trace with the values of the maximum slope (jerk) indicated. Below this is the first derivative of the acceleration trace, or the trace that would result if jerk itself were recorded. Note that the peaks or maximum values of the jerk curve are equal to the slope of the acceleration nodes. As the jerk curve is not actually constructed, the procedure consists of analyzing the entire chart or a representative portion of it by measuring the maximum slopes of each trace, to arrive eventually at the average value of maximum jerk experienced in each direction. In Fig. 5, the average maximum jerk of 2.36 g's per second is represented by the broken horizontal line in the center. Although the roughness can be evaluated in terms of the average maximum jerk, this value is multiplied by 60, expanding it to represent an area of the chart under the average maximum jerk line. This considers the roughness to be the result of one minute of riding

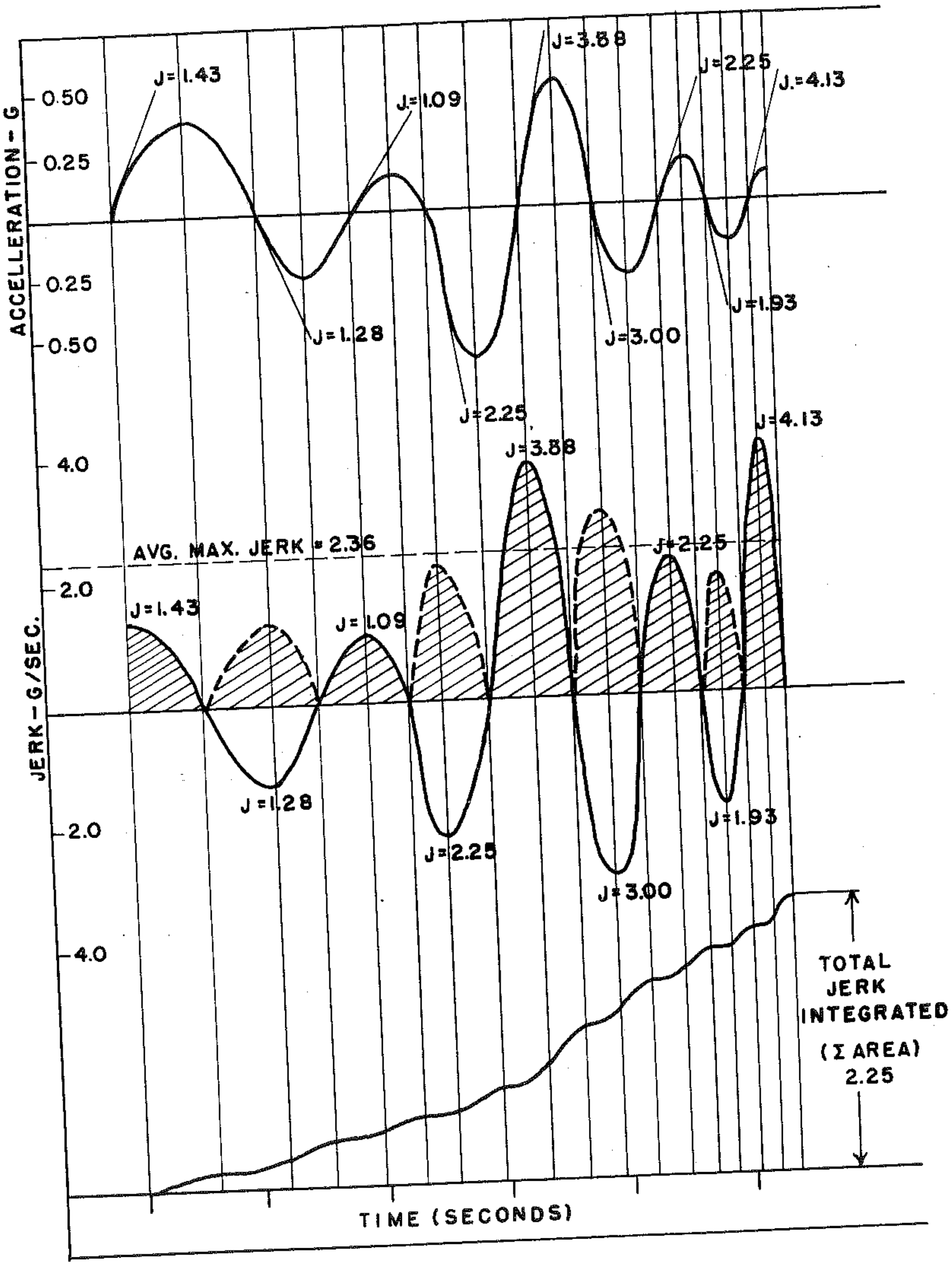
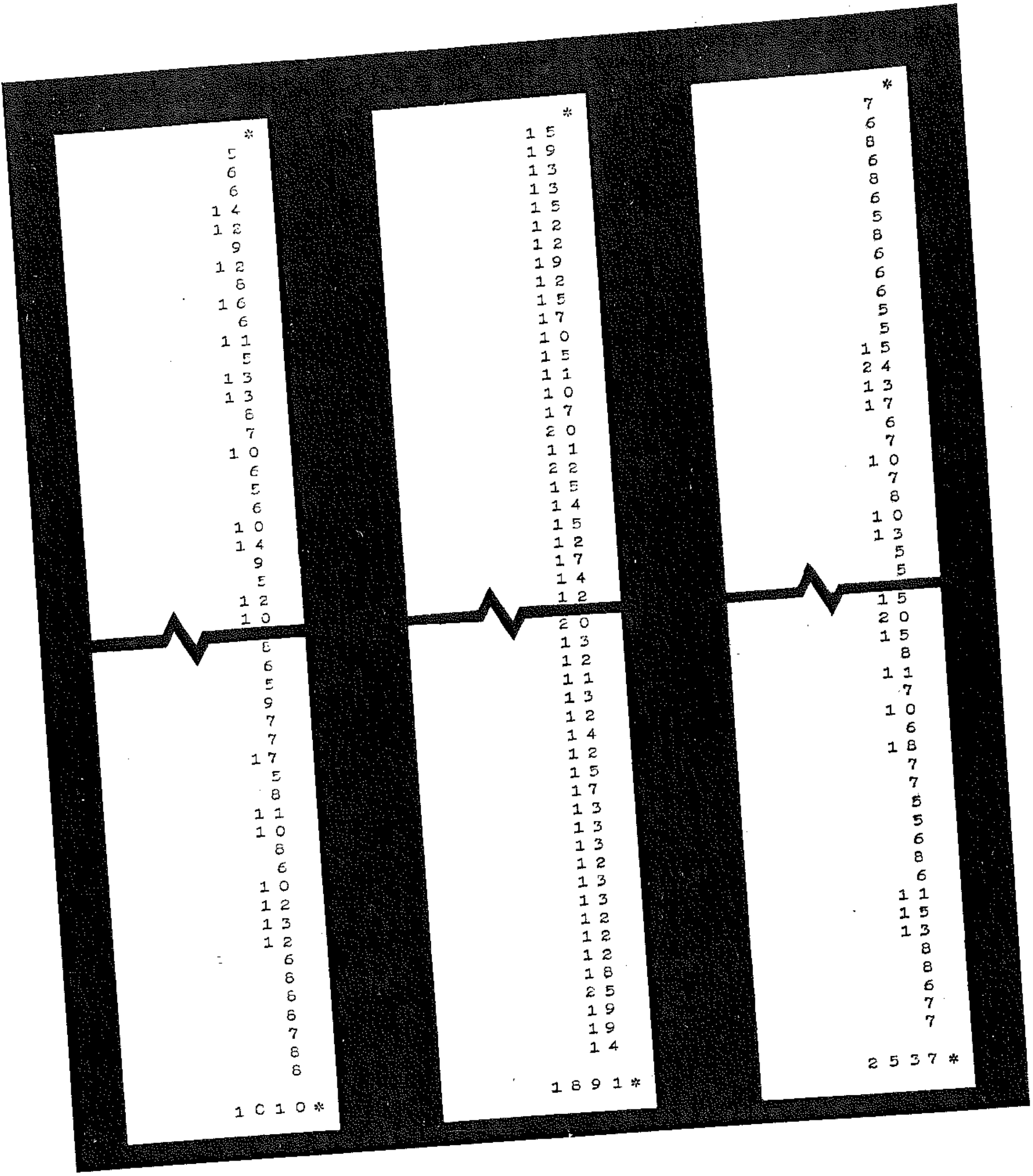


Fig. 5 - Relationships Between Acceleration, Jerk, and Integrated Jerk

time and also permits the use of more expressive numerals for the relative comparison of pavements.

Fig. 6 is a typical tabulation of the individual jerks derived from a pavement record, with the mean values calculated and multiplied by 60 seconds per minute to arrive at the proportional area of roughness. As can be seen from the chart in Fig. 3, the traces are often not rough over the entire length of the record. Smooth sections of pavement exist and as no measurement of jerk is made in these sections, reductions in gross roughness must be made to correct for this factor. In this process the charts are carefully inspected and the percentage of the rough portion of the chart estimated for each trace. This estimated corrective factor is applied to the gross roughness figure to arrive at an adjusted evaluation of the pavement.

For example, assume that a pavement exhibited 98 measurements of maximum jerk in the transverse direction, totaling 244 g's per second. The arithmetical average value of the measured jerk would be 244 divided by 98, or 2.5 g's per second. This would be factored by 60 to produce the gross roughness value of 150.0 g's per second per minute of riding time. By visually inspecting the oscillograph record, sporadic smooth sections may be located. Several examples of these smooth sections are contained in the pavement record in Fig. 3, particularly in the transverse and longitudinal traces. The person making the analysis would



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No. of Entries = 119

Mean Max Jerk = $\frac{101.0}{119}$ = 0.85

0.85 X 60 = 51.0

Gross Roughness = 51.0

Percentage of Chart = 60

Net Roughness = 0.60 X 51.0
= 30.6

No. of Entries = 135

Mean Max Jerk = $\frac{189.1}{135}$ = 1.40

1.40 X 60 = 84.0

Gross Roughness = 84.0

Percentage of Chart = 75

Net Roughness = 0.75 X 84.0
= 63.0

No. of Entries = 251

Mean Max Jerk = $\frac{253.7}{251}$ = 1.01

1.01 X 60 = 60.6

Gross Roughness = 60.6

Percentage of Chart = 80

Net Roughness = 0.80 X 60.6
= 48.5

OVERALL ROUGHNESS = 142.1

Fig. 6 - Sample Calculations, Showing Tabulation of Jerks and Roughness Computations

estimate the percent of the length of the chart that is rough and has been measured, and apply this percentage to the gross roughness value. If the percentage for this example were 40 percent (if 40 percent of the chart showed roughness), the net roughness or riding quality would be 40 percent of 150.0 (the gross value) or 60.0 *g*'s per second per minute of riding time.

To demonstrate the result of an analysis in which the percentage of roughness is not estimated, consider the previous example of a record containing 98 measurements totaling 244 *g*'s per second and averaging 2.5 *g*'s per second and compare it with another hypothetical pavement record which contains only one measurement of 2.5 *g*'s per second. Note that the average in both cases is 2.5 *g*'s per second and that the first example had 98 measurements while the second had only one. It is apparent that the first pavement would be many times as uncomfortable as the second although the average jerk would be the same. However, while the percentage of roughness in the first record is 40 percent, in the second it would probably be 0.5 percent. The net roughness for the second pavement would then be 7.5 as compared to 60.0 for the first. This appears to give a more satisfactory evaluation of the relative roughness of the two pavements.

The estimations necessary in this method of analysis are, however, detrimental to the accuracy and reliability of evaluation. The factor of the percentage of roughness is estimated by the person performing the analysis and is consequently subject to human errors which often become quite large. There is no relatively simple procedure by which the percentage may be calculated or measured, although it could be done. It would, however, be excessively tedious and time-consuming.

One may suspect that an accurate method of evaluating roughness to eliminate the estimations would consist of merely summing the individual maximum jerks and comparing pavement roughness on the basis of total jerk. If this were done, the evaluation of the example given above would be 244 for the first pavement and 2.5 for the second. This might appear to indicate a more realistic comparative roughness of the two pavements and is, in fact, the method presented in the initial report (1). But the error in this method becomes visible upon consideration of another example. Assume that one record consists of 200 measurements of 2.0 g's per second each, the total of the maximum jerk values being 400 g's per second. Another pavement has 600 measurements of 2.0 g's per second each, giving a total of 1200 g's per second. The analysis would report the second pavement to be three times as rough as the first, which would not actually be the case. As the individual jerks are the same, the roughness would be the same for both pavements, according to the information furnished by Janeway (2), although the frequency of the second is three times that of the first.

The correct solution to the problem of analysis can be found in a procedure which would measure and sum the shaded area under the rectified jerk curve in Fig. 5. If this were done, the influences of the smooth sections and of the varying frequency would automatically be eliminated. Also, errors due to deviation of the vibrations from a trigonometric wave form or to inaccuracies in measuring each individual jerk value would be prevented. The roughness or riding quality would then be represented by the area of the shaded portion of Fig. 5 and expressed in units of g's per second per minute of riding time. Each of the three directions of motion - transverse, vertical, and longitudinal - would be analyzed in this manner to represent the over-all riding quality of pavements. Although the three values would be combined to give the over-all roughness, they would also be recorded separately for individual comparisons with other pavements. In this way, various features of the pavement causing roughness could be studied with respect to their relative importance.

The equipment might also be used to evaluate the efficiency of maintenance and improvements by determining the differential roughness values before and after the operations. This technique has already been applied experimentally to U.S. 60 between Middletown and Eastwood, east of Louisville. The riding quality for this section of pavement was determined to be 133.7 in August, 1955, before extensive maintenance, including drainage and resurfacing, was begun. After the improvements were completed, an analysis made by the same method gave a roughness value of 97.2, showing a decrease of 27.3 percent. Although the latter analysis demonstrated that some roughness continues to exist, the pavement is now classified as relatively smooth.

Another improvement measured by the use of comparative roughness values was made on U.S. 27 between Falmouth and Alexandria, a portland cement concrete pavement. Consolidation of fill material over a pipe culvert had produced the uncomfortable disturbance recorded on the chart which is reproduced in Fig. 7. After the pavement was leveled by mudjacking the displaced slabs, the abrupt vibrational disturbance disappeared, as illustrated by Fig. 8. The exact location of the pipe culvert is recorded on both charts by the event marker, the top trace on each chart.

Of course, there are other potential applications of the equipment which could likewise be evaluated; but until the method of analysis becomes more accurate the inherent possibilities for errors will make this impractical.

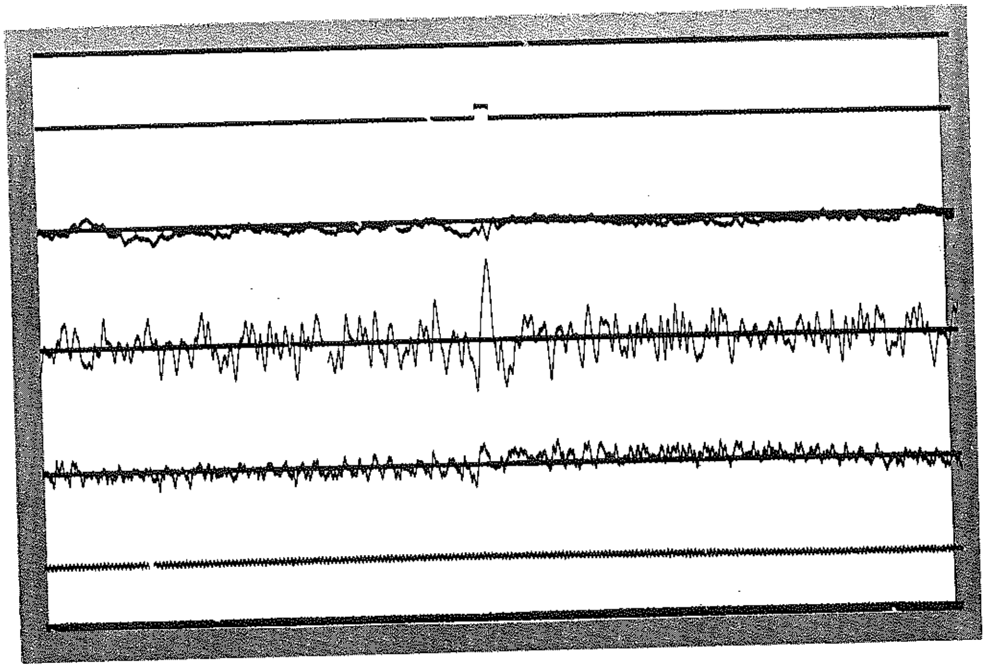


Fig. 7 - Oscillographic Acceleration Record of Pavement Deformation Over a Pipe Culvert on US 27 Between Falmouth and Alexandria. The disturbance is marked at the top of the chart by means of the event marker.

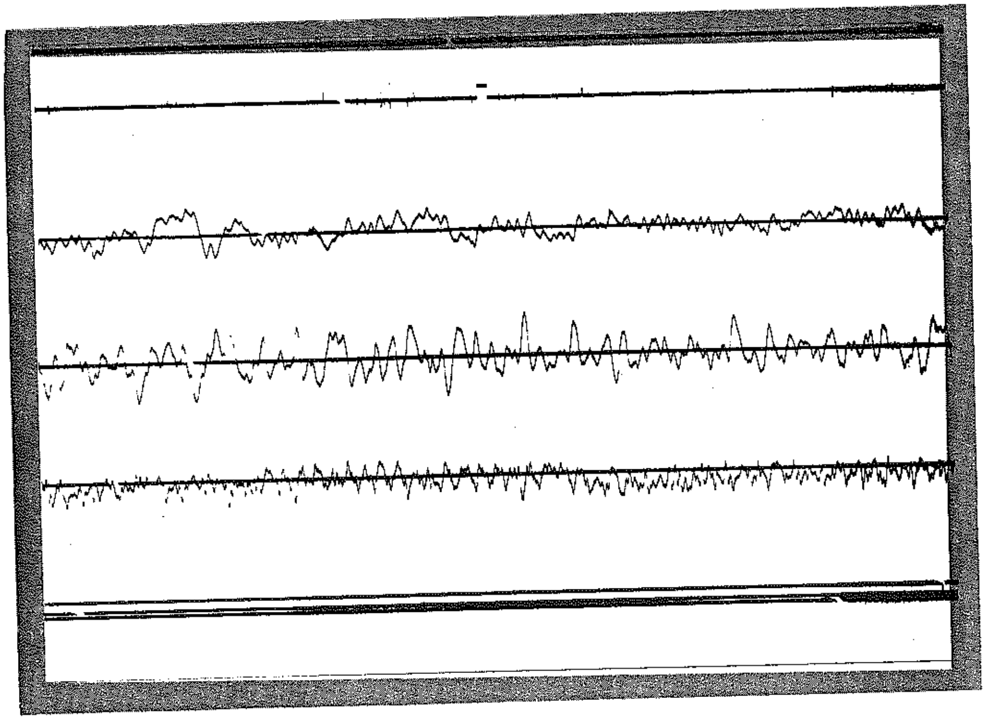


Fig. 8 - Oscillographic Acceleration Record of the Same Pavement Section as in Figure 7. Note that the disturbance over the pipe culvert has disappeared as the result of maintenance measures. The location is recorded by the event marker.

## RESULTS OF ANALYSIS

Figs. 9 and 10 are statistical plots of data derived from typical pavement charts. The tabulation of measured jerks in Fig. 6 is used in plotting Fig. 9, which consists of three sets of curves. The lower bell-shaped curves show frequency distributions of the jerk values for a one-minute period of test for each of the three directions. Note that the magnitude of jerk as the abscissa is plotted against the number of jerks over a 0.2 g per sec. range as the ordinate. The upper elongated curves represent the percent of jerks with values greater than any one magnitude of jerk. For instance, in the blue curve representing the vertical component, 100 percent of the uncomfortable jerks have values greater than 1.0 g's per second, while 30 percent are greater than 2.1 g's per sec.

It is possible to extract additional statistical functions from the curves to use in comparing the different types of roughness, as an aid in determining causes and/or possible cures. By visual comparison of the statistical plots, distinct characteristics of the frequency distribution curves may be observed. For example, they may exhibit a high value of kurtosis, indicating that a particular severity of jerk is highly predominate and could be caused by rigid pavement joints or by some resonance on vehicle-instilled roughness in flexible type pavements.

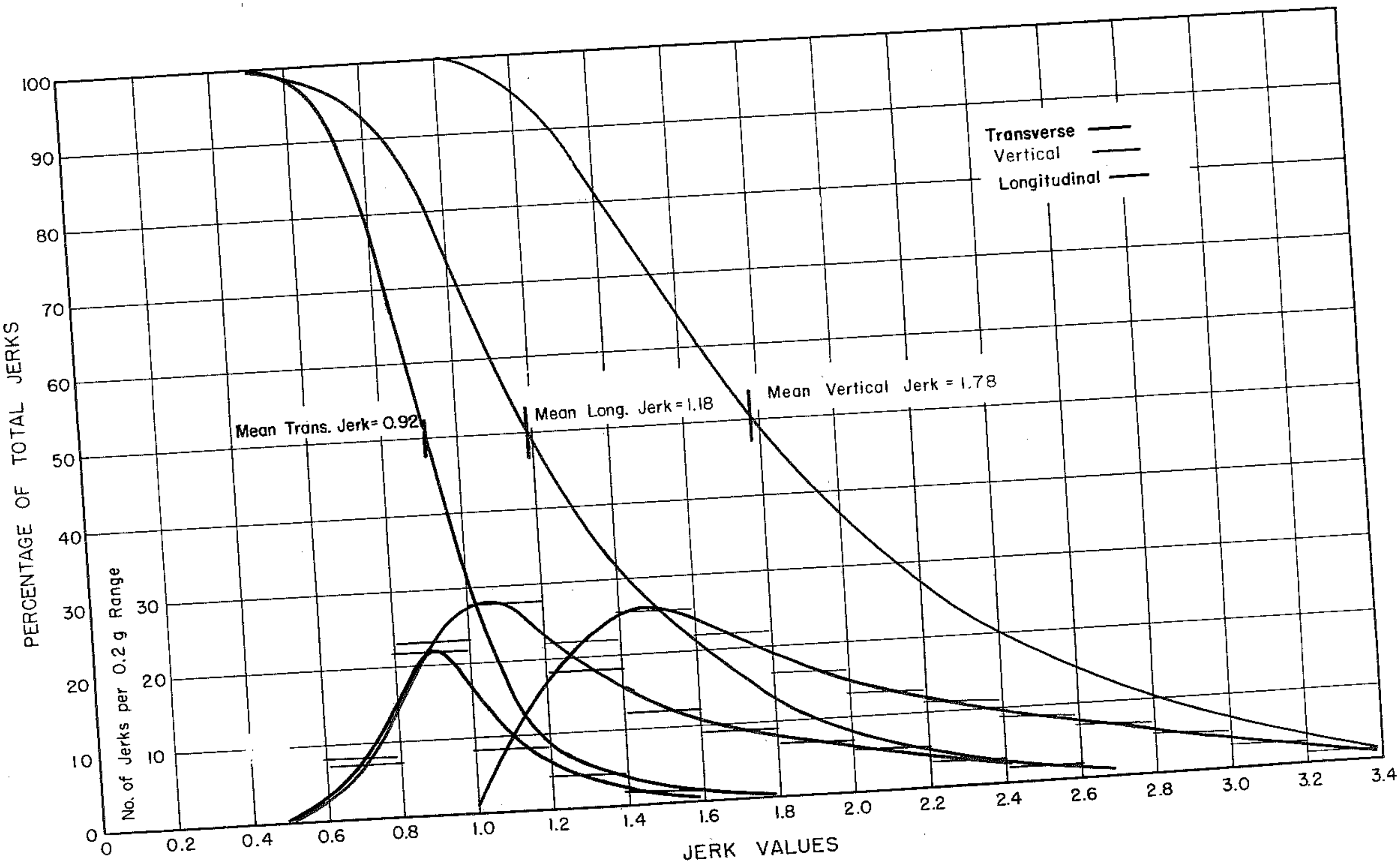


Fig. 9 - Frequency Distribution of Roughness Data for One Pavement. Upper curves represent percent of jerks with values greater than any selected value. Lower curves indicate actual number of jerks with values within each increment of 0.2 g per sec.

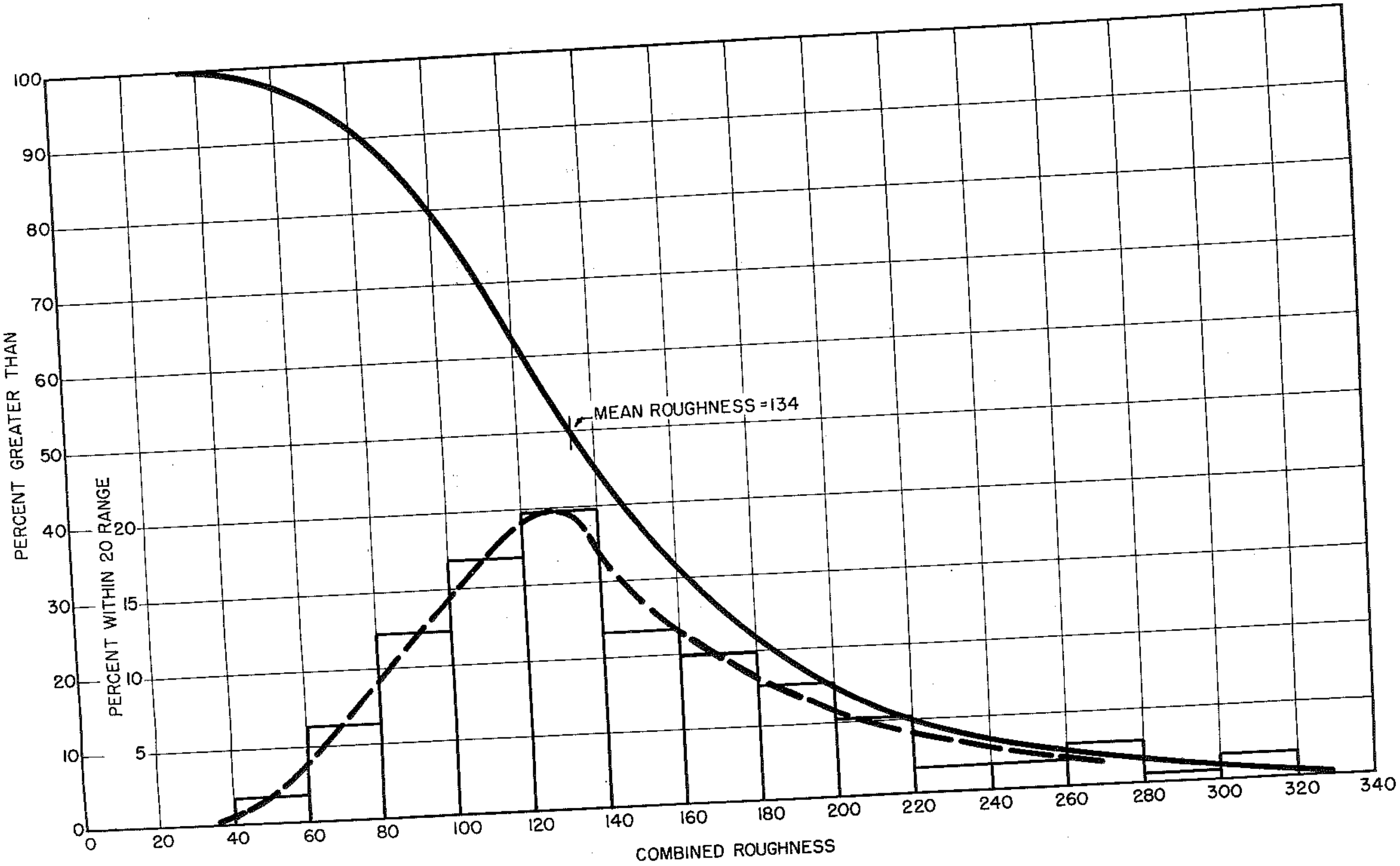


Fig. 10 - Graphical Representation of Roughness Values for a Variety of Pavements, as Tabulated in the Appendix. Upper curve represents percent of pavements with roughness exceeding a given value. Note that mean roughness is 134. Lower curve shows percent of pavements within each roughness range of 20.

The latter condition may be of either or both of two types. As the vehicle is suspended on springs, its mass may vibrate in a natural frequency, damped of course by its shock absorbers. Even though damped, several decreasing vibrations are required for the vibrational energy to be dissipated. In the meantime, the downsurges of the vehicle are imposing increased impact loads upon the pavement. On a flexible pavement this action could produce deformation of the base or subgrade under the point of impact of the wheels. This would, in time, produce resonant roughnesses at the natural frequency of the vehicle.

Another type of resonance can be caused by the natural vibration of the vehicle's wheel assembly on its springs. This bouncing of the wheels produces sufficient impact forces to instill permanent differential deformation of the base or subgrade; and creep or flow of a bituminous mix can result, producing a corrguated or wash boarded condition. The latter is not commonly found in an advanced state but probably occurs to some extent on all flexible pavements. The other type -- that caused by the vibrating mass of the whole vehicle on springs -- induces roughness at a much lower frequency and is very pronounced in some pavements, depending largely upon several factors: the soil type of the subgrade, the type of base construction, the type of pavement surface mix, the type and amount of traffic, and the history of the climatic and weather conditions.

Fig. 10 is the same type of statistical plot as Fig. 9 except that it represents the over-all combined roughness of the roads listed in the Appendix. The bell-shaped curve gives the frequence distribution of roughness with the number of pavements within ranges of counts as ordinate, plotted against the roughness value of the pavements as abscissa. The geometry of the curve illustrates the wide dispersion of this sample of the state's pavements. From the elongated curve, the percentage of roads with roughness greater than any given roughness may be found. Note that the mean roughness of all roads is 134.

Although much more information can be derived from the statistical analysis it is not included in this report since it will be valuable only for research and investigation in an attempt to improve pavement riding quality.

## RECOMMENDATIONS

Under the present method of analysis approximately one hour of experienced labor is required to abstract the data from each chart. In addition to this large amount of work, results are not immediately available and discrepancies can appear. To eliminate these objections in the future, instruments may be employed to perform the complete analysis. With such equipment the acceleration impulses would be differentiated into jerk, which would be automatically summed-up, or time-integrated over a known time. The total area under the jerk curve - the shaded area in Fig. 5 - would be available as a representation of discomfort. This would eliminate the need for personnel to extract data from the charts, as the data would be available immediately upon completion of the test run; and errors inherent in taking manual measurements from the charts and in estimating the percentage of actual roughness would not exist.

# SUPPLEMENT: A COMPARISON OF THREE DEVICES USED FOR DETERMINING PAVEMENT ROUGHNESS

In May, 1956, the Missouri Department of Highways invited the California and the Kentucky highway departments to make roughness measurements on a section of concrete pavement located on State Route 22, a few miles west of Mexico, Missouri. The primary intent of the study was to observe the effects of temperature on the contours of pavement slabs. To do this, the California profilograph was transported to the site for use in determining the surface variations of the concrete slabs.

Since the Missouri Department of Highways had a roughness measuring device, the situation permitted a secondary study in which three different types of roughness measuring equipment could be applied on the same section of pavement. This procedure would thereby provide data for possible correlation of the three devices.

A description of the riding quality equipment has been previously presented in this report and a brief discussion of the other two devices follows. These instruments are commonly referred to as the profilograph, developed by the California Division of Highways, and the roughometer, originated by the Bureau of Public Roads.

## The Profilograph

The profilograph, shown in Fig. 1, consists essentially of a long rigid frame suspended at each end on multiple wheel assemblies. A mechanical linkage recorder is positioned at the midpoint of the long

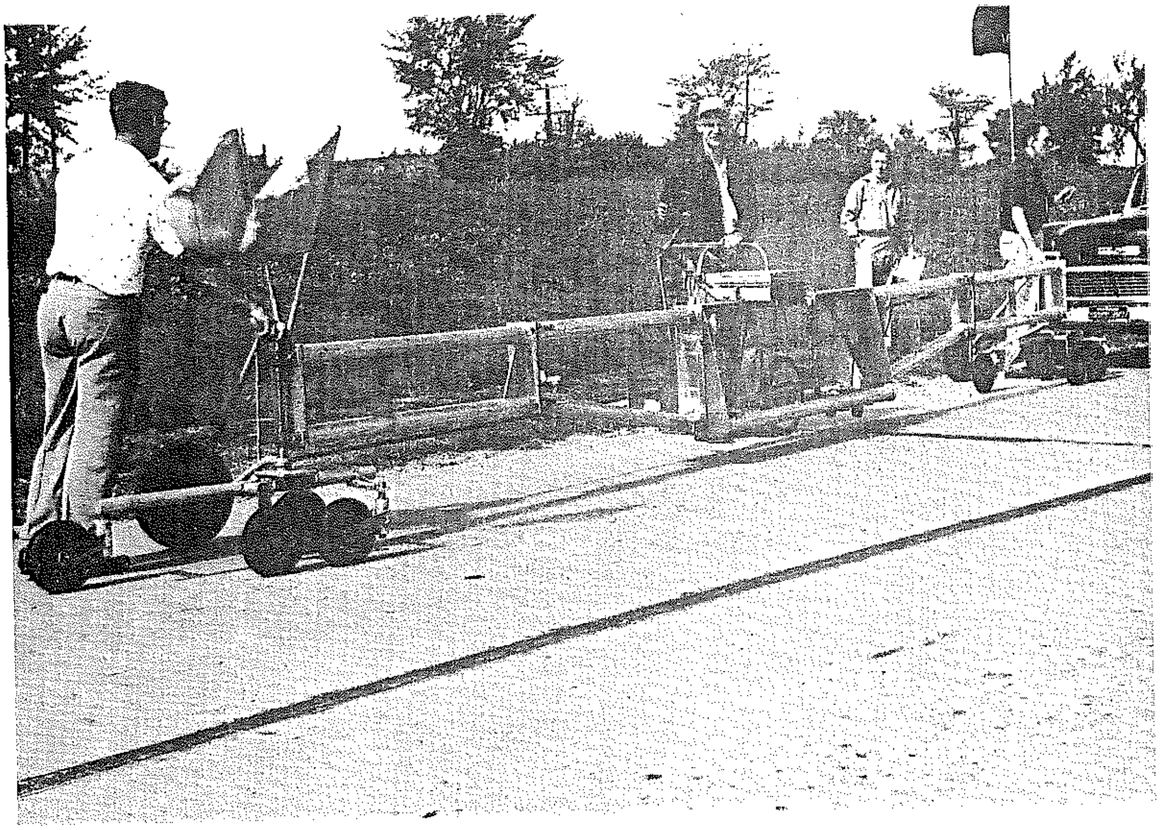


Fig. 1 - Profilograph Developed by the California Division of Highways.

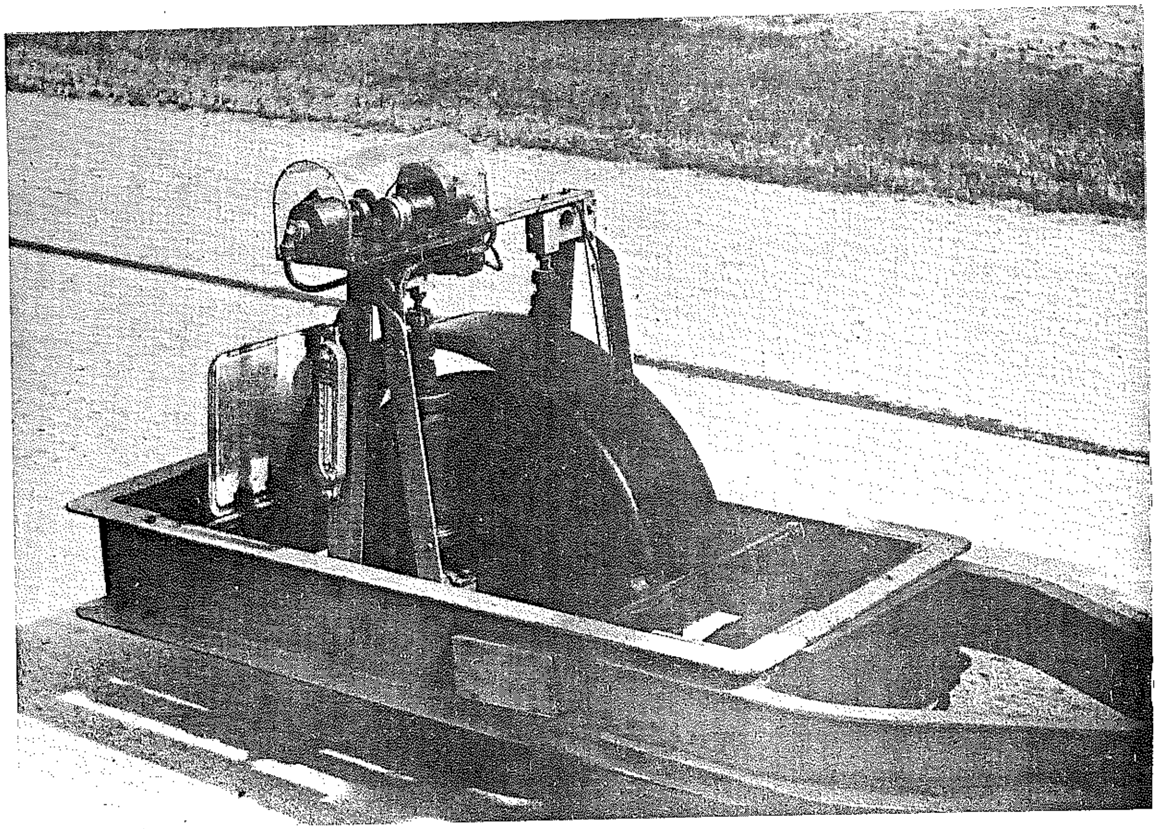


Fig. 2 - Roughometer Developed by the Bureau of Public Roads.

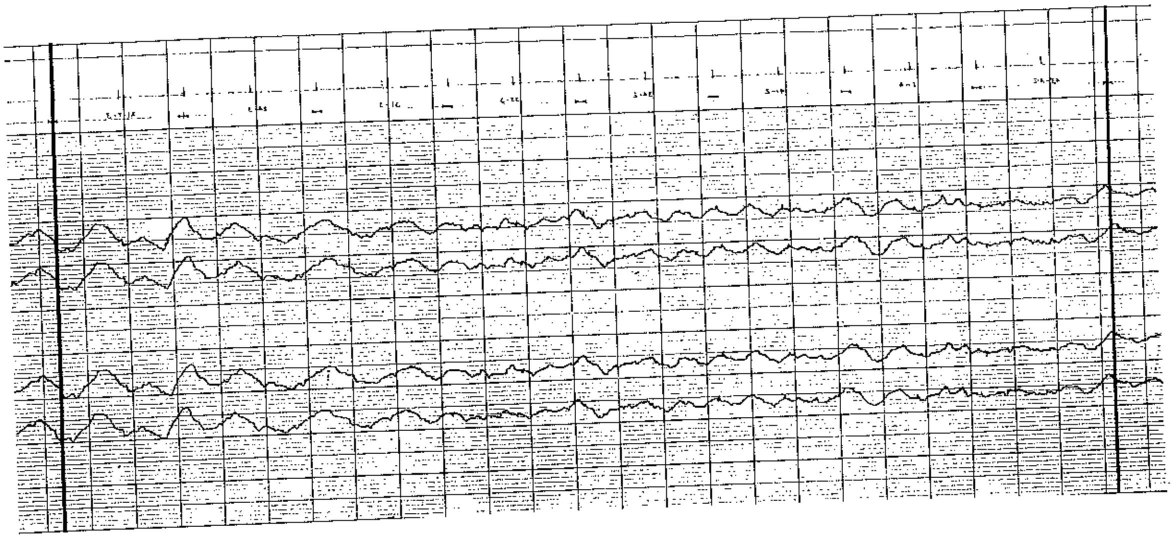
frame, and this records relative displacements of a center wheel suspended from the frame and recorder. Thus, as the apparatus is pushed along the pavement the recorder reproduces on a graph the vertical deviations of the center wheel from its zero position. The multiple wheel assembly at each end of the rigid frame reduces the effects of any spurious displacement of one of the multiple wheels.

This device is capable of reproducing the profile of a pavement surface fairly accurately on sudden displacements, such as spalls and faulted or extruded joints, as well as other types of roughness where displacement of the end wheel assemblies does not cause appreciable relative deflection of the center wheel.

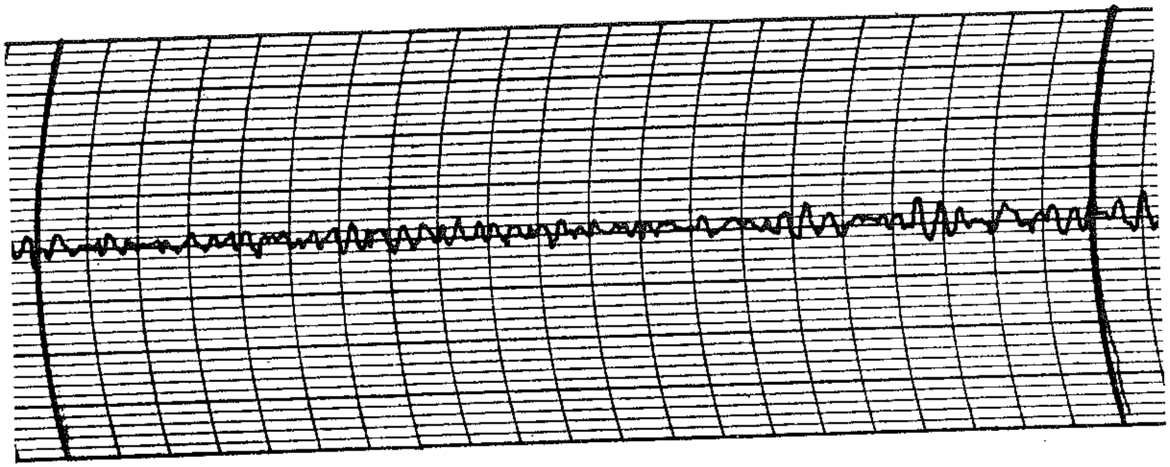
The upper portion of Fig. 3 illustrates the profilograph record of the section of pavement between Sta. 134+50 and Sta. 140+50 on Missouri Route 22. The original chart paper is 12 inches in width so that several records can be taken of the same section of pavement by rewinding the paper and establishing a new zero reference point.

The paper is ruled into one-inch squares with one-tenth-inch divisions in the vertical scale. The calibration of the equipment provides scales of one inch to 25 feet horizontally and one inch to one inch vertically. Pavement joints are recorded at the top of the chart and can usually be detected in the plotted profile. The 37.5 ft. joint spacing is indicated by the joint marker at intervals of 1.5 inches.

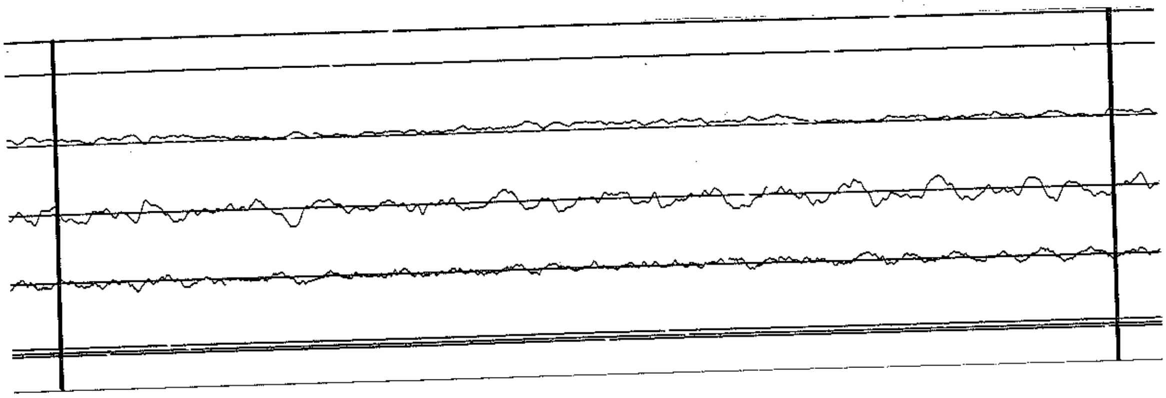
Since the equipment reproduces vertical displacements to full scale while the longitudinal scale is 1:300, considerable exaggeration is developed. Thus, minor differences in records made of the same pavement at different times can be easily detected, as in the four different traces appearing in the illustration in Fig. 3. These probably result from temperature changes in the concrete pavement slabs.



Sta. 134+50 Profilograph Sta. 140+50



Sta. 134+50 Roughometer Sta. 140+50



Sta. 134+50 Riding Quality Equipment Sta. 140+50

Fig. 3 - Graphs Taken by Each of the Three Devices over the Same Section of Roadway and Reduced to the Same Horizontal Scale. Normally the profilograph record is read from right to left; but for purposes of this illustration it has been printed in reverse so that all of the charts may be read in the same direction, from left to right, for comparison.

## The Roughometer

Pavement roughness may also be detected and analyzed by the device illustrated in Fig. 2. This equipment consists essentially of a one-wheel trailer towed by a vehicle containing the recording instruments. The wheel supports a spring mounted, damped load which simulates the loaded condition of a vehicle wheel. The spring is similar to one normally found on an automobile and the damping device duplicates a shock absorber.

The roughness is determined by measuring and summing the upward components of the vertical bounce of the spring-mounted wheel in relation to the frame of the trailer. Roughness is then expressed in inches of bounce per mile of pavement. Thus, one effect of the pavement upon the wheel can be evaluated.

The center portion of Fig. 3 reproduces the record taken by the equipment between Sta. 134+50 and Sta. 140+50 of the Missouri pavement. In addition to the permanent record, the analysis in inches of bounce is also indicated on a dial for observation by the operator.

## Conclusions

Fig. 3 includes, in addition to the record of the profilograph and roughometer, a record of the riding quality between Sta. 134+50 and Sta. 140+50. Note that all three of these records were taken from the same section of pavement. The profilograph chart had a horizontal scale of one inch to 25 ft. and the roughometer scale was one inch to approximately 140 ft., while the riding quality chart scale in this case was one inch to 40 ft. These three horizontal scales were photographically adjusted so that in Fig. 3 they are the same. Thus, each of the records may be compared with the others and specific similarities noted.

Although some likeness is evident between the three records, there are considerable irregularities and no completely satisfactory correlation has been made. Differences in the design and response of the equipment severely impede any correlation, particularly with the riding quality method.

Actually, each of the three methods is designed and intended to evaluate a different form of roughness and although they may partially overlap, they accomplish entirely different purposes.

The profilograph records roughness in terms of the amplitude, shape, and length of vertical pavement deviations from a straight line; the roughometer evaluates roughness in terms of wheel bounce produced by such deviations; while the riding quality equipment evaluates the discomfort induced by pavement roughness.

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# APPENDIX

The following table, presenting roughness determinations of 156 pavements in Kentucky, is included only to illustrate the type of results to be expected and the wide variations of pavement roughnesses. It is not intended to be used for comparisons of pavements, as human factors involved in the analysis limit the validity of the evaluations.

The roughness values given are combinations of roughness in the transverse, vertical, and longitudinal directions. For this table, the values in each direction have been given equal weight. By attempting to compare each of the pavements with the others, one may strongly suspect that the values given are not satisfactory. If, however, the transverse and longitudinal values are assigned more weight, the relative pavement evaluations appear to be more correct. For example, if all transverse values were assigned five times as much influence as the vertical, and all longitudinal values given three times as much as the vertical, the pavement roughness would then be:

$$R = \frac{5T + V + 3L}{\frac{5 + 1 + 3}{3}} = \frac{5T + V + 3L}{3}$$

where T, V, & L are values of the transverse, vertical, and longitudinal roughness respectively, and R is the over-all roughness of the pavement.

Each of the pavements listed in the following tabulation has been re-evaluated with relative values of five to the transverse, one to the vertical, and three to the longitudinal. These results are recorded in parentheses immediately below the value obtained by using equal weight for each direction.

Additional information is required before the final relative weights can be definitely ascertained. As published information of this phase of the study is very limited, it is very probable that extensive research will be necessary to determine fully the most realistic possible relations between the three directions.

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 399 | US 60 | Fort Knox - Hardinsburg: 4 mi. west of Fort Knox in westbound lane. | Bit. | 44.8<br>(36.1) |
| 599 | US 25 | Berea - Mount Vernon: 2 mi. south of Berea in northbound lane. | Bit. | 47.7 |
| 512 | US 31E | Glasgow - Hodgenville: 1 mi. north of Glasgow in northbound lane. | Bit. | 55.5 |
| 571 | US 27 | Lexington-Nicholasville: 7 mi. south of Lexington in southbound lane. | Bit. | 65.4<br>(52.6) |
| 418 | US 60 | Henderson-Morganfield: 8 mi. east of Morganfield in westbound lane. | Bit. | 66.7<br>(57.0) |
| 454A | US 62 | Approach to Kentucky Dam: in eastbound lane. | Bit. | 67.2<br>(49.9) |
| 517 | US 31W | Horse Cave-Cave City: 1 mi. north of Barren & Hart Co. line in northbound lane. | Bit. | 69.2<br>(59.3) |
| 446 | US 68 | 1 mi. west of Kentucky Lake in westbound lane. | Bit. | 73.5<br>(71.0) |
| 400 | US 60 | 8 mi. west of Fort Knox in westbound lane. | Bit. on Conc. | 74.1<br>(67.4) |
| 740 | US 60 | Bardstown-Bloomfield: east of Bardstown in eastbound lane. | Bit. | 75.4<br>(54.1) |
| 516 | US 31W | Horse Cave-Cave City: 0.9 mi. south of Barren & Hart Co. line in southbound lane. | Bit. | 76.7<br>(65.4) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 444 | Ky. 94 | Murray-Kentucky Lake: 12 mi. east of Murray in eastbound lane. | Bit. | 77.8<br>(65.0) |
| 706 | US 25 | Corbin-London: 3-1/2 mi. south of London in northbound lane. | Bit. | 77.9<br>(93.8) |
| 597 | US 25 | Berea-Mt. Vernon: 6 mi. north of Mt. Vernon in southbound lane. | Bit. | 80.2<br>(88.3) |
| 395 | Watterson Expressway | Louisville-Jct. Ky. 738: in westbound lane. | Bit. | 80.4<br>(69.6) |
| 355 | US 27 | Lexington-Nicholasville: 8 mi. south of Lexington in southbound lane. | Bit. | 81.1<br>(90.6) |
| 384 | US 421 | Lexington-Frankfort: 13 mi. west of Lexington in westbound lane. | Bit. | 84.0<br>(83.6) |
| 382 | US 68 | Lexington-Harrodsburg: 8 mi. south of Lexington in southbound lane. | Bit. | 84.1<br>(82.7) |
| 380 | US 62 | Lawrenceburg-Tyrone: 1 mi. east of Lawrenceburg in eastbound lane. | Bit. | 84.2<br>(77.5) |
| 424 | US 60 | Marion-Smithland: 7 mi. west of Marion in westbound lane. | Bit. | 86.2<br>(89.7) |
| 386 | US 60<br>&<br>US 421 | Frankfort-Versailles: 2 mi. east of Frankfort in westbound lane. | Bit. | 89.5<br>(83.8) |
| 397 | US 31W | Louisville-Elizabethtown: 3 mi. south of West Point in southbound lane. | Bit. on Conc. | 89.5<br>(79.4) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 598 | US 25 | Berea-Mt. Vernon: 5 mi. south of Berea in northbound lane. | Bit. | 89.9<br>(55.2) |
| 367 | US 27 | Lexington-Nicholasville: 7 mi. south of Lexington in southbound lane. | Bit. | 90.7<br>(99.9) |
| 388 | US 60<br>&<br>US 460 | Truck Lane: 0.4 mi. west of Frankfort in westbound lane. | Bit. on Conc. | 90.8<br>(73.3) |
| 540 | US 27 | Lexington-Nicholasville: 7 mi. south of Lexington in southbound lane. | Bit. | 90.9<br>(65.5) |
| 427 | US 60 | Burna-Smithland: 2 mi. west of Burna in westbound lane. | Bit. | 92.9<br>(88.6) |
| 454B | US 62<br>&<br>US 641 | Kentucky Dam-Eddyville: west approach to Ky. Dam in eastbound lane. | Bit. | 93.0<br>(75.5) |
| 510 | US 31E | 6 mi. north of Glasgow in northbound lane. | Bit. | 95.4<br>(70.3) |
| 687 | Northern Lexington Bypass | Bryan Station Pike to Underpass at Winchester Road. | Bit. | 95.7<br>(73.0) |
| 712 | Ky. 80 | London-Somerset: 20 mi. west of London in westbound lane. | Bit. | 96.0<br>(76.3) |
| 604 | US 27 | Falmouth-Alexandria: 1 mi. north of Alexandria in northbound lane. | Conc. | 97.1<br>(55.7) |
| 752 | US 60 | Middletown-Eastwood: Middletown east junction to Eastwood on inside eastbound lane. | Bit. | 99.1<br>(78.5) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 495 | US 31W | Bowling Green-Munfordville: 8 mi. north of Bowling Green in northbound lane. | Bit. | 102.4<br>(95.2) |
| 383 | US 421 | Lexington-Frankfort: 3 mi. west of Lexington in westbound lane. | Conc. | 103.0<br>(72.9) |
| 500 | Ky. 100 | Franklin-Russelville: 1 mi. west of Franklin in westbound lane. | Bit. | 103.6<br>(88.4) |
| 572 | US 25 | Lexington-Georgetown: 6-1/2 mi. north of Lexington in northbound lane. | Bit. | 104.4<br>(89.2) |
| 381 | US 68 | Lexington-Harrodsburg: 15 mi. north of Harrodsburg in northbound lane. | Conc. | 104.8<br>(78.7) |
| 713 | Ky. 80 | London-Somerset: 4 mi. east of Somerset in westbound lane. | Bit. | 105.2<br>(99.8) |
| 749 | US 60 | Middletown-Eastwood: Middletown east junction to Eastwood on outside eastbound lane. | Bit. | 105.9<br>(104.6) |
| 423 | US 60 | 2 mi. west of Marion in westbound lane. | Bit. | 107.2<br>(79.9) |
| 499 | US 31W | Tennessee line-Franklin: 2 mi. north of Tennessee line in northbound lane. | Conc. | 108.8<br>(122.9) |
| 718 | US 27 | Somerset Bypass | Bit. | 108.9<br>(92.1) |
| 750 | US 60 | Eastwood-Middletown: End of 4 lanes at Eastwood to east junction at Middletown in inside westbound lane. | Bit. | 109.4<br>(88.2) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 467 | US 41 | Nortonville-Hopkinsville: 4 mi. south of Nortonville in southbound lane. | Bit. on Conc. | 110.2<br>(92.2) |
| 686 | Northern Lexington Bypass | Newtown Pike-Russell Cave Pike. | Bit. | 112.0<br>(86.2) |
| 420 | US 60 | Sturgis-Marion: 4 mi. west of Sturgis in westbound lane. | Conc. | 112.5<br>(102.6) |
| 692 | US 25 | Berea-Mt. Vernon: 4 mi. south of Berea in southbound lane. | Bit. | 112.9<br>(78.8) |
| 689 | US 25 | 2 mi. south of Richmond in southbound lane. | Bit. | 113.9<br>(81.3) |
| 493 | US 31W | 4 mi. north of Bowling Green in northbound lane | Bit | 114.3<br>(87.8) |
| 481 | US 431 | 2 mi. north of Russellville in northbound lane. | Bit. | 114.6<br>(108.4) |
| 489 | US 231 | Beaver Dam-Morgantown: 10 mi. south of Beaver Dam in southbound lane. | Bit. | 115.0<br>(101.9) |
| 739 | US 31E | Bardstown-Hodgenville: 7 mi. north of Hodgenville in northbound lane. | Bit. | 115.4<br>(99.2) |
| 389 | US 60<br>&<br>US 460 | Frankfort-Shelbyville: 7 mi. west of Frankfort in westbound lane. | Bit. | 116.1<br>(101.8) |
| 696 | US 25 | Berea-Mt. Vernon: 3 mi. north of Mt. Vernon in northbound lane. | Bit. | 116.1<br>(79.5) |
| 738 | US 31E | Hodgenville-Bardstown: 2 mi. north of Hodgenville in southbound lane. | Bit. | 119.5<br>(106.8) |
| 636A | US 60 | Middletown-Eastwood: city limits of Eastwood in westbound lane. | Bit. | 120.3<br>(89.0) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 390 | US 60<br>&<br>US 460 | Frankfort-Shelbyville: 5 mi. east of Shelbyville in westbound lane | Bit. on Conc. | 121.0<br>(127.7) |
| 404 | US 60 | Cloverport-Hawesville: 1 mi. west of Cloverport in westbound lane. | Bit. | 123.2<br>(110.4) |
| 456 | US 62<br>&<br>US 641 | 3 mi. east of Kentucky Dam in eastbound lane. | Bit. | 123.2<br>(97.6) |
| 605 | US 27 | 10 mi. north of Falmouth in southbound lane. | Conc. | 124.8<br>(74.1) |
| 419 | US 60 | 3 mi. west of Morganfield in westbound lane. | Bit. | 124.8<br>(95.2) |
| 494 | US 31W | Bowling Green-Cave City: 4 mi. north of Bowling Green in northbound lane. | Bit. | 125.4<br>(100.5) |
| 402 | US 60 | Hardinsburg-Cloverport: 3 mi. west of Hardinsburg in westbound lane. | Bit. | 126.1<br>(123.3) |
| 428 | US 60 | Burna-Smithland: 1 mi. east of Smithland in westbound lane. | Conc. | 126.4<br>(124.1) |
| 542 | US 27 | Lexington-Nicholasville: 1 mi. south of Lexington in northbound lane. | Conc. | 126.7<br>(111.5) |
| 471 | US 41 | Nortonville-Hopkinsville: 5 mi. north of Nortonville in southbound lane. | Bit. on Conc. | 126.8<br>(98.4) |
| 693A | US 25 | Berea-Mt. Vernon: 9 mi. south of Berea in southbound lane. | Bit. | 127.0<br>(85.0) |
| 703 | US 25 | 4 mi. north of London in southbound lane. | Bit. | 127.5<br>(89.8) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 710 | Ky. 80 | London-Somerset: 12 mi. west of London in westbound lane. | Bit. | 127.8<br>(100.0) |
| 472 | US 41 | Hopkinsville-Nortonville: 9 mi. north of Hopkinsville in southbound lane. | Bit. on Conc. | 128.1<br>(133.6) |
| 502 | Ky. 73 | Franklin-South Union: 2 mi. north of Franklin in northbound lane. | Bit. | 128.2<br>(115.2) |
| 706A | US 25 | London-Corbin: 3 mi. south of London in northbound lane. | Bit. | 129.6<br>(93.8) |
| 688 | US 60 | Lexington-Winchester: 5 mi. west of Lexington in westbound lane. | Bit. | 129.8<br>(96.5) |
| 431 | US 45 | Paducah-Mayfield: 5 mi. south of Paducah in southbound lane. | Bit. on Conc. | 130.4<br>(92.2) |
| 426 | US 60 | Burna-Smithland: 1 mi. west of Burna in westbound lane. | Bit. | 130.7<br>(112.8) |
| 478 | US 68 | Hopkinsville-Russellville: 12 mi. west of Russellville in eastbound lane. | Bit. | 130.8<br>(120.0) |
| 411 | US 60 | Owensboro-Henderson: 2 mi. west of Owensboro in westbound lane. | Conc. | 130.8<br>(100.0) |
| 734 | US 31E | Glasgow-Hodgenville: 14 mi. north of Glasgow in northbound lane. | Bit. | 131.6<br>(116.5) |
| 458 | US 62<br>&<br>US 641 | 5 mi. east of Kentucky Dam in eastbound lane. | Bit. | 131.8<br>(126.4) |
| 748 | US 62 | 8 mi. east of Versailles in eastbound lane. | Bit. | 133.9<br>(103.1) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 704 | US 25 | London-Corbin: 5 mi. south of London in southbound lane. | Bit. | 134.6<br>(97.9) |
| 505 | US 68 | Bowling Green-Glasgow: 12 mi. east of Bowling Green in eastbound lane. | Bit. | 135.4<br>(128.6) |
| 497 | US 31W | Bowling Green-Franklin: 5 mi. south of Bowling Green in southbound lane. | Bit. | 136.2<br>(115.6) |
| 525 | US 25 | Lexington-Richmond: 3 mi. south of Lexington in northbound lane. | Bit. | 136.5<br>(118.4) |
| 385 | US 421 | Frankfort-Lexington: 12 mi. east of Frankfort in westbound lane. | Bit. | 137.1<br>(116.4) |
| 701 | US 25 | Mt. Vernon-London: 17 mi. south of Mt. Vernon in southbound lane. | Bit. | 137.8<br>(103.6) |
| 636B | US 60 | Middletown-Eastwood: Eastwood city limits in westbound inside lane. | Bit. | 139.2<br>(89.4) |
| 443 | Ky. 94 | Murray-Kentucky Lake: 3 mi. east of Murray in eastbound lane. | Bit. | 139.4<br>(110.5) |
| 469 | US 41 | Nortonville-Hopkinsville: 5 mi. south of Nortonville in southbound lane. | Conc. | 142.5<br>(135.4) |
| 408 | US 60 | Lewisport-Owensboro: 5 mi. west of Lewisport in eastbound lane. | Conc. | 142.7<br>(110.5) |
| 694 | US 25 | Berea-Mt. Vernon: 8 mi. south of Berea in northbound truck lane. | Bit. | 143.7<br>(98.9) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 691 | US 25 | Berea-Mt. Vernon: 2-1/2 mi. south of Berea in southbound lane. | Bit. | 144.0<br>(132.5) |
| 690 | US 25 | Berea-Richmond: 4 mi. north of Berea in southbound lane. | Bit. | 144.6<br>(119.3) |
| 698 | US 25 | Mt. Vernon-Berea: 3 mi. north of Mt. Vernon in southbound truck lane. | Bit. | 144.6<br>(115.0) |
| 637 | US 60 & US 460 | Eastwood-Middletown: 2 mi. west of Eastwood in eastbound outside lane. | Bit. on Conc. | 147.1<br>(106.3) |
| 539 | US 25 | Lexington-Richmond: 7 mi. north of Richmond in northbound lane. | Conc. | 147.4<br>(134.4) |
| 521 | US 27 | Lexington-Nicholasville: 7 mi. south of Lexington in southbound lane. | Bit. | 148.4<br>(124.5) |
| 709 | Ky. 80 | London-Manchester: 2 mi. west of London. | Bit. | 148.7<br>(119.1) |
| 536A | US 25 | Lexington-Richmond: 8 mi. north of Richmond in northbound lane. | Conc. | 149.3<br>(156.7) |
| 413 | US 60 | Owensboro-Henderson: 10 mi. west of Owensboro in westbound lane. | Conc. | 150.0<br>(135.3) |
| 699 | US 25 | Mt. Vernon-Berea: 3 mi. north of Mt. Vernon in southbound lane. | Bit. | 151.5<br>(120.8) |
| 496 | US 31W | Bowling Green-Franklin: 5 mi. south of Bowling Green in northbound lane. | Bit. | 151.5<br>(115.1) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 490 | US 231 | Morgantown-Beaver Dam: 5 mi. north of Morgantown in northbound lane. | Bit. | 152.0<br>(124.0) |
| 487 | US 62 | Central City-Beaver Dam: 3 mi. east of Central City in eastbound lane. | Bit. | 153.5<br>(143.7) |
| 742 | US 62 | Bloomfield-Lawrenceburg: 2 mi. east of Bloomfield in eastbound lane. | Bit. | 153.7<br>(138.2) |
| 538 | US 25 | Lexington-Richmond: 1 mi. north of Clay's Ferry Bridge in northbound lane. | Conc. | 154.0<br>(149.5) |
| 715 | US 27 | Somerset-Burnside: Pitman Creek Bridge in northbound lane. | Conc. | 155.7<br>(119.4) |
| 727 | US 31W | 4 mi. south of Franklin in northbound lane. | Conc. | 157.9<br>(120.5) |
| 422 | US 60 | Morganfield-Marion: 8 mi. east of Marion in westbound lane. | Bit. on Conc. | 161.8<br>(132.8) |
| 409 | US 60 | Lewisport-Owensboro: Daviess county line in westbound lane. | Bit. on Conc. | 162.2<br>(118.6) |
| 429 | US 60 | Smithland-Paducah: 1/2 mi. west of Smithland in westbound lane. | Conc. | 166.4<br>(138.5) |
| 440 | Ky. 94 | 7 mi. west of Murray in eastbound lane. | Bit. | 166.9<br>(160.1) |
| 504 | US 68 | 15 mi. west of Bowling Green in eastbound lane. | Bit. | 168.2<br>(158.6) |
| 603 | US 27 | 10 mi. north of Falmouth in southbound lane. | Conc. | 168.3<br>(106.5) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 463 | US 62 | Dawson Springs-Nortonville: 1/2 mi. east of Dawson Springs in eastbound lane. | Conc. | 168.3<br>(160.3) |
| 695 | US 25 | Berea-Mt. Vernon: 7 mi. south of Berea in southbound truck lane. | Bit. | 168.4<br>(115.1) |
| 693B | US 25 | Berea-Mt. Vernon: 7 mi. south of Berea in southbound lane. | Bit. | 171.9<br>(143.9) |
| 507 | US 68E | Bowling Green-Glasgow: 12 mi. east of Bowling Green in eastbound lane. | Bit. | 172.9<br>(154.3) |
| 466 | US 62 | Dawson Springs-Nortonville: 1 mi. east of Dawson Springs in eastbound lane. | Conc. | 173.0<br>(157.1) |
| 685 | US 27<br>&<br>US 68 | Lexington-Paris: 7 mi. north of Lexington in southbound lane. | Bit. | 173.1<br>(142.4) |
| 700 | US 25 | Livingston-Mt. Vernon: 2 mi. north of Livingston in southbound lane. | Bit. | 174.6<br>(121.0) |
| 492 | US 231 | Morgantown-Bowling Green: 16 mi. south of Morgantown in southbound lane. | Bit. | 177.5<br>(163.1) |
| 417 | US 60 | Henderson-Morganfield: 4 mi. west of Henderson in westbound lane. | Conc. | 178.5<br>(156.7) |
| 405 | US 60 | Hawesville-Owensboro: 3 mi. west of Hawesville in westbound lane. | Conc. | 180.9<br>(162.9) |
| 479 | US 68 | Elkton-Russellville: 4 mi. east of Elkton in eastbound lane. | Bit. | 184.4<br>(168.5) |

| Chart No. | Route No. | Descrition of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 465 | US 62 | Dawson Springs-Nortonville: 4 mi. east of Dawson Springs in westbound lane. | Conc. | 184.6<br>(149.0) |
| 476 | US 68 | Fairview-Elkton: East city limits Fairview in eastbound lane. | Bit. | 185.1<br>(175.7) |
| 754 | US 60 | Eastwood-Middletown: 1 mi. west of Eastwood in westbound lane. | Bit. | 186.1<br>(92.3) |
| 461 | US 62 | Dawson Springs-Nortonville: 1 mi. east of Dawson Springs in eastbound lane. | Bit. | 186.3<br>(170.9) |
| 482 | US 431 | Russellville-Central City: 10 mi. north of Russellville in northbound lane. | Bit. | 189.2<br>(149.8) |
| 601 | US 27 | Falmouth-Alexandria: 10 mi. north of Falmouth in northbound lane. | Conc. | 189.7<br>(122.4) |
| 407 | US 60 | Hawesville-Owensboro: 1/2 mi. east of Lewisport in westbound lane to Lewisport. | Conc. | 199.9<br>(191.5) |
| 484 | US 431 | Dunmore-Drakesboro: North city limits of Dunmore in northbound lane. | Bit. | 202.2<br>(176.1) |
| 442 | Ky. 94 | Murray-Kentucky Lake: 2.0 mi. east of Murray in eastbound lane. | Bit. | 208.6<br>(176.8) |
| 763 | Ky. 151 | Frankfort-Lawrenceburg: 3 mi. south of Junction US 60 in southbound lane. | Bit. | 209.1<br>(156.3) |
| 488 | US 231 | Beaver Dam-Morgantown: 1/2 mi. south of Beaver Dam in southbound lane. | Bit. | 209.5<br>(188.1) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 736 | US 31E | Glasgow -Hodgenville: 17 mi. south of Hodgenville in northbound lane. | Bit. | 212.8<br>(180.4) |
| 416 | US 60 | Henderson-Owensboro: 5 mi. east of Henderson in westbound lane. | Conc. | 212.8<br>(210.5) |
| 706B | US 25 | London-Corbin: 3-1/2 mi. south of London in northbound lane. | Bit. | 213.1<br>(159.9) |
| 459 | US 62 | Eddyville-Princeton: 2 mi. east of Eddyville in eastbound lane. | Conc. | 213.1<br>(224.1) |
| 498 | US 31W | Franklin-Tennessee line: 2 mi. south of Franklin in southbound lane. | Conc. | 214.9<br>(198.3) |
| 486 | US 431 | Russellville-Central City: 12 mi. south of Central City in northbound lane. | Bit. | 229.7<br>(178.9) |
| 474 | US 68 | Hopkinsville-Russellville: 4 mi. east of Hopkinsville in eastbound lane. | Bit. | 233.1<br>(217.9) |
| 491 | US 231 | Morgantown-Bowling Green: 4 mi. south of Bowling Green in southbound lane. | Bit. | 238.3<br>(223.3) |
| 436 | Ky. 94 | 18 mi. west of Murray in eastbound lane. | Bit. | 242.7<br>(257.6) |
| 765 | Ky. 151 | Lawrenceburg-Frankfort: 1 mi. north of Lawrenceberg in southbound lane. | Bit. | 243.5<br>(187.6) |
| 534B | US 25 | Lexington-Richmond: 8 mi. north of Richmond in northbound lane. | Conc. | 244.3<br>(209.4) |

| Chart No. | Route No. | Description of Location | Type Surface | Roughness No. |
|---|---|---|---|---|
| 439 | Ky. 94 | 12 mi. west of Murray in eastbound lane. | Bit. | 262.4<br>(234.1) |
| 730 | US 31W | Franklin-Tennessee Line: 5 mi. south of Franklin in northbound lane. | Conc. | 264.4<br>(208.1) |
| 728 | US 31W | Franklin-Tennessee Line: 8 mi. south of Franklin in northbound lane. | Conc. | 270.0<br>(217.2) |
| 410 | US 60 | 7 mi. west of Lewisport in westbound lane. | Conc. | 275.6<br>(218.0) |
| 536B | US 25 | 8 mi. north of Richmond in northbound lane. | Conc. | 277.0<br>(257.6) |
| 434 | Ky. 303 | 8 mi. south of Mayfield in southbound lane. | Bit. | 285.8<br>(267.4) |
| 415 | US 60 | 8 mi. east of Henderson in westbound lane. | Conc. | 308.0<br>(297.8) |
| 535 | US 25 | 10 mi. north of Richmond in southbound lane. | Bit. on Conc. | 318.0<br>(278.6) |