MEASUREMENT OF RUT DEPTHS IN ROAD SURFACES BY THE TRRL HIGH-SPEED PROFILOMETER

by

P G Jordan and P B Still

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MEASUREMENT OF RUT DEPTHS IN ROAD SURFACES BY THE TRRL HIGH-SPEED PROFILOMETER

ABSTRACT

The existing method of measuring deformation in the wheel paths of roads in the UK is by straightedge; it is slow and is hazardous on busy roads. A safer and faster method of measurement using the new TRRL high-speed profilometer has been developed at the Laboratory.

This Report describes the method of measurement and the evaluation of the factors affecting the accuracy of measurement.

Comparison of the high-speed and existing method of measurement show agreement to within 2 mm on major roads and within 3 mm on other roads. The difference between the measurements is caused in part by the sampling error of the straightedge method and in part by the operator in controlling the line of measurement of the high-speed system. Repeatability of measurement is found to be such that on average 80 per cent or more of the repeat measurements differ by 1.5 mm or less.

Criteria for rut depth derived from existing maintenance criteria are presented for use with the high-speed system.

Alternative and less costly equipment than the profilometer that would measure rut depth and surface texture is briefly described.

1. INTRODUCTION

In assessing the maintenance needs of roads, the development of rutting in the wheel paths is an important factor because of its implications for road safety and its significance as an indicator of structural condition. In urban areas, ponding of rain water in ruts can also result in the splashing of pedestrians.

The existing methods of measuring rut depth in the UK are based on conventional survey measurements of the transverse profile or on the use of a straightedge-and-wedge system. Both methods are slow; provide a relatively small sample of measurements and, unless the road is closed to traffic, can be hazardous to operators. To provide a safer and faster method the TRRL profilometer has been applied to the measurement of rut depth.

The method of measurement and the investigation into the factors affecting the accuracy of measurement are described and discussed. Criteria for rut depth derived from existing maintenance criteria are presented for use with the high-speed system of measurement.
2. METHOD OF MEASUREMENT

2.1 TRRL high-speed profilometer

A detailed description of the TRRL high-speed profilometer\textsuperscript{3,4} and its laser sensors\textsuperscript{5} is given elsewhere but the main features, insofar as they relate to the measurement of rut depth, are described below.

The profilometer consists of a two-wheeled trailer supporting a 4.5 metre long beam on to which four laser sensors\textsuperscript{5} are mounted in the configuration shown in Plate 1. Each sensor measures the height of the beam from the road surface at rates up to 3300 measurements per second and has a working range of 72 mm centred at a distance of 270 mm from the sensor.

The power supply system, computer and associated peripherals required to operate the system are housed in the towing vehicle, which in the commercial version of the profilometer, is a Ford van as shown in Plate 2. In operation, the beam is encapsulated in polyurethane foam to eliminate undesirable effects of temperature change and has a plastic weather-cover.

2.2 Rut-depth measurement

The method adopted for measuring rut depth using the TRRL profilometer is illustrated in Figure 1. The wheels of the trailer ride in the ruts and the height of the axle from the road surface is measured by the laser sensors, along a line centred between the wheel paths. The difference between the axle height on a deformed surface and that obtained on a plane surface gives the rut depth averaged over both wheel paths as shown in Figure 1.

On the profilometer beam the configuration of sensors is such that none of the sensors are positioned on the line of the axle (see Plate 1). Consequently the axle height is obtained, as described in Appendix 1, from a linear interpolation of the height measurements made by the sensors positioned on either side of the axle.

3. FACTORS AFFECTING THE MEASUREMENT

3.1 Trailer axle length

The measurement depends on the trailer-wheels riding in the ruts and consequently the axle length must be chosen to satisfy this requirement. To determine the required axle length some 97 transverse profiles of roads, ranging from principal type to motorway, were measured using a laser levelling technique. The distance between the points of maximum rut depth in the nearside and offside wheel path was determined from each of the measured profiles and the results obtained are shown in histogram form in Figure 2. The figure shows that the largest proportion (69 per cent) of measured distances occurred at 1.8 metres and this value has therefore been chosen to define the axle length.

3.2 Effect of trailer suspension

During a measurement the motion of the trailer on its suspension introduces an oscillatory trend into the axle-height measurements obtained from the laser sensors. Trials in which the trailer was towed over a variety of surfaces have shown the resonant frequency of the trailer suspension of 4.5 Hz to be the dominant frequency component in the oscillatory motion of the trailer suspension. The trials also showed that, though the amplitude of oscillation varied randomly with distance, it rarely exceeded 10 mm over the range of profiles and speeds examined.
To reduce the effect of this oscillatory trend on measurements to an acceptable level, determinations of axle height are averaged over a length, \( l \), of road that is determined by the operating speed, \( V \), of the measuring system. If the oscillatory trend is represented by a sine wave,

\[
A \sin \frac{2\pi fx}{V}
\]

of amplitude, \( A \), and frequency \( f \), equal to the resonant frequency of the trailer suspension it can be shown that the averaging length, \( l \), required to give a limiting error \( e \) for a trailer operating at speed, \( V \), is given by:

\[
l \geq \frac{AV}{\pi fe}
\]  \hspace{1cm} (1)

For \( A = 10 \text{ mm} \), \( V = 12.5 \text{ m/sec (45 km/h)} \) and \( f = 4.5 \text{ Hz} \) the averaging length, \( l \), required to give an error, \( e \), less than or equal to 0.5 mm is:

\[
l \geq 17.6 \text{ metres}
\]  \hspace{1cm} (2)

If the operating speed is changed the averaging length must also be changed pro rata to maintain the error level.

### 3.3 Road camber

The method of measuring rut depth, described in Section 2, gives the depth of rutting relative to the level of the line centred between the wheel paths. Consequently rut depths measured by the high-speed system on roads having a consistently significant camber will include a component attributable to the camber. Although dual-carriageway roads are not designed to have cambers single-carriageway roads in rural and urban areas are usually cambered. The magnitude of this effect and hence the possible need for correction was therefore investigated.

Lane-camber is defined in Figure 3 as the deviation of the surface at the mid-point between the wheel paths from a straight line (1.8 metres long) joining the wheel paths. Figure 3 shows measurements obtained from newly constructed and resurfaced roads. On roads that are 6.6 metres wide or more the figure shows the camber values are distributed about zero with 90 per cent of the values within \( \pm 2 \text{ mm} \). For these roads the camber magnitudes were found to vary randomly along any given length of road and when averaged over road lengths of 20 metres the averaged values were found to be within the range 0 \( \pm 0.5 \text{ mm} \). On roads wider than 6.6 metres therefore camber will not introduce a significant offset in the rut-depth measurements.

For roads less than 6.6 metres wide Figure 3 shows lane-camber values ranging from 1.5 to 8.5 mm. Over road lengths of 20 metres the averaged values were within the range 4 \( \pm 1 \text{ mm} \). Consequently, on these roads 4 mm is deducted from the measured rut depth. The variation in camber reduces the accuracy of measurement on these roads, relative to that obtained on major roads. However the levels of rut depth obtained on roads less than 6.6 metres wide are usually substantially greater than that on the wider major roads and the accuracy expressed as a percentage of the rut depth is not significantly different.

### 3.4 Tyre and speed effects

Changes in the effective rolling radius of the tyres fitted to the trailer have a direct effect on the height of the equipment and thus on the amplitude of the rut depth measured. To measure rut depths
accurately it is necessary to eliminate, where possible, effects that alter the radius and where this is not possible to compensate automatically for them; these are load, tyre pressure, temperature and speed of rotation. In the experiments described in this report Avon Super Safety cross-ply tubeless 5.20–10 4 ply rating tyres were fitted to the HSP system.

The effect of tyre pressures on the axle height was determined by measuring the average axle height on a 100m section of non-rutted road at 7 different tyre pressures. Each measurement was carried out at a constant speed and the distance travelled between the tests was kept to a minimum to avoid any significant change in the temperature of the tyres. The results are presented in Table 1 and they show that the axle height changes by approximately 3.3 mm/kgf/cm².

<table>
<thead>
<tr>
<th>Tyre pressure (kgf/cm²)</th>
<th>Change in axle height from height at 1.4 kgf/cm² (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.98</td>
<td>-1.7</td>
</tr>
<tr>
<td>1.12</td>
<td>-1.0</td>
</tr>
<tr>
<td>1.26</td>
<td>-0.2</td>
</tr>
<tr>
<td>1.40</td>
<td>0.0</td>
</tr>
<tr>
<td>1.54</td>
<td>0.6</td>
</tr>
<tr>
<td>1.68</td>
<td>0.7</td>
</tr>
<tr>
<td>1.82</td>
<td>1.1</td>
</tr>
</tbody>
</table>

When the HSP trailer is moving, the temperature of the tyres will rise above the ambient temperature and cause the tyre pressures to increase. Tyres set to a pressure of 1.4 kgf/cm² when cold have been observed to increase to 1.8 kgf/cm² after a long motorway journey. To determine the combined effect of an increase in tyre temperature and pressure on axle height, the average axle height over a 3 kilometre section of concrete road was repeatedly measured by the HSP system at a fixed speed. In between each measurement the HSP system was driven over a distance of approximately 12 km at high speed to increase the temperature of the tyres.

No trend was observed in the average axle heights measured and all values measured were within 0.4 mm of the initial value. The increase in axle height expected from the increased tyre pressure appears to be compensated for by a decrease in tyre stiffness at the higher temperatures.

The effective rolling radius of a cross-ply tyre also changes with its rotational speed due to centrifugal forces and can cause a significant change in the axle height. To determine the relationship between the axle height and speed of rotation of the trailer tyres the average axle height was measured using the profilometer on a 100m section of non-rutted road at speeds of 15, 25, 50 and 75 km/h. The increase (Δh mm) in axle height with speed (V km/h) had the relationship:

\[ Δh = 0.062V \] (3)

To compensate for the speed effect the rut measuring programme therefore continuously calculates the vehicle speed (V) and applies a correction of 0.062V mm to the rut depth measurements before they are
stored on disc. Applying this correction factor on the HSP system reduces the speed effect error to less than 0.5 mm over the speed range of 15 to 75 km/h.

If different tyres are fitted to the rut measuring system the above test must be repeated and the derived speed correction factor entered into the rut measuring programme.

Although the effective rolling radius of the trailer tyres is affected by variations in load, the trailer load on the profilometer system is essentially constant.

3.5 Operator control

The effect of operator control of the high-speed system on the measurement of rut depth was examined by carrying out repeat measurements of rutting on each of two 20-kilometre lengths of motorway. The measurements were made at an operating speed of 45 km/h with the computed rut depths averaged over consecutive 20-metre lengths in the manner described in Section 3.2.

Figure 4 shows a comparison of the distributions of rut depths obtained from the repeat measurements on each of the two 20-kilometre test lengths, A and B. The difference between the distribution averages is shown to be 0.5 mm and 0.1 mm for test lengths A and B respectively. A more detailed investigation of the differences between corresponding rut measurements from the repeat runs showed that, on both test lengths, over 80 per cent of these differences were less than, or equal to, 1.5 mm.

4. MODEL OF MEASUREMENT FACTORS

The overall effect of the factors, described in Section 3, on the measurement of rut depth may be described using a mathematical model of the measurement process. In the Appendix the relationship between the rut depth, \( \bar{r} \), and the axle height difference, \( \Delta h_A \), obtained from a flat and rutted surface, the operator control error, \( \bar{O} \), the suspension effect, \( \bar{S} \), and the effect of road camber, \( \bar{C} \), all averaged over a length, \( \ell \), is shown to be:

\[
\bar{r} = \Delta h_A - \bar{O} - \bar{S} - \bar{C} \tag{4}
\]

By selecting the averaging length, \( \ell \), such that it complies with Inequality 1 of Section 3, the effect of the suspension term, \( \bar{S} \), on the measured rut depths is reduced to within \( \pm 0.5 \) mm. In addition on major roads the camber term, \( \bar{C} \), is shown in Section 3.3 to be reduced on averaging to zero, for all practical purposes. The operator control tests, in Section 3.5, have shown that the term, \( \bar{O} \), is less than or equal to 1.5 mm for over 80 per cent of the rut-depth values, \( \bar{r} \).

On major roads, therefore, the averaged rut depths, \( \bar{r} \), would be expected to be accurate to within 2 mm for at least 80 per cent of the measurements.

On roads less than 6.6 metres wide, where the averaged lane-camber, \( \bar{C} \), has been shown in Section 3.3 to be within the range 4 to 1 mm, the expected accuracy of measurement would, after deducting the offset of 4 mm, be within 3 mm for over 80 per cent of the measurements.
5. COMPARISON WITH STRAIGHTEDGE MEASUREMENTS

5.1 Straightedge measurements

The method of measuring rut depth, for maintenance purposes, in the UK consists of placing a 2 metre straightedge transversely on the road surface with one end positioned on the near edge of the near-side lane; a calibrated wedge is then used to determine the maximum depth of rut relative to the datum provided by the straightedge.

For comparison with profilometer measurements, rut-depth values were determined using both the conventional straightedge method and laser level surveys of transverse profiles of the test roads. A simulated straightedge was used to compute the rut depths from the measured transverse profiles. Because rut depth varies along the length of a road between three and five separate measurements were made in each of the 20-metre or 30-metre test lengths. These measurements were then averaged over both wheel paths and over the test length to provide the data for a comparison with profilometer measurements.

5.2 Comparison

Figure 5 shows the comparison of the straightedge and profilometer-measured rut depths. The test lengths were selected from Trunk and Principal roads. As described in Section 5.1, the straightedge measurements, unlike the profilometer measurements, are derived from a limited sample of measurements within each test length and are therefore subject to sampling error. The magnitude of the sampling error depends on the degree of variability of rut depths with distance in each of the test lengths and this variation is shown in Figure 5 by the range of straightedge measurements obtained from each test length. The profilometer gives, for all practical purposes, a continuous measure of rut depth with distance and consequently its measurements are free from sampling error. It is of course subject to the other measurement errors described in Section 4.

Allowing for the errors associated with both methods of measurement the comparison in Figure 5 shows good agreement. The deviations of the measured values from the equality do not exceed ± 2 mm which is in general agreement with the error model results of Section 4. This level of accuracy is adequate for the purposes of monitoring the road network at normal traffic speeds. Lengths of road warranting further inspection can be quickly located from the data and can be examined in greater detail using a straightedge.

6. OPERATION OF MEASUREMENT SYSTEM

6.1 Measurement

Because of the effect of tyre pressure on axle height (see Section 3.4) it is important to check the trailer tyre pressures before beginning a measurement; for cold tyres a pressure of 1.4 ± 0.05 kgf/cm² is recommended. At weekly intervals, the axle height should also be checked on a section with a known rut depth so that tyre wear and any change in the characteristics of the suspension units can be detected and allowed for in the measurement of rut depths.

The procedure for measuring wheel path rutting on a section of pavement using the HSP system is:

1. Specify averaging length and axle height.
2. OPTIONAL Enter start text to describe experiment.
3. Press RUN switch at start of section.
4. *OPTIONAL The operator can press one of the following marker switches whenever required
   DISTANCE MARKER
   BLACK TOP MARKER
   CONCRETE MARKER
   JUNCTION MARKER
5. *OPTIONAL Press SKIP ON and SKIP OFF switches to indicate when measured rut depths are not
   to be processed. This facility would be used, for instance, when the desired measuring line cannot be
   maintained (e.g. passing outside an obstruction).
6. *OPTIONAL Enter End text.
7. Press STOP switch at end of section.

The data obtained from each section of road is stored as a file on a replaceable floppy disc. On each disc,
a maximum of 51 files is allowed and, when using a 20m averaging length, each disc will hold the data from
1000 km of road. During a measurement, the visual display unit fitted to the system informs the operator
of the rut depths being measured and other information relating to the current operation of the system.

6.2 Analysis facilities

An analysis program is provided within the HSP system to allow the contents of a complete rut file
(or part) to be analysed by the operator in either a printed or a graphical format. Typical outputs are
shown in Plate 3 and Figure 6 respectively. The SPEC LEVEL and OFFSET features are described below:

SPEC LEVEL  Set by the operator: To identify quickly rut depths greater than a given value it restricts
the listing of individual rut measurements to those which are greater than this fixed value.

OFFSET  Set by the operator: To allow for the camber an offset is added to the rut depths
measured on roads less than 6.6 metres wide (see Section 3.3).

A LOOK and LIST program is provided to enable the operator to examine the file contents of a disc and
the text and marker positions for any specified file.

7. CRITERIA FOR RUT DEPTH

7.1 Criteria for rut depth based on straightedge measurement

Criteria for rut depth, based on measurements with straightedge, for use in maintenance assessment
have been proposed in the CHART6 system; the warning levels for rural and urban roads are summarised
in Column 4 of Table 2.

The straightedge warning levels are based on measurements made on either the nearside or offside
wheel path (whichever is greater) of the nearside lane. Because the basic treatment length in the CHART6
system is 100 metres and because 5 rut measurements only are made in each 100 metre length (1 measurement
per 20 metres) the percentages of road lengths exceeding the warning levels are expressed to the
nearest 20 per cent.
TABLE 2
Rut depth criteria based on straightedge measurements and those proposed for the HSP

<table>
<thead>
<tr>
<th>Defect</th>
<th>Road group</th>
<th>Warning level</th>
<th>Rut depth</th>
<th>Percentage of length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel path rutting (hazard and nuisance)</td>
<td>Rural</td>
<td>Straightedge</td>
<td>≥15 mm</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td></td>
<td>≥40 mm</td>
<td>20</td>
</tr>
<tr>
<td>Wheel path rutting (structural)</td>
<td>All</td>
<td>Straightedge</td>
<td>No cracking present</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10–19 mm</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥20 mm</td>
<td>10</td>
</tr>
<tr>
<td>Wheel path cracking</td>
<td>All</td>
<td>Straightedge</td>
<td>Single crack or multiple</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤½ width</td>
<td>15 (rutting only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rut depth 0–9 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10–19 mm</td>
<td>10 (rutting only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥20 mm</td>
<td>10 (rutting only)</td>
</tr>
</tbody>
</table>

7.2 Criteria for rut depth for use with the HSP

Because the rut depths measured by the HSP are averaged over some specified length (see Section 3), the variability of these measurements is less, for a given road condition, than that of individual straightedge measurements. Consequently, for a given profile of rut depths, the percentages exceeding the warning levels in Table 2 as measured by the high-speed system will be less than those by straightedge measurements. The averaging of the rut depth over both wheel paths by the high-speed system, as against a measurement on the nearside or offside wheel path only by the straightedge, will also reduce the mean level of the distribution of high-speed measurements relative to that of the straightedge measurements.

An examination has been made of the reduction in variability caused by averaging over lengths of 10 and 20 metres in the high-speed measurements and of the reduction in mean level of these measurements caused by averaging over both wheel paths. This indicates that, for use with the HSP, the percentage levels in Table 2 should be reduced to half the corresponding straightedge values. The revised percentage values for use in assessing the significance of rut depth with the high-speed system are shown in the last column of Table 2.

For the implementation of the revised criteria on the CHART basic length of 100 metres, the rut depths should be averaged over 10 metres. The increase in measurement error in reducing the averaging length from 20 to 10 metres while maintaining a speed of 45 km/h is less than 0.5 mm (see Section 3.2). Consequently an averaging length of 10 metres and an operating speed of 45 km/h can be used for implementing the revised CHART criteria.
8. ECONOMIC ALTERNATIVE SYSTEM

The high-speed profilometer system is capable of accurately measuring longitudinal profile, surface macro-texture as well as the measurement of rut depths described in this report. Its speed and on-board data processing capability therefore make it an efficient and effective tool for the assessment of most aspects of the surface condition of major roads.

On rural and urban roads the simpler Bump-integrator, with its microcomputer enhancement, provides an economic method of assessing ride. High-speed measurement of rutting and macro-texture could also be made on these roads using simpler equipment, based on a single laser sensor.

This would consist of a single sensor fitted to the axle of a short two-wheeled trailer that had a distance transducer fitted to one of its wheels. Sensor and transducer measurements would be processed by a small microcomputer and the calculated rut depths stored on a magnetic-tape cartridge for subsequent analysis. An alternative arrangement to the two-wheeled trailer would be to fit the sensor to the rear axle of the vehicle towing the Bump-integrator so that ride and rutting measurements could be made simultaneously. Control of the measurements would be through a control panel linked to the microcomputer.

9. CONCLUSIONS

1. A high-speed method of measuring wheel path rutting using the TRRL high-speed profilometer has been described in this report. The method gives the depth of rut averaged over both wheel paths and over a length of road. For a given accuracy, this length is governed by the maximum nominal operating speed. For an averaging length of 20 metres operating speeds can range up to a maximum of 45 km/h and the averaging length is increased pro rata with increase in the maximum speed.

2. Comparison of the high-speed measurements with measurements made with a straightedge-and-wedge on major roads agree to within 2 mm and on roads with a camber to within 3 mm.

3. Operator control tests have shown that on repeat runs over lengths of 20 kilometres that over 80 per cent of the differences between corresponding rut depths obtained on the repeat runs are less than or equal to ± 1.5 mm.

4. Control of the equipment is through a simple control panel and measurements are stored on a magnetic medium which has a capacity of storing data for a thousand kilometres of road.

5. The road network can be measured at normal traffic speeds using the profilometer and sections requiring further examination can be quickly located using the on-board computer.

6. Criteria for rut depth derived from existing straightedge criteria are presented for use with the high-speed equipment.

7. A brief description is given of alternative simpler equipment that could be used in conjunction with the Bump-integrator for the assessment of road surface deterioration on rural and urban roads.
10. FUTURE DEVELOPMENTS

The crossfall of the road, important in assessing the problem of surface drainage of rain water, is one of the few characteristics of the road surface that is not, at present, measured by the TRRL high-speed profilometer.

An investigation is therefore being made into the measurement at high speed of road crossfall simultaneous with the measurement of rut depth. Preliminary tests have shown satisfactory measurements of crossfall on straight lengths of road but problems arise in interpreting the measurements obtained when travelling round bends. Further work is therefore required before the system for measuring crossfall can be implemented.

11. ACKNOWLEDGEMENTS

The work described in this Report was carried out in the Construction and Maintenance Division (Division Head: Mr P D Thompson) of the Highways Department of TRRL.

12. REFERENCES


Fig. 1 Rut-depth measurement

\[ h_0 - h_r = \frac{r_1 + r_2}{2} \] hut depth averaged over both wheel paths
Fig. 2 Distribution of distances between wheel paths measured on nearside lanes of trunk and principal roads
Fig. 3 Distribution of camber values measured on left hand lanes of roads.
Fig. 4 Comparison of distributions of rut depths obtained from repeat measurements on each of two 20 kilometre lengths of motorway
Fig. 5 Comparison of rut depths measured by straightedge and profilometer on roads, with and without, a camber.
Fig. 6 Example plot of rut depths measured on a trunk road using analysis program
RUT DISC 10
FILE 11
START 50M
END 7500M
OFFSET 0.00MM
SPEC LEVEL 10MM

TEXT: A1 BUCKDEN 24/4/80 SOUTH

<table>
<thead>
<tr>
<th>POSITION (M)</th>
<th>RUT (MM)</th>
<th>RUT DEPTH BAR CHART</th>
</tr>
</thead>
<tbody>
<tr>
<td>602</td>
<td>+11.6</td>
<td>= = = = = = = = = = =</td>
</tr>
<tr>
<td>622</td>
<td>+13.6</td>
<td>= = = = = = = = = = =</td>
</tr>
<tr>
<td>5922</td>
<td>+10.9</td>
<td>= = = = = = = = = = =</td>
</tr>
</tbody>
</table>

DISTRIBUTION OF 368 RUT DEPTHS
(AVERAGE = +3.94 MM)

10% I
9% I
8% I
7% I
6% I
5% I
4% I
3% I
2% I
1% I
0% I

<1 1 1 1 1 1 9 8 7 6 5 4 3 2 1+0->
4 3 2 1 0 RUT DEPTH (MM)

Plate 3 Sample output from program for rut analysis (averaging length = 20m)
13. APPENDIX
AXLE DISPLACEMENT AND RUT-MEASUREMENT MODEL

13.1 Calculation of axle displacement

On the high-speed profilometer none of the four laser sensors are positioned on the line of the trailer axle. Consequently, to obtain the axle height, it is necessary to interpolate the height measurements made from the two lasers nearest to, and to either side of the axle. If the distances of the axle, measured along the profilometer beam, from the two nearest sensors is $x_1$ and $x_2$ then the axle height $h_A$, in terms of these sensor heights $h_1$ and $h_2$, is given by:

$$h_A = h_1 + \frac{x_1 (h_2-h_1)}{x_1 + x_2} \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (1)$$

Because the point on the road surface directly beneath the axle may not be colinear with the points beneath the sensors, the value of $h_A$ derived from a single height measurement of each of the sensors may be in error. If however the heights $h_1$ and $h_2$ are averaged over a length, $\ell$, greater than twice the between-sensor distance (ie $2(x_1 + x_2)$) then the averaged axle height $\bar{h}_A$ derived from Equation 1, but using the averaged sensor heights $\bar{h}_1$ and $\bar{h}_2$ as in the following expression, will have a negligible error.

$$\bar{h}_A = \bar{h}_1 + \frac{x_1 (\bar{h}_2-\bar{h}_1)}{x_1 + x_2} \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (2)$$

where $\bar{h}_1$ and $\bar{h}_2$ are the sensor heights averaged over length $\ell$.

13.2 Model of rut measurement

From Figure 1 the rut depth measured by the high-speed profilometer is shown to be the averaged rut depths of the nearside and offside wheel paths of a road. In Section 3 it is shown that this averaged rut-depth measurement is affected by the motion of the suspension of the profilometer trailer, by the operator control of the towing vehicle, by the camber of the road lane and by tyre diameter changes that are influenced by rotational speed. If $r(x)$ is the true rut depth averaged over both wheel paths and $S(x)$, $t(x)$, $O(x)$, $C(x)$ and $K$ are the suspension, texture, operator, lane-camber and tyre contributions to the axle height, $h_A(x)$, measurement at point $x$ along the road then $h_A(x)$ can be expressed in the form:

$$h_A(x) = r(x) + S(x) + t(x) + O(x) + C(x) + K + D \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (3)$$

where $K$ is a function of operating speed and is independent of $x$ for any given operating speed. $D$ is the axle height measured on a flat surface with the profilometer at rest.

Because of the high rate of measurement of the sensors (2500 measurements per second) the height $h_A(x)$ can be considered a continuous function of $x$ and the axle height $\bar{h}_A$ averaged over a length $\ell$ of rutted surface is therefore given by:

$$\bar{h}_A = \frac{1}{\ell} \int_{x-\ell/2}^{x+\ell/2} h_A(x) \, dx = \frac{1}{\ell} \int_{x-\ell/2}^{x+\ell/2} (r(x) + S(x) + t(x) + O(x) + K + C(x) + D) \, dx \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (4)$$

$$= \bar{r} + \bar{S} + \bar{O} + \bar{K} + \bar{C} + D$$

where, on averaging, the texture term becomes zero.
On a flat surface the axle height $h'_{A}$ averaged over a length, $l$, is:

$$h'_{A} = D + K$$ .................................................. (5)

The operator and lane camber terms of Equation 4 are both zero for a flat surface and the suspension and texture terms are negligibly small. As shown in Section 3.4 the term $K$ is a function of operating speed and for a given speed $K$ will take the same value in Equations 4 and 5. Substituting Equation 5 into Equation 4 gives the following expression for the true rut depth, $r$, averaged over length, $l$:

$$r = [\bar{h}_{A} - \bar{h}'_{A}] - \bar{S} - \bar{O} - \bar{C}$$

$$= \Delta \bar{h}_{A} - \bar{S} - \bar{O} - \bar{C}$$ .................................................. (6)
ABSTRACT

Measurement of rut depths in road surfaces by the TRRL high-speed profilometer:
P G JORDAN and P B STILL: Department of the Environment Department of Transport, TRRL Laboratory Report 1037, Crowthorne, 1982 (Transport and Road Research Laboratory). The existing method of measuring deformation in the wheel paths of roads in the UK is by straightedge; it is slow and is hazardous on busy roads. A safer and faster method of measurement using the new TRRL high-speed profilometer has been developed at the Laboratory.

This Report describes the method of measurement and the evaluation of the factors affecting the accuracy of measurement.

Comparison of the high-speed and existing method of measurement show agreement to within 2 mm on major roads and within 3 mm on other roads. The difference between the measurements is caused in part by the sampling error of the straightedge method and in part by the operator in controlling the line of measurement of the high-speed system. Repeatability of measurement is found to be such that on average 80 per cent or more of the repeat measurements differ by 1.5 mm or less.

Criteria for rut depth derived from existing maintenance criteria are presented for use with the high-speed system.

Alternative and less costly equipment than the profilometer that would measure rut depth and surface texture is briefly discussed.

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