Rational Approach to Cross-Profile and Rut Depth Analysis

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Procedures for obtaining transverse profiles and rut depths on highway pavements are described. This information can be obtained using automated equipment and procedures presently available without disrupting traffic. Results of one of these procedures (which has been used to evaluate rutting on the Strategic Highway Research Program's long-term pavement performance studies sites) is compared with results of the straight edge and dipstick methods. Comparisons and information on the speed, accuracy, and safety of the survey are provided. The benefits of cross profiles versus other rutting measurements are also discussed.

Since the early days of wheeled travel, rutting of traveled ways has been a cause for concern and probably was a major reason for some of the first pavements to be placed.

Dictionaries define a rut as a furrow or a groove in which something runs, such as a wheel. A furrow is, in turn, defined as a marked, narrow depression. Pavement-related textbooks refer to rutting as a permanent deformation or surface distortion.

Ruts are usually associated with wheel paths; however, in practice, pavements respond in variable combinations of consolidation and displacement. Rutting usually stems from permanent deformations in any or all of the pavement layers or subgrade, usually caused by consolidation or lateral movement of the materials because of traffic loads. Rutting may also be the result of plastic movement in the mix in hot weather, inadequate compaction during construction, or abrasion and raveling caused by tire wear. Because of the nature of rut development, a transverse profile is needed to get a true measure of the location and severity of the worst rutting. From the transverse profile, an estimate of the actual rutting mechanism that is useful in selecting corrective actions can be made.

Today, pavement designers generally indicate a typical pavement cross section by a straight transverse profile having a uniform grade across each lane. Sometimes parabolic sections have been used, but in either case the intent is to have a smooth transverse profile across the lane.

Depending on construction procedures, there may be some variations built into the surface even before traffic begins. Most specifications for pavement construction include longitudinal surface tolerances, but transverse tolerances may not be included.

The development of rutting begins with the introduction of traffic, especially truck traffic. Today's traffic stream contains an ever-increasing volume of trucks, which are becoming heavier and heavier. These trucks are riding on modern tires with advanced-structure sidewall designs, which operate at higher and higher inflation pressures. The increasing number and size of trucks, changes in tire design, increased tire inflation pressures, and possible changes in the quality of asphaltic cement used in flexible pavements, have combined to create serious rutting concerns in areas that have seldom, if ever, had rutting problems. These changes have brought renewed interest in and concern with pavement rutting.

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Rutting was first seriously recognized as a concern of highway engineers at the AASHO Road Test in 1956 to 1960, when it was identified as having an impact on the performance of highway pavements. Rutting was found to be of such importance that it was included as one of the terms in the serviceability equation for flexible pavements. In establishing the performance equation, rutting measurements from 50 pavements in three states were used. The average rutting for the 50 sections was 0.12 in., with ranges of 0 to 0.34-in. mean rut depth for each of the sections (*1*).

Rutting is of concern to the highway community for the following reasons:

- Safety. Ruts can contribute to steering difficulties and erratic movement. Ruts interfere with surface drainage and when filled with water during rain, they affect vehicle stability and can contribute to reduced friction or hydroplaning.
- Rehabilitation. The type of rutting observed on the transverse profile can provide information helpful in selecting rehabilitation methods. If rutting appears to be mostly consolidation and shear, then added structural strength might be needed and a heavier overlay used. If rutting appears to be primarily from lateral distortion, then rehabilitation by milling or leveling, with a new wearing course, or by recycling the surface might be selected.
- Serviceability. Rut depths are factors in establishing the public acceptance of pavements and in calculating the present serviceability index.

Rutting is widely known as a process in pavement deterioration and ruts are commonly referred to in pavement-related discussions. However, there is little uniformity in the method in which ruts are measured, or the acknowledged degrees of rutting that are meaningful.

In measuring transverse profiles or rut depths, a number of decisions need to be made in which the uses planned for the data should be taken into consideration. More detailed measurements are justified in evaluating pavement conditions for a research project than in evaluating pavement conditions for input into a pavement management system.

Decisions have to be made in selecting the type of measuring procedure or system, the longitudinal interval for obtaining transverse profile or rut depth measurements, the interval for transverse profile measurements, and the method by which the measurements are to be analyzed and reported.

HOW TO OBTAIN MEASUREMENTS

Over the years, both static and dynamic methods have been used to measure transverse profile and rut depth. The static procedures include such means as stringlines, straight edges, and profiling devices. The static methods share some common problems including slow measurement rate, traffic control requirements, and exposure of the operators to safety hazards.

The dynamic procedures include automated systems that use either sensors or photographic means to record the necessary information. The dynamic systems have high measurement rates, require no traffic controls, operate safely in traffic, and can collect more complete data than the static procedures.

Static Procedures

Tripod Method

This method uses a three-legged device to measure rut depth. Two of the legs are opened to a width of 4 ft and placed on the pavement's surface in such a manner as to straddle the observed location of maximum rut depth. This method measures only the rut depth of wheel paths, is slow, requires extensive traffic control, is extremely hazardous to the persons performing the measurements, and does not consider the fact that sometimes the center of the road may also be lower or higher than the edges. Indeed, the measurements are only as accurate as the person's care and judgment in selecting the location of the measurement. Figure 1 shows an example of how this method could record an erroneous rut depth.

Stringline Method

This method involves stretching a piece of mason's cord across the lane and measuring the difference in elevation between the stringline and the pavement's surface. The stringline can be either held on the pavement's surface, at the lane edges, or it can be held level at some height above the pavement's surface. Measurements are typically taken at 1-ft intervals, but other intervals can be used. Although the stringline method is acceptable for measuring transverse profile and rut depth, it is still limited in that the procedure is extremely slow, requires great care in execution to be accurate, requires extensive traffic control, and exposes the operators to extreme hazard.

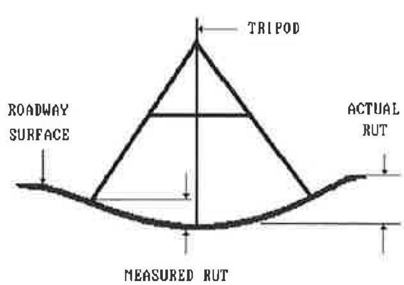

FIGURE 1 Erroneous rut measurement with tripod.

Straight Edge Method

This method involves placing a straight wooden or metal beam across the lane and measuring the distance between the pavement surface and the beam at regular intervals. The beam should be somewhat longer than the lane width and should typically have adjustable legs at each end to level the beam. Measurements are typically taken at 1-ft intervals, but other intervals can be used. Commercially available devices based on this method take and record continuous measurements or profiles along a straight edge. Although the straight edge method is an acceptable method for obtaining transverse profile and rut depth, it is still limited in that the procedure is slow, requires careful operation, requires extensive traffic control, and exposes the operators to hazardous situations.

Short Straight Edge Method

Falling somewhere between the tripod and straight edge methods, this method uses straight wooden or metal beams usually 4 to 6 ft in length to collect measurements usually over each half-lane. This method typically requires a measurement at the maximum depth point, but other intervals may be used. When the shorter beams are used, the method does not consider the fact that sometimes the center of the road is higher or lower than the edge of the road. The shorter straight edges can also be too short to span the high points defining the rut profile. In general, this method is slow, requires extensive traffic control, and is extremely hazardous to the persons performing the measurements. Indeed, the measurements are only as accurate as the person's care and judgment in making them.

Dipstick Method

This method uses a precise electronic level and profiler instrument (dipstick) to measure transverse profile. The dipstick uses a pendulum device to measure the difference in elevation between its legs. The two legs are adjustable in 2-in. increments up to 1 ft apart. By walking the dipstick across the pavement lane, a series of sequential readings is recorded, usually at 1-ft intervals, which allows the collection of adequate data to enable the plotting of a transverse profile and determination of rut depth from the profile. This method requires extensive traffic control, has the possibility of missing the point of maximum rut depth (when the 1-ft measuring interval is used), and exposes the operator to hazardous situations.

Dynamic Procedures

Automatic Sensor Systems

These systems use either ultrasonic or laser sensors to take and record measurements from 3 to 13 or more times across the width of the lane. Commercially available systems use a variety of sensors. The systems that use fewer sensors can only give an indication of whether rutting is present, because there are not enough points across the lane to develop a transverse profile. The systems that use 12 or more sensors can measure transverse profiles, similar to the straight edge method, provided that the sensors cover the full lane width. Unlike the static procedures, these systems, which operate on a moving vehicle, do not require traffic control.

The output from the sensors, which sample longitudinally at intervals of several inches, is usually analyzed and reported as an average rut depth over some distance, typically 0.1 mi. These systems are also limited in that to cover the full width of lane, wings containing the sensors are attached to the rut bars. The wings extend across the lane to the shoulder, thus creating some interference with traffic. In the systems with fewer sensors, the accuracy of the rut depth measurements depends on how well the driver stays in the actual wheel path.

35-mm Photography Systems

These systems project a line onto, and across, the pavement's surface. The line, which assumes the pavement's transverse profile, is then photographed from directly overhead. Using the film record of the transverse profile, selected coordinates along the line can be analyzed by a computer that simulates the stretching of a wire from the high points of the transverse profile. Rutting is determined by analyzing the difference in elevation (perpendicular to the wire) between the surface of the pavement and the wire. This method is commonly referred to as the "wire method" of analysis. The Strategic Highway Research Program (SHRP) uses one of the commercially available systems that uses this method for analyzing the rutting present in SHRP's long-term pavement performance (LTPP) study sites. The photographic systems have a number of advantages over the other systems in that they provide permanent records of the transverse profiles on the days of the survey, they record 15-ft transverse profiles without encroaching on either the adjacent lane or the shoulder, and they operate only at night, which minimizes interference with the traveling public. Additional information is also contained in the profiles, such as lane-shoulder dropoff and conditions.

TRANSVERSE PROFILES VERSUS OTHER RUTTING MEASUREMENTS

Transverse profiles can provide the shape, depth, and lateral location of longitudinal pavement deformations. This information can be used in determining the causes of the deformations and in determining quantities of the leveling, milling, or grinding required to correct the deformations. In addition, transverse profiles can be used to determine the potential for water to accumulate on the pavement during rain that could lead to hydroplaning. Sequential transverse profiles can also be used to help determine the extent of the deformations.

Single-measurement rut depths can only indicate whether rutting is present. They provide no information as to the shape of the deformation, the lateral location of the maximum rut, nor, in some cases, the maximum rut depth.

COMPARISON OF TRANSVERSE PROFILE MEASUREMENT METHODS

Since January 1989, the wire method used in the LTPP project has been compared to two of the accepted static methods of measuring transverse profile. In the following subsections, the wire method is compared with the straight edge and dipstick methods. The test using the straight edge method was a planned test, whereas the test using the dipstick method was an incidental opportunity.

Wire Method Versus Straight Edge Method

In January and February of 1989, PASCO USA, Inc., with the assistance of the New Jersey Department of Transportation (NJDOT) and SHRP, conducted a series of measurements on SHRP Site 341003 (*2*). This site is located on Traffic Route 15 about 10 mi north of Interstate 80.

While NJDOT provided traffic control, the locations for transverse profile measurements were marked.

Rut depth measurements were made at each location using a steel scale held vertically from a horizontal wire attached to an aluminum I-beam with adjustable supports. Measurements were made at 1-ft intervals beginning at the inside edge of the right paint stripe of the right lane.

Three sets of measurements, reading to 1/32 in., were taken at each 100-ft station. In order to verify the repeatability of the straight edge method, a second setup was made and three additional sets of measurements were taken at Station Marker 5. Repeated measurements were found to be within 1/16 in.

Three passes were made over the test site with a survey vehicle equipped with a photographic system for recording transverse profile (RoadRecon-75). The 35-mm film frames were digitized and the maximum rut depths computed using the wire method.

Table 1 presents a comparison of the straight edge measurements with the measurements from the survey vehicle. Table 1 indicates that the rut depths determined from 35-mm film taken with the survey vehicle are comparable with those obtained using the straight edge method.

Table 2 presents the effects of variations in the longitudinal interval of transverse profiles. For network level data, transverse profiles can be taken and analyzed at up to 500-ft intervals without significant effects on condition data results.

The uniform variation between the digitized data from the survey vehicle and the calculated rut depths from the measured straight edge values occurs as a result of the smoothing

TABLE 1 RUT DEPTHS—COMPARISON OF UNIT 1 WITH STRAIGHT EDGE (mm)

	Straight Edge		RoadRecon-75	
Station Mark	Left Wheel Path	Right Wheel Path	Left Wheel Path	Right Wheel Path
0	13	17	17	21
1	13	13	16	17
2	14	17	19	19
3	15	22	18	25
4	15	18	18	22
5	16	20	18	23

TABLE 2 EFFECT OF LONGITUDINAL INTERVAL ON MAXIMUM RUT DEPTH VARIABILITY (mm) USING STRAIGHT EDGE MEASUREMENTS AND WIRE METHOD OF ANALYSIS

	Left Wheel Path			Right Wheel Path		
Interval	High	Low	Average	High	Low	Average
Average of six stations (Within ±5 ft)	17	12	14.4	23	12	17.9
Within 50 ft (10-ft interval)	21	16	18.3	22	18	20.3
Within 100 ft (20-ft interval)	20	15	17.7	22	17	19.2

process in the digitized solution versus the incremented solution in the calculations from measured values.

Overall, the comparison of the wire method and the straight edge method indicates that these methods are comparable and that either one could be used to obtain transverse profiles.

Wire Method Versus Dipstick Method

In an effort to assess the feasibility of using the dipstick method on SHRP project sites when the photographic survey vehicles were not available, an unplanned comparison of the two methods was performed in Vermont (*3,4*).

In this comparison, profile measurements were performed on five SHRP sites in Vermont. These sites are located on U.S. Routes 2 and 7. The survey vehicle transverse profile measurements were taken on the night of August 9, 1989. The dipstick measurements were performed by Vermont Agency of Transportation personnel on the days of August 4, November 1, and November 17, 1989.

The survey vehicle transverse profile measurements were collected at 50-ft intervals at 30 mph, in accordance with standard SHRP procedures. The profiles were then analyzed using the wire method and standard software to determine transverse profile and rut depth.

The dipstick transverse profile measurements were collected manually at 100-ft intervals. The measurements at each transverse profile location were taken from the outside edge to the inside (centerline) of the pavement. These measurements consisted of elevations taken at 1-ft intervals with the first reading being set to zero, and the following readings taken relative to it. These measurements provide a direct measure of the pavement cross slope as well as transverse profile.

The dipstick readings were provided to SHRP by the Vermont Agency of Transportation and were used in this comparison. The readings were converted to millimeters, adjusted to remove the cross slope, and transposed to correspond to the order in which the survey system measurements were analyzed. The adjusted readings were then placed in computer datafiles identical to the files generated when the survey system films are digitized. The files were then analyzed using standard analysis software. Figure 2 is a typical plot of a transverse profile created using the adjusted dipstick measurements. Figure 3 is a typical plot of a transverse profile produced from the survey systems measurements.

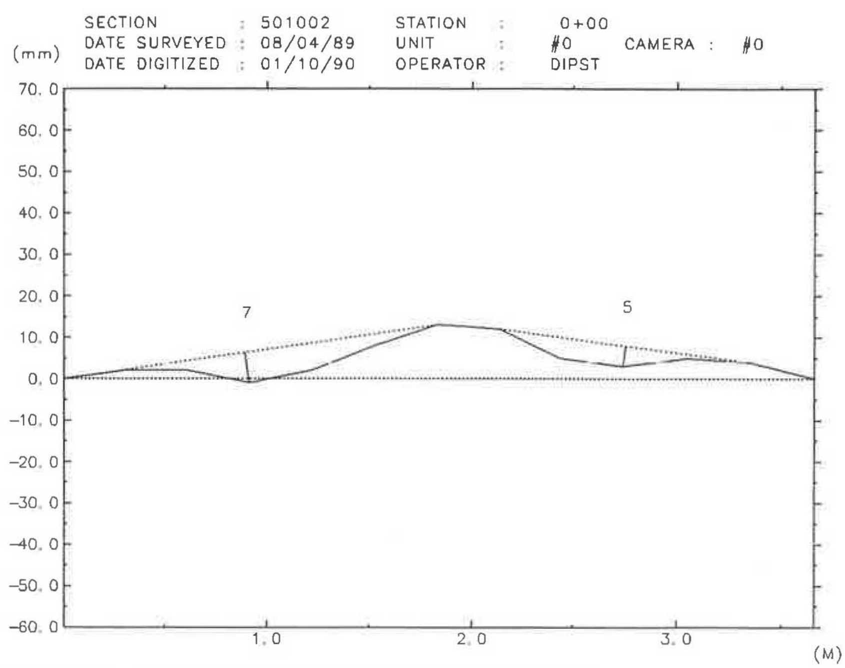

FIGURE 2 Typical plot of transverse profile with dipstick.

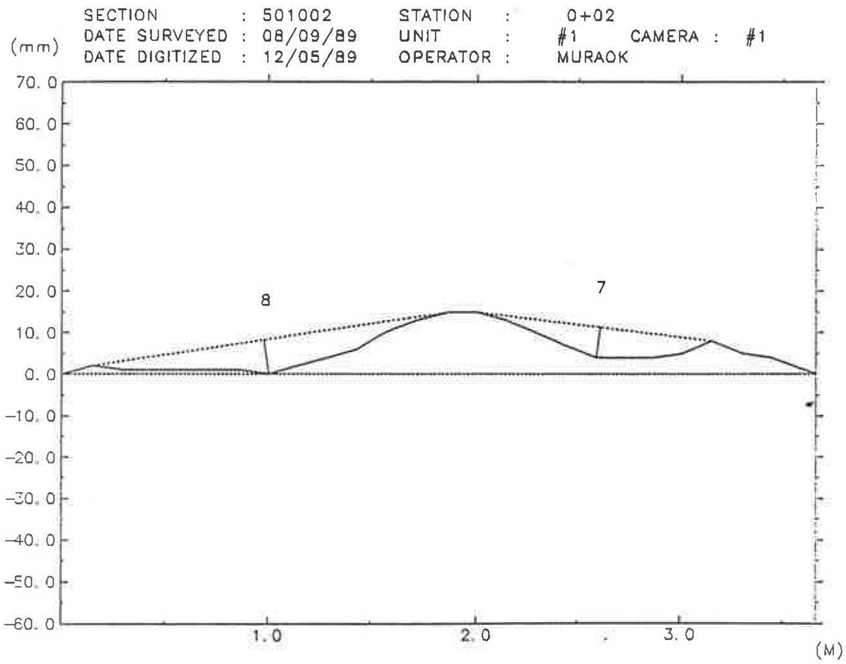

FIGURE 3 Typical plot of transverse profile with RoadRecon-75.

The points of maximum rut generated by both methods were compared for both magnitude and location. These comparisons were made in each wheel path at each 100-ft station. Table 3 presents the comparison of maximum rut magnitude and Table 4 presents the comparison of maximum rut location.

As presented in Table 3, the longitudinal placement of the transverse profile measurements varied by as much as 4 ft at any station between these methods. Yet, even with this difference in location, and the fact that the dipstick only takes measurements every foot, the average difference in magnitude for the maximum rut of all the profiles was only 0.5 mm. This difference was arrived at by subtracting the rut magnitude of the dipstick from the rut magnitude of the RoadRecon-75 for each profile and dividing by the total number of profiles. Overall, the range on the rut depths was ±3 mm (≈ ±⅛ in.) and the standard deviation was 1.3 mm.

In Table 4, the average difference in lateral location of the maximum rut was 3 mm (0.01 ft). However, the range and standard deviation of the lateral location was much larger than that of the rut magnitude. The difference in lateral location ranged from 1033 mm (3.39 ft) to −646 mm (≈ −2.12 ft) with a standard deviation of 220 mm (0.72 ft). Considering the difference in longitudinal location and measuring interval, this is considered to be good correlation.

CONCLUSIONS

Transverse profile and rut depth evaluations continue to be of great and growing importance to the highway industry. With the growing number of both static and dynamic methods to measure transverse profile and rut depth, the need for a standardized method of measurement and reporting is of increasing importance. The use of the wire method of analysis provides the highway industry with a method that can be used

TABLE 3 COMPARISON OF MAXIMUM RUT MAGNITUDES FOR SURVEY VEHICLE VERSUS DIPSTICK

Survey Vehicle		Dipstick		
Station	Rut Depth (mm)	Station	Rut Depth (mm)	Difference (mm)
Section 501681, Left Wheel Path				
0+04	10	0+00	11	−1
1+02	10	1+00	9	1
2+00	10	2+00	9	1
3+01	11	3+00	11	0
5+01	13	5+00	13	0
Section 501681, Right Wheel Path				
0+04	8	0+00	10	−2
1+02	10	1+00	10	0
2+00	9	2+00	9	0
3+01	12	3+00	10	2
5+01	10	5+00	11	−1
Section 501682, Left Wheel Path				
0+04	5	0+00	4	1
1+02	5	1+00	3	2
2+02	3	2+00	2	1
3+02	6	3+00	3	3
4+02	5	4+00	3	2
5+01	4	5+00	4	0
Section 501682, Right Wheel Path				
0+04	4	0+00	5	−1
1+02	5	1+00	5	0
2+02	3	2+00	5	0
3+02	6	3+00	6	0
4+02	6	4+00	4	2
5+01	3	5+00	5	−2

TABLE 3 (*continued on next page*)

TABLE 3 (*continued*)

Survey Vehicle		Dipstick		
Station	Rut Depth (mm)	Station	Rut Depth (mm)	Difference (mm)
Section 501683, Left Wheel Path				
0+01	20	0+00	21	−1
1+01	17	1+00	17	0
2+02	15	2+00	14	1
3+03	21	3+00	21	0
4+02	24	4+00	24	0
5+02	17	5+00	16	1
Section 501683, Right Wheel Path				
0+01	19	0+00	18	1
1+01	15	1+00	16	−1
2+02	9	2+00	10	−1
3+03	15	3+00	13	2
4+02	23	4+00	23	0
5+02	15	5+00	14	−1
Section 501002, Left Wheel Path				
0+02	8	0+00	7	1
1+01	10	1+00	8	2
2+01	8	2+00	7	1
3+00	8	3+00	6	2
3+98	7	4+00	6	1
4+98	9	5+00	8	1
Section 501002, Right Wheel Path				
0+02	7	0+00	5	2
1+01	8	1+00	6	2
2+01	4	2+00	4	0
3+00	5	3+00	8	−3
3+98	5	3+00	8	−3
4+98	7	5+00	5	2
Section 501004, Left Wheel Path				
0+03	6	0+00	5	1
1+03	5	1+00	3	2
2+03	5	2+00	4	1
3+00	5	3+00	4	1
4+00	5	4+00	4	1
5+01	5	5+00	5	0
Section 501004, Right Wheel Path				
0+03	4	0+00	5	−1
1+03	3	1+00	2	1
2+03	3	2+00	4	−1
3+00	4	3+00	2	2
4+00	4	4+00	3	1
5+01	3	5+00	1	2

Rut Magnitude Difference Statistics: maximum = 3 mm; minimum = −3 mm; average = 0.5 mm; and standard deviation = 1.3 mm.

for both static and dynamic survey methods, enabling the exchange and comparison of similar information. The use of this method by SHRP for obtaining transverse profile and rut depth data for their LTPP sites has been the first step towards some uniformity for transverse profile and rut depth analysis.

RECOMMENDATIONS

Because the wire method of analysis can be used both with manual and with automated survey techniques, and because it is used by SHRP on the LTPP sites, it is believed that the various highway agencies should strive towards adoption of the wire method as a standard for analysis of transverse profile and rut depth.

TABLE 4 COMPARISON OF MAXIMUM RUT LOCATIONS FOR SURVEY VEHICLE VERSUS DIPSTICK

Survey Vehicle		Dipstick		
Station	Rut Location (mm)	Station	Rut Location (mm)	Difference (mm)
Section 501681, Left Wheel Path				
0+04	1166	0+00	1219	−53
1+02	1309	1+00	1219	90
2+00	1275	2+00	1524	−249
3+01	1243	3+00	1219	24
5+01	1153	5+00	1219	−76
Section 501681, Right Wheel Path				
0+04	2901	0+00	3048	−147
1+02	2900	1+00	3048	−148
2+00	2857	2+00	3048	−191
3+01	2956	3+00	3048	−92
5+01	2872	5+00	3048	−176
Section 501681, Left Wheel Path				
0+04	977	0+00	1220	−243
1+02	1154	1+00	915	239
2+02	1250	2+00	1220	30
3+02	1179	3+00	1220	−41
4+02	1090	4+00	1220	−130
5+01	956	5+00	915	41
Section 501682, Right Wheel Path				
0+04	2544	0+00	2774	−230
1+02	2871	1+00	2439	432
2+02	2699	2+00	2439	260
3+02	2755	3+00	2744	11
4+02	2661	4+00	2744	−83
5+01	2718	5+00	2439	279
Section 501683, Left Wheel Path				
0+01	1272	0+00	917	355
1+01	1068	1+00	1222	−154
2+02	1034	2+00	1222	−188
3+03	992	3+00	916	76
4+02	845	4+00	915	−70
5+02	902	5+00	915	−13
Section 501683, Right Wheel Path				
0+01	3012	0+00	2748	264
1+01	2929	1+00	2748	181
2+02	2619	2+00	2748	−129
3+03	2861	3+00	2747	114
4+02	2602	4+00	2745	−146
5+02	2626	5+00	2744	−118
Section 501002, Left Wheel Path				
0+02	1005	0+00	914	91
1+01	1201	1+00	1219	−18
2+01	1249	2+00	1219	30
3+00	995	3+00	1219	−224
3+98	1136	4+00	1220	−84
4+98	1216	5+00	1220	−4
Section 501002, Right Wheel Path				
0+02	2587	0+00	2743	−156
1+01	2649	1+00	2743	−94
2+01	2678	2+00	2743	−65
3+00	2721	3+00	2744	−23
3+98	2733	3+98	2744	−11
4+98	2639	4+98	2744	−105

TABLE 4 (*continued on next page*)

TABLE 4 (*continued*)

Survey Vehicle		Dipstick		
Station	Rut Location (mm)	Station	Rut Location (mm)	Difference (mm)
Section 501004, Left Wheel Path				
0+03	885	0+00	914	−29
1+03	968	1+00	914	54
2+03	894	2+00	914	−20
3+00	1088	3+00	914	174
4+00	966	4+00	914	52
5+01	906	5+00	914	−8
Section 501004, Right Wheel Path				
0+03	2463	0+00	2438	25
1+03	2096	1+00	2743	−647
2+03	3471	2+00	2438	1033
3+00	2384	3+00	2134	250
4+00	2842	4+00	2743	99
5+01	2522	5+00	2438	84

Rut Location Difference Statistics: maximum = 1033 mm; minimum = −647 mm; average = 3 mm; and standard deviation = 220 mm.

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