# The Effect of Faulting on IRI Values for Jointed Concrete Pavements

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## Abstract

This paper presents a study on the effects that faulting of joints and cracks in concrete pavements have on International Roughness Index (IRI) values for the pavements. Three methods for comparing faulting to IRI values for roadways are evaluated in this study. The first method is a parametric study on the effect that idealized faulted profiles consisting or rotated line segments having various slab lengths and fault sizes (a saw-tooth pattern) have on IRI values. The second method is a road profile based fault size estimation routine using data from non-contact moving road profilers. Profile based faulting estimates were obtained from over 1000 GPS3 pavement profiles. The third fault measurement method evaluated is the official LTPP field measurement of faulting using the Georgia Faultmeter. This direct measurement method uses the Faultmeter placed over each joint to measure fault sizes. Faulting and IRI can be presented in the same units, m/km (in/mi) for comparison purposes. Based on this study, faulting along the roadway has gain of about 1.75 when converted to IRI. In other words for each 1.58 m/km (100 in/mi) of faulting present, about 2.76 m/km (175 in/mi) of IRI will develop, with gain increasing slightly with increasing fault spacing. The IRI gains measured for real pavement faulting matches the gain values calculated for the ideal saw-tooth patterns. Faulting data can be reliably obtained from relatively inexpensive road profile data that is being obtained for major roadways.

## Introduction

Faulting is an irritating type of roadway distress, and is a difficult form of distress to repair for jointed concrete pavements. It is essentially the loss of load transfer and continuity between adjoining concrete slabs at a joint or crack, and the development of a significant vertical offset at the joint or crack. When a vehicle drives over a fault, it is like driving off a small cliff. The vehicle mass drops and the suspension will undergo a complete transient dynamic oscillation response, working the vehicle shock absorbers. The definition of the International Roughness Index (IRI) is directly related to how much movement a shock absorber goes through in a given distance, and IRI is usually reported in units of m/km or inches per mile. Therefore, it is clear that faults will affect IRI. Past studies regarding IRI have tended to focus on roadway wave content, treating the roadway as a continuous signal, and have not focused on imperfections and discontinuities in the profile, where the curvature, or structural cross section, of the roadway is clearly not

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continuous. This study focuses on how these sudden fault type imperfections, or discontinuities, affect IRI.

The Federal Highway Administration's (FHWA) Long Term Pavement Performance (LTPP) study is the largest and most comprehensive pavement study ever undertaken. The pavement profile data within LTPP is an excellent large controlled data set of pavement profiles and has great research potential. Field measurements for faulting are also available within the LTPP database. However, based on the recent study FHWA-RD-00-076 (Selezneva et al 2000), and based on a LTPP faulting study by Byrum (2001a, 2001b), the quality of the existing field survey faulting data has been questioned and there is not much available. In addition, the recent FHWA LTPP data faulting study has recommended that profile based methods for evaluation of faulting be developed. This study compares the LTPP field survey fault measurements using the Georgia Faultmeter, to a profile based faulting index developed by Byrum (2001a) for the LTPP GPS3 jointed concrete pavements. Results from both of these methods are compared to IRI values calculated from idealized saw-tooth shaped faulted profiles. This data is used to quantify the effect of faulting on IRI values for jointed concrete pavements. This study shows that for each 1.58 m/km (100 in/mi) of faulting present along a roadway, about 2.76 m/km (175 in/mi) of IRI will accumulate in the overall IRI for that roadway.

**Effect of Idealized Faulting on IRI**

This paper starts with a simple theoretical exercise to calculate the IRI values for idealized profiles having only faulting type roughness. Figure 1 below shows idealized profiles consisting of line segments that are rotated slightly into a saw-tooth pattern to create approximately 22 mm (0.87 in) faults at joints, for 3.66 m, 4.88 m, 6.10 m, and 7.32 m (12-ft, 16-ft, 20-ft and 24-ft) slab lengths. These profiles simulate faulting due to slab rotations (rocking) from water pumping effects beneath the slabs. For IRI calculation purposes, 146.3 m (480-ft) long profiles were fabricated for each of the slab lengths shown and for repeating fault sizes of 2 mm, 5 mm, 8 mm, 11 mm, 14 mm, and 22 mm (0.08 in, 0.20 in, 0.31 in, 0.43 in, 0.55 in and 0.87 in). This idealized data set covers the range of slabs lengths and faulting encountered in typical jointed plain concrete pavements.

Figure 2 shows the resulting trends for IRI for the idealized faulted profiles. In general, IRI increases linearly with increasing fault size and decreases exponentially with respect to joint (fault) spacing. The following expression can be used to predict the IRI for pure saw-tooth shaped faulting (slab rocking type faulting) as a function of the average fault size and the joint, or fault, spacing:

$$IRI_{Faults}, \text{ in/mi} = 1346.45(\text{Avg. Fault Size, in})\, e^{-0.0461(\text{Fault Spacing, ft})}$$

(1 m/km ≈ 63.36 in/mi)

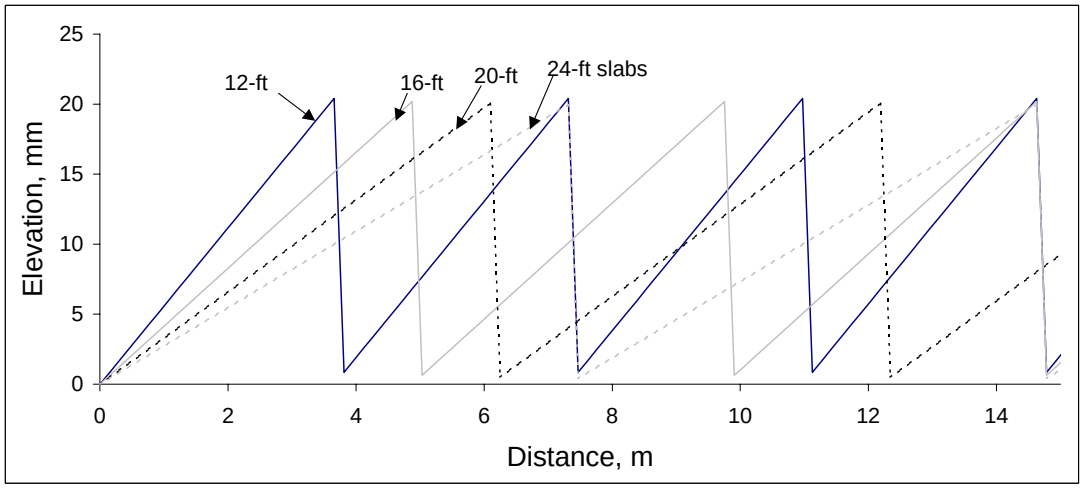



Figure 1. Idealized faulted profile data points used for IRI calculations.

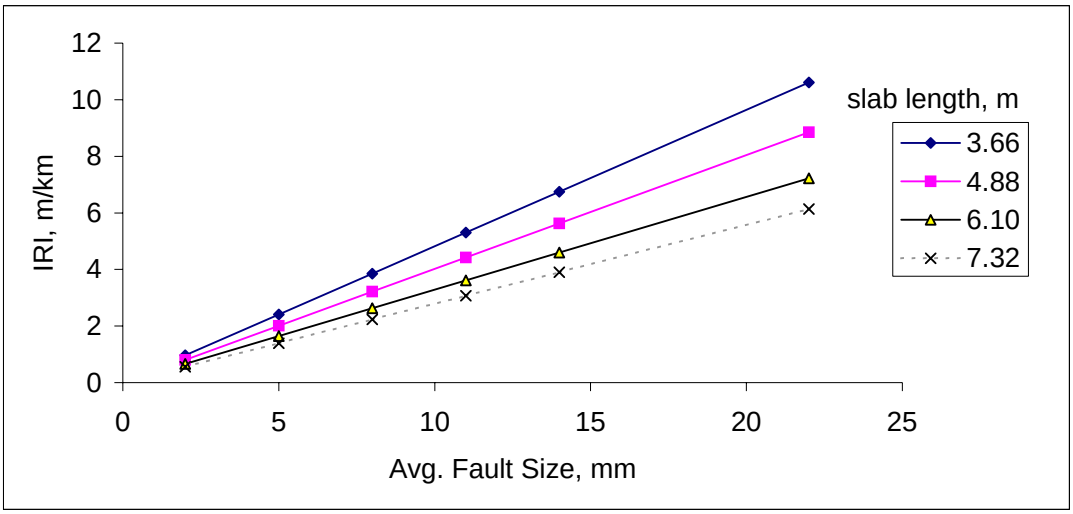



Figure 2. IRI results for the idealized faulted (saw-tooth) profile data.

## LTPP GPS3 Fault Size from the Georgia Faultmeter

Fault measurements are performed routinely at the LTPP pavement test sites using the Georgia Faultmeter (FHWA 2003). In order to measure the faulting at an LTPP test site the roadway is typically closed in order for staff to take measurements in the travel lanes. The relatively high cost of lane closures is in part why there is not a large amount of data already available regarding the factors responsible for faulting of roadways. Modern non-contact profiling devices travel down the roadway at normal driving speeds. This study will show that modern profiling devices can measure faulting reliably and can provide pavement management system data for faulting for entire profiled pavement networks at low cost without traffic interruption.

The Georgia Faultmeter was developed by Georgia Department of Transportation staff and refined for use in the LTPP program (Stone 1991). The Faultmeter is a small hand held device that allows one person to read the size of a fault ergonomically without bending down or kneeling near the pavement fault. The device is rested over the joint with two fixed feet resting on the traffic leave side of a fault, matching the slope of the Faultmeter device to the slope of the typical lower elevation slab near a fault. A linear variance displacement transducer (LVDT) probe then rests on the traffic approach side slab and reports the difference in elevation between the plane of the Faultmeter device and the adjacent slab. A digital display presents the fault size number to the operator. Purely mechanical versions using dial gages to read fault size are also available. The distance between the LVDT probe and the inner fixed leg is 100 mm and the fault is roughly centered within this distance. Therefore, Faultmeter measurements are primarily influenced by the slope and elevation present about 25 mm to 75 mm (1 to 3 inches) in each direction from the faulted joint or crack. Fault size estimates are reported to the nearest 1 mm (0.04-in) in the LTPP database. This reporting resolution is considered too large (Selezneva et al 2000). It is shown later that the average fault size for the LTPP GPS3 test sections is between 3 mm and 4 mm (0.12 in to 0.16 in). Therefore, the measurement rounding error for reporting can be 10% to 15% of the average GPS3 fault size. The measurement reporting error can be up to 50% for smaller faults near 1 mm (0.04-in) in size. Once faults become larger than about 10 mm (0.39 inches), the Faultmeter error is relatively small.

Perera and Kohn (2004) performed a study to investigate the relationship between IRI and faulting for jointed plain concrete pavements using the GPS-3 experiment data that was available in the LTPP database. The data for this study was obtained from the LTPP database in January 2003. For each GPS-3 section, the IRI corresponding to the "last" available profile date was obtained from the database (Perera and Kohn, 2004). Thereafter, the fault measurement date closest to the "last" profile date was identified in the database. Then, the fault data measured along the right wheel path corresponding to the identified date was extracted from the database. For each section, the faulting was represented by the total faulting over a given length of roadway, or the sum of the faulting measured at the joints and cracks divided by the length of roadway. There were only a very few cases where faulting was recorded at cracks, with the faulting at most of the sections occurring at the constructed joints.

When evaluating the relationship between IRI at last profile date and the total faulting, a strong relationship between IRI and total faulting was observed for the non-doweled pavements, with higher faulting values corresponding to higher IRI values. This trend was weaker for the doweled pavements. A total faulting greater 50 mm per 500-ft test section, or 0.33 m/km (21 in/mi), was observed at 7 % of the doweled sections compared to 41 % for non-doweled sections. The data from this study is included in figure 7, and is discussed more in the following sections.

**Obtaining Fault Size from Profile Data**

The profile data used in this study is the LTPP profile data from the early and mid 1990's from the KJ Law DNC690 profiling device. Starting in about 1996, a different profiling device, T-6600, became standard for LTPP profiles. The two devices behave differently at joints and cracks. One must use these two data sets together with caution when looking at the effect joints and cracks have on profile data because the data from the two devices is slightly different. In order to estimate fault size with profile data, some sort of automated numerical algorithm must be developed to first identify the location of a probable joint or crack, and then to estimate the size of the fault. If down-spikes are likely in the profile data, a more complex algorithm is required to estimate the fault size. If the combination of the sensors used and pre-filtering used reliably removes down-spikes, a more-simple algorithm can be used to predict fault size.

The K.J. Law based LTPP profile elevation data is provided at 152.4 mm (6-inch) intervals along the 152.4 meter (500-ft) LTPP GPS3 test sections. Figure 3 shows a segment of profile data points surrounding a relatively large fault. The profile data contains only point elevations evenly spaced along the roadway. Pre-filtering is performed on the LTPP profiles prior to them being made available in the LTPP database. Pre-filtering includes a moving average. The raw profile data is reported in 25.4 mm (1-inch) intervals. A 12-point centered moving average is then overlapped every 152.4 mm (6 inches) to develop the 152.4 mm (6-inch) data point spacing provided in the LTPP database. This is a smoothing technique that reduces the effect of texture and profile device variations on profile calculations. However, this smoothing technique dramatically affects profile data points near faults.

The two points within the circle in figure 3 are completely fictitious and greatly distort the data near these sudden discontinuity features. The actual fault is located somewhere between these two points within the circle. The fine dashed line in the figure is an interpretation of the real pavement shape at a fault, showing a vertical offset at a structural discontinuity. The problem with applying a moving average over a discontinuity such as a fault is that the feature becomes attenuated and a fictitious wave-form is created in the filtered profile. The fault appears as a rounded roughness feature with wave content, where in reality it is a vertical offset without wave content. It is clear based on the relative elevations of the data points near the fault in figure 3 that the profile data point just left of the fault was "moving averaged" using about 75% of data from left of the fault and 25% of the data from right of the fault. For the point right of the fault it was "moving averaged" using about 25% of data from left of the fault and 75% of the data from right of the fault. The fault is roughly centered between the 152.4 mm (6-inch) interval data points within the circle. The elevations of these two data points near a fault will vary significantly depending on where the moving average is performed relative to the fault. In the absence of down-spikes into cracks and joints, the filtered profile data will always reveal less elevation difference at a fault compared to the real fault size. With down-spikes into joints and cracks, the profile data can reveal much greater elevation differences at faults compared to the actual fault size. The presence of down-spikes caused when elevation sensors drop into joints and cracks must be

carefully considered when using profile data to estimate fault sizes. There are very few down spikes in the early LTPP road profiles.

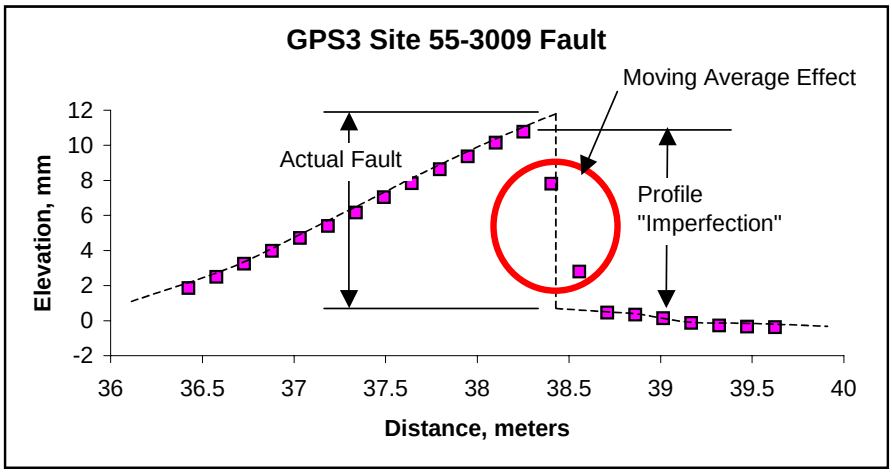



Figure 3. Profile data points near a fault. The fine dashed line is an interpretation of the real pavement fault. The two points within the circle are fictitious being affected by a pre-filtering moving-average.

Because many different features can show up in profile data and because the shape of a profile imperfection is different than the real fault, using a different name for profile discontinuity features is warranted. A method for quantifying faults within profile data has been developed by Byrum (2001a, 2001c, 2004) and has been applied to the LTPP GPS3 and GPS4 jointed concrete pavement profile data. The method refers to apparent faults in profile data as “profile imperfections”, or areas that are clearly “different” than the typical pavement profile texture.

The algorithm first reads a 152.4 m (500-ft) long profile sample and uses the finite difference forms of the first and second derivatives, using 152.4 mm (6-inch) interval data points, to develop the arc curvature vs. distance plot for the profile (Byrum, 2001a). Based on the arc curvature vs. distance data, the algorithm then determines a Curvature Variation Threshold (*CVT*) based on the unique properties of the profile to be analyzed. This parameter is designed to separate slab regions of the profile, from zones near imperfections. Profile points that exist within about 610 mm (2 feet) of a curvature estimate greater in magnitude than the *CVT* are identified as an imperfection zone and ignored. Curvature estimates used in this process are discrete curvatures as defined below:

$$curvature_n = \frac{slope_{n+i} - slope_n}{x_{n+i} - x_n} \quad , \; slope_n = \frac{y_{n+i} - y_n}{x_{n+i} - x_n}$$

where, for LTPP profiles reported on 152.4 mm (6-inch) intervals:

$i$ = 1 for the LTPP 152.4 mm (6-inch) interval roadway elevation data

The *CVT* is profile specific because a wide range of surface textures and roughness conditions can be encountered. A way of automating the determination of this parameter for profiles was developed. The *CVT* function has a minimum value (recommended as .010 $m^{-1}$ (0.003 $ft^{-1}$)) for use on very smooth texture conditions where one would expect a report of zero imperfections. The *CVT* function has a maximum value (recommended as .049 $m^{-1}$ (0.015 $ft^{-1}$)) so that profile features associated with normal cracking and joints are not overlooked. A higher upper threshold is needed for very rough textures. Finally, the *CVT* function has a working range between the lower and upper values representing the typical LTPP GPS3 pavement profiles. The upper and lower cut-off values are recommended based on the authors trial and error analyses using the K.J. Law based LTPP profile data and correlation to actual reported joint spacing and cracking for several sites. To determine a function for the *CVT*, *CVT* values were determined manually, by trial and error, for a sample group of 42 profiles of varying smoothness, age, distress, and texture. Regression analysis was then performed using various statistics determined from the profiles to back predict the *CVT* values determined manually. The resulting regression relation is used for determining the initial *CVT* values used in the analyses of profiles. When programming this method, it is best to have a visual verification and manual override feature associated with the *CVT* parameter for use with odd profiles or profiles with large down spikes, coarse texture, or for very rough profiles from older roadways. In general, seek the CVT value that reveals the maximum number of slabs greater than 4 feet (1.22 m) in length per unit length of roadway (Byrum, 2001a). The resulting non-linear regression developed to predict a *CVT* for a typical filtered LTPP 6-inch (152.4 mm) interval data profile is:

$$CVT = {}^{1}/_{12}[\ -0.0213+0.03242(all06CvStDev)^{0.8045} + 0.00665(all24CvStDev)^{1.1446} - 0.06631(all48CvStDev)^{3.7819}]\ ft^{-1}$$

$$0.003 < CVT < 0.015\ ft^{-1}$$

$$(0.0098 < CVT < 0.0492\ m^{-1})$$

where,

*all06CvStDev* = Standard deviation of all 152.4 mm (6-inch interval) moving-arc curvatures, 1/ft x 1000 (LTPP range ≈ 2 to 12)
*all24CvStDev* = Standard deviation of all 609.6 mm (24-inch interval) moving-arc curvatures, 1/ft x 1000 (LTPP range ≈ 0.4 to 3)
*all48CvStDev* = Standard deviation of all 1219 mm (48-inch interval) moving-arc curvatures, 1/ft x 1000 (LTPP range ≈ 0.2 to 1.2)
(1 m = 3.2808 feet)

Once the areas of the profile have been detected that have curvature spikes exceeding the curvature variation threshold, the sizes of the imperfections within

each of these curvature spike regions are estimated. The equation used for determining the reported imperfection size is as follows:

$$Imperfection\ Size_i = 1.125(Max\ Elevation_i - Min\ Elevation_i)$$

where,

*Imperfection Size*$_i$ = Fault size estimate for curvature spike region, *i*
*Max Elevation*$_i$ = maximum elevation within curvature spike region *i*
*Min Elevation*$_i$ = minimum elevation within curvature spike region *i*

The 1.125 factor is from a geometric study and reflects that the maximum elevation difference in the profile data points after the pre-filtering is performed is typically less than the actual fault size, as shown in figure 3. Based on the 152.4 mm (6-inch) data spacing used, and the typical range of slope values at faults from factors such as slab rotation and warping, the actual fault size could be up to 15% larger than the maximum elevation difference between data points in the pavement profile curvature spike region. A 12.5% size increase factor was selected for estimating the fault size from pre-filtered LTPP profile data for this study. The final statistics accumulated from the profile include the average imperfection size, minimum imperfection size, maximum imperfection size and the total imperfections for 152.4 mm (500-ft) profile sample intervals. The expression used for what was found to be the most important faulting statistic, *Total Imperfections* is as follows:

$$Total\ Imperfections = \sum_{i=1}^{n} Imperfection\ Size_i$$

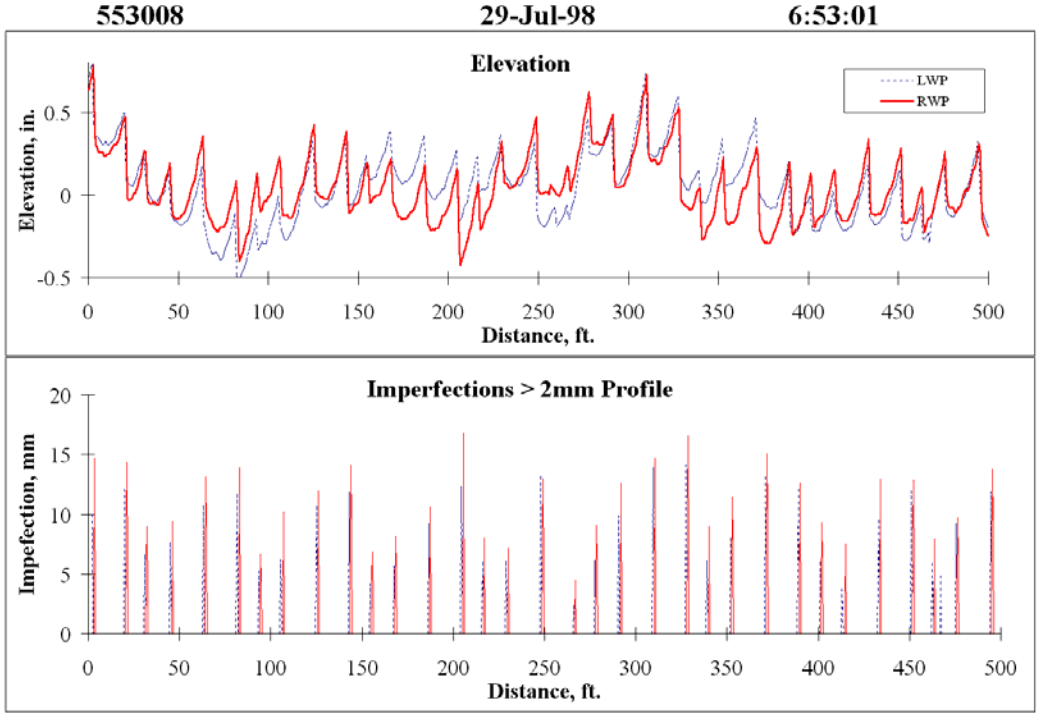
Where,

*Total Imperfections* = sum of sizes > 2mm, in the 500-ft pavement sample.
*n* = total number of imperfections > 2 mm for the 500-ft pavement sample.

The profile analysis method will also attempt to identify and quantify imperfections below 2 mm in size. However, these very small imperfections are not reported as faults, only hinges. Only fault sizes estimated to be greater than 2 mm were reported or accumulated in the summary faulting statistics used for this study. This 2 mm cut-off value is somewhat arbitrary but is also based on typical PCC texture size. For very smooth pavement texture, 2 mm fault size is reliably visible in profile data. However, for typical large rough texture, a 2 mm fault is as small or smaller than the texture size. Faulting, or the total imperfections parameter, should also be reported in the same units as IRI so that the two parameters can be compared directly.

Figure 4 shows the LTPP profile for site 55-3008 and provides a profile based fault size estimate plot for the imperfection statistics. Fault sizes are shown as spikes in the lower plot. Table 1 provides the summary statistics for the profile shown. The profile based fault detection method identifies each joint location and its fault size. The lower fault plot reveals the alternating joint spacing used for construction of this roadway. An alternating joint spacing of 3.96 m, 4.27 m, 5.79 m, and 5.49 m (13-ft, 14-ft, 19-ft, 18-ft) was used. The estimated fault sizes range from about 3 mm to about 17 mm (0.12-in to 0.67-in). The faulting in the right wheel path is significantly larger than in the left wheel path with total imperfection estimates of 2.4 m/km and 1.96 m/km (152 in/mi and 124 in/mi) of faulting, respectively. The slabs between the faults have a noticeable upward warp with a curvature magnitude of about 1.31 1/mx1000 (0.40 1/ftx1000) (Byrum, 2001a). This type of road roughness is very troublesome for trailers without suspensions, or for vehicles having very stiff suspensions with low damping. For this roadway segment, only one imperfection in addition to the joints was detected, in the left wheel path at about 141.7 m (465 feet). Otherwise, all observed faulting at this site is at the constructed joints. This pavement section has large faults, fine texture and warped slabs, a combination that allows for easy detection of faults and quantification of fault size and warping magnitude (2). As faulting gets smaller and smaller approaching the size of texture, the faults will eventually get lost within the profile "noise" related to the pavements texture and profiler sensor resolutions.

Figure 4. Output plot for the profile based faulting (imperfection)




detection analysis results for the site 55-3008 showing the profile elevation data and the estimated fault sizes and locations. (1-ft ≈ .3048 m, 1 in ≈ 25.4 mm)

Table 1. Summary Statistics Output for the Profile Data in Figure 4

**Site ID:** 553008
**Profile Date:** 7/29/98
**ProfileTime:** 6:53:01

| ***500-ft Summary Statistics*** | **LWP** | **RWP** |
|---|---|---|
| # Imperfections detected | 34 | 33 |
| Average Size, mm | 8.8 | 11.1 |
| Maximum Size, mm | 14.2 | 16.7 |
| Minimum Size, mm | 2.4 | 4.4 |
| Total Imperfections, mm | 298.7 | 367.8 |
| **Total Imperfections, m/km** | **1.96** | **2.41** |
| **Calculated IRI, m/km** | **4.42** | **5.43** |

The fault size statistics shown in Figure 4 and Table 1 were collected for all of the early GPS3 and GPS4 pavement profiles within the LTPP Database. IRI values calculated from these same profiles are also included within the LTPP database. Figure 5 shows the frequency distribution for the average fault sizes detected from the GPS3 right wheel path profiles used for this study. The average "per-site" wheel path fault size detected for the 152.4 m (500-ft) long LTPP road profiles was 3.1 mm (0.12 inches) and ranged from 0 mm to about 32 mm (0 to 1.26 inches) per test site. Per-site average fault size values greater than about 10 mm (0.39 inches) are typically anomalies or sites with localized pavement failures. These profile fault size measurements are compared to the IRI values and also to the actual field measurements of fault sizes in the following sections.

Figure 6 shows how the profile faulting trends developed with time for each of the GPS3 test sites. This plot includes the early KJ Law based profile data (2) and also includes data from the "last" or most recent profile obtained for the LTPP study (Perera and Kohn, 2004). Two plots are presented one for doweled pavements and one for pavement with no dowels at joints. Both plots have a large mass of good performers that generally follow the same trend having a trend slope value less than 3.0. The general trend lines shown indicate that on average, joints with no dowels will fault at about 30% to 35% faster than doweled joints for the design methods employed for the GPS3 test sections. This data set for LTPP GPS3 test section faulting vs. time would be an excellent data set for developing a faulting prediction model (Byrum, 2001b). The time trends are smoother than those observed for the Faultmeter data, and there is more profile based faulting data available for each site.

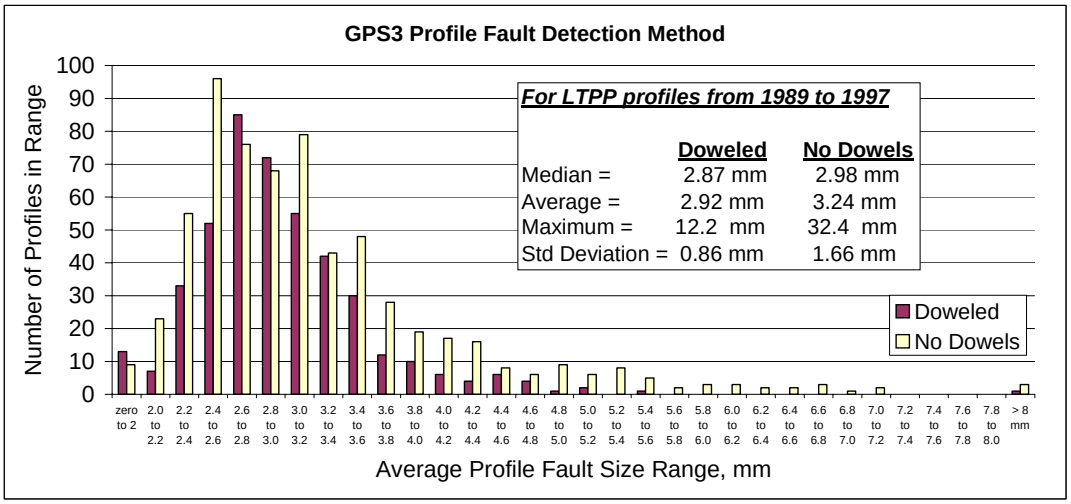



Figure 5.Frequency distribution for the average per-site fault sizes for the LTPP GPS3 152.4 m (500-ft) long road profiles from the 1990's KJ Law device.

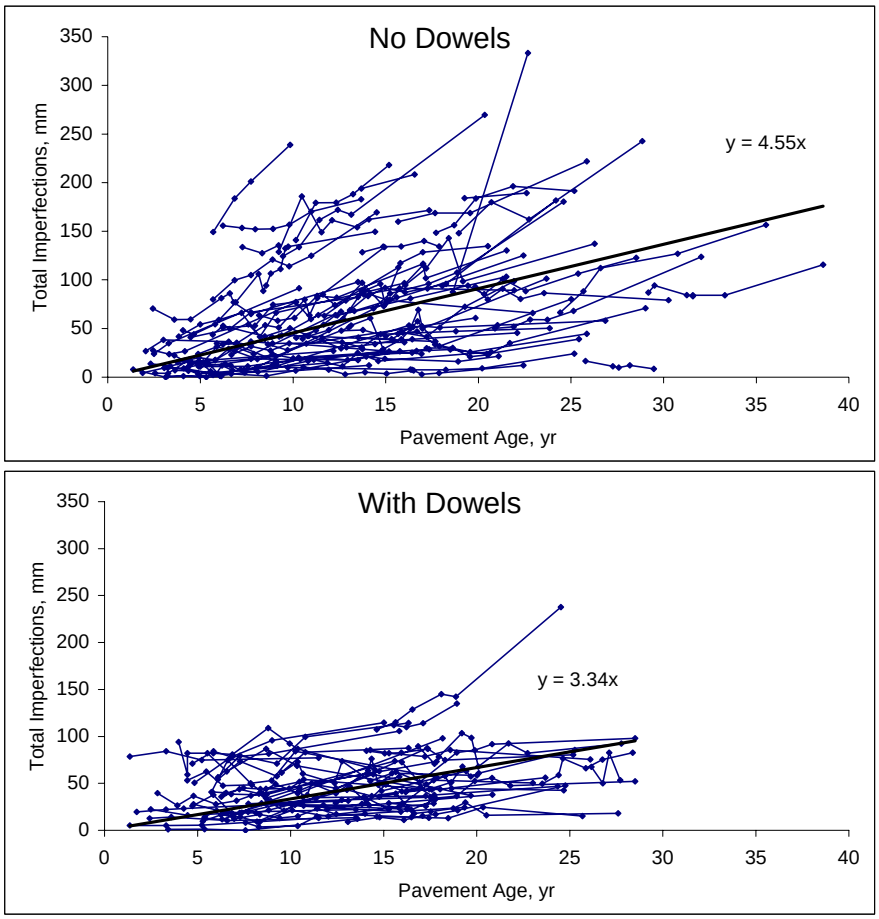



Figure 6. Time series trends for faulting observed in the road profile data for the GPS3 test sites.

## Results

Figure 7 shows the overall scatter plot for GPS3 IRI vs. the *Total Faulting* statistics for the Faultmeter measurements, the profile based fault size quantification method, and the idealized saw-tooth profile data. Because the total faulting and IRI are plotted using the same units, the slope of the trend lines shown represents the "gain" of the IRI filter in response to faults. The four fine gray lines show the IRI trends for the ideal saw-tooth patterns for slabs between 3.66 m and 7.32 m (12-ft and 24-ft) in length. These trend lines were arbitrarily given a y-intercept value of 1.1 to match the observed y-intercept for the real GPS3 pavement profile data. These plots have increasing gain values between about 1.76, for the 3.66 m slabs (12-ft), to about 2.04 for the 7.32 m (24-ft) slabs. The decreasing gain with decreasing fault spacing indicates there is some negative interference between the overlapping transient suspension responses from each fault as slab lengths decrease, especially for fault spacing less than 4.88 m (16 feet).

The trend slopes, or IRI gains, predicted from the profile method vs. the Faultmeter method are 1.76 and 1.46, respectively. However, the slope value for the trend fit through the Faultmeter survey data may be shifted due to inherent bias in the LTPP database faulting data. Notice how there are many data points for the field surveys that report zero faulting but have high IRI values. These erroneous zero-values were also noted to be a problem by other research projects. The quality of these reported zero values are suspect. For a given roadway test section, there are often these zero values reported in the LTPP database immediately before and after surveys that had identified significant faulting, which further puts these zero values in question. If these suspect data points are removed, the gain values from both data sets are near 1.75. Any reports in the LTPP database of zero faulting for sites having IRI values higher than 1.5 m/km (95 in/mi) be carefully reviewed or arbitrarily eliminated as they are likely in error and some faults are probably present. The current 2002 mechanistic empirical pavement design guide (NCHRP 1-37) methodology uses a faulting gain factor of 1.5 within the performance model used to predict IRI of jointed concrete pavements as shown on page 22 of Appendix PP in the 2002 design guide (Titus-Glover et al 2003). The IRI model in the design guide was calibrated based on LTPP data, and the gain factor used in the model is close to the same as the gain factor observed in this study for the LTPP field Faultmeter survey data trend when including the questionable zero-fault data.

Notice how the trend for the profile based fault measurement method (the heavy black line) matches the trend for ideal saw tooth profiles with slab lengths of about 3.66 m (12-ft). Recall that the author used a size adjustment factor of 12.5% increase for the profile based fault size estimates. Without the size adjustment the slope or gain factor would be increased by 12.5% and would be about 1.98 matching the ideal trends for longer slabs. The 1.76 gain factor is the gain estimated on average for the true fault sizes, and the 1.98 gain factor would apply to the imperfection size within the profile data. This makes sense because about 60% of the LTPP GPS3 pavement test sites have slab lengths between 4.26 meters and 5.18 meters (14 feet and 17 feet), with an average slab length of 5.1 meters (16.6 feet). The ideal saw-tooth pattern gain for a 4.88 m (16-ft) joint spacing is about 1.96. The

LTPP GPS3 test sections have slab lengths ranging from 3.47 m to 9.14 m (11.4 feet to 30 feet) with only 13% of test sites having joint spacing less than 4.26 meters (14 feet). Based on the profile based faulting method and considering all of the zero fault size measurements described above, the gain factor of 1.75 should be used for estimating faulting effects on IRI values.

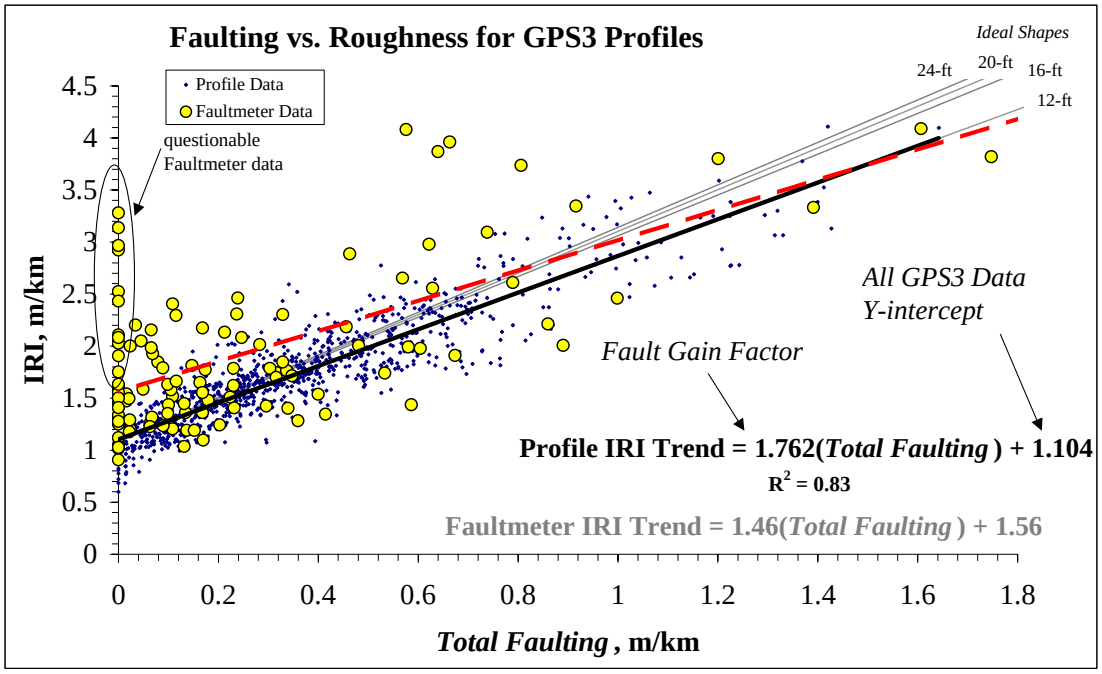



Figure 7. Results for the three different methods of predicting the effect of faulting on IRI values.

Figure 8 shows trends for the profile based fault prediction method compared to the Faultmeter measurements for an individual LTPP test site (GPS3 55-3009) that developed large faults. Four sets of profiles were obtained from this test section for the LTPP study, between 1990 and 1994. Two field distress surveys were performed for the test section between 1991 and 1995, after which this test section was terminated, rehabilitated and overlaid. The estimation of fault sizes from rapid profile measurements taken without road closures are suitably similar to the field measurements of fault sizes. The author has experience using the faultmeter in the field and also the profile based faulting analysis. Both methods have inherent errors. For example, if several readings are taken at a joint using the faultmeter, the standard deviations of those readings can be high. This is more-true for pavements that have rough exposed texture or spalling surrounding the faults. The faultmeter uses the zone about 75 mm (3-inches) on each side of the joint for the fault size measurement, where as the profile technique uses a zone extending about 0.61 m (2 feet) in each direction and is using pre-smoothed and filtered data points. Faultmeter size estimates are affected by the slopes of the slabs on each side of the fault. Based on experience, the faultmeter based LTPP data has more variability within the time-series faulting development trends from site to site, compared to the profile based

faulting time trends. With both of the measurement methods, the ability to measure the fault size diminishes with decreasing fault size. The differences between the two methods would be greater for smoother roadways where fault sizes are near the measurement resolution levels of the measurement methods.

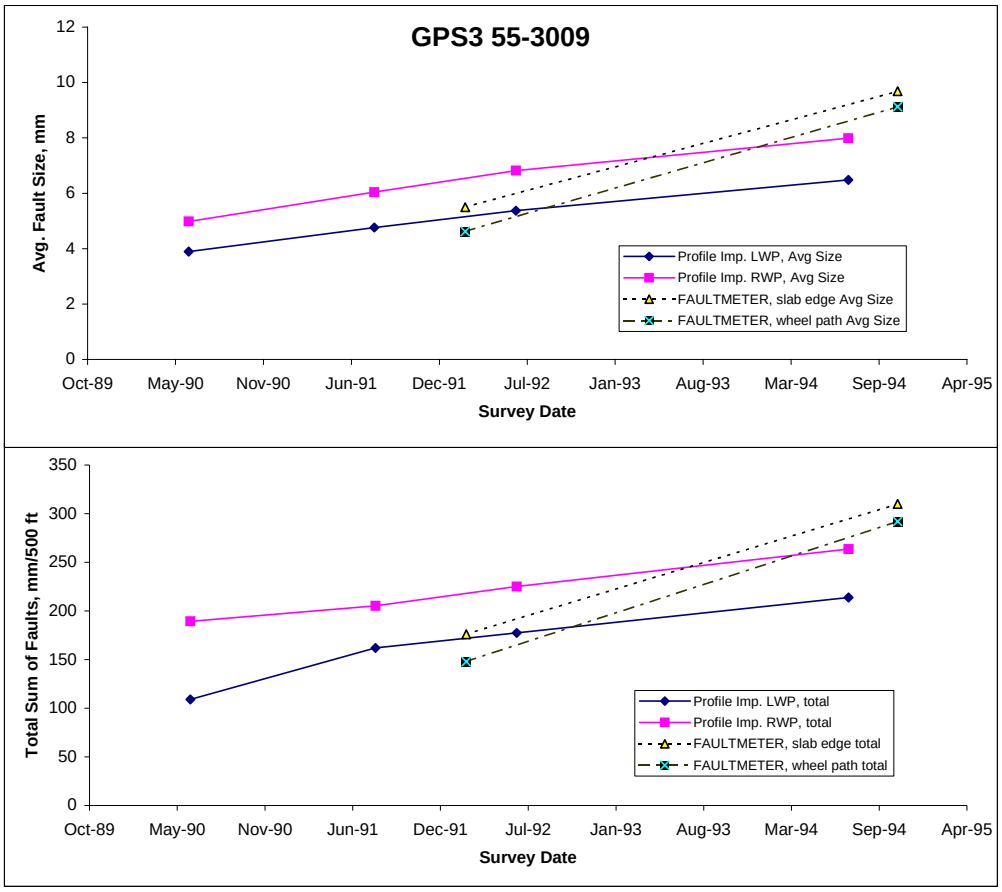



Figure 8. Site-specific comparison of profile based fault predictions and actual Faultmeter measurements.

## Conclusions

This paper presents a detailed comparison of three methods for predicting the effect of faulting on IRI measurements for LTPP GPS3 type jointed concrete pavement profiles. The three methods are; 1.) Calculating IRI directly for idealized faulted saw-tooth shaped profiles, 2.) Correlating LTPP database IRI values with the field Georgia Faultmeter survey measurements of fault sizes, and 3.) Estimating fault sizes directly from the LTPP profiles and comparing them to the calculated IRI values from those profiles. Faulting and IRI can be presented in the same algebraic units. When reported in the same units, the apparent gain for the IRI profile filter with respect to faulting can be analyzed. Idealized saw-tooth profiles simulating fault sizes and spacing encountered in real pavements have apparent gains between about 1.75 and 2.0 for slab lengths between 3.66 m and 7.32 m (12 feet and 24 feet) in

length. Based on the profile based fault quantification method by Byrum, the GPS3 pavements have an average gain value of about 1.76 for faulting to IRI, for an average slab length of about 5.06 m (16.6 feet). This matches well with the ideal saw-tooth profile analyses. The average gain for the "last" Georgia Faultmeter to IRI data set is about 1.46 when including questionable value for sites having very high IRI but reporting no faulting. When these questionable zero-fault data points are removed from the Faultmeter data set, the apparent gain is about 1.76, which matches both the ideal saw-tooth pattern trends and the profile based fault prediction trends. The current NCHRP 1-37 Mechanistic Empirical Design Guide IRI performance model is using a gain factor of 1.5, which matches the Faultmeter trend with the questionable zero-fault data included. In closing, based on this study a gain factor of 1.75 is recommended for general use in predicting the effects of faulting on IRI values. The NCHRP 1-37 mechanistic empirical design team should consider increasing the fault gain factor in the current IRI performance prediction model for JPCP.

The relations between faulting and IRI resulting from this study are valuable to pavement engineers. They allow pavement engineers to estimate the magnitude of faulting at a site directly from the IRI values from profiles obtained from the site. The pavement engineer would first estimate the initial IRI value for the site, and the average fault spacing. For most typical freeway jointed concrete roadways that don't have extensive spalling or slab warp, the difference between the current IRI and the initial IRI is mostly due to faulting. That IRI change from initial to current time can be used to estimate the average fault size by dividing the IRI difference assumed to be from faulting by the 1.75 gain factor, and dividing again by the number of joints per unit length of roadway.

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