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PROFILE ANALYSIS OF THE LTPP SPS-6 SITE IN ARIZONA

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16. Abstract

This report characterizes the longitudinal profiles of five pavement sections within the Arizona Specific Pavement Studies 6 project throughout their service life. This project was built and monitored as part of the Long-Term Pavement Performance Study. Road profile measurements were collected on this site about once per year since the fall after it was opened to traffic. This study analyzed the profiles in detail by calculating their roughness values, examining the spatial distribution of roughness within them, viewing them with post-processing filters, and examining their spectral properties. These analyses provided details about the roughness characteristics of the road and provided a basis for quantifying and explaining the changes in roughness with time, relating post-rehabilitation roughness with rehabilitation type, surface preparation, and profile properties, as well as linking profile properties to each section's maintenance history and observations of surface distress.

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Introduction

This report provides the results of profile and roughness analyses for the Long-Term Pavement Performance (LTPP) Specific Pavement Studies 6 (SPS-6) site in Arizona. SPS-6 sites were established for the study of jointed Portland cement concrete pavement rehabilitation strategies, including the surface preparation type, overlay material and overlay thickness. *(1)*

These test pavements were constructed in the travel lane of eastbound Interstate 40 in the summer of 1990. The site extends from Milepost 195 to 205. Eight sections were constructed as part of the standard experiment. These sections have the same design characteristics as the standard eight sections on the SPS-6 sites throughout the LTPP study, as well as the same guidelines for pre-construction maintenance and subsequent rehabilitation. This SPS-6 site also included eleven supplemental test sections designed by the Arizona Department of Transportation (DOT).

Table 1 summarizes the rehabilitation designs for the test sections. Minimum restoration "includes joint and crack sealing, partial and full-depth patching, and full surface diamond grinding." *(1)* Maximum restoration "includes removing and replacing existing joint and crack sealing, performing additional joint and crack sealing, removing and replacing existing partial and full-depth patching, performing additional partial and full-depth patching, correcting poor load transfer at joints, full surface diamond grinding, retrofitting subsurface edge drains, and undersealing." *(1)*

This report seeks to characterize the surface roughness of these sections over time, and link the observations to records of pavement distress and its development. Road profile measurements were collected on this site about once per year since the fall after it was opened to traffic. This study analyzed the profiles in detail by calculating their roughness values, examining the spatial distribution of roughness within them, viewing them with post-processing filters, and examining their spectral properties. These analyses provided details about the initial roughness of the road and provided a basis for quantifying and explaining the changes in roughness with time.

Profile Data Synchronization

Profile data were collected at the Arizona SPS-6 site on fifteen dates, listed in Table 2. Raw profile data were available for all fifteen visits. Each visit produced a minimum of six repeat profile measurements. Visit 00 took place before the original rehabilitation, and only covered sections 0601-0663. Visit 01 took place just after the original rehabilitation. Profiles of visit 01 excluded sections 0660, 0663, 0608, and 0607, because data collection was triggered in an incorrect location. Sections 0601, 0602, and 0605 were removed from the study after visit 04. In visits 02 through 08, the raw measurements covered the entire site in one long profile. In visits 09 through 13, the raw measurements covered "leading" sections 0603-0663 in one profile and "trailing" sections 0664-0669 in another.

Table 1. Arizona SPS-6 Site Rehabilitation Alternatives.

Section	Surface Preparation	Overlay Material	Overlay Thickness (in)
0601	Routine Maintenance	None	—
0602	Minimum	None	—
0603	Minimum	AC	4
0604	Saw and Seal/Minimum	AC	4
0605	Maximum	None	—
0606	Maximum	AC	4
0607	Crack and Seat	AC	4
0608	Crack and Seat	AC	8
0659	Fabric/Crack and Seat	AC	4
0660	Rubblize	AC	8
0661	Crack and Seat	ARAC/AC	2/2
0662	Crack and Seat	AC/ARAC	2/2
0663	Crack and Seat	PCC/AC	10/1
0664	None	AR-ACFC	0.5
		ARAC/AC	2/3
0665	Crack and Seat	AR-ACFC	0.5
		ARAC/AC	2/3
0666	Rubblize	AR-ACFC	0.5
		ARAC/AC	2/3
0667	Crack and Seat	AR-ACFC	0.5
		ARAC/AC	2/3
0668	None	AR-ACFC	0.5
		ARAC/AC	2/3
0669	Rubblize	AR-ACFC	0.5
		ARAC/AC	2/3

AC — Asphalt Concrete
PCC — Portland Cement Concrete
ARAC — Asphalt Rubber Asphalt Concrete
ACFC — Asphalt Concrete Friction Course
AR-ACFC — Asphalt Rubber-Asphalt Concrete Friction Course

Table 2. Profile Measurement Visits of the SPS-6 Site.

Visit	Date	Time	Rep's	Sections Missing
00	09-Apr-1990	19:14	7	0664-0669
01	27-Sep-1990		7	0607, 0608, 0660, 0663
02	16-Sep-1991	12:32-14:15	6-7	—
03	27-Feb-1992	00:56	6	—
04	12-Feb-1993	14:29-17:13	9	—
05	21-Jan-1994	06:24-08:33	9	—
06	02-May-1995	14:04-16:57	9	—
07	19-Feb-1997	11:06-13:11	9	—
08	17-Apr-1998	10:16-11:33	7	—
09	02-Mar-1999	10:36-12:28	7	—
10	14-Mar-2000	10:43-12:17	7	—
11	17-Aug-2000	10:40-12:39	8-9	—
12	07-Feb-2001	10:50-12:46	9	—
13	15-Feb-2002	10:24-12:21	9	—
14	28-Oct-2002	17:52-19:54	9	—

Data Extraction

Profiles of individual test sections were extracted directly from the raw measurements. Raw profiles provided data recorded at a short interval of 0.98 in for visits 07 through 13 and 0.77 in for visit 14. The raw profiles included multiple (if not all) test sections within each pass. As such, they provided the opportunity to refine the consistency of section boundaries over time.

Three clues helped extract the correct profile segments from the long raw measurements: (1) the design layout, (2) event markers in the raw profiles showing the start and end of each section, and (3) automated searching for the longitudinal offset between repeat measurements.

Cross Correlation

Searching for the longitudinal offset between repeat profile measurements that provides the best agreement between them is a helpful way to refine their synchronization. This can be done by inspecting filtered profile plots, but it is very time consuming. Visual assessment is also somewhat subjective when two profiles do not agree well, which is often the case when measurements are made a year or more apart. An automated procedure, rather than visual inspection, was used for finding the longitudinal offset between measurements.

The procedure is based on a customized version of cross correlation. *(2)* In this procedure, a "basis" measurement is designated that is considered to have the correct longitudinal positioning. A "candidate" profile is then searched for the longitudinal offset that provides the highest cross correlation to the basis measurement. A high level of cross correlation requires a good match of profile shape, the location of isolated rough spots, and overall roughness level. Therefore, the correlation level is often only high when the two measurements are synchronized. When the optimal offset is found, a profile is extracted from the candidate measurement with the proper overall length and endpoint positions. For the rest of this discussion, this process will be referred to as *automated synchronization*.

For this application, cross correlation was performed after the International Roughness Index (IRI) filter was applied to the profiles, rather than using the un-filtered profiles. This helped assign the proper weighting to relevant profile features. In particular, it increased the weighting of short-wavelength roughness that may be linked to pavement distress. This enhanced the effectiveness of the automated synchronization procedure. The long-wavelength content within the IRI output helped ensure that the longitudinal positioning was nearly correct, and the short-wavelength content was able to leverage profile features at isolated rough spots to fine-tune the positioning.

Visits 01 through 14

For visits 01 through 14, profiles of individual test sections were extracted from the raw measurements using the following steps:

1. Establish a basis measurement for each section from visit 02.

This was done using the event markers from a raw measurement. The first repeat measurement was used for this purpose. Event markers appeared at the start and end of every section. The locations of the event markers were compared to the layout provided in the construction report. (*1*) Unlike the event markers for the later visits, the events markers from repeat 1 of visit 02 exhibited a linear relationship with the section starting locations listed in the construction report. In particular, the event markers for section 0663 were not consistent with the construction report in later visits.

2. Automatically synchronize the other eight repeats from visit 02 to the basis set.
3. Automatically synchronize the measurements from the next visit to the current basis set.
4. Replace the basis set with a new set of synchronized measurements from the first repeat of the current visit.
5. Repeat steps 3 and 4 until visit 14 is complete.

A basis set for visit 01 was extracted from repeat 1 using automated synchronization to the basis set from visit 02. The remaining repeat measurements were then synchronized to the new basis set.

Visit 00

Visit 00 was difficult to synchronize to later visits, because it took place before major rehabilitation was performed on most of the test sections. A basis set of measurements from visit 01 only produced a significant match for sections 0601 and 0602, because all the other test sections received extensive surface preparation and most of them received a subsequent overlay. To further complicate matters the profiles from visit 00 included several spurious event markers.

For visit 00, profiles of individual test sections were extracted from the raw measurements using the following steps:

1. Extract basis measurements of section 0601 and 0602 from repeat 1 of visit 00 using automated synchronization to visit 02 profiles.

    Repeat 2 from visit 02 was selected for this purpose, because it was more consistent to the longitudinal distance measurement in visit 00 than the other repeats.

2. Extrapolate the expected boundaries of the remaining test sections and extract a basis set from repeat 1 of visit 00. Assume a linear relationship between the design layout and the distribution of sections within the profile, given the distance between sections 0601 and 0602 found using automated synchronization.
3. Automatically synchronize the other repeat measurements to the new basis set from visit 00.

Special Observations

Section 0668

The construction report listed test section 0668 as 400 ft long. However, the event markers in the raw profile for the start and end of the section appeared 500 ft apart in all visits. It was assumed that the section was 500 ft long. Note that this affects the profiles for section 0669, which start at the end of section 0668.

Sections 0601, 0602 and 0605

The data extraction and synchronization procedures described above produced profile boundaries that were quite consistent with LTPP database profiles for sections 0603, 0604 and 0606-0608. In most cases, the synchronized data overlapped profiles from the LTPP database by more than 99 percent. This was not the case for sections 0601, 0602 and 0605. LTPP database profiles of section 0601 lead the actual section start by more than 50 ft in visit 00, and lag the actual section start by nearly 200 ft in visit 03. LTPP database profiles of section 0602 from visit 00 lead the actual section start by about 40 ft in visit 00, and lag the section start by at least 175 ft in visits 02 through 04. For section 0605, LTPP database profiles from visit 00, 02, and 04 lead the actual section start by about 10-30 ft.

Longitudinal Distance Measurement

The basis measurements for visit 02, established in step 1, above, were set using the event markers in one raw profile measurement (the first repeat). The locations of these markers agreed very well, but not perfectly, with the layout provided in the construction report. For example, a least-squares linear fit was drawn between the layout of the event markers and the starting locations listed in the construction report. For the leading group of sections (from the start of the site to the end of section 0603), the slope of the fit was 0.9932. This implies that the longitudinal distance measurement made by the profiler was consistent with the construction report to within 0.68 percent, and that the profiler measured distances slightly longer than expected. No individual section boundary deviated from the best-fit line by more than a foot.

The other eight repeats from visit 02 were automatically synchronized to the basis set. When the layout of section starting locations for the leading group of sections was compared to the locations listed in the construction report for each of these repeats, the slope of the linear fit ranged from 0.9971 to 1.0023. Thus, the longitudinal distance measurement for the nine profile measurements of visit 02 was consistent within 0.52 percent.

Figure 1 shows the disagreement in longitudinal distance measurement for each visit of the leading group of sections, using the event markers from repeat 1 of visit 02 as a reference. The leading group terminates at the end of section 0601 for visits 00 through 04, and at the end of section 0603 for the other visits. In the figure, a range of disagreement for each visit exists because up to nine repeat profile measurements were made. The variation between repeat measurements from the same visit appears as the width of each bar in the figure. Since the longitudinal distance measurement was based on the rotation of a drive wheel, the variations were most likely caused by variations in speed, lateral wander, and tire inflation pressure. (*3*) If tire inflation pressure were the dominant cause, the disagreement would grow more negative (or less positive) with each successive repeat measurement as the tire heated up. This is because the tire rolling radius would increase, and the profiler would register less wheel rotation for the same travel distance. This appeared to be the case for visits 08 through 13. However, the effect was weak, which indicates that the tires were warmed up to some extent before the measurements began. The only visit that exhibited a level of disagreement between repeat measurements that may interfere with the analyses described in this report was 02.

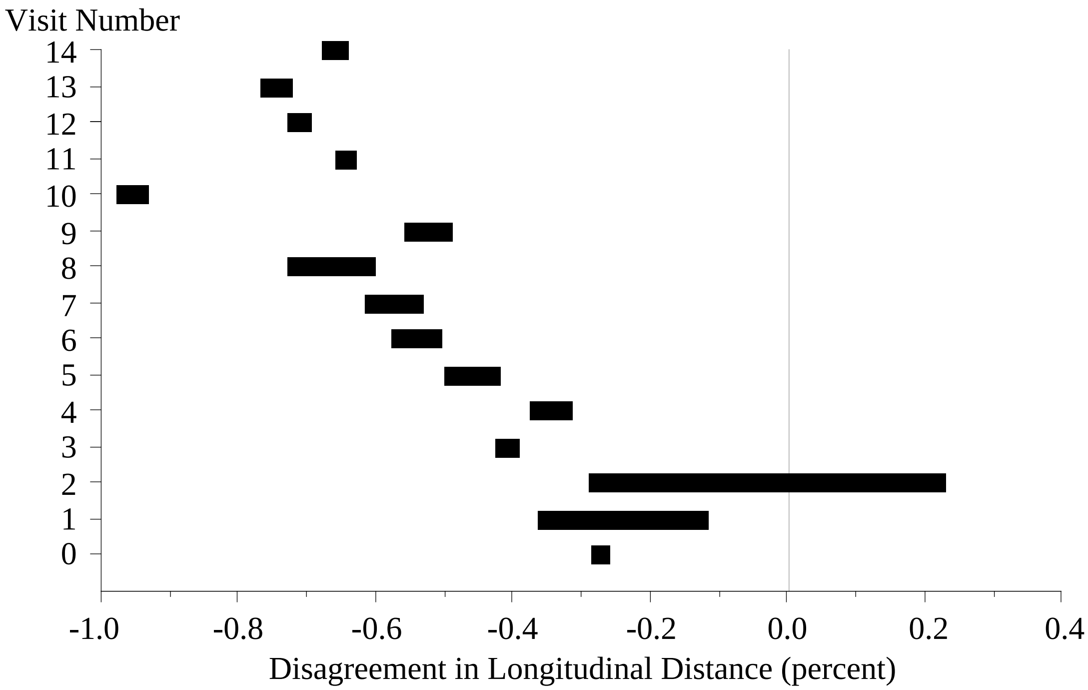

Figure 1. Consistency in longitudinal distance, leading sections.

The variation between visits in Figure 1 is caused by differences in distance measurement instrument calibration. The longitudinal distance measured by a profiler is not true horizontal distance. It always includes some additional component because the profiler must travel up and down the undulations in the road. Calibrating the profiler to true horizontal distance can minimize this component. However, if a profiler operates on a road with grade changes and roughness that are not similar to the site used for longitudinal distance measurement calibration, some error will exist. Tire inflation pressure must also be close to the level that existed during calibration for consistent results.

Modest inconsistency in longitudinal distance measurement between visits in not critical as long as the profiles of individual sections are extracted using event markers or automated synchronization rather than longitudinal distance from the start of each raw profile measurement. A high level of inconsistency, however, could interfere with comparisons between profile features and distress surveys. Errors in profile index values, such as the IRI, are also roughly of the same order as errors in longitudinal distance measurement. (*3*) With the exception of visit 02, longitudinal distance was measured with enough consistency to avoid bias in the IRI values above 1 percent.

Figure 2 shows the disagreement in longitudinal distance measurement for the trailing group of sections (0664 through 0669). Overall, the disagreement is similar to that observed for the leading group, with the exception that earlier visits were less repeatable.

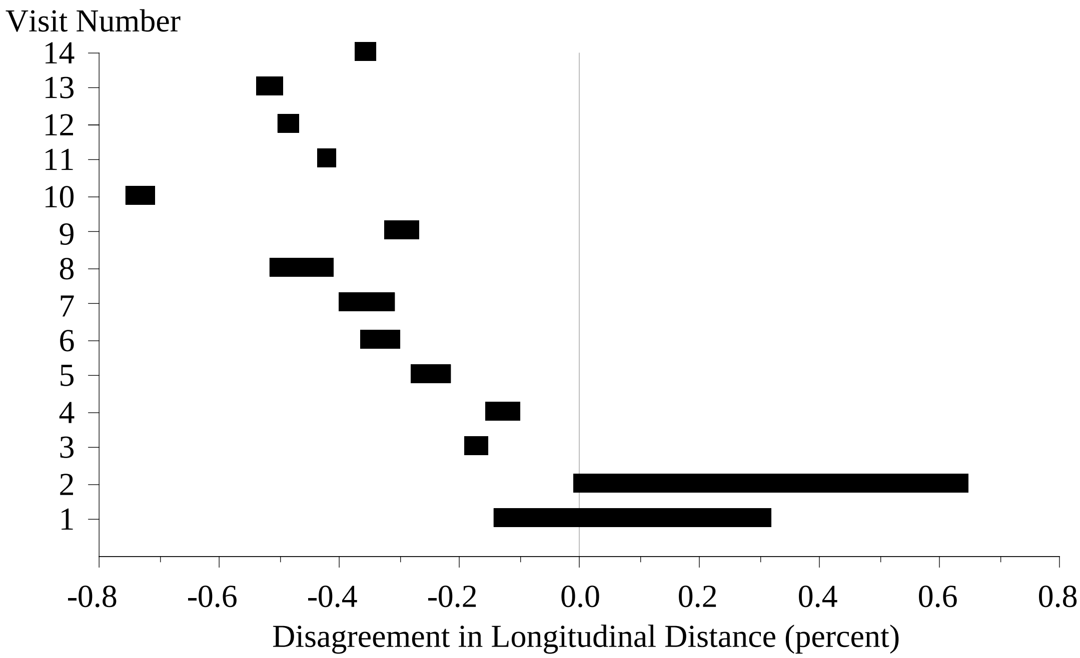

Figure 2. Consistency in longitudinal distance, trailing sections.

Data Quality Screening

Data quality screening was performed to select five repeat profile measurements from each visit of each section. The five measurements among the group of available runs were selected which exhibited the best agreement with each other. In this case, agreement between any two profile measurements was judged by cross correlating them after applying the IRI filter. The details of this method are described elsewhere. (*2*) In this method, the IRI filter is applied to the profiles, and then the output signals are compared rather than the overall index. High correlation by this method requires that the overall roughness is in agreement, as well as the details of the profile shape that affect the IRI. The IRI filter was applied before correlation in this case for several reasons:

- Direct correlation of un-filtered profiles places a premium on very long wavelength content, but ignores much of the contribution of short wavelength content.
- Correlation of IRI filter output emphasizes profile features in (approximate) proportion to their effect on the overall roughness.
- Correlation of IRI filter output provides a good trade-off between emphasizing localized rough features at distressed areas in the pavement and placing too much

weight on the very short-duration, narrow features (spikes) that are not likely to agree between measurements. This is because the IRI filter amplifies short wavelength content, but attenuates macrotexture, megatexture, and spikes.

- A relationship has been demonstrated between the cross correlation level of IRI filter output and the expected agreement in overall IRI. *(2)*

Note that this method was performed with a special provision for correcting modest longitudinal distance measurement errors.

Each comparison between profiles produced a single value that summarized their level of agreement. When nine repeat profile measurements were available, they produced a total of thirty-six correlation values. Averaging the relevant ten correlation values summarizes any subgroup of five measurements. The subgroup that produced the highest average was selected, and the other repeats were excluded from most of the analyses discussed in the rest of this report. Since the number of available profiles ranged from six to nine, the number of measurements that were excluded ranged from one to four. Tables 3 through 21 list the selected repeats for each visit of each section, and the composite correlation level produced by them.

The process described above for selecting five repeat measurements from a larger group is similar to the practice within LTPP, except that it is based on composite agreement in profile, rather than the overall index value. The correlation levels listed in Tables 3 through 21 provide an appraisal of the agreement between profile measurements for each visit of each section. When two profiles produce a correlation level above 0.82, their IRI values are expected to agree within 10 percent most (95 percent) of the time. Above this threshold, the agreement between profiles is usually acceptable for studying the influence of distresses on profile. When two profiles produce a correlation level above 0.92, they are expected to agree within 5 percent most of the time. Above this threshold, the agreement between profiles is good. Correlation above 0.92 often depends on consistent lateral tracking of the profiler, and may be very difficult to achieve on highly distressed surfaces. Note that the IRI values provided in this report will be the average of five observations, which will tighten the tolerance even further.

Table 3. Selected Repeats, Section 0601.

Visit	Repeat Numbers					Composite Correlation
00	5	6	7	8	9	0.949
01	3	4	6	7	8	0.814
02	1	2	3	4	5	0.835
03	1	3	5	6	7	0.870
04	1	2	5	6	9	0.703

Table 4. Selected Repeats, Section 0602.

Visit	Repeat Numbers					Composite Correlation
00	2	4	6	7	8	0.978
01	5	6	7	8	9	0.952
02	1	4	5	6	7	0.959
03	1	3	5	6	7	0.952
04	1	2	3	4	6	0.956

Table 5. Selected Repeats, Section 0603.

Visit	Repeat Numbers					Composite Correlation
00	1	2	5	6	8	0.923
01	4	5	6	8	9	0.900
02	1	2	3	5	6	0.835
03	1	4	5	6	7	0.814
04	3	4	5	8	9	0.846
05	1	2	3	4	5	0.866
06	2	3	5	6	7	0.884
07	1	2	6	7	9	0.927
08	1	3	5	6	7	0.972
09	1	3	4	5	7	0.955
10	1	2	3	4	7	0.985
11	1	2	3	8	9	0.972
12	1	2	3	5	6	0.973
13	1	2	7	8	9	0.959
14	1	3	4	7	9	0.919

Table 6. Selected Repeats, Section 0604.

Visit	Repeat Numbers					Composite Correlation
00	2	6	7	8	9	0.958
01	4	5	6	7	8	0.932
02	2	3	4	5	6	0.892
03	1	4	5	6	7	0.863
04	3	4	7	8	9	0.870
05	1	2	3	7	9	0.843
06	4	6	7	8	9	0.883
07	3	4	6	7	8	0.926
08	2	3	5	6	7	0.883
09	2	3	4	6	7	0.915
10	1	2	3	5	6	0.956
11	4	5	6	8	9	0.974
12	1	2	3	5	6	0.956
13	1	2	3	6	7	0.964
14	1	3	4	5	9	0.925

Table 7. Selected Repeats, Section 0605.

Visit	Repeat Numbers					Composite Correlation
00	4	5	6	8	9	0.958
01	3	4	5	6	8	0.906
02	1	2	3	5	7	0.914
03	1	3	4	5	6	0.943
04	3	5	6	7	8	0.944

Table 8. Selected Repeats, Section 0606.

Visit	Repeat Numbers					Composite Correlation
00	1	2	7	8	9	0.934
01	4	5	7	8	9	0.929
02	1	2	5	6	7	0.850
03	1	3	4	6	7	0.864
04	1	4	5	8	9	0.854
05	2	5	6	7	9	0.903
06	2	3	5	6	8	0.892
07	3	4	6	7	9	0.904
08	2	3	4	5	7	0.917
09	2	4	5	6	7	0.950
10	1	3	5	6	7	0.927
11	1	2	6	8	9	0.963
12	1	3	5	7	9	0.967
13	1	3	6	8	9	0.976
14	1	2	5	6	8	0.947

Table 9. Selected Repeats, Section 0607.

Visit	Repeat Numbers					Composite Correlation
00	2	5	6	8	9	0.890
02	1	3	5	6	7	0.821
03	1	3	4	5	6	0.864
04	1	4	6	7	9	0.839
05	2	5	6	8	9	0.891
06	3	5	6	7	8	0.854
07	2	3	6	7	8	0.933
08	2	3	4	5	6	0.922
09	2	4	5	6	7	0.969
10	1	2	4	6	7	0.960
11	2	3	5	7	8	0.956
12	2	3	4	7	9	0.966
13	2	3	5	6	8	0.965
14	1	2	4	5	6	0.880

Table 10. Selected Repeats, Section 0608.

Visit	Repeat Numbers					Composite Correlation
00	1	4	6	7	8	0.963
02	1	2	5	6	7	0.868
03	1	3	4	5	7	0.834
04	1	2	6	8	9	0.863
05	4	5	6	7	9	0.905
06	2	3	6	8	9	0.805
07	2	4	5	6	9	0.883
08	2	3	4	5	7	0.784
09	1	2	3	4	6	0.906
10	1	3	4	5	6	0.899
11	3	4	5	6	8	0.919
12	1	2	3	4	8	0.910
13	1	2	5	7	9	0.898
14	3	4	5	7	8	0.852

Table 11. Selected Repeats, Section 0659.

Visit	Repeat Numbers					Composite Correlation
00	2	3	4	5	6	0.949
01	3	5	6	7	8	0.943
02	2	3	5	6	7	0.911
03	1	3	5	6	7	0.824
04	1	3	5	6	8	0.878
05	1	2	3	4	9	0.915
06	1	2	3	5	6	0.827
07	3	4	5	8	9	0.923
08	2	4	5	6	7	0.949
09	1	2	3	4	7	0.902
10	2	4	5	6	7	0.912
11	2	3	5	6	9	0.953
12	1	2	3	4	6	0.970
13	2	3	5	8	9	0.963
14	3	4	5	7	8	0.940

Table 12. Selected Repeats, Section 0660.

Visit	Repeat Numbers					Composite Correlation
00	2	4	6	8	9	0.959
02	1	3	4	5	7	0.941
03	3	4	5	6	7	0.913
04	1	2	4	5	6	0.913
05	2	5	6	7	9	0.957
06	3	4	6	7	9	0.949
07	4	5	6	8	9	0.971
08	1	3	4	6	7	0.958
09	1	2	3	4	7	0.979
10	1	2	3	4	5	0.973
11	1	2	3	6	9	0.980
12	2	3	7	8	9	0.980
13	1	4	6	7	9	0.977
14	1	3	5	6	9	0.865

Table 13. Selected Repeats, Section 0661.

Visit	Repeat Numbers					Composite Correlation
00	3	5	6	7	9	0.986
01	1	3	5	6	7	0.937
02	1	4	5	6	7	0.886
03	1	3	5	6	7	0.837
04	3	5	6	8	9	0.790
05	2	3	5	7	8	0.871
06	1	5	6	7	9	0.853
07	1	2	3	4	5	0.907
08	2	3	4	5	6	0.879
09	1	2	3	5	6	0.831
10	1	2	4	6	7	0.934
11	1	3	4	7	8	0.964
12	1	2	5	6	7	0.959
13	2	3	4	6	7	0.962
14	1	4	5	6	8	0.894

Table 14. Selected Repeats, Section 0662.

Visit	Repeat Numbers					Composite Correlation
00	1	2	4	6	7	0.963
01	1	2	5	6	8	0.910
02	1	3	4	5	7	0.900
03	3	4	5	6	7	0.906
04	1	2	3	4	7	0.857
05	2	4	5	6	8	0.925
06	2	3	4	7	9	0.842
07	2	3	4	6	9	0.948
08	1	2	3	4	7	0.958
09	1	2	4	5	6	0.941
10	1	2	4	5	7	0.970
11	1	4	6	8	9	0.972
12	2	3	5	6	8	0.947
13	1	3	4	5	7	0.961
14	1	2	5	8	9	0.904

Table 15. Selected Repeats, Section 0663.

Visit	Repeat Numbers					Composite Correlation
00	1	5	6	8	9	0.981
02	1	3	4	5	7	0.920
03	3	4	5	6	7	0.926
04	1	4	5	6	8	0.911
05	1	3	4	5	8	0.934
06	1	3	6	8	9	0.909
07	3	5	6	8	9	0.949
08	1	2	4	5	7	0.901
09	2	3	5	6	7	0.947
10	2	3	4	5	7	0.944
11	1	3	5	6	9	0.931
12	1	3	5	6	7	0.954
13	1	4	6	8	9	0.955
14	1	6	7	8	9	0.909

Table 16. Selected Repeats, Section 0664.

Visit	Repeat Numbers					Composite Correlation
01	2	4	5	7	8	0.856
02	2	3	4	5	6	0.907
03	1	3	5	6	7	0.912
04	5	6	7	8	9	0.861
05	4	6	7	8	9	0.868
06	4	5	7	8	9	0.891
07	1	2	3	6	9	0.926
08	1	3	4	5	7	0.898
09	1	2	3	5	7	0.920
10	1	2	3	4	6	0.934
11	1	3	4	5	7	0.936
12	1	4	5	7	9	0.943
13	1	2	3	4	7	0.952
14	3	4	6	7	9	0.853

Table 17. Selected Repeats, Section 0665.

Visit	Repeat Numbers					Composite Correlation
01	5	6	7	8	9	0.841
02	1	3	4	5	6	0.907
03	1	3	5	6	7	0.940
04	1	3	5	7	9	0.902
05	1	3	4	6	9	0.919
06	2	4	5	8	9	0.905
07	2	3	5	6	9	0.940
08	2	3	4	6	7	0.902
09	1	2	3	4	7	0.908
10	1	2	4	5	6	0.932
11	1	3	4	6	7	0.942
12	1	3	4	7	8	0.950
13	2	3	6	8	9	0.948
14	2	3	6	7	9	0.891

Table 18. Selected Repeats, Section 0666.

Visit	Repeat Numbers					Composite Correlation
01	4	6	7	8	9	0.807
02	1	2	4	5	6	0.895
03	1	3	5	6	7	0.940
04	2	3	4	6	8	0.880
05	2	3	5	7	9	0.889
06	2	4	5	8	9	0.870
07	3	5	6	7	9	0.902
08	1	2	4	6	7	0.908
09	3	4	5	6	7	0.902
10	1	2	4	5	6	0.912
11	3	4	6	7	8	0.914
12	1	3	5	6	8	0.942
13	1	2	3	6	7	0.918
14	1	2	3	7	8	0.882

Table 19. Selected Repeats, Section 0667.

Visit	Repeat Numbers					Composite Correlation
01	2	5	6	7	9	0.914
02	1	2	3	4	6	0.957
03	1	4	5	6	7	0.955
04	1	2	4	5	6	0.949
05	2	3	5	6	9	0.947
06	2	5	6	7	9	0.943
07	1	2	4	6	8	0.965
08	1	3	4	5	6	0.959
09	2	3	4	5	6	0.956
10	1	2	3	4	5	0.964
11	1	2	4	6	7	0.968
12	1	3	4	7	9	0.971
13	2	5	6	7	8	0.972
14	1	2	7	8	9	0.927

Table 20. Selected Repeats, Section 0668.

Visit	Repeat Numbers					Composite Correlation
01	4	6	7	8	9	0.682
02	2	3	4	5	6	0.861
03	1	3	4	6	7	0.890
04	1	2	7	8	9	0.849
05	2	3	6	8	9	0.873
06	1	3	4	6	8	0.864
07	1	2	3	6	7	0.890
08	1	3	4	5	6	0.863
09	2	3	4	5	6	0.873
10	1	2	3	5	6	0.901
11	1	2	3	4	8	0.900
12	1	2	3	5	8	0.915
13	2	5	6	7	9	0.918
14	1	2	7	8	9	0.826

Table 21. Selected Repeats, Section 0669.

Visit	Repeat Numbers					Composite Correlation
01	1	3	4	7	8	0.852
02	2	3	4	5	6	0.932
03	1	3	4	5	7	0.952
04	1	3	5	6	8	0.931
05	1	2	5	6	7	0.924
06	4	5	7	8	9	0.932
07	2	3	7	8	9	0.944
08	2	4	5	6	7	0.918
09	3	4	5	6	7	0.940
10	1	2	3	4	6	0.947
11	2	4	5	6	8	0.955
12	1	2	4	7	9	0.962
13	1	2	3	4	6	0.945
14	1	2	5	6	8	0.878

Overall, most of the groups of measurements listed in Tables 3 through 21 exhibited acceptable correlation, and nearly half of them exhibited good or excellent correlation. Agreement was lowest overall for visits 01 through 04, and these accounted for the majority of cases that are discussed below. Agreement improved significantly for the later visits, and was good or excellent on every section in visits 10 through 13. Any group of repeat measurements that produced a composite correlation level below 0.82 was investigated using filtered plots, and they are discussed here along with other cases of low but acceptable correlation.

In many cases, correlation was diminished because of modest disagreement in the severity of narrow bumps that had reflected upward from the original joints. This was found to be most problematic in visit 02 of sections 0603 and 0607, visit 03 of section 0603, 0608 and 0661, visit 04 of section 0607 and 0661, and visit 06 of section 0608.

Uncorrelated short wavelength content diminished the correlation in a few cases: visit 01 of section 0665, visit 04 of section 0661, visit 08 of section 0608, and visit 09 of section 0661. In the latter two cases, the effect of the resulting "chatter" that appeared in the profiles was severe. Visit 01 of section 0668 also showed diminished correlation because of severe chatter in the right side profiles.

Other observations were:

Section 0601, Visit 01: Inconsistency in the severity of deep narrow dips at distressed joints reduced the correlation level.

Section 0601, Visit 02: Three of the seven profiles (repeats 5-7) did not cover the entire section. Repeat number 5 was selected, because it was the longest, but the lack of seven viable repeat measurements left no room for exclusion of profiles with other problems.

Section 0601, Visit 04: Repeat numbers 4-8 exhibited artificial roughness caused by lost lock. (*4*) This was the least severe in repeats 5 and 6, so they were selected, but this significantly diminished the composite correlation level.

Section 0608, Visit 14: These measurements included several deep spikes on the right side. Repeat measurements did not agree on their severity. The measurements also did not agree on the shape of a very rough section of pavement on the left side from 365 to 390 ft into the section. Evidence of this rough section first appeared in visit 08.

Section 0659, Visit 03 and 06: These visits showed general disagreement in short wavelength content, including some uncorrelated upward spikes.

Section 0662, Visit 06: These measurements did not agree on the shape, severity, or existence of a 6-ft wide bump in the right profile about 160 ft from the start of the section.

Section 0666, Visit 01: These profiles showed general disagreement in short wavelength content, primarily on the left side.

Section 0668, Visit 01: This group included poorly correlated short wavelength content in the left side profiles.

Section 0668, Visit 14: This visit showed general disagreement in short wavelength content on both the left and right side. In particular, repeat number 1 agreed with the others to a much lesser extent than they agreed with each other.

Summary Roughness Values

Figures 3 through 21 show the left and right IRI values for each pavement section over their monitoring period. For most of the sections, this includes at least twenty-eight summary IRI values; two per visit over fourteen visits. (See Table 2.) The figures show the IRI values versus time in years. In this case, "years" refers from the number of years between the measurement date and the date that the site was opened to traffic after rehabilitation, which was 6-October-1990. Fractions of a year are estimated to the nearest day.

To supplement the plots, Appendix A lists the IRI, Half-car Roughness Index (HRI), and Ride Number (RN) of each section for each visit. These roughness values are the average of the five repeat measurements selected in the data quality screening. These are not necessarily the same five repeat measurements selected for the LTPP database. Appendix A also provides the standard deviation of IRI over the five repeat measurements. This helps identify erratic roughness values that are the result of transverse variations in profile caused by surface distresses.

Figures 3 through 21 provide a snapshot of the roughness history of each pavement section. The remainder of this report is devoted to characterizing the profile content that made up the roughness, and explaining the profile features that contributed to roughness progression.

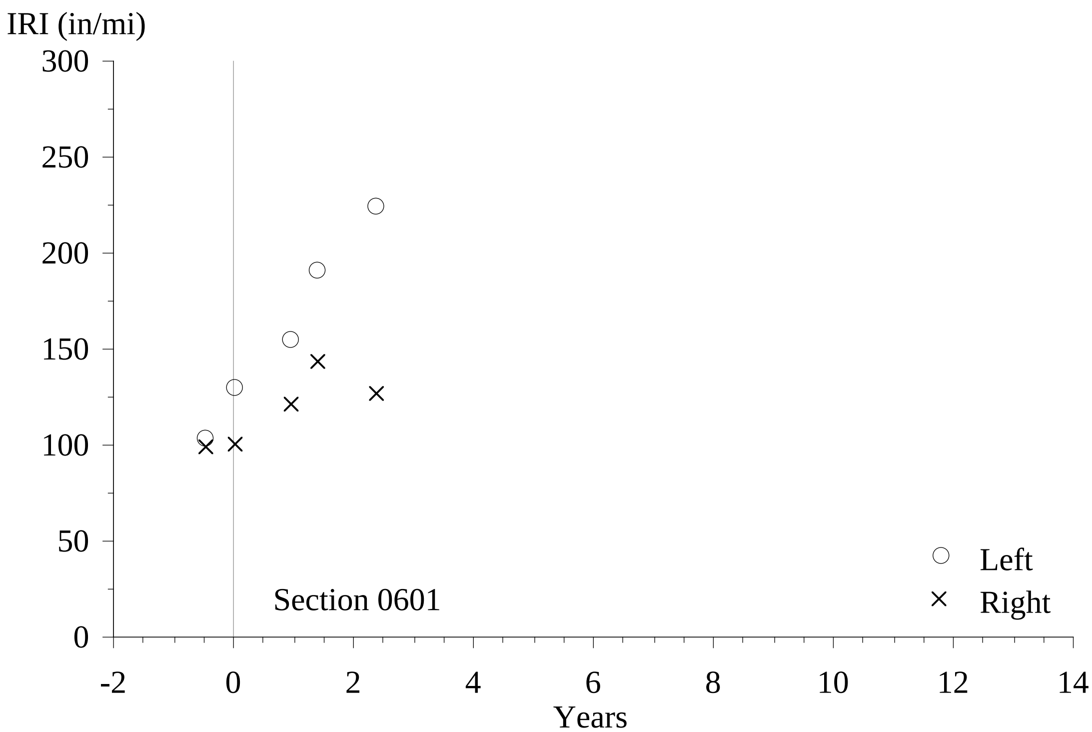

Figure 3. IRI progression, section 0601.

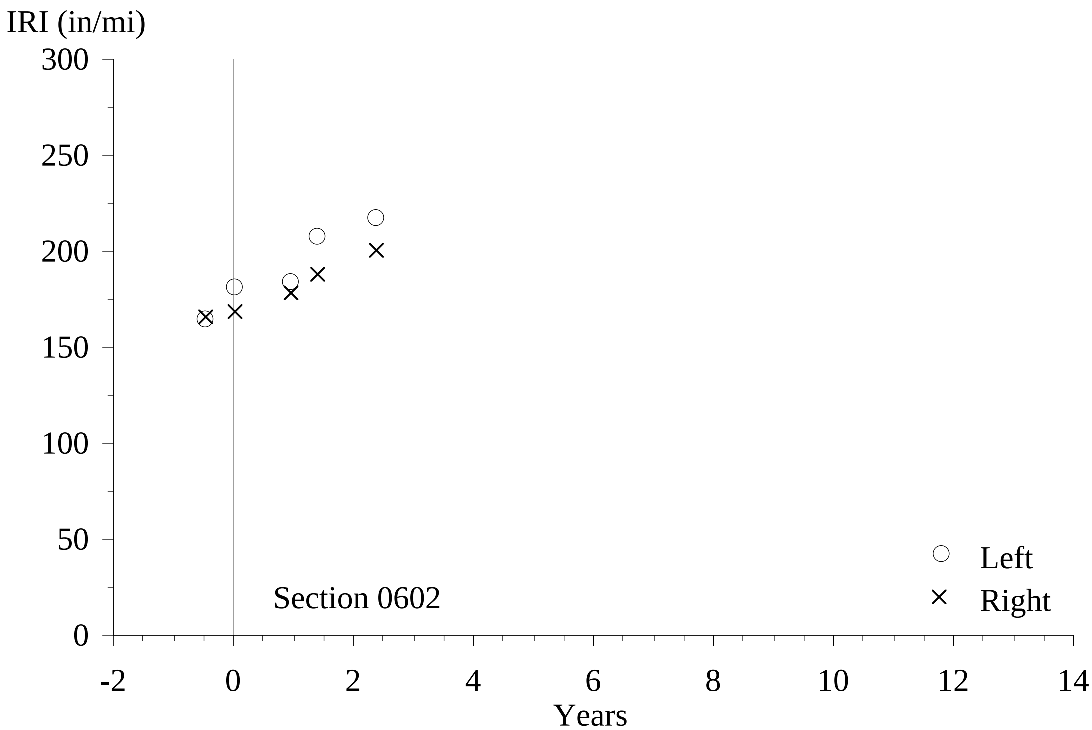

Figure 4. IRI progression, section 0602.

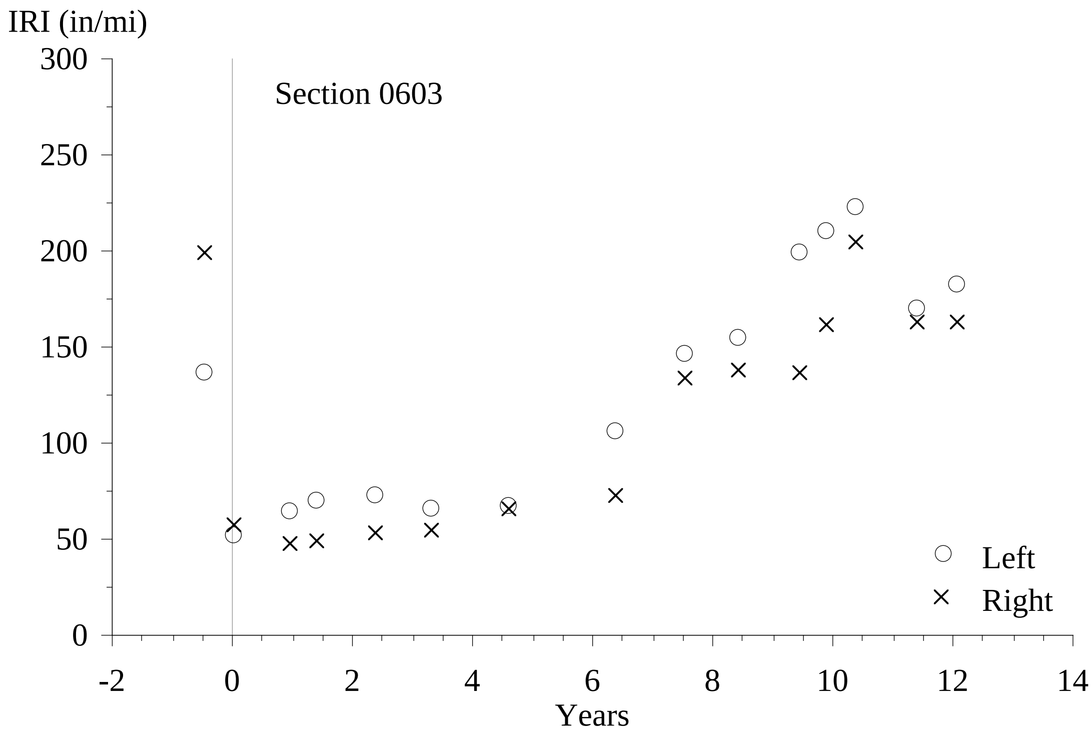

Figure 5. IRI progression, section 0603.

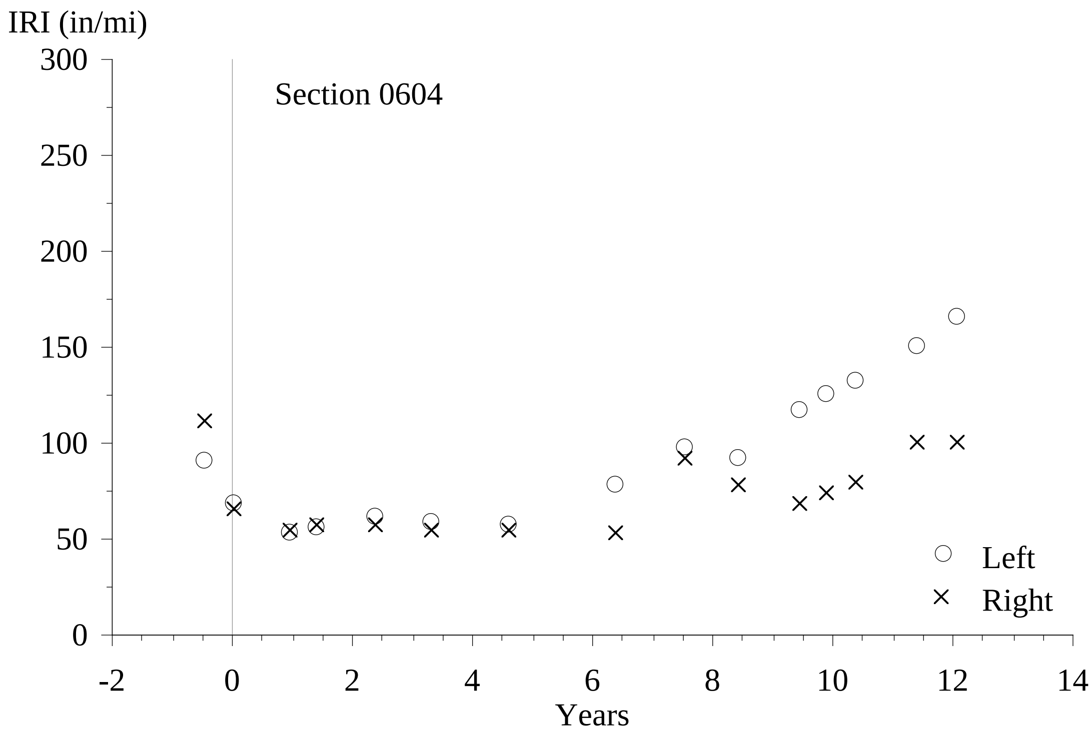

Figure 6. IRI progression, section 0604.

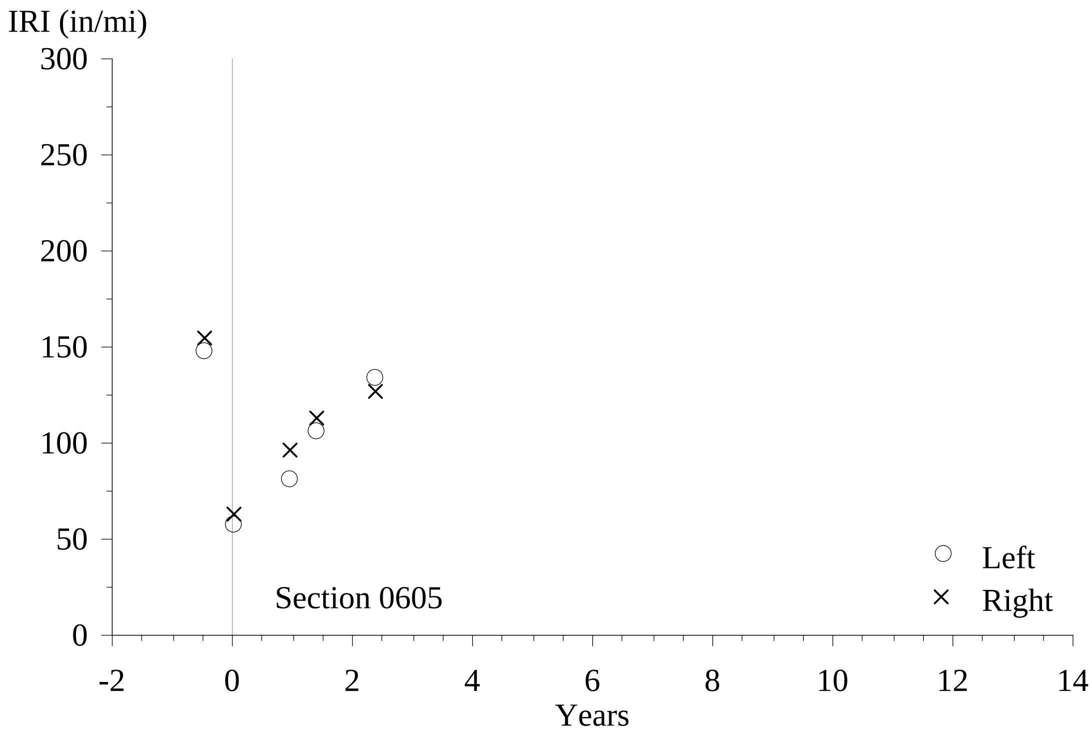

Figure 7. IRI progression, section 0605.

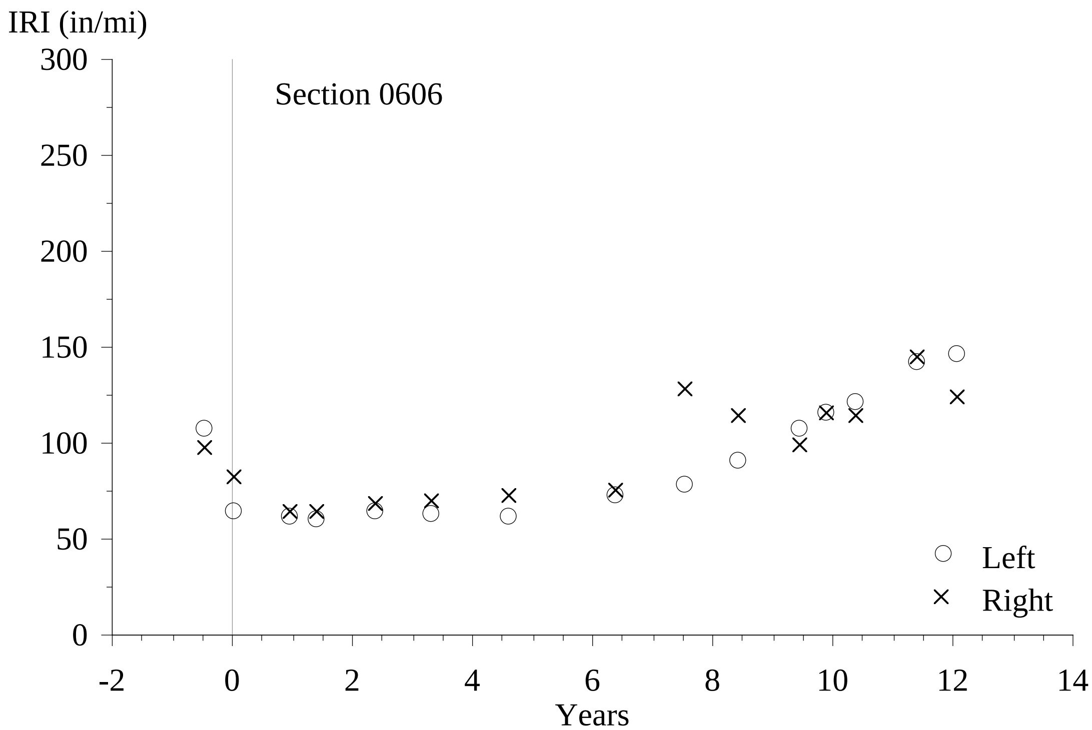

Figure 8. IRI progression, section 0606.

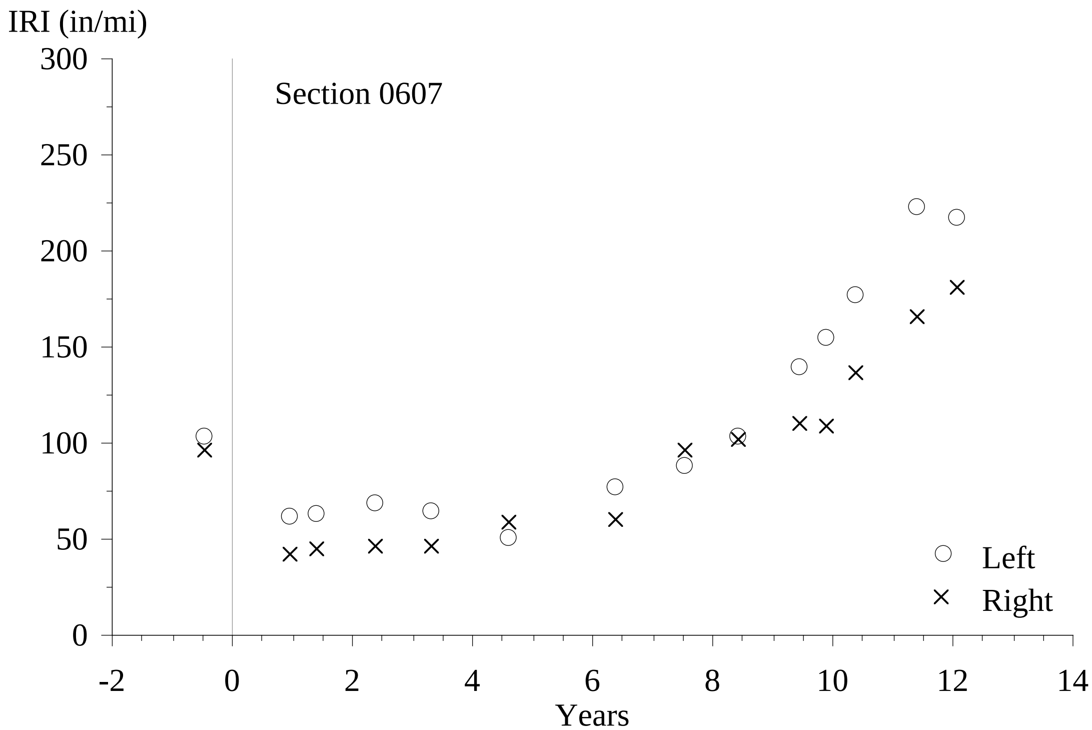

Figure 9. IRI progression, section 0607.

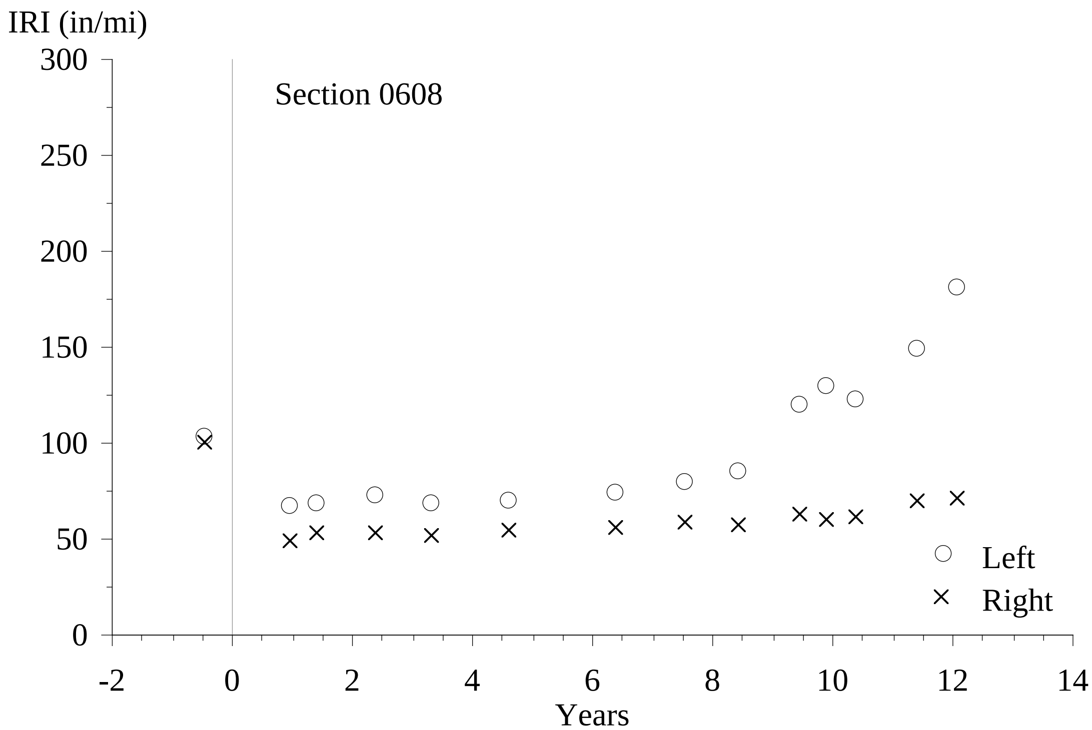

Figure 10. IRI progression, section 0608.

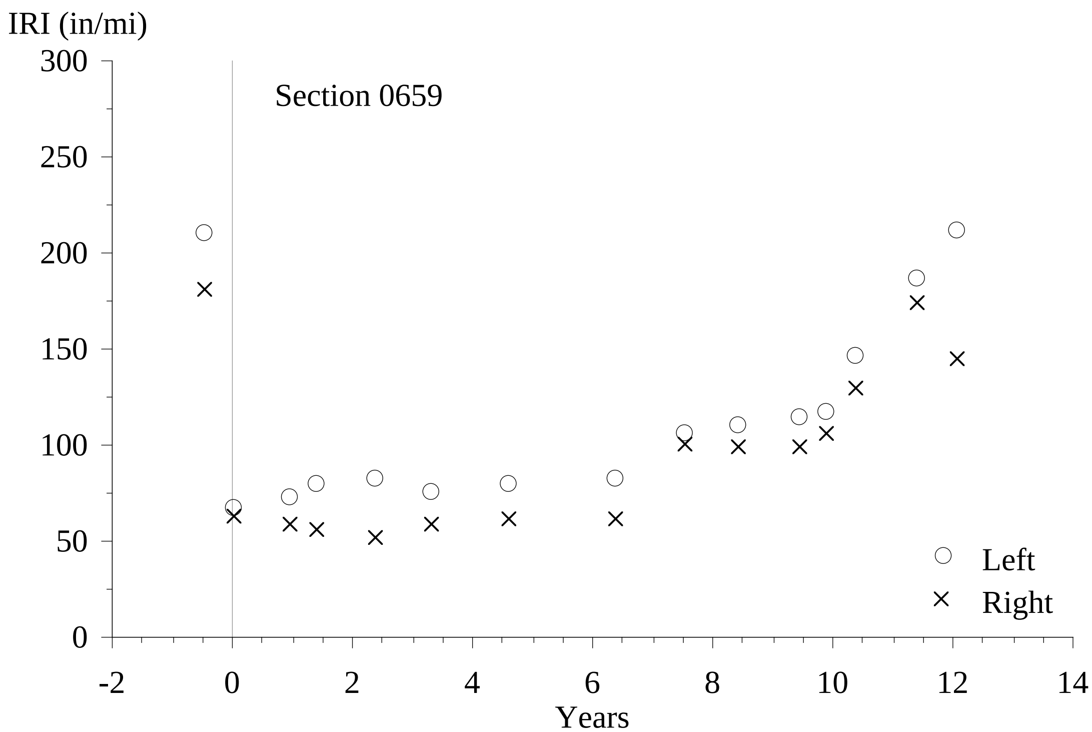

Figure 11. IRI progression, section 0659.

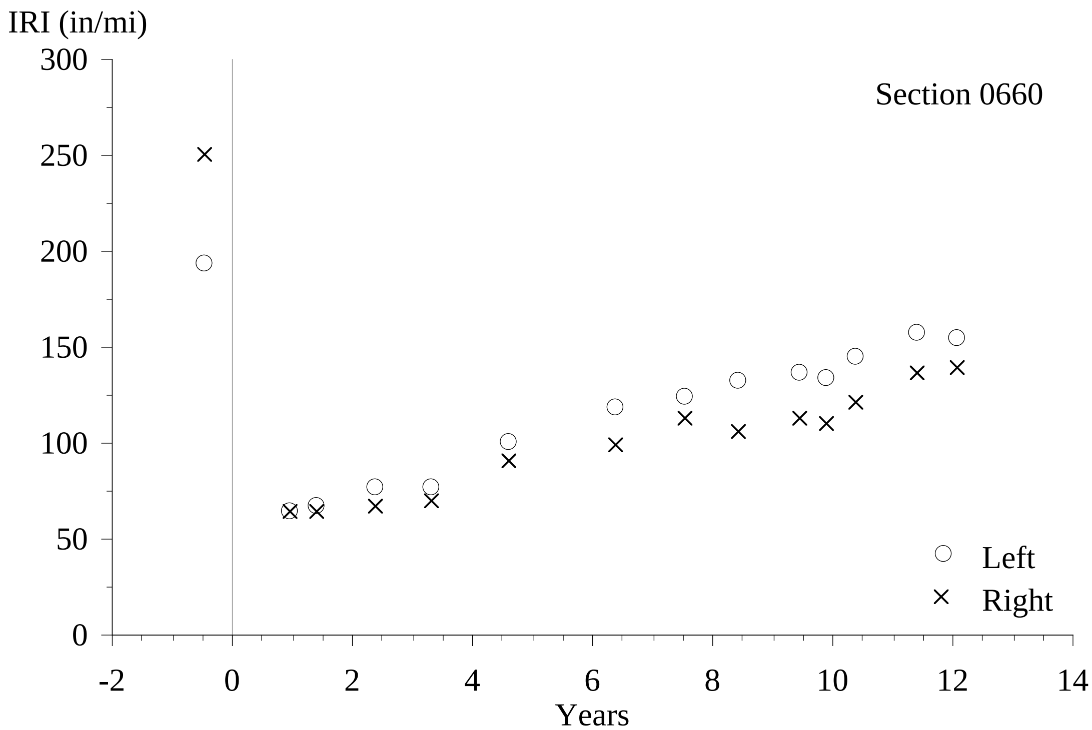

Figure 12. IRI progression, section 0660.

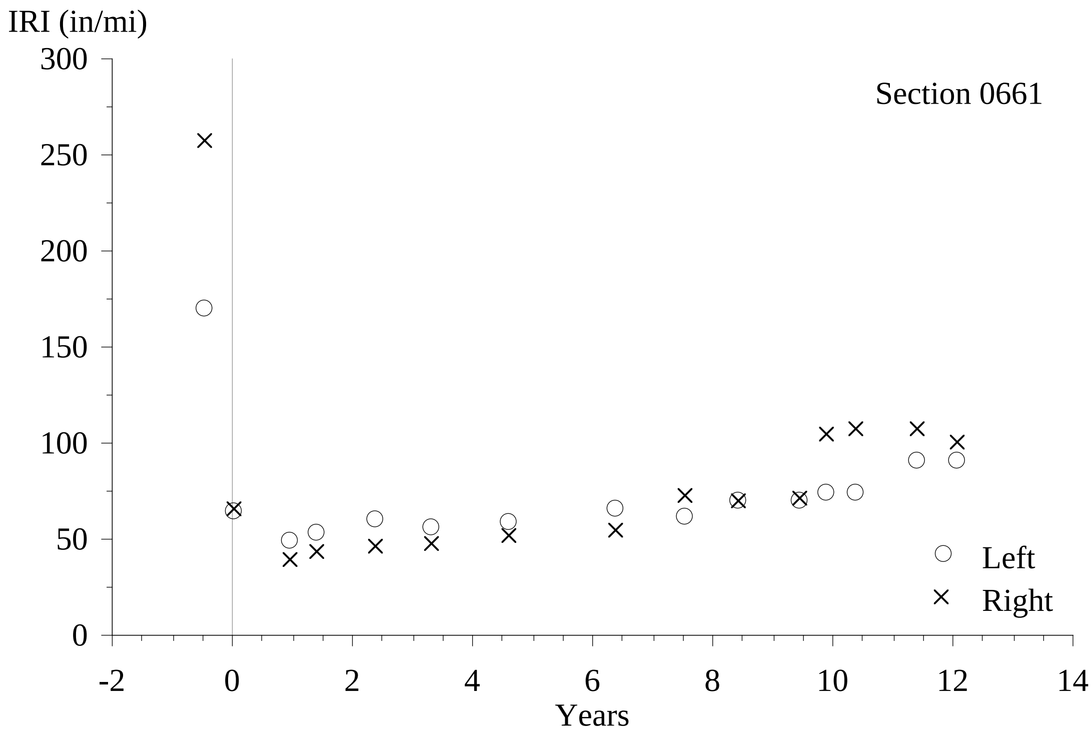

Figure 13. IRI progression, section 0661.

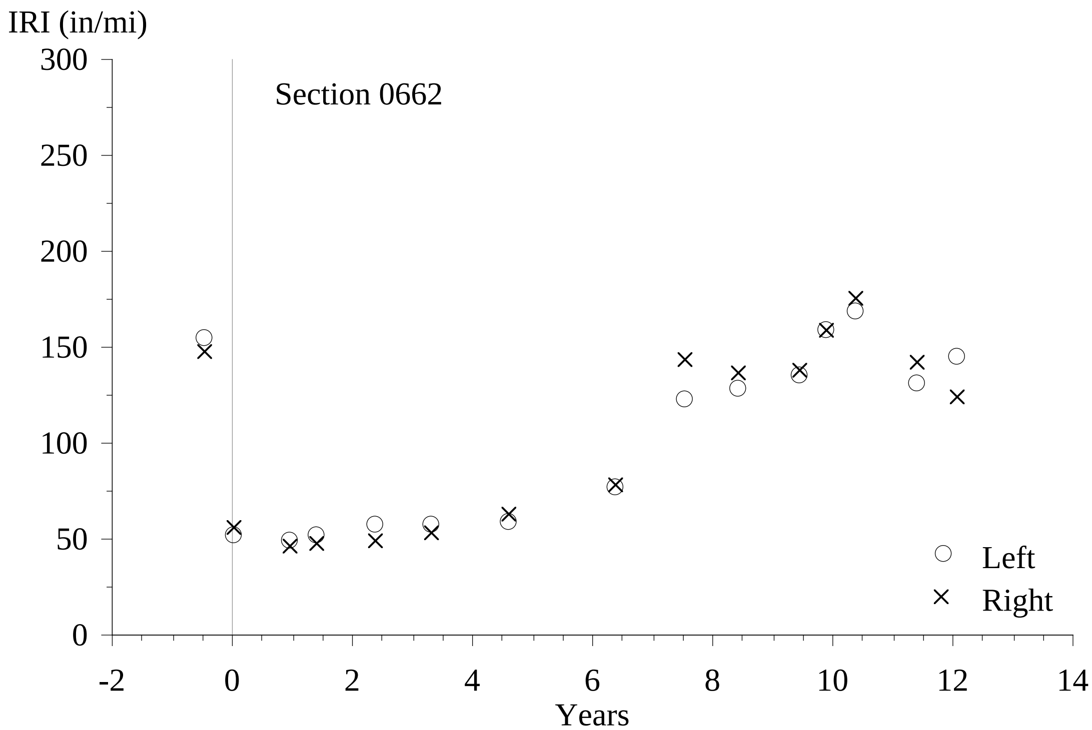

Figure 14. IRI progression, section 0662.

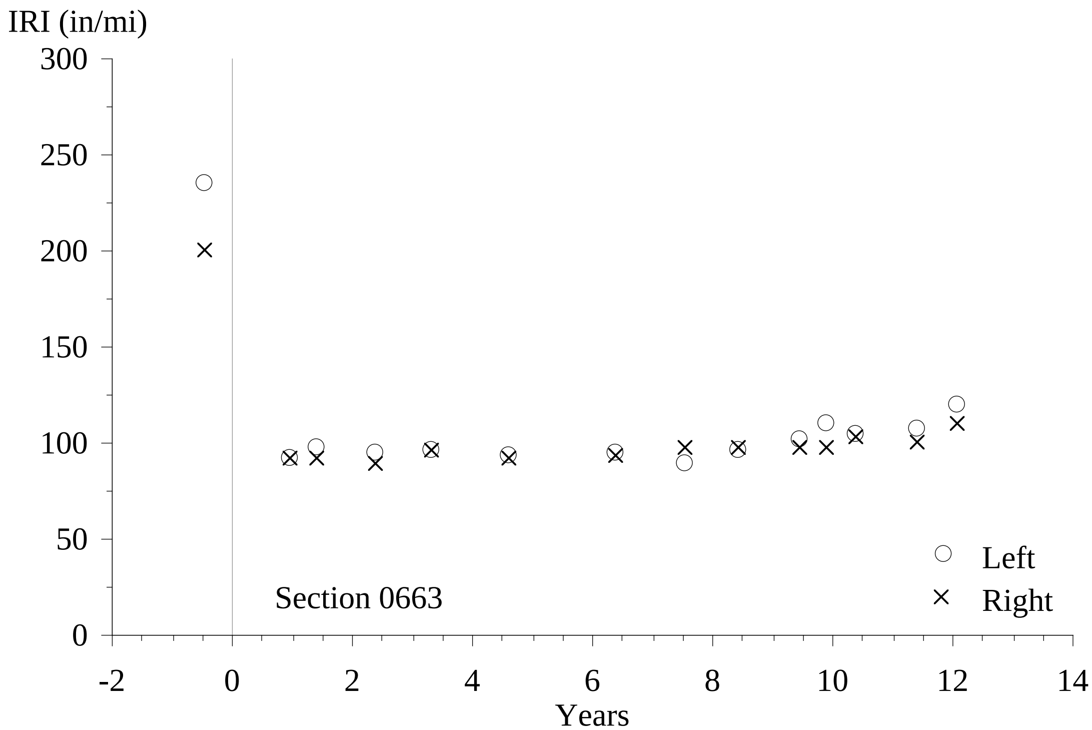

Figure 15. IRI progression, section 0663.

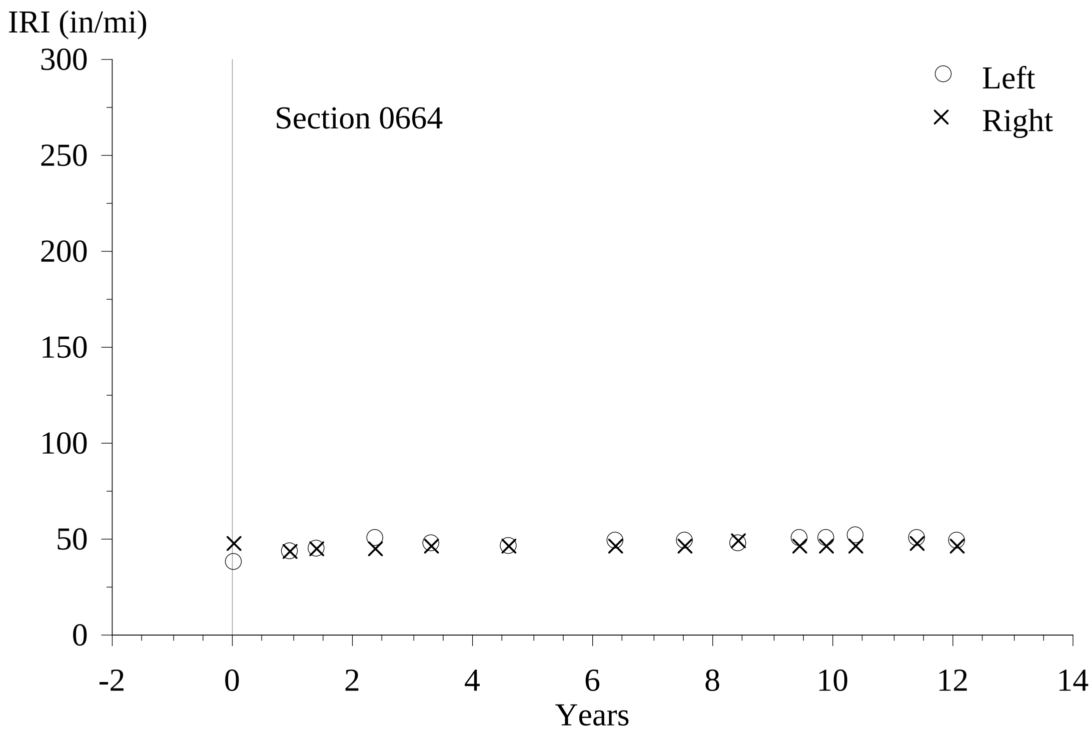

Figure 16. IRI progression, section 0664.

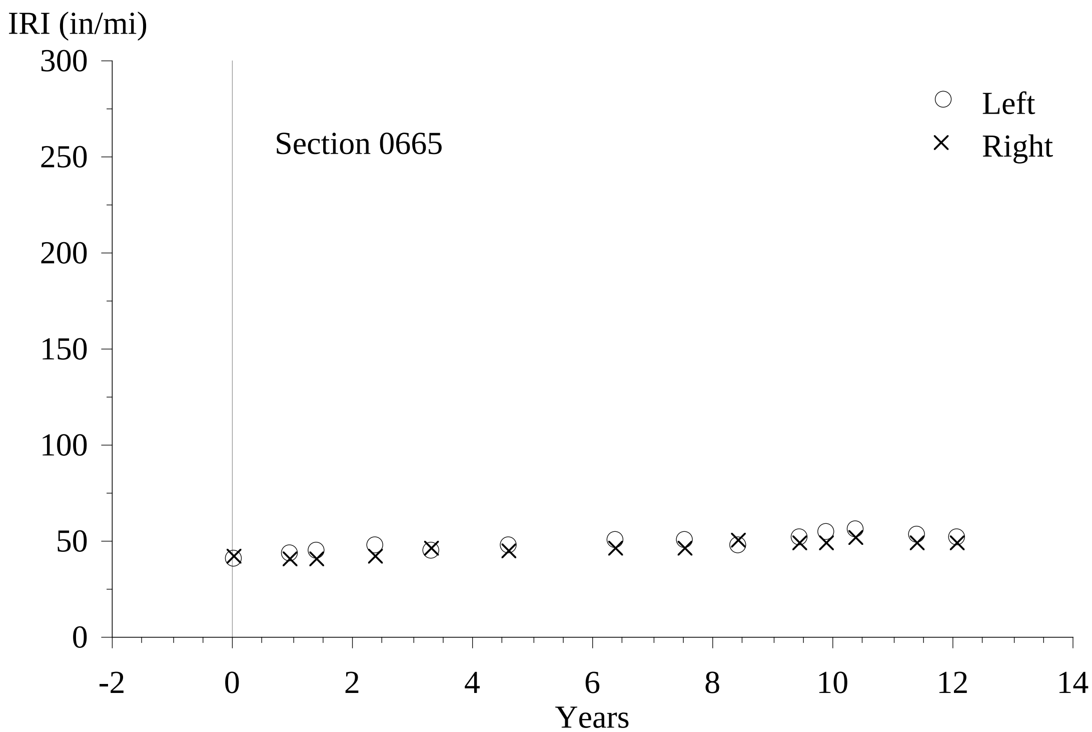

Figure 17. IRI progression, section 0665.

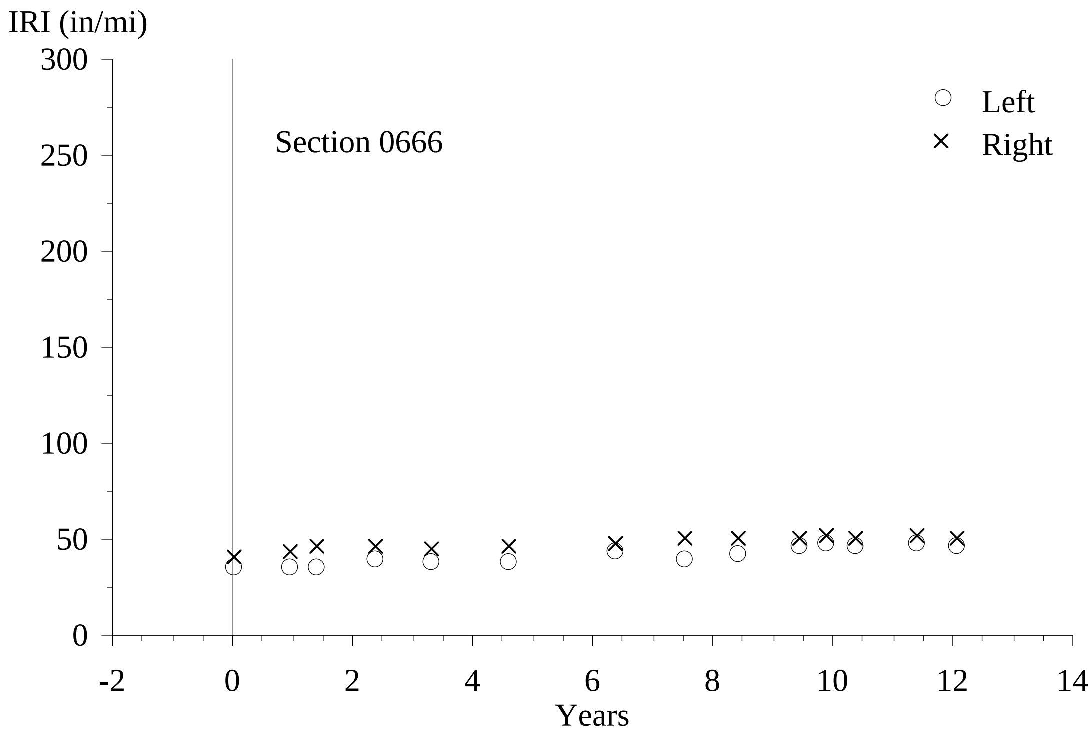

Figure 18. IRI progression, section 0666.

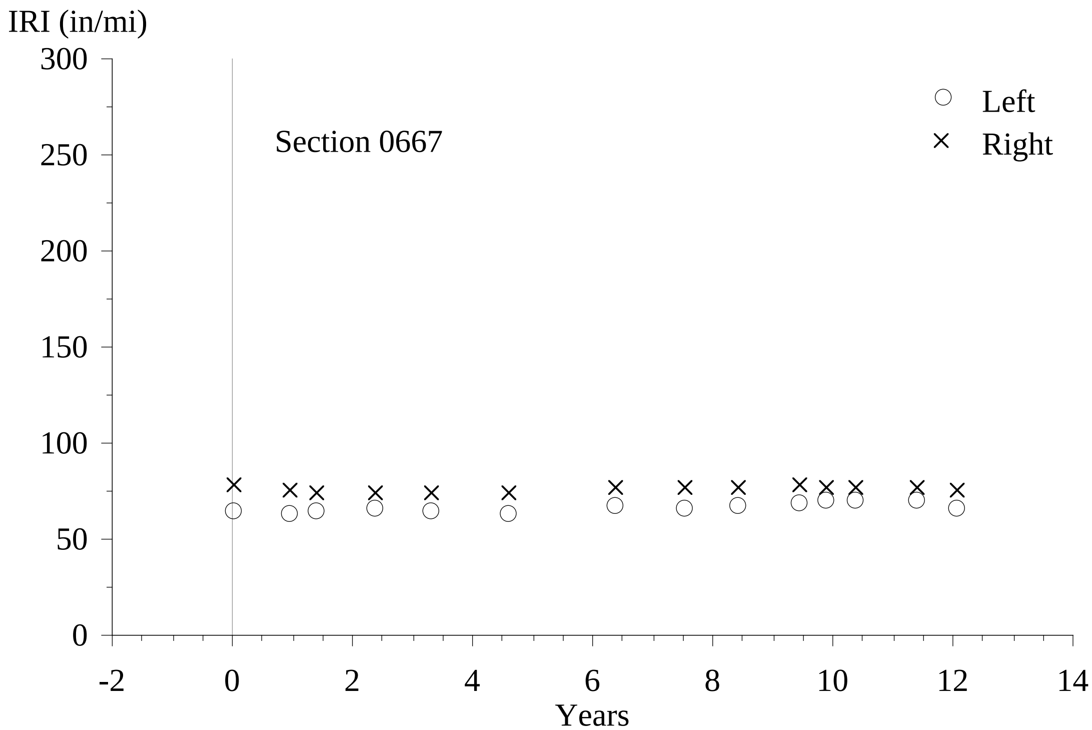

Figure 19. IRI progression, section 0667.

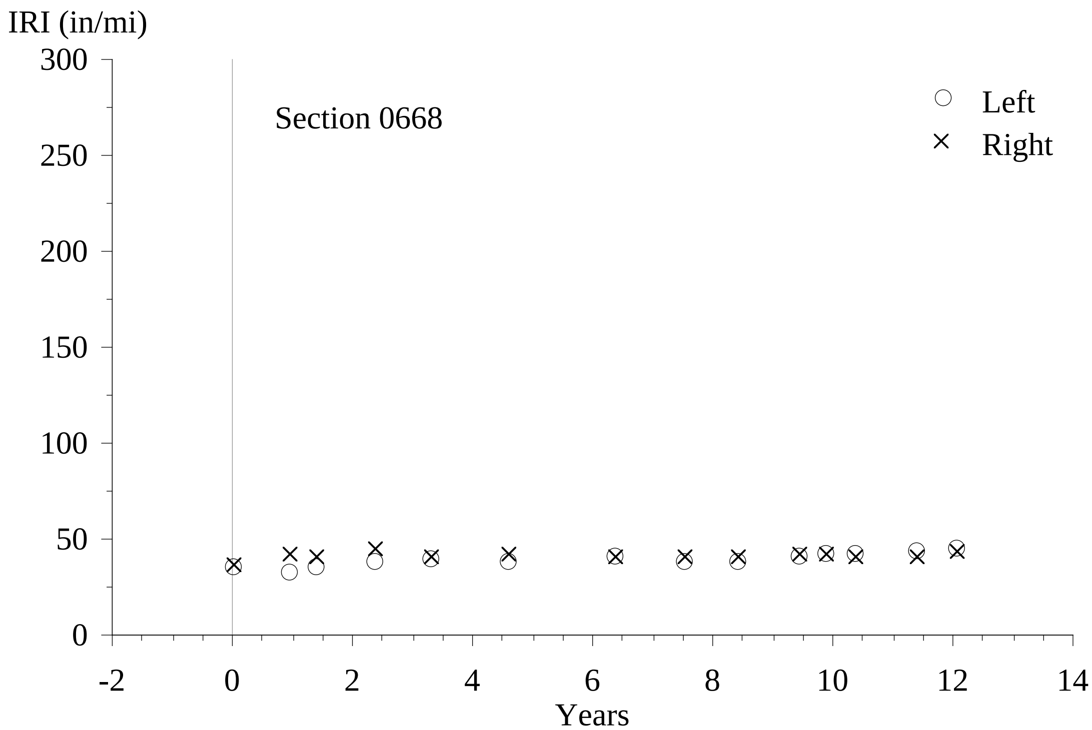

Figure 20. IRI progression, section 0668.

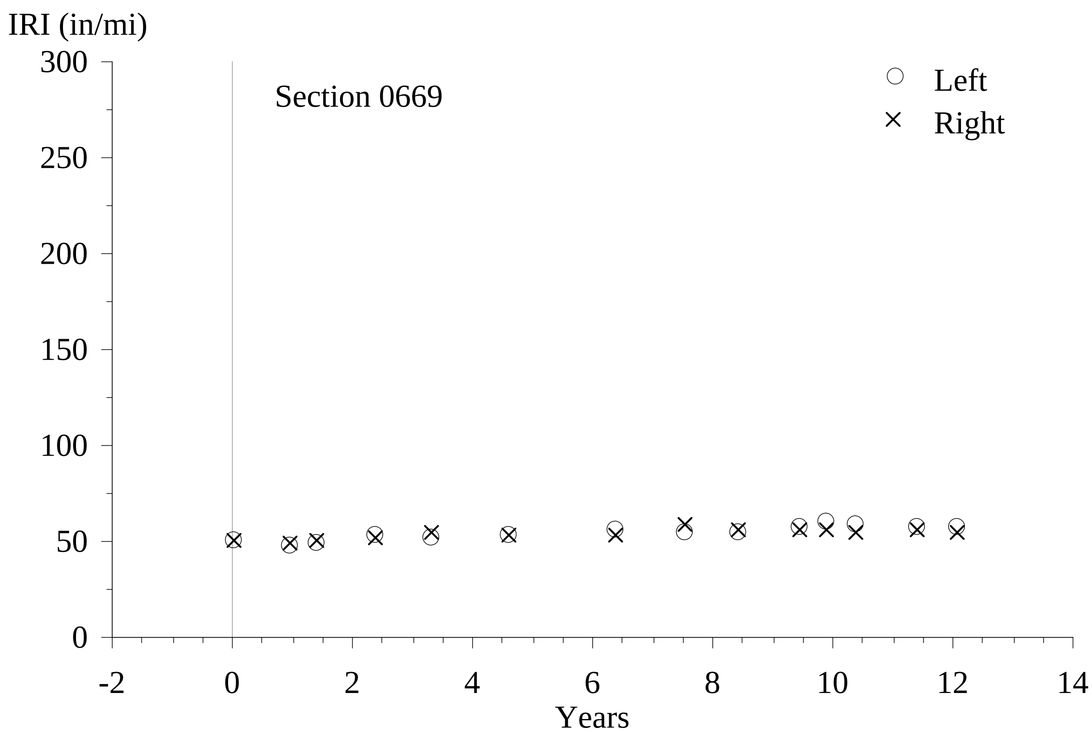

Figure 21. IRI progression, section 0669.

Profile Analysis Tools

This section of the report describes analysis techniques that were used to study the profile characteristics of each pavement section, and their change with time. These tools help study roughness, roughness distribution, and roughness progression of each section, including concentrated roughness that may be linked to pavement distress. The discussion of each analysis and plotting method is rather brief. However, some examples are provided, and all of the methods listed here are described in detail elsewhere. *(5)*

Summary Roughness Values

Left IRI, right IRI, Mean Roughness Index (MRI), HRI, and RN values were calculated. Appendix A reports the average value of each index for each visit of each section. The discussion of roughness in this report emphasizes the left and right IRI. Nevertheless, comparing the progression of HRI and RN to that of the MRI provides additional information about the type of roughness that is changing. For example, a low HRI value relative to MRI indicates roughness that exists on only one side of the lane. Further, aggressive degradation of RN without a commensurate growth in MRI signifies that the developing roughness is biased toward short wavelength content.

Filtered Profile Plots

A simple way to learn about the type of roughness that exists within a profile is to view the trace. For example, Figure 22 shows the raw profile trace for five visits of section 0603 throughout its monitoring history. The plot shows that the long wavelength content, or the trend, in each plot is quite consistent with time. Of particular interest is the consistency in long wavelength content between the profile measured in April 1990, which occurred before rehabilitation, and the profile measured in September 1990, which occurred after placement of a 4-in think AC overlay.

Figure 22 illustrates some features of the roughness and its progression on section 0603. The profile measured before rehabilitation includes multiple disturbances in a saw-tooth shape. The downward steps at the trailing edge of each “tooth” are joint faults, and the saw tooth shape is present as a result of the associated slab tilt.

Several short-duration disturbances (i.e., bumps and dips) appear in the profile measured in May 1995 that do not appear in the profiles measured in September 1990. In the two subsequent visits shown, roughness progresses with time in the form of narrow dips. Transverse cracking and the associated surface deformation at the borders of the cracks caused most of the narrow dips and small bumps.

By August 2000 the narrow dips are deep and numerous enough to stand out in the raw profile plot. However, the raw profile plot is not ideal of recognizing the first appearance of the dips, or characterizing their shape and width. Figure 23 provides a closer look at one of the dips after the application of an anti-smoothing moving average filter using a base length of 10 ft. This high-pass filter removes much of the roughness in the profile associated with changes in elevation over distances longer than 10 ft (including the long trends visible in Figure 22), and leaves most of the very short duration changes in elevation intact.

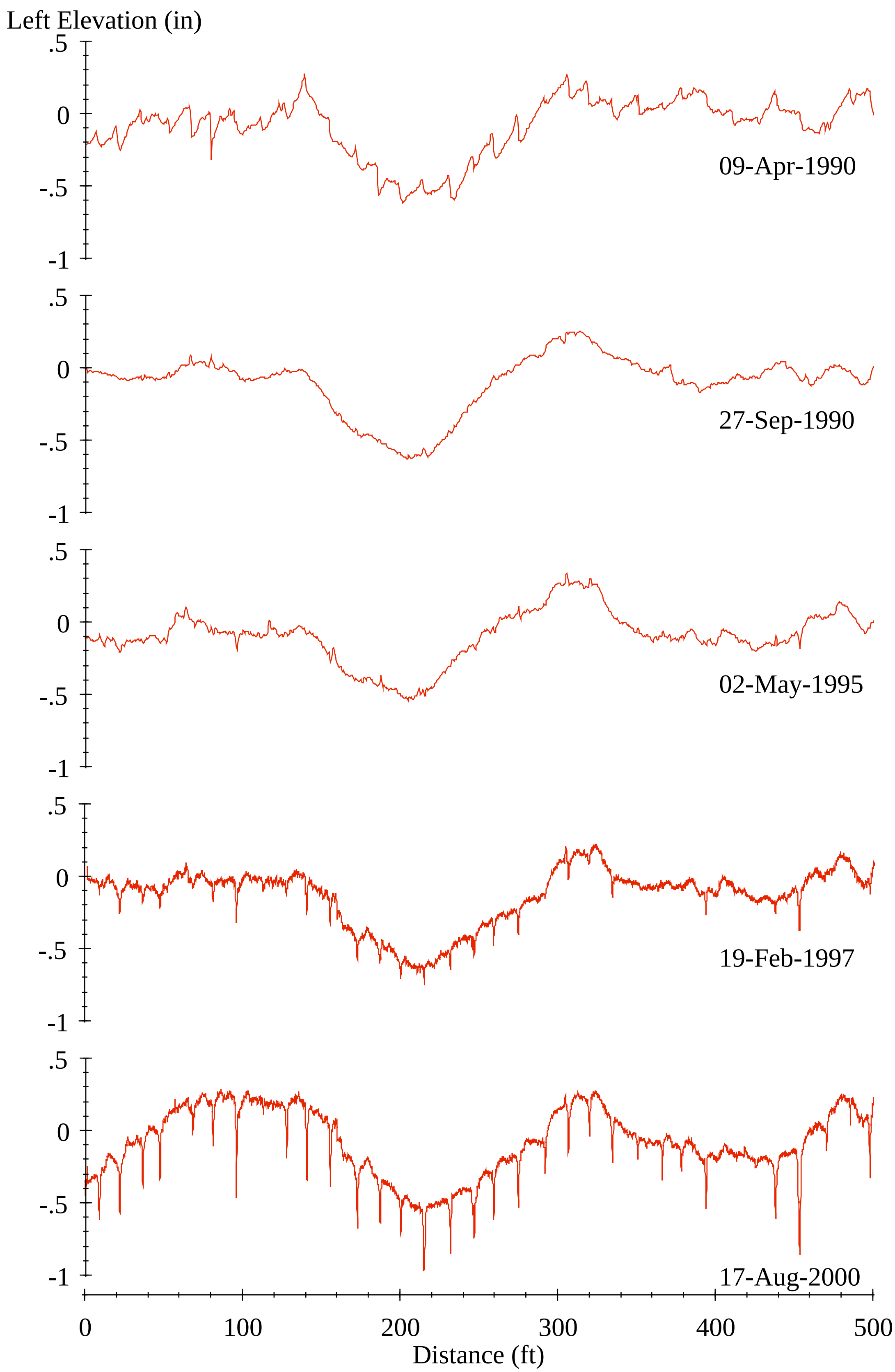

Figure 22. Raw profiles of section 0603.

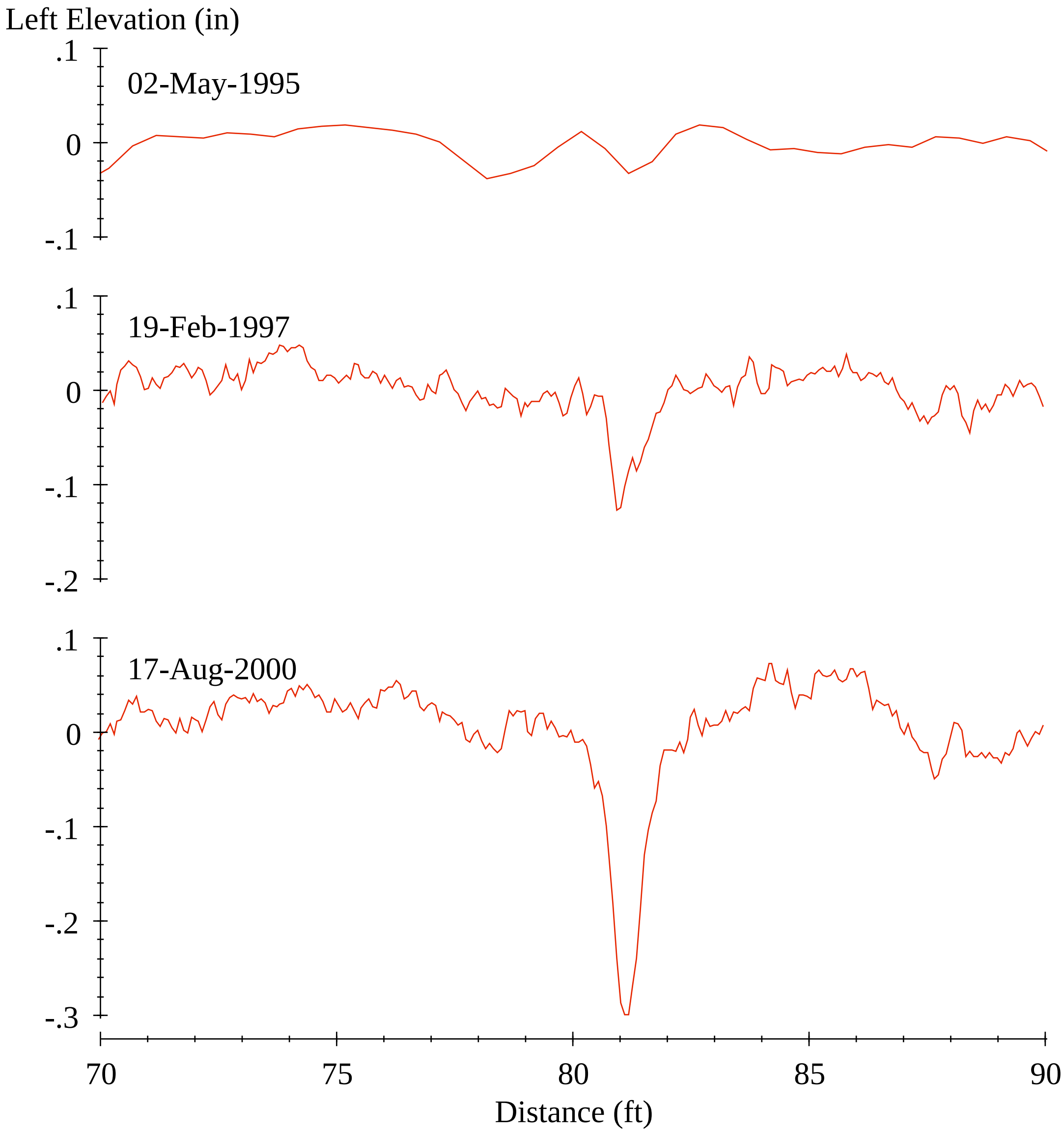

Figure 23. High-pass filtered profiles of section 0603.

Figure 23 shows a clear progression in the depth of the dip over time from a small ripple in May 1995 to a deep narrow dip in August 2000. An important feature of the dip is its width. The dip is about 1 ft wide, which is much wider than the crack that caused it. This dip is likely to degrade ride quality and penalize the IRI value much more than a narrower dip with the same depth.

Like the dips in Figure 23, any of the dips that stand out in the February 1997 profile measurements appear as much shallower dips in the same location in May 1995. (This was the case on all of the test sections with significant transverse cracking.) The change in severity between these two measurement dates has two potential causes. First, the dip itself may have grown more severe. However, the dip was rated as “medium severity” in distress surveys in August 1994, October 1997 and December 1999. (In October 2000 and later the crack was rated as “high severity”.) Second, the profile measurement was made with a K. J. Law DNC 690 in 1995 and a K. J. Law T-6600 in 1997. This is important because the T-6600 used a height sensor footprint with a transverse dimension of 1.5 in and a longitudinal dimension of 0.24 in, whereas the DNC 690 used a a height sensor footprint with a transverse dimension of 5.9 in and a longitudinal dimension of 0.24 in. (*6*) The larger footprint of the DNC 690 may have blunted the dips more than that of the T-6600.

On section 0603, profiles late in the monitoring history (starting in August 2000) included narrow dips throughout the entire section, and in the same locations where joint faults appeared in the pre-rehabilitation profiles. Figure 24 illustrates the close relationship. The figure shows segments from both profiles after application of an anti-smoothing moving average filter with a base length of 10 ft. In the faulted profile of April 1990 the filter distorts the faults, and they appear as abrupt downward changes in elevation that follow each upward spike. However, the filter makes the faults easier to see.

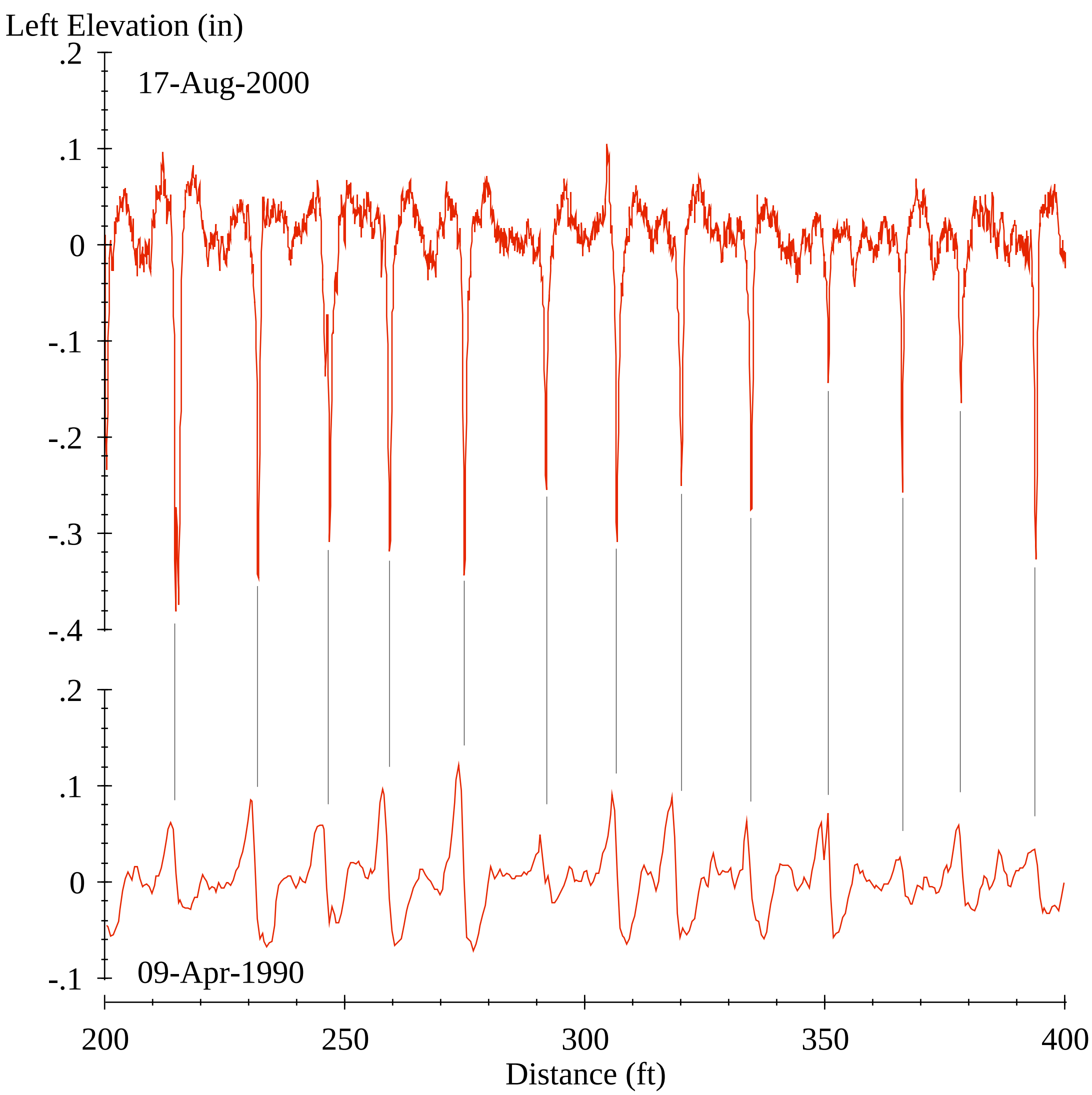

Figure 24. Joint and crack locations on section 0603.

Figure 24 shows that the narrow dips on section 0603 appear in the same pattern and in the same locations as the faults on the left side of the lane, which occurred in a pattern that approximated the original joint spacing of 15-13-15-17 ft. On the right side, not shown, the same pattern of faults before rehabilitation and narrow dips caused by transverse cracks late in the monitoring history is also present. However, the pattern is shifted about 1 ft downstream because of the skewed saw cuts. The synchronization process itself did not guarantee this alignment. Profiles collected before rehabilitation were only aligned to those afterward using data within section 0601 and extrapolation over the rest of the site.

Many of the sections on this SPS-6 project exhibited the same behavior, and the profiles included narrow dips at transverse cracks that could be linked to joints through faulting detected in the pre-rehabilitation profiles.

Two types of filtered plots were inspected for every visit of every section:

Raw profiles: This is a plot of profile with no filtering except the filters applied before conversion to an ASCII format. In some cases, a moving average anti-smoothing filter was applied with a base length of 100 ft.

Short Wavelength: This is a plot of profile anti-smoothed using a moving average with a base length of 10 ft.

These plots were used to screen profiles for changes with time and features of interest.

The raw profiles provided a broad view of the surface properties and an opportunity to identify the roughest features within a given test section. The short wavelength elevation plots provided a closer view of key features of interest, because short-duration features such as faults and narrow dips stood out more readily. The most common features studied using the short wavelength plots were: (1) joint faulting, (2) narrow dips at saw cuts, (3) narrow dips at transverse cracks, (4) deep dips at potholes, and (5) short wavelength content of high amplitude over areas of high-severity fatigue and rough patching.

Roughness Profile Plots

A roughness profile provides a continuous report of road roughness using a short segment length. Instead of summarizing the roughness by providing the IRI for an entire pavement section, the roughness profile shows the details of how IRI varies with distance along the section. It does this by displaying the IRI of every possible segment of given base length along the pavement, using a sliding window. (*7*)

A roughness profile displays the spatial distribution of roughness within a profile. As such, it can be used to distinguish road sections with uniform roughness from sections with roughness levels that change over their length. Further, the roughness profile can pinpoint locations with concentrated roughness, and provide an estimate of the contribution of a given road disturbance to the overall IRI.

Figure 25 shows an example of a roughness profile of section 0660 measured in September 1991. The roughness profile was generated using a base length of 100 ft. That means that every point in the plot shows the IRI of a 100-ft long segment of road, starting

50 ft upstream and ending 50 ft downstream. No data are shown over the 50 ft at each end of the section, because the plot was generated using a profile that terminated at the section boundaries. The plot shows that the first 250 ft of the section are more than twice as rough as the last 200 ft.

The profile featured in Figure 25 was measured shortly after rehabilitation, and it represents the status of the section just after rehabilitation. The construction process itself caused the roughness in the first half of the section. Figure 26 shows the elevation profile that corresponds to Figure 25 after application of an anti-smoothing moving average filter with a base length of 100 ft. The figure shows that some very long duration features cause the roughness. The “long dip” running 30 to 90 ft from the start of the section deteriorated over time, and eventually became so rough by growing in depth that a skin patch was placed over it.

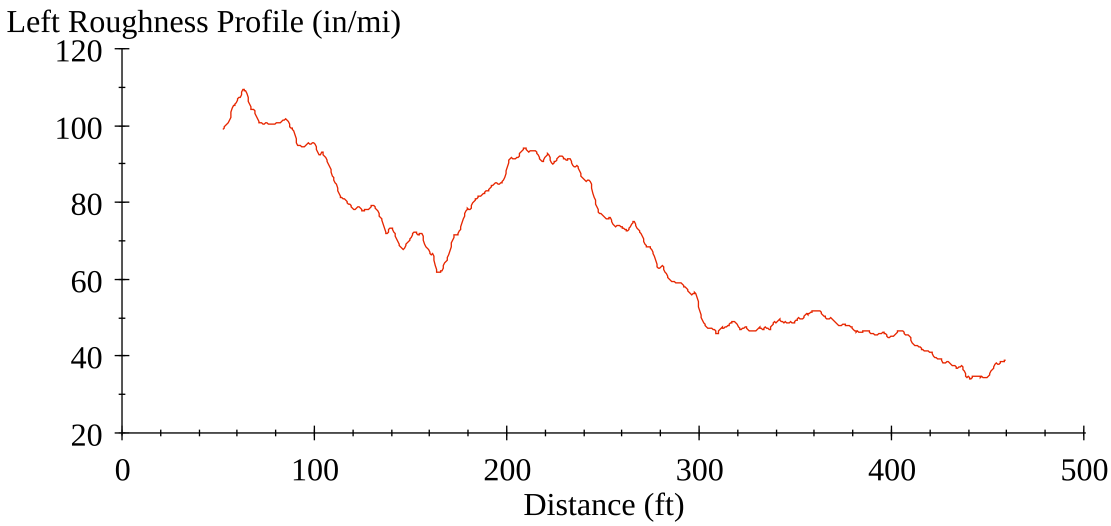

Figure 25. Roughness profile of section 0660, 100-ft base length.

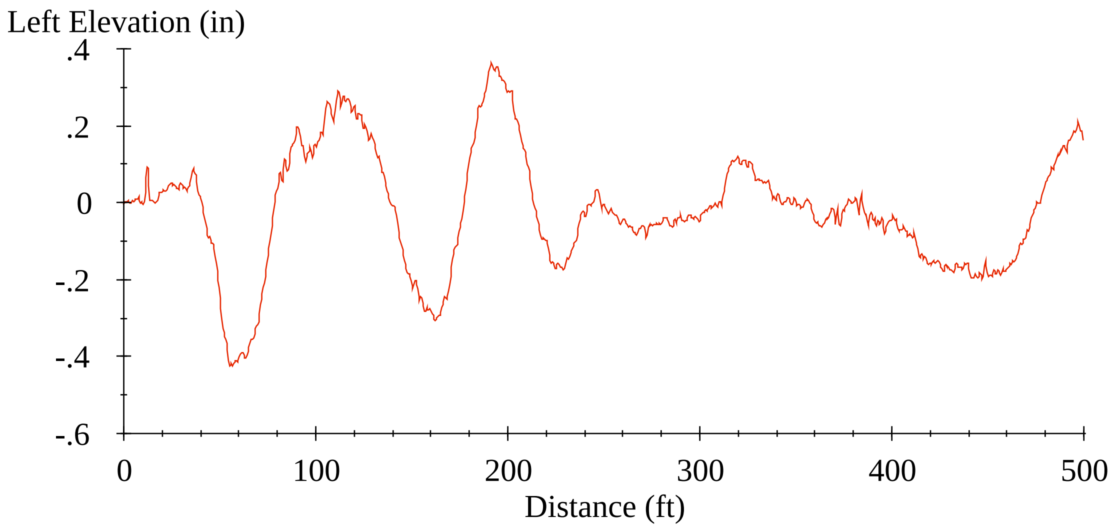

Figure 26. Elevation profile of section 0660 in September 1991.

Figure 27 shows how a roughness profile can help find localized roughness and quantify its impact on the overall roughness of a section. The figure shows the roughness profile of section 0603 for the three most recent profiles shown in Figure 22. The plot was generated using a 5 ft base length, so each point shows the contribution to the IRI that has accumulated over 5 ft. With a 5 ft base length, isolated roughness is easy to identify. For example, many of the dips highlighted in Figure 24 produced peak values over 400 in/mi in Figure 27. Since these peaks correspond to roughness over 1 percent of the section length, they each account for over 4 in/mi of the overall IRI of the section.

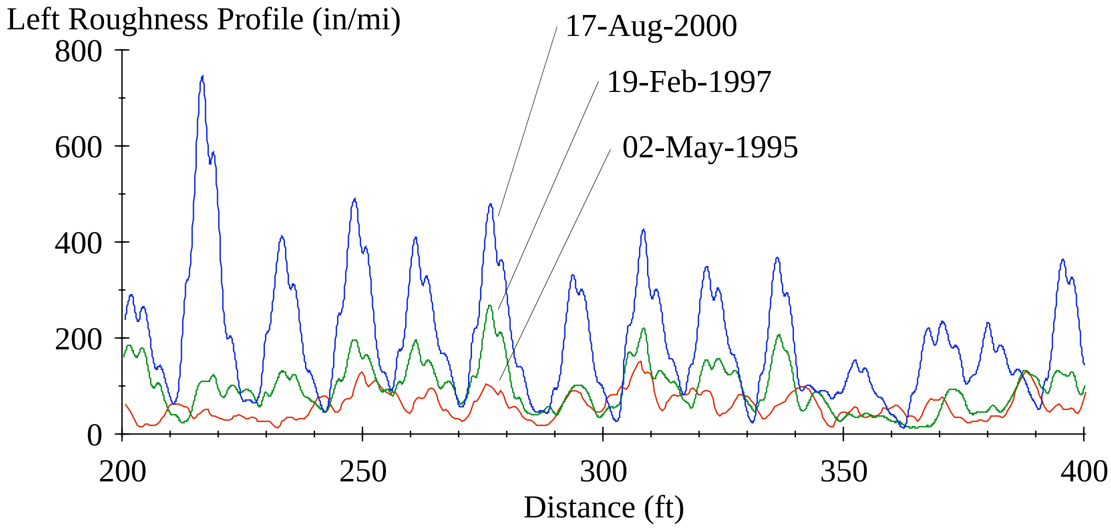

Figure 27. Roughness profiles of section 0603, 5-ft base length.

The 5 ft base length illustrated in Figure 27 is very short, but a short base length was required to isolate the closely spaced dips from each other. A base length of 25 ft is more standard for the purpose of seeking localized roughness. (*8, 9*)

Figure 28 shows how a roughness profile can help find and quantify isolated roughness. The figure shows the right roughness profile of section 0661 from August 2000 using a 25 ft base length. With a 25 ft base length, the area of concern about 375 ft from the start of the section is easy to identify. The peak value there is about 678 in/mi, which is more than 575 in/mi above the prevailing roughness level surrounding it. This is a difference of 575 in/mi over 25 ft. Since that value represents the roughness over just one twentieth of the segment, it suggests that a rough feature here increased the overall IRI of the section by nearly 29 in/mi.

Figure 29 shows the elevation profile that produced the roughness profile of Figure 28, and Figure 30 provides a photo of the distress that caused the disturbance. As shown, the profile includes a significant dip, and significant disturbances within the dip. Figure 30 illustrates that significant localized fatigue is present between the fog line and about 5 ft into the section from the right side. This fatigue cracking developed in the winter/spring of 1999/2000, and is consistent with a “soft spot” in the pavement structure, possibly caused by excessive water buildup in the unbound layers. Many of the fines have pumped up to the pavement surface and are visible in Figure 30.

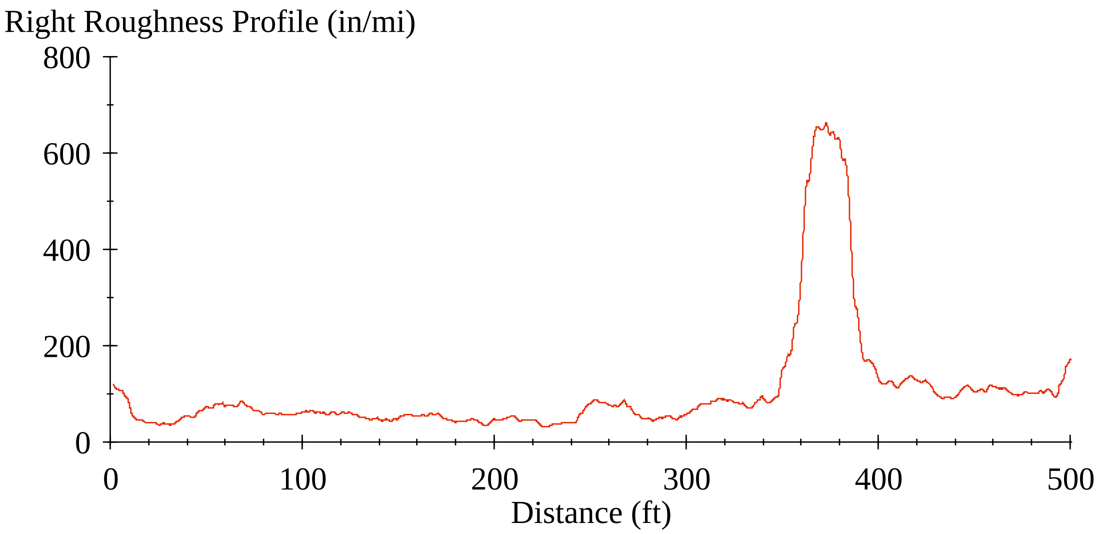

Figure 28. Right roughness profile of section 0661 in August 2000.

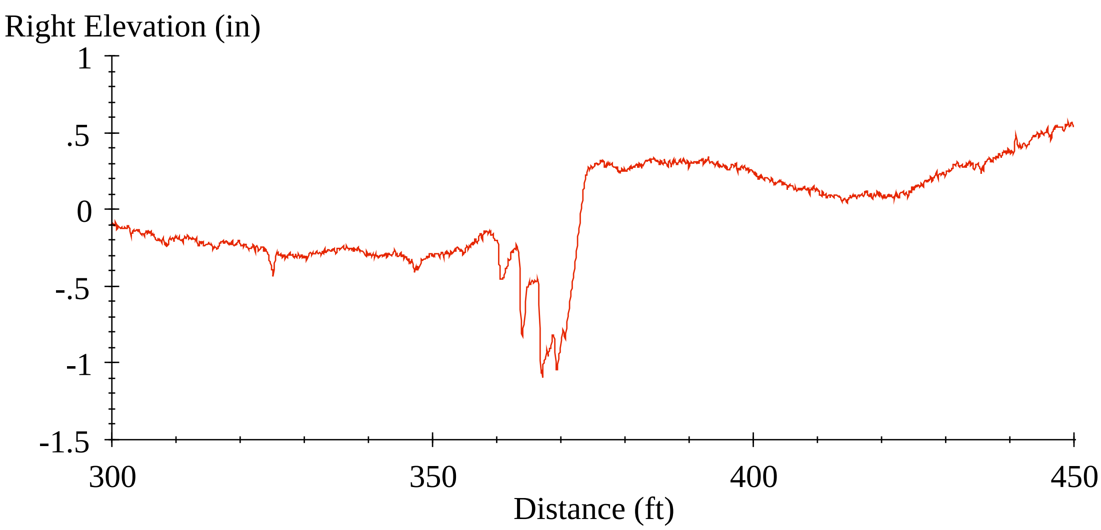

Figure 29. Right side profile of section 0661 in August 2000.

Figure 30. A fatigued area with pumping on section 0661 in august 2000.

In the case discussed above, the roughness was obvious using all three sources of information (elevation profile, roughness profile, and distress survey data). This is not always the case. The roughness profile provided a systematic method of prioritizing rough features for further analysis. Any area is considered to have localized roughness when the roughness profile (with a base length of 25 ft) reaches a peak value that is greater than 2.5 times the average IRI for the whole section. Of the 1225 profile pairs analyzed in this study 372 included localized roughness in the left side and 203 included localized roughness on the right side. Detection of localized roughness prompted more careful examination of the filtered elevation profiles, distress surveys and maintenance records.

Power Spectral Density Plots

A power spectral density (PSD) plot of an elevation profile shows the distribution of its content within each waveband. An elevation profile PSD is displayed as mean square elevation versus wave number, which is the inverse of wavelength. A PSD plot is generated by performing a Fourier transform on a profile. The value of the PSD in each waveband is derived from the Fourier coefficients, and represents the contribution to the overall variance of the profile in that band.

Often, the wavebands used in a PSD plot are given a uniform spacing on a log scale. In this work, PSDs were typically displayed using twelve bands per octave. In other words, the center of each waveband was a factor of $2^{1/12}$ larger than the waveband to its left on the plot and a factor of $2^{1/12}$ smaller than the waveband to its right. This spacing provided enough detail to search for roughness that was isolated at a given wavelength, but enough averaging to eliminate spurious content that is common when PSDs are displayed using a linear wave-number scale. PSD plots were also calculated from the slope profile, rather than the elevation profile. This aided in the interpretation of the plots, because the content of a slope PSD typically covers fewer orders of magnitude than an elevation PSD.

PSD plots provided a very useful breakdown of the content within the profiles from this study. In particular, the plots revealed: (1) cases in which significant roughness is concentrated within a given waveband, (2) the type of content that dominates the profile (e.g., long, medium, or short wavelength), (3) the effectiveness of rehabilitation in eliminating roughness over each waveband, (4) the type of roughness that increases with time, and (5) the type of roughness that is stable with time.

Figure 31 shows the PSD of the left profile for section 0604 measured in February 1997 and February 2001. This PSD plot includes several noteworthy features:

- The plot shows the PSD of slope, rather than elevation. Thus, the vertical axis has units of slope^2/(wave number), as opposed to elevation^2/(wave number).
- The plot covers a range of wave numbers from 0.01 cycles/ft to 1 cycle/ft. This is includes the range that affects IRI most.
- The spectral content from about 25 ft to 100 ft (wave numbers between 0.01 cycles/ft and 0.04 cycles/ft) did not change significantly with time.

- The spectral content for wavelengths below 25 ft increased between visits. Roughness in this range progressed in every visit from 1997 through 2001.
- In both profile measurement visits, the trend in the PSD grew in content with decreasing wavelength (increasing wave number) for wavelengths below 10 ft. This should be interpreted cautiously, however, because a single anomalous reading in the elevation profile or a single severe narrow dip would appear on a PSD plot this way. Alternatively, it may indicate uniform growth in short wavelength roughness over the entire length of the profile. In this case, the growth was caused by narrow dips in the profile at saw cuts that were placed over the underlying PCC joints and grew rougher as the sealant deteriorated.
- The peak at about 0.067 cycles/ft indicates emerging periodic roughness concentrated at a wavelength of about 15 ft. This is present in the PSD because the enough transverse cracks (and associated dips) appeared to form a pattern with a spacing of roughly 15 ft. The narrow dips were present in both visits, but they were much more severe in February 2001.

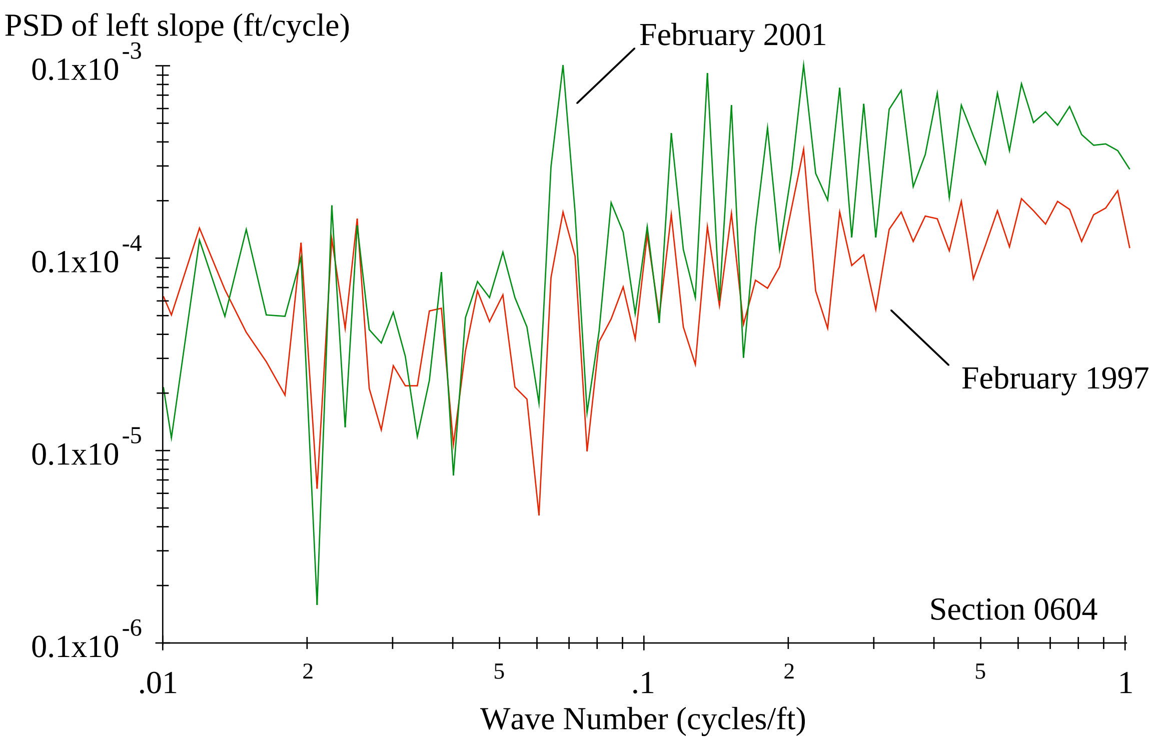

Figure 31. PSD of section 0604 profile, left side.

Each of the final four observations listed above provide important information about the nature of the roughness on section 0604 and its progression. However, the PSD provides no information about where the roughness exists within the section. Further, if the roughness within a profile is concentrated in a single location, the PSD plot may provide misleading information. The filtered profile plots and the roughness profiles, discussed below, provide a more complete assessment of the roughness on a given pavement.

The PSD plot provides insight into the filtering practices of the profiler that made the measurements. Figure 32 shows the PSD of the left profile for section 0664 during for profiles measured in September 1990, February 1997, and October 2002 over the maximum range allowed by the section length and sample interval. The measurements were made by a K. J. Law DNC 690 (1990 through 1995), a K. J. Law T-6600 (1997 through 2001) and an International Cybernetics Corporation (ICC) MDR 4086L3 (2002), respectively. Some items of note with regard to this plot include:

- Content at wave numbers below 0.01 cycles/ft (i.e., wavelengths above 100 ft) dominates the content in the PSD from September 1990. This is a common trait in the PSD plot for an elevation profile collected just after an overlay is placed, since the process of placing an overlay often leaves little short wavelength roughness, but changes the long wavelength trends in the road very little.
- The spectral content for wave numbers between 0.01 and 0.25 cycles/ft (100 and 4 ft) is about the same in all three visits. This is the range that affects IRI most. (*10*)
- The spectral content differs for very long wavelengths (low wave numbers). This is not caused by a change in the true profile of the section. Rather, it is the result of the changes in profiler, and an associated change in the high-pass filtering methods. (*6*) In particular, the content below a wave number of 0.01 cycles/ft is much lower in October 2002, after the transition from K.J. Law profilers to an ICC profiler.

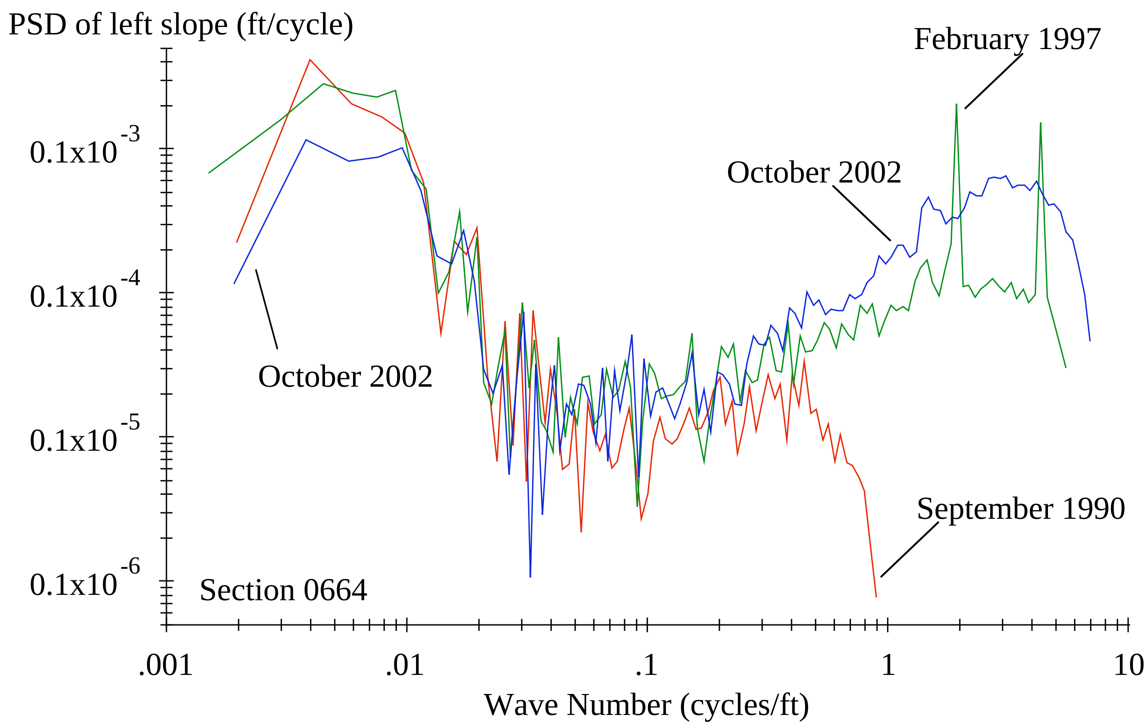

Figure 32. PSD of section 0664 profiles, left side.

- The spectral content in each trace decreases at short wavelengths (high wave numbers) near the end of the plotted range. This is an artifact of low-pass filtering applied at the time of the measurement, which is a combination of digital filtering and height sensor footprint. (*10*) Since each profiler stores data at a different interval, each profile applies a low-pass filter with a different cut-off value.
- The PSD plot for February 1997 includes a spike at a wave number of about 1.9 cycles/ft, and another at a higher value. This is also an artifact of the measurement process, but the source is not clear. The spikes were present in all of the measurements made by the T-6600 profiler. However, the spikes did not occur at the same wave number in each visit, or in each repeat measurement within a given visit. The wave number where the left-most spike occurred ranged from about 1.67 cycles/ft to 3.06 cycles/ft.

As described above, the PSD plots provided significant information about the three profilers used to make measurements throughout the life of this SPS-6 project. The plots also helped to study slab-related effects within pre-rehabilitation profiles and profiles of sections with PCC surfaces. However, most of the insight into the behavior of AC overlays over time came from elevation profile plots and roughness profile plots.

Distress Surveys and Maintenance Records

Once the analysis and plotting described above was completed, all of the observations were compared to the manual distress survey performed on each section. Manual distress surveys were available for each section starting in 1991, and covering up to six other visits throughout the rest of the study. This provided a means of relating profile features to known distresses. For this SPS-6 project, one observation was common. Dips that grew progressively rough with time were often found in the vicinity of transverse cracks or saw cuts, which in turn appeared in the locations where joint faulting was detected before rehabilitation.

Observations of changes in profile properties were also compared to maintenance records. for example, section 0603, 0659, 0660, and 0661 received skin patching that affected their roughness late in the project.

Detailed Observations

This section summarizes observations from the study of roughness index progression, filtered profile plots, roughness profile plots, PSD plots, and distress surveys. The test sections are grouped by overlay type here. For example, sections 0601, 0602 and 0605 did not receive an overlay; sections 0603, 0604, 0606, 0607 and 0659 each received a 4-inch AC overlay; sections 0661, 0662 and 0664 through 0669 each received an overlay constructed with a combination of ARAC and AC. These groupings are used to help compare the performance of each overlay type to the others, and to distinguish the performance of each surface preparation alternative within a given overlay type.

In many cases, similar behavior was noted for multiple sections. Appendix B provides much more detailed observations.

Pre-rehabilitation

Before rehabilitation, all of the test sections included roughness that could be linked to faulting, spalling, corner breaks, shattered slabs, or other slab effects. However, the level of roughness and distress varied significantly along the site. This may have affected the relative performance of each rehabilitation alternative. Often, groups of adjacent test sections had similar properties. Table 22 lists the roughness level, number of faulted joints, and an estimate of the faulting magnitude with sections listed as they appear from east to west along the site.

Table 22. Pre-rehabilitation Roughness.

Section	MRI (in/mi)	Portion of joints with faulting	Faulting magnitude (in)
0660	196	All	0.05-0.40
0663	218	All	0.05-0.30
0608	103	Most	0-0.10
0607	100	None	—
0606	104	Few	0-0.10
0659	223	Most	0.05-0.25
0661	215	All	0.05-0.25
0604	102	Most	0-0.15
0662	152	Most	0-0.15
0603	169	All	0.05-0.30
0605	152	All	0.05-0.25
0602	166	All	0.05-0.30
0601	102	Few	0-0.1

No Overlay

Distress at joints accounted for most of the roughness in all three sections at the end of their service life. Faulting caused much of the roughness on sections 0602 and 0605 before surface preparation, and faulting caused most of the roughness at the end of their service life. Section 0601 was not faulted before surface preparation. On section 0601, narrow dips at joints, rather than faulting, caused most of the roughness at the end of its service life.

Section 0601 (routine surface preparation): The MRI of this section increased from 102 in/mi to 177 in/mi in less than three years before it was taken out of the study. Most of the roughness and its increase were caused by narrow dips at spalled joints. Some of the dips grew to as wide as 4 ft and up to 1 in deep.

Section 0602 (minimum surface preparation): The MRI of this section increased from 166 in/mi to 210 in/mi in less than three years before it was taken out of the study. Faulting at joints and mid-slab cracks and the associated tilting of the pieces caused most of the roughness and its increase. Localized roughness was observed at a map-cracked slab.

Section 0605 (maximum surface preparation): The MRI of this section decreased from 152 to 61 in/mi as a result of the surface preparation. It then increased to 131 in/mi in less than three years before it was taken out of the study. Faulting at joints and mid-slab cracks and the associated tilting of the pieces caused most of the roughness and its increase over time. The roughness properties (types of features and spectral content, but not spatial distribution) were very similar in the last profiling visit to those of the section before surface preparation.

PCC Overlay

Section 0663: This section received a 10-in thick unbonded overlay over a 1-in thick AC course. The MRI of this section decreased from 218 to 93 in/mi as a result of the rehabilitation. It then increased very little in the next seven years, but a total of 23 in/mi over the monitoring history.

Narrow dips appeared at a regular spacing of 15 ft throughout the section, and the increase in their depth caused most of the increase in roughness over time. No significant distress was observed on this section. Since the dips at the joints were narrow and did not include significant faulting, the increase in MRI did not cause a commensurate reduction in ride quality. The removal and subsequent replacement of weigh in motion scales on the section caused a somewhat erratic change in roughness over the second half of the monitoring history.

AC Overlay, 4-in Thick

Section 0603 (minimum surface preparation): The MRI of this section increased by 12 in/mi over the first five years after rehabilitation, then increased at a much higher rate to a peak value of 214 in/mi by the eleventh year. Transverse cracking at the locations of the underlying joints caused most of the roughness progression, and a narrow dip appeared over most of the joints by the seventh year after rehabilitation. By the eleventh year, most of the dips were 1-2 ft wide and at least 0.25 in deep. Subsequent skin patching over the last 380 ft of the section reduced the MRI by about 40 in/mi. Narrow dips still appeared at most of the joints, but they were less severe.

Section 0604 (saw and seal): The MRI of this section decreased from 218 to 93 in/mi as a result of the rehabilitation. It then increased very little in the next seven years, by a total of 23 in/mi over the monitoring history. Narrow dips that appeared at saw cuts as the sealant wore away caused the increase in roughness. By the end of the monitoring history narrow dips appeared at most of the saw cuts that were 1-1.5 ft wide and up to 0.3 in deep.

Section 0606 (maximum surface preparation): The MRI of this section increased by 1 in/mi over the first six years after rehabilitation, then increased at a higher rate to a peak value of 145 in/mi by the eleventh year. Transverse cracking at the locations of the underlying joints caused most of the roughness progression, and a narrow dip appeared within the profiles over most of the joints by the end of the monitoring period. By the final visit, most of the dips were 1-2 ft wide and at least 0.2 in deep. However, a small number of dips at high-severity transverse cracks stood out as more severe than the rest. Nothing was detected in the pre-rehabilitation profiles that could explain the most severe dips.

Section 0607 (crack and seat): The MRI of this section increased by 14 in/mi over the first six years after rehabilitation, then increased at a higher rate to a peak value of 200 in/mi by the end of the monitoring period. Transverse cracking at the locations of the underlying joints caused the majority of the roughness progression, and a narrow dip appeared within the profiles over most of the joints by the end of the monitoring period. Several dips 1-2 ft wide and more than 1 in deep appeared where high severity transverse cracks were recorded. Gouges in the pavement, a longitudinal crack, an area of fatigued pavement, and a patch in poor condition also contributed to roughness of the left side of the lane in the last three years of the experiment.

Section 0659 (fabric/crack and seat): The MRI of this section increased by 7 in/mi over the first six years after rehabilitation, then increased at a higher rate to a value of 179 in/mi by the end of the monitoring period. Transverse cracking at the locations of the underlying joints caused the majority of the roughness progression, and a narrow dip appeared within the profiles over about half of the joints by the end of the monitoring period. Most of the dips were less than 1 ft wide and less than 0.5 in deep. However, a few dips over 1 in deep appeared at cracks with fatigue in the wheel path. Localized roughness appeared at potholes, an area of high severity fatigue with potholes, and at a fatigued area with a patch.

AC Overlay, 8-in Thick

Section 0608 (crack and seat): The MRI of this section increased by 68 in/mi over the post-rehabilitation monitoring history. This included 5 times as much growth in the IRI of the left side compared to the right side. A 20-ft long fatigued area on the left side of the lane with rough patches at both ends caused more of the roughness progression than any other feature, and accounted for 40-60 in/mi of roughness on the left side in the final profiling visit. Transverse cracking caused the majority of the roughness progression on the right side of the lane and some of the roughness progression on the left side of the lane. A narrow dip appeared within the profiles over most of the locations where transverse cracks were recorded. The cracks may have appeared at the locations of underlying joints, but this could not be confirmed.

Section 0660 (rubblize): The MRI of this section increased by 83 in/mi over the post-rehabilitation monitoring history. Three types of distress caused the progression in roughness: (1) narrow dips at transverse cracks, (2) localized roughness at a 20-ft long fatigued area on the right side, and (3) roughness at the leading and trailing edge of a long dip 50-90 ft from the start of the section. A skin patch was placed over the long dip, but this did not completely remove the dip, and it added roughness at the borders of the patch.

Rubberized AC Overlay

Section 0661 (crack and seat, ARAC/AC): The MRI of this section increased erratically after rehabilitation from a minimum value of 45 in/mi to a final value of 97 in/mi. Three features accounted for the majority of the post-rehabilitation increase in roughness. First, an area about 15 ft long appeared on the right side with pumping and several cracks in 1999 and 2000 and caused severe localized roughness in 2000. Second, the leading edge of a skin patch placed in 2001 (extending from the rough area to the end of the section) caused localized roughness on both sides. Third, the skin patch itself was rougher than the pavement it covered, with the exception of the area where the patch covered cracking and pumping.

Section 0662 (crack and seat, AC/ARAC): The MRI of this section increased after rehabilitation from a minimum value of 55 in/mi to 173 in/mi in 2001. A skin patch decreased the roughness to 137 in/mi, although the transition at the start of the patch caused localized roughness. Transverse cracking at the locations of the underlying joints caused most of the roughness progression, and a narrow dip appeared within the profiles over most of the joints by the end of the monitoring period.

Section 0664 (no surface preparation): This section was very smooth throughout the monitoring history. The initial MRI value was 44 in/mi, and the MRI only ranged from 48 to 50 in/mi from February 1993 until October 2002. The roughest portion of the section occurred from 350 to 400 ft from the start, because of a very long dip over that range.

Section 0665 (crack and seat): This section was very smooth throughout the monitoring history. The MRI progressed from an initial value of 43 in/mi to a final value of 51 in/mi, but was roughest in February 2001 with an MRI value of 55 in/mi. In all visits, a rise in elevation of about 0.2 in appeared about 200 ft from the start of the section, followed by a series of small bumps. These features were harsh enough to qualify as localized roughness in the left side profiles.

Section 0666 (rubblize): This section was very smooth throughout the monitoring history. The MRI progressed somewhat steadily from an initial value of 39 in/mi to a value of 49 in/mi in March 2000, then it held steady for the rest of the monitoring period. No localized roughness appeared on this section. However, the roughest locations within the section were found at two bumps 4 to 6 ft long and about 0.1 in high. These did not correspond to any observed distress.

Section 0667 (crack and seat): This section experienced little change in roughness throughout the monitoring history, with a total range in MRI of 70 to 74 in/mi. Content in the wavelength range from 45 to 60 ft accounted for most of the MRI. Localized roughness (or nearly so) was detected in the profiles because of a long bump near the middle of the section with a sharp peak (i.e., a crest).

Section 0668 (no surface preparation): This section was very smooth throughout the monitoring history. The MRI increased from 37 to 45 in/mi. The profiles included a small amount of roughness isolated at a wavelength of 15 ft, and the right side profiles included some content isolated at a wavelength of 7.5 ft. In the second half of the monitoring history, small dips 0.5 ft long and up to 0.25 in deep appeared at the only three locations where distress survey recorded slightly skewed transverse cracks that spanned the entire lane. No localized roughness was detected.

Section 0669 (rubblize): This section remained smooth throughout the monitoring history. The MRI ranged from 49 to 59 in/mi. Content in the wavelength range from 45 to 60 ft accounted for most of the MRI. Localized roughness was detected in the left side profiles because of a sharp slope change at the apex of a very long bump. This was not nearly as severe on the right side.

Summary

As part of the LTPP Program, Arizona DOT constructed nineteen SPS-6 test sections on I-40 near Flagstaff, Arizona. The experiment was designed to study the effectiveness of rehabilitation strategies on PCC pavements. There were two sets of test sections on this project: eight core sections to match similar projects constructed by other Highway Agencies with SPS-6 projects eleven supplemental sections to investigate alternative design characteristics as selected by ADOT. Details regarding the sections are summarized in Table 1. The rehabilitation activities were performed in the summer of 1990 and the sections were placed out-of-study in the fall of 2002, with three exceptions to be discussed below.

This report provided details about the pre-rehabilitation and post-rehabilitation roughness of the road and provided a basis for quantifying and explaining the changes in roughness with time, and relating the observations to distress and maintenance.

Table 23 summarizes the observations for the sections that received an overlay. The sections are grouped in Table 23 by overlay type. The table summarizes the roughness progression, distresses that contributed to roughness progression, and pre-rehabilitation status of each section. The table lists MRI values just after rehabilitation, 6.4 years afterward, at the end of the project, and the overall post-rehabilitation range. Figure 33 provides these values graphically.

Pre-rehabilitation status did not have a clear relationship to post-rehabilitation roughness progression. However, any comparison of performance by surface preparation technique should consider the roughness and faulting levels that were present before rehabilitation. For example, among the sections that received a 4-inch AC overlay, roughness progressed more slowly on the section with maximum surface preparation (0606) than on the section with minimum surface preparation (0603). On both sections, roughness progressed due to reflective cracking. However, the lower roughness progression on section 0606 may have been caused by a combination of the additional surface preparation and status of the joints before rehabilitation. The pre-rehabilitation status of sections 0664-0669 is not known, but was reported as being similar to that of the other sections on this project.

Table 23 shows that the most prevalent contributor to roughness on this project was reflective and transverse cracking. Late in the history of the project, transverse and reflective cracking often dominated as a source of roughness in the roughest sections. Table 23 identified the sections with localized roughness. Since an instance of localized roughness required that the severity stand out relative to the rest of the section, the threshold for localized roughness was lower on smooth sections than on rough sections. Localized roughness was often associated with a particular type of distress cited in the distress surveys. In some cases, such as on sections 0665, 0667, and 0669, localized roughness occurred directly after rehabilitation and was probably built in.

Figure 33 summarizes the roughness progression of all of the sections that received an overlay. The figure shows the entire range of MRI values observed in post-rehabilitation profile measurements with a gray bar. (Appendix A provides values for each visit.) The figure also provides markings at two landmark visits. First, the value 6.4 years after rehabilitation is marked to distinguish sections with high initial MRI or roughness that progressed early from those that may have held their roughness for several years before losing their functional performance. Second, the final value (12 years after rehabilitation) is also marked, and the test sections are sorted using this value in the figure.

At a glance, Figure 33 shows that sections with ARAC/AC overlay progressed in roughness much less than the rest of the sections. Figure 33 also shows that, while the PCC overlay started out rougher than the rest, it progressed in roughness very little over the 12-year life of the project. Lastly, sections 0603 and 0662 reached peak roughness values much higher than their final roughness. This is because they both received skin patching that reduced their roughness.

The following summarizes the performance (in terms of surface roughness) of the nineteen test sections:

- Roughness on the six sections with a rubberized friction course covering 2 in of ARAC on top of 3 in of AC (0664 through 0669) progressed very little after rehabilitation.
- The seven supplemental sections constructed with ARAC over AC (0661 and 0664 through 0669) outperformed the other test sections with an asphalt overlay.
- Using 2-in thick ARAC over 2 in of AC (0661) provided a significant improvement in smoothness as compared to using 2-in thick AC over 2 in of ARAC (0662). Only the latter exhibited significant reflective cracking.
- The unbonded concrete overlay (0663) was the roughest in the first visit after rehabilitation among all of the sections that received an overlay. However, the section increased in roughness very slowly and held its functional performance and structural integrity at the surface throughout the entire monitoring history.
- Roughness on the pavement with a crack and seat and an 8-in thick AC overlay (0608) progressed more slowly than its rubblized counterpart (0659), and much more slowly than its counterpart with a 4-in AC overlay (0607).

Table 23. Roughness Behavior Summary.

Section	0603	0607	0659	0606	0604	0660	0608	0663
Overlay material	AC	AC	AC	AC	AC	AC	AC	PCC/AC
Overlay thickness (in)	4	4	4	4	4	8	8	10/1
Surface preparation	Min.	CS	F/CS	Max.	SS	Rub.	CS	CS
MRI (in/mi)								
Minimum	55	53	66	64	55	65	59	93
6.4 yrs after rehabilitation	91	69	73	75	67	110	66	95
Final	173	200	179	137	135	148	127	117
Range	55-214	53-200	66-181	64-145	55-135	65-148	59-127	93-117
Contributors to roughness								
Reflective cracking	✓	✓	✓	✓				
Transverse cracking					✓	✓		
Longitudinal cracking			✓					
Fatigue		✓	✓			✓	✓	
Potholes			✓					
Patches		✓	✓				✓	
Gauges		✓						
Transition at skin patch								
Cracks and pumping								
Localized roughness	✓	✓	✓			✓	✓	
Pre-rehabilitation								
Roughness (MRI)	M	L	H	L	L	H	L	H
Faulting severity	H	L	H	L	M	H	M	H

Surface prep.: CS-Crack and seat; F/CS-Fabric/Crack and seat; SS-Saw and seal; Rub.-Rubblize; Min.-Minimum; Max.-Maximum

Roughness: H-High (> 170 in/mi); M-Medium (120-170 in/mi); L-Low (< 120 in/mi)

Faulting severity: H-High; M-Medium; L-Low

Table 23 (cont). Roughness Behavior Summary.

Section	0662	0661	0665	0667	0664	0668	0666	0669
Overlay material	AC ARAC	ARAC AC	ARAC AC	ARAC AC	ARAC AC	ARAC AC	ARAC AC	ARAC AC
Overlay thickness (in)	2 2	2 2	2 3	2 3	2 3	2 3	2 3	2 3
Surface preparation	CS	CS	CS	CS	None	None	Rub.	Rub.
MRI (in/mi)								
Minimum	49	45	43	70	44	37	39	49
6.4 yrs after rehabilitation	79	61	49	73	49	42	47	56
Final	136	97	51	73	49	45	49	58
Range	49-173	45-100	43-55	70-74	44-50	37-45	39-50	49-59
Contributors to roughness								
Reflective cracking	✓							
Transverse cracking								
Longitudinal cracking								
Fatigue								
Potholes								
Patches								
Gauges								
Transition at skin patch	✓	✓						
Cracks and pumping		✓						
Localized roughness	✓	✓	✓	✓				✓
Pre-rehabilitation								
Roughness (MRI)	M	H						
Faulting severity	M	H						

Sections 0664-0669 also included a 0.5 in thick asphalt rubber-asphalt concrete friction course.

Surface prep.:	CS-Crack and seat	Rub.-Rubblize
Roughness:	H-High (> 170 in/mi)	M-Medium (120-170 in/mi)
Faulting severity:	H-High	M-Medium

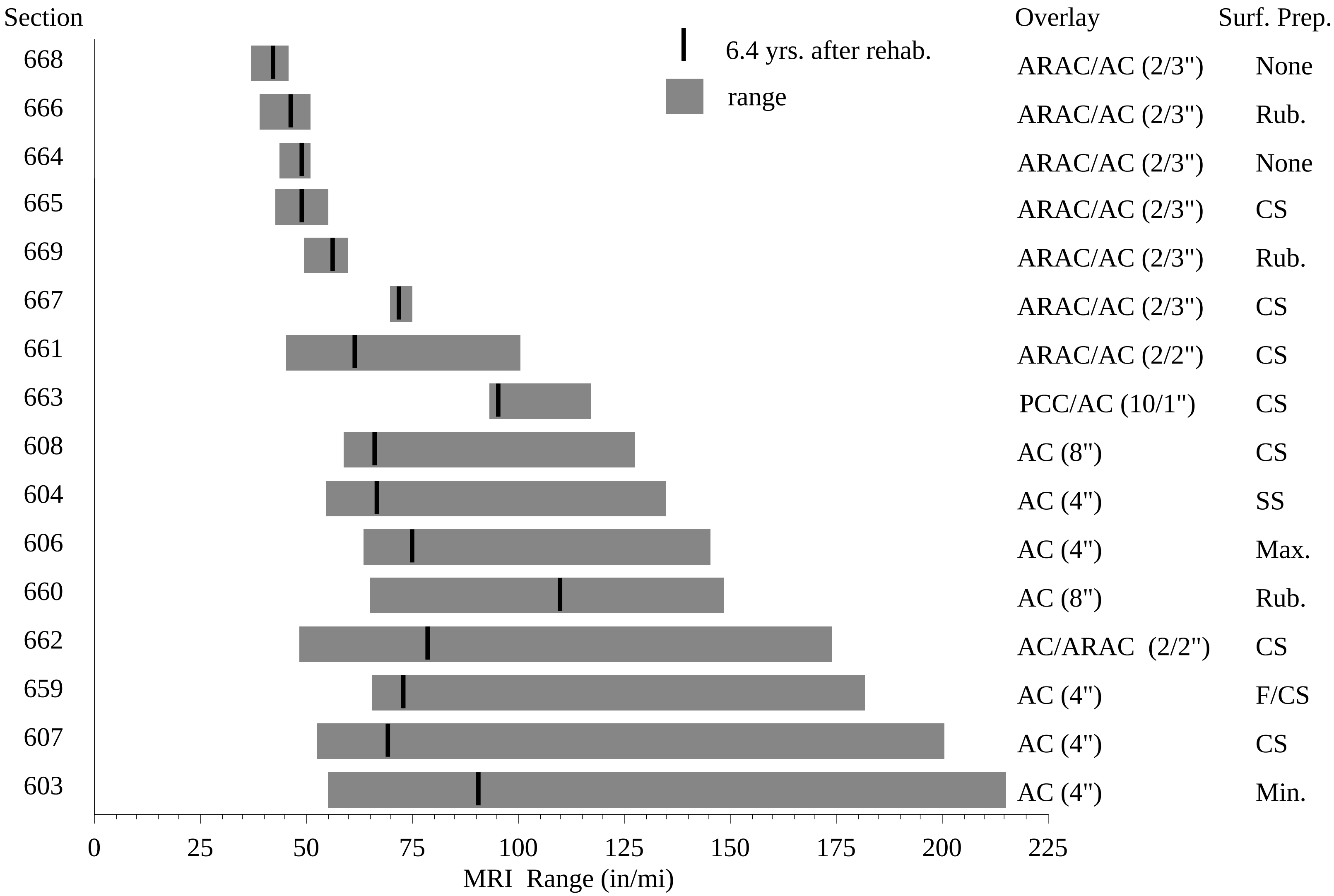

Figure 33. Roughness summary.

- Disturbances at transverse cracks dominated the roughness on of the sections with a 4-in AC overlay (0603, 0604, 0606, 0607, 0659) by the end of the experiment. (These were reflective cracks in all of the sections except 0604, where the cracks were sawed and sealed.) However, they did not all perform equally.
  - These sections retained their smoothness quite well for the first six years, at which point roughness began to increase aggressively—particularly for sections receiving minimal restoration.
  - The saw and seal section (0604) and the section with maximum restoration (0606) finished the experiment with the lowest roughness, and the least amount of roughness at transverse cracks.
  - Among the sections with minimum restoration (0603 and 0604), the saw and seal section (0604) was affected by roughness at transverse cracks the least, but wearing away of the sealant took its toll by the end of the experiment. In contrast, the section without saw and seal (0603) included a rough reflective cracks over each underlying joint.
  - Both sections with crack and seat (0607 and 0659) included roughness caused by other distress in addition to reflective cracks. Roughness progressed less rapidly on the section with geotextile (0659), but neither section outperformed saw and seal (0604) or maximum restoration (0606).
- The three sections not receiving overlays (0601, 0602, 0605) reached their terminal serviceability within three years. Performing the maximum rehabilitation activities (0605) on the PCC only extended the service life by one year as compared to the routine maintenance and minimum restoration sections, but the section offered better functional performance (i.e., less roughness) over the interval between rehabilitation and terminal serviceability.
- In 2000, sections 0603, 0661 and 0662 received substantial thin overlay patching covering up to 70 percent of the test sections. Sections 0660 and 0659 also received patching to a lesser extent in 1999. Patching did not always decrease roughness, and localized roughness sometimes appeared at the borders of the patched area.

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Appendix A: Roughness Values

This appendix lists the left International Roughness Index (IRI), right IRI, mean roughness index (MRI), Half-car Roughness Index (HRI), and Ride Number (RN) values for each visit of each section. The roughness values are the average for five repeat runs. The five runs were selected from a group of as many as nine by automated comparison of profiles, as described in the main report. Values of standard deviation are also provided for left and right IRI to reveal cases of high variability among the five measurements. However, the screening procedure used to select five repeats usually helped reduce the level of scatter.

The discussion of roughness in the main report emphasizes the left and right IRI. Nevertheless, the other indexes do provide useful additional information. MRI is simply the average of the left and right IRI value. HRI is calculated by converting the IRI filter into a half-car model. (*1*) This is done by collapsing the left and right profile into a single profile in which each point is the average of the corresponding left and right elevation. The IRI filter is then applied to the resulting signal. The HRI is very similar to the IRI, except that side-to-side deviations in profile are eliminated. The result is that the HRI value for a pair of profiles will always be lower than the corresponding MRI value. Comparing the HRI and MRI value provides a crude indication of the significance of roll (i.e., side by side variation in profile) to the overall roughness. When HRI is low compared to MRI, roll is significant. This is common among asphalt pavements. (*2*) Certain types of pavement distress, such as longitudinal cracking, may also cause significant differences between HRI and MRI.

Figure A-1 compares the HRI to MRI for all of the profile measurements that are covered in this appendix. This includes 1225 pairs of roughness values. The figure shows a best fit line and a line of equality. The slope of the line is 0.865. This is close to values observed for asphalt pavement.

RN has shown a closer relationship to road user opinion than the other indexes. (*3*) As such, it may help distinguish the segments from each other by ride quality. Further, the effect on RN may help quantify the impact of that distress on ride when a particular type of distress dominates the roughness of a section. In particular, a very low RN value coupled with moderate IRI values indicates a high level of short wavelength roughness, and potential sensitivity to narrow dips and measurement errors caused by coarse surface texture.

Table A-1 provides the roughness values. The tables also list the date of each measurement, and the time in years since the site was opened to traffic. Negative values indicate measurements that were made before rehabilitation.

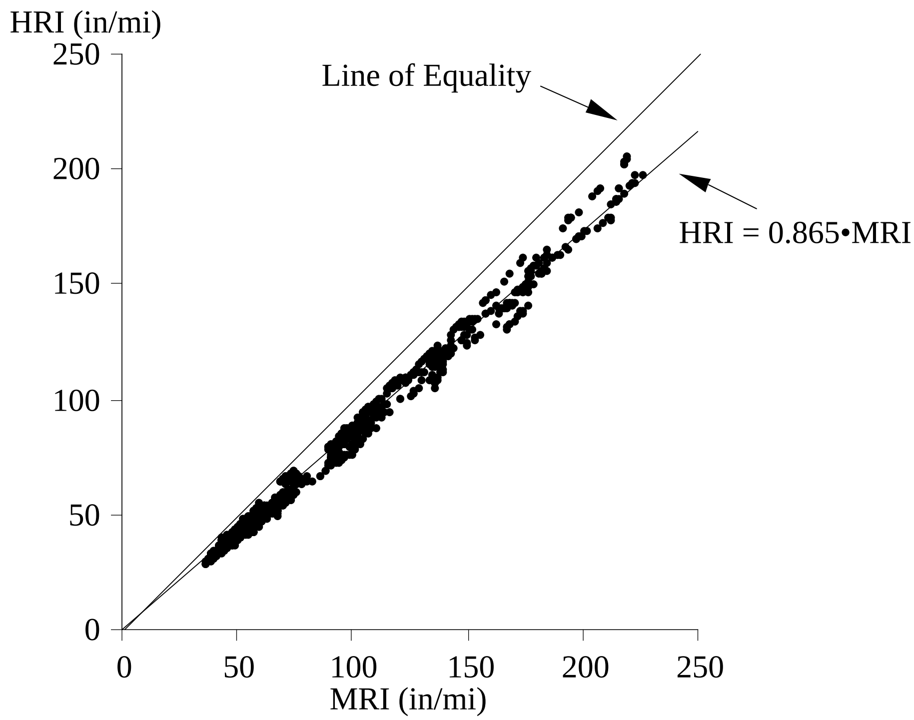

Figure A–1. Comparison of HRI to MRI.

Table A-1. Roughness Values.

Section	Date	Years	Left IRI (in/mi)		Right IRI (in/mi)		MRI (in/mi)	HRI (in/mi)	RN
			Ave	St Dev	Ave	St Dev			
0601	09-Apr-90	-0.49	104	0.7	102	1.7	103	83	2.84
0601	27-Sep-90	-0.02	131	6.3	102	1.3	116	97	2.19
0601	16-Sep-91	0.94	156	5.1	122	1.1	139	118	1.95
0601	27-Feb-92	1.39	191	12.6	145	5.8	168	144	1.77
0601	12-Feb-93	2.35	225	13.3	128	6.6	177	155	1.87
0602	09-Apr-90	-0.49	166	2.1	167	0.8	166	140	2.65
0602	27-Sep-90	-0.02	182	2.3	170	1.4	176	149	2.58
0602	16-Sep-91	0.94	185	2.1	179	1.6	182	156	2.50
0602	27-Feb-92	1.39	208	6.0	188	2.9	198	171	2.35
0602	12-Feb-93	2.35	218	2.7	202	4.3	210	178	2.20
0603	09-Apr-90	-0.49	138	7.4	200	2.6	169	155	2.43
0603	27-Sep-90	-0.02	52	0.9	58	1.9	55	44	4.12
0603	16-Sep-91	0.94	66	2.5	49	1.2	57	48	3.83
0603	27-Feb-92	1.39	71	2.0	50	1.5	61	50	3.81
0603	12-Feb-93	2.35	73	3.0	55	1.1	64	52	3.66
0603	21-Jan-94	3.29	66	0.5	56	2.3	61	49	3.68
0603	02-May-95	4.57	68	1.0	67	1.6	67	54	3.56
0603	19-Feb-97	6.37	107	2.8	74	2.9	91	73	3.05
0603	17-Apr-98	7.53	148	1.7	134	1.8	141	121	1.98
0603	02-Mar-99	8.40	155	1.4	140	3.3	147	127	2.03
0603	14-Mar-00	9.44	200	0.9	138	1.3	169	142	1.90
0603	17-Aug-00	9.86	211	2.0	163	4.8	187	162	1.70
0603	07-Feb-01	10.34	224	1.7	205	3.7	214	187	1.45
0603	15-Feb-02	11.36	171	2.4	164	2.7	168	133	2.06
0603	28-Oct-02	12.06	183	2.0	164	3.4	173	139	1.96

Table A-1 (cont). Roughness Values.

Section	Date	Years	Left IRI (in/mi)		Right IRI (in/mi)		MRI	HRI	RN
			Ave	St Dev	Ave	St Dev	(in/mi)	(in/mi)	
0604	09-Apr-90	-0.49	91	1.5	113	1.4	102	87	3.06
0604	27-Sep-90	-0.02	69	1.0	67	0.7	68	55	3.91
0604	16-Sep-91	0.94	55	0.7	55	1.2	55	44	3.83
0604	27-Feb-92	1.39	57	1.6	58	2.1	58	46	3.71
0604	12-Feb-93	2.35	62	1.8	58	2.2	60	48	3.66
0604	21-Jan-94	3.29	59	0.8	55	3.4	57	45	3.71
0604	02-May-95	4.57	58	1.0	55	0.3	57	44	3.82
0604	19-Feb-97	6.37	79	1.5	55	0.8	67	52	3.56
0604	17-Apr-98	7.53	99	3.4	93	6.8	96	77	2.64
0604	02-Mar-99	8.40	93	3.5	79	2.7	86	68	3.00
0604	14-Mar-00	9.44	119	1.7	70	1.0	94	74	2.98
0604	17-Aug-00	9.86	126	0.5	75	0.6	101	83	2.91
0604	07-Feb-01	10.34	134	1.3	81	2.3	107	87	2.78
0604	15-Feb-02	11.36	152	1.9	101	1.6	127	104	2.54
0604	28-Oct-02	12.06	167	6.3	102	4.0	135	112	2.41
0605	09-Apr-90	-0.49	149	2.6	155	1.5	152	133	2.88
0605	27-Sep-90	-0.02	58	0.6	64	0.9	61	54	3.99
0605	16-Sep-91	0.94	82	0.4	97	1.0	89	80	3.33
0605	27-Feb-92	1.39	107	2.3	114	2.2	111	100	2.94
0605	12-Feb-93	2.35	135	2.0	127	3.2	131	119	2.88
0606	09-Apr-90	-0.49	109	2.6	99	1.4	104	88	3.04
0606	27-Sep-90	-0.02	66	1.4	83	3.4	74	63	3.94
0606	16-Sep-91	0.94	62	1.4	65	1.4	64	54	3.89
0606	27-Feb-92	1.39	61	1.7	66	2.1	64	54	3.83
0606	12-Feb-93	2.35	65	1.0	69	2.4	67	57	3.72
0606	21-Jan-94	3.29	64	1.9	70	0.9	67	58	3.73
0606	02-May-95	4.57	62	1.3	74	0.9	68	58	3.81
0606	19-Feb-97	6.37	74	2.0	76	1.8	75	66	3.42
0606	17-Apr-98	7.53	79	4.0	129	1.9	104	92	2.66
0606	02-Mar-99	8.40	91	1.8	115	2.4	103	91	2.70
0606	14-Mar-00	9.44	108	1.1	100	4.6	104	93	2.64
0606	17-Aug-00	9.86	117	1.1	116	1.8	116	106	2.49
0606	07-Feb-01	10.34	122	1.3	115	3.2	118	107	2.32
0606	15-Feb-02	11.36	144	1.0	146	1.9	145	132	1.90
0606	28-Oct-02	12.06	148	2.5	125	4.0	137	124	1.98
0607	09-Apr-90	-0.49	104	1.1	97	2.2	100	85	2.29
0607	16-Sep-91	0.94	62	1.9	43	2.0	53	43	3.88
0607	27-Feb-92	1.39	64	0.9	46	0.6	55	45	3.80
0607	12-Feb-93	2.35	69	2.6	47	1.5	58	47	3.73
0607	21-Jan-94	3.29	65	1.6	48	0.6	56	47	3.80
0607	02-May-95	4.57	51	2.1	60	1.0	55	45	3.78
0607	19-Feb-97	6.37	78	1.1	61	1.2	69	58	3.55
0607	17-Apr-98	7.53	88	4.5	97	1.6	93	82	2.63
0607	02-Mar-99	8.40	104	1.2	103	1.0	103	91	2.49
0607	14-Mar-00	9.44	141	3.1	111	1.9	126	112	2.21
0607	17-Aug-00	9.86	156	2.4	110	2.5	133	120	2.11
0607	07-Feb-01	10.34	177	3.8	138	1.6	158	144	1.75
0607	15-Feb-02	11.36	223	2.2	167	1.4	195	180	1.40
0607	28-Oct-02	12.06	218	13.3	182	2.7	200	185	1.08

Table A-1 (cont). Roughness Values.

Section	Date	Years	Left IRI (in/mi)		Right IRI (in/mi)		MRI	HRI	RN
			Ave	St Dev	Ave	St Dev	(in/mi)	(in/mi)	
0608	09-Apr-90	-0.49	105	0.6	102	1.3	103	91	3.16
0608	16-Sep-91	0.94	68	1.8	50	1.8	59	48	3.83
0608	27-Feb-92	1.39	69	2.3	54	0.7	61	50	3.79
0608	12-Feb-93	2.35	74	2.0	54	0.8	64	52	3.69
0608	21-Jan-94	3.29	70	0.9	52	0.7	61	49	3.77
0608	02-May-95	4.57	71	3.6	56	1.0	64	51	3.66
0608	19-Feb-97	6.37	74	1.2	57	0.9	66	52	3.63
0608	17-Apr-98	7.53	80	5.2	60	1.2	70	56	3.32
0608	02-Mar-99	8.40	87	3.1	58	0.7	72	57	3.21
0608	14-Mar-00	9.44	121	3.6	64	0.8	93	76	2.74
0608	17-Aug-00	9.86	131	1.3	61	1.3	96	81	2.54
0608	07-Feb-01	10.34	123	4.8	62	1.1	93	79	2.52
0608	15-Feb-02	11.36	150	2.2	71	2.5	111	94	2.07
0608	28-Oct-02	12.06	182	7.3	72	1.8	127	112	1.67
0659	09-Apr-90	-0.49	211	6.8	181	2.0	196	170	2.17
0659	27-Sep-90	-0.02	68	1.4	64	1.1	66	56	4.11
0659	16-Sep-91	0.94	74	1.6	60	1.1	67	56	3.99
0659	27-Feb-92	1.39	80	3.4	57	3.1	69	58	3.91
0659	12-Feb-93	2.35	84	2.2	52	1.2	68	57	3.90
0659	21-Jan-94	3.29	76	0.9	60	1.0	68	57	3.94
0659	02-May-95	4.57	80	3.5	63	0.9	71	59	3.82
0659	19-Feb-97	6.37	83	0.6	62	1.0	73	61	3.62
0659	17-Apr-98	7.53	107	2.2	102	1.6	104	90	2.64
0659	02-Mar-99	8.40	112	4.5	100	1.8	106	89	2.70
0659	14-Mar-00	9.44	115	0.3	100	5.3	107	91	2.79
0659	17-Aug-00	9.86	118	2.3	107	2.5	113	98	2.61
0659	07-Feb-01	10.34	148	2.2	131	2.1	139	121	1.98
0659	15-Feb-02	11.36	187	4.0	175	2.2	181	160	1.36
0659	28-Oct-02	12.06	213	7.1	146	4.4	179	159	1.54
0660	09-Apr-90	-0.49	194	1.0	251	3.1	223	197	1.81
0660	16-Sep-91	0.94	65	0.8	65	0.3	65	55	4.07
0660	27-Feb-92	1.39	68	1.2	66	0.8	67	57	4.02
0660	12-Feb-93	2.35	77	1.1	68	0.5	73	62	3.89
0660	21-Jan-94	3.29	77	0.3	71	0.8	74	65	3.97
0660	02-May-95	4.57	102	0.9	92	1.4	97	87	3.58
0660	19-Feb-97	6.37	119	0.8	101	2.2	110	96	3.26
0660	17-Apr-98	7.53	125	2.2	114	1.2	119	108	2.87
0660	02-Mar-99	8.40	133	0.9	107	1.1	120	109	2.94
0660	14-Mar-00	9.44	138	0.5	114	1.1	126	112	2.80
0660	17-Aug-00	9.86	135	0.6	111	0.7	123	110	2.83
0660	07-Feb-01	10.34	146	0.8	122	1.6	134	119	2.58
0660	15-Feb-02	11.36	158	0.8	138	1.1	148	133	2.23
0660	28-Oct-02	12.06	156	2.5	140	8.4	148	133	1.93
0661	09-Apr-90	-0.49	171	1.9	259	0.9	215	189	2.25
0661	27-Sep-90	-0.02	66	1.5	67	1.1	66	50	4.08
0661	16-Sep-91	0.94	50	0.3	41	0.9	45	37	4.22
0661	27-Feb-92	1.39	55	1.4	44	1.2	50	41	4.18
0661	12-Feb-93	2.35	61	2.0	47	1.1	54	44	4.08
0661	21-Jan-94	3.29	57	1.2	49	1.0	53	43	4.11

Table A-1 (cont). Roughness Values.

Section	Date	Years	Left IRI (in/mi)		Right IRI (in/mi)		MRI (in/mi)	HRI (in/mi)	RN
			Ave	St Dev	Ave	St Dev			
0661	02-May-95	4.57	60	1.2	53	1.6	56	45	4.01
0661	19-Feb-97	6.37	66	1.5	56	1.1	61	49	3.81
0661	17-Apr-98	7.53	63	1.7	74	1.3	68	55	3.46
0661	02-Mar-99	8.40	71	3.2	71	4.5	71	56	3.62
0661	14-Mar-00	9.44	71	1.0	72	0.8	72	58	3.54
0661	17-Aug-00	9.86	75	0.5	106	0.7	90	75	2.96
0661	07-Feb-01	10.34	75	0.7	108	1.3	92	75	3.04
0661	15-Feb-02	11.36	92	1.5	109	1.7	100	80	3.20
0661	28-Oct-02	12.06	92	3.1	102	2.7	97	76	3.16
0662	09-Apr-90	-0.49	156	3.3	148	2.0	152	126	2.73
0662	27-Sep-90	-0.02	52	1.1	57	0.5	55	43	4.26
0662	16-Sep-91	0.94	50	0.9	47	0.8	49	41	4.19
0662	27-Feb-92	1.39	53	1.6	48	0.7	51	43	4.16
0662	12-Feb-93	2.35	58	2.8	50	0.7	54	45	4.07
0662	21-Jan-94	3.29	58	1.2	54	1.2	56	46	4.07
0662	02-May-95	4.57	60	0.8	63	1.6	62	51	3.85
0662	19-Feb-97	6.37	78	1.2	80	0.9	79	65	3.30
0662	17-Apr-98	7.53	124	1.8	145	1.9	134	116	2.12
0662	02-Mar-99	8.40	129	6.0	138	0.6	133	115	2.13
0662	14-Mar-00	9.44	136	0.9	139	1.2	138	117	2.10
0662	17-Aug-00	9.86	160	2.3	160	2.8	160	139	1.90
0662	07-Feb-01	10.34	170	5.3	177	2.3	173	149	1.68
0662	15-Feb-02	11.36	132	1.0	143	2.3	137	112	2.32
0662	28-Oct-02	12.06	146	1.3	125	1.6	136	108	2.16
0663	09-Apr-90	-0.49	235	2.2	201	1.2	218	204	2.16
0663	16-Sep-91	0.94	94	1.2	93	1.6	93	81	3.47
0663	27-Feb-92	1.39	98	1.9	93	1.5	96	85	3.40
0663	12-Feb-93	2.35	97	1.3	90	1.9	93	83	3.38
0663	21-Jan-94	3.29	97	1.7	97	2.3	97	87	3.42
0663	02-May-95	4.57	95	1.6	93	1.9	94	84	3.39
0663	19-Feb-97	6.37	96	1.4	95	0.9	95	85	3.26
0663	17-Apr-98	7.53	91	2.7	98	2.6	94	83	3.07
0663	02-Mar-99	8.40	97	2.8	99	1.6	98	84	3.02
0663	14-Mar-00	9.44	103	1.3	98	2.0	101	89	2.94
0663	17-Aug-00	9.86	111	2.0	99	1.6	105	95	2.88
0663	07-Feb-01	10.34	106	0.9	104	1.2	105	95	2.79
0663	15-Feb-02	11.36	108	1.9	102	1.5	105	96	2.93
0663	28-Oct-02	12.06	121	1.8	112	1.1	117	107	2.16
0664	27-Sep-90	-0.02	40	1.8	48	1.3	44	38	4.23
0664	16-Sep-91	0.94	44	1.0	44	1.7	44	38	4.34
0664	27-Feb-92	1.39	46	0.3	45	1.7	46	40	4.29
0664	12-Feb-93	2.35	52	0.9	46	0.8	49	42	4.17
0664	21-Jan-94	3.29	49	2.1	47	1.6	48	41	4.18
0664	02-May-95	4.57	47	1.6	48	1.5	48	40	4.15
0664	19-Feb-97	6.37	51	0.7	47	0.7	49	41	4.12
0664	17-Apr-98	7.53	50	1.3	47	1.1	49	41	3.92
0664	02-Mar-99	8.40	48	0.9	50	0.9	49	40	4.01
0664	14-Mar-00	9.44	51	0.8	48	0.6	50	41	4.05
0664	17-Aug-00	9.86	52	0.8	47	0.3	49	40	4.08

Table A-1 (cont). Roughness Values.

Section	Date	Years	Left IRI (in/mi)		Right IRI (in/mi)		MRI	HRI	RN
			Ave	St Dev	Ave	St Dev	(in/mi)	(in/mi)	
0664	07-Feb-01	10.34	53	1.1	47	0.3	50	42	4.09
0664	15-Feb-02	11.36	52	0.9	49	0.3	50	41	4.06
0664	28-Oct-02	12.06	50	0.8	47	1.1	49	41	3.96
0665	27-Sep-90	-0.02	42	1.2	43	0.8	43	38	4.30
0665	16-Sep-91	0.94	44	1.5	42	0.8	43	40	4.42
0665	27-Feb-92	1.39	46	0.5	41	0.2	44	40	4.39
0665	12-Feb-93	2.35	49	1.0	43	0.6	46	41	4.32
0665	21-Jan-94	3.29	46	0.7	47	0.7	46	42	4.29
0665	02-May-95	4.57	48	0.5	46	0.7	47	42	4.29
0665	19-Feb-97	6.37	51	1.0	47	0.3	49	43	4.17
0665	17-Apr-98	7.53	51	0.4	48	0.6	50	43	3.94
0665	02-Mar-99	8.40	49	0.3	51	0.7	50	44	4.03
0665	14-Mar-00	9.44	53	0.8	50	0.6	52	44	4.11
0665	17-Aug-00	9.86	55	0.9	50	0.1	52	45	4.09
0665	07-Feb-01	10.34	57	0.7	52	0.3	55	47	4.11
0665	15-Feb-02	11.36	54	0.9	50	0.7	52	44	4.10
0665	28-Oct-02	12.06	53	1.6	50	0.8	51	44	4.02
0666	27-Sep-90	-0.02	37	1.7	42	1.8	39	33	4.21
0666	16-Sep-91	0.94	36	0.7	45	0.9	40	34	4.37
0666	27-Feb-92	1.39	36	0.1	47	1.1	42	35	4.34
0666	12-Feb-93	2.35	40	1.4	47	0.7	44	36	4.17
0666	21-Jan-94	3.29	38	0.6	46	0.7	42	34	4.20
0666	02-May-95	4.57	39	1.1	48	1.0	44	35	4.19
0666	19-Feb-97	6.37	45	0.9	49	1.5	47	37	4.11
0666	17-Apr-98	7.53	41	0.8	51	1.3	46	37	3.88
0666	02-Mar-99	8.40	43	0.6	51	1.1	47	37	4.03
0666	14-Mar-00	9.44	47	0.7	51	1.2	49	41	4.05
0666	17-Aug-00	9.86	49	0.7	52	0.8	50	41	4.01
0666	07-Feb-01	10.34	47	1.1	52	0.5	49	40	4.05
0666	15-Feb-02	11.36	48	1.1	52	1.1	50	41	4.03
0666	28-Oct-02	12.06	47	0.6	52	1.5	49	40	4.00
0667	27-Sep-90	-0.02	66	1.5	79	0.9	72	67	4.08
0667	16-Sep-91	0.94	63	1.1	76	1.3	70	66	4.26
0667	27-Feb-92	1.39	65	1.2	74	0.8	70	65	4.25
0667	12-Feb-93	2.35	66	0.7	75	0.9	71	66	4.13
0667	21-Jan-94	3.29	66	0.4	75	0.8	70	66	4.15
0667	02-May-95	4.57	64	0.2	75	1.3	70	65	4.14
0667	19-Feb-97	6.37	68	0.9	77	0.3	73	67	4.06
0667	17-Apr-98	7.53	67	0.3	78	0.7	73	67	3.86
0667	02-Mar-99	8.40	68	0.6	78	0.9	73	67	3.97
0667	14-Mar-00	9.44	69	1.0	79	0.7	74	68	4.01
0667	17-Aug-00	9.86	72	0.6	77	0.6	74	69	4.00
0667	07-Feb-01	10.34	71	0.9	77	0.5	74	68	4.02
0667	15-Feb-02	11.36	70	0.7	78	0.4	74	68	4.00
0667	28-Oct-02	12.06	67	1.6	76	1.4	72	65	3.89
0668	27-Sep-90	-0.02	36	1.6	38	1.0	37	30	4.22
0668	16-Sep-91	0.94	34	1.2	43	1.9	38	33	4.38
0668	27-Feb-92	1.39	37	1.9	42	0.6	39	34	4.35
0668	12-Feb-93	2.35	40	1.3	47	1.4	43	38	4.21
0668	21-Jan-94	3.29	40	1.9	41	1.2	41	35	4.24

Table A-1 (cont). Roughness Values.

Section	Date	Years	Left IRI (in/mi)		Right IRI (in/mi)		MRI (in/mi)	HRI (in/mi)	RN
			Ave	St Dev	Ave	St Dev			
0668	02-May-95	4.57	39	0.8	43	1.6	41	35	4.21
0668	19-Feb-97	6.37	42	1.4	42	0.9	42	34	4.15
0668	17-Apr-98	7.53	39	1.2	42	1.7	40	33	3.93
0668	02-Mar-99	8.40	38	0.5	42	1.4	40	33	4.07
0668	14-Mar-00	9.44	41	0.3	43	1.6	42	35	4.05
0668	17-Aug-00	9.86	42	0.8	43	1.1	43	35	4.07
0668	07-Feb-01	10.34	43	1.1	41	1.0	42	35	4.08
0668	15-Feb-02	11.36	44	0.6	42	0.7	43	36	4.06
0668	28-Oct-02	12.06	45	1.4	45	1.3	45	37	3.90
0669	27-Sep-90	-0.02	51	1.5	52	1.0	52	47	4.17
0669	16-Sep-91	0.94	48	0.6	51	1.6	49	45	4.46
0669	27-Feb-92	1.39	50	1.0	52	0.5	51	46	4.40
0669	12-Feb-93	2.35	54	0.5	53	1.0	54	48	4.29
0669	21-Jan-94	3.29	53	1.4	55	0.6	54	48	4.27
0669	02-May-95	4.57	54	0.5	54	0.5	54	49	4.23
0669	19-Feb-97	6.37	57	0.9	55	0.5	56	50	4.13
0669	17-Apr-98	7.53	55	0.9	59	1.7	57	52	3.88
0669	02-Mar-99	8.40	56	0.6	57	1.0	56	51	4.04
0669	14-Mar-00	9.44	58	0.6	57	0.4	57	52	4.10
0669	17-Aug-00	9.86	61	0.7	57	0.7	59	54	4.09
0669	07-Feb-01	10.34	59	0.3	56	0.4	58	53	4.13
0669	15-Feb-02	11.36	59	1.1	57	0.8	58	52	4.10
0669	28-Oct-02	12.06	59	0.9	55	1.5	57	50	3.98

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1. Sayers, M. W., “Two Quarter-Car Models for Defining Road Roughness: IRI and HRI.” *Transportation Research Record 1215*, (1989) pp 165-172.

2. Karamihas, S. M., Gillespie, T. D., and S. M. Riley, “Axle Tramp Contribution to the Dynamic Wheel Loads of a Heavy Truck.” *Proceedings of the 4th International Symposium on Heavy Vehicle Weights and Dimensions*, Ann Arbor, Michigan. Ed. C. B. Winkler. (1995) pp. 425-434.

3. Sayers, M. W. and S. M. Karamihas, “Estimation of Rideability by Analyzing Road Profile.” *Transportation Research Record 1536*, (1996) pp 110-116.

Appendix B: Detailed Observations

This appendix provides detailed observations from the roughness trends, profiles and distress surveys of each section within the Arizona Specific Pavement Studies 6 project. Observations regarding profile features are made using power spectral density (PSD) plots, filtered elevation profile plots, and roughness profiles. Each section is discussed individually.

Typically, roughness profiles provided the most information about the location of features that affected the International Roughness Index (IRI) most, including areas of localized roughness. In this appendix, roughness profiles were made using a base length of 25 ft unless otherwise specified. An area is considered to have localized roughness when the roughness profile (with a base length of 25 ft) reaches a peak value that is greater than 2.5 times the average IRI for the whole section. Detection of localized roughness usually prompted more careful examination of the filtered elevation profiles.

Section 0601

Roughness: The IRI of the left side increased from 104 to 225 in/mi in less than three years. The IRI values vary significantly within the last two visits before this section was taken out of the study. The IRI of the right side increased from 102 in/mi in visit 00 to 122 in/mi in visit 04, but reached a peak value of 145 in/mi in visit 03. The Half-car Roughness Index (HRI) was about 20 in/mi below the Mean Roughness Index (MRI) throughout the monitoring history.

Elevation profile plots: The elevation profiles were fairly consistent throughout the monitoring period in the medium wavelength range, and very consistent in the long wavelength range, but not very consistent in the short wavelength range.

In visit 00 a disturbance appeared at the majority of the joints. This included some shallow bumps, some narrow dips, and some faults up to 0.1 in deep. Narrow dips appeared in the left side profiles 3 ft, 17 ft, 62 ft, 122 ft, 257 ft, 273 ft, 289 ft, 302 ft, and 498 ft from the start of the section. The dips were usually less that 2 ft wide, and were up to 0.3 in deep. In the range from 257 to 302 ft from the start of the section, the dips were wider along the trailing edge. From visit 00 through visit 03, the dips grew in number and severity until many of them were more than 0.3 in deep. In visit 03 narrow dips appeared throughout the section with a spacing that roughly followed a 15-13-15-17 ft pattern. The pattern was not as obvious in visit 04. However, some of the dips were still more severe. For example, a narrow dip up to 1 in deep appeared about 360 ft from the start of the section, and a dip 6 ft wide and about 0.6 in deep appeared about 257 ft from the start of the section.

Narrow dips also appeared in the right side profiles, but there were fewer of them and they were less severe in most cases. The most noteworthy dip in the right side profiles appeared about 411 ft from the start of the section. It was about 0.2 in deep in visit 01, but more than 4 ft wide. By visit 03, its depth had grown beyond 0.5 in. In visit 04, another dip that was about 0.5 in deep and more than 2 ft wide appeared 34 ft from the start of the section.

Roughness profile plots: Many of the narrow dips within the profiles contributed significantly to roughness, and the instances of significant roughness at narrow dips increased with each visit.

By visit 03, the left side profiles included increased roughness at all of the narrow dips in a regular pattern. Localized roughness appeared in the left side profiles 360 ft from the start of the section in visit 04. The roughness at the deep dip there contributed more than 20 in/mi to the roughness of the entire section.

The dip in the right side profile 411 ft from the start of the section consistently contributed significant roughness to the section. In visit 03, localized roughness appeared 156 ft and 411 ft from the start of the section. In visit 04, the dip 34 ft from the start of the section also caused localized roughness.

PSD plots: PSD plots for the left side profiles included a spike at 15 ft, and elevated content at some upper harmonics (7.5 ft, 5 ft) in every visit. In some cases, PSD plots from the right side profiles also showed some roughness that stood out at a wavelength of 25.5 ft. The spectral content was high in the short wavelength range because of spikes that appeared in the profile at joints. The short wavelength content grew significantly with time.

Distress surveys: Distress data were only available for 26 September 1991. The survey confirmed that the spikes within the profile appeared at the joints. Significant distress was recorded at many of the joints, although the joints where the roughness was worst did not always correspond to those with the most distress.

Maintenance history: Partial depth patching (47 sq. ft) was performed on this section in November 1991.

Section 0602

Roughness: The IRI increased steadily on the left side from 166 to 218 in/mi and on the right side from 167 to 202 in/mi in less than three years. The HRI was 14 to 16 percent below the MRI.

Elevation profile plots: Before rehabilitation the entire section was faulted. Faults appeared with a pattern that closely approximated the saw cut spacing 15-13-15-17 ft. (The actual pattern was closer to 14.8-12.9-15.1-16.9 ft.) Each fault on the right side appeared about 1 ft downstream of a fault on the left side from the same joint. Faults 0.05 to 0.3 in deep appeared in the left side and faults 0.05 to 0.15 in deep appeared on the right side.

The profiles from both sides include abrupt downward steps of up to 0.2 in throughout the entire section followed by a fairly steep upward slope. The downward steps are typically 7 to 15 ft apart. A very large downward step appeared about 561 ft from the start of the section. In many of the profile measurements, the step was 0.7 in downward on the left side and 0.5 in downward on the right side.

Roughness profile plots: Many of the downward steps within the profiles contributed significant roughness to the section, and the roughness at these locations grew steadily with time. The severity of roughness caused by the downward steps was uniform along the section, with the exception of a moderate increase in roughness on the left side in the last 100 ft of the section. Localized roughness appeared 561 ft from the start of the section.

PSD plots: Much of the roughness in the left side profiles was concentrated at a wavelength of 14.8 ft, as well as 11.9, 8.4, 7.5, and 6.6 ft. On the right side, roughness was concentrated at 14.8 ft, 8.6 ft and 7.5 ft.

Distress surveys: Distress data were only available for 26 September 1991. Although faulting measurements were not reviewed for this study, the downward steps followed by an upward slope provide clear profiles of faulted slabs and half slabs that are often tilted over the first several feet after the faults. The localized roughness about 561 ft from the section start appears in a location where map cracking that was recorded in the 26 September 1991 distress survey.

Section 0603

Roughness: Rehabilitation decreased the IRI from 138 to 52 in/mi on the left side and from 200 to 58 in/mi on the right side. After rehabilitation, the MRI held somewhat steady in visits 01 through 06, then increased more rapidly throughout the rest of the monitoring history. The HRI was 8 percent below the MRI before rehabilitation and 13-21 percent below MRI after rehabilitation.

Elevation profile plots: Before rehabilitation the entire section was faulted. Faults appeared with a pattern that crudely approximated the saw cut spacing 15-13-15-17 ft. (The actual pattern was closer to 15.1-12.7-15.4-16.8 ft.) Each fault on the right side appeared about 1 ft downstream of a fault on the left side from the same joint. Faults 0.05 to 0.2 in deep appeared in the left side and faults 0.05 to 0.3 in deep appeared on the right side.

The profiles did not change much in visits 01 through 06. In visit 07, narrow dips appeared in a regular pattern that resembled the underlying joint spacing over much of the section on the left side and in several locations on the right side. The dips were up to 2 ft wide. The dips grew to up to 0.4 in deep (with a few exceptions) by visit 12, but were less severe in visits 13 and 14. On the right side some dips also appeared at center slab locations near the middle of the section.

The section included a few dips that stood out as more severe than the others: (1) 453 ft from the start of the section on the left side that began growing in starting with visit 04, (2) 438 ft from the start of the section on the left side that stood out in visit 10 and later, (3) 141 ft from the start of the section that stood out on the left side starting in visit 08 and was more than 2 ft wide and 1 in deep by visit 14,

(4) 96 ft from the start of the section that first stood out on the left side in visit 05 and first stood out in visit 09 on the right side, and (5) 201 ft from the start of the section on the right side that first stood out in visit 09.

The dips in visits 13 and 14 were less severe than the dips in visit 12. Profiles from visit 13 and 14 included a sharp rise of 0.2 in on the left and 0.35 in on the right about 120 ft from the start of the section. At visit 13, the long wavelength content had changed downstream of the rise, but not upstream.

Roughness profile plots: The left side profiles did not include localized roughness, although the dip 438 ft from the start of the section caused a very high value in the short base length roughness profile. The dip 97 ft from the start of the section caused localized roughness on the right side in visits 13 and 14.

PSD plots: Before rehabilitation the PSD plots included content concentrated around a wavelength of 15 ft, 7.5 ft, 5 ft, etc. The content below a wavelength of 20 ft, and especially below 5 ft, increased over visits 01 through 12. Content at wavelengths between 1 and 20 ft decreased significantly between visits 12 and 13.

Distress surveys: Distress surveys included transverse cracks throughout the monitoring history. Transverse cracks were noted at some locations in September 1991 including the 97 ft, 141 ft, 201 ft and 458 ft from the start of the section, where the deepest narrow dips eventually appeared in the profiles. The dip 438 ft from the start of the section was first noted as a transverse crack in September 1994. By December 1999, transverse cracks that covered the entire width of the lane appeared in a regular pattern that matched the joint spacing of the underlying pavement. Per the LTPP Distress Identification Manual, transverse cracks were not recorded on the skin patch in visits 13 and 14. Narrow dips in the profile at the same pattern found in earlier visits confirm the presence of the cracks.

Maintenance history: Crack sealing (700 ft) was performed on this section in March 1995. The section received skin patching over 4400 sq. ft in September 2001.

Section 0604

Roughness: Rehabilitation decreased the IRI from 91 to 69 in/mi on the left side and from 113 to 67 in/mi on the right side. After rehabilitation, the MRI did not increase significantly in visits 01 through 07 and increased more rapidly throughout the rest of the monitoring history. The HRI was 14 percent below the MRI before rehabilitation and 17-23 percent below MRI after rehabilitation.

Elevation profile plots: Before rehabilitation the majority of joints in this section were faulted. Faults up to 0.15 in deep (with the exception of one 0.4-in deep fault) appeared with a pattern that crudely approximated the saw cut spacing 15-13-15-17 ft, with some gaps at joints without faulting. When faults appeared on both sides at the same joint, the fault on the right side appeared about 1 ft downstream of the fault on the left. In many cases, a smaller fault appeared between the larger faults (at a center slab position).

The profiles before rehabilitation also included a dip 158 ft from the start of the section on the left side 0.2 in deep. Dips up to 0.2 in deep also appeared in the right side 280 ft, 401 ft and 429 ft from the start of the section.

Post rehabilitation profiles inherited much of the long wavelength content that was present before rehabilitation.

Visit 01 profiles included more short wavelength content over the first 220 ft than the rest of the section on the left side. Visit 01 left side profiles also included a dip 5 ft wide and 0.15 ft deep about 163 ft from the start of the section and a sharp upward step of 0.15 in over 2 ft near 227 ft from the start of the section. Visit 01 agreed with the later visits in long wavelength content, but agreed only somewhat in the medium wavelength range and not at all in the short wavelength range.

Profile features were consistent in visits 02 through 06 on the right side and in visits 02 through 07 on the right side. Afterward, the narrow dip began to appear in the profiles throughout much of the section, starting with dips 1 ft wide and up to 0.1 in deep of the left side in visit 07. By visit 14, the dips appeared on both sides in a regular pattern over the last 440 ft of the section. The dips were up to 0.3 in deep on the left side and up to 0.2 in deep in the right side. These dips appeared in the same locations where faults were detected in visit 00 profiles. Two of the repeat measurements in visit 14 included a dip 0.7 in deep 213 ft from the start of the section.

On the left side, a bump 5 ft long and 0.15 in deep appeared 380 ft from the start of the section in visits 02 through 14. Short wavelength content in the left side profiles was higher over the first half section in visits 07 through 14.

Roughness profile plots: The narrow dips at the joints caused most of the roughness and its progression over visits 07 through 14. No localized roughness was detected on this section.

PSD plots: Before rehabilitation the PSD plots included elevated content in the range of wavelengths from 15 to 16 ft.

The PSD plots were fairly consistent over visits 02 through 07. Spectral content increased in the wavelength range shorter than 5 ft over the rest of the monitoring history. Content isolated at 15 ft and upper harmonics (7.5 ft, 5 ft, etc.) also increased throughout visits 07 through 14.

Distress surveys: Distress surveys show slightly skewed, sealed saw cuts throughout the entire section after rehabilitation. In October 1997 the seals were intact across the lane at the majority of the saw cuts, but not intact at any of the saw cuts by December 1999.

Maintenance history: Crack sealing (450 ft) was performed on this section in March 1995.

Section 0605

Roughness: Rehabilitation decreased the IRI from 149 to 58 in/mi on the left side and from 155 to 64 in/mi on the right side. Over less than three years after rehabilitation, the IRI increased to 135 in/mi on the left and 127 in/mi on the right. The HRI was 10 to 12 percent below the MRI.

Elevation profile plots: Before rehabilitation the entire section was faulted. Faults 0.05 to 0.25 in deep appeared with a pattern that crudely approximated the saw cut spacing 15-13-15-17 ft. (The actual pattern was closer to 15.1-13.0-14.8-16.7 ft.) Each fault on the right side appeared about 1 ft downstream of a fault on the left side from the same joint. The left side profiles included a dip 0.4 in deep and 1.5 ft wide that was 897 ft from the start of the section.

The visit 01 profiles (after rehabilitation) do not include the faults. Many areas of visit 01 profiles include 12 to 18 ft intervals in a “bowl” shape, in which the ends of the area are up to 0.1 in higher than the center.

By visit 03, faulting appears throughout the profiles that are 6 to 15 ft apart. On the left side, a steep upward slope typically follows the faults. Many of these are simply narrow downward spikes with an aggressive leading edge. The faults and spikes grow in severity by visit 04. On the right side, a constant upward slope typically follows the faults to the next fault.

The right side profiles in visits 02 through 04 included a dip about 2 ft wide and up to 1 in deep that appeared about 5 ft from the start of the section.

Roughness profile plots: The majority of the roughness within this section occurred at the joints, both before and after rehabilitation. Many of the faults within the profiles contributed significant roughness to the section, and the roughness at these locations grew steadily with time after visit 01. The severity of roughness caused by the faults was fairly uniform along the section. An exception was severe localized roughness in the right side profile in the first 10 ft of the section. By visit 04, this was severe enough to add 12 in/mi to the roughness of the entire section. Localized roughness also appears on the left side about 897 ft from the start of the section in visits 00 and 04.

PSD plots: Some of the roughness in the profiles was concentrated at a wavelength of 15 ft and 7.5 ft. PSD plots from the left side also included spikes at about 8.5 ft and 12 ft. The spectral content decreased significantly in the wavelength range below 20 ft between visit 00 and 01, but hardly at all for wavelengths above 20 ft. After visit 01, the content for wavelengths below 20 ft steadily grew with time until the visit 04 PSD plots were very similar to those from visit 00. (The spatial distribution of roughness was not the same, only the distribution of roughness within each wavelength range.)

Distress surveys: Distress data were only available for 12 April 1991 and 26 September 1991. Although faulting measurements were not reviewed for this study, the downward steps followed by an upward slope provide clear profiles of faulted slabs and half slabs that are often tilted over the first several feet after the faults. The localized roughness at the narrow dip found on the right side at the start of the section corresponds to a distressed joint. Rough narrow dips also appeared at other joints where distress was noted, but many distressed joints were noted without corresponding localized roughness.

Section 0606

Roughness: Rehabilitation decreased the IRI from 109 to 66 in/mi on the left side and from 99 to 83 in/mi on the right side. After rehabilitation the IRI of the left side progressed at an increasing rate to 148 in/mi over the monitoring history. The IRI of the right side progressed at an increasing rate to a final value of 125 in/mi, but some erratic values appeared in visits 08, 09 and 14. The HRI was 15 percent below the MRI before rehabilitation and 9-16 percent below MRI after rehabilitation with values that decreased with time.

Elevation profile plots: Before rehabilitation the section exhibited early signs of faulting both at joints and at mid-slab positions, but faults greater than 0.1 in were rare. Many of the faults seemed to appear as upward step changes in elevation. The left side profiles included several narrow dips: 37 ft from the start of the section 0.4 in deep and 2 ft wide, 66 ft from the start of the section 0.2 in deep and 1.5 ft wide, 186 ft from the start of the section 0.15 in deep and 1.5 ft wide, and 461 ft from the start of the section 0.25 in deep and 1.5 ft wide. The left side profiles also included two more severe dips that were about 5 ft wide: 173-178 ft from the start of the section about 0.1 in deep with a round shape and 413-418 ft from the start of the section about 0.25 ft deep with a rectangular shape.

By visit 05, three small bumps appeared along the section. The bumps were 2-3 ft wide and up to 0.1 in high, and remained throughout the rest of the monitoring history. Narrow dips about 1 ft wide and up to 0.1 in deep appeared along the section in visit 07 with an irregular spacing. By visit 10, more than 20 narrow dips appeared that were up to 0.3 in deep. (Once exception was a dip 0.7 in deep and 370 ft from the section start on the right side.) By visit 13 narrow dips appeared with a pattern that approximated the underlying joint pattern, with dips missing at four joint locations.

The most severe dips on the left side were: (1) 0.7 in deep, 85 ft from the start of the section, (2) 0.7 in deep (in two of five repeat measurements), 205 ft from the start of the section, (3) 1 in deep, 221 ft from the start of the section, (4) 0.6 in deep, 266 ft from the start of the section, (5) 0.4-0.8 in deep, 369 ft from the start of the section, (6) 0.5-1 in deep (depending on which repeat measurement is plotted), 445 ft from the start of the section. The most severe dips on the right side were: (1) 0.6 in deep, 86 ft from the start of the section, (2) 0.3-0.5 in deep (depending on which repeat measurement is plotted), 207 ft from the start of the section, (3) 0.5 in deep, 267 ft from the start of the section, and (4) 0.4-0.6 in deep (depending on which repeat measurement is plotted), 370 ft from the start of the section.

The dips were less severe on the right side in visit 14 than in visit 13 in some locations.

Roughness profile plots: Before rehabilitation, the deep dip on the left side 413-418 ft from the start of the section was severe enough to qualify as localized roughness.

The profiles did not include any localized roughness after rehabilitation. However, more roughness was detected in the presence of the deepest dips (such as those listed above) than in other locations. Further, very short interval roughness profiles confirm that the narrow dips account for most of the roughness on this section.

PSD plots: Before rehabilitation the PSD plots included elevated content at wavelengths of 15 ft, 7.5 ft, etc.

From visit 07 through 14, the roughness grew in two wavelength ranges: (1) at about 15 ft, and (2) in the range below 10 ft. The exception was visit 13 on the right side, which included higher content than visits 12 and 14 in both ranges.

Distress surveys: The pre-rehabilitation distress survey shows a corner break on the left side where localized roughness was detected, and the profile shows localized settlement within the corner break.

By August 2000 transverse cracks appeared with a pattern that approximated the underlying joint spacing, with a few gaps. This pattern of transverse cracks developed gradually over the previous four distress surveys starting in September 1991.

The locations and first appearance of narrow dips in the profiles corresponds closely with the locations and first appearance of transverse cracks in the distress surveys. Further, the absence of a transverse crack at the location of an underlying joint is usually accompanied by the lack of a narrow dip in the profile.

Maintenance history: Crack sealing (640 ft) was performed on this section in March 1995.

Section 0607

Roughness: Rehabilitation decreased the IRI from 104 to 62 in/mi on the left side and from 97 to 43 in/mi on the right side. After rehabilitation, the MRI held somewhat steady in visits 01 through 06, then increased more rapidly throughout the rest of the monitoring history with a final value of 200 in/mi. The HRI was 15 percent below the MRI before rehabilitation and 7-18 percent below MRI after rehabilitation with values that decreased with time.

Elevation profile plots: Before rehabilitation the profiles over the first half of the section included narrow dips up to 0.15 in deep on both sides in a pattern that crudely approximated the joint spacing of 15-13-15-17 ft. The second half of the section included a few narrow bumps at joints. Four deep narrow dips about 2 ft wide appeared in the profiles: 289 ft from the start of the section 0.9 in deep on the right side, 21 ft from the start of the section 0.3 in deep on the left side, 201 ft from the start of the section 0.65 in deep on the left side, and 261 ft from the start of the section 0.3 in deep on the left side.

Visit 02 profiles included seven small bumps along the section. The bumps were 2-4 ft wide and up to 0.15 in high. The highest bump appeared 369 ft from the start of the section. Some of the bumps, including the one 369 ft from the start of the section, remained throughout the monitoring history.

Visit 07 profiles included a bump 0.2 in high and about 3 ft wide that was 235 ft from the start of the section.

Narrow dips (1-3 ft wide and up to 0.2 in deep) appeared in visit 07 profiles at five locations on both sides of the lane. The dips increased in number and severity throughout the rest of the monitoring period. By visit 14 narrow dips appeared with a pattern that approximated the underlying joint pattern, with dips missing at five joint locations on the left side and six joint locations on the right side.

Short wavelength profile plots revealed some locations with roughness that stood out visually compared to the rest of the section. On the left side:

A narrow dip appeared 132 ft from the start of the section. In visit 09, it was 0.5 ft wide and 0.5 in deep. By visit 13, the dip had grown to over 1 ft wide and 0.9 in deep.

Narrow dips about 1 ft wide appeared 148 ft, 172 ft, 189 ft, 219 ft and 249 ft from the start of the section. These dips appeared in visits 07 and 08, and increased in severity to 0.8-1 in deep by visit 14.

In visit 10, a rough area appeared 277 to 289 ft from the start of the section. This included a narrow dip at the start and chatter (rapid changed in elevation within a 0.1 in band) over the rest of the area. By visit 14, the area was quite rough, starting with a dip 1 ft wide and over 1.2 in deep.

In visit 11, a rough area appeared 397 to 411 ft from the start of the section. This included chatter (rapid changed in elevation within a 0.1 in band) over entire area followed by a narrow dip at the end. By visit 13, the area was quite rough. In visit 14, the chatter was no longer present, but a narrow dip appeared at both ends.

In visit 09, a dip 1 ft wide and 0.6 in deep appeared 445 ft from the start of the section just downstream of a shallow bump.

On the right side:

Narrow dips grew to over 1 in deep 39 ft, 173 ft, 190 ft, 219 ft, 353 ft, and 411 ft from the start of the section by visit 14.

<u>Roughness profile plots</u>: Before rehabilitation, the deep dips on the left side 201 ft from the start of the section and on the right side 289 ft from the start of the section were severe enough to qualify as localized roughness.

Throughout the post-rehabilitation monitoring history the bumps and narrow dips discussed above caused areas of much greater roughness than the surrounding pavement. However, two features were so rough that they qualified as localized roughness when compared to the overall section average: (1) the narrow bump 445 ft from the start of the section on the left side in visit 09, and (2) the narrow bump 277 ft from the start of the section on the left side preceding the rough area in visit 12. This dip alone contributed over 20 in/mi to the overall roughness of the section.

PSD plots: Before rehabilitation the PSD plots included elevated content on the right side at wavelengths of 15 ft, 12.5 ft, and 7 ft and on the left side at wavelengths of 25 ft, 15 ft, 12.5 ft and 7.5 ft.

After rehabilitation, much more growth in spectral content occurred after visit 08 than before. On the left side, the content grew in the wavelength range under 10 ft up to visit 09, then grew in the wavelength range below 50 ft through the rest of the monitoring history. On the right side, the largest growth was found in the wavelength range below 10 ft between visit 08 and 09.

Distress surveys: Distress surveys show transverse cracking throughout the monitoring history. Four transverse cracks that covered the width of the lane were recorded in 1991. The number of transverse cracks grew steadily with time. By October 2002, 30 transverse cracks appeared with a pattern that approximated the underlying joint spacing, with a few gaps.

The pattern and first appearance of narrow dips in the profiles corresponds with the locations and first appearance of transverse cracks in the distress surveys. Further, the absence of a transverse crack at the location of an underlying joint is usually accompanied by the lack of a narrow dip in the profile. Often, the deepest dips were found in the profile in the same locations where the distress survey cited high-severity cracks, and the shallowest dips were found in the profile where the distress survey recorded medium and low severity cracks.

Distress surveys show a longitudinal crack from 395 to 413 ft from the start of the section on the left side of the lane starting in August 2000. This explains the narrow dip and chatter found in the profile starting in visit 11.

Distress surveys show an area of fatigued pavement from 276 to 287 ft from the start of the section on the left side starting in December 1999. This area became a stretch of moderately fatigued pavement deteriorating into a small area of highly fatigued pavement by August 2000. Starting in August 2000, a 1 sq. ft patch in very poor condition appeared at the lead end of this area. These features explain the localized roughness found in the profile starting 277 ft from the start of the section.

Distress surveys include a high severity transverse crack about 445 ft from the start of the section starting in December 1999. In December 1999 the survey indicated the presence of a “splattered fox carcus” (sic) on the left side of the lane just downstream of the crack. In August 2000 the survey showed gouges over an area on the left side of the lane just downstream of the crack. These odd features correspond to the localized roughness cited above for visit 09. (The area continued to be as rough in later visits, but the roughness level was overcome by the rest of the section after visit 09.)

Maintenance history: Crack sealing (550 ft) was performed on this section in March 1995. In May 2000 potholes were hand patched and compacted by a truck. No corresponding changes in the profile were detected between visits 10 and 11.

Section 0608

Roughness: Rehabilitation decreased the IRI from 105 to 68 in/mi on the left side and from 102 to 50 in/mi on the right side. After rehabilitation, the IRI on the left side held somewhat steady in visits 02 through 09, then increased more rapidly throughout the rest of the monitoring history. The IRI on the right side grew at a steady, modest rate to 72 in/mi over the monitoring history. The HRI was 12 to 21 percent below the MRI.

Elevation profile plots:

Before rehabilitation: The majority of joints in this section were faulted up to 0.1 in deep. Faults appeared with a pattern that closely approximated the saw cut spacing 15-13-15-17 ft, with some gaps at joints without faulting and some joints with narrow dips rather than faults. When faults appeared on both sides at the same joint, the fault on the right side appeared about 1 ft downstream of the fault on the left. In some cases, a smaller fault appeared between the larger faults (at a center slab position). The most severe narrow dips were: a dip 3 ft wide, 0.25 in deep and 93 ft from the start of the section; and a dip 2 ft wide, 0.25 in deep and 409 ft from the start if the section.

After rehabilitation, left side: Visit 02-14 profiles included bumps 2-4 ft wide and up to 0.2 in high that were 189 ft, 210 ft and 238 ft from the start of the section. The most severe was 210 ft from the start.

Two narrow dips, 367 ft and 386 ft from the start of the section, appeared in visit 08. They were less than 2 ft wide. The leading dip was 0.1 in deep and the trailing dip was 0.2 in deep. The dips bounded an area of high short wavelength roughness (i.e., chatter) in three of the five repeat measurements. This appeared in all five repeats of visits 09 through 14:

In visit 09 the trailing dip was 0.4 in deep with very heavy chatter in one repeat.

In visit 10 the leading dip was 0.4 in deep, the trailing dip was 0.6 in deep, and both dips were 2 ft wide. Two other dips emerged within the bounded area.

In visit 11 the leading dip was 1.6 in deep and the trailing dip was 0.6 in deep.

In visit 12 the leading dip was 0.7 in deep and the trailing dip was 0.8 in deep. The chatter in the bounded area was reduced, and the dip that had appeared in visit 10 was not present.

In visit 13, the dips at the edges had reduced in severity, but the two dips inside the area had re-appeared. Of the four dips, the most severe was 1.2 in deep, and was 372 ft from the start of the section.

In visit 14, the severity of the dips was not consistent over the five repeat measurements. In the most severe case, some of the dips were 2 in deep.

<u>After rehabilitation, right side</u>: Visits 02 through 08 included elevated medium wavelength roughness from 175 to 215 ft

In visit 09 narrow dips up to 0.15 in deep appeared in four locations. The dips grew in number (to 14) and severity through the rest of the monitoring history. In visit 14, dips under 0.5 ft wide but more than 1.5 in deep appeared 471 and 490 ft from the start of the section.

<u>Roughness profile plots</u>: In visits 02 through 07, one or more of the bumps 189 ft, 210 ft, and 238 ft from the start of the section on the left side caused localized roughness.

The rough area 367 through 386 ft from the start of the section on the left side caused localized roughness in visits 08 through 14. With the exception of visit 12, the severity of roughness in this area progressed with time. For example, the roughness in this area contributed 35 in/mi to the overall roughness of the section in visit 11, and 40-60 in/mi to the overall roughness of the section in visit 14.

Localized roughness was detected about 201 ft from the start of the section in some repeat measurements from 03 through 08. Roughness was elevated in that location throughout the rest of the monitoring history.

<u>PSD plots</u>: Before rehabilitation the PSD plots included a relatively high contribution from longer (30-60 ft) wavelength content than most of the other sections.

After rehabilitation, the left side PSD plots showed little change through visit 07. Roughness grew in the range of wavelengths below 10 ft in visits 08 and 09, and in the wavelength range below 100 ft after visit 09.

After rehabilitation, the right side PSD plots showed change through visit 07. Roughness grew erratically in the range of wavelengths below 5 ft in visits 08 through 13, and in the wavelength range below 10 ft in visit 14.

<u>Distress surveys</u>: No transverse cracks or fatigue was recorded in the 1991 and 1994 distress surveys. Distress surveys from 1997 through 2002 included increasingly more transverse cracks, and the October 2002 survey included 13 transverse cracks that covered the width of the lane and several others that did not. The locations of narrow dips found within the profiles correspond to the locations of these cracks.

The October 1997 distress survey included a longitudinal crack along the wheel path in the left side of the lane 366 through 386 ft from the start of the section. A transverse crack across the entire lane appeared at the trailing end. All of the subsequent distress surveys recorded an area of high-severity fatigue where the longitudinal cracks were recorded in 1997. These four surveys also recorded small (1-1.5 sq. ft) patches on one or both sides of the fatigued area (366 and 386 ft from the start of the section). Starting in August 2000 the surveys showed a transverse crack across the lane at the start of the fatigued area.

Maintenance history: Crack sealing (240 ft) was performed on this section in March 1995. In May 2000 potholes were hand patched and compacted by a truck.

Section 0659

Roughness: Rehabilitation decreased the IRI from 211 to 68 in/mi on the left side and from 181 to 64 in/mi on the right side. After rehabilitation, the IRI on both sides held fairly steady over visits 01 through 07, and then rose at an increasing rate over the rest of the monitoring period. The HRI was 12 to 17 percent below the MRI.

Elevation profile plots: Before rehabilitation the entire section was faulted. Faults appeared with a pattern that approximated the saw cut spacing 15-13-15-17 ft. Each fault on the right side appeared about 1 ft downstream of a fault on the left side from the same joint. Over most of the section, the magnitude of faulting ranged from 0.05 to 0.2 in. However, the area from 390 to 480 ft from the start of the section included faulting as deep as 0.4 in. A pattern over much of this area indicated that there were a series of shattered slabs, and the slab pieces were tilting.

The profiles before rehabilitation also included a long dip from 265 to 320 ft from the start of the section about 0.7 in deep.

In visits 02 through 06 the most obvious roughness was at a narrow bump 31 ft from the start of the section and a narrow dip 51 ft from the start of the section on the left side.

Short duration and short wavelength roughness, such as narrow dips and patches of “chatter”, increased from visit 08 through 14.

Narrow dips up to 1 ft wide and 0.3 in deep appeared at 11 locations in visit 08. The number and severity of these dips increased through the rest of the monitoring history, and increased in severity most in visits 11 through 13. By visit 14, the profiles included narrow dips at 19 locations on the left side and 21 narrow dips on the right side. Most of the dips were 0.2-0.5 in deep, with a few exceptions described below.

Plots of elevation in the short wavelength range revealed a few severe features:

A dip 115 ft from the start of the section that grew to 2 ft wide and 1 in deep on the right side by visit 14.

An area of increased short wavelength roughness, including several dips and short sunken areas (up to 0.6 in deep), that appeared 266 to 272 ft from the start of the section on the left side in visits 08 and 09. Roughness of this kind was also found in visits 12 through 14, but it was not found in all repeat measurements.

A dip 290 ft from the start of the section on the left side 0.3 ft wide that grew to more than 1.5 in deep in visit 14.

A dip about 0.5 ft wide and 0.3 in deep that appeared 492 ft from the start of the section on the left side in visit 14. In one of the repeat measurements, the dip was nearly 2 in deep.

Roughness profile plots: Before rehabilitation, the severely tilted slab and abrupt upward step caused severe localized roughness on the left side.

By visit 06, the bump and dip 31 ft and 51 ft from the start of the section, respectively, were severe enough to classify as localized roughness.

Severe localized roughness appeared 115 ft from the start of the section on the right side. In visit 13, this area contributed more than 25 in/mi to the overall IRI of the section. However, the roughness here was about half as severe in visits 12 and 14.

The area of roughness about 265 through 275 ft from the start of the section caused localized roughness in visits 08 and 09, and in two repeat measurements in visit 14. (This area stood out as rougher than the rest of the section in every visit starting with visit 08.)

PSD Plots: Before rehabilitation the PSD plots included very slightly elevated content at wavelengths of 15 ft and 7.5 ft. Throughout the rest of the monitoring history, the content in the PSD plots below a wavelength of 20 ft grew over time.

Distress surveys: All of the narrow dips in visits 08 through 14 all appeared in locations where transverse cracks were recorded. Often, the widest and deepest dips appeared at transverse cracks that included small areas of fatigue in the wheel path. However, not all transverse cracks caused a dip in the profiles.

The 2-ft wide dip 115 ft from the start of the section appeared at a transverse crack with a small area of fatigue. A photo taken in August 2000 shows that this is a fatigued area that had been patched.

An area of fatigue was recorded in the left wheel path 265 to 275 ft from the start of the section in December 1999. This accounts for the area of localized roughness described above for visits 08 and 09. Subsequent distress surveys show a long area of high severity fatigue here, and a photo from October 2002 shows the narrow area of fatigued pavement with a few narrow potholes.

Maintenance history: Crack sealing (470 ft) was performed on this section in March 1995. In August 1997, September 1999, May 2000 and September 2001 potholes were hand patched and compacted by a truck.

Section 0660

Roughness: Rehabilitation decreased the IRI from 194 to 65 in/mi on the left side and from 251 to 65 in/mi on the right side. After rehabilitation, the IRI on both sides rose at a steady rate over the rest of the monitoring period. The HRI was 12 percent below the MRI before rehabilitation and 9-15 percent below MRI after rehabilitation with values that decreased overall with values that decreased overall with time.

Elevation profile plots: Before rehabilitation the majority of joints in this section were faulted, including all of the joints in the last 400 ft of the section. Faults 0.05 to 0.25 in deep appeared with a pattern that closely approximated the saw cut spacing 15-13-15-17 ft. When faults appeared on both sides at the same joint, the fault on the right side appeared about 1 ft downstream of the fault on the left. In many cases, a smaller fault appeared between the larger faults (at a center slab position).

The profiles before rehabilitation also included three severe dips: a dip 3 ft wide and 1.25 in deep that appeared 48 ft from the start of the section on the right side, a dip 3 ft wide and 0.5 in deep that appeared 43 ft from the start of the section on the left side and a dip 5 ft and 0.5 in deep that appeared 52 ft from the start of the section on the left side.

After rehabilitation the roughness in the long wavelength range was greater in the first half of the section than in the second half. The profiles did not change significantly in visits 02 through 05. The profiles included a dip from 50 to 90 ft from the start of the section. In visit 06, the dip grew to more than 1 in deep on the left side and 0.6 in deep on the right side. On the left side, the dip included rapid changes in elevation at the leading and trailing edges, such that it appears as a sunken area.

The dip grew deeper through visit 09, and its roughest feature was a downward change in elevation at the leading edge of more than 1 in over a distance of 2.5 ft. The dip was half as severe in visits 10 through 14, and it was preceded by an upward step in elevation of over 0.3 in over a few feet starting about 35 ft from the start of the section. The dip was followed by a downward change in elevation of 0.3 in over 5 ft starting about 95 ft from the start of the section. A narrow dip appears within the larger dip about 52 ft from the start of the section. This is the at the start of the low area within the dip.

Starting in visit 07, narrow dip appeared on both sides that grew in severity over time about 112 ft and 149 ft from the start of the section. By visit 14, the dips were about 2 ft wide and 0.3 in deep. A bump also appeared 202 ft from the start of the section, which grew in severity through visit 14. By visit 14, the bump was 3 ft wide and 0.5 in high on the left side.

A rough area with much higher short wavelength content than the surrounding profile appeared on the right side from 260 to 280 ft from the start of the section. In later visits the “chatter” in this area included an overall vertical range of 0.4 in.

This area is followed by a very narrow dip 290 ft from the start of the section that grew in severity through visit 14, when it was about 0.3 ft wide and over 2 in deep. On the left side, an area with similar properties appeared 290 to 310 ft from the start of the section. In addition, shallow bumps developed 251 and 268 ft from the start of the section.

Roughness profile plots: Before rehabilitation the three dips mentioned above caused extreme localized roughness. For example, the 1.25 in deep dip on the right side contributes 31 in/mi to the overall roughness of the section.

After rehabilitation the first half of the section was consistently more than twice as rough as the second half of the section on the left side. The dip from 50 to 90 ft from the start of the section contributed significantly to the overall roughness. For example, localized roughness appeared at the steep downward slope in the profile at the leading edge of the dip, which contributed more than 30 in/mi to the overall IRI of the section on the left side in visits 07 through 09 and about 15 in/mi to the overall IRI on the right side. Localized roughness also appeared at the trailing edge of the dip, and it contributed about 20 in/mi to the overall roughness on the left side and over 10 in/mi to the overall roughness in the right side. In visits 10 and later, the leading edge was half as rough.

The bumps, narrow dips, and areas of increased short wavelength content contributed to increased roughness at their locations. The only feature that caused localized roughness was the area of “chatter” from 260 to 280 ft from the start of the section on the right side.

PSD plots: Before rehabilitation the PSD plots included slightly elevated content at wavelengths of 15 ft and 7.5 ft. Overall, the content was very uniform over the wavelength range that affects the IRI. Throughout the rest of the monitoring history, the content in the PSD plots below a wavelength of 30 ft grew over time.

Distress surveys: The dip at 112 ft, the dip at 149 ft, the bump at 202 ft and the dip at 290 ft all correspond to high severity transverse cracks recorded in all of the distress surveys beginning in December 1999. The localized roughness found on the right side 260 to 280 ft from the start of the section corresponds to an area of fatigue in the wheel path. The fatigue in this area was rated as low severity or medium severity in all of the distress surveys beginning in December 1999.

Maintenance history: Crack sealing (80 ft) was performed on this section in March 1995. The section received skin patching over 800 sq. ft in September 1999. The skin patching extended between 33 to 98 ft from the start of the section.

Section 0661

Roughness: Rehabilitation decreased the IRI from 171 to 66 in/mi on the left side and from 259 to 67 in/mi on the right side. After rehabilitation, the IRI on both sides increased at a somewhat erratic but increasing rate over the rest of the monitoring period. The HRI was 12 percent below the MRI before rehabilitation and 17 to 23 percent below the MRI after rehabilitation.

Elevation profile plots: Before rehabilitation the entire section was faulted. Faults appeared with a pattern that approximated the saw cut spacing 15-13-15-17 ft. Each fault on the right side appeared about 1 ft downstream of a fault on the left side from the same joint. The magnitude of faulting ranged from 0.05 to 0.25 in. The profiles also included a few “v-shaped” dips that only appeared on one side or the other. These were most likely partial slabs tilted downward followed by partial slabs tilted upward. The most severe cases appeared on the left side 61 to 70 ft from the start of the section (0.7 in deep), on the left side from 320 to 326 ft from the start of the section (0.6 in deep), on the left side 347 to 357 ft from the start of the section (0.5 in deep), and on the right side 117 to 127 ft from the start of the section (0.9 in deep). Multiple instances of this feature appeared from 340 to 360 ft from the start of the section on the right side.

Few features stood out in visits 01 through 06. The largest feature in the short wavelength elevation plots was a bump 0.1 in high and about 2 ft wide that appeared 127 ft from the start of the section on the left side. In the later visits, some shallow (0.1 in high) bumps appeared on the left side in the area 205 to 225 ft from the start of the section. In visits 08 and 09, and some repeats in visit 10, a dip 0.15 in deep and 3 ft wide appeared on the right side starting 273 ft from the start of the section.

In visit 10, a rough area appeared 360 to 375 ft from the start of the section on the right side. This area included three consecutive dips, including a dip 0.4 in deep and 3 ft wide with a sharp trough. In visit 11, the area included three much more severe dips, and some very sharp changes in elevation at the transitions (two 0.5 in downward steps and a rise in elevation of 1 in over 4 ft of pavement). By visit 12, the profiles included a rough sunken area about 0.5 in below the prevailing pavement that extended from 361 ft from the start of the section to 376 ft from the start of the section. The roughness was not present after visit 12.

Profiles from visits 13 and 14 included two steep upward changes in elevation on the left side: (1) a 0.4 in rise in elevation over 2 ft starting 264 ft from the start of the section, and (2) a 0.2 in rise in elevation over less than 1 ft starting 286 ft from the start of the section. The second upward step was the leading edge of a 6-ft wide bump. On the right side the profiles rose 0.6 in over 3 ft starting 265 ft from the start of the section. The right side profiles also included a downward step of about 0.2 in that appeared 346 ft from the start of the section.

Roughness profile plots: Before rehabilitation, the tilted, fractured slab components mentioned above caused highly elevated roughness in the left side and localized roughness in the right side.

The progression in roughness on the right side in visits 07 through 09 occurred primarily at the disturbances described above 273 ft and 360 to 375 ft from the start of the section. The area 360 to 375 ft from the start of the section on the right side progressed in roughness, and caused severe localized roughness in visits 11 and 12. Roughness at this area alone contributed 32 in/mi to the overall IRI of the section in visit 11 and 27 in/mi to the overall IRI of the section in visit 12.

In visits 13 and 14, the upward steps about 265 ft from the start of the section on both sides caused localized roughness. On the right side, the roughness was higher downstream of the step.

PSD plots: Before rehabilitation the PSD plots included very slightly elevated content at wavelengths of 15 ft and 7.5 ft. After rehabilitation, roughness progression was not isolated to any particular waveband.

Distress surveys: The distress surveys recorded an area with pumping and a network of cracks on the right side of the lane in August 2000. This area extended from 361 to 374 ft from the start of the section. This was not present in December 1999 or October 2001.

Maintenance history: Crack sealing (25 ft) was performed on this section in March 1995. The section received skin patching over 2100 sq. ft in September 2001. The disturbances discussed above for visits 13 and 14 occurred at the leading edge of the skin patch.

Section 0662

Roughness: Rehabilitation decreased the IRI from 156 to 52 in/mi on the left side and from 148 to 57 in/mi on the right side. After rehabilitation, the IRI held somewhat steady in visits 01 through 06, increased rapidly over the next two visits, and changed erratically over a wide range of rough values throughout the rest of the monitoring history. The HRI was 13 to 22 percent below the MRI.

Elevation profile plots: Before rehabilitation the majority of joints in this section were faulted. Faults 0.05 to 0.15 in deep appeared with a pattern that approximated the saw cut spacing 15-13-15-17 ft, with some gaps at joints without faulting. When faults appeared on both sides at the same joint, the fault on the right side appeared about 1 ft downstream of the fault on the left. The profiles also included a 2 ft wide dip about 0.3 in deep on the left side 182 ft from the start of the section and a 2 ft wide dip about 0.35 in deep on the right side 156 ft from the start of the section.

Before rehabilitation, the area from 380 to 430 ft from the start of the section included several abrupt elevation and slope changes. The profile appeared to indicate the presence of three slabs that had shattered into multiple fragments. The severity was greatest on the right side.

In visits 02 through 05, three features stood out in the short wavelength plots: (1) a bump 0.15 in high from 34 to 42 ft on the left side, (2) a 2-ft wide bump 0.1 in high at 101 ft on the left side, (3) a dip 0.15 in deep from 455 to 460 ft on the left side, and (4) a dip 0.15 in deep (in visit 05) preceded by a small bump at 378 ft on the right side. Visit 06 also included a bump 0.2 in high and 4 ft wide at 239 ft on the left side and a few narrow bumps and dips on the right side.

In visit 07, several dips 1 to 4 ft wide appeared in locations with either no dip or a very shallow dip in visit 06. The deepest dips were: (1) 0.15 in deep, 43 ft from the start of the section on the left side, (2) about 0.2 in deep, 116 ft from the start of the section on the left side and 117 ft from the start of the section on the right side, (3) 0.3 in deep, 377 ft from the start of the section on the left side (4) 0.2 in deep, 378 ft from the start of the section on the right side, and (4) 0.2 in deep, 452 ft from the start of the section on the left side.

Visit 08 profiles included narrow dips in a pattern that approximately matched the spacing of underlying joints on both sides, with a few joint locations omitted in the last third of the section. The dips grew in severity through visit 12, which included dips 0.1 to 0.8 in deep.

Visit 13 profiles were very similar to those of visit 12 over the first 135 ft of the section. A 0.35 in upward step appeared 135 ft from the start of the section. The rest of the section included dips in the same locations as in visit 12, but much less severe. Visit 14 profiles were very similar to visit 13 profiles, except that a 1 ft wide dip grew from 0.4 in deep to 0.8 in deep. The most severe dip in visits 13 and 14 was 0.5 in deep and 4 ft wide. It appeared about 421 ft from the start of the section on the right side.

Roughness profile plots: Before rehabilitation, the three fractured slabs mentioned above caused localized roughness in the right side profiles.

The narrow dip 377 ft from the start of the section on the left side caused localized roughness in visit 09, but not in visit 08 or visit 10. On the right side, the dip 421 ft from the start of the section contributed more than 10 in/mi to the overall IRI of the section starting in visit 11.

In visits 08 and later, most of the roughness of this section was concentrated at narrow dips in a regular pattern.

Roughness profiles show a decrease in roughness after visit 12 for the portion of the section past 150 ft from the start of the section on the left side and past 170 ft from the start of the section on the right side. However, in visit 13 the smoother area was preceded by localized roughness.

PSD plots: Before rehabilitation the PSD plots included elevated content at a wavelength of 15 ft on both sides, but this was overwhelmed by highly elevated content in the right side PSD plot in the wavelength range from 12-13.5 ft.

The increase in roughness over time primarily occurred in the wavelength range below 10 ft. In visit 08 and later, weak evidence of content from the underlying slabs appeared.

Distress surveys: The pattern and first appearance of narrow dips in the profiles corresponds with the locations and first appearance of transverse cracks in the distress surveys. Further, the absence of a transverse crack at the location of an underlying joint is usually accompanied by the lack of a narrow dip in the profile. Often, the deepest dips were found in the profile in the same locations where the distress survey cited high-severity cracks, and the shallowest dips were found in the profile where the distress survey recorded medium and low severity cracks.

Maintenance history: Crack sealing (490 ft) was performed on this section in March 1995. The section received skin patching in May 2001. The skin patching reduced the roughness of the section overall, but the transition caused localized roughness.

Section 0663

Roughness: Rehabilitation decreased the IRI from 235 to 94 in/mi on the left side and from 201 to 93 in/mi on the right side. After rehabilitation, the IRI held somewhat steady in visits 02 through 09 then increased erratically in visits 10 through 14. By visit 14, the IRI of the left side was 121 in/mi and the IRI of the right side was 112 in/mi. The HRI was 6 percent below the MRI before rehabilitation and 8 to 14 percent below the MRI after rehabilitation.

Elevation profile plots: Before rehabilitation the entire section was faulted. Faults 0.05 to 0.3 in deep appeared with a pattern that crudely approximated the saw cut spacing 15-13-15-17 ft. (The actual pattern was closer to 14.7-13.5-14.7-17.3 ft.) Each fault on the right side appeared about 1 ft downstream of a fault on the left side from the same joint. Faults of lesser magnitude also appeared in the center of some slabs.

The elevation profiles were consistent in visits 02 through 06. In visits 07 though 14, narrow dips appeared with a very regular spacing of 15 ft throughout the section. (Evidence of narrow dips that had passed through the low-pass filter native to the profiler was also present in visits 02 through 06.) The narrow dips were roughly 0.2 to 0.3 in deep in visits 07 through 13, but ranged from 0.3 to 1.0 in deep in visit 14.

Narrow dips also appeared 409 and 411 ft from the start of the section. In visits 10 through 12 a single dip 0.4 in deep and about 1.5 ft wide was there instead. These features were not present in visits 13 and 14.

All of the narrow dips appeared at the same location on both sides of the lane. (The profile features indicate that this section was built with a fixed joint spacing of 15 ft and no skew.)

The profiles also include a 0.75 in rise over the 10 ft leading up to the section on the right side and a ride about half as severe in the left side.

Roughness profile plots: An area of elevated roughness appears about 410 ft from the start of the section on the right side in visits 08, 09 and 12. An area of slightly elevated roughness also appeared 410 ft from the start of the section on the left side in visits 11 through 14. These were not severe enough to classify as localized roughness.

An area of severe localized roughness appears just ahead of the test section and just behind the end of the test section on both sides.

PSD plots: Before rehabilitation the PSD plots included strong content isolated at wavelengths of 15 ft and 7.5 ft.

After rehabilitation the PSD plots included slightly elevated content at a wavelength of 15 ft. The PSD plots for visit 14 included significantly higher content for wavelengths below 2 ft than in the other visits. This was caused by the narrow dips.

Distress surveys: No distress appeared within the wheel paths of this section over the monitoring period. Photographs and distress survey forms show that the peculiar roughness about 410 ft from the start of the section appeared at the site of some weigh in motion scales. A bending plate scale was in that location during visits 08 and 09. An asphalt patch appeared in that location in visits 10 through 12, and a new scale was there during visits 13 and 14.

The photos also show that the severe localized roughness at the section boundaries was caused by transitions from asphalt pavement to concrete and back to asphalt.

Maintenance history: The section received two partial depth patches at joints in September 1999.

Sections 0664-0669

Pre-rehabilitation information was not collected on sections 0664-0669, but it was observed that the pavement condition was similar to those of 0601-0663. The observations below pertain to post-rehabilitation data only.

Section 0664

Roughness: The IRI of the left side increased erratically from 40 to 50 in/mi over the monitoring period, with a peak value of 53 in/mi in visit 12. The IRI of the right side held within a range from 44 to 50 in/mi over the entire monitoring period, with an initial value of 48 in/mi and a final value of 47 in/mi. The HRI was 13 to 19 percent below the MRI.

Elevation profile plots: The elevation profiles were fairly consistent throughout the monitoring period in the medium wavelength range, and very consistent in the long wavelength range, but not very consistent in the short wavelength range.

The profiles included a long dip from about 350 to 400 ft from the start of the section. On the right side, a bump about 0.15 in high appeared from 360 to 370 ft from the start of the section (within the dip). The right side profiles included a bump about 0.15 in high from 110 to 116 ft from the start of the section.

Roughness profile plots: A rough area appears from 350 to 430 ft from the start of the section on both sides. On the left side, this area has an average roughness of about 90 to 100 in/mi. On the right side, the overall roughness is lower, but a peak appears about 415 ft from the start of the section with a maximum value over 110 in/mi in most visits. The right side roughness profiles also included peaks about 116 ft from the start of the section that ranged from 80 to 100 in/mi.

PSD plots: The spectral content is skewed toward very long wavelength content. On the right side, a minor peak appears in the PSD plots at about 15 ft, but it is not a significant contributor to the roughness.

Distress surveys: No distress appeared within the wheel paths of this section over the monitoring period. Nothing in the distress surveys explain the two bumps described above.

Section 0665

Roughness: The IRI of the left side increased erratically from 42 to 53 in/mi over the monitoring period, with a peak value of 57 in/mi in visit 12. The IRI of the right side increased overall from 43 to 50 in/mi and half of the increase occurred between visits 04 and 05. The HRI was 8 to 15 percent below the MRI.

Elevation profile plots: The elevation profiles were fairly consistent throughout the monitoring period in the medium wavelength range, and very consistent in the long wavelength range. Both sides of the lane included an increase in elevation of up to 0.2 in over 5 ft of longitudinal distance ending 200 ft from the start of the section. This was followed by a series of small bumps over the next 20 ft. The bumps and the sudden rise in elevation were more severe on the left side.

Roughness profile plots: The roughness was not evenly distributed throughout the section. In particular, peaks appeared in the roughness profiles about 210 ft from the start of the section. These were caused by the upward change in elevation and the bumps that followed, as described above. The series of bumps on the left side caused an area of localized roughness, with peak values in the roughness profiles above 140 in/mi in visits 03 through 14 about 212 ft from the start of the section.

The right side roughness profiles from visit 12 include a rough area in the first 50 ft of the section. This is caused by a roughly 20 ft long bump at the very start of the section. This does not appear in the left side profiles, or in any other visit.

PSD plots: The spectral content is skewed somewhat toward long wavelength content.

Distress surveys: Almost no distress appeared within the wheel paths of this section over the monitoring period. Nothing in the distress survey explains the bumps described above.

Section 0666

Roughness: The IRI of the left side increased somewhat erratically over the monitoring period from 37 to 47 in/mi, with a peak value of 49 in/mi in visit 11. The IRI of the right side increased from 42 to 52 in/mi over the monitoring period, with values ranging from 51 to 52 in/mi in the last seven visits. The HRI was 15 to 20 percent below the MRI.

Elevation profile plots: The elevation profiles were fairly consistent on the left side throughout the monitoring period in the medium wavelength range, and very consistent in the long wavelength range. The elevation profiles on the right side were very consistent in the last eight visits.

The left side profiles included bumps about 0.1 in high from 185 to 191 ft from the start of the section and 233 to 237 ft from the start of the section. The right side profiles included a bump from 185 to 191 ft from the start of the section that was about 0.15 in high.

The left side profiles also include very narrow (0.5 ft long) dips 344 and 395 ft from the start of the section. The dips first appear in visit 07, but do not appear in every repeat measurement in every visit until after visit 11.

Roughness profile plots: The roughness was not evenly distributed throughout the section, since some roughness was concentrated around the bumps described above. In visit 14 these caused peaks in the left side roughness profile of about 100 in/mi and a peak in the right side roughness profile of up to 120 in/mi. The progression in roughness in the left side profiles was distributed evenly across the section.

PSD plots: The spectral content is skewed somewhat toward long wavelength content. The PSD plots show a peak at a wavelength near 38 ft.

Distress surveys: Almost no distress appeared within the wheel paths of this section over the monitoring period. Nothing in the distress surveys explain the bumps or the narrow dips described above.

Section 0667

Roughness: The IRI of the left side changed erratically over the monitoring period, and had values between 63 and 72 in/mi. However, initial and final values were nearly equal. The IRI of the right side held steady between 74 and 79 in/mi. The HRI was 6 to 9 percent below the MRI. This is the lowest range of any section within this site.

Elevation profile plots: The elevation profiles were consistent throughout the monitoring period, particularly on the right side. A bump appeared in the profiles on both sides from 185 to 245 ft from the start of the section. The bump was about 0.8 in high on the right side, and came to a narrow peak with an unusually sharp change in slope 221 ft from the start of the section. The bump was about 0.5 to 0.6 in high on the left side, but the change in slope at the peak was nearly as severe on the right side.

Roughness profile plots: The right side roughness profiles were very consistent with time, and the left side roughness profiles were fairly consistent with time. The section was roughest at the crest of a long bump 221 ft from the start of the section. The peak values in the roughness profiles at this location were high enough to qualify as localized roughness in about half of the repeat measurements. The severity of roughness at the bump did not progress with time, but the bump increased the IRI of the entire section by about 10 in/mi on the left side and about 15 in/mi on the right.

PSD plots: Content in the profile at wavelengths from 45 to 60 ft dominated the contributions to the IRI.

Distress surveys: Very little distress appeared within the wheel paths of this section over the monitoring period. The exception was a small amount of longitudinal cracking in the left side of the lane noted in October 2002.

Section 0668

Roughness: The IRI of the left side increased erratically from 36 to 45 in/mi over the monitoring period. The IRI of the right side increased erratically from 38 to 45 in/mi over the monitoring period. The HRI was 13 to 15 percent below the MRI in visits 02 through 06 and 17 to 19 percent below the MRI in the rest.

Elevation profile plots: Very few features stood out in the elevation profiles. The exceptions were narrow (about 0.5 ft long) dips that were up to 0.25 in deep 40 ft, 250 ft, and 475 ft from the start of the section on the left side. The dips did not appear, or were barely detectable, in visits 01 through 06, but were very obvious in all of the other visits. Companion dips appeared in the right side profiles about 1 ft downstream of each location starting in visit 08. (The 1 ft offset downstream on the right side is a consequence of the joint skew in the underlying pavement.)

Roughness profile plots: The overall level of roughness and much of the spatial distribution were fairly consistent with time, but the details of the plots were not. The three dips contributed to the roughness in some visits, but were not severe enough to cause localized roughness.

PSD plots: The left side PSD plots included a small peak at a wavelength of 15 ft. The right side profiles show a stronger peak at a wavelength of 15 ft, and a companion peak at a wavelength of 7.5 ft.

Distress surveys: Very little distress appeared within the wheel paths on this section over the monitoring period. Three transverse cracks appeared in all distress surveys that cut across the lane at an angle such that the intersection of the crack and the left lane edge was about 2 ft upstream of the intersection of the crack and the right lane edge. These were about 40, 250, and 475 ft from the start of the section. As described above, they did cause narrow dips in the elevation profiles, particularly in later visits. A patch of wheel path cracking on the right side from 240 to 255 ft from the start of the section was recorded in October 2002, but it did not affect the profiles.

Section 0669

Roughness: The IRI of the left side increased erratically from 51 in/mi to 59 in/mi over the monitoring period. The IRI of the right side covered a range from 52 in/mi in visit 02 to 59 in/mi in visit 08, with a final value of 55 in/mi. The HRI was 9 to 13 percent below the MRI.

Elevation profile plots: The profiles were very consistent over the entire monitoring period. An exception was some noise in the short wavelength plots for the left side in the early visits. No rough features stood out on the right side, but a sharp transition occurred between upward and downward slope at the apex of a long bump on the left side. This appeared 348 ft from the start of the section.

Roughness profile plots: The roughness profiles changed very little throughout the monitoring period. The roughness was not evenly distributed along the section on either side of the lane. The roughest area extended from 325 to 425 ft from the start of the section.

Localized roughness (or increased roughness severe enough to nearly qualify as localized roughness) appeared with a peak value 375 ft from the start of the section on the left side in all visits. This was caused by the sharp slope change described above. The peak value in the roughness profile occurred 25 ft downstream of the apex because it excited a transient in the IRI filter with a very long characteristic wavelength.

PSD plots: Content in the profile at wavelengths from 45 to 60 ft dominated the contributions to the IRI.

Distress surveys: Very little distress was recorded for this section. Nothing in the distress surveys explain the features described above.