Preliminary Evaluation and Analysis of LTPP Faulting Data — Final Report

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Prepared by:

FHWA LTPP Data Analysis Technical Support Contractor
ERES Consultants, Inc.
9030 Red Branch Road, Suite 210
Columbia, Maryland 21045

Prepared for:

Office of Engineering and Highway Operations R&D
Long-Term Pavement Performance Division, HNR-30
Federal Highway Administration
6300 Georgetown Pike
McLean, Virginia 22101
(703) 285-2730

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

Joint and crack faulting measurements are among the key data collected to monitor the performance of concrete pavements in the Long Term Pavement Performance (LTPP) Program. This report documents an assessment of LTPP faulting data undertaken to evaluate their potential use in more in-depth performance analyses. Results of this investigation included: (1) identification, investigation, and correction (as appropriate) of anomalous faulting data; (2) the creation of an LTPP database table with section summary statistics for faulting; and (3) findings regarding the effect of various design features on the occurrence of faulting and the relationship between ride quality and faulting.

This report will be of interest to those concerned with the management and design of portland cement concrete pavements.

T. Paul Teng, P.E.
Director
Office of Infrastructure
Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

A major goal of the Long-Term Pavement Performance (LTPP) study is the development of recommendations for improving the design and construction of new and rehabilitated pavements to provide longer lasting pavements. As part of the condition monitoring of the LTPP test sections, joint and crack faulting data are being collected on a regular basis at each jointed concrete pavement test site.

The LTPP faulting data are collected using the Georgia Faultmeter. Data are collected at joints and cracks along the wheelpath and along the outside pavement edge. As part of the study reported here, the quality of the faulting data was evaluated, and missing and questionable data were identified. The data were then used to develop faulting data indices (average joint faulting for each visit) and related statistical parameters.

Also, data analysis was carried out to determine the usefulness of joint faulting and related data in identifying factors that affect joint faulting. The analysis indicated that doweled joints exhibit very little faulting even after many years of service and that the effect of design features such as drainage, tied-concrete shoulder use, and joint spacing is not as significant when doweled joints are used. For non-doweled jointed plain concrete (JPC) pavements, the following design features were found to significantly reduce faulting: use of widened lanes, effective drainage system, stabilized base/subbase, and shorter joint spacing. Effect of faulting on ride quality was also investigated using jointed plain concrete pavements (JPCP) sections with three or more faulting and International Roughness Index (IRI) surveys. A strong correlation was found between rate of change in faulting values versus rate of change in IRI values for JPCP sections. The results indicate that faulting is a major component of increased roughness of JPC pavements.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1. INTRODUCTION

Background

Faulting of transverse joints and cracks is one of the key distress types for jointed rigid pavements. The change in faulting with time serves as an important indicator of jointed concrete pavement (JCP) performance. The greater the faulting, the greater the pavement roughness and potential erosion and loss of support beneath the slab. Faulting is defined as the difference in elevation across a joint or a crack and is measured at each joint or crack at two locations, 0.3 m and 0.76 m from the outside slab edge.

The electronic digital faultmeter developed by the Georgia Department of Transportation is used for the faulting measurements in LTPP program [1]. The Faultmeter readout provides the faulting measurement in millimeters and indicates whether the measurement is positive or negative. Typically, joint mean faulting in excess of 3 mm is considered unacceptable for jointed plain concrete pavements (JPCP), and mean joint faulting in excess of 6 mm is considered unacceptable for jointed reinforced concrete pavements (JRCP). The readout unit essentially limits the precision of faulting measurement to ±1 mm. There have been some concerns that this level of precision may not be adequate to allow the desired degree of sensitivity in joint faulting prediction procedures.

Transverse joint and crack faulting is being monitored regularly at the jointed concrete pavement test sections under the Long-Term Pavement Performance (LTPP) program. Faulting data are available for the following pavement types:

- JPCP (GPS-3, SPS-2, SPS-4, SPS-6, and SPS-8).
- JRCP (GPS-4).
- JPCP over JRCP (GPS-9).
- JPCP over JPCP (GPS-9).
- JRCP over JPCP (GPS-9).
- JRCP over JRCP (GPS-9).
- JPCP over continuously reinforced concrete pavement (CRCP) (GPS-9).
- JRCP over CRCP (GPS-9).

The General Pavement Studies (GPS) experiment looks at existing pavements. These pavement materials and structural designs reflect standard engineering practices in the United States and Canada. The Specific Pavement Studies (SPS) were designed and constructed to provide the data required to investigate and quantify the critical factors that affect pavement performance. Each SPS project consists of a series of sections at a single location. The sections vary in structure, maintenance treatments, or rehabilitation strategy, with all other factors being similar. The purpose of the SPS-2 experiment is to evaluate the effect of structural factors on rigid pavement performance. The SPS-4 experiment is designed to study the effectiveness of preventive maintenance on rigid pavements. The SPS-6 experiment evaluates the rehabilitation of jointed concrete pavements, and the SPS-8 experiment evaluates environmental effects in the absence of heavy loads.

The spring 1998 LTPP data (release 8.2) were used in this study. Faulting data in the LTPP Information Management System (IMS) database include faulting measurements at doweled and non-doweled joints and also some measurements at transverse crack locations. In addition to the joint-by-joint faulting data currently available in the IMS, it is desirable to have available representative faulting values and companion statistics for each site for each measurement cycle (site visit). The availability of computed representative values of edge and wheelpath faulting would minimize duplication of effort in future analysis work and provide a consistent set of data to be used for joint and crack faulting studies. The representative faulting values for each test section can be used for the investigation of time-series trends and for proof testing of the faulting data. Pavement analysts can make use of the representative faulting indices and statistics to develop mechanistic-based prediction models for joint faulting. To provide LTPP users with representative faulting indices and statistics, a new table was developed during the course of the present study and was proposed for inclusion in the IMS database.

Previous analysis of joint faulting data has identified concerns with some of the data, including the following:

- The presence of negative faulting values.
- The poor correlation between joint faulting and roughness (in terms of International Roughness Index [IRI]) at some sites.
- Joint faulting decreasing with time at some sites.
- Large differences between wheelpath and edge faulting at each joint/crack location.

To date, no serious attempt has been made to assess the quality of the faulting data. This report addresses the assessment of the quality of the faulting data and the development of representative faulting indices and companion statistics for each site for each measurement cycle (site visit). This report also contains the results of faulting data analysis that was obtained using computed faulting indices. These results address the effect of key pavement design features on faulting values.

Objectives and Scope of Work

Following are the objectives of this study:

- Examine the quality of the joint faulting data.
- Identify questionable data.
- Provide recommendations for resolving questionable data.
- Develop representative faulting indices and statistics for each JCP test section.
- Perform a limited study of factors that affect joint faulting.

The scope of work included a detailed evaluation of the joint faulting data for 307 doweled and non-doweled pavement sections. The variability of the faulting data over the 154-m length of each section was studied, and representative faulting indices and statistics for each section were determined and grouped in the new MON_DIS_FAULT_SUMMARY table that is included in the LTPP database.

Report Organization

This report documents the results of the LTPP faulting data assessment. The report consists of six chapters and two appendices. Chapter 1 discusses the background information, objectives, and scope of work. Issues related to the assessment of faulting and complementary data quality and recommendations for resolving data quality issues are addressed in chapter 2. Chapter 3 describes the development of representative faulting indices and statistics for the proposed computed parameter tables to be included in the IMS database. Chapter 4 presents the results of the faulting trend analysis conducted using the developed representative faulting indices and statistics. A summary of findings is presented in chapter 5. Finally, recommendations for future advances in faulting data quality are presented in chapter 6.

The description of the new IMS table MON_DIS_JPCC_FAULT_SECT containing faulting indices and summary statistics is given in appendix A. Appendix B provides time-series plots showing faulting and IRI trends with time for the test sections included in this study.

2. ASSESSMENT OF FAULTING AND COMPLEMENTARY DATA QUALITY

To determine availability and usability of data for the development of representative faulting statistics and for the preliminary faulting data analysis, data from LTPP IMS release Quarter 1, 1998, were reviewed in terms of faulting and companion inventory information, including environmental factors, material characteristics, and traffic. As a result of this study, a comprehensive list of missing and questionable data was developed. The missing data, which include both faulting and companion data, were categorized by experiment type, section number, identification of the missing parameters, and the source of the extracted data.

Questionable data include both faulting and traffic data. The criteria necessary to identify questionable faulting data were developed and applied to the faulting database. The criteria include assessment of negative faulting values, a comparison of wheelpath and edge faulting, rate of faulting (for sections with two or more observations), and additional factors based on a thorough review of the faulting data. The questionable traffic data were assessed through comparison of trends in historical and monitoring equivalent single axle load (ESAL) data and by comparison of calculated truck factors for each section to an acceptable range (0.5 to 2.5). A discussion of the quality of the joint (and crack) faulting data and related data in the LTPP IMS database is presented below.

Joint Faulting Data Quality Evaluation

The April 1998 version of the MON_DIS_JPCC_FAULT data table (LTPP data module MO8) was obtained from the LTPP IMS. The table contained 24,018 records. This table contained faulting data for both wheelpath and edge (corner) locations at each joint or transverse crack for each jointed concrete pavement section in the inventory. Joints and cracks were designated by the letters J and C, respectively. The locations of the cracks or joints were given as the distance, in meters, from the beginning of the test section. Each data record provided additional information regarding joint or crack spalling and sealing. The faulting data records were sorted by survey date and crack or joint location. Example faulting profiles are given in figure 1 for a JPCP section with a single faulting survey and in figure 2 for a JRCP section with three faulting surveys.

Faulting data are available for the sections conducted under GPS-3, GPS-4, GPS-9, SPS-2, SPS-4, SPS-6, and SPS-8 experiments. A thorough review of the data indicated that not all of the sections within these experiments have available faulting data. A summary of the availability of faulting data within each experiment is presented in table 1. Based on the currently available faulting data, a total of 307 sections were considered suitable for development of joint faulting indices and statistics.

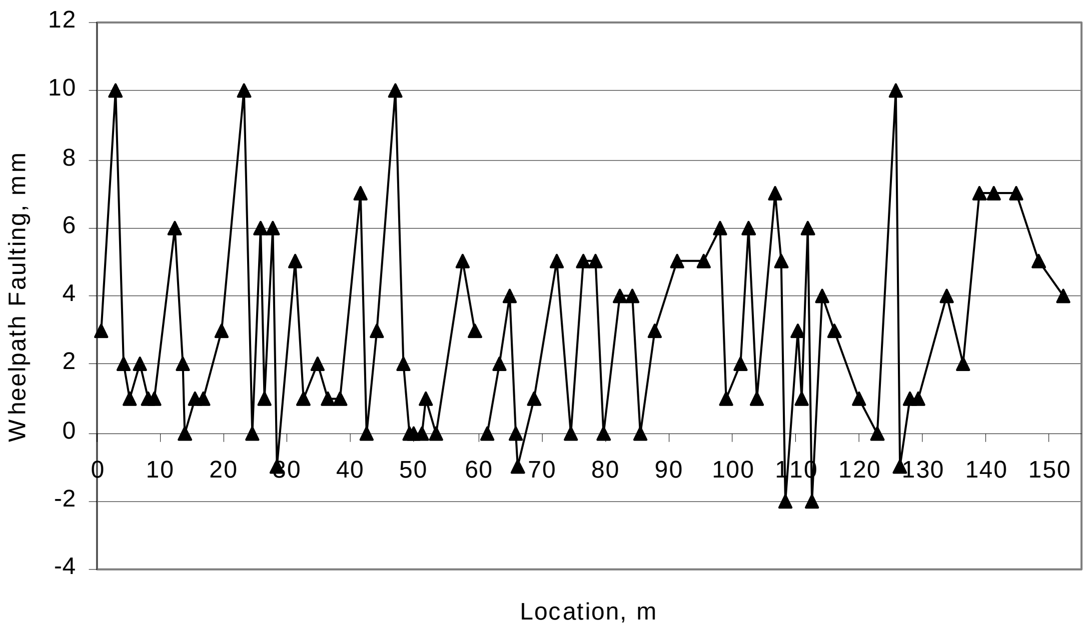


Figure 1. Example of faulting profile for GPS-3 section 063005, survey date: August 10, 1992.

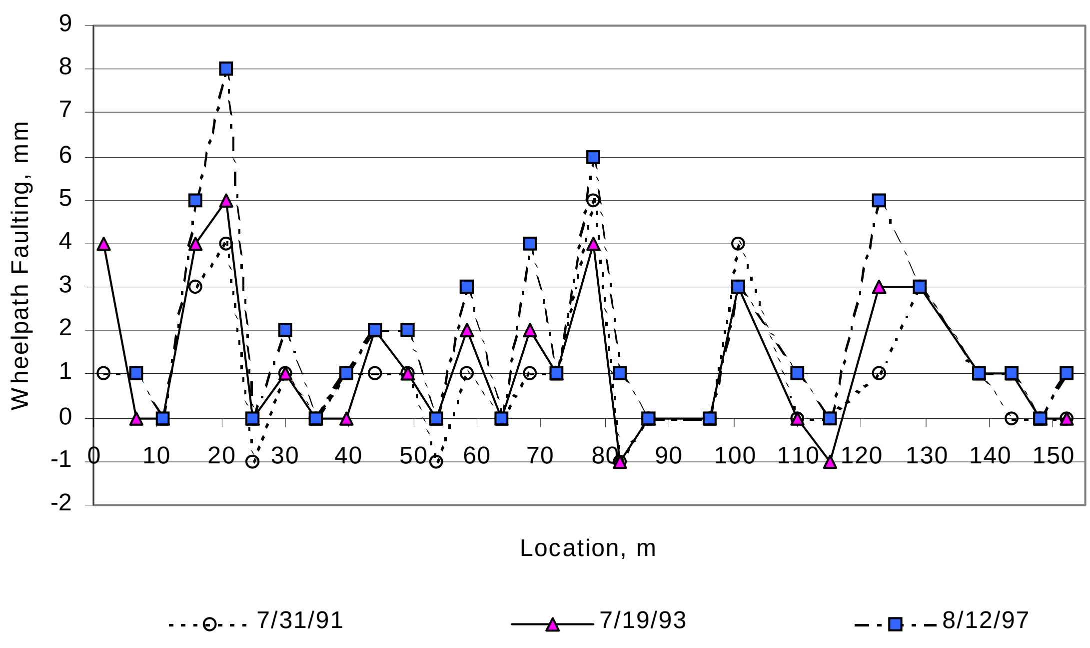


Figure 2. Example of faulting profile for GPS-4 section 314019.

Table 1. Summary of the availability of faulting data by experiment type.

Experiment Type	Total Number of Sections Released	Number of Sections With Available Faulting Data	Number of Sections Lacking Faulting Data
GPS-3	133	121	12
GPS-4	69	52	17
GPS-9	26	18	8
SPS-2	75	65	10
SPS-4	68	43	25
SPS-6	39	6	33
SPS-8	12	2	10
All	422	307	115

For any of the sections with faulting data, the number of faulting surveys varies from one to nine. The total number of faulting surveys per section per experiment is presented in table 2. Note that more than half of the sections with faulting data reported contain two or fewer observations.

Table 2. Total number of faulting surveys.

Experiment Type	Number of Sections With										Total Sections
	1 Survey	2 Surveys	3 Surveys	4 Surveys	5 Surveys	6 Surveys	7 Surveys	8 Surveys	9 Surveys	10 Surveys	
GPS-3	36	33	24	20	2	1	3	1	1	—	121
GPS-4	17	8	13	7	2	1	1	2	1	—	52
GPS-9	10	2	5	1	—	—	—	—	—	—	18
SPS-2	20	31	8	4	—	1	—	1	—	—	65
SPS-4	—	8	9	8	3	6	3	1	—	5	43
SPS-6	—	2	1	2	1	—	—	—	—	—	6
SPS-8	—	2	—	—	—	—	—	—	—	—	2
Total Sections	83	86	60	42	8	9	7	5	2	5	307
% Distribution	27.0	28.0	19.5	13.7	2.6	2.9	2.3	1.6	0.7	1.6	100

Missing Data

Data for a total of 422 JCP sections were available in the IMS database at the time of the study. Out of 422 released sections, 115 sections did not have any records in the faulting data table MON_JPCC_FAULT. This magnitude of missing data is considered very serious because faulting is one of the key distress types associated with jointed concrete pavements. Future efforts should be focused on ensuring that faulting data are collected as required.

The records in the faulting table exhibit numerous missing observations. The missing information may be either a complete lack of faulting data for a section or more than 25 percent observations missing for a given survey and section. The missing faulting data, differentiated by GPS or SPS section number—as well as the percentage and type of missing information—were reported to the Federal Highway Administration (FHWA) in an LTPP Feedback Report. The list of sections and survey dates with excessive numbers of missing faulting observations is given in tables 3 and 4 for crack and joint observations, respectively. Missing data were further classified to identify whether the edge or wheelpath is missing faulting data.

Table 3. List of sections with excessive number of missing crack faulting observations.

Section ID	Survey Date	Experiment Type	Number of Missing Edge Crack Point Locations	Number of Missing Wheelpath Crack Point Locations	Total Number of Crack Point Locations	% Missing Edge Faulting Data	% Missing Wheelpath Faulting Data
014084	19-Sep-91	GPS-4		13	17		76
053059	11-Sep-91	GPS-4		2	2		100
054021	10-Sep-91	GPS-4		3	3		100
054021	29-Nov-94	GPS-4	4	4	4	100	100
054046	11-Jun-97	GPS-4	1	1	1	100	100
063030	18-Mar-97	GPS-3		3	7		43
06B410	11-Jan-94	SPS-4	13	13	13	100	100
06B420	11-Jan-94	SPS-4	12	12	12	100	100
06B430	11-Jan-94	SPS-4	6	6	6	100	100
123811	03-Oct-91	GPS-3		4	14		29
174074	08-May-91	GPS-4	13		13	100	
174082	07-May-91	GPS-4	16		16	100	
224001	11-Jul-94	GPS-4	8	8	8	100	100
294069	04-Feb-91	GPS-4	24		24	100	
32A420	09-Aug-91	SPS-4		6	6		100
483699	09-Jul-91	GPS-4		1	2		50
484152	02-Apr-92	GPS-4		10	10		100
48C410	20-Jun-91	SPS-4		1	1		100
48C420	20-Jun-91	SPS-4		1	1		100
48C430	20-Jun-91	SPS-4		3	3		100
48D410	29-Jun-90	SPS-4		9	9		100
48D410	10-Jul-91	SPS-4		9	9		100
48D410	02-Apr-92	SPS-4		9	9		100
48D420	29-Jun-90	SPS-4		16	16		100
48D420	10-Jul-91	SPS-4		15	15		100
48D420	02-Apr-92	SPS-4		16	16		100
48D430	29-Jun-90	SPS-4		13	13		100
48D430	10-Jul-91	SPS-4		16	16		100
48D430	02-Apr-92	SPS-4		16	16		100
49C410	27-Jan-92	SPS-4	1	1	1	100	100
49C430	21-Jul-93	SPS-4	1	1	1	100	100
724121	18-Jan-90	GPS-3		13	13		100
724121	28-Feb-91	GPS-3		13	13		100

Table 4. List of sections with excessive number of missing joint faulting observations.

Section ID	Survey Date	Experiment Type	Number of Missing Edge Joint Point Locations	Number of Missing Wheelpath Joint Point Locations	Total Number of Joint Point Locations	% Missing Edge Faulting Data	% Missing Wheelpath Faulting Data
01-3028	19-Sep-91	GPS-3		23	25		92
01-4007	19-Sep-91	GPS-4		5	14		36
01-4084	19-Sep-91	GPS-4		7	9		78
04-7614	15-Dec-94	GPS-3		34	34		100
04-A410	13-Jul-95	GPS-4	35	35	35	100	100
04-A430	13-Jul-95	GPS-4	39	39	39	100	100
05-3059	11-Sep-91	GPS-4		33	33		100
05-3073	10-Sep-91	GPS-4		9	33		27
05-3074	11-Sep-91	GPS-4		28	33		85
05-4019	11-Sep-91	GPS-4		34	34		100
05-4021	15-May-91	GPS-4		33	33		100
05-4021	10-Sep-91	GPS-4		32	33		97
05-4021	29-Nov-94	GPS-4	33	33	33	100	100
05-4046	10-Sep-91	GPS-4		9	33		27
05-4046	11-Jun-97	GPS-4	35	35	35	100	100
05-B410	11-Sep-91	GPS-4		33	33		100
05-B430	11-Sep-91	GPS-4		33	33		100
05-C410	09-Sep-91	GPS-4		34	34		100
05-C430	09-Sep-91	GPS-4		34	34		100
06-B410	11-Jan-94	GPS-4	32	32	32	100	100
06-B420	11-Jan-94	GPS-4	29	29	29	100	100
06-B430	11-Jan-94	GPS-4	31	31	31	100	100
12-3811	03-Oct-91	GPS-3		22	25		88
13-3011	24-Sep-91	GPS-3		9	26		35
13-3015	24-Sep-91	GPS-3		10	25		40
13-3016	23-Sep-91	GPS-3		9	25		36
13-3017	24-Sep-91	GPS-3		21	26		81
17-4074	08-May-91	GPS-4	13		13	100	
17-4082	07-May-91	GPS-4	13		13	100	
18-3031	01-May-91	GPS-3	32		32	100	
20-0201	06-Apr-93	SPS-2	32	32	32	100	100
20-0202	07-Apr-93	SPS-2	32	32	32	100	100
20-0203	05-Apr-93	SPS-2	31	31	31	100	100
20-0204	06-Apr-93	SPS-2	31	31	31	100	100
20-0205	08-Apr-93	SPS-2	32	32	32	100	100
20-0206	07-Apr-93	SPS-2	27	27	27	100	100
20-0207	08-Apr-93	SPS-2	32	32	32	100	100
20-0208	09-Apr-93	SPS-2	32	32	32	100	100
22-4001	04-Nov-91	GPS-4		9	9		100
22-4001	11-Jul-94	GPS-4	9	9	9	100	100
28-3018	01-Nov-91	GPS-3		14	26		54
28-4024	11-Sep-91	GPS-4		8	8		100
29-4069	04-Feb-91	GPS-4	8		8	100	
32-A420	09-Aug-91	GPS-4		33	33		100
40-3018	08-Oct-91	GPS-3		26	33		79

Table 4. List of sections with excessive number of missing joint faulting observations (continued).

Section ID	Survey Date	Experiment Type	Number of Missing Edge Joint Point Locations	Number of Missing Wheelpath Joint Point Locations	Total Number of Joint Point Locations	% Missing Edge Faulting Data	% Missing Wheelpath Faulting Data
40-3018	03-Nov-94	GPS-3	27	27	27	100	100
40-4160	16-Oct-91	GPS-3		19	32		59
45-3012	16-Mar-92	GPS-3		23	23		100
48-3010	02-Apr-92	GPS-3		30	30		100
48-3589	20-Jun-91	GPS-3		33	34		97
48-3699	09-Jul-91	GPS-4		11	24		46
48-4142	03-Apr-92	GPS-4		25	25		100
48-4146	02-Apr-92	GPS-4		33	33		100
48-4152	02-Apr-92	GPS-4		17	17		100
48-B410	05-Sep-89	GPS-4		25	25		100
48-B410	29-Jun-90	GPS-4		25	25		100
48-B410	11-Jul-91	GPS-4		25	25		100
48-B410	03-Apr-92	GPS-4		25	25		100
48-B420	05-Sep-89	GPS-4		25	25		100
48-B420	29-Jun-90	GPS-4		25	25		100
48-B420	11-Jul-91	GPS-4		25	25		100
48-B420	03-Apr-92	GPS-4		25	25		100
48-B430	05-Sep-89	GPS-4		25	25		100
48-B430	29-Jun-90	GPS-4		25	25		100
48-B430	11-Jul-91	GPS-4		25	25		100
48-B430	03-Apr-92	GPS-4		25	25		100
48-C410	03-Dec-90	GPS-4	33	33	33	100	100
48-C410	20-Jun-91	GPS-4		33	33		100
48-C420	03-Dec-90	GPS-4	33	33	33	100	100
48-C420	20-Jun-91	GPS-4		33	33		100
48-C430	03-Dec-90	GPS-4	33	33	33	100	100
48-C430	20-Jun-91	GPS-4		33	33		100
48-D410	29-Jun-90	GPS-4		18	18		100
48-D410	10-Jul-91	GPS-4		18	18		100
48-D410	02-Apr-92	GPS-4		18	18		100
48-D420	29-Jun-90	GPS-4		17	17		100
48-D420	10-Jul-91	GPS-4		17	17		100
48-D420	02-Apr-92	GPS-4		17	17		100
48-D430	29-Jun-90	GPS-4		17	17		100
48-D430	10-Jul-91	GPS-4		17	17		100
48-D430	02-Apr-92	GPS-4		17	17		100
48-E410	28-Jun-90	GPS-4		25	25		100
48-E410	11-Jul-91	GPS-4		25	25		100
48-E410	03-Apr-92	GPS-4		25	25		100
48-E420	28-Jun-90	GPS-4		24	24		100
48-E420	11-Jul-91	GPS-4		24	24		100
48-E420	03-Apr-92	GPS-4		24	24		100
48-E430	28-Jun-90	GPS-4		25	25		100
48-E430	11-Jul-91	GPS-4		25	25		100
48-E430	03-Apr-92	GPS-4		25	25		100

Table 4. List of sections with excessive number of missing joint faulting observations (continued).

Section ID	Survey Date	Experiment Type	Number of Missing Edge Joint Point Locations	Number of Missing Wheelpath Joint Point Locations	Total Number of Joint Point Locations	% Missing Edge Faulting Data	% Missing Wheelpath Faulting Data
49-3010	01-Aug-91	GPS-3		33	33		100
49-3011	30-Nov-93	GPS-3	33	33	33	100	100
49-7086	06-Jul-94	GPS-3	38	38	40	95	95
49-C410	21-Jul-93	GPS-4	41	41	41	100	100
49-C430	21-Jul-93	GPS-4	47	47	47	100	100
49-E410	10-Jul-91	GPS-4	40	40	40	100	100
49-E430	10-Jul-91	GPS-4	40	40	40	100	100
56-3027	18-Aug-94	GPS-3	32	32	32	100	100
72-3008	22-Jan-90	GPS-3		22	26		85
72-4121	18-Jan-90	GPS-3		27	27		100
72-4121	28-Feb-91	GPS-3		27	27		100
83-3802	09-Jun-93	GPS-3	35	35	35	100	100

Negative Faulting Values

A slab that is lower on the leave side of the joint will register as positive faulting, which is the typical case. If the leave side of the joint is higher, then negative faulting will be registered. Cases of positive and negative faulting are shown in figure 3. The preliminary assessment of questionable faulting data revealed a number of sections with negative faulting values. At least one negative faulting value was recorded for 52 percent of all sections evaluated. However, the total number of negative faulting measurements per section is very low. As a result, the total number of negative faulting points in the faulting data table is 4 percent of the total number of faulting measurements, and negative faulting measurements less than -1 mm are only 1 percent. In most cases, the negative values were random occurrences, with a few repeated at the same joint/crack locations. Since only 45 percent of all the sections considered had faulting data from more than two surveys, trends in the negative values are difficult to assess. A list of sections and survey dates with a large number of points with negative faulting values less than -1 mm (25 percent or more) is given in table 5.

While reasons for negative faulting values of -1 mm (majority of negative faulting measurements) can be attributed to the precision of the Georgia Faultmeter, reasons for negative faulting values that are less than -1 mm were investigated. It was discovered that on certain survey dates, sections 067456, 344042, 364018, 497085, 533019, 533813, and 833802 exhibited negative faulting profiles that are mirror images of the positive faulting profile measured on a different date. An example of the negative mirror image faulting is given in figure 4. This phenomenon was reported to FHWA, and the response from the Regional Centers indicated that in some cases the mirror image occurred because the faultmeter was turned in the wrong direction during data collection. In other cases, negative faulting values were attributed to faulting measurements over patched or sealed joints.

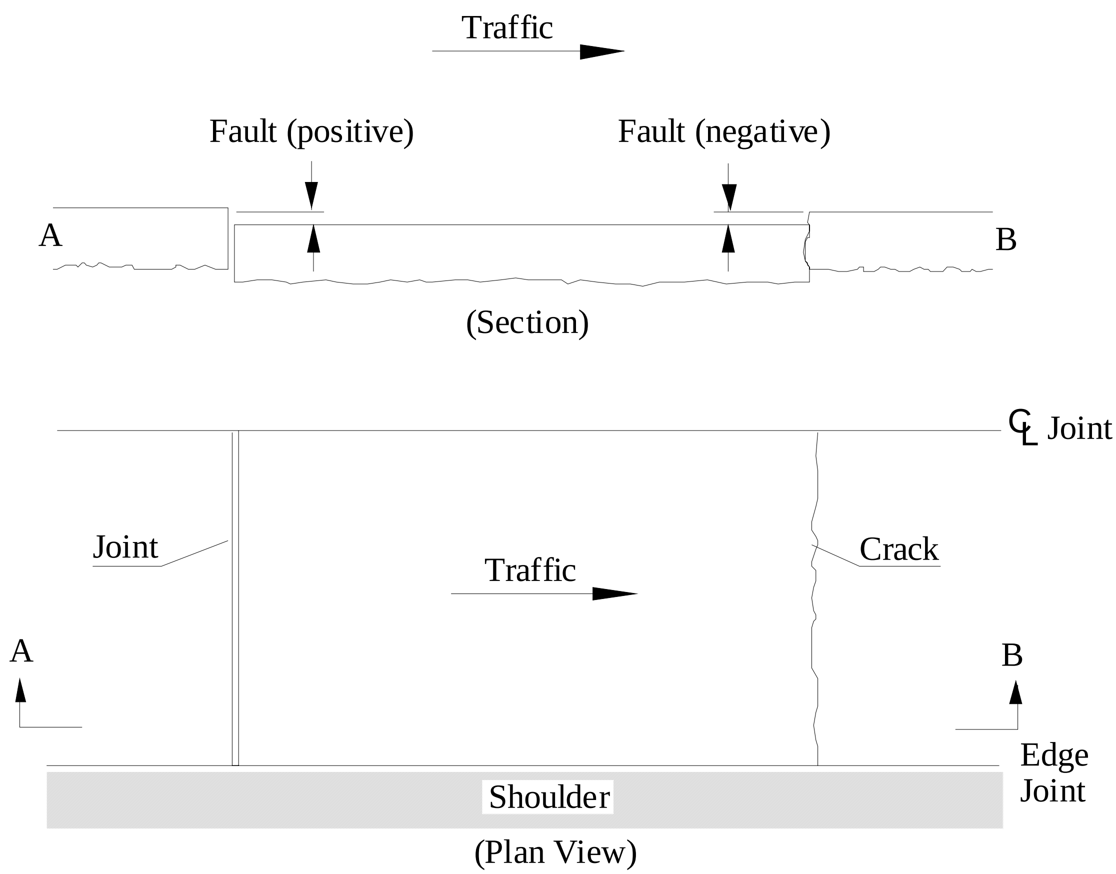


Figure 3. Faulting of transverse joints and cracks.

Table 5. List of surveys with 25 percent or more negative faulting values less than -1 mm.

Section ID	Survey Date	Crack or Joint	% Edge Faulting Data <= -2 mm	% Wheelpath Faulting Data <= -2 mm	Total Number of Point Locations
06-9048	29-Jan-97	C	50		2
55-3010	25-Feb-92	C	100	100	1
53-3813	18-Jul-95	C		50	2
05-4021	15-May-91	J	58		33
06-3042	20-Jun-96	J	100	97	32
06-7456	19-Oct-95	J	82	70	33
17-0602	26-Jun-92	J	31		13
34-4042	28-Jun-95	J		29	7
34-4042	10-Oct-96	J		29	7
48-3589	05-Aug-93	J		29	34
49-3015	07-Jul-94	J	100	100	40
49-7085	08-Jul-94	J	100	100	40
53-3813	25-Jun-96	J	100	97	34
83-3802	29-Mar-95	J	30	33	27

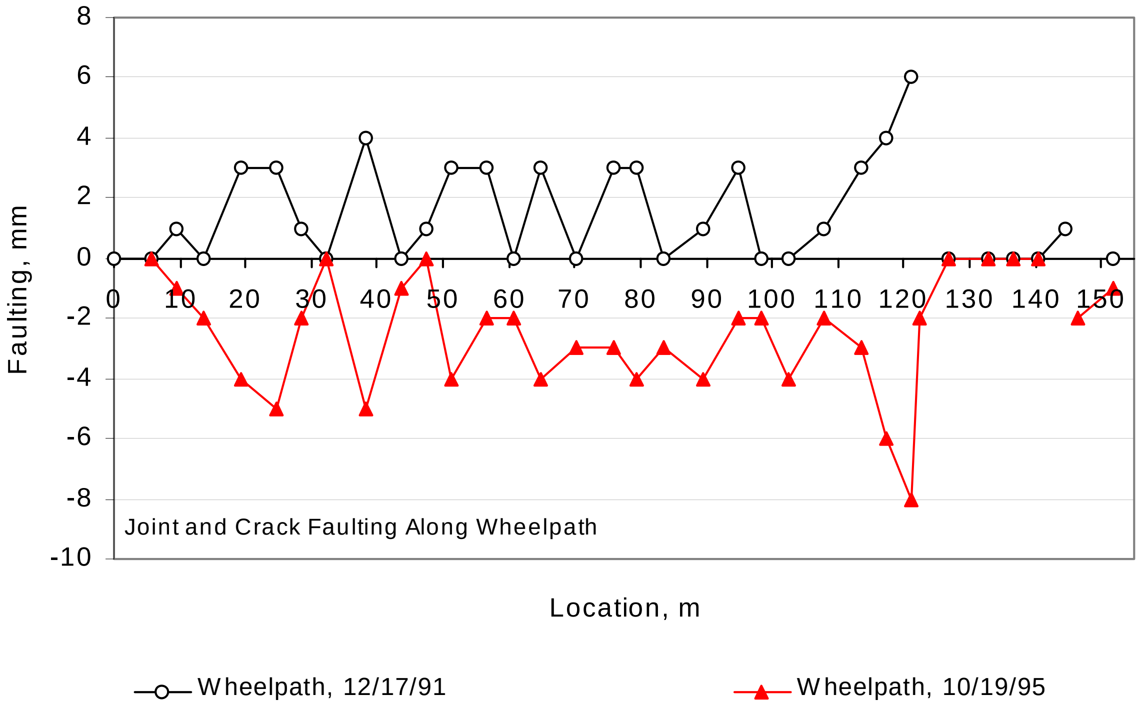
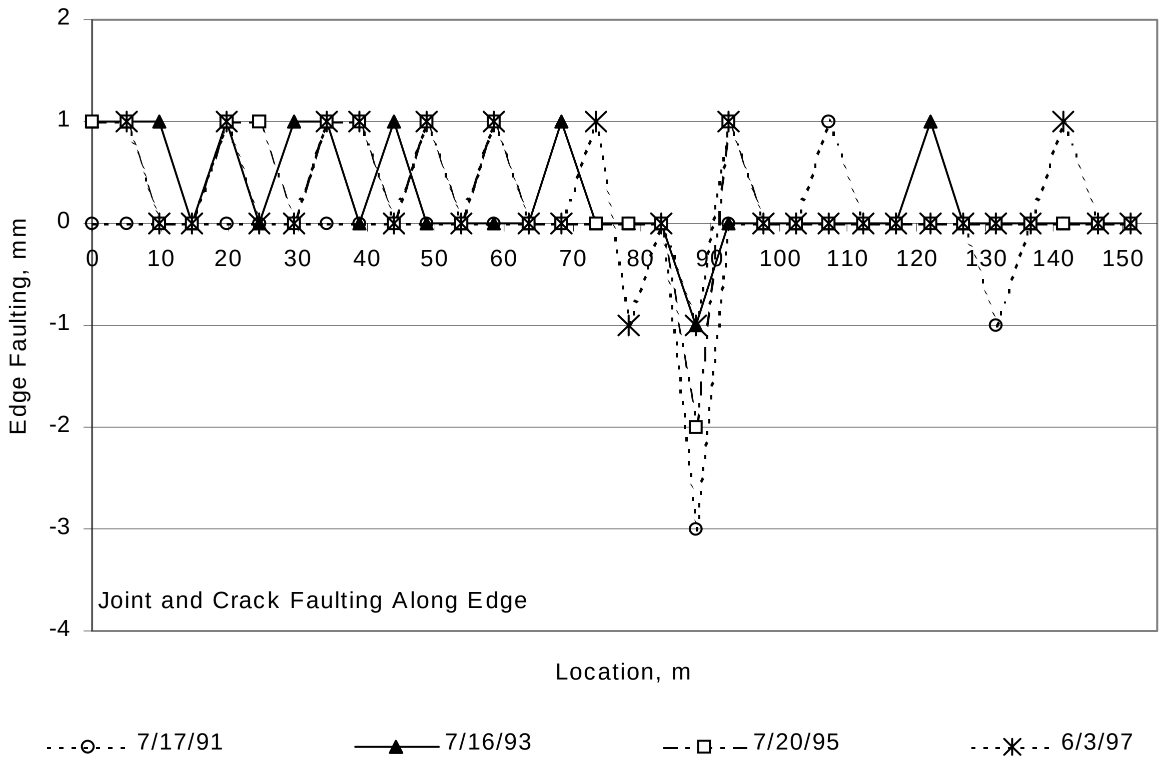


Figure 4. Example of the negative mirror image faulting (GPS-3 section 067458).

Several sections consistently show high negative faulting values from visit to visit at the same locations. These sections are: 063010, 180602, 180605, 553010, and 893016. Also, section 180602 exhibits negative faulting of almost 20 mm at one edge joint location. Examples of consistent negative faulting are shown in figure 5.

To investigate the possible reasons for negative faulting, SPS-2 sites were used to examine "as-built" faulting. These sites contain monitoring history from the beginning of a pavement's in-service life. When faulting records obtained from the first faulting survey since construction were initially investigated, it was found that 40 percent of SPS-2 sections had at least one joint that exhibited a negative faulting value. However, this number of sections was greatly reduced to 4.6 percent when negative faulting records of -1 mm were excluded. The substantial number of joints with negative faulting of -1 mm on a first survey since construction could be attributed to random positive and negative measurement variation taken on joints with zero faulting, as would be expected for new construction (built-in surface texture and the precision of the Georgia Faultmeter being ±1 mm).

To find an explanation for negative faulting, a hypothesis was tested whereby negative faulting values can be explained by the fact that "faulting is more of a joint step-off due to slab curling and/or warping caused by environmental factors rather than ESAL loading." This hypothesis was developed and well documented by Gordon Wells of Caltrans [2]. To test the hypothesis, frequency distributions of measured faulting values were compared between SPS-8 environmental (no traffic loading) sections and the rest of LTPP concrete sections.



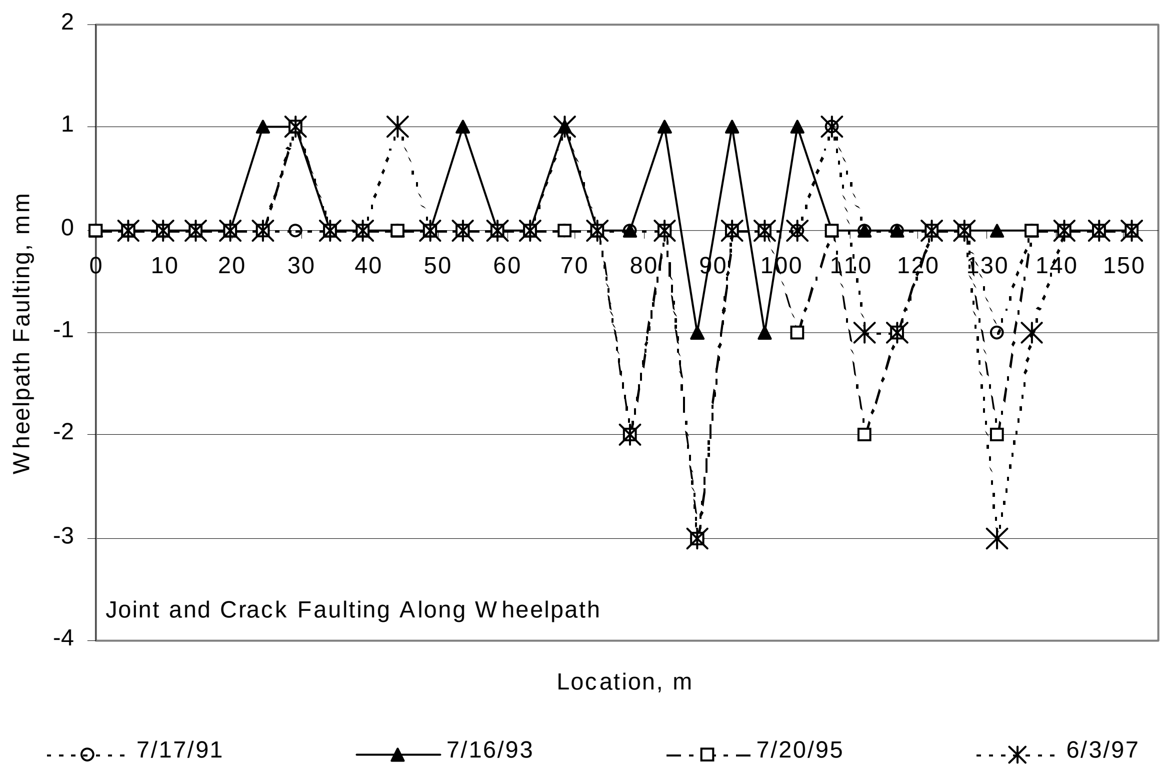


Figure 5. Example of consistent negative faulting (GPS-3 section 893016).

The histograms of comparison in figure 6 show that, in absence of traffic loading, a very minor percentage of faulting measurements for SPS-8 sections were outside the limits of the Georgia Faultmeter precision of ±1 mm. For SPS-8 sections tested, only 4 percent of measurements were outside the precision range of the Georgia Faultmeter (±1 mm). For these 4 percent of faulting observations, the probability of positive and negative faulting values was about the same for SPS-8 sections.

The frequency distributions of faulting measurements for sections exposed to traffic loading were found to be distinctly different from the frequency distributions for environmental sections. These distributions were clearly skewed toward positive faulting values with a very small percentage of measurements being less than -1 mm. This observation means that LTPP sites, unlike the sites used in Caltrans study, develop faulting primarily because of traffic loading rather than environmental curling or warping. Traffic loads lead to the positive faulting values. For LTPP sites examined in this study, negative faulting values less than -1 mm constituted only 1 percent of total faulting observations and were found to be the exception than the rule.

To develop representative faulting indices and statistics, negative faulting values of -1 mm were included. Negative faulting values of -2 mm or less were not considered because of the inconsistency with faulting development mechanisms. Whenever a large negative faulting occurs at a joint, it is usually caused by a settlement of the approach joint, or a repair placed at the joint that was not finished properly, or excessive sealant on the leave side of the joint. These causes are very different from the pumping-erosion mechanism that traditionally causes faulting. The decision was made not to use surveys with more than 25 percent of excessive negative faulting measurements (-2 mm or less) in the development of representative faulting indices and statistics until the reasons for excessive negative faulting could be explained. Since the number of surveys with more than 25 percent of excessive negative faulting measurements was only 1 percent of the total number of surveys, the decision had little impact on the quantity of data used for faulting trend analysis. Responses to the submitted LTPP Feedback Reports indicated that, in some cases, excessive negative faulting values resulted from faulting measurements over:

- Improperly sealed joints.
- Partial depth spall repairs.
- Full-depth repair patches.
- Misuse of the device (faultmeter was turned in the wrong direction).

These measurements did not represent true faulting at the joint and, therefore, were not used in computing faulting indices and summary statistics.

Mismatched Joints

Faulting data were recorded for each crack or joint within a section. The crack and joint locations are based on a measurement from the beginning of the section. During the process of faulting data evaluation, a large number of mismatched joints was encountered. The cases of mismatched joint locations can be divided into the following groups:

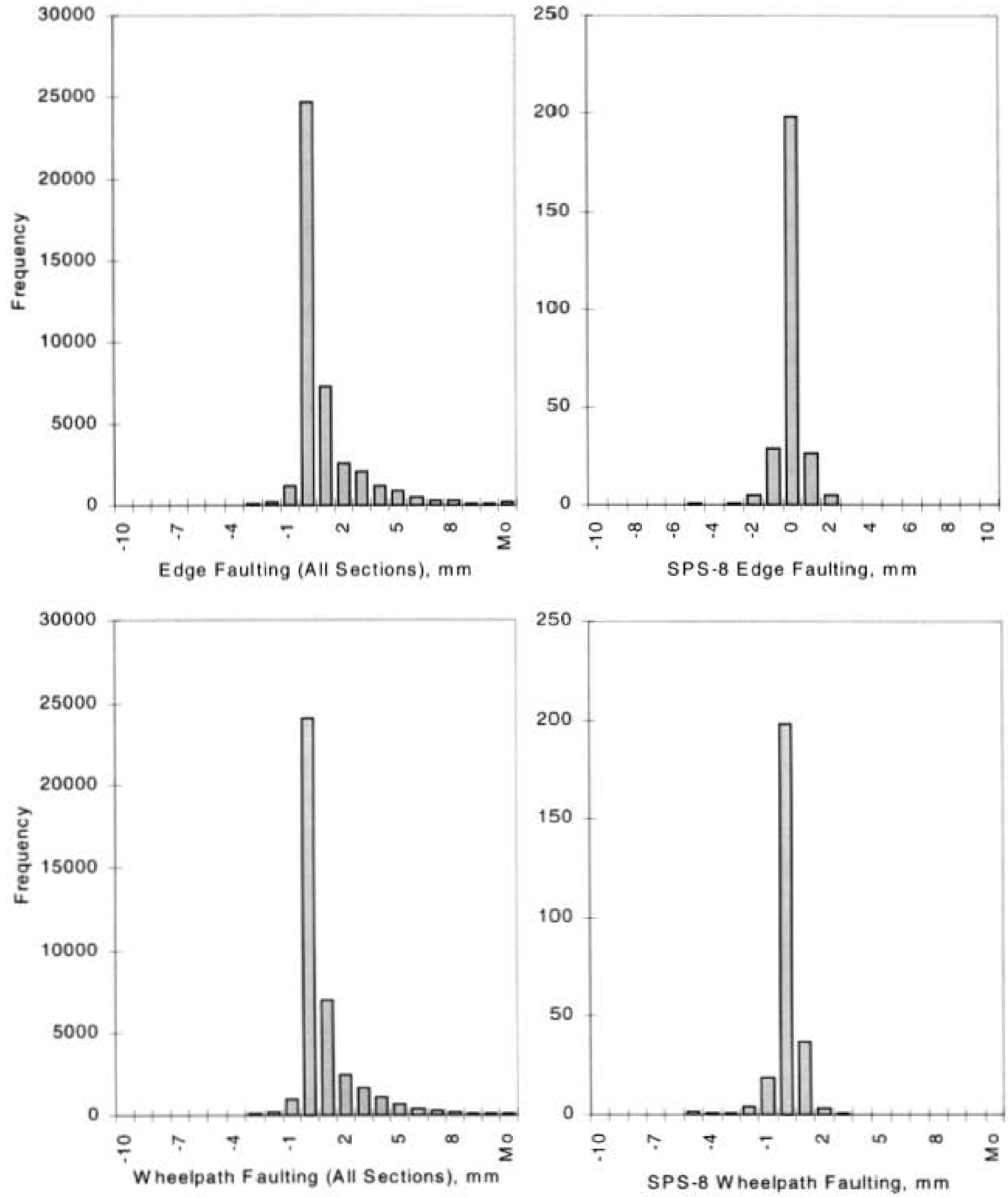


Figure 6. Comparison of faulting frequency distribution for sections subjected to traffic loading and sections without traffic (SPS-8 experiment).

- Joint locations do not coincide from one survey to another.
- Number of joints changes from one survey to another.
- Number of joints from faulting survey is significantly different from the number obtained from the inventory record or distress survey maps.

If joint locations did not coincide from one survey to another, the differences were assumed to be the result of measurement errors or oversight. Joints and cracks that showed similar locations (within 0.5 m) between surveys were considered reliable data. Joint and crack locations that were not within 0.5 m were regarded as erroneous data.

Furthermore, the total number of joint data was compared with the following three sources: 1) number of joints surveyed at a specific survey date, 2) number of joints counted from PASCO distress maps, and 3) number of joints computed from joint spacing data in IMS database table INV_PCC_JOINT. For a large number of section surveys, the number of joints from faulting surveys did not match the number based on inventory joint spacing data, and for some sections the number of joints from PASCO distress maps is different from the number from the faulting survey. It is likely that data in INV_PCC_JOINT are incorrect for those test sections where there is no difference between the number of joints from the distress map and the number of joints from the faulting survey. Table 6 contains a list of sections and survey dates for which the number of joints from faulting surveys did not coincide with the number from an inventory record or with the number from the distress maps. A total of 124 faulting survey dates had numbers of joints that did not match the inventory-based number, and 35 faulting survey dates had numbers of joints that did not match the number of joints from PASCO distress maps. Sections with mismatched numbers of joints were reported to FHWA in LTPP Feedback Reports.

Table 6. Mismatched joints in faulting surveys, inventory records, and distress maps.

State Code	SHRP ID	Experiment Type	Survey Date	Random Joint Spacing	Number of Joints From Inventory	Number of Joints From Distress Map	Number of Joints From Faulting Survey	Difference B/w Inventory and Faulting Number of Joints	Difference Between Distress Faulting and No. of Joints
5	3059	GPS-4	09-Sep-91		11	33	30	-19	3
5	3059	GPS-4	11-Sep-91		11	33	33	-22	0
5	3059	GPS-4	06-Dec-94		11	33	33	-22	0
5	3059	GPS-4	07-Aug-97		11	33	33	-22	0
5	3073	GPS-4	10-Sep-91		11	33	33	-22	0
5	3073	GPS-4	28-Nov-94		11	33	33	-22	0
5	3073	GPS-4	09-Jun-97		11	33	33	-22	0
5	3074	GPS-4	11-Sep-91		11	33	33	-22	0
5	3074	GPS-4	02-Dec-94		11	33	33	-22	0
5	3074	GPS-4	11-Jun-97		11	33	33	-22	0
5	4019	GPS-4	11-Sep-91		11	33	34	-23	-1
5	4019	GPS-4	05-Dec-94		11	33	33	-22	0
5	4019	GPS-4	05-Aug-97		11	33	33	-22	0
5	4021	GPS-4	15-May-91		11	33	33	-22	0
5	4021	GPS-4	10-Sep-91		11	33	33	-22	0
5	4021	GPS-4	29-Nov-94		11	33	33	-22	0
5	4023	GPS-4	10-Sep-91		11	33	32	-21	1
5	4023	GPS-4	30-Nov-94		11	33	34	-23	-1

Table 6. Mismatched joints in faulting surveys, inventory records, and distress maps (continued).

State Code	SHRP ID	Experiment Type	Survey Date	Random Joint Spacing	Number of Joints From Inventory	Number of Joints From Distress Map	Number of Joints From Faulting Survey	Difference B/w Inventory and Faulting Number of Joints	Difference Between Distress Faulting and No. of Joints
95	4023	GPS-4	06-Aug-97		11	33	33	-22	0
5	4046	GPS-4	10-Sep-91		11	33	33	-22	0
5	4046	GPS-4	01-Dec-94		11	33	33	-22	0
5	4046	GPS-4	11-Jun-97		11	33	35	-24	-2
6	3005	GPS-3	10-Aug-92	12,13,19,18	32	35	35	-3	0
6	3024	GPS-3	20-Nov-91	13,12,15,14	37	32	32	5	0
6	3024	GPS-3	13-Feb-97	13,12,15,14	37	32	32	5	0
6	7493	GPS-3	20-Nov-91	13,19,18,12	32	38	38	-6	0
6	7493	GPS-3	30-Jan-97	13,19,18,12	32	38	37	-5	1
8	7776	GPS-3	10-Apr-92		36	38	38	-2	0
8	9020	GPS-9	09-Apr-92		25	37	38	-13	-1
10	4002	GPS-4	15-Jun-93		11	12	17	-6	-5
12	4138	GPS-3	05-Oct-91	20-22-18	25	29	22	3	7
12	4138	GPS-3	21-Apr-97	20-22-18	25	30	29	-4	1
17	0602	SPS-6	17-Dec-91		10	13	13	-3	0
17	0602	SPS-6	26-Jun-92		10	13	13	-3	0
17	0602	SPS-6	03-Aug-93		10	13	13	-3	0
17	0602	SPS-6	20-Jun-95		10	13	13	-3	0
17	0605	SPS-6	17-Dec-91		5	27	27	-22	0
17	0605	SPS-6	02-Jul-92		5	27	27	-22	0
17	0605	SPS-6	03-Aug-93		5	27	27	-22	0
17	0605	SPS-6	21-Jun-95		5	27	27	-22	0
17	0605	SPS-6	02-Jul-95		5	27	23	-18	4
18	0602	SPS-6	10-Sep-92		25	50	50	-25	0
18	0602	SPS-6	10-Aug-93		25	50	50	-25	0
18	0605	SPS-6	10-Sep-92		25	50	50	-25	0
18	0605	SPS-6	10-Aug-93		25	50	50	-25	0
19	0213	SPS-2	18-Oct-94		33	N/A	30	3	
19	0214	SPS-2	18-Oct-94		33	N/A	31	2	
19	0215	SPS-2	17-Oct-94		33	N/A	30	3	
19	0216	SPS-2	18-Oct-94		33	N/A	31	2	
19	0217	SPS-2	17-Oct-94		33	N/A	31	2	
20	0203	SPS-2	05-Apr-93		33	33	31	2	2
20	0204	SPS-2	06-Apr-93		33	33	31	2	2
20	0205	SPS-2	27-May-97		33	33	31	2	2
20	0206	SPS-2	07-Apr-93		33	33	27	6	6
20	4016	GPS-4	01-May-91		8	10	10	-2	0
20	4016	GPS-4	27-Apr-93		8	10	10	-2	0
20	9037	GPS-9	12-May-94	15'+-12"	33	34	36	-3	-2
21	3016	GPS-3	18-Apr-91	12-13-17-18	33	34	1	32	33
27	4040	GPS-4	28-Jul-93		19	19	23	-4	-4
31	3018	GPS-3	19-Apr-95	18 ft.	32	33	36	-4	-3
37	3044	GPS-3	05-Nov-91		17	20	20	-3	0
37	3044	GPS-3	27-Apr-93		17	20	20	-3	0
37	3044	GPS-3	17-Jul-95		17	20	21	-4	-1
39	4018	GPS-4	30-Apr-91		13	12	11	2	1
40	3018	GPS-3	03-Nov-94		33	33	27	6	6

Table 6. Mismatched joints in faulting surveys, inventory records, and distress maps (continued).

State Code	SHRP ID	Experiment Type	Survey Date	Random Joint Spacing	Number of Joints From Inventory	Number of Joints From Distress Map	Number of Joints From Faulting Survey	Difference B/w Inventory and Faulting Number of Joints	Difference Between Distress Faulting and No. of Joints
40	4160	GPS-3	18-Feb-91		33	32	10	23	22
42	1691	GPS-4	13-Oct-89		8	N/A	13	-5	
46	6600	GPS-3	24-Apr-95	16'-17'-21'-22'	27	27	30	-3	-3
48	3010	GPS-3	10-Jul-91		33	33	30	3	3
48	3010	GPS-3	02-Apr-92		33	33	30	3	3
48	3699	GPS-4	09-Jul-91		8	24	24	-16	0
48	3699	GPS-4	27-Apr-93		8	24	24	-16	0
48	3699	GPS-4	06-Jun-95		8	24	24	-16	0
48	4142	GPS-4	11-Jul-91		8	25	25	-17	0
48	4142	GPS-4	03-Apr-92		8	25	25	-17	0
48	4142	GPS-4	30-Apr-93		8	25	25	-17	0
48	4142	GPS-4	11-Jan-95		8	25	25	-17	0
48	4142	GPS-4	11-Apr-95		8	25	25	-17	0
48	4142	GPS-4	08-Jun-95		8	24	24	-16	0
48	4142	GPS-4	08-Jul-97		8	25	25	-17	0
48	4142	GPS-4	26-Sep-97		8	25	25	-17	0
48	4143	GPS-4	11-Jul-91		8	25	25	-17	0
48	4143	GPS-4	03-Apr-92		8	25	25	-17	0
48	4143	GPS-4	29-Apr-93		8	25	25	-17	0
48	4143	GPS-4	10-Jan-95		8	25	25	-17	0
48	4143	GPS-4	10-Apr-95		8	25	25	-17	0
48	4143	GPS-4	08-Jun-95		8	25	25	-17	0
48	4143	GPS-4	09-Jul-97		8	25	25	-17	0
48	4143	GPS-4	25-Sep-97		8	25	25	-17	0
48	4146	GPS-4	10-Jul-91		8	33	33	-25	0
48	4146	GPS-4	02-Apr-92		8	33	33	-25	0
48	4146	GPS-4	28-Apr-93		8	33	33	-25	0
48	4146	GPS-4	07-Jun-95		8	33	33	-25	0
53	3011	GPS-3	07-May-97		44	43	42	2	1
53	3813	GPS-3	18-Jul-95	13,19,18,12	32	34	34	-2	0
53	3813	GPS-3	20-Nov-95	13,19,18,12	32	34	34	-2	0
53	3813	GPS-3	21-Feb-96	13,19,18,12	32	34	34	-2	0
53	3813	GPS-3	25-Jun-96	13,19,18,12	32	34	34	-2	0
54	4003	GPS-4	13-Nov-91		8	12	12	-4	0
54	4003	GPS-4	04-Nov-93		8	12	12	-4	0
54	4003	GPS-4	26-Oct-95		8	12	12	-4	0
56	3027	GPS-3	06-Feb-92	14/16/13/12	36	32	32	4	0
56	3027	GPS-3	18-Aug-94	14/16/13/12	36	32	32	4	0
56	3027	GPS-3	25-Jul-97	14/16/13/12	36	32	31	5	1
72	4121	GPS-3	18-Jan-90		25	N/A	27	-2	
72	4121	GPS-3	28-Feb-91		25	N/A	27	-2	
72	4121	GPS-3	10-Feb-93		25	N/A	27	-2	
72	4121	GPS-3	10-Mar-94		25	N/A	27	-2	
83	3802	GPS-3	09-Jun-93	12-13-17-18	33	35	35	-2	0
83	3802	GPS-3	15-Feb-94	12-13-17-18	33	35	35	-2	0
83	3802	GPS-3	22-Aug-94	12-13-17-18	33	35	27	6	8
83	3802	GPS-3	29-Mar-95	12-13-17-18	33	35	27	6	8

Table 6. Mismatched joints in faulting surveys, inventory records, and distress maps (continued).

State Code	SHRP ID	Experiment Type	Survey Date	Random Joint Spacing	Number of Joints From Inventory	Number of Joints From Distress Map	Number of Joints From Faulting Survey	Difference B/w Inventory and Faulting Number of Joints	Difference Between Distress Faulting and No. of Joints
83	3802	GPS-3	15-Oct-96	12-13-17-18	33	35	35	-2	0
83	3802	GPS-3	15-Sep-97	12-13-17-18	33	35	35	-2	0
84	3803	GPS-3	22-Aug-91	13,17,16,12	34	35	1	33	34
89	3015	GPS-3	16-Jul-91		31	26	26	5	0
89	3015	GPS-3	16-Jul-93		31	26	26	5	0
89	3015	GPS-3	19-May-94		31	26	26	5	0
89	3015	GPS-3	11-Aug-94		31	26	26	5	0
89	3015	GPS-3	13-Jun-95		31	26	26	5	0
89	3015	GPS-3	19-Nov-96		31	26	25	6	1
89	3015	GPS-3	20-May-97		31	26	24	7	2
89	3015	GPS-3	23-Sep-97		31	26	25	6	1
89	9018	GPS-9	05-Oct-94		31	31	29	2	2

Comparison of Wheelpath and Edge Faulting Data

One concern about the faulting data quality from previous analysis was the large differences between wheelpath and edge faulting at each joint/crack location. To examine these two paired measurements, frequency distributions of the differences of wheelpath faulting and edge faulting values are provided in figure 7. As shown, for more than 90 percent of the cases, the difference is between -1 mm and 1 mm. Since this is the same as the precision of the faultmeter, these discrepancies are considered insignificant.

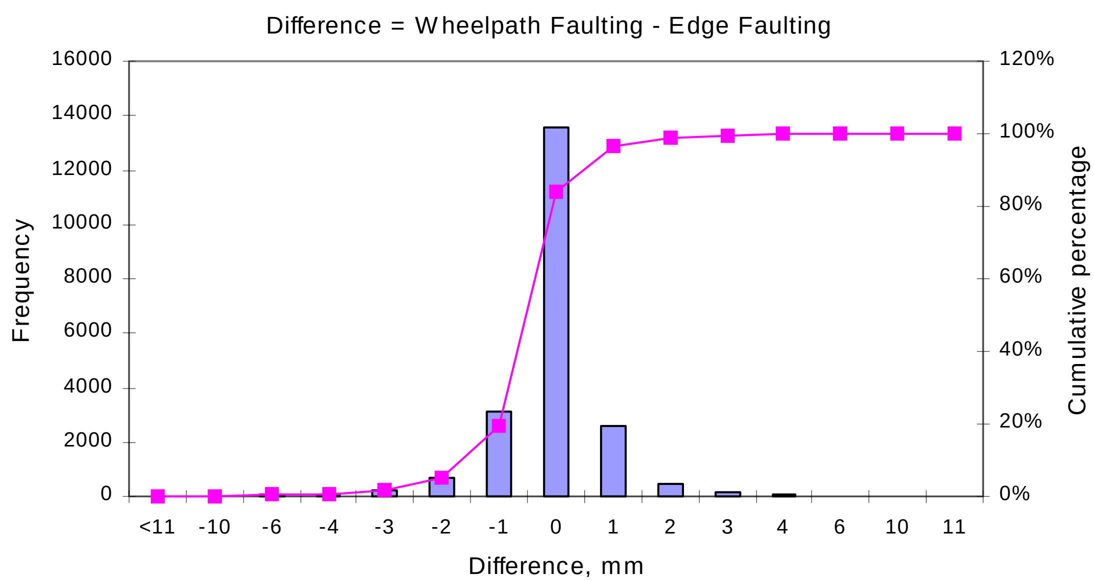


Figure 7. Frequency distribution of the difference between wheelpath and edge faulting data.

Complementary Data Quality Evaluation

As part of this study, a complementary database with joint and pavement design features, traffic, and environmental data that may be of use in analysis of joint/crack faulting was assembled and examined. The results of the evaluation of this data are presented in this section.
Selection of the related data was based on data used in existing faulting models and engineering judgment. The faulting complementary data were extracted from the inventory, material testing, environmental, and traffic modules of the April 1998 release of the IMS database. These data were subsequently divided into critical information and other information deemed useful but not critical. Assessments of missing and questionable data are based on the critical/noncritical classification.

Inventory Data

Inventory data include general information about each section, including section identification, pavement type, construction date, original design, shoulder type, drainage type, load transfer information, and joint spacing. The variables considered are shown below:

- Construction Number
- Status
- Assign Date
- Deassign Date
- Construction Date
- Traffic Open Date
- Year Widened
- Original Number of Lanes
- Final Number of Lanes
- Lane Added Number
- Pavement Type
- Pavement Type (Other)
- Number of Lanes
- Lane Width
- Subdrainage Location
- Subdrainage Type
- Subdrainage Type (Other)
- Longitudinal Drain Diameter
- Outlet Lateral Spacing
- Depth to Rigid Foundation
- Construction Number
- Layer Number
- Average Contraction Joint Spacing
- Random Joint Spacing
- Mean Expansion Joint Spacing
- Joint Skewness
- Joint Load Transfer Type
- Joint Load Transfer Type (Other)

- Dowel Bar Spacing
- Dowel Diameter
- Distance Between Edge and Dowel
- Dowel Coating
- Dowel Coating (Other)
- Load Transfer Device Placement Method
- Load Transfer Device Placement Method (Other)
- Transverse Joint Cut Method
- Transverse Joint Cut Method (Other)
- Longitudinal Joint Cut Method
- Longitudinal Joint Cut Method (Other)
- Shoulder Traffic Lane Joint Method
- Shoulder Traffic Lane Joint Method (Other)
- Percent Longitudinal Steel (JRCP)

Missing information from the inventory was differentiated by GPS or SPS sections, critical or other information, and the design parameters. A compilation of the sections with missing information and the corresponding IMS table and file extension are shown in tables 7 through 10. The feedback reports for each of the tables with missing information were submitted to FHWA.

Material Characterization

To characterize material type for pavement layers, field core testing information was used from the file TST_L05B.T32. For sections with missing testing information, the values from the inventory table INV_LAYER.I03 were used. There is adequate information on base/subbase type and thickness and on subgrade type. The list of material variables considered is shown below:

- Subgrade Type
- Subgrade Material Type
- Subbase Type
- Subbase Material Type
- Subbase Representative Thickness
- Base Type
- Base Material Type
- Base Representative Thickness
- Binder Course Type
- Binder Material Type
- Binder Course Representative Thickness
- Original Surface Type
- Original Surface Material Type
- Original Surface Representative Thickness
- Overlay Type
- Overlay Material Type
- Overlay Representative Thickness

Table 7. Missing GPS inventory information considered critical for faulting analysis.

Design Parameter	No. of Sections With Missing Data	Sections With Missing Data	Table	File Extension
LANE_WIDTH	1	27-3009	INV_GENERAL	I01
TRANS_CONT_JLTS	14	08-3032, 13-3011, 16-3023, 20-3060, 32-3010, 32-3013, 37-3807, 72-4121, 89-3001, 17-9327, 29-4036, 08-9019, 08-9020, 18-9020	INV_PCC_JOINT	I06
ROUND_DOWEL_DIAMETER	15	08-3032, 13-3011, 16-3023, 20-3013, 20-3060, 32-3010, 32-3013, 37-3807, 72-4121, 89-3001, 89-3002, 05-3074, 08-9019, 08-9020, 18-9020	INV_PCC_JOINT	I06
DOWEL_MLTD_SPACING	17	08-3032, 13-3011, 16-3023, 20-3013, 20-3060, 32-3010, 32-3013, 37-3807, 39-3801, 72-4121, 89-3001, 89-3002, 05-3074, 05-4021, 08-9019, 08-9020, 18-9020	INV_PCC_JOINT	I06

Table 8. Missing noncritical GPS inventory information useful for faulting analysis.

Design Parameter	No. of Sections With Missing Data	Sections With Missing Data	Table	File Extension
DOWEL_DISTANCE	33	08-3032, 13-3011, 16-3023, 18-3003, 20-3013, 20-3060, 21-3016, 26-3069, 32-3010, 32-3013, 37-3008, 37-3011, 37-3044, 37-3807, 37-3816, 72-4121, 89-3001, 89-3002, 05-3074, 05-4021, 21-4025, 26-4015, 27-4033, 27-4034, 27-4037, 27-4040, 27-4054, 27-4055, 08-9019, 08-9020, 18-9020, 26-9029, 26-9030	INV_PCC_JOINT	I06
DOWEL_COATING	26	08-3032, 13-3011, 16-3023, 18-3003, 20-3013, 20-3060, 21-3016, 26-3069, 32-3010, 32-3013, 39-3801, 45-3012, 72-4121, 89-3001, 05-3074, 05-4021, 17-5217, 17-9327, 21-4025, 26-4015, 39-4018, 08-9019, 08-9020, 18-9020, 26-9029, 26-9030	INV_PCC_JOINT	I06
MLTD_METHOD	28	08-3032, 13-3011, 16-3023, 18-3003, 20-3013, 20-3060, 21-3016, 26-3069, 32-3010, 32-3013, 35-3010, 55-6352, 55-6355, 72-4121, 89-3001, 89-3002, 05-3074, 05-4046, 17-5217, 21-4025, 26-4015, 27-4040, 27-4055, 08-9019, 08-9020, 18-9020, 26-9029, 26-9030	INV_PCC_JOINT	I06
TRANS_METHOD	13	12-4000, 12-4138, 32-3010, 40-4160, 40-4162, 72-3008, 89-3001, 89-3002, 17-9327, 22-4001, 18-9020, 27-9075, 89-9018	INV_PCC_JOINT	I06
LONG_TYPE	20	01-3028, 32-3010, 40-4160, 40-4162, 46-3053, 55-6352, 55-6353, 55-6354, 55-6355, 72-3008, 89-3001, 89-3002, 89-3015, 89-3016, 17-5217, 17-9327, 27-4054, 18-9020, 27-9075, 89-9018	INV_PCC_JOINT	I06
SH_TRAFFIC_LANE_TYPE	44	01-3028, 12-4000, 12-4059, 12-4109, 12-4138, 13-3011, 13-3018, 13-3019, 19-3006, 19-3028, 27-3003, 27-3013, 32-3010, 37-3008, 37-3011, 37-3044, 37-3816, 39-3013, 39-3801, 40-3018, 40-4162, 48-3003, 55-3015, 55-3016, 72-3008, 89-3001, 89-3002, 89-3015, 89-3016, 05-3074, 17-9327, 20-4016, 20-4052, 27-4034, 27-4037, 27-4040, 27-4054, 27-4055, 54-4003, 54-4004, 18-9020, 20-9037, 27-9075, 89-9018	INV_PCC_JOINT	I06

Table 9. Missing SPS inventory information considered critical for faulting analysis.

Design Parameter	No. of Sections With Missing Data	Sections With Missing Data	Table	File Extension
DATE_COMPLETE	12	38-0213, 38-0214, 38-0215, 38-0216, 38-0217, 38-0218, 38-0219, 38-0220, 17-0601, 17-0602, 17-0605, 46-0601	SPS_ID	X01
LANE_WIDTH	9	20-0201, 20-0202, 20-0203, 20-0204, 20-0205, 20-0206, 20-0207, 20-0208, 46-0601	SPS_GENERAL	X02
DRAINAGE_LOCATION	9	20-0201, 20-0202, 20-0203, 20-0204, 20-0205, 20-0206, 20-0207, 20-0208, 46-0601	SPS_GENERAL	X02
DRAINAGE_TYPE	9	20-0201, 20-0202, 20-0203, 20-0204, 20-0205, 20-0206, 20-0207, 20-0208, 46-0601	SPS_GENERAL	X02
AVG_CONTRACTION_SPACING	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
AVG_CONTRACTION_SPACING	1	46-0601	INV_PCC_JOINT	I06
RANDOM_SPACING	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
RANDOM_SPACING	1	46-0601	INV_PCC_JOINT	I06
JOINT_SKEWNESS	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
JOINT_SKEWNESS	1	46-0601	INV_PCC_JOINT	I06
TRANS_CONT_JLTS	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
TRANS_CONT_JLTS	1	46-0601	INV_PCC_JOINT	I06
ROUND_DOWEL_DIAMETER	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
ROUND_DOWEL_DIAMETER	1	46-0601	INV_PCC_JOINT	I06
ROUND_DOWEL_DIAMETER	2	39-0809, 39-0810	SPS8_PCC_JOINT_DATA	811
DOWEL_SPACING	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
DOWEL_SPACING	1	46-0601	INV_PCC_JOINT	I06

Table 10. Missing noncritical SPS inventory information useful for faulting analysis.

Design Parameter	No. of Sections With Missing Data	Sections With Missing Data	Table	File Extension
DATE_OPEN_TRAFFIC	4	17-0601, 17-0602, 17-0605, 46-0601	SPS_ID	X01
DOWEL_DISTANCE	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
DOWEL_DISTANCE	1	46-0601	INV_PCC_JOINT	I06
DOWEL_COATING	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
DOWEL_COATING	1	46-0601	INV_PCC_JOINT	I06
MLTD_METHOD	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
MLTD_METHOD	1	46-0601	INV_PCC_JOINT	I06
TRANS_METHOD	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
TRANS_METHOD	4	17-0601, 17-0602, 17-0605, 46-0601	INV_PCC_JOINT	I06
LONG_TYPE	6	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222	SPS2_PCC_JOINT_DATA	211
LONG_TYPE	4	17-0601, 17-0602, 17-0605, 46-0601	INV_PCC_JOINT	I06
SH_TRAFFIC_LANE_TYPE	13	04-0217, 08-0213, 08-0215, 08-0218, 08-0220, 08-0222, 38-0213, 38-0215, 38-0216, 38-0217, 38-0218, 38-0219, 38-0220	SPS2_PCC_JOINT_DATA	211
SH_TRAFFIC_LANE_TYPE	1	46-0601	INV_PCC_JOINT	I06
SH_SURFACE_TYPE	9	20-0201, 20-0202, 20-0203, 20-0204, 20-0205, 20-0206, 20-0207, 20-0208, 46-0601	SPS_GENERAL	X02

Traffic

Traffic loading is an important factor affecting joint faulting [3, 4]. Quality traffic data over the whole pavement life is very important for the study of the effect of cumulative traffic on faulting. To obtain traffic data, the following data tables from the traffic module of IMS database, April 1998 release, were used:

- TRF_MONITOR_BASIC_INFO.F00
- TRF_EST_ANL_TOT_LTPP_LN.F02

Analysis of monitoring traffic data (measured by automated equipment) from the table TRF_MONITOR_BASIC_INFO revealed that data were missing for a number of sections and that the available ESAL data were reported for very few recent years. Some of the sections with missing monitoring information had historical ESAL data (estimated by the State highway agencies [SHAs]) available in the table TRF_EST_ANL_TOT_LTPP_LN. A summary table of traffic data availability (in terms of ESALs) for sections with available faulting data is presented in table 11. A list of sites missing both historical and monitoring data is given in table 12.

Table 11. Traffic (80-kN ESALs) data availability summary for sections with available faulting data.

Description of Traffic Data Availability (80-kN ESALs)	**No. of Sections**	**Percent of Sections**
Both Historical and Monitoring Data Available	104	34
Only Monitoring Data Available	14	5
Only Historical Data Available	64	21
No Data Available	125	41
Total Number of Sections Considered	307	100

Table 12. Sections missing both historical and monitoring 80-kN ESAL traffic data.

State Code	SHRP ID	Experiment Type	State Code	SHRP ID	Experiment Type	State Code	SHRP ID	Experiment Type
1	4007	GPS-4	19	0218	SPS-2	38	0218	SPS-2
4	0213	SPS-2	19	0219	SPS-2	38	0219	SPS-2
4	0214	SPS-2	19	0220	SPS-2	38	0220	SPS-2
4	0215	SPS-2	19	B410	SPS-4	39	0809	SPS-8
4	0216	SPS-2	20	0202	SPS-2	39	0810	SPS-8
4	0217	SPS-2	20	0203	SPS-2	39	B410	SPS-4
4	0218	SPS-2	20	0204	SPS-2	40	3018	GPS-3
4	0219	SPS-2	20	0205	SPS-2	40	4157	GPS-3
4	0220	SPS-2	20	0206	SPS-2	42	1623	GPS-3
4	0221	SPS-2	20	0207	SPS-2	42	1691	GPS-4
4	0222	SPS-2	20	0208	SPS-2	42	A410	SPS-4
4	0223	SPS-2	26	0214	SPS-2	42	A430	SPS-4
4	0224	SPS-2	26	0215	SPS-2	42	C410	SPS-4
4	A410	SPS-4	26	0217	SPS-2	42	C430	SPS-4
4	A430	SPS-4	26	0218	SPS-2	48	9355	GPS-9
5	B410	SPS-4	26	0219	SPS-2	48	B410	SPS-4
5	B430	SPS-4	26	0220	SPS-2	48	B420	SPS-4
5	C410	SPS-4	26	0221	SPS-2	48	B430	SPS-4
5	C430	SPS-4	26	0222	SPS-2	48	C410	SPS-4
6	A410	SPS-4	26	0223	SPS-2	48	C420	SPS-4
6	A420	SPS-4	26	0224	SPS-2	48	C430	SPS-4
6	A430	SPS-4	32	A410	SPS-4	48	D410	SPS-4
6	B410	SPS-4	32	A420	SPS-4	48	D420	SPS-4
6	B420	SPS-4	32	A430	SPS-4	48	D430	SPS-4
6	B430	SPS-4	37	0201	SPS-2	48	E410	SPS-4
8	0213	SPS-2	37	0202	SPS-2	48	E420	SPS-4
8	0214	SPS-2	37	0203	SPS-2	48	E430	SPS-4
8	0215	SPS-2	37	0204	SPS-2	49	7083	GPS-3
8	0218	SPS-2	37	0205	SPS-2	49	7085	GPS-3
8	0220	SPS-2	37	0206	SPS-2	49	7086	GPS-3
8	0222	SPS-2	37	0207	SPS-2	49	C410	SPS-4
9	4008	GPS-4	37	0208	SPS-2	49	C430	SPS-4
10	1201	GPS-4	37	0209	SPS-2	49	D410	SPS-4
17	0602	SPS-6	37	0210	SPS-2	49	D430	SPS-4
17	0605	SPS-6	37	0211	SPS-2	49	E410	SPS-4
18	0605	SPS-6	37	0212	SPS-2	49	E430	SPS-4
18	A410	SPS-4	37	3008	GPS-3	53	3014	GPS-3
19	0213	SPS-2	38	0213	SPS-2	72	3008	GPS-3
19	0214	SPS-2	38	0214	SPS-2	72	4121	GPS-3
19	0215	SPS-2	38	0215	SPS-2	89	3001	GPS-3
19	0216	SPS-2	38	0216	SPS-2	89	3002	GPS-3
19	0217	SPS-2	38	0217	SPS-2			

Table 13. Sections with questionable traffic data (80-kN ESALs, truck factors).

No. of Observations	Sections With Questionable and Missing Data
42	124000, 124138, 133007, 163017, 183002, 283018, 283019, 313018, 313028, 353010, 453012, 533812, 537409, 284024, 295503, 364018, 394018, 484146, 289030, 429027, 489167, 260213

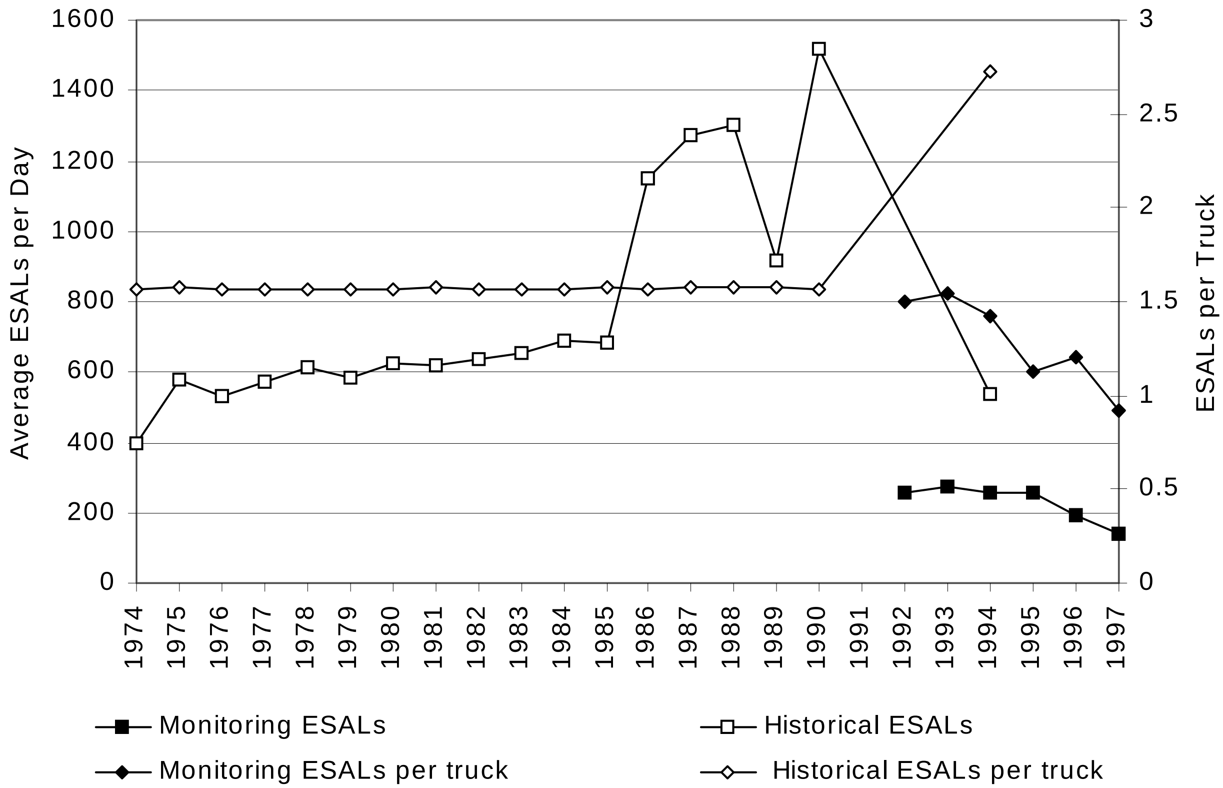


Figure 8. Example of questionable trend between historical and monitoring ESALs for section 124000.

Validity of the available traffic data was assessed through comparison of historical and monitoring ESAL data and by comparison of calculated truck factors for each section to an acceptable range (0.5 to 2.5). Analysis of the ESAL values for the sections that have both monitoring and historical ESALs showed that the quality and quantity of the available historical and monitoring traffic data vary considerably. Sections with questionable data were defined as those that showed unusually high or low values (ESALs or truck factors) or major discrepancies between the surveys. A list of sites with questionable data is given in table 13, and an example of a questionable trend between historical and monitoring ESAL data is presented in figure 8. The historical trend for this section indicates a substantial increase in truck loads, whereas the trend for monitoring data is declining. Particularly disturbing is the decline in ESALs per truck between 1992 and 1997. An opposite trend is expected, especially for recent years, because of increased competitiveness in the trucking/shipping industry and advances in wireless communications. Sites with missing and questionable traffic data were reported to FHWA in an LTPP Feedback Report.

Since knowledge of cumulative traffic loads is crucial for the performance analysis process, cumulative traffic loads for the entire pavement lifespan need to be estimated using the available fragmented historical and monitoring traffic data. Closer examination of the available monitoring data revealed that, in order to obtain cumulative traffic loads for the entire in-service life of pavement sections, monitoring data have to be projected to cover the years with missing monitoring information–starting from section opening to traffic date and up to the year of the last available faulting survey. The method for traffic projection used in this study is discussed in more detail in chapter 4.

Environmental Factors

Climate is another important factor that affects faulting measurement. Climatic parameters considered for this study include annual precipitation, annual freeze index, maximum temperature range for the day and for the year, and annual numbers of days above 32°C and below 0°C. Some of these parameters are not directly available in the current version of the IMS and had to be calculated based on the available monthly parameters. Variables used to calculate these parameters with the source of information for each variable are given in table 14.

Annual parameters were calculated based on available monthly variables. Several GPS sections and all SPS-6 and SPS-8 sections are missing links to weather stations. A list of these sections is given in table 15. Environmental data from a nearby GPS section may be considered for SPS sections missing links to weather stations. The possibility of these sections being linked to other GPS experiments is currently being investigated.

It should be noted that after the analysis presented here was completed, the climatic data available as part of the ENV module were removed from the LTPP IMS and replaced with a new set of climatic data stored in the CLIMATE module in the IMS. As such, some of the information presented in tables 14 and 15 may not be applicable.

Table 14. Data elements used for calculation of climatic parameters.

IMS	File Name	File Ext.	Table Name	Experiment Type	List of Parameters
Q1_1998	Env	E02	ENV_MONTHLY_DERIVED	All GPS	WEATHER STATION
					ANNUAL FREEZE INDEX
					ANNUAL FREEZE THAW CYCLES
					AVG DAILY TEMP RANGE OVER YEAR
					ANNUAL SNOWFALL
					ANNUAL PRECIP
Q4_1997	Env	E03	ENV_MONTHLY_PARAMETER	All GPS	AVG MAX MONTHLY TEMP
					AVG MIN MONTHLY TEMP
Q4_1997	Aws82	w06	AWS_PRECIPITATION_MONTH	All SPS	AWS_ID
					TOTAL_MON_PRECIP
					WET DAYS
Q4_1997	Aws82	w08	AWS_TEMP_MONTH	All SPS	MAX_MON_TEMP_AVG
					MIN_MON_TEMP_AVG
					MAX_MON_TEMP
					MIN_MON_TEMP
					DAYS ABOVE 32°C
					DAYS BELOW 0°C
					FREEZE-THAW CYCLES
					FREEZE INDEX

Table 15. Sections missing links to weather stations.

Experiment Type	Section ID
GPS-3	047614
GPS-3	273005
GPS-3	273007
GPS-3	273009
GPS-3	273010
GPS-3	273012
GPS-3	327084
GPS-3	466600
GPS-3	497085
GPS-3	497086
GPS-3	553008
GPS-4	264015
GPS-4	295503
GPS-9	395569
GPS-9	399022
GPS-6	170601
GPS-6	170602
GPS-6	170605
GPS-6	180602
GPS-6	180605
GPS-6	460601
GPS-8	390809
GPS-8	390810

Summary and Recommendations for Resolving Data Quality Issues

Data for a total of 422 jointed concrete pavement sections were available in the IMS database at the time of the study. Out of 422 sections, only 307 sections had records in the faulting data table MON_JPCC_FAULT, for a total of 24,108 records. This magnitude of missing data is considered very serious because faulting is one of the key distress types associated with JCP. Future efforts should focus on ensuring that faulting data are collected as required.

The available faulting data were evaluated in terms of missing and questionable data. The records in the faulting table exhibit numerous missing observations. Missing faulting data were difficult to quantify for many sections because of a lack of one-to-one mapping of the crack and joint locations. Measurement errors in stationing are the most probable cause of this problem. However, crack development between surveys and full-depth repairs are other plausible reasons. A 0.5-m allowable deviation in the location of a crack or joint was used between surveys for purposes of establishing missing data.

The assessment of questionable faulting data revealed a number of sections with negative faulting values. The number and location of negative faulting values within each section were determined. A comparison of faulting values at the same location (in the case of multiple surveys) and between the wheelpath and edge was made to determine if the negative values were a random occurrence (survey error) or were actually negative values.

The possible reasons for negative faulting were investigated using SPS-2 sites. It was found that 40 percent of SPS-2 sections had at least one joint that exhibited a negative faulting value on the first faulting survey after construction. Most of the negative faulting values were equal to -1 mm. The -1 mm values could be attributed to random positive and negative measurement variation taken on joints with zero faulting, as would be expected for new construction (built-in surface texture and the precision of the Georgia Faultmeter being ±1 mm).

The responses to the submitted LTPP Feedback Reports indicated that excessive negative faulting values were sometimes attributable to having taken faulting measurements over the patched or sealed joints. These measurements did not represent the "true" faulting at the joint and, therefore, were not used in computation of faulting indices and summary statistics. In some other cases, negative faulting values were recorded because the faultmeter was turned in the wrong direction during data collection. The decision was made not to use excessive negative faulting data (-2 mm or less) in the development of representative faulting indices and statistics until the reasons for excessive negative faulting could be explained.

The companion data were evaluated in terms of critical and noncritical parameters. Critical parameters were those previously used in the development of faulting models and other potentially important factors identified by the project team. The noncritical factors have a lesser effect on faulting. The missing critical companion data and noncritical data were reported to FHWA in LTPP Feedback Reports.

An assessment of availability and quality of the traffic data revealed that 41 percent of sections with faulting data were missing traffic data. Sections with missing traffic data and sections with questionable data quality were reported in an LTPP Feedback Report. Validity of the available traffic data was assessed through comparison of historical and monitoring ESAL data and by comparison of calculated truck factors for each section to an acceptable range (0.5 to 2.5). It is recommended that, in order to improve traffic data quality, SHAs and regional offices need to resolve data conflicts between historical and monitoring data and conflicts in traffic data trends observed in time-series analysis. Because of the pressing need for cumulative traffic values, a systematic procedure is needed for establishing traffic growth rates using available limited traffic data.

The overall quality of the faulting data reported in the IMS database was found to be acceptable for the development of faulting indices and summary statistics in terms of data availability. Assessment of the available data indicated that up to 95 percent of faulting surveys could be used for the development of representative indices and summary statistics. Only 1 percent of surveys were dismissed because of a large number of points with excessive negative faulting (more than 25 percent of measurements per survey with less than -2 mm), and 4 percent of surveys were dismissed because of a large number of points with missing faulting observations (more than 25 percent of measurements per survey).

The faulting data quality issue addressed in this study was limited by the precision of the Georgia Faultmeter that is standard equipment for LTPP program faulting measurements. A review of numerous faulting records indicated that the equipment's accuracy of ±1 mm is inadequate due to the fact that representative maximum faulting values, obtained as an average of all maximum faulting values for all sections and surveys, were about 5 mm for undoweled sections and 3 mm for doweled sections.

It is recommended that the Georgia Faultmeter be modified to read to 0.1 mm. Use of a more precise device would significantly improve the quality of future faulting data collection and benefit future pavement performance analysis, especially for the SPS-2 and Seasonal Monitoring Program (SMP) sections that are still in the early stages of pavement service life.

Available faulting data were also evaluated in terms of usefulness for faulting trend analysis. It was found that less than 45 percent of sections had faulting data available from three or more surveys. Therefore, the trend analysis reported in this report is to be viewed as "limited" or "preliminary." It is recommended that more extensive trend analysis be conducted as more data become available. The lack of faulting measurements over time must be corrected in the future if the LTPP program is to produce significant findings on ways to reduce faulting.

Questionable faulting and companion data, reported to FHWA, are summarized in table 16. This table contains a summary of the data quality issues, actions recommended, and response status of each Feedback Report. As shown in this table, a total of 20 Feedback Reports were submitted to FHWA as part of this study. As of January 20, 2000, partial or complete responses were received from LTPP regional offices for 11 of the 20 Feedback Reports. These responses were very helpful for resolving faulting data quality issues.

Table 16. Summary of feedback reports.

Feedback No.	Issues	Recommended Action	Date Responded	Resolved
ERES_BW_31	Missing data from the SPS2_PCC_JOINT_DATA table, extension 211.	WRCO to collect the design or as-built missing data.	WRCO - 11/01/98	Y
ERES_BW_32	Missing data from the SPS8_PCC_JOINT_DATA table, extension 811.	NCRCO to collect the design or as-built missing data.		N
ERES_BW_33	Missing data from the SPS_GENERAL table, extension X02.	NCRCO to collect the design or as-built missing data.		N
ERES_BW_34	Missing data from the SPS_ID table, X01.	NCRCO to collect the design or as-built missing data.		N
ERES_BW_35	Missing data from the INV_PCC_JOINT table, extension I06.	RCOCs to collect the design or as-built missing data.	SRCO - 1/28/00	Y for SRCO only
ERES_BW_36	Missing data from the INV_GENERAL table, extension I01.	NCRCO to collect the design or as-built missing data.		N
ERES_BW_37	Missing data from the INV_PCC_STEEL table, extension I07.	RCOCs to collect the design or as-built missing data.	SRCO - 1/27/00	Y
ERES_BW_38	For SPS-6 experiment sections information is needed regarding the location of full depth patching or undersealing to account for rehabilitation effects on joint faulting values. Available IMS tables SPS6_PCC_FULL_DEPTH and SPS6_UNDERSEALING do not contain such information.	RCOCs to collect the design or as-built missing data.	SRCO - 1/27/00	Y
ERES_BW_39	Section 55-3009 has surface layer milled (0.38 inch) in 1995. Due to the change in surface condition, joint faulting data collected for this section after 1995 will not be useful for joint faulting study of the original surface. This section need no longer be monitored as it will become a case study.	For information only.	N/A	N/A
ERES_BW_40	137 sections have mismatched joint locations (mismatched greater than 0.5 m)from one survey to another in faulting table MON_DIS_JPCC_FAULT with file extension M09.	RCOCs to use a template for each section to record the joint faulting data.	N/A	N

WRCO = Western Region Coordination Office
NCRCO = North Central Region Coordination Office
RCOC = Regional Coordination Office Coordinator

NARCO = North Atlantic Region Coordination Office
SRCO = Southern Region Coordination Office

Table 16. Summary of feedback reports (continued).

Feedback No.	Issues	Recommended Action	Date Responded	Resolved
ERES_BW_41	Sections 05-3074, 12-4138, 27-4040, 32-3010, 34-4042, 40-4160, 46-0601, 46-6600, 48-4143, 49-3011, 53-3813, and 83-3802 have average faulting values decreasing or fluctuating with time.	RCOCs to review the data.	WRCO - 11/30/98 NCRCO - 12/03/98 NARCO - 04/06/99 SRCO - 01/27/00	Y
ERES_BW_42	Negative faulting values were recorded for 160 of the 264 sections evaluated. Several special cases involving high values of negative faulting are discussed in the Feedback Reports.	RCOCs to review the data.	NCRCO - 12/08/98 SRCO - 12/11/98 WRCO - 11/02/98 NARCO - 10/06/99	Y
ERES_BW_43	On some survey dates, sections 06-7456, 34-4042, 36-4018, 49-7085, 53-3019, 53-3813, and 83-3802 exhibited negative faulting profiles that are mirror images of the positive faulting profile measured on a different date.	RCOCs to review the data.	WRCO - 11/30/98, NARCO - 11/17/98, NCRCO - 12/03/98	Y
ERES_BW_44	Sections 06-3010, 18-0602, 18-0606, 55-3010, and 89-3016 consistently show high negative faulting values from visit to visit at the same locations. Also, section 18-0602 exhibits faulting of almost 20 mm at one edge joint location. This appears to be too high a value.	RCOCs to review the data.	WRCO - 11/30/98, NCRCO - 12/03/98 NARCO - 11/03/99	Y
ERES_BW_45	Seven survey dates were excluded from the faulting analysis table due to large amount of high value negative faulting data, and 52 survey dates were excluded due to large amount of missing data.	RCOCs to perform faulting surveys at all available joint (crack) locations and to verify negative faulting values of -2 mm or larger. Provide a comment identifying a possible reason for negative faulting (e.g., spalling at the joint/crack, patching at joint/crack, etc.).		N
ERES_BW_46	Total of 124 faulting survey dates had number of joint mismatched with inventory-based number and 35 faulting surveys had number of joints mismatched with the number of joints from PASCO distress maps.	RCOCs to review the data and make corrections, as necessary.	WRCO - 10/21/98, NARCO - 11/05/98, NCRCO - 12/03/98, SRCO - 12/02/98	Y

WRCO = Western Region Coordination Office
NCRCO = North Central Region Coordination Office
RCOC = Regional Coordination Office Coordinator
NARCO = North Atlantic Region Coordination Office
SRCO = Southern Region Coordination Office

Table 16. Summary of feedback reports (continued).

Feedback No.	Issues	Recommended Action	Date Responded	Resolved
ERES_BW_47	For several JRCP sections from GPS-4 experiment, both faulting survey data and PASCO distress maps gave an unusually large number of joints (resulting average joint spacing was found around 4.5-6 m [15-20 ft]) . All of these sections are located in two Southern Region states: Arkansas and Texas.	SRCO to review the data and provide appropriate feedback to the Data Analysis Technical Support (DATS) team. Also, make corrections, as necessary	SRCO - 11/19/98	Y
ERES_BW_48	Sections 84-3803, 21-3016, and 40-4160 had faulting measured at fewer locations than the number of joints indicated as available in inventory data and on PASCO distress maps.	RCOCs to review and update the data. If no update is available, we recommend the removal of the above records or to maintain them at non-level E QC.	SRCO - 11/30/98	Y for SRCO data only
ERES_BW_58	Outlier faulting data for each section survey have been identified using the following criteria: any point from a faulting survey was considered as an outlier if its value was outside the region bounded by the values of the section average faulting for the survey date +/- two standard deviations.	RCOCs to review faulting data at the locations provided in the attached tables to make sure that the data are valid.		N
ERES_BW_61	Sections used in faulting data analysis that miss historical and monitoring ESAL data and sections with questionable trends in ESAL values and truck factor values outside the acceptable range (0.5 to 2.5).	RCOCs to review the available traffic data and provide reasons (or resolve situation) for missing or questionable ESAL data.		N

WRCO = Western Region Coordination Office
NCRCO = North Central Region Coordination Office
RCOC = Regional Coordination Office Coordinator

NARCO = North Atlantic Region Coordination Office
SRCO = Southern Region Coordination Office

3. REPRESENTATIVE FAULTING INDICES AND STATISTICS

Representative faulting indices and statistics for transverse joint and crack faulting will serve the needs of pavement engineers interested in evaluating time-series trends of the faulting data and in developing prediction models for joint faulting. A new database table, entitled MON_DIS_JPCC_FAULT_SECT, has been developed to make this information available in the LTPP database.

Development of a New IMS Table, MON_DIS_JPCC_FAULT_SECT

MON_DIS_JPCC_FAULT includes representative faulting indices and statistics that summarize faulting data for each survey at each monitored section. Faulting statistics that may be useful for future analysis of faulting data are also included in this table. Following is a list of the faulting computed parameters for each test section for each survey date (site visit):

- Location type (joint or crack).
- Total number of points available for wheelpath or edge faulting measurements.
- Average edge faulting in mm.
- Minimum edge faulting in mm.
- Maximum edge faulting in mm.
- Standard deviation for edge faulting in mm.
- Number of edge faulting observations per survey with values greater than -2 mm.
- Number of missing edge faulting observations per survey.
- Number of negative edge faulting observations per survey with values less than -1 mm.
- A code describing reasons for absence of computed edge faulting indices.
- Average wheelpath faulting in mm.
- Minimum wheelpath faulting in mm.
- Maximum wheelpath faulting in mm.
- Standard deviation for wheelpath faulting in mm.
- Number of wheelpath faulting observations per survey with values greater than -2 mm.
- Number of missing wheelpath faulting observations per survey.
- Number of negative wheelpath faulting observations per survey with values less than -1 mm.
- A code describing reasons for absence of computed wheelpath faulting indices.

The schema for the new table, as well as quality control (QC) and filter specifications, are presented in appendix A.

Criteria for Valid Faulting Observations

To develop meaningful faulting statistics, raw faulting data obtained from IMS table MON_DIS_JPCC_FAULT were first examined and filtered using the criteria discussed below. MON_DIS_JPCC_FAULT contains point-by-point joint and crack faulting data collected along the outer pavement edge and wheelpath. The number of crack and joint locations within each section typically exceeds 30 observations for JPCP sections and 15 for JRCP sections. Ideally, the number of joints and joint locations surveyed for faulting should remain identical between surveys. This is not the case in reality, since some surveys contain either missing faulting measurements or invalid values at certain joint locations. A threshold of 25 percent missing observations within a section was deemed acceptable. The following additional criteria were used to identify sections with valid faulting observations: a section was considered to be acceptable for the faulting statistics calculation if the faulting data contained no more than 25 percent of missing data, negative data with values -2 mm or less, or a combination of missing and negative data with values -2 mm or less. Based on these criteria, the four possible faulting data statuses, presented in table 17, were identified and used as a guideline for the faulting statistics calculation.

Table 17. Faulting data status.

Faulting Status	Description
1	Faulting statistics are acceptable since more than 75 percent of points have reasonable faulting values.
2	Faulting statistics were not calculated because of a large number of points with missing faulting observations (25 percent or more).
3	Faulting statistics were not calculated because of a large number of points with negative faulting values in excess of 1 mm (25 percent or more).
4	Faulting statistics were not calculated because of a large number of points with either missing or negative faulting values in excess of 1 mm (25 percent or more combined).

Using the above criteria, 66 edge and 171 wheelpath survey dates were excluded from faulting statistics calculation because of missing data, and 9 edge and 10 wheelpath survey dates were excluded from the study because of negative data. Edge faulting records for sections 174074, 174082, and 294069 do not have enough valid information for any of the available survey dates. Wheelpath faulting records for section 040602 do not have enough valid information for any of the available survey dates. No surveys were excluded because of a combination of missing and negative data. Joint and crack faulting statistics were evaluated for 1427 edge and 1322 wheelpath survey dates. For the total of 1,503 survey dates, 95 percent of edge faulting surveys and 88 percent of wheelpath surveys contained faulting records valid for faulting statistics calculation based on the established 25 percent data availability threshold. A summary of the status of faulting data is given in table 18.

Table 18. Summary of the status of faulting data.

STATUS	No. of Surveys With EDGE_STATUS			No. of Surveys With WHEELPATH_STATUS			Total Edge Surveys, %	Total Wheelpath Surveys, %
	Crack	Joint	Total	Crack	Joint	Total		
1	297	1130	1427	276	1046	1322	95	88
2	19	47	66	39	132	171	4	11
3	3	6	9	4	6	10	1	1
4	0	1	1	0	0	0	0	0
TOTAL	319	1184	1503	319	1184	1503	100	100

Computation Algorithms

To compute representative faulting indices and statistics for the proposed new IMS table MON_DIS_JPCC_FAULT_SECT, a computational algorithm (presented as a flowchart in figure 9) was developed. Step-by-step procedures for the routine calculation of faulting statistics are given below.

Step 1. Obtain Faulting Data From IMS Database

Raw faulting data should be obtained from table MON_DIS_JPCC_FAULT in the IMS database. This table needs to be imported into Access® or another database management package for further processing.

Step 2. Pre-Process Faulting Data

Step 2.1 – Create a template for the new table MON_DIS_JPCC_FAULT_SECT according to the schema provided in appendix A.

Step 2.2 – Use table MON_DIS_JPCC_FAULT to obtain counts of faulting records with values above -2 mm, NULL faulting records, and records with negative faulting values less than or equal to -2 mm. To accomplish these activities, use SQL statements to group the data in the table MON_DIS_JPCC_FAULT by STATE_CODE, SHRP_ID, SURVEY_DATE, and CRACK_OR_JOINT and obtain the following counts for the grouped data:

2.2.a Number of POINT_LOC to get total number of points for the column NO_TOTAL_POINT_LOC of the new table MON_DIS_JPCC_FAULT_SECT.

2.2.b Number of empty fields per column for columns EDGE_AVG_MM and WHEELPATH_AVG_MM to get number of NULL faulting observations for the fields NO_NULL_EDGE_FAULT and NO_NULL_WHEELPATH_FAULT of the new table MON_DIS_JPCC_FAULT_SECT.

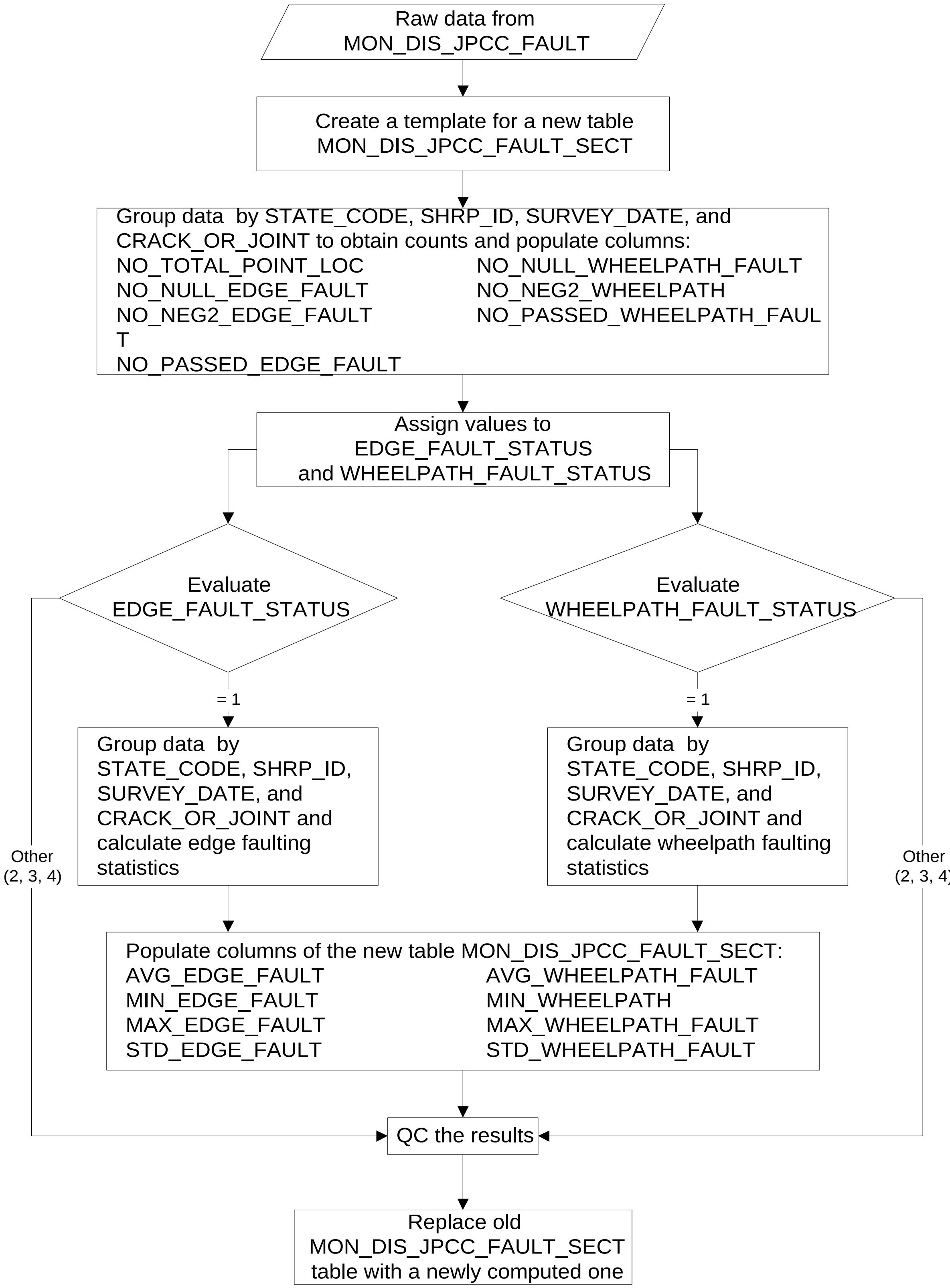


Figure 9. Flowchart for computation of faulting statistics.

2.2.c. Number of fields with negative values equal to or less than -2 mm per column for columns EDGE_AVG_MM and WHEELPATH_AVG_MM to get number of observations with negative faulting values for the fields NO_NEG2_EDGE_FAULT and NO_NEG2_WHEELPATH_FAULT of the new table MON_DIS_JPCC_FAULT_SECT.

2.2.d. Number of non-empty fields with values above -2 mm per column for columns EDGE_AVG_MM and WHEELPATH_AVG_MM to get number of valid faulting observations for the fields NO_PASSED_EDGE_FAULT and NO_PASSED_WHEELPATH_FAULT of the new table MON_DIS_JPCC_FAULT_SECT.

Step 2.3 – In the new table MON_DIS_JPCC_FAULT_SECT, populate columns containing key fields and columns of the following parameters calculated in step 2.2: NO_TOTAL_POINT_LOC, NO_PASSED_EDGE_FAULT, NO_PASSED_WHEELPATH_FAULT, NO_NULL_EDGE_FAULT, NO_NULL_WHEELPATH_FAULT, NO_NEG2_EDGE_FAULT, and NO_NEG2_WHEELPATH_FAULT. Sort records in the new table by STATE_CODE, SHRP_ID, SURVEY_DATE, and CRACK_OR_JOINT designation.

Step 2.4 – To populate columns EDGE_FAULT_STATUS and WHEELPATH_FAULT_STATUS of the new table MON_DIS_JPCC_FAULT_SECT, run a search routine through the columns NO_TOTAL_POINT_LOC, NO_NULL_EDGE_FAULT, NO_NULL_WHEELPATH_FAULT, NO_NEG2_EDGE_FAULT, and NO_NEG2_WHEELPATH_FAULT and assign the values in the EDGE_FAULT_STATUS and WHEELPATH_FAULT_STATUS columns according to the following logic:

If 100*(NO_PASSED_EDGE_FAULT over NO_TOTAL_POINT_LOC)> 75 percent then EDGE_FAULT_STATUS = 1

If 100*(NO_NULL_EDGE_FAULT over NO_TOTAL_POINT_LOC) > = 25 percent then EDGE_FAULT_STATUS = 2

If 100*(NO_NEG2_EDGE_FAULT over NO_TOTAL_POINT_LOC) > = 25 percent then EDGE_FAULT_STATUS = 3

If 100*((NO_NULL_EDGE_FAULT + NO_NEG2_EDGE_FAULT) over NO_TOTAL_POINT_LOC) > = 25 percent then EDGE_FAULT_STATUS = 4

If 100*(NO_PASSED_WHEELPATH_FAULT over NO_TOTAL_POINT_LOC) > 75 percent then WHEELPATH_FAULT_STATUS = 1

If 100*(NO_NULL_WHEELPATH_FAULT over NO_TOTAL_POINT_LOC) > = 25 percent then WHEELPATH_FAULT_STATUS = 2

If 100*(NO_NEG2_WHEELPATH_FAULT over NO_TOTAL_POINT_LOC) > = 25 percent then WHEELPATH_FAULT_STATUS = 3

If 100*((NO_NULL_WHEELPATH_FAULT + NO_NEG2_EDGE_FAULT) over NO_TOTAL_POINT_LOC) > = 25 percent then WHEELPATH_FAULT_STATUS = 4

Step 3. Conduct Faulting Statistics Calculation

Step 3.1 – Use tables MON_DIS_JPCC_FAULT and MON_DIS_JPCC_FAULT_SECT to query the records from the table MON_DIS_JPCC_FAULT that have corresponding records with EDGE_FAULT_STATUS = 1, WHEELPATH_FAULT_STATUS = 1, or both in the table MON_DIS_JPCC_FAULT_SECT. Save query results for edge and wheelpath faulting in two separate intermediate tables EDGE_STATISTICS and WHEELPATH_STATISTICS.

Step 3.2 – In the intermediate tables EDGE_STATISTICS and WHEELPATH_STATISTICS, group records by STATE_CODE, SHRP_ID, SURVEY_DATE, and CRACK_OR_JOINT designation to calculate joint or crack faulting statistics for each group following the steps below:

Use column WHEELPATH_AVG_MM of the table WHEELPATH_STATISTICS to evaluate:

3.2.a. Average wheelpath faulting to populate a column AVG_WHEELPATH_FAULT.

3.2.b. Minimum wheelpath faulting to populate a column MIN_WHEELPATH_FAULT.

3.2.c. Maximum wheelpath faulting to populate a column MAX_WHEELPATH_FAULT.

3.2.d. Standard deviation of wheelpath faulting to populate a column STD_WHEELPATH_FAULT.

Use column EDGE_AVG_MM of the table EDGE_STATISTICS to evaluate:

3.2.e. Average edge faulting to populate a column AVG_EDGE_FAULT.

3.2.f. Minimum edge faulting to populate a column MIN_EDGE_FAULT.

3.2.g. Maximum edge faulting to populate a column MAX_EDGE_FAULT.

3.2.h. Standard deviation of edge faulting to populate a column STD_EDGE_FAULT.

Mean values are calculated based on the entire population using the following formula:

$$Average = \frac{\sum_{1}^{N} x}{N}$$

Standard deviations are calculated based on the entire population using the following formula:

$$StDevP = \frac{\sqrt{\sum (x - \bar{x})^2}}{N}$$

All the computed quantities should be rounded to a single decimal place.

Step 3.3 – Populate columns AVG_WHEELPATH_FAULT, MIN_WHEELPATH_FAULT, MAX_WHEELPATH_FAULT, STD_WHEELPATH_FAULT, AVG_EDGE_FAULT, MIN_EDGE_FAULT, MAX_EDGE_FAULT, STD_EDGE_FAULT of the table MON_DIS_JPCC_FAULT_SECT.

Step 4. Upload Data Into IMS

Perform all QC checks (levels A to E) and upload the newly created table MON_DIS_JPCC_FAULT_SECT into IMS.

Outlier Faulting Data

The computed faulting statistics were used to determine the outlier faulting observations. Outlier data testing was performed based on ASTM E-178 guidelines [5]. Any point from a faulting survey was considered an outlier if its value was outside the region bounded by the values of the section average faulting for the survey date ± two standard deviations. Since the precision of the Georgia Faultmeter equals ±1 mm, this should be considered the second source of error for the faulting measurements. The two error sources should be pooled together to provide the overall estimate of the error bounds.

The distribution of the faulting measurements at different locations within a section can be approximated as a normal distribution. The variance of this distribution is then:

$$(\text{Computed Standard Deviation})^2$$

The maximum rounding error caused by the ±1 mm precision of the Georgia Faultmeter is ±0.5 mm. The distribution of the faulting measurement error can be thought of as a completely random occurrence. In other words, the error distribution is a uniform distribution from -0.5 mm to +0.5 mm of the device reading. The variance of the measurement errors with a uniformly distribution is:

$$1/12 * [+0.5-(-0.5)]^2 = 1/12$$

Therefore, the limits of the outliers should be computed as follows:

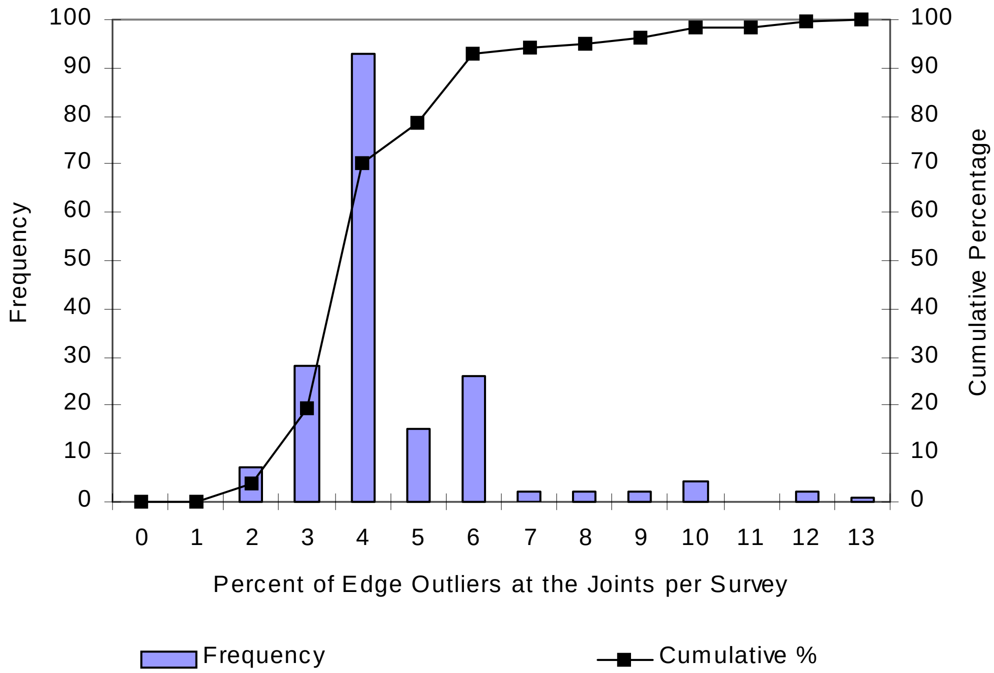
$$Outlier\_Limit = Section\_Average \pm 2 * \sqrt{(Standard\_Deviation)^2 + 1/12}$$

where: *Outlier_Limit* = Limit for evaluating outlier observations of each faulting survey.
Section_Average = Section average faulting for the survey.
Standard_Deviation = Standard deviation of the faulting observations for a specific survey.

Both crack and joint faulting data were investigated along the pavement outer edge and wheelpath. Only section surveys with FAULTING_STATUS equal to 1 (indicates more than 75 percent of valid faulting observations) were used in this study. For these sections, only points with faulting values -1 mm or larger were considered. The results of the outlier study are summarized in table 19. As shown in this table, the average percentage of outlying observations per survey with outliers is about 4 percent for edge and wheelpath observations. Frequency distribution plots in figure 10 show that the sections with the most frequent outliers have about 4 percent of outlying observations. Representative examples of sections with outliers are given in figure 11. Most of the cases with outlying observations can be attributed to random variability inherent in the data.

Table 19. Outlier statistics summary.

	Edge Observations			**Wheelpath Observations**		
	Crack	**Joint**	**Total**	**Crack**	**Joint**	**Total**
Number of Surveys With Outliers	38	182	220	36	132	168
Total Number of Valid Surveys	299	1137	1436	278	1052	1330
Percent of Surveys With Outliers	22	34	31	20	28	26
Number of Outlier Points in Surveys With Outliers	45	194	239	49	145	194
Total Number of Points in Surveys With Outliers	889	5339	6345	963	3858	4821
Percent of Outlier Points in Surveys With Outliers	5	4	4	5	4	4



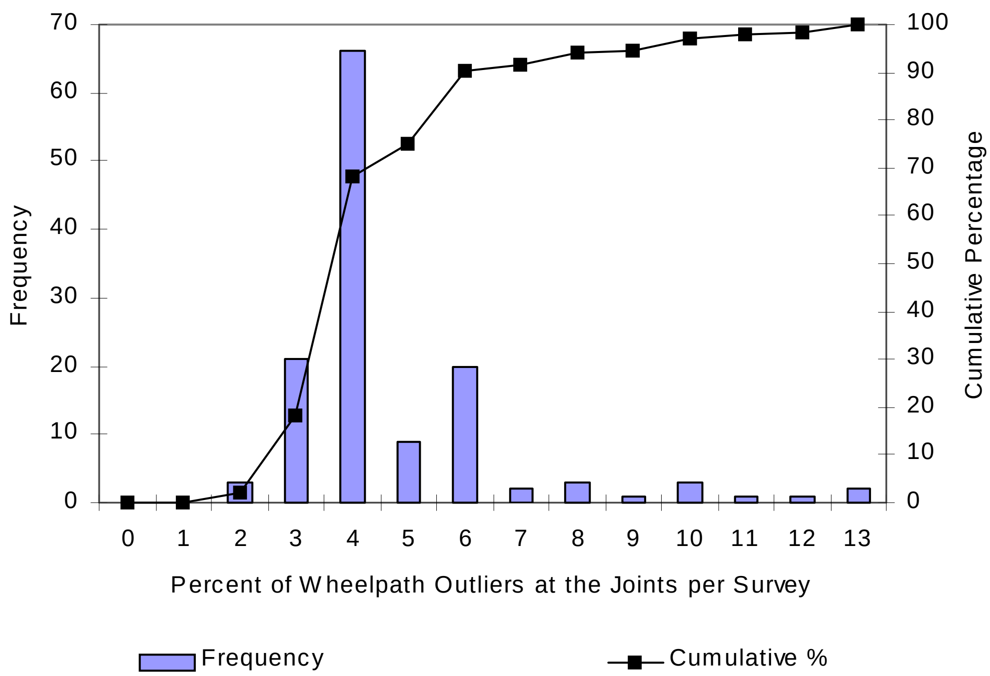
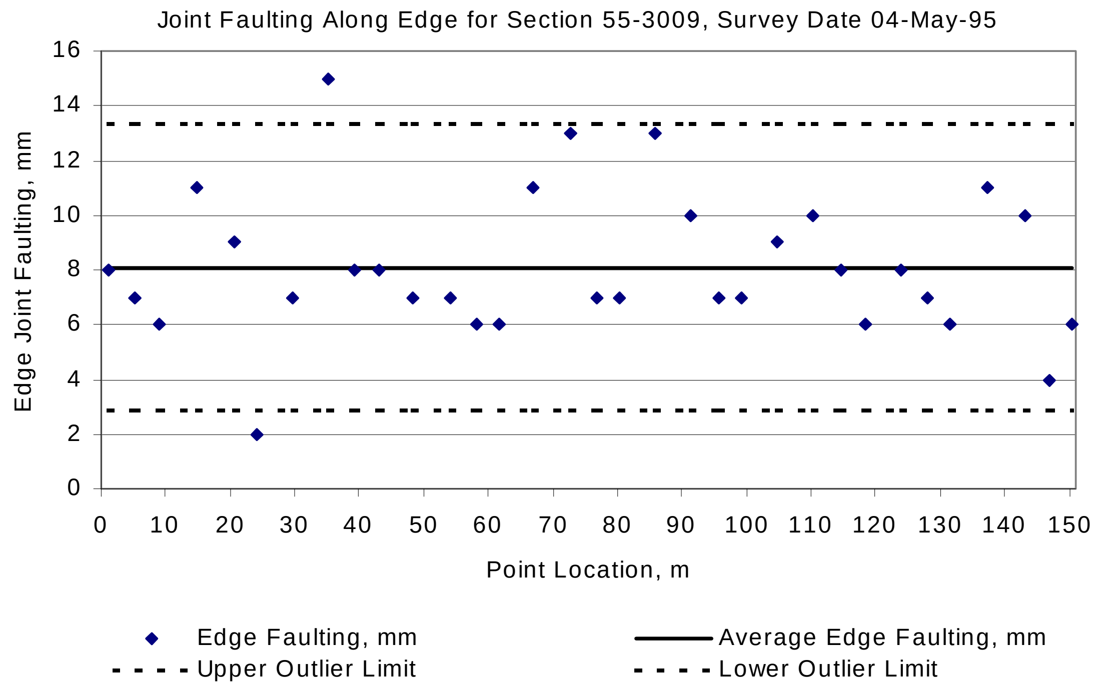


Figure 10. Outlier frequency distribution plots for sections with outliers.



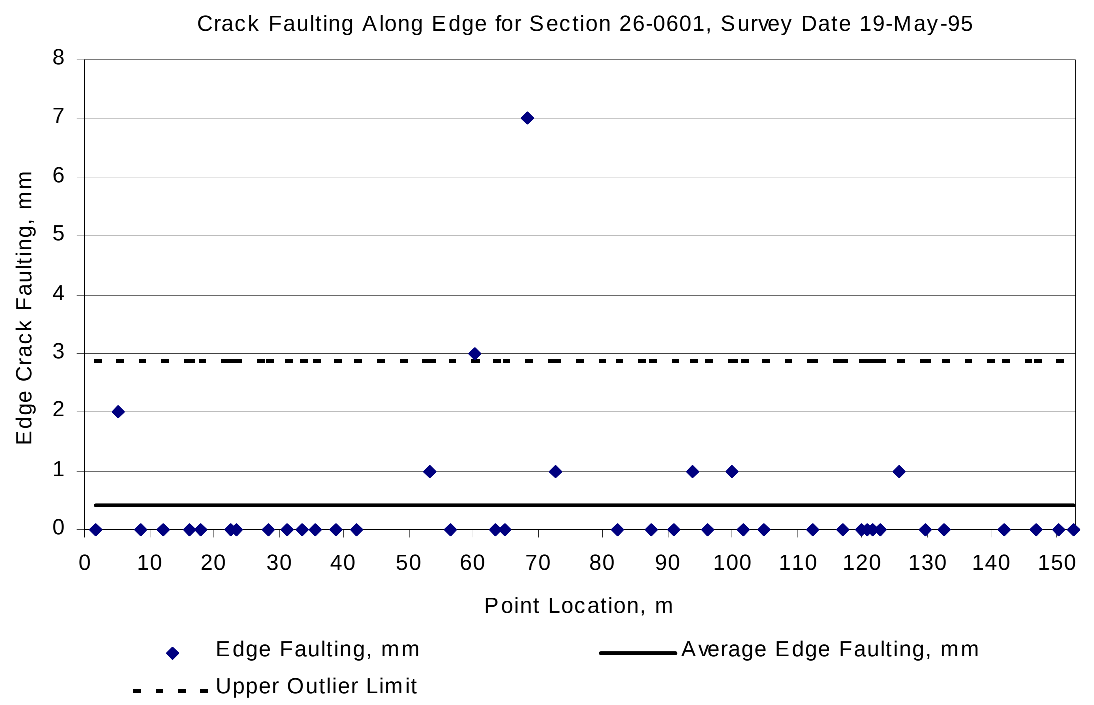


Figure 11. Representative examples of sections with outliers.

Summary of Representative Faulting Indices and Statistics

In this chapter, the necessity of representative faulting indices for evaluation of faulting time-series trends and for the development of joint faulting prediction models was discussed. To satisfy this need, a set of representative faulting indices and statistics for transverse joint and crack faulting, summarizing faulting data for each survey at each monitored section, was developed for all LTPP sites with monitoring faulting survey data that satisfied the proposed criteria for valid faulting observations. The computed faulting summary will be stored in the new LTPP database table entitled MON_DIS_JPCC_FAULT_SECT. The algorithm for computation of representative faulting indices and summary statistics for transverse joints and cracks was developed as part of this study and presented in this chapter of the report. A description of the new table MON_DIS_JPCC_FAULT_SECT is given in appendix A.

The computed faulting statistics were used to determine the outlier crack and joint faulting observations for each faulting survey reported in the LTPP database. As a result of the outlier study, it was determined that the average percentage of outlying observations per survey that had outliers is about 4 percent for edge and wheelpath observations. These percentages seem reasonable in light of the random variability inherent in the faulting measurement data and the limitations in precision of measurement using the Georgia Faultmeter. Therefore, the developed representative faulting indices could serve as faulting indicators for each LTPP section. The computational procedure is set to account for possible improvements in future faulting data resolution (through use of more precise equipment for faulting measurements).

4. FAULTING TREND ANALYSIS

To proof-test computed faulting indices and statistics, the following types of limited data analysis were conducted:

- Initial faulting measurement.
- Time-series faulting trend analysis.
- Faulting versus IRI data trend.
- Effect of various design features and site conditions on faulting.

Initial Faulting Measurement

An assumption of zero average faulting values at the start of pavement in-service life was tested using computed average faulting values for SPS-2 experiment sites. A frequency distribution plot was also developed to show the average edge and wheelpath faulting values computed using faulting data collected on the first faulting survey after construction, as shown in figure 12. The mean faulting measurements for all SPS-2 sections was 0.2 mm for both wheelpath and edge on the first survey since construction. Also, the distributions indicate that 97 percent of the computed absolute average edge faulting values and 99 percent of the computed absolute average wheelpath faulting values are less than 1 mm. These results indicate that the mean faulting of newly constructed SPS-2 joints is very close to zero, as would be expected.

Time-Series Faulting Trend Analysis

The time histories of the computed average faulting of each section were generated and examined. Several criteria characterizing faulting trends were developed, as discussed below.

- If the difference between faulting values from different surveys is within 1 mm, this trend is considered *"stable."*

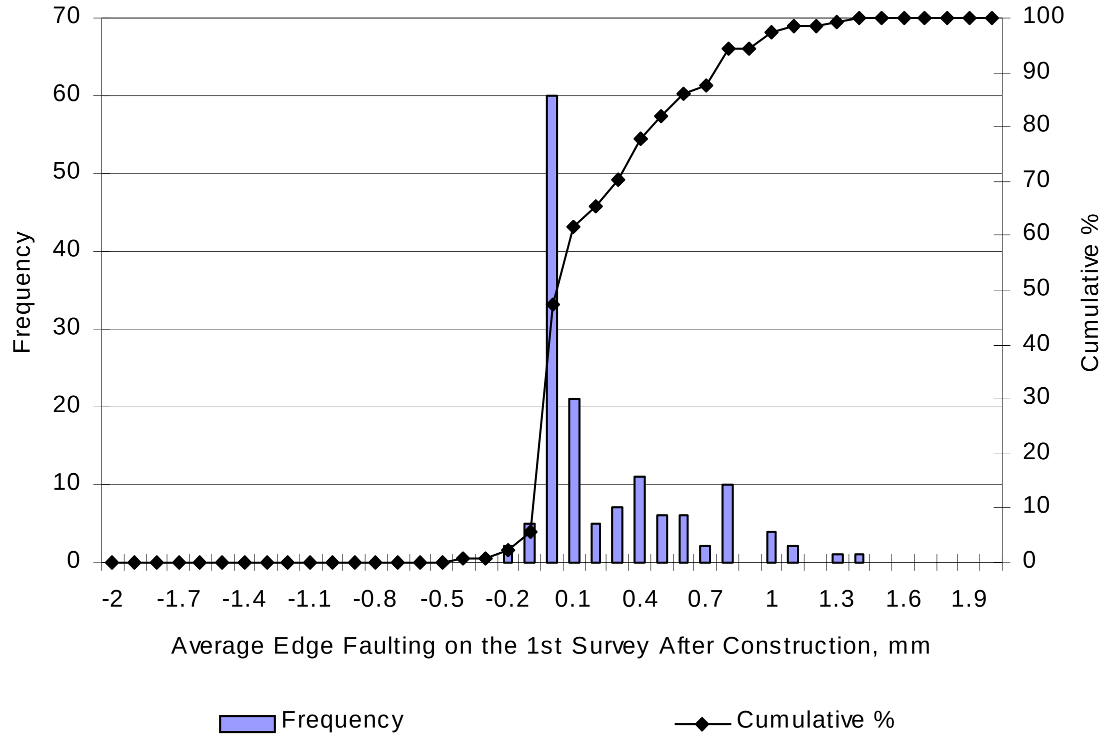
- If the difference between faulting values from different surveys is above 1 mm and the values do not show a clear increase or decrease with time, this trend is called *"fluctuating."*

- If the difference between faulting values from different surveys is above 1 mm and the values show a clear increase with time, this trend is called *"increasing."*

- If the difference between faulting values from different surveys is above 1 mm and the values show a clear decrease with time, this trend is called *"decreasing."*

- If only one faulting survey was available for a section, then no faulting trend could be determined, and such sections were not considered in the faulting trend analysis.

The threshold of 1 mm was established on the basis of the precision of the Georgia Faultmeter. A summary of faulting trend analysis is presented in table 20. Faulting data time



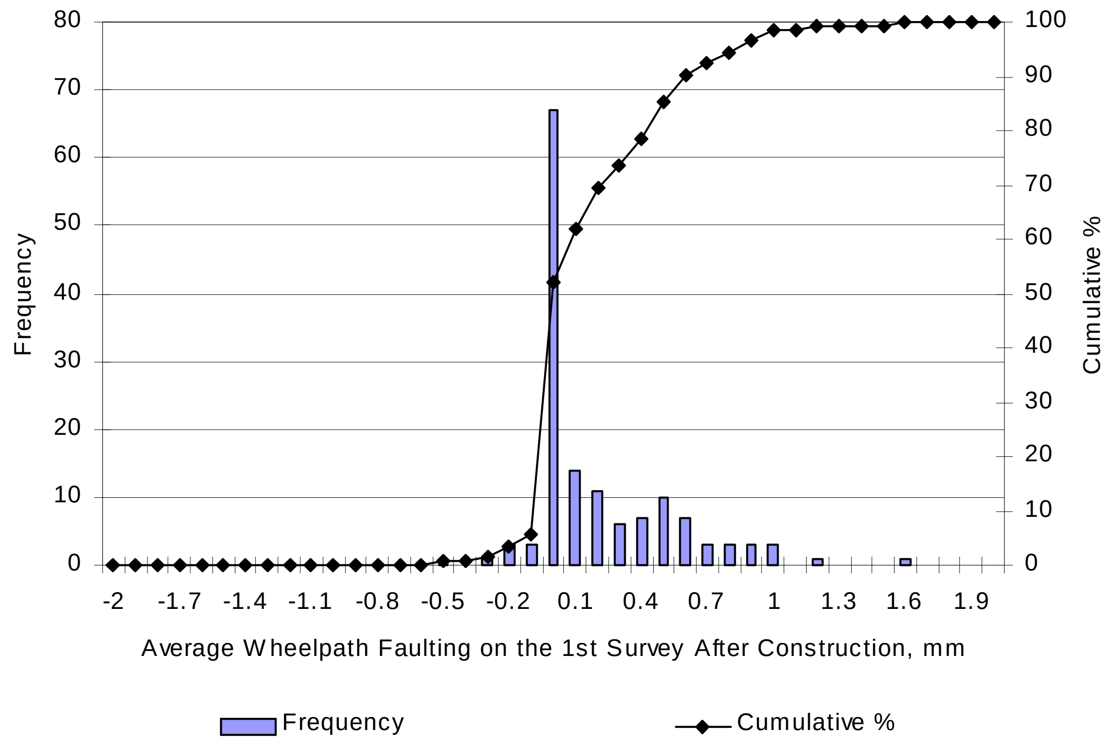


Figure 12. Frequency distribution of the average faulting values from the first survey after construction for SPS-2 sites.

Table 20. Summary of faulting time-series trend analysis.

No. of Surveys	Time-series Trend	No. of Sections Along the Edge	No. of Sections Along the Wheelpath
1	Not Applicable	98	108
2	Stable	70	78
2	Increasing	14	20
2	Decreasing	2	1
3 or more	Stable	80	66
3 or more	Increasing	8	8
3 or more	Decreasing	1	0
3 or more	Fluctuating	31	24

histories of all the sections are presented in appendix B. Most of the sections show a reasonable trend with time—average faulting values increasing or remaining stable with age, as shown in figure 13. However, a few sections exhibited questionable time trends of average faulting—either decreasing or fluctuating with time. Figure 14 provides an example graph of the questionable faulting time trend. A list of questionable sections is given in table 21. Sections with questionable trends were reported in LTPP Feedback Reports. Most of the questionable trends resulted from zero faulting reported on one of the surveys when non-zero faulting was reported on the previous or on the following surveys. As was found through the response from the Regional Centers, zero values were entered by default when null values should have been used instead.

Table 21. Sections with questionable faulting time trends.

No.	Section ID	Description of Questionable Trends and Possible Causes
1	053074	Average faulting decreases to "0" at last survey date.
2	170605	Average faulting decreases to "0" at last survey date.
3	323010	Average faulting decreases to "0" at last survey date.
4	533813	Average faulting decreases to "0" at last survey date.
5	124138	Average faulting decreases to "0" at one survey date then goes up again.
6	466600	Average faulting decreases to "0" at one survey date then goes up again.
7	833802	Average faulting decreases to "0" at one survey date then goes up again.
8	493011	Average faulting decreases to "0" at one survey date then goes up again, then decreases again for three consecutive survey dates.
9	404160	Decrease in average faulting can be explained by a small number of points used in calculation of statistics for one of the surveys; this survey date was included in a Feedback Report to be dropped from statistics calculation.
10	460601	Decrease is only in crack average faulting for one survey date. This can be explained by a small number of points used in statistics calculation (three and four points). Average faulting decrease was caused by inclusion of an extra "0" faulting observation (new crack) in the calculation of the average.
11	284024	Wheelpath faulting is "0" at all points on all surveys. Average edge faulting increases first, then goes down for three following survey dates.

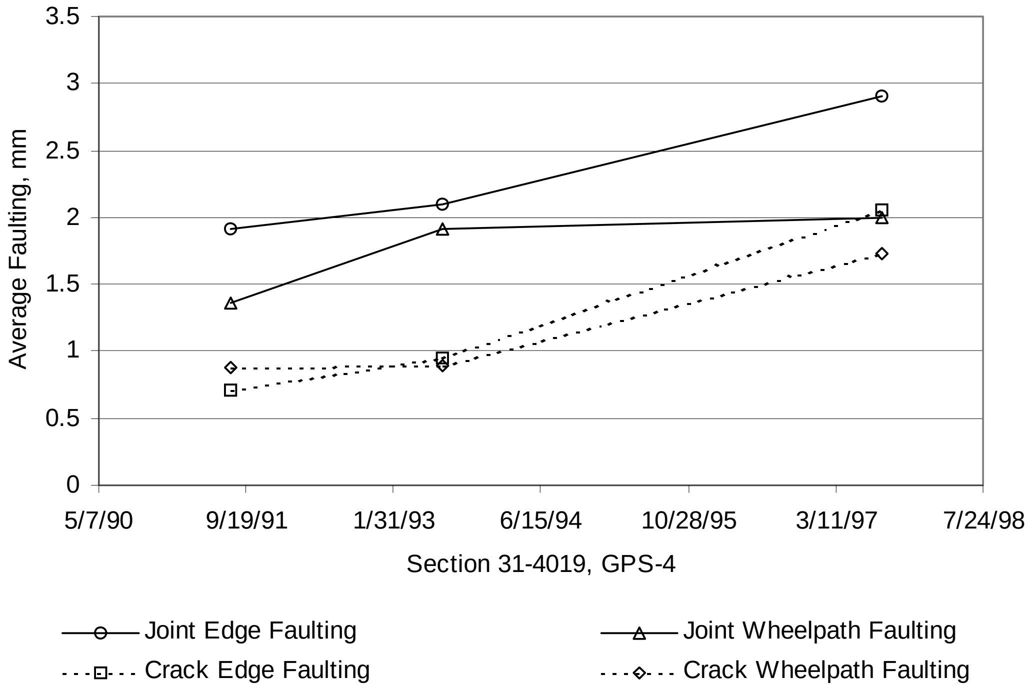


Figure 13. Example of a reasonable average faulting trend with time.

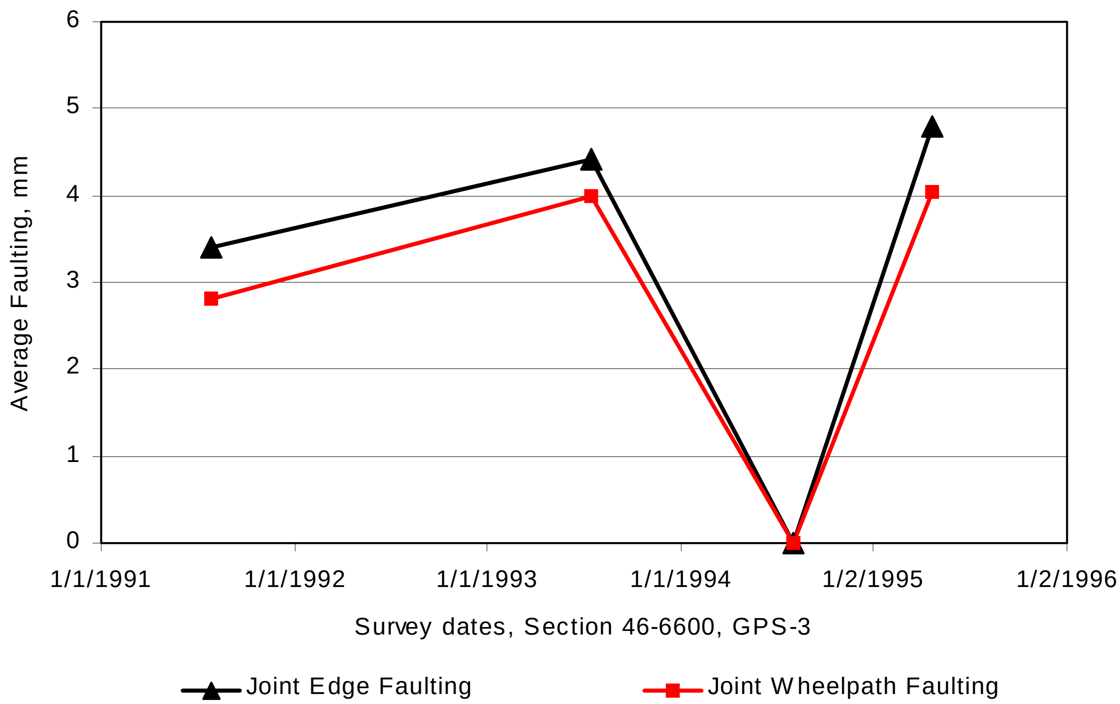


Figure 14. Example of a questionable average faulting trend with time.

Faulting Versus IRI Data Trends

Previous studies have indicated that, at some sections, there is a questionable relationship between joint faulting and pavement roughness. This section presents the results of an analysis performed to compare faulting time history data and IRI time history data.

General Trend Comparison

Plots of computed average faulting values and average IRI values for each section and each survey date were developed, as presented in appendix B. Only sections with two or more valid faulting and IRI surveys were considered in the trend analysis. Using this filter, a total of 162 sections were considered. For the sections under investigation, approximately 54 percent showed good correlation, meaning that both faulting and IRI trends followed a similar pattern: either increasing in value or staying stable with time. Examples of “good” and “bad” correlation examples in faulting and IRI trends are given in figures 15 and 16, respectively.

Computed average faulting values were compared with average IRI data collected at the closest dates to faulting surveys. Plots of average faulting values versus IRI are presented in figures 17 and 18 for JPCP and JRCP, respectively. To account for the sensitivity of IRI values to the number of joints, cumulative joint faulting values were computed and used instead of average values. With this approach, between two sections with the same average faulting values, the section with the larger number of joints will have higher cumulative faulting values. Cumulative faulting of each section was also compared with the average IRI data from the IMS database. Figures 19 and 20 provide cumulative faulting versus IRI graphs for JPCP and JRCP, respectively. As shown, there is a generally positive trend line between cumulative faulting and IRI; however, the correlation is not as high as expected. One probable reason is that the effect of the built-in initial roughness in the IRI was not considered. It is well known that the future IRI of a pavement is highly dependent upon its initial IRI. Another possible reason could be that IRI values were calculated using filtered longitudinal profile.

Faulting Rate Versus IRI Rate for JPCP Sections

To eliminate the effect of the built-in initial roughness in the IRI versus faulting trends, rates of change in IRI and faulting values with time were calculated and used in the regression analysis. Only JPCP sections with three or more faulting and IRI surveys were considered in this analysis. Rates of change (slopes) in IRI and faulting values were calculated for 63 JPCP sections. A number of sections showed negative values in either IRI or faulting slopes. One section (GPS-3 section 893002) showed a very high rate of faulting (exceeding the value of average faulting rate plus two standard deviations) compared with the rest of the sections. These sections were excluded from further analysis so as to examine only the typical trends. As a result, the total number of eligible sections was narrowed to 33.

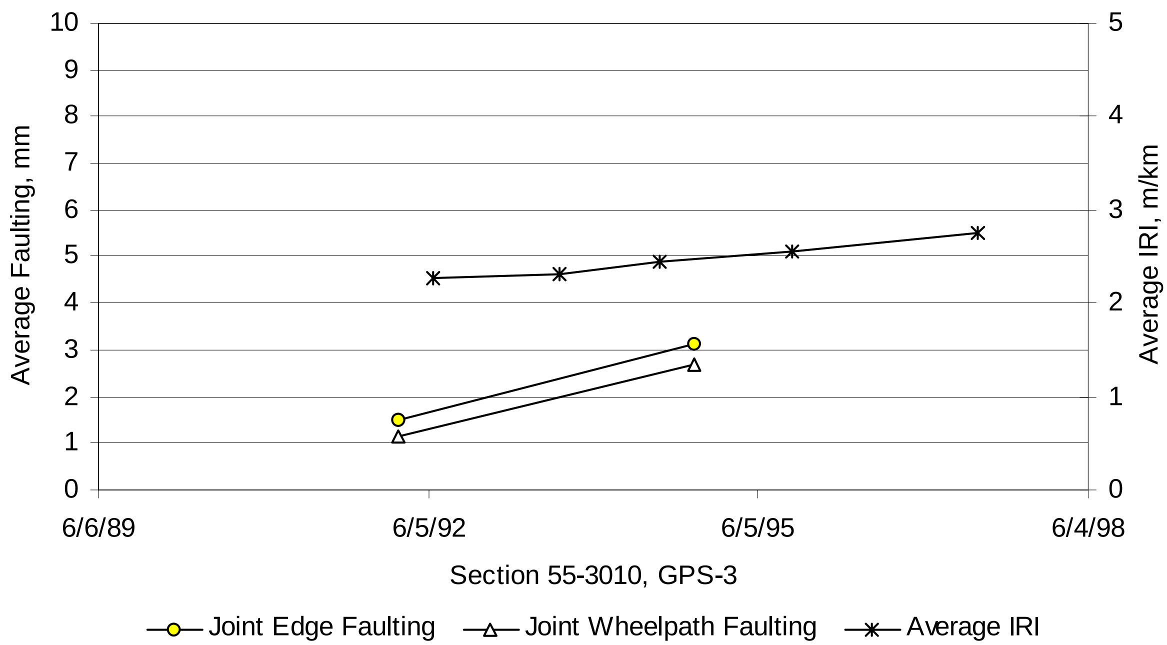


Figure 15. Example of "good" correlation between faulting and IRI trends.

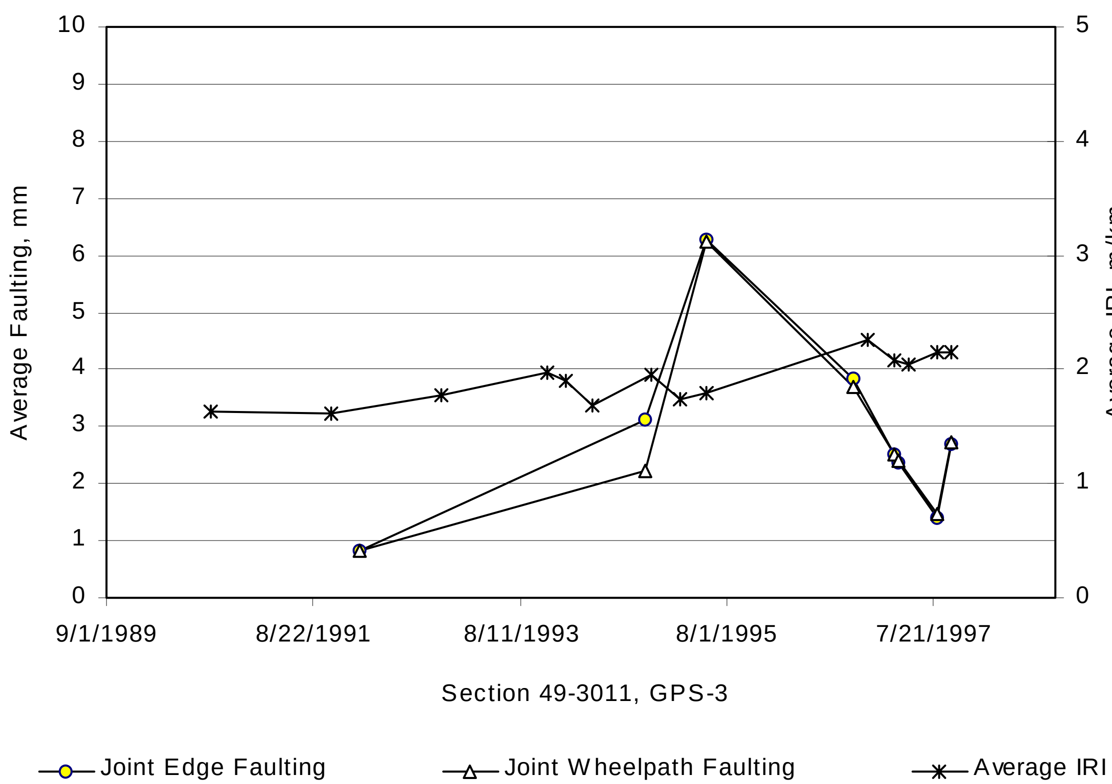


Figure 16. Example of "poor" correlation between faulting and IRI trends.

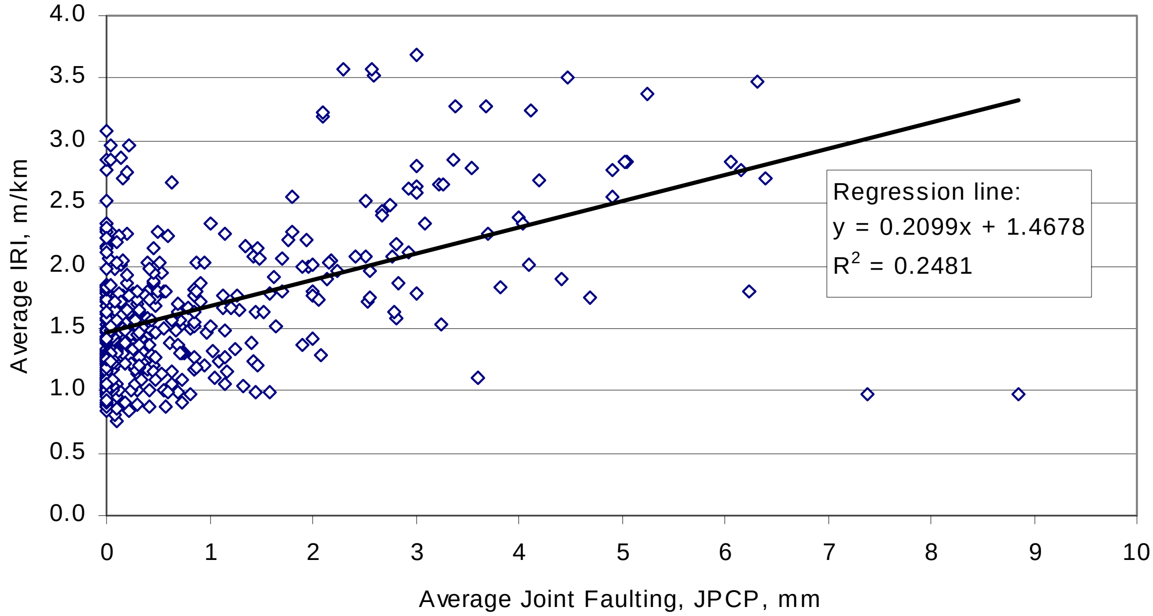


Figure 17. Average faulting versus average IRI for JPCP sections (initial IRI not considered).

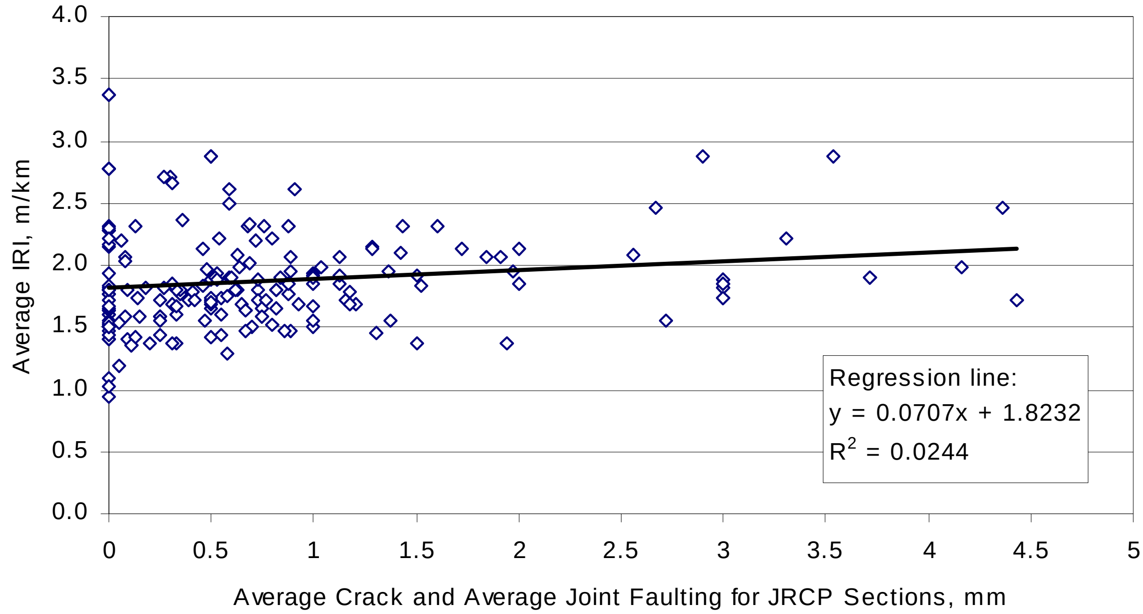


Figure 18. Average faulting versus average IRI for JRCP sections (initial IRI not considered).

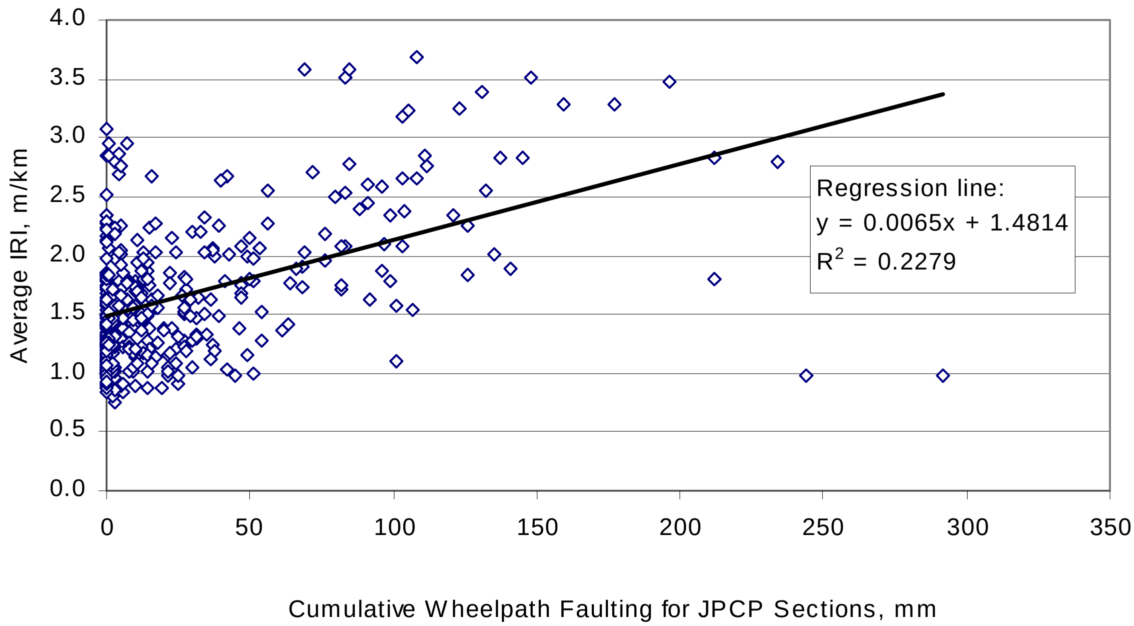


Figure 19. Cumulative faulting versus average IRI for JPCP sections (initial IRI not considered).

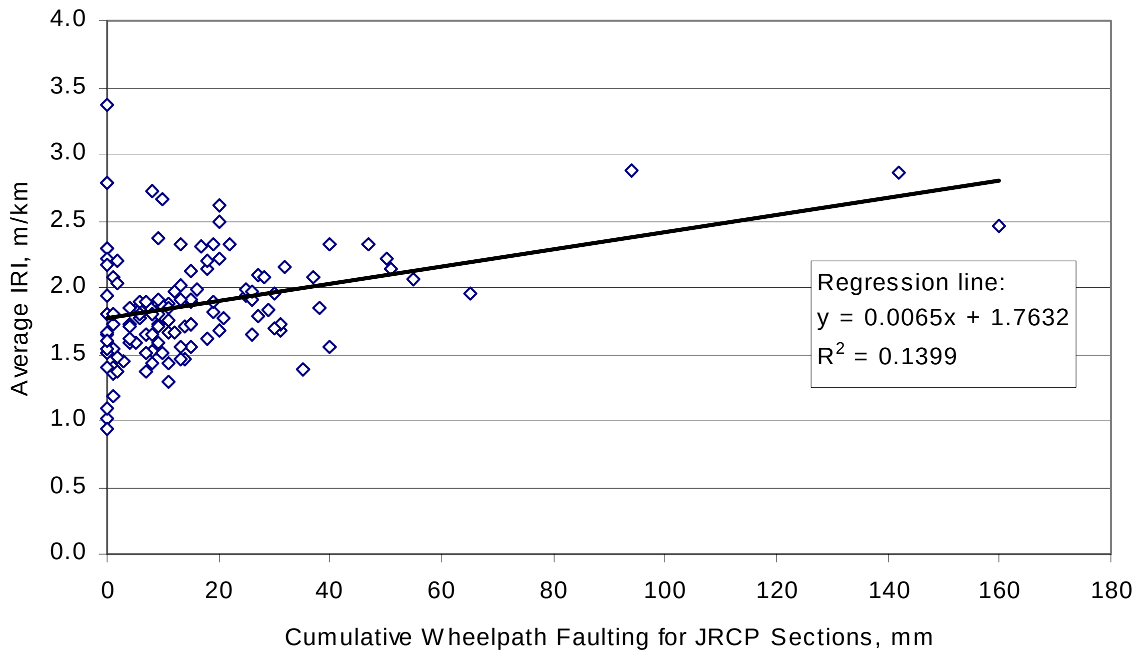


Figure 20. Cumulative faulting versus average IRI for JRCP sections (initial IRI not considered).

Two other parameters affecting IRI values were considered in the analysis: joint spacing and age. Joint spacing was directly included in the multiple linear regression analysis as an independent parameter together with the rate of faulting. The effect of age on IRI rate was considered indirectly by dividing all the sections under study into two age subgroups: sections with average age of all observations equal to or less than 10 years and sections with average age of all observations exceeding 10 years. All faulting observations were divided into two age groups based on the findings from earlier LTPP studies that showed a higher rate of faulting in earlier years than in the later years of pavement life [6]. Plots of the rate of change of IRI versus rate of change of faulting values are given in figure 21 for both age subgroups. Both subgroups showed appreciable correlation between faulting rate and IRI rates. Calculated R-square coefficients were equal to 0.81 for the young sections subgroup and 0.70 for the old sections subgroup. Linear multiple regression analysis resulted in the following relations for young and old section subgroups:

$$Young\_IRI\_Rate = 0.044979 + 0.525313 * Faulting\_Rate - 0.01089 * Joint\_Spacing$$
$$Old\_IRI\_Rate = 0.025055 + 0.170382 * Faulting\_Rate - 0.00289 * Joint\_Spacing$$

where

Young_IRI_Rate	=	IRI rate of change for sections with average age of all observations equal to or less than 10 years, m/km-year.
Old_IRI_Rate	=	IRI of change rate for sections with average age of all observations exceeding 10 years, m/km-year.
Faulting_Rate	=	Rate of change in average faulting, mm/year.
Joint_Spacing	=	Joint spacing, m.

Regression statistics are summarized in tables 22 and 23. The results of regression analysis for the 33 JPCP sections considered in the analysis indicated high correlation between faulting rate and IRI rates. The effect of joint spacing was not found to be significant, as indicated by the high P-values in table 23. For these 33 JPCP sections, an increase in faulting explains about 70 percent of the increase in IRI. These results are bounded and limited to the above subgroups of sections. As more faulting data become available, more generalized algorithms can be established. The results of this limited study indicate that the effect of build-in roughness needs to be considered in establishing relations between faulting and IRI trends.

Table 22. Regression statistics summary.

	Age 0-10	**Age 10+**
Multiple R	0.903	0.847
R-Square	0.816	0.718
Adjusted R-Square	0.780	0.685
Standard Error, m/km - year	0.048	0.018
Observations	13	20

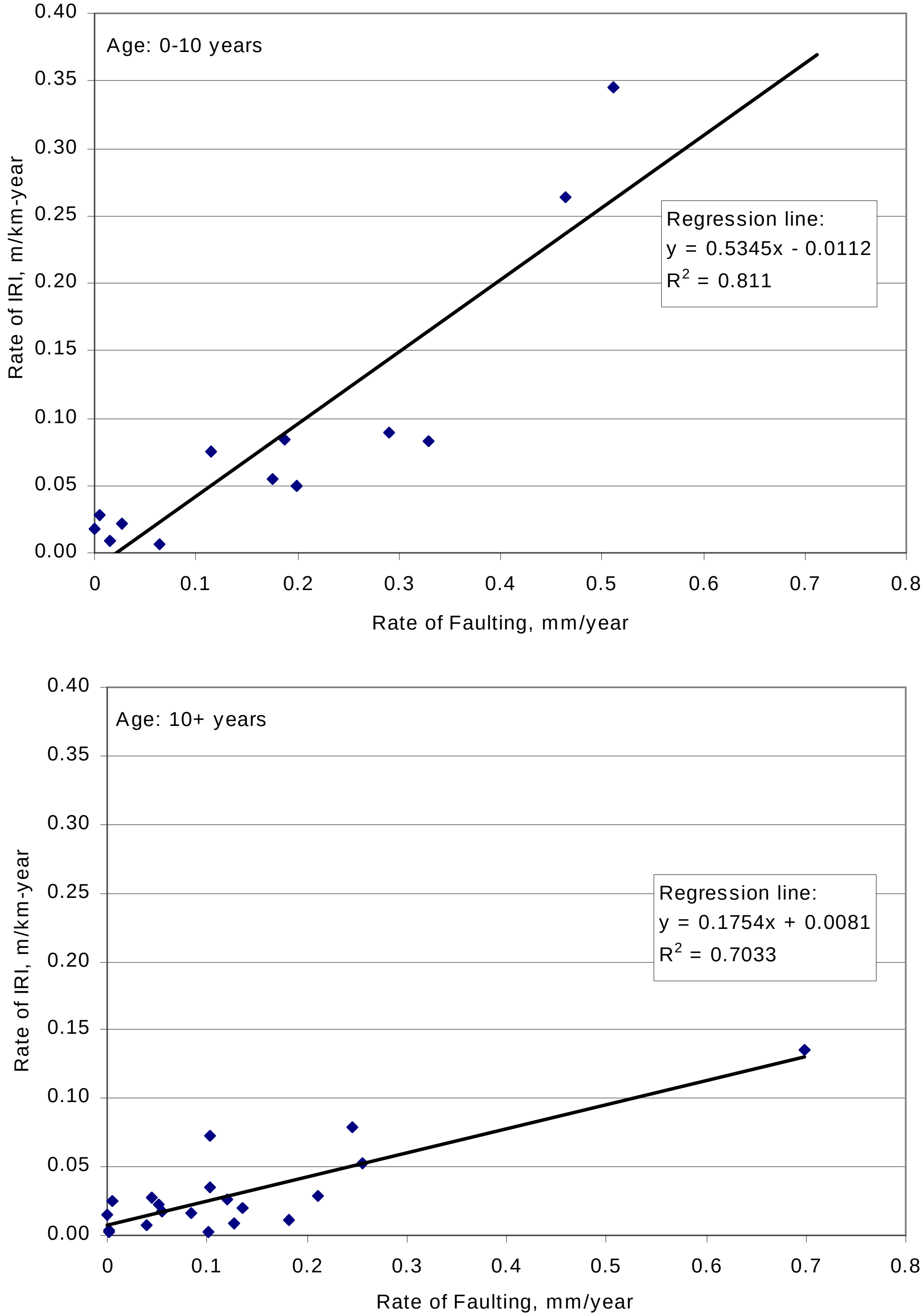


Figure 21. Rate of change of IRI versus rate of change of average faulting values.

Table 23. Regression statistics summary.

	Age 0-10		Age 10+	
	Coefficients	**P-Value**	**Coefficients**	**P-Value**
Intercept	0.044979	0.668815	0.025055	0.191485
Joint Spacing	-0.01089	0.587329	-0.00289	0.348862
Wheelpath Slope	0.525313	7.78E-05	0.170382	9.34E-06

Effect of Various Design Features and Site Conditions on Faulting

Several studies have been performed to determine the design features, site conditions, and construction practices that significantly influence JCP faulting [6, 7, 8, 9]. In this section newly computed average faulting values were used to analyze the effect of key jointed concrete pavement design features on faulting values. A faulting analysis was conducted using t-tests for the following design features and site conditions:

- Use of load transfer devices (LTDs).
- Dowel bar diameter.
- Use of tied concrete shoulders.
- Use of widened lanes.
- Use of drainage features.
- Base/subbase type.
- Joint spacing for JPCP.
- Joint spacing for JRCP.
- Truck volume.
- Reinforcement amount (for JRCP).
- Climatic region.
- Joint orientation (skewed versus perpendicular).

Prior to statistical testing, all sections under investigation were divided into three separate groups based on the pavement type: JPCP sections without dowel bars, JPCP sections with dowel bars, and JRCP sections (all with dowel bars). Series of two-sample t-tests were carried out separately for each group. The purpose of the t-tests was to determine whether the two sample means were significantly different based on a 95 percent confidence interval. Discussion of the effects of each design feature or site condition on faulting for each of three pavement types is presented below.

Age of the pavement section is an important factor affecting faulting values. To account for this effect, all pavement sections were divided into three age categories:

- Young (0 to10 years old at survey date).
- Middle (10 to 20 years old).
- Old (more than 20 years old).

Figure 22 shows the distribution of the age of the pavement sections at the time of the faulting survey. Age category division was used in statistical tests when there were enough data for all age categories. If one of the two samples of sections did not have enough data in one of the age categories, the age categories were not considered. For these cases, only sections with comparable ages were used in statistical analyses.

Results of t-tests for various design features and site conditions are summarized in tables 24 and 25 for JPCP sections without dowel bars and with dowel bars, respectively. Results of t-tests for JRCP sections are summarized in table 26.

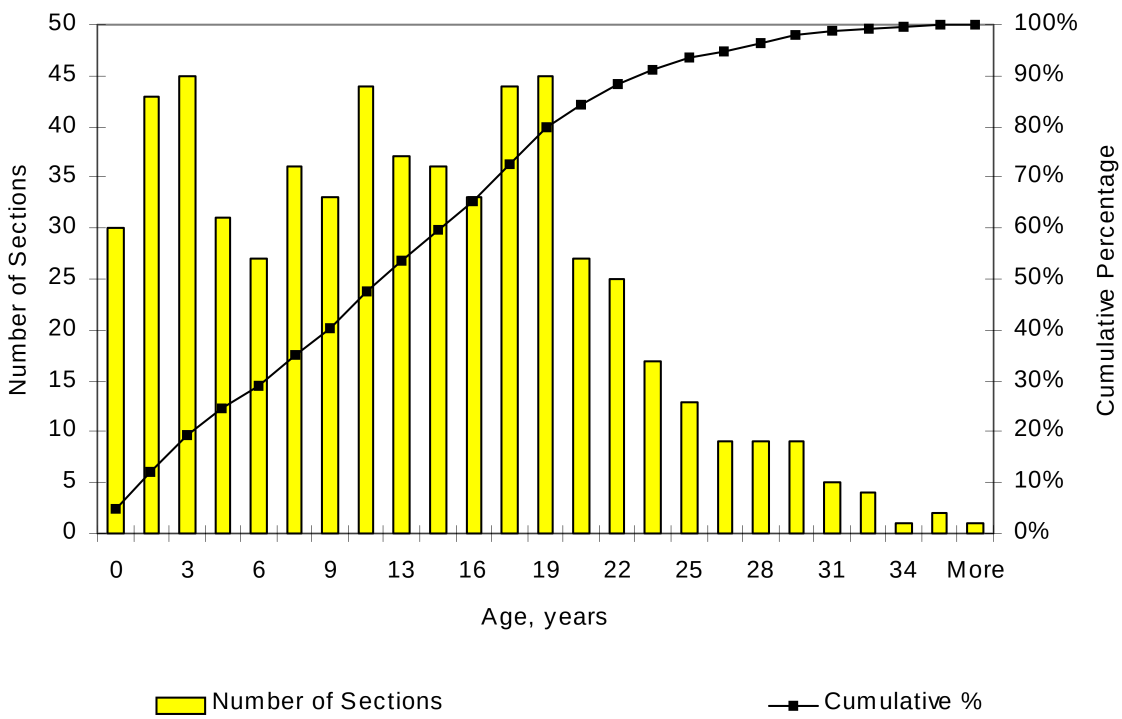


Figure 22. Frequency distribution of pavement section ages at the times of faulting surveys.

Table 24. t-test results for JPCP sections without dowels.

Comparison Pair											
Feature 1	Feature 2	Feature 1 Statistics			Feature 2 Statistics			One-Tail P-Value	Difference of means	Significant ?
		Number of Sections	Mean of Avg. Fault	Standard Deviation	Number of Sections	Mean of Avg. Fault	Standard Deviation			
Widened Lane	Conventional Width	6	0.34	0.47	38	0.83	1.17	0.04420	0.49	Y
Drainage	No Drainage	33	1.35	1.25	132	2.08	2.05	0.00514	0.74	Y
Tied PCC Shoulder	No Tied PCC Shoulder	46	1.66	1.92	115	2.09	1.95	0.09863	0.44	N
Joint Spacing <= 4.6 m	Joint Spacing > 4.6 m	70	1.57	1.70	86	2.25	2.13	0.01392	0.68	Y
Treated Base	Granular Base	87	1.58	1.52	65	2.78	2.62	0.00065	1.21	Y
Dry-Freeze Zone	Dry-No-Freeze Zone	35	1.56	1.70	24	1.10	0.94	0.09523	-0.46	N
Wet-Freeze Zone	Wet-No-Freeze Zone	55	3.17	2.93	50	2.04	1.64	0.00801	-1.13	Y
Dry-Freeze Zone	Wet-Freeze Zone	35	1.56	1.70	55	3.17	2.93	0.00072	1.61	Y
Dry-No-Freeze Zone	Wet-No-Freeze Zone	24	1.10	0.94	50	2.04	1.64	0.00131	0.94	Y

Table 25. t-test results for doweled JPCP sections.

Comparison Pair									One-Tail P-Value	Difference of Means	Significant?
		Feature 1 Statistics			Feature 2 Statistics						
Feature 1	Feature 2	Number of Sections	Mean	Standard Deviation	Number of Sections	Mean	Standard Deviation				
Widened Lane	Conventional Width	59	0.17	0.24	132	0.28	0.38	0.01120	0.10	Y
Drainage	No Drainage	88	0.56	0.82	166	0.36	0.55	0.02018	-0.20	Y
Tied PCC Shoulder	No Tied PCC Shoulder	23	0.42	0.54	114	0.66	0.82	0.44609	0.24	N
Joint Skewed	Straight Joints	41	0.51	0.75	140	0.50	1.28	0.48007	-0.01	N
Joint Spacing <= 4.6 m	Joint Spacing > 4.6 m	154	0.28	0.52	94	0.68	0.79	0.00002	0.39	Y
Treated Base	Granular Base	109	0.47	0.72	131	0.72	1.38	0.03561	0.25	Y
Wet-Freeze Zone	Wet-No-Freeze Zone	52	0.60	0.80	68	0.64	0.73	0.40561	0.03	N

Table 26. t-test results for JRCP sections.

Comparison Pair								One-Tail P-Value	Difference of Means	Significant?
		Feature 1 Statistics			Feature 2 Statistics					
Feature 1	Feature 2	Number of Sections	Mean	Standard Deviation	Number of Sections	Mean	Standard Deviation			
Tied PCC Shoulder	No Tied PCC Shoulder	8	0.48	0.26	24	0.38	0.39	0.23465	0.09	N
Joint Skewed	Straight Joints	15	0.73	0.83	15	0.58	0.28	0.24867	0.16	N
Joint Spacing <15.25 m	Joint Spacing >=15.25 m	73	0.73	0.80	58	1.33	1.94	0.01500	-0.60	Y
Steel<0.14, %	Steel>=0.14, %	20	0.27	0.38	19	1.31	1.02	0.00015	-1.04	Y
Cracks	Joints	70	1.08	1.33	70	1.19	1.58	0.33407	-0.11	N
Treated Base	Granular Base	64	0.85	1.18	68	1.43	1.78	0.01326	-0.58	Y
Wet-Freeze Zone	Wet-No-Freeze Zone	86	1.15	1.42	49	1.09	1.73	0.41925	0.06	N

The purpose of these t-tests was to examine whether the design features and site conditions lead to significantly decreased or increased mean joint faulting values for the given sample of sections. From a statistical point of view, the results indicate a significant difference at a 95 percent level of significance if calculated P-values are less than 0.05. These results are discussed in the next sections.

Use of Load Transfer Devices

The effect of dowel bar use on the computed average joint faulting values was investigated for JPCP sections. Previous research findings have indicated a major influence of dowel bar use on the reduction of joint faulting [3, 4, 9]. T-tests conducted for three different age groups of JPCP sections indicated that dowel bar use significantly reduced joint faulting for all pavement age categories. As shown in table 27, faulting of JPCP sections without dowels is twice as high as for the JPCP sections with dowel bars. To investigate a general trend of faulting development with time for doweled and non-doweled JPCP sections, a line passing through each of three mean faulting values calculated for each age category was plotted against age, in years, for doweled and non-doweled sections, as shown in figure 23. Zero average faulting values were assumed at the traffic opening date based on the results obtained from the SPS-2 experiment sites.

For both JPCP and JRCP, as indicated in figure 23, faulting development follows a similar trend with time: average faulting values are low for the first 10 years of service

Table 27. Effect of dowels on JPCP faulting.

Age, Years	No Dowels			Doweled			P(T<=t) One-tail	P(T<=t) Two-tail
	Number of Sections	Mean (mm)	Standard Deviation (mm)	Number of Sections	Mean (mm)	Standard Deviation (mm)		
0 - 10	44	0.69	1.03	170	0.16	0.23	0.00067	0.00134
10 - 20	84	2.10	2.10	63	0.83	0.96	1.4E-06	2.7E-06
over 20	28	2.53	1.87	16	1.02	1.07	0.00073	0.00146

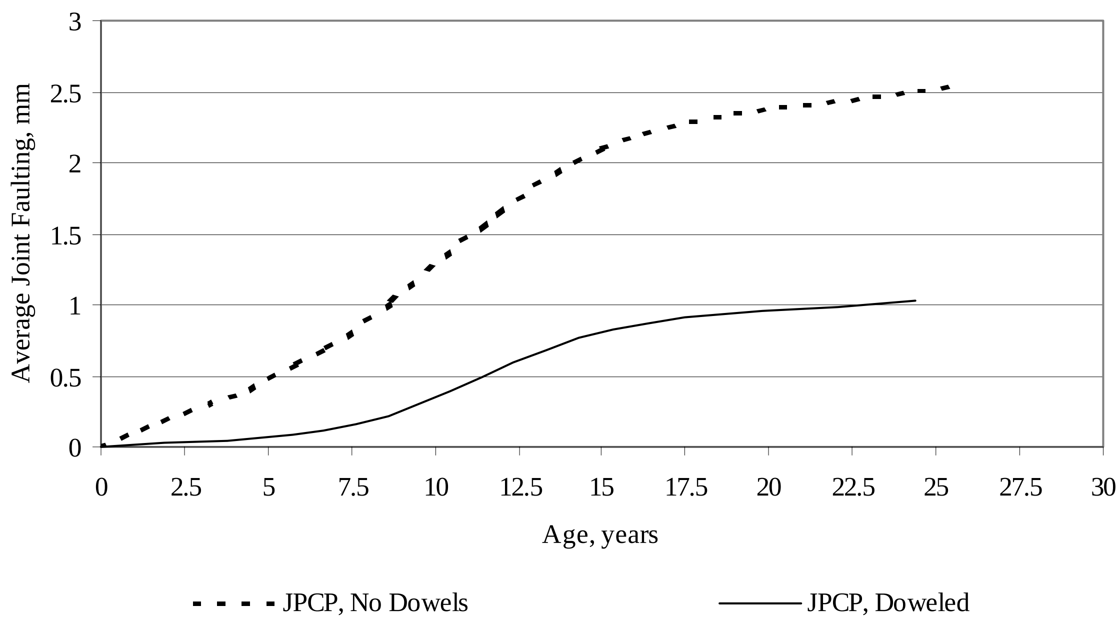


Figure 23. General trend of faulting development with time for doweled and non-doweled JPCP sections.

(although non-doweled sections indicate a high rate of faulting development), then faulting values increase rapidly for the next 10 years. After 20 years of service, faulting continues to progress, but at much lower rate, especially for doweled JPCP sections. These conclusions are based on, and limited to, the results of the very broad age group division discussed previously.

Effect of Dowel Bar Diameter

Previous studies indicated that the larger diameter dowel bars reduce faulting because of less steel/concrete bearing stress [6]. This hypothesis was tested using computed average joint faulting values for three different age groups of JPCP sections. The general pattern showing reduction in average faulting values with increase in dowel bar diameter was observed for all age categories. The results of comparisons for different dowel bar diameters are presented in table 28 and figure 24.

Table 28. Effect of dowel bar diameter on faulting of JPC pavements over time.

Age, Years	Dowel Diameter, mm								
	0	**19**	**25**	**28**	**29**	**31**	**32**	**35**	**38**
0-10	0.7*	0.6	0.3		0.1		0.3	0.3	0.15
10-20	2.2		0.6	1.4	0.6	1.0	0.6	0.6	0.2
Over 20	2.6		2.1	1.7			1.1		

* mean faulting in mm

Use of Tied Concrete Shoulders

The effect of tied concrete shoulders on the computed average edge faulting was investigated for JRCP sections and doweled and non-doweled JPCP sections. Information about shoulder type was available only for a limited number of sections. No sections beyond 20 years of age had records indicating tied concrete shoulder use; therefore, all sections were divided into two age categories: less than 10 years old and 10 to 20 years old. The results showed that tied concrete shoulder use did not significantly affect the average edge faulting values for JRCP sections. For JPCP sections, t-test results were inconsistent. The results showed that average edge faulting values for non-doweled JPCP sections less than 10 years old were significantly reduced when tied concrete shoulder was used, but for non-doweled JPCP sections more than 10 years old, the use of tied concrete shoulders did not significantly affect average edge faulting values. For doweled JPCP sections, the use of tied concrete shoulders did not significantly affect average edge faulting values for the group of sections less than 10 years of age, but showed significant reduction in average edge faulting values for sections greater than 10 years old.

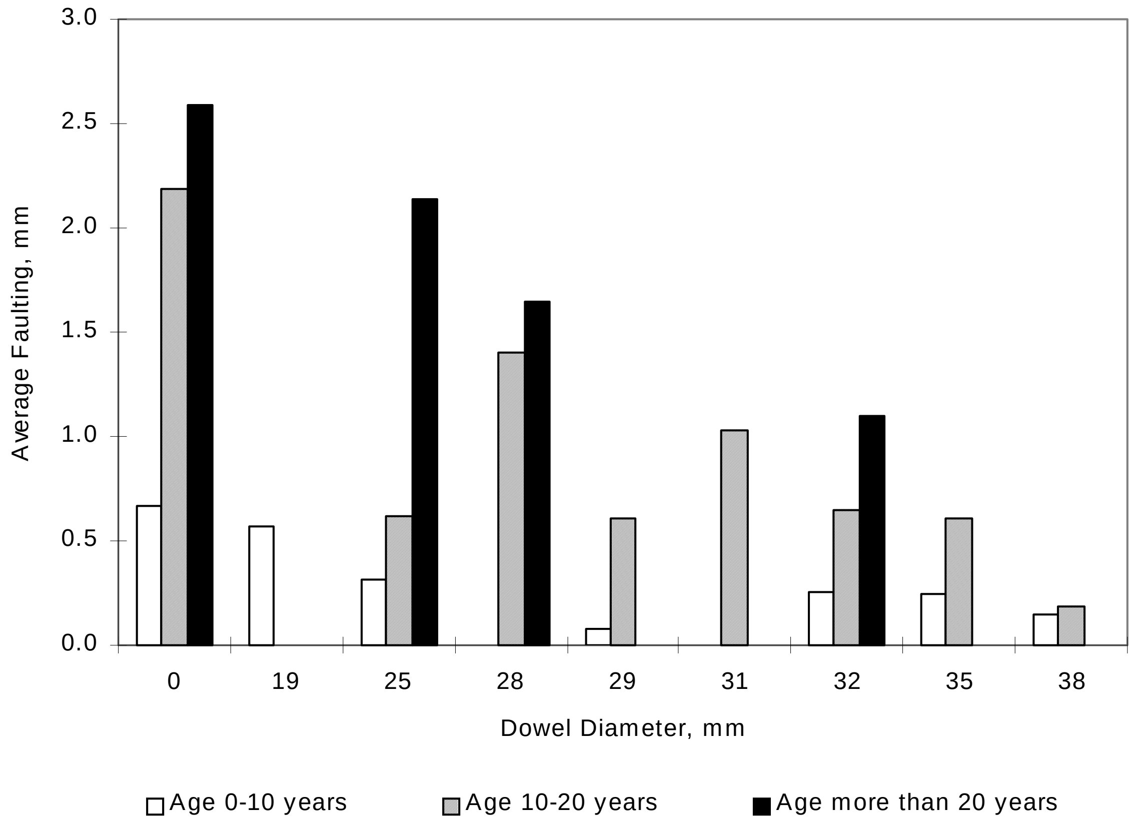


Figure 24. Effect of dowel bar diameter on faulting of JPCP.

Use of Widened Lanes

Study of the effect of widened lane on average faulting values was conducted for JPCP sections only, because none of the JRCP sections under investigation had a widened lane. JPCP sections were presented by three different lane widths: conventional widths of 3.66 m (12 ft) and 3.36 m (11 ft) (only two sections) and a widened lane width of 4.27 m (14 ft). Depending on the lane width, all sections were divided into two groups: sections with lane width less than or equal to 3.66 m and sections with lane width equal to 4.27 m. The majority of sections with widened lane were less than 10 years old. Only two sections were 10 to 20 years old (10.7 and 11.7 years), and none were over 20 years old. Therefore, no age effect was considered in the t-tests. Separate t-tests were performed for doweled and non-doweled JPCP sections.

The results of the t-tests showed a significant decrease in faulting values along the edge for the non-doweled JPCP sections with widened lane. For doweled sections, results of the t-tests (P-values) also indicated statistically significant reduction in faulting values for widened lane sections.

Use of Drainage Features

The effect of drainage use on faulting values was studied for JPCP and JRCP sections. All sections within each pavement type were divided into two groups: those sections with some sort of positive drainage system and those without. Because of unequal sample sizes in age groups, no age category division was implemented in this analysis. Separate t-tests were performed for doweled and non-doweled JPCP sections. The results of the t-tests did not show a significant effect of drainage use on faulting values for JRCP sections. For JPCP non-doweled sections, use of drainage significantly reduced faulting for both wheelpath and edge observations. This supports the findings of the NCHRP 1-34 study on the effect of subsurface drainage on the reduction of faulting in non-doweled JPC pavements [9]. Results for doweled JPCP sections were inconclusive, mainly because of the very low level of faulting.

Base/Subbase Type

The effect of stabilized base/subbase type versus untreated aggregate base on faulting values was tested for JPCP and JRCP sections. The results of t-tests showed a significant reduction in faulting values for non-doweled JPCP sections with stabilized bases/subbases compared with the values of non-doweled JPCP sections with granular bases/subbases. For doweled JPCP and JRCP sections, the absolute difference between average faulting values was too small for practical consideration.

Joint Spacing

Before any analysis of the effects of joint spacing on faulting values was performed, plots of joint spacing frequency distribution were developed for the following groups of pavements: JPCP/no dowels, JPCP/doweled, and JRCP, as shown in figure 25. Based on the distribution plots, JPCP doweled and non-doweled sections were divided into two groups each: sections with joint spacing 4.6 m or less and sections with joint spacing more than 4.6 m. This division permits testing of groups of similar sizes. Similarly, JRCP sections were divided into two groups: sections with joint spacing less than 15.25 m and sections with joint spacing greater than or equal to 15.25 m. Separate t-tests were carried out for each pavement group pair. The results of the t-tests showed that joint spacing significantly affects faulting for all pavement categories under study. Shorter joint spacings show smaller faulting values.

Joint Orientation (Skewed Versus Perpendicular)

The effect of joint skewness on faulting values was studied for doweled JPCP and JRCP sections. There was not enough information on joint orientation for non-doweled sections in the IMS database. The results of the tests did not show a significant effect of joint skewness for JRCP sections. For JPCP doweled sections, the results were not consistent. There is some evidence that doweled JPCP sections with skewed joints more than 10 years old show an increase in faulting; however, sample sizes were small, and other design features may have affected the faulting values. Thus, for doweled joints, skewed joints did not show significant faulting differences.

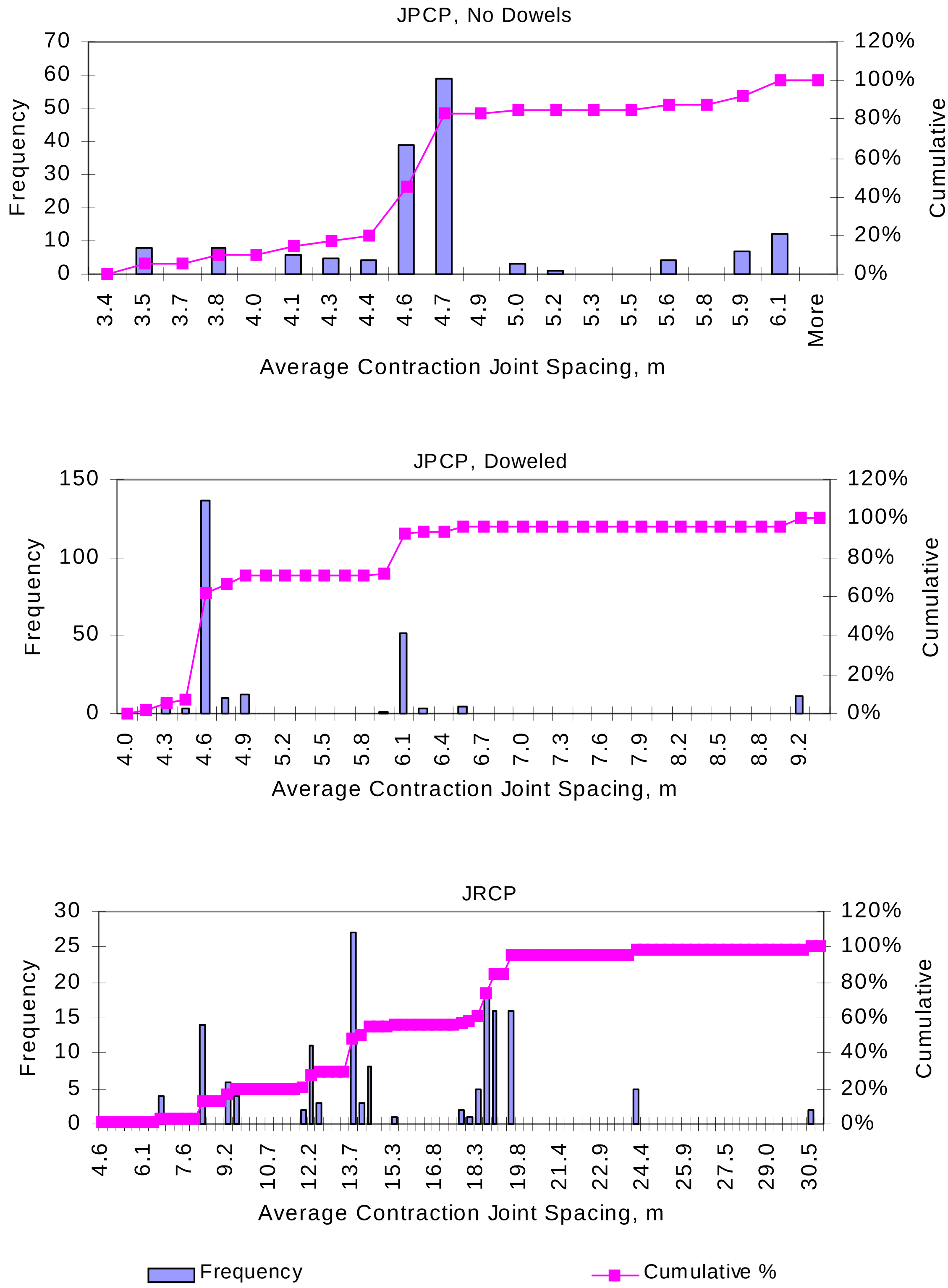


Figure 25. Joint spacing frequency distribution for different types of JCP.

Truck Volume

Traffic data are one of the most important factors affecting joint faulting [3, 4]. Good quality traffic data over the whole pavement life is very important for the study of the effect of cumulative traffic on faulting. Available traffic data were obtained from the IMS table TRF_MONITOR_BASIC_INFO for the sections under study. An analysis of monitoring traffic data revealed that data were missing for a number of sections, and the available ESAL data represented only a few years in pavement life, with large differences in values between different years. Some of the sections with missing monitoring information had estimated information available. Comparison of the ESAL values for the sections that have both monitoring and estimated information showed large differences between the two.

Since the traffic data obtained from the LTPP IMS database were available only for a few years, the traffic data for the remaining years were backcasted to the year when the pavement was opened to traffic and forecasted to the year of the latest faulting survey in order to estimate the cumulative traffic. Traffic data for the latest monitored year were assumed to be most accurate and, therefore, were used in backcasting and forecasting procedures. In this study, a constant growth factor of 2 percent was assumed for all the sections. The use of the 2 percent growth factor was considered conservative, as it results in a high level of cumulative traffic loading. The following equation incorporating the 2 percent growth factor was used to calculate the estimated traffic at the beginning year for the test section:

$$T_0 = \frac{T_c}{(1 + 0.02)^{n-1}}$$

where: T_0 = Estimated annual ESALs for the first full year *(Year of T_0)* since traffic opening date.
T_c = Annual ESALs for the last available year *(Year of T_c)*in traffic record.
n = *Year of T_c - Year of T_0*.

To be consistent with the backcasting approach, a constant growth rate of 2 percent was again assumed to calculate the cumulative traffic at the time of the distress survey. The following equation was used to compute the cumulative traffic:

$$CESAL = T_0 * \frac{\left[(1 + 0.02)^m - 1\right]}{0.02} + 0.98T_0 * days$$

where: *CESAL*= Cumulative ESALs since traffic opening date to the time of faulting survey.
days = Number of days since traffic opening date to the end of the traffic opening year, converted to a fraction of the year.
m = *Full Date of Faulting Survey - Year of T_0*.

Figure 26 shows the distribution of CESALs with age. There is a general trend of higher CESALs for older pavement sections; however, no strong correlation can be established. This can be explained by different road functionalities that result in lower or higher ESALs per year. Attempts were made to correlate faulting values with CESALs, but no meaningful relations were achieved.

The quality of the traffic data used is very questionable, as was addressed in chapter 2 of this report. There is a strong need for a systematic procedure/guideline for traffic backcasting applicable to all LTPP sections. This procedure should account for differences in traffic stream (vehicle distribution by class) and growth rates specific to different road functional classes and geographical regions. Available historical and monitoring data need to undergo QC analysis to resolve conflicts between historical and monitoring traffic trends.

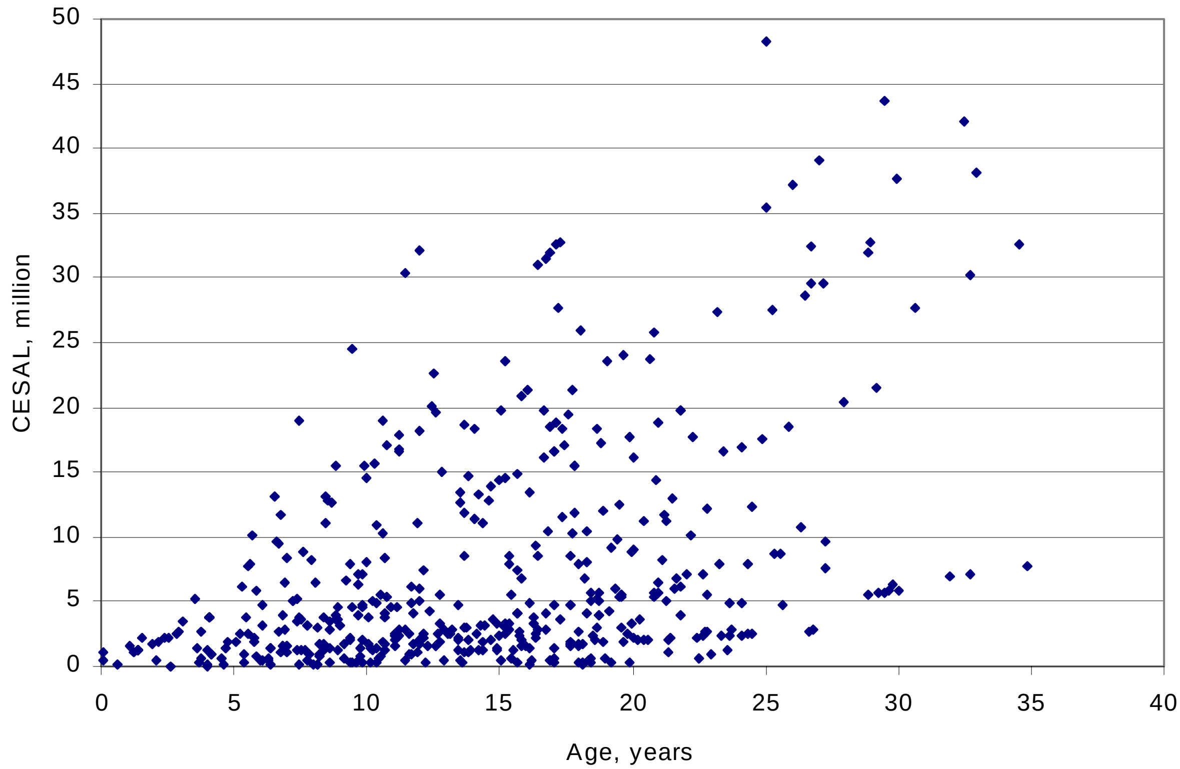


Figure 26. Distribution of CESALs with age.

Reinforcement Amount (for JRCP)

An attempt was made to relate reinforcement amount with crack faulting values. No conclusive relations were established because of the overpowering effect of joint spacing on crack faulting and the interdependent relationship between reinforcement amount and joint spacing.

Climatic Region

The difference between faulting values for different climatic regions was tested. Most of the available sections with faulting status 1 were located in wet-freeze and wet-no-freeze zones, as indicated in table 29. No JRCP sections with faulting status 1 and only three JPCP doweled sections were found in dry-freeze and dry-no-freeze zones. JPCP sections without dowels had enough sections for the comparative analysis in all four climatic zones.

Table 29. Number of available observations with faulting status 1.

		DF Region	**DNF Region**	**WF Region**	**WNF Region**
JPCP, No Dowels	Wheelpath	34	24	53	44
	Edge	35	24	55	50
JPCP, Doweled	Wheelpath	3	3	52	63
	Edge	3	3	52	68
JRCP	Wheelpath	0	0	93	38
	Edge	0	0	96	49

Results of the t-tests for JPCP sections without dowels showed no significant difference between joint faulting for sections located in dry-freeze and dry-no-freeze zones. There was a significant increase in joint faulting for sections located in the wet-freeze zone (mean faulting 3.2 mm) compared with the wet-no-freeze zone (mean faulting 2.0 mm), as well as for sections located in the wet-freeze zone (mean faulting 3.2 mm) compared with the dry-freeze zone (mean faulting 1.6 mm), and for sections located in the wet-no-freeze zone (mean faulting 2.0 mm) compared with the dry-no-freeze zone (mean faulting 1.1 mm).

For doweled JPCP sections, the results of the t-test did not show a significant difference between joint faulting for sections in the wet-freeze zone and the wet-no-freeze zone. For JRCP sections, the results of the t-test showed statistically higher joint faulting values for sections in the wet-freeze zone (mean faulting 1.1 mm) compared with the wet-no-freeze zone (mean faulting 1.0 mm). However, these differences for JRCP sections have no practical significance because of the very low values of faulting that exist for JRCP sections.

A comparison of the mean faulting values obtained for JPCP and JRCP sections in different climatic zones is presented in figure 27. It should be noted that non-doweled JPCP sections in wet-freeze zones exhibited the worst mean faulting among all the categories—five times higher than the mean faulting for doweled JPCP sections in the same climatic zone.

Summary of Faulting Trend Analysis

In this chapter, newly computed faulting indices and summary statistics were used to investigate trends in faulting with time for sections with two or more surveys. The results of time-series faulting trend analyses indicated that most of the sections exhibited a reasonable

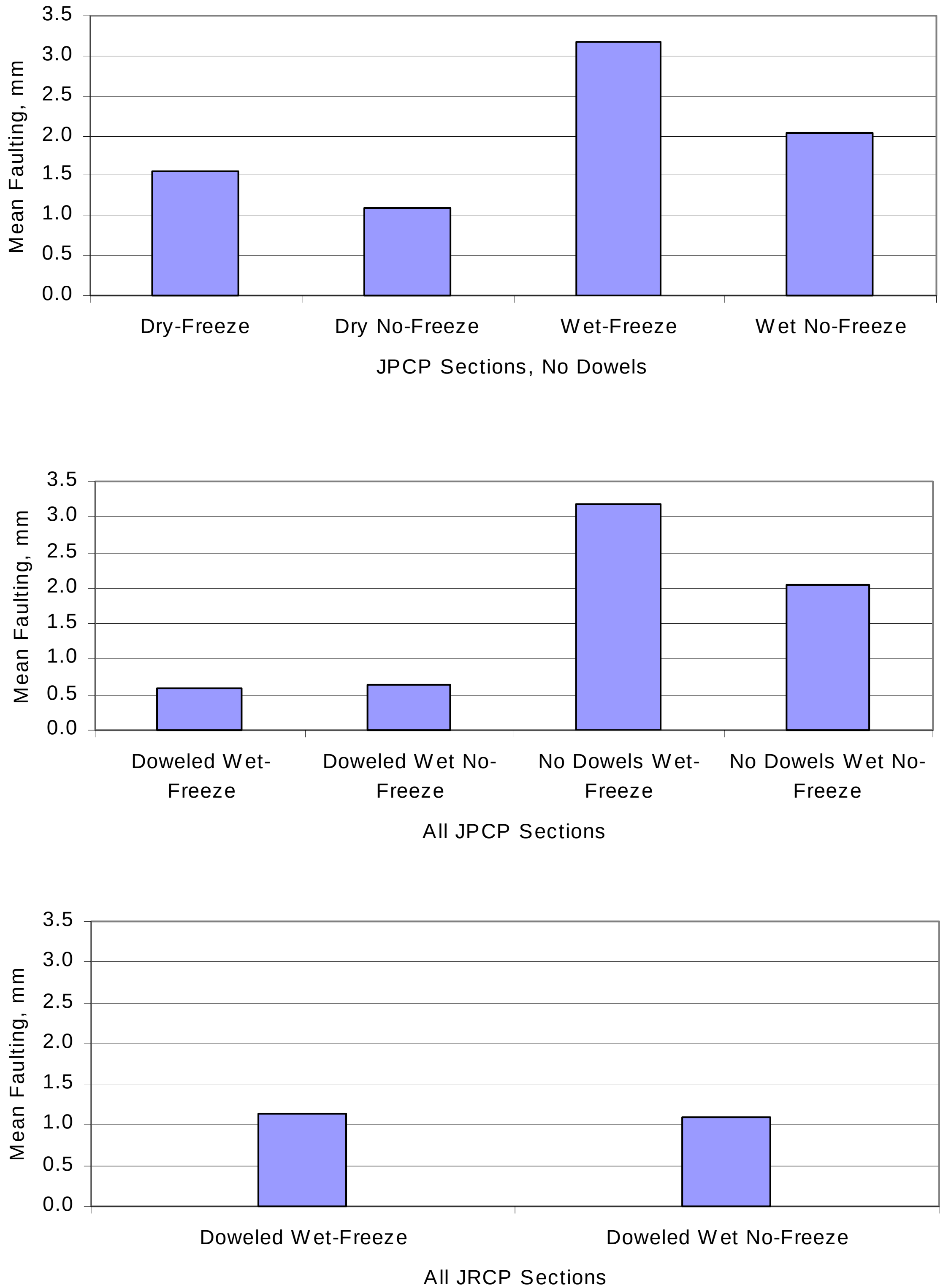


Figure 27. Comparison of mean faulting values for JPCP and JRCP sections located in different climatic zones.

trend: average faulting values were increasing or remaining stable with age. Few sections with questionable trends were identified. The reasons for these trends were investigated at the regional offices and, as it was found, zero values were entered by default in the database when null values should have been used instead. This change has been completed.

An assumption of zero average faulting values at the start of pavement in-service life was tested using computed average faulting values for SPS-2 experiment sites. Ninety-seven percent of the computed average edge faulting values and 99 percent of the computed average wheelpath faulting values were less than 1 mm. Since the precision of the Georgia Faultmeter is ±1 mm, all the values more than -1 mm and less than +1 mm can be reasonably assumed to be equal to zero. Therefore, an assumption of initial zero faulting is correct.

The effect of faulting on ride quality was investigated using JPCP sections with three or more faulting and IRI surveys conducted no more than 1 year apart from each other. A strong correlation was found between rate of change in faulting values and rate of change in IRI values.

An analysis was carried out to determine the usefulness of joint faulting and other related LTPP data in identifying factors that affect joint faulting. The results of the data analysis indicated that the following factors affect faulting:

- Use of load transfer devices has the greatest effect on the amount of joint faulting. Use of dowel bars reduces joint faulting of JPCP sections by the factor of two.
- Use of larger diameter dowels results in lower faulting values for JPCP sections.
- Use of widened lanes results in reduced edge faulting values, especially for JPCP sections.
- Use of drainage features significantly reduces faulting, especially for JPCP non-doweled sections.
- Use of stabilized base/subbase significantly reduces faulting, especially for JPCP non-doweled sections.
- Shorter joint spacing significantly reduces faulting in all pavement categories.
- Use of skewed joints did not show significant difference in faulting values for doweled joints.
- Non-doweled JPCP sections located in wet-freeze zones exhibited the worst faulting among all sections.
- Doweled joints exhibit very little faulting even after many years of service. The effect of design features such as drainage, tied-concrete shoulder use, and joint spacing is not as significant when doweled joints are used.

The results obtained in this chapter are limited by the resolution of the Georgia Faultmeter of ±1 mm. This resolution seems to be too large, since average faulting measurements are on the order of 3 mm. The other limitation of the analysis was the difficulty of establishing a full set of variables because of the large amount of missing complementary data.

5. SUMMARY

The primary objectives of the study reported here were to examine the quality of the joint and crack faulting data, provide recommendations for resolving questionable data, and develop representative faulting indices and statistics for each jointed concrete pavement test section in the LTPP program. In addition, preliminary analysis of the faulting data was conducted to identify practical trends in faulting development.

The following observations and conclusions regarding faulting data availability, quality, and relationships between faulting data and other pavement design features or characteristics were derived from this study:

Faulting Data Availability

Data for 422 JCP sections were available in the IMS database at the time of the study. Out of 422 sections, only 307 sections had records in the faulting data table MON_DIS_JPCC_FAULT, for a total of 24,108 records. The number of faulting surveys for these sections ranged from one survey to nine, with 31 percent of sections having only one survey in the database. This magnitude of missing data is considered very serious because faulting is one of the key distress types associated with jointed concrete pavements. Future efforts should be focused on ensuring that faulting data are collected as required.

Faulting Data Quality

The available faulting data were evaluated in terms of missing and questionable data.

- *Missing Faulting Data* – For the faulting data studied, many sections have missing faulting measurements at some joint and crack locations along the section. In some cases, faulting measurement locations for joints from different surveys do not correspond to each other. In other cases, different total numbers of joints were reported on different surveys. Furthermore, the total number of joints counted from joint faulting tables did not always agree with either the number of joints computed from the joint spacing data in the inventory table or with the number of joints counted from PASCO distress maps. This problem was reported in LTPP Feedback Reports.

- *Negative Faulting Data* – Negative faulting values are present in 4 percent of all faulting observations. The majority of negative faulting records were equal to -1 mm (73 percent of all negative faulting cases). In most cases, the negative faulting values were random occurrences, with a few repeated at the same joint/crack locations. In several instances, negative faulting profiles were mirror images of the positive faulting profiles measured on a different survey date. All cases of negative faulting were reported to FHWA.

- *Reasons for Negative Faulting* – The reasons for excessive negative faulting values were investigated at the Regional Centers, and a few causes were identified. Negative mirror image faulting resulted from the fact that the faultmeter was turned in the wrong direction during data collection. Other negative faulting values were attributed to measurements over patched or sealed joints.

- *Negative Faulting of -1 mm* – The possible reasons for negative faulting were investigated using SPS-2 sites. It was found that 40 percent of SPS-2 sections had at least one joint that exhibited a negative faulting value on the first faulting survey after construction. Most negative faulting values were equal to -1 mm. This fact can be attributed to random positive and negative measurement variation taken on joints with zero faulting, as would be expected for new construction (because of built-in surface texture and the precision of the Georgia Faultmeter being ±1 mm).

- The overall quality of the faulting data reported in the IMS database is acceptable for the development of faulting indices and summary statistics, in terms of data availability. Assessment of the available data indicated that up to 95 percent of faulting surveys could be used for the development of representative indices and summary statistics. Only 1 percent of surveys were dismissed because of a large number of points with excessive negative faulting (more than 25 percent of measurements per survey with less than -2 mm), and 4 percent were dismissed because of a large number of points with missing faulting observations (more than 25 percent of measurements per survey).

- *Precision of Georgia Faultmeter* – The faulting data quality issue addressed in this study was affected by the precision of the Georgia Faultmeter, which is the standard faulting measurement equipment used in LTPP studies. A review of numerous faulting records indicated that accuracy of ±1 mm is inadequate because representative maximum faulting values, obtained as an average of all maximum faulting values for all sections and surveys, were about 5 mm for non-doweled sections and 3 mm for doweled sections. It is recommended that the Georgia Faultmeter be modified to read to 0.1 mm. Use of a more precise device would significantly improve the quality of future faulting data collection and benefit future pavement performance analysis, especially for the SPS-2 and SMP sections that are still in the early stages of pavement service life.

- Available faulting data were also evaluated in terms of usefulness for faulting trend analysis. It was found that less than 45 percent of sections had faulting data available from three or more surveys. Therefore, trend analysis reported in this report is to be viewed as “limited” or “preliminary.” It is recommended that more extensive trend analysis be conducted as more data become available. The lack of faulting measurements over time must be corrected in the future if the LTPP program is to provide significant findings on ways to reduce faulting.

Computed Faulting Indices and Summary Statistics

- *Representative Faulting Values for Each Survey* – Mean faulting values were computed for each section and each survey date where 75 percent or more measurements were present and valid. Standard deviations, minimum and maximum faulting values, and other related quantities were also computed for these cases. Computed faulting indices and summary statistics can be found in a new LTPP database table, MON_DIS_JPCC_FAULT_SECT.

- *Outliers* – The computed faulting statistics for each section survey were used to determine the outlier faulting observations for each survey. About 30 percent of all the surveys contain at least one outlier point along the section. The average percentage of outlier points (for surveys that contain outliers) is about 5 percent.

Faulting Trend Analysis

- *Faulting Data Time History* – Time history plots of mean faulting data were generated and examined for all the sections. Most of the sections show a reasonable trend over time, with average faulting values increasing or remaining stable with age. Few sections exhibited questionable time trends of average faulting—either decreasing or fluctuating with time.

- *Reasons for Questionable Faulting Trends* – Sections with questionable trends were reported in LTPP Feedback Reports. Most of the questionable trends resulted from zero faulting reported on a survey when non-zero faulting was reported on the previous or on the following surveys. As was found through the response from the Regional Centers, zero values were entered by default in the database when null (resulting in an empty table cell) values should have been used instead.

- *Initial Faulting* – An assumption of zero average faulting values at the start of pavement in-service life was tested using computed average faulting values for SPS-2 experiment sites. The mean faulting measurements for all SPS-2 sections was 0.2 mm for both wheelpath and edge on the first survey since construction. Also, the distributions indicate that 97 percent of the computed average edge faulting values and 99 percent of the computed average wheelpath faulting values are less than 1 mm. These results indicate that the mean faulting of newly constructed SPS-2 joints is very close to zero, as would be expected.

Faulting Rate Versus IRI Rate for JPCP Sections

- The effect of faulting on ride quality was investigated using JPCP sections with three or more faulting and IRI surveys conducted no more than 1 year apart from each other. A strong correlation was found between rate of change in faulting values and rate of change in IRI values for JPCP sections. Thus, faulting was found to be a major component of increased roughness of JCP.

Effects of Various Design Features and Site Conditions on Faulting

Computed faulting values were compared for key JCP design features, such as dowel bars, joint spacing, drainage, and traffic, for different pavement age groups. The results of the data analysis indicated that the following factors affect faulting:

- Use of load transfer devices has the greatest effect on the amount of joint faulting. Use of dowel bars reduces joint faulting of JPCP sections by a factor of two.
- Use of larger diameter dowels results in lower faulting values for JPCP sections.
- Use of widened lanes results in significant reduction of edge faulting values, especially for JPCP sections.
- Use of drainage features significantly reduces faulting, especially for JPCP non-doweled sections.
- Use of stabilized base/subbase significantly reduces faulting, especially for JPCP non-doweled sections.
- Shorter joint spacing significantly reduces faulting in all pavement categories.
- Use of skewed joints did not show a significant difference in faulting values for doweled joints.
- Non-doweled JPCP sections located in a wet-freeze climatic zone exhibited the worst faulting among all sections.
- Doweled joints exhibit very little faulting even after many years of service. The effects of design features such as drainage, tied-concrete shoulder use, joint spacing, and climatic zone are not as significant when doweled joints are used.

The results obtained in this study are affected by the resolution of the Georgia Faultmeter (±1 mm). This resolution seems to be too large, because average faulting measurements are on the order of 3 mm.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

To improve the reliability of the collected faulting data, the following recommendations are made:

- The measurement of faulting needs to be given a high priority. A large amount of data is missing, and time-series data are scarce.

- More accurate faulting measurements should be obtained. It is recommended that the Georgia Faultmeter be modified or an alternative device be used to read to 0.1 mm. Use of the more precise device would significantly improve the quality of future faulting data collection and benefit future pavement performance analysis, especially for the SPS-2 and SMP sections that are still in the early stages of pavement service life.

- Use of automated profilometer data to detect faulting and slab curvature should be investigated as a means of improving the quality of faulting data.

- Whenever negative faulting values are recorded at multiple points along the section, or if faulting records for the section do not contain any positive readings (possibility of mirror image), the Faultmeter should be calibrated and measurements should be repeated and the reasons for negative faulting should be commented upon.

- To avoid inconsistency in records of joint/crack locations currently found in faulting data, it is recommended that the Regional Offices use a template for each section to record the joint faulting data. This way, the same joint and crack locations will be used in every survey, and joint/crack location data will be more consistent.

- Recording the time of faulting measurement during the day will allow analysts to account for the effect of temperature gradient through the slab on joint faulting.

- Joint and crack load transfer efficiency at each joint and crack, loss of support data, and slab curling data should be utilized in future analyses.

These recommendations for improvement of reliability of the collected faulting data have been submitted to FHWA as an LTPP Data Analysis Feedback Report numbered ERES_BW_70.

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APPENDIX A – COMPUTATION AND STORAGE OF LTPP PCC JOINT FAULTING SUMMARY STATISTICS

Joint faulting is one of the key distress types that leads to decline in ride quality of jointed rigid pavements. Transverse joint faulting is being monitored regularly at the jointed concrete pavement test sections under the Long-Term Pavement Performance (LTPP) program. Faulting data are available for the GPS-3, GPS-4, GPS-9, SPS-2, SPS-4, SPS-6, and SPS-8 experiments. These sections represent the following pavement types:

- Jointed plain concrete pavement (JPCP).
- Jointed reinforced concrete pavement (JRCP).
- JPCP over JRCP.
- JPCP over JPCP.
- JRCP over JPCP.
- JRCP over JRCP.
- JPCP over continuously reinforced concrete pavement (CRCP).
- JRCP over CRCP.

Joint faulting is measured at each joint at two locations, the edge (corner) and at the outside wheelpath, using the Georgia Faultmeter. Faulting is also measured at some transverse crack locations.

In addition to the joint-by-joint faulting data currently available in the Information Management System (IMS), it is preferable to have available representative faulting values and companion statistics for each site for each measurement cycle (site visit). The availability of computed representative values of edge and wheelpath faulting would minimize duplication of effort in future analysis work and provide a consistent set of data to be used for study of joint and crack faulting. The representative faulting values for each test section can be used for the investigation of time-series trends and proof testing of the faulting data. Analysts can make use of the representative faulting indices and statistics for the development of mechanistic-based prediction models for joint faulting. To provide LTPP users with representative faulting indices and statistics, a new computed parameters table is proposed for inclusion in the IMS database.

Structure of Table MON_DIS_JPCC_FAULT_SECT

The new table, **MON_DIS_JPCC_FAULT_SECT**, resides in the monitoring module within the IMS database. The data source for table **MON_DIS_JPCC_FAULT_SECT** is the IMS table **MON_DIS_JPCC_FAULT**. The new table includes calculated statistical values developed separately for joint faulting and for transverse crack faulting for each site for each measurement cycle (site visit). Therefore, each test section may contain up to two records per site visit: one for joint faulting statistics and one for transverse crack faulting statistics. A specially coded column is used to indicate whether it is a joint or crack record. Each record contains separately calculated statistical indices for wheelpath and for edge faulting. Calculated statistical faulting indices include average, minimum, and maximum faulting, standard deviation, number of observations used in developing statistics, number of missing observations, number of observations with negative faulting, and total number of observations per visit. Comment fields indicate the reasons that faulting statistics are not provided for certain survey dates.

Table 30 contains the schema and field definitions for the new table **MON_DIS_JPCC_FAULT_SECT**. Table 31 contains the description of codes used to define availability of data for computation of faulting indices and summary statistics. The description of computational algorithm to produce faulting indices and summary statistics can be found in chapter 3 of the report entitled *Assessment of LTPP Faulting Data*.

Table 30. Schema and field definition for table **MON_DIS_JPCC_FAULT_SECT.**

Field Name	Unit	Field Type	Codes	Data Dictionary Description
STATE_CODE		NUMBER(2,0)		Code identifying the State or Province
SHRP_ID		VARCHAR2(4)		SHRP section identification
SURVEY_DATE		DATE		The date the survey was performed
CRACK_OR_JOINT		VARCHAR2(1)	see desc	A code indicating whether the faulting is at cracks (C) or joints (J)
CONSTRUCTION_NO		NUMBER(1,0)		Event number indicating pavement layer changes in a section. Set to 1 when a section is chosen for inclusion in the LTPP study and incremented after each pavement layer change. It is in all tables that relate to a section at a specific time
RECORD_STATUS		VARCHAR2(1)		Status code related to level of QC, set to Level A initially
NO_TOTAL_POINT_LOC		NUMBER(3,0)		Total number of points available for wheelpath or edge faulting measurements
AVG_EDGE_FAULT	mm	NUMBER(3,0)		Average edge faulting calculated per site per survey
MIN_EDGE_FAULT	mm	NUMBER(3,0)		Minimum edge faulting per site per survey
MAX_EDGE_FAULT	mm	NUMBER(3,0)		Maximum edge faulting per site per survey
STD_EDGE_FAULT	mm	NUMBER(3,0)		Standard deviation for edge faulting calculated per site per survey
NO_VALID_EDGE_FAULT		NUMBER(3,0)		Number of edge faulting observations per survey with values greater than −1 mm
NO_NULL_EDGE_FAULT		NUMBER(3,0)		Number of missing edge faulting observations per survey
NO_NEG2_EDGE		NUMBER(3,0)		Number of negative edge faulting observations per survey with values less than −2 mm
EDGE_FAULT_STATUS		NUMBER(1,0)	see [1]	A code describing the availability of data to compute edge faulting indices
AVG_WHEELPATH_FAULT	mm	NUMBER(3,0)		Average wheelpath faulting calculated per site per survey
MIN_WHEELPATH_FAULT	mm	NUMBER(3,0)		Minimum wheelpath faulting per site per survey

Field Name	Unit	Field Type	Codes	Data Dictionary Description
MAX_WHEELPATH_FAULT	mm	NUMBER(3,0)		Maximum wheelpath faulting per site per survey
STD_WHEELPATH_FAULT	mm	NUMBER(3,0)		Standard deviation for wheelpath faulting calculated per site per survey
NO_VALID_WHEELPATH_FAULT		NUMBER(3,0)		Number of wheelpath faulting observations per survey with values greater than –1 mm
NO_ NULL_WHEELPATH_FAULT		NUMBER(3,0)		Number of missing wheelpath faulting observations per survey
NO_ NEG2_WHEELPATH		NUMBER(3,0)		Number of negative wheelpath faulting observations per survey with values less than –2 mm
WHEELPATH_FAULT_STATUS		NUMBER(1,0)	see [1]	A code describing the availability of data to compute wheelpath faulting indices

Note: [1] see table 31 for a list of codes for fields WHEELPATH_FAULT_STATUS and EDGE_FAULT_STATUS.

Table 31. Code list for fields WHEELPATH_FAULT_STATUS and EDGE_FAULT_STATUS.

Code Name	**Code Description**
1	Faulting statistics are calculated since more than 75% of points have faulting values equal to or above zero.
2	Faulting statistics were not calculated because of a large number of points with missing faulting observations (25% or more).
3	Faulting statistics were not calculated because of a large number of points with negative faulting values in excess of 1 mm (25% or more).
4	Faulting statistics were not calculated because of a large number of points with either missing and negative faulting values in excess of 1 mm (25% or more combined).

APPENDIX B – AVERAGE FAULTING AND AVERAGE IRI TIME HISTORY PLOTS

Appendix B contains time history plots for 307 sections (121 GPS-3 sections, 52 GPS-4 sections, 18 GPS-9 sections, 65 SPS-2 sections, 43 SPS-4 sections, 6 SPS-6 sections, and 2 SPS-8 sections). These sections are presented sequentially by Experiment Type, State ID, and Section ID.

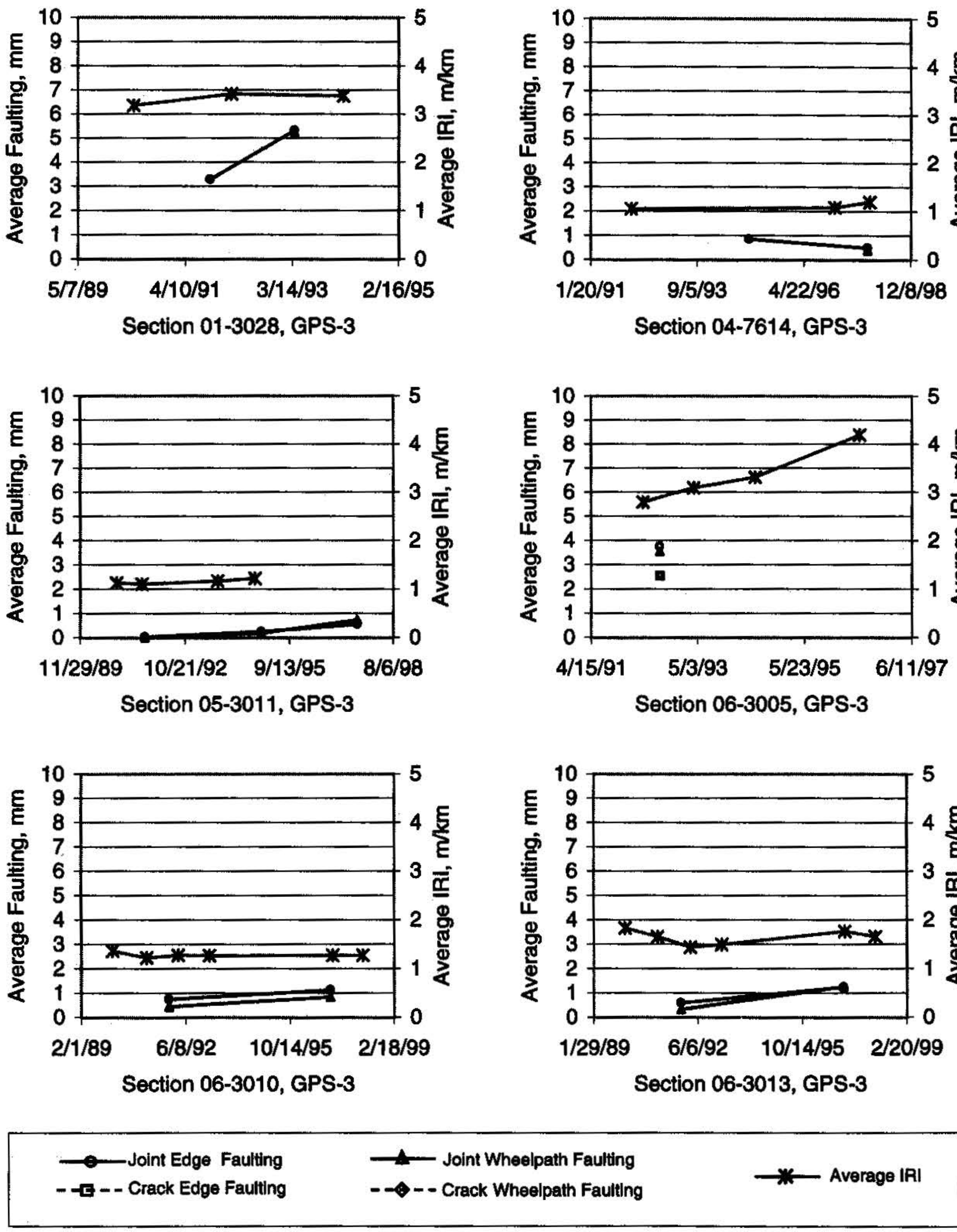

Figure 28. Time series plots for GPS-3 sections 013028, 047614, 053011, 063005, 063010, and 063013.

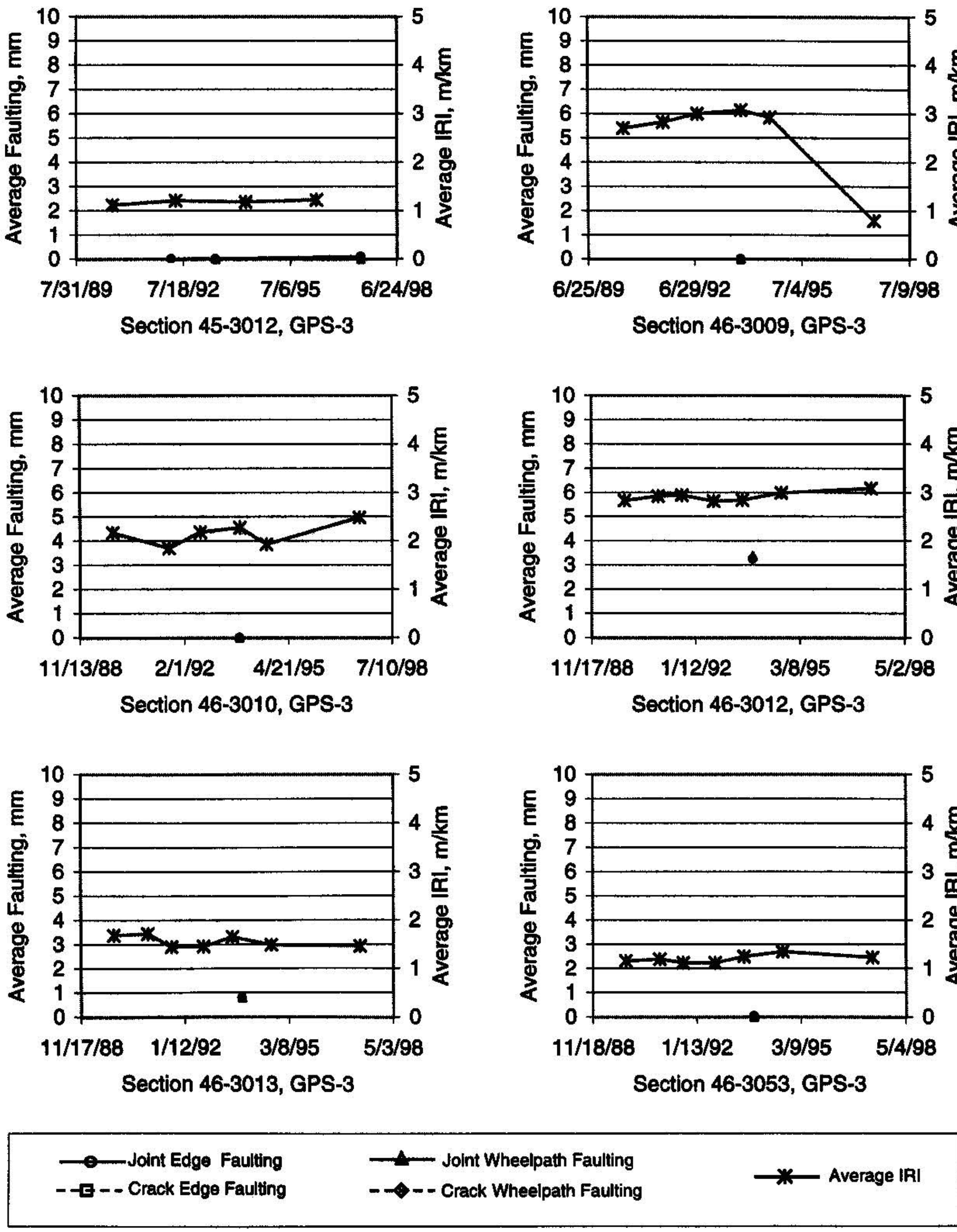

Figure 41. Time series plots for GPS-3 sections 453012, 463009, 463010, 463012, 463013, and 463053.

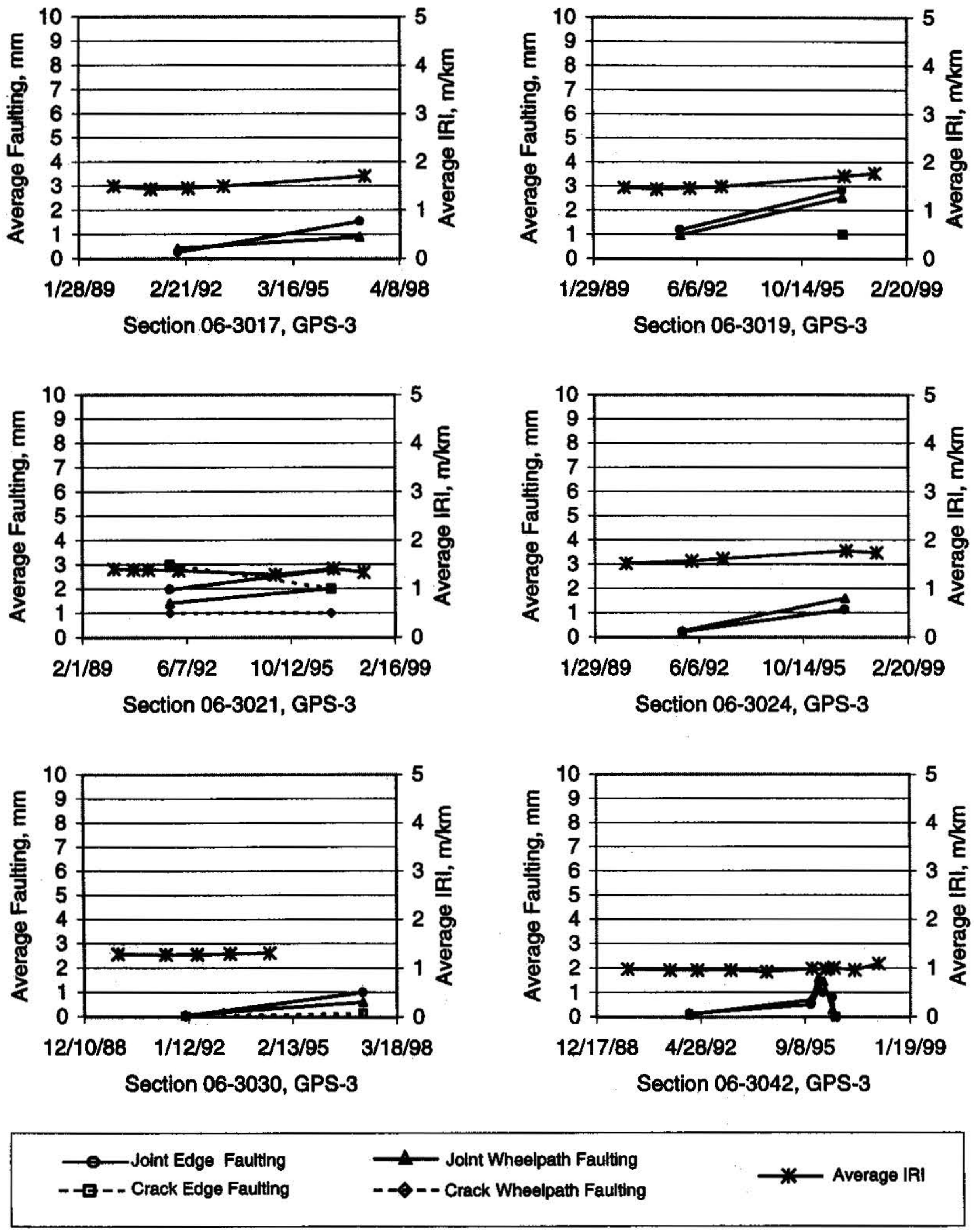

Figure 29. Time series plots for GPS-3 sections 063017, 063019, 063021, 063024, 063030, and 063042.

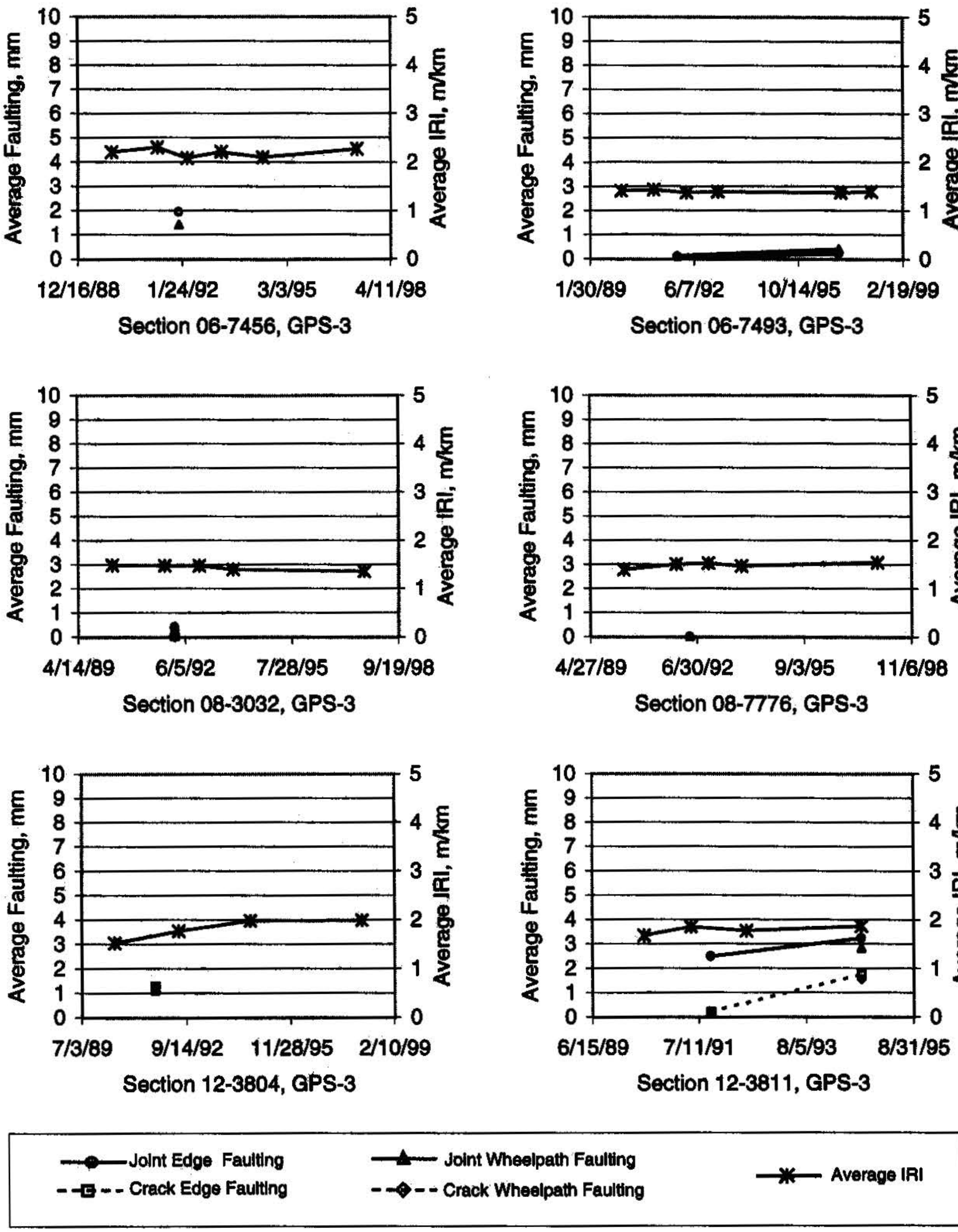

Figure 30. Time series plots for GPS-3 sections 067456, 067493, 083032, 087776, 123804, and 123811.

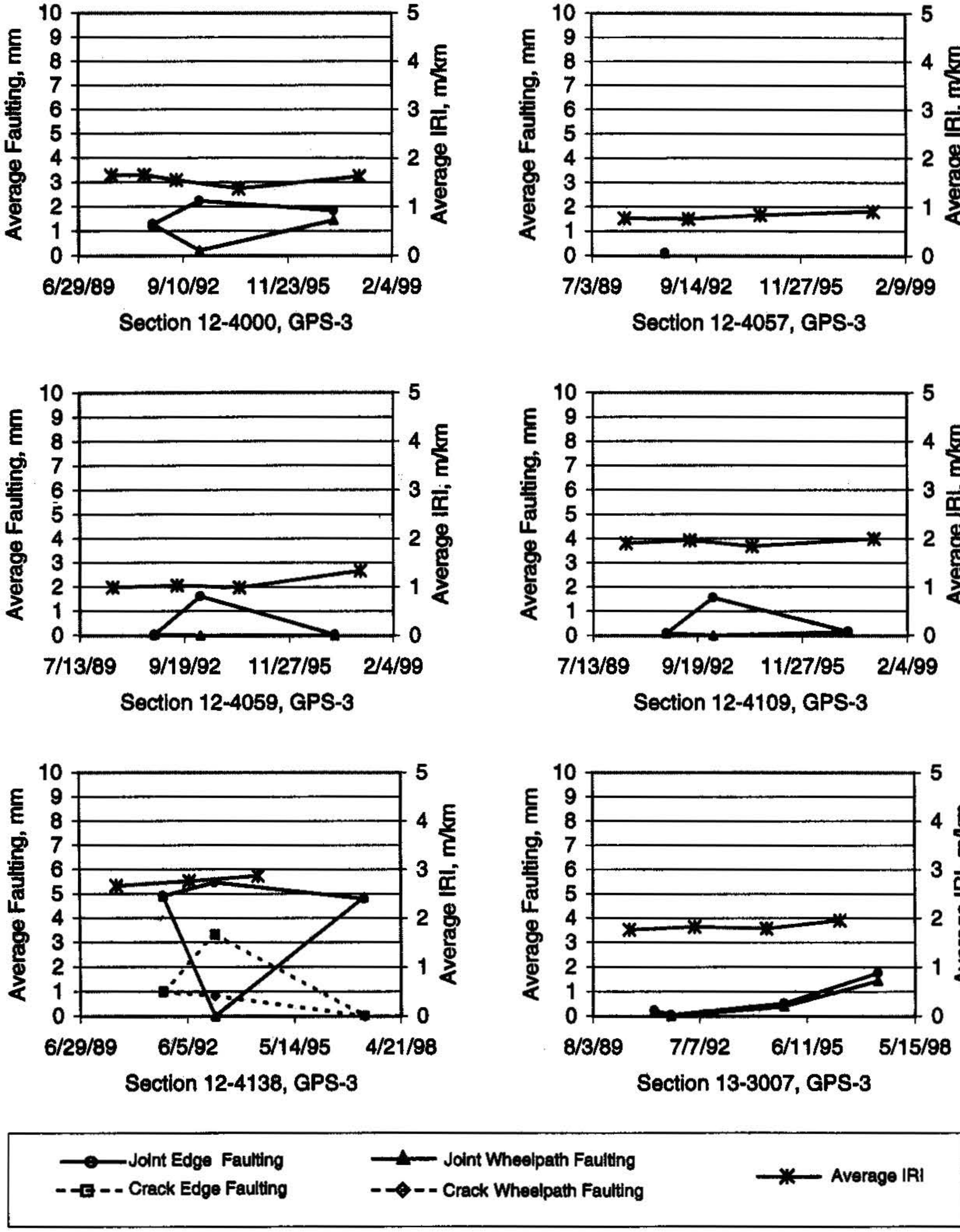

Figure 31. Time series plots for GPS-3 sections 124000, 124057, 124059, 124109, 124138, and 133007.

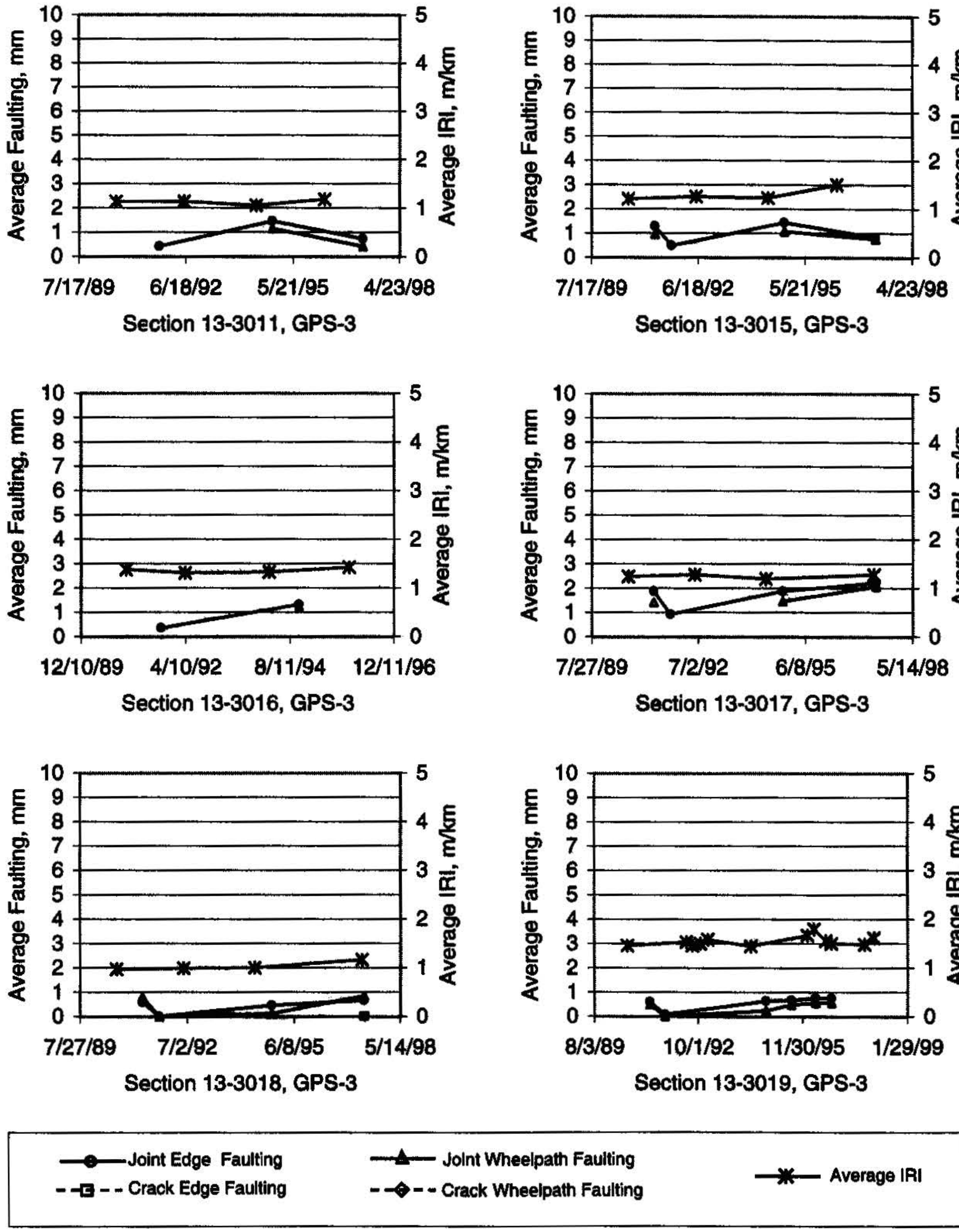

Figure 32. Time series plots for GPS-3 sections 133011, 133015, 133016, 133017, 133018, and 133019.

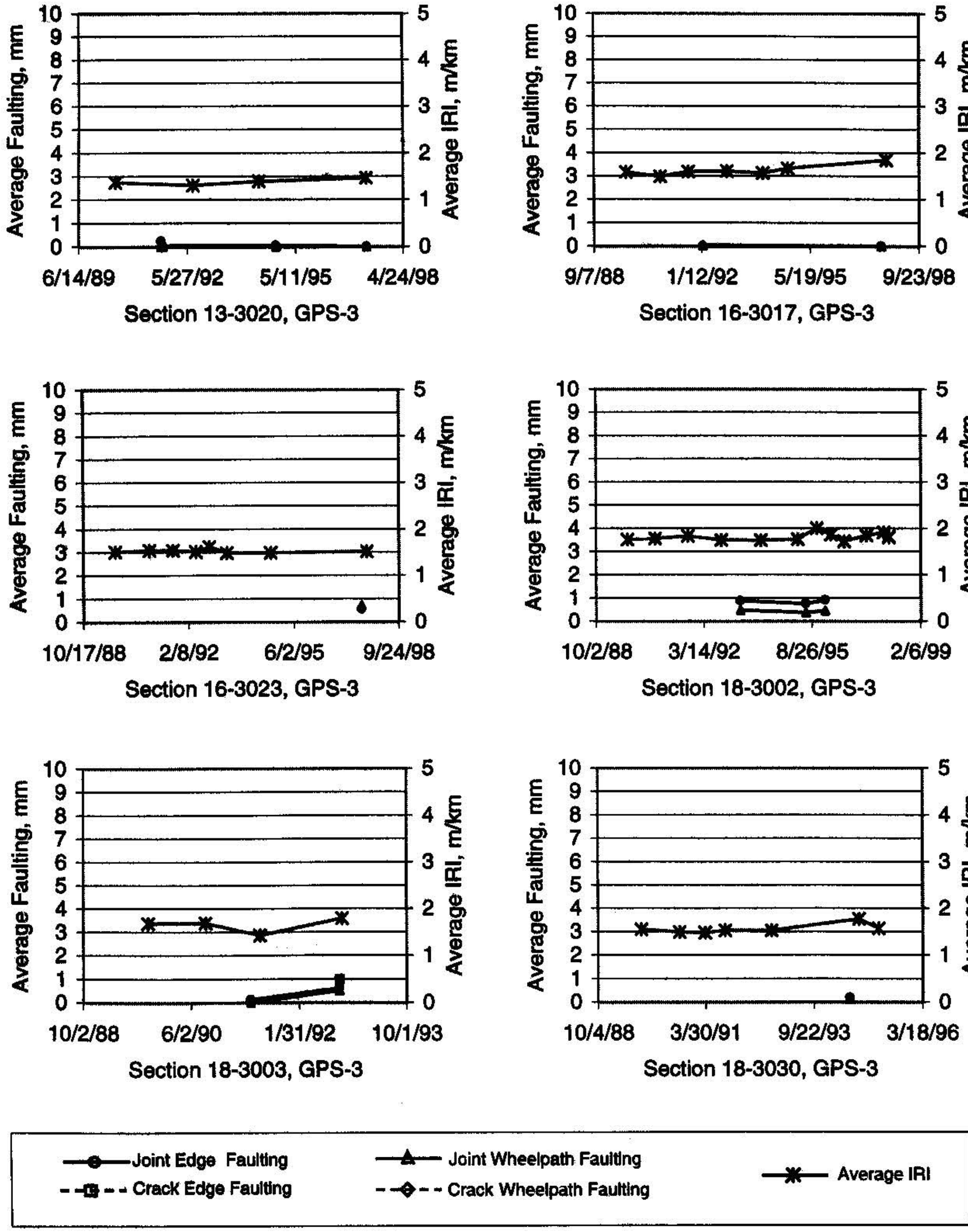

Figure 33. Time series plots for GPS-3 sections 133020, 163017, 163023, 183002, 183003, and 183030.

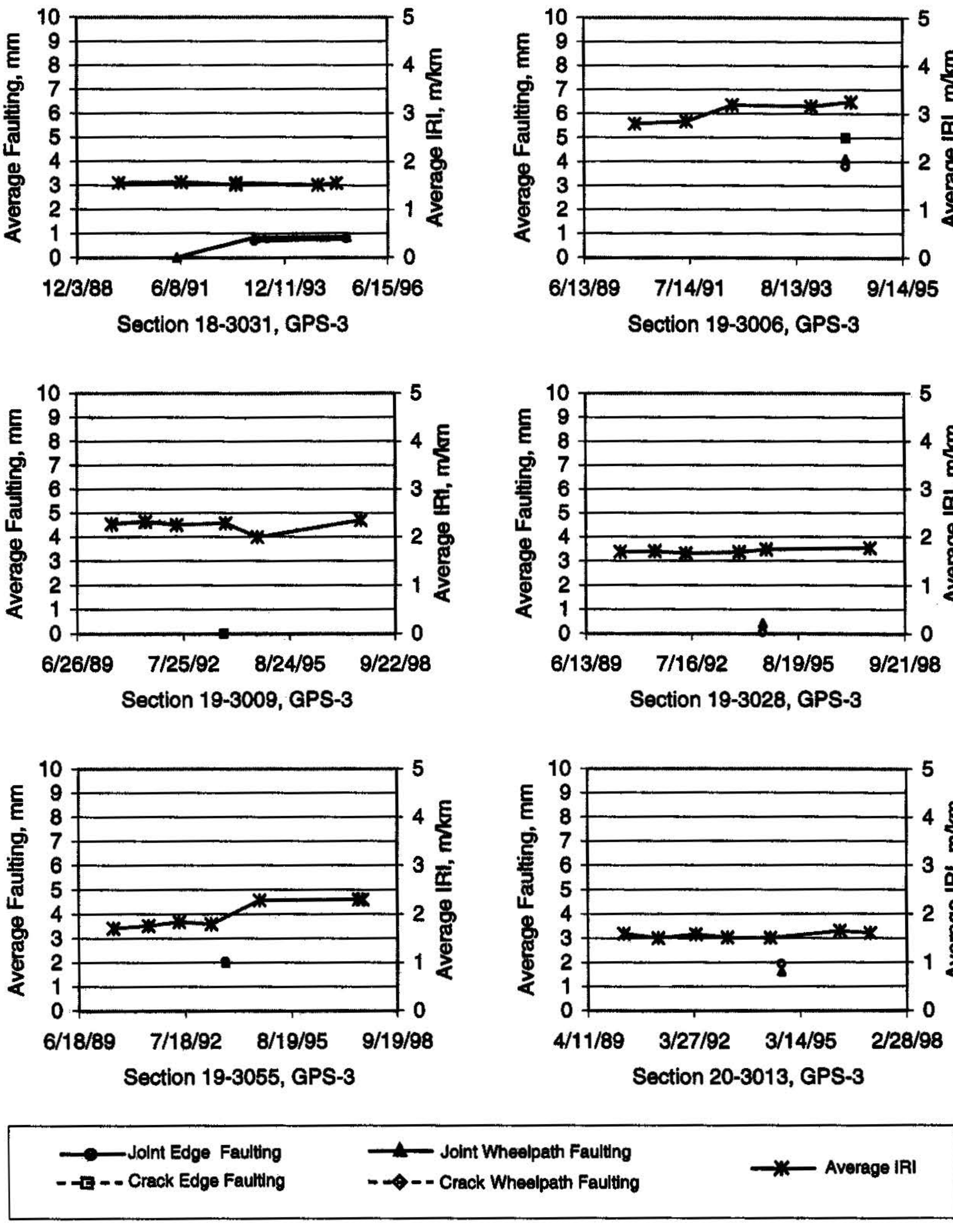

Figure 34. Time series plots for GPS-3 sections 183031, 193006, 193009, 193028, 193055, and 203013.

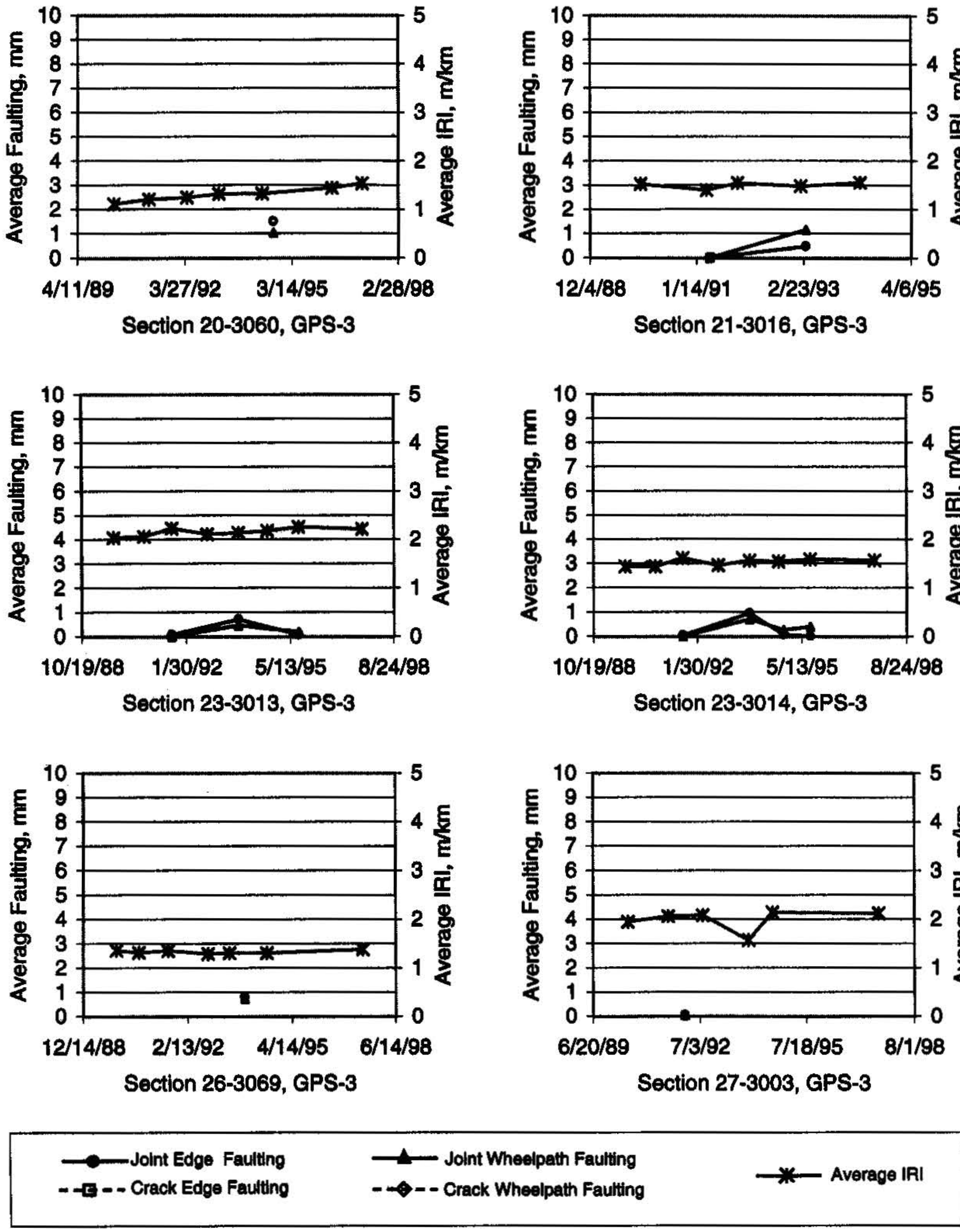

Figure 35. Time series plots for GPS-3 sections 203060, 213016, 233013, 233014, 263069, and 273003.

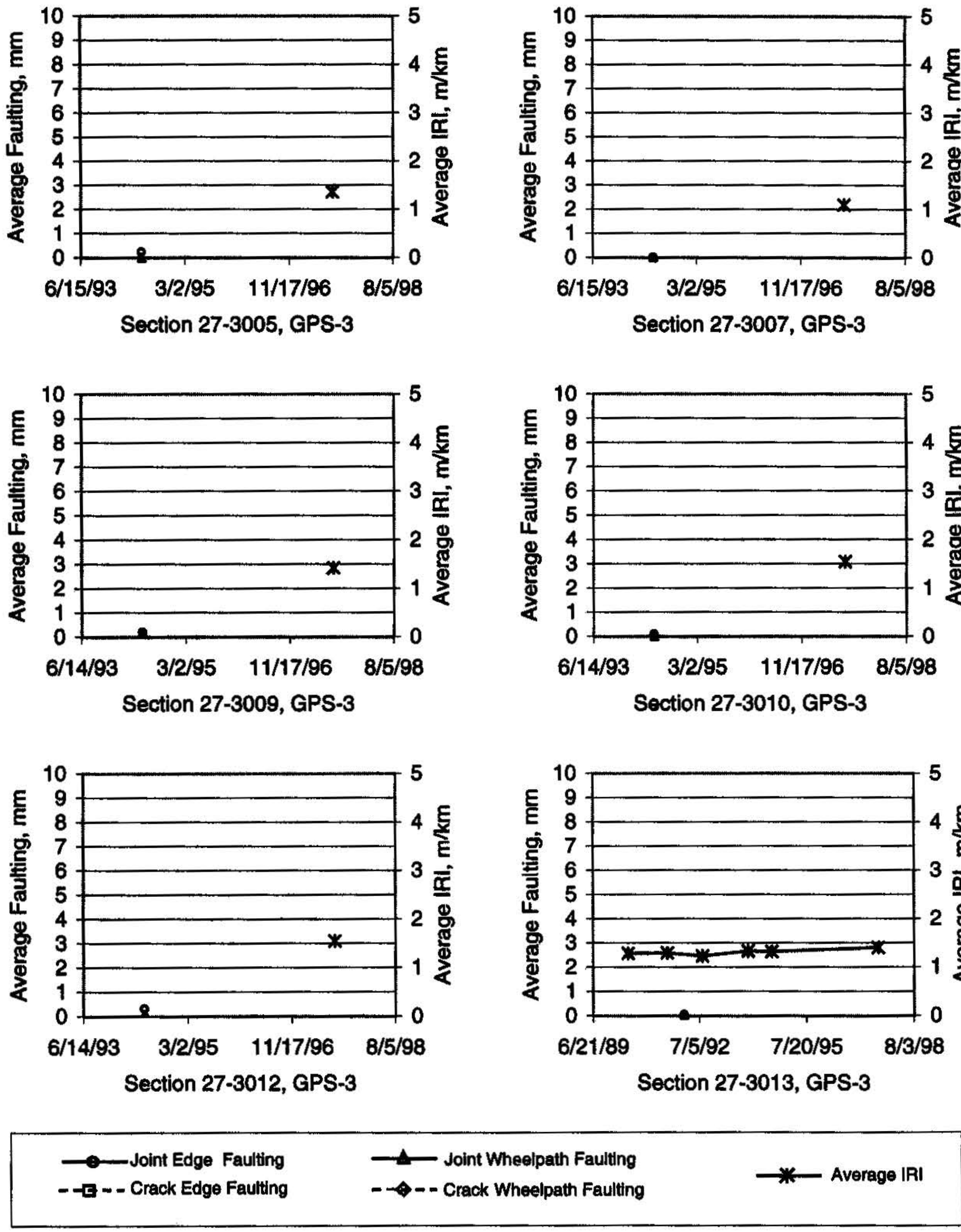

Figure 36. Time series plots for GPS-3 sections 273005, 273007, 273009, 273010, 273012, and 273013.

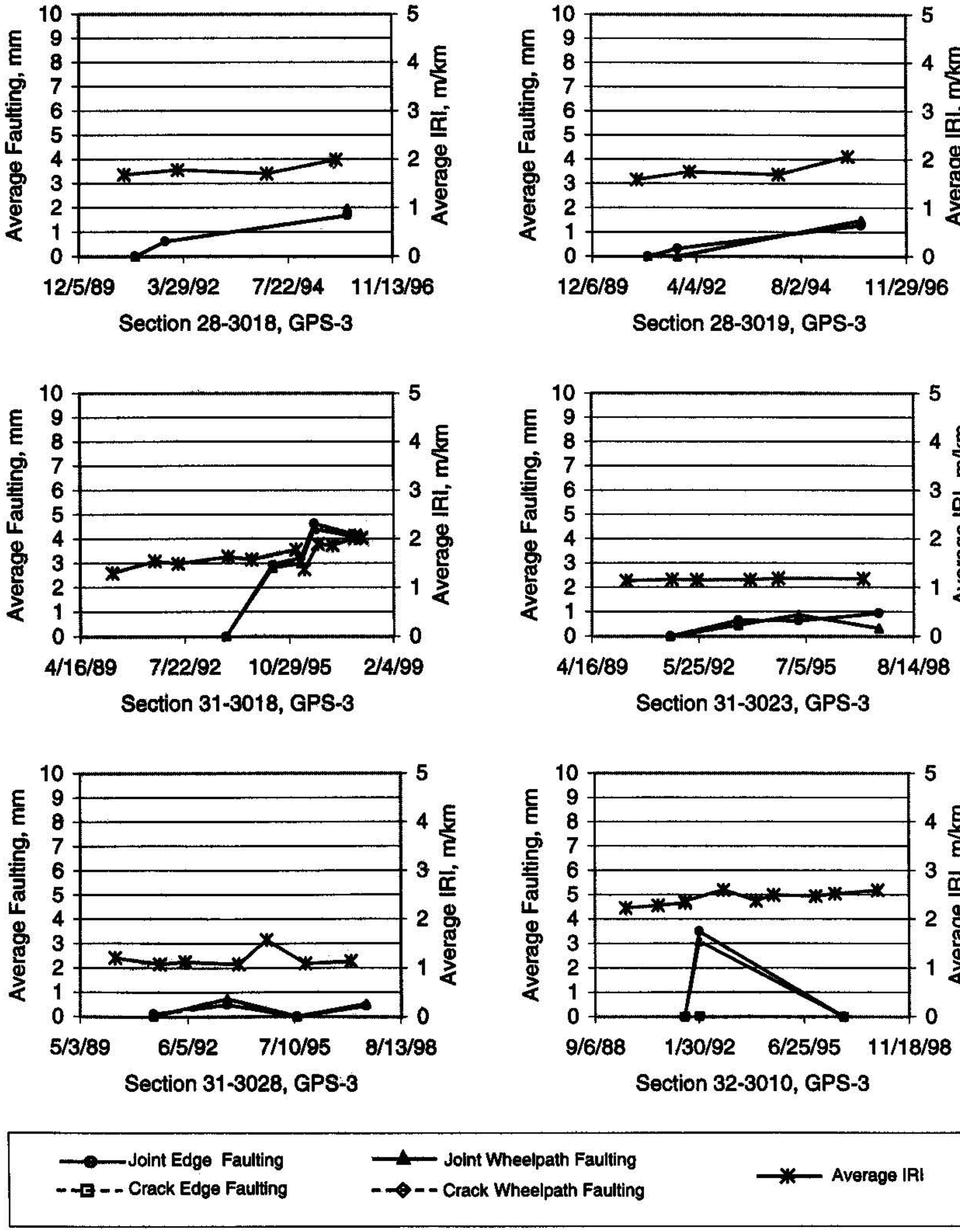

Figure 37. Time series plots for GPS-3 sections 283018, 283019, 313018, 313023, 313028, and 323010.

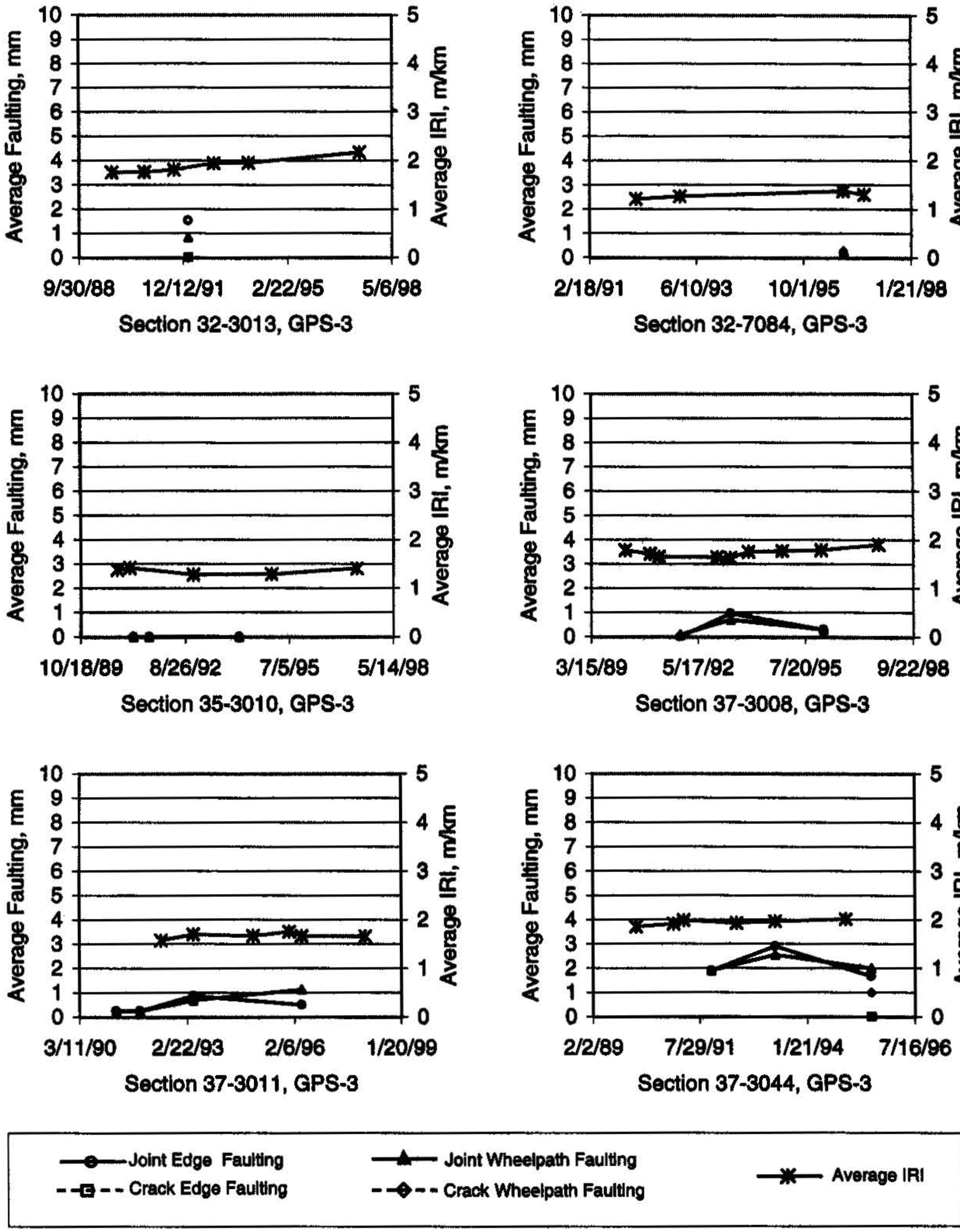

Figure 38. Time series plots for GPS-3 sections 323013, 327084, 353010, 373008, 373011, and 373044.

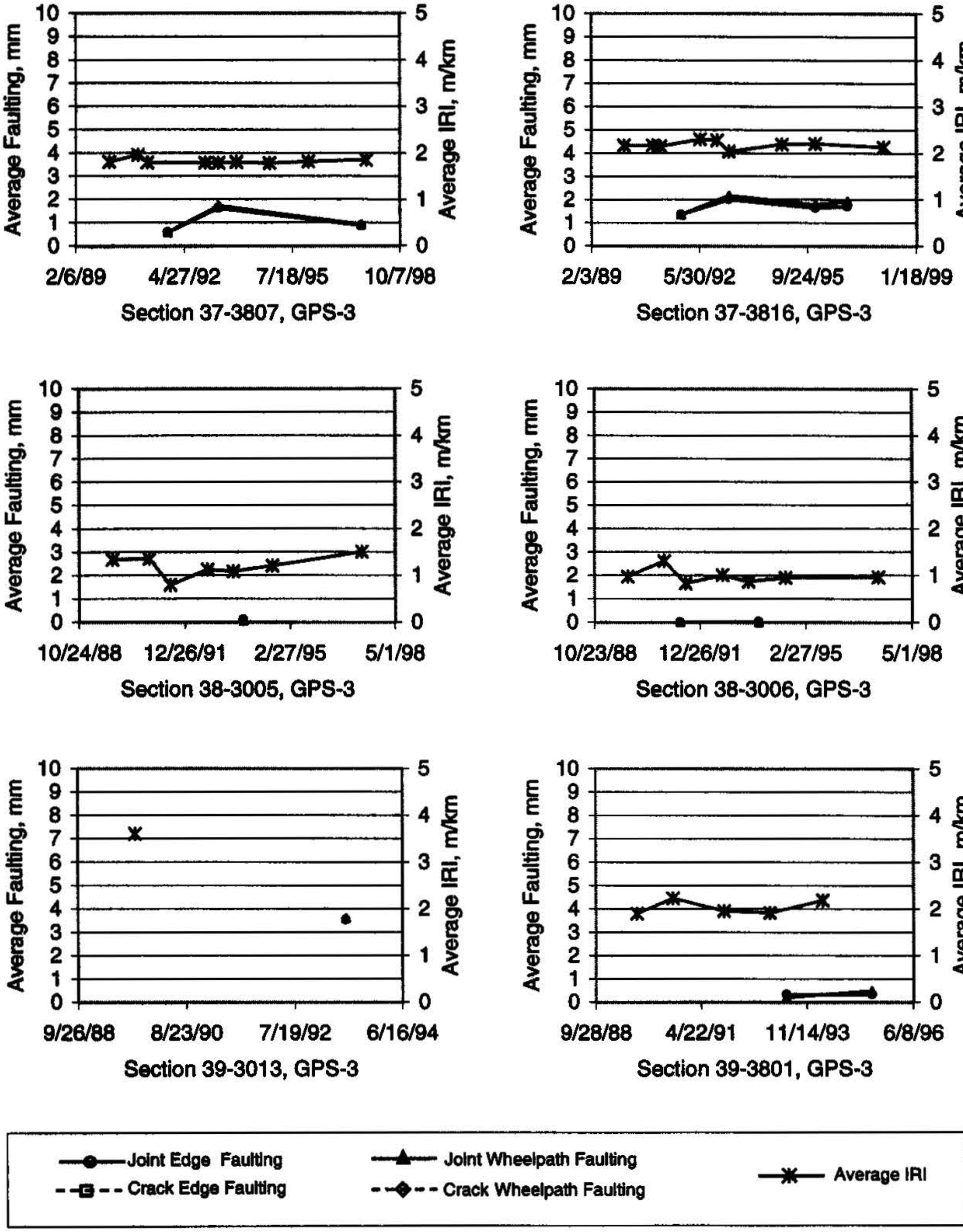

Figure 39. Time series plots for GPS-3 sections 373807, 373816, 383005, 383006, 393013, and 393801.

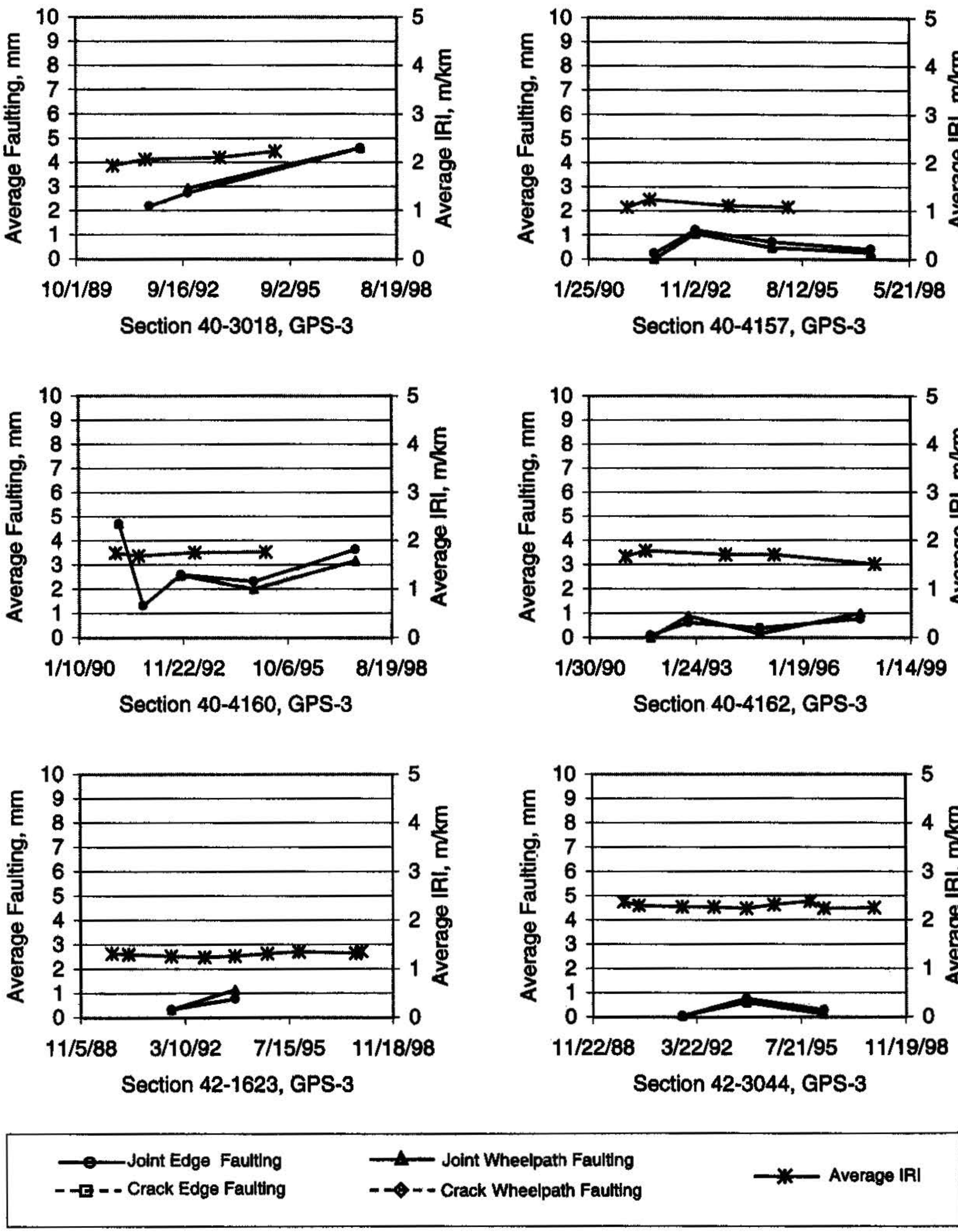

Figure 40. Time series plots for GPS-3 sections 403018, 404157, 404160, 404162, 421623, and 423044.

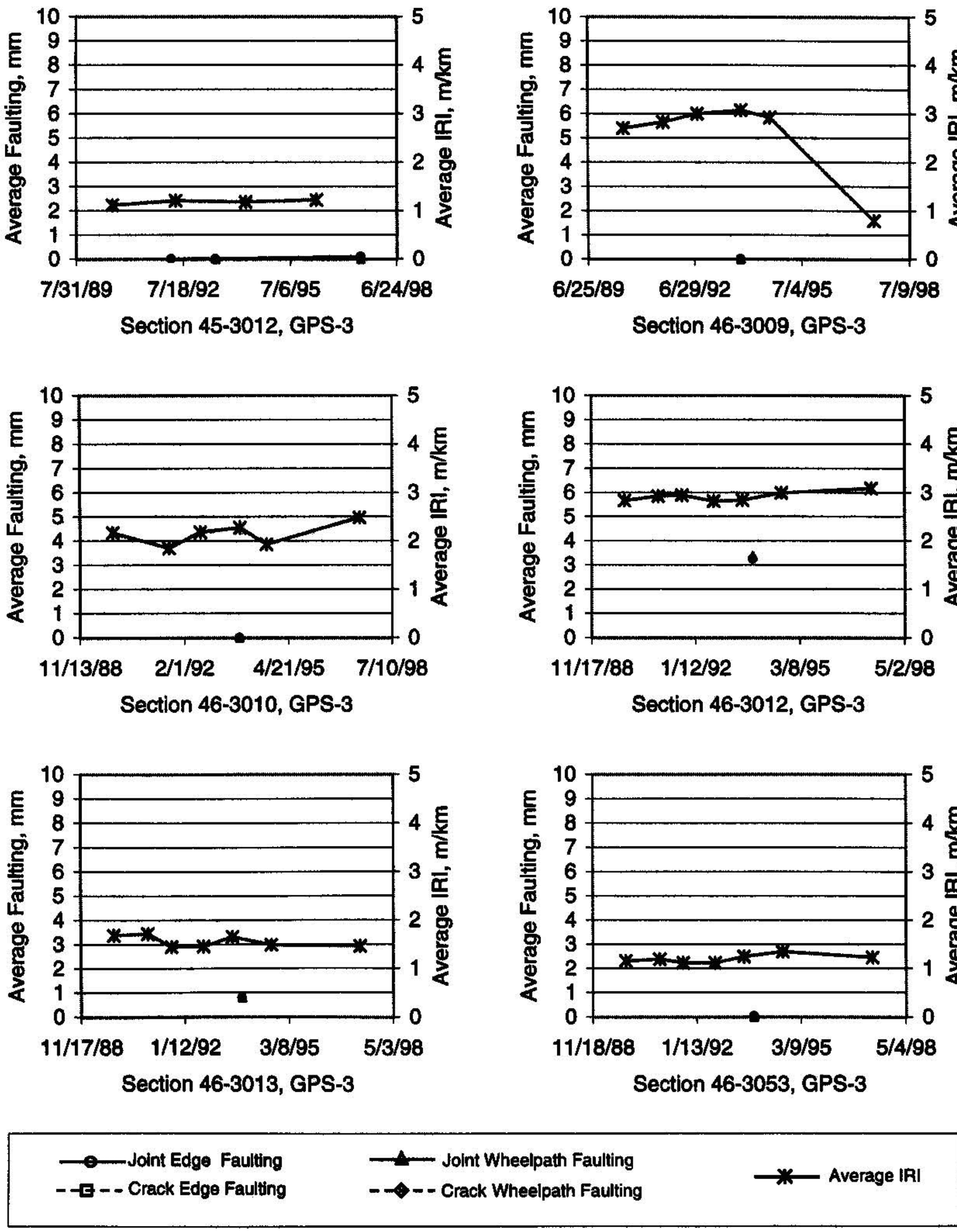

Figure 41. Time series plots for GPS-3 sections 453012, 463009, 463010, 463012, 463013, and 463053.

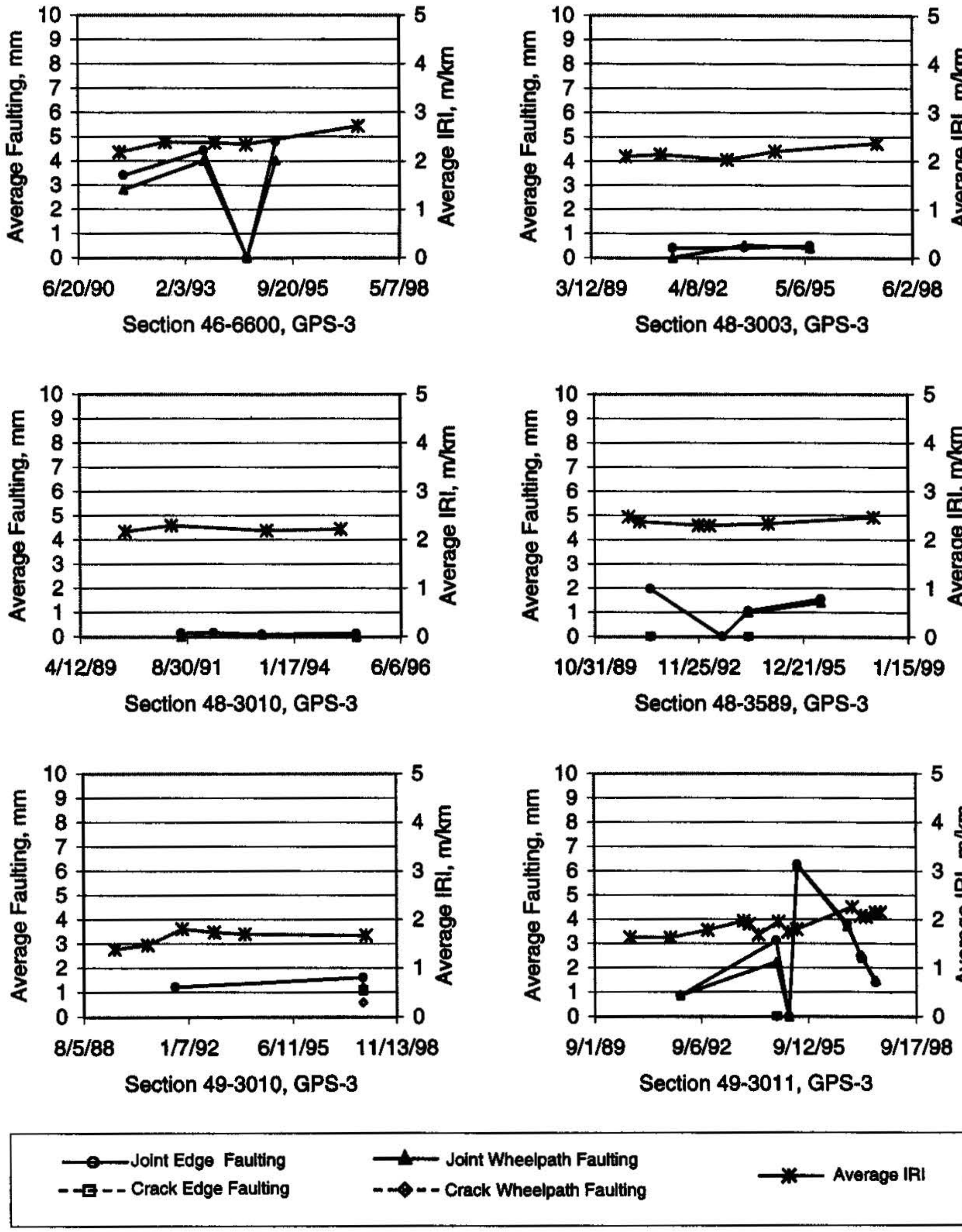

Figure 42. Time series plots for GPS-3 sections 466600, 483003, 483010, 483589, 493010, and 493011.

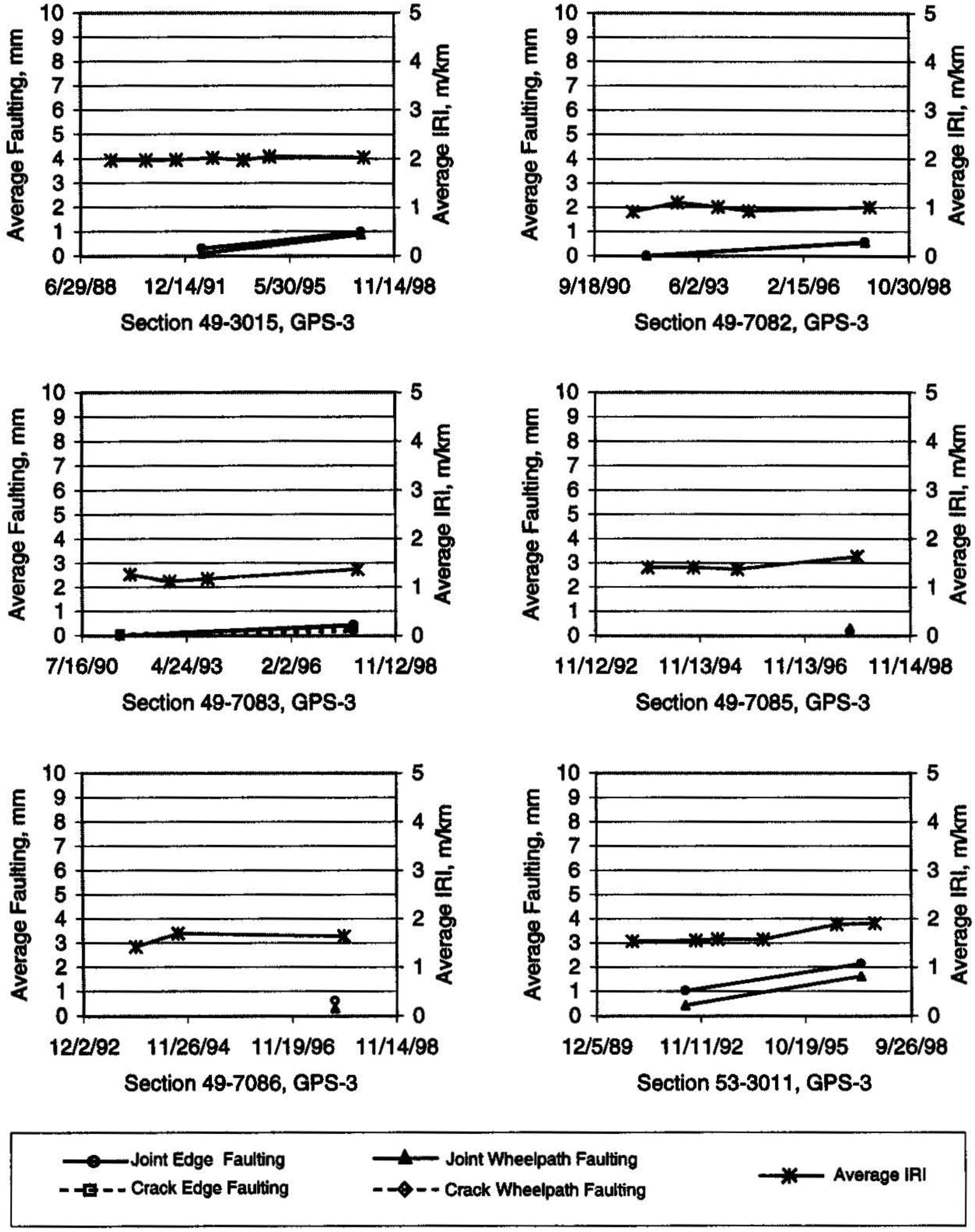

Figure 43. Time series plots for GPS-3 sections 493015, 497082, 497083, 497085, 497086, and 533011.

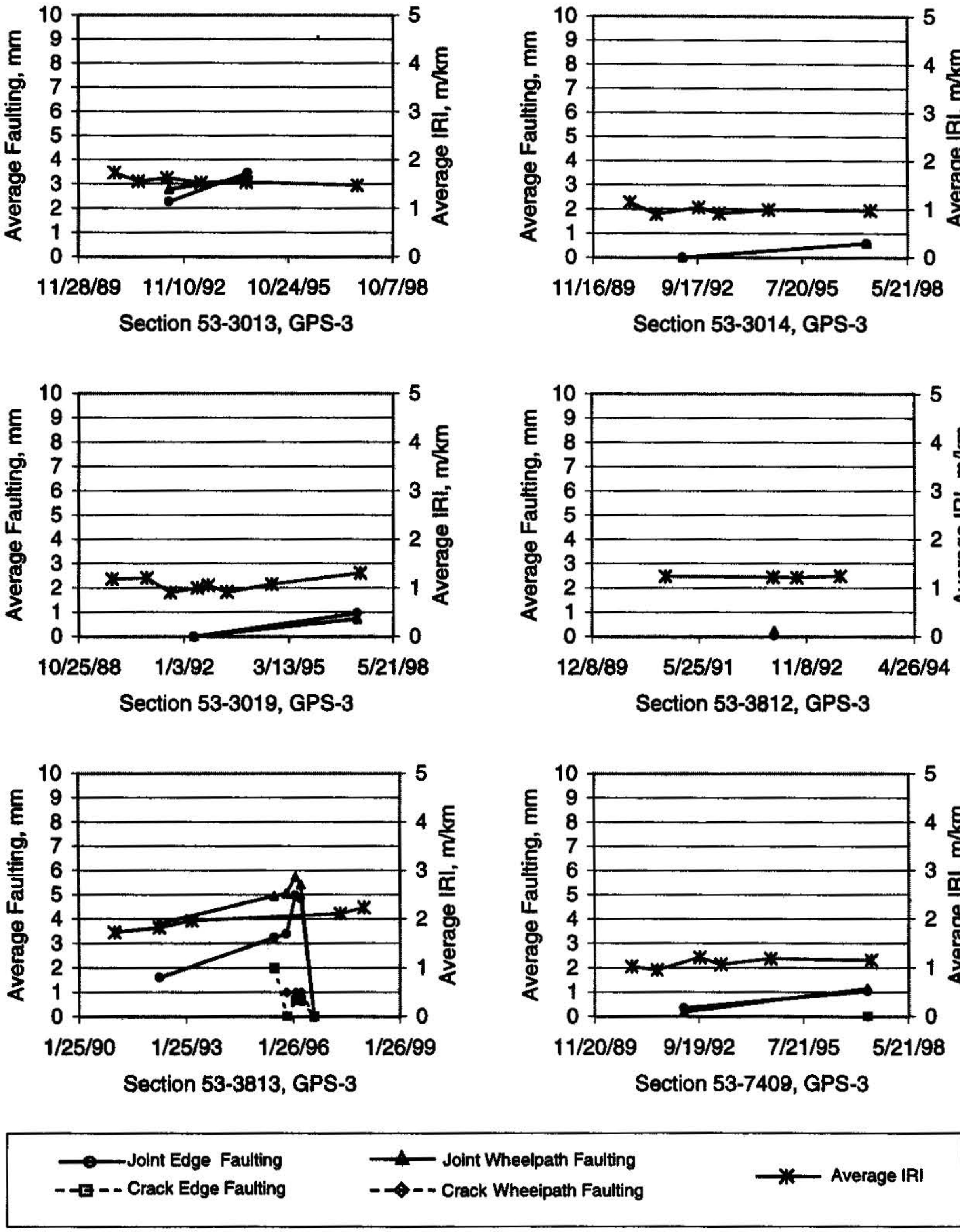

Figure 44. Time series plots for GPS-3 sections 533013, 533014, 533019, 533812, 533813, and 537409.

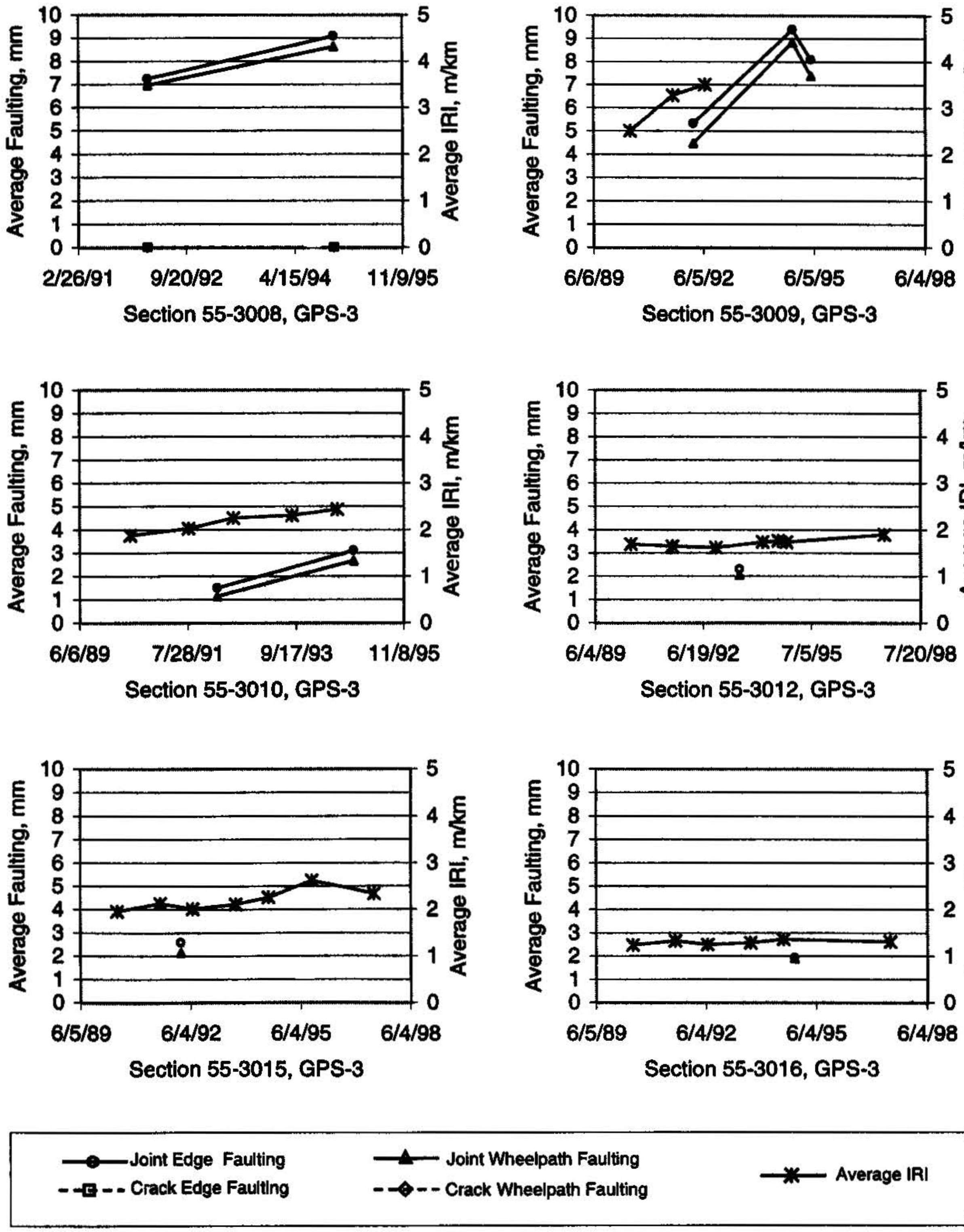

Figure 45. Time series plots for GPS-3 sections 553008, 553009, 553010, 553012, 553015, and 553016.

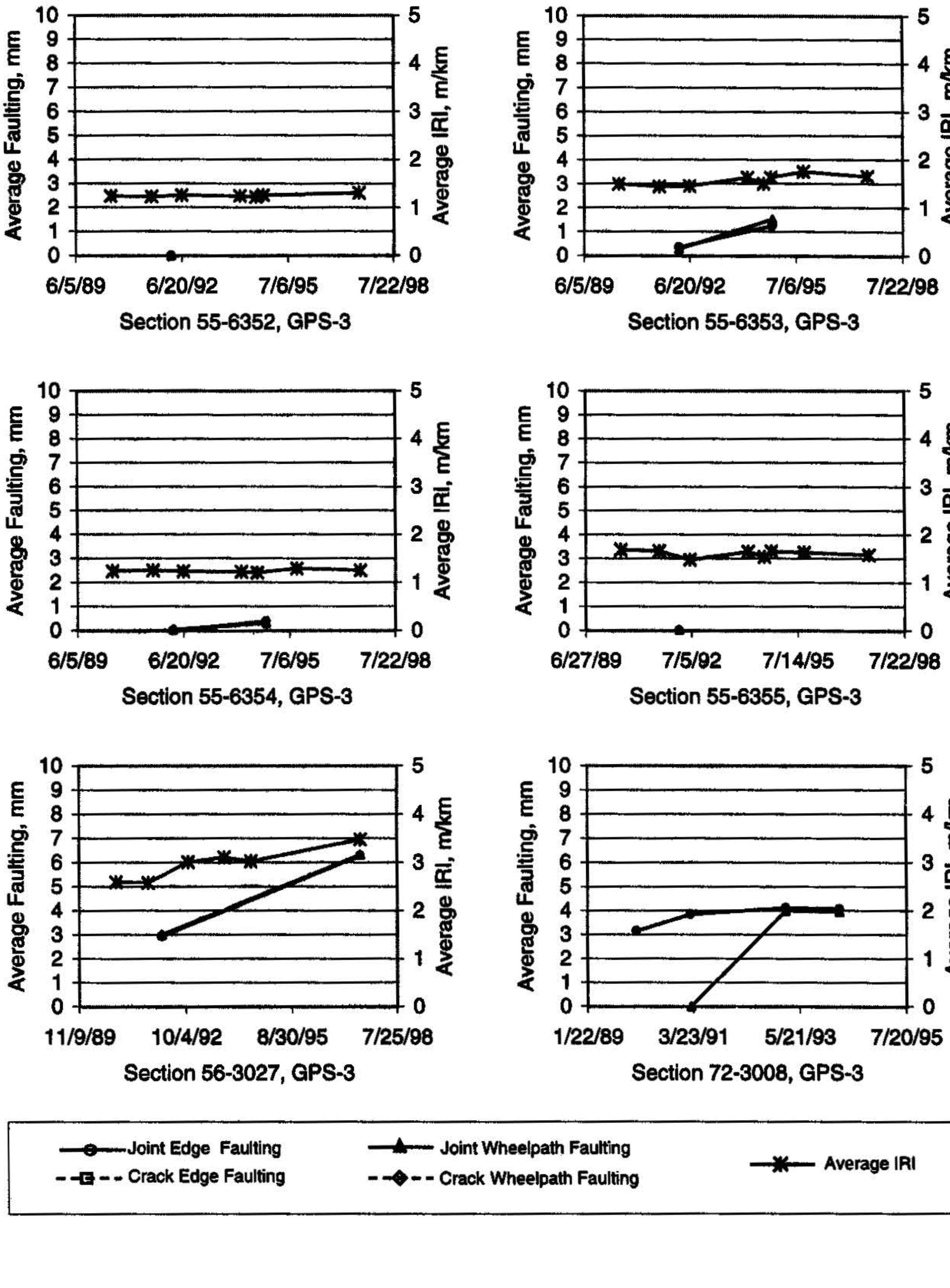

Figure 46. Time series plots for GPS-3 sections 556352, 556353, 556354, 556355, 563027, and 723008.

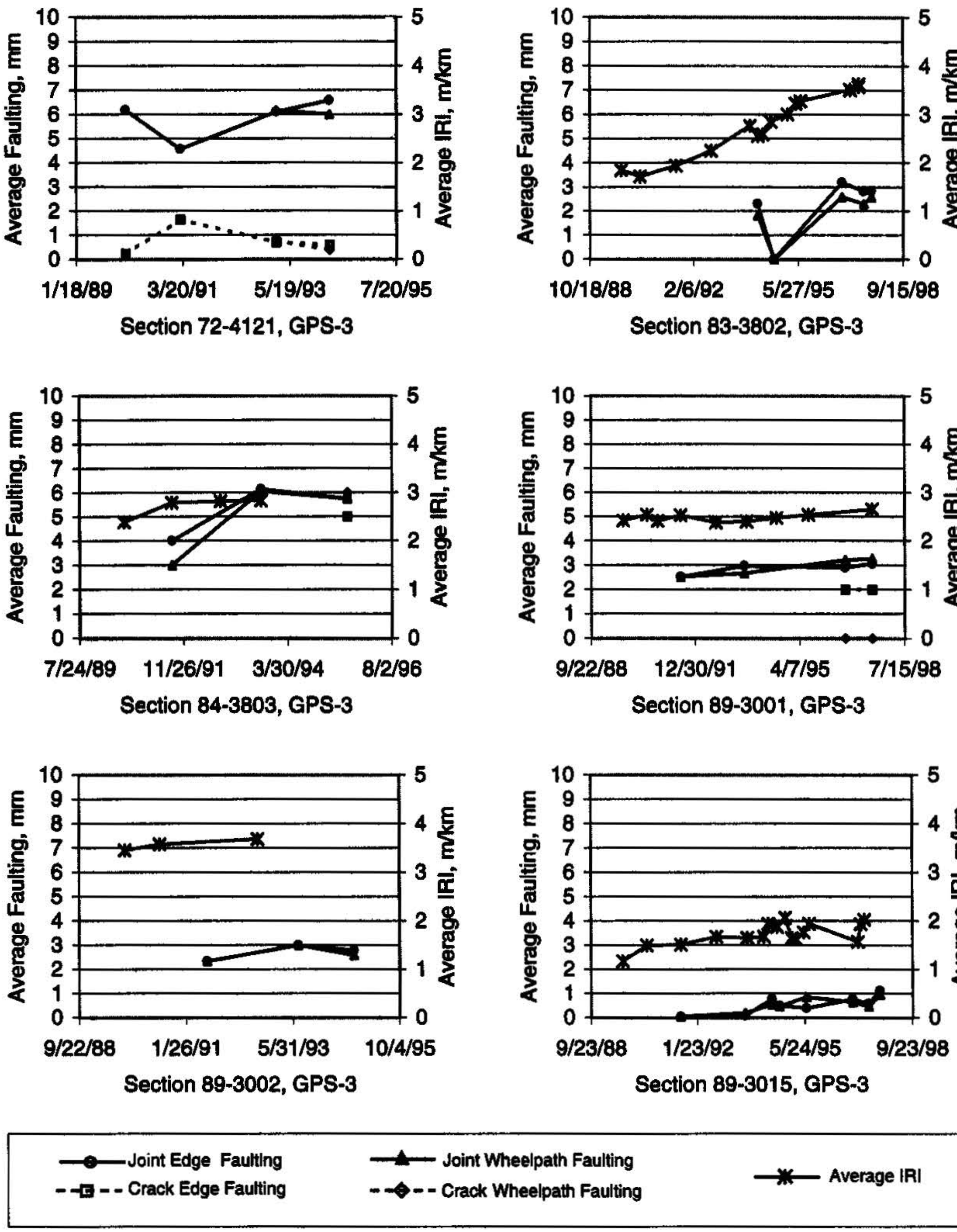

Figure 47. Time series plots for GPS-3 sections 724121, 833802, 843803, 893001, 893002, and 893015.

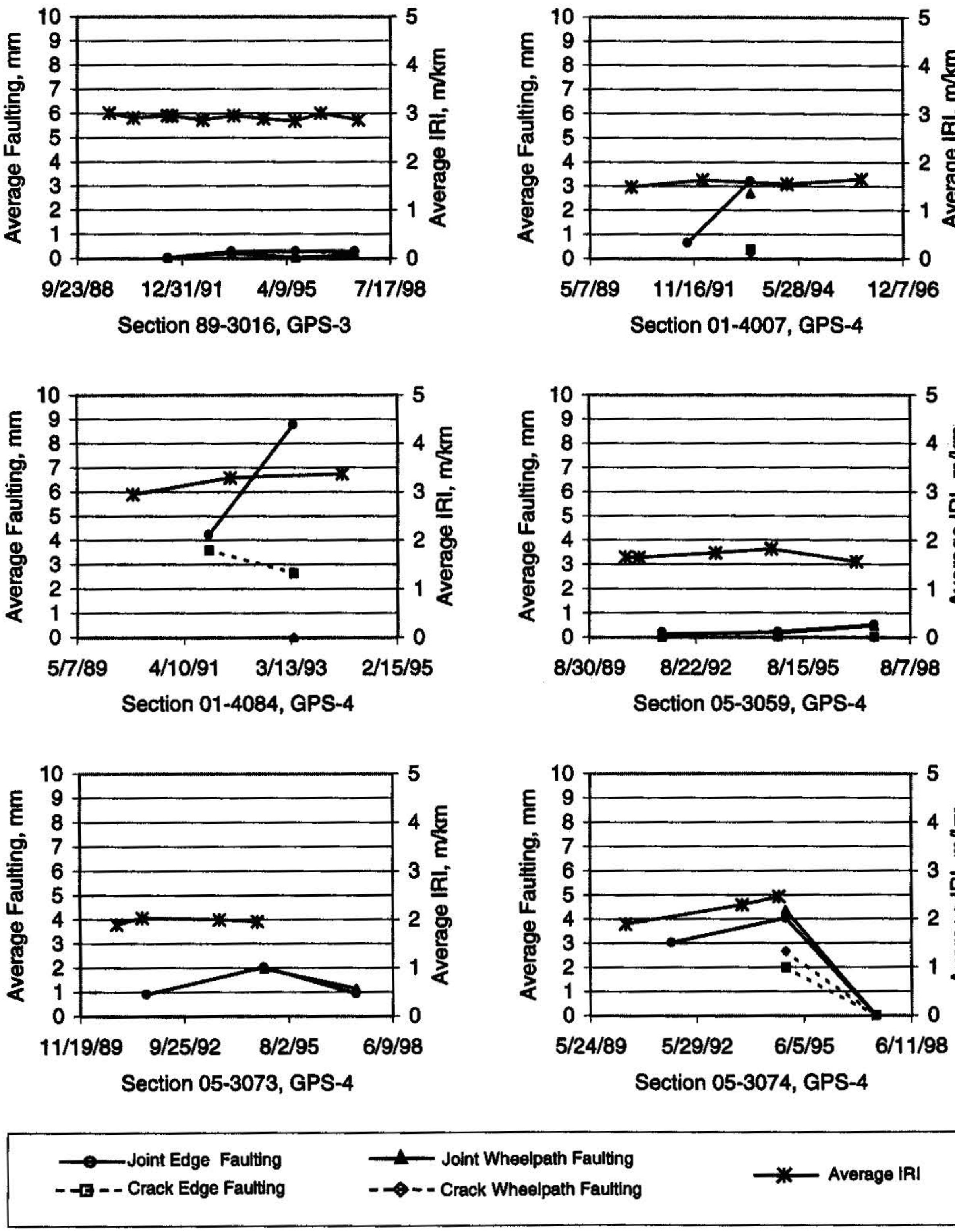

Figure 48. Time series plots for GPS-3 section 893016 and GPS-4 sections 014007, 014084, 053059, 053073, and 053074.

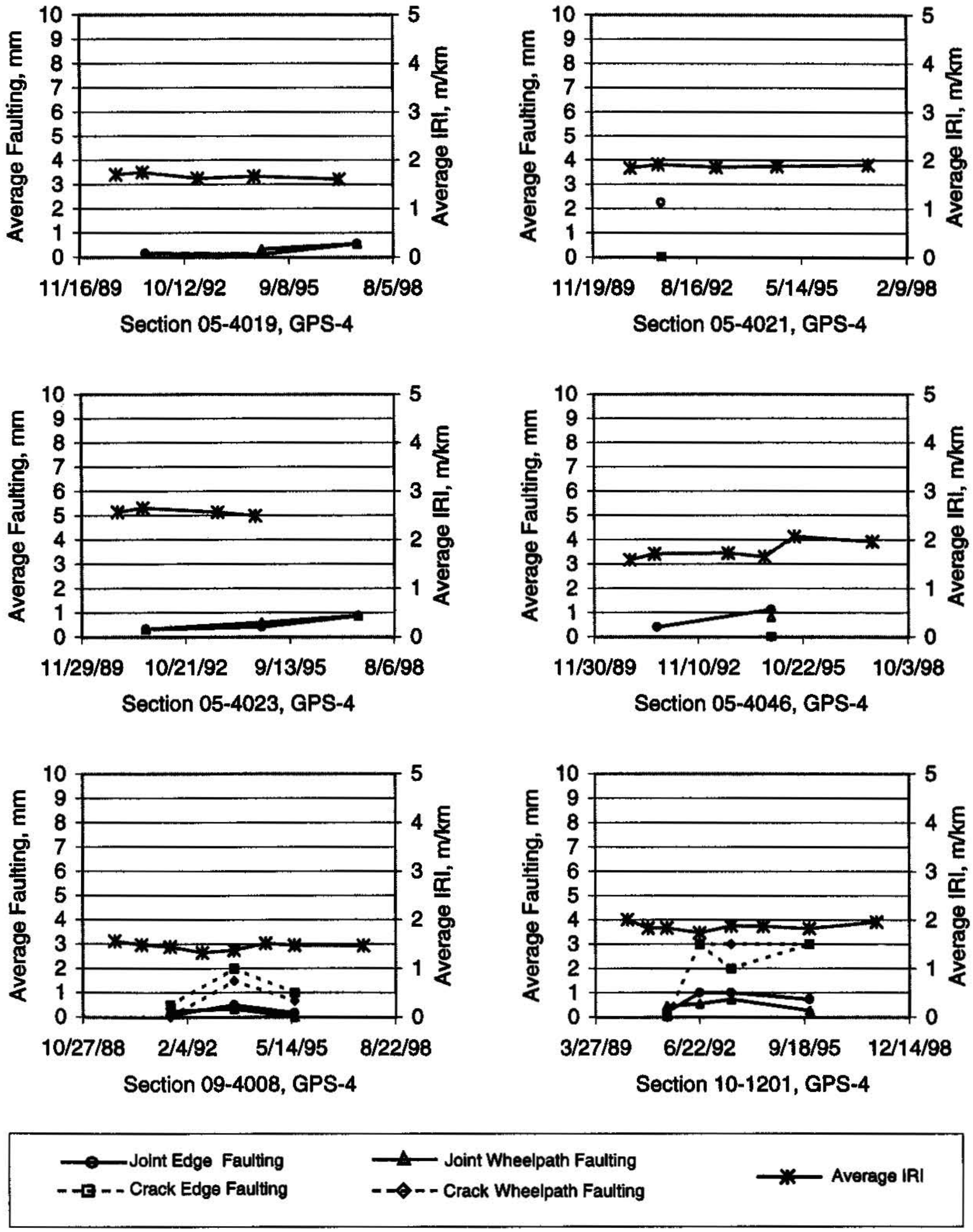

Figure 49. Time series plots for GPS-4 sections 054019, 054021, 054023, 054046, 094008, and 101201.

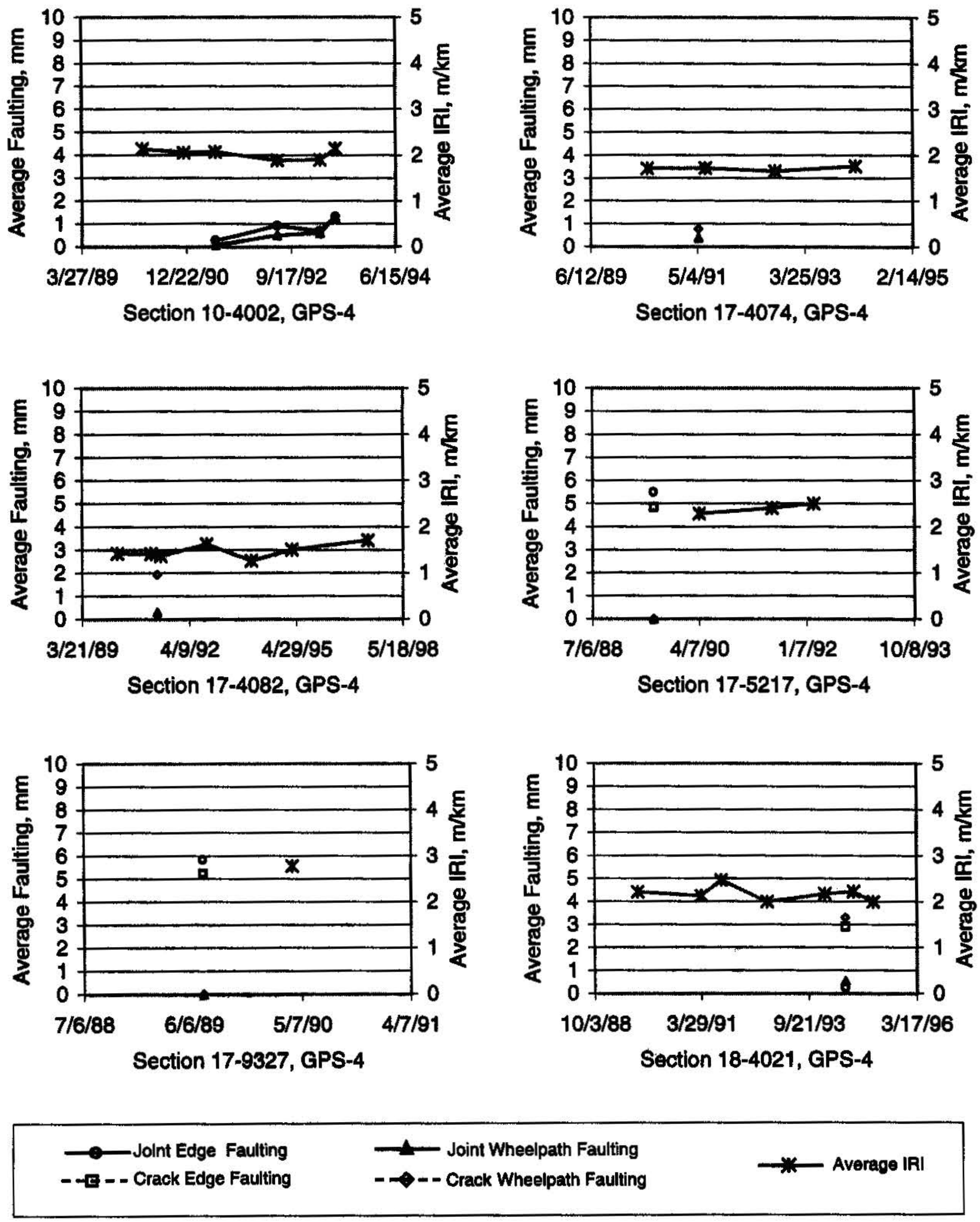

Figure 50. Time series plots for GPS-4 sections 104002, 174074, 174082, 175217, 179327, and 184021.

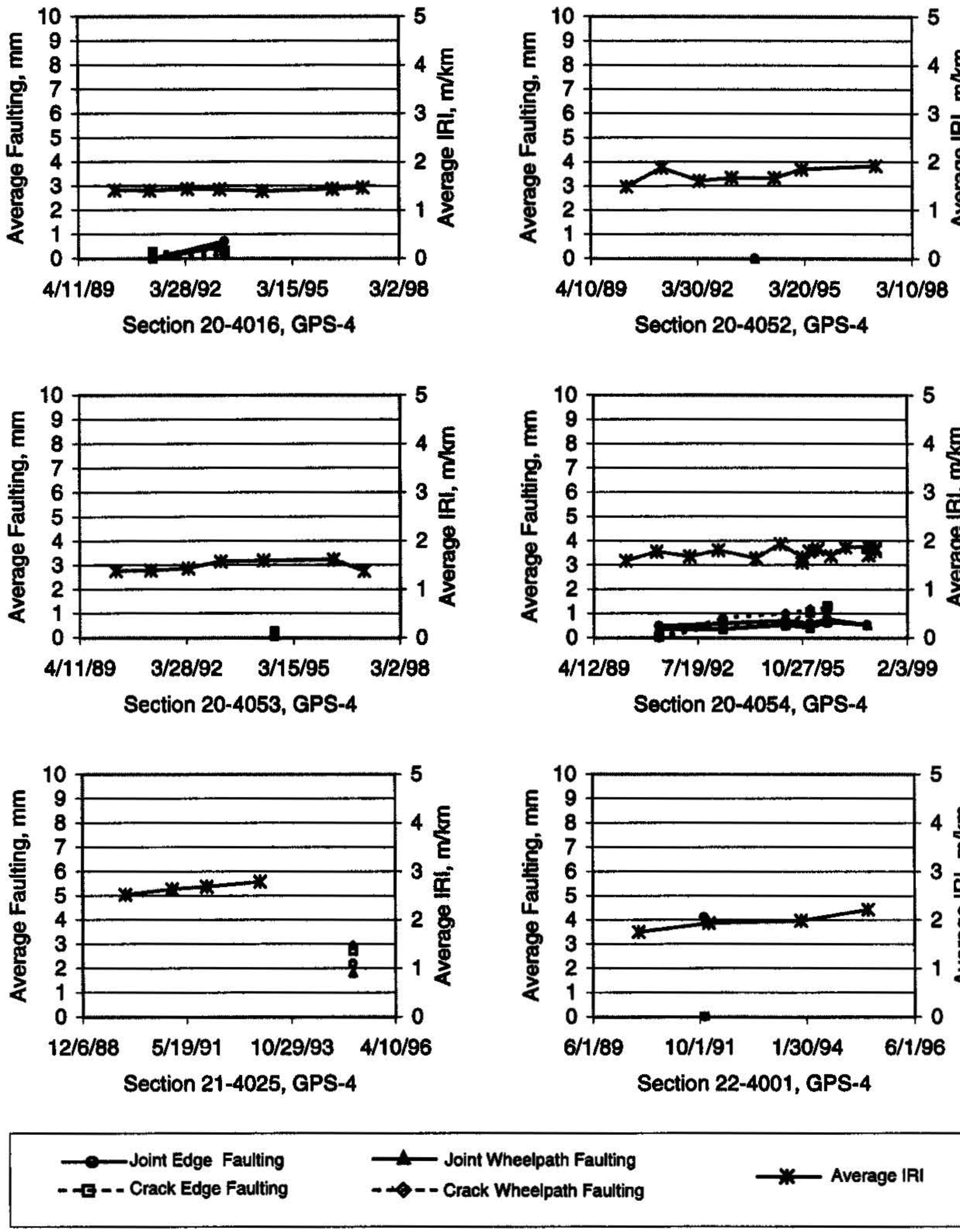

Figure 51. Time series plots for GPS-4 sections 204016, 204052, 204053, 204054, 214025, and 224001.

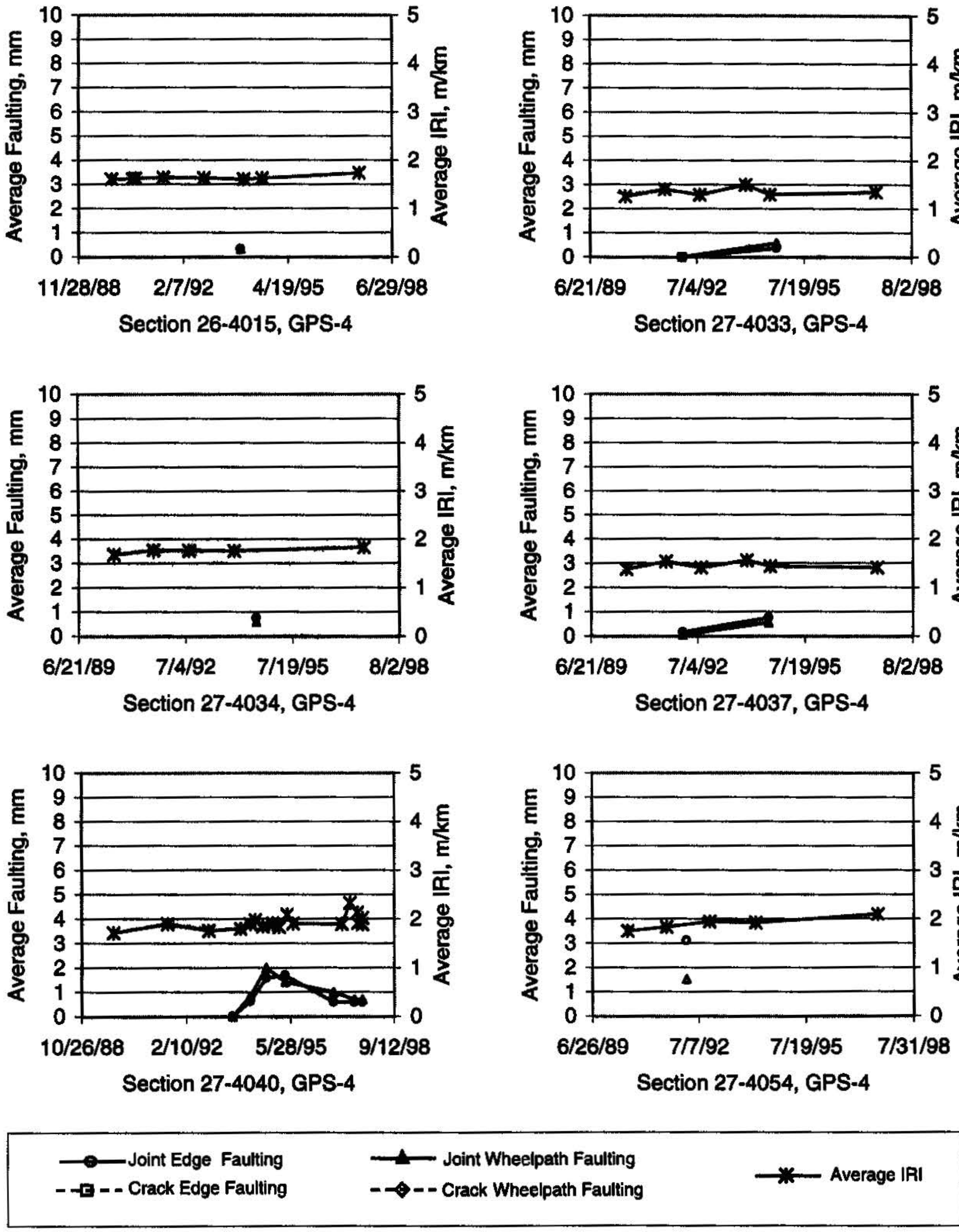

Figure 52. Time series plots for GPS-4 sections 264015, 274033, 274034, 274037, 274040, and 274054.

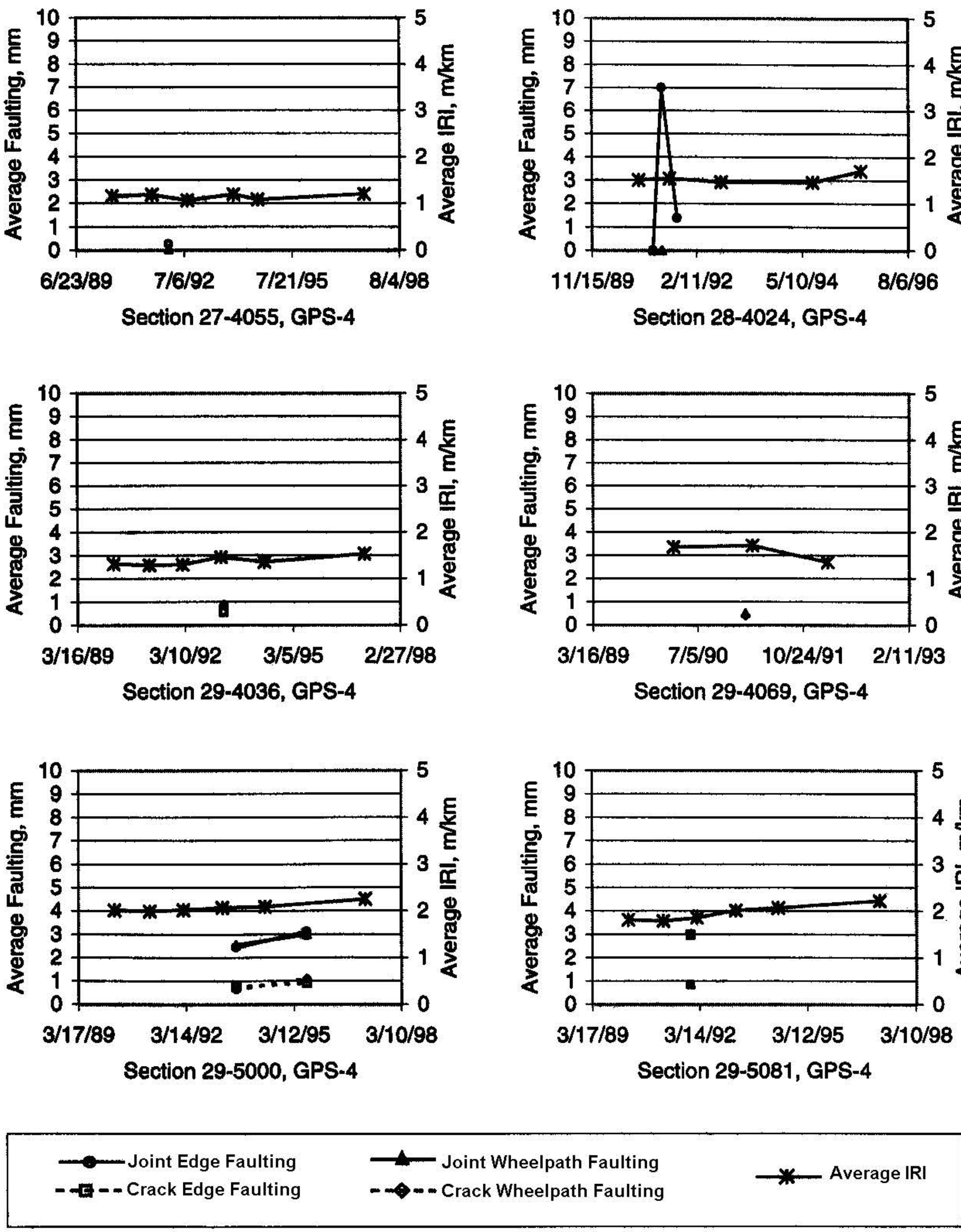

Figure 53. Time series plots for GPS-4 sections 274055, 284024, 294036, 294069, 295000, and 295081.

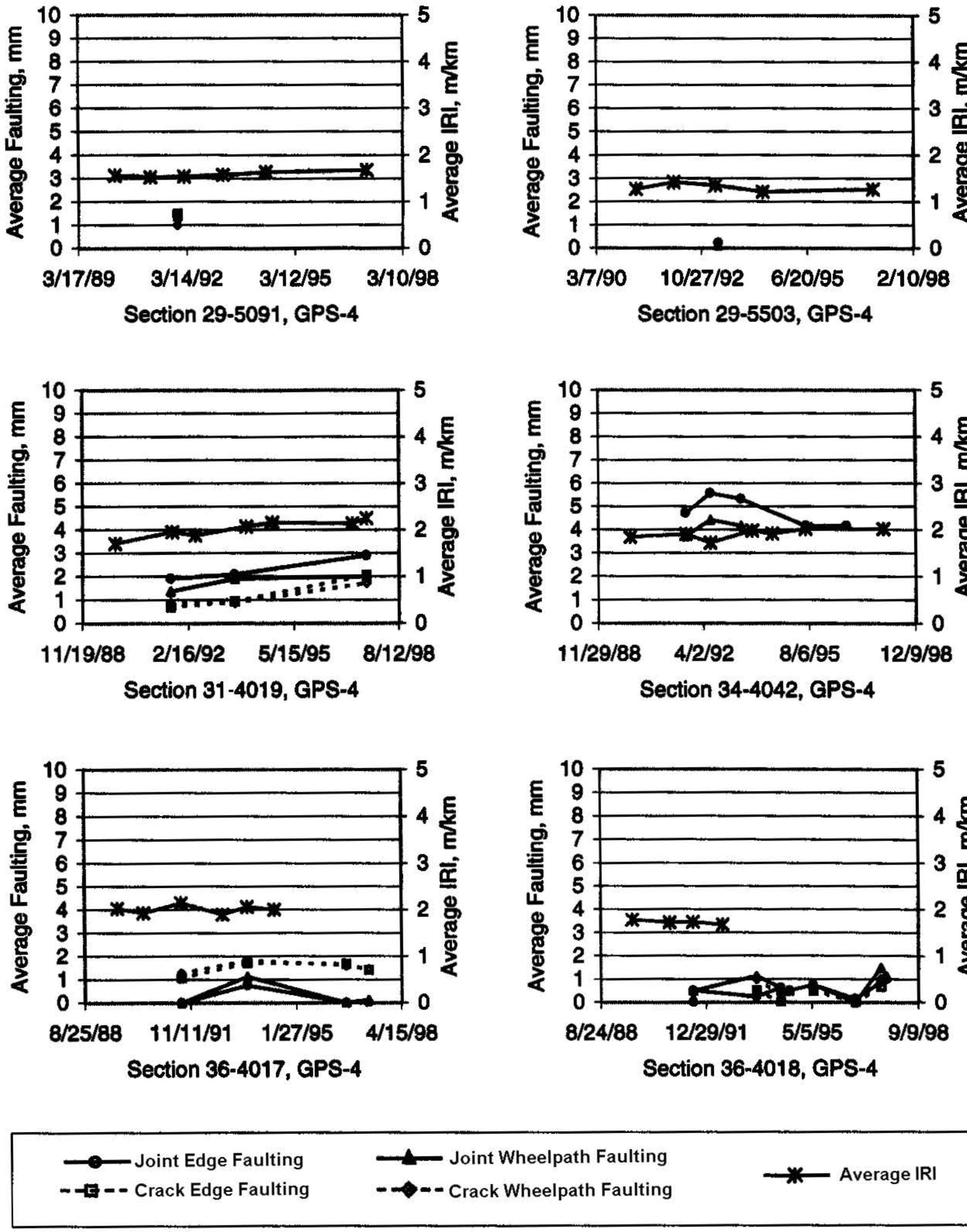

Figure 54. Time series plots for GPS-4 sections 295091, 295503, 314019, 344042, 364017, and 364018.

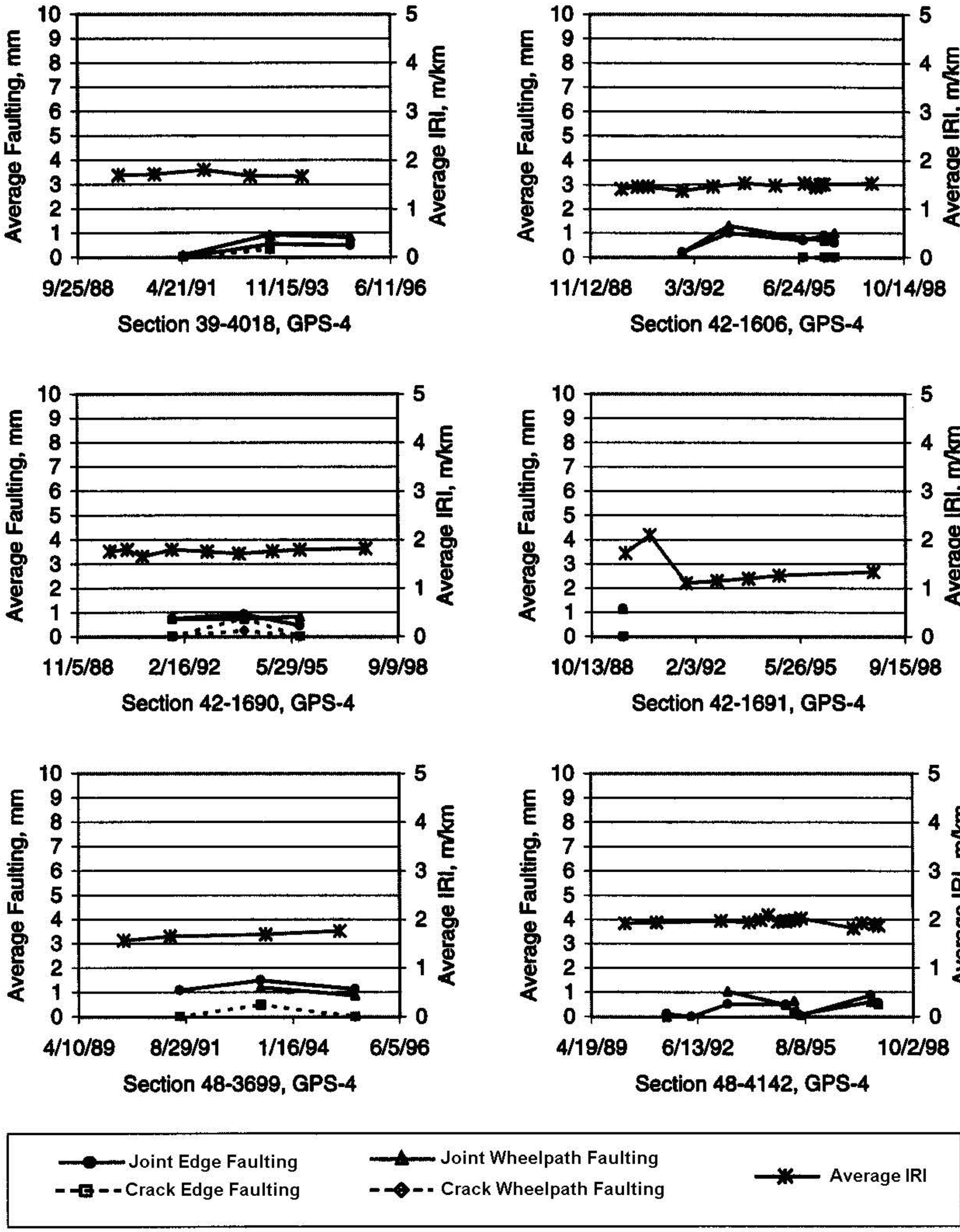

Figure 55. Time series plots for GPS-4 sections 394018, 421606, 421690, 421691, 483699, and 484142.

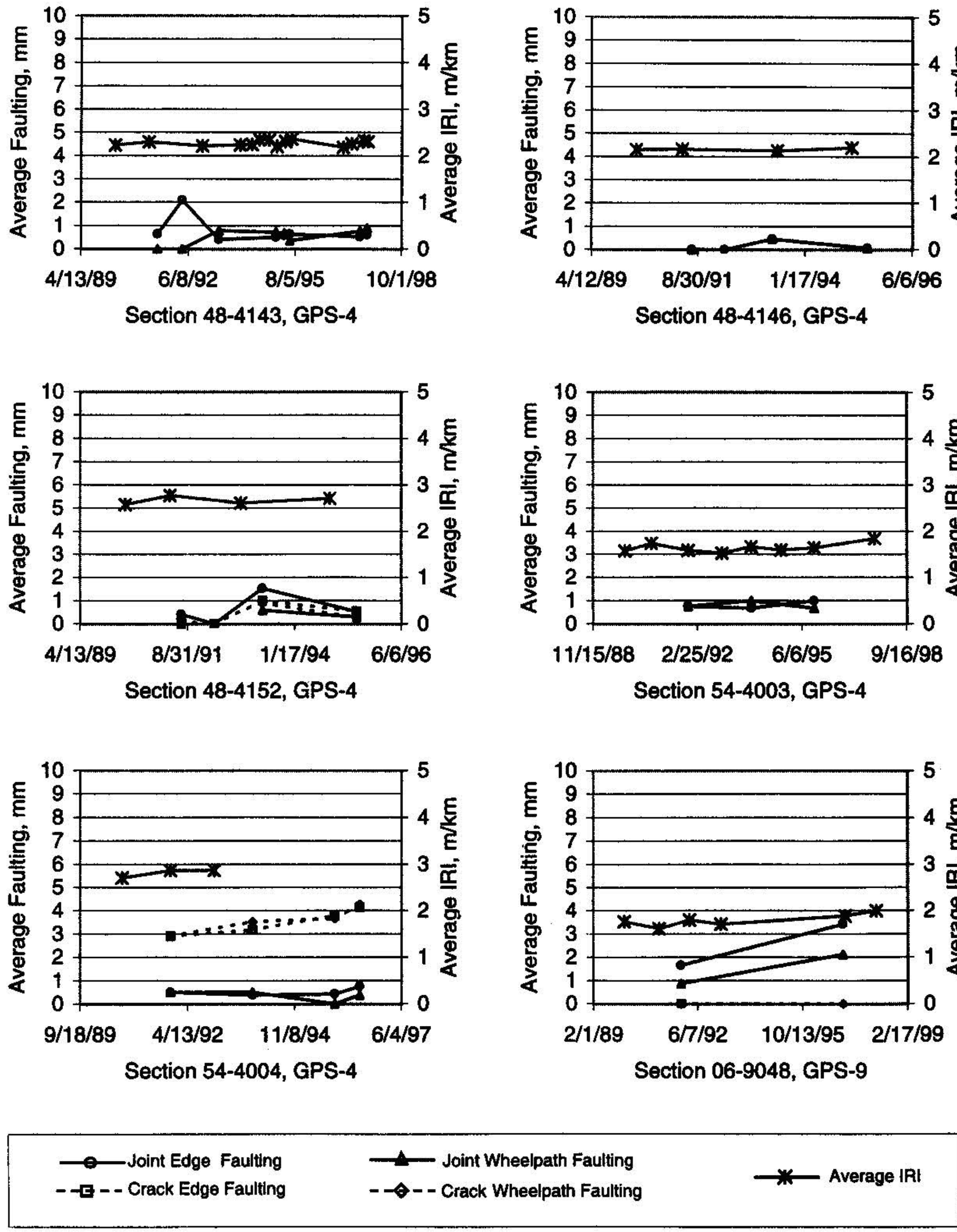

Figure 56. Time series plots for GPS-4 sections 484143, 484146, 484152, 544003, and 544004, and GPS-9 section 069048.

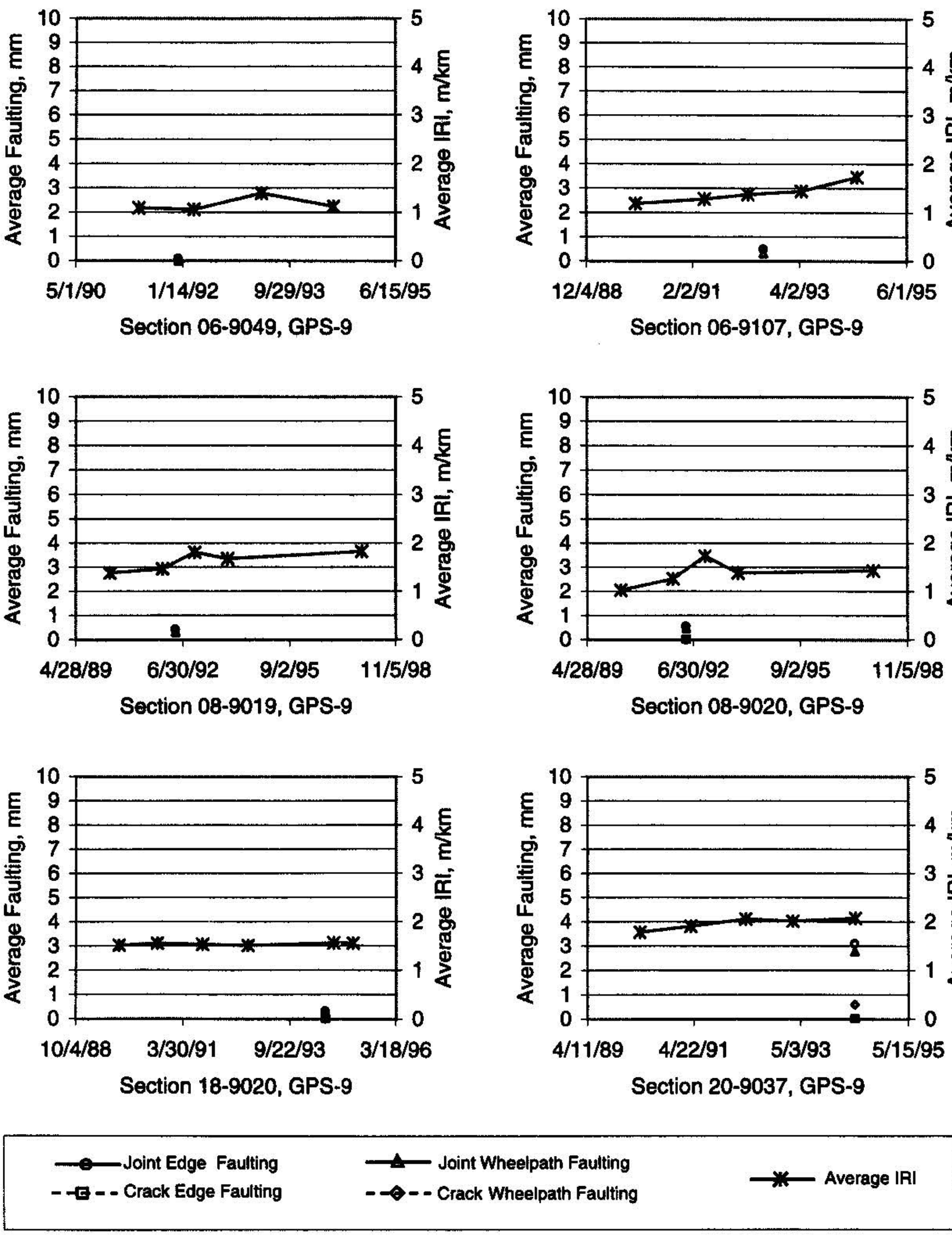

Figure 57. Time series plots for GPS-9 sections 069049, 069107, 089019, 089020, 189020, and 209037.

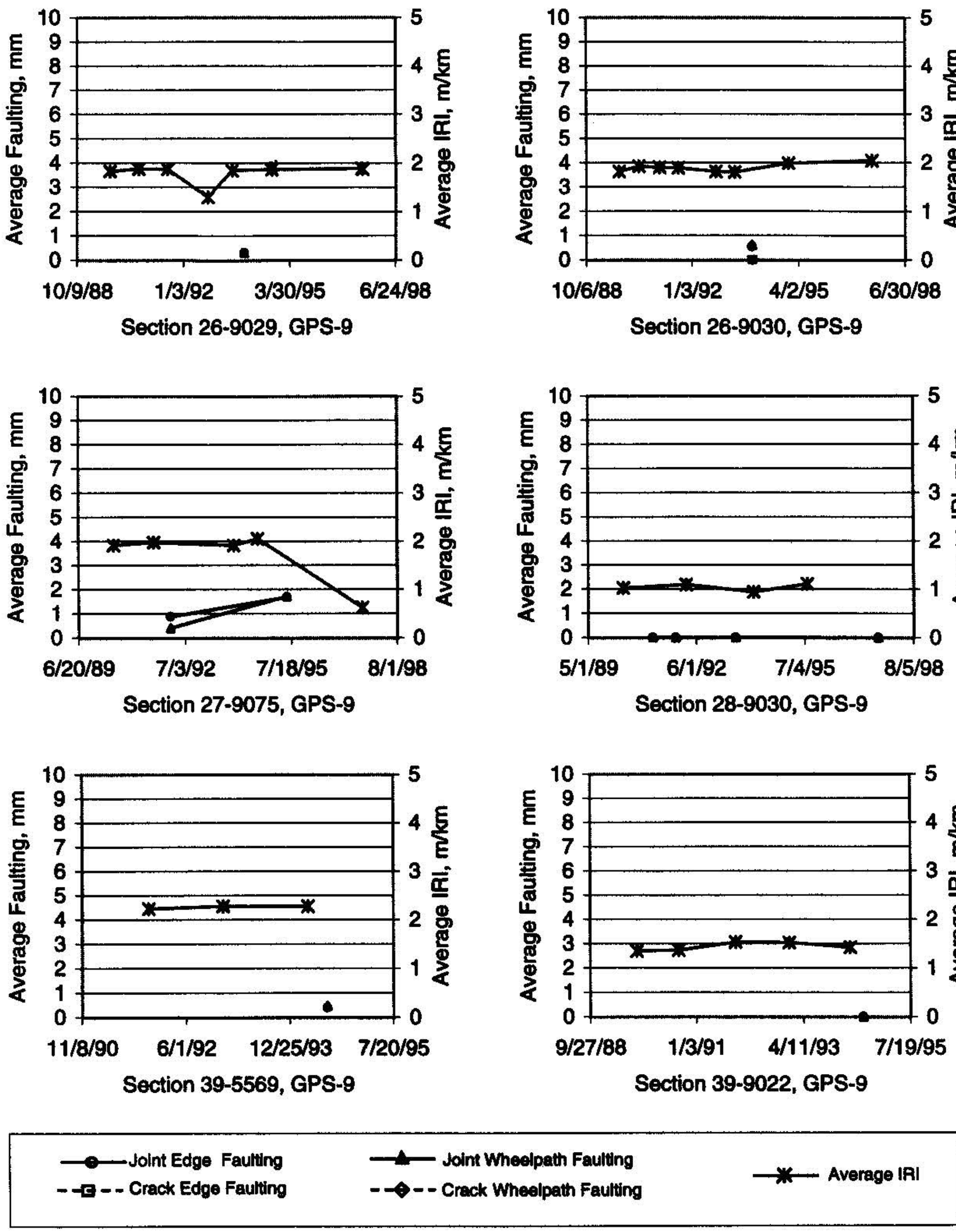

Figure 58. Time series plots for GPS-9 sections 269029, 269030, 279075, 289030, 395569, and 399022.

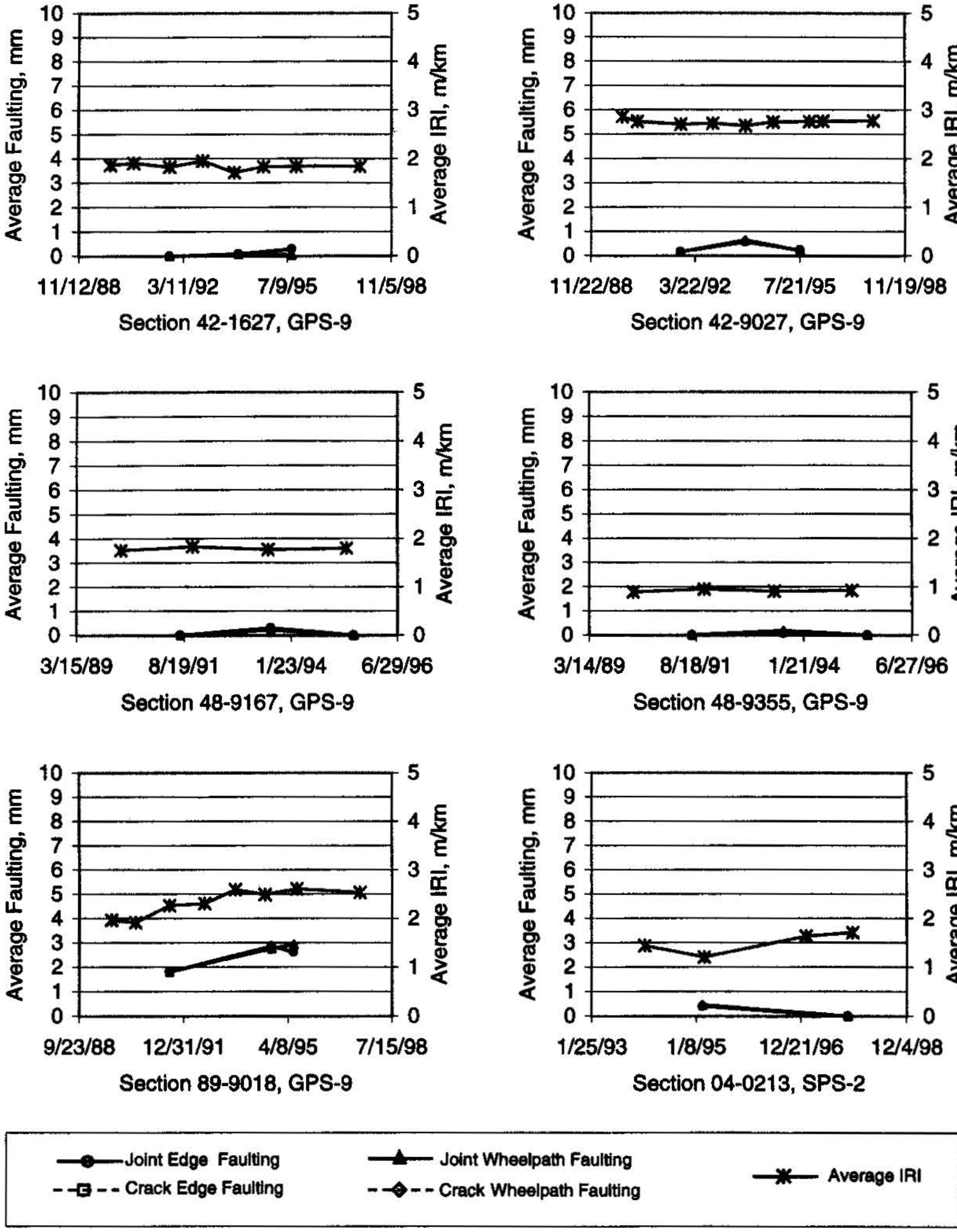

Figure 59. Time series plots for GPS-9 sections 421627, 429027, 489167, 489355, and 899018, and SPS-2 section 040213.

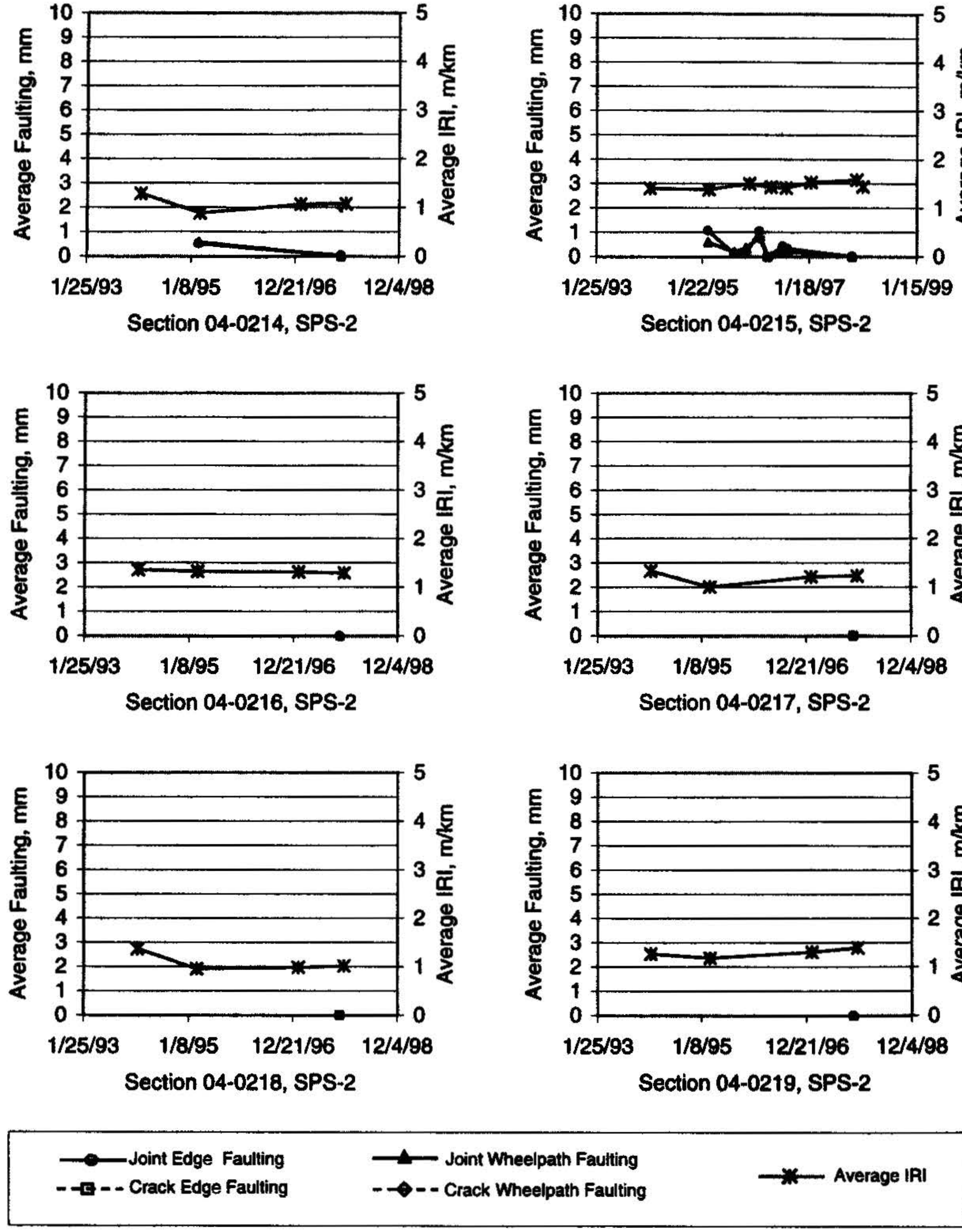

Figure 60. Time series plots for SPS-2 sections 040214, 040215, 040216, 040217, 040218, and 040219.

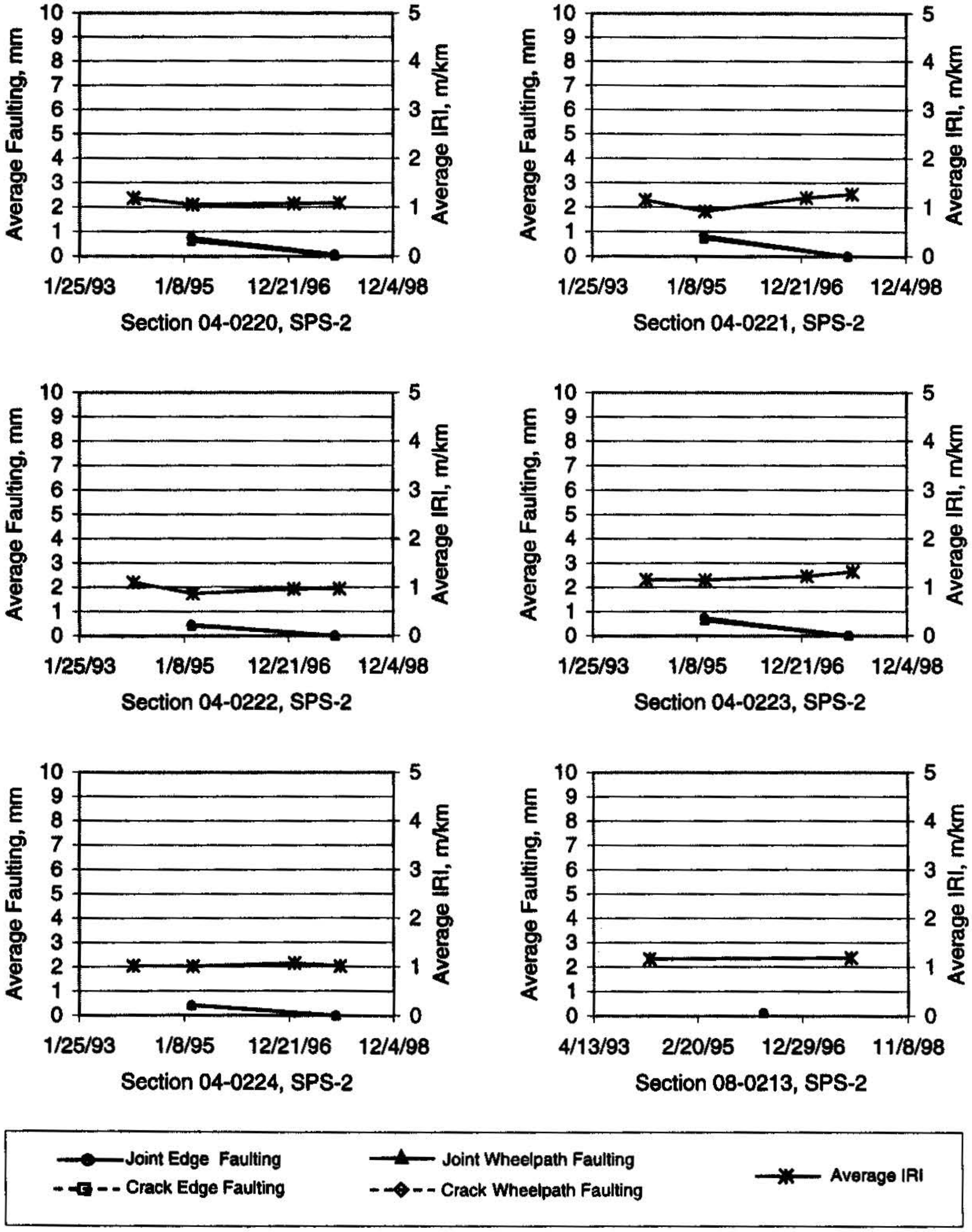

Figure 61. Time series plots for SPS-2 sections 040220, 040221, 040222, 040223, 040224, and 080213.

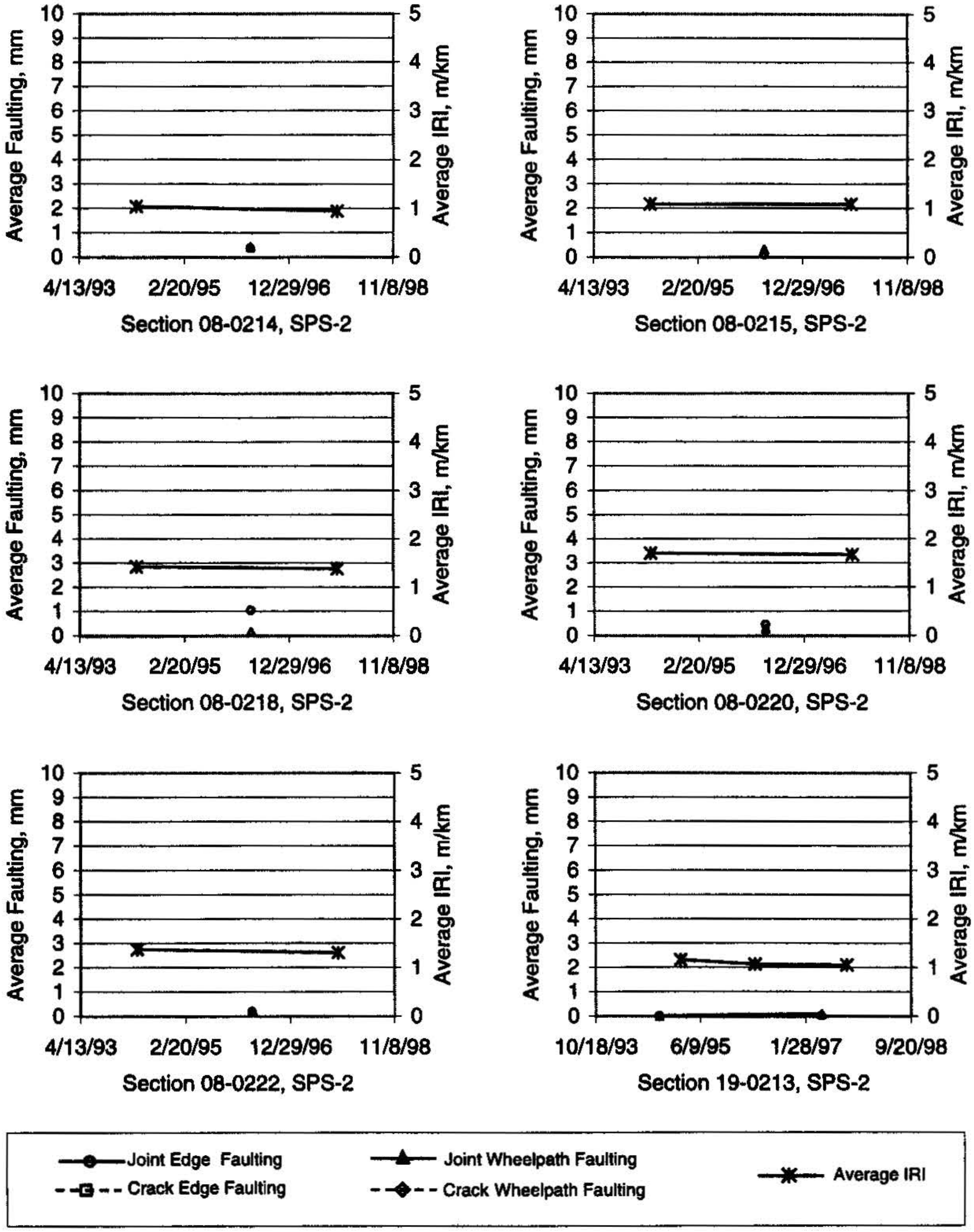

Figure 62. Time series plots for SPS-2 sections 080214, 080215, 080218, 080220, 080222, and 190213.

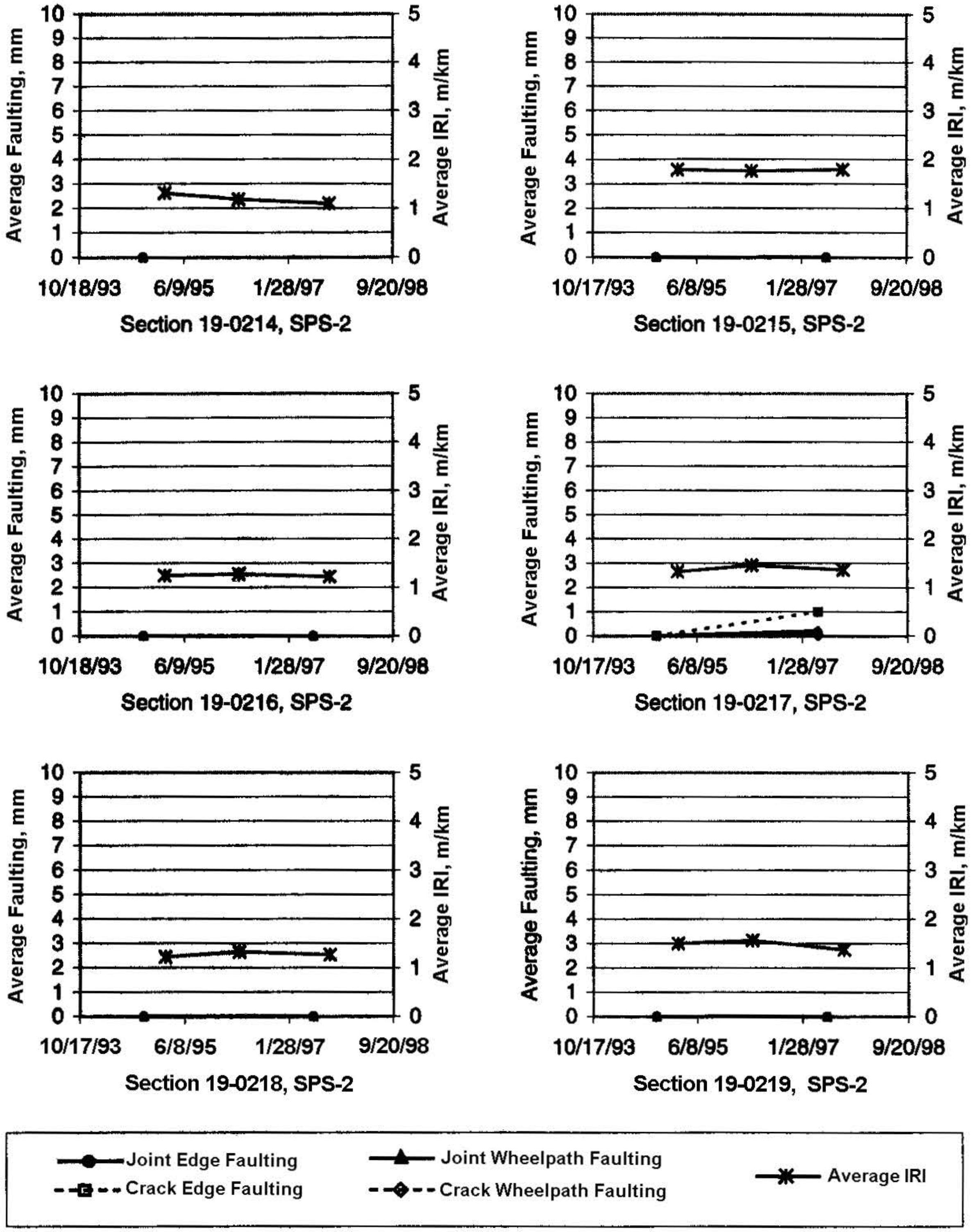

Figure 63. Time series plots for SPS-2 sections 190214, 190215, 190216, 190217, 190218, and 190219.

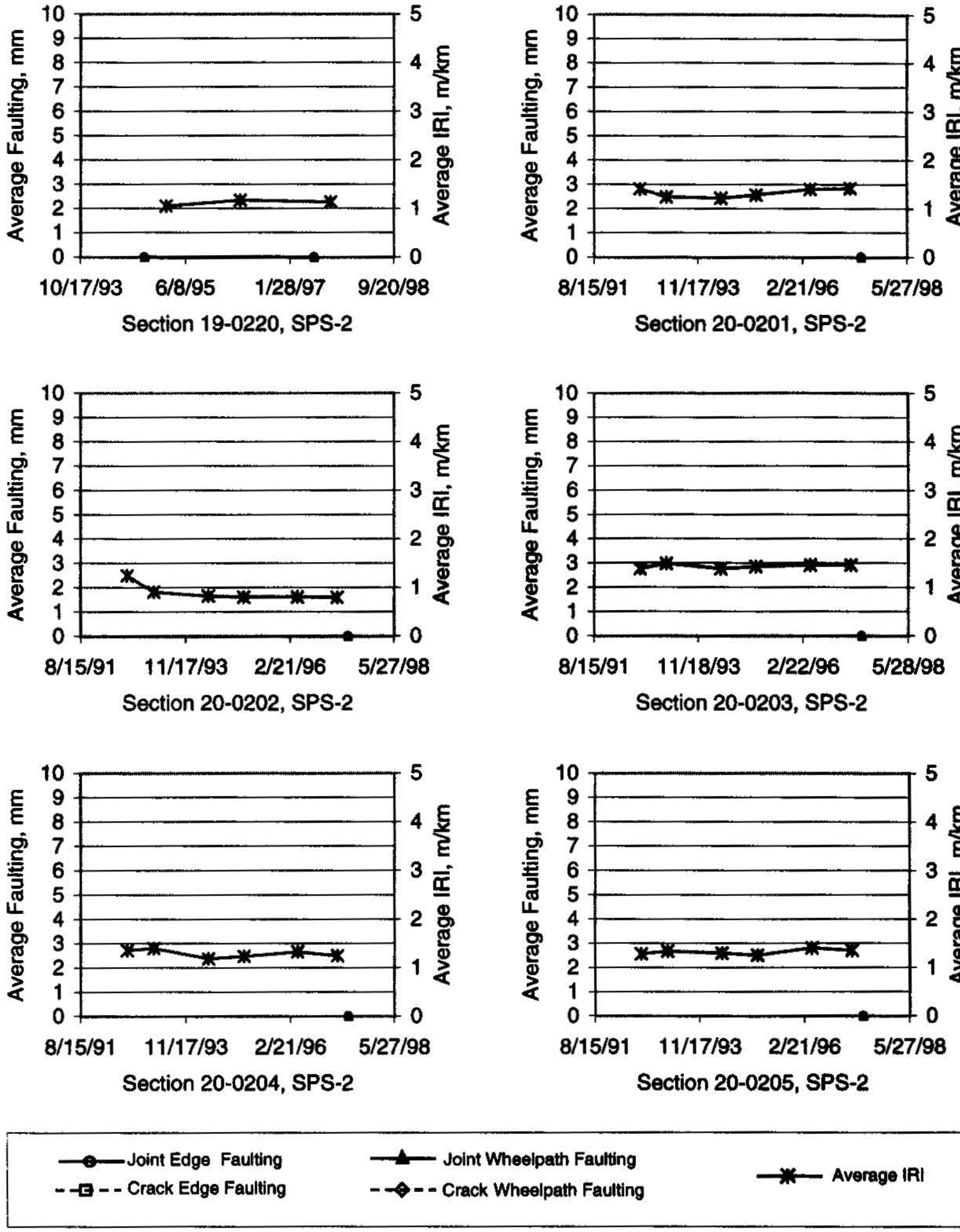

Figure 64. Time series plots for SPS-2 sections 190220, 200201, 200202, 200203, 200204, and 200205.

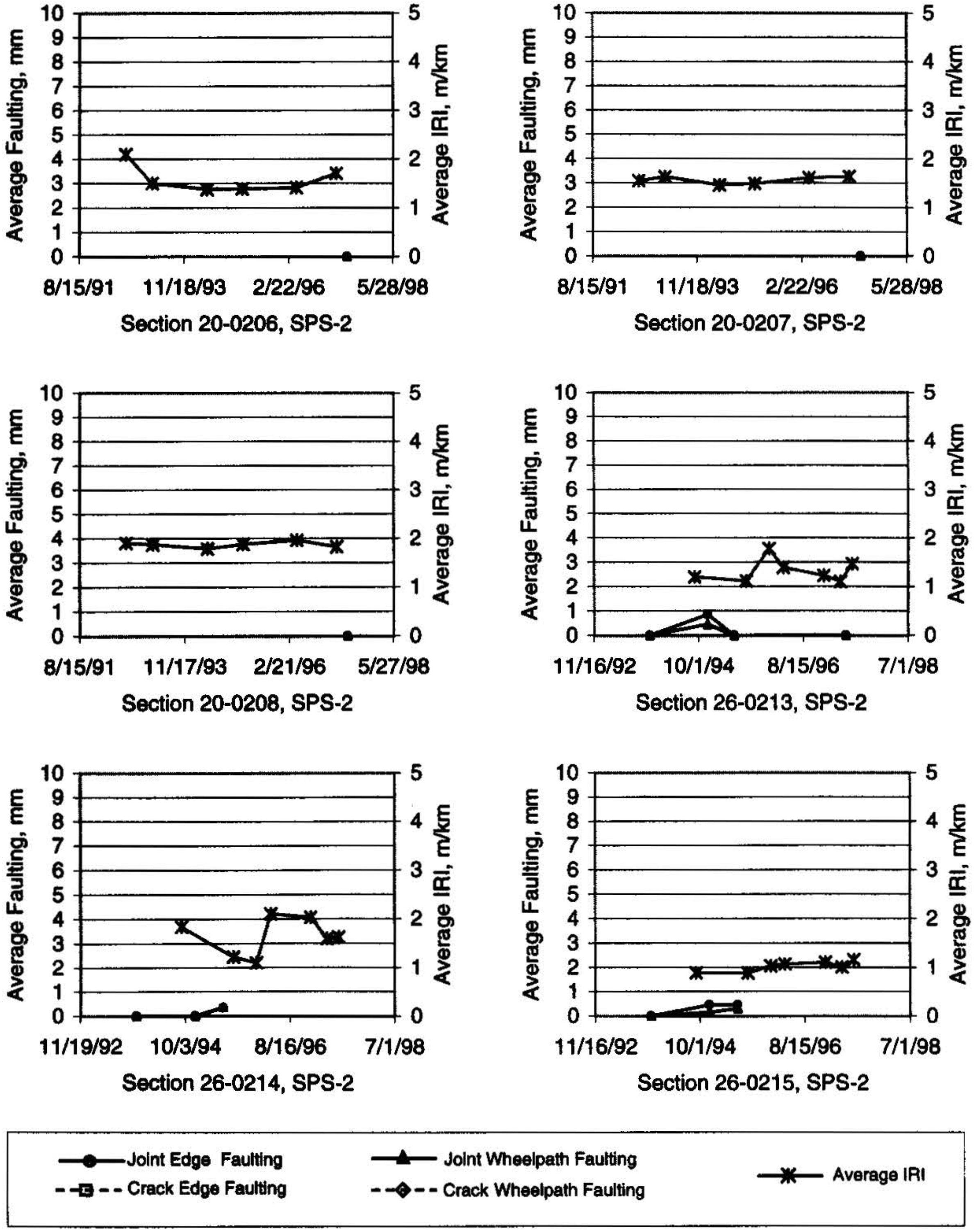

Figure 65. Time series plots for SPS-2 sections 200206, 200207, 200208, 260213, 260214, and 260215.

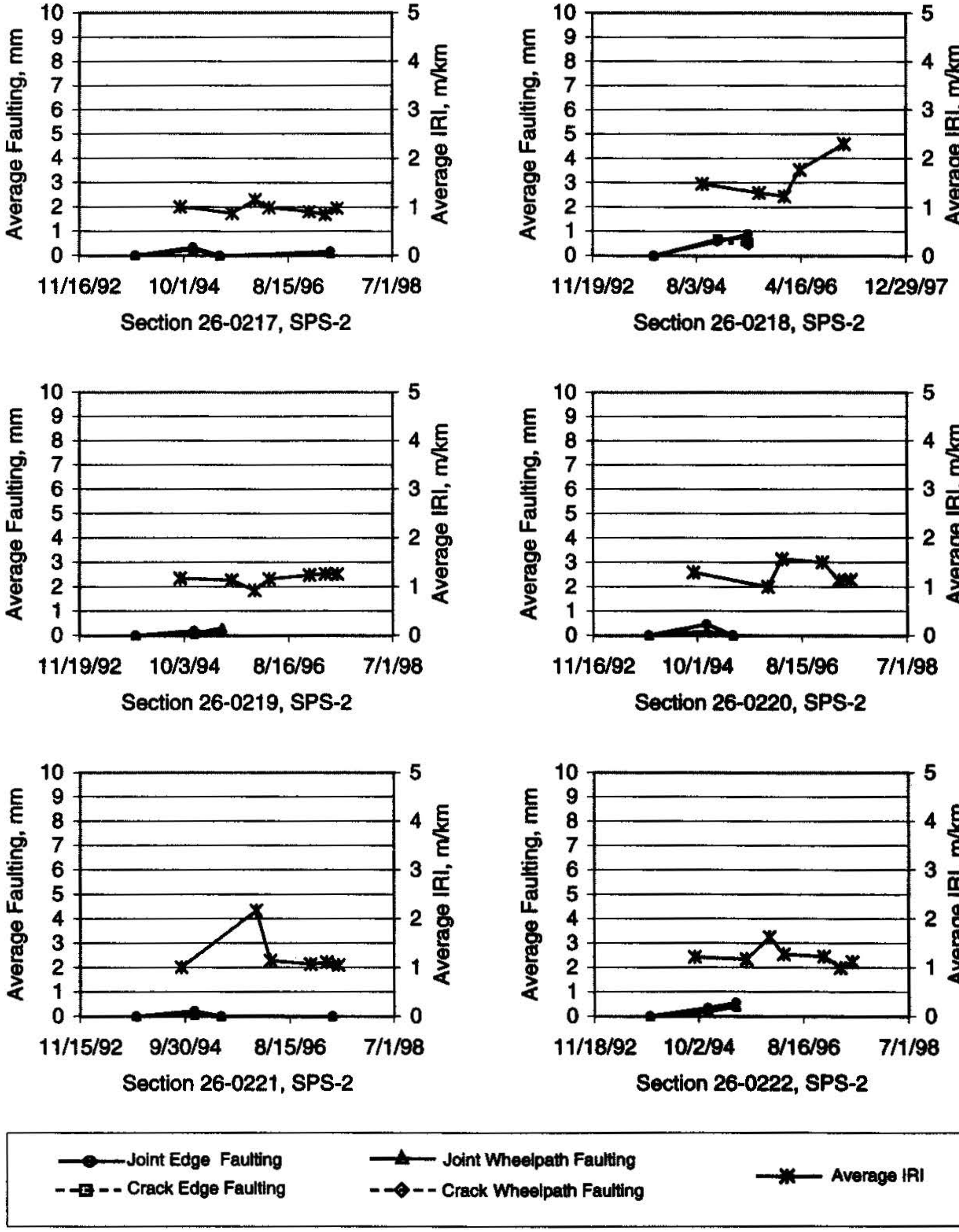

Figure 66. Time series plots for SPS-2 sections 260217, 260218, 260219, 260220, 260221, and 260222.

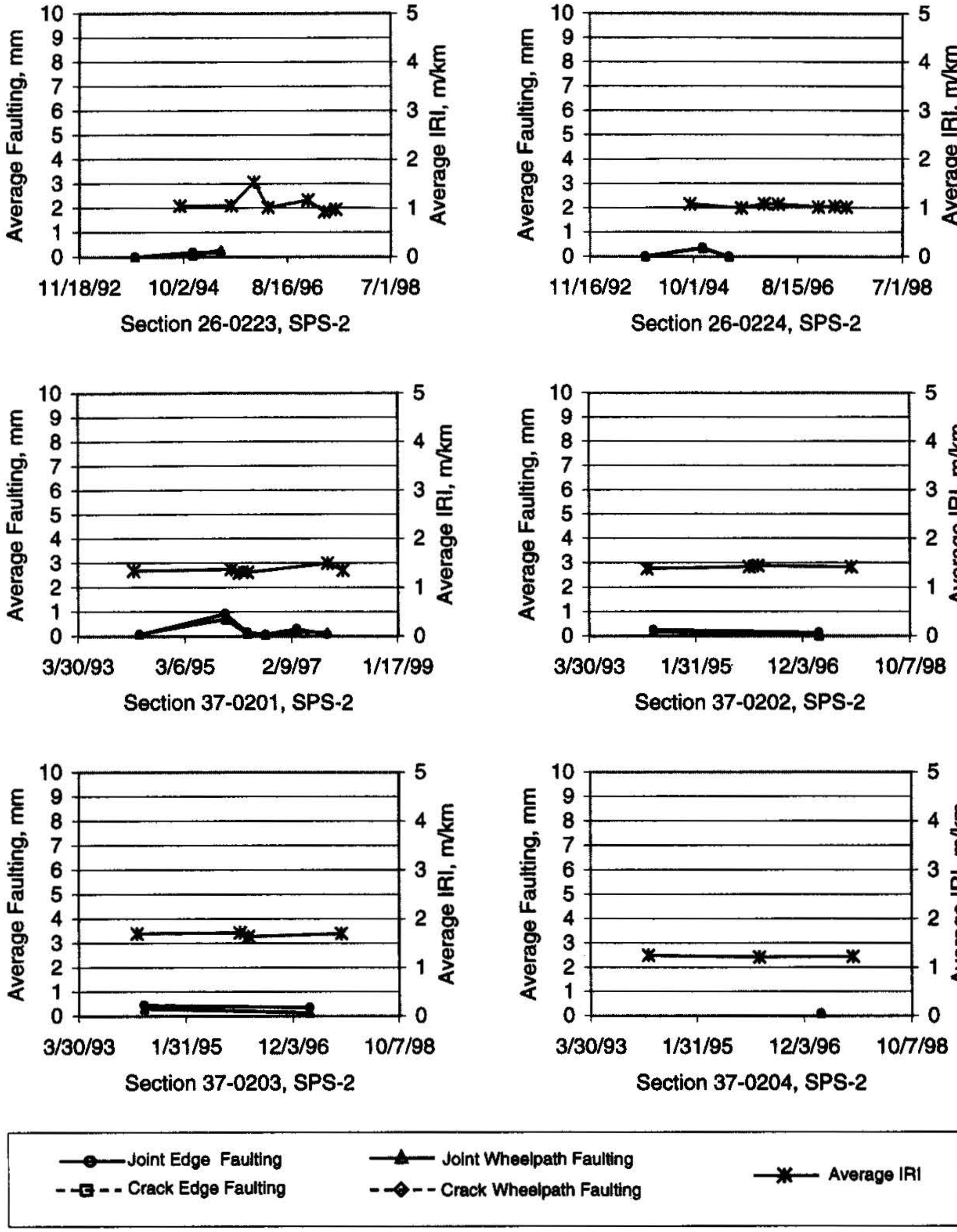

Figure 67. Time series plots for SPS-2 sections 260223, 260224, 370201, 370202, 370203, and 370204.

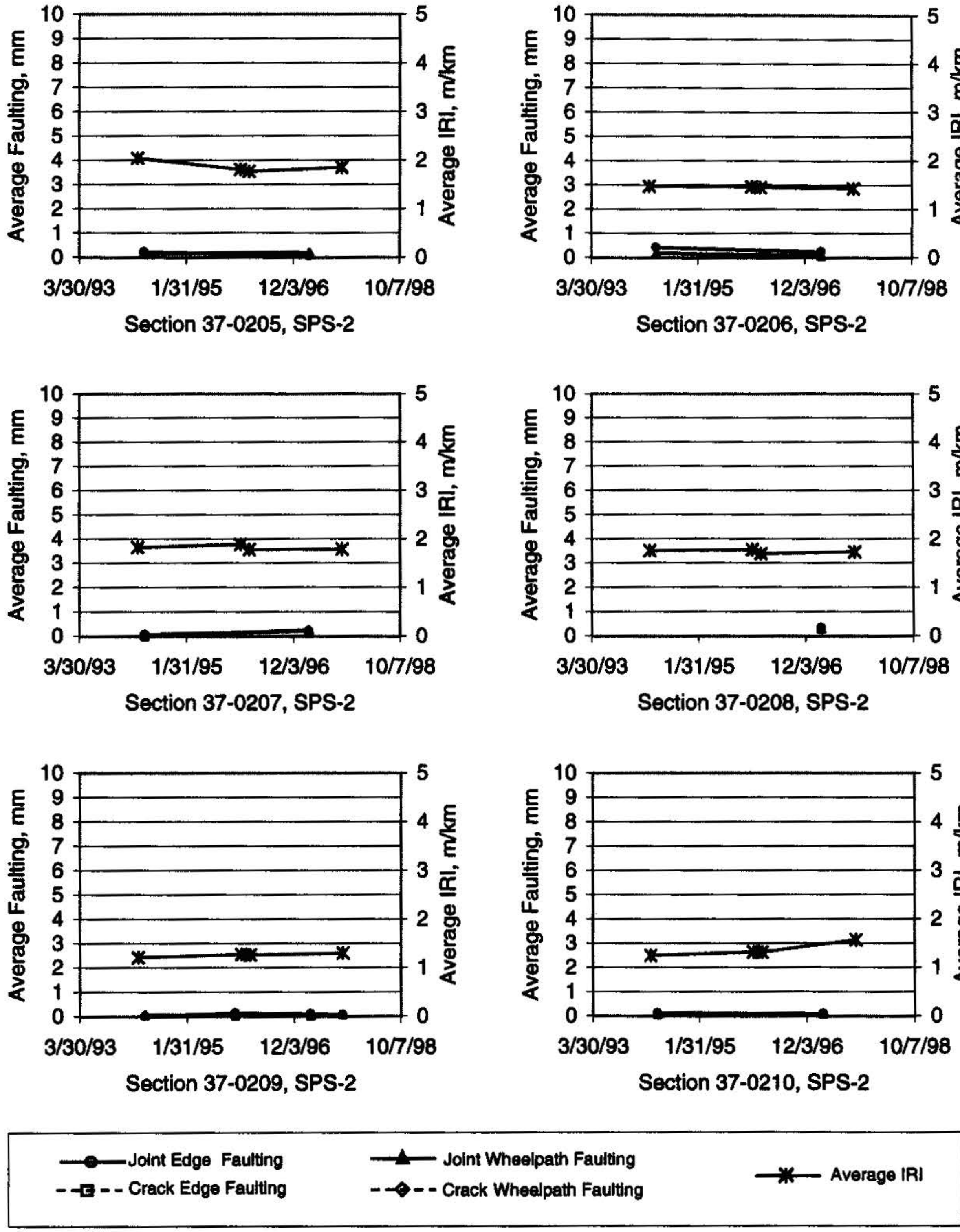

Figure 68. Time series plots for SPS-2 sections 370205, 370206, 370207, 370208, 370209, and 370210.

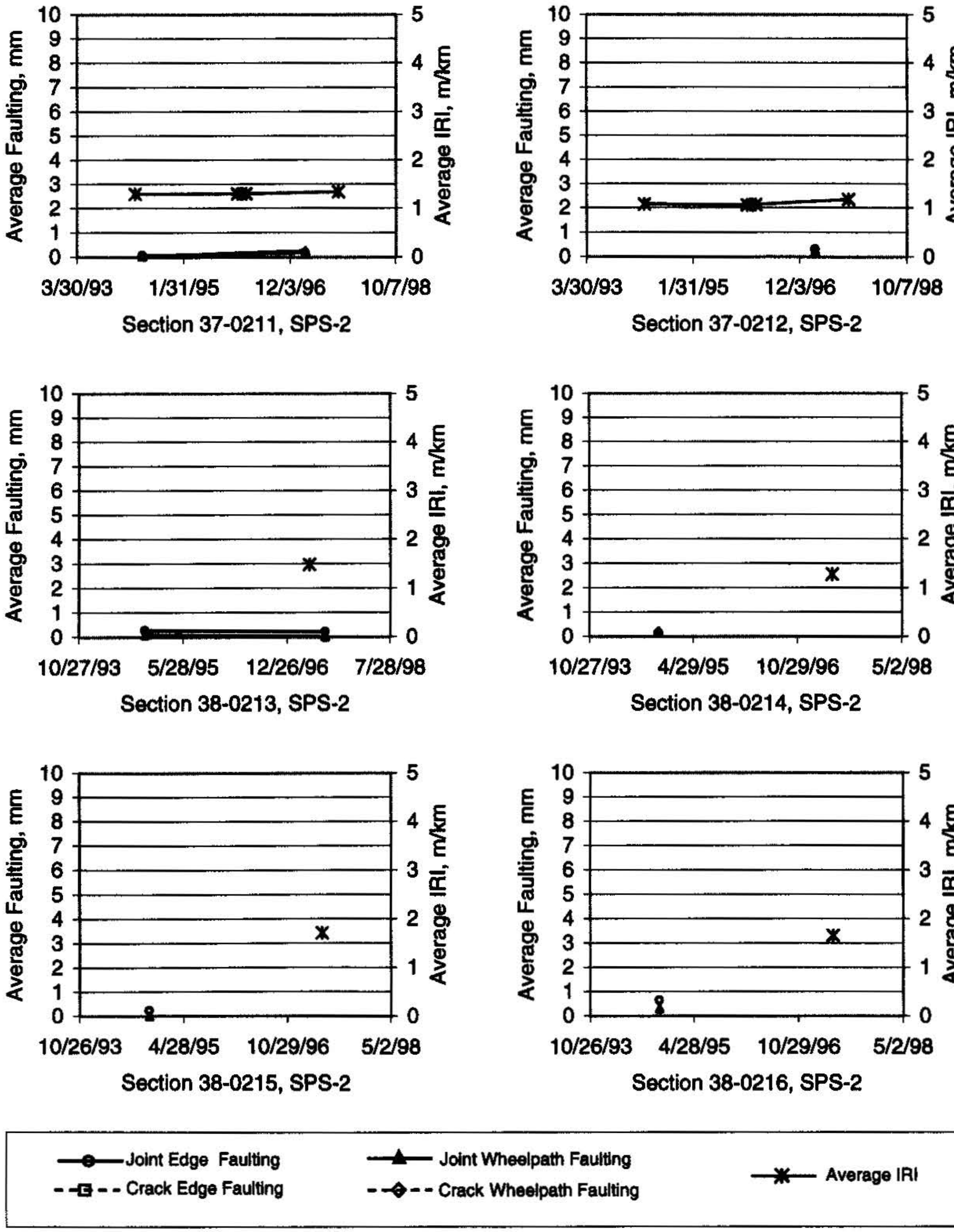

Figure 69. Time series plots for SPS-2 sections 370211, 370212, 380213, 380214, 380215, and 380216.

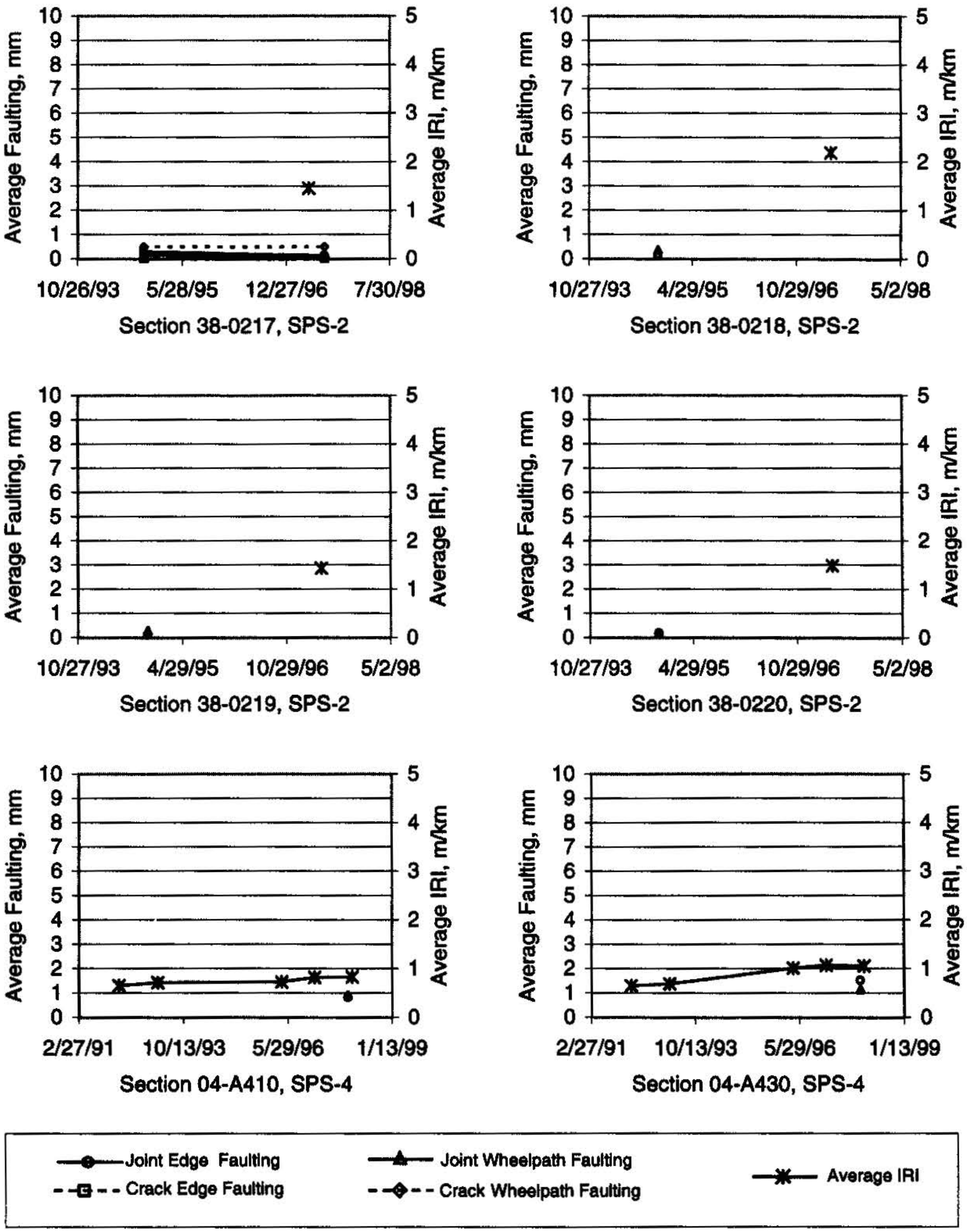

Figure 70. Time series plots for SPS-2 sections 380217, 380218, 380219, and 380220 and SPS-4 sections 04A410 and 04A430.

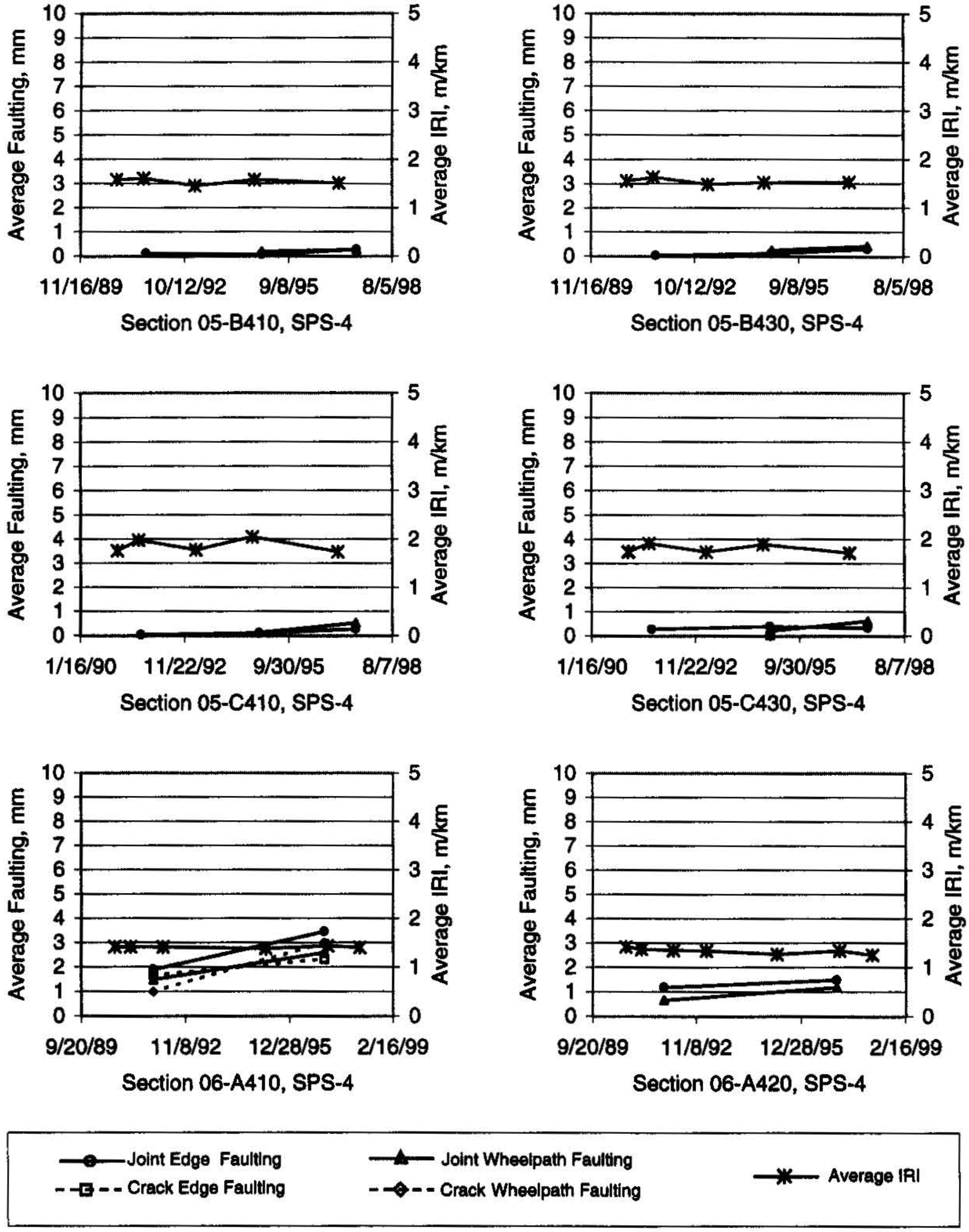

Figure 71. Time series plots for SPS-4 sections 05B410, 05B430, 05C410, 05C430, 06A410, and 06A420.

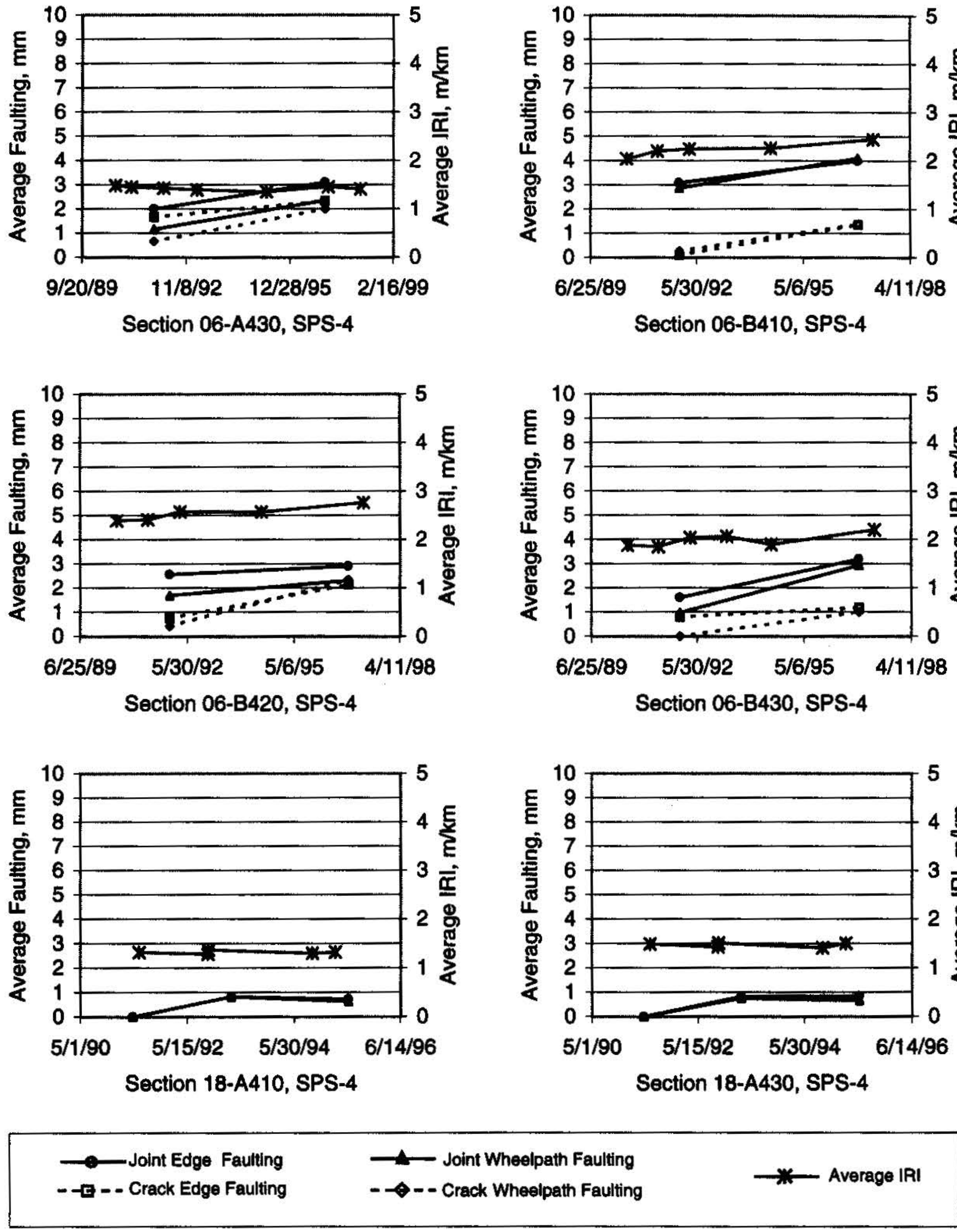

Figure 72. Time series plots for SPS-4 sections 06A430, 06B410, 06B420, 06B430, 18A410, and 18A430.

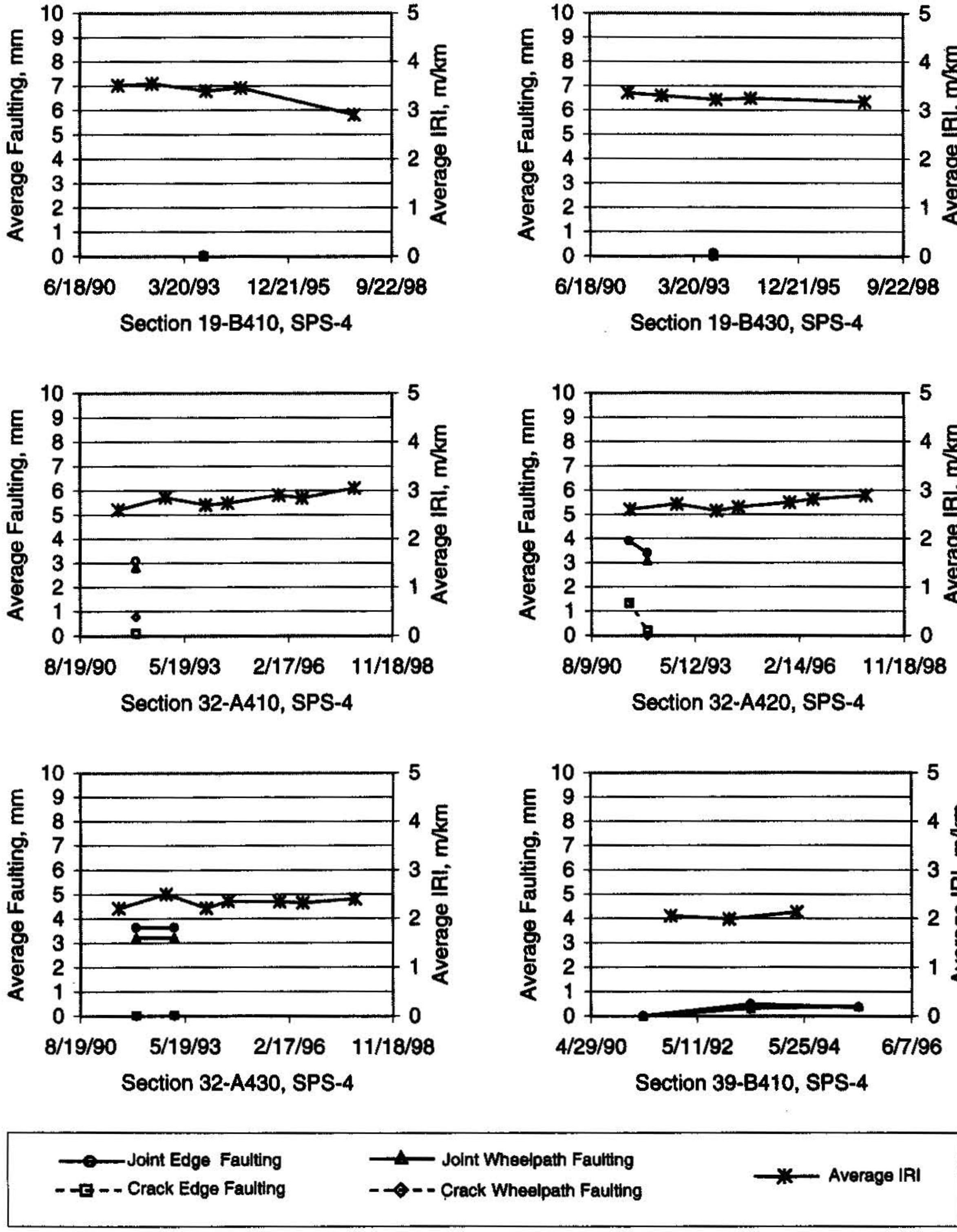

Figure 73. Time series plots for SPS-4 sections 19B410, 19B430, 32A410, 32A420, 32A430, and 39B410.

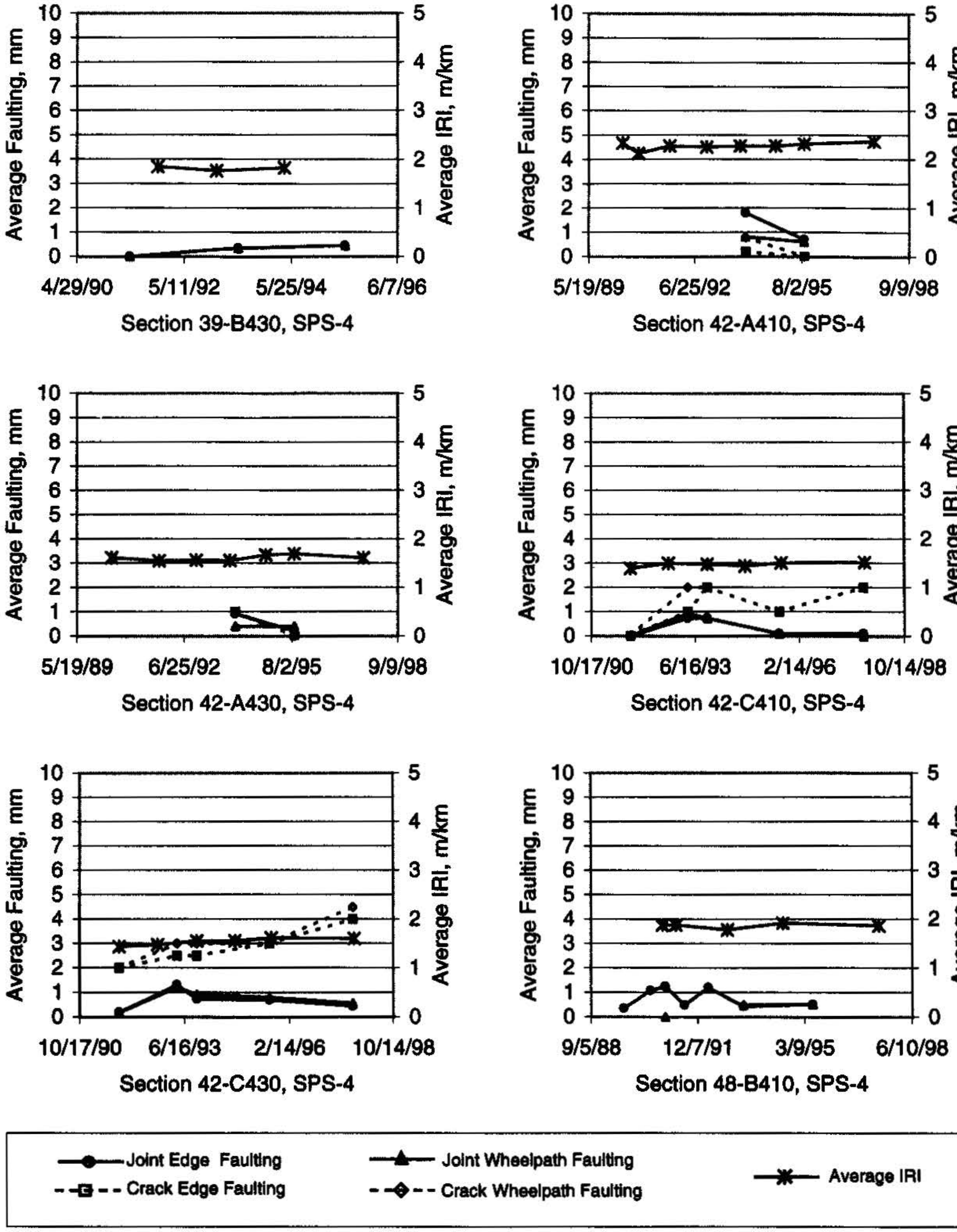

Figure 74. Time series plots for SPS-4 sections 39B430, 42A410, 42A430, 42C410, 42C430, and 48B410.

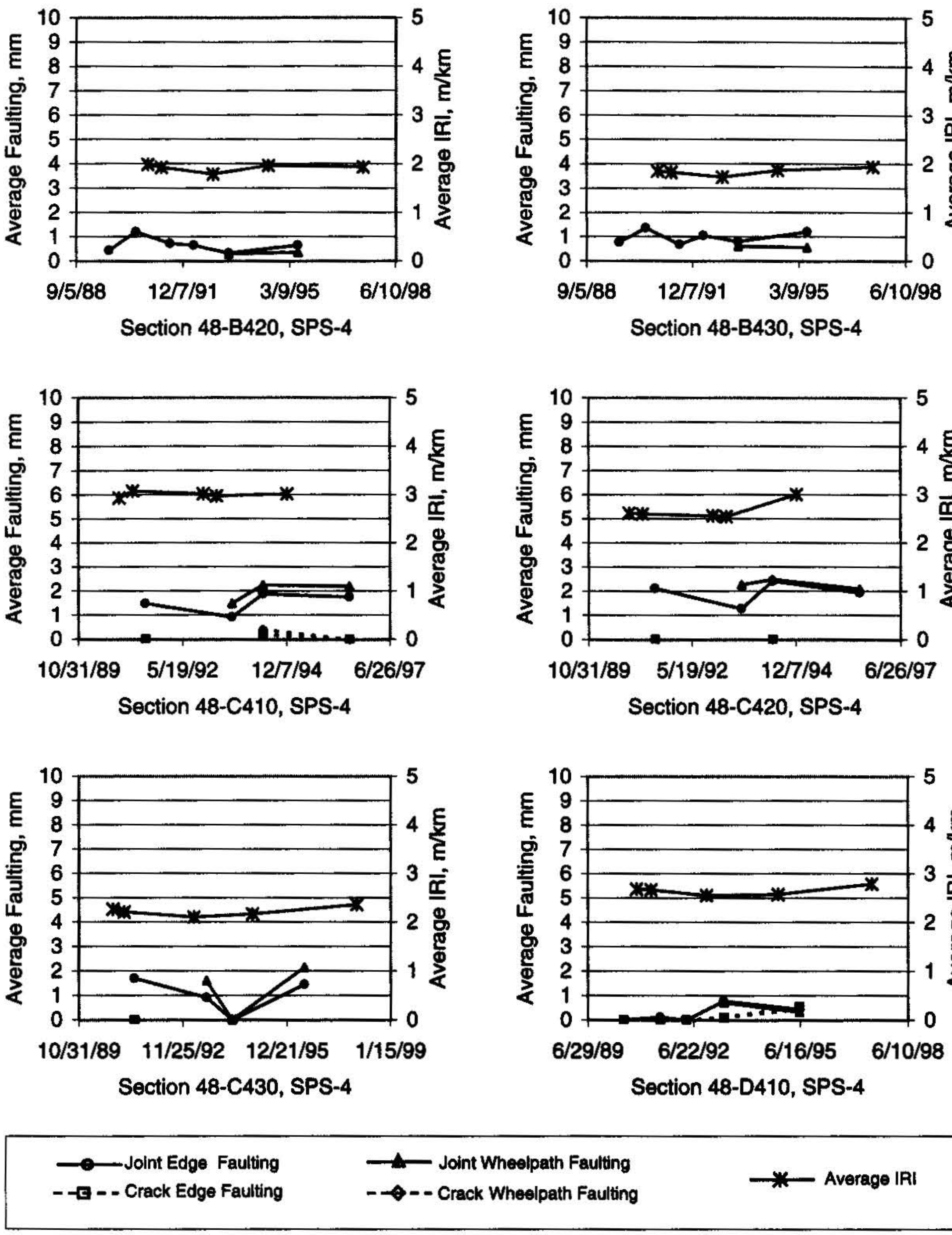

Figure 75. Time series plots for SPS-4 sections 48B420, 48B430, 48C410, 48C420, 48C430, and 48D410.

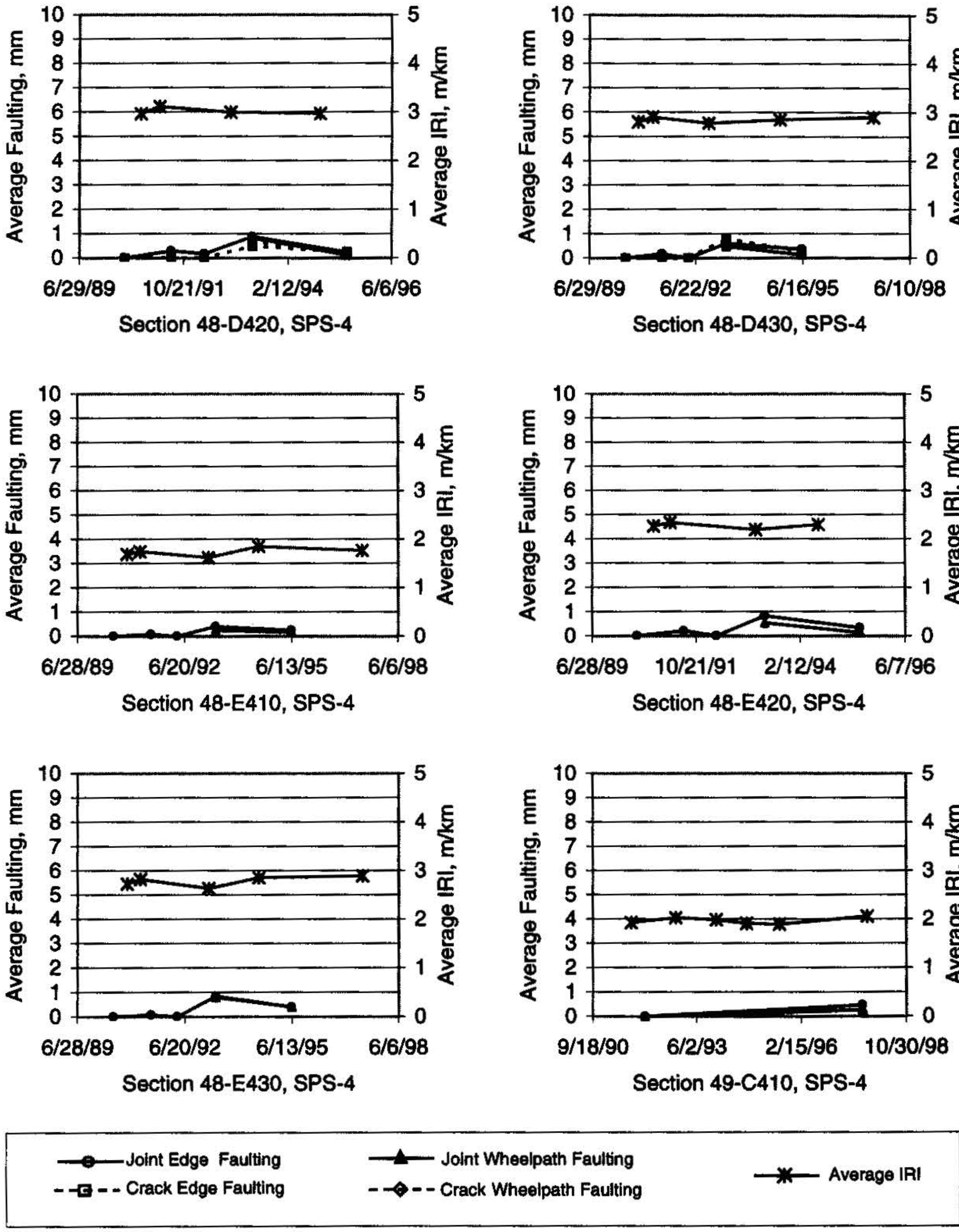

Figure 76. Time series plots for SPS-4 sections 48D420, 48D430, 48E410, 48E420, 48E430, and 49C410.

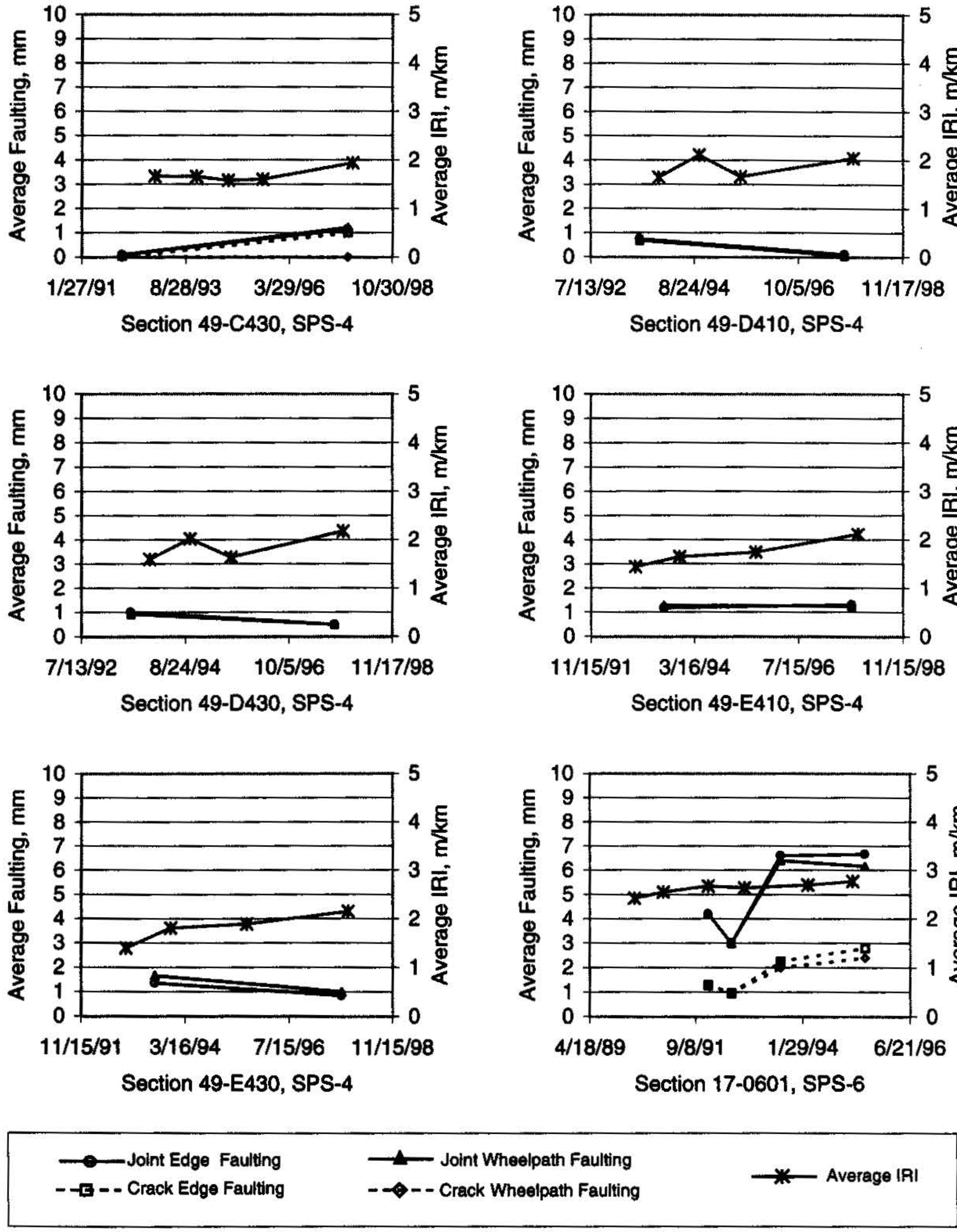

Figure 77. Time series plots for SPS-4 sections 49C430, 49D410, 49D430, 49E410, and 49E430, and SPS-6 section 170601.

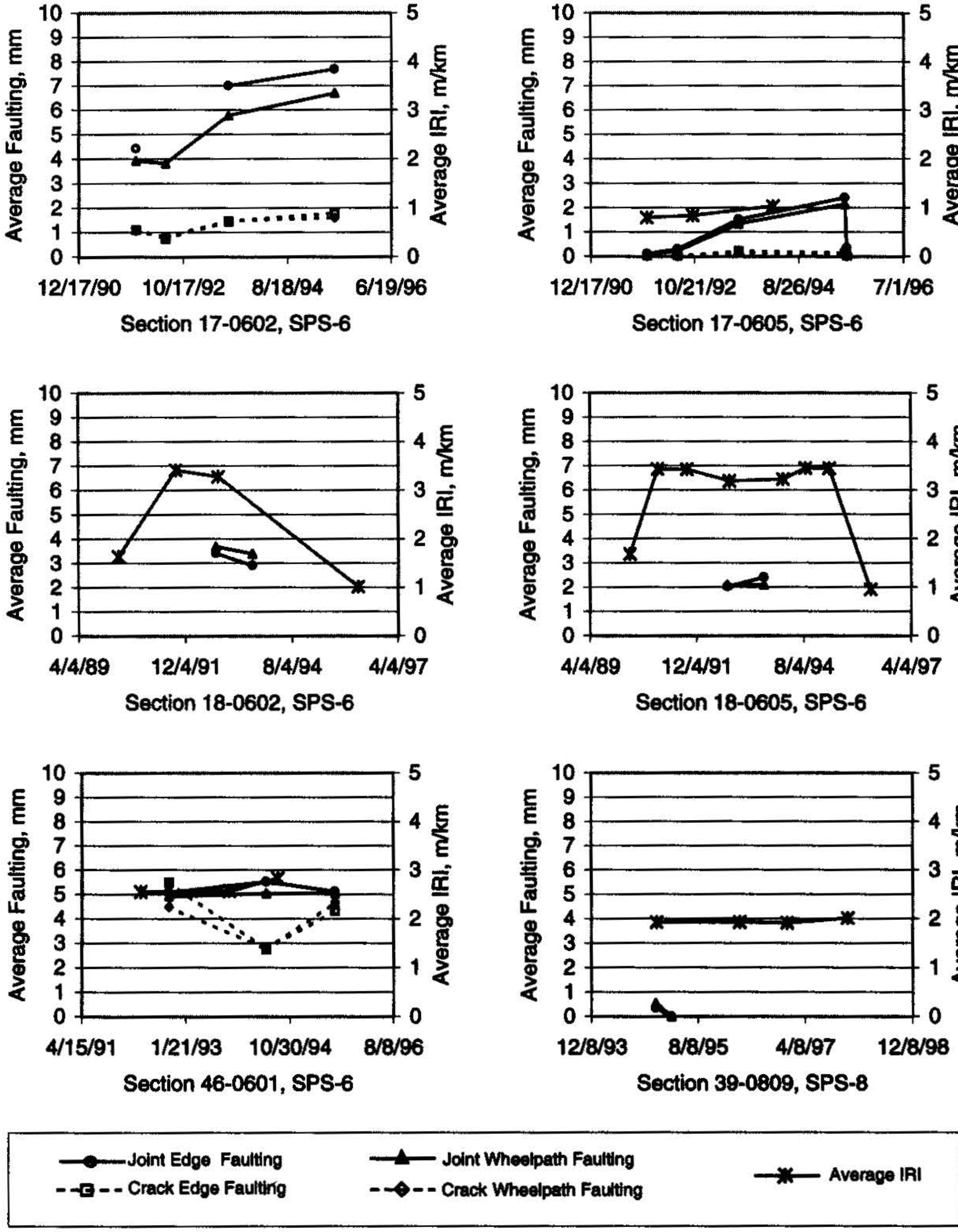

Figure 78. Time series plots for SPS-6 sections 170602, 170605, 180602, 180605, and 460601, and SPS-8 section 390809.

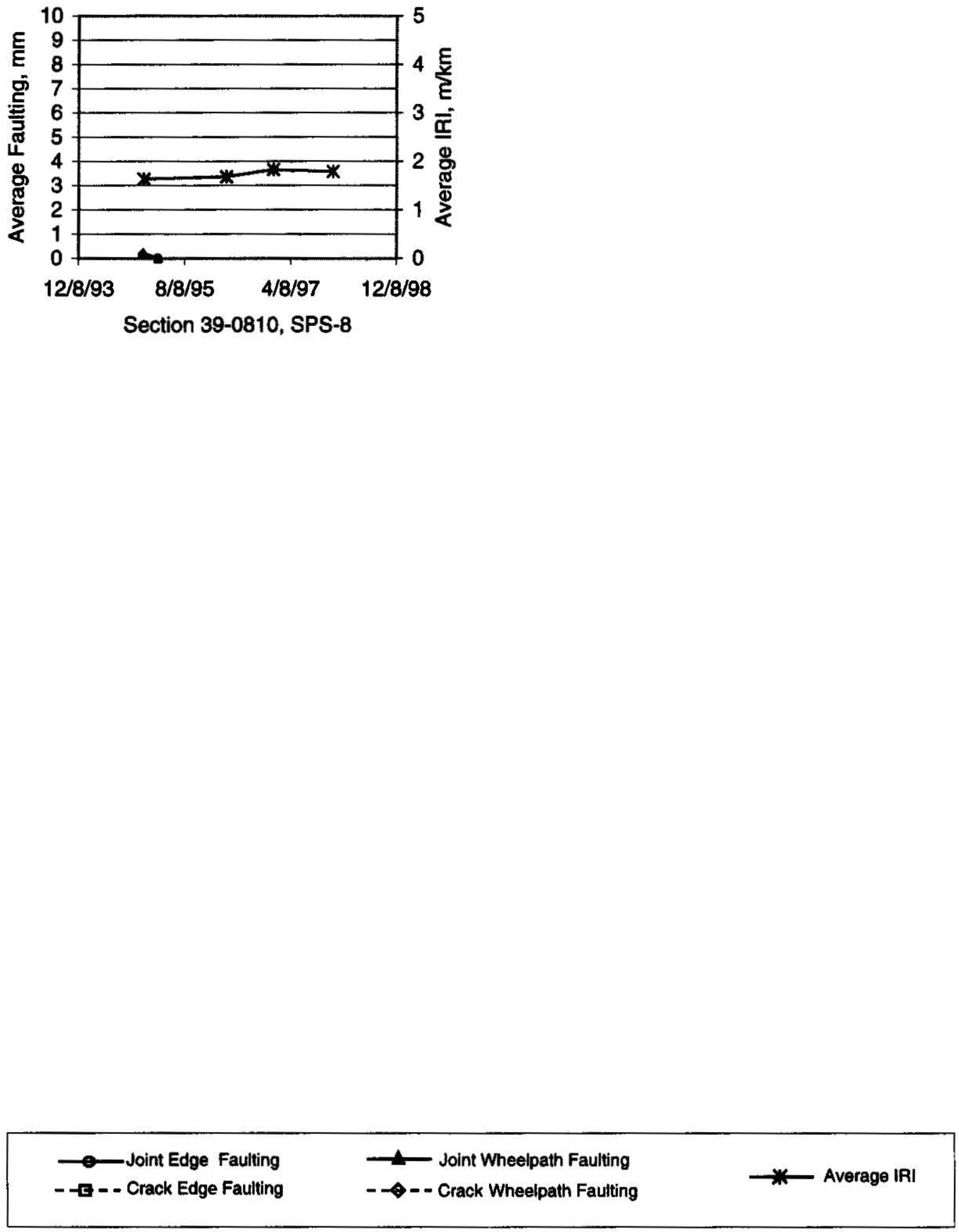

Figure 79. Time series plots for SPS-8 section 390810.