RUBBERIZED ASPHALT CONCRETE WARRANTY PILOT PROJECTS

VOLUME 2 – INTERIM PERFORMANCE MONITORING REPORT

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EXECUTIVE SUMMARY

In 2002, Caltrans embarked on a study to evaluate the overall effectiveness of using rubberized asphalt concrete (RAC) overlays under a warranty-type setting in which the contractor would repair (at his own expense) any significant distress that occurs in the first three or five years after construction, depending on the type of the project. The overall purpose of the study was to help provide a "level playing field" for all rubber-modified mixtures that contain a minimum of 15 percent scrap tire rubber. These sections could be constructed using the "wet process" (RAC-G), "terminal blend" (MB), or the "dry process". Seven pilot projects were originally considered for roadway maintenance/rehabilitation. These projects were all to be constructed during the 2002, 2003, and 2004 construction seasons. Five were chosen for construction and all were classified as rehabilitation projects with a five-year warranty requirement for performance.

Caltrans Office of Flexible Pavement Materials (OFPM) was charged with providing assistance and support to the Resident Engineer responsible for contract administration of the projects. The OFPM was also to provide a thorough evaluation of construction and post construction activities. As part of the process, the OFMP recommended guidelines for data collection to assess the following:

- Conformance to the warranty specification – The warranty specification for each RAC project called for certain minimum levels of materials and construction quality, as well as future performance. Accordingly, various types of data needed to be gathered during construction and in the future to determine conformance to the specifications.

- Performance – Data gathered and analyzed as part of a well-coordinated plan were to be used to evaluate the overall performance and cost effectiveness of the use of RAC.

This report represents Volume 2 of a report series that documents the work performed under the RAC warranty studies. It provides the data that have been collected through August 2005 pertaining to field performance, i.e., pavement condition and nondestructive deflection test data. Volume 1 of the report series (i.e., the Construction Report) documents the data collected prior to and during construction.

Within each project, four to nine 152-meter performance evaluation sections (PESs) were established for long-term performance monitoring. The tests and surveys described in this report serve as key components of the performance monitoring program.

- Detailed pavement condition surveys – Distress surveys were conducted according to standard Caltrans definitions for distress type, severity, and extent. The surveys involved measurements of rutting, cracking, raveling, flushing, and other distresses as well as digital photographs.

- FWD deflection testing – Nondestructive pavement surface deflection measurements were made using a falling weight deflectometer, which provides a basis for pavement structural capacity and subgrade soil strength assessment.

The performance data collected for the five RAC projects are presented within five separate sections of this report. The report concludes with a summary of the findings thus far and recommendations for continued testing within each of the RAC projects. Overall, the results to date indicate that the RAC projects should generally perform well over the 5-year warranty period and the intended 10-year design lives. It is likely that some projects may deteriorate sooner and require more maintenance than others. However, the expectation is that the overall performance should be satisfactory and that RAC overlays are a good candidate for use under a warranty-type specification.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

1.0 INTRODUCTION 1
- 1.1 BACKGROUND 1
- 1.2 PURPOSE AND ORGANIZATION OF REPORT 2

2.0 VENTURA COUNTY, HIGHWAY 150 3
- 2.1 PROJECT INFORMATION 3
- 2.2 DATA COLLECTION SUMMARY 3
- 2.3 CONDITION SURVEY SUMMARY 5
- 2.4 FWD TESTING SUMMARY 5
- 2.5 STRUCTURAL ADEQUACY ASSESSMENT 5

3.0 FRESNO COUNTY, HIGHWAY 33 9
- 3.1 PROJECT INFORMATION 9
- 3.2 DATA COLLECTION SUMMARY 9
- 3.3 CONDITION SURVEY SUMMARY 11
- 3.4 FWD TESTING SUMMARY 11
- 3.5 STRUCTURAL ADEQUACY ASSESSMENT 11

4.0 MERCED COUNTY, HIGHWAY 140 20
- 4.1 PROJECT INFORMATION 20
- 4.2 DATA COLLECTION SUMMARY 20
- 4.3 CONDITION SURVEY SUMMARY 22
- 4.4 FWD TESTING SUMMARY 22
- 4.5 STRUCTURAL ADEQUACY ASSESSMENT 22

5.0 SAN DIEGO COUNTY, HIGHWAY 75 27
- 5.1 PROJECT INFORMATION 27
- 5.2 DATA COLLECTION SUMMARY 27
- 5.3 CONDITION SURVEY SUMMARY 29
- 5.4 FWD TESTING SUMMARY 29
- 5.5 STRUCTURAL ADEQUACY ASSESSMENT 29

6.0 LASSEN COUNTY, HIGHWAY 395 33
- 6.1 PROJECT INFORMATION 33
- 6.2 DATA COLLECTION SUMMARY 33
- 6.3 CONDITION SURVEY SUMMARY 35
- 6.4 FWD TESTING SUMMARY 35
- 6.5 STRUCTURAL ADEQUACY ASSESSMENT 35

7.0 SUMMARY AND RECOMMENDATIONS 42
- 7.1 SUMMARY 42
- 7.2 RECOMMENDATIONS 45

8.0 REFERENCES 47

APPENDIX A - Distress Survey Protocol
APPENDIX B - FWD Test Protocol
APPENDIX C - Pavement Condition Survey Results
C.1 - Ventura County, Highway 150
C.2 - Fresno County, Highway 33
C.3 - Merced County, Highway 140
C.4 - San Diego County, Highway 75
C.5 - Lassen County, Highway 395
APPENDIX D - Deflection Database

LIST OF FIGURES

Figure 1.1. Location of five RAC Warranty projects. 2
Figure 2.1. Layout of Ventura County, Highway 150 RAC Warranty project. 4
Figure 2.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path, Ventura Highway 150, February 2005 data 7
Figure 2.3 Structural adequacy assessment – the Ventura County Highway 150 project 8
Figure 3.1. Layout of Fresno County, Highway 33 RAC Warranty project. 10
Figure 3.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path, Fresno Highway 33, September 2003 data 16
Figure 3.3. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path, Fresno Highway 33, September 2004 data 17
Figure 3.4. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, Fresno Highway 33, February 2005 data. 18
Figure 3.5. Structural adequacy assessment – the Fresno County Highway 33 Project 19
Figure 4.1. Layout of Merced County, Highway 140 RAC Warranty project. 21
Figure 4.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, Merced Highway 140, February 2005 25
Figure 4.3. Structural adequacy assessment – the Merced County Highway 140 project 26
Figure 5.1. Layout of San Diego County, Highway 75 RAC Warranty project. 28
Figure 5.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, San Diego Highway 75, February 2005 data. 31
Figure 5.3. Structural adequacy assessment – the San Diego County Highway 75 project 32
Figure 6.1. Layout of Lassen County, Highway 395 RAC Warranty project. 34
Figure 6.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, Lassen Highway 395, December 2004 data. 40
Figure 6.3. Structural adequacy assessment – the Lassen County Highway 395 project 41

LIST OF TABLES

Table 1.1. Caltrans pilot RAC Warranty projects. 1
Table 2.1. Location and description of six PESs selected for Ventura County, Highway 150 RAC Warranty project. 3
Table 2.2. Weather conditions during FWD testing and condition survey evaluation. 3

Table 2.3. Normalized deflections (in milli-inches) for sensor 1 and sensor 5 for the outside wheel path, Ventura Highway 150, February 2005 data. 6
Table 3.1. Location and description of six PESs selected for Fresno County, Highway 33 RAC Warranty project. 9
Table 3.2. Dates and conditions of condition survey evaluation. 9
Table 3.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Fresno Highway 33, September 2003 data. 12
Table 3.4. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Fresno Highway 33, September 2004 data. 13
Table 3.5. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Fresno Highway 33, February 2005 data. 14
Table 3.6. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Fresno Highway 33, February 2005 data. 15
Table 4.1. Location and description of six PESs selected for Merced County, Highway 140 RAC Warranty project. 20
Table 4.2. Weather conditions during FWD testing and condition survey evaluation. 20
Table 4.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Merced Highway 140, September 2003 data. 23
Table 4.4. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Merced Highway 140, February 2005 data. 24
Table 5.1. Location and description of four PESs selected for San Diego County, Highway 75 RAC Warranty project. 27
Table 5.2. Weather conditions during FWD testing and condition survey evaluation. 27
Table 5.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, San Diego Highway 75, February 2005 data. 30
Table 6.1. Location and description of nine PESs selected for Lassen County, Highway 395 RAC Warranty project. 33
Table 6.2. Weather conditions during FWD testing and condition survey evaluation. 33
Table 6.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Lassen Highway 395, December 2004 data. 36
Table 6.4. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Lassen Highway 395, December 2004 data. 38
Table 7.1. Calendar summarizing the data collection status for each of the RAC Warranty projects during their respective 5-year warranty period. 43
Table 7.2. Distribution of PES based upon average maximum surface deflection (measured during last test period). 44
Table 7.3. Recommended FWD testing schedule for remainder of five-year monitoring schedule. 45

1.0 INTRODUCTION

1.1 BACKGROUND

Between 2002 and 2003, Caltrans investigated seven candidate projects for roadway maintenance/ rehabilitation that would contain specifications for rubberized asphalt concrete (RAC) and include a warranty on the RAC material and workmanship. These projects were all to be constructed during the 2002, 2003, and 2004 construction seasons.

The Office of Flexible Pavement Materials (OFPM) of Caltrans Materials Engineering and Testing Services (METS) provided guidelines to the Resident Engineers for the collection of data from these projects to:

- Determine their conformance to the warranty specification – The warranty specification for each RAC project called for certain minimum levels of materials and construction quality, as well as future performance. Accordingly, various types of data needed to be gathered during construction and in the future to determine conformance to the specifications.

- Evaluate their performance – Data gathered and analyzed as part of a well-coordinated plan were to be used to evaluate the overall performance and cost effectiveness of the use of RAC.

The emphasis of this report is on the experimental data that has been collected pertaining to the performance evaluation. As the pavements within the RAC warranty projects age and deteriorate, it is anticipated that Caltrans will play the key role in surveying and recording the condition of the pavements for warranty conformance purposes.

The overall purpose of the study was to help provide a "level playing field" for all rubber-modified mixtures that contain a minimum of 15 percent scrap tire rubber. These sections could be constructed using the "wet process" (RAC-G), "terminal blend" (MB), or the "dry process". The study plan called for a five-year post construction data collection and evaluation phase.

Five projects were constructed. Each was classified as a rehabilitation project and targeted for five years of monitoring and evaluation. Table 1.1 provides basic information on the five pilot RAC Warranty projects. Project locations are shown in Figure 1.1. Additional information relative to the construction of these projects may be found in the construction report [Caltrans, 2005]. Within each project, four to nine 500-ft (152.4-m) performance evaluation sections (PESs) were established and are being used to evaluate the overall performance of each project.

Table 1.1. Caltrans pilot RAC Warranty projects

District	County	Route	Region	Project Limits		Project Length	
				Post Mile (PM)	Kilo Post (KP)	(mi)	(km)
02	Lassen	395	Mountainous	11.8-24.8	19.0 – 39.9	13.0	19.9
06	Fresno	33	Central Valley	62.4-69.4	100.4 – 111.7	7.0	11.3
07	Ventura	150	Coastal	15.2-24.0	24.4 – 38.6	8.8	14.2
10	Merced	140	Central Valley	27.0-30.2	43.4 – 48.6	3.2	5.2
11	San Diego	75	Coastal	11.0-17.4	17.7 – 28.0	6.4	10.3

Figure 1.1. Location of five RAC Warranty projects

1.2 PURPOSE AND ORGANIZATION OF REPORT

This report documents the key field testing and distress surveys that have been carried out on the PESs within each RAC project. These tests and surveys (identified below) are a key component of the monitoring program that is being carried to provide the needed data for evaluating the overall performance of the RAC sections. These data include following:

- Detailed pavement condition surveys – Distress surveys were conducted according to standard Caltrans definitions for distress type, severity, and extent [Caltrans, 2000]. Custom forms and tables (as presented in Appendix A) that evolved as part of other recent studies [Caltrans, 2002] were used to collect and record detailed distress data for each PES. The surveys involved measurements of rutting, cracking, raveling, flushing, and other distresses as well as digital photographs.

- FWD deflection testing – Surface deflection measurements were made according to a standard protocol established for this experiment (see Appendix B). This involved testing at 50-ft (15.2-m) intervals along the mid-lane and the outer wheel path.

The performance data collected for these projects are presented in five separate chapters: chapters 2 through 6 include the performance data summaries for the five projects; and chapter 7 provides an overall summary and recommendations.

2.0 VENTURA COUNTY, HIGHWAY 150

2.1 PROJECT INFORMATION

The Ventura RAC Warranty project (EA No. 07-105484) is primarily a two-lane roadway located along State Highway 150 in District 7, Ventura County, in and beyond Ojai, CA. The project extends from PM 15.2 (KP24.4 Loma Drive) to PM 24.0 (KP 38.6 near Lion Canyon Creek Bridge) for a total of 8.8 mi (14.2 km).

The overlay for this project was constructed in October 2002 and consisted of a 2.36-in (60-mm) RAC-G mixture. Because of localized areas of pavement deterioration, overlay placement was preceeded by the removal and replacement, full-depth repair, or partial-depth repair (i.e., mill and fill) operations. More detailed construction information is provided in the Volume 1, Construction Report [Caltrans, 2005].

Six PESs were identified for this project based upon deflection measurements obtained prior to construction. Table 2.1 identifies the starting point and basic deflection level for each of the PESs. Figure 2.1 provides a plan view showing the PES locations.

Table 2.1. Location and description of six PESs selected for Ventura County, Highway 150 RAC Warranty project

PES ID	Begin KP	Begin PM	Relative Deflection Level
EB-1	26.738	16.43	Low
EB-2	31.446	19.35	High
WB-3	38.480	23.72	Moderate
WB-4	31.850	19.60	Low
WB-5	29.436	18.10	High
WB-6	25.652	15.75	Moderate

2.2 DATA COLLECTION SUMMARY

Only one round of post-construction performance monitoring consisting of condition surveys and FWD deflection testing was conducted on this project. The date of this testing, along with the prevailing weather conditions, are summarized in Table 2.2.

Table 2.2. Weather conditions during FWD testing and condition survey evaluation

Date	FWD Testing	Condition Survey	Weather Conditions
2/9/05	Yes	Yes	Mostly sunny with air temperatures in the range of 47 to 75°F (8 to 24°C)

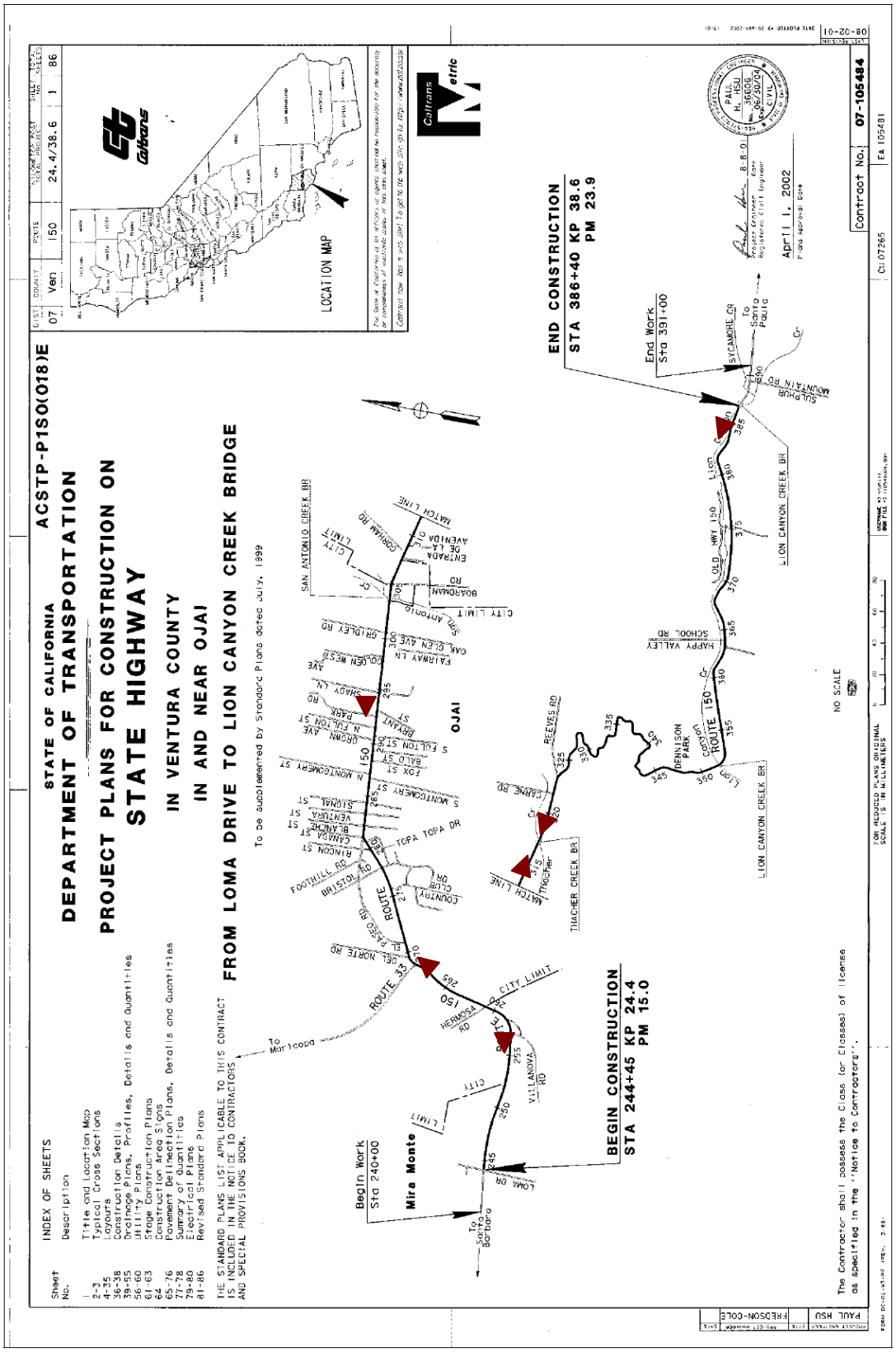

Figure 2.1. Plan showing location of six PESs along Ventura County, Highway 150

2.3 CONDITION SURVEY SUMMARY

Appendix C.1 provides example photos and summarizes the condition survey results for each of the six PESs located along the project. The overall condition of the pavements in the six PESs was good, with generally little distress observed. However, several embankment failures associated with heavy rains were observed adjacent to sections WB-3 and WB-4. The transverse cracks observed in section WB-3 are likely related to the embankment failure. Section WB-4 exhibited no distress. A single 3-ft (1-m) long transverse crack was observed in section WB-5. No other significant pavement distress was observed throughout the project. The age of the overlay at the time of the survey was 2.5 years and, although there are some early signs of distress, they are related to the instability of the underlying embankment, not to the quality of the RAC materials or construction. Overall, it is expected that the RAC overlay will provide good performance over the remainder of the warranty period.

2.4 FWD TESTING SUMMARY

Table 2.3 provides a summary of the processed FWD test data obtained from each of the PESs. The table includes surface deflection values (normalized to the standard 9,000-lb [40-kN] deflection load) from the outer wheel path for two key sensor locations:

- Sensor 1 – Maximum deflection beneath the load, i.e., at a radial distance (r) equal to zero inches (0 mm) from the center of the load plate. The deflection from this sensor is normally used for assessment of structural capacity and overlay thickness design.
- Sensor 5 – Deflection at a radial distance (r) equal to 36 in (914 mm) from the center of the load plate. The deflection from this sensor is highly correlated with the modulus of the subgrade soil.

Figure 2.2 provides graphs showing the deflection profiles for each PES. These graphs are based on the normalized deflection data presented in Table 2.3. Overall, the data within these sections exhibit a wide range in both average maximum deflection and within section variability.

Raw deflection data are stored in a relational database described in Appendix D. For the first (and only) round of deflection testing performed thus far, no mid-lane deflection testing was performed.

2.5 STRUCTURAL ADEQUACY ASSESSMENT

A general assessment of the structural adequacy of this project was conducted using the deflection data from the first round of testing (after RAC overlay construction) and traffic (TI) data used in the original rehabilitation design (provided in the Volume 1 - Construction Report). This structural adequacy assessment is based solely on an evaluation of the six PESs. Since these sections were selected to cover the range of deflections measured along the project, the results of the assessment should reflect a range of structural capacity that emphasizes the highs and lows.

The two key inputs required for the structural adequacy assessment are defined below.

- Traffic Index (TI) = 9 (from Volume 1 - Construction Report)
- Total HMA thickness (including RAC overlay) = 12.0 in (306 mm)

The tolerable deflection corresponding to these two inputs, as determined using the criteria in the Caltrans Flexible Pavement Rehabilitation Manual [Caltrans, 2001], is 14.08 milli-inches (0.358 mm), assuming the criteria are also applicable to RAC. The 80th percentile deflection for each of the six PESs was calculated using the deflection values measured in the outside wheel path.

Table 2.3. Normalized deflections (in milli-inches) for sensor 1 and sensor 5 for the outside wheel path, Ventura Highway 150, February 2005 data

Location (ft)	Pavement Evaluation Section											
	EB-1		EB-2		WB-3		WB-4		WB-5		WB-6	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	9.469	2.841	16.154	4.521	11.697	7.579	13.567	3.354	45.453	8.157	7.202	3.529
50	9.293	2.935	18.175	4.315	10.248	4.698	15.495	5.310	53.376	7.315	7.873	4.064
100	7.640	1.867	14.286	3.569	23.494	8.661	10.565	3.451	40.725	5.559	9.604	4.941
150	5.977	1.482	13.706	3.268	14.288	7.240	14.921	3.854	46.859	7.162	7.991	4.037
200	9.476	3.332	14.075	3.218	15.669	7.280	13.435	4.689	35.454	6.903	9.437	4.530
250	5.930	1.666	16.133	3.484	7.764	5.041	7.010	2.472	26.472	7.628	9.889	4.403
300	6.011	2.118	17.537	4.342	11.653	5.812	6.423	2.662	9.989	4.484	10.366	4.323
350	9.750	2.287	13.722	3.709	15.281	5.665	6.418	3.113	10.550	6.222	11.529	4.112
400	8.011	2.168	15.217	4.473	10.798	6.116	6.041	2.640	26.455	8.562	10.626	5.021
450	16.096	5.486	18.260	4.560	9.692	6.784	4.596	2.016	38.834	7.055	8.812	4.354
500	11.475	4.836	20.483	4.759	14.364	6.556	5.257	2.296	33.442	9.769	8.153	3.764
Mean	9.012	2.820	16.159	4.020	13.177	6.494	9.430	3.260	33.419	7.165	9.226	4.280
Std Dev	2.965	1.292	2.231	0.573	4.242	1.173	4.214	1.025	14.069	1.438	1.340	0.451

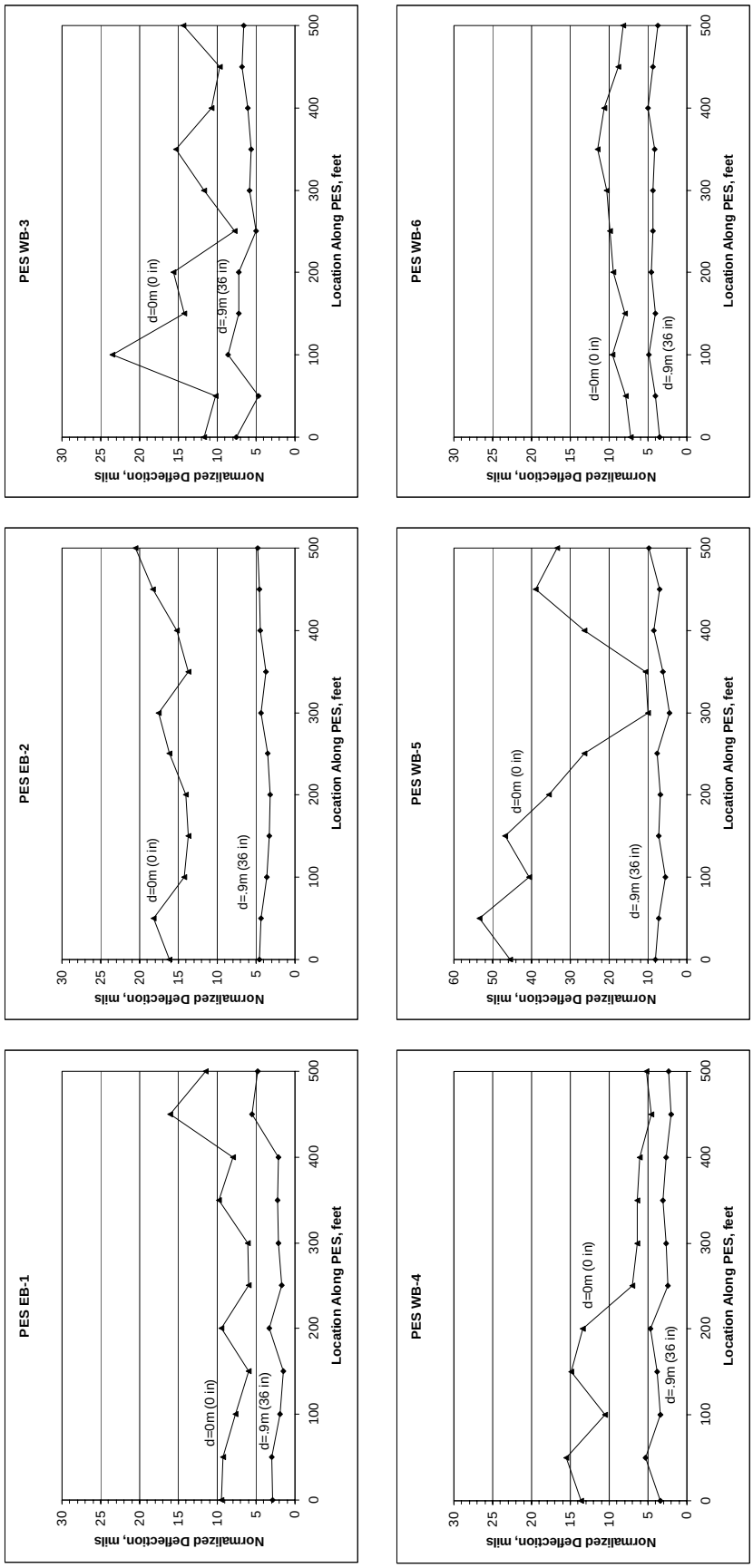

Figure 2.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path, Ventura Highway 150, February 2005 data

Figure 2.3 provides a bar graph that compares these 80th percentile deflections with the tolerable value. Those sections that have an 80th percentile deflection less than the tolerable value are considered to be structurally adequate for the design conditions. Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

Inspection of Figure 2.3 indicates that four of the PESs have 80th percentile deflections that exceed the tolerable value, while only two exhibit 80th percentile deflections that are less. Of the four PESs that have high deflections, section WB-5 is extremely high. Its 80th percentile deflection is four times that of the tolerable deflection and is likely to exhibit structural distress within the first five years of its intended 10-year design life. Sections EB-2 and WB-3 are likely to perform satisfactorily for seven to eight years before they start to show significant structural distress.

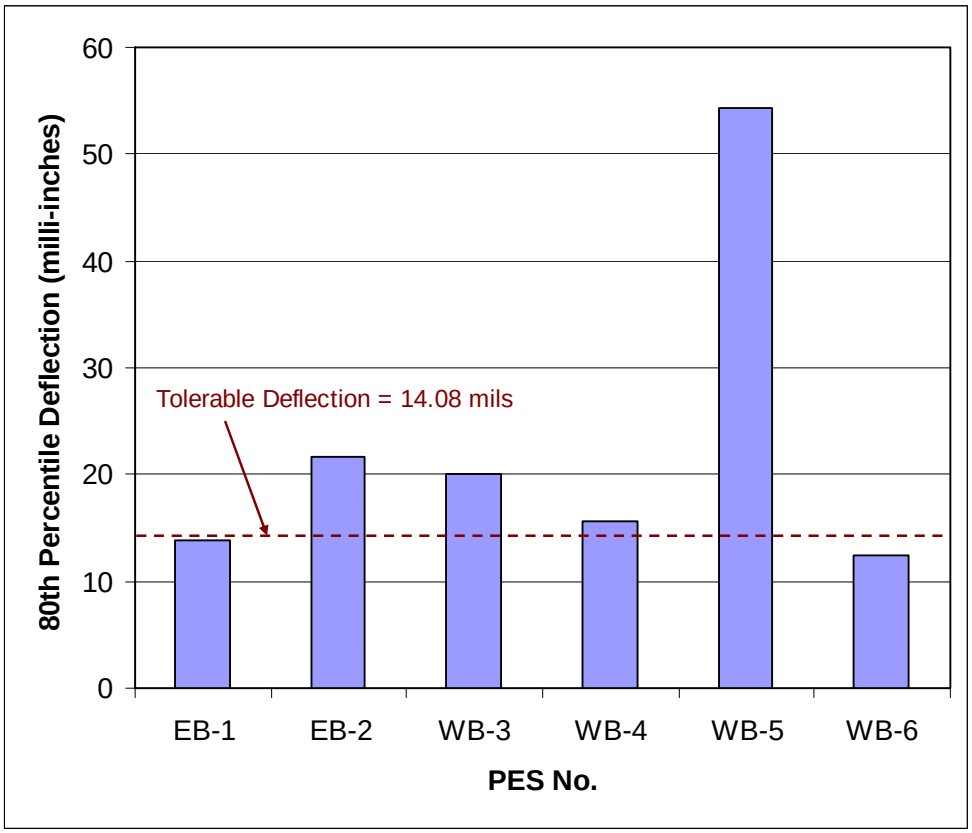

Figure 2.3. Structural adequacy assessment - the Ventura County Highway 150 project

3.0 FRESNO COUNTY, HIGHWAY 33

3.1 PROJECT INFORMATION

The Fresno RAC Warranty project (EA No. 06-343534) is a two-lane roadway located along State Highway 33 in District 6, Fresno County, between Mendota and Firebaugh, CA. The project extends from PM 62.4 (KP 100.4 near Bass Avenue) to PM 69.4 (KP 111.7 near Main Canal Bridge) for a total of 7.0 mi (11.3 km).

The overlay for this project was constructed in August 2003 and consisted of a 2.36-in (60-mm) RAC-G mixture. More detailed construction information is provided in the Volume 1, Construction Report [Caltrans, 2005].

Six PESs were identified for this project based upon deflection measurements obtained prior to construction. Table 3.1 identifies the starting point and basic deflection level for each of the PESs. Figure 3.1 provides a plan view showing the PES locations.

Table 3.1. Location and description of six PESs selected for Fresno County, Highway 33 RAC Warranty project

PES ID	Begin KP	Begin PM	Relative Deflection Level
NB-1	103.31	64.25	High
NB-2	106.37	66.15	Low
NB-3	109.50	68.10	Moderate
SB-1	110.07	68.45	Low
SB-2	107.49	66.85	High
SB-3	105.39	65.54	Moderate

3.2 DATA COLLECTION SUMMARY

Three rounds of post-construction performance monitoring were conducted on the project. FWD testing was performed during all three rounds; however, a condition survey was performed only in the last round. The dates of the testing, along with the prevailing weather conditions, are summarized in Table 3.2.

Table 3.2. Dates and conditions of condition survey evaluation

Date	FWD Testing	Condition Survey	Weather Conditions
9/15/03	Yes	No	Air temperature ranged from 81 to 111°F (27 to 44°C)
9/22/04	Yes	No	Surface temperature ranged from 62 to 74°F (17 to 23°C)
2/9/05	Yes	Yes	Sunny skies with air temperatures ranging from 57 to 72°F (14 to 22°C)

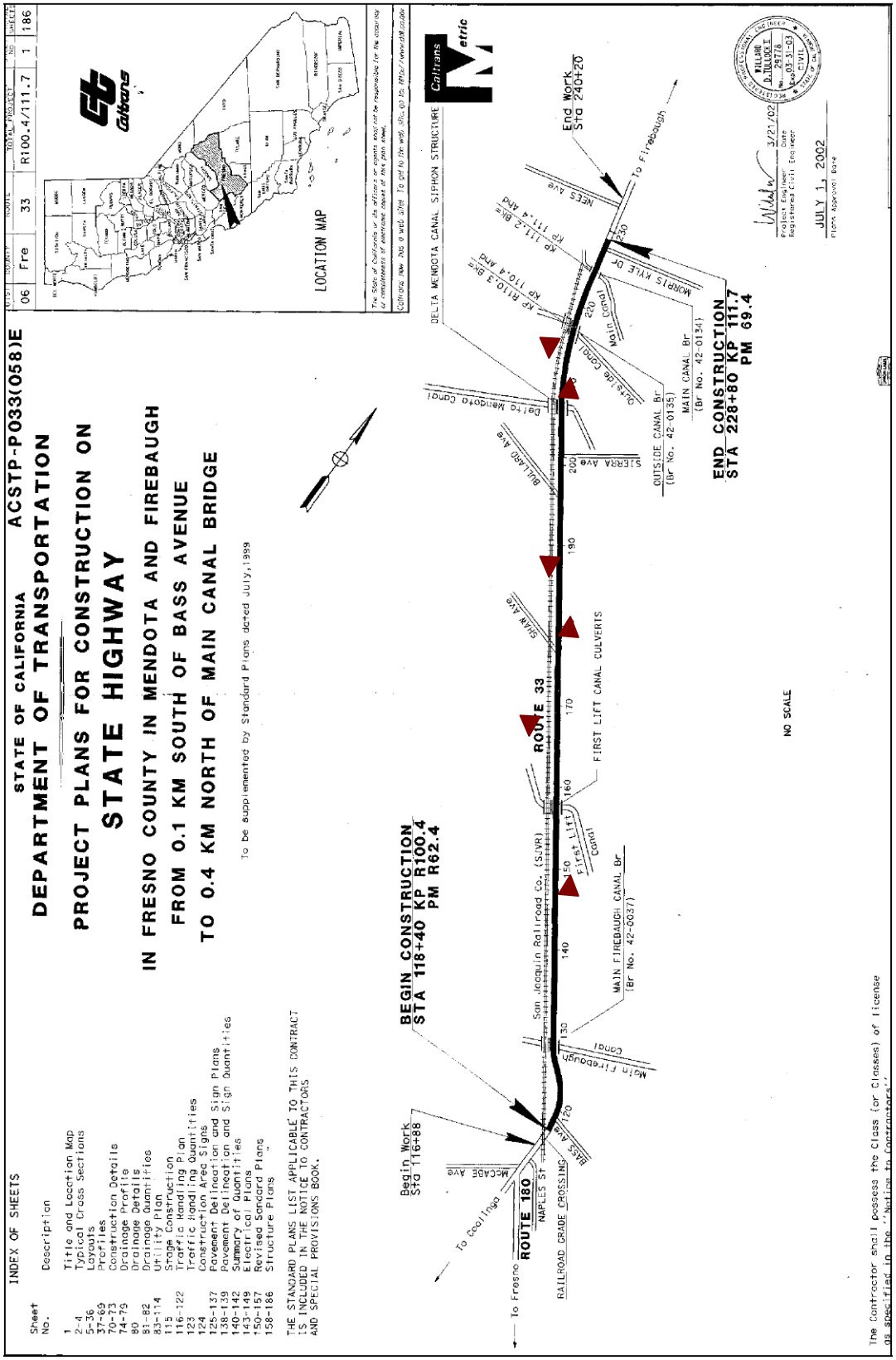

Figure 3.1. Plan showing location of six PESs along Fresno County, Highway 33

3.3 CONDITION SURVEY SUMMARY

Appendix C.2 provides example photos and summarizes the condition survey results obtained during February 2005 for each of the six PESs located along the project. As can be seen, almost no distress was observed in the PESs. Only a very small amount of raveling (less than one square meter) was observed in section SB-1. Although the age of the overlay is only 1.5 years, there is no indication that it will not provide good performance over the remainder of the warranty period.

3.4 FWD TESTING SUMMARY

Tables 3.3 through 3.6 provide a summary of the processed FWD test data obtained from each of the PES during the three rounds of testing. The tables include surface deflection values (normalized to the standard 9,000-lb [40-kN] deflection load) for two key sensor locations, 1 and 5.

The data in both Tables 3.3 and 3.4 represent deflection values obtained in the outer wheel path during the first two rounds of testing (no mid-lane testing was performed during these rounds). Tables 3.5 and 3.6 provide deflection values from the third round of testing for the outside wheel path and mid-lane locations, respectively.

Figures 3.2 through 3.4 provide graphs showing the individual deflection profiles for each PES. The graphs in these figures are based on the normalized deflection data presented in Tables 3.3 to 3.6. Raw deflection data are stored in the relational database (Appendix D).

Overall, the deflection data from these RAC PESs indicate relatively low deflection values, a low range in average maximum deflection (between the PESs), and relatively low within section variability. The variation of average maximum deflection between the three time intervals is also generally consistent, although two of the PESs (SB-2 and SB-3) reflect a significant, but temporary increase in deflection in 2004.

3.5 STRUCTURAL ADEQUACY ASSESSMENT

A general assessment of the structural adequacy of this project was conducted using the deflection data from the first round of testing (after RAC overlay construction) and traffic (TI) data used in the original rehabilitation design (provided in the Volume 1 - Construction Report). This structural adequacy assessment is based solely on an evaluation of the six PESs. Since these sections were selected to cover the range of deflections measured along the project, the results of the assessment should reflect a range of structural capacity that emphasizes the highs and lows.

The two key inputs required for the structural adequacy assessment are defined below.

- Traffic Index (TI) = 9.5 (from Volume 1 - Construction Report)
- Total HMA thickness (including RAC overlay) = 7.7 in (196 mm)

The tolerable deflection corresponding to these two inputs, as determined using the criteria in the Caltrans Flexible Pavement Rehabilitation Manual [Caltrans, 2001], is 13.04 milli-inches (0.331 mm), assuming the criteria are also applicable to RAC. The 80th percentile deflection for each of the six PESs was calculated using the deflection values measured in the outside wheel path.

Table 3.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Fresno Highway 33, September 2003 data

Location (ft)	Pavement Evaluation Section											
	NB-1		NB-2		NB-3		SB-1		SB-2		SB-3	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	15.643	8.910	9.830	6.702	12.091	6.468	9.062	5.013	11.546	7.320	11.390	7.454
50	16.336	9.041	12.151	7.624	12.806	6.516	9.380	5.086	11.394	7.462	7.049	3.616
100	16.281	9.031	13.607	7.736	13.870	6.479	7.478	4.629	12.607	7.453	11.852	7.669
150	17.170	9.074	13.234	7.515	12.938	6.404	9.125	4.933	10.689	6.766	11.423	7.584
200	15.416	8.725	12.754	5.750	12.964	6.477	9.021	4.620	11.316	7.351	12.034	7.421
250	16.056	8.778	15.140	7.764	13.348	6.604	7.854	4.448	12.953	7.281	12.387	7.333
300	18.075	9.689	13.252	7.231	11.905	6.542	7.229	4.026	11.256	6.623	9.643	6.501
350	17.101	9.791	13.577	7.488	12.667	6.221	7.058	4.072	11.076	6.714	9.803	6.570
400	18.031	10.262	12.812	7.120	13.022	6.120	7.984	4.076	11.440	7.077	9.272	5.983
450	18.502	10.518	12.331	6.817	12.219	6.366	7.292	4.177	12.088	7.077	9.776	6.147
500	17.724	10.210	13.268	7.134			6.897	4.381	13.265	7.775	11.482	6.966
Mean	16.940	9.457	12.905	7.171	12.783	6.420	8.034	4.497	11.784	7.173	10.556	6.659
Std Dev	1.058	0.656	1.292	0.589	0.596	0.149	0.939	0.392	0.828	0.359	1.596	1.168

Table 3.4. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Fresno Highway 33, September 2004 data

Location (ft)	Pavement Evaluation Section											
	NB-1		NB-2		NB-3		SB-1		SB-2		SB-3	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	12.287	6.649	12.287	6.649	8.455	5.490	8.455	5.490	13.775	7.556	15.051	8.143
50	9.901	5.824	9.901	5.824	9.135	5.875	9.135	5.875	14.904	7.979	13.393	7.768
100	11.986	6.726	11.986	6.726	9.021	5.739	9.021	5.739	14.924	7.960	14.960	7.990
150	14.529	7.093	14.529	7.093	9.859	5.993	9.859	5.993	15.609	8.043	15.777	7.453
200	13.772	6.196	13.772	6.196	9.148	5.961	9.148	5.961	14.293	7.639	14.461	7.755
250	11.871	7.176	11.871	7.176	8.674	5.888	8.674	5.888	14.361	7.719	15.081	7.912
300	10.769	7.198	10.769	7.198	7.914	5.575	7.914	5.575	13.581	7.362	13.335	7.288
350	8.557	5.701	8.557	5.701	10.035	6.761	10.035	6.761	13.990	7.649	15.935	8.580
400	8.326	5.506	8.326	5.506	8.948	6.275	8.948	6.275	12.763	6.839	16.678	8.923
450	8.183	5.261	8.183	5.261	7.069	5.271	7.069	5.271	12.654	7.037	16.920	7.942
500												
Mean	11.018	6.333	11.018	6.333	8.826	5.883	8.826	5.883	14.085	7.578	15.159	7.976
Std Dev	2.257	0.730	2.257	0.730	0.873	0.420	0.873	0.420	0.941	0.400	1.219	0.487

Table 3.5. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Fresno Highway 33, February 2005 data

Location (ft)	Pavement Evaluation Section											
	NB-1		NB-2		NB-3		SB-1		SB-2		SB-3	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	9.143	5.551	7.452	4.330	8.890	4.860	9.759	3.734	9.269	4.700	9.739	5.211
50	8.429	5.233	8.104	4.596	8.875	4.869	10.681	4.250	8.646	4.027	6.347	3.234
100	8.472	5.063	7.931	4.648	8.625	4.817	8.248	3.716	9.597	5.039	9.131	5.304
150	8.952	5.238	8.437	4.697	8.800	4.834	9.266	3.925	8.488	4.475	9.671	5.086
200	8.116	4.978	10.492	4.540	10.017	5.044	10.372	3.729	9.531	5.345	9.743	4.605
250	8.211	4.870	9.681	4.886	8.773	4.718	8.878	3.771	10.064	5.047	9.392	4.432
300	9.078	5.380	7.811	4.495	9.559	4.648	7.075	3.214	8.510	4.530	8.518	4.401
350	8.392	5.127	7.971	4.532	9.964	4.675	7.526	3.270	9.131	4.428	8.264	4.157
400	9.032	5.450	7.271	4.334	8.941	4.556	7.911	3.408	8.984	4.406	7.363	4.039
450	9.322	5.470	7.664	4.241	9.301	4.595	8.156	3.454	10.383	5.054	6.889	4.107
500	9.760	5.497	7.335	4.232	9.016	4.564	8.089	3.760	10.982	5.154	8.867	4.699
Mean	8.810	5.260	8.195	4.503	9.160	4.744	8.724	3.657	9.417	4.746	8.539	4.480
Std Dev	0.519	0.229	1.012	0.204	0.485	0.154	1.171	0.302	0.801	0.407	1.198	0.604

Table 3.6. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Fresno Highway 33, February 2005 data

Location (ft)	Pavement Evaluation Section											
	NB-1		NB-2		NB-3		SB-1		SB-2		SB-3	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	12.629	6.726	7.075	4.269	12.320	5.448	10.822	3.868	9.439	4.463	10.091	5.291
50	11.081	5.949	7.921	4.613	13.681	5.635	11.998	4.222	9.693	4.142	7.162	3.044
100	10.859	5.773	7.706	4.660	13.816	5.584	9.972	3.945	10.452	5.180	11.441	5.483
150	10.668	5.655	6.784	4.222	12.986	5.535	10.409	4.154	8.522	4.578	11.007	5.050
200	10.113	5.569	6.091	3.270	14.761	5.711	11.874	4.179	10.318	5.440	10.814	4.684
250	9.793	5.296	8.234	4.607	14.044	5.552	9.181	3.804	9.440	5.023	10.168	4.656
300	12.703	6.494	7.852	4.392	13.739	5.188	8.125	3.469	8.151	4.485	9.313	4.249
350	11.130	5.988	8.339	4.460	14.396	5.311	7.711	3.465	9.069	4.479	9.732	4.316
400	11.738	6.350	7.634	4.584	14.816	5.310	8.724	3.890	9.552	4.399	8.763	4.223
450	10.368	5.687	7.153	4.262	15.323	5.283	8.561	4.113	11.631	5.282	8.661	4.080
500	11.812	6.018	7.201	4.073	15.372	5.273	9.032	4.274	11.635	5.103	8.937	4.397
Mean	11.172	5.955	7.454	4.310	14.114	5.439	9.674	3.944	9.809	4.780	9.644	4.497
Std Dev	0.961	0.427	0.668	0.394	0.946	0.174	1.457	0.282	1.124	0.434	1.243	0.666

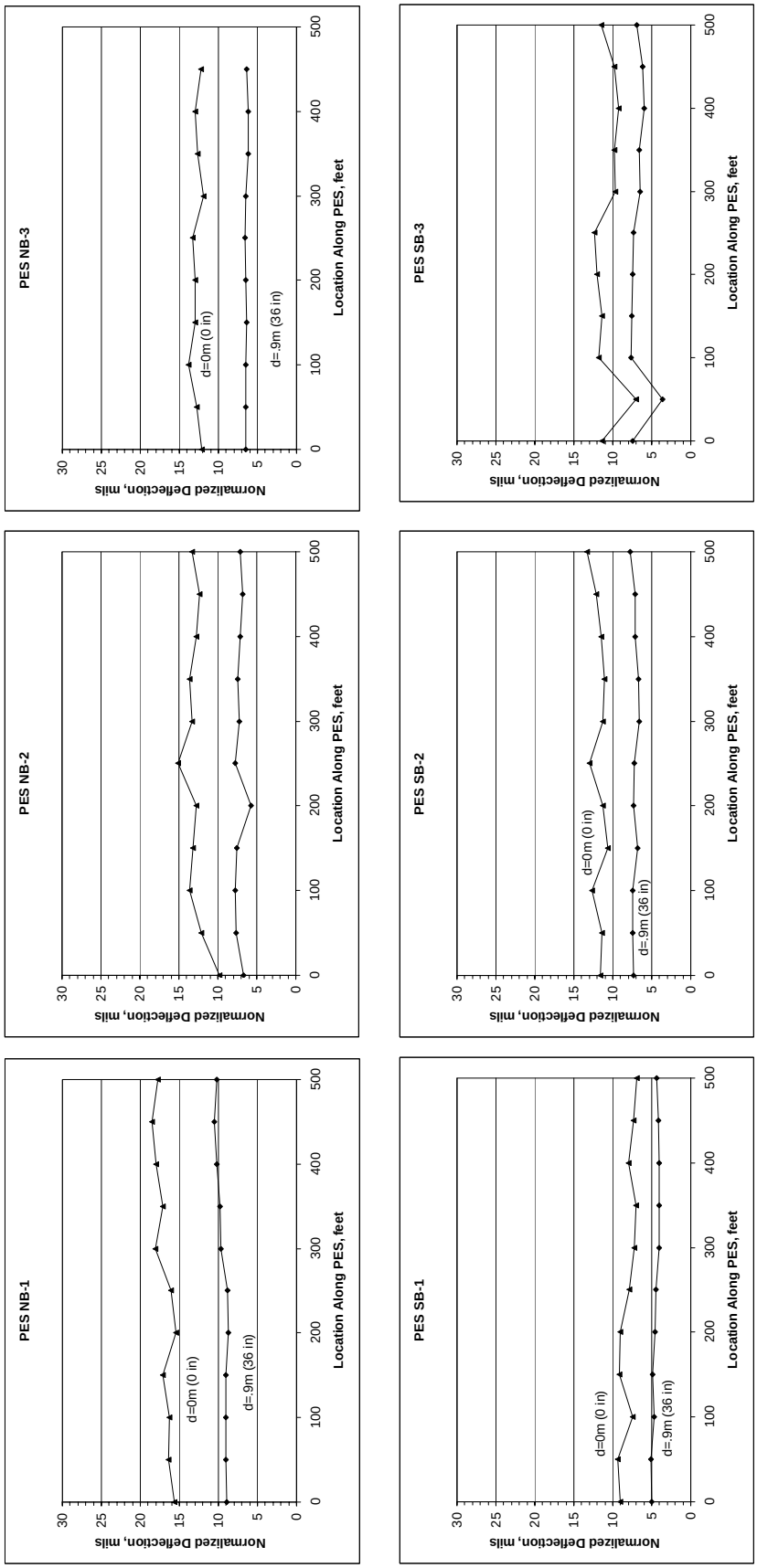

Figure 3.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path, Fresno Highway 33, September 2003 data

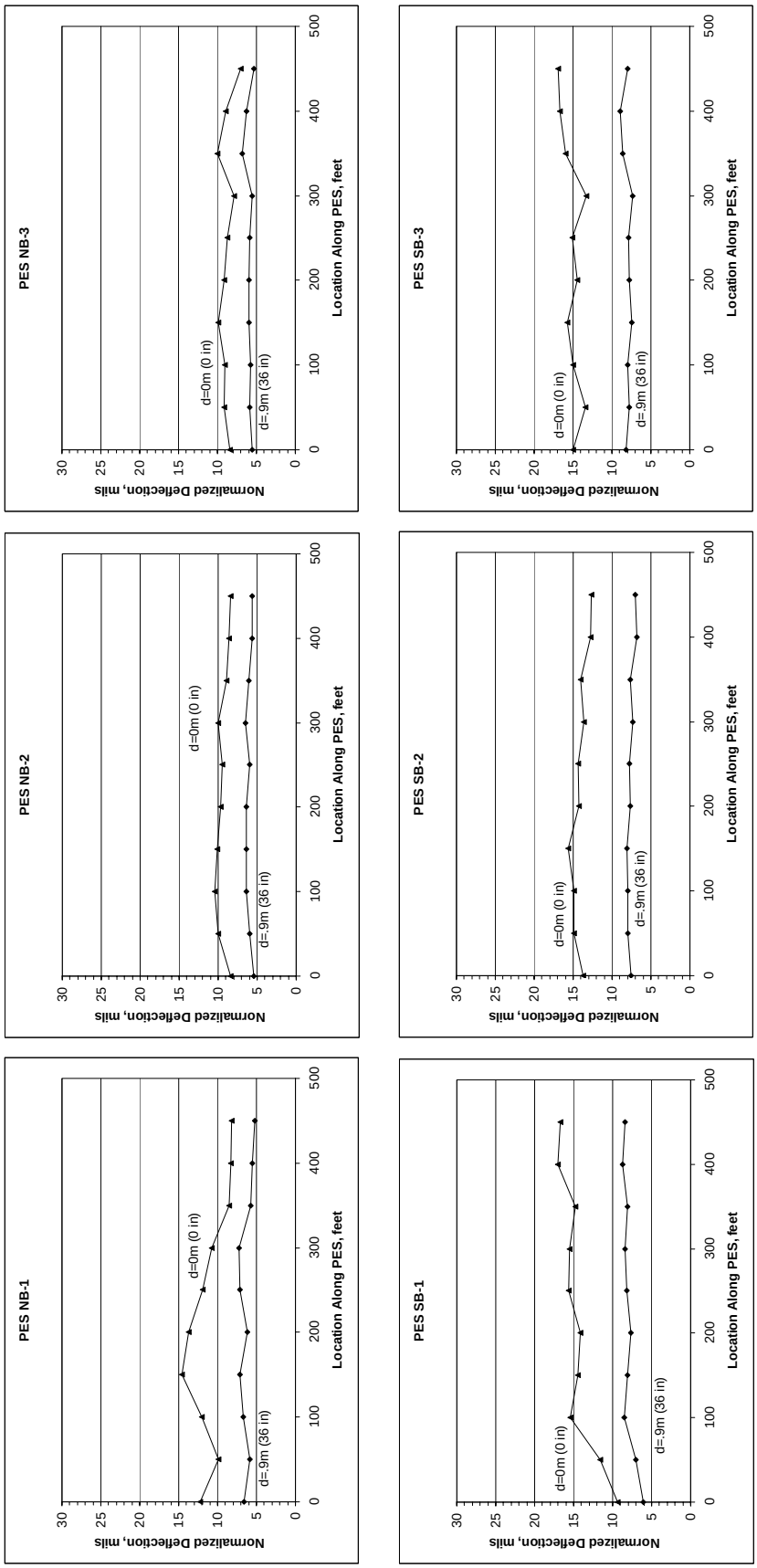

Figure 3.3. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path, Fresno Highway 33, September 2004 data

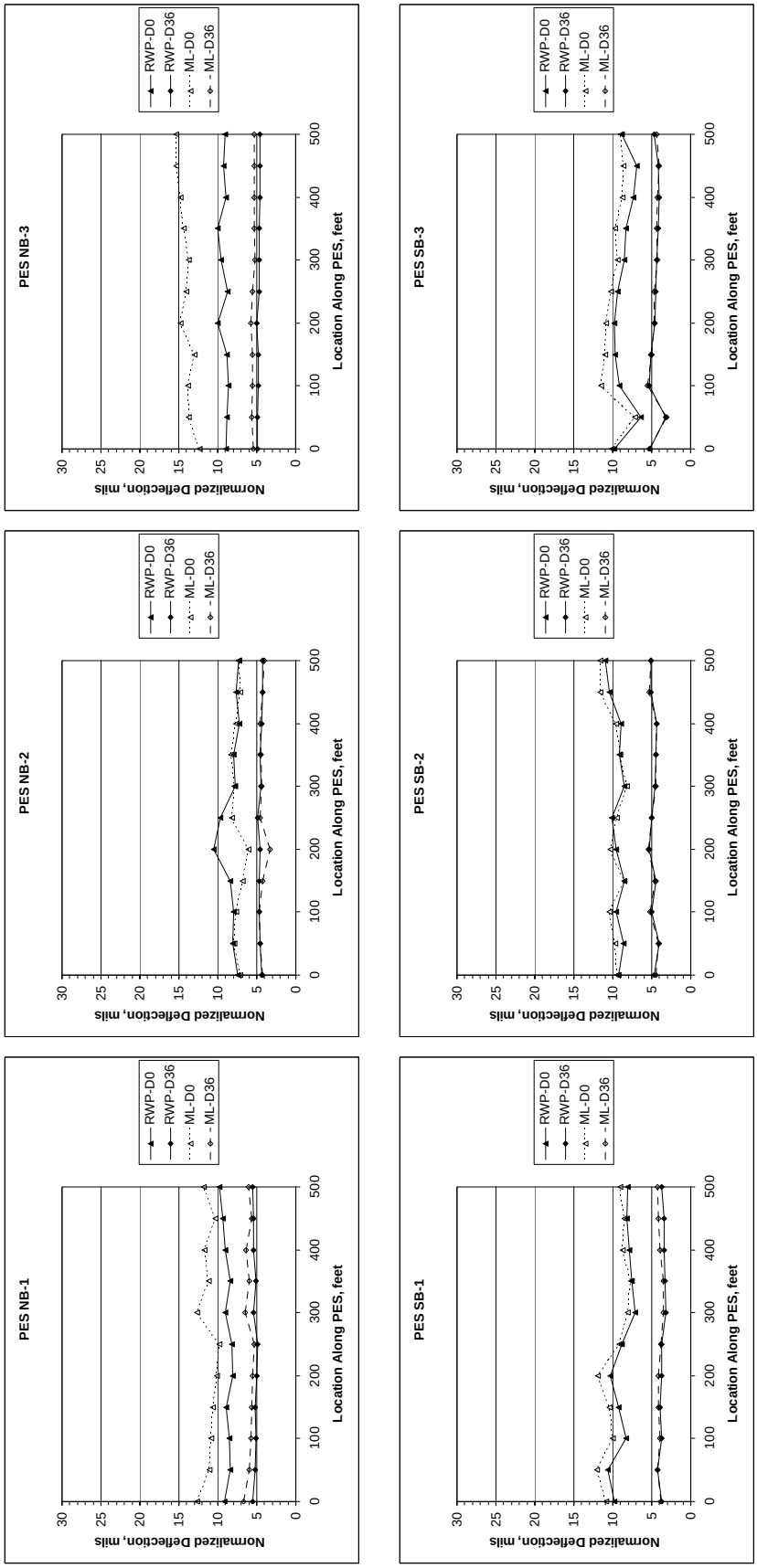

Figure 3.4. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, Fresno Highway 33, February 2005 data

Figure 3.5 provides a bar graph that compares these 80th percentile deflections with the tolerable value. Those sections that have an 80th percentile deflection less than the tolerable value are considered to be structurally adequate for the design conditions. Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

Inspection of Figure 3.5 indicates that five of the PESs have 80th percentile deflections that exceed the tolerable value, while only one exhibits an 80th percentile deflection that is less. Of the five PESs that have high deflections, only section NB-1 is significantly high. Its 80th percentile deflection is about 50 percent higher than that of the tolerable deflection. Thus, it is likely to exhibit significant structural distress during the last four to five years. The other sections with marginally higher deflections, i.e., NB-2, NB-3, SB-2, and SB-3 are likely to perform satisfactorily for eight to nine years before they start to show the effects of their higher deflections.

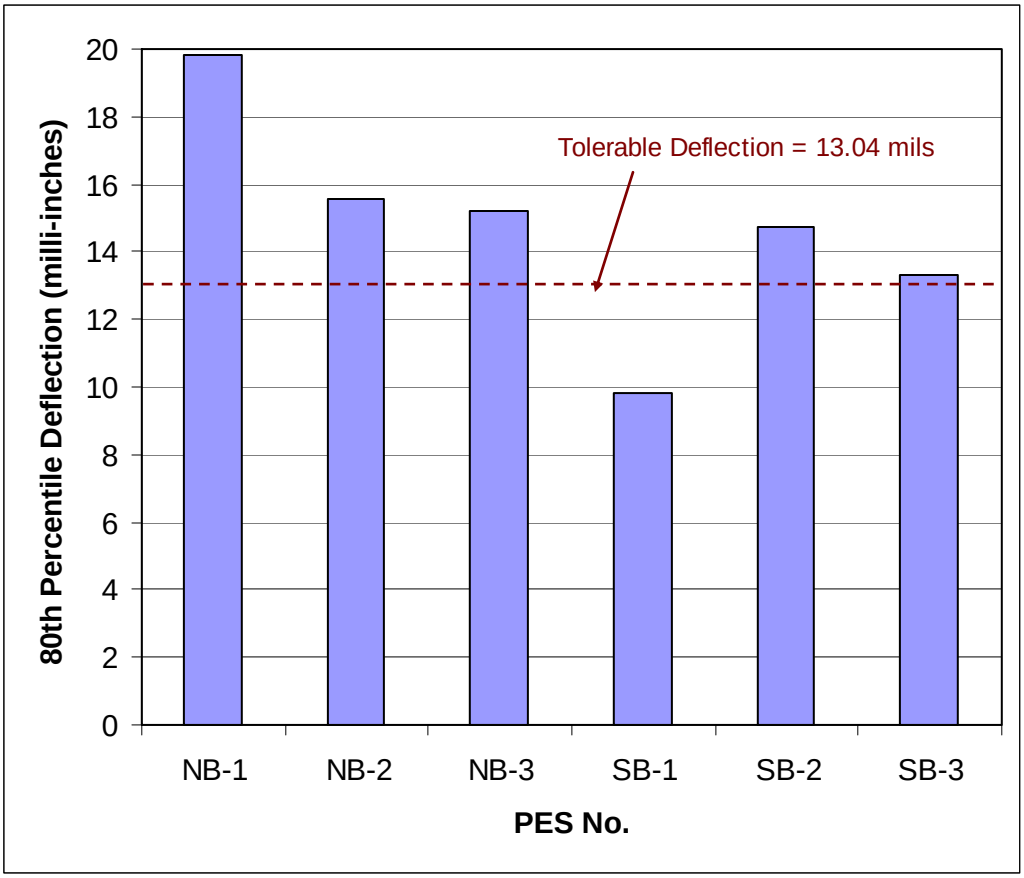

Figure 3.5. Structural adequacy assessment - the Fresno County Highway 33 project

4.0 MERCED COUNTY, HIGHWAY 140

4.1 PROJECT INFORMATION

The Merced RAC Warranty project (EA No. 10-0A5804) is a two-lane roadway located along State Highway 140 in District 10, Fresno County, near Merced, CA. The project extends from PM 27.0 (KP 43.4) near McSwain Road to PM 30.2 (KP 48.6), 0.8 mi (1.2 km) east of Applegate Road for a total 3.2 miles (5.2 km).

The overlay for this project was constructed in September 2003 and consisted of a 2.36-in (60-mm) RAC-G mixture. More detailed construction information is provided in the Volume 1, Construction Report [Caltrans, 2005].

Six PESs were identified for this project based upon deflection measurements obtained prior to construction. Table 4.1 identifies the starting point and basic deflection level for each of the PESs. Figure 4.1 provides a plan view showing the PES locations.

Table 4.1. Location and description of six PESs selected for Merced County, Highway 140 RAC Warranty project

PES ID	Begin KP	Begin PM	Relative Deflection Level
WB-1	47.737	29.69	High
WB-2	46.931	29.19	Moderate
WB-3	44.759	27.84	Low
EB-1	44.221	27.50	Low
EB-2	45.258	28.15	High
EB-3	45.894	28.54	Moderate

4.2 DATA COLLECTION SUMMARY

Only one round of post-construction performance monitoring consisting of condition surveys and FWD deflection testing was conducted on this project. The date of this testing along with the prevailing weather conditions are shown in Table 4.2.

Table 4.2. Weather conditions during FWD testing and condition survey evaluation

Date	FWD Testing	Condition Survey	Weather Conditions
2/17/05	Yes	Yes	Mostly sunny with air temperatures ranging from 52 to 57°F (11 to 14°C)

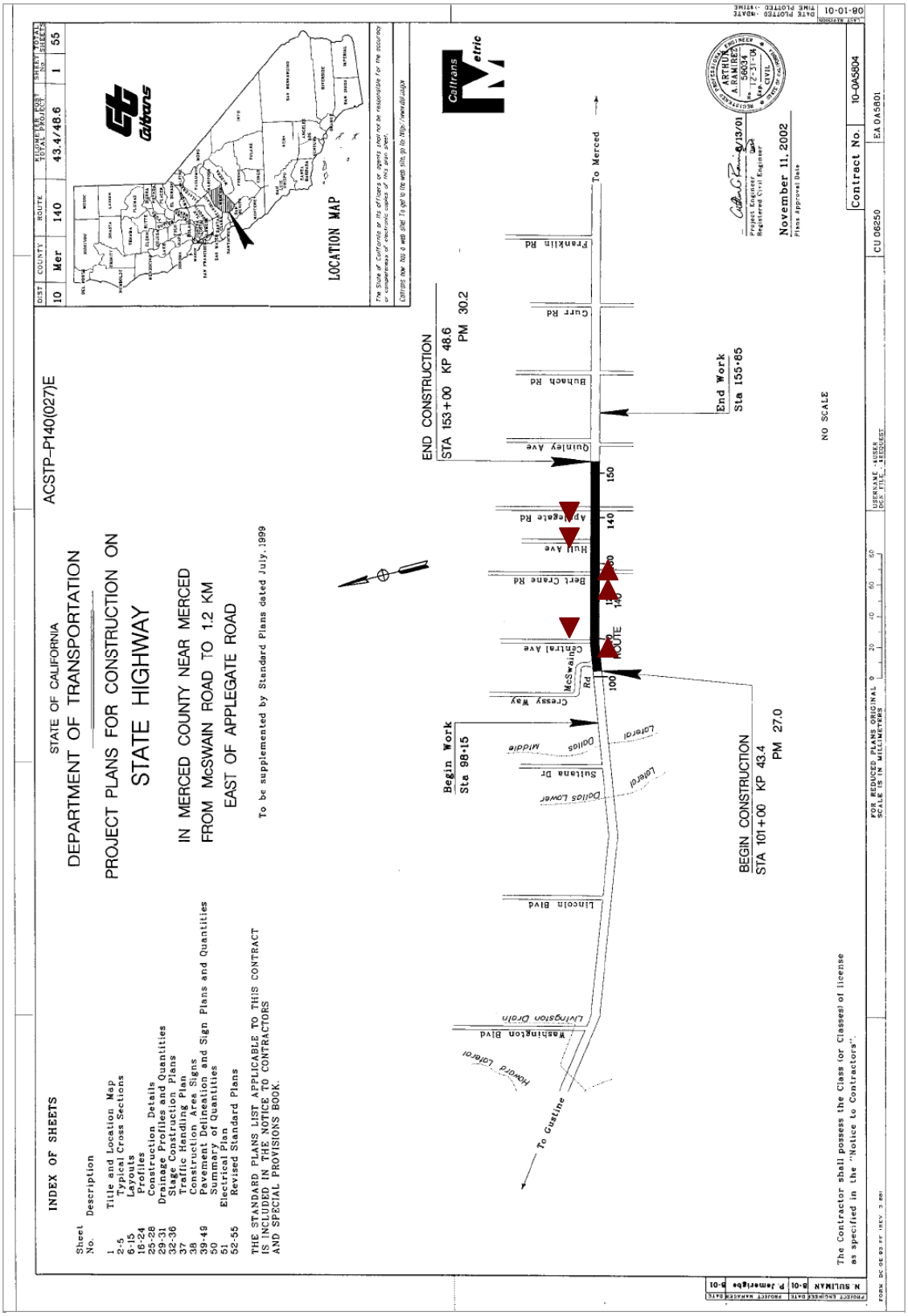

Figure 4.1. Plan showing location of six PESs along Merced County, Highway 140

4.3 CONDITION SURVEY SUMMARY

Appendix C.3 provides example photos and summarizes the condition survey results for each of the six PESs located along the project. None of the PESs exhibit any distress, although some surface grinding to improve profile was observed in sections WB-1 and EB-3. Although the age of the overlay is only 1.5 years, there is no indication that it will not provide good performance over the remainder of the warranty period.

4.4 FWD TESTING SUMMARY

Tables 4.3 and 4.4 provide a summary of the processed FWD test data obtained from each of the PES. The table includes surface deflection values (normalized to the standard 9,000-lb [40-kN] deflection load) from mid-lane and the outer wheel path for two key sensor locations, 1 and 5.

Figure 4.2 provides graphs showing the deflection profiles for each of the six PESs. These graphs are based on the normalized deflection data presented in Tables 4.3 and 4.4. The raw deflection data are stored in the relational database (Appendix D).

Overall, the data from the one round of deflection testing indicate that the RAC PESs are in the very low to moderate range in terms of average maximum deflection. PES EB-1 has an average maximum value of about 5 milli-inches (0.013 mm) while PES WB-1 has an average maximum value of about 9 milli-inches (0.023 mm). The within section variability for these sections is also in the very low to moderate range. PES EB-1 has very low variability while the other sections are more in the moderate range.

4.5 STRUCTURAL ADEQUACY ASSESSMENT

A general assessment of the structural adequacy of this project was conducted using the deflection data from the first round of testing (after RAC overlay construction) and traffic (TI) data used in the original rehabilitation design (provided in the Volume 1 - Construction Report). This structural adequacy assessment is based solely on an evaluation of the six PESs. Since these sections were selected to cover the range of deflections measured along the project, the results of the assessment should reflect a range of structural capacity that emphasizes the highs and lows.

The two key inputs required for the structural adequacy assessment are defined below.

- Traffic Index (TI) = 9.5 (from Volume 1 - Construction Report)
- Total HMA thickness (including RAC overlay) = 9.4 in (239 mm)

The tolerable deflection corresponding to these two inputs, as determined using the criteria in the Caltrans Flexible Pavement Rehabilitation Manual, is 13.04 milli-inches (0.331 mm), assuming the criteria are also applicable to RAC. The 80th percentile deflection for each of the six PESs was calculated using the deflection values measured in the outside wheel path.

Table 4.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Merced Highway 140, September 2003 data

Location (ft)	Pavement Evaluation Section											
	WB-1		WB-2		WB-3		EB-1		EB-2		EB-3	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	7.677	3.853	6.602	3.215	8.391	4.343	4.800	2.245	11.242	4.566	5.029	2.789
50	8.919	4.419	6.346	3.108	7.365	3.882	5.030	2.377	11.212	4.605	5.522	3.177
100	7.684	3.677	9.724	3.181	6.822	3.514	4.718	2.092	9.012	3.322	5.974	3.294
150	9.966	4.051	10.204	3.327	6.356	2.767	6.187	2.878	6.605	3.252	10.985	5.733
200	11.183	4.208	7.885	3.160	5.528	2.501	5.713	2.416	6.878	3.062	8.374	4.775
250	9.471	4.080	4.260	2.248	6.261	3.012	5.372	2.795	7.900	3.618	6.987	2.858
300	13.919	4.714	4.459	2.275	6.297	3.014	6.245	2.983	6.371	3.083	6.660	2.494
350	7.004	3.502	4.199	2.186	5.716	2.587	4.240	1.935	4.389	2.370	6.908	2.904
400	6.342	3.433	5.746	2.827	5.398	2.401	3.646	1.586	4.558	2.462	6.678	2.756
450	11.577	3.822	4.623	2.408	4.029	1.595	3.504	1.530	6.498	3.049	5.660	2.420
500	6.088	2.750	4.828	2.540	3.443	1.588	3.919	1.693	6.898	3.240	5.799	2.513
Mean	9.075	3.864	6.262	2.771	5.964	2.837	4.852	2.230	7.415	3.330	6.780	3.247
Std Dev	2.444	0.532	2.163	0.446	1.401	0.857	0.964	0.516	2.287	0.717	1.668	1.050

Table 4.4. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Merced Highway 140, February 2005 data

Location (ft)	Pavement Evaluation Section											
	WB-1		WB-2		WB-3		EB-1		EB-2		EB-3	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	6.354	3.167	5.670	2.698	7.920	3.919	4.579	2.043	12.648	4.295	5.161	2.596
50	7.361	3.549	5.971	2.825	7.060	3.499	4.595	2.171	11.766	4.348	5.798	3.119
100	6.367	3.028	7.584	2.778	5.925	2.968	4.683	1.916	10.123	3.303	5.936	3.176
150	7.566	3.372	7.906	2.969	5.899	2.541	7.076	3.172	6.862	3.096	10.324	5.436
200	8.844	3.653	5.634	2.635	4.780	2.166	6.081	2.616	6.201	2.678	6.940	3.998
250	8.989	3.723	3.563	1.756	5.724	2.717	6.874	2.959	9.104	4.032	6.505	2.525
300	12.717	4.199	3.605	1.813	5.916	2.722	7.577	2.910	6.844	2.973	5.990	2.111
350	9.372	3.521	3.333	1.727	5.403	2.245	4.301	1.835	4.648	2.258	6.480	2.649
400	7.334	3.095	4.628	2.319	4.823	2.014	3.491	1.513	4.957	2.442	6.196	2.509
450	6.729	2.612	3.764	1.903	3.616	1.448	3.698	1.330	6.608	2.936	5.207	2.095
500	4.948	2.142	4.464	2.288	3.345	1.326	4.191	1.502	7.210	3.162	5.823	2.276
Mean	7.871	3.278	5.102	2.337	5.492	2.506	5.195	2.179	7.906	3.229	6.396	2.954
Std Dev	2.073	0.563	1.598	0.472	1.343	0.789	1.441	0.644	2.652	0.713	1.407	0.992

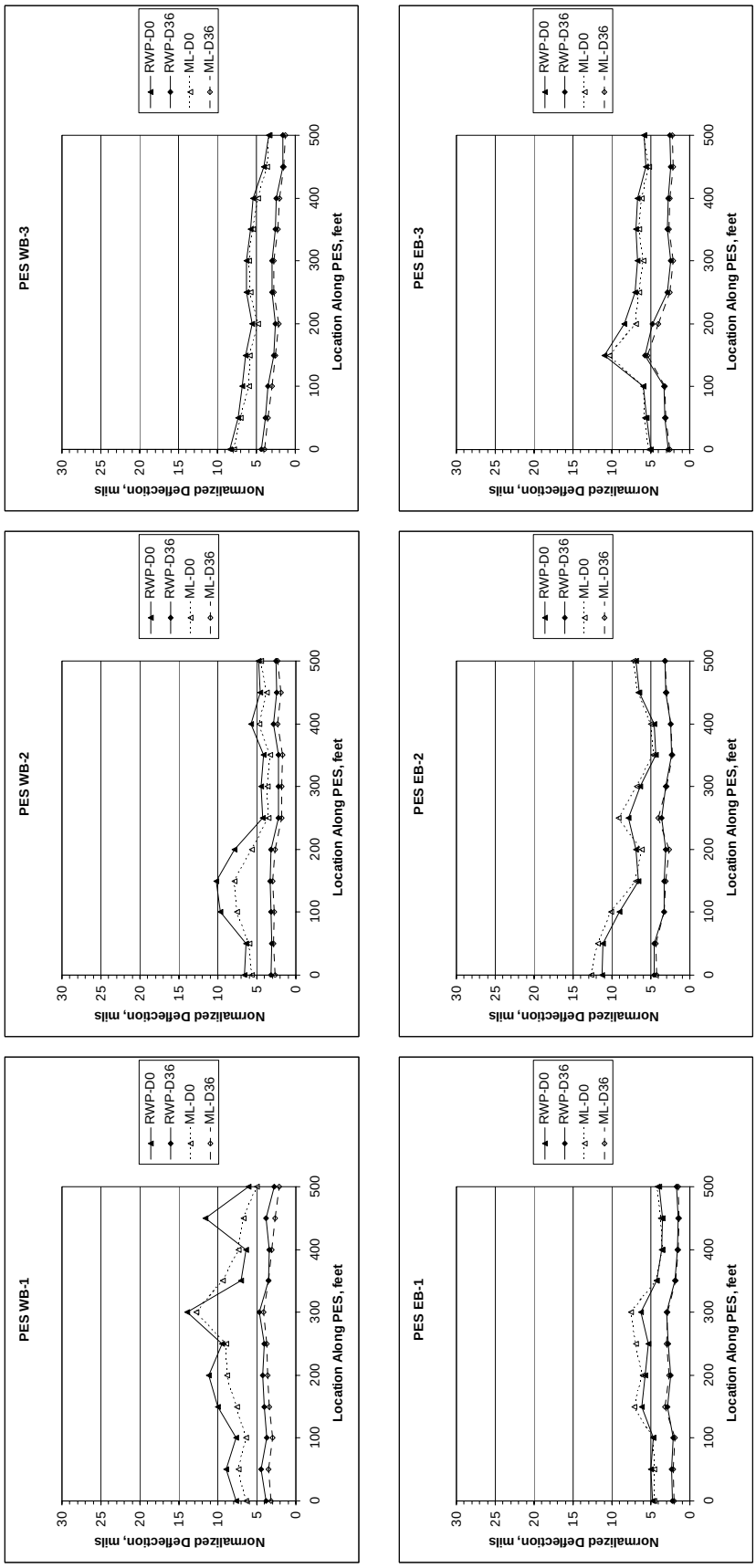

Figure 4.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, Merced Highway 140, February 2005 data

Figure 4.3 provides a bar graph that compares these 80th percentile deflections with the tolerable value. Those sections that have an 80th percentile deflection less than the tolerable value are considered to be structurally adequate for the design conditions. Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

Inspection of Figure 4.3 indicates that all six of the PESs have 80th percentile deflections that (essentially) satisfy the tolerable deflection criteria. Accordingly, all can be expected to provide good structural performance over the 10-year design period.

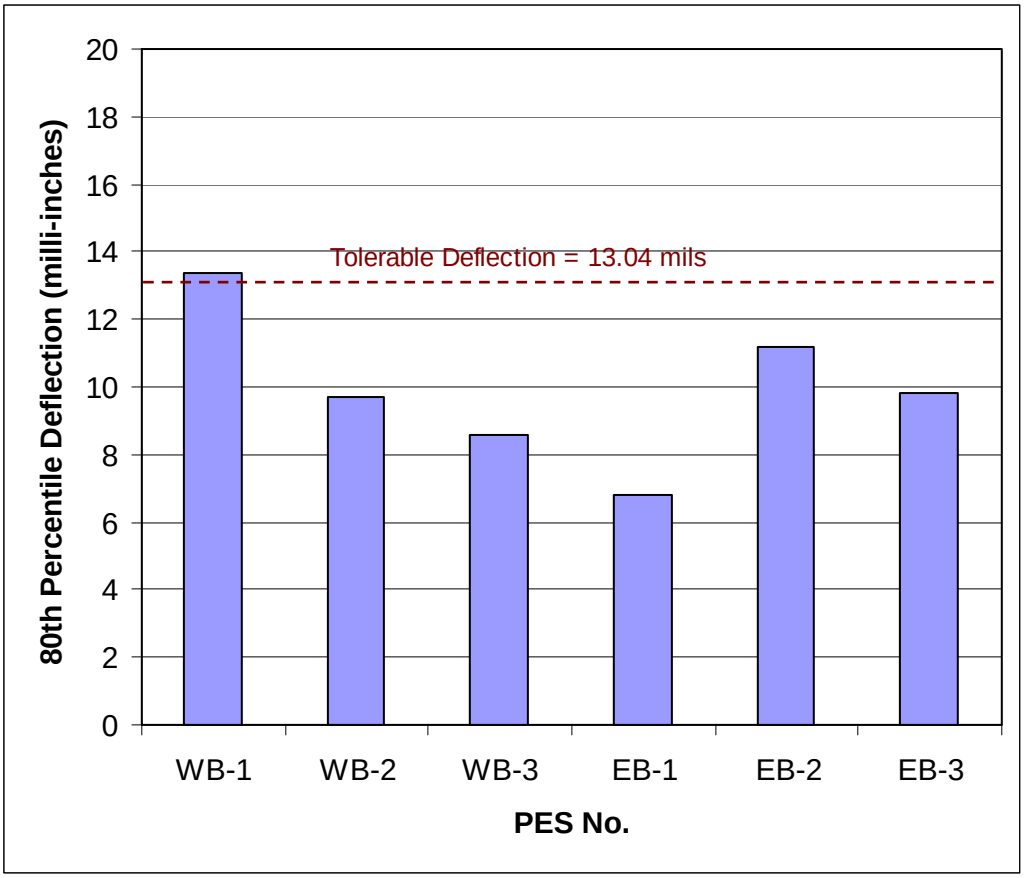

Figure 4.3. Structural adequacy assessment - the Merced County Highway 140 project

5.0 SAN DIEGO COUNTY, HIGHWAY 75

5.1 PROJECT INFORMATION

The San Diego RAC Warranty project (EA No. 11-230104) is located along the two southbound lanes of State Highway 75, District 11, San Diego County, between Coronado and Imperial Beach, CA. The project extends from PM 11.0 (KP 17.7) to PM 17.4 (KP 28.0) for a total of 6.4 mi (10.3 km).

The overlay for this project was constructed in May 2003 and consisted of a 2.36-in (60-mm) RAC-G mixture. More detailed construction information is provided in the Volume 1, Construction Report [Caltrans, 2005].

Four PESs were identified within the outside southbound lanes of this project based upon deflection measurements obtained after construction. Unlike the first three RAC projects, it was not possible to obtain deflection measurement just prior to overlay construction. Thus, PES selection was based on deflection measurements obtained in February 2005. Table 5.1 identifies the starting point and basic deflection level for each of the PESs. Figure 5.1 provides a plan view showing the PES locations.

Table 5.1. Location and description of four PESs selected for San Diego County, Highway 75 RAC Warranty project

PES ID	Begin KP	Begin PM	Relative Deflection Level
SB-1	26.50	16.48	Low
SB-2	23.07	14.35	High
SB-3	20.48	12.74	Moderate
SB-4	18.81	11.70	Moderate

5.2 DATA COLLECTION SUMMARY

Only one round of post-construction performance monitoring consisting of condition surveys and FWD deflection testing was conducted on this project. The date of this testing along with the prevailing weather conditions are shown in Table 5.2.

Table 5.2. Weather conditions during FWD testing and condition survey evaluation

Date	FWD Testing	Condition Survey	Weather Conditions
2/7/05	Yes	Yes	Clear skies with air temperatures ranging from 52 to 57°F (11 to 14°C)

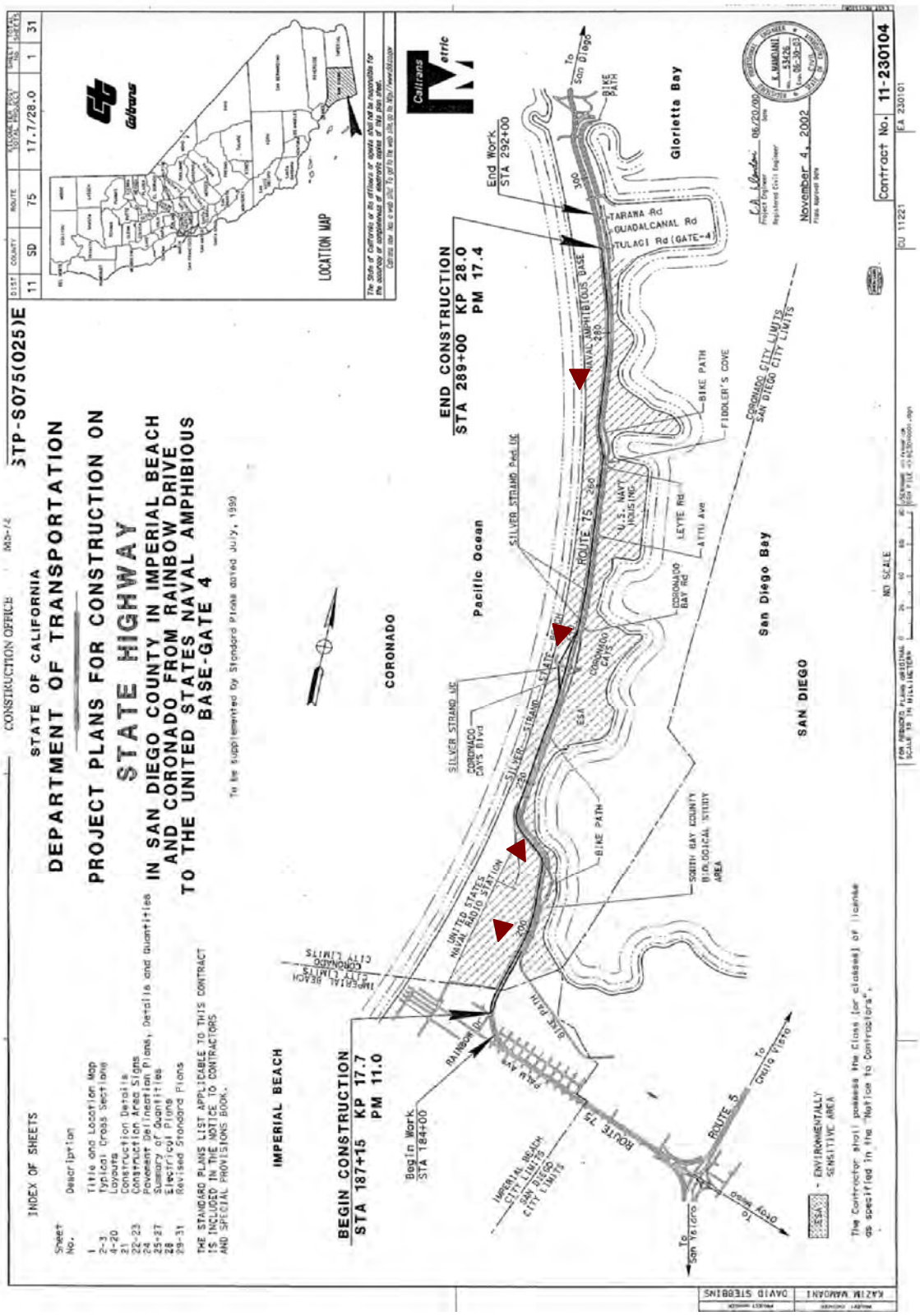

Figure 5.1. Plan showing location of four PESs along San Diego County, Highway 75

5.3 CONDITION SURVEY SUMMARY

Appendix C.4 provides example photos and summarizes the condition survey results for each of the four test sections located along the project. Based upon the last survey, none of the PESs exhibit any distress. Given that the overlay was about 1.7 years old at the time of the survey, there is a good indication that the RAC overlay will provide very good performance over the remainder of the 5-year warranty period.

5.4 FWD TESTING SUMMARY

Table 5.3 provides a summary of the processed FWD test data obtained from each PES. The table includes surface deflection values (normalized to the standard 9,000-lb [40-kN] deflection load) from the outer wheel path for two key sensor locations, 1 and 5.

Figure 5.2 provides graphs showing the deflection profiles for each of the four PESs. These graphs are based on the normalized deflection data presented in Table 5.3. Raw deflection data are stored in the relational database (Appendix D). For the first (and only) round of deflection testing performed thus far, no mid-lane deflection testing was performed.

Examination of the deflection data (from Figure 5.2 in particular) indicate that three of the PESs (SB-1, -3 and -4) exhibit low average maximum deflections while one (PES SB-2) is near the high end. The within section variability in deflection is typical, although the variability of PES SB-2 is comparatively high. Because of its high relative deflection, it is likely that PES SB-2 will deteriorate faster and require more maintenance than the other three PESs.

5.5 STRUCTURAL ADEQUACY ASSESSMENT

A general assessment of the structural adequacy of this project was conducted using the deflection data from the first round of testing (after RAC overlay construction) and traffic (TI) data used in the original rehabilitation design (provided in the Volume 1 - Construction Report). This structural adequacy assessment is based solely on an evaluation of the four PESs. Since these sections were selected to cover the range of deflections measured along the project, the results of the assessment should reflect a range of structural capacity that emphasizes the highs and lows.

The three key inputs required for the structural adequacy assessment are defined below.

- Traffic Index (TI) = 8.5 (from Volume 1 - Construction Report)
- Total HMA thickness (including RAC overlay) = 5.8 in (148 mm)
- Underlying pavement is PCC (and treated as a cement treated base in the analysis)

The tolerable deflection corresponding to these three inputs, as determined using the criteria in the Caltrans Flexible Pavement Rehabilitation Manual, is 12.81 milli-inches (0.325 mm), assuming the criteria are also applicable to RAC. The 80th percentile deflection for each of the four PESs was calculated using the deflection values measured in the outside wheel path.

Table 5.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, San Diego Highway 75, February 2005 data

Location (ft)	Pavement Evaluation Section							
	SB-1		SB-2		SB-3		SB-4	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	6.347	2.907	12.118	4.056	6.735	4.039	8.873	4.202
50	4.832	2.721	12.143	3.763	8.142	3.825	8.067	4.836
100	4.010	2.478	13.282	3.613	6.211	3.524	6.961	3.785
150	4.068	2.407	12.997	3.526	6.384	3.638	7.727	3.693
200	4.004	2.475	16.108	3.640	5.817	3.476	7.014	3.901
250	5.781	2.891	16.795	3.757	7.124	4.280	7.092	4.035
300	6.362	2.743	17.958	3.590	9.098	4.706	5.601	2.953
350	6.272	2.802	18.068	3.708	6.300	3.980	5.921	3.138
400	6.904	2.973	14.945	4.171	7.257	3.873	9.551	3.618
450	4.505	2.232	15.367	3.616	6.313	3.749	7.115	3.243
500	5.285	2.251	15.180	3.628	6.465	3.883	6.924	3.167
Mean	5.307	2.625	14.996	3.734	6.895	3.907	7.350	3.688
Std Dev	1.081	0.267	2.150	0.202	0.969	0.352	1.161	0.555

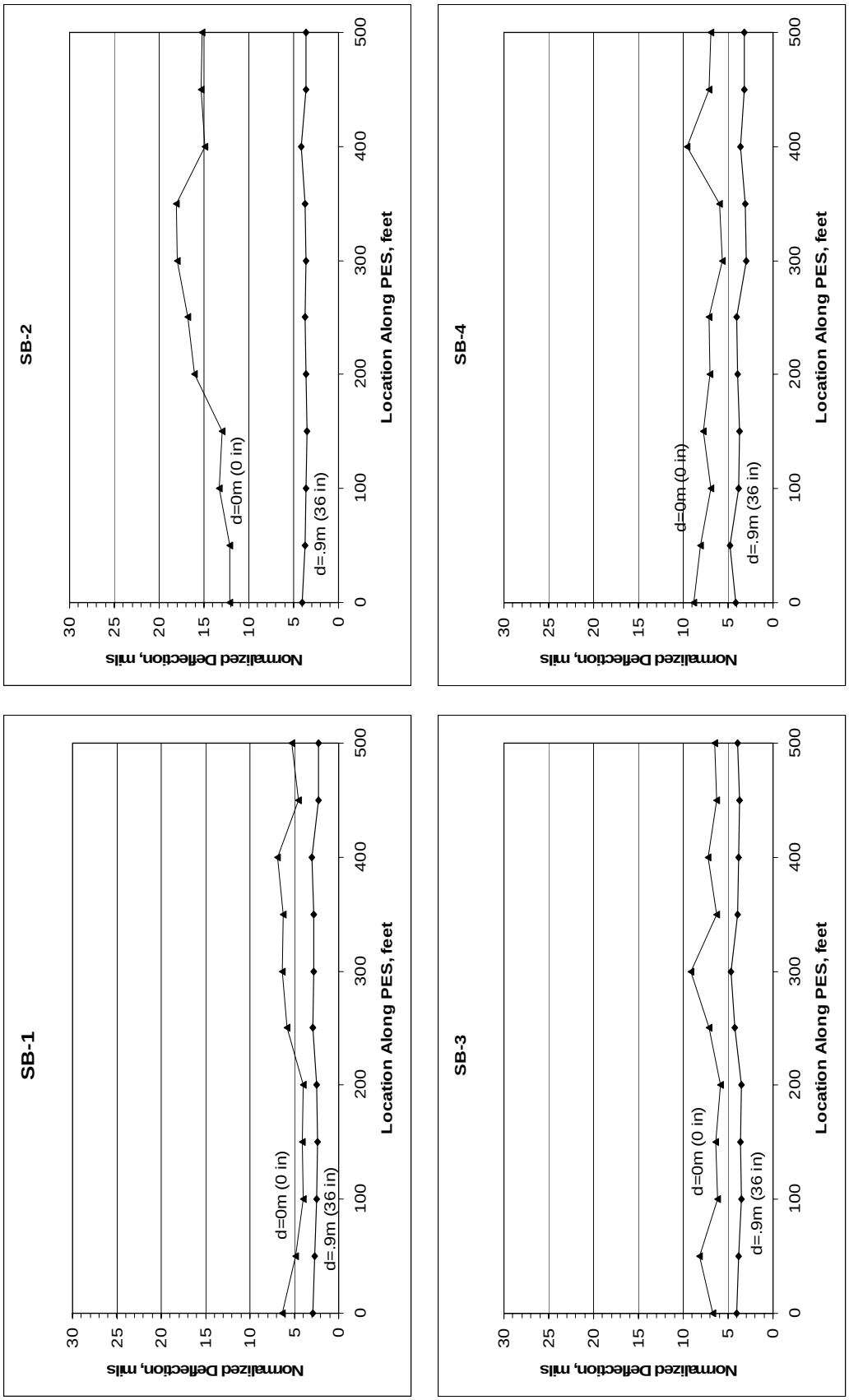

Figure 5.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, San Diego Highway 75, February 2005 data

Figure 5.3 provides a bar graph that compares these 80th percentile deflections with the tolerable value. Those sections that have an 80th percentile deflection less than the tolerable value are considered to be structurally adequate for the design conditions. Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

Inspection of Figure 5.3 indicates that three of the four PESs have 80th percentile deflections that clearly satisfy the tolerable deflection criteria and can be expected to provide good structural performance over the 10-year design period. Section EB-2, on the other hand, exhibits an 80th percentile deflection that is roughly 60 percent higher than the tolerable deflection. Thus, this section is likely to exhibit structural distress well before the 10-year design life.

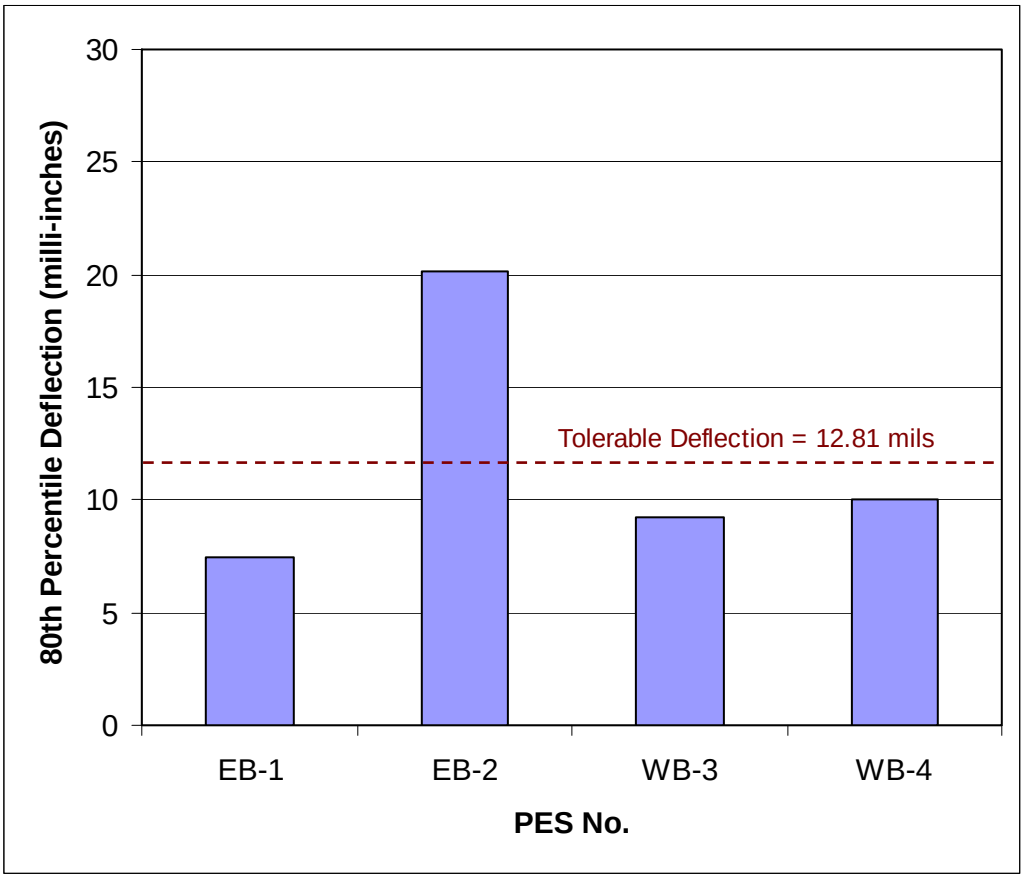

Figure 5.3. Structural adequacy assessment - the San Diego County Highway 75 project

6.0 LASSEN COUNTY, HIGHWAY 395

6.1 PROJECT INFORMATION

The Lassen RAC Warranty project (EA No. 02-258504) is a two-lane roadway located along State Highway 395 in District 2, Lassen County, near Doyle, CA. The project extends from PM 11.8 (KP 19.0) to PM 24.8 (KP 39.9) for a total of 13.0 mi (20.9 km).

The overlay was constructed in August 2004 and consisted of a 2.36-in (60-mm) modified-binder (MB) dense-graded asphalt concrete mixture (MB-D) with a nominal ¾-in (19-mm) maximum size coarse aggregate. More detailed construction information is provided in the Volume 1, Construction Report [Caltrans, 2005].

Nine PESs were identified within this project based upon deflection measurements obtained after construction. Unlike the first three RAC projects, it was not possible to obtain deflection measurements on this project just prior to overlay construction. Thus, PES selection was based on deflection measurements obtained in December 2004. Table 6.1 identifies the starting point and basic deflection level for each of the PESs. Figure 6.1 provides a plan view showing the PES locations.

Table 6.1. Location and description of nine PESs selected for Lassen County, Highway 395 RAC Warranty project

PES ID	Begin KP	Begin PM	Relative Deflection Level
NB-1	24.89	15.48	Low
NB-2	27.48	17.09	Moderate
NB-3	33.91	21.09	High
NB-4	34.72	21.59	Moderate
NB-5	35.52	22.09	Low
NB-6	36.23	22.53	Moderate
NB-7	37.92	23.58	High
SB-8	38.06	23.67	High
SB-9	28.43	17.68	High

6.2 DATA COLLECTION SUMMARY

Only one round of post-construction performance monitoring consisting of condition surveys and FWD deflection testing was conducted on this project. The dates of this testing along with the prevailing weather conditions are shown in Table 6.2.

Table 6.2. Weather conditions during FWD testing and condition survey evaluation

Date	FWD Testing	Condition Survey	Weather Conditions
12/4/04	Yes	No	Overcast with temperatures ranging from 34 to 46°F (1 to 8°C).
2/13/05	No	Yes	Partly cloudy with temperatures about 50°F (10°C).

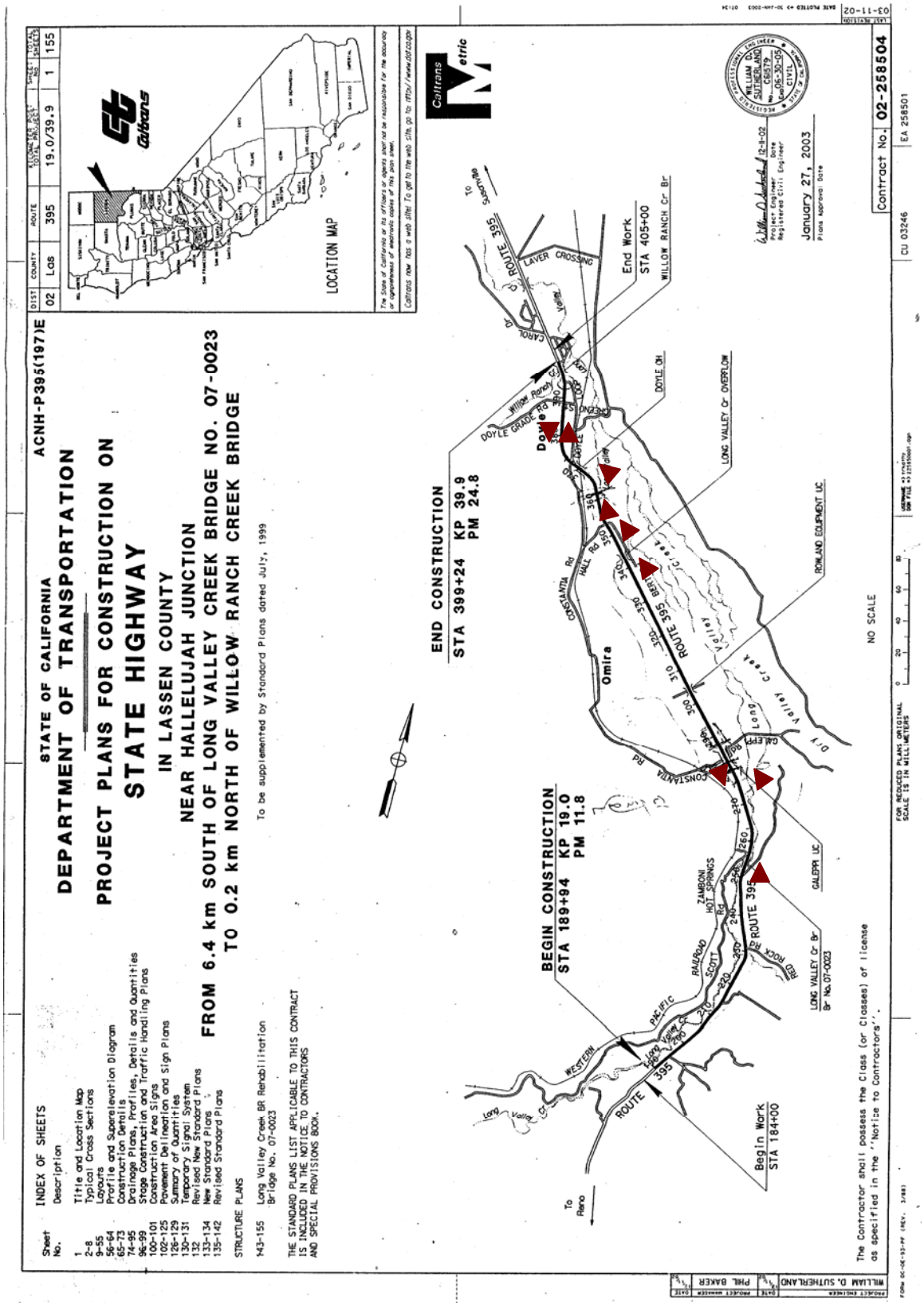

Figure 6.1. Plan showing location of nine PESs along Lassen County, Highway 395

6.3 CONDITION SURVEY SUMMARY

Appendix C.5 provides example photos and summarizes the condition survey results for each of the nine PESs. Based on the survey, none of the sections exhibited any pavement distress. This is expected since the overlay was only 6 months old at the time of the survey. Overall, all of the PESs are expected to provide good performance during the remainder of the 5-year warranty period.

6.4 FWD TESTING SUMMARY

Tables 6.3 and 6.4 provide a summary of the processed FWD test data obtained from each PES. The tables include surface deflection values (normalized to the standard 9,000-lb [40-kN] deflection load) from the outer wheel path for two key sensor locations, 1 and 5.

Figure 6.2 provides graphs showing the deflection profiles for each PES. These graphs are based on the normalized deflection data presented in Tables 6.3 and 6.4. Raw deflection data are stored in the relational database (Appendix D).

The deflection testing for this project was carried out during winter when air temperatures were just above freezing. This had a definite effect on the stiffness of the asphalt surface layers and resulted in an overall reduction in measured deflection. Still, the average maximum deflection values for each PES (as depicted in Figure 6.2) indicate a range from low, 4 milli-inches (0.010 mm), to moderate, 11 milli-inches (0.028 mm). PES NB-1 exhibited the lowest overall deflection at one end of the project, while NB-7 and SB-8 had the highest at the other end. The average maximum deflection for the remaining six projects is much smaller, in the range of 7 to 9 milli-inches (0.018 to 0.023 mm), indicating that some of these sections are probably redundant and could be eliminated from the experiment. The within section deflection variability most of these sections is generally low. Even the sections with the highest deflection variability could be considered low by comparison.

6.5 STRUCTURAL ADEQUACY ASSESSMENT

A general assessment of the structural adequacy of this project was conducted using the deflection data from the first round of testing (after MB-D overlay construction) and traffic (TI) data used in the original rehabilitation design (provided in the Volume 1 - Construction Report). This structural adequacy assessment is based solely on an evaluation of the nine PESs. Since these sections were selected to cover the range of deflections measured along the project, the results of the assessment should reflect a range of structural capacity that emphasizes the highs and lows.

The two key inputs required for the structural adequacy assessment are defined below.

- Traffic Index (TI) = 9.5 (from Volume 1 - Construction Report)
- Total HMA thickness (including RAC overlay) information is not available; however, it is assumed to be greater than 6 in (152 mm) for purposes of this analysis.

The tolerable deflection corresponding to these three inputs, as determined using the criteria in the Caltrans Flexible Pavement Rehabilitation Manual, is 13.04 milli-inches (0.331 mm), assuming the criteria are also applicable to the MB-D mix. The 80th percentile deflection for each of the nine PESs was calculated using the deflection values measured in the outside wheel path.

Table 6.3. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Lassen Highway 395, December 2004 data

Location (ft)	Pavement Evaluation Section									
	NB-1		NB-2		NB-3		NB-4		NB-5	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	4.464	3.495	8.194	4.142	8.798	4.491	8.563	4.317	10.298	4.279
50	4.277	3.323	8.415	4.110	8.621	4.429	9.550	4.683	7.971	3.768
100	4.766	3.510	9.249	4.057	9.090	4.744	11.845	4.901	11.229	3.753
150	4.218	3.269	10.214	4.268	9.533	4.589	8.013	4.564	9.817	3.545
200	4.170	3.004	9.376	4.199	9.372	4.487	9.293	4.421	10.258	3.550
250	3.480	2.756	7.755	3.893	7.560	4.431	7.953	4.152	6.033	3.857
300	3.572	2.715	7.768	4.015	9.569	4.734	8.034	4.182	9.280	3.537
350	4.859	3.675	7.075	3.751	8.087	4.834	10.495	3.968	10.483	4.038
400	4.480	3.453	7.393	3.761	9.386	4.886	10.515	4.021	6.276	3.656
450	4.213	3.447	7.124	3.889	9.080	4.726	7.052	3.732	6.328	3.268
500	4.831	3.644	6.920	3.705	9.256	4.819	9.491	4.169	6.447	3.420
Mean	4.303	3.299	8.135	3.981	8.941	4.652	9.164	4.283	8.584	3.697
Std Dev	0.459	0.334	1.079	0.193	0.635	0.171	1.412	0.340	2.005	0.287

Table 6.3 (cont.). Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the outside wheel path, Lassen Highway 395, December 2004 data

Location (ft)	Pavement Evaluation Section							
	NB-6		NB-7		SB-8		SB-9	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	5.834	3.631	13.855	7.926	11.251	6.148	10.372	5.935
50	9.450	4.193	8.205	5.614	10.932	6.402	11.601	6.171
100	7.971	3.869	8.383	5.578	11.058	6.720	10.767	5.919
150	10.394	4.670	7.895	5.364	10.290	6.222	11.045	6.026
200	9.060	4.456	9.721	6.228	11.775	7.065	8.956	6.012
250	9.161	4.481	11.909	6.949	11.490	6.381	7.526	5.027
300	7.344	4.427	10.817	6.716	11.362	6.883	7.866	5.295
350	7.297	4.363	10.344	6.354	12.482	7.259	10.405	5.543
400	7.560	4.363	11.622	7.017	13.308	7.813	7.491	4.708
450	7.345	4.292	12.250	7.300	11.572	6.779	6.695	4.680
500	6.770	4.149	12.543	6.650	6.254	4.184	12.968	6.360
Mean	8.017	4.263	10.686	6.518	11.070	6.532	9.608	5.607
Std Dev	1.344	0.295	1.965	0.789	1.785	0.920	2.016	0.594

Table 6.4. Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Lassen Highway 395, December 2004 data

Location (ft)	Pavement Evaluation Section									
	NB-1		NB-2		NB-3		NB-4		NB-5	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	4.045	3.172	6.328	3.777	9.066	4.100	8.539	4.083	8.847	3.997
50	4.250	3.046	7.953	3.694	8.963	4.355	8.335	4.507	9.147	3.843
100	4.316	3.049	7.873	3.804	10.700	5.095	10.205	4.850	8.492	3.508
150	4.258	2.990	9.267	3.940	10.049	4.405	7.418	4.235	8.585	3.660
200	3.149	2.449	10.182	4.138	9.573	4.231	9.162	4.418	6.275	2.998
250	2.639	2.151	7.543	3.685	6.851	4.297	7.758	3.940	5.930	3.637
300	2.692	2.155	6.892	3.549	9.273	4.452	7.476	3.973	6.103	2.838
350	4.414	3.269	7.312	3.539	7.553	4.780	9.792	4.319	8.353	3.609
400	3.864	2.841	5.871	3.209	8.009	4.468	9.127	4.123	5.429	3.191
450	4.039	3.184	6.216	3.556	7.502	4.291	6.224	3.375	5.441	2.787
500	4.078	3.115	5.838	3.224	7.440	4.385	8.582	3.982	5.988	2.858
Mean	3.795	2.856	7.389	3.647	8.635	4.442	8.420	4.164	7.145	3.357
Std Dev	0.652	0.411	1.392	0.278	1.237	0.276	1.154	0.378	1.509	0.436

Table 6.4 (cont.). Normalized deflections for sensor 1 (r=0 in) and sensor 5 (r=36 in) for the mid-lane, Lassen Highway 395, December 2004 data

Location (ft)	Pavement Evaluation Section							
	NB-6		NB-7		SB-8		SB-9	
	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5	Sensor 1	Sensor 5
0	5.565	3.446	11.173	6.689	10.508	5.311	11.118	6.119
50	7.995	3.955	7.101	5.000	12.134	6.320	10.700	6.259
100	6.481	3.725	7.392	5.081	11.236	6.643	10.439	5.780
150	9.494	4.500	6.832	4.607	9.645	5.981	12.064	6.016
200	7.182	3.984	7.479	5.390	10.265	6.378	9.300	5.734
250	7.911	3.791	10.874	6.549	9.260	5.824	7.508	4.857
300	6.235	3.868	9.244	5.860	9.964	6.129	7.300	4.880
350	6.234	3.871	8.827	5.738	9.215	5.686	11.010	5.758
400	6.351	3.862	11.278	6.670	12.732	7.103	7.114	4.740
450	6.764	4.019	11.340	6.957	10.270	5.534	7.310	4.873
500	6.141	3.732	9.067	5.219	5.900	4.071	12.392	6.103
Mean	6.941	3.887	9.146	5.796	10.103	5.907	9.660	5.556
Std Dev	1.129	0.257	1.788	0.809	1.787	0.796	2.030	0.594

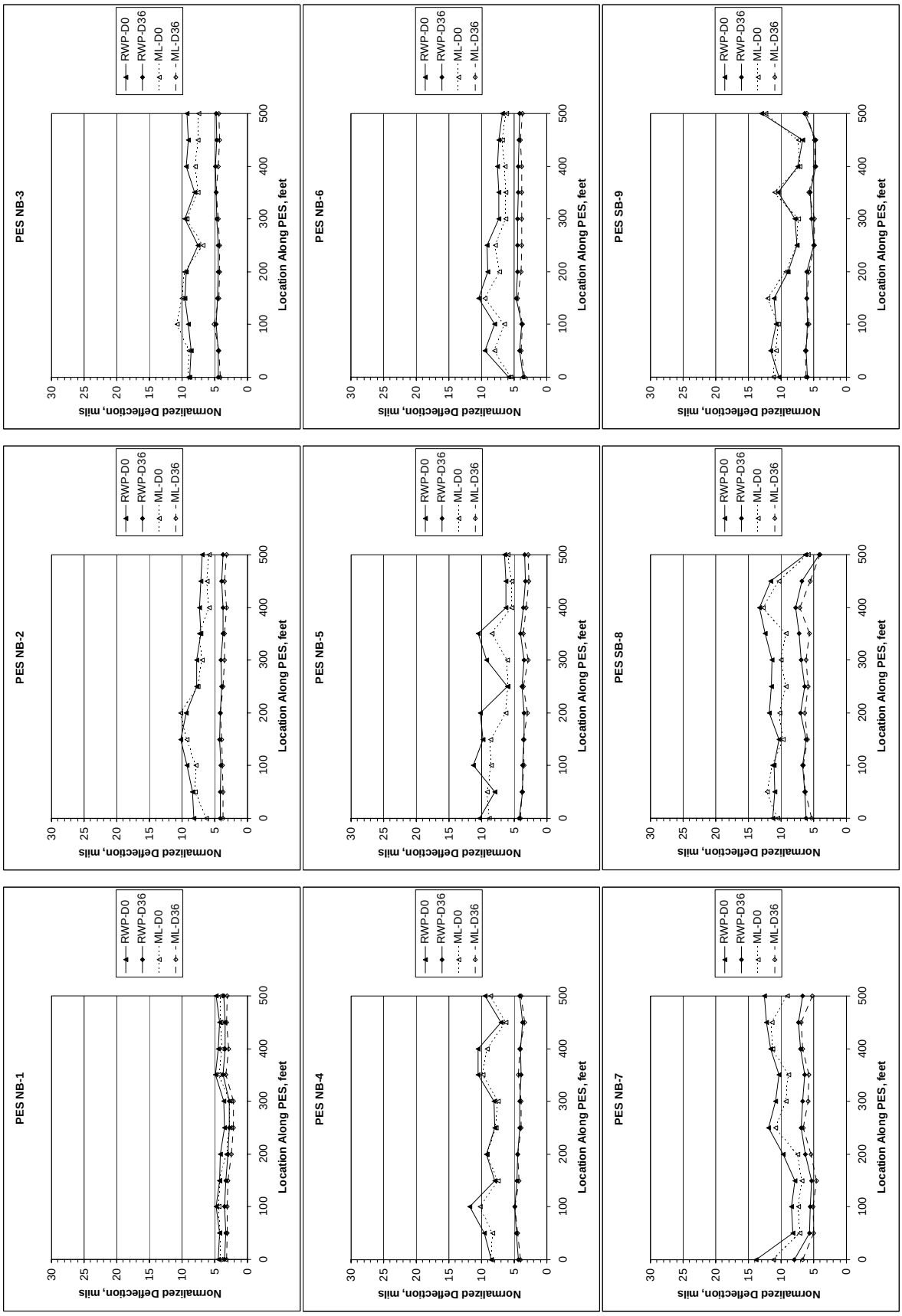

Figure 6.2. Sensor 1 and Sensor 5 deflection profiles for the outside wheel path and mid-lane, Lassen Highway 395, December 2004 data

Figure 6.3 provides a bar graph that compares these 80th percentile deflections with the tolerable value. Those sections that have an 80th percentile deflection less than the tolerable value are considered to be structurally adequate for the design conditions. Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

Inspection of Figure 6.3 indicates that six of the nine PESs have 80th percentile deflections that clearly satisfy the tolerable deflection criteria and can be expected to provide good structural performance over the 10-year design period. Sections NB-7, SB-8, and SB-9, on the other hand, exhibit 80th percentile deflection values that exceed the tolerable. Of these, only section NB-7 and SB-8 exceed the criteria enough to have a significantly impact on the 10-year design life. Thus, these PESs may start showing signs of structural distress before the others.

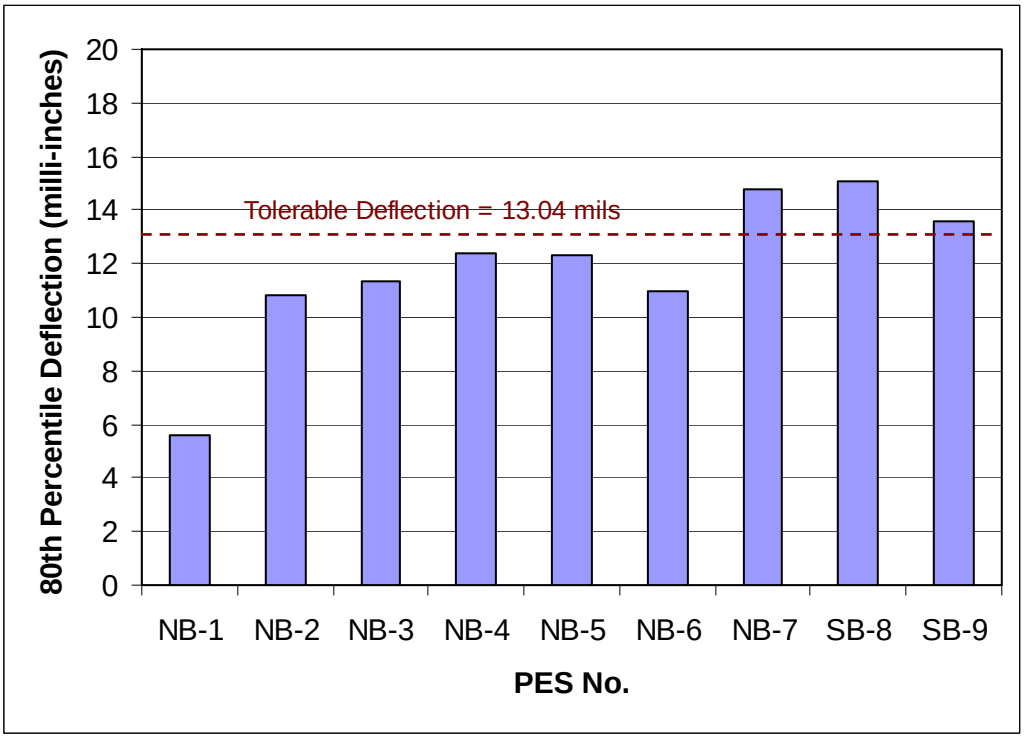

Figure 6.3. Structural adequacy assessment - the Lassen County Highway 395 project

7.0 SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY

The first RAC Warranty project was constructed in October 2002. After that, four additional projects were constructed during the following two years for the purpose of evaluating the performance of RAC and MB mixes. Four of the five projects were constructed using the RAC-G mix. The last, the Lassen County project, was constructed using a terminal blended MB mix. All binders contained a minimum of 15 percent CRM (by total mass of binder).

Several PESs were identified within each project to provide the basis for a thorough performance monitoring. The primary criteria for monitoring the performance of the PESs within each project include distress condition and pavement surface deflection. This report documents the results of condition surveys and deflection testing on each PES within each RAC Warranty project.

Table 7.1 provides a chart summarizing the status of performance data collection on the five RAC Warranty projects within the individual 5-year warranty period for each. Originally, the plan was to collect performance data immediately after construction and at one to two-year intervals thereafter. However, the data collection effort was abruptly discontinued in November 2003 because of funding constraints related to the state budget crisis. As can be seen, two of the projects, Fresno County and Lassen County, are in good shape based on testing conducted shortly after construction and at the regularly scheduled intervals following construction. However, the three other projects, Ventura County, Merced County, and San Diego County, lack data from soon after construction that might be helpful in future analyses. Since all of the sections exhibit little or no distress, the lack of older distress survey data is not as significant an issue as it is for deflection data.

For each RAC Warranty project, the average maximum pavement surface deflection (in the outside wheel path) was originally used to identify distinctive PESs. For three projects, Ventura County, Fresno County, and Merced County, the PESs were selected using pre-construction deflection data. For the projects in San Diego County and Lassen County, post-construction deflection data were used. The individual PESs were selected to cover a range of low to high average deflections. To provide a basis for re-evaluating the selection, a new matrix was prepared based upon the California climate surrounding the RAC Warranty projects and the deflection data obtained during the last round. This experimental matrix is presented in Table 7.2. As can be seen, many of the experimental cells are empty, while others contain as many as four PESs. Because some of the cells have more replicates than needed, it may be worthwhile discarding some of the PESs. Thus, there are seven candidate PESs that could be eliminated without adversely affecting the experiment. They include: Ventura County WB-4, Fresno County NB-1 and SB-1, Merced County WB-3, and Lassen County NB-2, NB-4, and NB-5. These PESs are shown as shaded section in Figure 7.2.

Based upon the last condition of the PESs in each RAC Warranty project, it is expected that the RAC overlays in each project would generally perform well over their 5-year warranty period and their 10-year design lives. Based upon the assessment of structural adequacy and the deflection variability of several of the PESs, however, it is likely that some sections may deteriorate sooner and require more maintenance than the others. In general, the RAC overlays along Highway 33 in Fresno County and Highway 150 in Ventura County are likely to experience more deterioration, while the RAC overlay along Highway 140 in Merced County, Highway 75 in San Diego County, and Highway 395 in Lassen County are likely to experience less.

Table 7.1. Calendar summarizing the data collection status for each of the RAC Warranty projects during their respective 5-year warranty period

| RAC Warranty Project | No. of PES | Description | Calendar | | |

Table 7.2. Distribution of PES based upon average maximum surface deflection (measured during last test period)

California Environment	RAC Site	FWD Deflection Range (milli-inches)															
		3-5	5-7	7-9	9-11	11-13	13-15	15-17	17-19	19-21	21-23	23-25	25-27	27-29	29-31	31-33	33-35
Coastal	Ventura County				EB-1 WB-4 WB-6		WB-3	EB-2									WB-5
	San Diego County		SB-1 SB-3	SB-4			SB-2										
Central Valley	Fresno County			NB-1 NB-2 SB-1 SB-3	NB-3 SB-2												
	Merced County	EB-1	WB-2 WB-3 EB-3	EB-2	WB-1												
High Desert	Lassen County	NB-1		NB-2 NB-3 NB-5 NB-6	NB-4 NB-7 SB-9	SB-8											

Note: Shaded cells identify those Performance Evaluation Sections that could be removed from the experiment.

7.2 RECOMMENDATIONS

For a valid assessment of the RAC Warranty projects, it is important that performance data continue to be collected. Following are our data collection recommendations:

- Post-Construction Condition Data (for Performance Evaluation) – Condition survey data on the PESs should be collected at roughly one-year intervals using the standard forms and procedures established as part of this study.

- Future Condition Monitoring (for Warranty Enforcement) – Pavement condition information needed for warranty enforcement should also be collected at the time of deflection testing as shown in Table 7.3. For consistency, these should be performed through a cooperative effort between the local Caltrans District staff and the condition survey team that conducts the PES condition surveys.

- Future Deflection Testing (for Performance Evaluation) – Additional deflection testing should be carried out on each of the PESs during the remainder of each project's five-year warranty period. The recommended schedule is presented in Table 7.3. This schedule is designed to gather data that can provide an assessment of the seasonal effects as well as overall structural deterioration over time.

Collection of these data will allow a relative performance assessment of RAC overlays in three different environments under a range of traffic and pavement surface deflection levels. Although it will not be possible to compare the performance with that of overlays constructed with typical dense-graded mixes or to evaluate the overall effect of RAC overlay thickness, the results should demonstrate the overall effectiveness of RAC overlays and help identify areas where improvements can be made.

Table 7.3. Recommended FWD testing schedule for remainder of five-year monitoring schedule

RAC Warranty Project	Recommended Future Testing Date(s)
Ventura County, Route 150	June 2006
	September 2007
Fresno County, Route 33	July 2008
Merced County, Route 140	November 2006
	August 2008
San Diego County, Route 75	September 2006
	April 2008
Lassen County, Route 395	October 2006
	July 2009

Following are several recommendations relative to analyses of the data that can be performed during and after field data collection. These analyses should be included in the final report. These analyses will provide some useful information for validating, improving, and/or calibrating the current Caltrans overlay design procedure as well as evaluating the performance of RAC overlays. The results of these analyses may also be helpful to developing a mechanistic-empirical (M-E) overlay design procedure to meet California environments and Caltrans practices.

- Compare after overlay deflection measurements with before overlay deflections and other factors developed as part of the overlay design process. Attention should be given to accounting for the effect of temperature and environmental effects on measured deflections, so that a valid comparison can be made. These analyses should provide a basis for assessing the structural improvement provided by the overlay (in comparison with the overlay design). They should also produce data that could be used to revise the design models and criteria.

- Compare the performance of the PESs in the three different California environments and three different traffic levels to determine the relative effect of each. If significant differences are observed, some improvements and/or calibration of the overlay design procedure may be required.

- Evaluate the progression of pavement distresses in the different PESs to determine if RAC mixes are more effective at deterring one than another. Using the pre-overlay condition survey data, this can help confirm the belief that RAC mixes are more effective at reducing reflective cracking.

- Evaluate the key as-constructed material properties of the RAC mixes used within each project to confirm that the overlays were built substantially within compliance.

- Perform backcalculation analyses and analyze the state of stress for each of the RAC projects using deflection data obtained during each field monitoring. The results of these analyses will be helpful in the development and calibration of an M-E based overlay design procedure.

8.0 REFERENCES

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