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Technical Memorandum:

Causes of Failure of District 11 Asphalt Rubber Chip Seal 11-Imp-86-PM 37.3/43.3 (EA 11-241101)

Technical Memorandum Prepared For

CALIFORNIA DEPARTMENT OF TRANSPORATION

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INTRODUCTION

A rubberized asphalt chip seal project on SR-86 in District 11 exhibited flushing and rutting shortly after construction. These defects occurred within the 1-year performance warranty period specified in Section 10-1.22 of the Special Provisions of Contract No. 11-241104. Results of California Test 342 performed by Caltrans confirmed a coefficient of friction of less than 0.30, which is less than the minimum required. The contractor declined to perform the specified repair at contractor's expense, saying they followed Caltrans specifications. The contractor concluded they are not responsible for a defect due to an "inadequate specification" (given the project condition).

On December 17, 2004, Caltrans Headquarters Maintenance and the Pavement Research Center (PRC) agreed on a study to address four objectives. The PRC was asked to investigate as a part of Strategic Plan item 4.14. This Technical Memorandum addresses Objective #1. A future Technical Memorandum will address Objectives #2 through #4.

The scope of Objective #1 is to investigate if the causes of failure of the asphalt rubber chip seal can be determined. Specifically, the PRC planned to perform the following tasks:

- Determine compliance with prescriptive specifications and relate them to failure of the chip seal,
- Collect test and construction records related to the chip seal to see if the cause of failure can be determined, and
- Conduct lab testing of the chip seal if it is apparent that it may help determine causes of failure (no lab testing was required; any lab testing was subject to costs, schedule, and resource constraints).

PROJECT SETTING

The project is located on northbound SR-86 just south of the SR-78 junction and north of the city of Westmorland (see Figure 1) in Imperial County. The transportation network in the region has been characterized as "an economic pipeline that links the movement of agricultural and cross-border goods and services with the border region, California, other States in the U.S., and international markets."(*1*)

A Caltrans Fact Sheet on the SR-86 expressway says "State Route 86 is the main north-south access between I-8 and I-10…and is one of the principal farm-to-market routes to the Los Angeles distribution points. There is a very high percentage of large trucks using SR-86, up to 48 percent at times, and heavy recreational traffic on the weekends, mainly in the fall, winter, and spring."(*2*) In addition, because of the extended growing season in the region, truck traffic hauling agricultural goods in the spring can comprise 35 percent of travel on SR-86.(*1*)

In 1993, Caltrans and partner agencies identified specific corridors (including SR-86) that "are critical to the efficient movement of goods and services" from other states and from international Ports of Entry. These routes are included in a network (referred to originally as NAFTA NET) now known as the IBTC, International Border Trade Corridors. Caltrans subsequently designated SR-86 as part of the ICES System (Intermodal Corridors of Economic Significance).(*1*)

Accommodating the increases in freight and agricultural goods required substantial improvements and expansion of SR-86 (mainly to four-lane expressway) during the past decade. The bulk of these construction projects were completed by 2001.(*3*)

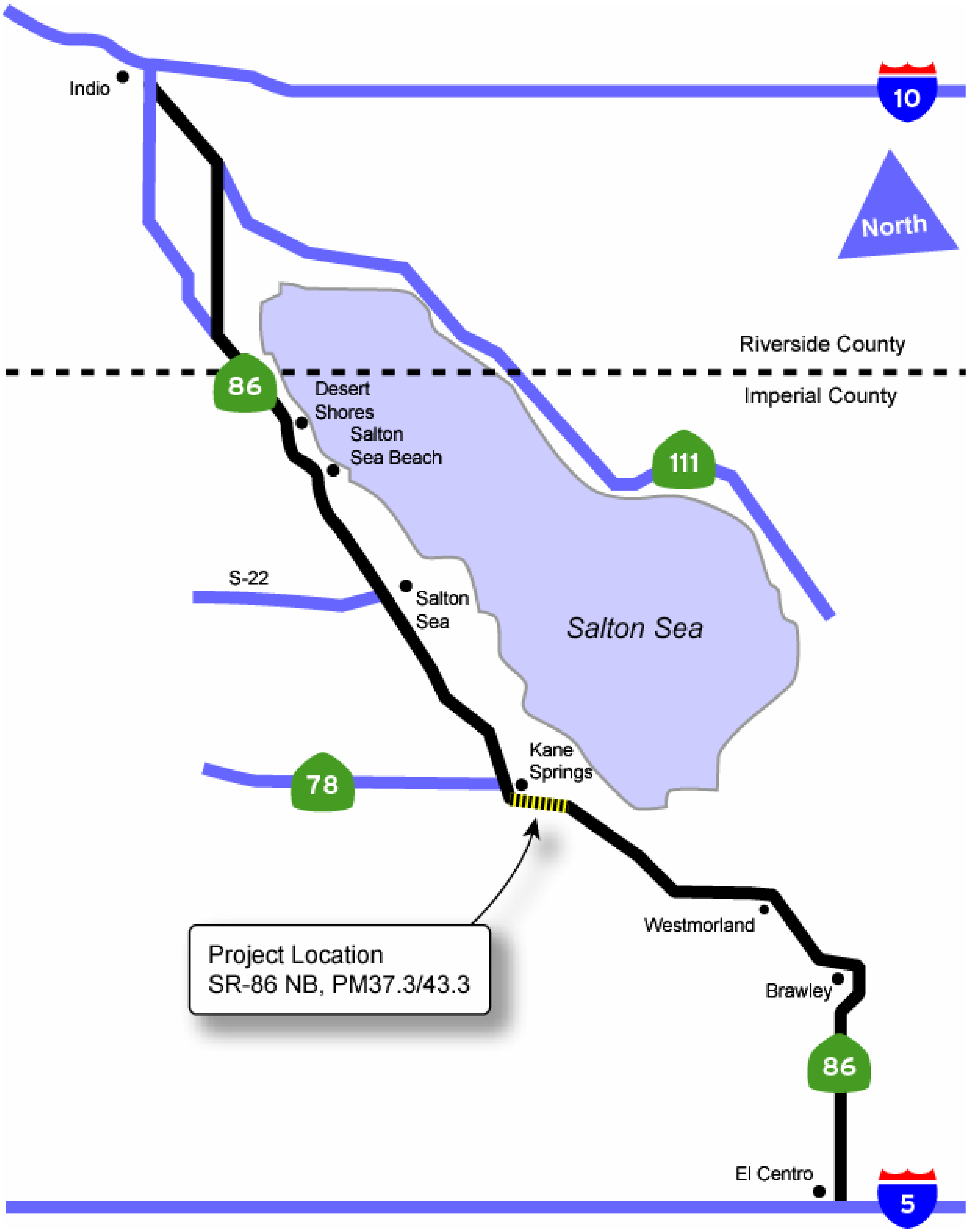

Figure 1. Project setting and location map for 11-Imp-86-PM 37.3/43.3.

INVESTIGATION PLAN

Areas of investigation conducted by the PRC include the following:

- (i) Conduct field site visit and (ii) observe coring and obtain cores for assessment and potential lab testing
- Collect additional project information including data provided from contact with Resident Engineer
- (i) Perform laboratory testing if possible and (ii) present results from laboratory testing conducted by Caltrans
- Review chip seal specifications and examine relationship to failure

The PPRC planned its investigation based on five hypotheses of potential causes or contributors to failure:

1. Chip seal binder contaminated and softened the underlying AC, which led to bleeding and rutting
2. An emulsion rejuvenator surface treatment (referred to as a PASS treatment) applied to the AC led to bleeding and rutting
3. Higher than normal temperatures during late 2003 and 2004
4. Heavier than normal traffic loading during late 2003 and 2004
5. A combination of Hypotheses 3 and 4

FINDINGS FROM INVESTIGATION

Field Site Visit

The findings reported in this Technical Memorandum follow information presented in a previous Technical Memorandum.*(4*) The earlier document describes a field site visit by PRC staff to collect data and accompany a District 11 coring crew that collected samples from the project in January 2005. Information compiled in the earlier document along with subsequently collected information is presented in a project timeline shown in Figure 2.

The previous Technical Memorandum contains a project map. A project schematic showing locations of coring and distress observed during the PRC field site visit of January 20, 2005 is shown in Figure 3. The condition survey revealed flushing and rutting throughout the entire pavement section in the #2 lane along the wheel paths except for the 1-mile section south of the Immigration and Naturalization Services (INS) Station. An open-graded asphalt concrete (OGAC) layer was placed previously in this area because of braking and extended durations of heavy loading near the INS Inspection Station.

The project timeline begins in November 1997 with widening of the previously 2-lane SR-86 into a 4-lane divided highway. This project was part of a series of expansion projects on SR-86 to accommodate increases in freight and agricultural goods movement.(*1-3*) Two new southbound lanes throughout the project limits were constructed using portland cement concrete (PCC), which is typical for much of SR-86 in both directions south of the project limits. The original 2-lane highway became the two northbound lanes of SR-86 and a DGAC overlay was placed. No distress was noted prior to placing the overlay. A maintenance surface treatment (emulsion rejuvenator referred to as a PASS treatment) was applied in October 2000. Details about the PASS treatment were not available for assessment.

A chip seal was placed in September 2003 for preventive maintenance. There were no signs of distress during two chip seal pre-warranty pilot project inspections in mid-2002 and March 2003, though the surface was noted as appearing “dry” during the second inspection. Bleeding and minor rutting were first noticed and documented in the northbound #2 lane during

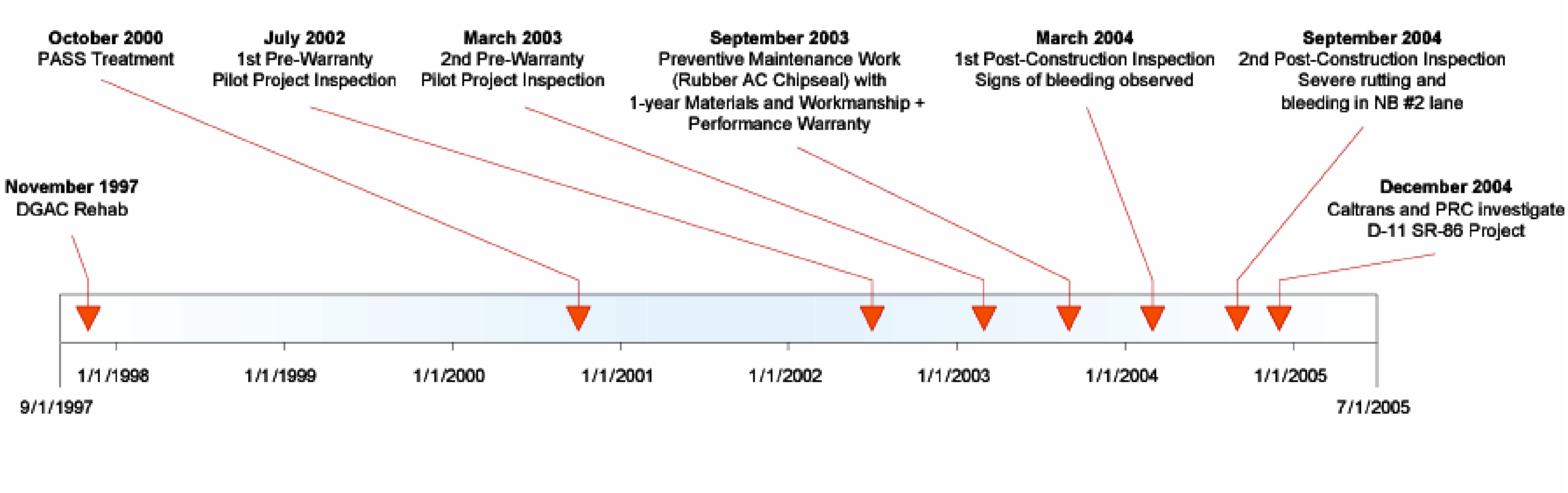

Figure 2. Timeline of project events for 11-Imp-86-PM 37.3/43.3

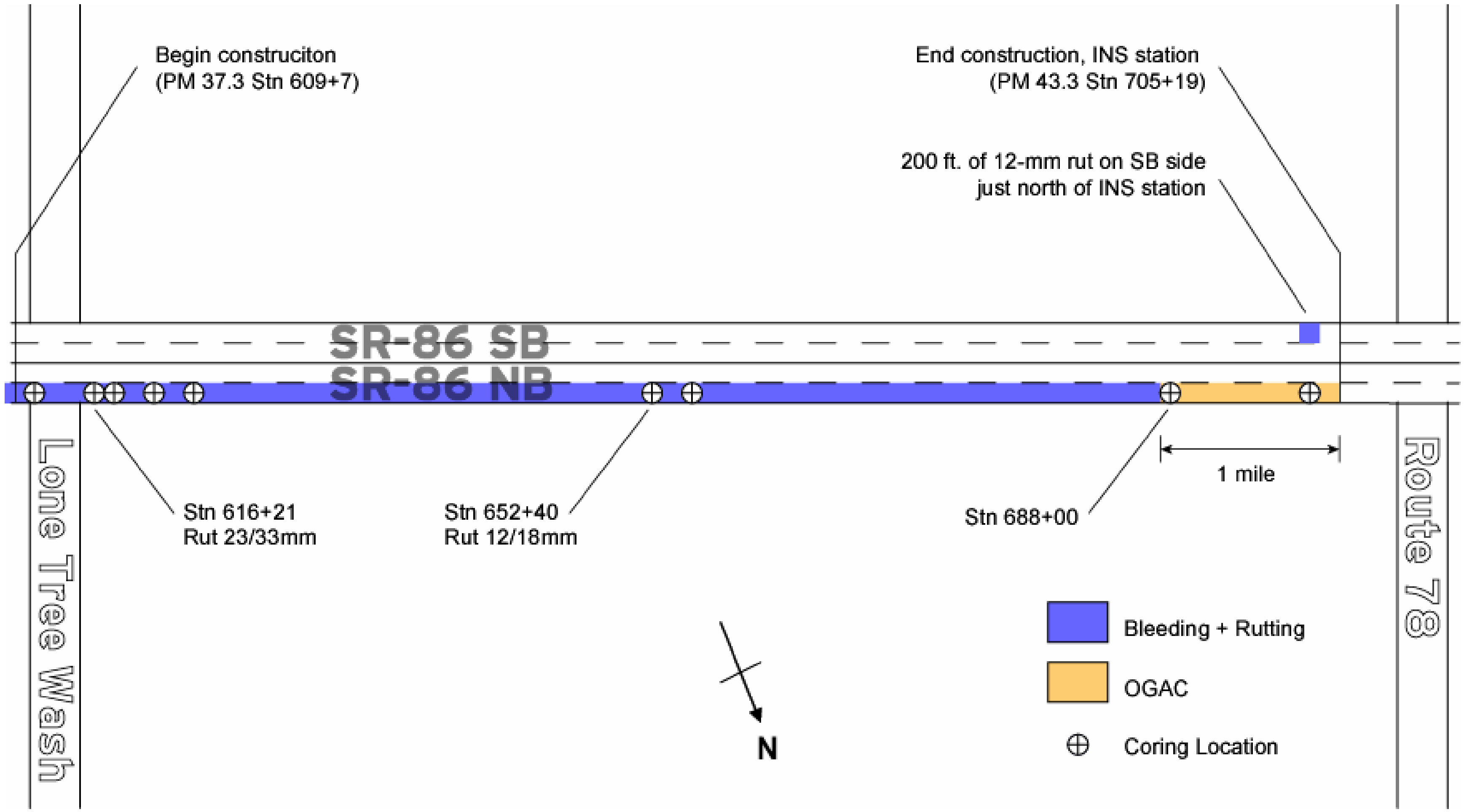

Figure 3. Condition survey of 11-Imp-86-PM 37.3/43.3 during PRC field site visit in January 2005.

the first post-construction inspection in March 2004. By the time HQ Caltrans conducted its second post-construction inspection in September 2004, bleeding and rutting in the wheelpaths had severely worsened throughout the entire project, but was limited to the northbound #2 lane.

According to a Caltrans HQ Maintenance report (Ron Jones), there were no signs of distress prior to placing the asphalt rubber chip seal in September 2003. Examples of the surface condition prior to the chip seal appear in Figures 4 and 5.

The first signs of bleeding and minor rutting were documented during the first post-construction inspection by Caltrans on March 29, 2004. By September 2004, when Caltrans conducted a second post-construction inspection, severe wheelpath rutting had developed to depths of 2 to 38 mm (see Figures 6 and 7).

Pavement distress, both bleeding and rutting, were severe by the time of the PRC field site visit in January 2005. Figure 8 shows an example of the pavement surface condition at that time. It was evident during the site visit that bleeding and rutting were limited to the #2 (outside) lane in the northbound direction.

Following the field site visit, when distress was noted only in the truck lane, the PRC investigated traffic data to determine if there were changes in truck loading or volume that may have contributed to observed distresses. The nearest Caltrans Weigh-In-Motion (WIM) site on SR-86 is near Riverside, which is far to the north of the project, so no suitable WIM data was available for analysis. In addition, there were no indications that portable WIM data might be available. As a result, information about truck weights and trends in the project area was not available for this investigation.

PRC staff found traffic volume data available from the Caltrans Traffic and Vehicle Data Systems Unit.(*5*) Also known as traffic counts, these values are verified periodically or estimated

Figure 4. First pre-construction inspection with no signs of distress, July 2002 (Caltrans Maintenance – Ron Jones).

Figure 5. Second pre-construction inspection with no signs of distress, May 2003 (Caltrans Maintenance – Ron Jones).

Figure 6. First post-construction inspection showing rutting in northbound #2 lane, March 2004 (Caltrans Maintenance – Ron Jones).

Figure 7. Second post-construction inspection showing rutting in northbound #2 lane, September 2004 (Caltrans Maintenance – Ron Jones).

Figure 8. PRC site visit showing 33-mm rut and bleeding, January 2005 (Station 616+21, northbound #2 lane).

from counts verified at more distant locations on the route. For the segment of SR-86 that includes the project limits, counts were last verified in 1981 and estimated in 2000 and 2003. Figure 9 shows total trucks (Annual Average Daily Truck Traffic) on SR-86 from PM 0 to 43.59 for years 2000 through 2003. Truck counts include estimated trucks combined for both northbound and southbound directions.

Truck count data for the project limits do not show an increase in truck volumes during the years leading up to placing the chip seal in late 2003 nor are traffic volumes in 2003 higher than in previous years. Traffic data and thus truck counts are not available for 2004 at the time of this writing.

The lack of WIM data and the inability to determine actual traffic volumes makes it difficult to identify truck traffic as a cause or contributing factor to rutting and bleeding on SR-86.

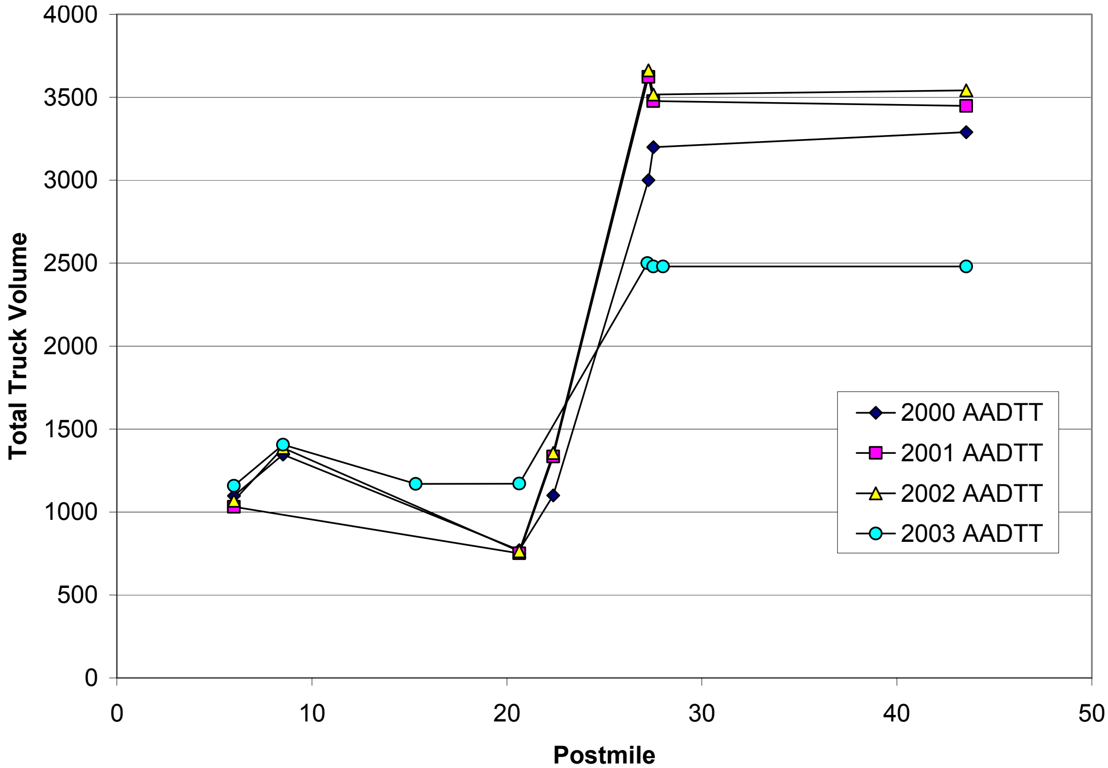

Figure 9. Truck volume on State Route 86 over years 2000–2003.

To examine if environmental factors may have contributed to early distress, PRC staff collected historical data on air temperature near the project. Temperature data was obtained from the National Climatic Data Center (NCDC) Website.(*6*) NCDC collects daily data from weather stations throughout the U.S. Data was obtained for the NCDC weather station located in the City of Brawley, which is the site closest to the project on SR-86.

Average monthly maximum air temperature was collected for each year from January 1998 to March 2005 and is presented in Figure 10. This Figure shows mean maximum temperature (ºF) for each month of year.

Temperature data for the time period studied do not show unusual extremes during the months preceding the first indications of distress seen in March 2004. Trends and values are consistent throughout most of the year for each year shown. Wider variation occurred early in the

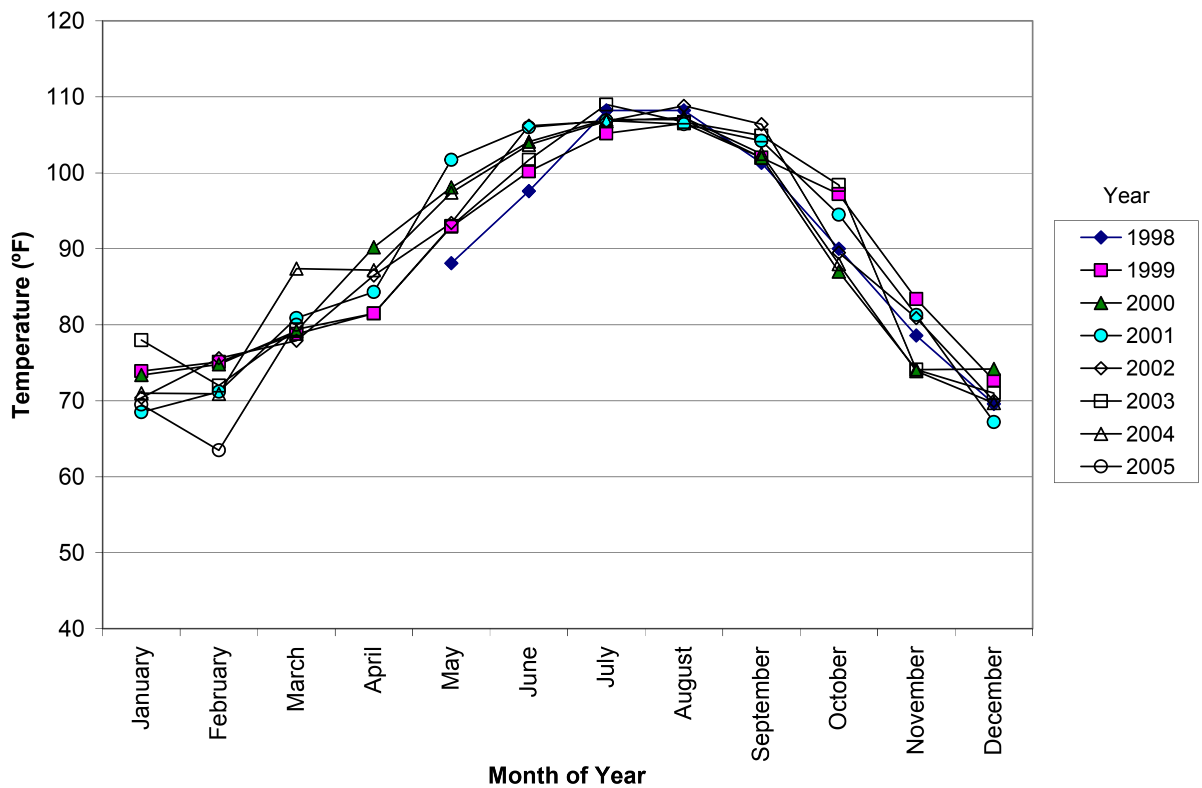

Figure 10. Average monthly maximum temperature.(*6*)

year for several years including March 2004, when distress was first documented. The average monthly maximum temperature during March 2004 was nearly 88ºF, about 8ºF higher than typical in previous years. However, temperatures in preceding months (January and February 2004) were closer to the typical value of approximately 70ºF.

Assessment of Cores

The coring plan developed by District 11 for field work performed on January 20, 2005 is shown in Figure 11.

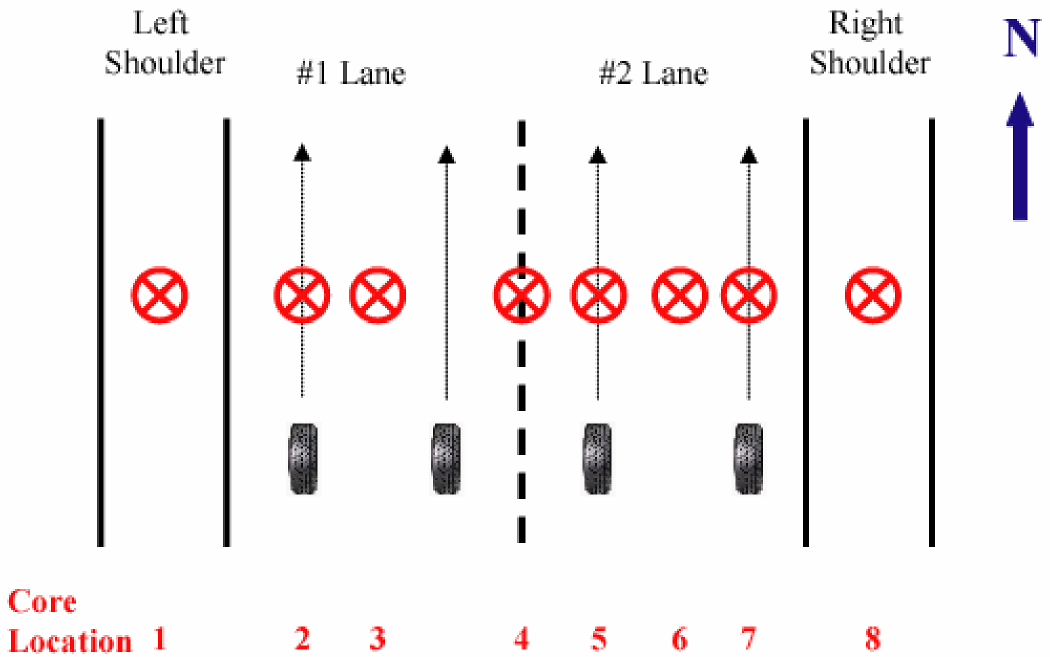

Figure 11. District 11 coring pattern for SR-86.

A total of 35 wet cores were collected at 9 different locations. Assessment of cores first involved measurement of chip seal thickness. Rut depths at coring locations also were measured. Digital photos documenting the appearance of all cores were taken and archived for future study. The surface of the cores taken between wheelpaths showed aggregate that appeared competent and well-embedded. The surface of cores from within wheelpaths showed aggregate that appeared abraded.

Chip seal thickness and rut depth measurements are presented in Table 1. Chip seal thickness was reasonably consistent for all coring locations and did not correlate with rut depths. Caltrans collected three of the 35 cores (not shown in Table 1) from Station 696, where no distress was observed and OGAC (no chip seal) had been placed. The chip seal was placed within 0.5 miles of the INS station and another OGAC layer was placed afterward. This is in the 1-mile long section where the Construction Engineer approved a CCO for the contractor to place OGAC to address the bleeding prior to the second post-construction review in September 2004.

Table 1 Chip Seal Thickness from Cores and Rut Depths at Coring Locations

Station	Chip Seal Thickness at Core Location, mm							Rut Depth in Wheelpath, mm	
	2	3	4	5	6	7	8	Left Wheelpath	Right Wheelpath
610+40	11	10		9	10	13		2	2
616+21				14	13	14		23	33
616+37	11	11	13	12	15	10	13	18	38
617+60				12	13	11		6	16
618+00				10	10	10		11	16
652+40	10	11		10	11	9		12	18
654+00				10	12	10		2	11
688+40				10	10	10		0	0

Note: Refer to Figure 11 for diagram of coring locations.

Of the cores collected during January 2005, Caltrans provided 16 cores to the PRC for potential further evaluation. Visual assessment of the cores led to the following observations:

1. No homogeneous underlying AC structure was found. Cores varied in total AC thickness from approximately 5 to 13 in. Some of the shorter cores may have resulted from additional AC layers being left in the core-hole. Both AC thickness and the number of detectable layers varied substantially, indicating various rehabilitation and maintenance treatments applied in the project area over the years.
2. No aggregate migration from the chip seal in to the underlying AC layer was observed.
3. The chip seal did not appear to have shoved or pushed sideways along the wheel-path and, at a given coring location, the chip seal thickness was reasonably uniform thickness across the lane within and between wheelpaths.

Observations 2 and 3 lead to a logical inference that the chip seal was not the primary location of rutting. This also is evident from the magnitude of rut depths, which far exceeded the thickness of the chip seal at several locations. In the absence of the chip seal rutting, then rutting must have occurred in the underlying AC. Cutting a trench to determine the degree of rutting attributable to each individual structural pavement layer was not possible.

The potential role of the chip seal in contributing to rutting and bleeding (perhaps by contaminating the underlying AC) was subsequently examined in laboratory tests described in the section, “Laboratory Tests,” later in this Technical Memorandum.

Additional Project Information

After field coring, the PRC followed up with Caltrans District 11 for clarification of existing documentation and to obtain further information related to the asphalt rubber chip seal project performance. Questions about background details enabled development of a project history presented in the timeline shown in Figure 2. Discussions with the District 11 Construction Engineer (Shawn Rizzutto) and a memorandum and testing reports provided by the district included the following highlights of the maintenance and rehabilitation history for SR-86:

1. Construction of a DGAC overlay on northbound SR-86 was completed in late 1997 under Contract 11-100714 (Resident Engineer: Michael G. Moen). According to Don Jones (District 11 Maintenance, Region Manager), the pavement surface prior to overlay had a dry appearance (caused by aging) but otherwise showed no distress so the overlay was a thin maintenance blanket. The design requirements and other details about the overlay project were not investigated because they are beyond the scope of the work for the current study.
2. The contractor’s plant produced mix that was out of compliance in June 1997, during the summer before construction of the DGAC overlay. A memo from Caltrans to the contractor in June 1997 indicated that a street sample grading was finer than the plant grading for most sieve sizes by as much as 18% on the #4 sieve. Subsequent documentation showed that the issue was resolved in October 1997 and acceptable to the RE. Despite this matter, it is noteworthy that the DGAC overlay provided

satisfactory performance for 6.5 years (from late 1997 till March 2004) but showed distresses within six months after placing the asphalt rubber chip seal.

3. A maintenance treatment was applied in the project area in October 2000. According to the District 11 Maintenance Region Manager, the northern end of the project, from PM 37.3 to 43.3, had a PASS seal applied on all AC portions (traveled way, shoulders, turn pockets, median crossovers, etc). The seal consisted of a 50/50 solution of PASS QB (Quick Break) and water, applied at 0.10 gal./sq. yd. Further information about this surface treatment was not found.
4. There are no further indications of other maintenance and rehabilitation activities until placing the chip seal in September 2003.
5. The District 11 Construction Engineer was asked about any knowledge or experience of patterns of increasing truck traffic (e.g., large construction projects in the area) preceding the surface distresses observed in 2004, but no information or indications of increased truck traffic were suggested.

Subsequent discussions with the District 11 Maintenance Region Manager led to identifying a short AC section (approximate length 200 ft.) of southbound SR-86 just south of San Felipe Creek Bridge (and immediately south of the INS Station) within the project limits. A chip seal was placed here in 2003 as part of the same contract for the northbound chip seal project. Like the northbound #2 lane, this short southbound section showed comparable severity of rutting and bleeding in the #2 lane by March 2004. In contrast to the northbound project, a PASS treatment had not been applied in this short southbound AC section. This suggests little or no connection between the PASS treatment and eventual distresses whereas the chip seal appears more closely associated with these distresses.

Laboratory Tests

Laboratory testing by the PRC was not required in the scope of work unless it was apparent that such testing may have helped determine causes of failure. Such testing would have been subject to costs and scheduling constraints, availability of resources, and further discussion.

Following coring operations in January 2005, three tins of retained asphalt rubber binder and the upper 10-cm section from 11 cores were sent to the Road Materials Testing Laboratory at the CSIR Transportek (subcontractor to the PRC). The purpose of testing by the CSIR was to test for the possibility of contamination of the chip seal or the underlying AC binder that may have resulted in softening of the binder and contributed to observed surface distresses.

Tests on the cores included the following:

- Gas chromatographic (GC) analysis to determine the extent to which "lighter" solvents might be present. Binders from the cores were recovered using Abson method (ASTM D1856, benzene) followed by determination of recovered binder properties.
- High performance liquid chromatography (HPLC) was used to determine the presence of "heavier" oil-like contaminants.

Further discussion of test methods, background information, analyses, and results are included in a separate document.*(7)*

Testing by the CSIR also included determining the aggregate gradation of the chip seal based on the recovered aggregate. The resulting gradations are shown in Figure 12. Gradations from cores removed from the right wheelpath (indicated by "#2") are comparable, though one core is from Station 610+40 and the other is from Station 654+00. A second core from Station 610+40, taken from between wheelpaths, shows a coarser gradation. This corresponds with the appearance (noted for all cores) of a rough/coarse surface for cores between wheelpaths and worn/smoother

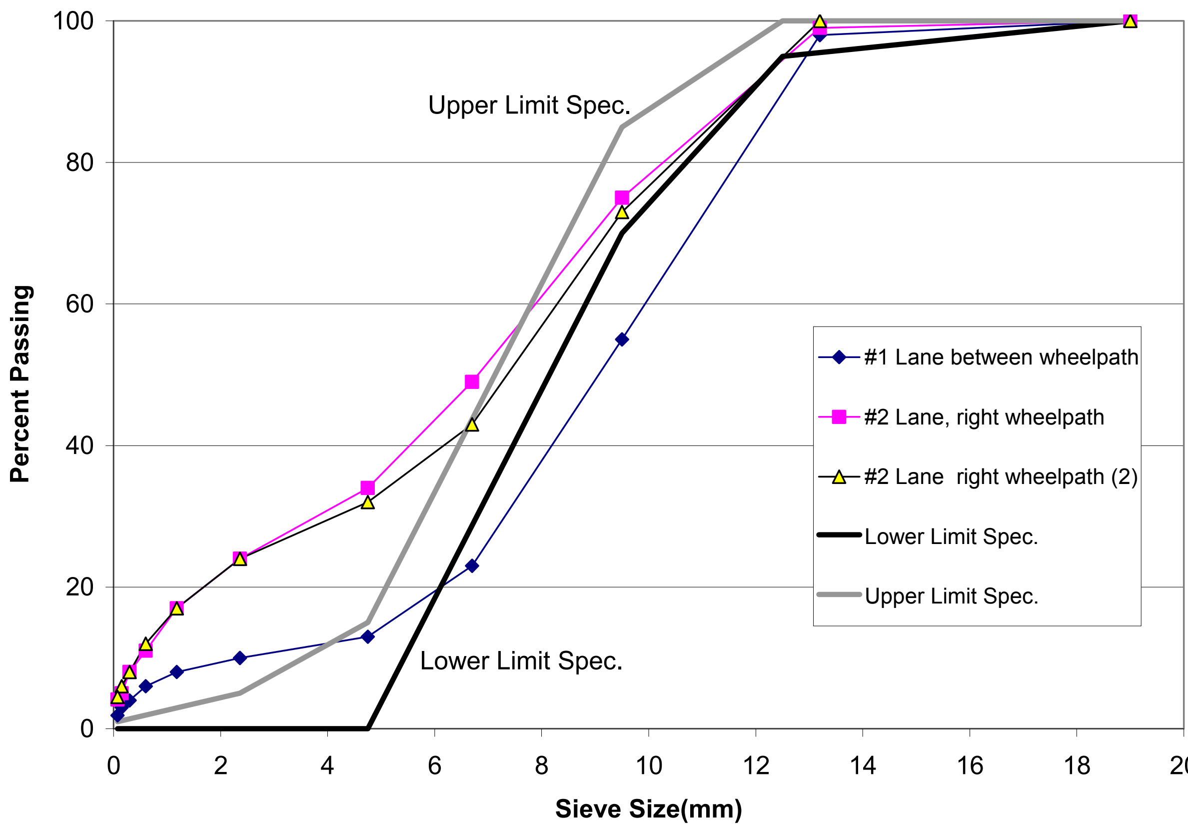

Figure 12. Asphalt rubber chip seal recovered aggregate gradations.

appearance for cores within wheelpaths. It is noteworthy that many transportation agencies worldwide specify single-size chip seals. Caltrans may want to consider either using single-size chips or tightening gradation specifications.

Two complicating factors confound the analysis. First, the presence of recycled shredded tires, solvents, and oils in the chip seal adversely affected the response of lighter components when using GC analysis. Second, the high percentage of fines in the chip seal made it difficult to sample the binder in a purer form. As a result, results from the GC analysis are approximate and should not be considered absolute.

Results from the CSIR laboratory tests do not identify the chip seal as the clear cause of bleeding and rutting observed on SR-86. Limits on accuracy and the presence of complicating factors preclude clear determination. Highlights of results from the CSIR laboratory tests on cores are summarized below:

- Results for the chip seal show significant variation in patterns for chip seal material from different cores.
- In contrast to the chip seal, results for underlying AC composition are similar for all cores. Contamination of the underlying AC layer is, therefore, ruled out as such contamination would require an overlapping of contaminant patterns for both layers. No such overlap is evident.
- Lighter fractions found in the AC (present in all cores) are concluded to:
  1. have been present before the chip seal treatment, and
  2. not have adversely affected stability of the AC (this also suggests the PASS treatment did not adversely affect the underlying AC).
- Despite the rubber, solvents, and oils in the chip seal binder, qualitative assessment of chromatograms shows no “heavy” solvent/oil peaks.
- The softening point of the chip seal binder is high enough to exclude it as a contributory factor to rutting or shoving and correlates well with the softening point of the original retained binder.
- The binder application rate calculated for the chip seal varies from 2.4 to 2.6 l/m^2. The binder content is consistent across the lane.

The Caltrans District 11 Materials Lab conducted laboratory testing on some of the cores obtained in January 2005. The District 11 Construction Engineer asked the Materials Lab to perform the following tests: Stability (CTM 366), Specific Gravity (CTM 308), Sieve Analysis (CTM 202), and Extraction (CTM 310). According to the Construction Engineer these tests have been completed. Copies of the test results have been requested by the PRC but are not available as of the date of this Technical Memorandum.

Review of Specification

This project was part of the "1 Year Warranty Pilot Project Program" organized by Caltrans HQ Maintenance. The Warranty Review Committee reviews the four-year performance history data (percent cracked percent patched, IRI, etc.) of proposed highway sections. A pavement condition survey is performed to provide an updated assessment of the highway conditions. If adequate, then a 1-year preventive warranty pilot project is identified and carried out. The project is subsequently monitored and changes in conditions are documented. Appropriate actions are taken at the first sign of distress.

Project documents were reviewed by the PRC for compliance with specifications and to relate the specifications to failure of the asphalt rubber chip seal. According to the records provided by the District 11 Construction Engineer, available test results do not indicate non-compliance with materials specifications.

Analysis of the chip seal as placed to determine if it conforms to specifications was not possible due to the unfeasible number of cores that would have been needed to perform the required laboratory tests. It was not possible to compare the extracted binder (in the CSIR laboratory tests) to the original binder because of the high percentage of fine aggregate.

CONCLUSIONS

Conclusions from the tasks originally planned in order to complete Objective #1 are summarized below.

- **Objective:** Determine compliance with prescriptive specifications and relate them to failure of the chip seal.

  Conclusion: It was not possible to compare the extracted binder to the original binder of the chip seal because of the high percentage of aggregates passing the 0.75mm sieve. In addition, determining compliance of the seal with specifications was not possible because an unfeasible number of cores would have been needed to gather sufficient binder material for analysis.

- **Objective:** Collect test and construction records related to the chip seal to see if the cause of failure can be determined.

  Conclusion: Available test and construction records related to the chip seal do not identify a clear cause of rutting and bleeding.

- **Objective:** Conduct lab testing of the chip seal if it is apparent that it may help determine causes of failure (no lab testing was required; any lab testing was subject to costs, schedule, and resource constraints).

  Conclusion: Within the accuracy limits and complicating factors, results from laboratory testing do not determine causes of failure.

Conclusions about the five hypotheses of potential causes or contributors to failure of the asphalt rubber chip seal on SR-86 are as follows:

- **Hypothesis #1:** The chip seal binder contaminated and softened the underlying AC layer and led to bleeding and rutting.

  Conclusion: Assessment of cores and subsequent laboratory tests conducted by the CSIR do not show contamination or softening of the underlying AC, though complicating factors (the presence of solvents/oils and high percentage of fines in the chip seal binder) affect the accuracy of test results. CSIR lab test results show significant variation in chip seal material from different cores but the underlying AC composition is similar for all cores. However, contamination is ruled out because it would require an overlapping of contaminant patterns for both chip seal and AC layers. No such overlap was found.

- **Hypothesis #2:** An emulsion rejuvenator surface (PASS) treatment applied to the AC in 2000 eventually led to bleeding and rutting.

  Conclusion: Laboratory tests conducted by the CSIR do not show contamination or softening of the underlying AC. Lighter fractions found in the AC are present in all cores so they were present before the chip seal was placed. These fractions have not adversely affected the stability of the AC, suggesting that the PASS treatment did not contribute to bleeding and rutting. The complicating factors mentioned previously apply to this hypothesis as well.

- **Hypothesis #3:** Higher than normal temperatures during late 2003 and 2004 led to bleeding and rutting.

  Conclusion: Temperature data do not show unusual extremes during the months preceding the first indications of distress seen in March 2004. Trends and values are comparable to previous years.

- **Hypothesis #4:** Heavier than normal truck traffic loading during late 2003 and 2004 led to bleeding and rutting.

  Conclusion: Truck traffic counts in 2003 are not higher than in previous years in the project area on SR-86. Traffic counts are two-way, so changes in northbound truck traffic are unknown. A lack of WIM data for the project area precludes evaluation of truck weights and potential effects on bleeding and rutting. Because of previous projections of increases in heavy truck traffic on SR-86, it is reasonable to infer that both the number of trucks and the magnitude of axle loads have increased since the DGAC overlay was placed in 1997. However, WIM data and directional truck traffic counts are not available to identify potential correlation.

- **Hypothesis #5:** A combination of Hypotheses #3 and #4 led to bleeding and rutting. **Conclusion:** It appears unlikely that temperature contributed much if at all to surface distresses. The contribution of truck weights and counts is unknown as discussed above.

In summary, results from investigations observed on the asphalt rubber chip seal project do not clearly identify the cause(s) of failure. The PASS maintenance treatment is an unlikely cause or contributing factor. The rutting in both the northbound #2 lane and the short AC section in the southbound #2 lane suggests some unidentified aspect of the chip seal may have contributed to failure. Heavy truck loading (either ongoing or sporadic events) may have contributed to failure but this can not be further investigated with available information.

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