STATE OF CALIFORNIA
DEPARTMENT of TRANSPORTATION

Caltrans

**DIVISION OF
ENGINEERING SERVICES**

**MATERIALS ENGINEERING
and TESTING SERVICES**

**5900 Folsom Boulevard
Sacramento, California 95819**

**Interstate 15 – South Bound
PM 55.7 to PM 53.5**

POST CONSTRUCTION REVIEW

DISTRICT 8
San Bernardino County
Interstate 15 – South Bound

CONTRACT NUMBER: 08-4277U4

June 2001

ACKNOWLEDGEMENTS

The Office of Rigid Pavements and Structural Concrete would like to express our gratitude to the following for their participation, assistance, and support:

District 08

Materials Engineering

Construction - Barstow/Victorville

Maintenance - Barstow

Federal Highway Administration

Western Resource Center

California Division Office

POST CONSTRUCTION REVIEW
District 08
San Bernardino County
Contract Number: 08-4277U4

This report reflects the observations, findings, conclusions, and recommendations of the authors. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration.

This report does not constitute a standard, specification, or regulation. The Office of Rigid Pavements and Structural Concrete is responsible for the accuracy of the information and data presented in this report.

Principal Investigator .... Doran Glauz

Co-Investigators .... Karl Smith
Raul Alarcon

Report Prepared by .... Raul Alarcon

DORAN GLAUZ, P.E.
Senior Materials & Research Engineer

KEN BEEDE, Senior Transportation Engineer
Consultations and Investigations

TOM PYLE, Office Chief
Office of Rigid Pavement
and Structural Concrete

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SUMMARY

A recent concrete pavement project, completed in May 2000 on Interstate 15 (I-15) near Barstow in San Bernardino County, began to exhibit signs of premature deterioration. The project widened a segment of I-15 between Powerline Road and WildWash Road in the southbound direction. Recent counts show that this segment is subjected to an Annual Average Daily Traffic (AADT) of 41,000 vehicles.

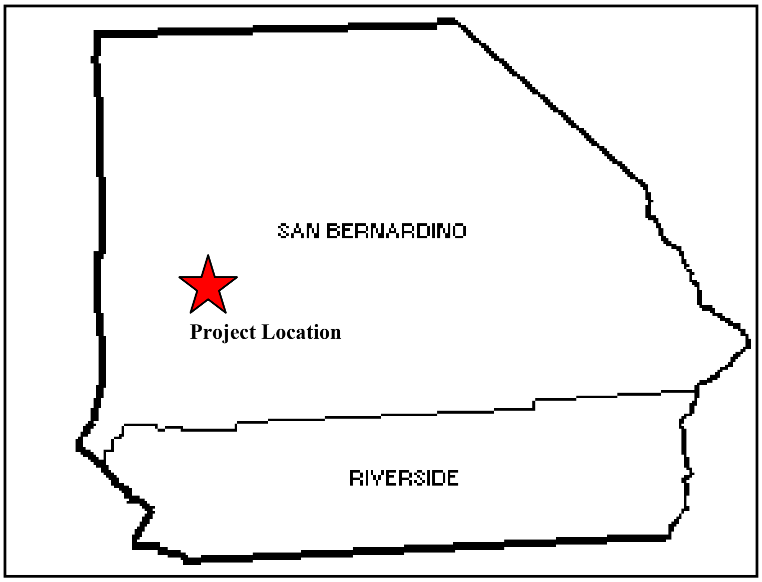

Figure 1. Project Location

District 08 expressed concerns over the premature deterioration of the newly constructed concrete pavement and requested that the Office of Rigid Pavement and Structural Concrete assess the condition of the concrete pavement and make recommendations.

Two on-site visits were made to evaluate the present status of the concrete pavement. Core samples were taken during the initial site inspection.

Data and information were obtained from the following sources:

a. Project documents, records, and plans
b. Meetings and verbal communication with the District 08 staff
c. Observations during the on-site visits.
d. Core samples
e. Archived weather data

This investigation focused primarily on the concrete mix, weather conditions, and pavement distresses observed at the project site.

A review of construction documents showed the amount of cementitious material in the concrete mix was lower than the amount specified in the project special provisions.

Archived weather data indicates that the concrete pavement was placed under conditions consisting of warm temperatures, low humidity, and high velocity winds. These conditions significantly affect moisture loss and shrinkage.

The inspection revealed most sections had low severity distresses. Among the distresses observed were:

1. Longitudinal and transverse cracking
2. Spalls in the transverse joints
3. Poor consolidation in the concrete pavement
4. Cracks across longitudinal and transverse joints
5. Irregularities in the pavement surface

The southern end of the project exhibited moderate severity distresses. Many panels in this section displayed excessive cracking.

The Federal Highway Administration (FHWA) was notified of the inspection results. At their request, a second on-site visit was made on November 2, 2000. Many of the locations examined during the first inspection were revisited. FHWA has released a field report, dated November 9, 2000, detailing their observations, findings, conclusions, and recommendations.

PROJECT DESCRIPTION

This project widened a 3.66-km long segment of I-15 by adding two lanes of Portland Cement Concrete Pavement (PCCP) to the existing asphalt concrete lanes in the southbound direction. The project limits extended from 2.4-km north of Powerline Road (Sta. 210+80) to Wildwash Road (Sta. 247+36). The new lanes currently serve as a truck climbing lane and a shoulder (to be opened as a traffic lane in the future).

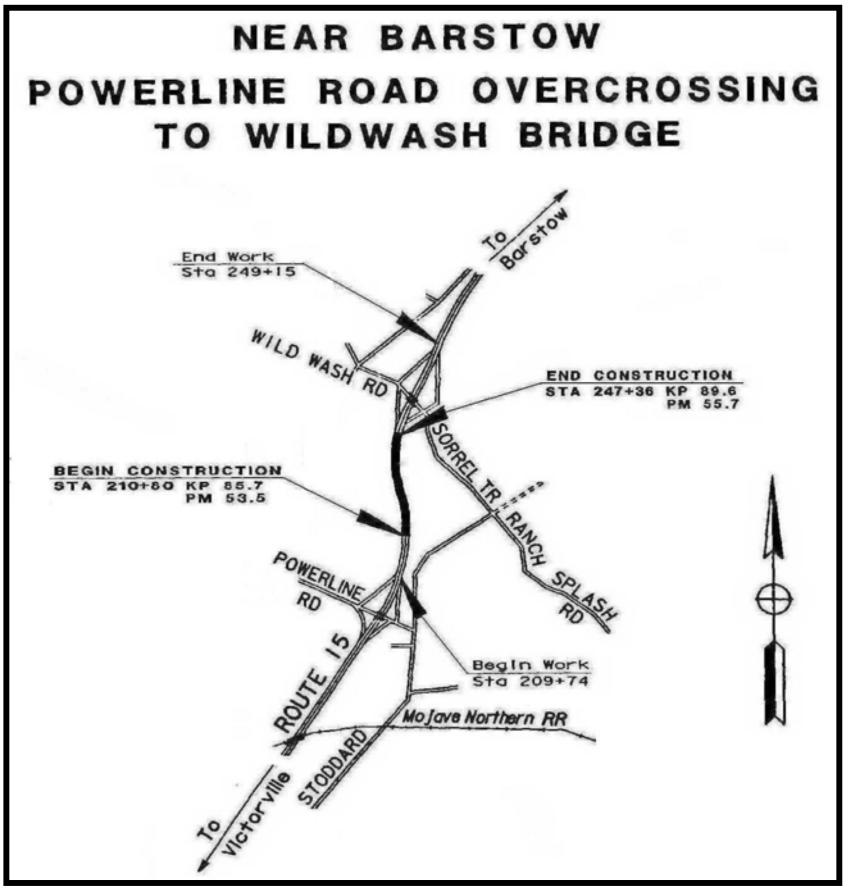

Figure 2. Project Limits

Construction Details

The widened segment was completed in May 2000. The concrete was placed monolithically at a width of 7.5-m in the direction of travel (north to south). Construction documents required longitudinal joints at the lane lines and transverse joints at 3.6-m, 4.0-m, 4.3-m, and 4.6-m intervals.

The longitudinal joint between PCCP lanes was constructed by the sawing method. It required tie bars. The tie bars specified were epoxy-coated #19 deformed bars, 750 mm long. Tie bars were evenly spaced at 710-mm intervals, on center, and at least 380-mm from transverse joints (Figure 3).

Transverse joints required dowel bars. The transverse joints were constructed by the sawing method, except at the contact joints. The dowel bars specified were 460-mm long, 38-mm diameter epoxy-coated smooth bars evenly spaced at 300-mm intervals, on center.

Splice coupling bars were specified on the shoulder edge to allow for future expansion.

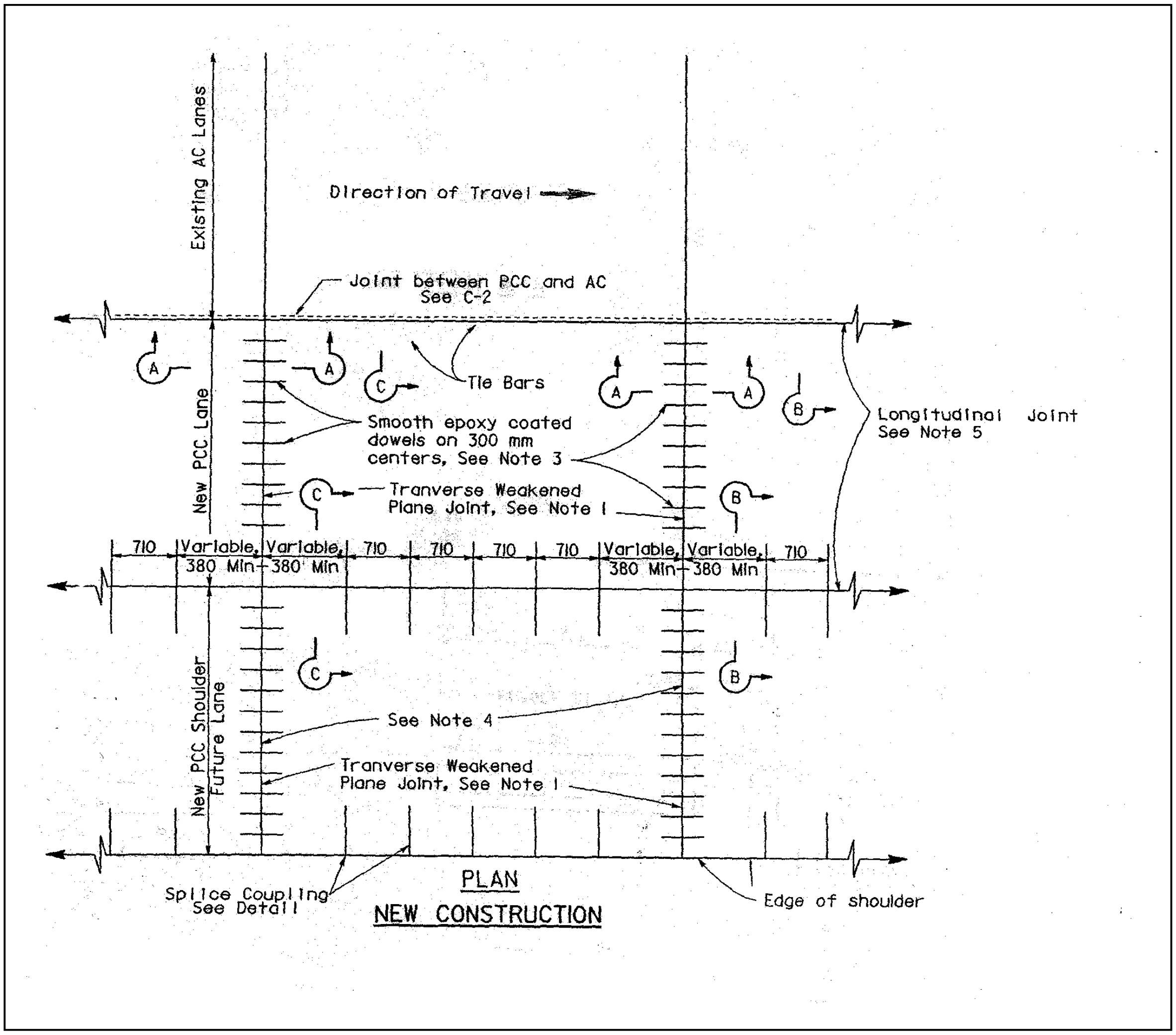

Figure 3. Pavement Construction Plan

Figures 4a – 4c show the various details associated with the longitudinal, transverse joints, and shoulder edge.

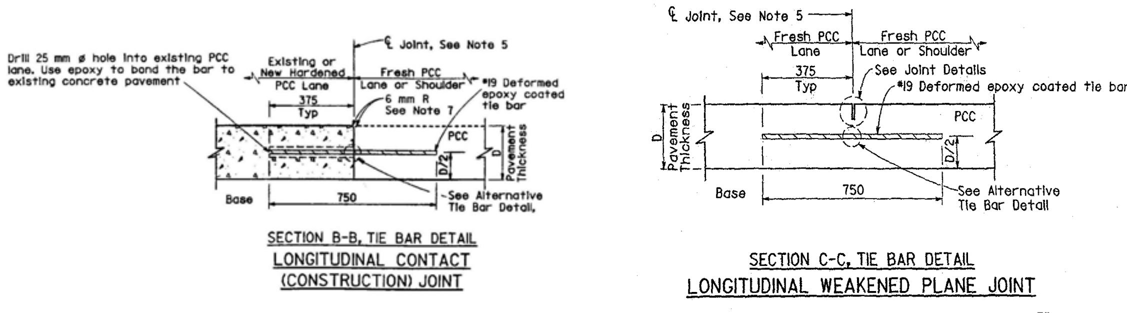

Figure 4a. Longitudinal Joint Details

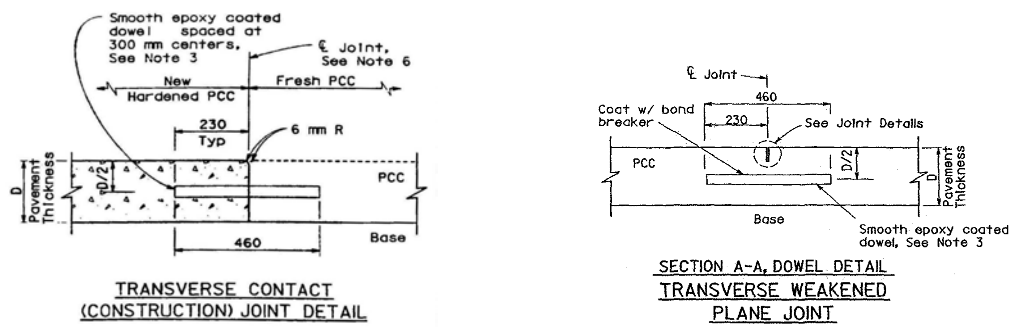

Figure 4b. Transverse Joint Details

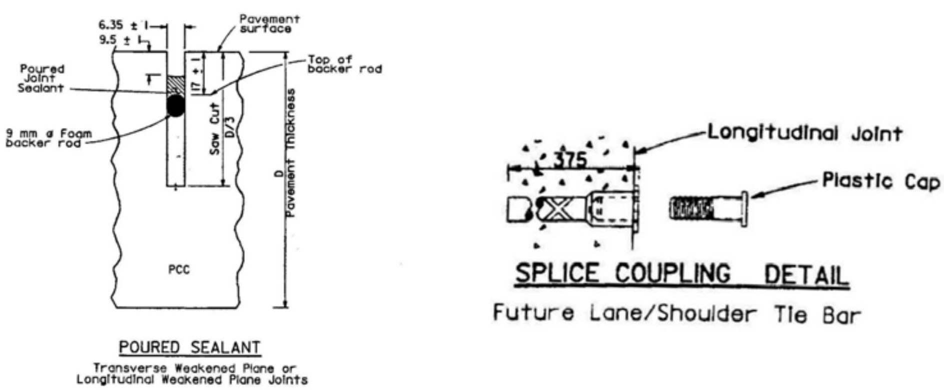

Figure 4c. Miscellaneous Joint Details

Structural Section

The structural section is portland cement concrete (PCC) on a lean concrete base (LCB) and an aggregate subbase (AS CL3). The PCC varies in thickness from 340 to 305 mm. The underlying LCB is 150-mm thick and the AS CL3 is 225-mm thick (Figure 5).

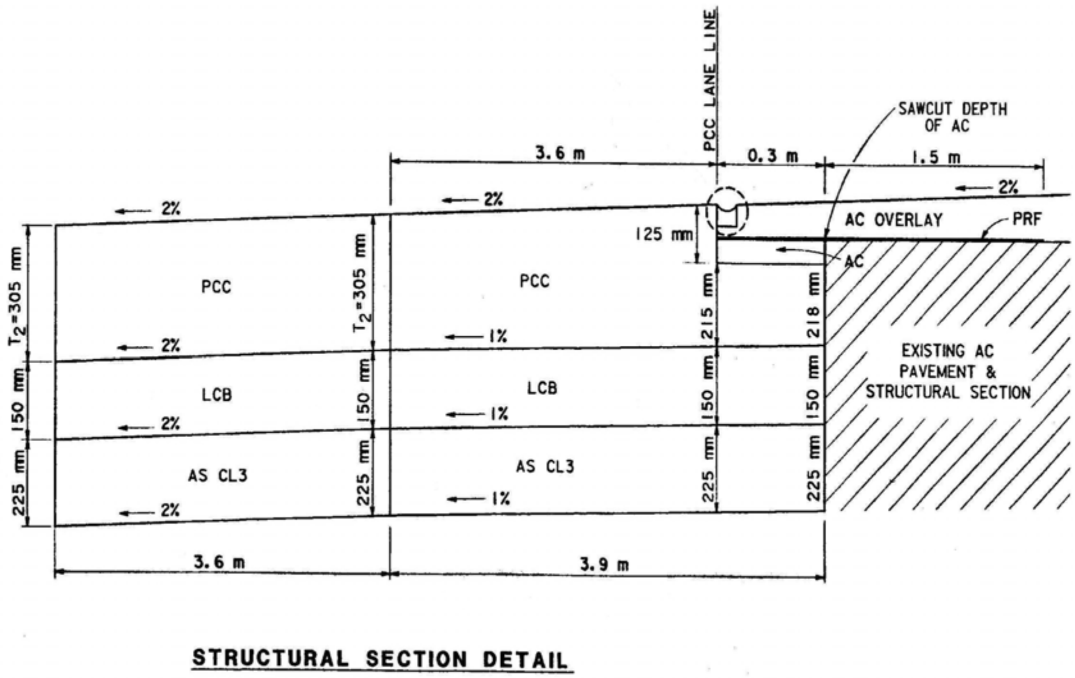

Figure 5. Pavement and Structural Section

Two coats of paraffin-based curing compound were placed on the lean concrete base. The first coat was applied immediately after placing the LCB layer. The second coat was applied prior to placing the PCC layer.

INSPECTION TEAMS

Pavement inspections were performed by:

Office of Rigid Pavement and Structural Concrete

Doran Glauz	Senior Materials & Research Engineer
Karl Smith	Maintenance Manager I
Raul Alarcon	Transportation Engineer

District 08 Materials Engineering

Bruce Kean	District Materials Engineer
Francis Carson	Materials & Research Engineering Associate

District 08 Construction - Barstow/Victorville

Joe Lopez	Senior Resident Engineer
Sue Sarkin	Project Resident Engineer
Frank Lozano	Resident Engineer

District 08 Maintenance - Barstow

John Harper	Maintenance Supervisor

Federal Highway Administration

John Klemunes	Highway Engineer
Steve Healow	Highway Engineer

OBSERVATIONS

The initial pavement inspection was performed on Monday, October 16, 2000. The inspection began at Sta. 247+36 (north end) and proceeded to Sta. 210+80. Several panels along the widened segment were examined. Core samples (100-mm ∅) were taken at various locations to evaluate the concrete.

Irregularities in the tined surface were found on many panels throughout the project, as shown in Figures 6 through 9.

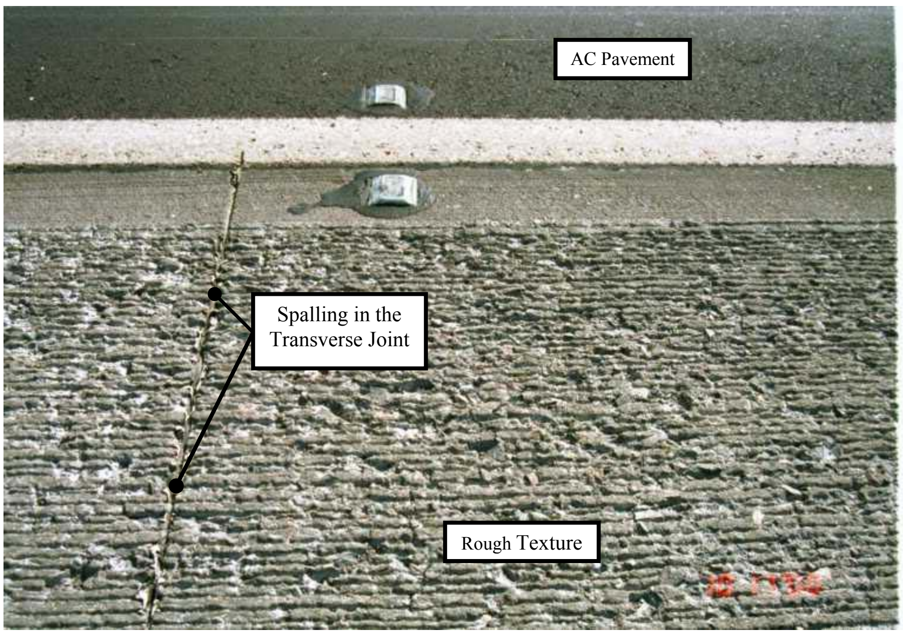

Figure 6. Exceptionally Rough Texture

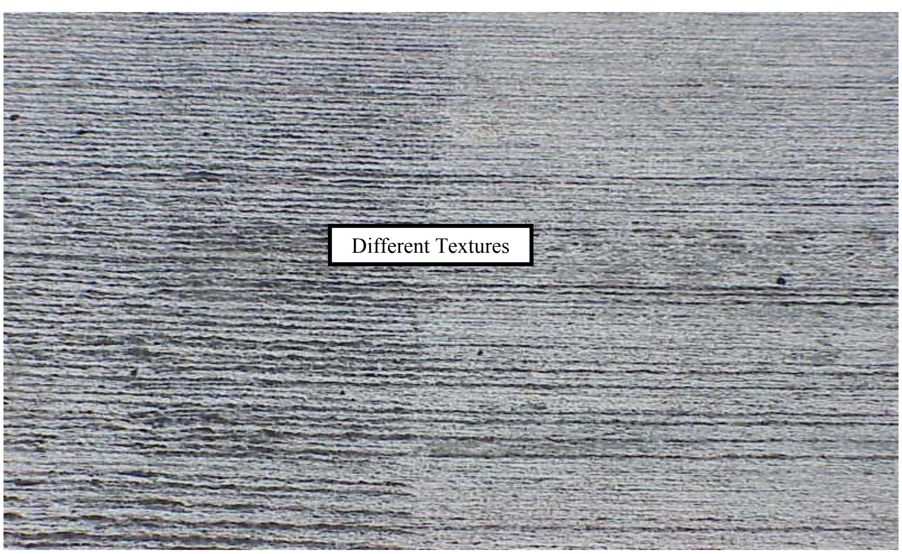

Figure 7. Overlapped Tining

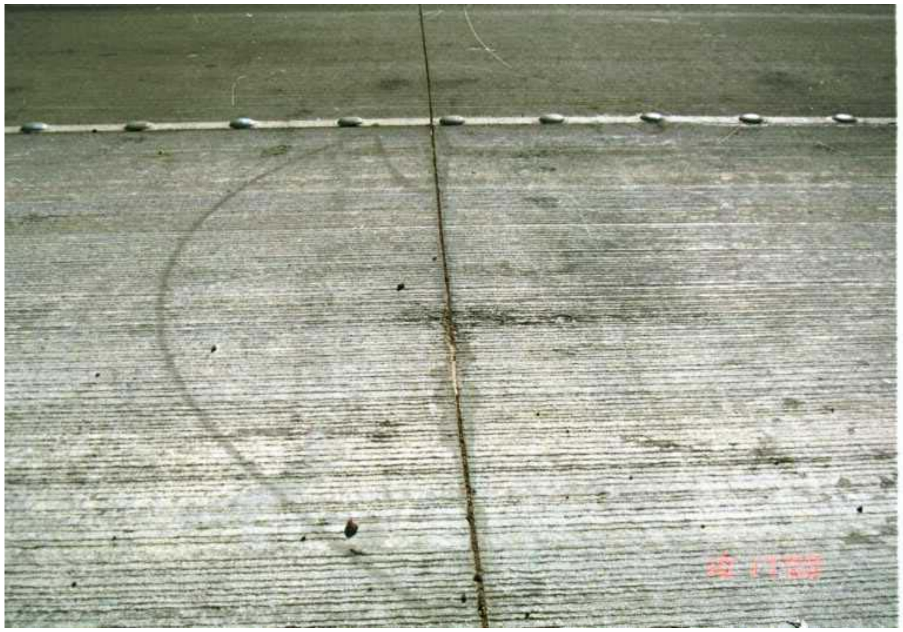

Figure 8. Surface Irregularity at a Transverse Joint

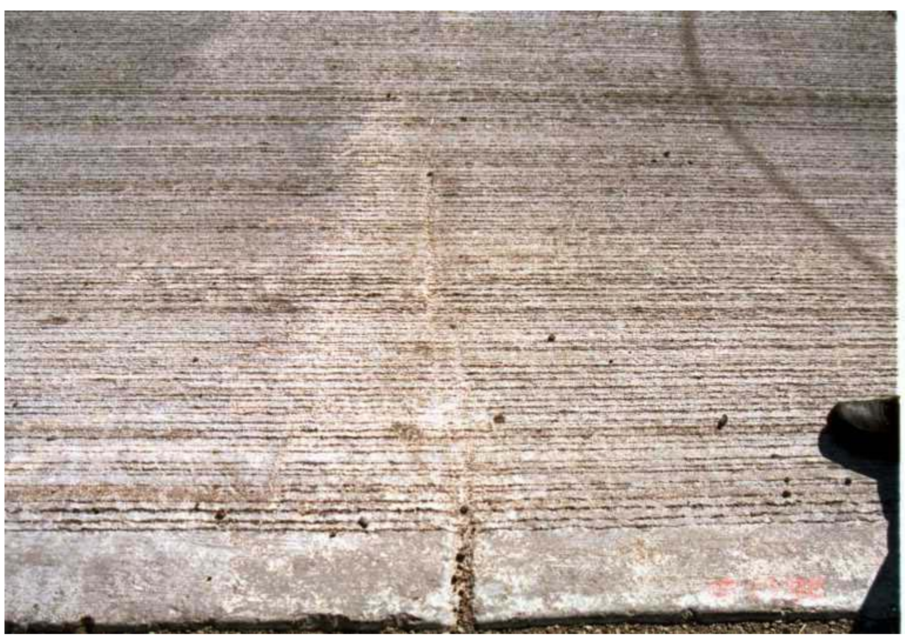

Figure 9. Surface Irregularity at the Shoulder Edge

Transverse cracks across the longitudinal joint were frequently observed. A core sample was taken over the crack to determine if it was over a tie bar and how deep it extended into the concrete (Figure 10).

The core sample revealed the crack was over a tie bar, but did not extend full depth into the pavement section. Voids can be seen above the tie bar (Figure 11).

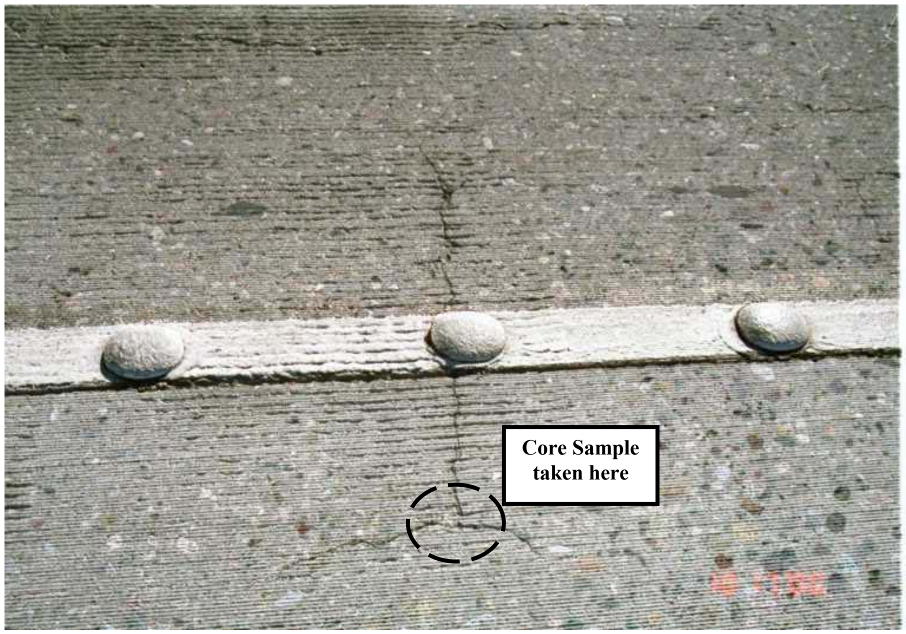

Figure 10. Crack across the Longitudinal Joint

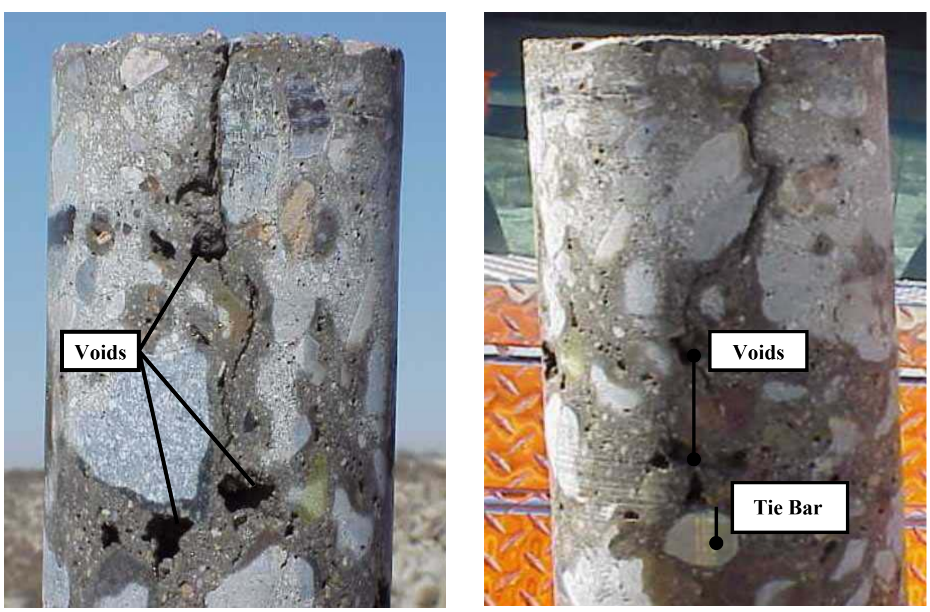

Figure 11. Core Sample

A surface flaw, shown in Figure 12, near a transverse joint created suspicion of poor consolidation. A core sample was taken to determine if the underlying concrete was poorly consolidated.

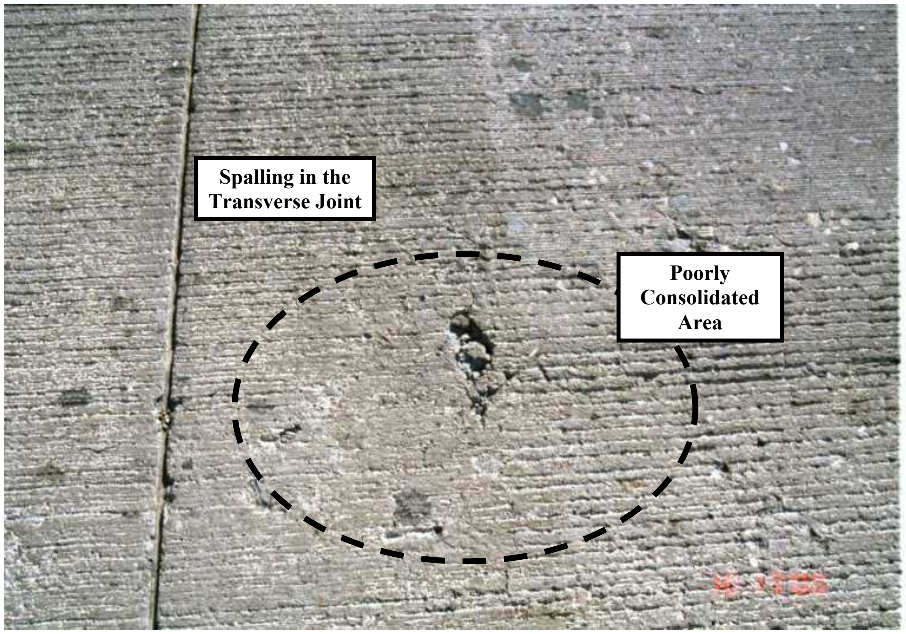

Figure 12. Suspect Surface Flaw

While coring, the sample crumbled. Coring was stopped momentarily to remove loose aggregate from the core hole (Figure 13).

Figure 13. Core Hole

The lack of cement paste on aggregate particles was evident in the remains of the core sample (Figure 14).

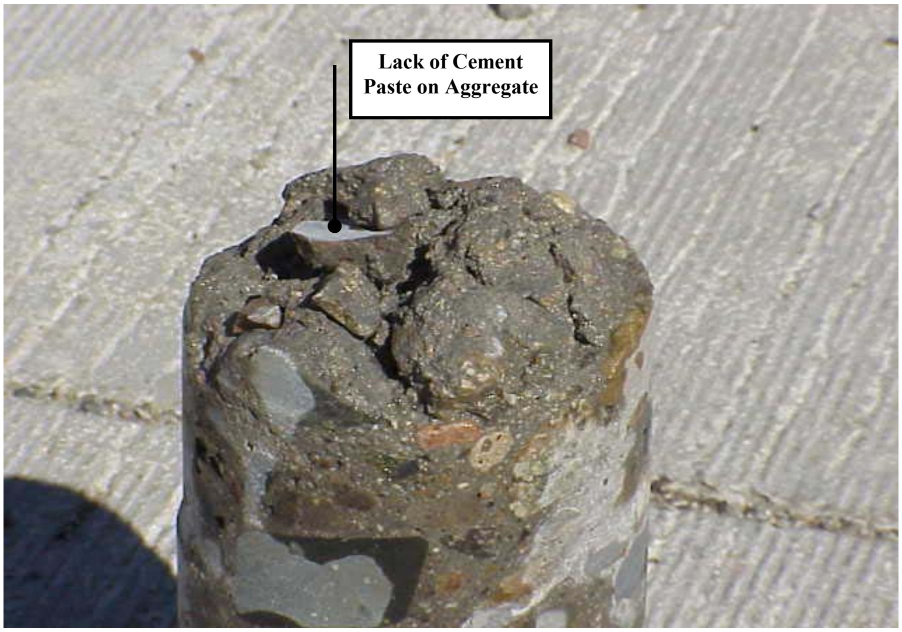

Figure 14. Remains of Core Sample

The core hole (Figure 15) revealed that the underlying concrete section was poorly consolidated. There were significant voids between coarse aggregate particles due to lack of mortar.

Figure 15. Core Hole Side

Core samples were taken at a saw-cut longitudinal joint and at a longitudinal crack about 0.5 m from the joint. Both were cored to determine which was functioning as stress relief for the pavement.

Figure 16. Core Hole - Longitudinal Joint

Figure 17. Core Hole - Longitudinal Crack

The core samples showed that neither extended full depth into the PCC layer, but the longitudinal crack did penetrate deeper than the induced crack at the saw-cut joint.

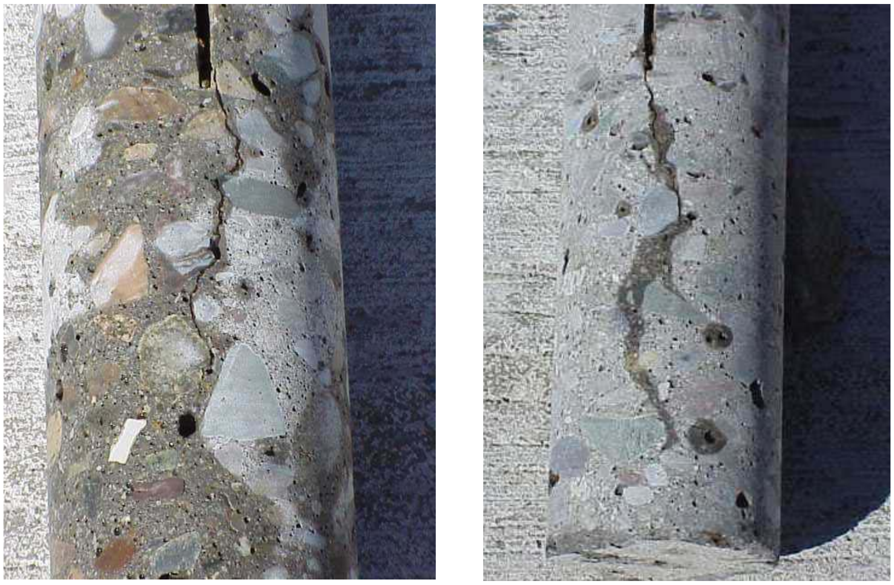

Figure 18. Core Sample - Longitudinal Joint

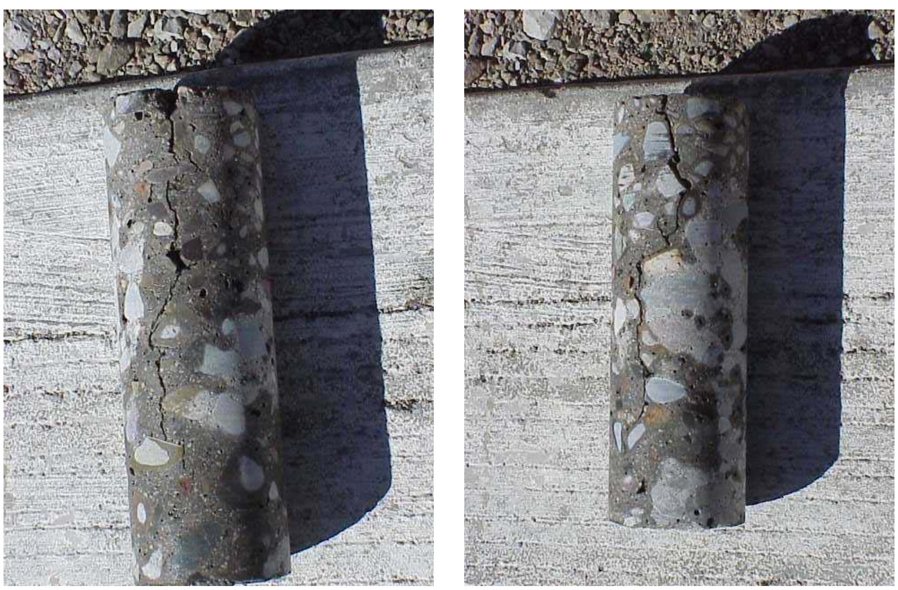

Figure 19. Core Sample - Longitudinal Crack

The panel shown is located in the truck-climbing lane at the southern end of the widened segment. Many panels in this section exhibited widespread cracking in the wheel path and across the longitudinal and transverse joints.

Figure 20. Southern End of Project

FINDINGS

Concrete Mix

A comparison of the material amounts for the approved mix design and concrete mix is shown in Table 1. At first glance, there are a number of differences in the material amounts. The water content differs by 49 kilograms (kg). The water-to-cementitious material (w/c) ratio of the mix design is 0.49 and the concrete mix is 0.35. The reduced water content tends to decrease the workability of the mix (i.e. stiffens the mix).

Table 1. Comparison of Mix Design and Concrete Mix* (per m^3)

Material	Mix Design	Concrete Mix
Portland Cement, kg	251	244
Fly Ash, kg	84	80
Coarse Aggregate, kg	1086	1110
Fine Aggregate, kg	663	708
Water Content, kg	163	114
W/C Ratio	0.49	0.35

* Based on Approved Mix Design and Quality Control Reports, dated May 10, 2000 (see Appendix A)

The water content and the w/c ratio for the concrete mix in Table 1 can be deceiving. As shown on the Quality Control Reports, the moisture contents for the 37.5-mm rock, 25-mm rock, and sand are 0.5%, 0.5%, and 5.0%, respectively. When the moisture contents are considered, the amounts for the concrete mix are revised as follows:

Table 2. Revised comparison of Mix Design and Concrete Mix (per m^3)

Material	Mix Design	Concrete Mix
Portland Cement, kg	251	244
Fly Ash, kg	84	80
Coarse Aggregate, kg	1086	1104
Fine Aggregate, kg	663	672
Water Content, kg	163	156
W/C Ratio	0.49	0.48

Upon further review of the construction documents, the following was discovered:

According to Section 10-1.31 in the Project Special Provisions, **"<u>The concrete for pavement shall contain a minimum amount of 375 kilograms of portland cement per cubic meter</u>"** [1].

Weather Conditions

The sections of pavement at the southern end of the widened segment displayed the most distress. According to the Resident Engineer, the pavement in this section was placed between May 10 and May 14. The Quality Control Reports were printed on May 10, 2000 at approximately 13:00 hr (1:00 p.m.).

Weather data recorded at the Daggett-Barstow Airport [2], approximately 20 miles north of the project site, for May 10, 2000 shows:

Table 3. Hourly Summary for May 10.

Time	12:55	13:55	14:55	15:53	16:56
Temp,°C	28.0	27.0	26.0	26.0	24.0
Dew Point, °C	3.0	-3.0	0.0	1.0	-1.0
Rel. Humidity, %	20	14	18	20	19
Wind, kph	42.6	46.3	48.2	50.0	38.9
Gusts, kph	59.3	64.8	70.4	68.5	59.3

Table 4. Daily summaries for May 3-4 and 10-14.

Date	May 3	May 4	May 5-9	May 10	May 11	May 12	May 13	May 14
Mean Temp, °C	28.1	24.4	No Data Available	22.2	15.6	16.4	21.4	29.2
Max Temp, °C	37.0	36.0		28.0	23.0	26.0	32.0	32.0
Min Temp, °C	17.0	17.0		14.0	10.0	8.0	12.0	25.0
Rel. Humidity, %	20	24		24	24	21	16	17
Avg Wind, kph	25.9	16.8		41.6	28.2	11.5	13.7	27.4
Max Wind, kph	33.3	22.2		50.0	51.9	18.5	22.2	38.9
Gusts, kph	37.0	N/A		70.4	64.8	N/A	N/A	48.2

Core Samples

Core samples, taken by the contractor, were examined and found to have numerous voids. The core shown has a large void directly above a tie bar.

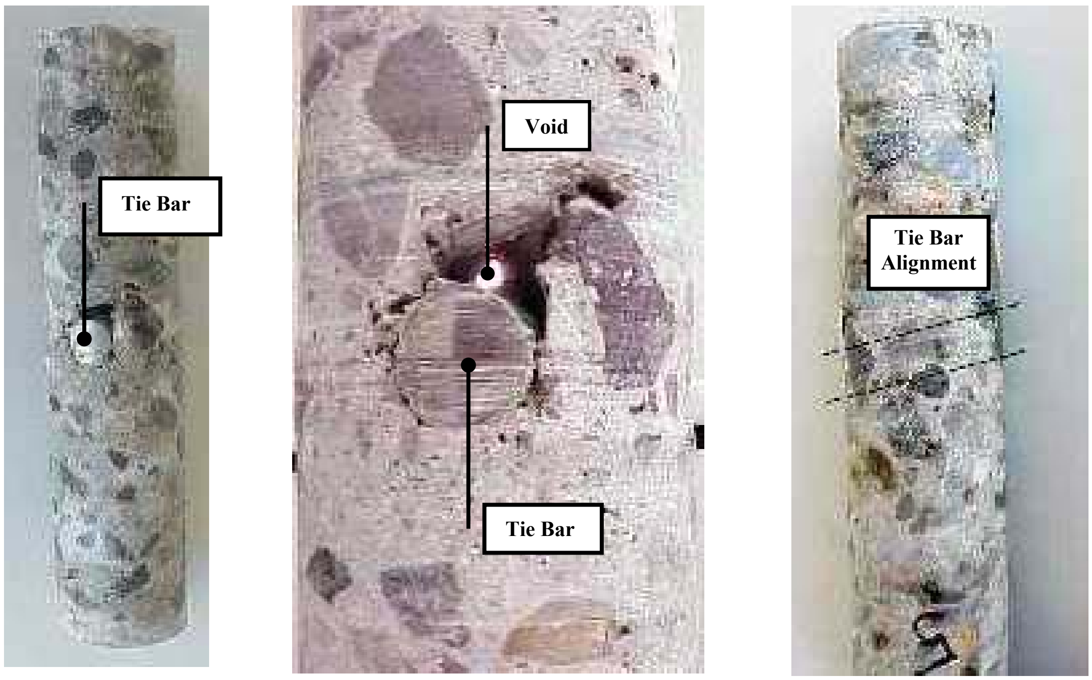

Figure 21. Core Sample, taken by Contractor

CONCLUSIONS

Concrete Mix

Neither the amount of cementitious material in the approved mix design (335 kg/m^3) nor the concrete mix (324 kg/m^3) complied with the amount specified in the project special provisions (375 kg/m^3). A subsequent Contract Change Order (CCO) or other construction document may have authorized the use of the lower amount.

The concrete mix essentially conformed to the approved mix design. The contractor opted to use a Type A water-reducing admixture in accordance with Section 90-4.05 of the Standard Specifications [3]. This was not identified on the approved mix design.

Weather Conditions

Weather data show the concrete pavement was subjected to warm temperatures, low humidity, and high velocity winds. These factors influence the rate of evaporation on the concrete surface.

According to the American Concrete Institute (ACI) Manual of Concrete Practices, "when the rate of evaporation exceeds **0.5 $kg/m^2/hr$**, measures to prevent excessive moisture loss from the surface of unhardened concrete may be needed" [4]. These measures vary from project to project, but may include the application of a curing compound, a continuous fog spray; or covering the concrete surface with burlap or cotton mats, impervious paper, or plastic sheeting.

Even when curing compound is properly applied, the moisture loss rate can still exceed 0.5 $kg/m^2/hr$.

With the assumption that the weather conditions at the project site were similar to those at the Daggett-Barstow Airport on May 10 (Table 3) and that the concrete temperature was 32°C upon delivery, the rates of evaporation can be estimated using Figure B-1:

Table 5. Rates of Evaporation and Estimated Moisture Loss Rates

Time	Rate of Evaporation w/o curing methods	Estimated Moisture Loss Rate* with curing compound
12:55	3.7 $kg/m^2/hr$	0.46 $kg/m^2/hr$
13:55	4.2 $kg/m^2/hr$	0.53 $kg/m^2/hr$
14:55	4.4 $kg/m^2/hr$	0.55 $kg/m^2/hr$
15:53	4.6 $kg/m^2/hr$	0.58 $kg/m^2/hr$
16:56	3.5 $kg/m^2/hr$	0.44 $kg/m^2/hr$

* The estimated moisture loss rate is derived from information available in Section 90-7.01B of the Standard Specifications and California Test 534 [5,6], see Appendix B.

Consolidation

Poorly consolidated concrete entraps air and forms honeycombs and rock pockets, which weaken the pavement section. The voids found in the core samples and the underlying pavement revealed the lack of consolidation in the PCC layer. Inadequate consolidation can result from poorly proportioned concrete or poor workmanship.

The cracks across the longitudinal and transverse joints are related to poor consolidation and/or finishing of the concrete around the tie bars and dowel bars. After mechanically inserting the tie bars, the disturbed concrete was not adequately reworked and refinished. The concrete placed near the dowel bar assemblies (cages) was also inadequately worked and finished.

<u>RECOMMENDATIONS</u>

Concrete Mix

The concrete produced must equal the concrete designed. The approved mix design should list the recommended amounts and/or dosages of all materials used to prepare the concrete mix, including optional materials such as Type A chemical admixtures.

Weather Conditions

Weather conditions should be monitored when placing concrete pavement. Air temperature, relative humidity, and wind speed affect moisture loss and shrinkage. Changes in temperature and atmospheric conditions have a pronounced affect on the rate of evaporation, especially if they occur simultaneously and supplement each other [7]. Typical effects of weather conditions on the rate of evaporation are:

1. If the temperature is 26.7°C (80°F), the humidity is 20%, the concrete temperature is 32°C (90°F), and the wind speed increases from 32 to 40 kph (20 to 25 mph); then the rate of evaporation increases from 2.9 to 3.5 kg/m^2/hr (0.58 to 0.7 lb/ft^2/hr).

2. If the temperature is 26.7°C (80°F), the humidity decreases from 30% to 10%, the concrete temperature is 32°C (90°F), and the wind speed is 32 kph (20 mph); then the rate of evaporation increases from 2.5 to 3.2 kg/m^2/hr (0.5 to 0.62 lb/ft^2/hr).

The use of a properly applied curing compound alone may not be sufficient to prevent excessive moisture loss. In such cases, additional measures should be taken.

Consolidation

Future specifications should address the reconsolidation and refinishing of concrete after the mechanical insertion of tie bars.

As of February 2001, the Standard Special Provision, **40-010 "CONCRETE PAVEMENT (WITH DOWELED TRANSVERSE WEAKENED PLANE JOINTS)"**, has been revised to read (under **'Installing Tie Bars'**, method 2):

"2. By inserting the tie bars into the plastic slipformed concrete before finishing the concrete. Inserted tie bars shall have full contact between the bar and the concrete. When tie bars are inserted through the pavement surface, the concrete over the tie bars shall be reworked and refinished to such an extent that there is no evidence on the surface of the completed pavement that there has been any insertion performed. Any …."

Curing Compound Application

The application rate of curing compounds should be determined and recorded in accordance with California Test 535 [8].

Protection of the Concrete Pavement

Section 40-1.12 of the Standard Specifications states:

- Concrete pavement shall be protected in conformance with the provisions in Section 90-8, "Protecting Concrete," and as specified below.
- The Contractor shall protect new pavement from damage by any cause, and any damage shall be repaired by the Contractor at the Contractor's expense.

REFERENCES

1. Project Special Provisions, Section 10-1.31 "Concrete Pavement", July 26, 1999.

2. National Oceanic and Atmospheric Administration (NOAA), National Data Center - Daggett, California.

3. Standard Specifications, Section 90-4.05 "Optional Use of Chemical Admixtures", July 1999.

4. American Concrete Institute (ACI) Manual of Concrete Practices 2000, ACI 308-92 "Standard Practice for Curing Concrete", Part 2.

5. Standard Specifications, Section 90-7.01 "Curing Compound Method", July 1999.

6. California Test 534, December 1995.

7. American Concrete Institute (ACI) Manual of Concrete Practices 2000, ACI 305R-91 "Hot Weather Concreting", Part 2.

8. California Test 535, November 1999.

POINTS OF CONTACT

Office of Rigid Pavement and Structural Concrete

Tom Pyle	Office Chief	(916) 227-7281
Ken Beede	Consultations and Investigations	(916) 227-7060
Doran Glauz	Materials & Research	(916) 227-7272
Karl Smith	Maintenance Liaison	(916) 227-7230
Raul Alarcon	Consultations and Investigations	(916) 227-7913

District 08 Materials Engineering

Bruce Kean	District Materials Engineer	(909) 383-4044
Francis Carson	Construction	(909) 383-4040

District 08 Construction - Barstow/Victorville

Joe Lopez	Senior Resident Engineer	(760) 241-9519
Sue Sarkin	Project Resident Engineer	(760) 241-2429
Frank Lozano	Resident Engineer	(760) 256-7316

District 08 Maintenance - Barstow

Armand Silva	Maintenance Superintendent	(760) 252-2314
John Harper	Maintenance Supervisor	(760) 252-2313

Federal Highway Administration

John Klemunes	No longer with FHWA	N/A
Steve Healow	California Division Office	(916) 498-5849

APPENDIX A

APPROVED MIX DESIGN
QUALITY CONTROL REPORTS

PORTLAND CEMENT CONCRETE

Cement to be added to comply w/ specs.=	0.51	
Amount of AIR to be entrained =	1.08	
Volume to be adj. by dec. H2O & fine Agg.=	1.59	
Apply 33% to H2O & 67% to Fine Agg.; resptvly =	0.52	1.06

	SSD Specific Gr.	Percent Abs.
Fine Aggregate	2.60	1.50%
1" X No.4	2.60	1.10%
1 1/2" X 3/4"	2.62	0.70%

SSD Sp. Gr. X 62.4				$\frac{Ft^3}{Yd^3}$
Absolute Volume of **CEMENT** =	423	3.15	$\frac{W}{3.15 \times 62.4}$	2.15
Absolute Volume of **POZZOLAN** =	141	2.32	$\frac{W}{2.32 \times 62.4}$	0.97
Absolute Volume of **WATER** =	275	1	$\frac{W}{1.00 \times 62.4}$	4.41
Absolute Volume of **AIR** =	5%	27	Percent x 27	1.35
			TOTAL =	**8.88**
				$\frac{Ft^3}{Yd^3}$
Absolute Volume of **AGGREGATE** =			27.00 - 8.88	18.12
FINE AGGREGATE =	38%		.38 x 18.12	6.88
1" X No.4 Agg. =	35%		.35 x 18.12	6.34
1 1/2" __ 3/4 __ Agg. =	27%		.27 x 18.12	4.89

(#4) Design For 1 Cubic Yard			$\frac{Lb}{Yd^3}$
WEIGHT OF CEMENT =			423
WEIGHT OF ADMIXTURE=			141
WEIGHT OF WATER =			275
WEIGHT OF SSD Fine Agg. =		6.88 x 2.60 x 62.4	1117
WEIGHT OF SSD 1" x No. 4 Agg. =		6.34 x 2.60 x 62.4	1029
WEIGHT OF SSD 1 1/2" x 3/4" Agg. =		4.89 x 2.62 x 62.4	800
		TOTAL =	**3784**

Abs Vol. & Des. 1 CY

Figure A-1. Approved Mix Design

Sapper Construction

Quality Control Report printed on 10-May-00 13:02:37/13:04:42

Mix ID	: 99-303PC	Ticket ID	: 167	Truck ID	:
Job ID	: 99-303	Plant ID	: Mixer #1	Batch #	: 167
Load Size	: 8.50y(6.50m)				
Water Trim:	0.75	Moist Wtr	: 67.06	Allow Wtr	: 0.00
Tgt W/C	: 0.35	Act W/C	: 0.35		

>> One or more materials adjusted manually.

Material	Target	Actual			
SAND	10103.10	10140.00 lb	(	4599.50 kg)	Moist = 5.0%
1"ROCK	8884.20	8940.00 lb	(	4055.18 kg)	Moist = 0.5%
1.5"ROCK	6902.42	6960.00 lb	(	3157.06 kg)	Moist = 0.5%
CEMENT	3417.00	3490.00 lb	(	1583.06 kg)	
FLYASH	1139.00	1143.00 lb	(	518.46 kg)	
WATER	194.31	196.00 gal	(	741.92 l)	
1AIR1000	42.50	43.00 oz	(	1271.63 ml)	Dose = x 1.0
3WRDA 64	51.00	51.00 oz	(	1508.21 ml)	Dose = x 1.0

Sapper Construction

Quality Control Report printed on 10-May-00 13:05:05/13:06:17

Mix ID	: 99-303PC	Ticket ID	: 168	Truck ID	:
Job ID	: 99-303	Plant ID	: Mixer #1	Batch #	: 168
Load Size	: 8.50y(6.50m)				
Water Trim:	0.75	Moist Wtr	: 67.06	Allow Wtr	: 0.00
Tgt W/C	: 0.35	Act W/C	: 0.35		

>> One or more materials adjusted manually.

Material	Target	Actual			
SAND	10103.10	10180.00 lb	(	4617.65 kg)	Moist = 5.0%
1"ROCK	8884.20	8920.00 lb	(	4046.11 kg)	Moist = 0.5%
1.5"ROCK	6902.42	6920.00 lb	(	3138.91 kg)	Moist = 0.5%
CEMENT	3417.00	3410.00 lb	(	1546.78 kg)	
FLYASH	1139.00	1152.00 lb	(	522.55 kg)	
WATER	194.31	195.00 gal	(	738.13 l)	
1AIR1000	42.50	43.00 oz	(	1271.63 ml)	Dose = x 1.0
3WRDA 64	51.00	51.00 oz	(	1508.21 ml)	Dose = x 1.0

Figure A-2. Quality Control Reports - May 10, 2000

APPENDIX B

RATE OF EVAPORATION
ESTIMATED MOISTURE LOSS RATE

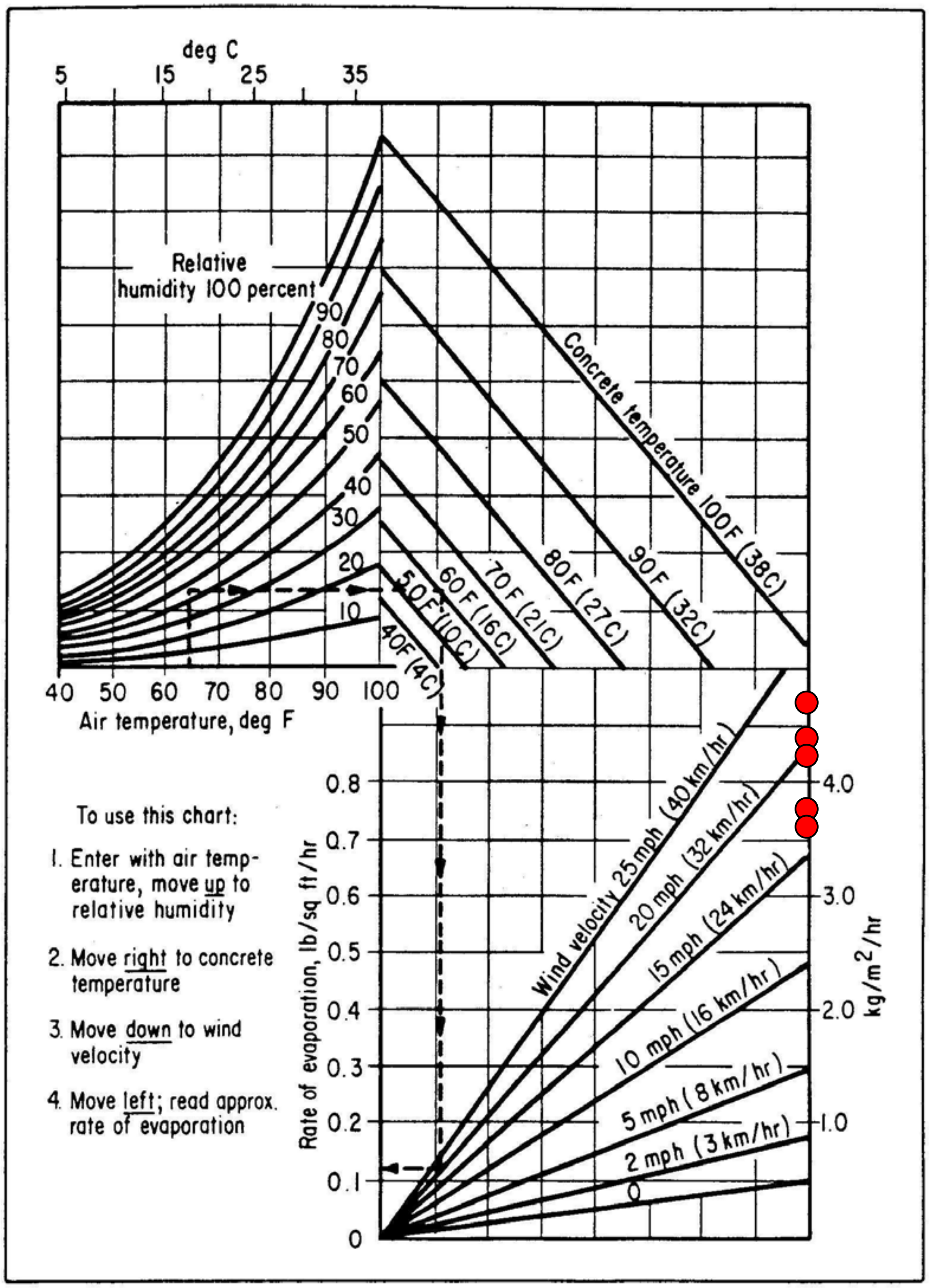

Figure B-1. Rate of Evaporation [4]

Estimated Moisture Loss Rate with Curing Compound

Test Conditions: *(California Test 534)*

Air Temperature =	38°C (100°F)
Relative Humidity =	30%
Mortar Temperature =	23°C (72°F)
Wind Speed =	0 kph (0 mph)

Rate of Evaporation, E_R = 0.05 kg/m^2/hr (0.01 lb/ft^2/hr)
(from Figure B-1)

Specification Limit: *(Section 90-7.01B)*

Moisture Loss, *ML* =	0.15 kg/m^2/24 hr (0.03 lb/ft^2/24 hr)
Moisture Loss Rate, *MLR* =	0.063 kg/m^2/hr (0.0013 lb/ft^2/hr)

Reduction Factor due to Curing Compound:

$$\text{Reduction Factor, } R_F = \frac{E_R}{MLR} = \frac{0.050\ \text{kg/m}^2\text{/hr}}{0.0063\ \text{kg/m}^2\text{/hr}} = 8$$

Field Conditions: *(from Table 3)*

Air Temperature =	28°C (82°F)
Relative Humidity =	20%
Concrete Temperature =	32°C (90°F)
Wind Speed =	42 kph (26.6 mph)

Rate of Evaporation, E_R = 3.70 kg/m^2/hr (0.74 lb/ft^2/hr)
(from Figure B-1)

Estimated Moisture Loss Rate, *MLR*, with curing compound:

$$MLR = \frac{E_R}{R_F} = \frac{3.70\ \text{kg/m}^2\text{/hr}}{8} = 0.46\ \text{kg/m}^2\text{/hr}\ \ (0.092\ \text{lb/ft}^2\text{/hr})$$