STATE OF CALIFORNIA
DEPARTMENT of TRANSPORTATION

DIVISION OF
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MATERIALS ENGINEERING
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EVALUATING LOAD TRANSFER RESTORATION

DISTRICT 1
Mendocino County
Route 101 – North Bound

DISTRICT 3
Placer County
Route 80 – West Bound

July 2002

EVALUATING
LOAD TRANSFER
RESTORATION
Districts 1 and 3

This report reflects the observations, findings, conclusions, and recommendations of the authors.

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

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Cover Photo: FWD testing on westbound I-80 near Colfax

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INTRODUCTION

Since 1950, concrete pavements in California have been constructed without dowel bars in the transverse joints. Consequently, aggregate interlock has been the primary mechanism for load transfer across adjacent slabs. As these pavements age and are subjected to repetitive heavy loads, aggregate interlock is diminished and load transfer decreases. This causes the slabs to act independently of one another resulting in step faulting, transverse cracks, corner breaks, pumping and other distresses.

Load transfer restoration is a rehabilitation strategy for increasing the load transfer capability and extending the service life of concrete pavements [1]. The most common technique for restoring load transfer is dowel bar retrofit (DBR), which involves the installation of dowel bars across the transverse joints or cracks of the existing pavement.

Recently, Caltrans has moved towards using DBR to rehabilitate pavements throughout the state. Extensive DBR projects have been constructed in Districts 6, 7, and 12.

To evaluate the effectiveness of DBR, a test site on Route 80 near Colfax in Placer County was constructed in October 1998 (Figure 1). Several panels were retrofitted with dowel bars. Load transfer testing has been conducted on a continuing basis to monitor performance. Recent counts show that this site is subjected to an Annual Average Daily Traffic (AADT) of 30,000.

Another test site, located on Route 101 near Ukiah in Mendocino County, was constructed in January 2001. Several tests, including load transfer, were conducted by the University of California, Berkeley. This site has a recent AADT count of 23,000.

These sites were chosen primarily because the pavement exhibited low load transfer across transverse joints/cracks.

This report evaluates the DBR performance at each site based on the test data and other information collected.

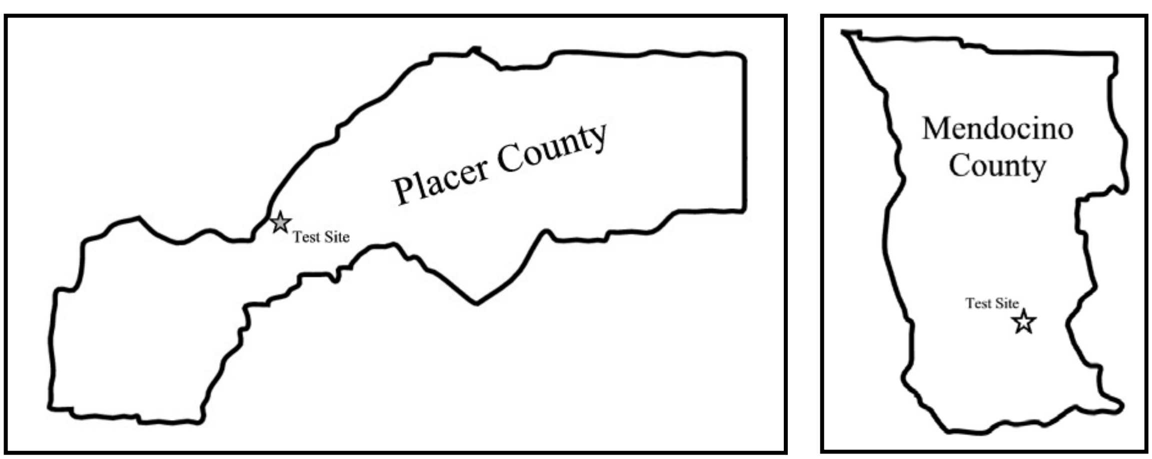


Figure 1. Test Site Locations

COLFAX TEST SITE

Originally constructed around 1960, the existing roadway of westbound I-80 near Colfax is concrete pavement with an asphalt concrete shoulder (Figure 2), and has required only minor maintenance; mainly spall repairs, crack sealing and occasional panel replacements [2]. It is at an elevation of about 1,067 m (3500 ft) in a mountainous area where winter snowfalls often require vehicular traffic to have snow chains, contributing to the wear and tear of pavement.

Figure 2. Route 80 - WestBound

The test site is a 300-m (1,000-ft) long segment in lane 2, extending from PM 33.75 to PM 33.94. It is composed of 68 continuous concrete panels including two sections where the panels have been retrofitted with dowel bars [2]. Roadside markers indicate the start and end of each retrofitted section (Figure 3).

Figure 3. Test Section Markers

CONSTRUCTION

Construction of the test site took place on October 6, 1998. The Penhall Company performed the DBR (Figure 4). A total of six dowel bars were placed at each retrofitted joint, three each in the inner and outer wheel paths.

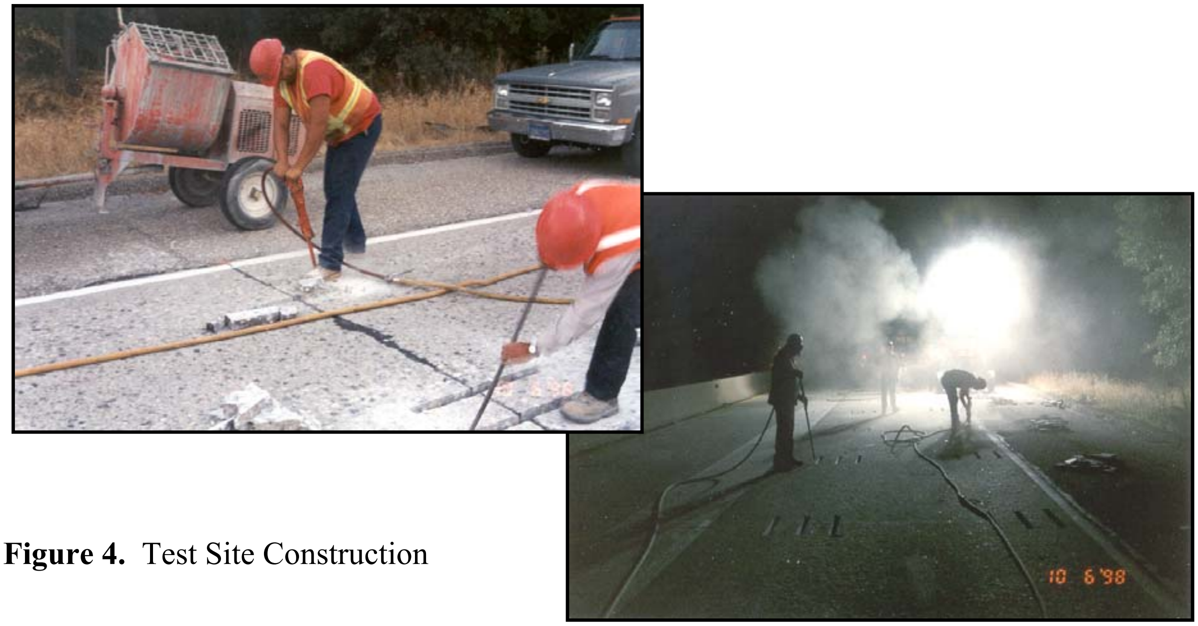


Figure 4. Test Site Construction

Dowel bars were installed by saw-cutting slots parallel to the direction of traffic in the existing pavement (Figure 5). A dowel bar with chair supports, expansion caps, and a foam board insert and was placed in each slot. The slots were then backfilled with Fosroc/Patchroc 10-60 (now known as Thoroc 10-60), a fast setting grout.

Figure 5. Dowel Bar Installation

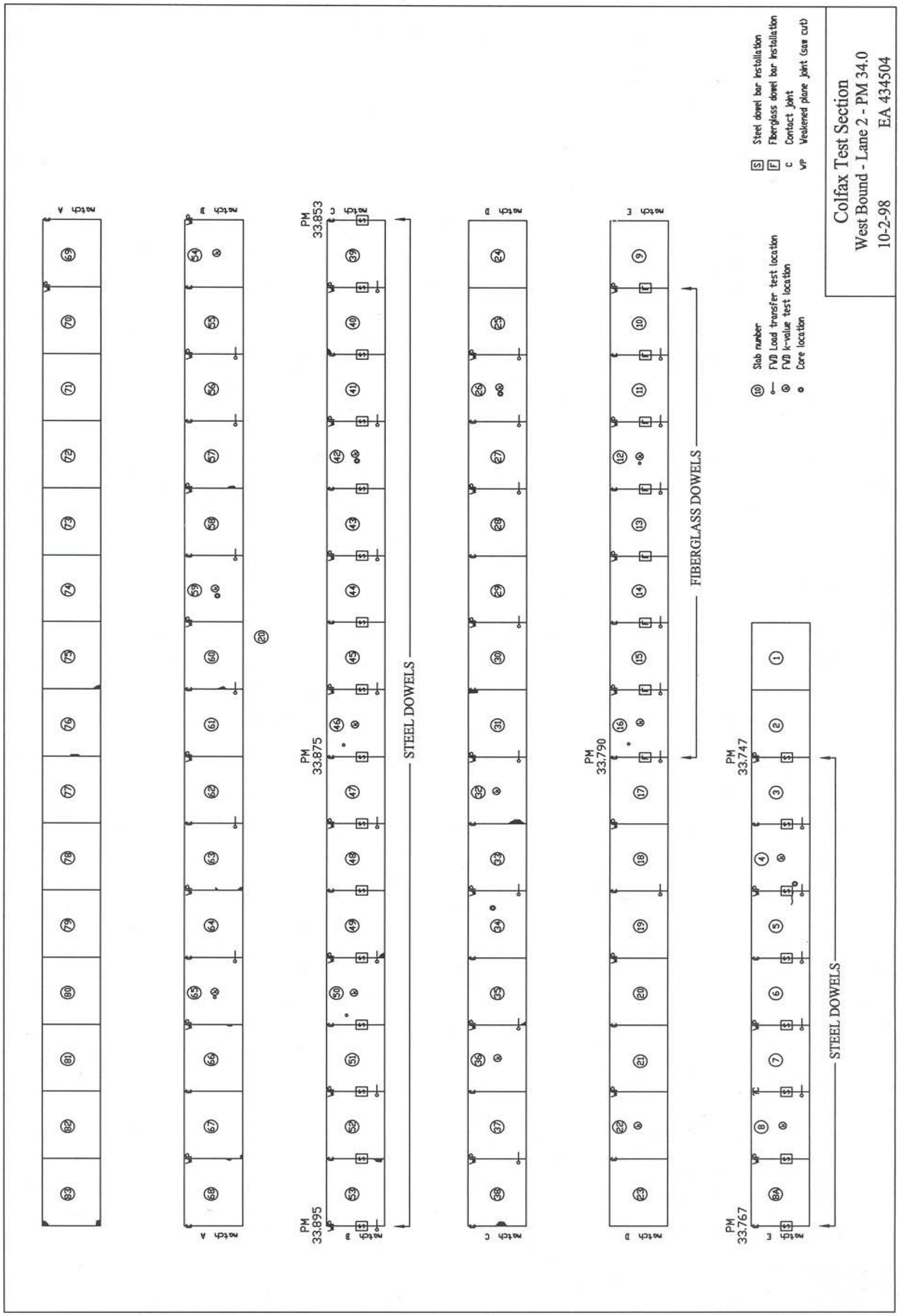


Figure 6. Colfax Test Site - Plan Layout

Figure 6 is a plan layout of the test site showing test sections and numbered panels. Two types of dowel bars were installed in the designated sections of the test site. Epoxy-coated steel dowel bars were placed in panels 3 through 8A (8 joints total), and also panels 39 through 53 (22 joints total). Fiberglass dowel bars were placed in panels 9 through 16 (8 joints total).

In addition to the DBR, fractured panels were removed and replaced. The entire test site was diamond ground to level and smooth the pavement surface and improve ride quality.

TESTING

Load transfer is the shifting of an applied load across a joint or crack through shear action. The Falling Weight Deflectometer (FWD) is the preferred method for measuring load transfer across joints or cracks in pavements. The FWD can apply a simulated truck wheel load in the outer wheel path on either side of a joint or crack and measure deflections on both sides. Applied loads, deflections, and pavement temperature are measured by sensors and recorded by computer [1] (Figure 7).

Figure 7. FWD Measurement

On March 25, 1999, almost 5 months after the test site was open to traffic, FWD measurements were taken again. The pavement temperature was recorded at 12ºC (54ºF). Core samples were taken at retrofit installations to determine pavement thickness and to verify the positioning and alignment of the dowel bars in the slots. The pavement was found to be 180mm (7 in) thick.

On March 27, 2001 and March 14, 2002, FWD measurements were again taken at the transverse joints. Pavement temperatures were recorded at 23ºC (73ºF) and 18ºC (65ºF), respectively.

PERFORMANCE

Results from the FWD tests show that the average load transfer in the joints with steel dowels improved from 30 % (before the DBR) to 82% or better (Table 1). The joints with fiberglass dowels improved from 15 % to 69% or better.

Table 1. Colfax Test Site - Average Load Transfer

FWD Test	Average Load Transfer Efficiency, %				Average Pavement Temperature, °C
	Test Site	Joints w/ Steel Dowels	Joints w/ Fiberglass Dowels	Undoweled Joints	
1998*	30	30	15	37	N/A
1999	58	82	71	41	12
2001	--	--	--	--	23
2002	77	86	69	73	18

* Before Dowel Bar Retrofit N/A - Not Available

At warmer temperatures, load transfer increased. Load transfer for undoweled joints was slightly greater than that of the joints with fiberglass dowels. At cooler temperatures, load transfer decreased, particularly in the undoweled joints. Load transfer in the retrofitted joints was minimally affected by the change in pavement temperature.

The March 2001 data was inconclusive because several inconsistencies were found in the deflection measurements.

A pavement inspection on March 27, 2001, revealed the pavement is in good condition, a few panels have third stage cracking and a number of transverse joints were spalled (Figure 8). The retrofit installations are in very good condition. The backfill grout remains intact and shows no signs of bond failure or cracking.

Figure 8. Pavement Condition - March 2001

Figure 9 is graph representation of the load transfer values at each joint. Values in are listed in Appendix A.

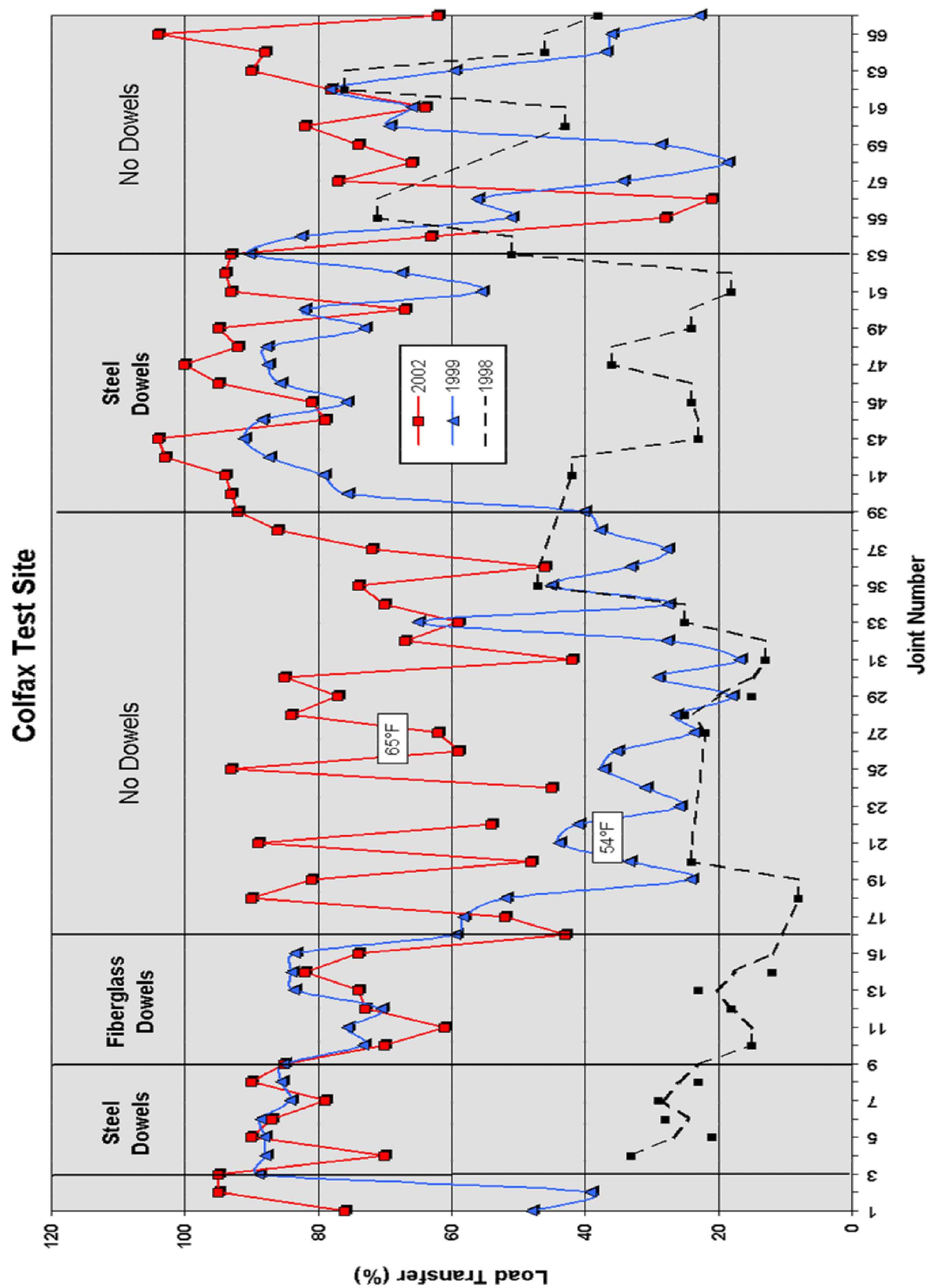


Figure 9.

UKIAH TEST SITE

Originally constructed in 1967, the existing roadway of northbound US-101 near Ukiah consists of concrete pavement, lanes 1 and 2, and an asphalt concrete shoulder (Figure 10). The concrete pavement is on a cement-treated base, has skewed joints and no dowels, and is approximately 200-mm (8-in) thick.

Figure 10. Route 101 – North Bound

The test site is a 179-m (587-ft) long segment in lane 2. The limits for the test site extend from post-mile (PM) 29.62 to PM 29.73 (Figure 11).

Figure 11. Test Site

DESIGN/CONSTRUCTION

The design of the test site was a coordinated effort between the California Department of Transportation (Caltrans), Washington State Department of Transportation (WSDOT) and the University of California, Berkeley (UC-Berkeley). Test site specifications were derived from Caltrans, District 7 and WSDOT specifications [3].

The test site was constructed in late January 2001. The Penhall Company performed the DBR under the guidance of Caltrans, WSDOT, UC-Berkeley, and Dynatest Consulting, Inc. The test site is comprised of 50 continuous concrete panels. Epoxy-coated steel dowel bars were installed in the transverse joints or cracks of panels 9, 16, 21, and 34 (8 joints/cracks total). A total of 8 dowel bars were placed at each retrofitted joint/crack, four each in the inner and outer wheel paths.

UC-Berkeley set up 6 sections where other testing was performed. The sections have been designated as 553(HVS), 553(LT), 554(HVS), 554(LT), 555(HVS), and 555(LT). HVS sections were subjected to testing with the Heavy Vehicle Simulator. LT sections were subjected to live traffic testing. Each section is identified by paint markings on the pavement (Figure 12). UC-Berkeley is currently preparing a report detailing the tests conducted at these sections.

Figure 12. UC Berkeley Test Section

Figure 13 is a plan layout of the site showing the test sections, retrofitted panels, and the numbering sequence of the joints/cracks and panels.

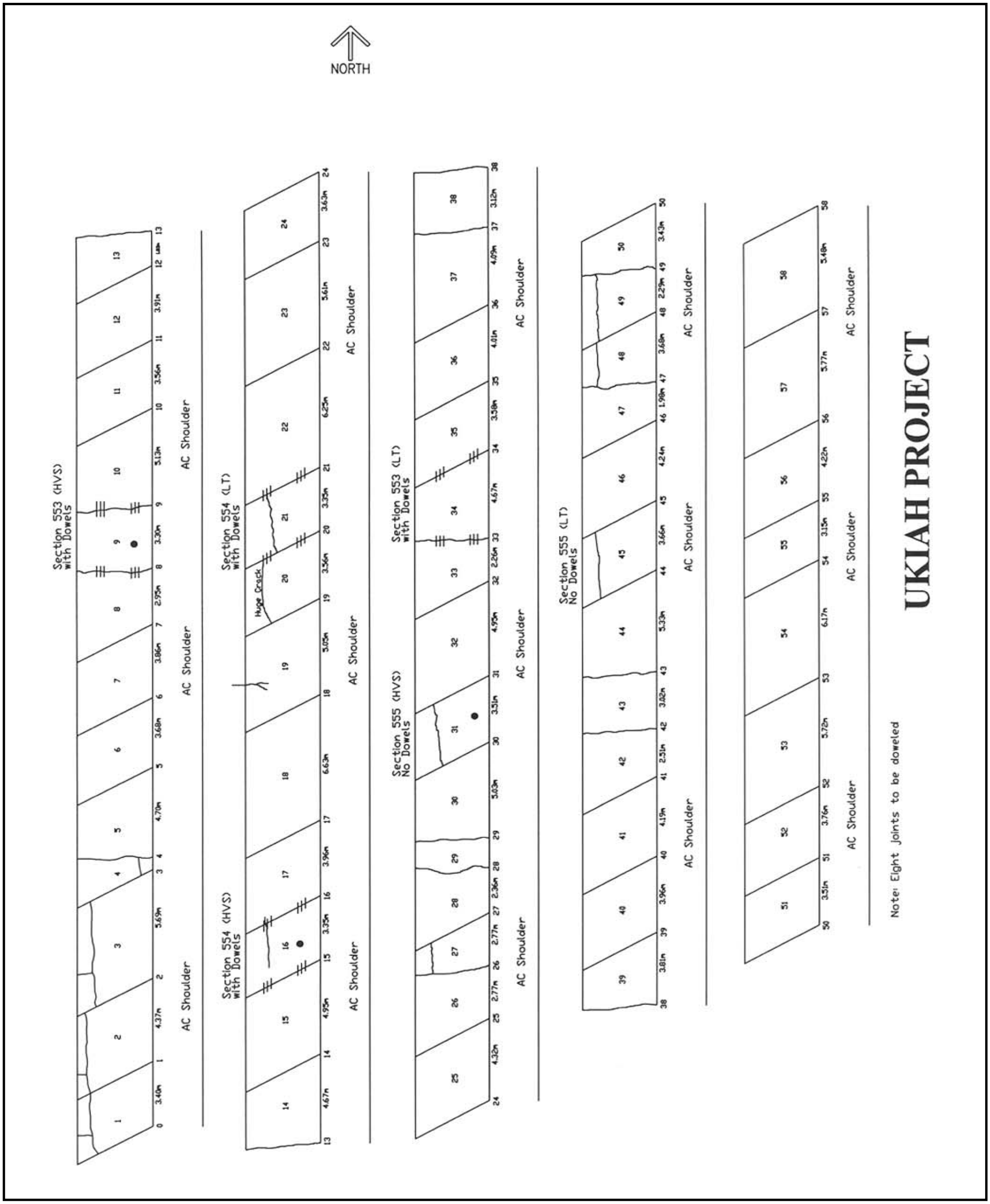


Figure 13. Ukiah Test Site - Plan Layout

TESTING

In January 2001, prior to construction of the test site, UC-Berkeley performed FWD testing across each transverse joints/cracks within the test site to record initial load transfer values (Figure 14). The average daytime air temperature was recorded at 8°C (46°F) and the average pavement temperature was 10°C (50°F). FWD tests were performed twice within a 24-hour period (day and night) at applied loads of 44.5, 67, and 89 kN (10, 15, and 20 kips).

Figure 14. FWD Measurement.

In February 2001, after the DBR and before HVS testing, FWD measurements were taken again at every transverse joint throughout the test site. The average daytime air temperature was 21°C (70°F) and pavement temperature was 21°C (70°F).

In May 2001, after HVS testing, FWD measurements were again taken at the transverse joints. Average daytime air temperature was recorded at 22°C (72°F) and the average pavement temperature was 31°C (87°F).

Caltrans performed FWD testing across the transverse joints in October 2001. FWD tests were performed at applied loads of 40 and 71 kN (9 and 16 kips). The average daytime air temperature was 15°C (60°F) and the pavement temperature was 17°C (63°F).

PERFORMANCE

Results from the FWD tests indicate that the average load transfer in the retrofitted joints/ cracks improved significantly from 49.2 % (before the DBR) to 85.3% or better (Table 1) .

Table 2. Ukiah Test Site - Average Load Transfer

FWD Test	Average Load Transfer, %			Average Pavement Temperature, °C
	Test Site	Retrofitted Joints/Cracks	Undoweled Joints/Cracks	
Before DBR[1]	40.5	49.2	39.7	10
After DBR[1]	85.5	90.0	83.9	21
After HVS[1]	96.1	96.8	95.9	31
Caltrans[2]	58.1	85.3	51.3	17

[1] Applied Load of 67 kN (15 kips)
[2] Applied Load of 71 kN (16 kips)

Again at higher pavement temperatures, load transfer increased throughout the test site. At lower temperatures, load transfer decreased, particularly in the undoweled joints/cracks. Load transfer in the retrofitted joints/cracks was minimally affected by the change in pavement temperature.

A pavement inspection in October 2001 revealed the retrofit installations remain intact, even after 10 months of service. The backfill grout shows no signs of bond failure, cracking, or other deterioration (Figure 15).

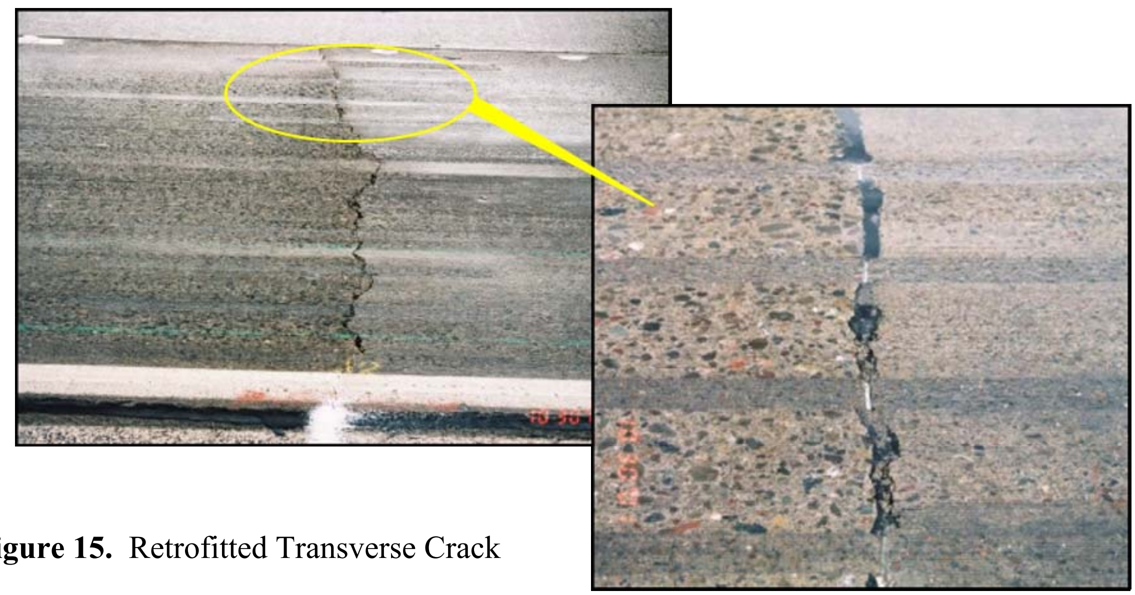


Figure 15. Retrofitted Transverse Crack

Figure 16 is graph representation of the load transfer values for each joint/crack in test section. These values are listed in Appendix A.

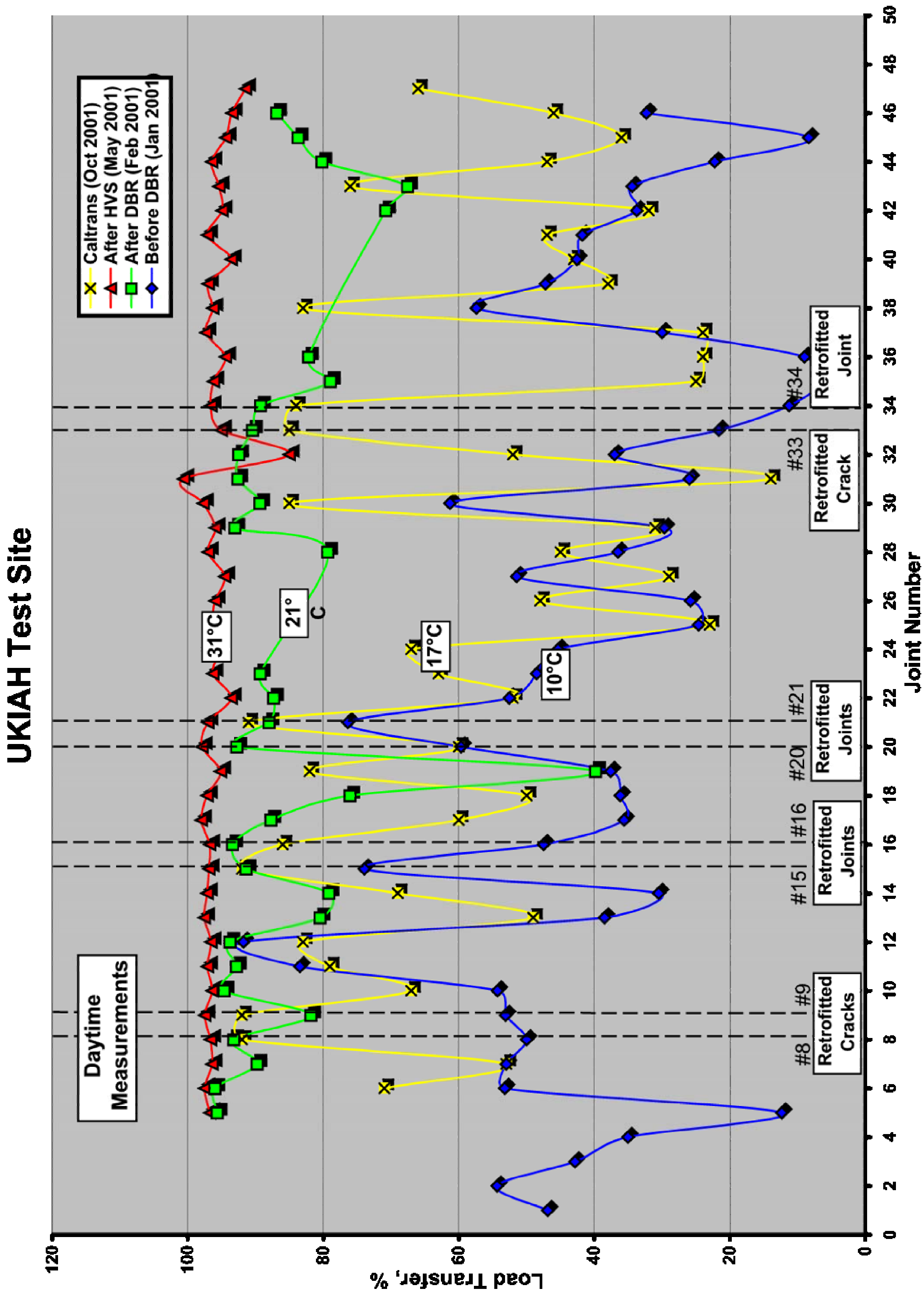

UKIAH Test Site
Daytime Measurements
Caltrans (Oct 2001)
After HVS (May 2001)
After DBR (Feb 2001)
Before DBR (Jan 2001)
31°C
21°C
17°C
10°C
#8
#9
Retrofitted Cracks
#15
#16
Retrofitted Joints
#20
#21
Retrofitted Joints
#33
Retrofitted Crack
#34
Retrofitted Joint
Load Transfer, %
Joint Number
0
20
40
60
80
100
120
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50

Figure 16.

CONCLUSIONS

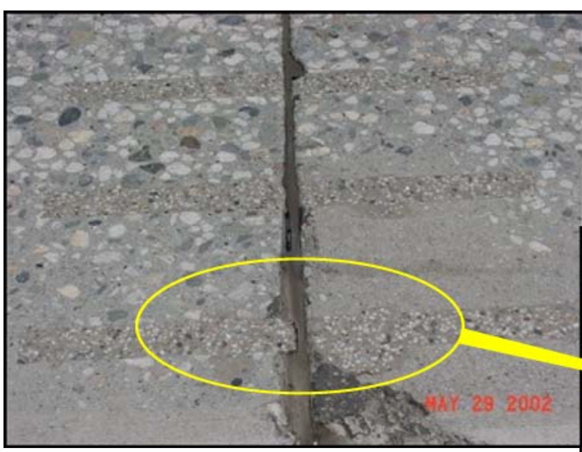
Significant improvements in load transfer have resulted from the retrofit installations at both test sites. The data indicates that DBR has performed well and have effectively restored load transfer.

At Colfax, the load transfer before the DBR was 30% on average for the test site. The two types of dowel bars have improved load transfer in the retrofitted joints, even after 3½ years of service. The joints with steel dowels showed the most improvement, increasing to an average of 86%. The joints with fiberglass dowels improved to an average of 69%.

At the Ukiah, the initial load transfer for the test site was 40% on average. After 10 months of service, dowel bars have improved load transfer to an average of 85% or better in the retrofitted joints/cracks.

At both test sites, pavement temperature demonstrated how it affects load transfer. In warmer temperatures, the panels expanded and increased load transfer. Values for undoweled joints were similar to those of the doweled joints. In cooler temperatures however, load transfer decreased, particularly in the undoweled joints, and illustrated the benefit of the DBR. Temperature changes had a minimal effect on the retrofitted joints; load transfer remained above 60%.

The backfill grout used in the retrofit installations remains intact. The material shows no signs of bond failure, cracking, or other deterioration. The grout seems unaffected by the distresses occurring in the existing pavement (Figure 17).



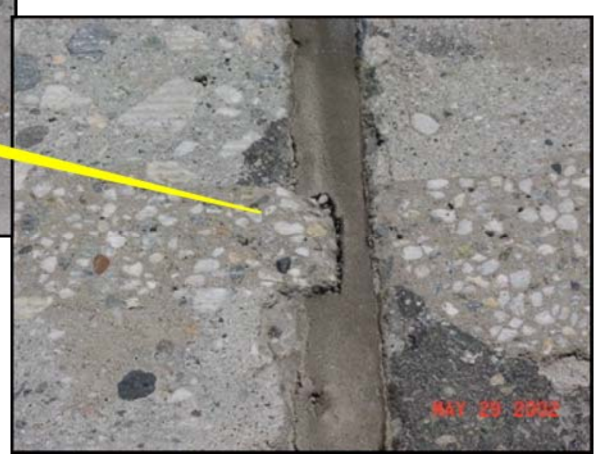


Figure 17. Backfill grout unaffected by joint spalling

RECOMMENDATIONS

Concrete pavements exhibiting an average load transfer of 60% or less should be considered as candidates for load transfer restoration. The test sites have shown that DBR has the ability to improve load transfer.

Evaluations of the DBR installations should be done yearly. Long-term performance data is needed to continue assessing the effectiveness of this rehabilitation technique for extending the service life of concrete pavement. Data collection should be performed during the same time of the year under similar weather conditions by an experienced crew and, if possible, the same FWD equipment. The data could provide valuable information for refining DBR installation and inspection guidelines. Currently, the only long-term data available is from the Colfax test site.

Additional test sites should be constructed in different locations throughout the state. These sites would allow for the opportunity to consider and evaluate other types of dowel bars and backfill material under different traffic and weather conditions.

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3. University of California - Berkeley, "Dowel Bar Rehabilitation of Rigid Pavements", Draft Report, November 2000.

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APPENDIX A

Load Transfer Efficiency Data

Table A1. FWD Date - Colfax Test Site

Joint Number	Load Transfer, %			
	1998*	**1999**	**2001**	**2002****
0/1	-	48		76
1/2	-	39		95
2/3	-	89		95
3/4	33	88		70
4/5	21	88		90
5/6	28	89		87
6/7	29	84		79
7/8	23	86		90
8/8A	-	85		85
8A/9	15	73		70
9/10	-	76		61
10/11	18	71		73
11/12	23	84		74
12/13	12	84		82
13/14	-	84		74
14/15	-	59		43
15/16	-	58		52
16/17	8	52		90
17/18	-	24		81
18/19	24	33		48
19/20	-	44		89
20/21	-	41		54
21/22	-	26		158
22/23	-	31		45
23/24	-	37		93
24/25	-	35		59
25/26	22	24		62
26/27	25	26		84
27/28	15	18		77
28/29	-	29		85
29/30	13	17		42
30/31	-	28		67
31/32	25	65		59
32/33	-	28		70
33/34	47	45		74
34/35	-	33		46
35/36	-	28		72
36/37	-	38		86
37/38	-	40		92
38/39	-	76		93
39/40	42	79		94
40/41	-	87		103
41/42	23	91		104
42/43	-	88		79
43/44	24	76		81
44/45	-	86		95
45/46	36	88		100
46/47	-	88		92
47/48	24	73		95

Table A1. FWD Date - Colfax Test Site (continued)

Joint Number	Load Transfer, %			
	1998*	**1999**		**2002****
48/49	-	82		67
49/50	18	56		93
50/51	-	68		94
51/52	51	90		93
52/53	-	83		63
53/54	71	51		28
54/55	-	56		21
55/56	-	34		77
56/57	-	19		66
57/58	-	29		74
58/59	43	69		82
59/60	-	66		64
60/61	76	78		78
61/62	-	60		90
62/63	46	37		88
63/64	-	36		104
64/65	38	23		62

Table A2. FWD Date - Ukiah Test Site

Joint Number	Load Transfer Efficiency , %			
	Before DBR	After DBR	After HVS	Caltrans
1	46.8			
2	54.3			
3	42.9			
4	35.0			
5	12.3	95.6	96.7	
6	53.2	95.9	97.5	71
7	53.0	89.7	96.4	53
8	50.0	93.2	96.6	92
9	53.1	81.8	97.5	92
10	54.3	94.6	96.4	67
11	83.4	92.8	97.1	79
12	91.8	93.7	96.6	83
13	38.5	80.4	97.5	49
14	30.5	79.2	97.1	69
15	73.9	91.4	96.8	92
16	47.5	93.3	96.7	86
17	35.6	87.7	98.0	60
18	36.2	76.0	97.1	50
19	37.6	39.8	95.2	82
20	59.7	92.7	97.9	60
21	76.3	88.0	97.0	91
22	52.5	87.3	93.6	52
23	48.5	89.2	96.3	63
24	45.3		95.3	67
25	24.6		96.4	23
26	25.8		95.9	48
27	51.4		94.5	29
28	36.5	79.3	97.0	45
29	29.7	93.0	95.9	31
30	61.3	89.3	97.7	85
31	26.0	92.6	100.6	14
32	82.2	92.4	85	52
33	37.0	90.4	95.0	84
34	21.6	89.2	96.6	25
35	11.3	78.9	96.2	24
36	6.7	85.0	94.4	24
37	9.0		97.3	83
38	30.0		96.3	38
39	57.4		96.9	43
40	42.6		97.1	47
41	41.8		94.9	32
42	33.7	70.7	95.4	76
43	34.4	67.5	96.4	47
44	22.2	80.2	94.4	36
45	8.4	83.7	93.5	46
46	32.3	86.8	91.4	66