Construction, Instrumentation, and Testing of Fast-Setting Hydraulic Cement Concrete in Palmdale, California

Report Prepared for

CALIFORNIA DEPARTMENT OF TRANSPORTATION

By

Jeffery R. Roesler, Clark W. Scheffy, Abdikarim. Ali, and David Bush

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Pavement Research Center
Institute of Transportation Studies
University of California Berkeley

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Most of the rigid pavements in urban areas in California are nearing or have passed their design lives and are in various stages of deterioration and disrepair (1). In addition, Caltrans engineers and policy makers have felt that existing methods of rigid pavement maintenance and rehabilitation are providing diminishing returns, in terms of additional pavement life from each rehabilitative action, due to the damage incurred by the pavements under increasing volumes of traffic.

The agency costs of applying lane closures in urban areas is very large compared to the actual costs of materials and placement, and increased need for maintenance forces to be in the roadway increases costs and safety risks. In addition, the costs to Caltrans clients, the pavement users, are increasing due to the increasing frequency of lane closures, which causes delays, and the additional vehicle operating costs from deteriorating ride quality.

In order to remedy this problem, Caltrans has formed the long-life pavement rehabilitation strategies (LLPRS) committee to evaluate and develop rehabilitation strategies. To minimize the lane closure time for construction, Caltrans is exploring the use of fast-setting hydraulic cement concrete (FSHCC). The principal property of the FSHCC is its high early strength gain. This accelerated strength gain would increase the lane-km productivity of urban rehabilitation projects (within a construction window of 67 hours, or 10 a.m. Friday to 5 a.m. the following Monday) and therefore allow normal traffic to resume 4 to 8 hours after maintenance or rehabilitation action had been taken. Design features such as load transfer devices, tied concrete shoulders, and widened truck lanes are also being investigated as part of LLPRS with the goal of providing longer pavement life (30+ years). The effects that certain design features have on the life of concrete pavements have been discussed in detail in other reports already delivered to Caltrans (1,2).

FSHCC has previously been used for concrete pavement patching and bridges in both California and other states. Caltrans has used FSHCC to quickly repair earthquake damaged bridges in Southern California after the Northridge quake in 1994 and to patch deteriorated concrete slabs on heavily trafficked corridors during overnight construction. Caltrans has also paved several test sections on Interstate 60/71 and Interstate 605. SEATAC (Seattle Tacoma) airport has used FSHCC to replace taxiway and runway slabs at night. Due to the growing need for quick rehabilitation on congested freeways, Caltrans has initiated laboratory and full-scale research projects to check the viability of FSHCC in long-life pavement rehabilitation projects.

In a recent FHWA published report (3), California pavements were found to have a very high incident of faulting and cracking. Load transfer devices, tied concrete shoulders, and widened truck lanes have been used successfully in many states (3). Most states use dowels in their transverse joints to limit faulting. Many states are beginning to build their new concrete pavements with widened lanes and/or tied concrete shoulders to reduce the pavement edge stress.

The University of California at Berkeley Pavement Research Center (PRC), Dynatest Consulting, Inc. of Ojai, California, and the Council for Scientific and Industrial Research (CSIR) of South Africa have joined Caltrans in a partnership to evaluate and analyze the goals of the LLPRS strategies.

2.0 OVERVIEW OF THIS REPORT

The Palmdale project work includes installation of internal (embedded in the pavement) and external pavement instrumentation, construction material sampling and testing, full-scale accelerated pavement testing on the field-constructed FSHCC pavements using the Caltrans Heavy Vehicle Simulator No. 2 (HVS2), and monitoring of the loaded and unloaded test sections with respect to dynamic and environmental loading. The project work also includes a laboratory component to validate the field HVS results, and computer modeling and analysis as outlined in the Test Plan for CAL/APT Goal LLPRS – Rigid Phase III report (2).

This report details the FSHCC field construction, instrumentation, and strength testing of the field HVS test site on State Route 14 near Palmdale, California, which took place from June 5-18, 1998.

3.0 SITE LOCATION

Given that many of the proposed LLPRS projects lie within Caltrans District 7, that district was chosen as the location for the HVS field test site. The test site is located on State Route 14 approximately 6 kilometers south of Palmdale. This particular site was chosen primarily because an HOV (High Occupancy Vehicle) project was proposed at this location and the space allotted for the HOV project provided adequate room to place HVS2 on the shoulder of the highway with little or no impact on the flow of traffic.

The test site is divided into two distinct areas, referred to as the North Tangent and the South Tangent. The South Tangent is located on the shoulder of the southbound (traffic flowing towards Los Angeles) lanes. The North Tangent is located on the shoulder of the northbound (traffic flowing towards Palmdale) lanes. The South Tangent is approximately 1 kilometer south of the North Tangent.

The North and South Tangent are both situated in road cuts with steep side slopes. Each tangent is approximately 210 m long and is divided into three different sections approximately 70 m long. The 70-m sections are each constructed using different pavement structures or design features, as described in Section 4. The general layout and location of the individual test sections can be found in the Test Plan for CAL/APT Goal LLPRS-Rigid Phase III (2).

4.0 PAVEMENT STRUCTURE AND MATERIALS

The North and South Tangent were both built with a fast-setting hydraulic cement concrete (FSHCC) surface layer. All pavement layers had to meet the material properties specifications included in the “Notice to Contractors and Special Provisions” (4). The following sections detail specifics about the pavement materials.

4.1 Subgrade

Both the North and South Tangent are constructed on the same native subgrade material. Only a brief visual examination of the subgrade material has been performed. The subgrade material appears to be uplifted alluvial deposits with large stones (> 5 cm diameter) included and some weak to relatively strong cementing of the sand and gravel. It is most likely an AASHTO A-1 soil.

4.2 Pavement Structures and Section Layout

The North and South Tangents at the Palmdale test site are each intended for different tests. The South Tangent sections are the subject of a fatigue study with the goal of developing a fatigue curve for the fast-setting hydraulic cement concrete under dynamic loading. The North Tangent sections are the subject of a distress evaluation study (fatigue cracking, faulting, environmental cracking). The specifics of the accelerated tests for the Palmdale test site are detailed in the LLPRS Rigid Test Plan (2).

4.2.1 North Tangent pavement structure

The three North Tangent test sections are each 70 m long. The North Tangent was constructed with 150 mm of Class 2 aggregate subbase (ASB) placed on compacted subgrade. A 100 mm thick layer of Class A cement treated base (CTB) was placed on the aggregate subbase. The CTB was designed to have a 7-day compressive strength of 1.9 MPa (275 psi) to simulate material meeting the pre-1964 Caltrans specification. The CTB mix design submitted to Caltrans by Coffman Specialties, Inc. is shown in Table 4.1 All concrete slabs on the North Tangent were nominally 200 mm thick and follow the mix design described in Section 4.3.

Table 4.1 Cement-Treated Base (CTB) Mix Design used on North Tangent.

Material	**Batch Weight (kg/m^3)**	**Batch Weight (lb./yd.^{3})**
Cement	94.5	159
Coarse Aggregate (25 mm)	925	1560
Sand	1389	2342
Water	100	168.6
Water-to-cement Ratio	1.06	1.06

The North Tangent test sections will be tested to evaluate the efficacy of various pavement design features, specifically, load transfer devices and widened truck lanes. Test Section 7 is plain jointed concrete without dowels, a standard asphalt concrete shoulder, and regular 3.7-meter wide lane. Test Section 9 has steel dowels placed in the transverse joints and tie bars bridging the existing inside lane slab with the new 3.7 m wide lane. Figure 4.1 shows a typical doweled joint layout. Figure 4.2 presents the layout and dimensions of the tie bars used for simulation of a tied concrete shoulder. The HVS test wheel will run at the edge of the FSHCC pavement adjacent to the existing inside lane. This setup will help evaluate the performance of tied concrete shoulders under accelerated load testing.

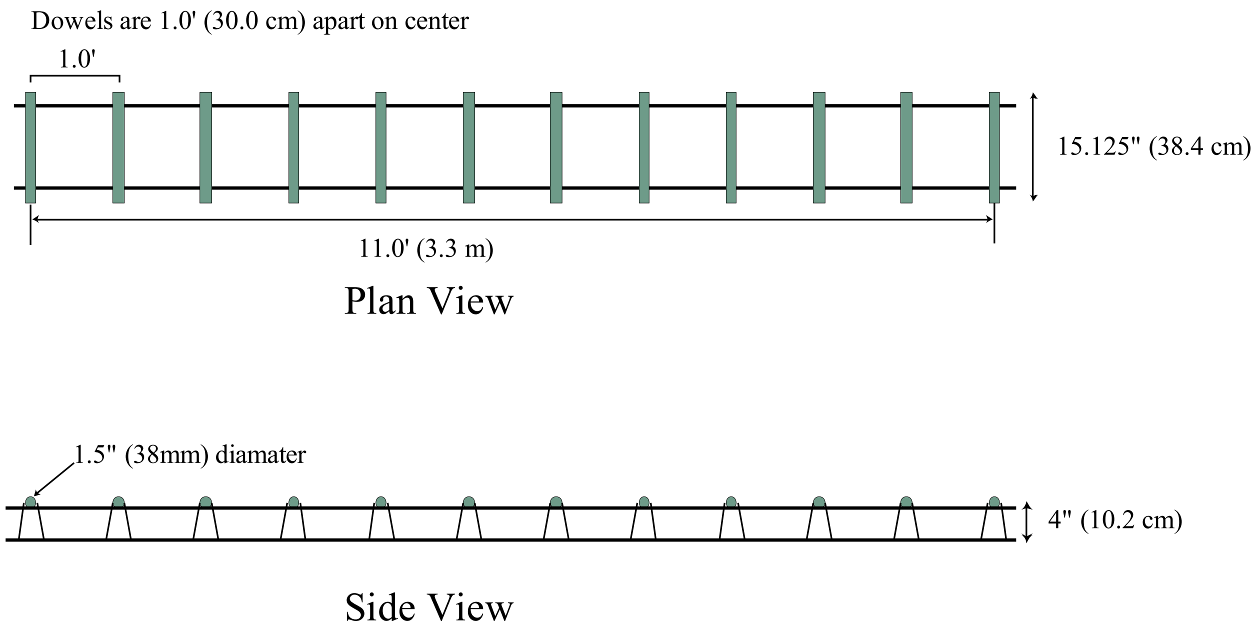

Figure 4.1. Illustration of Typical Dowel Bars.

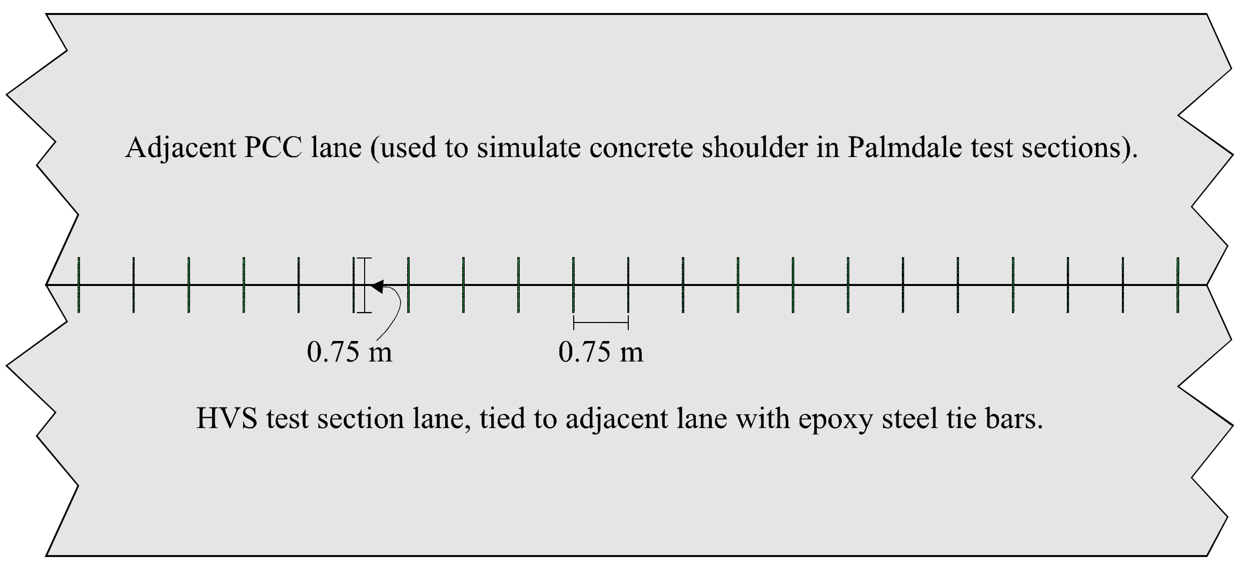

Figure 4.2. Layout and Dimensions of Dowels Used to Simulate a Tied Concrete Shoulder.

Test Section 11 has steel dowels across all the transverse joints, a standard asphalt concrete shoulder, and a 4.3-m wide truck lane. All slab joints have been sawed at 90° to match the existing joint spacing and orientation of the adjacent slabs. The joint spacing for the entire South Tangent approximately follows the pattern of 3.7, 4.0, 5.5, 5.8 m. Actual measured joint spacing is presented in Appendix A. The pavement structure of Test Sections 7, 9, and 11 are shown in Figure 4.3.

4.2.2 South Tangent Pavement Structure

All South Tangent test sections are plain jointed concrete slabs with 3.7-meter wide lanes and no load transfer devices. The South Tangent sections have 150-mm thick Class 2 aggregate base resting on compacted subgrade.

The three 70-meter South Tangent test sections all have different slab thickness – 100 mm in Test Section 1, 150 mm in Test Section 3, and 200 mm in Test Section 5 – to facilitate the development of a fatigue relation for the FSHCC. All slab joints have been sawed at 90 degrees to match the existing joint spacing and orientation of the adjacent slabs. The joint spacing for the entire South Tangent approximately follows the pattern of 3.7, 4.0, 5.5, 5.8 m. The pavement structure of Test Sections 1, 3, and 5 are shown in Figure 4.3.

4.2.3 Material Specifications and Type

This section briefly summarizes the material specifications required by Caltrans for the different paving layers. All materials utilized in the Palmdale construction had to meet Caltrans Standard Specifications (5) and the project's special provisions (4).

The aggregate base and subbase used were both Class 2. The cement treated base was required to have a 7-day compressive strength of 1895 kPa ±345 kPa when tested with CT 312. The concrete used for the surface layer had to contain a minimum cement content of 375 kg/m^3. The fast-setting concrete had to develop a flexural strength of 2.8 MPa after 8 hours and 4.1 MPa

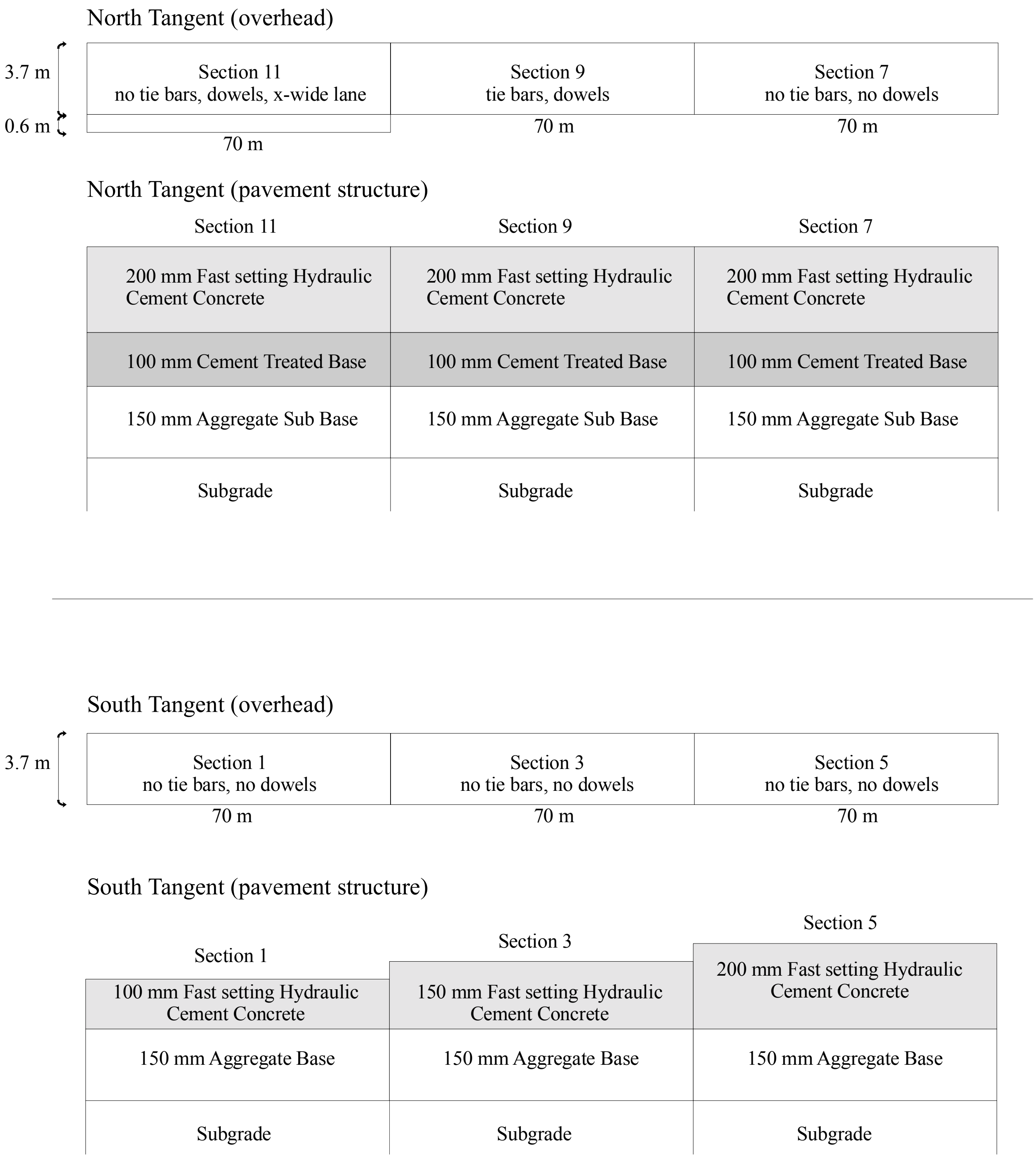

Figure 4.3. Pavement Structure Diagrams for North and South Tangents.

after 7 days in accordance with Caltrans Test 523. The hydraulic cement was required to achieve a 3-hour compressive strength of 17.2 MPa and a 3-day compressive strength of 34.5 MPa in accordance with ASTM C 109. Before the test sections were constructed, the contractor had to demonstrate through a trial slab that the 8-hour and 7-day strength specification could be met with his proposed mix design.

4.3 FSHCC Mix Design

The fast-setting concrete mix was designed by the contractor, Coffman Specialties, Inc. The concrete mix design was approved by Caltrans after the contractor paved a test slab and met the FSHCC material strength specifications included in the special provisions (4). The concrete mix design includes the following constituents: one coarse and fine aggregate, two cement types (PCC, Ultimax), water, air entraining agent, Delvo® liquid or solid retarder. Table 4.2 shows the proportion of each mix constituent for one cubic meter. Ultimax is a proprietary cement with its main chemical constituent being calcium sulfoaluminate. The contractor used a blend of two cements to achieve the required strength specifications. After trying several trial slabs with blends of cements ranging from 100 percent Ultimax / 0 percent Portland to 70 percent Ultimax / 30 percent Portland, the contractor finally chose an Ultimax to Portland cement blend of 80/20. All the fast-setting concrete placed on the University of California, Berkeley test sections was an 80/20 blend of Ultimax to Portland cement by weight.

The mix constituents weights are stock weights not SSD (saturated surface dry) weights. As shown in Table 4.2, the coarse and fine aggregate have a moisture content 1 and 4 percent greater than their SSD condition, respectively. The water-to-cement ratio in Table 4.2 includes the mix water and excess water from the coarse and fine aggregate. The mix water-to-cement ratio does not include any water that may have been added at the job site. The bulk specific gravity (saturdated surface dry [SSD]) for the coarse and fine aggregates was determined by UCB personnel to be 2.86 and 2.61, respectively. The absorption capacity of the coarse and fine aggregates measured 0.47 percent and 3.4 percent, respectively.

Table 4.2 Target FSHCC Mix Design (stock weights)

FSHCC Mix Constituent	Batch Weight (kg/m^3)	Batch Weight (lb./yd.^{3})
Coarse Aggregate (25mm)	1080	1820
Fine Aggregate	848	1429
Ultimax® Cement	332	560
Type II Portland Cement	83.0	140
Water	117	198
Delvo® Retarder (oz)	95.5	161
Micro-Air® Air Entraining Agent (oz)	1.36	2.3
Coarse Agg. Moisture (1%)	10.8, free water	18.2, free water
Fine Agg. Moisture (4%)	33.9, free water	57.2, free water
Total Water-to-cement Ratio	0.39	0.39

Tables 4.3 and 4.4 each present a list of the actual batch weights of all concrete trucks for the North and South Tangents, respectively. Batch weights were recorded by a UCB employee at the contractor’s batch plant. The batch weights are for a seven cubic yard transit truck. The column with estimated water added at the site was gathered from a UCB employee who recorded the amount of water that was missing from each the transit truck water tank. This additional water was added to the mix water and adsorbed water on the aggregates to calculate an estimated total water-to-cement ratio. Errors in the estimated water could exist if the transit truck driver forgot to fill his tank up between loads, the tank water was used to moisten the underlying base layer, and/or the water was used to clean off any testing and finishing equipment. The estimated average water-to-cement ratio at the site for the North and South Tangent was 0.44.

Table 4.3 Batch Weights Recorded at Batch Plant for North Tangent, 7 cu. yd. Trucks.

Truck #	Date and Time Batched	Daily Load #	Aggregate					Cement			Chemical		Est. Water Added at the site (gal.)	Batch Water (gal.)	Total Water Content (gal.)	W/C Ratio Batch Plant	W/C (lbs./lbs.) Ratio Site (Truck + Batch Plant Water) estimated	Air Entraining Agent (oz.)
			Absorbed Water Content of Coarse (gal.)	Coarse (lbs.)	Fine (lbs.)	Absorbed Water Content of Sand	Total Aggregate (lbs.)	PCC (lbs.)	Ultimax (lbs.)	Total Cement (lbs.)	Delvo Liquid (oz.)	Delvo Pucks (#)						
Target Weights			1061.2	12740	10003	3333.0	22743	**980**	**3920**	**4900**	**166**	**14**						**16**
32	16/6/98 6:20 AM	1	1064.6	12780	9960	3318.7	22740	990	3920	4910	1125	0	42	165	15827	0.39	0.46	16
35	16/6/98 6:30 AM	2	1061.2	12740	10002	3332.7	22742	980	3930	4910	1125	0	55	165	15835.3	0.39	0.48	16
41	16/6/98 6:45 AM	3	1069.6	12840	9940	3312.0	22780	990	3980	4970	1125	0	23	165	15827	0.38	0.42	16
39	16/6/98 7:05 AM	4	1064.6	12780	9970	3322.0	22750	980	3980	4960	1125	0	27	160	15485.5	0.37	0.42	16
31	16/6/98 7:15 AM	5	1069.6	12840	9960	3318.7	22800	980	3940	4920	1125	0	0	160	15485.5	0.38	0.38	16
32	16/6/98 7:23 AM	6	1069.6	12840	9840	3278.7	22680	980	3920	4900	1125	0	0	160	15443.8	0.38	0.38	16
35	16/6/98 7:38 AM	7	1069.6	12840	10560	3518.6	23400	980	3980	4960	1125	0	35	160	15685.4	0.38	0.44	16
41	16/6/98 7:45 AM	8	1061.2	12740	10002	3332.7	22742	980	3920	4900	1125	0	23	155	15143.9	0.37	0.41	16
39	16/6/98 8:00 AM	9	1066.2	12800	9880	3292.0	22680	980	3940	4920	1125	0	25	155	15110.6	0.37	0.41	16
31	16/6/98 8:10 AM	10	1056.2	12680	10062	3352.7	22742	980	3930	4910	1125	0	75	155	15160.6	0.37	0.50	16
32	16/6/98 8:25 AM	11	1074.6	12900	9780	3258.7	22680	980	3930	4910	1125	0	25	155	15085.6	0.37	0.41	16
35	16/6/98 8:44 AM	12	1062.9	12760	9982	3326.0	22742	980	3940	4920	1125	0	45	170	16176.9	0.39	0.47	16
41	16/6/98 9:00 AM	13	1061.2	12740	10010	3335.3	22750	980	3930	4910	1125	0	22	170	16185.2	0.40	0.43	16
39	16/6/98 9:12 AM	14	1066.2	12800	9900	3298.7	22700	980	3960	4940	1125	0	25	170	16160.2	0.39	0.43	16
32	16/6/98 9:30 AM	15	1066.2	12800	10120	3372.0	22920	980	3940	4920	1125	0	25	170	16226.8	0.40	0.44	16
41	17/6/98 6:15 AM	1	1066.2	12800	9880	3292.0	22680	980	3950	4930	1125	0	22	170	16151.9	0.39	0.43	16
31	17/6/98 6:25 AM	2	1061.2	12740	10060	3352.0	22800	990	3920	4910	1125	0	4	170	16201.9	0.40	0.40	16
32	17/6/98 6:35 AM	3	1066.2	12800	9960	3318.7	22760	980	3920	4900	1125	0	25	170	16176.9	0.40	0.44	16

Truck #	Date and Time Batched	Daily Load #	Aggregate					Cement			Chemical		Est. Water Added at the site (gal.)	Batch Water (gal.)	Total Water Content (gal.)	W/C Ratio Batch Plant	W/C (lbs./lbs.) Ratio Site (Truck + Batch Plant Water) estimated	Air Entrain-ing Agent (oz.)
			Ab-sorbed Water Content of Coarse (gal.)	Coarse (lbs.)	Fine (lbs.)	Ab-sorbed Water Content of Sand	Total Aggre-gate (lbs.)	PCC (lbs.)	Ultimax (lbs.)	Total Cement (lbs.)	Delvo Liquid (oz.)	Delvo Pucks (#)						
39	17/6/98 6:50 AM	4	1061.2	12740	9820	3272.0	22560	980	3930	4910	0	70	48	164	15710.4	0.38	0.47	16
35	17/6/98 7:03 AM	5	1069.6	12840	9630	3208.7	22470	1010	3930	4940	0	70	65	165	15727	0.38	0.49	16
31	17/6/98 7:17 AM	6	1059.6	12720	9840	3278.7	22560	1010	3990	5000	0	70	38	165	15785.4	0.38	0.44	16
41	17/6/98 7:31 AM	7	1059.6	12720	9870	3288.7	22590	980	3940	4920	0	70	38	165	15793.7	0.39	0.45	16
32	17/6/98 7:45 AM	8	1069.6	12840	9750	3248.7	22590	1000	3940	4940	0	70	35	165	15760.4	0.38	0.44	16
39	17/6/98 8:02 AM	9	1062.1	12750	9810	3268.7	22560	1010	3920	4930	0	70	51	175	16468.4	0.40	0.49	16
35	17/6/98 8:16 AM	10	1066.2	12800	9700	3232.0	22500	980	3910	4890	0	70	0	175	16435.1	0.40	0.40	16
31	17/6/98 8:27 AM	11	1062.1	12750	9950	3315.3	22700	1000	3940	4940	0	70	10	175	16518.4	0.40	0.42	16
41	17/6/98 8:44 AM	12	1069.6	12840	9960	3318.7	22800	970	3940	4910	0	70	25	175	16526.7	0.40	0.45	16
32	17/6/98 8:56 AM	13	1069.6	12840	9870	3288.7	22710	1010	3940	4950	0	70	12	185	17193.1	0.42	0.44	16
35	17/6/98 9:12 AM	14	533.1	6400	4930	1642.7	11330	390	1960	2350	0	35	30	89	8346.7	0.43	0.53	16
32	18/6/98 5:58 AM	1	1069.6	12840	9910	3302.0	22750	980	3920	4900	0	70	64	170	16160.2	0.40	0.50	16
35	18/6/98 6:08 AM	2	1066.2	12800	9990	3328.7	22790	980	3930	4910	0	70	50	170	16185.2	0.40	0.48	16
39	18/6/98 6:20 AM	3	1074.6	12900	9900	3298.7	22800	970	3940	4910	0	70	50	170	16168.5	0.40	0.48	16
31	18/6/98 6:37 AM	4	1062.1	12750	9930	3308.7	22680	990	3930	4920	0	70	10	170	16160.2	0.39	0.41	16
32	18/6/98 7:03 AM	5	1069.6	12840	9900	3298.7	22740	1030	3950	4980	0	70	15	180	16851.6	0.41	0.43	16
35	18/6/98 7:13 AM	6	1069.6	12840	9960	3318.7	22800	980	3930	4910	0	70	8	170	16176.9	0.40	0.41	16
39	18/6/98 7:31 AM	7	1079.6	12960	9780	3258.7	22740	990	3940	4930	0	70	32	170	16126.9	0.39	0.45	16
31	18/6/98 7:45 AM	8	1061.2	12740	10060	3352.0	22800	990	3930	4920	0	70	6	170	16201.9	0.40	0.41	16
32	18/6/98 7:56 AM	9	1062.1	12750	9950	3315.3	22700	980	3920	4900	0	70	20	170	16168.5	0.40	0.43	16

Table 4.4 Batch Weights Recorded at Batch Plant for South Tangent, 7 cu. yd. Trucks.

Truck #	Date and Time Batched	Daily Load #	Aggregate					Cement			Chemical		Est. Water Added at the site (gal.)	Batch Water (gal.)	Total Water Con-tent (gal.)	W/C Ratio Batch Plant	W/C (lbs./lbs.) Ratio Site (Truck + Batch Plant Water) estimated	Air Entrain-ing Agent (oz.)
			Water Content of Coarse (gal.)	Coarse (lbs.)	Fine (lbs.)	Water Content of Sand (gal.)	Total Aggre-gate (lbs.)	PCC (lbs.)	Ultimax (lbs.)	Total Cement (lbs.)	Delvo Liquid (oz.)	Delvo Pucks (#)						
Target Weights			**1061.2**	**12740**	**10003**	**3333.0**	**22743**	**980**	**3920**	**4900**	**166**	**14**						**16**
37	6/10/98 12:25 AM	1	1049.6	12600	9930	3308.7	22530	980	3920	4900	1125	0	0	165	11445.4	0.39	0.39	16
38	6/10/98 12:35 AM	2	1052.1	12630	9870	3288.7	22500	985	3940	4925	1125	0	0	165	11445.4	0.38	0.38	16
34	6/10/98 12:47 AM	3	1042.1	12510	9930	3308.7	22440	990	3940	4930	1125	0	12	135	9362.9	0.33	0.35	16
36	6/10/98 1:07 AM	4	1077.1	12930	9630	3208.7	22560	980	3975	4955	1125	0	40	160	11095.6	0.37	0.44	16
37	6/10/98 1:33 AM	5	1052.1	12630	10070	3355.3	22700	950	4030	4980	1125	0	10	160	11095.6	0.37	0.39	16
38	6/10/98 1:45 AM	6	1049.6	12600	10300	3432.0	22900	980	3950	4930	1125	0	25	155	10754.0	0.37	0.41	16
41	6/11/98 7:00 AM	1	1050.7	12614	9986	3327.3	22600	920	3920	4840	1125	0	40	150	10404.2	0.37	0.44	16
37	6/11/98 7:05 AM	2	1057.9	12700	9980	3325.3	22680	920	3960	4880	1125	0	45	150	10404.2	0.36	0.44	16
33	6/11/98 7:12 AM	3	1049.6	12600	9960	3318.7	22560	980	3940	4920	1125	0	20	160	11095.6	0.38	0.41	16
38	6/11/98 7:22 AM	4	1059.6	12720	9880	3292.0	22600	980	3940	4920	1125	0	55	160	11095.6	0.38	0.47	16
32	6/11/98 7:32 AM	5	1082.9	13000	9440	3145.4	22440	980	3980	4960	1125	0	50	160	11095.6	0.37	0.45	16
36	6/11/98 7:41 AM	6	1052.1	12630	9810	3268.7	22440	990	3920	4910	1125	0	50	160	11095.6	0.38	0.46	16
41	6/11/98 7:53 AM	7	1062.1	12750	9930	3308.7	22680	980	3920	4900	1125	0	40	160	11095.6	0.38	0.45	16
37	6/11/98 8:02 AM	8	1059.6	12720	9840	3278.7	22560	975	3930	4905	1125	0	55	160	11095.6	0.38	0.47	16
33	6/11/98 8:13 AM	9	1069.6	12840	9720	3238.7	22560	990	3980	4970	1125	0	32	160	11095.6	0.37	0.43	16
38	6/11/98 8:24 AM	10	1050.7	12614	9826	3274.0	22440	990	4000	4990	1125	0	100	163	11303.8	0.38	0.54	16
32	6/11/98 8:34 AM	11	1052.1	12630	10050	3348.7	22680	990	3925	4915	1125	0	26	170	11795.3	0.40	0.44	16
36	6/11/98 8:44 AM	12	1066.2	12800	9790	3262.0	22590	1025	4050	5075	1125	0	75	160	11095.6	0.36	0.49	16
41	6/11/98	13	1074.6	12900	9670	3222.0	22570	980	3935	4915	1125	0	53	160	11095.6	0.38	0.47	16

Truck #	Date and Time Batched	Daily Load #	Aggregate					Cement			Chemical		Est. Water Added at the site (gal.)	Batch Water (gal.)	Total Water Content (gal.)	W/C Ratio Batch Plant	W/C (lbs./lbs.) Ratio Site (Truck + Batch Plant Water) estimated	Air Entrain-ing Agent (oz.)
			Water Content of Coarse (gal.)	Coarse (lbs.)	Fine (lbs.)	Water Content of Sand (gal.)	Total Aggre-gate (lbs.)	PCC (lbs.)	Ultimax (lbs.)	Total Cement (lbs.)	Delvo Liquid (oz.)	Delvo Pucks (#)						
	8:54 AM																	
37	6/11/98 9:07 AM	14	1049.6	12600	10050	3348.7	22650	975	3930	4905	1125	0	75	160	11095.6	0.38	0.51	16
33	6/11/98 9:20 AM	15	1049.6	12600	9900	3298.7	22500	980	3970	4950	1125	0	42	165	11445.4	0.38	0.45	16
38	6/11/98 9:38 AM	16	1062.1	12750	9930	3308.7	22680	990	3940	4930	1125	0	30	170	11795.3	0.39	0.44	16
32	6/11/98 9:50 AM	17	1067.1	12810	9750	3248.7	22560	960	3930	4890	1125	0	14	165	11445.4	0.39	0.41	16
36	6/11/98 10:08 AM	18	1057.1	12690	9870	3288.7	22560	975	3930	4905	1125	0	25	160	11095.6	0.38	0.42	16
41	6/11/98 10:25 AM	19	1051.2	12620	9820	3272.0	22440	940	3930	4870	1125	0	46	160	11095.6	0.38	0.46	16
37	6/11/98 10:44 AM	20	1052.1	12630	9970	3322.0	22600	990	3920	4910	1125	0	30	160	11095.6	0.38	0.43	16
32	6/11/98 11:00 AM	21	529.8	6360	4780	1592.7	11140	470	2000	2470	560	0	8	85	5897.6	0.39	0.42	16
32	6/11/98 2:25 AM	22	1074.6	12900	9570	3188.7	22470	980	3930	4910	1125	0	19	180	12486.7	0.41	0.44	16
36	6/11/98 2:35 AM	23	1062.1	12750	9810	3268.7	22560	980	3980	4960	1125	0	57	160	11095.6	0.37	0.47	16

5.0 NON-DESTRUCTIVE TESTING OF THE PAVEMENT LAYERS

5.1 Dynamic Cone Penetrometer (DCP)

The DCP was used to determine the in-situ strength of the aggregate base and subgrade on the South Tangent. Table 5.1 lists the results of the DCP tests and correlated CBR (California Bearing Ratio) values and layer elastic moduli. Table 5.1 shows the DCP results were quite variable. Correlated CBR and moduli values were quite high for unbound granular layers and subgrade. In fact, CBR values greater than 100 suggest a treated or continuous material. In summary, the overall strength of the subgrade and base layer were quite high. The DCP was not originally designed to test high strength materials and this may be why a large variability exists in the DCP results for the Palmdale site.

Table 5.1 Dynamic Cone Penetrometer (DCP) Test Results for Aggregate Base on South Tangent.

Test #	Layer Type	Depth (mm)	Average Penetration (mm/blow)	Calculated CBR (%)	Calculated Average E-MOD (MPa)
1	Base	0-112	5.24	50	192
	Subgrade	113-800	8.31	28	118
2	Base	0-136	2.64	119	398
	Subgrade	137-800	2.37	136	447
3	Base	0-176	1.55	212	702
	Subgrade*	177-504	2.67	117	393
4	Base	0-112	5.24	50	192
	Subgrade*	113-520	1.71	193	631
5	Base	0-336	2.09	160	511
	Subgrade*	337-624	1.48	221	737
6	Base	0-344	2.00	169	535
	Subgrade*	345-640	2.83	109	369
7	Base	0-168	5.37	48	187
	Subgrade	169-800	2.69	116	390

* Bedrock probably reached during test.

5.2 Nuclear Density Gage

The density of aggregate base on the South Tangent was measured using a Nuclear Density Gage. Measurements were taken every ten meters starting from the south end of the section and moving in the longitudinal direction, and alternately at three points in the transverse direction: offset 0.92 meters (3 feet) toward the shoulder (west), on the center line, and offset 0.92 meters (3 feet) toward the traffic (east). Table 5.2 shows the results of the nuclear density gage tests on

Table 5.2 Nuclear Density Gage Test Results from South Tangent.

Longitu-dinal Distance (m)	Transverse Distance (m)	Density, Gage Oriented Parallel to traffic (g/cm^3)	Density, Gage Oriented Parallel to traffic (lbs./ft.^{3})	Density, Gage Oriented Perpendicular to traffic (g/cm^3)	Density, Gage Oriented Perpendicular to traffic (lbs./ft.^{3})
0	0.92 shoulder side	2.08	129.48	2.09	130.23
10	center line	2.10	130.79	2.10	131.10
20	0.92 traffic side	2.15	134.35	2.02	126.11
30	center line	1.96	122.55	2.03	126.80
40	0.92 shoulder side	2.02	125.99	2.01	125.42
50	center line	1.88	117.56	1.93	120.68
60	0.92 traffic side	1.91	119.00	1.88	117.50
70	center line	1.94	121.18	1.94	121.12
80	0.92 shoulder side	1.81	112.69	1.81	112.88
90	center line	1.87	116.81	1.86	116.06
100	0.92 traffic side	1.87	116.38	1.91	119.06
110	center line	1.92	119.81	1.97	122.87
120	0.92 shoulder side	2.04	126.98	1.92	120.06
130	center line	1.94	120.87	1.95	121.87
140	0.92 traffic side	2.03	126.36	2.01	125.11
150	center line	1.84	114.94	1.87	116.81
160	0.92 shoulder side	1.93	120.49	1.83	113.94
170	center line	1.93	120.68	1.85	115.56
180	0.92 traffic side	2.01	125.67	1.80	112.57
190	center line	1.92	120.06	2.12	132.48
200	0.92 shoulder side	1.91	118.93	1.85	115.19
210	center line	1.99	123.86	2.05	127.61
	Average	***1.96***	***122***	***1.945***	***121***
	Std. Dev.	***0.086***	***5.39***	***0.097***	***6.05***
	C.O.V. (%)	***4.4***	***4.4***	***5.0***	***5.0***

the South Tangent. No density measurements were taken on the North Tangent because it had a cement-treated base.

The average density of the entire South Tangent was 1.95 g/cm^3 (122 $lbs./ft.^3$). The coefficient of variation (C.O.V.) of the in-situ density was small, varying from 4.4 to 5.0 percent. The nuclear gage tests indicate that the density of the in-situ material had a low variability, but the test results do not suggest that the in-situ density was at its maximum. In order to determine the maximum density of the Class 2 base material, laboratory proctor tests would have to be completed. The results of the proctor tests could be compared to the in-situ density and a relative maximum density could be determined. UCB was not aware of any proctor tests of the aggregate base material.

6.0 TYPE, LAYOUT, AND PLACEMENT OF INSTRUMENTATION

Instruments were installed on the Palmdale test sections to measure pavement strain, deflection, and temperature due to the environmental and traffic loading. The purpose of the instrumentation was to validate existing pavement models and if necessary, to help create new models to explain the performance of the FSHCC test sections.

The layout of the instrumentation in each test section is shown in detailed figures in Appendix A. The construction of the test sections and placement of all instruments was a success except for the loss of one thermocouple due to the buried wire being severed by construction equipment. The lead cable to one of the Carlson A-8 strain meters on the South Tangent was also severed by construction equipment, but was successfully spliced and brought back into service without significant loss of data.

Two data acquisition systems, each with a compliment of gages, were used in this project: the HVS data acquisition system and the online data acquisition system. Gages designed to measure dynamic response of the pavement under the load of the HVS test wheel were connected to the HVS data acquisition system. The HVS data acquisition system is able to relate the HVS test wheel position to the dynamic response of the connected gage.

Gages designed to measure environmental or curing effects in the pavement were connected to an online data acquisition system. The online system can be programmed to acquire and store data at specific intervals for later download to a personal computer.

The following sections detail how the instruments were placed, how the two data acquisition systems operate, and the types of gages connected to data acquisition systems.

6.1 Placement of the Instruments

The instrument locations were first mapped out on a site plan. The instrument locations were then transferred to the actual site using nails and spray paint as markers. A crew of 25 University of California, Berkeley personnel helped with installing the Palmdale instrumentation. A total of 328 separate instruments were placed in the concrete pavement during Palmdale construction.

6.1.1 Instrumentation Placement Prior to Paving

On the South Tangent, shallow trenches were dug in the aggregate base and polyvinyl chloride (PVC) pipes were laid in the trenches. The wires running from each instrument were threaded through the PVC pipe system to the shoulder of the pavement where they could be connected to the online data acquisition system or to the HVS data acquisition system, as shown in Figure 6.1. The channels and pipe system were then backfilled with the aggregate base prior to paving.

On the North Tangent, which had a cement-treated base (CTB), a saw was used to cut shallow grooves in which to run the gage lead wires, as shown in Figure 6.2. After the wires were placed, fast-setting cement mixed with sand was used to backfill the channels, as shown in Figure 6.3.

All strain gages were placed and properly oriented on the base material with small steel frames, as shown in Figures 6.4 and 6.5. Each instrument was attached to its steel frame using a plastic zip tie. Each instrument was attached firmly enough so that it wouldn't become dislodged

Figure 6.1. South Tangent Instrument Wiring and Piping Laid in Aggregate Base.

Figure 6.2. Grooves cut in North Tangent CTB for Instrument Leads.

Figure 6.3. Backfilled Instrumentation Lead Channel on North Tangent CTB.

Figure 6.4. Steel Frame with Carlson A-8 Strain Meter Installed on South Tangent.

Figure 6.5. Steel Frames for Collocation of Dynatest PAST-2PCC (shown) and Tokyo-Sokki PMR-60-6L (not shown).

when the concrete was placed, but also in such a manner that the fasteners would not restrict gage movement once the concrete had set.

As shown in Figures 6.6 and 6.7, four-part sheet metal boxes with five-centimeter spikes at each corner were placed around all gages except for thermocouples. The sheet metal boxes prevented the flow of concrete from pushing any gages out of their intended location and orientation during paving. The spikes were driven into the base material to further stabilize the boxes. These boxes were then marked with “turkey tails” or wire flags affixed with duct tape so that they would be easily visible to the paving crew, as shown in Figure 6.8.

Figure 6.6. Steel Instrument Box Being Installed on South Tangent.

Figure 6.7. Steel Instrument Box Protecting Strain Gages on South Tangent.

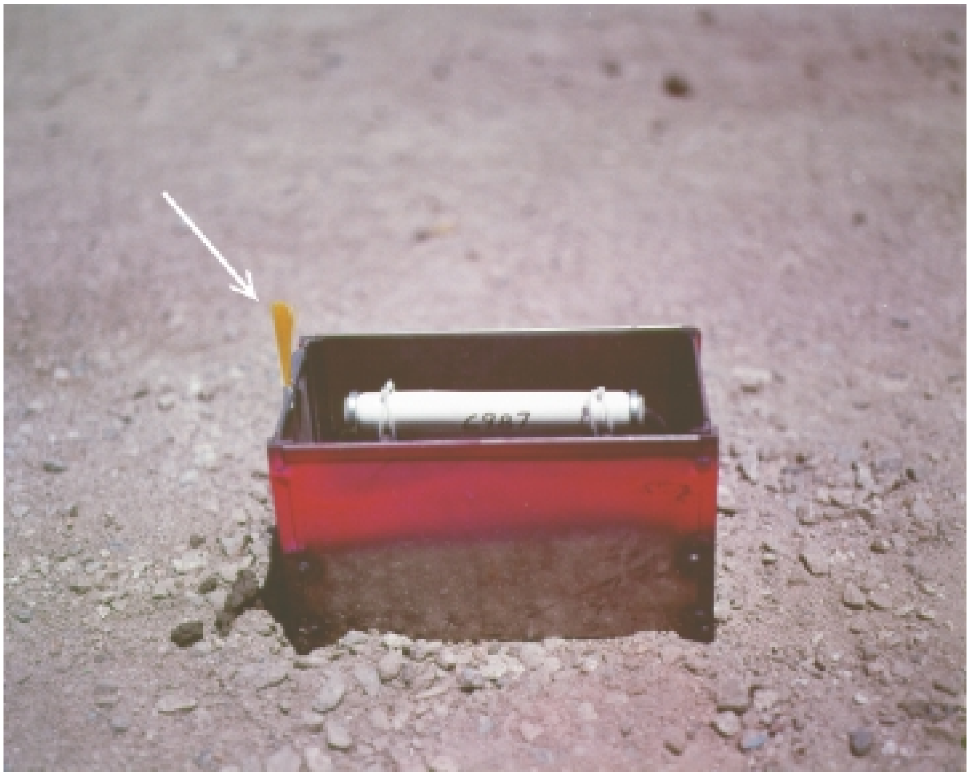

Figure 6.8. Instrument Box with Turkey Tail Attached.

Before paving began, all instrument locations and orientations were checked by an independent crew. Where applicable, instruments were calibrated and zeroed before paving began.

6.1.2 Instrumentation During Paving

When the concrete neared one of the instruments in its box, UCB personnel shoveled concrete into the box, as shown in Figure 6.9. Coffman Specialties personnel consolidated the mix inside the sheet metal box by vibrating all four sides of the box, as shown in Figure 6.10. The Coffman Specialties crew then ran a screed over the concrete surface. Both the wire flags

Figure 6.9. Instrument Box Being Filled by Shovel, North Tangent.

Figure 6.10. Vibrator Being Applied to Instrument Box to Consolidate Concrete.

Figure 6.11. Technician Lying on Bridge over Test Section Removing Instrument Box.

and turkey tails attached to the boxes popped up from the fresh concrete, even after a few passes of the screed. This allowed UCB personnel to quickly locate the sheet metal boxes.

A wooden "bridge" was then placed across the span of the freshly placed concrete. UCB personnel walked out on this bridge and pulled the sheet metal boxes before the final finish was applied to the concrete surface, as shown in Figure 6.11.

6.2 HVS Data Acquisition System

The first data acquisition system and class of gages relies on the HVS data acquisition system built by CSIR. This system consists of a 16-channel analog to digital converter (A/D) board connected to a PC and two rack-mount housings containing signal conditioners. Each rack-mount housing contains a series of signal conditioner modules specific to each particular instrument. Sixteen separate instruments can be connected at one time. However, data from only one single instrument or single group of MDDs (see Section 6) can be monitored at any given time.

The HVS data acquisition system is primarily designed to collect data while the pavement is undergoing dynamic loading of the HVS test wheel. This is achieved with a clock connected to the motion of the HVS wheel. As the test wheel moves closer to an instrument, the clock triggers the first data point and the acquisition system continues to record data until the wheel stops moving or a maximum of 256 clock ticks is reached. Dynamic data collection is performed manually at specified test load repetition intervals in accordance with the accelerated pavement test plan. Figure 6.12 shows the schematic of the HVS data acquisition system. The HVS data acquisition system can also be used to monitor gages without the use of the HVS clock.

6.3 Online Data Acquisition System

The core of the online data acquisition system is the CR10X system manufactured by Campbell Scientific. Four such units were installed at the Palmdale test site: one on the South Tangent and three on the North Tangent. A schematic of the online data acquisition system is presented in Figure 6.13. The CR10X boxes were placed approximately 4 meters from the edge of the pavement. Each CR10X box was placed in the ground and surrounded by a concrete containment box with a steel cover. This was done to prevent damage to the CR10X during construction.

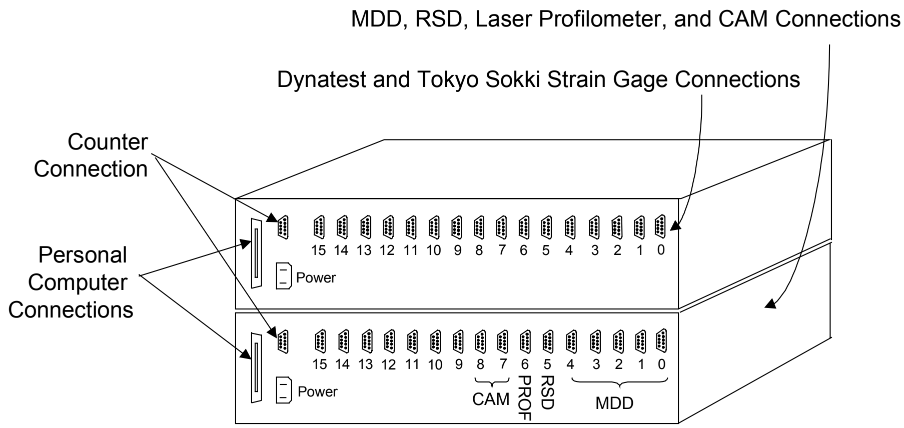

Figure 6.12. HVS Data Acquisition System Schematic.

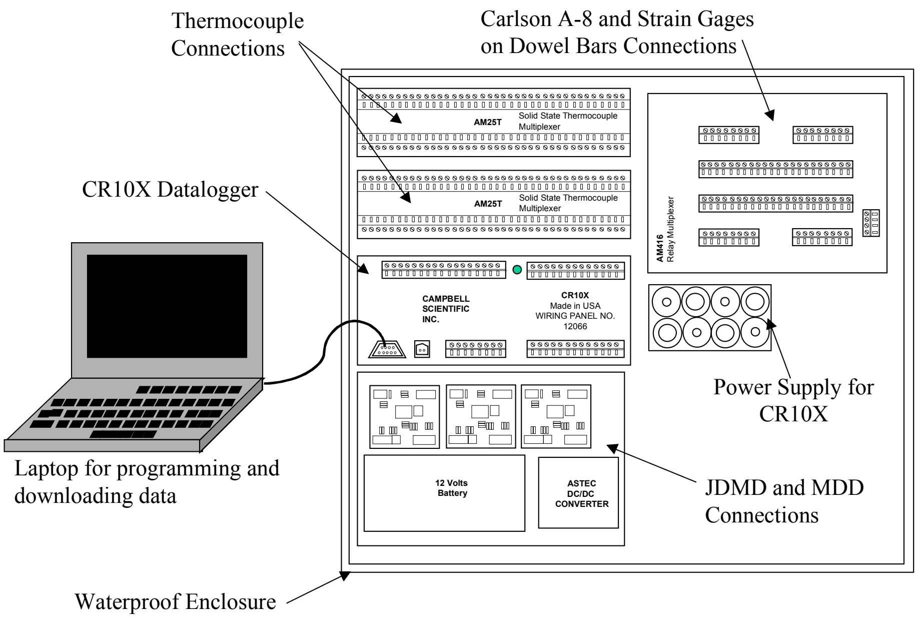

Figure 6.13. Online Data Acquisition System Schematic.

Figure 6.14. CR10X Acquisition System Being Placed on North Tangent.

The CR10X systems consist of a CR10X data logger, one AM 416 relay multiplexer, two AM 25 Thermocouple multiplexers, one ASTEC DC/DC converter, one external 12 volt power supply, three signal conditioners, and an alkaline battery pack, all of which are enclosed in a fiberglass box. The system is used to continuously monitor and record data from thermocouples, LVDTs, MDDs, and environmental strain gages embedded in the test sections. The stored data can then be downloaded to a PC. Figure 6.14 shows the CR10X. The following sections detail all instrumentation placed during Palmdale construction.

6.4 Dynamic Strain Gages

Two types of dynamic strain gages were installed in the test sections: Dynatest PAST-2PCC and Tokyo Sokki PMR-60-6L. These gages are monitored with the HVS data acquisition system while under dynamic load from the HVS test wheel.

The dynamic strain gages were also monitored while the FSHCC was curing using the HVS data acquisition system. For this type of measurement, the HVS clock was not used. This measurement process is perhaps more suitable for the online data acquisition system described in Section 6, however, moving gages from one acquisition system to another was not considered feasible. Instead, UCB personnel triggered the data collection period at specified times during the pavement curing process. A total of 24 Tokyo Sokki and Dynatest gages were installed in the test slabs. The figures in Appendix A show the location and depth of every dynamic strain gage in the Palmdale test section.

6.4.1 Dynatest PAST-2PCC

The Dynatest PAST-2PCC, manufactured by Dynatest Consulting Inc., of Ojai, is used to measure dynamic horizontal strains in the concrete. The device measures both the dynamic strains resulting from the HVS test wheel load and the strains resulting from curing of the FSHCC.

This instrument consists of an electrical resistance strain gage embedded within a strip of glass-fiber reinforced epoxy, with transverse steel anchors at each end to form an H-shape, as shown in Figures 6.15 and 6.16. This gage was embedded near the bottom of the concrete sections (exact locations are shown in Appendix A).

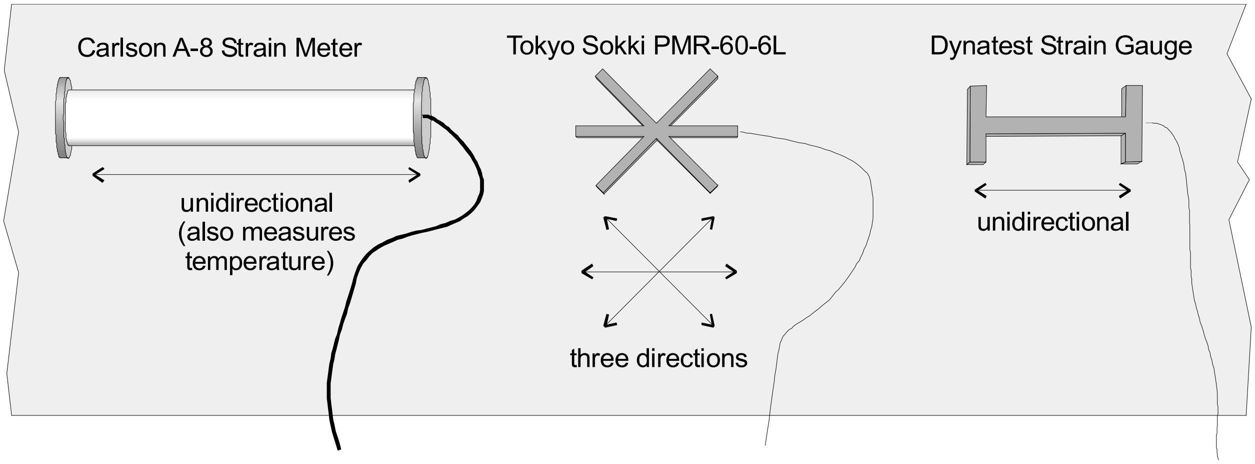

Figure 6.15. Diagram of all Strain Gages used on the Palmdale Test Sections.

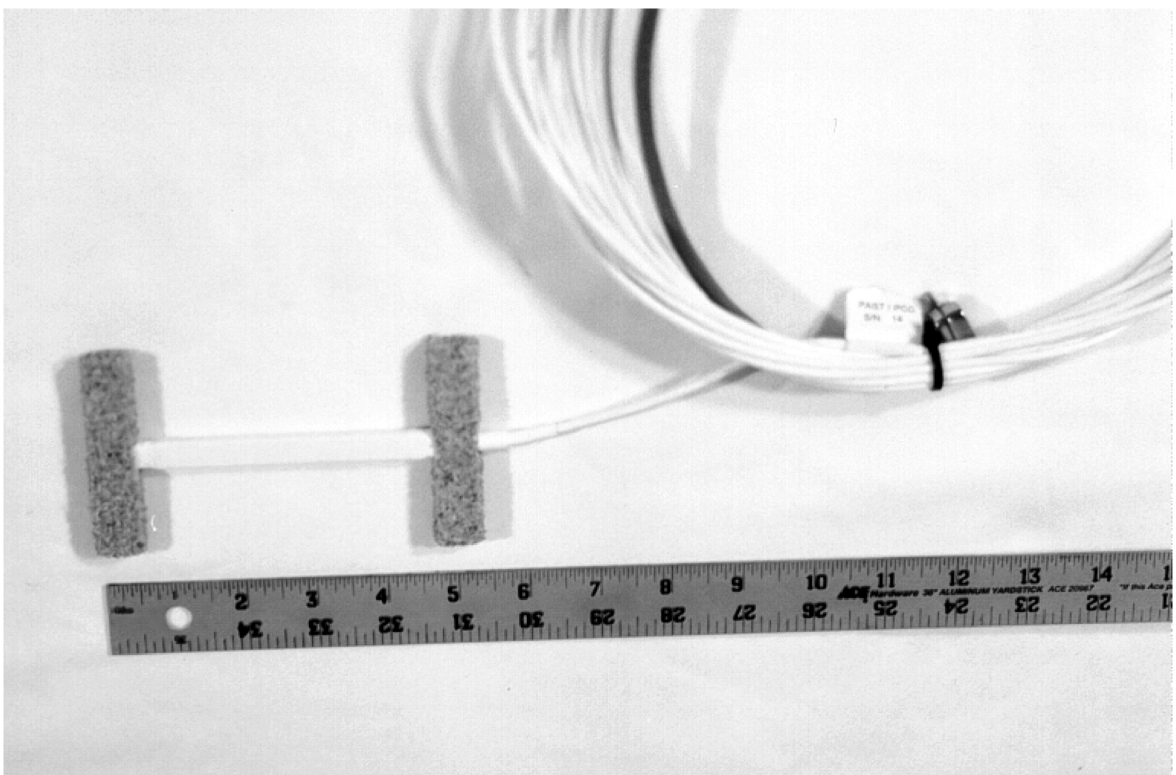

Figure 6.16. Dynatest PAST-2PCC Strain Gage.

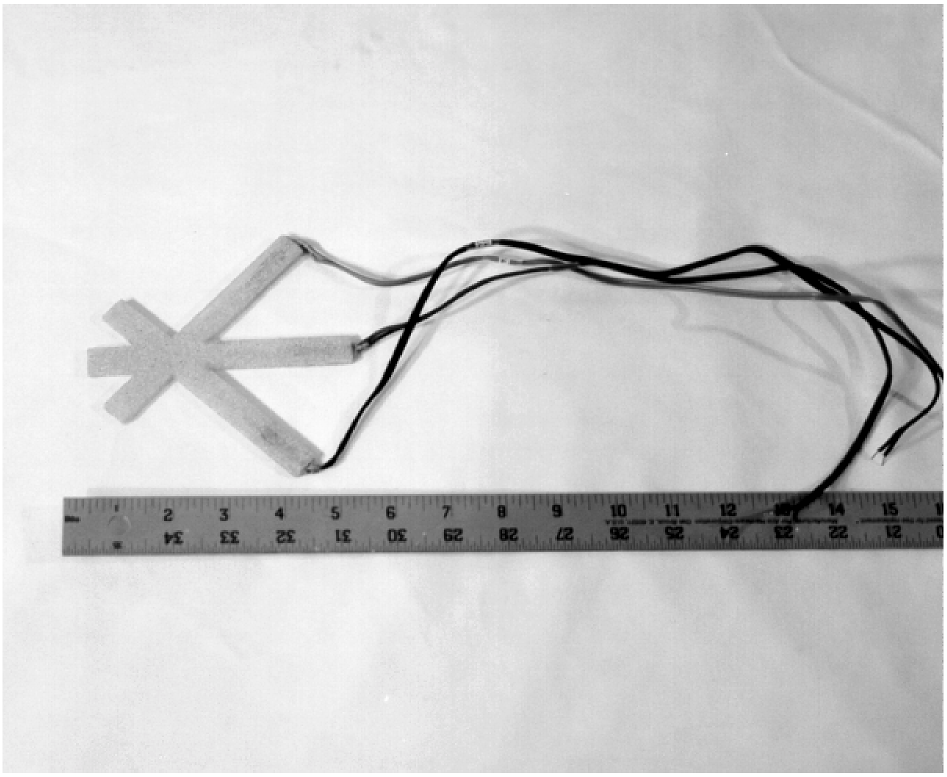

Figure 6.17. Tokyo-Sokki PMR-60-6L Strain Gage.

6.4.2 Tokyo Sokki PMR-60-6L

The Tokyo Sokki PMR-60-6L, manufactured by Tokyo Sokki Kenkyujo Co., Ltd., is used to measure dynamic horizontal strains in the concrete. The device measures both the dynamic strains resulting from the HVS test wheel load and the strains resulting from curing of the FSHCC.

The device consists of an electrical resistance wire gage rosette and lead wire hermetically sealed between thin resin plates, as shown in Figures 6.15 and 6.17. This type of gage was placed near the surface of the concrete pavement in various locations, as illustrated in Appendix A.

6.5 Multi-Depth Deflectometer (MDD)

Multi-depth deflectometers were installed after construction to measure vertical deflections at multiple depths in the pavement structure. Each MDD location consists of a hole drilled 3.3 m from the surface of the pavement into the subgrade. An anchor is fixed with concrete at the bottom of the 3.3-m hole. A "center rod" consisting of ferrous material "slugs" that serve as targets for the MDD modules is connected to the anchor. Each MDD module contains a Linear Variable Differential Transformer (LVDT) which reads displacement relative to the slugs. Each module can be affixed to the sides of the hole at a specified depth to measure total pavement deflection above that location. Figure 6.18 illustrates the MDD.

The Palmdale site uses MDDs in two roles. The first role is as a dynamic gage connected to the HVS data acquisition system. In this role, the MDD registers pavement deflection in various levels in the pavement structure under HVS wheel load. The second role is as an online gage. In this second role, the MDD registers environmentally induced displacements at various levels in the pavement structure.

6.5.1 South Tangent MDDs

The MDDs sites in the South Tangent have three modules installed. The South Tangent MDDs were installed in July and August of 1998. On section 5C, one of the MDD modules is being monitored by the CR10X until HVS trafficking begins on that section. When the HVS is placed on the sections with MDDs, they will be connected to the HVS data acquisition system to monitor pavement deflection under dynamic loading. Appendix A show the MDD locations of the six MDDs on the South Tangent.

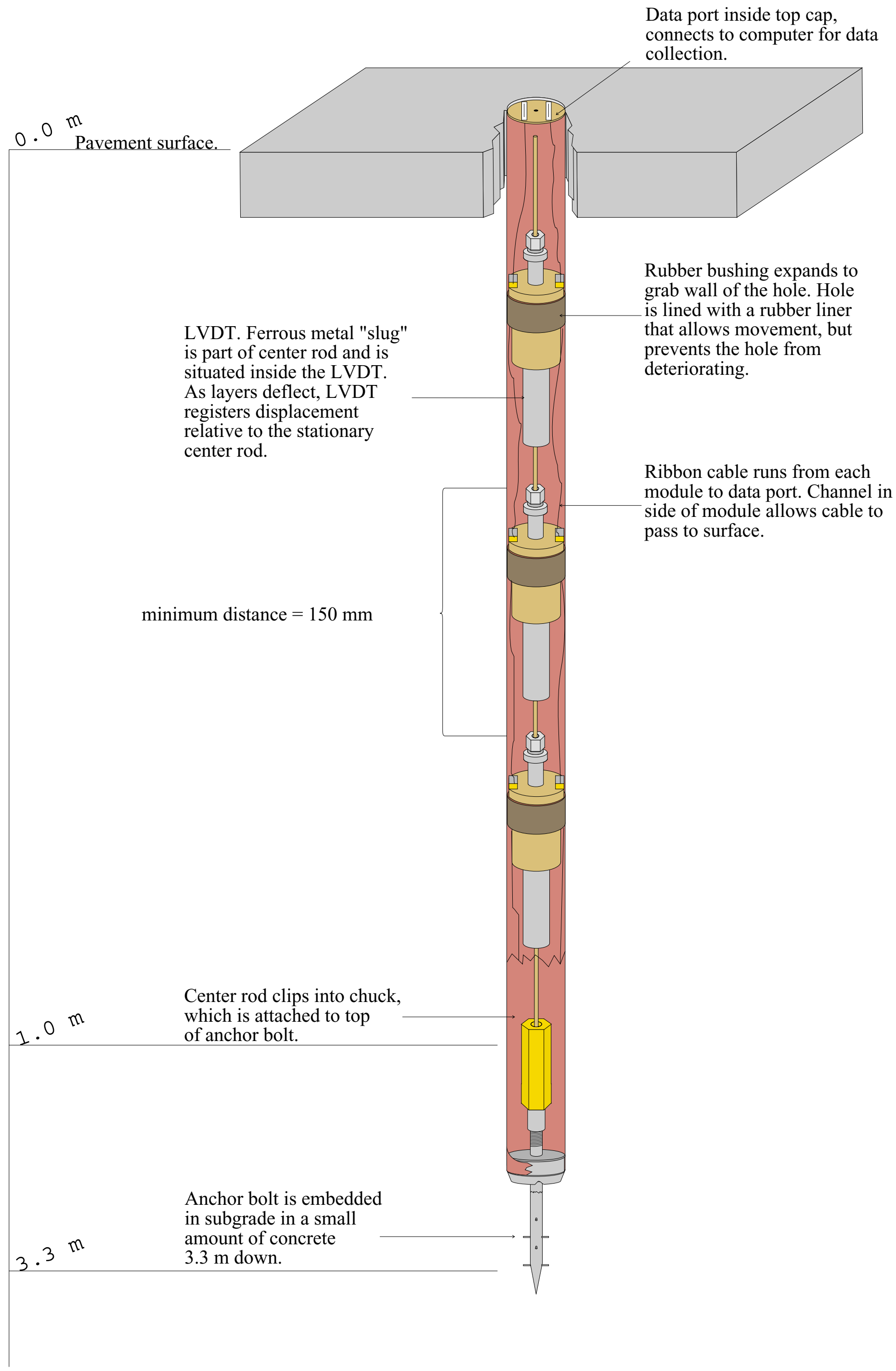

Figure 6.18. Schematic of Multi-Depth Deflectometer (MDD) Array.

6.5.2 North Tangent MDDs

The North Tangent MDDs will be installed in the beginning of 1999. Each MDD location will have five modules. One MDD location from each section on the North Tangent will be connected to the CR10X for continuous monitoring of the gages for measurement of environmental effects. The MDDs on sections 7C, 9C, and 11C will initially be connected to the CR10X. For each of these sections, when the HVS begins trafficking the section, the online MDDs will then be connected to the HVS data acquisition system. Appendix A shows the MDD locations of the 13 MDDs on the North Tangent.

6.6 Crack Activity Meter (CAM)

The Crack Activity Meter, manufactured by the Council for Scientific and Industrial Research (CSIR), is used to measure the horizontal and vertical displacement of cracks during dynamic loading. The device consists of two Linear Variable Differential Transformers (LVDT), one oriented horizontally and one oriented vertically, as illustrated in Figures 6.19 and 6.20. CAMs will be placed over joints on HVS loaded sections to measure the relative displacement between two adjacent slabs. The CAM data will be used for determination of the load transfer capacity between two slabs.

6.7 Thermocouples

The thermocouples used were assembled by the UCB Pavement Research Center. Type K (nickel-chromium and nickel-aluminum leads) and Number 24 American Wire Gage thermocouple wires were used. The thermocouple wires are manufactured by Omega

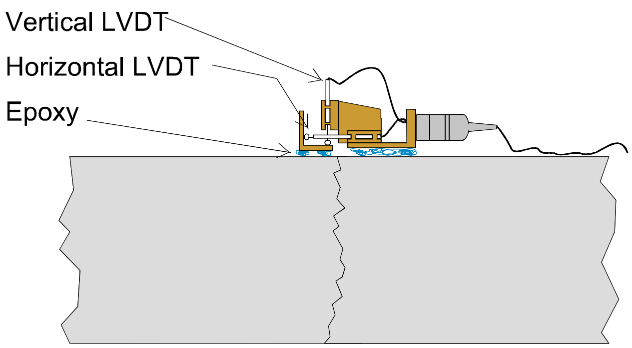

Figure 6.19. Diagram of Crack Activity Meter (CAM) on Cross-section of Pavement.

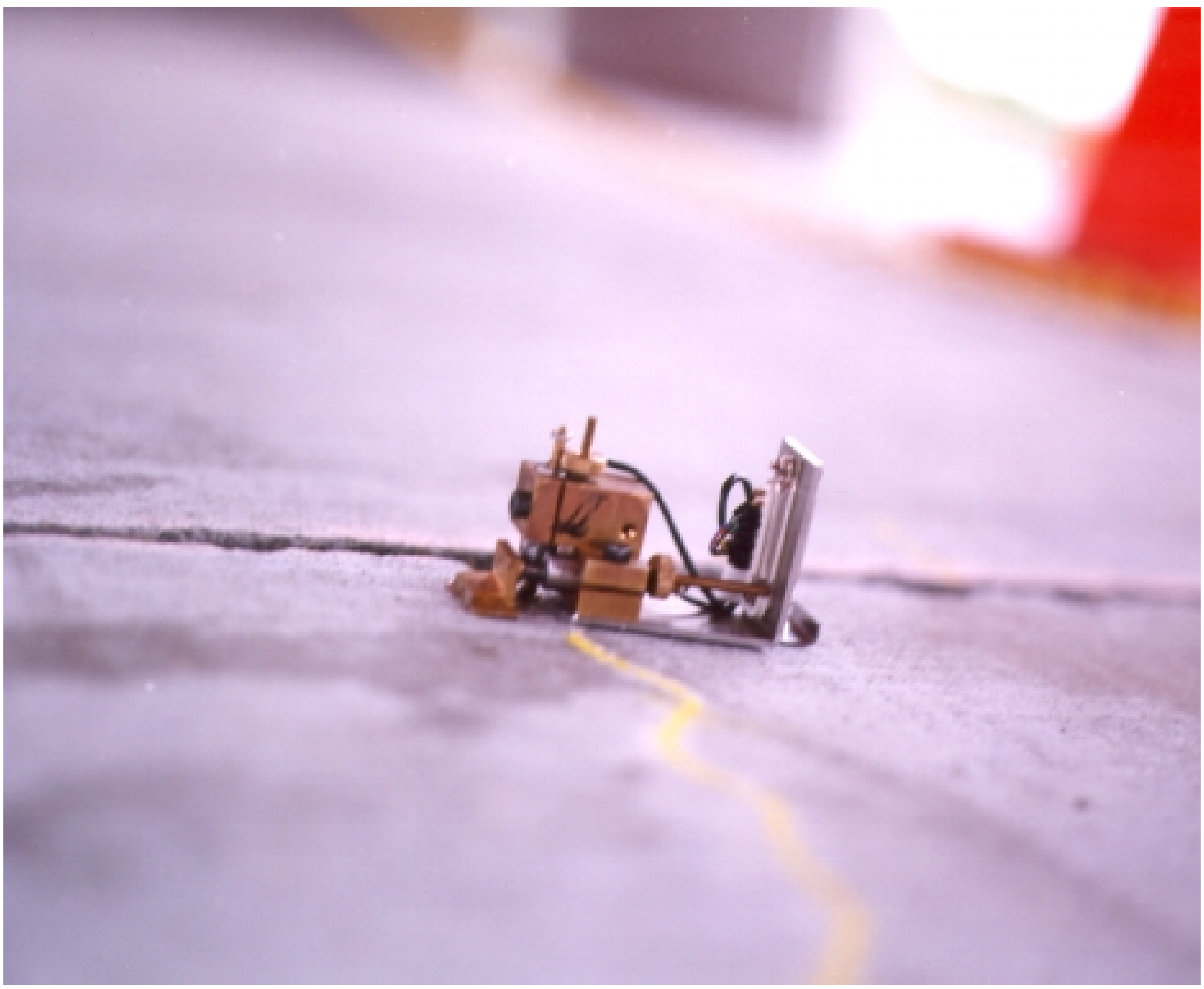

Figure 6.20. Crack Activity Meter (CAM) in Typical Position over a Crack.

Technologies Company and have a maximum temperature reading of 200°C. The thermocouples were constructed by twisting the stripped ends of the thermocouple wire and then adding a small amount of electrical solder. The thermocouples were then taped to wooden dowels so when the dowels were embedded in the concrete, the thermocouples would read the temperature at multiple depths. Most thermocouples were spaced at 50-mm intervals through the slab depth. The construction and orientation of a thermocouple is shown in Figures 6.21 and 6.22. The thermocouples are continuously monitored by the CR10X data acquisition system. A total of 226 thermocouples were installed in the pavement at Palmdale. Appendix A shows the location of all thermocouples.

6.8 Environmental Strain Gage

The environmental strain gages used were the Carlson A-8 strain meter, manufactured by RST Instruments, Inc. Shown in Figures 6.15 and 6.23, the instrument is tubular in construction and contains two coils of highly elastic steel wire. One coil increases in length and electrical resistance when strained, while the other decreases in length when unloaded or compressed. The gages were placed in the concrete pavement at various critical locations near the surface and bottom of the pavement to measure strains caused by length changes in the pavement due to thermal changes and curing. The Carlson A-8 gages are monitored continuously by the online data acquisition system. A total of 24 Carlson A-8 gages have been embedded in the Palmdale test sections. Appendix A shows the locations of the Carlson A-8 gages on the Palmdale test sections.

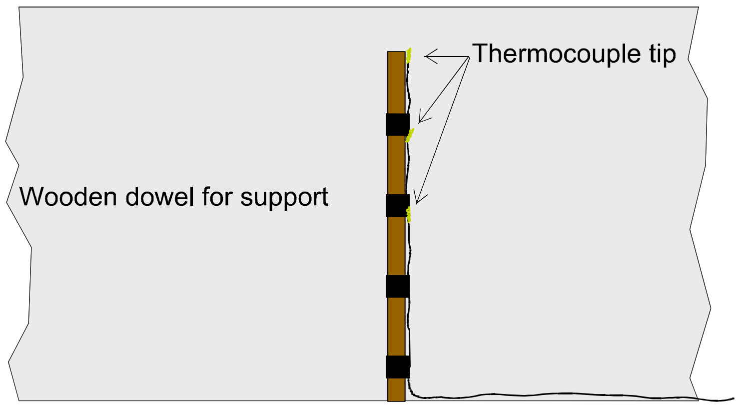

Figure 6.21. Diagram of Thermocouple as Oriented in Cross-section of Pavement.

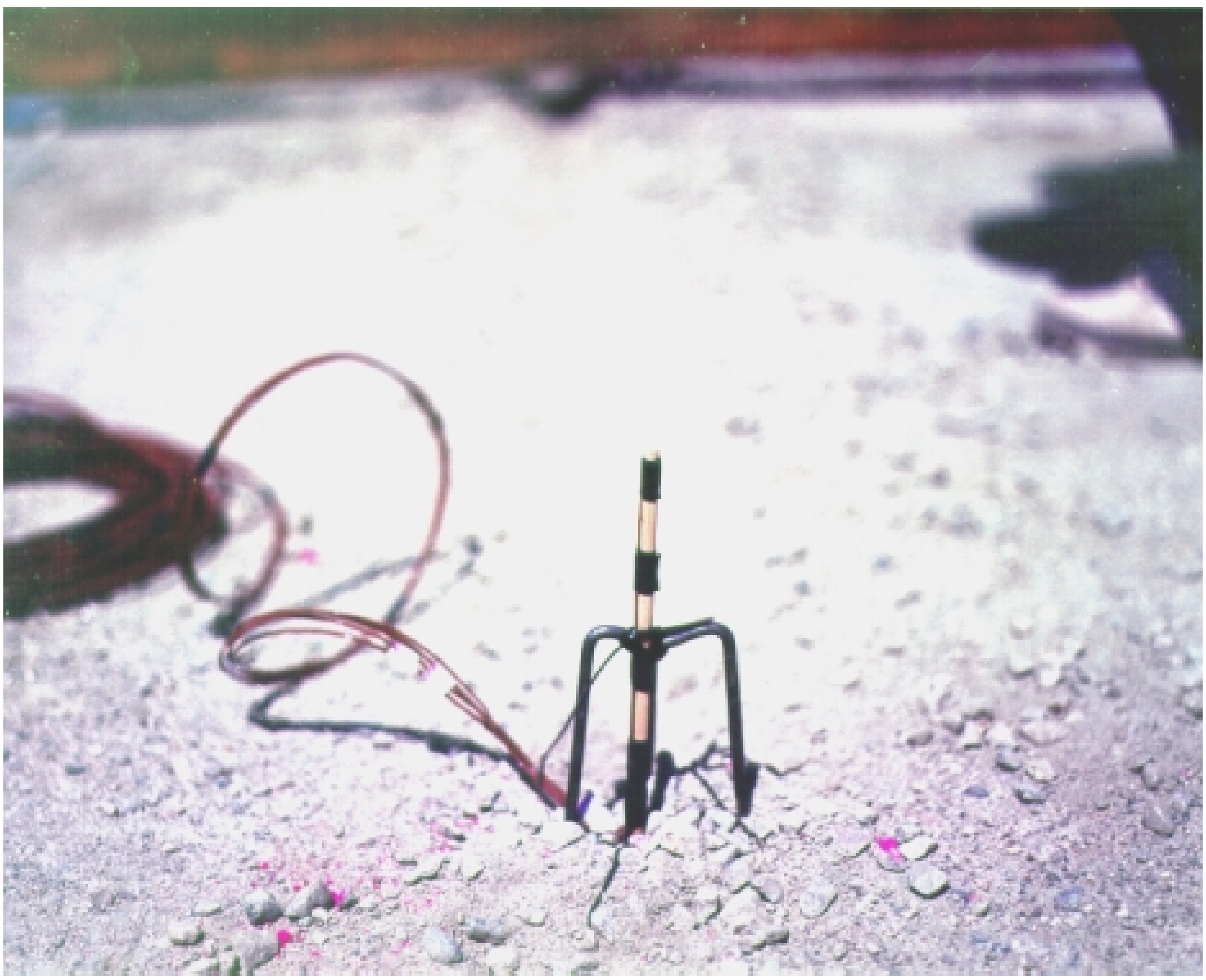

Figure 6.22. Thermocouple prior to Placement of Concrete, South Tangent.

Figure 6.23. Carlson A-8 Strain Meter prior to Placement of Concrete, South Tangent.

6.9 Joint Displacement Measuring Devices (JDMD)

The JDMDs, manufactured by the UCB Pavement Research Center, are used to measure vertical and horizontal joint displacement under dynamic loads and temperature changes. For environmental changes, the JDMDs can be used in two separate configurations. The first device can measure the relative vertical and horizontal displacement across a joint. Each device consists of one Linear Variable Displacement Transducer (LVDT) for vertical displacement and one LVDT for horizontal displacement, as shown in Figure 6.24. Section 7C on the North Tangent

Figure 6.24. Joint Displacement Measuring Device (JDMD) on South Tangent. ***(Edge Displacement Measuring Device is essentially identical except that it is placed in the middle of the slab instead of at the joint.)***

uses this type of setup to measure horizontal joint movement and relative deflection between the adjacent slabs.

Another configuration for JDMDs, used to measure environmental effects, utilizes an anchor piece that can be driven into the ground adjacent to the slab for absolute measurement of deflection at the slab corners. Sections 5C, 9C, and 11C have installed the two vertical JDMDs at the corner of two adjacent slabs. The purpose of these gages is to measure the corner lift of the slabs due to daily and seasonal temperature changes.

The second JDMD configuration is also being used with the HVS data acquisition system to measure joint displacement during HVS dynamic loading. The output of the JDMDs in this configuration will be used to measure the deterioration of load transfer efficiency across the joint within increasing HVS repetitions. Appendix A shows the locations of the JDMDs on the Palmdale test sections.

6.10 Edge Displacement Measuring Devices (EDMD)

Edge displacement measuring devices are similar to dynamic JDMDs except that they are used at the mid-slab edge to measure displacement during HVS dynamic loading (see Figure 6.24). The EDMDs are not connected to the online system at any location. Each HVS test section will have one EDMD and two JDMDs.

6.11 Instrumented Dowel Bars

In the North Tangent, three strain-gaged dowels have been installed at one joint in both Sections 11 and 7. These instrumented dowels were prepared by Professor Shad Sargand of Ohio University, and are being continuously monitored by the online data acquisition system. The purpose of gaging the dowels is to determine the effect of environmental changes on the strains in the dowels.

The instrumented dowels are 38 mm diameter by 450 mm long steel bars, spot welded to a frame to ensure the dowels were oriented properly in the slab. The dowels were spaced 300 mm center to center and 150 mm from the slab edge. Each instrumented dowel had two axial strain gages to measure bending strain and one strain gage rosette to measure bending and shear strain. Figure 6.25 shows the placement of the strain gages on the individual dowels prior to welding them into the dowel frame. Figures 6.26 and 6.27 show which dowels have strain gages