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Gordon K. Wells and Stephan M. Wiley

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16. ABSTRACT

This study involved various PCCP rehabilitation techniques to improve the rideability and structural integrity of the pavement system.

During this study, pavement grinding, slab replacements, asphalt concrete (AC) overlays, slab jacking, grout subsealing, joint and random crack sealants, and edge drains were evaluated. This resulted in specification changes and discontinuation of some techniques.

This study resulted in a moratorium on grout subsealing, provided tentative guidelines for the installation of retrofit edge drains, and provided the basis for further research to determine design strategies for rehabilitating PCCP.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

EVALUATE EFFECTIVENESS OF PCCP REHABILITATION TECHNIQUES

Study Supervised by . . . . Robert N. Doty, P.E.

Principal Investigators . . . . . . James H. Woodstrom, P.E.
Joseph B. Hannon, P.E.

Co-Principal Investigator . . . . . Gordon K. Wells

Report Prepared by . . . . Gordon K. Wells
Stephan Wiley

RAYMOND A. FORSYTH, P.E.
Chief, Office of Transportation Laboratory

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (1) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi$\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ (MPa$\sqrt{m}$)
	pounds per square inch square root inch (psi$\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ (KPa$\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

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INTRODUCTION

Most of California's portland cement concrete pavements (PCCP) have generally performed satisfactorily beyond their anticipated 20-year design life, even when traffic volumes exceeded those that were predicted for the initial design. These pavements have reached or are now approaching a stage of faulting or other type of failure which will reduce riding comfort and/or structural integrity to an intolerable level. Proper rehabilitation to slow down or correct this deterioration is becoming increasingly important.

When this Research Project was approved on October 1, 1981, the objectives were to:

1. Determine the relative effectiveness of various rehabilitation techniques and

2. Optimize particular techniques that would provide the most effective combined rehabilitation strategy for PCCP.

Rehabilitation techniques to restore riding quality to PCCP are dependent on the existing condition of the pavement as summarized below:

Rehabilitation Technique	Existing PCCP Condition
1. Pavement Grinding	Used where pavement faulting is severe but the overall pavement retains structural integrity.
2. Slab Replacements	Used where some panels have broken up but the overall pavement retains structural integrity.

3. Overlays

a. Asphalt Concrete (AC)	Used where PCCP has also lost most or all of its structural integrity.
b. Thick, unbonded PCCP	Same as for 3a, above.
c. Thin bonded PCCP	Used where a large portion of the pavement surface has deteriorated; however, the PCCP retains structural integrity.

4. Slabjacking	Used to raise settled PCCP panels to profile grade.

Rehabilitation techniques to restore PCCP structural integrity are dependent on several factors, such as load history, projected traffic, efficiency of the existing joint system, pavement drainage and the condition of the base. Some techniques used to address these problems are summarized below:

<u>Rehabilitation Technique</u>	<u>Intent</u>
1. Grout subsealing	To reduce slab deflections by filling voids and thereby restoring full slab support.
2. Joint and Random Crack Sealants	To reduce the amount of surface water available for the pumping process (that results in faulting) and the amount of incompressible materials entering the joint system or cracks (that results in spalling and faulting).

3. Edge Drains	To remove infiltrated surface water from the base to reduce pumping and slab faulting.

Specific rehabilitation techniques that will be discussed in this report are: grinding, slab replacements, asphalt concrete overlays, slabjacking, grout subsealing, joint and crack sealants, and edge drains. Other rehabilitation techniques, such as PCC overlays of PCCP and thin bonded overlays, are subjects of separate research efforts and are not discussed in this report. Therefore, the main thrust of the research reported herein is to describe and present the evaluation of rehabilitation techniques and strategies which are currently used in California to retain the PCCP as "white" pavement.

On December 31, 1982 the California Department of Transportation (Caltrans) mandated the use of two PCCP rehabilitation strategies to accelerate rehabilitation projects from the project report stage to the construction stage in order to take advantage of the new five-cent per gallon Federal and two-cent per gallon State gas tax revenues. Strategy No. 1 was to crack and seat PCCP slabs, place a 0.10' leveling course of DGAC, place a pavement reinforcing fabric and then place 0.25' of DGAC. An edge drain system was also included in this strategy. This strategy was intended for use when the PCCP was in an advanced stage of deterioration since it is more economical to overlay than to repair the PCCP.

Strategy No. 2 was to be used when most of the slabs were intact but the ride was becoming progressively worse due to pumping, faulting, and loss of slab support. A combination of the following rehabilitation techniques were to be used:

1. Grout subsealing.

2. Installation of edge drains.

3. Pavement grinding of the PCCP surface.

4. Joint and random crack sealing.

5. Slab replacements.

The intent was to obtain an additional 10 years of service with minimal maintenance cost. The above-mentioned techniques and their relative performance are described below. Also included are methods and procedures for monitoring the rate of pavement deterioration and unsuccessful attempts to locate or detect voids under PCCP prior to subsealing for the purpose of determining subsealing needs.

METHODOLOGY TO EVALUATE REHABILITATION TECHNIQUES

PCCP faulting or step-off at the transverse joints is caused by a pumping process that eventually causes uneven slab support leading to slab cracking and eventual slab breakup(1). To measure the progression of faulting on individual projects, a simple frame with a dial gage reading to the nearest 0.001 inch was used to measure the faulting of individual pavement slabs. The device (Figure 1) was placed so that the gage would measure (to the nearest 0.01 inch) the faulting one foot in from the shoulder at each pavement joint. Twenty-five consecutive joints were measured at each test site. The recorded measurements were then arithmetically averaged to obtain an average value for the twenty-five consecutive joints. By graphing "average fault" vs "time" for each test site, and then using a least squares linear regression, the faulting rate in "inches per year" was determined. Fault monitoring sites were established on rehabilitation projects where retrofit edge drains were the primary strategy and at sites where grout

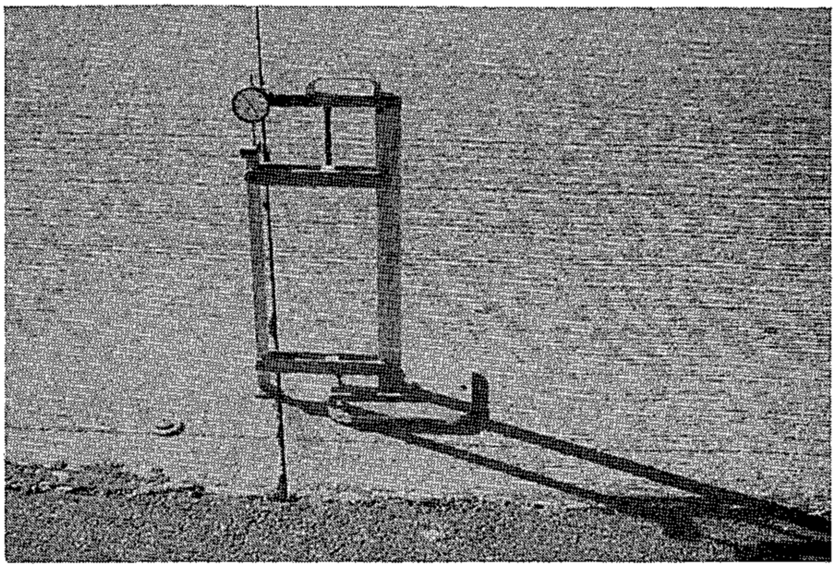

Figure 1 Fault Monitoring Gage

injection was combined with retrofit edge drains. By comparing the faulting rates at various test sites, the relative effectiveness of these rehabilitation techniques could be evaluated. Some other rehabilitation techniques that were used did not warrant this type of monitoring and were better evaluated by periodic visual inspections.

A Portland Cement Association (PCA) type road meter, similar to that used for the Caltrans Pavement Management System (PMS) for pavement condition surveys, was also used. PMS data are routinely collected by Caltrans every two years to determine the rideability and structural condition of all pavements to determine priorities for rehabilitation. By comparing the historical data from the PMS surveys on rehabilitation projects, the effectiveness of the rehabilitation techniques could also be evaluated.

On a PCCP rehabilitation project in District 6 (6-Ker-5-R0.0/29.0) where grout subsealing was evaluated, several pavement deflection testing devices were used. These were the Dynaflect, the Falling Weight Deflectometer (FWD), and the Road Rater. These devices and a radar device will be discussed in the following section and in Appendix 2 of this report.

To determine the effectiveness of cracking and seating PCCP prior to placing AC overlays, differential joint deflections (Δ-verts) under an 18 kip axle load were measured on several projects prior to and after the crack and seat operation.

EVALUATION OF REHABILITATION TECHNIQUE(S)

Pavement Grinding

The only effective method of grinding PCCP to restore a smooth riding surface is by using diamond impregnated blades and water. Milling machines that use carbide bits tend to spall the concrete, especially at the transverse joints, leaving a rough textured surface which creates a noisy, rough ride.

Pavement grinding has been used on California PCCP rehabilitation projects with Ride Scores $\geq$45 to reduce the Profile Index to 15 inches per mile or less, according to California Test 526. This has recently been reduced to 12 inches (maximum) per mile.

The first grinding project in California to restore ride quality was on I-10 near San Bernardino in 1963(2). The successful performance of this project led to the full-scale use of diamond blade grinding of PCCP throughout the state. Grinding provides a cost-effective alternative to an AC overlay over the entire pavement width when, in most cases, it is only the truck lane that has the rough ride.

Slab Replacements

Slab replacements in California generally consist of the complete removal of the shattered PCCP and underlying base. The subgrade is recompacted. Then a full depth (original PCCP thickness plus base thickness) repair is accomplished using a 7-sack concrete mix with up to 2% calcium chloride ($CaCl_2$).

The major problem with this technique has been spalling at the transverse joints in either the older abutting slab ends or in the new replacement concrete. Investigation has indicated that part of the problem occurs during the slab removal operation. If impact devices are allowed to operate next to the concrete which is to remain in place, the lower portion of the old slab is often damaged. This weakened concrete then spalls at the transverse joints and sometimes, along the longitudinal joint.

Spalling of the replacement concrete appears to be caused by the direct contact of the replacement concrete with the existing concrete at the transverse joints. When the surface of the old existing (thinner) slab cools in the evening, the temperature gradient through the slab causes curling which induces stresses in the new thicker concrete in contact along the remaining bottom lip of the original weakened plane joint in the existing concrete. This curling causes a spall to occur in the new concrete to the depth of the original weakened plane joint. To prevent this type of spalling, Caltrans' specifications now require full depth sawing of the perimeter of the concrete to be removed. Also, impact-type equipment cannot be used to break up the slab within 18 inches of the saw cut. After removal and prior to replacing the concrete, a 1/4-inch thick polyethelene flexible foam expansion joint filler is placed across the original transverse joint faces the full depth of the excavation, with the joint filler flush with the top of the slab. After the new slab is poured, any curling of the adjacent slab at the transverse joints is absorbed by the polyethelene joint filler, thereby reducing stresses that could cause spalling of the new concrete. Although our experience using this technique is limited, it appears to be successful at this time.

Asphalt Concrete Overlays

Because asphalt concrete (AC) overlays can be placed fairly rapidly and opened to traffic soon after placement and compaction, they are the most widely used means of rehabilitating PCCP which has reached an advanced state of structural distress. However, there are many instances where this has not been a successful rehabilitation technique. The primary problem has been the development of reflection cracking through the overlay from the underlying PCCP transverse and longitudinal joints.

PCCP slabs expand and contract from seasonal temperature variations. Also, daily temperature changes create thermal gradients that, in conjunction with moisture gradients through the slab, result in slab curl. Wheel loads crossing these curled slabs and rocking slab fragments result in differential slab deflections and, often, reflection cracks in the AC overlay. In addition, AC pavements become brittle at lower temperatures so a slight contraction of PCCP joints will cause eventual cracking of the AC. When cracks open in the AC surface, surface water infiltration increases as does the introduction of incompressible fines and oxidation of the asphalt, which results in a continuing enlargement of the crack. This eventually requires extensive maintenance and results in a rough riding pavement.

Recent research(3,4) indicates that reflection cracking through AC overlays can be effectively reduced by cracking slabs into subpanels and by rolling to seat them and reestablish full slab support prior to placement of the overlay. The benefits of cracking and seating PCCP are:

1. Reduces the slab size such that thermal movements of the subpanels are negligible.

2. Restores full slab support by the base.

3. Reduces the amount of slab curl.

The PCCP is cracked into segments nominally 6 feet transversely by 4 feet longitudinally and traffic is to be allowed to use the cracked PCCP for up to a maximum of 15 days prior to overlaying.

On PCCP rehabilitation project 06-Ker-99 near Bakersfield, completed in 1982, seven 600-foot-long test sections using different overlay strategies of AC over PCCP were the subject of "Construction Evaluated Research Project CA-82-11".

Table 1, which summarizes the performance to date, indicates that cracking and seating is effective in retarding reflective cracking.

Note that the total AC thickness is 0.30 feet for this project; however, the current Caltrans strategy for cracked and seated PCCP requires a 0.10 feet minimum AC leveling course, followed by a pavement reinforcing fabric that overlaps the pavement/shoulder joint by 2 feet, followed by 0.10 feet of AC, and then a final lift of 0.15 feet of AC, for a total AC thickness of 0.35 feet.

The use of pavement reinforcing fabric has often been effective in retarding reflective cracking; however, edge drains are also installed routinely to ensure that the cracked PCCP base will remain stable if surface water infiltration should penetrate the overlay.

Slabjacking

During the period of this research, only one rehabilitation project had a contract item for slabjacking. Unfortunately, the subcontractor doing the work was inexperienced and no meaningful data could be obtained. However, the slabs that were jacked using a cement/pozzolan grout are performing satisfactorily at this time. This technique should probably remain a maintenance procedure as discussed later.

Grout Subsealing

In the previously cited PCCP strategy No. 2 (Appendix 1), subsealing with a cement/pozzolan grout to fill voids under the slab (in order to restore full slab support) was recommended. This is a technique promoted by the FHWA, industry, and construction-related associations. This rehabilitation technique is the most controversial PCCP rehabilitation technique that Caltrans has used.

TABLE 1

CRACKING SUMMARY TABLE
06-Ker-99 - 9.0/10.5 SB (Bakersfield)
Rehabilitated June 1983

Test Sections	No. of Transverse Cracks (lane 3) 6/85	No. of Transverse Cracks (lane 3) 11/86	Approximate % of PCC Joints Reflected 6/85	Approximate % of PCC Joints Reflected 11/86
A. Control Section (No C&S*, No Fabric)	29	35	78	95
D. Typical Section** (except Pneumatic Roller Seating)	0	0	0	0
C. Control Section (With Fabric, No C&S)	20	20	53	53
B. Typical Section (except No Fabric)	0	0	0	0
E. Typical Section (except chisel end bit for cracking)	0	0	0	0
F. Typical Section (except no Seating)	0	0	0	0
G. Typical Section	0	0	0	0

*C&S = Cracked and Seated
**Typical Section = 0.30 feet AC overlay with fabric over cracked and seated PCCP. Cracking with blunt end bit.

Note:

1. All cracked and seated test sections were seated with a vibratory sheeps foot roller, except test Section D.

2. Edge drains were not installed in this project.

Caltrans subsealing specifications are based, to a large extent, on information contained in the 1982 AASHTO Task Force 23 Draft on "Subsealing and Slabjacking". Some of the salient points of the AASHTO draft are:

1. Injection pressures should normally be limited to <100 psi.

2. Slab uplift should be limited to <0.050 inch.

3. Injection holes should not penetrate more than 6 inches into the subgrade.

The final AASHTO Task Force 23 report(5) differs significantly from the aforementioned 1982 draft. Initial injection pressures as well as allowable slab uplifts are higher, the former significantly so.

Present Caltrans specifications limit injection pressure to <150 psi, slab uplift to 0.050 inch maximum, and injection hole depths to between 15 and 18 inches below the pavement surface. The Contractor is required to have the proposed grout pretested by a private testing laboratory for the initial set time and the one-, three-, and seven-day compressive strengths of the grout at 10, 12 and 14 second efflux times.

Table 2, "Summary of Retrofit Edge Drain and Grout Injection Sites," contains the results for the fault monitoring sites where the benefits of edge drains with and without grout injection have been studied.

A comparison of average faulting rates (inches per year) on projects having retrofit edge drains with and without grout injection, and control sections where no rehabilitation was done, is shown in Table 3.

TABLE 2

SUMMARY OF RETROFIT EDGE DRAIN AND GROUT INJECTION SITES

(1) Dist.	(2) Co.	(3) Rte.	(4) PM	(5) Direction	(6) Site	(7) Permeable Material	(8) Grout Take	(9) Faulting Rate	(10) Total Start	(11) Cracks Finish	(12) Constr. Year	(13) Rehab Year	(14) Time
2	Teh	5	0.00	NB	C	-	-	0.001	3	5	1966	-	30
2	Teh	5	0.11	NB	GI ED	CTPM	65	0.006	1	1	"	1983	"
2	Teh	5	1.00	NB	ED	CTPM	-	0.008	0	0	"	"	"
2	Teh	5	14.63	NB	ED	CTPM	-	0.009	0	0	"	"	"
2	Gle	5	28.56	SB	C	-	-	0.010	0	1	"	-	"
2	Teh	5	0.00	SB	GI ED	CTPM	65	0.005	1	2	"	1983	"
2	Teh	5	12.00	SB	GI ED	CTPM	65	0.005	10	10	"	"	"
2	Teh	5	21.00	SB	GI ED	CTPM	65	0.009	0	0	"	"	"
2	Sis	5	9.65	NB	GI ED	UTPM	88	0.003	7	9	1967	1982	40
2	Sis	5	11.17	NB	C	-	-	0.012	13	13	"	-	"
2	Sis	5	11.17	NB	ED	UTPM	-	0.008	13	13	"	1982	"
2	Sis	5	11.50	NB	GI ED	UTPM	88	0.009	5	6	"	"	"
2	Sis	5	11.50	SB	ED	UTPM	-	0.00002	0	0	"	"	"

TABLE 2 (Continued)

SUMMARY OF RETROFIT EDGE DRAIN AND GROUT INJECTION SITES

(1) Dist.	(2) Co.	(3) Rte.	(4) PM	(5) Direction	(6) Site	(7) Permeable Material	(8) Grout Take	(9) Faulting Rate	(10) Total Start	(11) Cracks Finish	(12) Constr. Year	(13) Rehab Year	(14) Time
2	Sis	5	11.50	SB	GI ED	UTPM	88	0.001	0	0	"	"	"
2	Sis	5	37.0	NB	GI ED	ATPM	16	0.004	21	21	1970	1984	25
2	Sis	5	37.0	SB	GI	ATPM	16	0.007	7	7	"	"	25
10	SJ	580	9.00	EB	ED	CTPM	-	0.008	0	1	"	1984	24
10	SJ	580	9.00	EB	GI ED	CTPM	16	0.009	0	0	1968	"	"
10	SJ	580	9.00	EB	C	-	-	0.009	0	0	1968	-	"

Legend:

(1) District
(2) County
(3) Route
(4) Post Mile
(5) Direction NB = Northbound, SB = Southbound, etc.
(6) C = Control, no rehabilitation technique used.
GI = Grout Injection
ED = Edge Drain
(7) Permeable Material
UTPM = Untreated permeable material
ATPM = Asphalt treated permeable material
CTPM = Cement treated permeable material
(8) Grout take (pounds per hole)
(9) Faulting rate (inches per year)
(10) Total number of slab cracks (start of study)
(11) Total number of slab cracks (end of study)
(12) Construction Year
(13) Rehabilitation year
(14) Monitoring period in months.

TABLE 3

COMPARISON OF FAULTING RATES

Dist.	Co.	Rte	PM	Grout Take lb/hole	Faulting Rates, Inches/Year: Grout Injection and Edge Drain	Edge Drain Only	Control (No Rehab)
2	Teh	5	0/23.0	65	0.006	0.008	0.011
2	Sis	5	6.2/12.6	88	0.004	0.004	0.012
2	Sis	5	36.3/43.0	16	0.006	-	0.007

Table 3 indicates that when a comparison could be made on the same project, only one project appears to have benefited from both grout injection and edge drains at this time (2-Teh-5).

Personnel of the Offices of Transportation Laboratory (TransLab) and the Highway Construction studied the grouting process during construction on three projects. The first was cored (District 2 at Mount Shasta) whereas on the other two, partial slabs were removed (at Cajon Pass and Colton in District 8). On the Mount Shasta project, the CTB had deteriorated to an aggregate base; on the other projects, the CTB was in good to excellent condition and the subseal grout was found only between the slab and base, indicating that the grout had filled the "void" due to the curling phenomenon of the slabs. On five other rehabilitation contracts where grout subsealing was done, the PCCP has developed significant additional distress in the form of accelerated third stage breakup and/or corner breaking.

In addition, the review of a sixth project (completed in 1983), revealed new hairline cracking in the slabs. The above projects will be subject to follow-up monitoring.

A matter of additional concern surfaced when maintenance forces recently replaced broken slabs on one of the above projects, they found the edge drain plugged in this location. Analysis of the material in the pipe indicated 7% by weight of CaO material. Thus, there is a possibility that some of this material could be subseal grout that has disintegrated or did not set up, and/or had been pulverized and then been pumped into the edge drain. Pretesting of the grout was not a specification requirement at the time of the subsealing on this project. Subsequent to this grouting operation, low grout strengths and out of specification cement/pozzolan grout mixtures on other projects led to the development of a pretest requirement.

Experience compiled by the Office of Highway Construction on contract subsealing is summarized in Appendix 3. These data illustrate the costly contract item adjustment problems encountered by Caltrans due to an inability to prelocate voids and to reasonably estimate grout-take prior to contract. To do this, TransLab completed field work in February, 1985, as part of an addendum to the original work plan for this research project titled, "Evaluate Void Detection and Subsealing of Portland Cement Concrete Pavement on 06-Ker-5-R0.0/29.0 (Contract No. 06-246004)." This work consisted of using various deflection devices and radar to determine the location of subsurface voids for purposes of subsealing (see Appendix 2). The test project was located on I-5 west of Bakersfield. Test sections were subsealed using modified grouting procedures consisting of variable injection hole depths and patterns, both cored and percussion drilled grout holes, greater allowable slab uplift, and higher injection pressures. The deflection devices consisted of a Dynaflect, a Falling Weight Deflectometer, and a Road Rater. The radar was a unit developed by Rodar, Inc. (Gulf Applied Radar Co.). Generally, there was fair correlation of the deflection devices as far as deflection was concerned; however, there was no correlation between deflection and grout take in the various test sections.

Later reviews of previously rehabilitated pavement and ongoing contracts incorporating cement/pozzolan grout subsealing led to a moratorium on the use of this technique on October 8, 1985. Caltrans' concern with grout subsealing was summarized in a research proposal submittal to the Transportation Research Board for a Division A - Group 2 "Outline for Research Problem Statement" titled, "A Study of Subsealing as a Rehabilitation Technique for Portland Cement Concrete Pavement (PCCP)" (see Appendix 4).

Joint and Random Crack Sealants

Weakened plane joints in PCCP are constructed to control random cracking of slabs due to drying shrinkage of the concrete. Sawing and plastic inserts are two methods which may be used to construct or form these joints.

The sawing method involves using a steel blade with impregnated diamond particles to saw to a depth of 25% of the slab thickness. Timing of this operation is critical if random cracking is to be avoided.

The plastic insert method involves placing the insert in fresh concrete by mechanical means. This technique generally ensures that the initial cracking will occur at the weakened plane joint.

Random cracks occur for a number of reasons, but appear to be related to environmental conditions and/or improper timing of sawing or placement of the insert. When random cracks occur, epoxy injection of cracks within 5 feet of a weakened plane joint has been used to force the crack to the planned joint.

The purpose of a joint seal is twofold:

1. Prevent surface water infiltration to the subgrade which contributes to the pumping process.

2. Prevent fine incompressible materials from accumulating in the joint, restricting slab expansion, and thereby causing joint spalling.

Joint sealants are either liquid (poured in place) or preformed (installed as a unit). Liquid seals are either thermosetting (become rigid by chemical reaction and not remeltable) or themoplastic (softened by heat and sometimes remeltable). Thermosetting materials include polysulphides, polyurethanes, and silicone rubbers. Thermoplastic materials include rubber asphalts and PVC coal tar polymers.

Research(6) indicates that when poured sealants are used, the joint must have the proper ratio of width to depth, known as the shape factor. This research indicated that increasing the width and decreasing the depth of a joint sealant generally reduces strains in the sealant and improves the performance of poured seals. The use of a bond breaker or backing rod is necessary to eliminate bonding of the seal to the bottom of the joint so that strains are reduced within the sealant.

Preformed seals are generally neoprene rubber. Care must be taken during installation to saw the joint to the proper width so that the seal will have sufficient compression to remain in place when the joint opens during winter, and also not be squeezed out of the joint when the joint closes in the summer.

Pavements utilizing both sawed and plastic insert joints constructed circa 1972 in the Weed and Yreka areas were reviewed as part of this study. These areas have a severe environment with hot summers and cold, wet winters, i.e., conditions that promote large joint movements. Sanding of the pavements is extensive during winter when the joint openings are widest. During the dry months, native volcanic sands are blown across the pavements.

Where sawed joints were constructed, there did not appear to be a joint spalling problem even though the joints were full of incompressibles. Nonsealed joints were performing as well as preformed and poured sealed joints. However, the joint seal performance has been unsatisfactory due to the seals becoming loose or dislodged. Where plastic inserts were used, a rounding of the joint surface has developed. Small spalls have also developed at a large number of joints. While joint performance is generally satisfactory, spalling of random cracks is severe throughout this area.

A review of several joint sealant test sections in the Red Bluff and Dunsmuir areas that were installed on rehabilitation jobs is summarized on Table 4. The Allied 9007 and CRS2/sand/Reclamite sealants have not performed satisfactorily. The Allied 9007 had poor bond and its soft consistency has allowed incompressibles to penetrate the sealant. The CRS2 has a hard consistency and involves placing a considerable amount of sand (an incompressible) in the joint.

All the other sealants generally appear to be performing satisfactorily. Workmanship in placing the sealants appears to be a major factor in performance. Shape factor did not appear to be a critical factor with the vulcanized rubber asphalt sealants at this time except for the field-mixed Arizona Refining material.

A review of core samples from several projects using epoxy injection of random volunteer cracks indicated 100% failure of this technique. Failure occurred primarily in bond of the epoxy to the concrete, usually on one side of the epoxy but occasionally on both, allowing the epoxy film to fall free upon opening the core. While all the cores were intact when retrieved, the core halves could be readily separated with no more than a slight prying action with a penknife blade. Cores taken at the intersection of epoxied cracks and joints (both sawed and insert) indicate that epoxy injection did not force the weakened plane joint to crack.

Reviews of rehabilitated PCCP indicate that sealing of joints, random cracks, and the longitudinal pavement/shoulder joint does not significantly reduce the amount of surface water infiltration. This was determined by observing edge drain outlet discharges during storms.

Surveys of California PCCP indicate that joint spalling is not a major problem and is usually isolated to specific areas; however, the cause of the spalling is not always apparent. Spalling of random cracks, however, is a major problem. Thus, random cracks should be routed and then sealed with a premixed vulcanized rubber asphalt joint material.

TABLE 4

JOINT SEALANT SUMMARY

Product	Dow Corning 888	Superseal 111	Superseal 444	Superseal 444	Allied 9007	Allied 9012	Crafco Overflex MS	Crafco Overflex MS	Ariz.Refining RA (field mixed)	CRS2 Sand and Reclamite
Location (PM, Direction, lane)	2-Sis-5 0.5 NB #1 Test Sect.I	2-Teh-5 28.8 NB #1	2-Sha-5 65.5 NB #1	2-Sis-5 0.4 NB #1	2-Sis-5 0.6 NB #1	2-Sis-5 0.56 NB #1	2-Teh-5 28.8 NB #1	2-Sha-5 65.5 NB #1 Test Sect.III	2-Sha-5 65.5 NB #1 Test Sect.II	2-Sha-5 65.5 NB #1 Test Sect. I
Joint Geometry Width x depth, inches.	1/2x2	7/16x2-1/4	3/8x2	3/8x2	5/16x1-3/4	3/8x2-1/4	5/8x1	7/16x2	3/8x2	3/8x2
Backing Rod	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No
Bond Estimate	Good	Good	Poor	Good	Poor	Good	Good	Good to Poor	Good to Poor	Good
Consistency	Resists knife point	Pliable, knife point penetrates	Knife penetrates easily.	Knife penetrates	Knife penetrates easily. Leaves asphalt coating.	Resists knife point	Pliable, resists knife point	Pliable, resists knife point	Knife penetrates	hard, resists knife point
Incompressible Rejection	Rejecting	Accepting	Accepting	Rejecting	Accepting	Rejecting	Rejecting	Accepting	Accepting	-0-
Comments:	-0-	-0-	-0-	-0-	-0-	-0-	-0-	Contains large voids.	Tear at bottom of joint.	Considerable sand at bottom of joint.

Edge Drains

The major portion of the portland cement concrete pavements constructed in California are of the plain jointed design. All of these PCCP eventually develop faulting, or step-off, at the transverse joints. However, the magnitude and rate of this faulting varies considerably throughout the State. Faulting, through the pumping process, has been found to be a major factor in slab cracking and subsequent poor pavement performance.

Previous Caltrans research in this area revealed the mechanism of pavement faulting via the pumping process(1). One of the major contributors is surface water that has become trapped in the relatively impermeable structural elements. A research study was initiated in 1981 to evaluate the use of edge drains as a method of providing rapid drainage of this water and thereby delaying or preventing pumping and subsequent faulting(7).

The objectives of this edge drain research were threefold:

1. Determine the effectiveness of edge drains in reducing pavement faulting.

2. Optimize design features that have been incorporated in previous edge drain systems dating back to 1974.

3. Investigate methods to restore the drainage capacity of dirty or inoperative drains.

The research indicates that retrofit edge drains are very effective in reducing step faulting of PCCP in California. This is based on monitoring pavement performance at sites with and without edge drains by direct measurement of the progression of faulting with time. The data in Table 5 indicate that retrofit edge drains can reduce the rate of faulting and, thereby, provide significantly longer pavement service life.

TABLE 5

Summary of Retrofit Edge Drain and Control Sites

(1) Dist.	(2) Co.	(3) Rte.	(4) PM	(5) Direction	(6) Site	(7) Permeable Material	(8) Faulting Rate	(9) Total Slab Cracks Start	(10) Total Slab Cracks Finish	(11) Time
2	Teh	5	23.05	NB	C	-	0.017	1	1	25
2	Teh	5	23.45	NB	D	UTPM	-0.010	6	6	46
2	Teh	5	25.65	NB	D	UTPM	-0.008	1	1	46
2	Sha	5	14.0	NB	D	UTPM	0.003	13	14	46
2	Sis	5	11.17	NB	C	-	0.012	13	13	116
2	Sis	5	11.17	NB	D	UTPM	0.003	13	13	29
3	Yol	5	9.98	NB	C	-	-0.009	0	0	27
3	Yol	5	9.98	NB	D	CTPM	-0.006	5	5	27
3	Col	5	18.72	NB	C	-	-0.003	3	3	46
3	Col	5	21.0	NB	D	UTPM	0.004	0	2	46
3	Col	5	21.48	SB	C	-	0.004	13	19	46
3	Col	5	21.48	SB	D	UTPM	0.0008	9	12	46
3	Gle	5	0.75	NB	C	-	0.009	0	0	46
3	Gle	5	0.75	NB	D	UTPM	0.005	0	0	46
3	Gle	5	7.15	SB	C	-	0.001	0	3	46
3	Gle	5	4.0	SB	D	UTPM	0.007	1	1	46
4	Son	101	45.02	NB	C	-	0.017	0	2	64
4	Son	101	45.02	NB	D	CTPM	-0.007	2	2	45
4	Son	101	44.90	NB	D	UTPM	-0.001	0	1	52
4	Son	101	45.50	NB	D	CTPM	0.002	5	5	34
4	Son	101	46.54	SB	C	-	0.0003	6	6	22
4	Son	101	46.54	SB	D	CTPM	-0.014	1	1	22
5	SB	101	69.0	SB	C	-	0.007	19	19	106
5	SB	101	71.4	SB	D	Sand	0.009	22	22	106
10	SJ	205	4.0	EB	C	-	0.012	0	0	104
10	SJ	205	4.0	EB	D	UTPM	0.003	0	0	57
10	SJ	205	11.0	WB	D	UTPM	-0.006	5	6	42
10	SJ	580	9.0	EB	C	-	0.009	0	0	23
10	SJ	580	9.0	EB	D	CTPM	0.010	0	2	23

Legend:

(1) District (2) County (3) Route (4) Post Mile
(5) Direction NB=northbound, SB=southbound, etc.
(6) C = Control, no edge drain
D = edge drain
(7) UTPM = untreated permeable material
CTPM = cement treated permeable material
(8) Faulting rate (inches per year).
(9) Total number of slab cracks (start of study).
(10) Total number of slab cracks (end of study).
(11) Monitoring period in months.

Average faulting rate of all the control sites = 0.006 inch/year
Average faulting rate of all the edge drain sites = -0.0003 inch/year

From: Wells, G. K., Evaluation of Edge Drain Performance
M&R 633363, F81TL16, Transportation Laboratory
California Department of Transportation, 1986

Because slab cracking is a primary indication of whether a PCCP will soon be in need of major rehabilitation, the edge drain locations reported in the above research were reevaluated to determine if the desired 10 years additional service life (before major rehabilitation is necessary) is being obtained using the retrofit edge-drain rehabilitation strategy. The age of the pavement, the percentages of first and third stage cracking prior to the installation of edge drains, and the accumulated ESAL between paving and the installation of retrofit edge drains were also determined.

Table 6 summarizes the research locations, the aforementioned parameters, and the performance rating (either failing or good) according to the 1985 Pavement Management Survey. Failing is defined as average third stage cracking (for the project) ≥10 percent.

Figure 2 shows the relationship between "mean percent first stage cracking" vs "accumulated ESAL," and Figure 3 shows the relationship between "years without retrofit edge drains" vs "accumulated ESAL," both in terms of the mean third stage cracking reported in the 1985 Pavement Management Survey.

These figures indicate that retrofit edge drain performance appears to be dependent on the age of the undrained PCCP, the mean percent first stage cracking, and the accumulated ESAL all at the time the retrofit edge drains are installed.

CONCLUSIONS

Pavement Grinding

When the existing PCCP is in good structural condition, grinding is the most economical method to restore ride quality. After grinding, edge drains should be installed to provide for drainage of surface water to reduce pumping and subsequent additional faulting.

TABLE 6

Retrofit Edge Drain Performance
1985 PMS Survey

Point No.	Dist	Co.	Rt	Edge Drain Limits	Year Paved	Year Installed	Years W/O Edge drains	Accum** ESAL x 10^6	Cracking Prior to Installation %1st L	R	%3rd L	R	1985 Performance Δ Failing* 0 Good
1	2	Teh	5	0/23.0	'66	'83	17	12.4	10	12	3	1	0
2	2	Teh	5	24.5/28.6	'65	'80	15	12.4	27	21	4	2	Δ
3	2	Sha	5	11.5/19.0	'67	'80	13	8.8	30	35	6	4	Δ
4	3	Yol	5	6.2/10.0	'69	'82	13	9.1	4	2	2	1	0
5	3	Col	5	18.7/21.5	'71	'79	8	7.2	7	8	3	1	0
6	3	Gle	5	0/7.6	'70	'79	9	8.0	3	1	1	0	0
7	4	Son	101	42.9/44.9	'75	'80	5	1.8	1	1	0	0	0
8	4	Son	101	44.8/48.8	'75	'81	6	2.1	19	16	1	3	0
9	6	Fre	5	52.4/55.2	'71	'82	11	10.2	1	1	0	1	0
10	10	SJ	205	4.0/13.1	'70	'79	9	12.2	7	6	0	0	0
11	10	SJ	580	9.0/15.3	'66	'81	15	15.5	6	4	0	1	Δ

L = Left outside lane.
R = Right outside Lane.
*The symbol Δ, failing indicates the PCCP is now a rehabilitation candidate.
**At the time edge drains were installed.

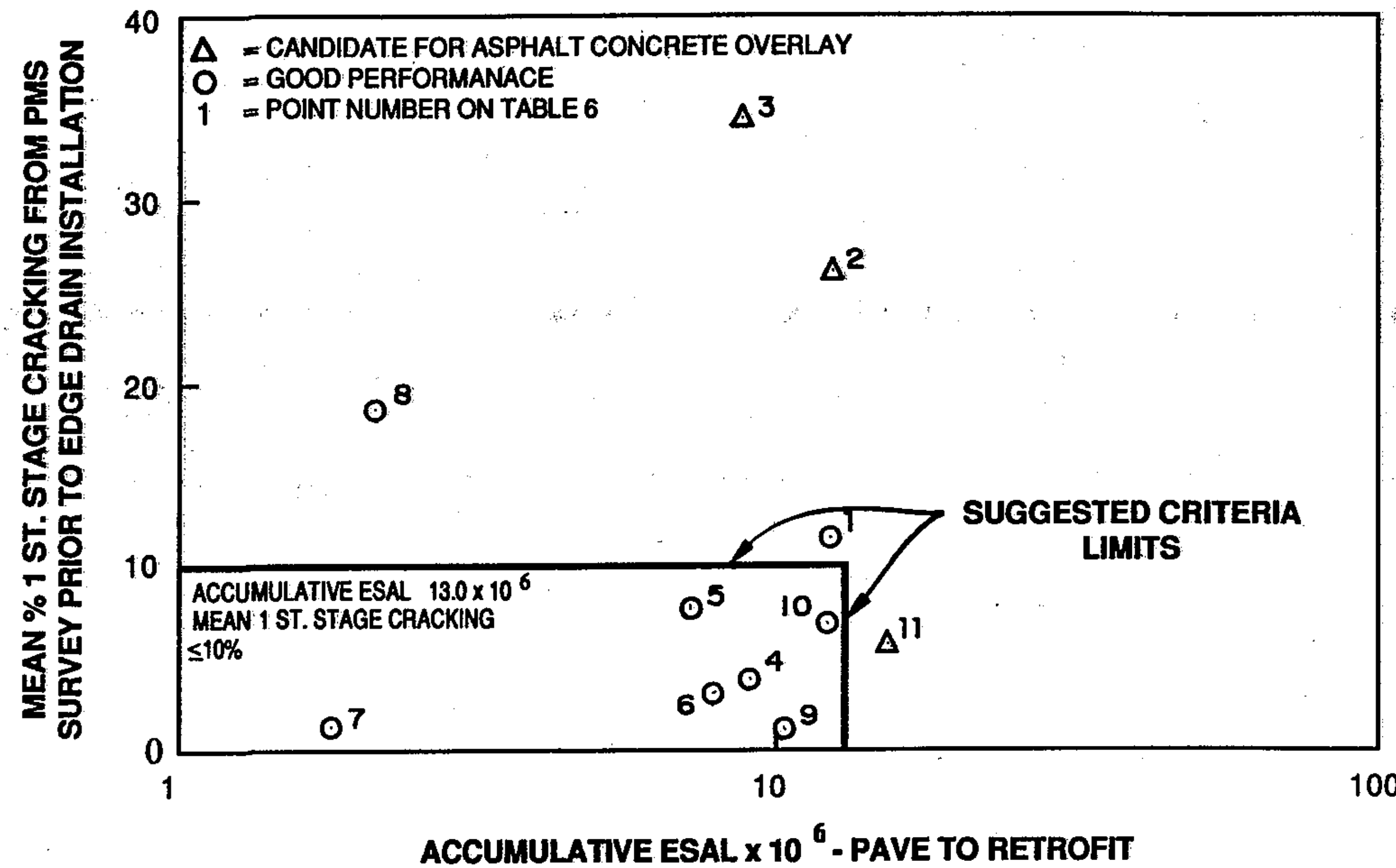

Figure 2, RETROFIT EDGE DRAIN PERFORMANCE 1985 PMS SURVEY

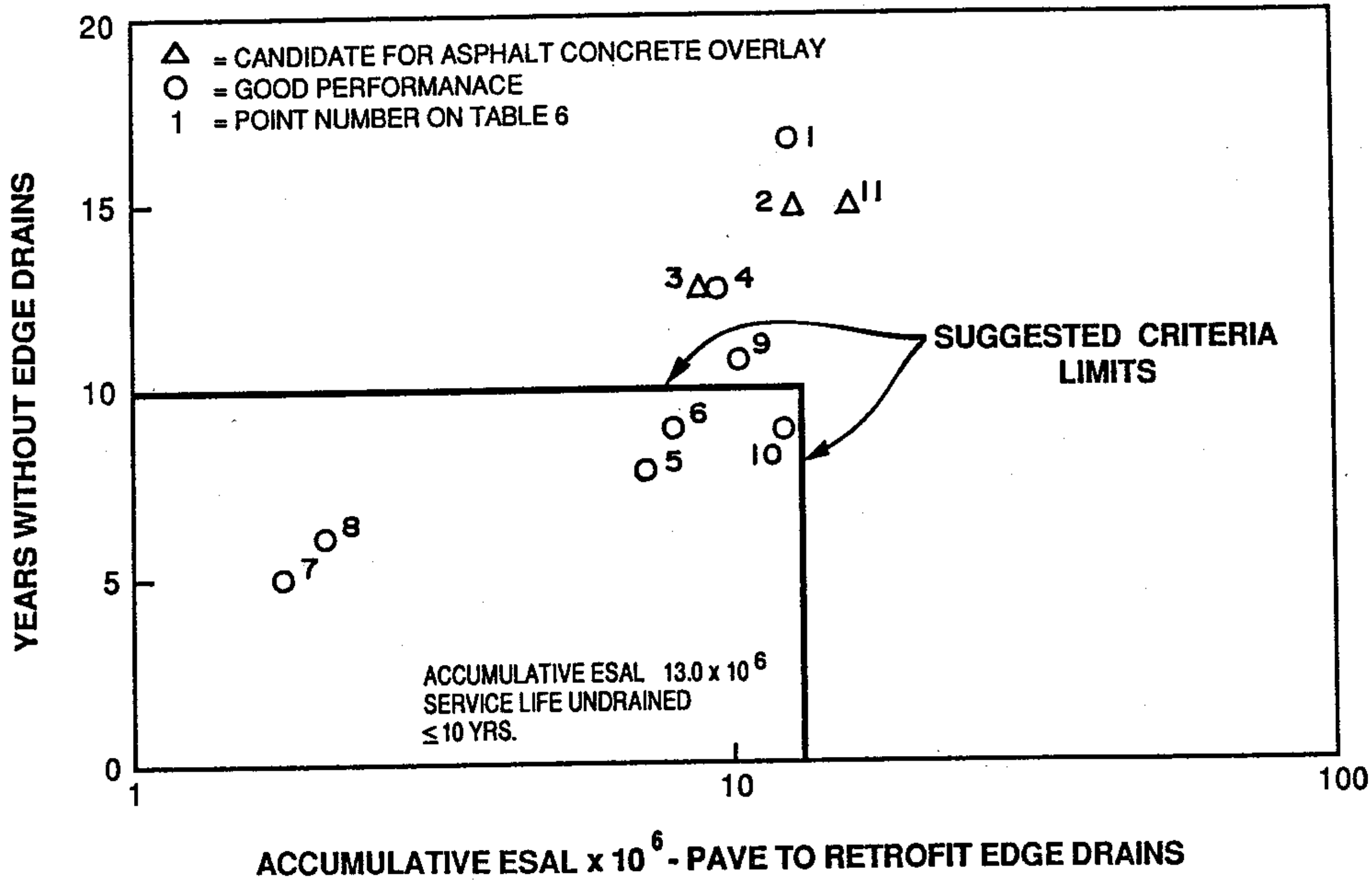

Figure 3, RETROFIT EDGE DRAIN PERFORMANCE 1985 PMS SURVEY

Slab Replacements

Experience to date indicates that slab replacement is a viable approach when shattered panels are present. However, the amount and rate of deterioration need to be analyzed in all cases because it may be more economical to crack and seat the PCCP and overlay with AC if the rate of slab breakup is accelerating rapidly.

Asphalt Concrete Overlays

Asphalt concrete overlays 0.35 feet thick with a pavement reinforcing fabric inner layer placed on cracked and seated PCCP have thus far proven to be successful in preventing reflective cracking from the underlying PCCP. As of this date, approximately 700 lane miles of PCCP have been rehabilitated in California by this technique. This rehabilitation strategy is considered by Caltrans to be the highest form of PCCP recycling. The annual condition survey report for Construction Evaluated Research Projects dated December 29, 1986, indicated that none of the AC overlays constructed since 1982 that incorporated this technique indicate any evidence of reflective cracking or distress. However, one project constructed in 1983 that is reported herein exhibits extensive reflective cracking of the noncracked- and seated-"control" sections.

Slabjacking

This technique should remain as a maintenance function and should be used only where depressed slabs constitute a hazard and where a rough ride exists ride at bridge approaches. Where differential settlement of embankments has occurred or expansive soils have heaved in cut sections, the best solution is to crack and seat the PCCP and overlay with AC to restore a good riding surface. This AC overlay strategy includes a pavement reinforcing fabric interlayer and edge drains. The use of this technique over expansive soils has been successful in preventing additional heaving of the pavement by stabilizing the moisture content of the underlying basement soil.

Grout Subsealing

Deflection testing does not provide a reliable means to identify "void locations" for subsealing. The radar unit studied appeared capable of locating large voids just below the PCCP. However, in an area taking 74 lb/hole of grout and where the radar indicated a void, coring indicated the void was still there when the injection hole was only one foot away. It would appear that subsealing, as presently done by Caltrans, is not totally effective in filling voids beneath PCCP, and of even greater significance, only one project using the combination of cement/pozzolan subsealing and edge drains reduced the faulting rate compared to sections that were not subsealed, but had edge drains. On a statewide basis, grout subsealing of PCCP has often been an unsatisfactory technique from either a construction or performance standpoint, so a moratorium has been placed on this technique until further notice.

Joint and Crack Sealants

If PCCP that is to be rehabilitated exhibits joint spalling or slab blowups, the joints should be resawed to a 5/8 inch x 5/8 inch dimension and a premixed vulcanized rubber asphalt sealant placed in the joint. In addition, random cracks should be routed and sealed with a premixed vulcanized rubber asphalt sealant. The advantages of this type of sealant are that it is nontoxic, easily applied, can be repaired by maintenance forces if necessary, and is generally cheaper than other sealant materials.

Edge Drains

Edge drain research indicated that untreated pea gravel permeable material, while providing good drainage, could not be compacted satisfactorily, nor would this material remain stable when placed next to the traveled way due to the dynamic movements of the slabs. This resulted in the same longitudinal shoulder distress characteristic of undrained pavements and required extensive maintenance. Also, the untreated permeable material becomes part of the material being pumped under the slab, thereby, contributing to the faulting process. To eliminate these problems, the use of cement or asphalt treated peameable material has been adopted. This has greatly reduced the problems of AC trench backfill settlement and has provided a nonerodible, highly permeable drainage material.

Research and investigation of retrofit edge drain performance indicates that the desired 10 years additional pavement service life will probably be obtained if retrofit edge drains are installed at locations complying with all the following guidelines:

1. The PCCP age is $\leq$10 years.
2. First stage cracking $\leq$ 10%.
3. Third stage cracking $\leq$ 1%.
4. Accumulated ESAL $\leq$ 13 million.

RECOMMENDATIONS AND IMPLEMENTATIONS

The rehabilitation techniques of pavement grinding, slab replacement, asphalt concrete overlays, slabjacking, grout subsealing, joint and random crack sealants, and edge drains have been discussed. The research findings presented herein have been the basis for timely revisions to Caltrans specifications to reflect changes needed to make these rehabilitation techniques cost-effective and to provide the desired additional 10 years pavement service at a minimal maintenance cost.

Continuing research is recommended (new study) to extend monitoring of previously rehabilitated PCCP projects and other future selected projects to further evaluate and refine present rehabilitation criteria and techniques.

The use of asphalt subsealing is also proposed for evaluation under a new research study. It has been reported that this technique has been used with some success by a few midwestern states and offers a more forgiving material than cement/pozzolan grout.

The class now being given at Caltrans contains most of the findings mentioned herein. This course outline will also eventually serve as the basis for Caltrans Manual on PCC Pavement Rehabiliation.

REFERENCES

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3. National Asphalt Paving Association, Cracking and Seating of PCC Pavements Prior to Overlaying With Hot Mix Asphalt, March 1985.

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6. Tons, E., A Theoretical Approach to Design of a Road Joint Seal, Highway Research Board Bulletin 229, 1959.

7. Wells, G. K., Evaluation of Edge Drain Performance, Caltrans publication FHWA/CA/TL-85/15, Nov. 1985.

APPENDICES

1. Caltrans Highway Design Manual, Index 611.8, "PCCP Rehabilitation Strategies".

2. Evaluate Void Detection and Subsealing of Portland Cement Concrete Pavement on 06-Ker-5-R0.0/29.0 (Contract No. 06-246004).

3. Grout subsealing Quantities through July 1985.

4. Transportation Research Board, Division A-Group 2, Outline for Research Problem Statement, titled, "A Study of Subsealing as a Rehabilitation Technique for Portland Cement Concrete Pavement (PCCP)".

APPENDIX 1

Caltrans Highway Design Manual,
Index 611.8, "PCCP Rehabiliation Strategies"

611.8 PCCP Rehabilitation Strategies

PCCP rehabilitation strategies should generally conform to the following guidelines. Significant variations from these guidelines must be documented in the project report.

Caltrans has experimented with edge drains to rapidly remove infiltrated surface water and thereby to inhibit the pumping action that results in step faulting. Other corrective or preventive techniques that have been tried include cement-pozzolan grout subsealing to fill under slab voids, replacement of cracked slabs, lane replacement, slab jacking (primarily at bridge approaches) to raise settled slabs back to a smooth profile, diamond grinding to correct the profile of step-faulted surfaces, longitudinal grooving to inhibit hydroplaning and reduce wet weather skidding accidents, thin resin and special cement concrete overlays to restore surface profile and texture, cracking and seating of slabs in conjunction with fabric reinforced asphalt concrete overlays, joint sealing, crack and joint spall repairs, thick unbonded concrete overlays, thin-bonded concrete overlays, and asphalt concrete overlays.

In the past, some of the above rehabilitation techniques have been used in a piecemeal manner to correct a symptom without getting to the root of the problem. For instance, step faulting at transverse joints has been corrected by grinding to restore a smooth surface profile without inhibiting the pumping action that created the faulting. As a result the pumping action continued and faulting, in some cases, built up to its pre-grinding level within 4 years. In other cases, asphalt overlays have been placed over deteriorated or rough concrete pavement without stabilizing rocking slabs or providing more positive structural section drainage. This has resulted in continued rocking of slabs, continued pumping action, the development of reflective cracking through the overlay, and additional step faulting. Thin overlays utilizing plastic resins and special cements are very high in cost and the potential benefits primarily are limited to improvements of profile, texture, and abrasion resistance.

Basic Rehabilitation Strategies. There are no hard, fast answers to rehabilitate PCCP. Caltrans' current practice, based on experience and experimentation over the past 15 years, is to use a single or a combination of several preventive or corrective techniques which will provide the best overall solution to extend the pavement life for 10 years or more. The choice of strategies depends primarily on the pavement condition and apparent rate of deterioration. The rate of deterioration is based on experience, field observation, and a review of progressive biennial PMS condition surveys.

(1) Install Edge Drains Only. This first basic strategy is a preventive measure that is generally applied to relatively "new" concrete pavement (up to 10 years of service) which is generally in very good condition but is beginning to show signs of pumping with little or no faulting. Retrofit edge drains are installed continuously at the outside edge of the truck lanes, for the sole purpose of inhibiting the pumping action which is the primary contributing factor in the progressive build up of step faulting and related deterioration of the concrete pavement and shoulders. Each installation must meet all of the following criteria:

- o Pavement age $\leq$ 10 years
- o Cumulative ESAL $\leq$ 13 x 10^6

- o First stage cracking $\leq$ 10%
- o Third stage cracking $\leq$ 1%

The edge drain collector and outlet system details are included in Standard Plans for Structural Section Drainage Systems.

It is anticipated that the rapid removal of the infiltrated surface water through edge drains will result in a significant extension of the service life of existing pavement that is still in good condition. Hopefully, instead of requiring extensive rehabilitation at a pavement age of 20 or 25 years, rehabilitation might be deferred an additional 5 to 10 years.

Research by Caltrans has shown that edge drains can dramatically reduce the rate of faulting development below that occurring before installation of edge drains.

*(2) Slab Replacement, *Subseal, Grind, and Install Edge Drains.* This second basic PCCP rehabilitation strategy is both a restorative and preventive strategy which includes the application of several techniques which, based on research, experience, and judgment are combined to address concrete pavement that has developed an unacceptable ride but which is still structurally sound. To warrant this strategy the pavement must generally have a ride score $\geq$ 45 and third stage cracking $\leq$ 10%.

Care should be taken to review the comparative % of slab cracking from PMS surveys to determine rate of deterioration. If the rate of deterioration (slab cracking) is increasing rapidly, consideration should be given to using the strategy discussed in Index 611.8(3).

The combined strategy used under these conditions is to: replace individual slabs which have multiple cracks and/or severe crack or joint spalling or depressions, *subseal to fill voids under existing slabs with cement-pozzolan grout, grind to remove faulting and thereby to restore a smooth surface profile, repair spalled joints and cracks as necessary, and install edge drains along the longitudinal pavement and shoulder joint. Where there are slab corner breaks they should be repaired by full lane width partial slab replacement, measuring a minimum of 6 feet in length, as covered by an SSP. Care should be taken in grinding no to leave vertical ridges in excess of 1/2 inch adjacent to lane lines (to save pavement markers) or adjacent to or at the edge of the traveled way.

Transverse joint sealing should be specified in freeze-thaw areas, where sanding in the winter tends to fill the joints with incompressible materials. It is not, however, practical or necessary that this be a completely watertight joint. The primary purpose for joint sealing is to keep out the incompressible material.

When sealing of transverse joints is specified on rehabilitation projects, the relatively low cost rubberized asphalt materials should generally to be utilized. Caltrans has experimented with the relatively high cost silicones for several years, but it is doubtful that the added cost is warranted on rehabilitation projects.

The slab replacement, *subsealing, grinding, and edge drain combination rehabilitation strategy is anticipated to provide a minimum of 10 years additional service without significant pavement maintenance.

* <u>Because of problems encountered in construction and potential adverse effects, a moratorium on subsealing was instituted in October of 1985. This moratorium will remain in effect until and if it can be shown that the technology and practice will result in improved performance, through its use on Caltrans PCCP rehabilitation projects.</u>

(3) Crack and Seat Slabs, Install Edge Drains, and Place an AC Overlay with Fabric Interlayer. The third basic PCCP rehabilitation strategy is a combination of recycling, restoration, and preventive techniques. This strategy is used where concrete pavement has an unacceptable ride and is in an intermediate to advanced stage of structural deterioration. Generally, this means there is extensive third stage cracking (over 10%) of individual concrete slabs and it appears to be futile to try to "keep up" by utilizing individual slab replacement and grinding. Slab replacement is not appropiate under this strategy, unless there is complete disintegration of a slab or segment.

In this case, the combination strategy used is to crack and seat the PCCP slabs, install edge drains, and place a 0.35-ft. fabric reinforced DGAC overlay. On four-lane divided freeways, both lanes in each direction are cracked and seated whereas on facilities with 3 or more lanes in each direction, if no significant distress or signs of deterioration exists in the median lane(s), they may be left intact.

The AC overlay includes a reinforcing fabric interlayer that extends at least 2 ft. outside the edge of PCCP into the shoulder area. The fabric interlayer retards infiltration of surface water and reflection cracking. It is assumed to be equivalent to 0.10 ft. of AC in its effectiveness to prevent reflective cracking. This reduction of 0.10 ft. in required thickness of AC can result in a significant savings, especially on multilane facilities. Where the slab deterioration is primarily limited to the outer lane or lanes on multilane facilities, particularly when there are three or more lanes in each direction, an economic analysis should be made to compare the cost of lane replacement with the cost of overlaying all lanes and shoulders.

Care must be taken to feather the end of the AC overlay at the transition back to PCCP or at structure approaches. This may be done either by the preferred method of feathering the AC on top of the PCCP or by milling a transition wedge taper into the PCCP.

In utilizing the cracking and seating procedure, which Caltrans considers to be one of the highest forms of recycling, the goal is to break the slabs into approximate 4 ft. x 6 ft. segments to serve as a stable base for the overlay. Prior to placement of the AC overlay, the slab segments are rolled to assure that the segments are firmly seated onto the underlying base. The cracking, seating, and rolling not only stabilizes the slab segments to minimize any differential vertical movement but it also reduces the magnitude of thermal movement and strains that are transmitted into the overlay and reinforcing fabric interlayer. This minimizes the reflective cracking tendency that has been observed on asphalt concrete overlays over PCCP.

The installation of edge drains, when combined with the fabric interlayer, minimizes the potential for entry and entrapment of water and pumping action of the PCCP segments under the AC overlay.

The PCCP rehabilitation strategy combination that includes cracking, seating, installation of edge drains, and an AC overlay with a fabric interlayer is anticipated to last a minimum of 10 years without requiring significant pavement maintenance.

(4) Partial or General Reconstruction. When PCCP has deteriorated to the point that some reconstruction is required, alternatives might include outer (truck) lane replacement with minor work on other lanes, thick PCCP overlay with AC or PCCP shoulders, recycling, and other strategies. The decision should be based primarily on economic considerations. On large projects, a life-cycle cost comparison should be done to substantiate project strategy decisions.

(5) Grooving, Grinding, and Special Thin Surface Treatments. In addition to the 3 basic strategy combinations discussed above, other individual concrete pavement rehabilitation strategies are used or considered to solve specific problems. These include longitudinal grooving to minimize the potential for hydroplaning and skidding accidents, grinding only, as an interim measure (on selected projects) to improve the ride quality on very rough pavement pending major rehabilitation or reconstruction, and the application of very thin resin or special cement concrete overlays to improve the surface profile and to restore the surface of pavement such as that which has been abraded by tire chains and studs.

Grooving has proven to be effective in the reduction of hydroplaning and wet weather skidding accidents. The grooved surface is expected to remain effective for at least 10 years based on experience on California's busiest metropolitan freeways. The life of grooving is reduced where there is exposure to tire chains and studs. The longevity apparently varies inversely with the volume and weight of vehicles with chains and directly with the durability or abrasion resistance of the concrete.

The thin resin or special cement based concrete overlays, such as those utilizing methacrylates, magnesium phosphate cement, polymers, etc. are still considered to be experimental and because of high cost their application is limited to unique conditions or problem areas. The greatest potential for their use is on bridge decks.

(6) Structure Approach Slab (Pavement) Rehabilitation. Structure or bridge approach pavement improvement is a key element of pavement rehabilitation, since this area is often the most difficult to maintain in a serviceable condition. Caltrans design practice is covered in Index 610.5 and Index 610.6.

(7) Positive Drainage Emphasis. Although all aspects of the rehabilitation strategies are important, the most critical factor addressed by the Caltrans PCCP rehabilitation practice is that of providing positive drainage, by installation of edge drains, to arrest the pumping action that has been so damaging, especially to truck lanes and to shoulders. The importance of improving drainage cannot be overemphasized.

APPENDIX 2

EVALUATE VOID DETECTION AND SUBSEALING OF PORTLAND CEMENT CONCRETE PAVEMENT ON 6-Ker-5-R0.0/29.0 (Contract No. 6-246004)

APPENDIX 2
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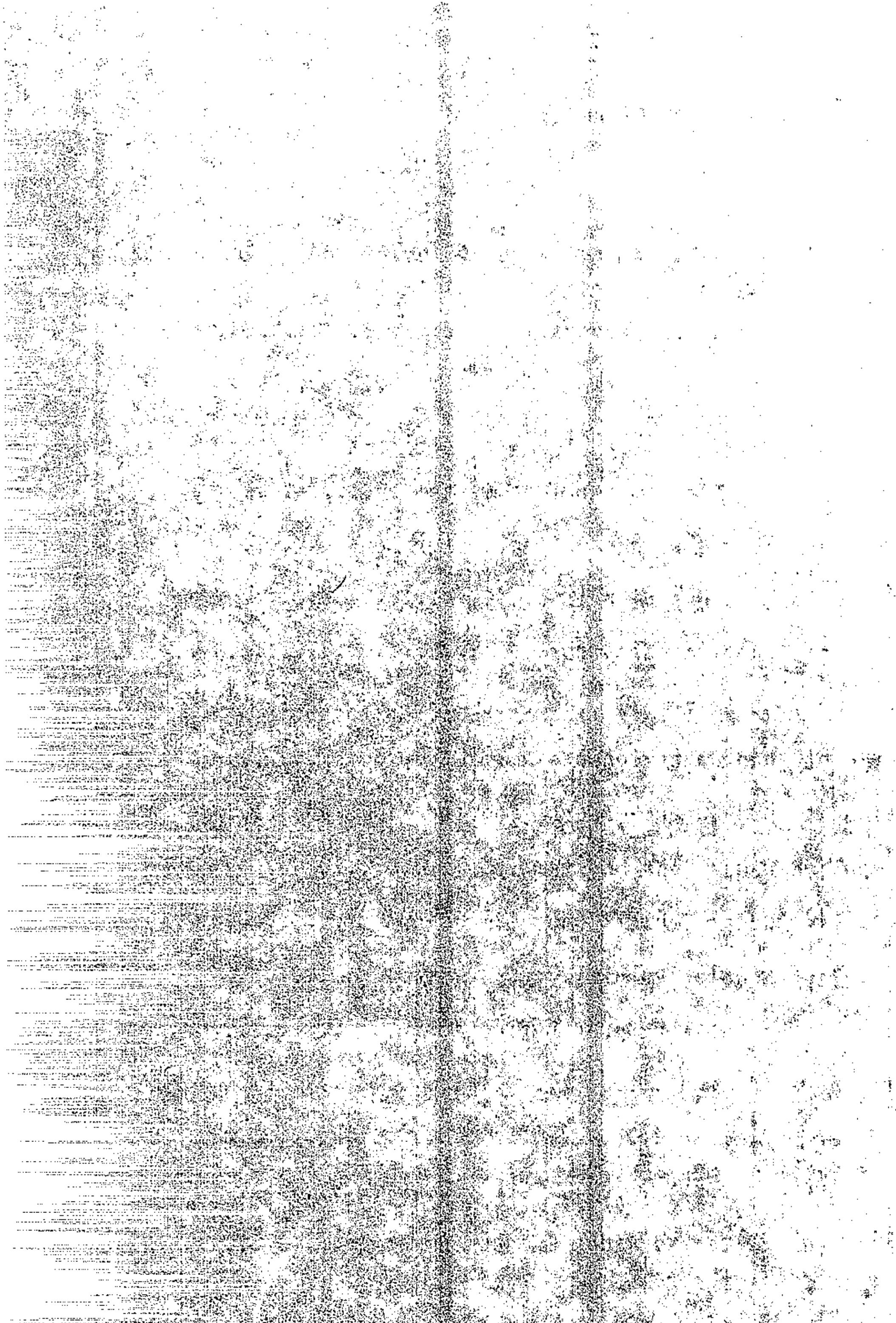


APPENDIX 2
LIST OF TABLES

EVALUATE VOID DETECTION AND GROUT SUBSEALING OF PORTLAND CEMENT CONCRETE PAVEMENT ON 06-KER-5-R0.0/29.0 (CONTRACT NO. 06-246004)

INTRODUCTION

One strategy for rehabilitating portland cement concrete pavement (PCCP) in California has been "grout subsealing". Estimating grout quantities for subsealing has proven to be very difficult. Other aspects of the grouting operation have also generated concerns. Therefore, a need existed to review grouting techniques and to try and develop a method to define areas requiring subsealing prior to a rehabilitation project actually going to construction. This would improve the accuracy of the grout quantity estimates while maximizing the effectiveness of the subsealing operation. Thus, this research involved a study of: (a) the use of four nondestructive testing devices to locate voids beneath PCCP and, (b) alternative grouting methods.

PROJECT SITE

The subsealing project selected for this study was on I-5 near Bakersfield (6-Ker- 5-R0.0/29.0, Contract No. 246004). Don McKenzie was the Resident Engineer, and Smith Electric the subsealing contractor.

A work plan for a construction evaluated research project on void detection and subsealing of PCC pavement was developed. The work was partially funded by the federally financed research project F82TL13, E/A 633369, "Evaluate Effectiveness of PCC Pavement Rehabilitation."

DISCUSSION OF WORK PLAN

The evaluation of grouting techniques and the determination of areas requiring subsealing were performed as follows:

1. The PCC pavement and AC shoulders were inspected for pavement distress in terms of cracking, spalling, faulting, shoulder settlement, and evidence of joint pumping.

2. Test areas were selected in the northbound No. 2 lane for testing with the Falling Weight Deflectometer (FWD), the Rodar (Ground Penetrating Radar Unit), and the Dynaflect. The Road Rater was not in the original work plan but was included in the evaluation at a later date.

3. Two 1,000-foot test sections were selected in the northbound No. 2 lane to evaluate 9-inch and 15-inch deep percussion-drilled grout holes.

4. A 500-foot test section in the northbound No. 2 lane was established to evaluate core-drilled grout holes 9 inches in depth.

5. A 500-foot test section in the northbound No. 2 lane was established to allow the contractor to pump grout until the vertical slab movement exceeded 0.100 inch, thus waiving the maximum limit of 0.050 inches.

6. Cores were taken at selected locations to determine grout flow characteristics.

BACKGROUND

Voids are caused by the interaction between water trapped beneath the PCCP slabs and the pumping action caused by slab deflection when a heavily loaded truck passes over the pavement. To fill these voids and restore full support to the pavement structure, a cement-pozzolan grout is injected into holes that have been drilled through the PCC slabs and the cement treated base. The grout injection holes are drilled in a designated pattern in each slab where voids generally occur. The location and size of the voids varies considerably under a given section of roadway: consequently, some areas may require subsealing and other areas may not.

Since 1982, eight minor research projects on subsealing have been conducted by TransLab without the establishment of conclusive subsealing policies. The following is a brief summary of the reports describing those projects:

1. The report dated October 18, 1982 (4-Ala-580-2.0/4.0) describes an attempt to compare differential vertical slab movement (Δ-vert) due to an 18 kip single axle load with subsealing quantities. Although the findings in this report indicated that subsealing can reduce differential vertical slab movement, it was recommended that additional subsealing operations be studied to confirm these findings.

2. The report dated October 25, 1982 (2-Sha-5-R3.9/R14.0) summarizes an evaluation of the effectiveness of subsealing in reducing slab movement. The conclusions in this report were that subsealing generally reduced Δ-vert movement at PCCP joints and that grout penetration into the voids appeared to have been extensive. However, a definite correlation could not be made between Δ-vert measurements and grout quantities. The report recommended that Δ-vert measurements be taken on subsealing projects in the future to create a larger database for subsealing evaluation.

3. The report dated January 6, 1983 (6-Ker-5-3.0/10.9) reported on slab-end deflections and Δ-vert measurements and concluded that no threshold values could be established above which slab subsealing should be required; thus, no conclusions could be made.

4. The report dated March 29, 1983 (5-SB-101-11.44/12.98) reported measured slab-end deflections and concluded that no threshold deflection had been established above which subsealing should be done. However, as a guideline, subsealing should be considered when slab-end deflections exceed 0.020 inch under an 18 kip single axle load.

5. The report dated February 22, 1984 (3-Pla-80) described an attempt to make a comparison between slab-end deflection measurements and grout-take quantities. Unfortunately, the deflections were too small to make a valid comparison and further investigation was recommended.

6. The report dated February 24, 1984 (11-SD-8) contained measured slab-end deflections and theorized that deflection measurements may be used to indicate if subsealing would be an appropriate rehabilitation strategy. However, no threshold deflection was established for subsealing slabs.

7. A memo (May 17, 1984) by Don McKenzie, the Resident Engineer, (6-Ker-5-2.0/11.0, Contract No. 222004) provided a brief summary for one day's subsealing on a project near Grapevine, California. It was concluded in this memo that a very low percentage of the holes accepted grout and several improvements in the subsealing procedures were recommended in order to improve grout acceptance quantities. The following improvements were recommended: (1) Holes must be thoroughly flushed by water at a minimum of 40 psi. (2) It is better to have a single 1/2-inch orifice for washing out the hole than to have 4 pin holes (as is sometimes used) because the volume of water is very important. (3) Hole spacing should be as shown on Figure A-3 (other hole configurations were tried with no better success.) (4) Don't subseal on the high side of super elevations. (5) Grout pressure should be a minimum of 175 psi. (Most of the time grout wouldn't begin to flow until the pressure built up to 175 psi. The pressure would then drop back to 100 to 120 psi until flow stopped).

8. The report dated July 26, 1984 (4-Son-101-36.3/38.0, 53.0/54.2, Contract No. 105754) described another attempt to correlate slab-end deflection values under an 18 kip single axle load to grout acceptance quantities. It was concluded that the magnitude of the measured deflection values and the grout take quantities were so low that a strong correlation could not be determined and, therefore, further

testing on additional subsealing projects was recommended. The following data were obtained:

Location	Average Grout Acceptance	Average Slab-end Deflection	Slab-end Deflection Range
Northbound	12.8 lb/hole	0.002 in.	0 - .004 in.
Southbound	32.2 lb/hole	0.003 in.	0 - .008 in.

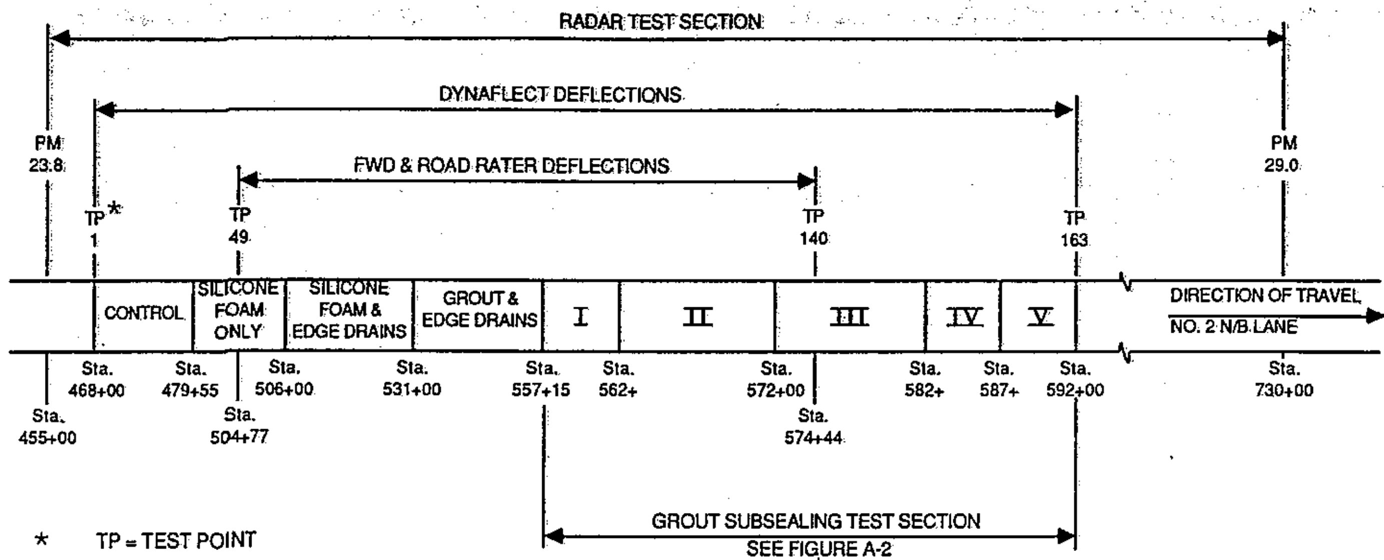
The common denominators for these reports were that, (1) slab-end deflections and Δ-vert measurements did not correlate with grout-take and, (2) additional subsealing operations should be studied to try and increase the effectiveness of the subsealing operation.

To improve the efficiency of subsealing, it is desirable to identify in advance areas where voids exist by the use of a nondestructive testing device. Four such devices examined in this study were:

1. Dynaflect
2. Falling Weight Deflectometer
3. Road Rater
4. Rodar System

DESCRIPTION OF TEST AREA

This section of highway was originally constructed in 1970 and presently has a traffic index of 12 to 13. The PCCP is 0.7 foot thick over 0.5 foot thick cement treated base. The PCCP panels have skewed random transverse joint spacings between 10 and 19 feet. The pavement was in relatively good condition at the start of subsealing with minimum cracking. The average daily truck count is about 5300. (See Figure A-1).



LAYOUT OF DEFLECTION, RADAR AND GROUT SUBSEALING TEST SECTIONS

06-Ker-5, 23.8/29.0
06-246003

FIGURE A-1

DEFLECTION TESTING SITE

Deflection test points (TP) were established every 5th transverse joint, i.e., at approximately 75 ft. intervals. The Dynaflect was used from TP 1 to TP 163, while the FWD and the Road Rater were used from TP 49 to TP 140. Deflection test points common to all three devices were between TP 49 and TP 140. Also included within this test site were test sections where silicone foam injection was used in lieu of grout injection. A separate report will be prepared regarding this research.

GROUT SUBSEALING TEST SITE

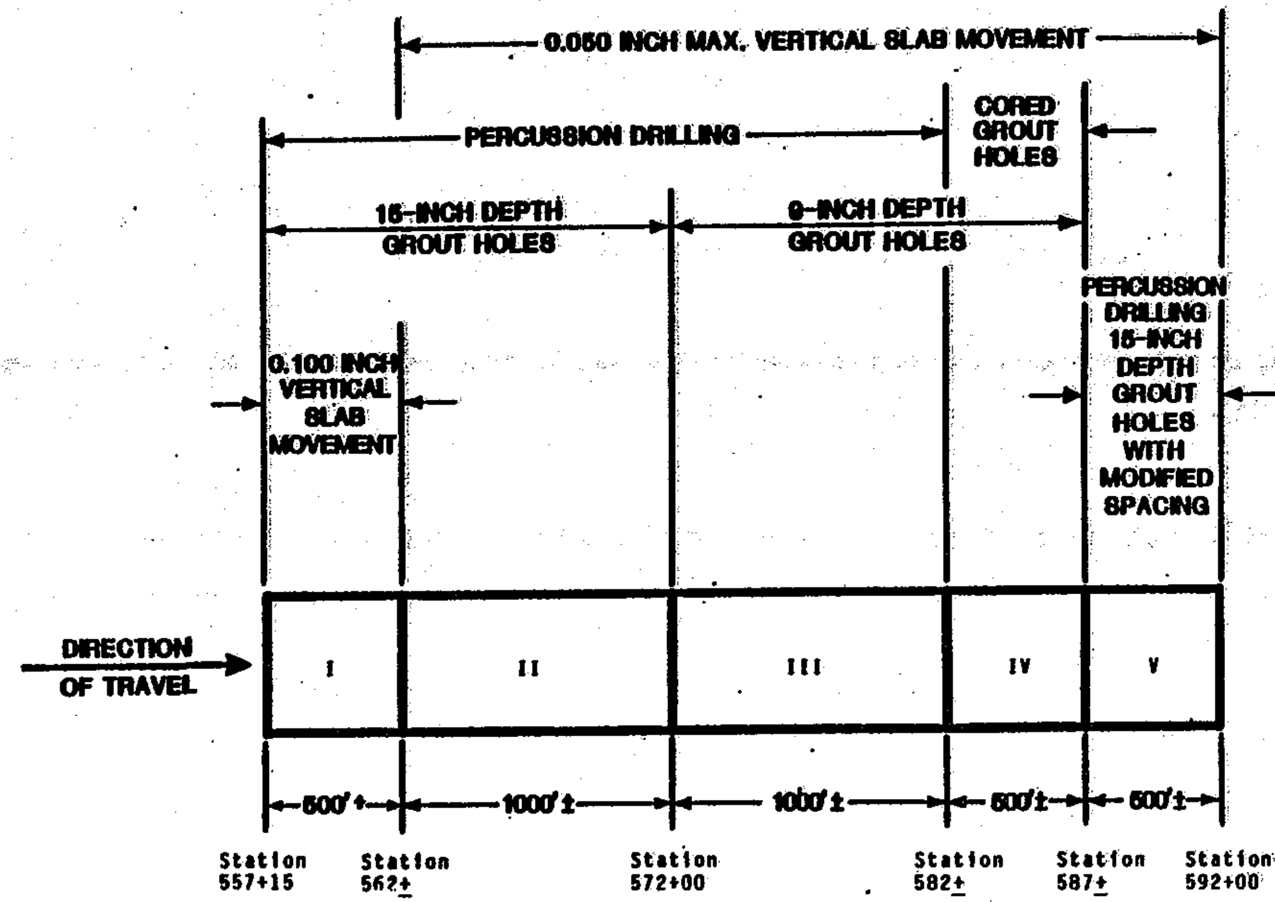
The grout subsealing test area was located between Station 557+15 and Station 592+00 and consisted of five test sections as shown in Figure A-2. Each test section involved different grouting techniques. Typical hole drilling pattern is shown in Figure A-3 and a modified hole drilling pattern used in TEST SECTION V is shown in Figure A-4.

DEFLECTION DEVICE TESTING PRIOR TO SUBSEALING

1. Falling Weight Deflectometer

The Dynatest Falling Weight Deflectometer (FWD) is sometimes used to determine the elastic moduli of PCCP and the underlying cement treated base (CTB). The FWD produces an impact load of up to 24,000 lbs for a 25 to 30 millisecond duration by dropping a weight onto a specially designed buffer system, thus simulating a heavy moving wheel load. Seven transducers are located on the measuring unit which monitors the deflections for each FWD test. The deflections are measured at the surface of the pavement out from the center of the loading plate to a distance of 1.5 to 2 meters (5 to 7 feet). See Figures A-5 and A-6.

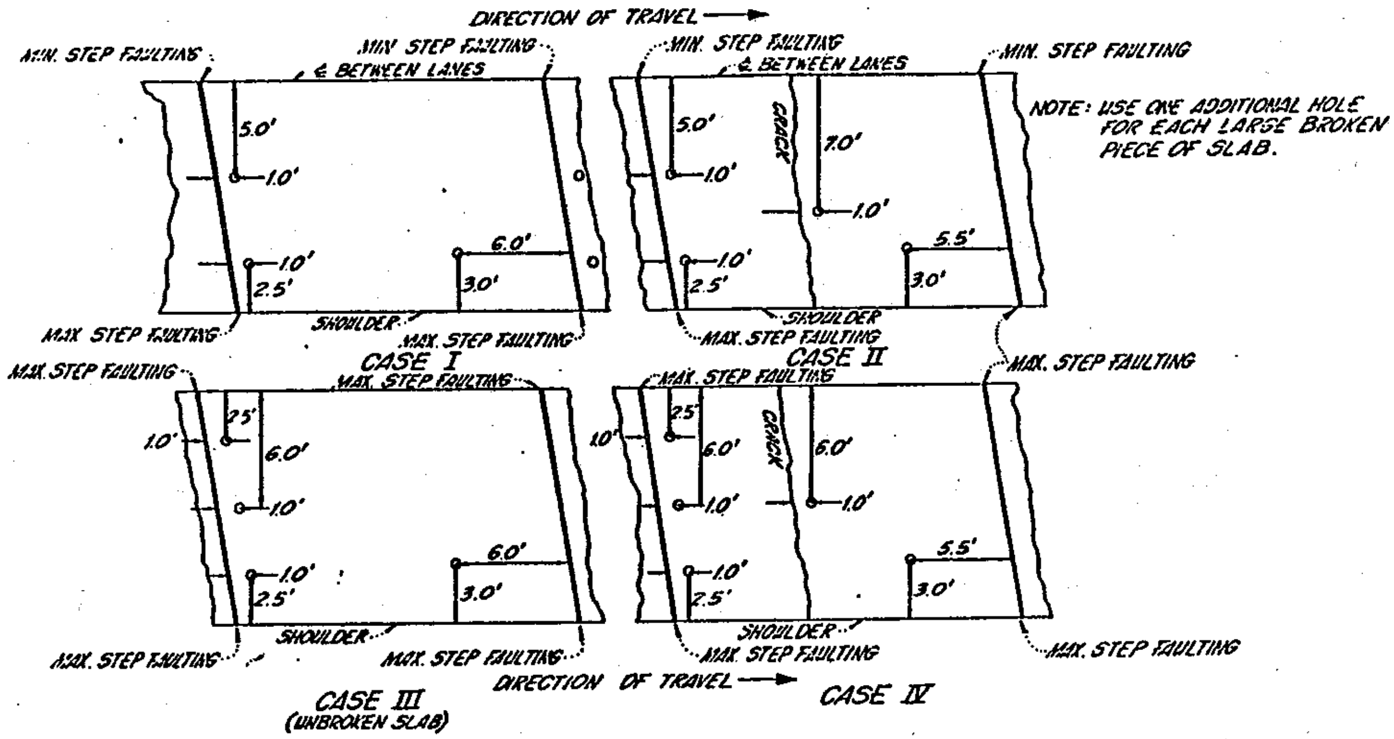
On February 20 and 21, 1985, Dynatest Consulting, Inc., performed deflection measurements with the Model 8000 Falling Weight Deflectometer. Measurements were taken during the morning hours at every 5th transverse joint.



TEST SECTION LAYOUT FOR SUBSEALING

(LIMITS TO BE ESTABLISHED)

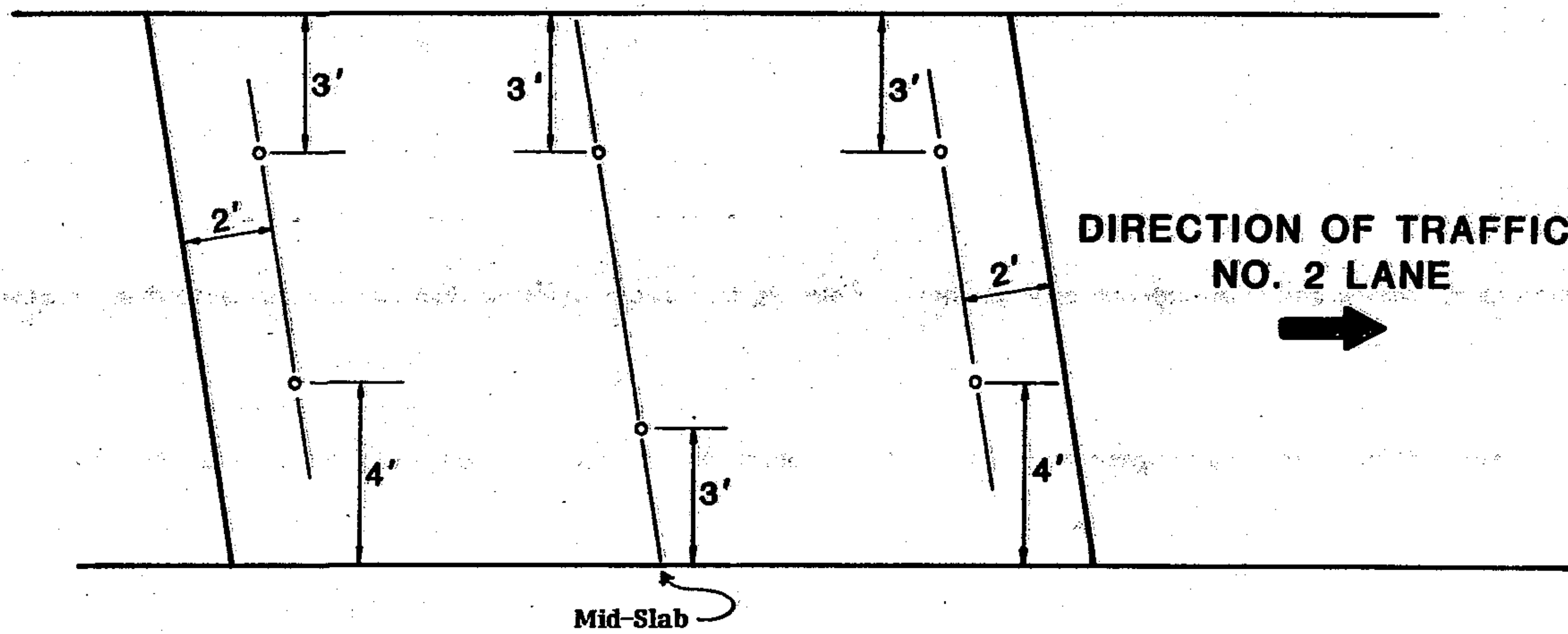
Figure A-2



TYPICAL HOLE DRILLING CONFIGURATION

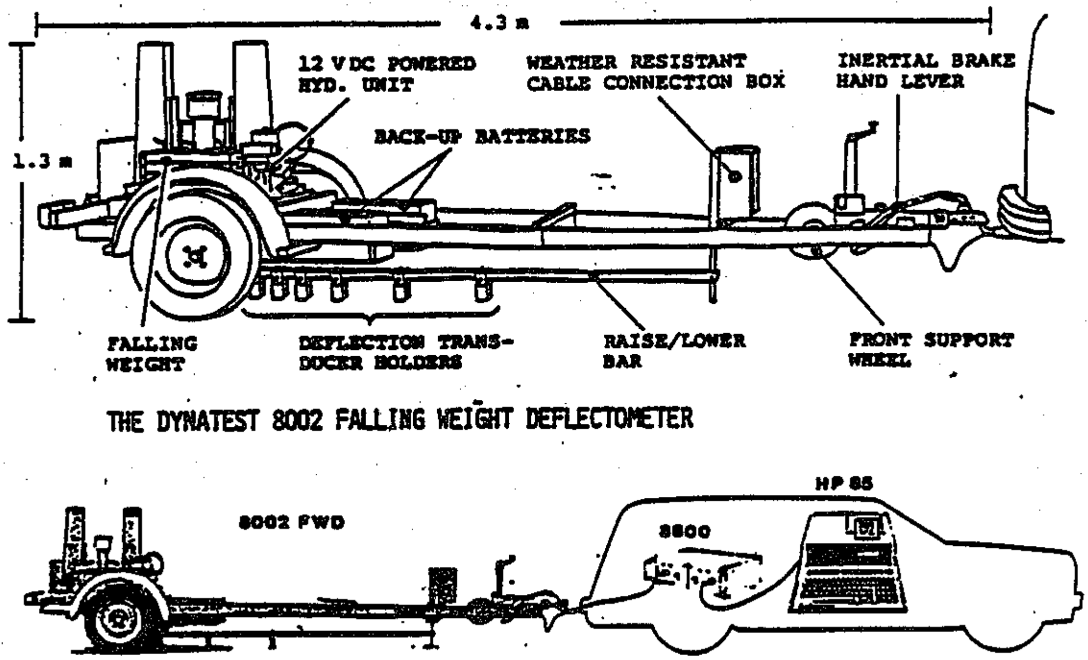
NO SCALE

Figure A-3



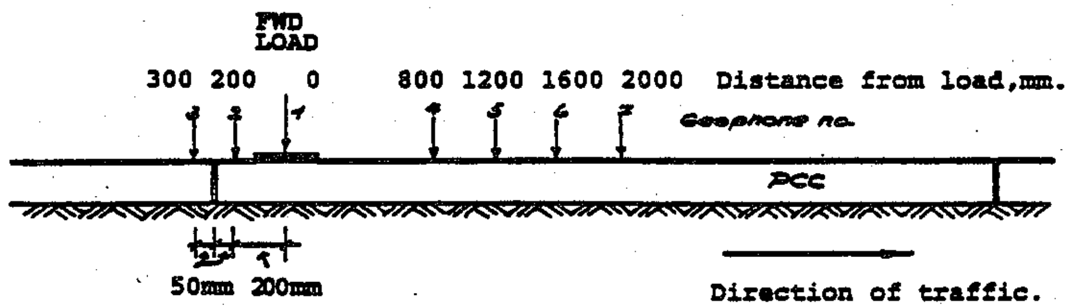
MODIFIED SPACING OF GROUT HOLES

FIGURE A-4



The Dynatest 8000 Falling Weight Deflectometer Test System (Courtesy of Dynatest, Ojai, CA)

Figure A-5



Position of FWD Deflection Sensors (Courtesy of Dynatest, Ojai, CA)

Figure A-6

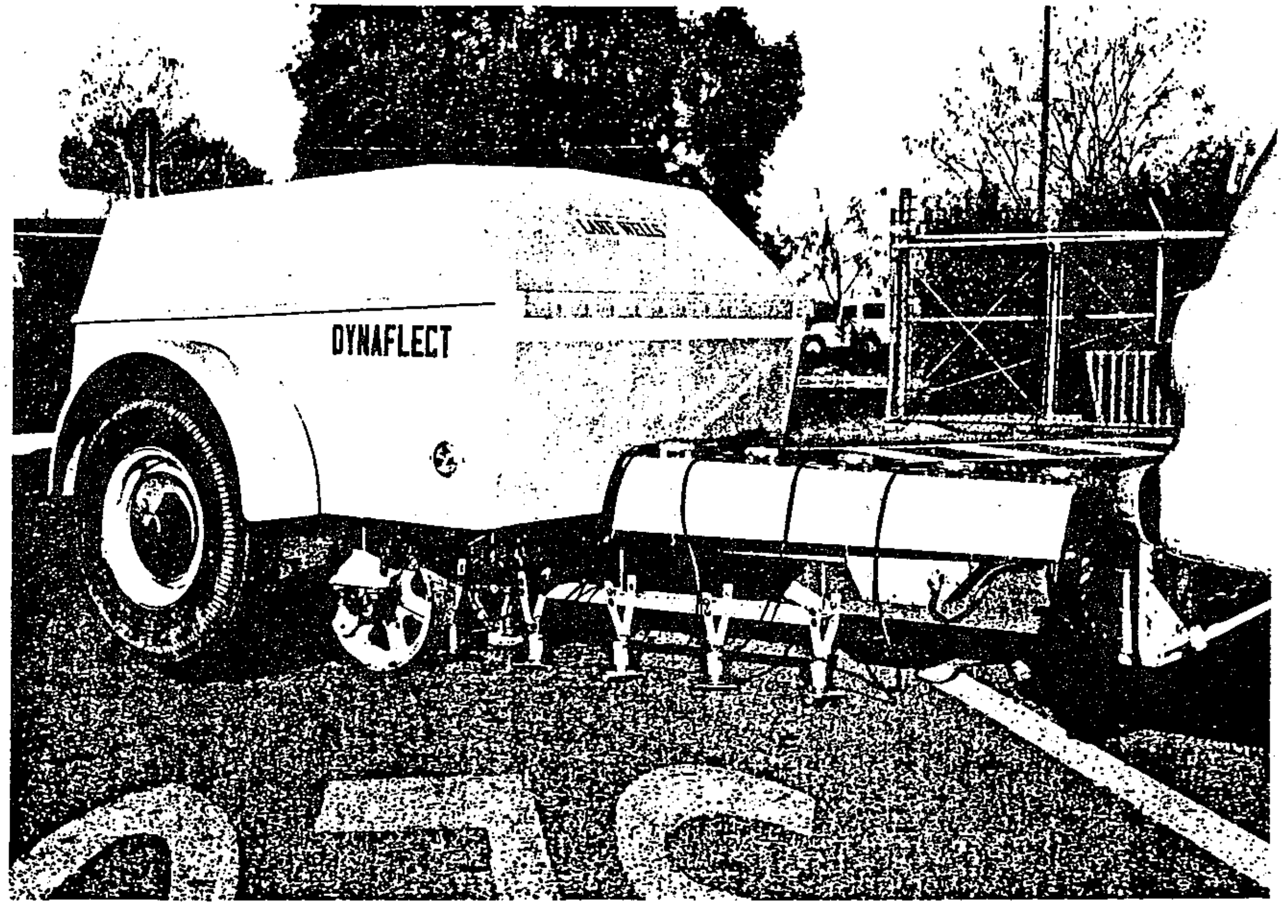
On the first morning of testing, the ambient temperature was in the low 50's and the pavement surface temperature was 50°F. The FWD began taking slab-end and midslab deflection measurements at 8:45 A.M., starting at TP 49 and ending at TP 80 at 11:30 A.M. when the surface temperature of the pavement was 70°F. Slab-end deflection measurements were repeated in the afternoon beginning at 2:30 P.M. at the same test points in order to examine the effect of slab curl due to the temperature gradient through the pavement.

At 7:00 A.M., on the second morning of testing, the ambient temperature was in the low 40's and the surface temperature of the pavement was 46°F. Slab-end and midslab deflection measurements began with TP 80 and ended at 11:00 A.M. with TP 140. The surface temperature of the pavement reached 60°F by 10:30 A.M. Slab-end deflection measurements were again repeated in the afternoon from TP 80 to TP 140 to detect slab curl.

2. Dynaflect

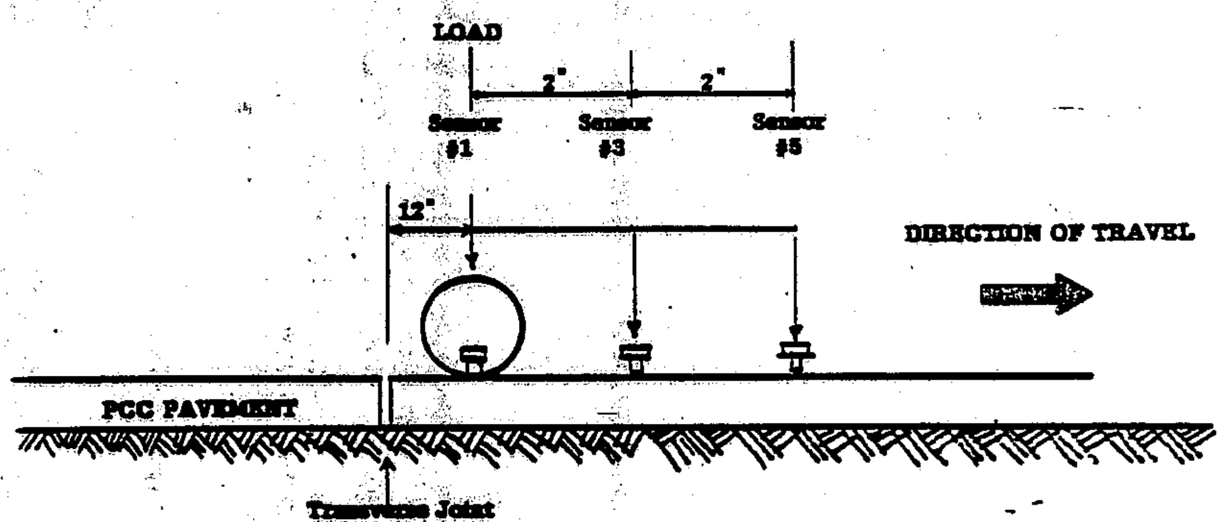
Deflection measurements were taken with the Dynaflect by TransLab personnel on February 20 and 21, concurrently with the FWD measurements. The Dynaflect used on this project is illustrated in Figure A-7. This particular unit applies an oscillatory load which varies from 1441 to 2685 lb. to the pavement at the rate of eight cycles per second.

At 9:10 A.M., Dynaflect testing began with slab-end deflection measurements at TP 1 and progressed to TP 117 by 11:00 A.M. The Dynaflect is capable of using five sensors to take deflection measurements. However, for this project, only three sensors were used (Figure A-8). Due to equipment problems, sensor Number 5 was inoperative from TP 1 to TP 68 during the first day of slab-end measurements so only two sensors were used. After lunch, the Dynaflect was used for midslab deflection measurements from TP 1 through TP 117. On the second day of testing, the Dynaflect was used for both slab-end and midslab deflection measurements from TP 118 to the end of the test section at TP 163.



DYNAFLECT IN TEST POSITION WITH FORCE WHEELS AND GEOPHONES DOWN

Figure A-7



Dynaflect Slab-end Sensor Position

Figure A-8

3. Road Rater

The Los Angeles County Road Department volunteered the use of a Model 400B Road Rater deflection device (Figure A-9). This particular unit is equipped to apply a static load of 1500 lb to the pavement at a frequency of 25 cycles per second. Four deflection sensors were mounted on the unit as illustrated in Figure A-10.

Deflection measurements were taken at every 5th joint and at midslab in the same manner as with the FWD. For slab-end deflection, the unit was positioned in the right wheel track so that the load and the #1 sensor were positioned approximately 4 to 6 inches from the transverse joint (Figure A-11). In the second position, the load and the #1 sensor were positioned at approximately the center of the slab. Due to the arrangement of the sensors on the unit, and in order to be consistent with the sensor orientation on the Dynaflect and the Dynatest, it was necessary to test while heading into traffic. Consequently, measurements were taken starting at TP 140 and finishing at TP 49.

On March 14, 1985, the weather conditions were sunny with an ambient temperature of 55°F. Slab-end deflection measurements were started at approximately 8:00 A.M. at TP 140, and completed at approximately 11:00 A.M. at TP 49. Midslab deflection measurements were taken between 11:30 A.M. and 2:30 P.M. from TP 140 to TP 49, respectively.

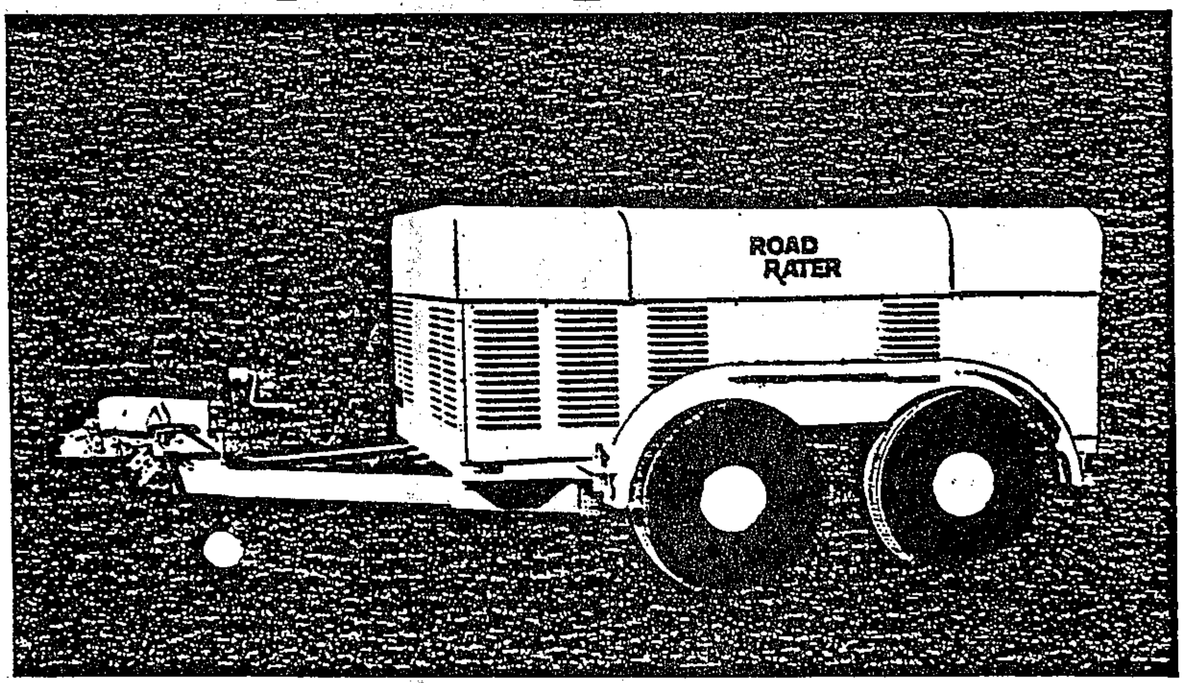
RADAR TESTING PRIOR TO SUBSEALING

The radar system (Figure A-12) operates on the following principle: A truck mounted radar unit employs an ultrahigh frequency, short pulse radar signal using two downward-facing radar antennae to obtain a profile of the subsurface structure along each wheel path. The radar pulse signal is recorded in analog form on a greyline strip chart recorder and is stored on magnetic tape. In addition, a data location reference unit simultaneously tracks and

Road Rater

Model

400B



General Specifications and Description

The Model 2000 Road Rater was designed to provide a highly mobile, air transportable dynamic deflection test system for non destructive testing of airfield pavements. The system is totally self-contained in a tandem axle trailer which may be towed by an automobile or light truck. The system may be operated from the tow vehicle by the driver and can average more than one test per minute.

Total System Weight	4000 pounds
Dimensions Overall	
Length	150 inches*
Width	86 inches
Height	66 inches

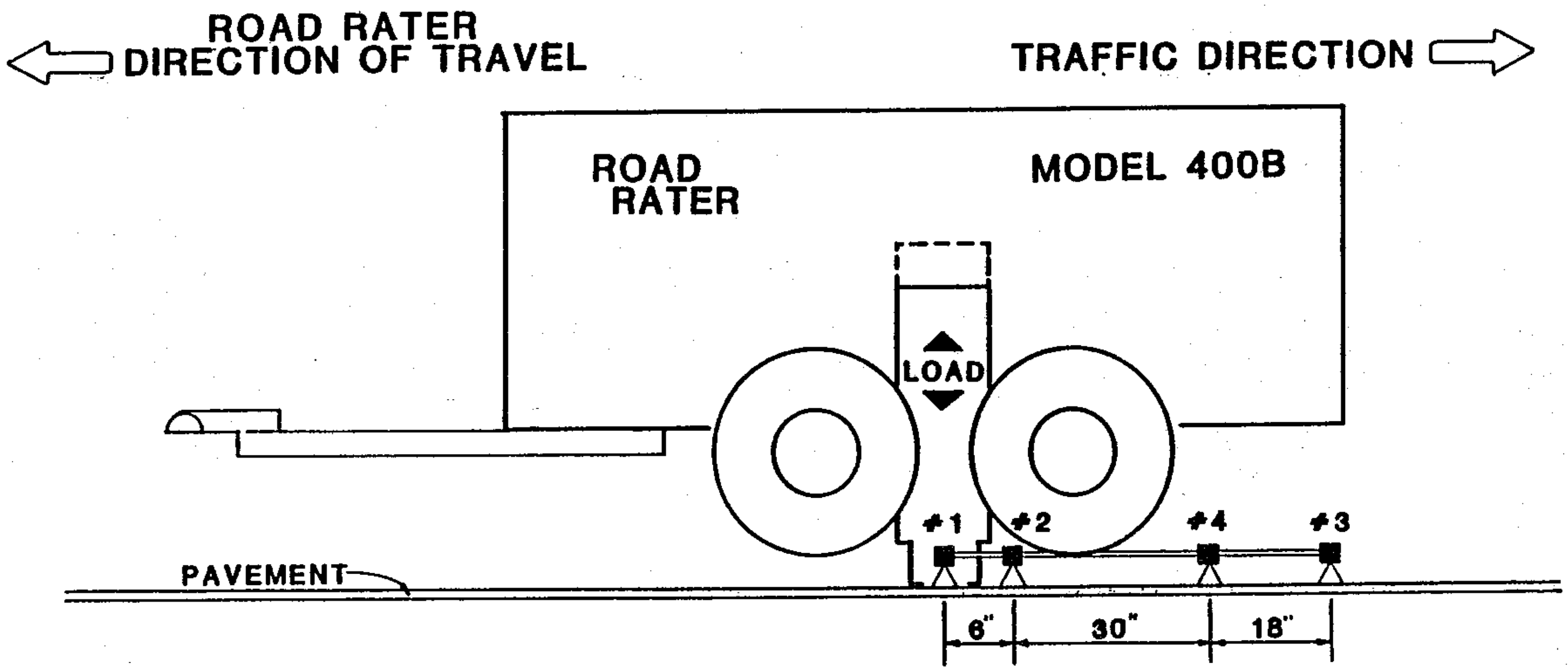
*Tongue may be detached to decrease shipping length to 96½ inches overall.

Road Rater

(Courtesy of Foundation Mechanics, Inc.)

(El Segundo, CA)

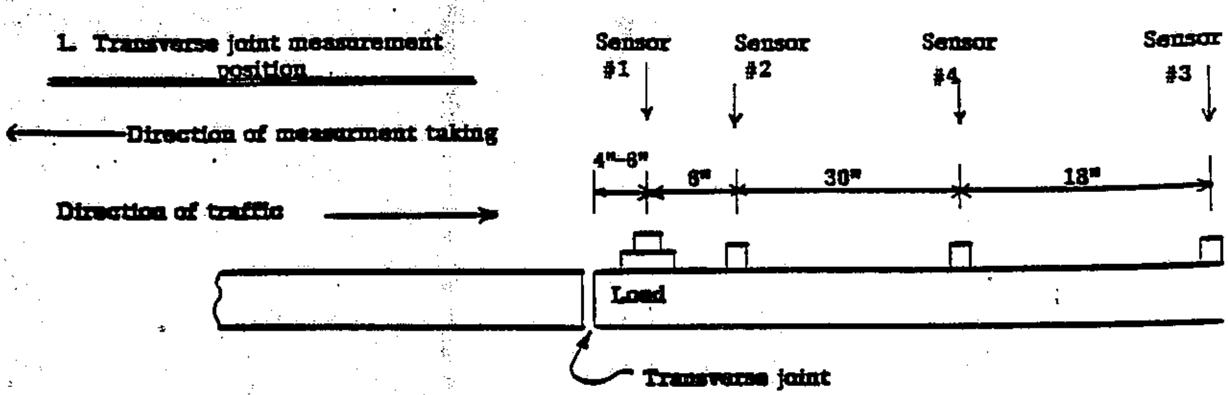
Figure A-9



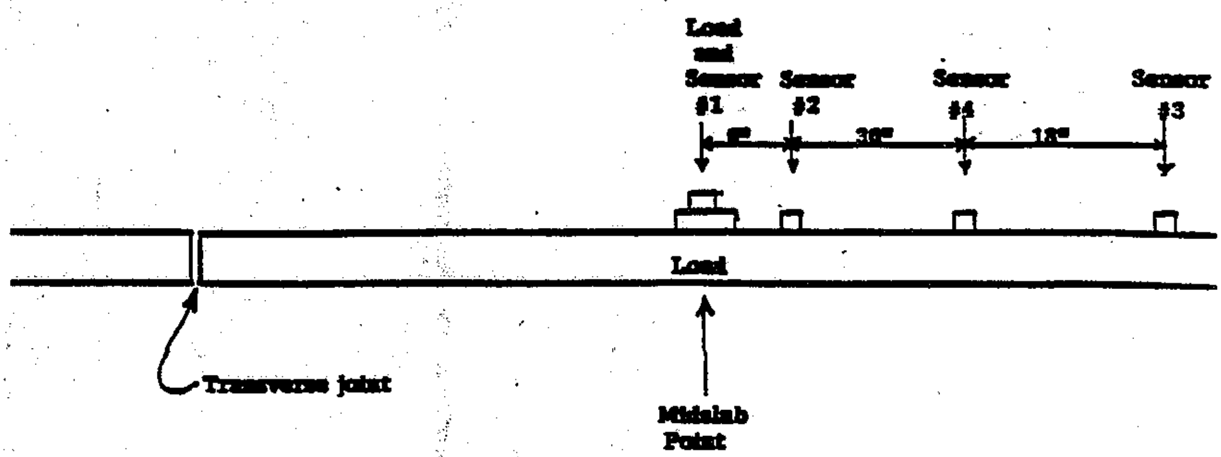
ROAD RATER SENSOR POSTIONS
(COURTESY OF LOS ANGELES COUNTY ROAD DEPARTMENT)

FIGURE A-10

1. Transverse joint measurement position



2. Mid Slab measurement position



Road Rater Sensor Positions

Figure A-11

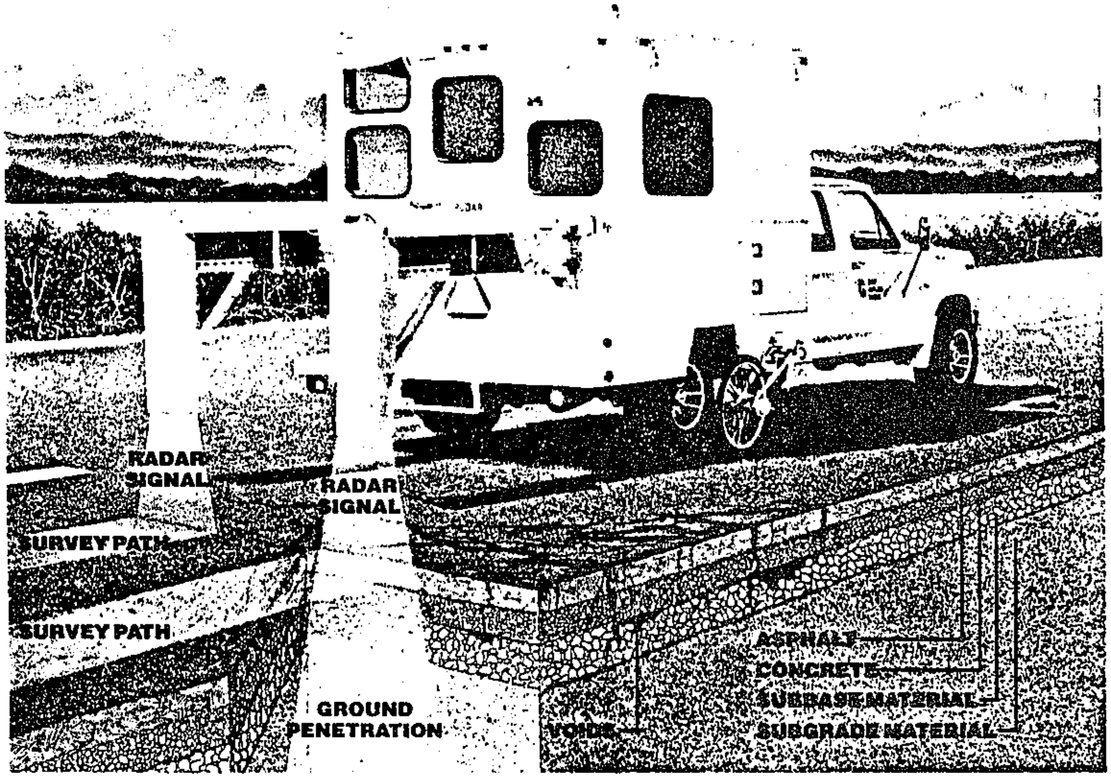
TECHNICAL FACT SHEET

GULF
APPLIED
RADAR

A publication of Gulf Applied Radar, a subsidiary of
Gulf Applied Technologies

May 1984

P.O. Box 56288
Houston, Texas 77256-6288
(713) 953-0335 or
(713) 981-3353



The RODAR™ pavement evaluation service penetrates below the surface to permit evaluation of pavement conditions. The innovative application of advanced but proven radar technology was developed in conjunction with Gulf Applied Research. Asphalt, concrete, subbase and subgrade conditions can be determined to assess voids and other anomalies, allowing economical, efficient evaluation of pavement inventory.

Gulf Applied Radar Rodar Unit

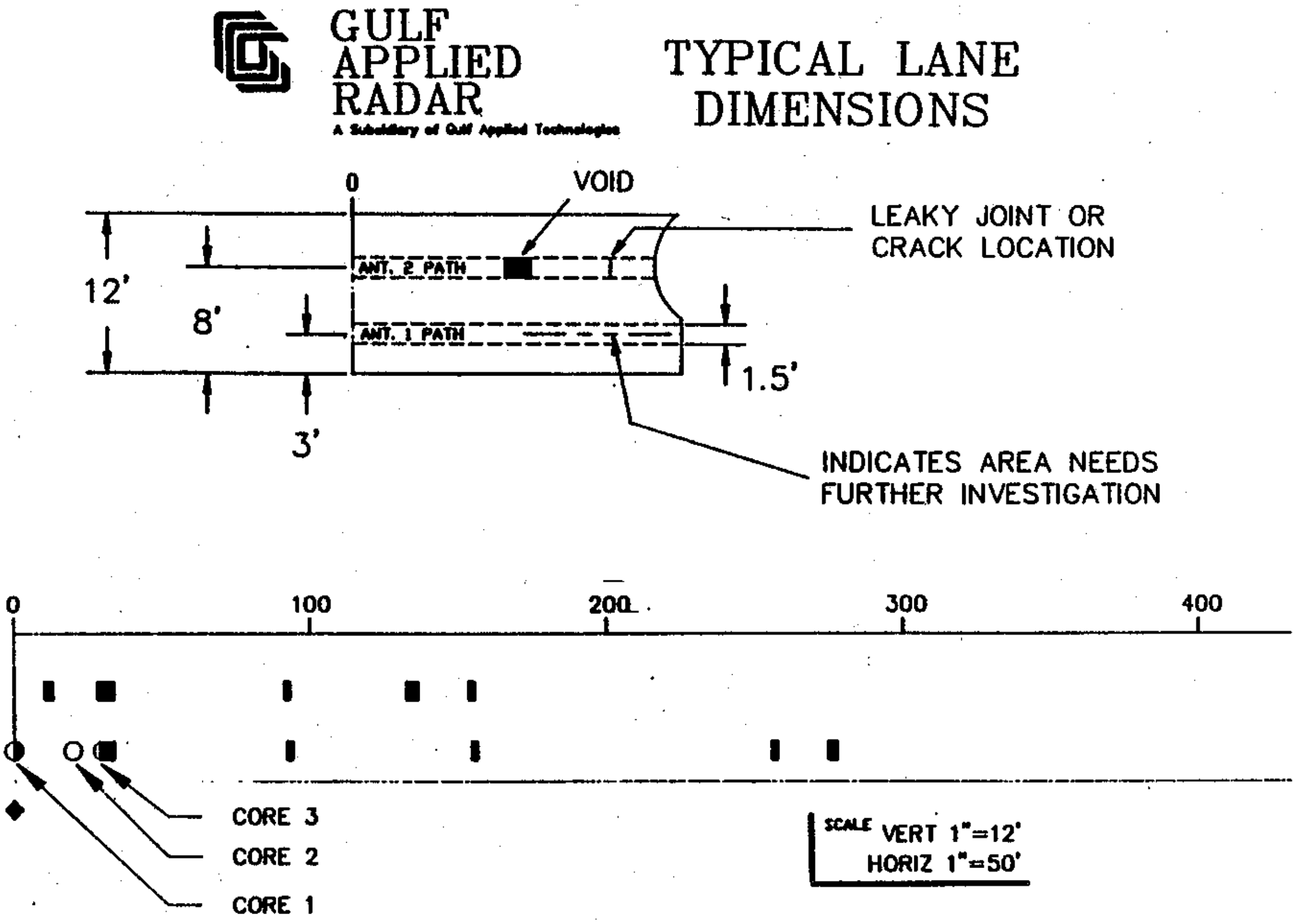
(Courtesy of GULF APPLIED RADAR)

Figure A-12

records linear distance along the pavement while a videotape of the pavement surface is also recorded for surface reference. On July 24, 1984, the Gulf Applied Radar (GAR) Company from Houston, Texas demonstrated the use of the Rodar void detection system for Caltrans on Interstate 80, just west of Fairfield, California. Analysis of the data after the demonstration revealed that the Rodar system could not detect voids in areas where the grout take was less than 60 pounds per hole. Later, modifications to the equipment, including a new computer, provided the means to enhance the resolution of the signal for greater sensitivity. When GAR analyzed the data obtained from the Fairfield project using the improved system, they were able to detect voids not previously found; therefore, a retest of the Rodar system on the experimental subsealing project on I-5 near Bakersfield was arranged.

On Thursday, February 28, 1985, the Rodar system was used on the northbound #2 lane from Station 455+00 (P.M. 23.8) to Station 730+00 (P.M. 29.0), a total length of 27,500 feet, prior to the subsealing operation. These limits (PM 23.8 to PM 29.0) include all the test sections for deflection testing as well as the silicone and grout subsealing test sections (Figures A-1, A-2).

Prior to testing, a 4-inch diameter core was taken in the right wheel path 6 to 8 inches from the transverse joint at the beginning of the test section, Station 455+00, to determine the actual depth of the concrete for calibration of the radar equipment. A 3/8-inch thick void was found between the PCC and the CTB. Calibration of the radar equipment was completed and the scanning operation began at 10:00 A.M., taking approximately 30 minutes to pass through the test section. After the radar unit passed through the test section, two additional cores were taken near the same location. The second core was taken in an area where the radar scan did not indicate voids and provided confirmation that voids were not present in this area. The third core was taken in an area where the radar scan indicated a void and this core indicated a 1/4-inch void present between the PCC and the CTB. Figure A-13 illustrates a layout sheet of a completed study.



(Courtesy of GULF APPLIED RADAR)

Figure A-13

DEFLECTION ANALYSIS

A graph of slab-end deflections vs test points is presented in Figures A-14a, b, and c. Also illustrated are radar events and a pavement condition survey for additional comparison and analysis. Test points common to all three deflection devices were from TP 49 to TP 140. It should be noted that the Dynaflect and the Road Rater measured deflections in units of 10^{-3} inches while the FWD measured deflections in units of microns, which were converted to units of 10^{-2} inches in order to fit all measurements on the same graph. Examination of Figures A-14a, b, and c indicates that there were some similarities in the various deflection patterns from TP 50 to TP 74, from TP 86 to TP 92, and from TP 108 to TP 123. Relatively few similarities exist for the other intervals.

A statistical analysis was performed on the deflection data and is summarized in Tables A-1 and A-2. The data in these tables indicate that the average slab-end deflections are consistently higher than the average midslab deflections for each device. Figures A-15, A-16, and A-17 are graphs of the FWD, Dynaflect, and Road Rater, respectively, comparing the slab-end deflection to midslab deflection at each test slab. The graphs illustrate that slab-end deflections are consistently higher than the midslab deflections. This should be the case when slab curl is taken into account.

In summary, all the deflection devices consistently show high slab-end deflections when compared to their respective midslab deflections. However, they do not show consistent slab-end deflections when compared to each other. This suggests that using slab-end deflections to locate voids under PCCP may not be a reliable technique because of these inconsistent responses.

SUBSEALING PROCEDURE

On Tuesday, April 16, the subsealing work began in the test area. The weather was cool with an ambient temperature of 55°F. Mixing and proportioning of the grout was done with a mobile-type grout plant mounted on a

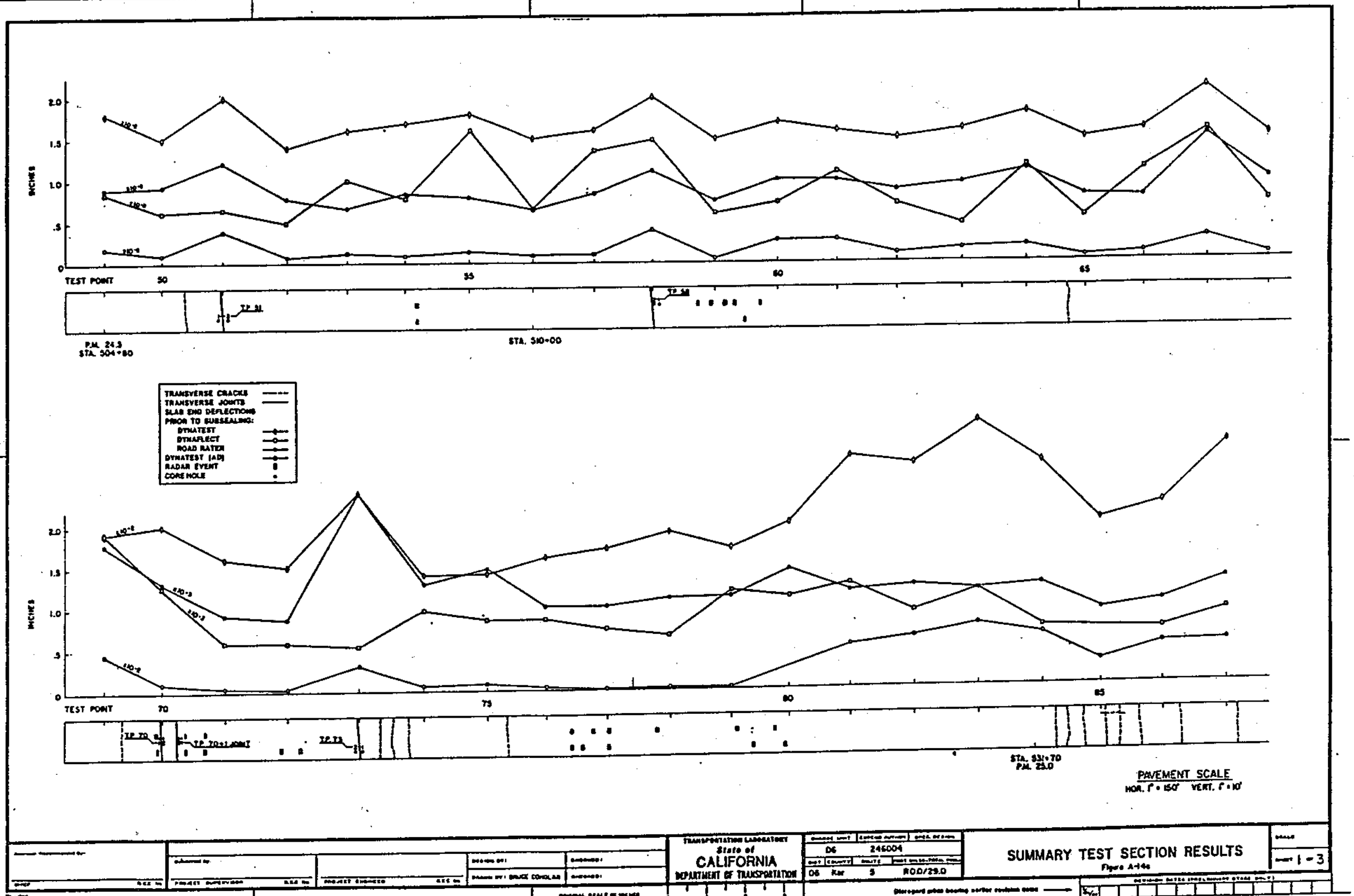

INCHES
TEST POINT
P.M. 24.3
STA. 504+80
STA. 510+00
TRANSVERSE CRACKS
TRANSVERSE JOINTS
SLAB END DEFLECTIONS
PRIOR TO SUBSEALING:
DYNATEST
DYNAFLECT
ROAD RATER
DYNATEST (AD)
RADAR EVENT
CORE HOLE
STA. 531+70
P.M. 25.0
PAVEMENT SCALE
HOR. 1" = 150' VERT. 1" = 10'
TRANSPORTATION LABORATORY
State of
CALIFORNIA
DEPARTMENT OF TRANSPORTATION
06 Ker 5 R0.0/29.0
246004
SUMMARY TEST SECTION RESULTS
Figure A-14a
1 – 3

Figure A-14a

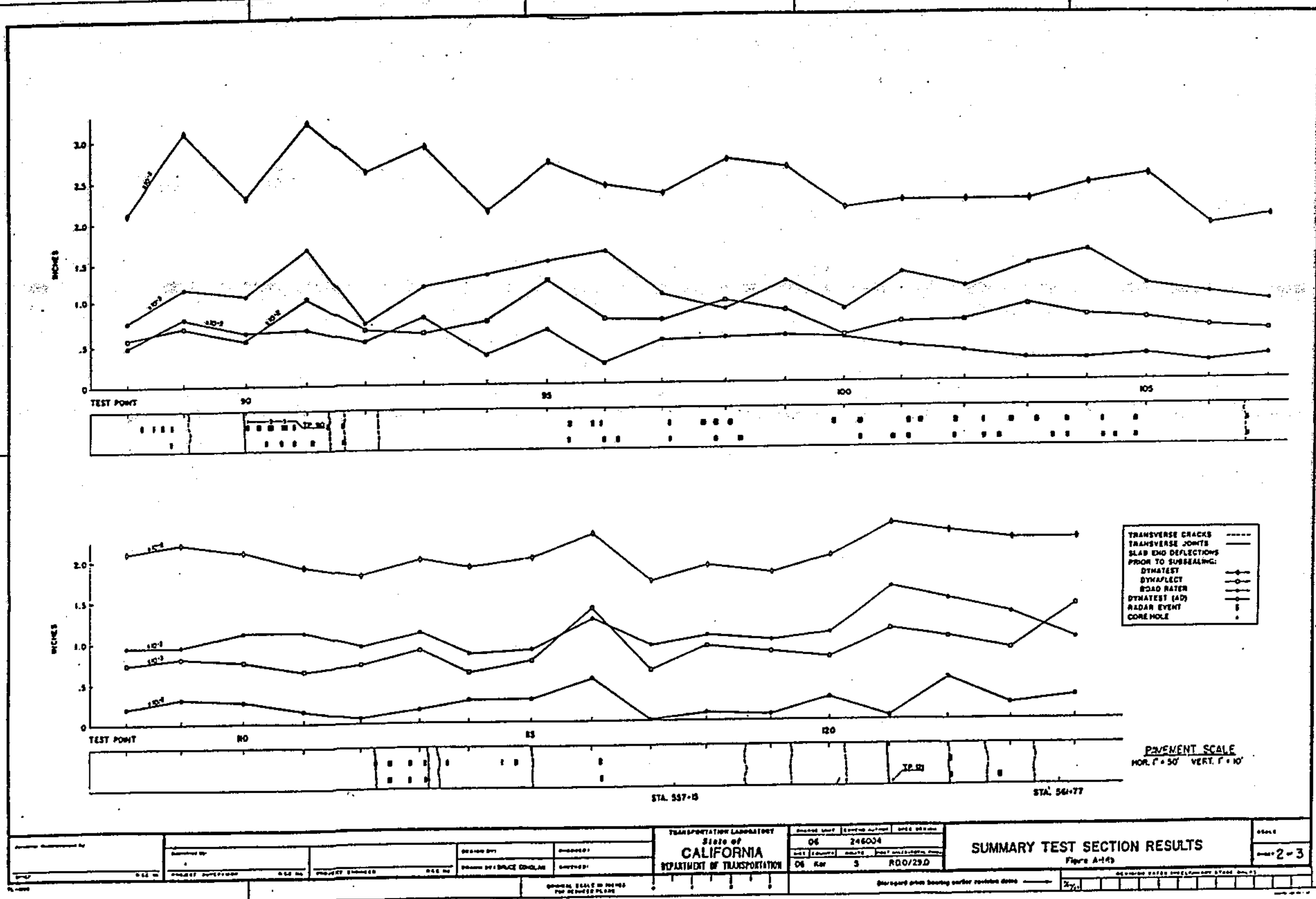
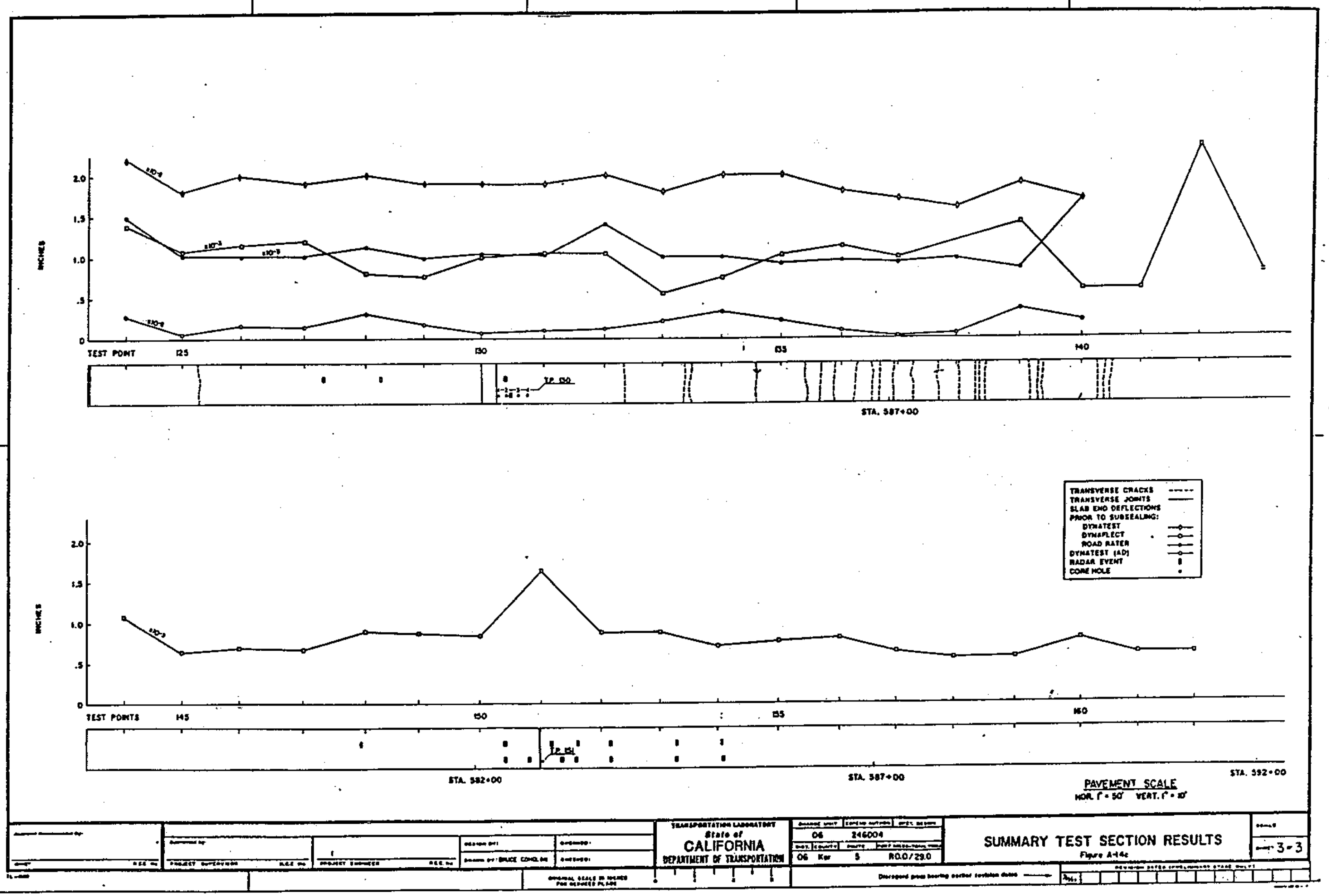

INCHES
TEST POINT
STA. 557+15
STA. 561+77
TRANSVERSE CRACKS
TRANSVERSE JOINTS
SLAB END DEFLECTIONS PRIOR TO SUBSEALING:
DYNATEST
DYNAFLECT
ROAD RATER
DYNATEST (AD)
RADAR EVENT
CORE HOLE
PAVEMENT SCALE
HOR. 1" = 50' VERT. 1" = 10'
TRANSPORTATION LABORATORY
State of
CALIFORNIA
DEPARTMENT OF TRANSPORTATION
06
246004
06 Ker
5
R0.0/29.0
SUMMARY TEST SECTION RESULTS
2-3

Figure A-14b



INCHES
2.0
1.5
1.0
.5
0
TEST POINT
125
130
135
140
x10-3
TP 130
STA. 587+00
TRANSVERSE CRACKS
TRANSVERSE JOINTS
SLAB END DEFLECTIONS
PRIOR TO SUBSEALING:
DYNATEST
DYNAFLECT
ROAD RATER
DYNATEST (AD)
RADAR EVENT
CORE HOLE
TEST POINTS
145
150
155
160
TP 151
STA. 582+00
STA. 587+00
STA. 592+00
PAVEMENT SCALE
HOR. 1" = 50' VERT. 1" = 10'
TRANSPORTATION LABORATORY
State of
CALIFORNIA
DEPARTMENT OF TRANSPORTATION
06
246004
06 Ker 5 R0.0/29.0
SUMMARY TEST SECTION RESULTS
Figure A-14c
3-3

Figure A-14c

TABLE A-1
SLAB-END DEFLECTION MEASUREMENTS
STATISTICAL DATA, 06-KER-5-R0.0/29.0

LOCATION	DEVICE	n	$\overline{X}$ *10-3 INCH	SD *10-3 INCH	Var *10-3 INCH	P-80 *10-3 INCH	RADAR EVENT /STAT	GROUT TAKE /HOLE
CONTROL								
TP84 - TP117	FWD	34	23	3.67	13.5	26.1	2.5	36
"	DYNAFLECT	33	.78	.181	.033	.932		
"	ROADRATER	34	1.13	.23	.055	1.32		
SECTION I								
TP118 - TP123	FWD	6	21	2.4	5.6	23.02	0.6	67
"	DYNAFLECT	6	.918	.126	.016	1.02		
"	ROADRATER	6	1.24	.26	.066	1.46		
SECTION II								
TP124 - TP136	FWD	13	19.4	1.12	1.26	20.34	0.8	32
	DYNAFLECT	13	.993	.227	.051	1.2		
	ROADRATER	13	1.04	.127	.016	1.15		
SECTION III								
TP137 - TP149	DYNAFLECT	12	.97	.496	.246	1.4	0.2	2
SECTION IV								
TP150 - TP156	DYNAFLECT	7	.93	.319	.102	1.20	2.6	11
SECTION V								
TP157 - TP162	DYNAFLECT	6	.63	.082	.007	.7	0	23
TP49 - TP140	FWD	92	20.3	4.04	16.29	23.7	1.5	N/A
TP49 - TP142	DYNAFLECT	90	.89	.283	.080	1.10		
TP49 - TP140	ROADRATER	92	1.11	.277	.077	1.34		

$\overline{X}$=Mean Deflection
n=Number of Test Points
SD=Standard Deviation
Var=Variance
P-80=80th Percentile Deflection

TABLE A-2.
MIDSLAB DEFLECTION MEASUREMENTS
STATISTICAL DATA, 06-KER-5-RO.0/29.0

LOCATIION	DEVICE	n	$\bar{x}$ *10-3 INCH	SD *10-3 INCH	VAR *10-3 INCH	P-80 *10-3 INCH	RADAR EVENT /STAT	GROUT TAKE /HOLE
CONTROL								
TP84 - TP117	FWD	33	15.4	2.75	7.6	17.71	2.5	36
"	DYNAFLECT	35	.572	.089	.008	0.647		
"	ROADRATER	34	.94	.22	.05	.0011		
SECTION I								
TP118 - TP123	FWD	6	15.7	1.51	2.27	16.97	0.6	67
"	DYNAFLECT	6	.505	.019	.0004	.521		
"	ROADRATER	6	.96	.23	.04	.001		
SECTION II								
TP124 - TP136	FWD	13	17	.913	.833	17.8	0.8	32
"	DYNAFLECT	13	.493	.027	.0007	.516		
"	ROADRATER	13	.93	.098	.01	.001		
SECTION III								
TP137 - TP149	DYNAFLECT	12	.434	.048	.002	.474	0.2	2
SECTION IV								
TP150 - TP156	DYNAFLECT	7	.46	.032	.001	.487	2.6	11
SECTION V								
TP157 - TP163	DYNAFLECT	6	.453	.048	.002	.493	0	23
TP49 - TP140	FWD	90	15.1	2.39	5.72	17.1	1.5	N/A
"	DYNAFLECT	92	.525	.078	.006	.590		
"	ROADRATER	92	.96	.184	.034	1.11		

$\bar{x}$=Mean Deflection
n=Number of Test Points
SD=Standard Deviation
Var=Variance
P-80=80th Percentile Deflection

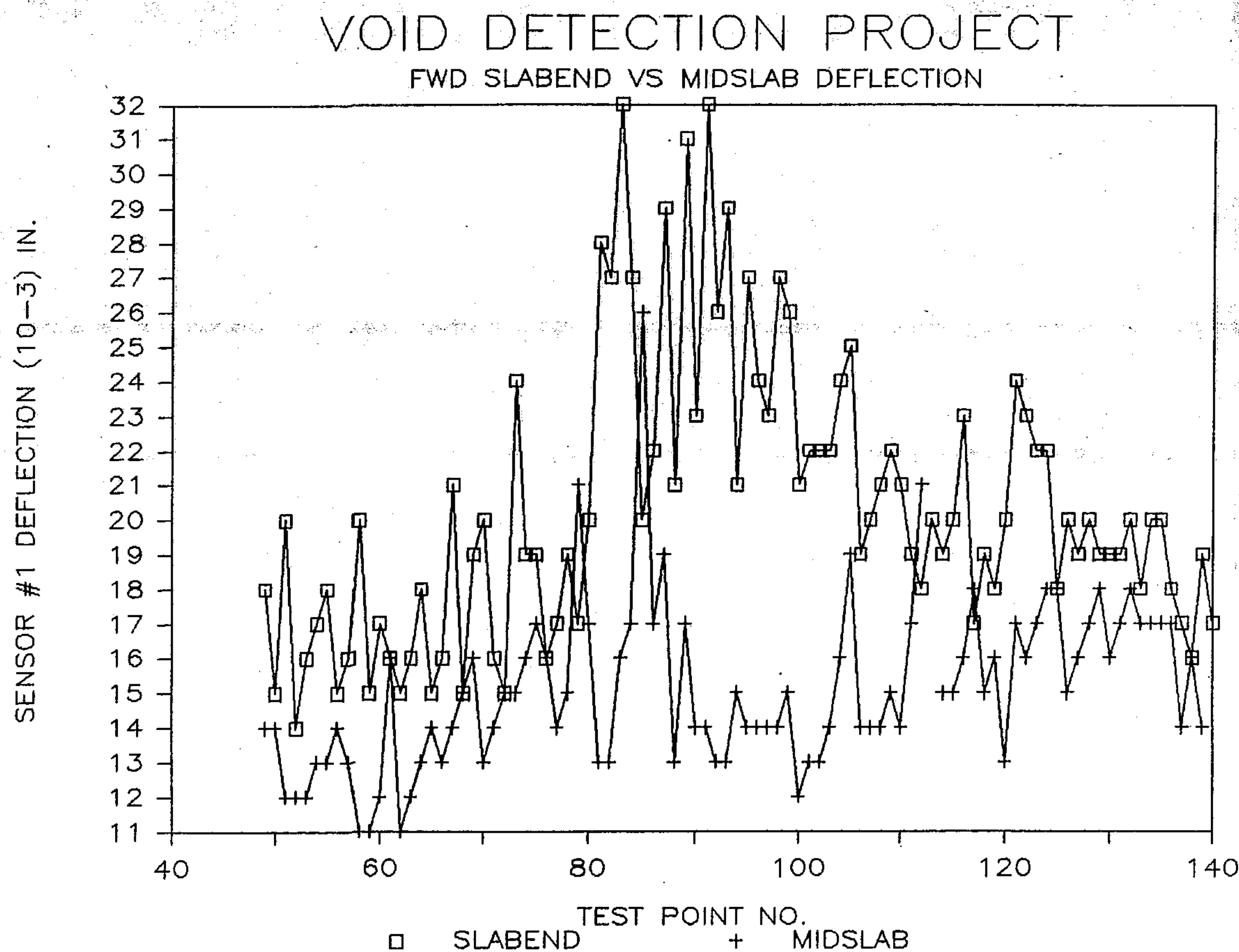

VOID DETECTION PROJECT
FWD SLABEND VS MIDSLAB DEFLECTION
SENSOR #1 DEFLECTION (10-3) IN.
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
40
60
80
100
120
140
TEST POINT NO.
SLABEND
+ MIDSLAB

Figure A-15

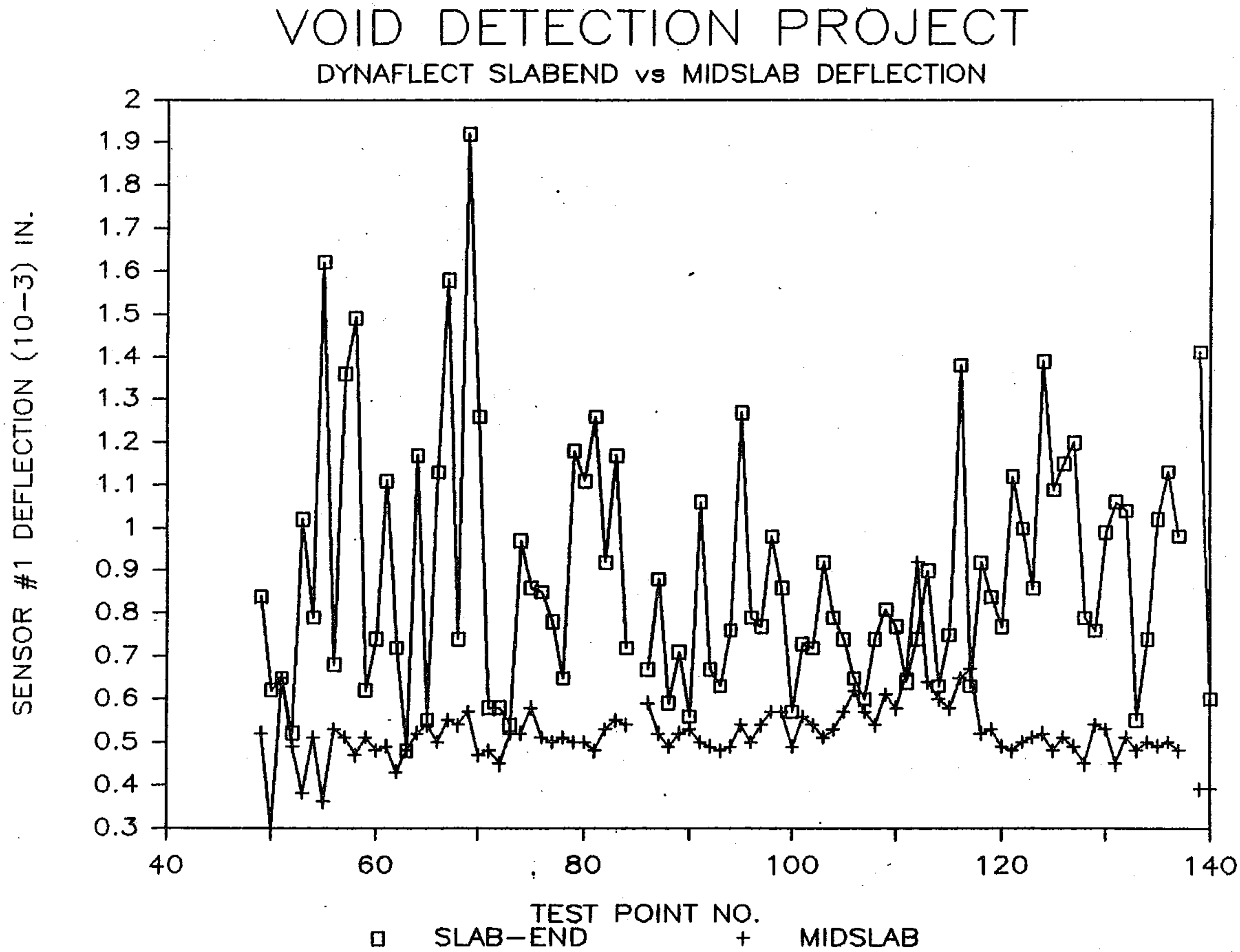

VOID DETECTION PROJECT
DYNAFLECT SLABEND vs MIDSLAB DEFLECTION
SENSOR #1 DEFLECTION (10−3) IN.
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
40
60
80
100
120
140
TEST POINT NO.
SLAB−END
MIDSLAB

Figure A-16

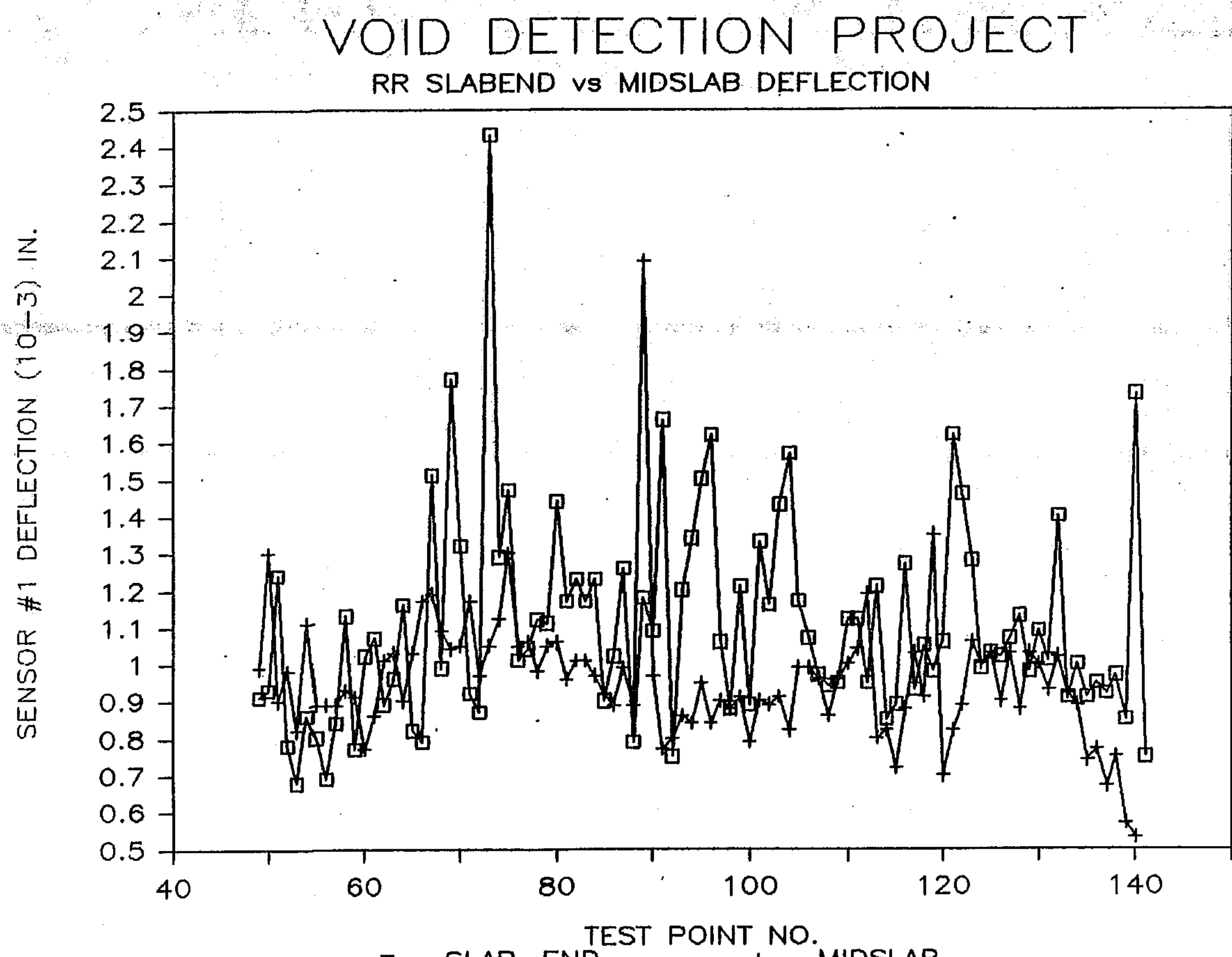

VOID DETECTION PROJECT
RR SLABEND vs MIDSLAB DEFLECTION
SENSOR #1 DEFLECTION (10-3) IN.
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
40
60
80
100
120
140
TEST POINT NO.
SLAB--END
MIDSLAB

Figure A-17

flatbed trailer. The grout consisted of three sacks of fly ash (totaling 240 pounds) and one sack of cement (94 pounds); thus, one dry batch weighed 334 pounds.

The parameters examined in this analysis are:

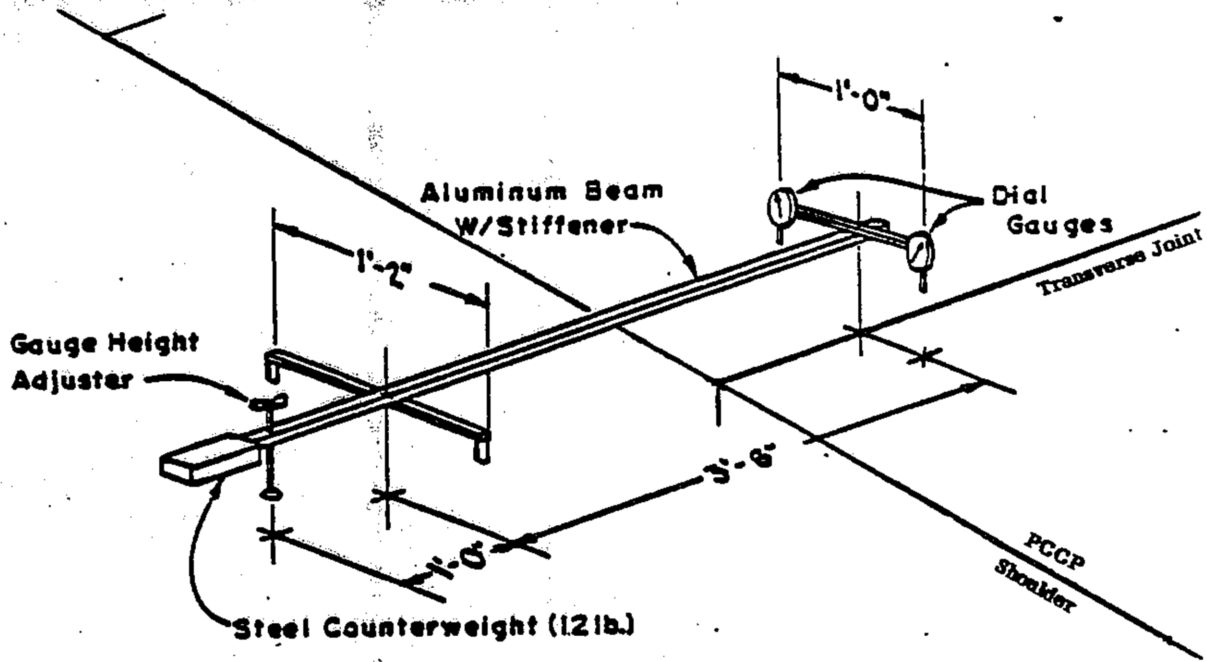
1. The injection depth for most effective subsealing, i.e., 9-inch depth vs 15-inch depth.

2. The location and spacing of the injection holes relative to the location of the voids under the pavement.

3. Coring injection holes vs percussion drilling of the injection holes.

4. Allowing 0.100-inch maximum vertical slab movement (uplift) vs 0.050-inch maximum vertical slab movement.

The maximum pumping pressure used was between 220 to 225 psi as measured by a gauge mounted on the discharge pipe near the holding tank. The efflux time of the grout was approximately 10 seconds as determined by the flow cone test described in California Test 541. A monitoring gauge was used by the inspector to monitor the vertical movement of each slab (Figure A-18). Prior to grouting, each grout hole was pressure-washed with water at 20 psi to remove broken fragments and cement dust at the slab/ base interface caused by drilling the hole as broken fragments and cement dust have been found to seal off voids. Pumping continued until: (1) a significant amount of slab movement was observed from the monitoring gauge, i.e., 0.050 inch or 0.100 inch maximum, (2) grout appeared at an adjacent longitudinal or transverse crack, or (3) seven seconds elapsed at a sustained grout pressure of 150 psi. After injecting grout in each hole, a temporary wooden plug was inserted until back pressure subsided sufficiently to assure that the grout would not be forced out of the hole. After the subsealing was complete, the holes were grout filled flush with the surface of the pavement.



Δ—Vert Gauge

Figure A-18

SUBSEALING RESULTS AND ANALYSIS

As previously discussed, the results of the deflection measurements and the GAR survey, prior to subsealing, are presented in Figures A-14a, b, and c. The control test section between Station 531+00 and Station 557+15 (2615 feet) consisted of 34 test points (TP 84 to TP 117), which was the greatest number of test points in any of the five test sections. The control section also produced the greatest number of radar events (areas of possible voids). Standard Caltrans subsealing procedures as described earlier in this report were utilized in this section. The average grout take (Figure A-19) was 36 pounds per hole and 66 radar events were recorded, (i.e., 2.5 radar events per station). Groups of radar events in this section occurred around test points 88 to 92, 95 to 98, 100 to 105, 112 to 113, and 116 (refer to Figure A-14b). Deflections fluctuated considerably between devices at these test points, indicating poor correlation between radar events and slab deflection.

Section I had only 6 test points and only 3 radar events (or 0.6 radar events per station). The allowable vertical slab movement was 0.100 inch uplift. A total of 110 holes were percussion drilled to a depth of 15 inches.

Of these holes, 48 (or 43.6%), accepted grout. Twenty-two batches of grout were used, producing the highest average grout take on the project - 67 lb per hole. Factors that may account for the higher grout-take are the increase in the maximum allowable vertical slab movement during grouting and, possibly, the presence of large voids. Since there were so few radar events and those that were present were of small magnitude, the increase in vertical slab movement from 0.050 inch to 0.100 inch uplift is the most likely cause for the high grout-take.

Section II had 13 test points but only 4 radar events, i.e., a rate of 0.4 radar events per station. The vertical slab movement was limited to 0.050

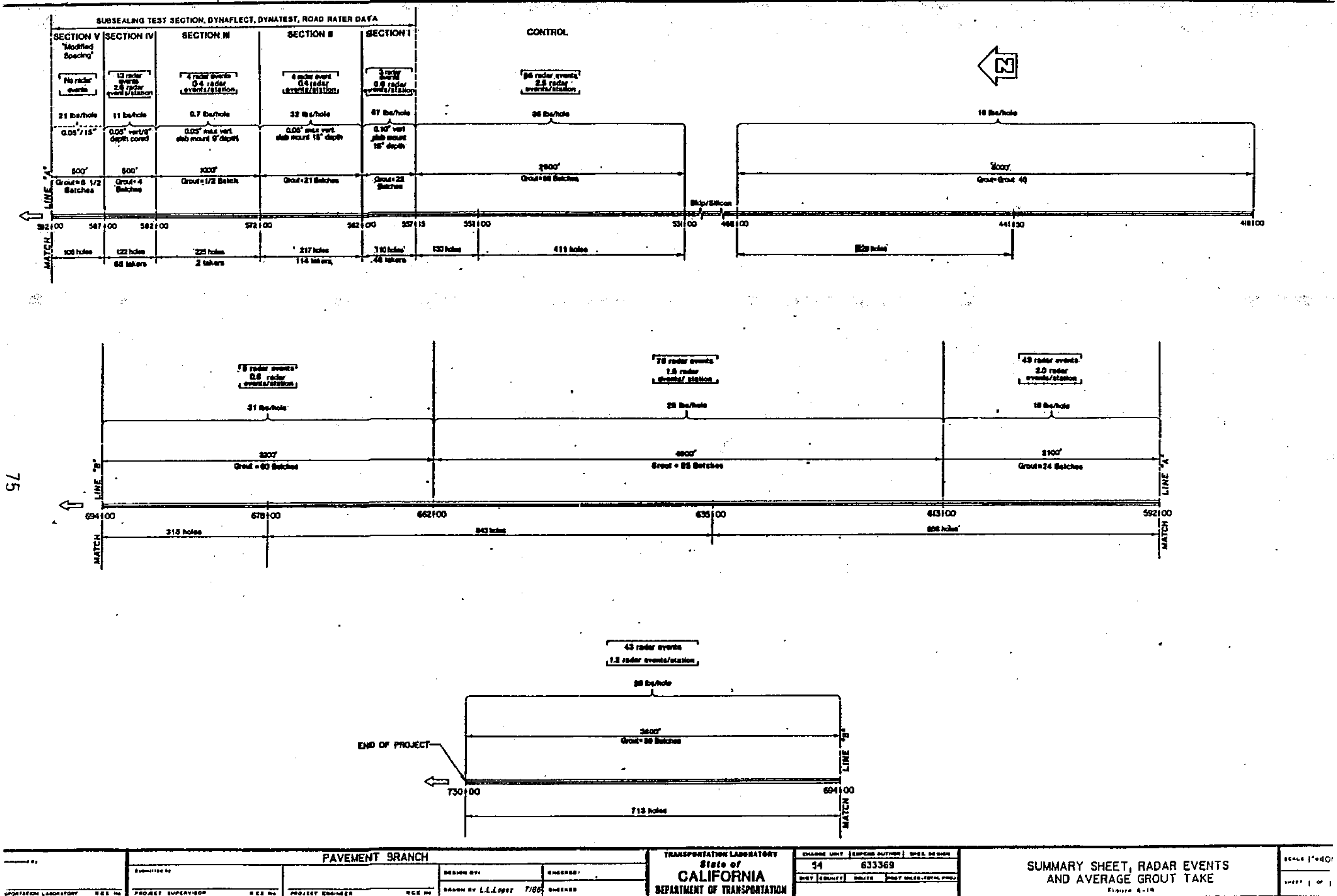

SUBSEALING TEST SECTION, DYNAFLECT, DYNATEST, ROAD RATER DATA
SECTION V
"Modified Spacing"
SECTION IV
SECTION III
SECTION II
SECTION I
CONTROL
END OF PROJECT
PAVEMENT BRANCH
TRANSPORTATION LABORATORY
State of
CALIFORNIA
DEPARTMENT OF TRANSPORTATION
54
633369
SUMMARY SHEET, RADAR EVENTS
AND AVERAGE GROUT TAKE

Figure A-19

inch. A total of 217 holes were percussion drilled to a 15-inch depth. One-hundred and fourteen of these accepted grout (52.5%). Twenty-one batches of grout were used producing an average grout-take of 32 lb per hole. The grout-take in Section II was less than half the grout-take in Section I. It is suspected that the decrease in maximum vertical slab movement from 0.100 inch to 0.050 inch caused this difference in grout-take.

In Sections III, IV, and V, only Dynaflect deflection data are available for analysis for reasons discussed earlier in this report. There were 225 holes percussion drilled in Section III with only 2 holes accepting grout (0.9%). Although this section was 1000 feet in length, it had only four radar events. Only about 1/2 batch of grout was used, producing the lowest average grout-take of all the test sections (0.7 lb per hole). Two reasons may account for such a small amount of grout-take: (1) an absence of voids, or (2) the nine-inch core depth wasn't sufficient to allow adequate penetration of the grout at the pavement-base interface. According to the condition survey that was performed for this study, several transverse cracks were present within this test section; however, no radar events occurred in the areas that exhibited cracking.

In Section IV there were 122 holes core drilled, in lieu of percussion drilling, with 65 holes (53.3%) accepting grout. Approximately 4 batches of grout were used, producing an average grout-take of approximately 11 lb per hole. There were 7 test points in this section and 13 radar events recorded (at 2.6 radar events per station). Although this section was only 500 feet in length, there was a high number of radar events recorded, compared to the previous section, 1000 feet in length and 4 radar events. The grout-take was relatively low. This doesn't appear consistent with 13 radar events. It is suspected that the 9-inch depth of the cored holes may not have allowed sufficient grout penetration at the pavement-base interface. No transverse or longitudinal cracks were found in this test section during the condition survey.

In Section V, the spacing of the grout holes was modified to 6 holes per slab. However, soon after the grouting began, it was discovered that 6 holes per slab caused too much grout to be wasted by escaping from adjacent holes during pumping. After subsealing the first 5 slabs, it was decided to resume grouting with the original 3-hole pattern for the remainder of the test section since the 6-hole pattern was not satisfactory. Thus, 105 holes were percussion drilled with 52 (50.5%) accepting grout. There were 6-1/2 batches of grout used which produced an average grout-take of approximately 21 lb per hole. This was higher than expected and probably due to the 6 holes per slab pattern. No radar events were recorded in this test section.

In summary, the use of 15-inch deep grout holes resulted in more grout-take than the 9-inch deep core drilled grout holes as shown in Table A-3. Grout acceptance per hole was improved by coring the injection holes instead of percussion drilling; however, even in this case, the grout-take in lb per hole was quite low (11 lb per hole vs a statewide average of 26 $\pm$ lb per hole).

DEFLECTION AND RADAR VOID DETECTION RESULTS

Cores were taken throughout the project after subsealing to determine if voids actually existed at locations indicated by high deflections and/or radar signals. A total of 28 cores were taken in the northbound Number 2 lane. Thirteen cores were taken in the left wheel track and 15 in the right wheel track.

Eight cores were taken in Test Sections I to V, (TP 49 to TP 163). At the first location where a core was taken (TP 51), the FWD and the Road Rater both indicated a relatively high deflection; however, the core did not indicate a void or the presence of grout beneath the PCCP. Radar did not indicate a void at this location.

TABLE A-3

SUMMARY OF GROUT RESULTS

Test Section	Holes Accepting Grout %	Average Grout/Hole (lb)	Type of Drilling	Maximum Slab Uplift (inches)	Remarks
I	43.6	67	Percussion 15-Inch Depth	0.100	Highest Grout-Take Per Hole
II	52.5	32	Percussion 15-Inch Depth	0.050	*Above Normal Grout Take
III	0.9	2	Percussion 9-Inch Depth	0.050	Insufficient Hole Depth
IV	53.3	11	Coring 9-Inch Depth	0.050	Insufficient Hole Depth
V	50.5	23	Percussion 15-Inch Depth with Modified Spacing	0.050	6-Hole Pattern not Practical

*Comments:

1. 15-inch depth provided more grout-acceptance than the 9-inch depth.
2. Appears to be an improved grout-acceptance/hole using coring.
3. Average grout per hole statewide is about 26 lb/hole.

At TP 58, higher than normal deflections were recorded by all three deflection devices. Two cores were taken, but no voids or grout were found. In the area of TP 70, radar indicated voids. Four cores were taken at this location and no voids or grout were found.

At TP 73, high deflection values were measured by the FWD and the Road Rater while the radar scan indicated no voids present prior to grouting. The cores taken at this location indicated silicone material was present on the bottom of the core. In the area of TP 90, all three deflection devices as well as the radar equipment indicated voids. The core taken here revealed 1/4-inch thick grout present at the PCC-CTB interface, indicating voids were present prior to grouting.

At TP 121, high deflections were measured by all three deflection devices prior to subsealing. The radar scan recorded no voids at this location and the core taken here revealed that no voids or grout were present.

At TP 130, all three deflection devices measured low deflections; however, the radar scan indicated two large voids. Four cores indicated a very thin layer of grout at the bottom of the cores.

Finally, at TP 151, the Dynaflect measured a high deflection and radar indicated voids in this area, but not specifically at the test point. The core indicated a layer of grout in the CTB portion of the core, confirming that a void was present prior to subsealing.

Additional cores were taken outside of the subsealing test sections from Station 592+00 to the end of the project at Station 730+00, (a total of four locations). At Station 675+00, the radar scan indicated no voids present. This was confirmed by a core which revealed no evidence of grout. At Station 704+50, the radar scan indicated voids present so four cores were taken - three in the left wheel track and one in the right wheel track. Two of the cores revealed evidence of grout between the PCCP and the CTB, indicating a void was present prior to grouting. The two additional cores taken indicated no void or grout present. At Station 717+50, the radar scan indicated no voids. This was confirmed by a core which revealed no evidence of voids or grout. At Station 720+00, the radar scan indicated large voids in the right and left wheel tracks. Three cores were taken - one in the left wheel track and two in the right wheel track. A large void, approximately 1/2 inch thick, was found in the left wheel track without any grout present. No voids were found from the cores taken in the right wheel track. These results are tabulated in Table A-4.

SUMMARY AND CONCLUSIONS

1. Use of Deflection Devices to Determine Void Locations

The deflection graphs in Figures A-14a, b, and c indicate a relative pattern in deflection response in certain areas of the project which suggests some correlation between the testing devices. One of the areas where the deflection pattern seems to have the strongest correlation occurs between TP 65 and TP 106. However, the pattern of radar events does not correlate well with the high-deflection response pattern in this area. Between TP 90 and TP 92, a group of radar events occurred; however, only one high-deflection response was measured in this area (at TP 91). The three cores taken at this location show a minimum amount of grout present. In addition, the condition survey does not correlate with either areas of high deflection response or radar events. Transverse cracks are present between TP 84 and TP 87 but neither the radar events nor deflection responses are significant at this location. This is probably due to the subpanel acting as a short slab with full subgrade support.

The data contained in Table A-4 suggest that none of the deflection devices used (Falling Weight Deflectometer, Road Rater, and Dynaflect) effectively determine the location of voids under PCCP (23,33 and 43 percent accuracy, respectively). In addition, the Dynatest FWD was expensive for this particular application, considering the number of test points that could be measured in a given length of time. These data suggest that the grout subsealing technique, as specified by Caltrans prior to the grout subsealing moratorium, was the most effective method. The Rodar radar device appears to be capable of locating voids under PCCP fairly well (71% accuracy).

TABLE A-4

SUMMARY OF VOID DETECTION DEVICE RESULTS

Deflection Devices*						Identified void/nonvoid location correctly.			
Test Points	FWD	RR	Dynaflect	Radar	Void Present	FWD	RR	Dynaflect	Radar
51	High	High	Low	No	No	No	No	Yes	Yes
58	High	High	High	No	No	No	No	No	Yes
70	-	-	-	Yes	No	-	-	-	No
73	High	High	Low	No	Yes	Yes	Yes	No	No
90	High	High	High	Yes	Yes	Yes	Yes	Yes	Yes
121	High	High	High	No	No	No	No	No	Yes
130	Low	Low	Low	Yes	Yes	No	No	No	Yes
151	-	-	High	Yes	Yes	-	-	Yes	Yes
675+00	-	-	-	No	No				Yes
704+50	-	-	-	Yes	No/Yes**				No/Yes**
717+50	-	-	-	No	No				Yes
720+00	-	-	-	Yes	No/Yes**				No/Yes**

Device	Detected Voids Correctly	Percentage Correct
FWD	2 out of 6 locations	33%
RR	2 out of 6 locations	33%
Dynaflect	3 out of 7 locations	43%
Radar	10 out of 14 locations	71%

* FWD = Falling Weight Deflectometer, RR = Road Rater

** Void found under one wheel track; however, no void found under the opposite wheel track.

2. Grout Subsealing Techniques.

The data from Test Section I indicate that increasing the maximum vertical slab movement to 0.100 inches will result in an increase in grout-take per hole, i.e., 67 lb per hole. When limiting the maximum vertical slab movement to 0.050 inches (in Test Section II) while all other parameters remained the same, the average grout-take was 32 lb per hole. This was still higher than that for the remaining test sections. Reducing the depth of the percussion drilled holes from 15 inches to 9 inches in Test Section III drastically reduced the average grout-take to 0.7 lb per hole. This suggests that the 15-inch depth allows more grout to penetrate the interface between the PCCP and the CTB.

When the 9-inch grout holes in Test Section IV were core drilled instead of percussion drilled, the average grout-take increased; however, grout appeared very quickly at the adjacent transverse and longitudinal joints, indicating that void penetration by the grout may not have been complete.

The modified hole pattern in Test Section V where six grout holes were percussion drilled in each slab provided no additional benefit. Unfortunately, not enough plugs were available for use in adjacent grout holes so grout probably escaped before total penetration of voids was complete.

RECOMMENDATIONS

The following recommendations are based on Caltrans' previous grout subsealing research, construction experience, and the findings presented in this research:

1. For California PCCP, slab deflection measurements should not be used to determine where grout subsealing should be done.

2. PCCP slab distress (cracking) should not be used to determine where grout subsealing should be done.

3. The current Caltrans specifications concerning grout subsealing materials, hole locations, hole depths, and hole drilling should be retained.

4. If the Caltrans pavement subsealing moritorium is lifted, a radar system similar to the type reported herein should be investigated further regarding the determination of where subsealing should be done.

APPENDIX 3

Grout Subsealing Quantities
Through July, 1985

GROUT SUBSEALING QUANTITIES THROUGH JULY 1985

PROJECT	EA	BID OPN	CONT'R (SUB)	QUANTITIES POUNDS/HOLE EST	ACT	% OF ORIGINAL
2-Sis-5-6.2/R12.6	144714	8-12-81	(Del Val) Smith	117	88	75
2-Teh-5-0.0/R23.0	191504	9-22-82	(Del Val) Teichert	50	65	130
2-Sis-5-36.8/43.0	144704	3-30-83	Willamette	48	16	33
2-Sha-5-56.2/60.0	191524	5-25-83	Smith	50	16	32
2-Sha-5-60.0/67.0	176014	11-2-83	Redding	48	4.3	9
2-Sis-5-70.1/70.6	196201	5-16-84	Kiewit	50	36	72
2-Sha-5-3.9/14.0	175904	6-30-82	(Del Val) Smith	51	60	117
3-Pla-80-4.0/11.4	253504	11-2-83	(Del Val) Teichert	33	32	97
3-Yol-5-23.0/27.0	276901	2-15-84	(Hunt) Kiewit	50	18	36
4-SCl-280-R2.8/11.5	110794	10-11-83	(Del Val) Teichert	33	21	64
4-Ala-580-11.7/16.0	111624	11-8-83	(Del Val) Teichert	40	35	88
4-Ala-80-3.0/3.7	111644	1-3-84	Jones	100	65	65
4-Ala-238-14.9/16.7	108584	-	Hunt	41	12	30
4-Ala-580-42.2/44.5	111634	-	Hunt	100	19	19
4-Ala-580-6.9/11.7, 16.0/21.0	112664	1-15-85	Kiewit	20.5	20.5	100
4-Ala-580-1.5/6.9	110774	-	Granite	32	25	78
4-SCl-101-46.8/52.6	105004	2-5-85	Raisch	70	9.1	13
4-SCl-17-7.9/R17.3	104939	3-5-85	Kasler	20.5	53	257
4-Son-101-36.3/54.2	105754	-	Gem	50	17.6	35
4-Ala-580-8.1/11.7	112664	2-14-85	Kiewit	22.2	20.6	92
5-SB-101-26.9/57.9	282684	8-24-83	Smith	42	20	22
5-SLO-59.0/64.8	279804	9-28-83	Madonna	43	16	37
5-SB-101-1.3/13.0	293604	2-15-84	Madonna	35	9	26
5-SB-101-16.2/17.6	294204	5-2-84	Hermreck	46	45	98

GROUT SUBSEALING QUANTITIES
THROUGH JULY 1985

PROJECT	EA	BID OPN	CONT'R (SUB)	QUANTITIES POUNDS/HOLE EST	ACT	% OF ORIGINAL
6-Ker-5-2.0/11.0	222004	11-16-83	Smith	51	7	14
6-Ker-5-85.8/87.0	239404	10-19-83	Smith	51	3.2	6
6-Ker-5-28.7/49.0	246104	8-6-84	Smith	32	23	71
6-Ker-5-0.0/29.0	246004	9-19-84	Smith	26	24	92
6-Fre-5-14.0/66.0	245504	10-16-84	Teichert	26	42	160
7-LA-5-53.0/56.3	261314	12-8-83	Kiewit	200	2.6	2
7-LA-5-R59.4/R77.9	061324	2-16-84	Yeager (Del Val)	50	4.2	8
7-LA-5-R79.0/R83.0	001734	2-28-85	Chumo	10.3	17.9	173
7-LA-10-38.5/40.7	001644	11-1-84	Chumo	31	11.5	37
8-Riv-91-17.5/21.6	255004	9-22-83	Smith	50	9.3	19
8-SBd-10-10.9/20.0	250604	10-6-83	Smith	50	9.2	18
8-Riv-215-41.1/43.2	255304	10-20-83	Kiewit	50	8.9	18
8-SBd-215-4.3/	255104	3-22-84	Kiewit (Del Val)	30	25	62
8-SBd-15-12.7/29.8	268804	11-15-84	Yeager	30	66.3	514
10-Sta-5-0.0/5.0	278504	10-18-83	Kiewit	50	30	60
10-Mer-5-8.0/32.5	278104	1-11-84	Smith	55	16.7	30
10-SJ-580-0.0/9.0	296874	1-4-84	Teichert (Hunt)	50	16	32
10-Sol-80-R9.7/R28.3	296841	3-7-84	Skinner	50	47	94
10-Mer-5-0.0/8.0	256024	8-22-84	Smith	41	24	58

APPENDIX 4

Transportation Research Board, Division A-Group 2, Outline for Research Problem Statement, titled, "A Study of Subsealing as a Rehabilitation Technique for Portland Cement Concrete Pavement (PCCP)".

TRANSPORTATION RESEARCH BOARD
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Division A - Group 2
Outline for Research Problem Statement

I. TITLE

A Study of Subsealing as a Rehabilitation Technique for Portland Cement Concrete Pavement (PCCP).

II. THE PROBLEM

The FHWA, industry, and construction-related associations are currently promoting the use of cement/pozzolan materials to fill voids under PCCP's, by subsealing, to restore "full slab support." It has been well established by previous research that most PCCP slab edges are in an upward curled or warped condition, to some extent, on a daily basis. Thus, "full slab support" is a condition that has seldom existed since the pavement was placed in service and, if reestablished when the slabs are curled, could possibly be detrimental.

Also, subsealing experience indicates that there is no reliable methodology to determine the location of voids in the structural section, nor is there general agreement on the most appropriate type of material to use for PCCP subsealing.

III. OBJECTIVES

The primary objective of this research is to determine the effectiveness of subsealing as a means to extend the service life of PCCP. A secondary objective is to analyze the effect on future pavement performance of introducing a non-yielding grout into the voids between the PCCP and base.

IV. CURRENT ACTIVITIES

A. Little or no research has been completed that addresses the desirability or likelihood of obtaining full PCCP support via "subsealing."

B. Some projects that were "subsealed" in 1982 are now exhibiting severe distress in the form of slab breakup.

C. Using deflection and radar devices prior to subsealing to locate structural section voids has been investigated. In many cases, deflection devices have not been effective in determining void locations. However, there is a radar device that appears to be capable of indicating where void areas exist directly under PCCP.

D. Relatively small amounts of grout implacement are being accomplished on many projects involving PCCP subsealing.

E. Edgedrains placed as part of subsealing projects have since become plugged with a fine material that may be the subsealing grout that has been pulverized by deflecting slabs and then deposited in the drains by surface water infiltration.

F. Suggested key words: Rigid pavements, warping, curling, pumping, base support, cement, pozzolans and injection.

V. URGENCY

This study of PCCP subsealing is considered urgent due to the amount of this form of rehabilitation presently underway. The construction difficulties being encountered and, of even greater importance, the erratic results being obtained per subsequent in-service pavement performance, make it imperative that this technique be investigated to determine its effect on "rehabilitated" PCCP service life.