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Experimental AC Overlays of PCC Pavement

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Roger D. Smith, P.E.

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16. ABSTRACT
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The report presents a description and discussion of AC mix batching, construction observations, laboratory testing, overlay coring, and initial performance evaluation. Periodic inspections of the overlays will be conducted to evaluate performance and to determine their relative effectiveness in providing resistance to surface abrasion (chain wear) and cracking. In the initial inspection after one winter of service, the rubberized AC test sections exhibited minor surface raveling. All of the other sections were in excellent condition.

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AC overlays, PCC, rubberized asphalt, interlayers, fibers, membranes

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

EXPERIMENTAL AC OVERLAYS OF PCC PAVEMENT

Study Supervised by .... R. A. Forsyth, P.E.

Principal Investigator .... Roger D. Smith, P.E.

Report Prepared by .... Roger D. Smith, P.E.

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

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/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)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal 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 (ft-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)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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Thomas Fellenz (TransLab) - construction documentation, materials sampling, laboratory testing and data assembly

Thomas Scrimsher, Ken Iwasaki, Ron Morrison, Al Rybicki (TransLab) - laboratory testing and test specimen fabrication

Doug Brown (District 3) - construction documentation and general field assistance

Lydia Burgin (TransLab) - report typing

The author also wishes to acknowledge the assistance and cooperation of the Arizona Refining Company representatives, especially Norm Peterson.

I. INTRODUCTION

This report deals with the construction of several experimental asphalt concrete (AC) overlays of existing portland cement concrete (PCC) pavement on I-80 near Boca, California (Figure 1).

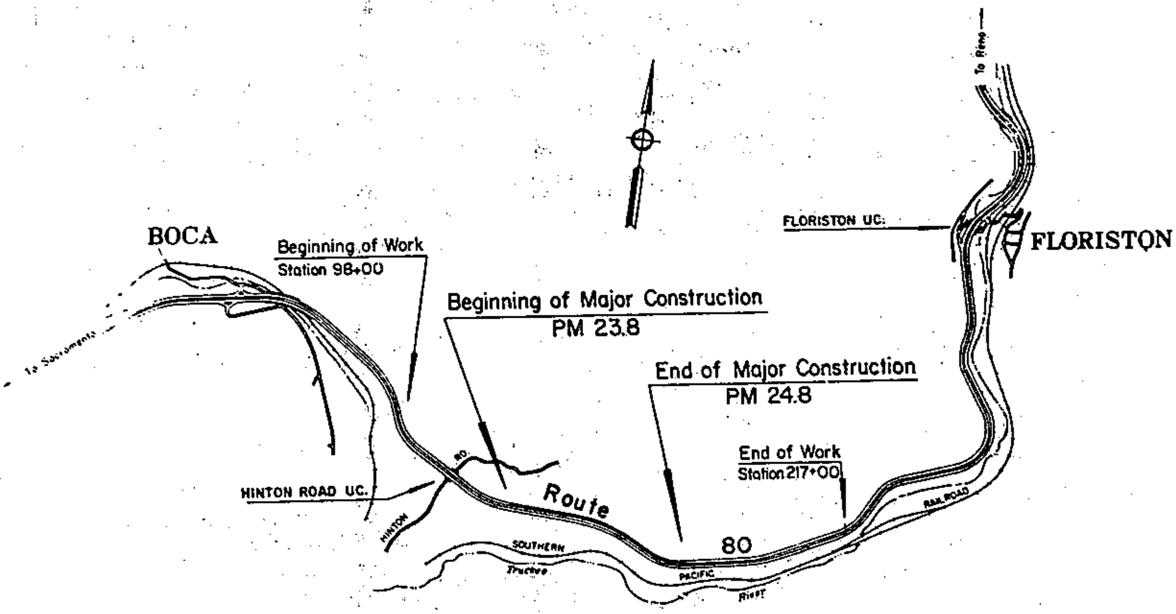
The goal of this research was to identify which experimental AC overlay treatments for PCC can be cost effective in terms of resistance to surface abrasion and thermally--induced problems.

The experimental overlays placed on this project were:

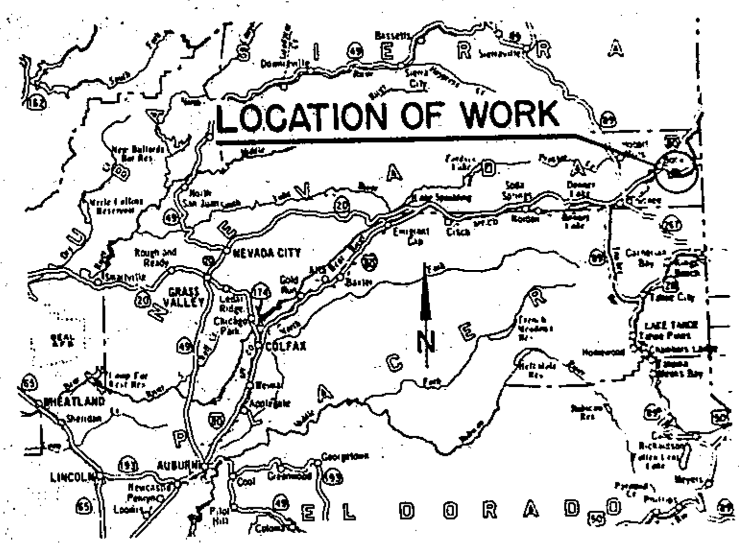
1. rubberized dense-graded AC (DGAC(R))
2. rubberized open-graded AC (OGAC(R))
3. a rubber "flush coat" interlayer (with chips)
4. dense-graded AC with Bonifibers (DGAC(F))
5. Bituthene membrane interlayer strips.

This report presents a description and discussion of the following items:

1. batching of the experimental AC mixes
2. construction observations
3. laboratory testing of the experimental AC mixes
4. post-construction pavement coring
5. performance evaluation after one winter of service.



VICINITY MAP
NO SCALE



LOCATION MAP

Scale in Miles

IN NEVADA COUNTY ABOUT 8.1 MILES EAST OF TRUCKEE
FROM 0.2 MILE EAST OF HINTON ROAD UNDERCROSSING
NEAR BOCA TO 2.6 MILES WEST OF TRUCKEE
RIVER BRIDGE AT FLORISTON

CONTRACT No. 03-217334

FIGURE 1

II. OBSERVATIONS AND CONCLUSIONS

A. Laboratory

1. All of the experimental AC mixes in this study were mixed and placed without major problems.

2. In the presence of a light (0.07 gal/yd^2) tack coat of emulsified asphalt, the OGAC(R) exhibited insufficient bond with existing PCC pavement. This seems to be due to some effect of the rubber additive and suggests the need for heavier tack coats with this type of overlay.

3. Rubberized AR-4000 asphalt, when used as a flush coat on "lean" OGAC, did not penetrate completely through the 0.10' OGAC layer.

4. Laboratory tests indicate that the addition of rubber to DGAC improves surface abrasion resistance, and lowers resilient modulus (M_R), but does not affect Hveem stability.

5. Rubberized asphalt binder content cannot be determined by the conventional hot extraction procedure (Calif. TM 310).

6. The addition of Bonifibers to a conventional DGAC mix resulted in improved resistance to surface abrasion, but reduced cohesion.

B. Field Performance

1. After one very severe winter of service, the two sections with DGAC(R) as the surface course have begun to ravel. All other sections are in excellent condition.

III. RECOMMENDATIONS

Recommendations pertaining to the use of these experimental overlays will only be made after observation of their long-term performance. However, with respect to the treatments involving rubberized asphalt, the following preliminary recommendations are offered:

1. Further study of bond between OGAC(R) and PCC should be undertaken.

2. Mix design procedures for OGAC(R) should be refined to account for the special "blotting" effects of the rubberized binder.

3. Further study should be devoted to developing a test method for determining the asphalt/rubber binder content of rubberized AC mixes.

IV. BACKGROUND

Approximately 70 miles of Interstate 80 in California are located in a severe freeze-thaw thermal environment where tire chains are frequently required in winter months. The highway crosses the Sierra Nevada mountains, reaching a peak elevation of about 7,200 feet. The existing pavement is jointed, unreinforced PCC with the final sections of the 4-lane (minimum) facility completed in 1964. The cumulative effects of traffic and environment have resulted in extensive surface wear, cracking, and some rutting at higher elevations.

While the pavement exhibits some of the defects tvpically found on aging PCC pavements (such as joint faulting, cracking and joint spalling), of major concern is the loss of the wearing surface due to abrasion by tire chains. In addition to creating a rough ride, this gradual surface wear eventually leads to a weakened slab and accelerates freeze-thaw deterioration where water collects in the wheel path ruts.

Restoring a satisfactory riding surface to the pavement has been a matter of concern for several years. Since most of the roadway is considered structurally adequate, complete reconstruction or thick (7"+) unbonded PCC overlays are not deemed cost effective strategies. Asphalt concrete overlays are commonly used in lower elevations, but have not performed satisfactorily in the mountain areas because of chain wear and the extreme thermal strains in underlying slabs. Therefore, a variety of other restorative measures have been selected for trial and evaluation. Those selected for construction include:

(1) a thin (3"±) bonded PCC overlay;

(2) very thin "exotic" concrete overlays; and

(3) experimental AC overlays.

The first two projects have been completed and are the subject of an earlier report. This report deals exclusively with item (3), experimental AC overlays.

V. DISCUSSION

A. Preliminary Work

Prior to overlay placement, all test sections were crack-mapped using enlarged aerial photos. Also, spot "estimates" of differential vertical movement (Δ-vert) at joints and cracks were made based on Dynaflect measurements. These measurements indicated that the existing PCC pavement was quite stable, even though extensive cracking and some faulting had developed.

It should also be noted that, as part of this project, pavement edge drains were installed adjacent to all the test sections prior to the construction of the overlay test sections.

B. General Paving Information

Between June 14 and June 17, 1982, several experimental AC overlay sections were constructed over PCC pavement on 03-Nev-80-23.8/24.8 (Contract No. 03-217334), approximately eight miles east of Truckee (Figure 1). The contractor was Teichert Construction Company.

Prior to placing the overlays, a light tack coat of 0.07 gal/yd^2 of SS1 emulsified asphalt was placed on the existing PCC pavement surface.

All paving was done with a Blaw-Knox PF500 paver. Dense graded AC was placed using the windrow method while open graded AC was end-dumped directly into the paver. All AC was produced at Teichert's Truckee plant.

Compaction of the DGAC consisted of one coverage of a RayGo 7204A vibratory roller (at 2300 vpm and the "high" amplitude setting) and two coverages of a Hyster RCF56 (12 ton) static roller.

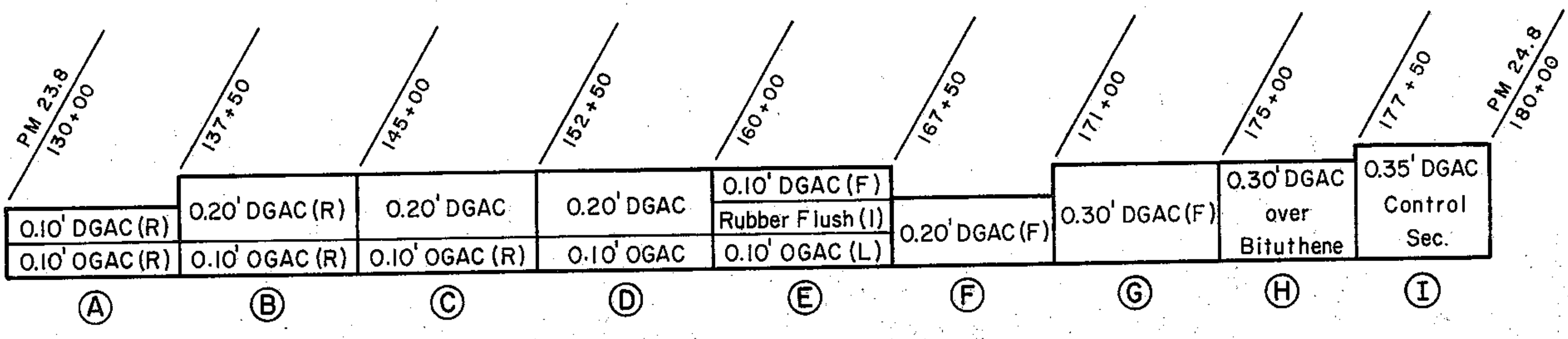
C. Experimental Overlays

The experimental overlay features are shown in Figure 2 and described below and in Appendix D. Comparative costs are shown in Table 1.

1. Rubberized AC

Rubberized AC mixes, both dense and open graded, were used as interlayers as well as surface courses in these experimental overlays. It was theorized that these mixes would have increased resilience and therefore resist surface abrasion and cracking.

These mixes contained a binder of rubberized asphalt made by the Arizona Refining Company (ARCO) (see Appendix A). The same rubberized asphalt, containing roughly 20% crumb rubber, 4% extender oil (lube stock), and 76% AR-4000 (Douglas-Elk Grove) paving grade asphalt, was used for all the rubberized AC mixes as well as for the rubberized asphalt "flush coat" interlayer. This binder was blended at 400°F by ARCO personnel in the yard of Teichert's Truckee batch plant and hauled by special tank truck to a heated underground storage tank 500 feet away from the batching area. From there it was pumped to the pugmill during batching of the AC.



(L) = Lean mix; no rubber.

(F) = Bonifibers.

(R) = Rubberized.

(I) = 0.6 → 0.7 gal/yd^2 rubber asphalt (A.R.CO.) topped with 3/8" x No. 6 screenings.

NOTES:

1. *Stations shown are design stations. Actual section limits differ slightly and are on record at Translab.*
2. *Edge drains were placed along outside e.o.p. throughout the length of this project.*

TEST SECTION LAYOUT 03-NEV-80 (WESTBOUND)

FIGURE 2

Test Section	Overlay Structural Section	Cost*/Yd^2
A	0.10' DGAC(R) 0.10' OGAC(R)	$10.75
B	0.20' DGAC(R) 0.10' OGAC(R)	$16.25
C	0.20' DGAC 0.10' OGAC(R)	$11.00
D	0.20' DGAC 0.10' OGAC	$ 8.60
E	0.10' DGAC(F) Rubber Interlayer 0.10' OGAC(L)	$ 8.80
F	0.20' DGAC(F)	$ 6.55
G	0.30' DGAC(F)	$ 9.80
H	0.30' DGAC Bituthene Strips	$11.90
I	0.35' Control	$10.00

TABLE 1. Cost Data

* Calculated using contractor's bid prices

The DGAC mixes, both with and without rubber or fibers, were designed to conform with the Type A, 3/4" max, medium gradation requirements of the Caltrans 1981 Standard Specifications. The design binder contents for the various DGAC mixes are listed below.

DGAC (Conventional)........6.5% by dry weight of aggregate
DGAC (Rubberized)..........7.5% (asphalt + rubber; by dry weight of aggregate)

For the OGAC mixes, the 1/2" max aggregate gradation specified in the Caltrans 1981 Standard Specifications was used. The design binder contents for the OGAC mixes are given below.

OGAC (Conventional)........6.5% by dry weight of aggregate
OGAC (Rubberized)..........7.0% by dry weight of aggregate

2. Open-graded Interlayers

Several of the experimental sections involved OGAC interlayers theorizing they would provide drainage and a stress-relieving effect to reduce reflection cracking in the overlay.

Details of the OGAC mix design are provided above in Section V,C.,1.

3. Rubberized Asphalt "Flush Coat" Interlayer

This overlay arrangement is quite similar to the stress-absorbing membrane interlayers (SAMI's) tried on previous projects in California and other states, primarily Arizona. Research by the Arizona Department of Transportation has indicated that this type of interlayer is very effective in reducing stress concentrations above existing joints and cracks, and in retarding or eliminating reflection cracking due to thermal expansion or contraction of underlying rigid pavement.

This experimental section extended from Station 160 to Station 167+50 (Figure 2) in both westbound lanes and consisted of a heavy flush coat of rubberized asphalt binder and 3/8x#6 screenings applied to a lean (5.5% asphalt) OGAC interlayer. The temperature of the rubberized asphalt flush coat was 400°F when applied by the distributor truck at a target spread rate of 0.65 gal/yd^2. A great deal of smoke was produced by the hot rubberized asphalt. The air temperature was 60°F when work began in the #1 lane. The contractor applied the flush coat to the interlayer in the #1 lane first and then overlayed the #1 lane for the entire length of the job (PM 23.8-24.8) before moving over to the #2 lane to apply the flush coat to the interlayer. This procedure, included in the special provisions, was followed to keep traffic off the screenings placed on the flush coat.

A self-propelled chip spreader immediately followed the distributor truck and spread the screenings onto the hot flush coat. The screenings were fed to the spreader via an attached dump truck. The surface dry chips were applied at a target spread rate of 33 lb/yd^2. The chips appeared to be quite dusty.

Rolling of the screenings took place immediately after spreading and was accomplished using two rubber-tired rollers. The rollers operated side by side and made two complete coverages. About four passes of a broom were then made to sweep the screenings.

Although it was difficult to see, it appeared that the rubberized asphalt flush coat did not penetrate very deeply into the OGAC interlayer beneath it. Observations prior to application of the flush coat raised suspicion that the OGAC was not as lean as intended, and thus may not have allowed the rubberized asphalt to penetrate. Subsequent laboratory testing confirmed this lack of penetration (see Appendix B). The rubberized asphalt filled all the surface voids in the OGAC, but these voids were rather shallow.

The rubber-asphalt flushed OGAC interlayer was overlaid with 0.10' of DGAC containing Bonifibers. No tack coat was placed on top of the screenings prior to overlaying, however, an emulsified tack coat was applied to the shoulder area because the shoulder did not have the OGAC interlayer. The shoulder of the #1 lane was placed using the wing extension on the paver.

4. Bonifiber/AC Mix

This experimental feature involved the addition of short (1/4") polyester "reinforcing" fibers, "Bonifibers" (from Kapejo, Inc., Wilmington, Delaware), to the regular DGAC at the rate of 5 lbs per ton (0.25%) of DGAC. The intended benefits from the fiber additive included improved cohesion and resistance to surface abrasion. Theoretically, both should be manifested in the field in the form of resistance to cracking, chain wear, and freeze/thaw-related deterioration.

The fibers and dry aggregate were premixed for 30 seconds and then the AR 4000 (Chevron) binder was added and mixed for 30 seconds. The design binder content in this DGAC(F) mix was increased to 6.8% from the normal 6.5%. No problems were encountered in either batching or placing this mix.

5. Bituthene Membrane Strips

Bituthene membrane strips with a rubber/asphalt backing were placed in "band-aid" fashion over joints (both transverse and longitudinal) and cracks in the PCC. Because of their thick, rubber/asphalt backing, these membranes are supposed to provide a waterproofing effect as well as a stress-relieving interlayer effect to reduce reflection cracking over PCC joints and cracks. Bituthene is a product of the W. R. Grace Company.

Two types of Bituthene were placed; the wax-coated type was applied to all cracks and to the transverse joints, and that without wax coating was placed on the longitudinal joints. (The wax coating helps achieve a better bond with the overlay and is reportedly used in states with lower temperature requirements for AC mixes.) The 12" wide strips were placed by hand on top of a primer applied with paint rollers.

Traffic ran on the exposed Bituthene without problems for about one week prior to placing the AC overlay. No problems were encountered in either placing the membrane or in paving over it.

6. Control Section

This section, consisting of 0.35' of DGAC, represented the minimum design (Caltrans) overlay thickness recommended for PCC pavement. It was placed in two lifts, 0.20' followed by 0.15'. Temperatures in the spread AC at the time of breakdown rolling ranged from 230°F to 250°F.

D. Construction Observations

The following observations were made by TransLab personnel during construction of the overlay test sections:

Sta. 130+00 to 137+50: OGAC(R), Lane 2

The lane 2 OGAC(R) interlayer ravelled severely as a result of opening it to traffic too soon (15 minutes) after paving.

Sta. 137+50 to 145+00: OGAC(R), Lane 2

Slight raveling due to the reason cited above.

Sta. 145+00 to 152+50: OGAC(R), Lane 1

- Mix arrived at street at approximately 250°F.

- Paving operation repeatedly had to wait about 15 minutes between truck loads of AC from the plant. This probably resulted in cold rolling as a result of cooling of the mix in and under the paving machine during these delays.

Sta. 152+50 to 160+00: OGAC, Lane 1

- Several loads of cool (160 to 180°F) OGAC mix arrived on the job. Some were rejected, but it is quite probable that some of this cool mix was placed between Sta. 152 and Sta. 155 before anyone was aware of the cool mix problem.

- Here again, the paving operation repeatedly had to wait up to 15 minutes for an AC mix truck to arrive. This probably resulted in cold rolling of the mix that sat in and under the paving machine.

Sta. 160+00 to 167+50: Rubber Flush

- The "lean" (5.5%) OGAC interlayer did not look lean.

- The rubberized asphalt flush coat did not appear to penetrate the "lean" OGAC.

- Approximately 50% of the screenings remained loose after rolling and prior to sweeping. These loose screenings were almost entirely removed by sweeping.

- The sweeping operation apparently removed the dust that was present on the chips.

- The screenings appeared to be securely embedded in the rubberized asphalt and had an elastic rebound when moved due to the rubber present in the asphalt.

- About 50% to 75% of the chip was embedded in the asphalt, and very few, if any, of the chips were completely cuvered with asphalt.

- A small section of the 0.10' overlay was removed from the flush coated interlayer with a shovel. The rubberized asphalt did not appear to have melted due to the heat of the overlying mat. Increased bond between these two layers may take place under the kneading action of traffic.

- The Bonifiber mix had a brownish appearance, suggesting a low asphalt content.

Sta. 167+50 to 175+00: Bonifibers

- 0.20' Bonifiber/AC mix was placed in two 0.10' lifts.
- 0.30' Bonifiber/AC mix was placed in two 0.15' lifts.
- Bonifiber/AC mix had a dull, brown appearance suggesting a low asphalt content.
- Mix temperature at the time of breakdown rolling was 250° to 270°F.

Sta. 175+00 to 177+50: Bituthene Membrane

- The 0.30' AC overlay was placed in two lifts, 0.20' and 0.10'.

- Temperatures measured in the mat just prior to breakdown rolling ranged from 230° to 250°F.

Sta. 177+50 to 180+00: 0.35' AC Control Section

- The 0.35' AC overlay was placed in two lifts; 0.20' and 0.15'.

- Temperatures measured in the AC mat prior to breakdown rolling ranged from 230° to 250°F.

- Breakdown rolling consisted of one coverage with the vibratory roller.

E. Materials Testing

Construction samples of the various AC mixes were obtained from the "street" and tested at TransLab. Also tested were pavement cores obtained approximately 7 weeks after construction. The results of these tests are summarized in Tables 2 and 3 and a brief discussion of the test results is presented below.

1. Asphalt Content Determinations

a. Conventional AC mixes

The asphalt contents of the conventional AC mixes - both DGAC and OGAC - were generally 0.5% below their design asphalt content of 6.5%.

b. Bonifiber - AC mix

The DGAC(F) mix had an asphalt content 0.4% to 0.5% below the design asphalt content of 6.8%.

c. Rubberized AC mixes

The measured binder (AR4000 + rubber) content for the OGAC(R) mix was 0.8% to 1.1% below the design target value

Mix Type	Station	Binder Content(%) Design	Actual	Mr (psi x 10^5)	Surface Abrasion (grams)	Stability	Cohesion (g/in)	% Air Voids
DGAC	155[3]	6.5	*	*	9.8	*	*	*
"	178[1]	6.5	6.1	6.16	29.1	35,39	295	4.4,3.6
"	176[1]	6.5	6.0	5.85,5.22	21.8	38,37,43	305,370	4.6,3.7,3.7
"	176+50[3]	6.5	*	3.24	*	*	145	3.5
"	179+00[3]	6.5	*	2.62	*	*	105	3.0
DGAC(F)	163+50[3]	6.8	*	*	25.1	*	*	*
"	169[1]	6.8	6.4	5.22	21.7	36,38	215	5.2,5.6
"	173+50[1]	6.8	6.3	5.39,6.10	19.3	35,40,40	245,225	6.3,5.9,6.3
"	169+50[3]	6.8	*	2.66	*	*	65	5.2
"	173+00[3]	6.8	*	2.32	*	*	55	6.1
DGAC(R)	132[1]	7.5	4.9[5]	2.50	8.2	46	300	8.8
"	132[2]	7.5	5.9[5]	*	*	37	*	*
"	140[4]	7.5	5.4[5]	2.46	6.4	33	393	6.2
"	134[3]	7.5	*	*	9.8	*	*	*
OGAC	156[1]	6.5	6.0	*	*	*	*	*
"	154+50[1]	6.5	6.0	*	*	*	*	*
OGAC(L)	160[1]	5.5	5.3	*	*	*	*	*
OGAC(R)	143[1]	7.0	5.9[5]	*	*	*	*	*
"	148+50[1]	7.0	5.9[5]	*	*	*	*	*
"	148+50[1]	7.0	6.2[5]	*	*	*	*	*

NOTES

1. Street sample (TransLab Tests)
2. Street sample (District 3 Tests)
3. Pavement core (TransLab Tests)
4. Recompacted core (TransLab Tests)
5. Asphalt is 80% of the total binder content shown
* No testing was done

TABLE 2. AC Mix Properties Summary

Mix Property	DGAC		DGAC(R)		DGAC(F)	
	Core	Lab Briq.	Core	Lab Briq.	Core	Lab Briq.
Resilient Modulus (M_R)	3.24 2.62	6.16 5.85* 5.22	2.46	2.50	2.66 2.32	5.22 5.39 6.10
Surace Abrasion	9.8	29.1 21.8	6.4 9.8	8.2	25.1	21.7 19.3
Stability	**	35 39 38 37 43	32	46 37	**	36 38 35 40 40
Cohesion	145 105	295 305 370	393	300	65 55	215 245 225
Specific Gravity	2.30 2.31	2.29 2.31 2.29 2.31 2.31	2.27	2.22	2.26 2.24	2.26 2.25 2.24 2.25 2.24

Notes:
*bracket denotes specimens made from the same sample (location)
**no test(s) run

Table 3. Test Results of Core Samples vs. "Street" Samples

of 7.0%. The binder content for the DGAC(R) mix measured 1.6% below the design value of 7.5%. These low values may be the result of the inability of the extraction procedure (Calif. TM 310) to totally remove the binder from the mix, as has been the case with most attempts at extraction tests on rubberized AC mixes. A limited amount of experimentation with extraction procedure modifications proved unsuccessful in removing all the rubber and asphalt comprising the binder. This appeared to be primarily due to clogging of the paper filter by rubber particles which do not break down or dissolve in the "cooking" process associated with the hot extraction procedure. Additional experimentation is planned in this area, including the use of a Troxler Nuclear Gauge, exclusively designed to measure asphalt content.

2. Hveem Stability

Stability did not vary appreciably among the various DGAC mixes tested. The following average stability values were obtained using briquettes made from street-sampled AC:

Mix	Stability
DGAC (conventional)	38
DGAC(F)	38
DGAC(R)	42.

3. Surface Abrasion

Although no definite criteria have been established for the surface abrasion test (Calif, TM 360B, steel ball method), it is generally felt that losses greater than 35 grams indicate problem mixes. Values from 25g to 35g are quite common, whereas values 20g or below are fairly uncommon. The average surface abrasion losses for the lab-compacted (95% static compaction) briquettes are listed below:

Mix	S.A. Loss
DGAC	25.5g
DGAC(R)	8.2g
DGAC(F)	20.5g

Each of these mixes exhibited low surface abrasion losses. The DGAC(R) mix, however, with a surface abrasion loss of only 8.2 g, was noticably superior to both the other mixes. The addition of the fibers, however, also resulted in a substantial decrease in surface abrasion loss.

4. Resilient Modulus (M_R)

These measurements were made primarily for informational purposes. The M_R values measured on DGAC and DGAC(F) lab briquettes were on the high end of the expected range of values for DGAC mixes. The M_R values measured on the DGAC(R) mix, on the other hand, were towards the low end of that range.

The M_R values measured on core samples were consistently only 30 to 35% of the values measured on lab-compacted briquettes. This is probably due to the fact that the degree of compaction in cores is usually lower than in lab-compacted specimens.

5. Cohesion

Cohesion tests were run on cores and lab-compacted briquettes at 140°F (Calif. TM 306).

The average cohesion values obtained on the various mixes are presented below:

Mix	Lab Briquettes	Cores
DGAC	323	125
DGAC(R)	300	393
DGAC(F)	228	60

No explanation is offered for the relatively low values exhibited by the DGAC(F). A close observance of specimen behavior will be made during upcoming tests of DGAC(F). It should be noted that low cohesion values were also measured in earlier TransLab testing of DGAC(F).

Only the DGAC(R) core exhibited the anticipated increase in cohesion expected when rubber or fiber is added to DGAC.

F. Pavement Coring

1. General

On August 6, 1982, approximately 7 weeks after construction, 12 four-inch cores were obtained from the westbound lane 2 test sections. Sampling was done with an Acker trailer-mounted coring rig (CHC37). One core was taken from each test section, except for the test section with the rubber "flush coat" where four cores were obtained. Table 4 summarizes the location and the actual and design overlay compositions for each core. Initial observations of the cores in the lab are presented below and summarized in Table 4.

Sta. 130+00 to 152+50: OGAC(R) Interlayer

Cores taken at stations 134+00, 140+00 and 147+00 separated during coring at the interface of the OGAC(R) interlayer and the PCC with only about 25% of the PCC surface exhibiting any asphalt adhesion. This condition suggests a bond problem between the AC overlay and the PCC surface and will be further discussed later in this report.

Sta. 152+50 to 160+00: OGAC Interlayer

The overlay did not separate at the OGAC-PCC interface. with the PCC.

Sta. 160+00 to 167+50: Rubber Flush Coat Interlayer

Four cores were obtained, two each at Sta. 163+50 and 165+50.

Core A at Sta. 163+50 separated (delaminated) during coring, with about 25 percent of the failure surface in the OGAC and 75 percent at the overlay-PCC interface, with an asphalt coating fully adhering to the PCC. Core B at Sta. 163+50 did not separate.

Coring Station	Distance From Lane Line (ft)[1]	Composition (Design)	Composition (Actual)	Remarks
134+00	7	0.10'AC(R)[2] 0.10'OGAC(R)	0.12'AC(R) 0.09'OGAC(R)	Poor bond with PCC (25% adherence)
140+00	7	0.20'AC(R) 0.10'OGAC(R)	0.20'AC(R) 0.11'OGAC(R)	Poor bond with PCC (25% adherence)
147+00	7	0.20'AC 0.10'OGAC(R)	0.24'AC 0.10'OGAC(R)	Poor bond with PCC (25% adherence)
155+00	7	0.20'AC 0.10'OGAC	0.25'AC 0.09'OGAC	Good bond with PCC
163+50A	5	0.10'AC(F)[3] Rubber Flush 0.10'OGAC(L)[4]	0.12'AC(F) Rubber Flush 0.12'OGAC(L)	Good bond with PCC 25% separation in OGAC layer
163+50B	11	0.10'AC(F) Rubber Flush 0.10'OGAC(L)	0.12'AC(F) Rubber Flush 0.11'OGAC(L)	Did not separate at PCC
165+50A	5	0.10'AC(F) Rubber Flush 0.10'OGAC(L)	0.11'AC(F) Rubber Flush 0.11'OGAC(L)	Poor bond with PCC (50% adherence)
165+50B	12	0.10'AC(F) Rubber Flush 0.10'OGAC(L)	0.12'AC(F) Rubber Flush 0.11'OGAC(L)	Poor bond with PCC (50% adherence)
169+50	7	0.20'AC(F)	0.21'AC(F)	Good bond with PCC
173+00	7	0.30'AC(F)	0.25'AC(F)	Did not separate at PCC. Crack in PCC filled with sealant.
176+50	7	0.30'AC over Bituthene	0.30'AC over Bituthene	Separated between overlay and Bituthene
179+00	7	0.35'AC Control Section	0.35'AC	Separated between AC&PCC; tack adherence unknown.

1 - Distance from stripe separating adjacent lanes (in truck lane).
2 - (R) = Rubberized
3 - (F) = Bonifibers
4 - (L) = Lean Mix

Table 4. Pavement Coring Data

Both cores A and B at Sta. 165+50 separated during coring at the OGAC-PCC interface. Only about 50 percent of the PCC surface area exhibited an asphalt coating on both cores. This suggests a bond (adhesion) problem, but not as severe as that observed with the OGAC(R).

Sta. 167+50 to 171+00: Bonifibers (0.20')

The core taken at Sta. 169+50 separated at the DGAC overlay-PCC interface, leaving an asphalt coating on the entire surface of the PCC.

Sta. 171+00 to 175+00: Bonifibers (0.30')

The core taken at Sta. 173+00 did not separate. This core, by chance, contained a PCC crack that had been filled with a sealant in a previous maintenance operation.

Sta. 175+00 to 177+50: Bituthene Membrane Strips

At Sta. 176+50 a core was taken that happened to have the Bituthene over its entire cross-sectional area. The core separated at the DGAC-Bituthene interface.

Sta. 177+50 to 180+00: Control

The core taken at Sta. 179+00 separated at the DGAC-PCC interface. The PCC segment was not recovered; therefore, it was not known how much asphalt remained on its surface.

2. Discussion of Cores

The three test sections between Stations 130+00 and 152+50 (Figure 2) had an OGAC(R) interlayer and all the cores in this area separated at the OGAC(R)-PCC interface, with little or no asphalt remaining on the PCC. In the test section that had OGAC without rubber, the core did not separate. Another test section involved a lean OGAC course with a rubber "flush coat" which was supposed to have penetrated the lean OGAC layer. Two of the four cores in the section also separated at the PCC interface with only about 50 percent of the PCC exhibiting asphalt adhesion. One core did not separate and the other separated with asphalt totally covering the PCC surface. Between Stations 167+50 and 180+00 no rubberized layers or flush coats were used. Of the cores from these sections, one did not separate while three did. Of these three, one core had asphalt completely coating the PCC and one had the Bituthene membrane on the PCC segment. For the third core, it was not known if tack coat remained on the PCC as the PCC portion of the core was not recovered.

The most obvious general problem observed in this set of cores was the apparent low bond between the rubberized open-graded mixes and the old PCC surface. Several possible explanations have been offered for this:

1) The rubberized OGAC(R) binder possibly tends to purge the SS1 tack coat from the old PCC surface. At four of the five stations cored, the rubberized overlays exhibited poor bond with the PCC, with only 50% or less of any core's PCC surface showing any coating of asphalt tack coat. Perhaps

the hot rubberized mix was placed before the SS1 "broke" and the presence of water (or vapor) caused the asphalt to "strip" from the PCC surface, freeing it to enter the overlay mix.

2) The viscosity of the rubberized binder in the OGAC(R) may be high enough to prevent any excess from "running off" and assisting in establishing bond with the PCC. This explanation, however, does not explain why the PCC surface was devoid of even the SS1 asphalt tack coat.

3) The contact area of any OGAC mix is significantly less than that of DGAC. But here again, this does not explain the absence of SS1 tack coat on the PCC. Also, those cores obtained involving non-rubberized OGAC on PCC exhibited better bond at the PCC-overlay interface.

4) An insufficient amount of the SS1 tack coat may have been placed. Several TransLab representatives witnessed the application and attest to the uniform placement of an SS1 tack coat. However, it is not known what the actual rate of application was or whether it was a "diluted" SS1. No application rate was specified, but 0.05 to 0.07 gal/yd^2 was supposedly applied.

(Subsequent discussions with ARCO representatives have brought to light the recognized need for a heavier tack coat on PCC surfaces prior to placing rubberized OGAC overlays. Addiditional laboratory testing will be done with respect to appropriate tack coats for use with rubberized mixes.)

5) The rubber in the OGAC mix tends to "blot" asphalt. Coupled with this is the fact that although the rubberized mix has more total binder, the asphalt portion (80%) of the binder actually amounts to only a 5.6% asphalt content, roughly 1% less than the asphalt content of the OGAC mix without rubber. These conditions lead to a somewhat drier mix having less asphalt available to promote bonding with the PCC. This may also have resulted in the SS1 tack coat being absorbed from the PCC surface, especially if any water had been present.

The rubberized mix designs developed by the District Lab for this job were based on conventional mix design procedures in which the pre-cooked (ARCO-supplied) rubberized asphalt was simply substituted for conventional binder.

6) In the case of the rubber flush coat interlayer, where two cores exhibited bond with the PCC and two only partially bonded, it was theorized that the degree of bond was a function of the amount of the flush coat actually penetrating the lean OGAC and reaching the PCC surface.

Tests were run (Appendix C) to determine if rubber had, in fact, fully penetrated the lean OGAC. These tests involved extraction of the asphalt from the bottom 1/4" of OGAC overlay cores, then examining the aggregate remains for rubber particles. Two cores were examined in this manner - one that had exhibited only partial bond between the overlay and the PCC and one that appeared to have bonded well. In each of the two tests no rubber particles were found, indicating that the rubber asphalt "flush" did not fully penetrate the OGAC and therefore could not have directly affected the overlay-to-PCC bond in this case.

G. Performance Monitoring

A condition survey will be performed at least annually to evaluate the performance of these experimental overlays. Pavement cores will be obtained as necessary to aid in this evaluation.

The first of these evaluations was made in April of 1983, after the first winter of service. The results are found in Appendix E. So far, test sections with the rubberized AC surface courses are exhibiting surface raveling while all other sections are not.

APPENDIX A

Report By District 03 Batch Plant Inspector

State of California

Business and Transportation Agency

Memorandum

To : File

Date: July 8, 1982

File : 03-Nev-80 23.8/24.8
03-217334
IR-080-4(85)199
Westbound lanes at
Hinton Road near Boca

From : DEPARTMENT OF TRANSPORTATION
Materials Section

Subject:

This project provided a series of asphalt concrete control and test sections in varying thicknesses over an existing PCC pavement. Various ½" open grade AC innerlayers were placed, asphalt/rubber innerlayer was placed in one section, and ¾" maximum, medium grading, Type A was placed, some using rubberized asphalt binder or polyester fiber additive.

Teichert Construction Company was prime contractor. Teichert Aggregates, Truckee Division, provided the completed mixes, and Arizona Refining Company provided the rubberized asphalt binder. The work was started in the fall of 1981, however the major experimental paving was placed June 15 through June 18, 1982.

With the exception of Arizona Refining Company rubber mixing equipment, only normally available asphalt paving equipment was utilized. Teichert Aggregates, Truckee Plant, is a Standard RM-804 8000 pound plant using Hardy 5W66-AW2-4 automatic batching controls.

M. E. Ryan was the State's Plant Inspector. G. V. Buckman acted as the State's Plant/Street Coordinator. Al Stevens, Teichert Project Superintendent, was the contractor's coordinator. Project Resident Engineer was George Ellis.

Arizona Refining brought their second generation equipment as follows:

1. 18,000 gallon storage trailer

2. Trailer-mounted mixing unit

3. Single boot truck with retort capability (a second boot truck was brought in June 18 to transport paving asphalt from Truckee to Redding. The 18,000 gallon trailer must be empty when on road).

This is the same equipment used by Arizona Refining here in District 3 on Contract 03-057334 (8-80).

Three-quarter inch design maximum, Type A, medium grading, asphalt concrete and ½" maximum open grade were used with various additives, asphalt contents and thicknesses.

¾" max, Type A, medium grading with 6.5% Chevron AR4000 was used as control.

When ¼% polyester fibers were added, 6.8% Chevron AR4000 was added.

When asphalt/rubber binder was added, 7.5% Douglas (Elk Grove) ~~rubber~~ was added.

½" maximum open grade AC:

5.5% Chevron AR4000 added 160+00 to 167+50
6.5% Chevron AR4000 added 152+50 to 160+00
7.0% Douglas AR4000 (Elk Grove) rubber added 130+00 to 152+50

Arizona Refining has made some changes in their formulation.

AR4000 Douglas Oil Co., Elk Grove, Santa Maria Crude	76%
Extender - Golden Bear, Bakersfield (Califlux GP)	4%
Devulcanized Rubber - GenStar C112, Chandler, AZ	8%
Whole tire grind rubber, GenStar C106, Chandler, AZ	12%

As in the past, the Califlux GP extender oil was blended with the AR4000 in the 18,000 gallon storage tank.

This year the GenStar 106 - whole tire grind rubber - was added first, then the GenStar 112 - devulcanized rubber. It is Arizona Refining's contention that the whole tire grind has a longer chemical reaction time than the devulcanized rubber. This statement was accepted. Visual observation and texture of the devulcanized rubber is much more tender, and logic tends to confirm that the C112 rubber would react more quickly.

The actual mixing consumes considerable heat. The AR4000/extender blend was 410° in the 18,000 gallon storage tank; 390° as it entered the mixer. The initial boot truck temperature was 340°. When the completed mix has covered the boot truck coils, the boot truck retorters were fired. Filling of the truck continued while retorting. After filling, retorting continued until the 400° cook temperature was achieved. The asphalt/rubber mixture was then ready for the contractor's normal asphalt storage tanks. Normal batching procedures were then followed. Should the temperature of the product in storage fall below

375° pumping into the weigh pot and discharge into the pug is 40-50% slower than normal paving asphalt. No other plant problems were encountered.

This contract also called for the introduction of ¼% polyester fibers into some of the test sections. These fibers came from Kapejo, Inc., Wilmington, Delaware. A 8,000 pound complete batch weight (aggregate and asphalt) was used. Two each 10# bags of the polyfibers were placed in each batch. Two laborers, working on the batch deck of the plant, put the two bags into the pugmill as the weigh bin was being discharged. A 30-second dry mix timer setting on the plant's Hardy console was used. For this plant the usual dry mix time is 0.4 second.

All actual plant production was routine. However, scheduling of exactly when the various types of mixes were to be produced required intense and constant communication and coordination between the plant and street. Paving schedules were made and updated daily and sometimes hourly by both the contractor's superintendent and the State's Plant Coordinator.

Original signed by

G. V. Buckman

GVB:mm

cc: GEllis, RE
Translab
OCastro

APPENDIX B

Method of Determining If Rubberized Asphalt "Flush Coat" Fully Penetrated the OGAC

Smec-h

Memorandum

To : File

Date: October 5, 1982

File : 19303-633252

From : DEPARTMENT OF TRANSPORTATION
Roy F. Bibbens, Soil Mechanics and Pavement Branch
Transportation Laboratory

Subject: Recovery of Rubber Particles from Rubberized Asphalt

On August 6, 1982, 12 pavement cores were sampled from an experimental overlay test section, 03-Nev-80-23.8/24.8, near Boca. The experimental section was originally constructed of PCC and had been overlaid (Contract No. 03-217334) with various AC compositions and thicknesses, during June, 1982. The cores were needed to determine the actual overlay thicknesses. All the cores were sampled from the number two (truck) lane.

The coring was performed by TransLab personnel Tom Fellenz, Sylvester Dalske, and Roy Bibbens.

One segment of the test section consisted of 0.10' AC with Bonifibers over a rubberized asphalt flush coat, over 0.10' open graded asphalt (OGAC), all over the original PCC. During the inspection of the pavement cores from this segment, questions arose regarding the amount of rubber particles, from the rubberized flush coat, that had actually penetrated the OGAC leveling course to reach the existing PCC surface (see Boca report of construction). Detecting the presence of rubber particles near the PCC surface required recovering identifiable particles from the bottom portion of the AC core.

The rubber particles used in the flush coat were a combination of 20 to 40 percent powdered, reclaimed, devulcanized rubber and 60 to 80 percent ground, vulcanized rubber.

Because trichloroethane extracts asphalt from aggregate, it was reasoned that the presence of rubber particles could be determined from the cores by soaking a portion of a core in trichloroethane, filtering the soaked core (i.e., pour the dissolved asphalt through a fine filter and recover the aggregate and any rubber particles present), and inspecting the recovered material. This process would only work if the trichloroethane would not affect the rubber, such that the rubber could not be filtered out or distinguished from the aggregate. Therefore, before the trichloroethane test was tried on any of the cores, rubber particles sampled at the time of construction were placed in trichloroethane, soaked overnight (about 18 hours), filtered from the trichloroethane, and examined. Qualitative inspection of the rubber indicated the rubber was apparently unaffected by the trichloroethane.

As a result of the outcome of the trichloroethane test, about 1/4" of AC from the bottom of two pavement cores was tested for rubber particles. After soaking in trichloroethane for 2 to 3 hours, a sufficient time to dissolve the asphalt, the residue was filtered through cotton pads. The retained aggregate was air dried, sieved, and inspected for the presence of rubber particles.

In this particular test, only a few rubber particles were identified. However, the rubber particle recovery process seemed to work well, was easy to perform, and did not require much time.

<u>Summary</u>

The trichloroethane tests on rubber particles and OGAC with rubberized flush coat indicated:

- rubber particles can soak in trichloroethane for at least 18 hours and remain qualitatively unaffected.
- rubber particles can be found in AC using a trichloroethane soak, filtering the residue through cotton pads, recovering the aggregate and rubber from the filter, air drying, sieving, and inspecting the material for the rubber particles.
- the process for finding rubber particles in AC is easy to perform and does not require much time.

Roy F. Bibbens

Roy F. Bibbens
Junior Civil Engineer
Soil Mechanics and Pavement Branch

RFB:EH

cc: RDoty
TScrimsher

APPENDIX C

Photos

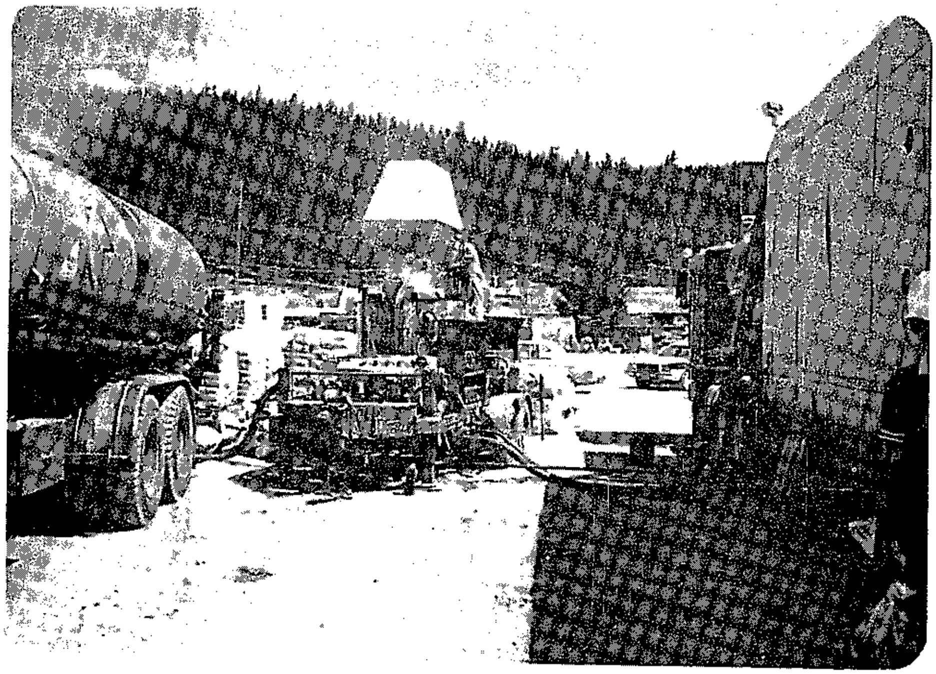


Photo 1. Rubber blending set-up (Arizona Refining Company)

Photo 2. Two rubber types in blender hopper (light = devulcanized; dark = vulcanized)

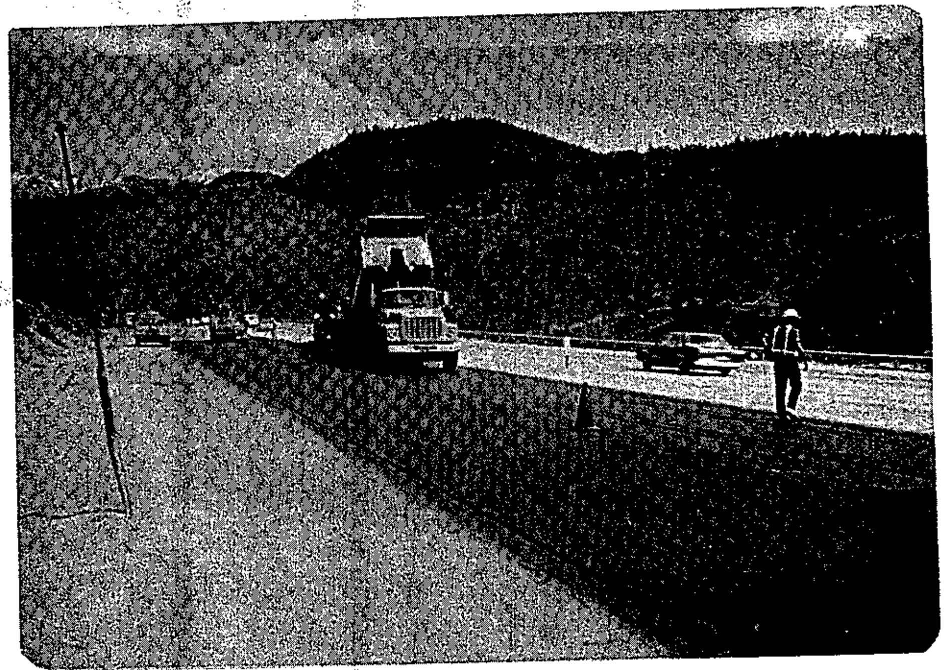


Photo 3. Placing lean OGAC prior to rubber flush coat.

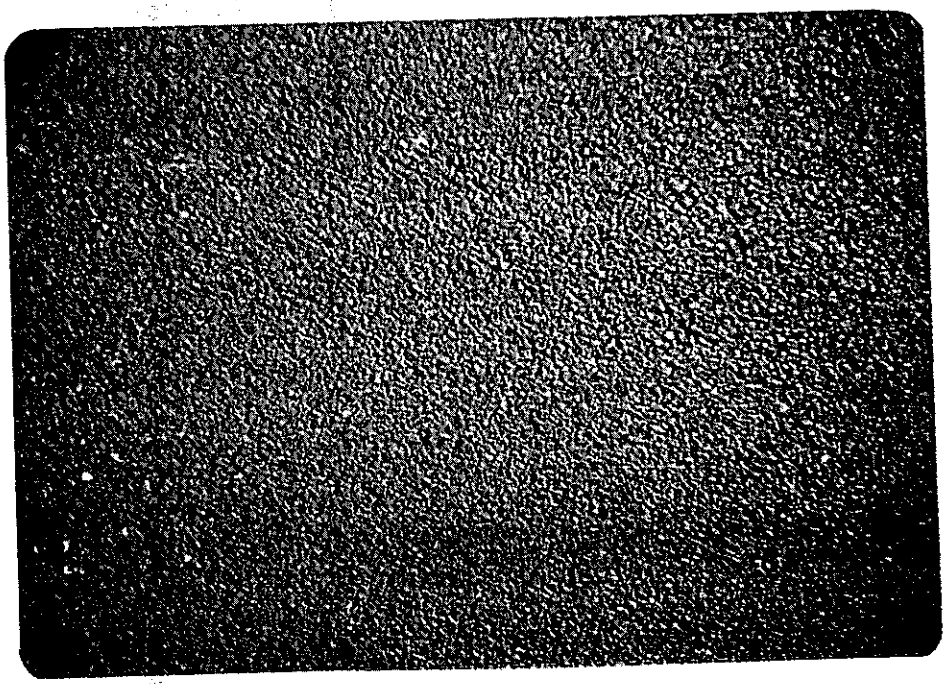


Photo 4. Lean OGAC after rolling, ready for flush coat. (Note dense appearance.)

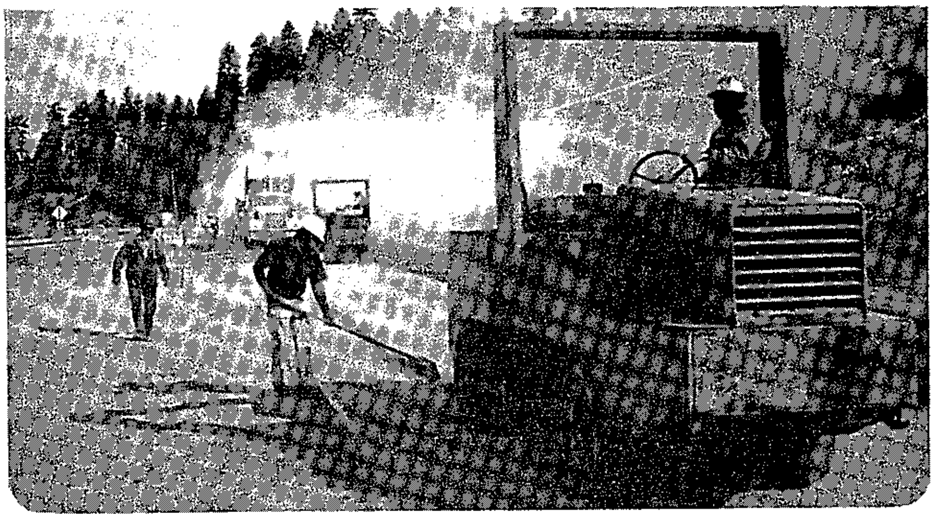


Photo 5.
Rolling of chips over rubberized flush coat.

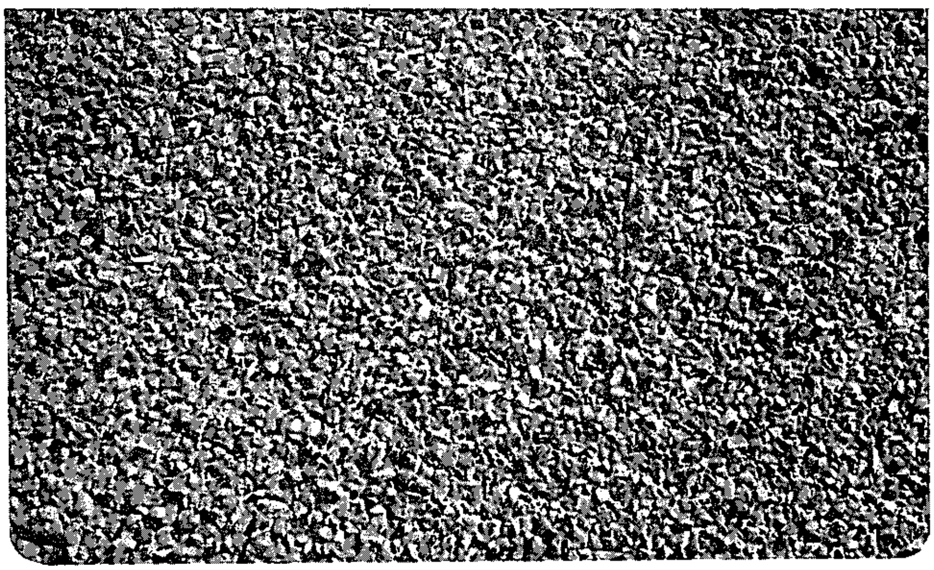


Photo 6.
Chip cover after rolling before sweeping.

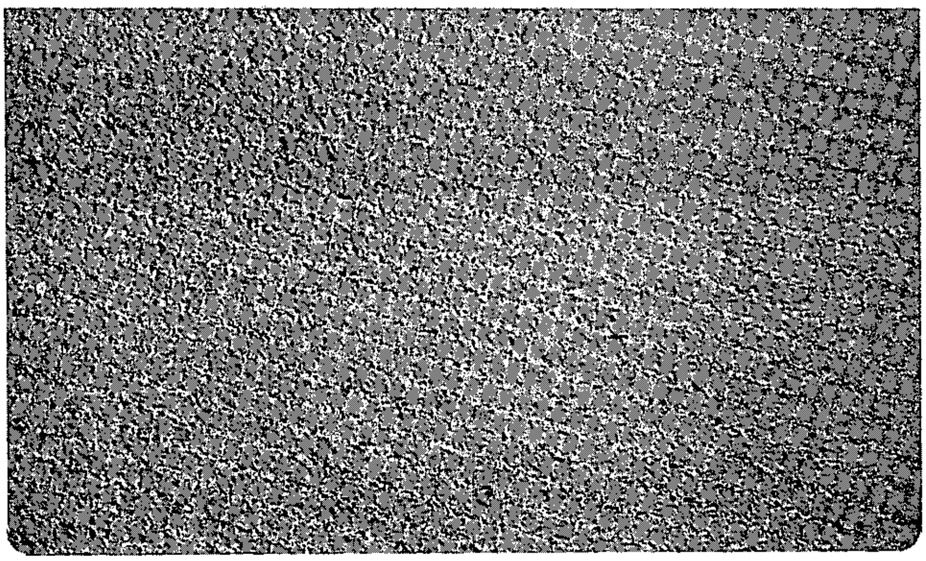


Photo 7.
Chip cover after sweeping. Ready for AC overlay.

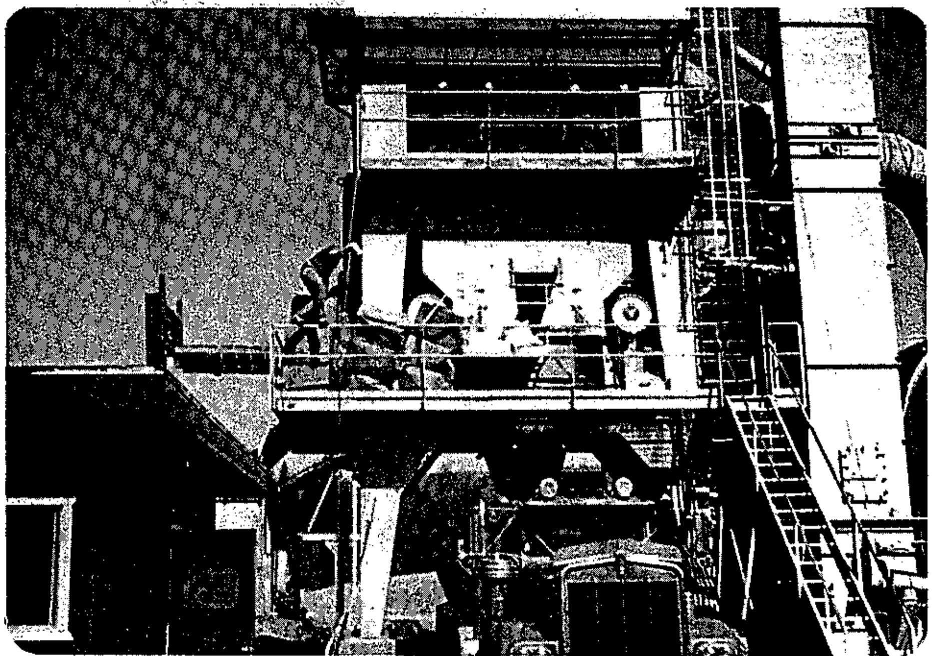


Photo 8. Bonifibers (boxes) being added to AC mix in the pug mill.

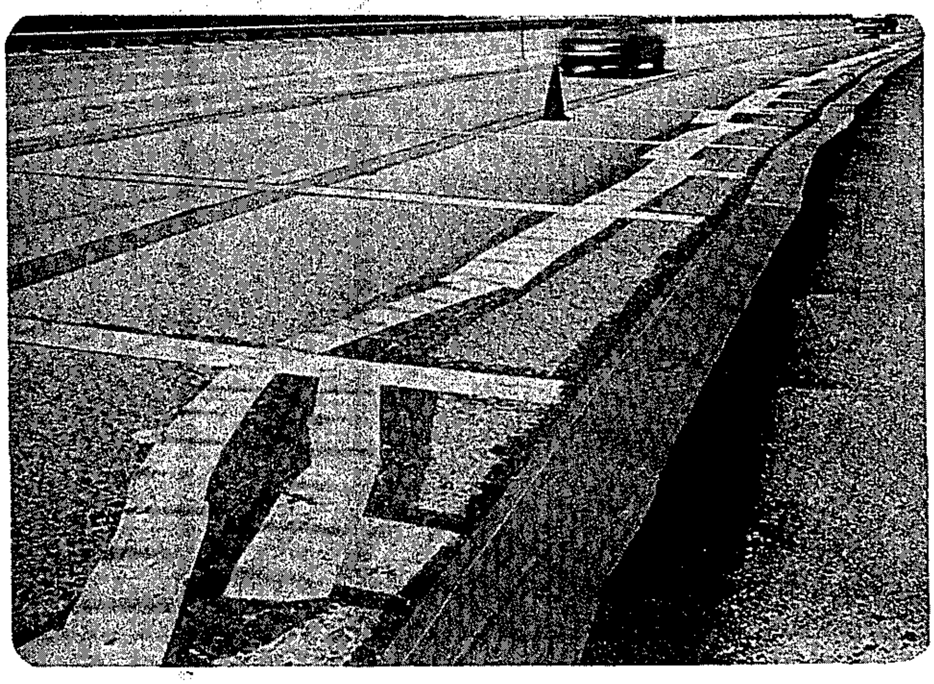


Photo 9. Bituthene membrane in place on PCC joints and cracks.

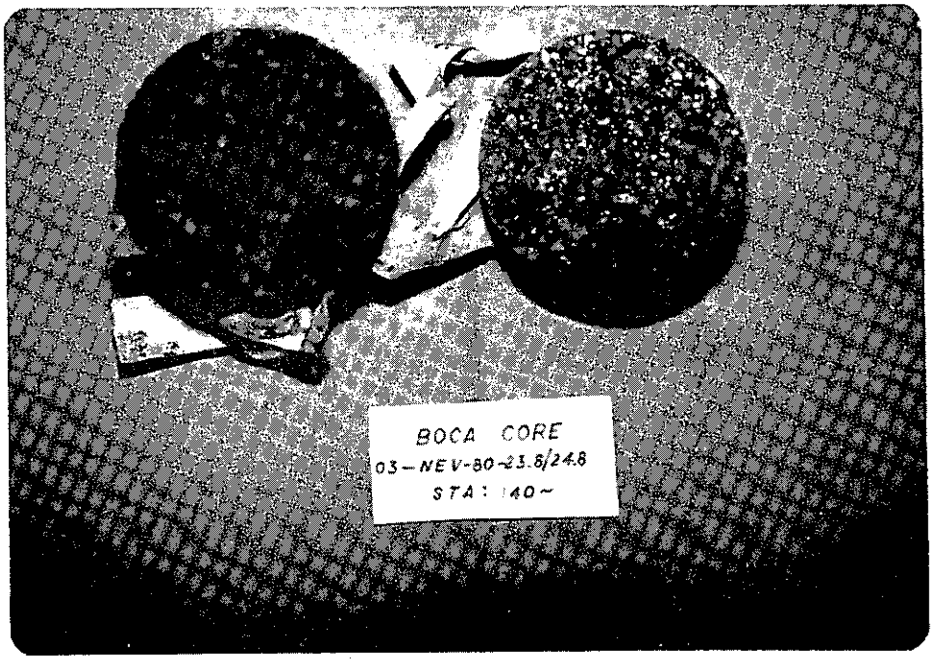


Photo 10. Rubberized OGAC/PCC interface, Station 140. Note lack of adhesion to PCC.

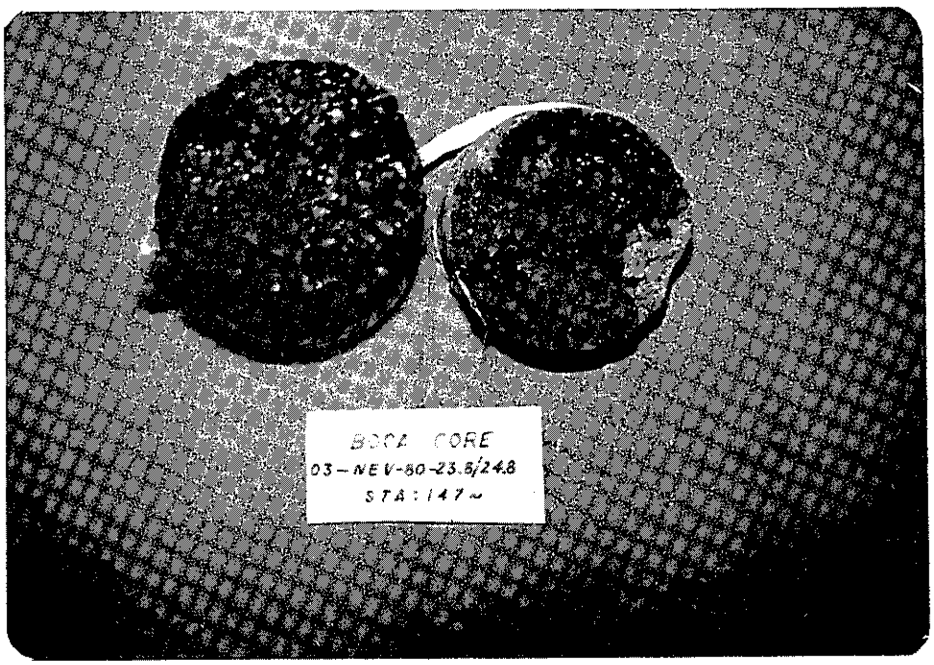


Photo 11. Rubberized OGAC/PCC interface, Station 147. Note lack of adhesion to PCC.

APPENDIX D

Excerpts From Special Provisions Pertaining to Experimental Overlays

STATE OF CALIFORNIA
BUSINESS, TRANSPORTATION AND HOUSING AGENCY
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISIONS

NOTICE TO CONTRACTORS PROPOSAL AND CONTRACT

FOR CONSTRUCTION ON

STATE HIGHWAY

IN

NEVADA COUNTY, ABOUT 8.1 MILES EAST OF TRUCKEE, FROM 0.2 MILE EAST OF HINTON ROAD UNDERCROSSING, NEAR BOCA, TO 2.6 MILES WEST OF TRUCKEE RIVER BRIDGE AT FLORISTON; DISTRICT 03, ROUTE 80.

For Use in Connection with Standard Specifications Dated January, 1981, Standard Plans Dated January, 1981, General Prevailing Wage Rates Dated July, 1981, and Labor Surcharge And Equipment Rental Rates.

CONTRACT NO. 03-217334

03-Nev-80-23.8/24.8

Federal Aid Project
IR-080-4(85)199

Bids Open: AUGUST 26, 1981

BOCA

10-1.08 ASPHALT CONCRETE.--Asphalt concrete shall be Type A and Open Graded, as shown on the plans, and shall conform to the provisions in Section 39, "Asphalt Concrete," of the Standard Specifications and these special provisions.

The fourth paragraph in Section 39-3.03B(2), "Proportioning for Continuous Pugmill Mixing or Drier Drum Mixing with Cold-Feed Control," of the Standard Specifications is amended to read:

> Asphalt meters and aggregate belt scales used for proportioning asphalt and aggregates shall be equipped with rate-of-flow indicators to show the rates of delivery of asphalt and aggregate, and resettable totalizers so that the total amounts of asphalt and aggregate introduced into the mixture can be determined.

The aggregate for Type A asphalt concrete shall conform to the 3/4 inch maximum, medium grading specified in Section 39-2.02, "Aggregate," of the Standard Specifications.

The aggregate for Open Graded asphalt concrete shall conform to the 1/2 inch maximum grading specified in Section 39-2.02, "Aggregate," of the Standard Specifications.

If the finished surface of the asphalt concrete on the Route 80 traffic lanes does not meet the specified surface tolerances, it shall be brought within tolerance by either (1) abrasive grinding (with fog seal coat on the areas which have been ground), (2) removal and replacement, or (3) placing an overlay of asphalt concrete. The method will be selected by the Engineer. The corrective work shall be at the Contractor's expense.

If abrasive grinding is used to bring the finished surface to specified surface tolerances, additional grinding shall be performed as necessary to extend the area ground in each lateral direction so that the lateral limits of grinding are at a constant offset from, and parallel to the nearest lane line or pavement edge, and in each longitudinal direction so that the grinding begins and ends at lines normal to the pavement centerline, within any ground area. All ground areas shall be neat rectangular areas of uniform surface appearance.

Pneumatic-tired rollers shall not be used to compact asphalt concrete to which rubber has been added.

In addition to the requirements in Section 39-5.01, "Spreading Equipment," of the Standard Specifications, asphalt paving equipment shall be equipped with automatic screed controls and a sensing device or devices.

When placing asphalt concrete to lines and grades established by the Engineer, the automatic controls shall control the longitudinal grade and transverse slope of the screed. Grade and slope references shall be furnished, installed and maintained by the Contractor. Should the Contractor elect to use a ski device, the minimum length of the ski device shall be 30 feet. The ski device shall be a rigid one piece unit and the entire length shall be utilized in activating the sensor.

When placing the initial mat of asphalt concrete on existing pavement, the end of the screed nearest the centerline shall be controlled by a sensor activated by a ski device not less than 30 feet long. The end of the screed farthest from centerline shall be controlled manually. When paving contiguously with previously placed mats, the end of the screed adjacent to the previously placed mat shall be controlled by a sensor that responds to the grade of the previously placed mat and will reproduce the grade in the new mat within a 0.01-foot tolerance. The end of the screed farthest from the previously placed mat shall be controlled in the same manner as when placing the initial mat.

Should the methods and equipment furnished by the Contractor fail to produce a layer of asphalt concrete conforming to the requirements, including straightedge tolerance, of Section 39-6.03, "Compacting," of the Standard Specifications, the paving operations shall be discontinued and the Contractor shall modify his equipment or furnish substitute equipment.

Should the automatic screed controls fail to operate properly during any day's work, the Contractor may use manual control of the spreading equipment for the remainder of that day, however, the equipment shall be corrected or replaced with alternative automatically controlled equipment conforming to the requirements in this section before starting another day's work.

The area to which paint binder has been applied shall be closed to public traffic. Care shall be taken to avoid tracking binder material onto existing pavement surfaces beyond the limits of construction.

A drop-off of more than 0.10-foot will not be allowed at any time at the edge of a lane adjacent to the shoulder.

The Contractor shall schedule his paving operations such that each layer of asphalt concrete is placed on all contiguous lanes of a traveled way each work shift. At the end of each work shift, the distance between the ends of the layers of asphalt concrete on adjacent lanes shall not be greater than 10 feet nor less than 5 feet. Additional asphalt concrete shall be placed along the transverse edge at the end of each lane and along the exposed longitudinal edges between adjacent lanes, hand raked, and compacted to form temporary conforms. Kraft paper, or other approved bond breaker, may be placed under the conform tapers to facilitate the removal of the taper when paving operations resume.

At locations where drop-offs exist along a traffic lane adjacent to a shoulder, portable delineators and C31 signs shall be placed on the shoulder, adjacent to the traffic lane, in accordance with the requirements specified under "Shoulder Backing" in these special provisions.

POLYESTER FIBERS.--Polyester fibers shall be added to the asphalt concrete mixture to be placed at the locations shown and as specified herein.

The Contractor shall obtain suitable polyester fibers from the following source:

Kapejo Incorporated
3 Pierce Road
Wilmington, DE 19803
Telephone (302) 654-1915

The prices are as listed for Bonifiber (Type B):

	For a batch size of 1 1/2 tons (and multiples of 1 1/2)	For a batch size of 2 tons (and multiples of 2)
Price per carton	$155.00	$152.00
Bags per carton	20	15
Pounds of fibers per bag	7 1/2	10
Pounds of fibers per carton	150	150

The above prices do not include sales tax and are FOB, Milford, Delaware.

The above prices will be firm for all orders placed through December 31, 1981.

Polyester fibers shall be approximately 1/4 inch long and added to the dry aggregate at the rate of 5 pounds per ton of asphalt concrete.

Polyester fibers shall be added to the dry aggregate and mixed for a minimum of 30 seconds before adding the paving asphalt, unless otherwise directed by the Engineer.

Polyester fibers will be measured and paid for by the pound as polyester fibers.

The contract price paid per pound for polyester fibers shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals and for doing all the work involved in furnishing and mixing polyester fibers as specified in these special provisions, and as directed by the Engineer.

PREFORMED MEMBRANE (BITUTHENE).--Preformed membrane shall be placed where shown on the plans and at locations desigated by the Engineer.

Preformed membrane shall consist of a rubberized asphalt sheet reinforced with a polypropylene mesh.

Arrangements have been made to insure that any successful bidder can obtain suitable preformed membrane from the following source:

W. R. Grace and Company
7237 East Gage Avenue
Los Angeles, CA 90040
Telephone No. (213) 927-1461

The price per square yard for the preformed membrane system is $5.00. This price does not include sales tax and is FOB jobsite.

The above price will be firm for all orders placed through December 31, 1981.

A primer shall be applied to the surface prior to placing preformed membrane.

The type of primer and rate of spread shall be as recommended by the manufacturer of the preformed membrane.

Before spreading primer, large cracks, spalls, and chuck holes shall be repaired as directed by the Engineer, and such repair work will be paid for as extra work as provided in Section 4-1.03D of the Standard Specifications.

Surfaces to receive preformed membrane shall be cleaned of all dirt, dust, gravel, loose particles, and other extraneous materials. The surface shall be dry at the time of applying the primer. The preformed membrane shall not be applied when the air temperature is less than 40° F. Sheets of preformed membrane shall be end lapped by not less than 6 inches. After being laid, the membrane sheets shall be rolled with hard rollers or other apparatus as necessary to develop a uniform and firm bond with the surfacing below. Wrinkles or air bubbles large enough to cause laps shall be cut. Tears and cuts shall be repaired with the same material and shall extend over the section to be repaired by at least 6 inches, except an approved adhesive shall be used to bond the 2 layers of membrane together.

Preformed membrane will be measured and paid for by the square yard. The quantity of preformed membrane (Bituthene) to be paid for will be determined from the dimensions shown on the plans, or such other dimensions as may be ordered in writing by the Engineer. No additional payment will be made for lapped areas. Payment will not be made for preformed membrane placed outside the limits shown on the plans.

The contract price paid per square yard for preformed membrane (Bituthene) shall include full compensation for furnishing all labor, materials (including primer), tools, equipment and incidentals, and for doing all the work involved in furnishing and placing preformed membrane (Bituthene), complete in place, as shown on the plans, as specified in these special provisions, and as directed by the Engineer.

ASPHALT-RUBBER BINDER.--Asphalt-rubber binder shall conform to these special provisions.

Asphalt-rubber binder shall consist of rubber and paving asphalt.

Asphalt-rubber binder shall conform to one of the following at the Contractor's option, except that once an option is selected it shall not be changed without the Engineer's written approval.

(OPTION 1)

Granulated rubber shall consist of a minimum of 80 percent by weight of vulcanized rubber. A blend of Type I (0 percent to 30 percent) and Type II (70 percent to 100 percent) rubber shall be used with Open Graded aggregate (asphalt concrete), and a blend of Type II (0 percent to 40 percent) and Type III (60 percent to 100 percent) rubber shall be used for aggregate (Type A asphalt concrete).

Granulated rubber shall meet the following gradation:

Sieve Sizes	Percentage Passing Type I	Type II	Type III
No. 8	100	--	--
No. 10	95-100	--	--
No. 16	--	100	100
No. 30	0-10	70-90	95-100
No. 50	0-5	0-20	60-90
No. 80	--	0-5	30-60
No. 200	--	--	0-20

The sieves shall comply with the requirements of AASHTO Designation: M 92.

The individual granualted rubber particles, irrespective of diameter, shall not be greater in length than 0.250-inch for Type I and 0.125-inch for Types II and III.

The granulated rubber shall have a specific gravity of 1.18 ± 0.05 and shall be free of loose fabric, wire and other contaminants except that up to 4 percent (by weight of rubber) calcium carbonate or talc may be added to prevent rubber particles from sticking together.

The percentage of paving asphalt shall be from 74 percent to 80 percent and the percentage of rubber 20 percent to 26 percent, both by weight of the total asphalt-rubber mixture. The exact rates shall be determined by the Engineer.

The temperature of the paving asphalt shall be between 350° F. and 425° F. at the time rubber is added. The asphalt and rubber shall be combined and mixed together in a blender unit to produce a homogeneous material.

The asphalt-rubber mixture shall be mixed for a minimum of 45 minutues.

The temperature of the asphalt-rubber mixture shall be not less than 325° F. during the mixing process.

The asphalt-rubber binder shall not be retained for more than 72 hours.

Asphalt-rubber binder shall be at a temperature of not less than 300° F. or more than 375° F. when added to the aggregate.

The temperature of the aggregate (Type A asphalt concrete) before adding the binder shall be not less than 300° F. or more than 350° F. The temperature of the Open Graded aggregate (asphalt concrete) shall be not less than 275° F. or more than 325° F.

The rate of asphalt-rubber binder to be added to the aggregate shall be determined by the Engineer.

(OPTION 2)

Rubber shall be a blend of 20 percent to 40 percent powdered reclaimed devulcanized rubber and 60 percent to 80 percent ground vulcanized rubber. The exact proportions will be determined by the Engineer.

Gradation of the rubber shall be such that 100 percent will pass a No. 10 sieve and no particle shall be longer than 1/4 inch in length.

When 40 to 50 grams of rubber retained on the No. 30 sieve are added to a tight set 6-inch rubber mill, the material shall band on the mill roll in one pass.

Extender oil shall be added to the paving asphalt at a rate of from 2 percent to 15 percent. The percentage of paving asphalt shall be from 78 percent to 82 percent and the percentage of rubber from 18 percent to 22 percent, both by weight of the total asphalt-rubber mixture. The exact rates shall be determined by the Engineer.

The temperature of the paving asphalt shall be between 375° F. and 425° F. at the time rubber is added.

The asphalt and rubber shall be combined and mixed together in a blender unit to produce a homogeneous mixture.

The asphalt-rubber mixture shall be mixed for a minimum of 45 minutes and until such time as a product is produced with the following properties:

Viscosity at 400° F.	1,000 cps. Maximum
Softening Point (R & B)	120° F. Minimum
Flex Temperature (90 Degree Bend Test)	20° F. Maximum

The mixture shall not be held longer than 72 hours at the mixing temperature.

Asphalt-rubber binder shall be at a temperature of not less than 375° F. or more than 425° F. when added to the aggregate.

The temperature of the aggregate (Type A asphalt concrete) before adding the binder shall not be more than 350° F. The temperature of the Open-Graded aggregate (asphalt concrete) shall not be more than 325° F.

The rate of asphalt-rubber binder to be added to the aggregate shall be determined by the Engineer.

GENERAL.--The Contractor's proposed formulization and a sample of the asphalt-rubber binder shall be submitted to the Engineer at least 10 days prior to starting work.

The method and equipment for combining the rubber, asphalt and diluent or extender oil shall be so designed and accessible that the Engineer can readily determine the percentages, by weight, of each of the materials being incorporated into the mixture.

Asphalt-rubber binder will be measured and paid for by the ton in the same manner specified for paving asphalt as provided in Section 39-8, "Measurement and Payment," of the Standard Specifications.

The contract price paid per ton for asphalt-rubber binder shall include full compensation for furnishing all labor, materials (including rubber), tools, equipment and incidentals, and for doing all the work involved in furnishing and mixing asphalt-rubber binder as specified in these special provisions, and as directed by the Engineer.

ASPHALT-RUBBER INTERLAYER.--Asphalt-rubber interlayer shall conform to the provisions in Section 37-1, "Seal Coats," of the Standard Specifications and these special provisions.'

GENERAL.--Asphalt-rubber interlayer shall consist of a layer of asphalt-rubber binder, and covered with screenings.

The Contractor's proposed formulization and a sample of the asphalt-rubber binder shall be submitted to the Engineer at least 10 days prior to starting work.

The method and equipment for combining the rubber, asphalt and diluent or extender oil shall be so designed and accessible that the Engineer can readily determine the percentages, by weight, of each of the materials being incorporated into the mixture.

A Certificate of Compliance shall be furnished for the rubber, verifying the conformance of the rubber to these special provisions, as specified in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

MATERIALS.--Bituminous binder shall be paving asphalt, the grade will be determined by the Engineer.

Asphalt-rubber binder shall conform to one of the following at the Contractor's option, except that once an option is selected it shall not be changed without the Engineer's written approval.

(OPTION 1)

Granulated rubber shall consist of a minimum of 80 percent by weight of vulcanized rubber. A blend of Type I (20 percent to 30 percent) and Type II (70 percent to 80 percent) rubber shall be added to the paving asphalt.

Granulated rubber shall meet the following gradation:

Sieve Sizes	Percentage Passing	
	Type I	Type II
No. 8	100	--
No. 10	95-100	--
No. 16	--	100
No. 30	0-10	70-90
No. 50	0-5	0-20
No. 80	--	0-5
No. 200	--	--

The sieves shall comply with the requirements of AASHTO Designation: M 92.

The individual granulated rubber particles, irrespective of diameter, shall not be greater in length than 0.250-inch for Type I and 0.125-inch for Type II.

The granulated rubber shall have a specific gravity of 1.18 ± 0.05 and shall be free of loose fabric, wire and other contaminants except that up to 4 percent (by weight of rubber) calcium carbonate or talc may be added to prevent rubber particles from sticking together.

The percentage of paving asphalt shall be from 74 percent to 80 percent and the percentage of rubber 20 percent to 26 percent, both by weight of the total asphalt-rubber mixture. The exact rates will be determined by the Engineer.

The temperature of the paving asphalt shall be between 350° F. and 425° F. at the time rubber is added. The asphalt and rubber shall be combined and mixed together in a blender unit to produce a homogeneous material.

The asphalt-rubber mixture shall be mixed for a minimum of 30 minutes.

The diluent shall be added to the asphalt-rubber mixture at a rate of from 0 percent to 7 percent, by volume, the exact rate will be determined by the Engineer.

The diluent shall be a solvent with an initial boiling point of 340° F. when tested in accordance with ASTM Designation: D 86.

The temperature of the asphalt-rubber mixture shall be not less than 325° F. during the mixing process.

The asphalt-rubber mixture shall be spread as soon as possible after reaching the desired consistency and shall not be held at temperatures over 325° F. for more than 4 hours.

The asphalt-rubber mixture shall not be applied after it has been retained for more than 48 hours.

(OPTION 2)

Rubber shall be a blend of 20 percent to 40 percent powdered reclaimed devulcanized rubber and 60 percent to 80 percent ground vulcanized rubber. The exact proportions will be determined by the Engineer.

Gradation of the rubber shall be such that 100 percent will pass a No. 10 sieve and no particle shall be longer than 1/4 inch in length.

When 40 to 50 grams of rubber retained on the No. 30 sieve are added to a tight set 6-inch rubber mill, the material shall band on the mill roll in one pass.

Extender oil shall be added to the paving asphalt at a rate of from 2 percent to 15 percent. The percentage of paving asphalt shall be from 78 percent to 82 percent and the percentage of rubber from 18 percent to 22 percent, both by weight of the total asphalt-rubber mixture. The exact rates will be determined by the Engineer.

The temperature of the paving asphalt shall be between 375° F. to 425° F. at the time rubber is added.

The asphalt and rubber shall be combined and mixed together in a blender unit to produce a homogeneous mixture.

The asphalt-rubber mixture shall be mixed for a minimum of 45 minutes and until such time as a product is produced with the following properties:

Viscosity at 400° F.	1,000 cps. Maximum
Softening Point (R & B)	120° F. Minimum
Flex Temperature (90 Degree Bend Test)	20° F. Maximum

The asphalt-rubber mixture shall be spread as soon as possible after reaching the desired consistency and shall not be held at temperatures over 400° F. for more than 4 hours.

The asphalt-rubber mixutre shall not be applied after it has been retained for more than 48 hours.

Screenings shall conform to the 3/8" x No. 6 size specified in Section 37-1.02, "Materials," of the Standard Specifications.

Screenings shall be surface dry at the time of application.

EQUIPMENT.--The equipment used by the Contractor shall include the following:

1. A self-propelled power broom capable of cleaning the existing pavement and removing loose screenings without dislodging screenings set in the asphalt-rubber mixture. A gutter broom or steel-tined broom shall not be used.

2. Two pneumatic-tired rollers conforming to the requirements specified in Section 39-5.02, "Compacting Equipment," of the Standard Specifications.

3. Self-propelled chip spreader conforming to the requirements specified in Section 37-1.06, "Spreading Cover Material," of the Standard Specifications.

4. A self-propelled distributor truck equipped with mixing equipment capable of producing a homogeneous mixture of rubber and asphalt and spreading the mixture at the specified rate.

SPREADING.--The surface shall be cleaned of all dirt and loose material before applying the asphalt-rubber mixture.

Asphalt-rubber interlayer shall be spread at the rate of 0.6- to 0.7-gallon per square yard at application temperature. The exact rate will be determined by the Engineer.

Asphalt-rubber interlayer shall not be placed when the atmospheric temperature is below 60° F. or above 100° F.

Immediately following the application of the asphalt-rubber interlayer, it shall be covered with screenings.

The chip spreader shall never be more than 50 feet behind the distribution truck. Screenings shall be spread at the rate of 35 to 39 pounds per square yard, the exact rate will be determined by the Engineer.

COMPACTING.--Initial rolling shall consist of a minimum of one complete coverage with one or more pneumatic-tired rollers and shall begin immediately behind the chip spreader. The distance between the rollers and the chip spreader shall not exceed 100 feet at any time during chip spreading operations. A minimum of 3 complete coverages as defined in Section 39-6.03, "Compacting," of the Standard Specifications with a pneumatic-tired roller, after the initial coverages, shall be made.

MISCELLANEOUS.--Loose screenings shall be removed by light brooming before asphalt concrete is placed over the screenings.

Screenings shall be covered with asphalt concrete on the same day as they are placed.

Public traffic shall not be allowed to travel on the screenings.

All joint edges shall be swept clean of overlapping cover material prior to application of the adjacent asphalt-rubber mixture. All reasonable precautions shall be taken to avoid skips and overlaps at joints. All defects shall be corrected. Correction of any such defects will be at the Contractor's expense. All transverse joints shall be made by placing building paper over the ends of the previous applications, and the joining application shall start on the building paper. The paper shall be removed and disposed of to the satisfaciton of the Engineer.

MEASUREMENT.--The quantities of asphalt-rubber interlayer will be measured and paid for by the square yard as determined from the actual dimensions of the asphalt-rubber interlayer applied.

PAYMENT.--The contract price paid per square yard for asphalt-rubber interlayer shall include full compensation for furnishing all labor, materials (including screenings, paving asphalt, rubber and diluent or extender oil), tools, equipment, and incidentals and for doing all the work involved in applying asphalt rubber interlayer, complete in place, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

APPENDIX E

Condition Survey Report
(April 1983)

State of California

Business and Transportation Agency

Memorandum

To : File

Date: April 21, 1983

File : 03-Nev-80 23.8/24.8
03-217334, 1982
HP&R Experimental Project
Westbound Lanes

From : **DEPARTMENT OF TRANSPORTATION**
District 3 - Materials Section

Subject: Review April 6, 1983

This section of Interstate 80 was completed in 1958. The mainline structural section consists of 0.67' of portland cement concrete pavement (PCCP) over 0.33" cement treated subgrade and 1.0' of imported subbase material. This route carries a large percentage of truck traffic, which is frequently required to use snow chains in the winter.

Prior to the construction of this structural overlay, Lane 2 exhibited considerable chain wear abrasion and continuous Stage 1 and 2 cracking. Lane 1 was in better condition, displaying large sections of crack-free pavement and intermittent sections of Stage 1 cracking and one localized Stage 3 cracked section.

For the purpose of developing economical and efficient strategies to use in future rehabilitation work of the failed PCCP on this route from Colfax to the Nevada state line, an experimental HP&R project was constructed in the summer of 1982 using the strategies shown in the attached layout plan.

In addition to the pavement's rehabilitation strategies used, a structural side drain system was installed along the entire length of the project.

The different strategies used have a double purpose. Rubberized asphalt interlayer and/or rubberized or not rubberized open graded asphalt concrete (OGAC-R and OGAC) and Bituthene strips over cracks and joints were used to stop or delay reflective cracking of the PCCP.

The Bonifibers and the rubber added to the asphalt in the AC in the finishing course had the purpose of increasing the AC mix resistance to chain abrasion. The snowfall in the vicinity of this project normally is not very heavy, the elevation is approximately 5800', very cold in the winter, and because of the proximity of the Truckee River, icing conditions are frequently critical.

On April 6, 1983, a quick informal review of the project was made by Materials Engineer Burt Brockett, Guy Buckman, and myself. Some photos and notes were taken and the full length of the project was walked.

During the field review, the following observations were made:

- The identification markers for each section are not solidly placed and some are down.
- Sections A and B exhibit continuous surface raveling or asphalt stripping, exposing the rock in the mat, giving it a rocky texture. Lane 1 is slightly better than Lane 2. This condition did not exist in the fall of 1982. The condition is not serious and probably will "heal" during the summer months.
- The right edge of the pavement is cracked continuously all along Sections A and B and is probably due to the thickness of the overlay (only 0.2').
- Sections C and D are in excellent condition. No abrasion, raveling or cracks at all.
- Sections E, F and G are in excellent condition. No abrasion or cracks.
- Sections H and the Control Section are in excellent condition. No cracks or abrasion.
- The surface texture and appearance of the Bonifiber AC and the Control Section AC are similar, and practically no visual difference exists.

CONCLUSIONS

As of now the entire overlay looks excellent, excepting the rubberized sections that can be rated as good. Hopefully, the edge cracking and the stripping or raveling of the rubberized AC sections don't get any worse. The limited conclusion is that the AC in the Control Section at this location, so far, is performing as well as the Bonifiber AC, and somewhat better than the rubberized AC sections.

It is too early to evaluate the benefits imparted by the OGAC-R and the rubberized interlayers as retardants of reflective cracking from the PCCP.

RECOMMENDATIONS

It is recommended that all the ID markers be checked and permanently set. It is very hard to differentiate between sections without the markers.

It is also recommended that complete reviews be performed this summer and in the fall of 1983, and that the first performance report be written at that time. A Bonifibers AC test section at a location of heavy snowfall and subjected to heavy chain abrasion is also recommended because of the great difference in price between the rubberized AC and the Bonifibers AC. The control section should be an enriched asphalt concrete preferably using an AR 2000 paving asphalt.

O. P. Castro

OPC:vlh

Attach.

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

RESULTS OF MINOR RESEARCH ON BAR-MAT PULLOUT TESTS

Study Supervised by .... Joseph B. Hannon, P.E.

Principal Investigator .... Joseph B. Hannon, P.E.

Co-Investigator .... Kenneth A. Jackura, P.E.

Report Prepared by .... Kenneth A. Jackura, P.E.

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

TECHNICAL REPORT STANDARD TITLE PAGE

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12. SPONSORING AGENCY NAME AND ADDRESS California Department of Transportation Sacramento, California 95807	13. TYPE OF REPORT & PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the Office of Structures, Department of Transportation, State of California, for the research project "Perform Pullout Resistance Tests on Bar-Mats in Soil"

16. ABSTRACT

Laboratory pullout resistance tests of Caltrans bar-mat embedded in soil types ranging from coarse gravel to sandy silt are presented. Field pullout resistance tests of Caltrans bar-mat embedded in sandy silt are presented and compared to the laboratory tests. A theoretical equation based on laboratory pullout resistance is presented for estimating peak bar-mat pullout resistance.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Reinforced soil, bar mesh reinforcement	No restrictions

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Unclassified	Unclassified	30	

DS-TL-1242 (Rev.6/76)

NOTICE

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/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)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal 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 (ft-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)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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RESULTS OF MINOR RESEARCH ON BAR-MAT PULLOUT TESTS

Introduction

In order to establish bar-mat pullout resistance values for Mechanically Stabilized Embankment (MSE) design, a series of eight laboratory pullout tests on bar-mat reinforcement were conducted at TransLab under a state financed research project (No. 643364) and results reported herein. The work was initiated in 1981 for the Office of Structures. Main objectives were to determine a relationship between bar-mat configuration, overburden pressure and soil type to bar-mat pullout resistance. A similar testing program was conducted by TransLab in 1977 with results of those tests published in TRB Research Record #640(1). Due to the paucity of data from the eight pullout tests, laboratory test results from other projects conducted by Caltrans (State of Georgia, 1982 and Caltrans MSE wall at Baxter, 1982-83) are included.

In addition to the laboratory tests, results from field pullout tests at Baxter are included. The embankment soil for the Baxter project is a sandy silt and subject to considerable strength loss when saturated. The silt was used for backfill and the bar-mats designed to accommodate its low strength. This project provided an excellent program study whereby the laboratory test pullout performance could be compared directly to field pullout test performance. These test comparisons thus added a practical element to the laboratory test information.

Soil type used in the Office of Structures tests was a well graded concrete sand while the soil used in the Georgia tests consisted of a fine gravelly sand passing the 1 1/2" sieve and a poorly graded coarse gravel passing the 6" sieve and retained on the 1 1/2" sieve. The Georgia gravel, along with the Baxter sandy silt, represents the probable extremes in soil conditions that would normally be used in an MSE project.

Also included in this report is a theoretical equation capable of predicting maximum pullout force of the bar-mats. The equation is based on the bearing capacity formula and provides a slightly conservative estimate of laboratory test bar-mat pullout resistance.

Conclusions

1. Bar-mat pullout resistance increases with increasing number of transverse bars. Overburden influences on pullout resistance are more pronounced with free draining material exhibiting high soil friction angles than with poor draining material exhibiting lower soil friction angles.

2. As presently indicated, spacing between longitudinal bars should be 6 inches and between transverse bars 24 inches, for strength and economy.

3. Field pullout tests in sandy silt (where a closed soil face exists) indicate approximately a minimum of 40 percent higher pullout resistance than laboratory tests (where a free soil face exists) for similar bar-mat configuration, soil type, and overburden.

4. Theoretical estimate of bar-mat pullout resistance for laboratory tests can be conservatively determined by Equation 1. Equation 1 is based primarily on the bearing capacity formula.

Comments and Recommendations

The information in this report is only a portion of the laboratory test data accumulated by TransLab. Additional TransLab information on pullout testing is available as are pullout tests from other public or private agencies (VSL, Utah State University). The purpose of this report was not to combine all available data but only sufficient data to indicate that a conservative estimate of pullout resistance can be developed from laboratory tests as compared to field pullout tests. Additional data are included to accomplish the original purpose of the study -- estimate maximum pull-out resistance of bar-mats placed in cohesionless soils and help illustrate the effectiveness of a theoretical formula for estimating peak bar-mat pullout resistance.

It is our recommendation that a more comprehensive report be constructed wherein all available data are included. Additionally, welds and welding technique must be examined thoroughly and addressed since some weld separation has occurred in our lab tests.

Further laboratory testing will include significantly greater precision in pullout rate control and monitorization techniques. Also, emphasis needs to be placed on the standardization of testing of fine grained soils that exhibit long consolidation times, and possible pore pressure generations when sheared in a wet state. Furthermore, consideration will be given to the conduct of laboratory tests without a free soil face to investigate influence of potential passive resistance pressures at that boundary.

Soil Type

Table I illustrates the gradation of the soils utilized in the laboratory pullout tests. Column A is the gradation for the concrete sand used in the eight tests conducted for Office of Structures; Column B represents the gradation for the coarse gravel and the fine gravelly sand used in the Georgia pullout tests, and Column C the gradation used for the Baxter project. Also indicated on Table I are the soils drained and/or undrained strength parameters, along with Atterberg limit ratings, and maximum density, if available.

Table I

Physical Soil Properties of Laboratory and Field Materials

	Office of Structures	Georgia		Baxter	
		Fine	Coarse	Field	Lab
Grading Analysis	A	B		C	
Sieve Size	% passing, by weight				
6"	—	—	100	—	—
3"	—	—	90	—	—
2-1/2"	—	—	71	—	—
2"	—	—	—	—	100
1-1/2"	—	98	14	—	99
1"	—	90	—	—	98
3/4"	—	86	1	100	98
1/2"	—	74	—	97	98
3/8"	—	68	—	94	98
#4	100	45	—	87	96
#8	98	34	—	82	95
#16	83	27	—	78	94
#30	47	22	—	74	92
#50	25	17	—	67	85
#100	10	12	—	56	71
#200	5	9	—	49	56
5M	—	2	—	18	19
1M	—	1	—	9	7
Angle of internal friction - Degrees	39	40	—	19	26
Cohesion - PSF	600	0	—	850	2200
Plasticity Index	NP	NP	—	3	1
Sand Equivalent	90	64	—	—	9
Density - PCF	125	140	—	118	120

Testing

Laboratory Testing

Laboratory pullout tests were conducted in the large scale shear box developed at the TransLab in the early 1970s(1). It consists of a rigid steel box 18 inches deep, 36 inches wide and 54 inches long (Photo 1). Vertical and horizontal loads are applied through hydraulic rams controlled by mechanically operated valves. Vertical loads equivalent to 50 feet of overburden and horizontal loads of 60 kips can be applied.

Soil test specimens are hand compacted to a minimum of 90% R.C. in the box via a pneumatic compactor. The bar-mat reinforcement is placed at the mid-height of the test specimen during the compaction process. For consolidation purposes, overburden loads are applied up to four hours prior to testing. Just before testing, the front face of the box is removed to expose the soil face. Average displacement rate of the reinforcement during pullout is approximately 0.2 in./min.

Bar-mats consisted of 5/16 inch or 3/8 inch diameter cold rolled A-36 steel bars welded at contact joints to form a rectangular mat of various sized grid openings. The mats were 4.5 feet long by either 1 foot or 2 feet wide. Number of longitudinal bars were either three (6-12 inches c to c spacing) or five (6 inches c to c spacing). Number of transverse bars varied from one to eight with either 6, 12, or 24 inch c to c spacing intervals (see Figure 1a).

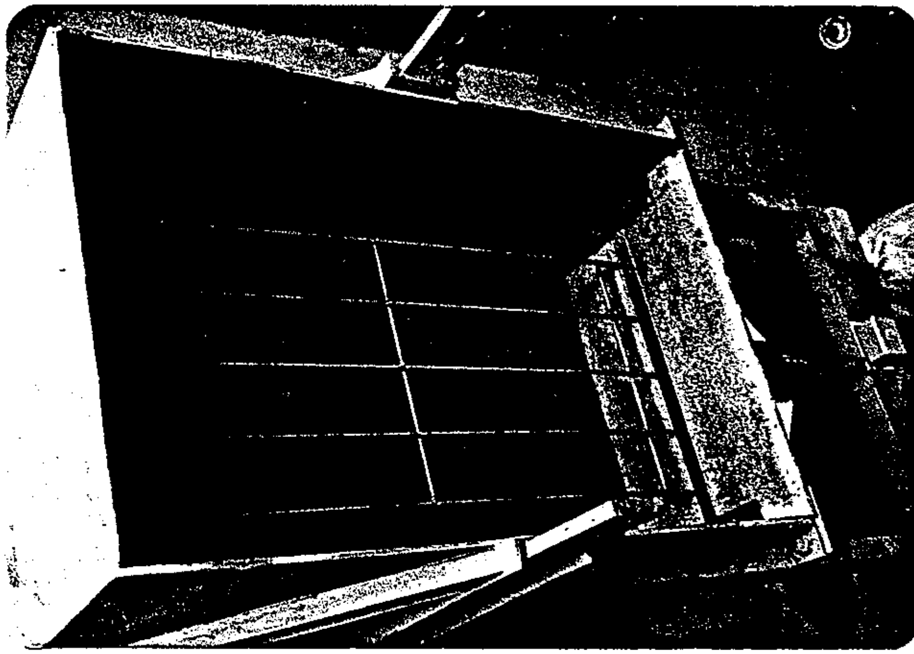
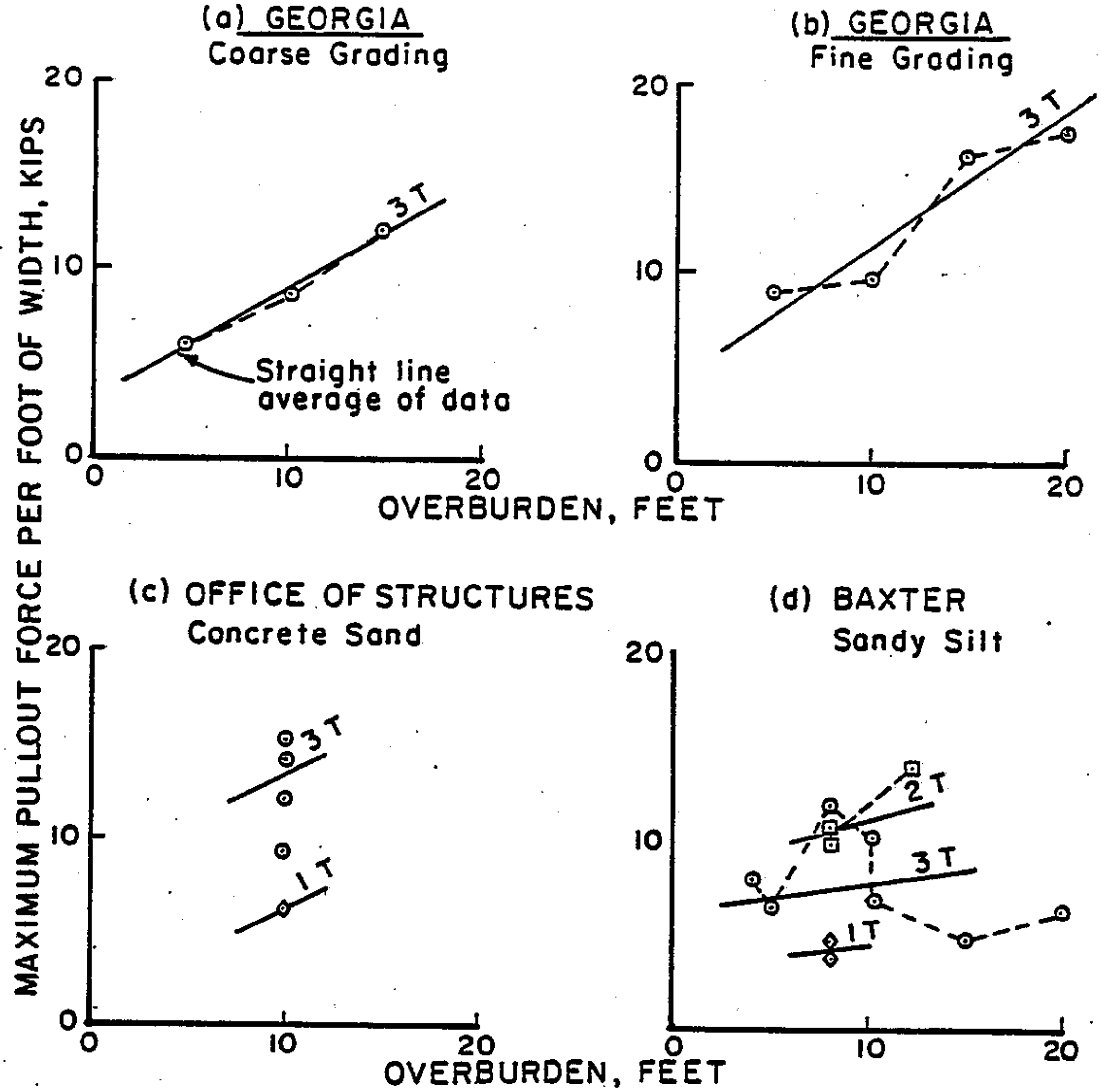


Photo 1 - Large Scale Shear Box Used For Pull-out Testing of Soil Reinforcement



LABORATORY MAXIMUM PULLOUT FORCE VERSUS OVERBURDEN HEIGHT

(T = Number of transverse bars.)

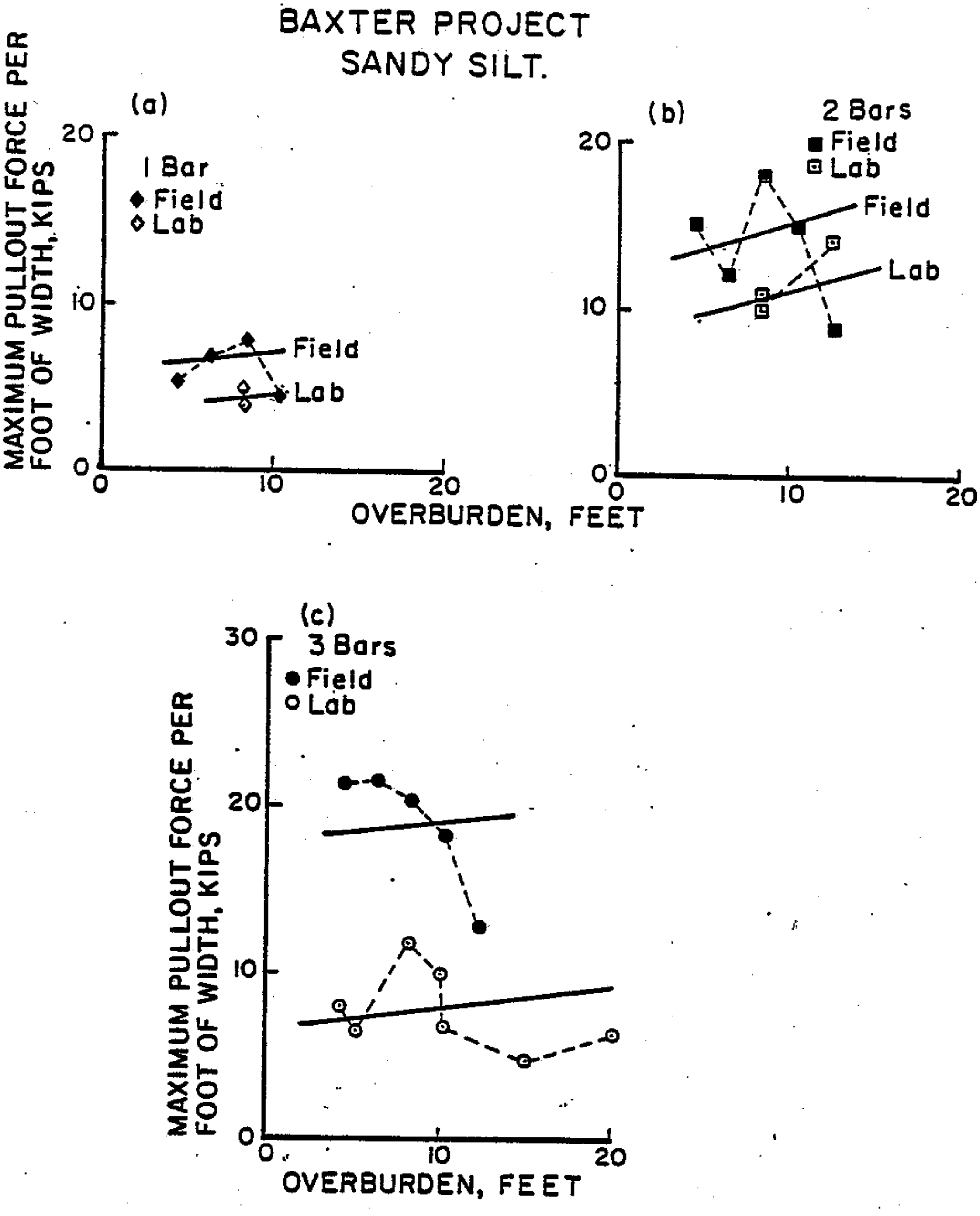
Figure 2

meager (Figure 2c) or highly scattered (Figure 2d), an attempt at an average is still provided. In these cases, it seems quite logical to expect an increased pullout resistance with increasing overburden for materials exhibiting sliding friction, hence, the solid lines are shown with a positive slope.

Field and Laboratory Comparisons

Figure 3 illustrates the field and laboratory bar-mat pullout resistance on sandy silt for the Baxter project. The laboratory test information on Figure 2c was redrawn into Figure 3 but separated into Figure 3a, b, c and corresponds to bar-mats with one, two or three transverse bars, respectively. Field data with similar bar-mat configurations are superimposed and indicate much higher pullout resistance than the laboratory tests. However, as in the laboratory tests, scatter is evident. Solid lines depict the field average and are assumed to conform to a positive slope. Tests on undisturbed samples from the field did not indicate major material gradation differences or large moisture content or density variations at the bar-mat test elevations, hence, the field trend to reduced bar-mat resistance with depth is not fully understood.

Speculation as to a possible reason is as follows. Field moistures indicate saturation or near saturation at all depths leading one to believe that pore water pressures may be partly responsible. The soil has a moderately high compressibility with low estimated permeability, thus, full effective vertical stresses at depth may not have been mobilized at the time of test. Additionally, if only the soil at depth is submerged, a capillary fringe zone will extend to the surface resulting in effective stresses



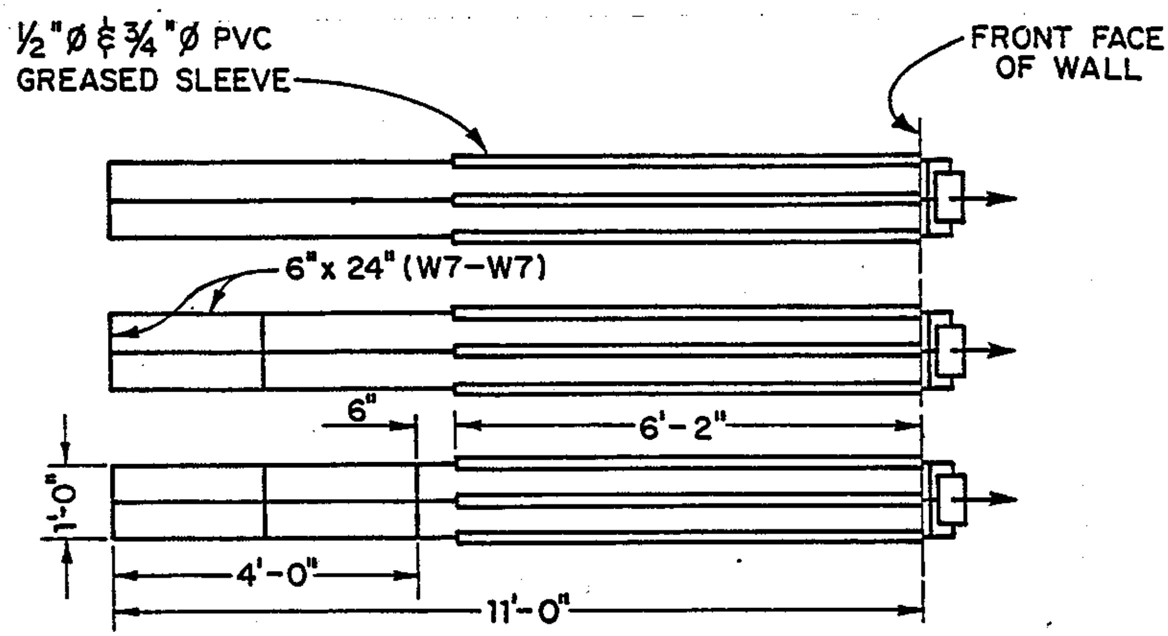
LABORATORY AND FIELD MAXIMUM PULLOUT FORCE VERSUS OVERBURDEN HEIGHT.

(FOR 1, 2 OR 3 TRANSVERSE BARS)

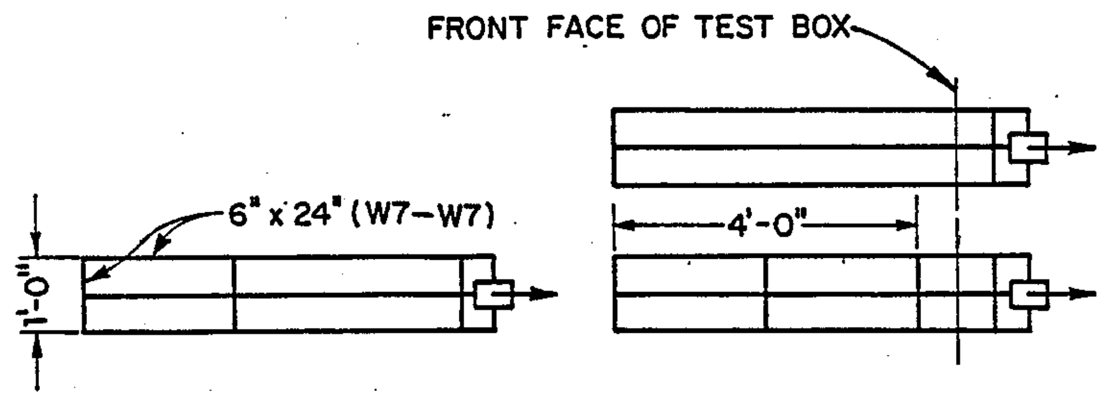
FIGURE 3

different from that computed. Also, there is a potential for higher pore pressure generation at depth due to bar-mat shearing stresses. The Baxter silt at depth should behave in an under, or possibly normally, consolidated manner with positive pore pressure development during shear as opposed to probable negative pore pressure development during shear exhibited by over-consolidated soils near the surface. Over-consolidation is induced by compaction and is overcome when overburden pressures exceed built-in compaction stresses.

Although the pore pressure concept appears to provide a partial answer to the field test anomalies, other factors not yet fully understood may be more dominating and further scrutiny of test data and possible additional field testing is being considered.



(b) DUMMY BAR-MATS FOR FIELD TEST



(a) LABORATORY TEST MATS

BAR-MAT CONFIGURATIONS FOR
LABORATORY AND FIELD TESTS

FIGURE 1

Field Testing

Field test dummy bar-mats were installed during construction of the Baxter project (mid 1982) and pulled approximately one year later (mid 1983). The mats were placed in the backfill and extended beyond the wall face 11 feet as shown in Photo 2. Mats were located at five elevation levels (overburden heights of 4, 6, 8, 10 and 12 feet) as shown in Photo 3.

The test bar-mats consisted of W-7 wire (approximately 5/16 inch diameter) welded together to form rectangular grids. Total bar-mat length was 11 feet, with the front 5 feet of the longitudinal bars equipped with greased sleeves to prevent soil bond. The back 4.5 feet was the bar-mat test section. The mat consisted of three longitudinal bars and one, two or three transverse bars. Six inch by 24 inch grid openings were formed with the two and three transverse bar configuration (see Figure 1b).

Field pullout testing was accomplished through the use of a hydraulic jack supported by a timber yoke at the wall face. Jacking pressure was adjusted to provide a displacement pull rate similar to the laboratory tests, 0.2 in./min. Loading continued until six inches of extension occurred.

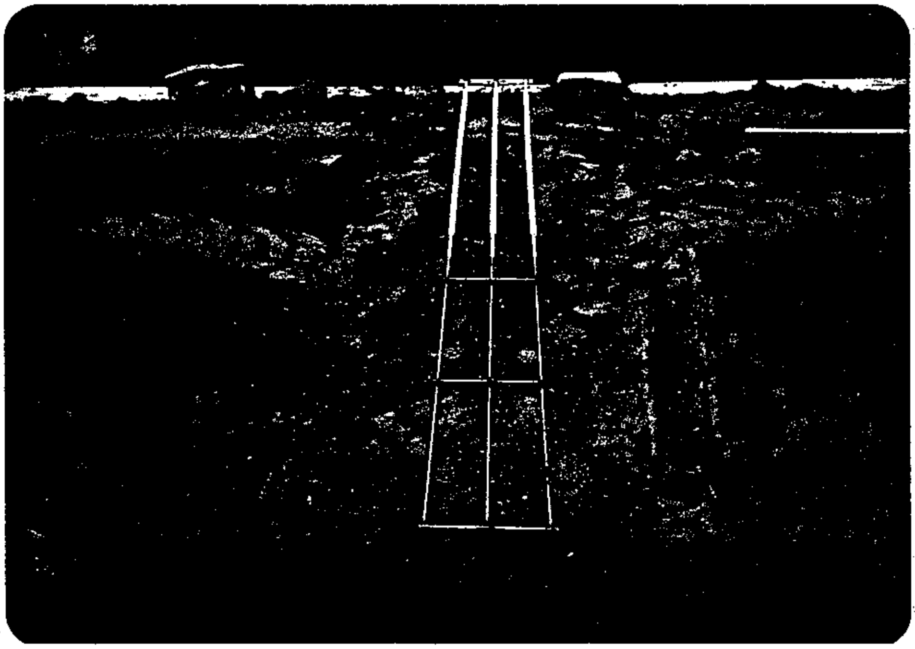


Photo 2 - Typical Dummy Bar-Mat (3 transverse bars) Placed in Backfill During Construction

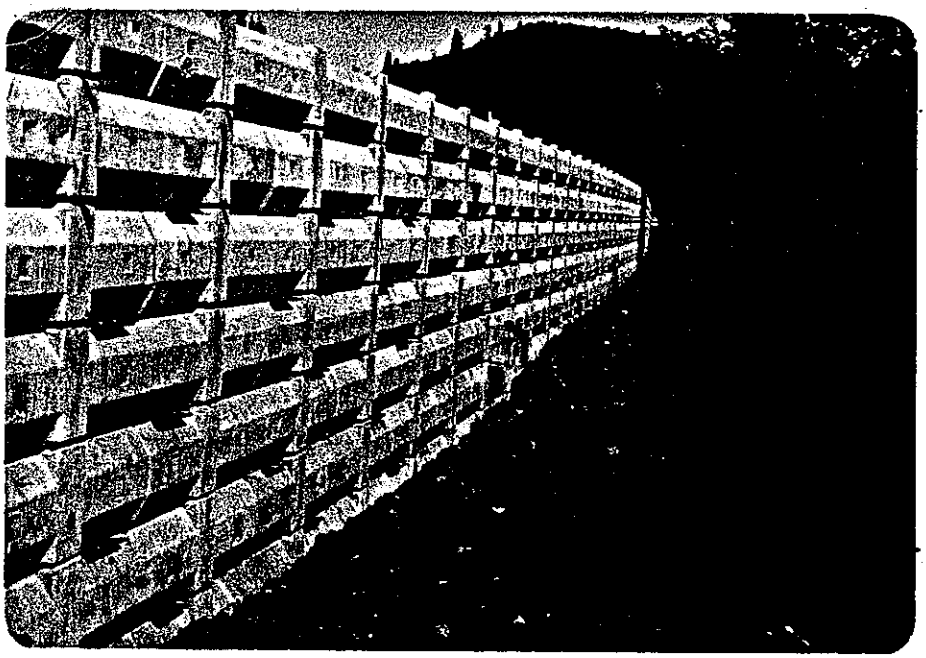


Photo 3 - Front Face of Wall at Instrument Location 2 (Wall 3) With Dummy Bar-Mats Extending From Face

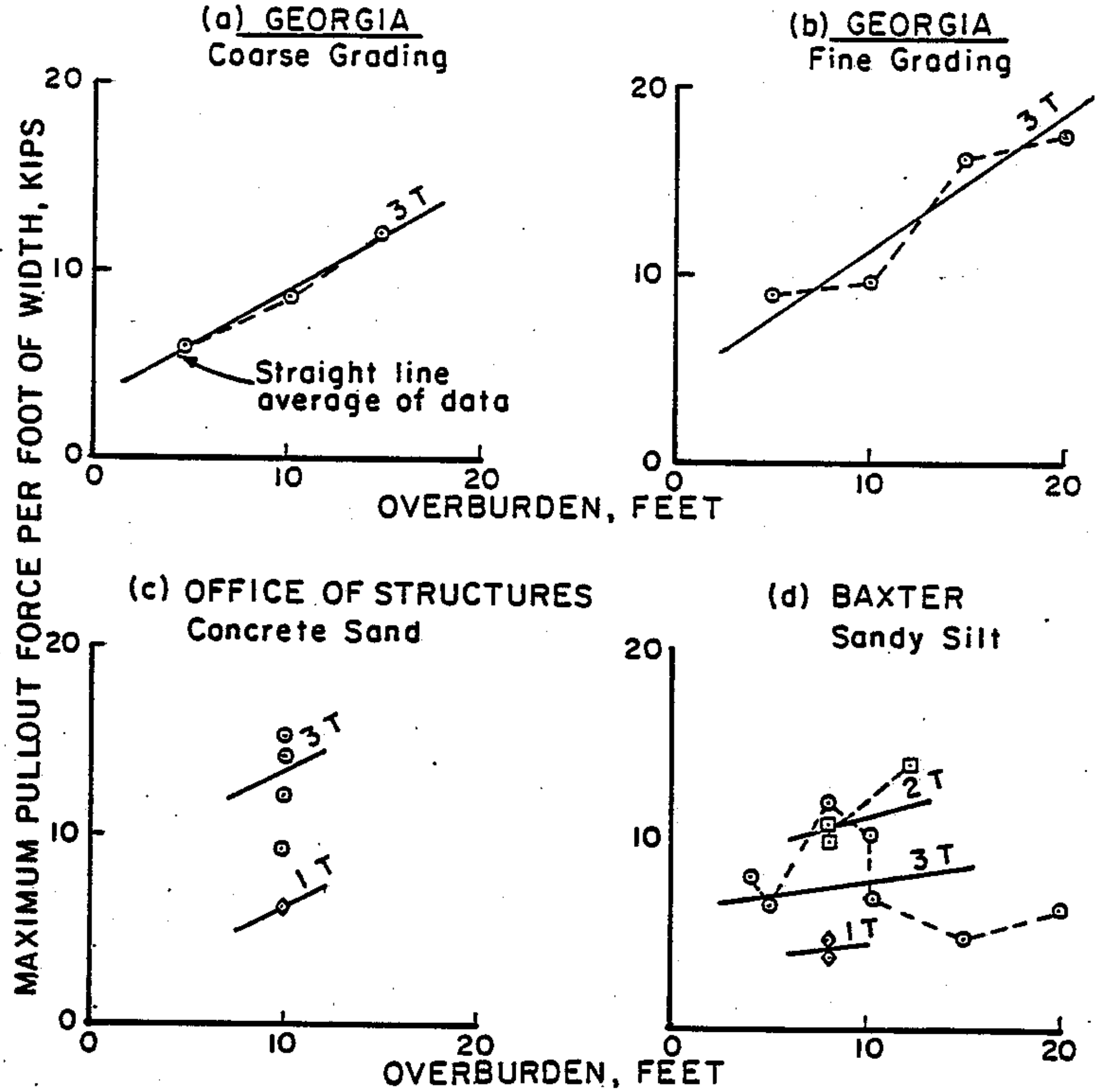
Test Results

All collected data were summarized and tabulated on "Summary TransLab Pullout Test Results" found at the end of this report. The summary sheets include a number of items such as project, date of test, soil friction and cohesion values, bar-mat configurations and pullout resistance force.

Due to a number of parameters that are difficult to control (uniform compacted density, uniform vertical pressure, uniform moisture, etc.), collected data are scattered. A significant amount of time was spent in trying to develop rationale for the pullout behavior variability and, in time, with more sophisticated testing and monitoring techniques the theories postulated for such behavior as discussed later, may be verified.

Laboratory Test Results

To simplify the collected data, graphs illustrating the majority of the tabulated information were developed. Figure 2 illustrates the laboratory maximum pullout resistance versus overburden for the four material gradations: a) coarse and, b) fine gravel grading for Georgia, c) concrete sand (well graded) for Office of Structures, and d) sandy silt for Baxter. Pullout resistance is based on a per foot width of bar-mat and includes test results for bar-mats with only one, two or three transverse bars. Other bar-mats with five and eight transverse bars are not shown to reduce data points and parameter variability. Data points for specific number of transverse bars are connected by short dashed lines. The solid line represents an average of the data points and in cases where data are



LABORATORY MAXIMUM PULLOUT FORCE VERSUS OVERBURDEN HEIGHT

(T = Number of transverse bars.)

Figure 2

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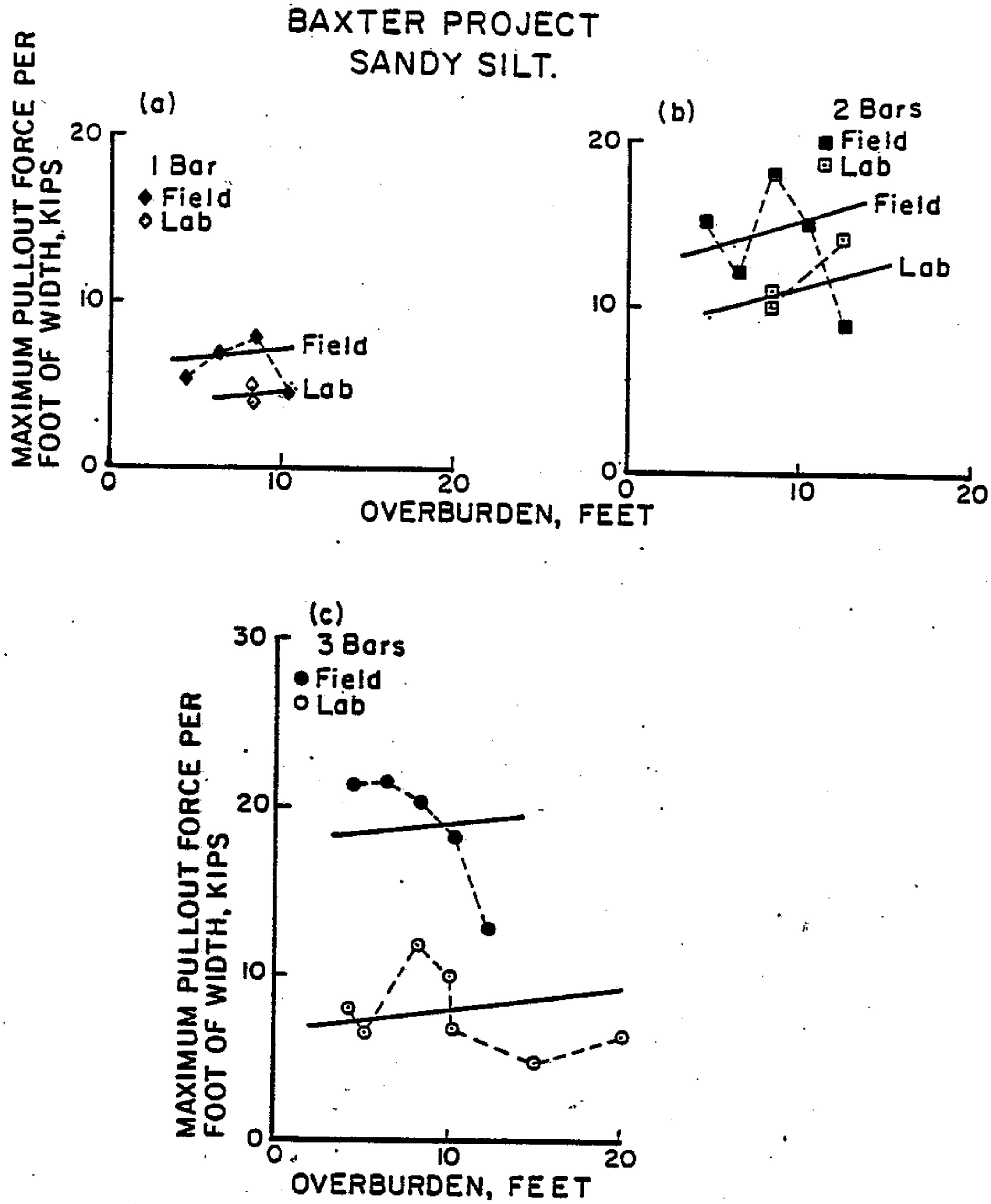


LABORATORY AND FIELD MAXIMUM PULLOUT FORCE VERSUS OVERBURDEN HEIGHT.

(FOR 1, 2 OR 3 TRANSVERSE BARS)

FIGURE 3

different from that computed. Also, there is a potential for higher pore pressure generation at depth due to bar-mat shearing stresses. The Baxter silt at depth should behave in an under, or possibly normally, consolidated manner with positive pore pressure development during shear as opposed to probable negative pore pressure development during shear exhibited by over-consolidated soils near the surface. Over-consolidation is induced by compaction and is overcome when overburden pressures exceed built-in compaction stresses.

Although the pore pressure concept appears to provide a partial answer to the field test anomalies, other factors not yet fully understood may be more dominating and further scrutiny of test data and possible additional field testing is being considered.

Theoretical Estimate of Bar-Mat Resistance

Figure 4 was developed to compare the theoretical maximum bar-mat pullout resistance as computed by Equation 1 below, to the laboratory maximum bar-mat pullout resistance. Soil strength parameters are also indicated on the figures. Since no strength tests were conducted on the Georgia coarse grading, a soil friction angle between 35° and 40° with no cohesion was assumed. Equation 1 was developed around the bearing capacity formula for estimating resistance of the transverse bars, and sliding friction concepts for the longitudinal bars. Equation 1 is as follows:

$$Q_{ult} = L_r \times A_s + T_r \times A_p \qquad 1)$$

where: Q_{ult} = Ultimate resisting capacity of bar-mat, kips

L_r = Frictional resistance of longitudinal bar per unit area, KSF

$L_r = 0.5\ (\sigma_v \mathrm{Tan} + c)$ KSF

σ_v = Effective overburden pressure, KSF

ϕ = Soil friction angle, degrees

c = Soil cohesion, KSF

0.5 = Coefficient of friction between soil and bar

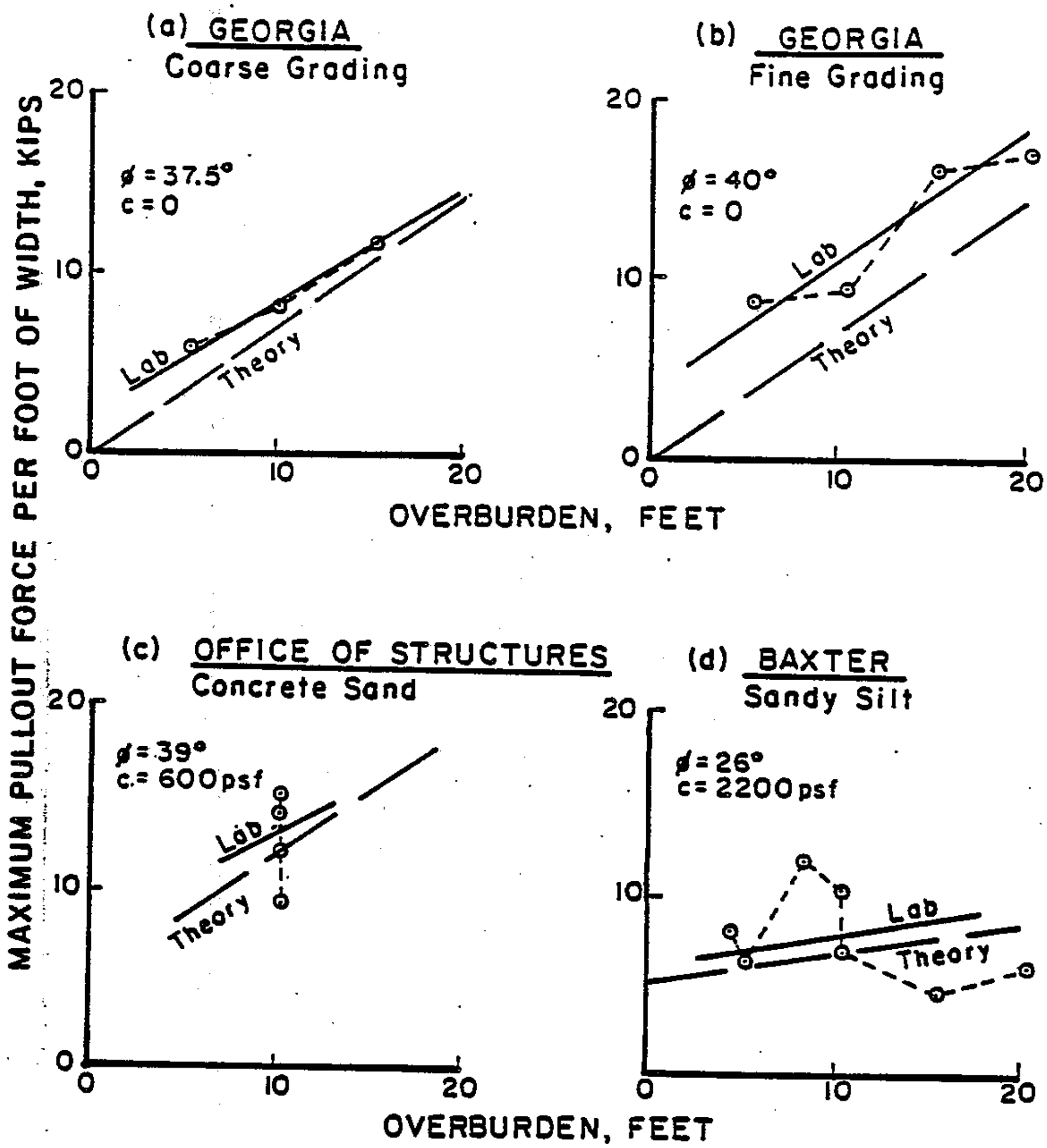
A_s = Surface area of longitudinal bar, ft^2

$A_s = N_L \times \pi \times D \times L_L$

N_L = Number of longitudinal bars

D = Bar diameter, ft

L_L = Length of longitudinal bar in soil, ft



COMPARISON OF AVERAGE OF LABORATORY BARMAT PULLOUT FORCE TO THEORETICAL BARMAT PULLOUT FORCE.

(SHOWN FOR THREE TRANSVERSE BARS ONLY)

Figure 4

T_r = Passive resistance per unit projected area of transverse bar, KSF

$T_r = CN_c + 2/3\ \sigma_v N_q$, KSF

N_c = Bearing capacity factor

N_q = Bearing capacity factor

A_p = Projected area of transverse bar, ft^2

$A_p = N_T \times D \times T_L$, ft^2

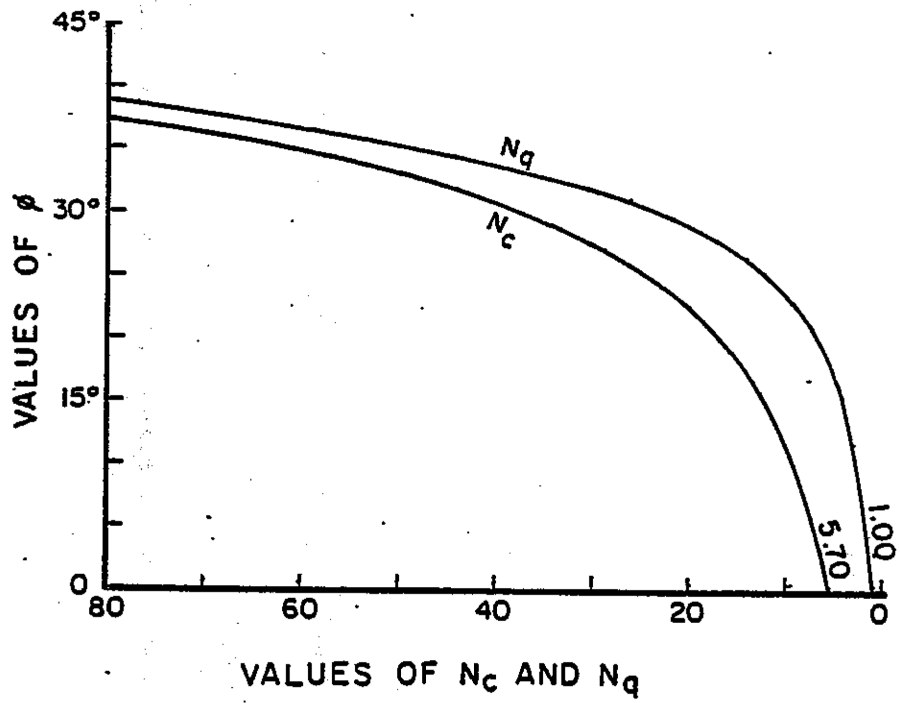
N_T = Number of transverse bars

D = Bar diameter, ft

T_L = Length of transverse bar, ft

The bearing capacity factors N_c, N_q are redrawn from a Terzaghi and Peck textbook and are indicated on Figure 5.

The information on Figure 4 indicates a reasonable but conservative approximation to the laboratory test data can be made by the use of Equation 1. More importantly, Equation 1 will provide a very conservative basis for estimating pullout resistance of field bar-mats as judged by information contained herein.



VALUES OF N_c AND N_q FOR VALUES OF ø FOR USE IN EQUATION I. (REDRAWN FROM TERZAGHI AND PECK.)

Figure 5

Reference

1. Chang, J. C., Hannon, J. B., Forsyth, R. A., "Poll Resistance and Interaction of Earthwork Reinforcement and Soil," California Department of Transportation, Transportation Laboratory, Sacramento, California, January 1977.

TABLE II
SUMMARY TRANSLAB PULLOUT TEST RESULTS

Sheet 1 of 2

	Date Mo-Yr	Sample Source	Soil Properties: Test No.	Soil Properties: ϕ	Soil Properties: c lbs/SF	Soil Properties: γ lbs/CF	Soil Properties: M_c %	Soil Classification	Bar Mats: Size of bars	Bar Mats: Spacing, In. Horiz.	Bar Mats: Spacing, In. Vert.	Bar Mats: No. of Trans. (Ft.)	Bar Mats: No. of Long. (Ft.)	Surface Area, In.: Trans.	Surface Area, In.: Long.	Surface Area, In.: Ratio Long./Trans.	Overburden Press., PSF: Ht. Ft.	Overburden Press., PSF: Calcu/Lab. Appl.	Displ. VS Pullout (In.) (Kips): ½ in.	Displ. VS Pullout: 1 in.	Displ. VS Pullout: 1½ in.	Displ. VS Pullout: Max Pull-out	Remarks
A	OFFICE OF STRUCTURES (CALTRANS)																						
	Mar-81	Teichert Aggregarts	1	39°	600	110	16	Teichert Concrete Sand	3/8"	6	6	3	5	84.8	282.7	3.33	10	1100	-	28.8	28.2	30.8	
			2	↓	↓	↓	↓	↓	↓	6	6	3	5	84.8	282.7	3.33	↓	1100	23.0	29.0	-	29.0	
			3	↓	↓	↓	↓	↓	↓	6	-	1	5	28.3	282.7	10.00	↓	1100	9.6	12.5	-	13.0	
			4	↓	↓	↓	↓	↓	↓	6	6	8	5	226.2	282.7	1.25	↓	1100	9.0	17.0	20.0	21.0	
			5	↓	↓	↓	↓	↓	↓	6	12	5	5	141.4	282.7	2.00	↓	1100	19.0	20.0	-	20.5	
	Apr-81		6	↓	↓	↓	↓	↓	↓	6	24	3	5	84.8	282.7	3.33	↓	1100	19.6	23.0	24.0	24.8	
			7	↓	↓	↓	↓	↓	↓	12	12	5	3	141.4	169.6	1.20	↓	1100	18.6	20.3	20.7	20.7	
			8	↓	↓	↓	↓	↓	↓	12	24	3	3	84.8	169.6	2.00	↓	1100	13.0	16.5	17.5	18.8	
B	GEORGIA (For Department of Transportation, Georgia State)																						
	Mar-82	Supplied by State of Georgia	4a	40°	0	139	3	Fine Grading, <1½"	3/8"	6	6	3	5	84.8	282.7	3.33	5	695/706	12.0	17.0	18.0	18.0	
			1	40°	0	139	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	10	1390/1397	8.0	17.5	18.8	19.0	
			3	40°	0	139	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	15	2085/2100	16.4	23.0	25.5	32.5	
			2	40°	0	139	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	20	2780/2795	25.0	34.0	35.0	35.1	
			5	-	-	103	-	Coarse Grading, 1½"-6"	↓	↓	↓	↓	↓	↓	↓	↓	5	515/706	3.5	6.0	8.0	12.0	
			6	-	-	103	-	↓	↓	↓	↓	↓	↓	↓	↓	↓	10	1030/1397	5.0	8.0	10.1	17.2	
			7	-	-	103	-	↓	↓	↓	↓	↓	↓	↓	↓	↓	15	1545/2100	9.5	12.7	14.7	24.3	
C	BAXTER (I-80, East Bound at Drum Forebay Chain-on Lane near Baxter, CA.)																						
	Apr-81	Sampled for Design	4	26°	2200	107	25	Local Sandy Silt	5/16"	6	24	3	5	70.7	235.6	3.34	5	535	7.5	9.6	10.8	13.4	
			1	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	10	1070	12.5	16.5	17.0	20.8	
			2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	15	1605	5.2	6.8	7.9	10.1	
			3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	20	2140	7.5	9.4	10.5	13.1	

ϕ=Angle of internal friction
c=Cohesion
γ=Unit weight
M_c=Moisture content

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TABLE II
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Sheet 2 of 2

	Date Mo-Yr	Sample Source	Soil Properties: Test No.	ø	c lbs/SF	γ lbs/CF	M_c %	Soil Classification	Bar Mats: Size of bars	Spacing, In.: Horiz.	Spacing, In.: Vert.	No. of Trans. (Ft.)	No. of Long. (Ft.)	Surface Area, In.: Trans.	Long.	Ratio Long./Trans.	Overburden Press., PSF: Ht. Ft.	Calcu/Lab. Appl.	Displ. (in.) VS Pullout (Kips): ½ in.	1 in.	1½ in.	Max Pull-out	Remarks
C	BAXTER (Continued)																						
	Nov-83	Collected during Construction	1	22°	1500	124	22.6	Local Sandy Silt	5/16"	6	24	3	3	70.7	141.4	2.00	4	496	5.0	5.5	6.5	8.0	
			2	↓	↓	↓	↓	↓	↓	↓	-	1	↓	23.6	↓	6.00	8	992	2.5	3.5	4.0	5.0	
			3	↓	↓	↓	↓	↓	↓	↓	24	2	↓	47.1	↓	3.00	8	992	6.5	8.5	9.0	11.0	
			4	↓	↓	↓	↓	↓	↓	↓	-	1	↓	23.6	↓	6.00	8	992	2.0	2.0	2.5	4.2	
			5	↓	↓	↓	↓	↓	↓	↓	24	3	↓	70.7	↓	2.00	8	992	5.0	7.0	9.0	12.2	
			6	↓	↓	↓	↓	↓	↓	↓	24	2	↓	47.1	↓	3.00	8	992	3.5	6.0	7.0	9.7	
			7	↓	↓	↓	↓	↓	↓	↓	24	3	↓	70.7	↓	2.00	10	1240	5.0	7.0	5.5	7.0	
			8	↓	↓	↓	↓	↓	↓	↓	24	2	↓	47.1	↓	3.00	12	1480	6.0	8.0	9.0	14.0	
	Jun-83	Field borings sampled near Dummy Bars for Field Pullout Test (1 year after construction)	3	34°	1340	124	21.6	Local Sandy Silt	5/16"	6	24	1	3	11.8	141.4	12.00	4	496/460	3.0	4.2	5.5	5.5	
			1	34°	1340	124	21.6	↓	↓	↓	↓	1	↓	11.8	↓	12.00	6	794/744	2.5	3.5	4.7	7.0	
			2	34°	1000	122	10.2	↓	↓	↓	↓	1	↓	11.8	↓	12.00	8	976/976	3.5	5.6	6.0	8.0	
			14	34°	1000	124	16.5	↓	↓	↓	↓	1	↓	11.8	↓	12.00	10	1240/1240	2.6	4.0	4.0	5.6	
			5	34°	2000	125	19.3	↓	↓	↓	↓	2	↓	23.6	↓	6.00	4	500/496	7.0	9.7	10.5	15.0	
			7	34°	2000	125	19.3	↓	↓	↓	↓	2	↓	23.6	↓	6.00	6	750/738	5.5	8.4	10.0	12.0	
			8	28°	1800	120	29.2	↓	↓	↓	↓	2	↓	23.6	↓	6.00	8	960/960	9.0	12.5	14.0	12.0	
			6	28°	1800	120	29.2	↓	↓	↓	↓	2	↓	23.6	↓	6.00	10	1200/1040	8.0	10.0	12.0	15.0	
			4	19°	950	116	25.5	↓	↓	↓	↓	2	↓	23.6	↓	6.00	12	1392/1207	5.0	6.8	7.0	8.8	
			11	34°	1000	122	10.2	↓	↓	↓	↓	3	↓	35.3	↓	4.00	4	488/456	6.2	12.0	14.2	21.4	
			13	34°	1000	122	10.2	↓	↓	↓	↓	3	↓	35.3	↓	4.00	6	732/738	4.4	13.5	14.5	21.8	
			10	34°	1000	122	10.2	↓	↓	↓	↓	3	↓	35.3	↓	4.00	8	976/984	10.0	14.5	17.0	20.5	
			12	26°	1200	122	22.2	↓	↓	↓	↓	3	↓	35.3	↓	4.00	10	1220/1240	6.0	10.0	13.5	18.5	
			9	26°	1200	122	22.2	↓	↓	↓	↓	3	↓	35.3	↓	4.00	12	1464/1464	4.6	8.5	12.5	13.0	

ø=Angle of internal friction γ=Unit weight
c=Cohesion M_c=Moisture content

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