ARIZONA DEPARTMENT OF TRANSPORTATION

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POROUS PAVEMENT FOR THE CONTROL OF HIGHWAY RUNOFF

Construction

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16. ABSTRACT
A three lane by 3500 linear feet portion of an urban highway was constructed of porous pavement. This design resulted from a research study of the use of porous pavement to provide highway drainage. The roadway utilized open-graded layers of asphalt concrete, asphalt treated base and untreated aggregate subbase. A filter fabric was placed for separation of the subbase and subgrade. The free draining pavement layers drain into a trench at the edge of the pavement. The drainage trench is filled with open-graded aggregate.

Construction precedures and problems are discussed along with initial performance indications.

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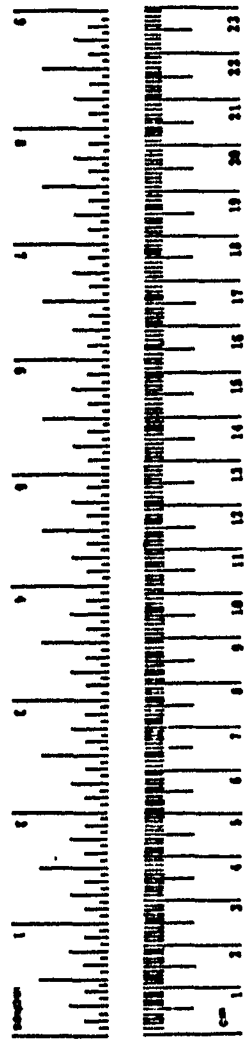
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

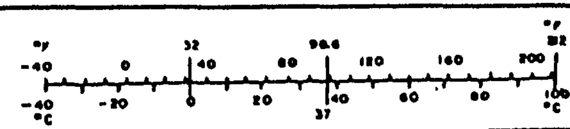
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares ($10,000\ m^2$)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

General

Project F045-1(4), Jct. I-10/Mesa Hwy (Knox Road to Baseline Road) consisted of widening and reconstructing 1.47 mi of State Route 87. The work included removing existing asphalt concrete pavement and existing portland cement concrete pavement, constructing new bituminous pavement, curb, gutter and sidewalk, installing new traffic signals at Warner Road, highway lighting and other incidental work. Approximately 0.67 mi of the northbound lanes of the project was paved using an open-graded porous pavement. Figure 1 is a typical cross-section of the control and experimental sections.

Location

The project was located on State Route 87 (Arizona Avenue) within the limits of the City of Chandler in Maricopa County, Arizona. Chandler is a rapidly growing and developing suburban city approximately 20 mi southeast of Phoenix. State Route 87 is heavily traveled by commuter traffic going to and from the Superstition Freeway which is approximately 2.5 mi north of the project. Figure 2 is a location map for the project.

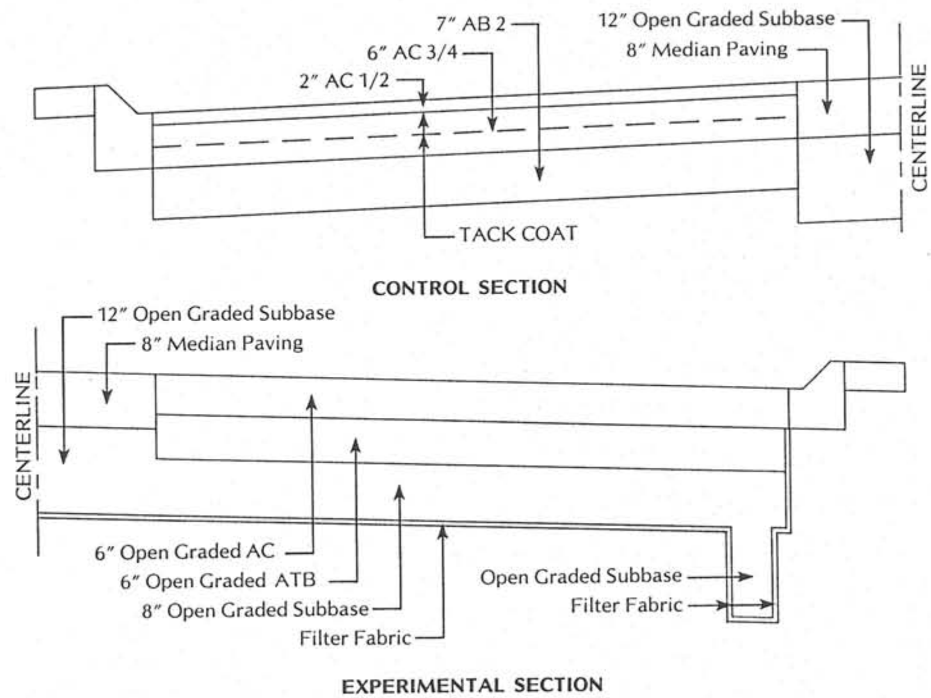

FIGURE 1 TYPICAL CROSS-SECTIONS

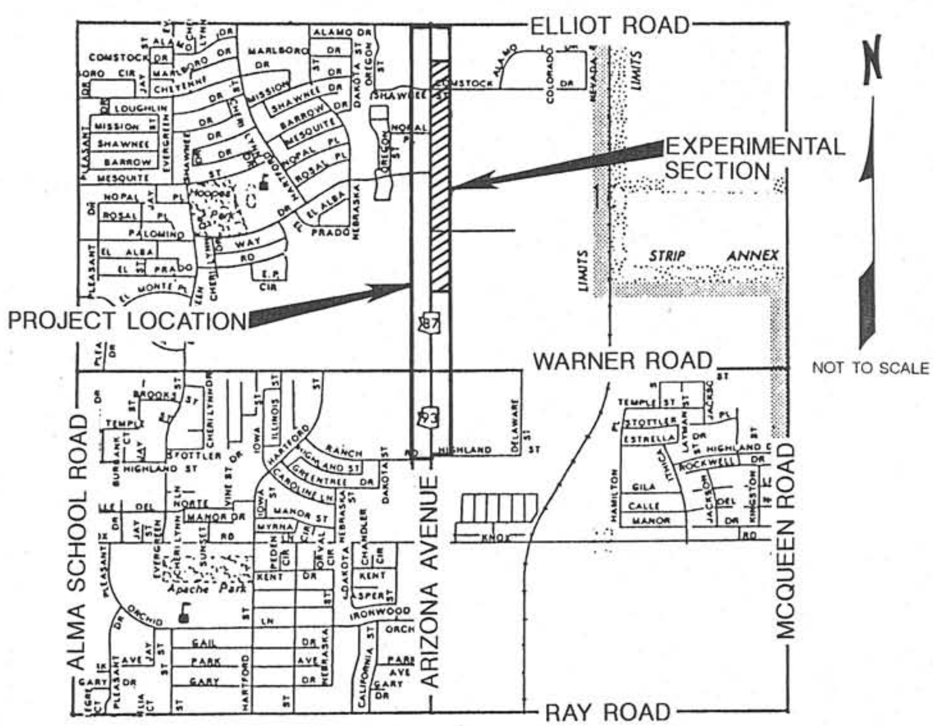

FIGURE 2 LOCATION MAP

Location of Experimental Section

The porous pavement section was located within the northbound lanes of the northern 3,500 ft of the project limits between Station 105+00 and 140+00 on State Route 87. The experimental section begins approximately 500 ft south of Elliot Road and extends southerly for 3500 ft. The length and location of the section were selected by the Arizona Department of Transportation.

HISTORY

Contract History

In October of 1985, the Arizona Department of Transportation advertised for bids for the construction of Project F045-1(4), Jct. I-10/Mesa Highway. The date for the bid opening was November 8, 1985. Seven bids were received by the Arizona Department of Transportation and on November 15, 1985 The Tanner Companies was notified that their bid was accepted. Their bid of $2,086,605 was approximately 10 percent over the State estimate of $1,890,450. The bids received ranged from $2,086,605 to $3,139,485.

Project History

The official start date for the project was December 16, 1985. The contractor commenced construction on January 10, 1986. The Tanner Companies' approach was to build the project half at a time beginning with the construction of the east side of the road.

This approach was selected in order to facilitate traffic during construction. During the periods February 10 to February 14 and March 13 to March 26, construction was stopped by rain and wet subgrade. The project was substantially completed in June 1986 and accepted by ADOT in July 1986.

PURPOSE OF PROJECT

The design of porous pavement is just emerging from the experimental phase. Although evaluations have so far been favorable in regards to service life, efforts for comparison purpose must be undertaken under various climatic and traffic conditions. The purpose of the porous pavement section was to determine the feasibility of constructing a porous pavement in an urban area and a desert environment and to evaluate its performance as a drainage system and pavement structure.

The performance aspects that will be evaluated and monitored are the porosity, stability, durability, rideability and drainage capacity. The performance of the experimental installation will be monitored for a 3 yr period.

DESIGN CHANGES

Decorative Median Pavement

By addendum, the Arizona Department of Transportation, Highways Division, incorporated decorative median pavement into the design of the porous pavement. The median pavement consisted of a colored 8 in. thick concrete slab that rested directly on the open-graded aggregate subbase.

Deletion of Porous Pavement from Southbound Lanes

During construction, the Arizona Department of Transportation determined the southbound lanes of State Route 87 should be constructed of conventional pavement between Station 105+00 and 140+00 Lt. instead of porous pavement as originally planned.

This action was taken because the porous pavement exhibited vertical deformation in excess of 5/8 in. at some locations after 3 wk of carrying detour traffic, resulting in questions about the performance of the pavement section. It was concluded that the northbound section of the roadway was sufficient to test the concept. If modifications or reconstruction of the experimental section were necessary, the southbound section of the roadway would be available for carrying traffic during rehabilitation. Placement dates for porous pavement can be found in Table 1.

TABLE 1. PLACEMENT DATES - POROUS PAVEMENT

<u>A.T.B.</u>			
5/6/86		1st Lift (All Lanes)	105+00 to 140+00
5/7/86		2nd Lift (All Lanes)	105+00 to 140+00
<u>A.C. Open Graded</u>			
5/8/86		1st Lift (Lanes 1 & 2)	105+00 to 140+00
	and	1st Lift (Lane 3)	115+00 to 140+00
5/9/86		1st Lift (Lane 3)	105+00 to 115+00
	and	2nd Lift (Lane 1)	105+00 to 140+00
6/23/86		2nd & 3rd Lifts (Lanes 2 & 3)	105+00 to 140+00

Measurements of pavement deformation can be found in Table 2.

TABLE 2. VERTICAL DEFORMATION MEASUREMENTS (IN.)
MAY 29, 1986

Station	From East Curb and Gutter (ft)							
	2.7	5.5	8.5	11.0	14.5	18.0	20.7	24.0
105	1/4	0	5/8	0	3/4	0	3/8	0
106	3/8	0	3/8	0	3/4	0	1/4	0
107	1/2	0	3/8	0	1	0	1/4	0
108	3/8	0	3/8	0	5/8	0	1/4	0
109	3/8	0	3/8	0	5/8	0	1/4	0
110	1/2	0	3/8	0	5/8	0	3/8	0
111	3/8	0	1/4	0	5/8	0	1/4	0
112	3/8	0	1/4	0	5/8	0	1/8	0
113	1/4	0	1/4	0	5/8	0	1/8	0
114	3/8	0	1/4	0	1/2	0	1/8	0
115	3/8	0	3/8	0	1/2	0	1/8	0
116	3/8	0	3/8	0	1/2	0	1/8	0
117	3/8	0	3/8	0	1/2	0	1/4	0
118	3/8	0	1/4	0	5/8	0	1/4	0
119	1/4	0	1/4	0	1/2	0	1/8	0
120	3/8	0	1/4	0	3/8	0	1/4	0
121	1/2	0	3/8	0	1/2	0	1/4	0
122	1/4	0	3/8	0	5/8	0	1/4	0
123	3/8	0	1/4	0	3/8	0	1/8	0
124	3/8	0	1/4	0	1/2	0	1/4	0
125	3/8	0	1/4	0	5/8	0	1/8	0
126	3/8	0	1/4	0	1/2	0	1/4	0
127	3/8	0	1/4	0	3/8	0	1/4	0
128	3/8	0	3/8	0	1/2	0	1/4	0
129	1/2	0	3/8	0	1/2	0	1/4	0
130	1/2	0	1/4	0	1/2	0	1/4	0
131	3/8	0	1/4	0	1/2	0	1/4	0
132	1/2	0	3/8	0	5/8	0	3/8	0
133	5/8	0	3/8	0	5/8	0	1/4	0
134	3/8	0	1/4	0	1/2	0	1/8	0
135	3/8	0	3/8	0	1/2	0	1/8	0
136	1/4	0	1/4	0	1/2	0	1/4	0
137	3/8	0	1/2	0	5/8	0	1/8	0
138	1/4	0	3/8	0	5/8	0	1/8	0
139	1/2	0	5/8	0	5/8	0	1/8	0
140	1	0	1/2	0	3/4	0	3/8	0

Relocation of Drainage Trenches

The original design called for the drainage trenches to be located beneath the sidewalk where new curb, gutter and sidewalk were constructed. However, the planned locations conflicted with irrigation lines and utilities.

To resolve these conflicts, the trenches were relocated either beneath or in front of the curb and gutter.

Specification Changes

Change Order No. 8 - Originated February 26, 1986 and changed the specified gradation limit for the open-graded aggregate subbase Class 6 as follows:

	Original Gradation % Passing	Revised Gradation % Passing
1 in.	100	100
3/4 in.	90-100	90-100
3/8 in.	30-50	25-50
No. 4	0-5	0-5
No. 8	0-2	0-2

This was done to enable the contractor to more efficiently use the portland cement concrete he had removed and was crushing.

Change Order No. 13 - Originated July 17, 1986, and changed the specified Grab Tensile Strength (wet) ASTM D1682 for the geotextile fabric from 200 lbs to 140 lb.

This was done because the material supplied was tested and found to have a grab tensile strength of 143 lb. The fabric had been placed on the basis of the manufacturer's certification. It was concluded that the fabric was sufficiently strong to remain in place with a price reduction rather than to be removed and replaced.

Change Order No. 10 - Originated May 30, 1986, permitted the contractor to pave after May 31, 1986 with open graded asphalt concrete and required the contractor to keep the open-graded asphalt concrete pavement free of traffic for 24 hours after the final lift of pavement had been completed.

Change Order No. 12 - Originated July 23, 1986, deleted the experimental porous pavement section from the southbound lanes of the project.

PROJECT CONSTRUCTION

Subgrade

The pavement subgrade was constructed by removing the existing pavement layers and recompacting the soil at the correct subgrade elevation. During subgrade construction, an abandoned irrigation ditch filled with unstable clayey material was discovered. It was excavated and replaced with satisfactory material. Care was taken within the porous pavement section to utilize soil of the same type as the subgrade for replacement material to obtain uniform permeability within the subgrade.

Portions of the project had existing curb, gutter and sidewalks while other locations had this construction performed as part of the current contract. Subgrade elevations and cross slope had to be adjusted to accommodate these factors.

Drainage Trenches

Following completion of subgrade construction, drainage trenches were excavated 2 ft wide and 4 ft deep with a backhoe. Excavated material was removed to other locations on the project with a scraper. The subgrade material on the project was capable of maintaining a vertical slope and little sluffing of the sides of the trench occurred even though time periods of 1 wk or more elapsed between the time the trenches were excavated and filled.

All trenches incorporated into the experimental project were constructed 1 ft in front of the curb and gutter except for a 1300 ft length from Sta 119+00 to Sta 132+35. At this location, the trench was constructed under the curb and gutter which was built after the drainage trench was filled. The plan to place this section of the trench under the sidewalk could not be carried out due to a conflict with a concrete pipe placed to allow the closing of an irrigation ditch.

Filter Fabric

The contractor selected Supac 4WS woven fabric for placement as a filter between the subgrade soil and open-graded subbase material. Fabric was placed according to specifications on the subgrade and within the drainage trenches. The fabric was unrolled on the subgrade and placed in the drainage trench by hand labor. The material was held in place with shiners driven into the subgrade. Fabric for covering the subgrade was unrolled and lapped over the adjacent fabric a minimum of 2 ft in a shingle pattern. Figure 3 and 4 show the fabric on the subgrade and the fabric lined drainage trench prior to open-graded aggregate placement.

Grab tensile strength tests performed by both Western Technologies and ADOT found the fabric to be below the minimum specified strength of 200 lb. Most of the fabric was in place at the time this was discovered and the material was left in place with a reduction in price. There are no particular standards by which the required strength for a geotextile can be determined. The primary purpose of the fabric is to serve as a separator between the subgrade and base course. The grab tensile strength is primarily required to allow placement without damaging the fabric. Since the subgrade is relatively flat, the grab tensile strength was sufficient for this purpose.

FIGURE 3 FILTER FABRIC IN PLACE

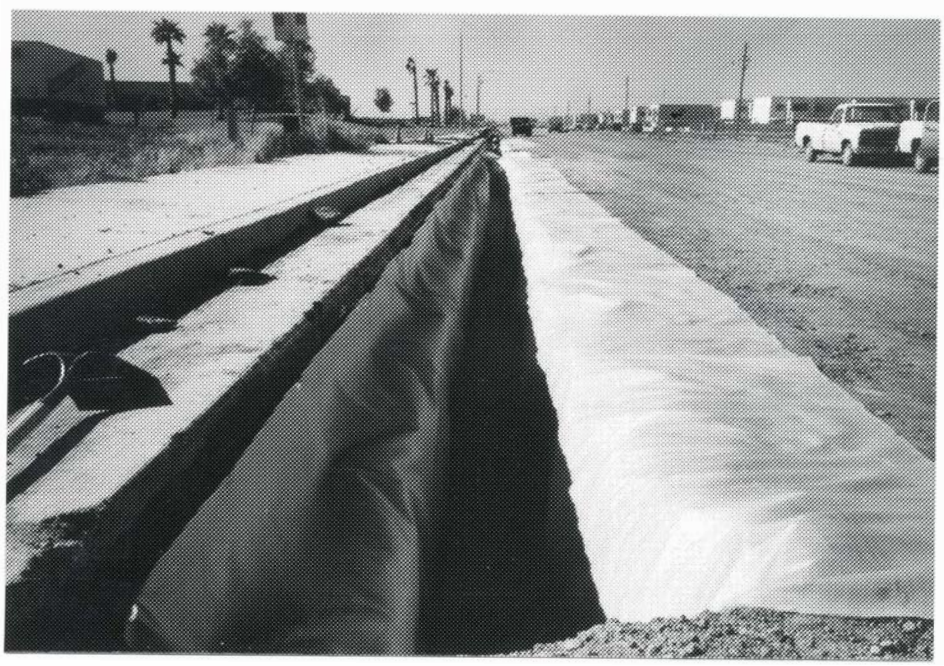

FIGURE 4 DRAINAGE TRENCH WITH FILTER FABRIC IN PLACE

Open-graded Aggregate Subbase

Specifications (see page 7) for the open-graded aggregate subbase were written on the basis of commercially produced river aggregate available within the project vicinity. However, the contractor elected to crush portland cement concrete pavement removed during construction for use as subbase material. All specifications were met except the amount of material passing the 3/8 in. sieve which was less than 5 percent below the minimum of 30 required by the specifications. This minor deviation in gradation was considered to be acceptable because the 3/8 in. sieve requirement was primarily for uniformity rather than quality of the aggregate. The specification change was approved under the contractor's cost incentive proposal. The use of the portland cement concrete pavement was considered to be an excellent application of recycling.

The open-graded subbase material was placed in the drainage trench and compacted in two lifts of 2 ft each with vibra-plate Wacker hand compactors. The placement of the subbase was accomplished shortly after placement of the underlying fabric to avoid excessive exposure of the fabric to ultraviolet rays. Specifications required that no traffic be permitted on the filter fabric until a layer of subbase material had been placed.

The contractor attempted to deposit aggregate and move it ahead with loaders or motor graders. Difficulty was encountered as hauling units would become stuck in the open-graded aggregate and often would tear the underlying fabric while trying to get free. As a result, trucks were allowed to travel on the fabric while unloading subbase material with no apparent harm to the fabric. Traffic, however, was restricted only to that necessary for depositing aggregate. Figure 5 and 6 show open-graded aggregate being placed.

The open-graded aggregate subbase would not support 1-x 2-x 10-in. grade stakes. Consequently, it became necessary to check grades of the subbase by stretching a stringline from the curb to an equivalent height above the subgrade and measuring down to the top of subbase elevation. This procedure left no permanent grade stakes and required repeated stringlining and measuring. Field records indicate that the subbase was placed in an 8 in. compacted layer to the proper elevation. The thickness of the aggregate treated base and aggregate subbase given in Table 8 indicate that the subbase may not have been compacted to the proper elevation. Also elevations taken on the pavement surface indicate variations in the cross slope. Compaction was by 8 ton galion steel drum rollers using two coverages while in the static mode.

FIGURE 5 PLACING AND LEVELING OPEN-GRADED AGGREGATE SUBBASE

FIGURE 6 HAULING AND PLACING OPEN-GRADED AGGREGATE SUBBASE

Asphalt Treated Base

The asphalt treated base utilized the same aggregate specifications as the subbase but was stabilized with an average of 2.2 percent of AC-40 asphalt cement. The contractor, however, used a crushed river aggregate produced in the proximity of his asphalt mixing plant's location rather than the recycled portland cement concrete pavement used for subbase material. The base course was mixed and placed in a heated condition. Temperatures of the asphalt treated base at the time of laydown ranged from 184 F to 240 F with a mean temperature slightly above 200 F.

Specifications required the 6 in. thick asphalt treated base be placed in two lifts. The top lift required placement with a conventional self-propelled asphalt paver. A Blaw-Knox Model DF 220 was used for the operation. The first lift did not have this requirement as it was anticipated that construction of the base course on the open-graded subbase would not be feasible with a paver.

The contractor elected to place the first lift of asphalt treated base with motor graders and compact with steel drum rollers operated in a static mode until no roller marks remained. However, delivery of material with bottom dump trucks was difficult on the open-graded aggregate subbase. The trucks loosened the compacted aggregate and had to be pushed through the length of travel on the subbase by motor graders. Although the trucks did not become stuck when being pushed, they did loosen and rut the compacted subbase as they passed over it. The disruption of the subbase resulted in variable thicknesses of the first lift of asphalt treated base. Figures 7, 8 and 9 are photographs taken during construction of the first lift of asphalt treated base.

FIGURE 7 MOTOR GRADER ASSISTING TRUCK OVER
OPEN-GRADED AGGREGATE BASE COURSE

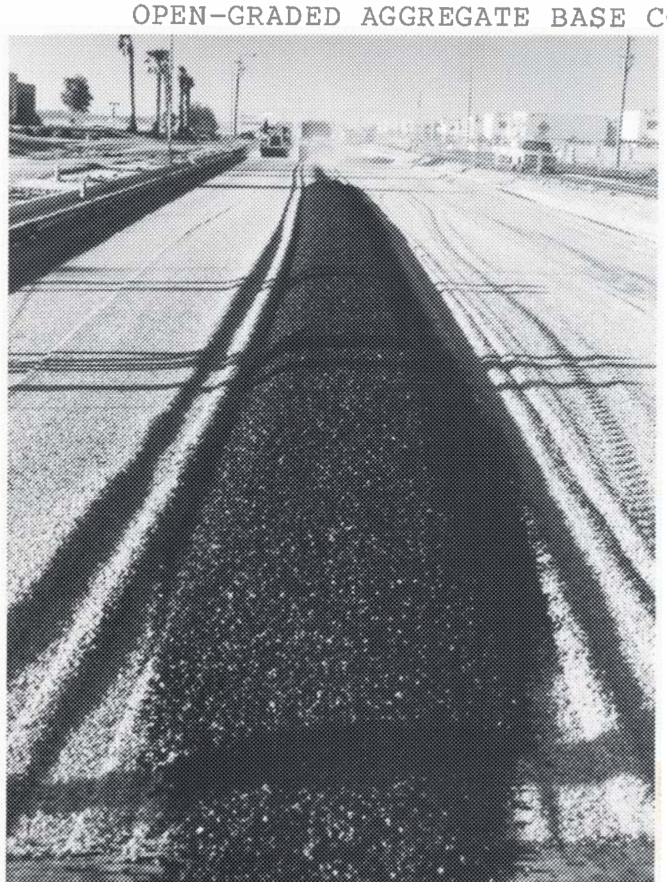

FIGURE 8 ASPHALT TREATED BASE COURSE SPREAD

FIGURE 9 MOTOR GRADER PLACING FIRST LIFT OF OPEN-GRADED ASPHALT TREATED BASE COURSE

The second lift of asphalt treated base was placed by delivering material into a windrow with bottom dump trucks and placing it by use of a pickup machine and asphalt paver. Figure 10 is a photograph of construction of the second lift of asphalt treated base. Plant and placement temperatures for the second lift of asphalt treated base are shown in Tables 3 and 4. The survey crew painted grades on the first lift and the contractor placed the second lift according to these grades.

This operation was satisfactory except that the paver occasionally broke through the first lift of asphalt treated base at locations that were thin from displacement of the subbase. In those cases, the paver had to be assisted with a motor grader. This happened

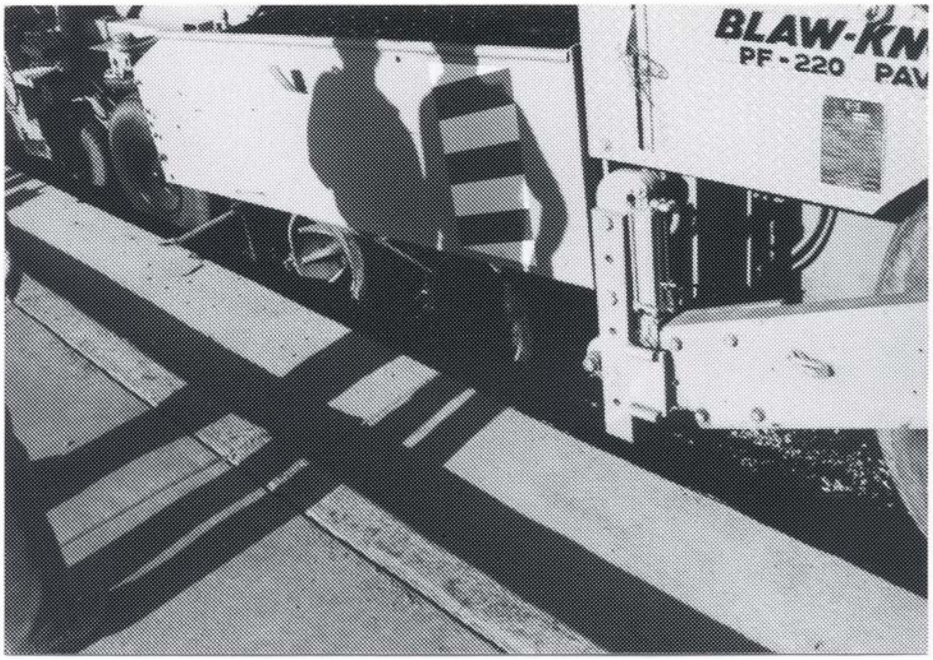

FIGURE 10 PAVER PLACING SECOND LIFT OF OPEN-GRADED SURFACE COURSE NEXT TO CURB AND GUTTER

TABLE 3. PLANT AND PLACEMENT TEMPERATURES
ASPHALT TREATED BASE
MAY 6, 1986

Time	Hot Plant Temps (F)	Time	Ongrade Temps (F)
0555-0615	230	0711	205
0700-0710	225	0804	210
0815-0825	230	0821	208
0900-0910	235	0829	205
1000-1010	225	0908	211
1055-1105	225	0924	208
1205-1220	240	0944	200
1310-1315	230	1000	205
1415-1425	235	1030	202
		1048	205
		1101	200
		1209	202
		1211	185
		1221	200
		1225	199
		1232	184
		1315	200
		1320	202
		1323	205
		1356	200
		1404	198
		1411	205
		1422	202
		1450	207
		1459	203
		1515	200
		1526	200

TABLE 4. PLANT AND PLACEMENT TEMPERATURES
ASPHALT TREATED BASE
MAY 7, 1986

Time	Hot Plant Temps (F)	Time	Ongrade Temps (F)
0550-0605	235	0639	250
0700-0710	235	0702	235
0810-0820	230	0659	240
0920-0930	240	0709	210
1000-1005	235	0730	199
1210-1220	225	0741	200
1310-1315	220	0750	205
1400-1410	235	0755	209
1500-1505	225	0821	200
		0915	220
		0927	200
		1008	205
		1011	210
		1025	203
		1027	205
		1105	208
		1123	200
		1154	204
		1157	210
		1201	201
		1229	205
		1234	201
		1236	200
		1246	200
		1259	200
		1410	201
		1412	201
		1416	212
		1419	195
		1429	205
		1501	219
		1518	223
		1545	208
		1557	210
		1610	198

at three or four locations which were not recorded. It is felt that the use of a track type paver would not have eliminated this problem due to weight of the pick up machine on the front of the paver. Compaction was achieved with steel drum rollers operated in a static mode until no roller marks remained.

Open-graded Asphalt Concrete Pavement

The open-graded asphalt concrete was placed in two 3 in. thick lifts and compacted with Dyna Pach CC50A steel wheel rollers operated in a static mode until no roller marks remained. Plant and placement temperatures can be found in Tables 5 and 6. The compacted pavement retained a tender and a somewhat unstable surface appearance for a day or two after placement. Ambient daytime air temperatures in the vicinity of 100 F contributed to this condition.

Porous Pavement Performance and Analysis

On May 10, 1986, traffic was moved onto the northbound lanes of the street where the porous pavement had been placed. One lane of traffic was provided in each direction. It was noted by the project inspection staff on May 28, 1986, that vertical deformation of the pavement surface had occurred and on May 29, 1986, studies of the pavement surface condition commenced. Surface deformations were measured from a straightedge placed on the pavement. Vertical displacements from the straight edge varied from 1/8 in. to 1 in. The average depth was 3/8 in. with 139 of the 144 readings taken being 5/8 in. or less.

TABLE 5. PLANT AND PLACEMENT TEMPERATURES
OPEN-GRADED ASPHALT CONCRETE
MAY 8, 1986

Time	Hot Plant Temps (F)	Time	Ongrade Temps (F)
0545	240	0639	208
0655	230	0654	202
0745	230	0659	206
0849	220	0706	204
0859	220	0731	200
0902	230	0740	210
0906	225	0748	204
0910	230	0808	211
0922	225	0832	210
0929	225	0841	206
0932	225	0846	203
0936	225	0849	203
0941	225	0851	201
0951	230	0909	204
0957	210	0930	205
1006	225	0958	203
1010	225	1005	206
1013	230	1013	200
1016	225	1026	201
1018	235	1041	200
1022	230	1045	200
1027	230	1058	199
1030	225	1100	201
1033	225	1106	201
1035	225	1120	200
1038	215	1220	201
1129	215	1228	211
1133	225	1232	210
1138	225	1236	212
1141	225	1242	210
1145	235	1303	216
1149	235	1308	202
1152	230		
1155	230		
1258	215		
1301	230		
1303	225		
1309	235		

TABLE 6. PLANT AND PLACEMENT TEMPERATURES
OPEN-GRADED ASPHALT CONCRETE
MAY 9, 1986

Time	Hot Plant Temps (F)	Time	Ongrade Temps (F)
0550	230	0633	206
0555	215	0649	204
0558	220	0703	179
0601	220	0731	195
0603	220	0735	221
0606	220	0738	203
0608	215	0742	206
0614	215	0745	200
0617	220	0800	212
0656	215	0838	211
0748	225	0842	210
0755	220	0856	196
0805	230	0908	204
0830	230	0917	198
0904	240	0936	216
0908	240	0943	210
0910	240	0952	212
0918	240	1145	202
0920	235	1157	200
0925	230	1218	200
0927	235	1225	203
0947	235	1237	200
0950	235	1251	202
1048	225	1312	202
1050	230		
1054	240		
1056	240		
1100	240		
1102	240		
1109	230		
1124	230		
1140	235		
1142	235		
1138	225		
1149	235		
1153	225		
1155	235		
1157	230		

Nuclear densities and cores were taken along wheel paths and between lanes in an effort to determine whether compaction of the pavement had occurred while under traffic. These data can be found in Table 7. Average unit weights within the wheel tracks were slightly higher than between lanes but not by a significant amount and not nearly the amount that would account for the deformations noted. It was further noted that the deformation was not confined to the wheel paths but appeared as a wide depression generally extending from wheel track to wheel track. The condition of plastic flow where material is pushed down in the wheel tracks and up between them was not observed. Figure 11 is a photograph of the deformation measured at Sta 107.

It was decided to examine the deformation by opening a trench across a portion of the pavement to observe movements in the separate pavement layers. The west half of the pavement at Sta 107 was selected to study. This was one of the two locations where 1 in. of deformation had been measured.

A trench approximately 2 ft wide was excavated down to the subgrade by sawing both sides through the asphalt concrete pavement and removing the material from this trench with a backhoe. Figure 12 is a photograph of the pavement layer exposed by this trench. Observation of the pavement layers indicated the top course of asphalt concrete to be of uniform thickness although displaced vertically along both top and bottom surfaces. As a result of intermingling of the asphalt treated base and the aggregate subbase, it was not possible to observe where the vertical deformation had occurred. However, it was concluded that

TABLE 7. UNIT WEIGHT OF POROUS PAVEMENT

Sta	Lane*	Location	Unit Weight, pcf Nuclear Gage	4" Dia Cores
105	2	A	119.6	
105	2	B	118.5	
110	1	A	117.6	
110	1	B	116.4	
115	2	A	118.3	
115	2	B	118.7	
120	1	A	118.9	117.1
120	1	B	116.4	113.3
125	2	A	118.5	
125	2	B	119.0	
130	1	A	118.2	116.6
130	1	B	114.8	113.8
135	2	A	119.0	
135	2	B	119.5	
140	1	A	119.4	
140	1	B	117.4	
	Mean, Location A		118.7	116.8
	Mean, Location B		117.6	113.6

* Lane 1 was adjacent to the east curb and carried northbound traffic during construction of southbound lanes.

Lane 2 was the next lane to the west and carried southbound traffic during this same period.

** Location A was within the wheel track depression.

Location B was between lanes adjacent to the wheel track depression.

FIGURE 11 PAVEMENT DEFORMATION AT STATION 107 RT

FIGURE 12 EXPOSED PAVEMENT LAYERS AT STATION 107 RT

as the hauling units deposited asphalt treated base, decompaction of the untreated subbase occurred thus causing an increase in the volume of the untreated subbase. The volume of the untreated subbase decreased by recompaction of this course during subsequent construction and traffic. This change in volume of the untreated subbase is the most probable cause for the deformation of the pavement structure.

It was noted from the excavated trench that the pavement section was deficient in thickness at locations furthest from the curb and gutter. This was found to be the result of difficulty in maintaining the correct cross slope on the pavement surface. Because the center median had not been built and the cross slope was variable, it was difficult for the contractor to maintain proper elevations during placement of the asphalt concrete surface course.

Pavement cores were taken on June 19, 1986, at 14 locations and the asphalt treated base and aggregate subbase were removed to allow measurement of the pavement layers. Pavement layer thicknesses are shown in Table 8. An additional lift of open-graded asphalt concrete was subsequently placed on June 27, 1986, to match the elevation of the concrete median after its construction. This lift varied in thickness from 1 to 3 inches.

Due to the amount of deformation in the northbound lanes while carrying detour traffic, ADOT requested that alternatives be developed for consideration prior to construction of the southbound lanes. The final recommendation developed by Western Technologies was to pick up 6 in. of the 8 in. of open-graded aggregate subbase and to replace this depth with asphalt treated base placed with a

TABLE 8. PAVEMENT LAYER THICKNESS MEASUREMENTS
JUNE 19, 1986

Hole No.	Station	Location	AC Open-Graded Thickness (in.)	A.T.B. and Agg. Subbase Thickness (in.)
1	107+00	7' 7" from C & G Lip	6.25	10.75
2	107+00	4'11" from C & G Lip	6.50	7.50
3	112+00	22' 4" right C.L.	5.50	13.50
4	112+00	25' 4" right C.L.	5.50	13.50
5	117+00	4' 8" from C & G Lip	6.12	12.88
6	117+00	1' 9" from C & G Lip	6.25	*
7	122+00	22' 5" right C.L.	5.00	13.50
8	122+00	19' 4" right C.L.	4.75	13.75
9	127+00	7' 8" from C & G Lip	7.25	12.75
10	127+00	4'11" from C & G Lip	7.75	12.25
11	132+00	22' 5" right C.L.	5.00	15.00
12	132+00	25' 0" right C.L.	5.00	15.00
13	137+00	5' 1" from C & G Lip	7.00	13.00
14	137+00	2' 2" from C & G Lip	7.25	*

* Unable to get depth due to hole located over trench area.
C.L. Centerline of Typical Roadway Section

paver with a pick-up machine. It was felt that improved compaction could be accomplished and retained with the stabilized material. The 2 in. subbase was to be left in place to prevent damage to the filter fabric and was felt to not preclude the use of the paver and hauling units for placement of the asphalt treated base. Use of coarser aggregate and portland cement in the open-graded asphalt concrete in an effort to produce a stiffer, more stable mixture were also recommended.

However, ADOT officials decided to eliminate the use of porous pavement on the southbound lane of the roadway and confine the experiment to the northbound lanes. The majority of the open-graded aggregate subbase that was in place was removed and a sufficient depth of dense-graded aggregate base was substituted to allow construction of a dense-graded pavement structure.

The porous pavement structure's performance was further studied in a special experiment. A 178 ft length of the porous pavement (curb and middle lane) was subjected to the 24 hr design storm runoff by placing soaker hoses in a line 22.5 ft from the front face of the east curb and gutter between Sta 136+32 and Sta 138+10. This was connected to an adjacent fire hydrant and flow was set to deliver the equivalent of a 2.18 in. rainfall over a 24 hr period. Soaking was started at 12:45 pm on June 13, 1986.

At the start of the soaking period, it was discovered that the City of Chandler water meter was not working. Flow was allowed to continue; however, it was not until 2:23 pm that a water meter was placed in line to allow adjustment of the flow. Flow was adjusted such that 12,060 gal of water was allowed to flow into the pavement by 12:45 pm on June 14, 1986. This would be a rate of 539 gal per hr for the 22+ hr since the meter was in place. If the 1.6 hr that was not metered was at the same rate, approximately 13,000 gal of water would have entered the pavement during this 24 hr period. The design storm of 2.18 would have deposited 12,000 gal of water on a 50 ft half roadway width for 178 ft length of project.

At 7:20 am on June 14, 1986, the contractor started traffic loading this section and a length of road beyond the section by driving a loaded 4,000 gal water truck ahead and back for an 8 hr period. The truck had a single front axle and a tandem rear axle. A total of 804 passages of the truck were recorded with a traffic counter.

The depth below a 10 ft straightedge was measured in both wheel tracks in the center lane at 1 hr intervals. These readings were taken at three locations within the section receiving water and one location approximately 100 ft beyond this section. The results are summarized in Table 9. Traffic loading was continued for another 8 hr on the following day (June 15, 1986) with insignificant further deformation.

Prior to the placement of the supplemental asphalt concrete to bring the porous pavement to final grade, the effect of further rolling of the surface to remove existing deformation was studied. Repeated passes with a pneumatic roller provided no further densification or leveling of the roadway section. A steel drum roller was operated in the static mode and also was ineffective in improving the roadway section.

TABLE 9. SUMMARY OF DEFORMATION DEPTHS FOR CENTER LANE
SURVEY DATE JUNE 14, 1986

	Deformation Depth, in.		
Location	Start of Loading	End of Loading	Net Change
Sta 136+50 West Wheelpath	1/8	3/8	1/4
Sta 136+50 East Wheelpath	5/8	7/8	1/4
Sta 137+00 West Wheelpath	1/8	1/4	1/8
Sta 137+00 East Wheelpath	7/8	1	1/8
Sta 137+50 West Wheelpath	1/4	3/8	1/8
Sta 137+50 East Wheelpath	5/8	1	3/8
Sta 139+00 West Wheelpath	1/8	1/2	3/8
Sta 139+00 East Wheelpath	3/4	1	1/4
AVERAGE	7/16	5/8	1/4

When operated in the vibratory mode, however, the steel roller compressed the high points within the roadway section and produced a more even surface, although at a slightly lower elevation. Three or four coverages with the vibratory steel roller were found to be the most effective and the entire porous pavement section was rolled in that manner.

Following completion of the concrete median surfacing, the porous pavement was further compacted with the vibratory steel roller as previously stated and received a final course of open-graded asphalt concrete. At the time of completion of the porous pavement, weather conditions were maximum summer conditions with daily high temperatures of 108 F to 115 F reached.

The porous pavement displayed a tenderness that caused concern for opening the road to traffic. In an effort to lower the pavement temperature, the roadway was sprayed by use of a water truck with lime water. Lime was added to the water at a rate of 2 bags per 1,000 gal of water. The lime water was applied at a rate of approximately 1 gal per sq yd. The application of lime water left a gray residue on the pavement surface and resulted in a reduction in the pavement temperature from near 160 F to 145 F. A second application of the lime water was carried out several days later and the road was opened to traffic shortly thereafter.

COMPARATIVE CONSTRUCTION COSTS

Costs of construction for the conventional and the porous pavement were developed to compare the costs on a unit basis. These costs were computed from the unit prices used by the successful bidder and are shown in Table 10 and 11.

TABLE 10. COST ANALYSIS FOR CONVENTIONAL PAVEMENT
Estimate Based on 3500 ft of
Typical Three-Lane Suburban Highway

Item	Unit	Rate	Amount
Aggregate Base	C.Y.	$ 12.00	$ 36,296.00
Asphalt Concrete (3/4")	Ton	18.00	76,072.00
Tack Coat	Ton	250.00	1,260.00
Asphalt Concrete (1/2")	Ton	22.00	30,992.00
Scuppers	Each	600.00	4,200.00
Curb & Gutter	L. Ft.	6.00	21,000.00
Asphalt Cement for 3/4" AC	Ton	200.00	47,331.00
Asphalt Cement for 1/2" AC	Ton	200.00	15,781.00
Apply Tack Coat	Hour	125.00	2,379.00
Retention Basin Excavation	C.Y.	6.00	11,667.00*
TOTAL			$246,978.00

3500' x 34.5' = 120,750 sq ft
246,978/120,750 = $2.05/sq ft

*Does not include right-of-way necessary for the retention basins.

The rates used in this cost analysis are the prices bid by The Tanner Companies for the construction of conventional pavement for project F045-1(4), Jct. I-10/Mesa Hwy.

TABLE 11. COST ANALYSIS FOR POROUS PAVEMENT
Estimate Based on 3500 ft of
Typical Three-Lane Suburban Highway

Item	Unit	Rate	Amount
Drainage Trench Excavation	C.Y.	$ 6.00	$ 6,222.00
Filter Fabric	S.Y.	1.00	22,306.00
Coarse Aggregate 6	C.Y.	19.00	88,667.00
Asphalt Treated Base	Ton	19.00	54,488.00
Asphalt Cement for ATB	Ton	200.00	12,619.00
Curb & Gutter	L.Ft.	6.00	21,000.00
Porous Pavement	Ton	19.00	68,827.00
Anti-Strip for Porous Pavement	Lb	1.00	3,680.00
Asphalt Cement for Porous Pavement	Ton	200.00	37,674.00
	Total		$315,483.00

3,500 ft x 34.5 ft = 120,750 sq ft
315,483/120,750 = $2.61/sq ft

The rates used in this cost analysis are the prices bid by The Tanner Companies for the construction of the porous pavement for project FO45-1-(4), Jct. I-10/Mesa Hwy.

COST COMPARISON

A comparison of the costs for the construction of porous pavement vs. conventional pavement indicated that the porous pavement was about 27 percent more expensive to construct. However, this comparison did not take into account the right-of-way that was necessary to provide the land for the retention basins that were necessary to drain conventional pavement. The cost of land in Chandler area is approximately $5.00 per sq ft. This value was obtained from a local real estate firm. An area of approximately 20,000 sq ft was required to construct the retention basins for the storage of runoff from 3,500 ln ft of three-lane highway. This would result in an increase of slightly more than $0.80 per sq ft for the conventional pavement where surface drainage had to be provided. This additional cost would make the cost of both pavements comparable.

LABORATORY ANALYSES OF POROUS PAVEMENT

Several tests were performed on cores taken from the open-graded asphalt concrete. Testing was performed within the Phoenix central laboratory of Western Technologies Inc.

Unit Weight

The unit weights of cores were measured by computing the core volume from measurements of the core dimensions and dividing this into the core's measured weight in air. Fourteen 6-in. dia cores were taken from the first two lifts of the asphalt concrete prior to the placement of the final lift. Results of unit weight tests are found in Table 12. Six 4-in. dia cores of the entire asphalt concrete thickness were tested in a similar manner. These cores, however, were sawed into two parts to allow testing of the upper and lower portions separately. Unit weight test results appear in Table 13.

Permeability

One of the 6-in. dia cores was tested in a constant head permeability test. This core was measured as 5 in. thick and had been placed in two lifts. The unit weight was measured at 122.8 pcf. Several tests were performed until the flow rate stabilized. Seven tests were performed and the mean flow rate calculated. The resulting coefficient of permeability was 154 ft per day. This compares favorably with the value of 216 ft per day measured for the preliminary mix design sample constructed in two lifts. The design requirement for a 10-yr, 10-min storm of 2.18 in. was 26 ft per day.

Resilient Modulus

The six 4-in. dia cores were tested for resilient modulus at 77F. The cores were cut to produce specimens each approximately 2 1/2 in. tall. The six specimen tops had resilient moduli ranging from 256,000 to 384,000 psi with a mean value of 337,000 psi. The bottom portion of the specimens yielded resilient moduli ranging from 196,000 to 332,000 psi with a mean value of 276,000 psi. Individual data are shown in Table 13.

TABLE 12. TEST RESULTS FOR UNIT WEIGHT
DATE TESTED JUNE 23, 1986

Core No.	Station	Location	Weight (pcf)
1	107+00	7'7" from C & G Lip	119.7
2	107+00	4'11" from C & G Lip	119.1
3	112+00	22'4" right C.L.	117.7
4	112+00	25'4" right C.L.	118.6
5	117+00	4'8" from C & G Lip	121.0
6	117+00	1'9" from C & G Lip	119.0
7	122+00	22'5" right C.L.	122.1
8	122+00	19'4" right C.L.	118.3
9	127+00	7'8" from C & G Lip	120.0
10	127+00	4'11" from C & G Lip	118.5
11	132+00	22'5" right C.L.	122.8
12	132+00	25'0" right C.L.	122.3
13	137+00	5'1" from C & G Lip	118.8
14	137+00	2'2" from C & G Lip	117.8
		AVERAGE	119.7

C.L. Centerline of Typical Roadway Section

TABLE 13. TEST DATA FOR OPEN-GRADED ASPHALT CONCRETE CORES
DATE TESTED OCTOBER 16, 1986

Station	Pavement Lift	Unit Weight pcf	*Resilient Modulus 100,000 psi
110	Top	117.9	3.47
115	Top	116.1	3.39
120	Top	112.4	2.56
125	Top	114.4	3.84
130	Top	117.4	3.49
135	Top	116.1	3.37
110	Bottom	115.9	3.32
115	Bottom	112.2	2.55
120	Bottom	116.1	2.47
125	Bottom	116.1	3.17
130	Bottom	119.3	3.06
135	Bottom	112.7	1.96
Mean	Top	115.7	3.37
Mean	Bottom	115.4	2.76

*Resilient modulus tested at 77F.

Mixture Properties

The 4-in. dia cores were tested for asphalt content, aggregate gradation and absolute viscosity of recovered asphalt following unit weight and resilient modulus testing. Asphalt contents and viscosities and aggregate gradations are shown in Table 13.

TABLE 13. MIX PROPERTIES FOR OPEN GRADED ASPHALT CONCRETE CORES

Sta	Pave Lift	Asphalt Content %	Asphalt Viscosity *	Percent by Weight Passing Sieve 3/8 in.	No. 4	No. 8	No. 50
110	Top	5.46		100	36	14	5
115	Top	5.39		100	36	14	5
120	Top	6.12	13,200	100	39	13	4
125	Top	5.92	14,000	100	37	14	4
130	Top	5.90	5,600	100	39	15	5
135	Top	5.78		100	36	14	3
110	Bottom	5.90	7,700	100	35	13	4
115	Bottom	6.19	10,700	100	34	12	4
120	Bottom	5.37		100	35	14	5
125	Bottom	6.16		100	35	13	4
130	Bottom	6.06		100	37	16	5
135	Bottom	6.19	14,100	100	37	12	4
Mean	Top	5.76	10,900	100	37	14	5
Mean	Bottom	5.98	10,900	100	36	13	4

* Measured in Poises

EXPERIMENTAL PROJECT MONITORING

The experimental features of the project are to be monitored for a 3 yr period following the completion of construction. A continuous recording rain gage is in place on the project just beyond the west right-of-way line at Sta 139+10. It will provide measurement of all rainfall and allow for an estimate of rainfall intensity.

Soil moisture monitoring devices are in place at two locations within the porous pavement and three locations in the control pavement. Six positions within the subgrade can be monitored at each location. Moisture monitoring locations are Sta 97+40, 138+00 and 143+25 in the northbound lanes and Sta 108+00 and 138+00 in the southbound lanes. Devices are placed at depths of 1 and 3 ft below top of subgrade at distances of approximately 5, 10 and 20 ft from the front face of the curb and gutter.

A well point was placed within the drainage trench at one location on the project. This location is in the east concrete gutter at Sta 130+00. The water depth in the trench can be monitored at this location when water has accumulated to a measurable depth. A device that will record the highest water level reached in the trench was developed and installed near the middle of February, 1987.

Pavement deformations will be monitored during this period by measuring the vertical depth from a straightedge. Actual vertical movements will be measured from elevations measured on P-K shiners set into the pavement and graded at the time of completion of the surface course prior to opening to traffic.

P.K. shiners were set and graded on June 25, 1986. These are located at Sta 106, every 500 ft from Sta 110 to Sta 135 and at Sta 139. The reference points are set at 1, 6, 11, 16.5, 22, 28 and 34 ft from the face of the curb and gutter and at locations intermediate between each of these. Consequently, there are 13 locations at each referenced station. Initial readings for deformation were taken from a straightedge on July 7, 1986 in the control section at Sta 102, 104, 141 and 143 and within the porous pavement section at 500 ft intervals from Sta 108 to Sta 138.

CONCLUSIONS

Conclusions and recommendations resulting from the experimental work carried out to date will be reserved for the final project report. However, some of the events that have occurred and preliminary conclusions reached are pointed out at this time.

It was concluded that the pavement structure would be more easily constructed and of a better quality if asphalt treated base had been used in lieu of the open-graded aggregate subbase. The aggregate subbase was difficult to construct and is suspected to be the primary cause of vertical deformation of the pavement surface which created considerable concern during the project construction.

The porous pavement design used for this project can be readily and economically constructed. Conventional highway construction equipment and procedures are feasible for this type of construction.

Unit weights, air voids and permeabilities measured in the laboratory from mix design specimens were reasonably achieved in actual construction. The drainage performance of the pavement anticipated from the preliminary laboratory testing appears to have been achieved in the project construction.

Further investigation of drainage of storm runoff in conditions different than encountered for this project are recommended.

APPENDIX A

TEST RESULTS

Subgrade Acceptance

Station	% by Weight Passing No. 200 Sieve	Liquid Limit	Plasticity Index
106 Rt	34.7	32	14
113 Rt	50.8	28	15
120 Rt	48.0	28	15
127 Rt	44.0	21	1

Subgrade Density

Station	Field Density (pcf)	% Compaction
115 + 50 Rt	115.9	97.4

Standard Density Values:	Maximum Density	119.0 pcf
	Optimum Moisture Content	13.0%

Open-graded Aggregate Subbase

Station	Percent by Weight Passing Sieve				
	1"	3/4"	3/8"	No. 4	No. 8
106 + 00	100	91	31	3.8	1.5
110 + 00	100	100	38	4.4	0.8
111 + 00	100	100	35	3.0	0.7
112 + 00	100	92	33	3.4	1.8
115 + 00	100	100	37	4.3	1.3
115 + 00	100	94	31	1.4	0.8
115 + 25	100	100	47	4.7	1.6
123 + 00	100	94	29	2.9	0.9
127 + 00	100	93	32	1.9	0.9
127 + 50	100	90	25	3.6	2.0
130 + 00	100	92	32	3.0	1.3
130 + 50	100	100	41	4.9	0.8
130 + 75	100	93	30	3.0	1.0
ADOT	100	92	30	3.0	2.0
ADOT	100	100	46	7.0	0.0
ADOT	100	100	35	4.0	0.4
ADOT	100	100	45	5.0	0.6
ADOT	100	100	46	3.5	0.5
ADOT	100	100	46	4.0	1.4
ADOT	100	100	51	5.0	1.0
Average	100	97	37	3.8	1.1
Specs	100	95/ 100	25/ 50	0/5	0/2

Asphalt Treated Base

Station	Percent by Weight Passing Sieve						% Asphalt
	1"	3/4"	1/2"	3/8"	No. 4	No. 8	
115 + 00	100	97	72	42	8.0	3.5	2.3
124 + 50	100	95	62	32	5.7	1.9	2.0
128 + 00	100	91	70	41	8.3	3.9	2.2
133 + 00	100	91	66	38	7.5	3.6	2.4
Average	100	94	68	38	7.4	3.2	2.2
Specs	100	90/ 100		30/ 50	0/5	0/2	1.8

Open-graded Asphalt Concrete

Date Sampled	Percent by Weight Passing Sieve						% Asphalt
	1/2"	3/8"	No. 4	No. 8	No. 40	No. 200	
5-8	100	100	32	10	8	1.4	5.4
5-9	100	99	26	8	7	1.4	5.7
5-9	100	100	28	9	7	1.2	4.8
5-9	100	100	31	10	8	1.5	5.5
6-23	100	100	32	11	8	1.6	5.3
6-23	100	100	32	11	8	1.6	5.1
6-23	100	100	33	11	9	1.8	4.9
Average	100	100	31	10	8	1.5	5.2
Specs	100	82/ 100	19/ 46	0/28	0/16	0/5	5.3

Grab Tensile Strength for Fabric

Test	Lengthwise		Widthwise	
No.	Load (lbs)	% Elongation	Load (lbs)	% Elongation
1	128	20	142	25
2	123	19	172	33
3	129	21	153	30
4	131	22	163	28
5	138	22	147	28
Average	130	21	156	29

Average Both Direction	Load (lbs)	143
	% Elongation	25

Designation: D 4123 - 82

Standard Method of
INDIRECT TENSION TEST FOR RESILIENT MODULUS OF BITUMINOUS MIXTURES[1]

This standard is issued under the fixed designation D 4123; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers procedures for preparing and testing laboratory-fabricated or field-recovered cores of bituminous mixtures to determine resilient modulus values using the repeated-load indirect tension test. The procedure described covers a range of temperatures, loads, loading frequencies, and load durations. The recommended test series consists of testing at 41, 77 (Note 1), and 104°F (5, 25 (Note 1), and 40°C) at one or more loading frequencies, for example, at 0.33, 0.5, and 1.0 Hz for each temperature. This recommended series will result in nine test values for one specimen which can be used to evaluate the overall resilient behavior of the mixture.

NOTE 1—Ambient laboratory temperature may be substituted as appropriate.

2. Applicable Documents

2.1 *ASTM Standards:*

D 1559 Test Method for Resistance to Plastic Flow of Bituminous Mixture Using Marshall Apparatus[2]

D 1561 Method for Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor[2]

D 3387 Test for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)[2]

D 3496 Method for Preparation of Bituminous Mixture Specimens for Dynamic Modulus Testing[2]

D 3515 Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures[2]

3. Summary of Method

3.1 The repeated-load indirect tension test for determining resilient modulus of bituminous mixtures is conducted by applying compressive loads with a haversine or other suitable waveform. The load is applied vertically in the vertical diametral plane of a cylindrical specimen of asphalt concrete (Fig. 1). The resulting horizontal deformation of the specimen is measured and, with an assumed Poisson's ratio, is used to calculate a resilient modulus. A resilient Poisson's ratio can also be calculated using the measured recoverable vertical and horizontal deformations.

3.2 Interpretation of the deformation data (Fig. 2) has resulted in two resilient modulus values being used. The instantaneous resilient modulus is calculated using the recoverable deformation that occurs instantaneously during the unloading portion of one cycle. The total resilient modulus is calculated using the total recoverable deformation which includes both the instantaneous recoverable and the time-dependent continuing recoverable deformation during the unloading and rest-period portion of one cycle.

4. Significance and Use

4.1 The values of resilient modulus can be used to evaluate the relative quality of materials as well as to generate input for pavement design or pavement evaluation and analysis. The test can be used to study effects of temperature, loading rate, rest periods, etc. Since the proce-

[1] This method is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.20 on Mechanical Tests of Bituminous Mixes.

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[2] *Annual Book of ASTM Standards*, Vol 04.03.

dure is nondestructive, tests can be repeated on a specimen to evaluate conditioning as with temperature or moisture. The method is not intended for use in specifications.

5. Apparatus

5.1 *Testing Machine*—The testing machine should have the capability of applying a load pulse over a range of frequencies, load durations, and load levels.

NOTE 2—An electrohydraulic testing machine with a function generator capable of producing the desired wave form has been shown to be suitable for use in repeated-load indirect tension testing. Other commercially available or laboratory constructed testing machines such as those using pneumatic repeated loading can also be used. However, these latter machines may not have the load capability to handle larger specimens at the colder testing temperatures.

5.2 *Temperature-Control System*—The temperature-control system should be capable of control over a temperature range from 41 to 104°F (5 to 40°C) and within ±2°F (±1.1°C) of the specified temperature within the range. The system should include a temperature-controlled cabinet large enough to hold at least three specimens for a period of 24 h prior to testing.

5.3 *Measurement and Recording System*—The measurement and recording system should include sensors for measuring and recording horizontal and vertical deformations. When Poisson's ratio is to be assumed, only a measurement system for horizontal deformation is required. The system should be capable of measuring horizontal deformations in the range of 0.00001 in. (0.00025 mm) of deformation. Loads should be measured and recorded or accurately calibrated prior to testing.

5.3.1 *Recorder*—The measuring or recording devices should be independent of frequency for tests conducted up to 1.0 Hz.

5.3.2 *Deformation Measurement*—The values of vertical and horizontal deformation can be measured by linear variable differential transducers (LVDTs) or other suitable devices. LVDTs should be at midheight opposite each other on the specimen's horizontal diameter. The sensitivity and type of measurement device should be selected to provide the deformation readout required in 5.3. A positive contact by spring loading or gluing attachments to the specimen should be provided if direct contact between the measuring device and sample is required.

NOTE 3—The Trans-TEX Model 350-000 LVDT[3] and Statham UC-3[4] transducers have been found satisfactory for this purpose. If the transducers are temperature-sensitive, such as Statham UC-3, the testing machine should be placed in a controlled temperature chamber. The gages should be wired to preclude the effects of eccentric loading so as to give the algebraic sum of the movement of each side of the specimen. Alternatively, each gage can be read independently and the results summed independently.

5.3.3 *Load Measurement*—Loads should be measured with an electronic load cell capable of satisfying the specified requirements for load measurements in 5.3.

5.4 *Loading Strip*—A metal loading strip with a concave surface having a radius of curvature equal to the nominal radius of the test specimen is required to apply load to the specimen. Specimens will normally be either a nominal 4 or 6 in. (102 or 152 mm) in diameter. The load strip shall be 0.5 or 0.75 in. (13 or 19 mm) wide for these diameters, respectively. Edges should be rounded by grinding to remove the sharp edge in order not to cut the sample during testing. For specimens with rough textures, a thin hard rubber membrane attached to the loading strip has been found effective in reducing stress concentration effects, but should be used only when vertical deformations are not measured.

6. Specimens

6.1 *Laboratory-Molded Specimens*—Prepare the laboratory-molded specimens in accordance with acceptable procedures such as Methods D 1561, D 1559, D 3496, and D 3387. The specimens should have a height of at least 2 in. (51 mm) and a minimum diameter of 4 in. (102 mm) for aggregate up to 1 in. (25 mm) maximum size, and a height of at least 3 in. (76 mm) and a minimum diameter of 6 in. (152 mm) for aggregate up to 1.5 in. (38 mm) maximum size.

6.2 *Core Specimens*—Cores should have relatively smooth, parallel surfaces and conform to the height and diameter requirements specified for laboratory specimens.

[3] Available from Trans-tek Inc., Route 83, Ellington, CT 06029.

[4] Available from Gould-Statham, 2230 Statham Blvd., Oxnard, CA 93033.

7. Procedure

7.1 Place the test specimens in a controlled-temperature cabinet and bring them to the specified test temperature. Unless the temperature is monitored, and the actual temperature known, the specimens should remain in the cabinet at the specified test temperature for at least 24 h prior to testing.

NOTE 4—A dummy specimen with a thermocouple in the center can be used to determine when the desired test temperature is reached.

7.2 Place a specimen into the loading apparatus and position the loading strips to be parallel and centered on the vertical diametral plane. Adjust and balance the electronic measuring system as necessary.

7.3 Precondition the specimen by applying a repeated haversine or other suitable waveform load to the specimen without impact for a minimum period sufficient to obtain uniform deformation readout. Depending upon the loading frequency and temperatures, a minimum of 50 to 200 load repetitions is typical; however, the minimum for a given situation must be determined so that the resilient deformations are stable (Note 5). Resilient modulus evaluation will usually include tests at three temperatures, for example, 41 ± 2, 77 ± 2, and 104 ± 2°F (5, 25, and 40 ± 1°C), at one or more loading frequencies, for example, 0.33, 0.5, and 1.0 Hz for each temperature. The recommended load range is that to induce 10 to 50 % of the tensile strength (Note 6). Tensile strength can be determined from a destructive test on a specimen and the equation of 8.3 (Note 7).

NOTE 5—As few as five repetitions have been found to be sufficient for loads such as 5 to 25 lbf.

NOTE 6—Loads as low as 10 lbf have been used.

NOTE 7—Load duration is the more important variable and it is recommended that the duration be held to some minimum which can be recorded. The recommended time for the load duration is 0.1 to 0.4 s, with 0.1 s being more representative of transient pavement loading. Recommended frequencies are 0.33, 0.5, and 1 Hz. Instead of tensile strength data, load ranges from 4 to 200 lbf/in. (4 to 35 N/mm) of core or specimen thickness can be used.

7.4 Monitor the horizontal and, if measured, the vertical deformations during the test. If total cumulative vertical deformation greater than 0.001 in. (0.025 mm) occurs during the test, reduce the applied load, the test temperature, or both.

NOTE 8—A typical load pulse-deformation trace is shown in Fig. 2, along with notations indicating the load-time terminology.

7.5 Each resilient modulus determination should be completed within 4 min from the time the specimens are removed from the temperature-control cabinet. The 4-min testing time limit is waived if loading is conducted within a temperature-control cabinet meeting the requirements in 5.2.

7.6 Test each specimen for resilient modulus twice: Following the first test, replace the sample in the temperature-control cabinet for 10 min, continue by rotating the specimen approximately 90°, and repeat the test. Three laboratory fabricated specimens or three cores are recommended for a given test series with variables of temperature, load duration, and load frequency. In order to reduce permanent damage to the specimen, testing should begin at the lowest temperature, shortest load duration, and smallest load. Subsequent testing on the same specimen should be for conditions producing progressively lower moduli. Bring the specimens to the specified temperature before each test.

7.7 Measure the average recoverable horizontal and vertical deformations over at least three loading cycles (see Fig. 2) after the repeated resilient deformation has become stable. The vertical deformation measurements can be omitted when Poisson's ratio is not to be determined.

8. Calculations

8.1 Calculate the resilient modulus of elasticity, E, in pounds-force per square inch (or megapascals), and Poisson's ratio, ν as follows:

$$E_{RI} = P(\nu_{RI} + 0.27)/t\Delta H_I$$

$$E_{RT} = P(\nu_{RT} + 0.27)/t\Delta H_T$$

$$\nu_{RI} = 3.59\, \Delta H_I/\Delta V_I - 0.27$$

$$\nu_{RT} = 3.59\, \Delta H_T/\Delta V_T - 0.27$$

where:

E_{RI} = instantaneous resilient modulus of elasticity, psi (or MPa),

E_{RT} = total resilient modulus of elasticity, psi (or MPa),

ν_{RI} = instantaneous resilient Poisson's ratio,

ν_{RT} = total resilient Poisson's ratio,

P = repeated load, lbf (or N),

t = thickness of specimen, in. (or mm),

ΔH_I = instantaneous recoverable horizontal deformation, in. (or mm),

ΔV_I = instantaneous recoverable vertical deformation, in. (or mm),

ΔH_T = total recoverable horizontal deformation, in. (or mm), and

ΔV_t = total recoverable vertical deformation, in. (or mm).

8.2 If Poisson's ratio is assumed, the vertical deformations are not required. A value of 0.35 for Poisson's ratio has been found to be reasonable for asphalt mixtures at 77°F (25°C).

8.3 Calculate the tensile strength, S_T, approximately as follows:

$$S_T = 2P_{ult}/\pi tD$$

where:

P_{ult} = ultimate applied load required to fail specimen, lbf (or N),

t = thickness of specimen, in. (or mm), and

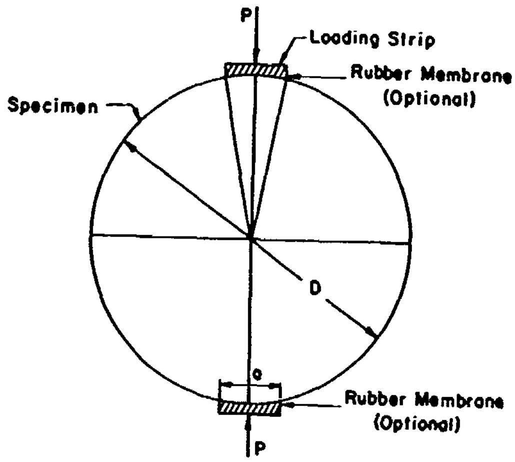
D = diameter of specimen, in. (or mm)

9. Report

9.1 Report the average resilient modulus at temperatures of 41, 77, and 104°F (5, 25, and 40°C) and load duration for each load and frequency used in the test.

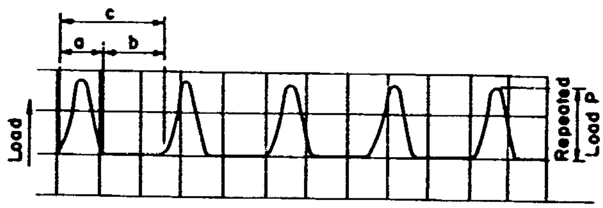
10. Precision

10.1 The precision of the method has not been established.



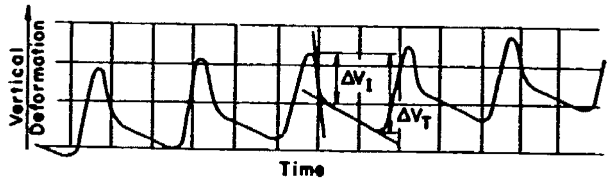
P = applied load
t = thickness of specimen
D = diameter of specimen
a = width of loading strip
= 0.5 in. (13 mm) for 4-in. (102-mm) diameter specimen
= 0.75 in. (19 mm) for 6-in. (152-mm) diameter specimen

FIG. 1 Indirect Tension Test

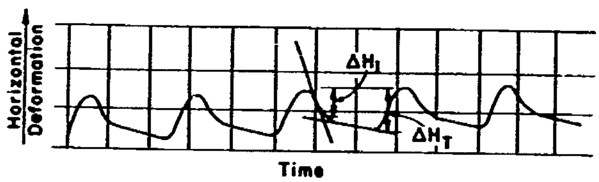


(a) Load-Time Pulse

a = duration of loading during one load cycle
b = recovery time
c = cycle time



(b) Vertical Deformation Versus Time



(c) Horizontal Deformation Versus Time

FIG. 2 Typical Load and Deformation Versus Time Relationships for Repeated-Load Indirect Tension Test

Moisture-Temperature Meter and Cells

Meters and Meter Sets Available

MC-300B Moisture-Temperature Meter Direct-reading 93-cycle AC-type ohmmeter with Fahrenheit temperature scale, 0° to 120°F. It is housed in a compact case with latches and handy carrying grip. Circuitry is all solid-state. Batteries and instructions are included. Case dimensions are 6⅞ inches long by 5 inches wide by 5 inches high. Purchase soil cells separately.

Shipping weight: 4 pounds (1.82 kilograms).
Net weight: 3 pounds (1.46 kilograms).

MC-302 Moisture-Temperature Meter Same as MC-300B but with a Celsius (centigrade) temperature scale −10° to 44°C.

Shipping weight: 4 pounds (1.82 kilograms).
Net weight: 3 pounds (1.46 kilograms).

MC-312 Moisture-Temperature Meter Set Includes one MC-300B Moisture-Temperature Meter and 25 MC-310A Standard Soil Moisture-Temperature Cells.

Shipping weight: 7 pounds (3.15 kilograms).
Net weight: 5 pounds (2.26 kilograms).

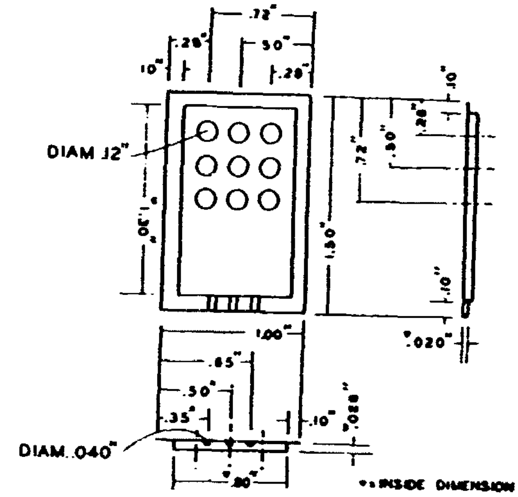
MC-315 Moisture-Temperature Meter Set Same as MC-312 but includes the MC-302 Moisture-Temperature Meter with Celsius (centigrade) Temperature scale.

Shipping weight: 7 pounds (3.15 kilograms).
Net weight: 5 pounds (2.26 kilograms).

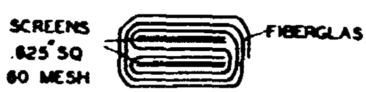
(See Cells available, page 6)

Soil Cell
Typical Construction Details

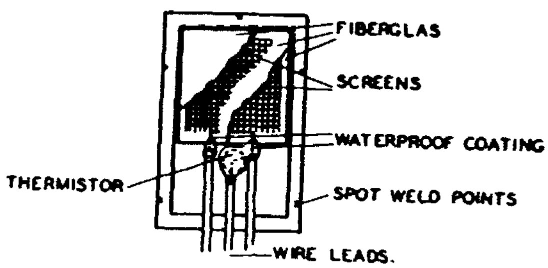
HALF-CASE OF SOIL UNIT
(Two required per unit)



ELECTRODE SANDWICH WRAPPING DIAGRAM
(End view, schematic)



ASSEMBLY VIEW
(Electrode Sandwich cut-away. Top half-case removed)



ASSEMBLED SOIL UNIT

(HALF-CASE FLANGES SPOT WELDED TOGETHER)

Fig. 2. Drawing of MC-310A soil cell for use with the Soiltest MC-300 Series Moisture-Temperature Meters.

WEIGHING/RECORDING RAIN AND SNOW GAGE

- 12-inch or 20-inch capacity
- Recorder built-in
- 0.5% accuracy
- Unattended recording up to 35 days

The Model 6032 weighing and recording precipitation gage converts the weight of collected precipitation into the equivalent depth of accumulated water in conventional units of inches or millimeters. An 8-inch-diameter, knife-edge orifice collects all forms of precipitation. Rain travels through a funnel into the galvanized weighing bucket. The funnel is removed to collect snow. When subfreezing temperatures are expected, antifreeze is added to the bucket.

The bucket rests on a platform mounted on the vertical link of a 4-bar linkage. This vertical link, or movement bracket, is supported from below by a precision extension spring assembly. Compression of the spring by the weight of collected precipitation is multiplied and modified for recording by a horizontal lever. This lever is connected to the pen arm through another link-and-lever assembly. Accuracy of the gage is better than 0.5% at ambient temperatures between -40 and 125°F.

A dual traverse system is used to record the accumulated precipitation on a rotating chart. Half of the gage capacity is recorded by the upward traverse of the pen, and the other half is recorded by the downward traverse. The pen is damped by a dashpot. A gage capacity of 12 inches (300 mm) is standard, but a 20-inch (500-mm) capacity gage is also available. The chart drive is either a spring-wound or a battery-operated clock. Each gage is provided with a standard drum rotation, determined by capacity (192 hours for 12 inches and 168 hours for 20 inches); optional change gears allow rotation periods of 24 hours, 48 hours, 96 hours, or 861 hours (35.9 days).

The Model 6032 is constructed of noncorrosive materials. A sliding door in the outer case provides access for chart changes. An anchor base is available for mounting the gage to a rigid surface. In strong wind areas, use of the Model 6411 wind screen is recommended. Weights are available to simplify gage calibration.

ORDERING INFORMATION

Model

6032	**Weighing/Recording Rain and Snow Gage**, 12" capacity, with spring-wound 192-hr. clock, pen, ink, dashpot fluid, and one pack of 192-hr. charts (specify English or metric)
6033	**Same as Model 6032** except with battery-operated 192-hr. clock
6034	**Weighing/Recording Rain and Snow Gage**, 20" capacity, with spring-wound 168-hr. clock, pen, ink, dashpot fluid, and one pack of 168-hr. charts (specify English or metric)
6035	**Same as Model 6034** except with battery-operated 168-hr. clock
6411	**Precipitation Gage Wind Screen**

Accessories:

60321	Change Gear for 24-hr. rotation, spring-wound clock
60322	Change Gear for 48-hr. rotation, spring-wound clock
60323	Change Gear for 96-hr. rotation, spring-wound clock
60331	Change Gear for 24-hr. rotation, battery-operated clock
60332	Change Gear for 48-hr. rotation, battery-operated clock
60333	Change Gear for 96-hr. rotation, battery-operated clock
60334	Change Gear for 861-hr. rotation, battery-operated clock
60324	Anchor Base for bolting gage to wood or concrete platform
60325	Calibration Weights for 12" capacity gage

Charts:

Cat. No.	Range	Drum Rotation	Charts/Pkg.
60326	0-12"	24 hrs.	100
60327	0-300 mm	24 hrs.	100
60328	0-12"	48 hrs.	100
60329	0-12"	96 hrs.	100
60330	0-12"	192 hrs.	100
60335	0-12"	861 hrs.	25
60336	0-300 mm	861 hrs.	25
60337	0-20"	168 hrs.	100
60338	0-500 mm	168 hrs.	100
60339	0-20"	861 hrs.	25
60340	0-500 mm	861 hrs.	25
60341	0-300 mm	192 hrs.	100

SPECIFICATIONS

Sensor	Weighing spring platform
Bucket capacity	12 inches or 20 inches
Recording range	0-12" (300 mm) or 0-20" (500 mm)
Accuracy	0.5% (-40 to 125°F)
Chart size	6" H × 11.5" L (152 × 292 mm)
Graduations:	
0-12" (0-300 mm) range	0.05", 1 mm
0-20" (0-500 mm) range	0.1", 2 mm
Resolution:	
0-12" (0-300 mm) range	0.025", 0.5 mm
0-20" (0-500 mm) range	0.05", 1 mm
Clock type	Spring-wound or 3 VDC battery-operated, tuning-fork-controlled
Drum rotation	192 hours (0-12" range) or 168 hours (0-20" range) standard; 24, 48, 96, or 861 hours optional
Pen type	Bucket V-point
Orifice	8" dia. (203 mm)
Size	35.5" H × 14" dia. (902 × 356 mm)
Weight/shipping	25 lbs./40 lbs. (11.4 kg/18.1 kg)