STABILITY AND DURABILITY OF PLANT-MIX MACADAM

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SYNOPSIS

ENGINEERS HAVE had little difficulty in designing bituminous paving mixes of adequate stability. It has been more difficult to provide protection against "stripping" of the asphalt film without sacrificing stability through the use of excessive amounts of asphalt. This hazard can be largely eliminated by use of a macadam-type aggregate with a sand-asphalt filler; it can be impregnated with enough asphalt to provide protection against stripping.

Four test specimens were prepared from each sample batch. One specimen was a cylinder of 4-in. diameter and 8 in. high, compacted by plunger under a steady load of 31,400 lb. for one minute. The remaining three specimens were 2–2–12-in. square bars compacted in two layers by a specially designed roller. The cylinders were prepared to be used in the closed system triaxial test, and the bars were prepared to be used in the freezing-and-thawing tests.

The stability of each mixture was determined by the standard closed-system triaxial compression test. The freezing and thawing tests were conducted by freezing the bars at −16 F., with one group frozen in air and another duplicate group frozen under water, and then thawing them at room temperature (72 F.). The specimens were maintained at the −16 F. temperature overnight, and were taken out in the morning, thawed at room temperature for 2½ hr., and left to dry for another 2 hr. The dry specimens were weighed, measured, and then subjected to the sonic test.

The following statements are suggested by the results of this investigation: (1) Adequate stability can be obtained in a mix where the voids between interlocking coarse aggregate are filled with a plastic matrix of sheet asphalt; (2) Such mixes are stable over a wide range of asphalt content, permitting use of sufficient asphalt to provide protection against stripping; (3) Rounded gravel is a satisfactory aggregate in this type of mix; (4) A square beam makes a good test specimen because the method of compaction can closely simulate ordinary construction practice in rolling; and (5) Lack of cohesion is accompanied by increased shrinkage.

●RECENT RESEARCH at the University of Washington has produced a new type of bituminous paving mix which is stable under load and durable under adverse climatic conditions and which appears to have values of internal friction insensitive to variations in asphalt content. This development was originally suggested by data from the soil mechanics laboratory, which disclosed the high degree of internal friction possessed by aggregations of uniform-size crushed rock or gravel. While this property of broken stone was appreciated by McAdam 150 years ago, there has been little effort to evaluate his findings, quantitatively, by modern laboratory procedures. Figure 1 shows the effect of size on the internal friction of stone and gravel of uniform particle size.[1] Further studies by Harold Mason[2] showed that the inclusion of smaller particles generally tended to lower frictional resistance by decreasing the amount of interlock between the particles of maximum size.

Engineers have had little difficulty in designing bituminous-paving mixes of adequate stability. It has been more difficult in some cases, to provide protection against stripping of the asphalt film without sacrificing stability through the use of excessive amounts of asphalt. However, this hazard can be largely eliminated by use of a macadam-type aggregate with a sand-asphalt filler, which assures adequate stability by preserving the mechanical interlock of the coarse aggregate. At the same time, since the sand filler is not essential for stability, it can be impregnated with enough asphalt to provide protection against stripping.

The experimental verification of this hypothesis was concerned primarily with measuring

[1] Thesis by G. Bryce Bennett, Univ. of Wash., (August, 1949). See also *Highway Research Abstracts,* September, 1949, p. 4.
[2] Research Fellow, Univ. of Wash., (1949–1950).

the stability and durability of test batches of various proportions. Rounded gravel was used

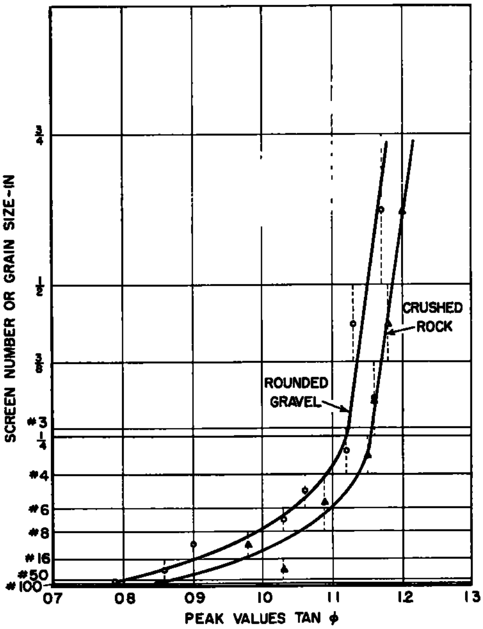

Figure 1. Variation of tan ø with grain size.

TABLE 1

A

GRADINGS OF SAND FOR SHEET ASPHALT (1950 TESTS)[a]

Passing Sieve No.	Retained on Sieve No.	Percent
10	40	21.0
40	70	29.0
70	200	27.8
200[b]		22 2

[a] Mixes 2, 3, 4, 5, 6, 7 and 8.
[b] Limestone dust (sp. gr. 2.43) is used as substitute

B

GRADINGS OF SAND FOR SHEET ASPHALT (1951 TESTS)[a]

Passing Sieve No.	Retained on Sieve No.	Percent
10	40	30.0
40	80	30.0
80	200	30 0
200		10 0[b]

[a] Mixes 3A, 3B, 3C, 4A, 4B, 5A, 5B, 6A, 6B, 7A, 7B, 8A, 8B.
[b] Includes 4 parts limestone to 5 parts screenings.

as the coarse aggregate, because it provides a more severe check and is more generally available in regions having a severe climate.

Type I mixes were used in a series of control tests. They were asphaltic concretes with graded crushed rock incorporated with varying amounts of 85–100 asphaltic cement. Type II was made of ½ in. to ¾ in. gravel mixed with sheet asphalt in different proportions. The sheet-asphalt mixture had ten percent of 85–100 asphalt cement with 90 percent sand of the grading shown in Table 1. Table 2 shows the proportions of sheet asphalt and aggregate

TABLE 2

COMPOSITION OF MIXES—TYPE II

Mix Designation No.	Gravel	Sheet Asphalt
	percent	*percent*
2	25.7	74.3
3, 3A, 3B, 3C	70.0	30.0
4, 4A, 4B	60.0	40.0
5, 5A, 5B	55.0	45.0
6, 6A, 6B	50.0	50.0
7, 7A, 7B	45.0	55.0
8, 8A, 8B	40 0	60.0

TABLE 3

ADOPTED GRADATION OF AGGREGATE

Passing Sieve No.	Retained on Sieve No.	Percent
¾-in.	½-in.	17.5
½-in.	4	23.5
4	10	14.6
10	40	18.8
40	70	6.8
70	200	7.8
200		11.0

TABLE 4

COMPOSITION OF MIXES—TYPE I

Mix Designation No.	Percent by Weight of Total Mix	
	Asphalt	Aggregate
1[a]	6.0	94.0
1A	5 0	95.0
1B	4.5	95.5
1C	4.0	96.0

[a] Mix No. 1 is taken as control mix.

for the various specimens of Type II. Type III was similar in grading to Type I, but with gravel substituted for the crushed rock. The composition of specimens of Types I and III is listed in Tables 3, 4, and 5, and the appearance of all mixes is shown in Figures 2, 3, 4 and 5.

Specimens of Type II were tested in two series, one during the summer of 1950, and the other during the summer of 1951.

For the 1950 tests, four specimens were

prepared from each sample batch. One specimen was a cylinder of 4-in. diameter and 8 in. high, compacted by plunger under a steady load of 31,400 lbs. for one minute. The remaining three specimens were square bars, 2–2–12-in., compacted in two layers by a specially designed roller. The cylinders were prepared to be used in the closed-system triaxial test, and the bars were prepared to be used in the freezing and thawing tests. (One bar was frozen in water, one frozen in air, and one kept at room temperature.)

For the 1951 tests, two to three cylinders were prepared from each sample batch, and were compacted as described above, except for Cylinders 3C and 4B. Because of excessive aggregate degradation under double plunger

TABLE 5
COMPOSITION OF MIXES—TYPE III

Mix Designation No.	Percent by Weight of Total Mix	
	Asphalt	Aggregate
9A	6	94
9B	5	95
9C	4	96

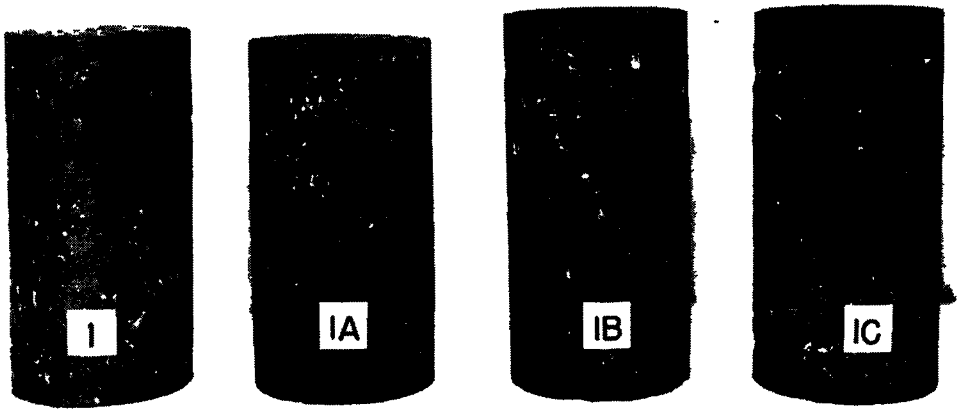

Figure 2. Type I mixes.

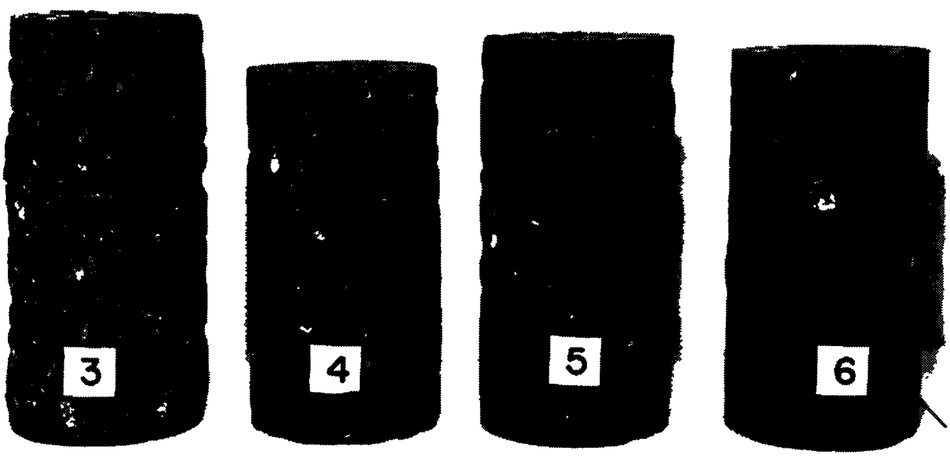

Figure 3. Type II mixes.

compaction, specimens of these two mixes were prepared in a kneading compactor of the de- to 300 psi. for Cylinder 3C. All specimens were tested in the closed-system triaxial cell.

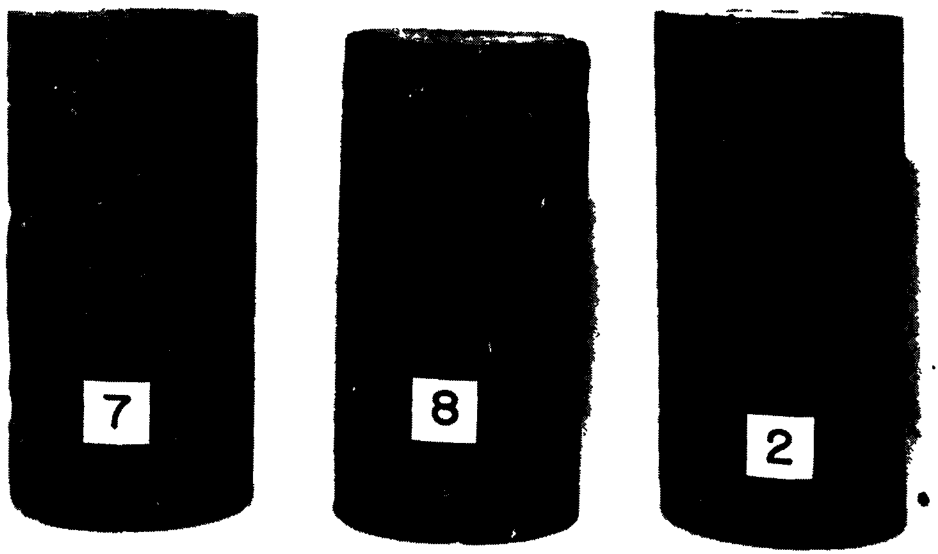

Figure 4. Type II mixes.

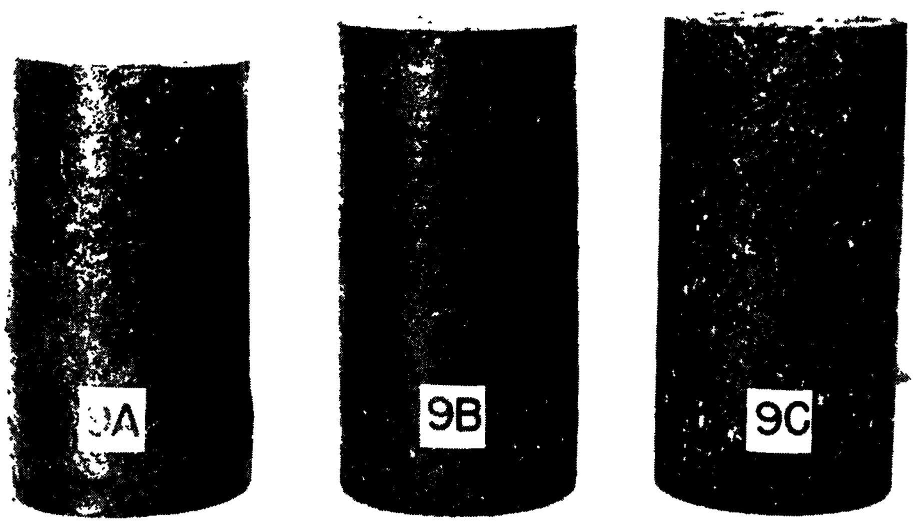

Figure 5. Type III mixes.

sign developed by the Triaxial Institute. For Cylinder 4B the compactor was adjusted to develop a foot pressure of 400 psi. for a period of 0.75 seconds. The fast pressure was reduced

The 1951 tests were run in response to a suggestion that the high limestone content of the 1950 mixes may have contributed inordinately to their stability. It was not felt necessary to repeat durability tests on these later specimens.

The equipment devised for obtaining a rolled compaction is shown in Figure 6, and consists of a metal mold 2–2–12-in. in which will fit a rocker made with face radius of 2 ft.; load is applied to the rocker by means of a wheel which supports a cage containing lead weights. The radius of the rocker and the weight (approximately 300 lb. per in. of width) were each selected with the idea of duplicating an actual road roller within practical limits. In using the roller the mold is half filled with the hot mixture and the wheel is rolled by hand from one end of the roller to the other and returned. The mold is then filled and the process repeated. It is of interest to note, in Tables 6, 7, and 8, the comparison between bulk densities as obtained by direct pressure and by rolling compaction.

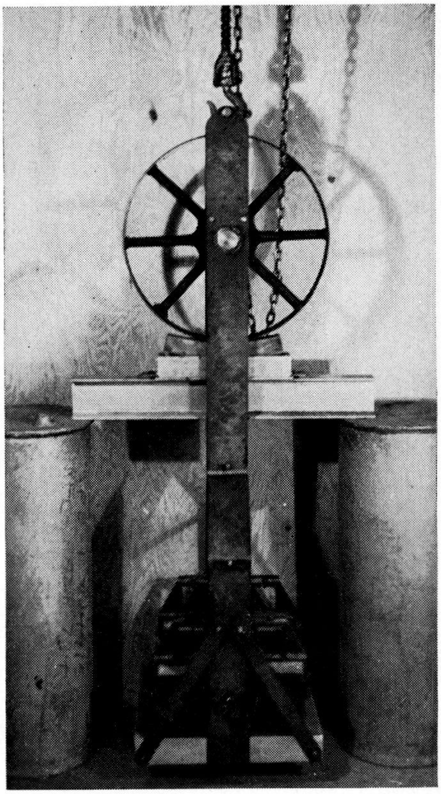

Figure 6. Roller compacter.

TABLE 6
COMPACTION RESULTS—MIXES TYPE I

Mix Designation No.	Percent by Weight of Total Mix		T.M.D.	Bulk Density		Air Voids	
	Aggregate	Asphalt		D. P.	R. C.	D. P.	R. C.
						Percent	
1	94.0	6.0	151.0	148.1	140.5	1.9	7.0
1A	95.0	5.0	153.1	143.3	138.1	6.4	9.8
1B	95.5	4.5	154.8	142.7	136.2	7.8	12.0
1C	96.0	4.0	155.0	142.3	138.6	8.2	10.1

The stability of each mixture was determined by the standard closed-system triaxial compression test, a set-up for which is shown in Figure 7. The freezing-and-thawing tests were conducted by freezing the bars at −16 F., with one group frozen in air and another duplicate group frozen under water, and then thawing them at room temperature (72 F.). The specimens were maintained at the −16 F. temperature overnight, and were taken out in the morning, thawed at room temperature for 2½ hr., and left to dry for another 2 hr. The dry specimens were weighed, measured, and then subjected to the sonic test.

The results of the stability tests are shown in Figure 8, which is the Asphalt Institute triaxial-compression test-evaluation chart. The regions labeled A, B, and C on the chart, according to the Asphalt Institute, provide the following information:

"Mixes falling in region A are lacking in internal friction. Mixes falling in region B lack sufficient cohesion, and those falling in region C lack both cohesion and internal friction."

The term "cohesion" is retained for convenience, although there are some objections to its use in this type of test.

It may be noted that the Type I mixes (graded crushed rock and 85–100 asphalt cement, numbered 1, 1A, 1B, 1C) are relatively sensitive to change in asphalt content as far as internal friction is concerned, although all of these control mixtures have satisfactory stability. It is also apparent that the Type III mixes (gravel graded as in Type I mixes with 85–100 asphalt cement and numbered 9A, 9B, 9C) are very sensitive to change in asphalt content, and only Mix 9C has satisfactory stability. A study of the plot of the Type II mixes (¾- by ½-in. gravel mixed with sheet asphalt and numbered from two to eight inclusive) brings out an interesting fact;

it may be noted that this type of mixture has its angle of internal friction changed only slightly as the asphalt cement content is varied over a wide range (7.4 percent to 3.0 percent). For this mixture, containing one size of gravel, there is also a good range of asphalt cement content (at least 3.0 percent to 5.5 percent) which exhibits satisfactory stability. It appears, however, that at some content slightly above 5.5 percent there is a rapid drop in unit cohesion, accompanied by loss of stability.

The authors are unable to explain the exceptionally high cohesion values obtained for specimens 3C, 4B, 5B, 6B, and 7B. These tests were carefully rechecked (the testing machine recalibrated) and are believed to be valid. It should be noted that discrepancy lies only in the cohesion, and that the friction values are quite consistent with earlier tests on the same mix. Possibly one should bear in mind that the stability of these mixes is believed to be mostly seated in the interlock of the coarse aggregate; hence any random arrangement of particles which involved segregation might create a relatively soft spot in the specimen, producing a drop from the stability of a specimen of uniform structure.

TABLE 7
COMPACTION—MIXES TYPE II

Mix Designation No.	Percent by Weight of Total Mix				T.M.D.	Bulk Density		Air Voids	
	Gravel	Sand	Limestone	A.C.		D.P.	R.C.	D.P.	R.C.
								Percent	
2	25.7	52.1	14.77	7.43	152.6	146.2	146.7	4.2	3.9
3	70.0	21.0	6.00	3.00	162.7	133.8	137.2	17.8	15.7
3A	70.0	25.8	1.2	3.00	160.4	147.8		7.8	
3B	70.0	25.8	1.2	3.00	160.4	145.4		9.3	
3C	70.0	25.8	1.2	3.00	160.4	145.4		9.3	
4	60.0	28 0	8.0	4.00	161.8	141.0	134.4	12.9	16.9
4A	60.0	34.4	1.6	4 00	157 9	143.8		8.9	
4B	60.0	34.4	1 6	4.00	157.9	147.6		6.5	
5	55.0	31.5	9.0	4.50	159.0	141.0	141.4	11.3	11.1
5A	55 0	38.7	1.8	4.50	156.6	143.0		8.7	
5B	55 0	38.7	1.8	4.50	156.6	141 8		9 5	
6	50.0	35.0	10.0	5.00	157.9	147 1	143.4	6 8	9 2
6A	50.0	43.0	2.0	5.00	155.4	141.4		9 0	
6B	50.0	43.0	2.0	5.00	155.4	140 2		9.8	
7	45.0	38.5	11.0	5.50	156 6	147.1	145 0	6.1	7.4
7A	45.0	52.7	2.2	5.50	154 1	143.6		6.8	
7B	45.0	52 7	2.2	5.50	154 1	139 8		9 3	
8	40.0	42 0	12.0	6.00	155.7	150.0	149.0	3.7	4 3
8A	40.0	51.6	2.4	6.00	152.9	137.2		10.2	
8B	40.0	51.6	2.4	6.00	152 9	138.4		9 5	

T.M.D. = Theoretical maximum density in pcf.
R.C. = Rolling compaction method.
D.P. = Double plunger method.
A.C. = Asphalt cement.

TABLE 8
COMPACTION RESULTS—MIXES TYPE III

Mix Designation No.	Percent by Weight of Total Mix			T.M.D.	Bulk Density		Air Voids	
	Gravel	Limestone	Asphalt		D.P.	R.C.	D.P.	R.C.
							Percent	
9A	83 7	10.3	6.0	155.8	150.7	155.3	3.3	0 3
9B	84.6	10.4	5.0	158.7	153.5	152.3	3.3	4 0
9C	85.4	10.6	4.0	159.6	149.7	145 0	6.2	9.2

T.M.D. = Theoretical maximum density in pcf.
D.P. = Double plunger method.
R.C. = Rolling compaction method.
A.C. = Asphalt cement.

The change of length of specimens is recorded in Table 9, and it will be noted most of the length changes are in the nature of shortening. There is an evident relationship between unit change in length and unit cohesion as shown in Figures 9 and 10; however it would be difficult to draw definite conclusions regarding the practical significance of this interesting phenomenon.

Early sonic determinations of Young's modulus of elasticity of specimens were handicapped by spurious resonances of parts of the testing apparatus, and even with later reliable data the moduli did not show any definite correlation with the number of freezing and thawing cycles.

The freezing and thawing tests indicate that mixtures of Type II and III are more durable than the control mixture, Type I. Although the specimen frozen in air did not show serious signs of deterioration, those frozen

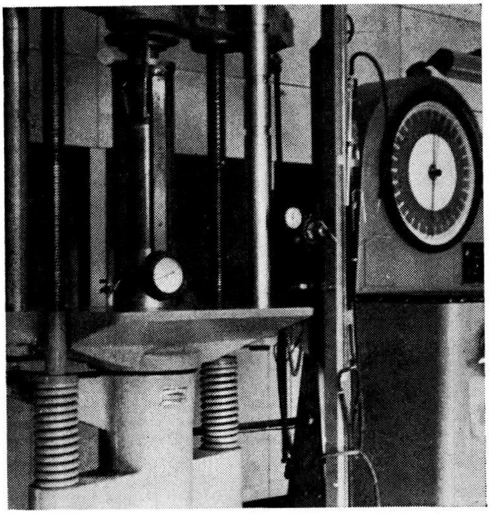

Figure 7. Closed-system triaxial cell.

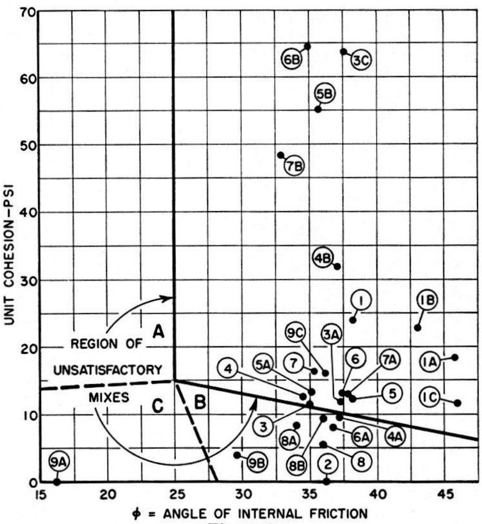

Figure 8.

TABLE 9
CHANGE IN LENGTH OF SPECIMENS

Mix No.	Change in Length	
	Specimen Frozen in Air[a]	Specimen Frozen in Water
	percent	*percent*
1	−0.58 (end of 149 cycles)	−0.17 (end of 149 cycles)[b]
1A	−0.17 (end of 104 cycles)	+1.25 (end of 104 cycles)[b]
1B	0.00 (end of 96 cycles)	0.00 (end of 19 cycles)
1C	0.00 (end of 20 cycles)	0.83 (end of 20 cycles)
2	−3.34 (end of 149 cycles)	−2.08 (end of 134 cycles)
3	−1.25 (end of 139 cycles)	−1.08 (end of 87 cycles)
4	−2.92 (end of 149 cycles)	−1.50 (end of 171 cycles)
5	−1.08 (end of 149 cycles)	−1.25 (end of 149 cycles)
6	−0.67 (end of 135 cycles)	−0.42 (end of 118 cycles)
7	−1.00 (end of 125 cycles)	−0.83 (end of 108 cycles)
8	−1.35 (end of 111 cycles)	−2.50 (end of 110 cycles)
9A	−1.42 (end of 120 cycles)	−3.00 (end of 119 cycles)
9B	−1.25 (end of 117 cycles)	−2.42 (end of 117 cycles)[b]
9C	−0.83 (end of 116 cycles)	−0.67 (end of 102 cycles)

[a] All samples frozen in air were intact at end of test.
[b] Sample still unbroken at end of test. All other specimens in this column broke at the cycle shown.
Minus sign indicates shortening of the specimen.

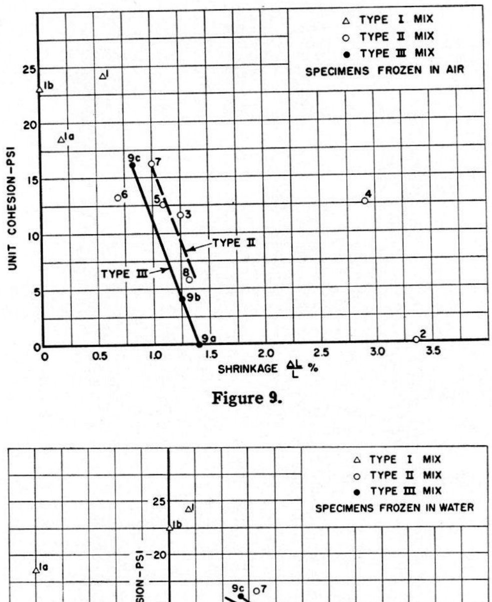

Figure 9.

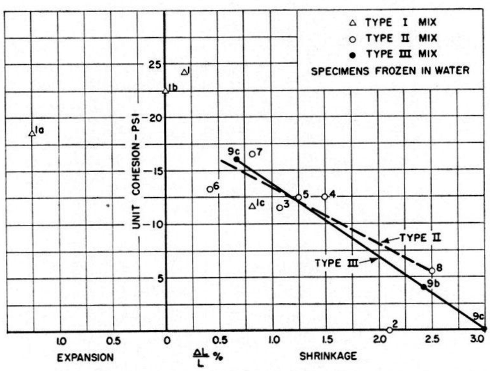

Figure 10.

in water did reach a state of failure. Table 9 also shows the number of cycles withstood up to the point of failure for all specimens. Most failures noted in the table were due to fracture of a specimen as it was handled after thawing. It seems quite apparent that gravel mixtures are more durable than more conventional mixtures of crushed rock.

While the evidence is not always conclusive, the following statements are suggested by the results of this investigation:

(1) Adequate stability can be obtained in a mix where the voids between interlocking coarse aggregate are filled with a plastic matrix of sheet asphalt.

(2) Such mixes are stable over a wide range of asphalt content. This fact permits use of sufficient asphalt to provide protection against stripping.

(3) Rounded gravel is a satisfactory aggregate in this type of mix.

(4) A square beam makes a good test specimen because the method of compaction can closely simulate ordinary construction practice in rolling.

(5) Lack of cohesion is accompanied by increased shrinkage.

No full-size test sections of this type of pavement have been laid in the field. Probably field experience would make it necessary to modify conclusions based wholly on laboratory tests, and the development of some sort of surface treatment might become desirable.

The investigation was carried out by H. H. Chen, H. K. Chang and R. K. Rippe[3] under the supervision of the authors.

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MOLDING SPECIMENS OF BITUMINOUS PAVING MIXTURES

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SYNOPSIS

THIS PAPER describes in brief the investigation conducted by the Texas Highway Department in 1939 to develop a molding machine and method which would produce satisfactory test specimens of bituminous-concrete paving mixtures. Nine machines were tested in the course of this investigation.

A method was evolved by which bituminous-concrete mixtures could be molded in the field laboratory, into cylindrical specimens 2 in. in height and 4 in. in diameter, having a density approximately equal to that obtained in a pavement produced from the mix and with approximately the same aggregate degradation.

The necessary equipment is a simple device to be used in conjunction with a hydraulic press found in most field laboratories. The molding principle employs gyratory shearing action of the mix at low initial pressures, allowing orientation of the aggregate particles. This is followed by direct compression at 1,590 psi. The procedure is most satisfactory and was used as a tentative method by the department from 1940 until 1946, when it was made standard and became a part of the specification requirements on all bituminous-paving mixtures.

This paper also describes a later adaptation of the gyratory molding method in producing specimens 4 in. in diameter and 8 in. in height for triaxial testing.

● ORGANIZED laboratory research by the Texas Highway Department in bituminous concrete was begun in 1939. The early stages of this research were devoted to the sound establishment of numerous fundamental concepts; to the development of adequate testing machines, equipment, and methods; and to the evolution of research tools, both mechanical and analytical. This phase of the work will never be completed, but progress has been made on an analysis of the effect of some of the variables upon the stability of the mix.

When testing a bituminous concrete mixture in order to ascertain the character of the pavement which will be produced from that mixture, it is essential that the physical characteristics of the specimen be as nearly identical as possible with the physical characteristics of the pavement.

A method was evolved by means of which