BENEFICIAL USE OF SULPHUR

IN

SULPHUR-ASPHALT PAVEMENTS

by

C. Y. Jacobs
D. E. Newcomb
D. Saylak
B. M. Gallaway

Final Report

Project RF 3644

For the Period

1 November 1977 to 30 October 1978

Prepared for

The U. S. Bureau of Mines

and

The Sulphur Institute

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

October, 1978

INTRODUCTION

A definite interrelationship exists between the U.S. 77 Kenedy County field trials and the laboratory evaluations of binders composed of sulphur and asphalt as pure sulphur. Fiscal support for these related areas of research come from two sources. The Sulphur Institute and the U.S. Bureau of Mines share equally in funding of the Kenedy County part construction evaluation; whereas the U.S. Bureau of Mines at Boulder City, Nevada supports the related laboratory studies which deal with specific and specialized studies of the more basic properties of these combination binders. It therefore seems logical that these related efforts be reported together.

This is the final report for the funding year's effort of testing and evaluation of the sand-asphalt-sulphur field trials on U.S. 77 in Kenedy County, Texas and the freeze-thaw testing of sulphur concrete. Therefore, this report consists of two parts. Part A pertains to data which have been collected on the Kenedy County field trials. This segment of the report contains all data collected through the trial testing period designated I+12.

Part B is a summary of the support effort TTI is providing to the U.S. Bureau of Mines in the area of freez-thaw testing of sulphur concrete.

Part A

Post Construction Evaluation of Sand-Asphalt Sulphur Test Section, Kenedy County, Texas

Part A

Purpose:

To conduct post-construction testing and evaluation of a sand-asphalt-sulphur (S-A-S) experimental test section located on U.S. 77 in Kenedy County, Texas, in District 21 of the Texas State Department of Highways and Public Transportation (SDHPT).

Background:

During the month of April, 1977, a 3,000 foot section of roadway being constructed on U.S. 77 in Kenedy County, Texas, five miles south of Sarita was set aside for a demonstration of sand-asphalt-sulphur paving mixtures. The experimental sections were placed in the two north bound lanes between stations 1985+00 and 2015+00 in conjuction with Highway Project TQF 913(13) under the jurisdiction of District 21, Texas State Department of Highways and Public Transportation. The pavement was constructed under a concept which was developed and patented by Shell Canada Limited. This concept involves the utilization of sulphur as a structing agent in paving mixtures which contains poorly graded sands. These sands are plentiful in many areas of the United States and particularly along the Gulf Coast States.

Through efforts initiated by the Sulphur Institute, and co-sponsored by the U.S. Bureau of Mines, the Texas Transporation Institute (TTI) has, during the past five years, conducted an extensive laboratory program to verify the sand-asphalt-sulphur concept developed by Shell Canada. This effort is directed toward introducing the use of sulphur in asphaltic concrete to United States highway agencies. The construction of this test section represents the next stage of verification through field evaluation.

A construction report describing the details of design and placement of the test section is available upon request. The report includes details of materials, mix designs, equipment, materials handling, quality control, and evolved gas analyses [1].

Upon completion of the test sections, cores were obtained by District 21 personnel and a series of tests was run [2]. Data were processed and a report was prepared. This testing period was designated as initial (I). At six month intervals following construction, TTI personnel took cores and performed a series of tests on these samples. During the same six month intervals SDHPT personnel collected field data in the form of Dynaflect deflections, Mays Ride Meter roughness measurements, and visual distress observations. Both in-situ testing and core testing are performed in accordance with the Test Matrix presented in Figure 1-A. Location of the cores within the test sections was established by station numbers. A schematic of the test sections is presented in Figure 2A.

Test Results

The results of the I+12 core testing are reported in Table 1-A. Tables 2-A(1) and 2-A(2) compares the results of core testing from the I, I+6, and I+12 testing periods. Specific methods of testing were in accordance with the following:

Test Description	Initial* I	6 mo.	Time Intervals 12 mo.	18 mo.	36 mo.
1. Traffic Analysis					
a. Average Daily Traffic Count	←	continuous			→
b. Truck and Axle Weight Distribution	○				○
2. Visual Evaluation	△	△	△	△	△
3. Mays Meter (PSI)	△	△	△	△	△
4. Dynaflect Deflections	△	△	△	△	△
5. Core Samples**				*** →	→
a. Field Density and Rice Specific Gravity	△	△	△	△	△
b. Stability, Marshall	△	△	△	△	△
c. Stability, Hveem	△	△	△	△	△
d. Resilient Modulus	△	△	△	△	△
e. Indirect Tension	△	△	△	△	△
6. Interim Reports	△	△	△	△	△

○ Loadometer Survey, 1-Week Duration
△ Evaluations on Both Sand-Asphalt-Sulphur Mixes and Conventional Asphaltic Concrete Sections
* Initial Testing Performed One Week After Pavement Opened To Traffic
** Set of 3 Cores (minimum) at Each Test Section Per Sampling Period (Each Lane)
*** Continuous at 6 Month Intervals Between 18 and 36 Months

Figure 1-A. Testing Matrix For Sand-Asphalt-Sulphur Trial, US 77, Kenedy Co., Texas

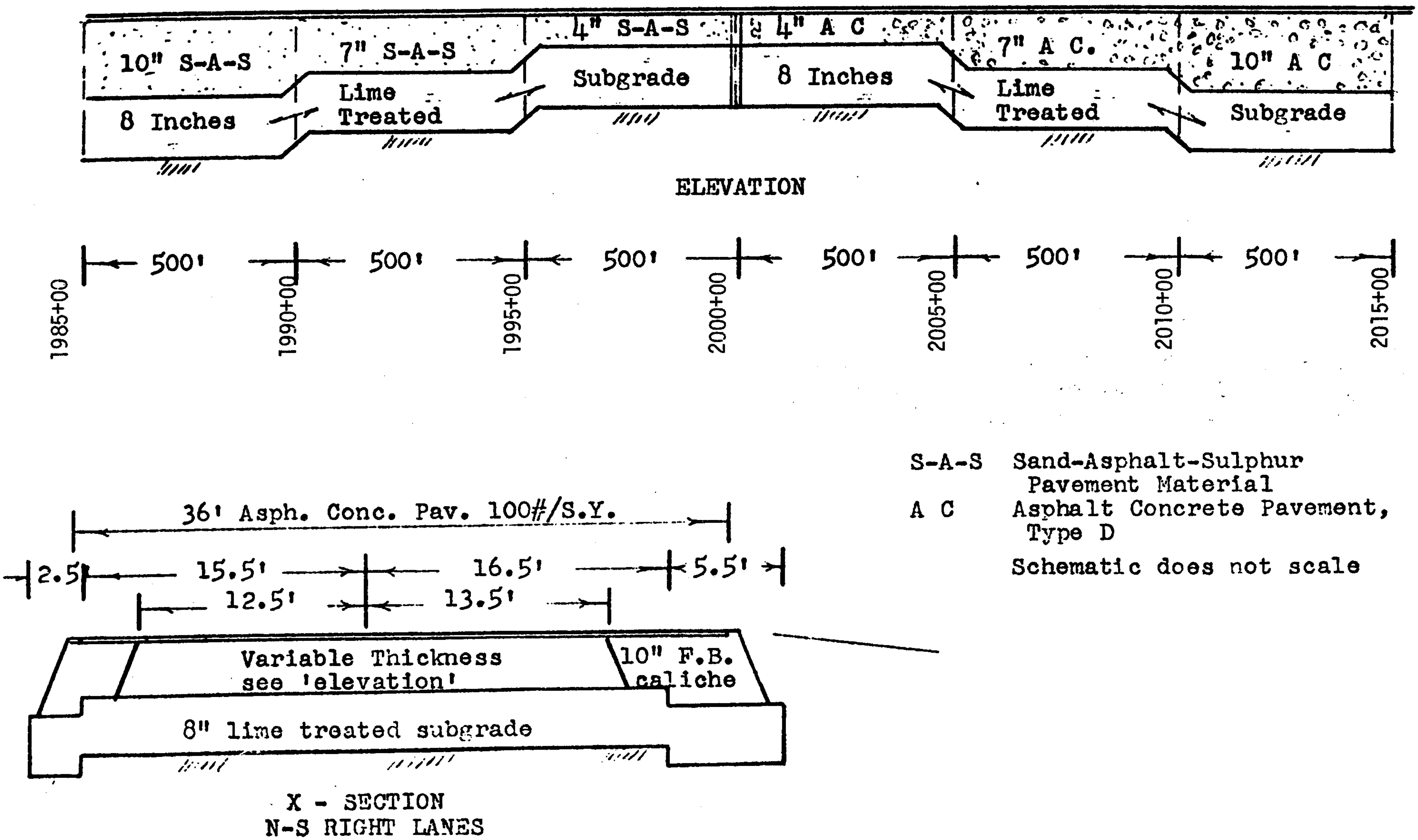


Figure 2-A. Mineral Aggregate-Asphalt-Sulphur Research Project Kenedy County - Highway U.S. 77

Table 1-A Test Results For Initial +12 Testing Phase

Sample		Location							
Type	Binder Content (wt.%)	Benchmark (Ft.)	Specific Gravity	Marshall Stability (lb.)	Marshall Flow (1/100 in)	Hveem Stability (Percent)	Resilient Modulus at 68°F ($psi \times 10^6$)	Splitting Tensile Strength (psi)	Rice Specific Gravity
SAS	6.2	1978+30	2.04	2070	10	42	0.48	200	2.36
SAS	6.2	1993+00	1.99	1210	10	28	0.48	205	2.29
SAS	6.2	1997+30	2.05	1450	9	30	0.55	235	2.29
AC	6.2	2003+00	2.25	930	14	27	1.16	325	2.40
AC	6.2	2007+00	2.25	685	14	26	0.99	273	2.38
AC	6.2	2013+00	2.27	420	12	24	1.02	310	2.39

Table 2-A(1). Test Results From Field Cores For I, I+6, I+12 Testing Periods.

Sample		Location			Test								
TYPE	BINDER CONTENT † (%)	BENCHMARK (FT.)			SPECIFIC GRAVITY			MARSHALL STABILITY (LB.)			MARSHALL FLOW (0.01 IN)		
		I	I+6	I+12	I	I+6	I+12	I	I+6	I+12	I	I+6	I+12
10" SAS	6.2	1978+50	1986+60	1987+30	2.02	2.20	2.04	1350	1445	2070	17	8	10
7" SAS	6.2	1992+50	1991+40	1993+00	2.01	2.04	1.99	1885	1740	1210	15	9	10
4" SAS	6.2	1997+50	1996+50	1997+30	2.01	2.05	2.05	1890	1875	1450	14	10	9
4" AC	6.2	2002+50	2001+60	2003+00	2.13	2.25	2.25	340	580	930	11	13	14
7" AC	6.2	2007+50	2006+80	2007+00	2.26	2.26	2.25	675	665	685	18	11	14
10" AC	6.2	*	2011+80	2013+00	*	2.24	2.27	*	705	420	*	12	12
AC Outside test section		*	1984+20	*	*	1.93	*	*	1665	*	*	8	*

* No Cores Available For Testing
† The mix design established for these systems was 6.2 weight percent asphalt and 13 weight percent sulphur. However, asphalt contents ranged from 5.8 to 6.8 weight percent. [2]

Table 2-A(2). Test Results From Field Cores For I, I+6, I+12 Testing Periods.

SAMPLE		TEST											
TYPE	BINDER CONTENT † (%)	HVEEM STABILITY (%)			RESILIENT MODULUS (68°F) (psi x 10^6)			SPLITTING TENSILE STRENGTH (psi)			RICE SPECIFIC GRAVITY		
		I	I+6	I+12	I	I+6	I+12	I	I+6	I+12	I	I+6	I+12
10" SAS	6.2	25	31	42	0.46	0.70	0.48	155	160	200	2.29	2.23	2.36
7" SAS	6.2	34	30	28	0.44	0.64	0.48	145	150	205	2.28	2.14	2.29
4" SAS	6.2	32	38	30	0.45	0.77	0.55	155	185	235	2.28	2.35	2.29
4" AC	6.2	36	26	27	0.73	1.28	1.16	215	290	325	2.38	2.36	2.40
7" AC	6.2	no test	27	26	0.81	1.23	0.99	240	255	273	2.37	2.39	2.38
10" AC	6.2	*	29	24	*	1.12	1.02	*	255	310	*	2.40	2.39
AC	Outside test section	*	36	*	*	0.54	*	*	180	*	*	2.26	*

* No Cores Available For Testing

† The mix design established for these systems was 6.2 weight percent asphalt and 13 weight percent sulphur. However, asphalt contents ranged from 5.8 to 6.9 weight percent. [2]

Density	ASTM D-2041-71
Marshall Stability and Flow	ASTM D-1559-73
Hveem Stability	ASTM D-1560-65
Resilient Modulus, 68°F	as per Schmidt [3]
Indirect (Splitting) Tension	ASTM C-0496-71
Rice Specific Gravity	ASTM D-2041-71

From Tables 2A(1) and 2A(2) it can be seen that the SAS mixtures are maintaining higher Marshall stability with lower Marshall flow as compared to the conventional asphaltic concrete sections. The Hveem stability values are lower for the conventional asphaltic concrete sections. The resilient moduli and splitting tensile strengths of the conventional AC sections are greater than those of the SAS sections. Tensile strength also seems to be increasing with time for all test sections.

SDHPT personnel took Dynaflect measurements in accordance with the procedure set forth by Scrivner and Moore [4]. A summary of the results of the STIF 2 computer treatment of the Dynaflect data is presented in Table 3-A. The differences between the data at I+6 and I+12 are probably due to seasonal (temperature) and variation which would explain why the maximum deflection is higher for the I+12 testing period (June, 1978) than the maximum deflection recorded for I+6 (December, 1977).

Table 4-A presents a summary of the Serviceability Index for each wheel path as computed from the Mays Ride Meter test performed by District 21 personnel. The Mays Ride Meter and its operations are described in Reference 5. The results from the initial testing period

TABLE 3-A. DYNAFLECT RESULTS AS COMPUTED BY STIF 2

BINDER CONTENT AND TYPE	SECTION	PAVEMENT THICKNESS* (IN)	MAXIMUM DYNAFLECT DEFLECTION (10^{-3} IN)	SURFACE CURVATURE INDEX	STIFFNESS COEFFICIENT OF PAVEMENT	STIFFNESS COEFFICIENT OF SUBGRADE	TIME
6.2% SAS	1985+00 to 1990+00	19	0.422 0.492	0.040 0.057	0.85 1.14	0.23 0.24	I+6 I+12
6.2% SAS	1990+00 to 2000+00	16	0.534 0.628	0.077 0.134	0.76 1.07	0.24 0.27	I+6 I+12
6.2% SAS	1995+00 to 2000+00	13	0.849 0.930	0.160 0.189	0.76 1.75	0.24 0.24	I+6 I+12
6.2% AC	2000+00 to 2005+00	13	0.796 0.921	0.121 0.165	0.83 1.85	0.23 0.24	I+6 I+12
6.2% AC	2005+00 to 2010+00	16	0.759 0.990	0.080 0.165	0.85 1.22	0.21 0.23	I+6 I+12
6.2% AC	2010+00 to 2015+00	19	0.486 0.762	0.031 0.072	0.97 1.26	0.21 0.21	I+6 I+12
Control (10 in Flexable Base)	1980+00 to 1985+00	19	0.439 0.456	0.087 0.091	0.65 0.84	0.26 0.28	I+6 I+12

* All Sections Have 1 Inch Asphaltic Concrete Wear Course And 8 Inch Lime Treated Subgrade.

TABLE 4-A. MAYS METER* TEST RESULTS FOR ROAD SERVICEABILITY INDEX

SERVICEABILITY INDEX (SI)

STATION NO.

N →

← SAS → ← CONTROL →

1988 1991 1994 1997 2000 2003 2006 2009 2012 2015

Wheel Path No. 1											
I	3.1	3.8	2.8	3.2	2.8	2.9	3.1	3.3	3.2	3.7	3.7
I+6	3.6	3.8	3.8	3.8	3.3	3.2	3.6	3.9	3.8	4.2	3.9
I+12	3.6	3.9	3.8	3.9	3.6	3.8	4.0	4.1	4.1	4.4	4.4
Wheel Path No. 2											
I	3.1	4.1	2.6	3.2	3.7	2.9	3.9	4.2	3.3	4.1	3.7
I+6	3.3	4.1	3.6	4.2	4.1	3.8	4.5	4.4	4.1	4.5	4.5
I+12	3.4	3.9	3.8	4.1	4.1	3.4	4.3	4.4	4.2	4.6	4.4
Wheel Path No. 3											
I	2.5	3.2	2.7	2.9	3.1	2.3	3.9	3.4	2.8	3.3	3.7
I+6	3.0	3.9	3.5	4.1	3.8	3.0	4.5	4.0	4.0	4.2	4.5
I+12	3.0	3.2	3.5	3.6	3.3	2.7	4.4	4.1	4.2	4.1	3.9
Wheel Path No. 4											
I	2.5	2.9	2.9	2.5	2.9	2.1	3.6	3.9	3.7	3.1	-
I+6	3.8	3.7	3.9	2.9	3.0	2.9	4.1	3.9	4.2	3.1	3.9
I+12	3.6	3.6	3.6	2.8	2.9	2.7	3.9	3.9	4.1	4.1	3.9

* MAYS METER VEHICLE STRADDLED THE WHEEL PATHS.

are somewhat lower than those from the last two periods. This was probably caused by an instrumentation error in the measuring device. It may be noted that the Serviceability Index (SI) increases from I+6 to I+12 for wheel path number 1. The reason for this could be that two wheels of the Mays Meter vehicle were on or near the shoulder during the I+6 testing period. This testing format makes the data from wheel path 4 suspect, also. Therefore, for the purpose of this analysis only the data taken from the inside wheel paths (Nos. 2 and 3) during the I+6 and I+12 testing periods will be considered.

The average serviceability index for all sections of wheel paths 2 and 3 was 4.0 during the I+6 testing period with a range from 3.0 to 4.5. During the I+12 testing period these wheel paths had an average SI of 3.8 with a range from 2.7 to 4.6. The I+6 average SI for the sand-asphalt-sulphur sections (stations 1985+00 to 2000+00) was 3.7 ranging from 3.0 to 4.1 while the average SI for the conventional asphaltic concrete sections (stations 2000+00 to 2015+00) was 4.3 with a range from 4.0 to 4.5. For the I+12 period the sand-asphalt-sulphur sections had an average SI of 3.5 ranging from 2.7 to 4.1 and the conventional asphaltic concrete sections' average SI was 4.3 with a range from 3.9 to 4.6. The average SI for U.S. highways in Texas is reported to be 3.6 with a standard deviation of 0.58 and a range from 0.5 to 4.9 [6].

It is evident from Table 4-A that the SI values for the sand-asphalt-sulphur sections are somewhat lower than those for the conventional asphaltic concrete sections. This is evident even in the initial measurements which were taken one week after construction. The lower SI values for the sand-asphalt-sulphur sections are believed to be due to inadequate construction control. The contractor had no previous experience with SAS mixtures or with the special equipment utilized in this type operation. The batch plant was old and in very poor condition. Temperature control was marginal and the pug mill was out of adjustment throughout the period when SAS was being produced. Operation of the lay down machine was such as to produce a poor quality riding surface. The machine stopped and started frequently and the screed temperature varied from too hot to too cold for proper placing of SAS mixtures.

A survey of cracking is presented in Table 5-A. It should be noted that almost all of the cracking has occured in the control section, and that the 4 inch AC section shows only a minute amount of distress.

It may be recalled that one of the original objectives of this field experiment was to compare the performance characteristics of hot-mix asphalt base with a paving material such as SAS. Hence, the U.S. 77 experimental section contains three subsections which utilize pure asphalt and graded aggregates for the base, and three subsections of SAS. The thickness of these subsections are 4, 7 and 10 inches all on 8 inches of lime stabilized subgrade. The pavement in the rest of the job (the control) consists of 10 inches of lime stabilized subgrade and 10 inches of caliche base. The entire pavement in this contract also has a 1-inch surfacing of Type D Item 340 hot-mix.

Data on traffic analysis for highway design are given in Table 6-A. These are estimated quantities based on statistical information gathered by the SDHPT Austin Office Personnel.

TABLE 5A. RECORD OF VISUAL DISTRESS

OUTSIDE LANE

STATION NUMBER	TIME	REMARKS
	I	None
	I+6	Transverse Cracks:
		1980 + 10 - Full lane width or 12 Ft.
		1980 + 27 - 8 Ft. from outside edge toward interior
		1980 + 52 - Full lane width or 12 Ft.
		1980 + 70 - 3 Ft. from inside edge of lane toward outside
1980 + 00 to		1980 + 77 - 6 Ft. from outside edge toward interior
1985 + 00		1980 + 92 - 6 Ft. from outside edge toward interior
(control)		1981 + 06 - 4 Ft. from outside edge toward interior
		1981 + 32 - 7 Ft. from outside from outside edge toward interior
		1981 + 48 - 5 Ft. from outside edge toward interior
		1981 + 65 - 7 Ft. from outside edge toward interior
		1981 + 82 - 4 Ft. from outside edge toward interior
		1982 + 00 - Construction joint (no cracks)
		1982 + 37 - 4 Ft. from outside edge toward interior
	I+12	Transverse Crack:
		1982 + 63 - 3 Ft. from outside edge toward interior
	I	None
1985 + 00 to	I+6	None
1990 + 00	I+12	None
	I	None
1990 + 00 to	I+6	None
1995 + 00	I+12	None
	I	None
1995 + 00 to	I+6	None
2000 + 00	I+12	None

TABLE 5A. (Continued)

OUTSIDE LANE

STATION NUMBER	TIME	REMARKS
	I	None
2000 + 00 to	I+6	None
2005 + 00	I+12	None
	I	None
2005 + 00 to	I+6	None
2010 + 00	I+12	None
	I	None
2010 + 00 to	I+6	None
2015 + 00	I+12	None

INSIDE LANE

STATION NUMBER	TIME	REMARKS
	I	None
1980 + 00 to	I+6	None
1985 + 00	I+12	None
	I	None
1985 + 00 to	I+6	None
1990 + 00	I+12	None
	I	None
1990 + 00 to	I+6	None
1995 + 00	I+12	None
	I	None
1995 + 00 to	I+6	1988 + 44 - 2 Ft. length begin 1 Ft. from outside edge
2000 + 00	I+12	None

TABLE 5A. (Continued)

INSIDE LANE

STATION NUMBER	TIME	REMARKS
2000 + 00 to 2005 + 00	I	None
	I+6	None
	I+12	None
2005 + 00 to 2010 + 00	I	None
	I+6	None
	I+12	None
2010 + 00 to 2015 + 00	I	None
	I+6	None
	I+12	None

TABLE 6-A. TRAFFIC ANALYSIS FOR HIGHWAY DESIGN

		1977	1978	1979
1.	AVERAGE DAILY TRAFFIC (ADT)	3970	4170	4400
2.	DIRECTIONAL DISTRIBUTION FACTOR	60-40%	60-40%	60-40%
3.	DESIGN HOURLY VOLUME (DHV)	13.7%	13.7%	13.7%
4.	PECENT TRUCKS			
	a. ADT	24.2%	24.2%	24.2%
	b. DHV	14.2%	14.2%	14.2%
5.	ANTICIPATED ANNUAL RATE OF GROWTH	5.0%	5.0%	5.0%
6.	AVERAGE OF TEN HEAVIEST WHEEL LOADS DAILY (ATHWLD)	10,700 lb.	10,700 lb.	10,700 lb.
7.	TANDEM AXLES IN ATHWLD	70%	70%	70%

Conclusion:

Although certain trends are emerging, it would be premature to draw any specific conclusions on the performance of one structural design with respect to the other at this point in time. The two thinner sections of the SAS and/or the black base would normally be expected to show distress in 3 to 6 years after construction. However, similar under designed sections on the U.S. 69 sulphur extended asphalt paving show no distress and these are three years old.

Part B

Laboratory Support Efforts for the U. S.

Bureau of Mines

Part B

Purpose:

To provide additional laboratory testing for the U.S. Bureau of Mines research projects in which sulphur is being investigated as an additive to binders of sulphur recycled pavement mixtures and sulphur concrete.

Background:

For the past three years TTI has been providing technical support to the U. S. Bureau of Mines' Metallurgy Laboratory in Boulder City, Nevada, in the area of sulphur recycled asphalt pavements and sulphur modified concretes. Specifically, this support has been in the form of freeze-thaw and flexure fatigue testing.

The past year's effort has included flexure fatigue testing for recycled Nellis Air Force Base material, recycled Boulder Highway material, recycled Los Angeles Freeway material and U.S. 95 sulphur-asphalt. TTI has also conducted freeze-thaw testing on a number of sulphur concrete samples received from the Bureau of Mines.

Test Results:

Flexure Fatigue

Flexure fatigue results from this year's testing appears in Figure 1-B through 4-B. The fatigue testing apparatus which was used to obtain these results is described in Reference 7.

It can be seen in Figure 1-B that the recycled mixture containing 1.0% virgin asphalt and 0.5% Paxole [8] maintains a consistantly higher strain level than the other two designs in Boulder Highway. The

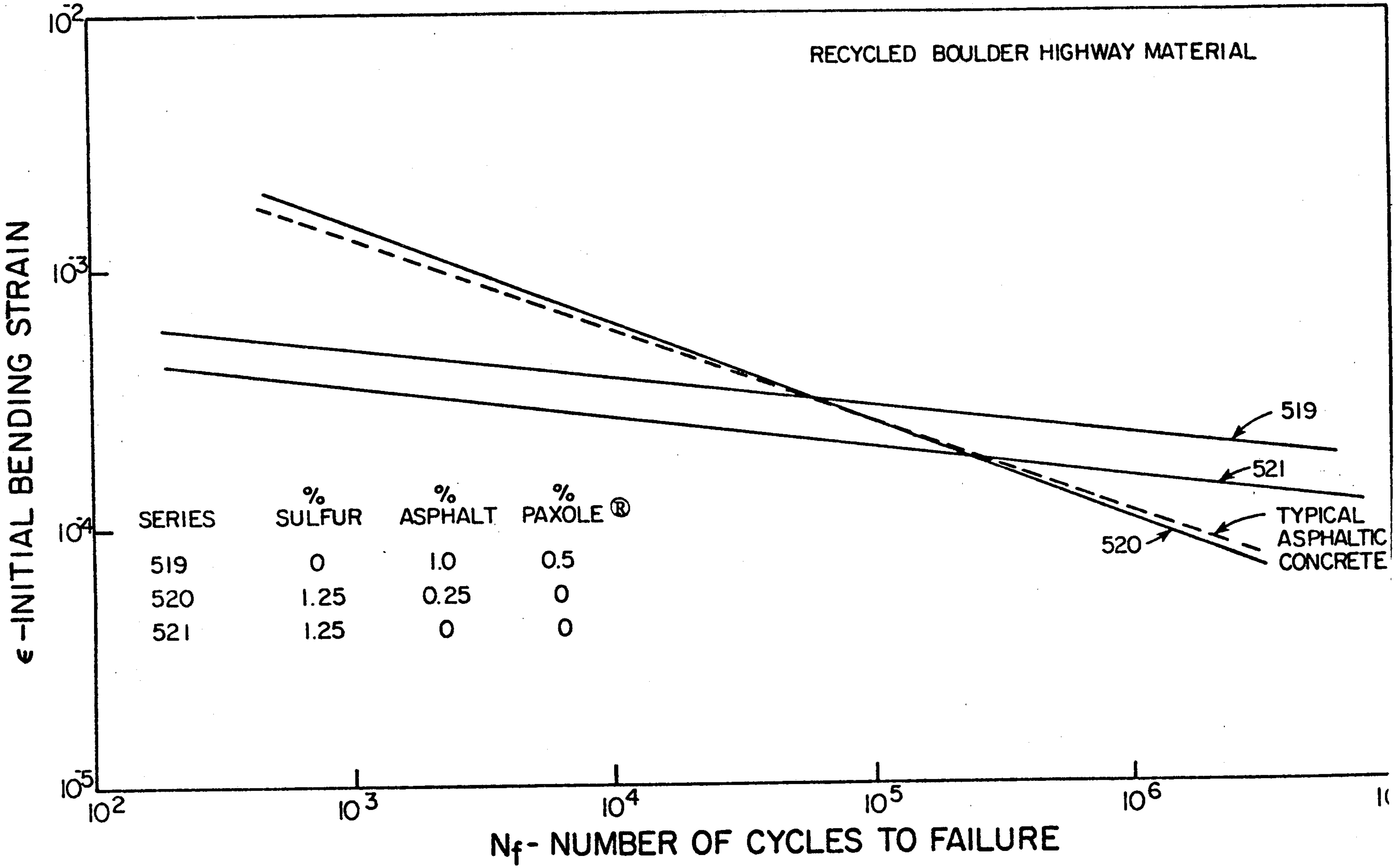


Figure 1-B. Fatigue Curves for Recycled Boulder Highway Material

recycled mixture containing only 1.25% sulphur has a curve which roughly parallels the curve of asphalt and Paxole mixture at a lower strain. The curve of the 1.25% sulphur and 0.25% asphalt mixture shows a fatigue curve similar to that of the typical asphaltic concrete which starts at a higher strain but becomes more susceptible to fatigue with time than the other two designs.

Figure 2-B once again shows that the asphalt and Paxole mixture maintains a higher strain level than the other two mixture designs from Nellis Air Force Base. Also similar to Figure 1-B the mixture recycled with sulphur alone parallels that recycled with asphalt and Paxole at a lower strain level. Once again the mixture containing sulphur and virgin asphalt possesses about the same fatigue properties as typical asphaltic concrete.

The general fatigue characteristics of the materials from the recycled Los Angeles Freeway do not greatly differ from those already discussed. Figure 3-B shows that the Paxole and asphalt mixture can initially sustain a higher strain than the mixture recycled only with sulphur. In this case, however, the slope of the fatigue curve for the Paxole and asphalt mixture is steeper than those for the same material at Boulder City and Nellis A.F.B.

The results from the flexure fatigue testing of the U.S. 95 Sulphur-Asphalt test section at Boulder City, Nevada are shown in Figure 4-B. These results indicate that while the sulphur-asphalt mixtures can initially withstand less strain they are less susceptible to fatigue over a longer period of time than the conventional asphaltic concrete mixture.

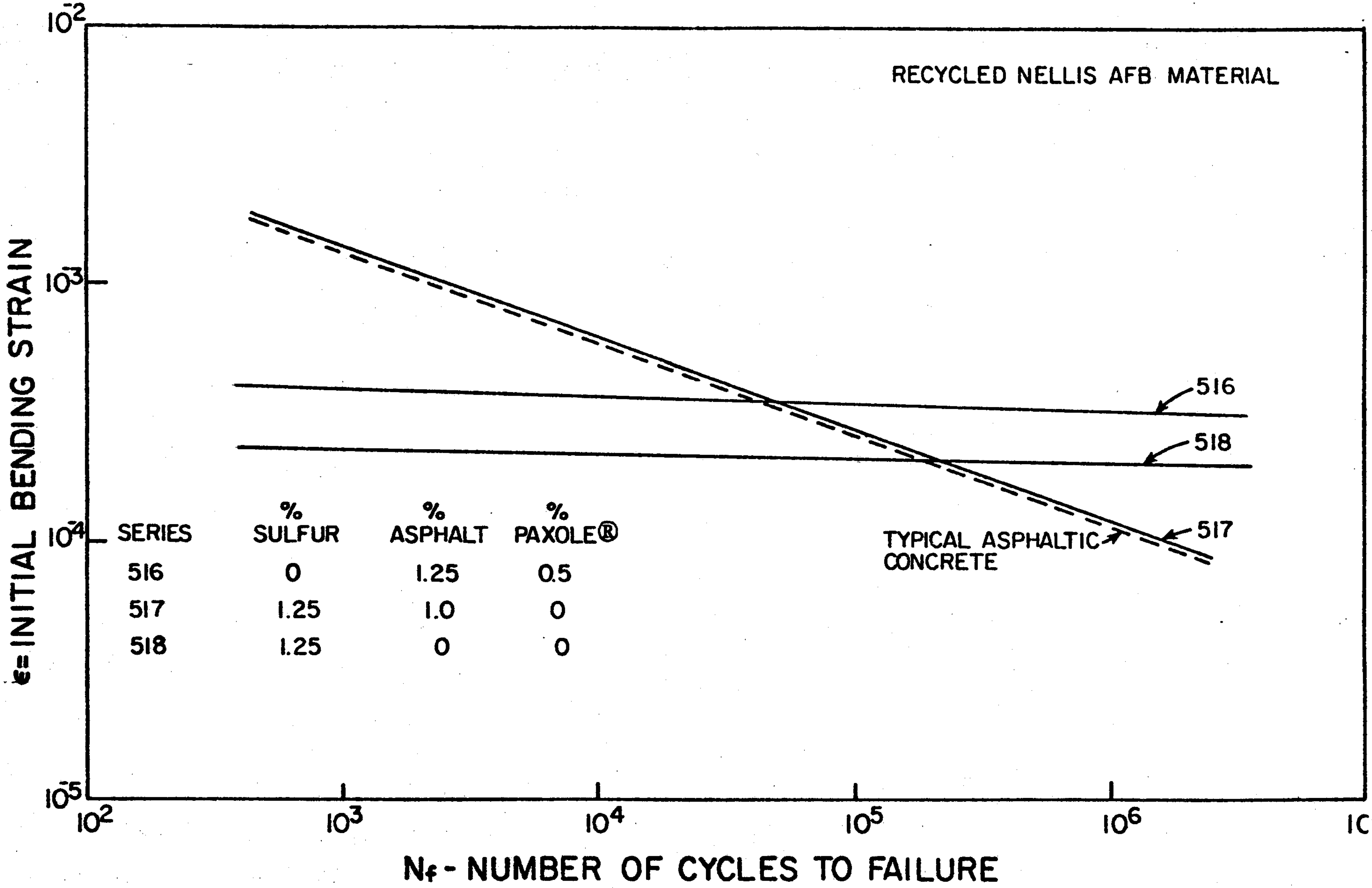


Figure 2-B. Fatigue Curves for Recycled Nellis A.F.B. Material

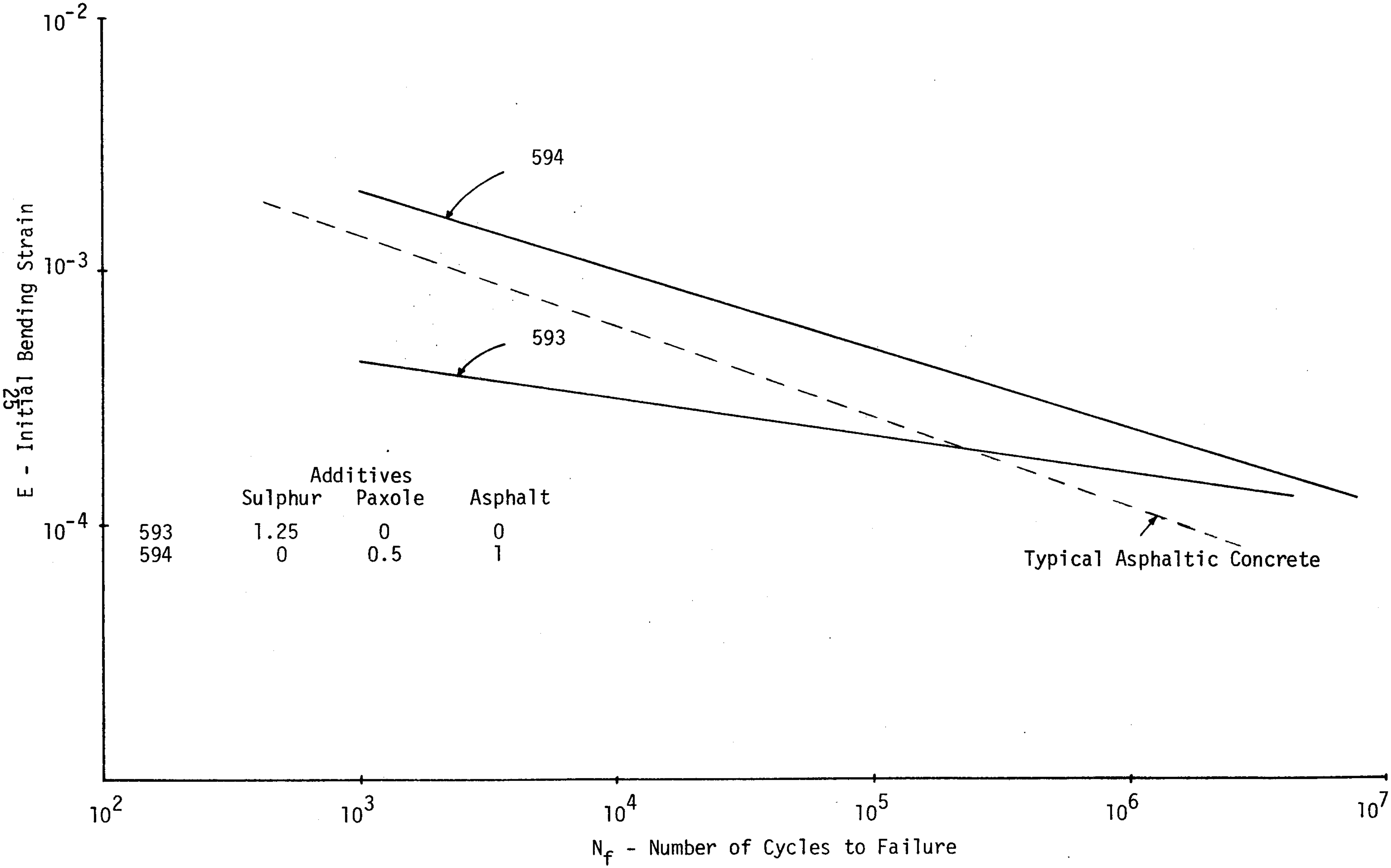
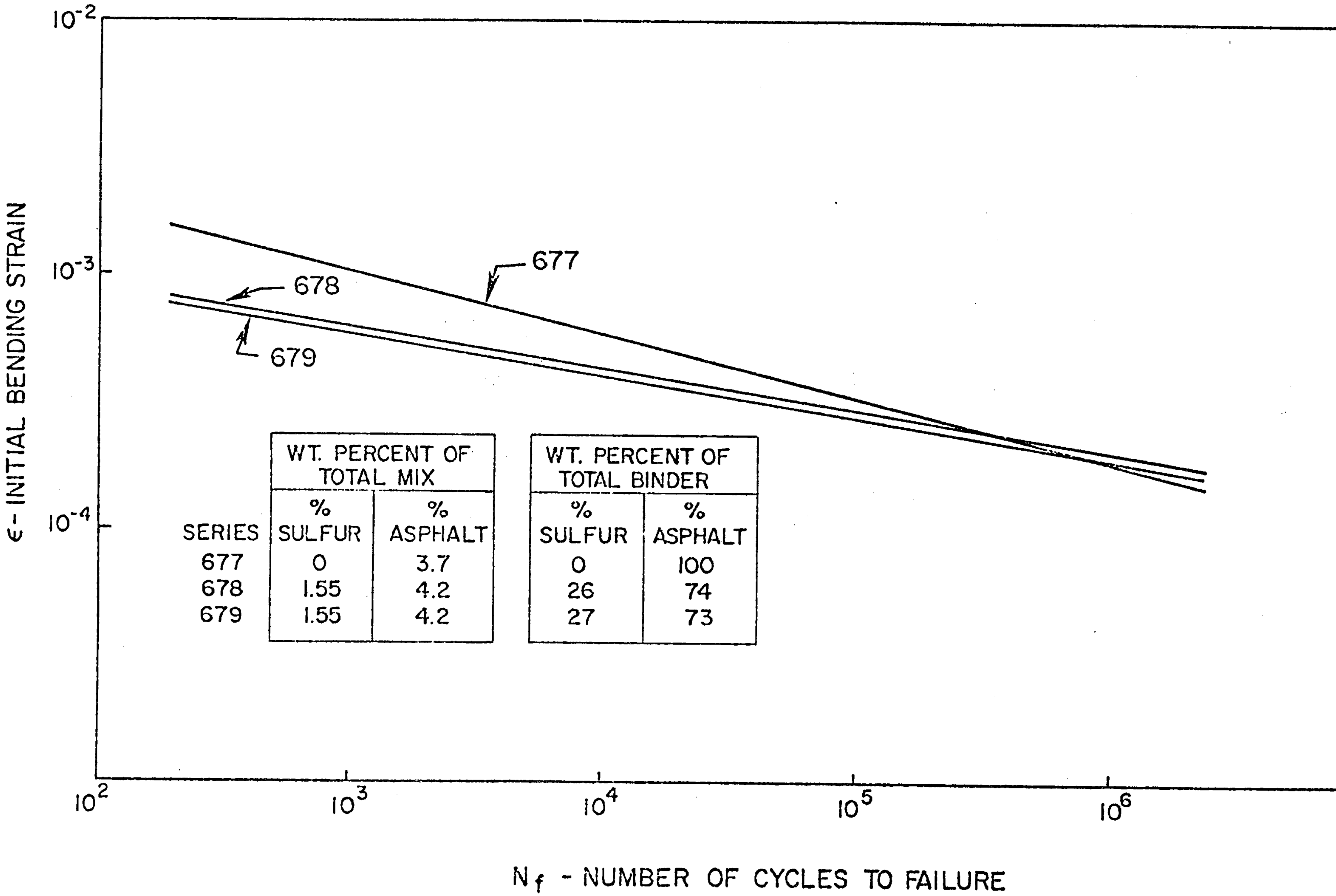


Figure 3-B. Fatigue Curves for Recycled Los Angeles Freeway Material.



SERIES	WT. PERCENT OF TOTAL MIX % SULFUR	WT. PERCENT OF TOTAL MIX % ASPHALT	WT. PERCENT OF TOTAL BINDER % SULFUR	WT. PERCENT OF TOTAL BINDER % ASPHALT
677	0	3.7	0	100
678	1.55	4.2	26	74
679	1.55	4.2	27	73

Figure 4-B. Fatigue Curves for Sulphur-Asphalt U.S. 95 Boulder City, Nevada.

Freeze-Thaw Testing:

Results of the freeze-thaw and residual flexual strength testing of sulphur-concrete beams received from the U.S. Bureau of Mines appear in Table 1-B.

The freeze-thaw testing was conducted under the specifications described in ASTM C666, procedure A. The relative dynamic modulus of elasticity was calculated according to the equation

$$P_c = n_1^2/n^2 \times 100$$

where: P_c = relative dynamic modulus of elasticity after c cycles of freezing and thawing (%),

n = fundamental transverse frequency at 0 cycles of freezing and thawing at dry weight (not SSD), and

n_1 = fundamental transverse frequency after c cycles of freezing and thawing. [9]

This calculation of P_c is based on the assumption that the weight and dimensions of the specimens remain constant. This assumption did not hold true for the sulfur concrete specimens tested. However, since this test will be used to make comparisons of the relative dynamic moduli of different formulations, P_c is assumed to be adequate for the purpose. [9]

Graphs of relative dynamic modulus of elasticity versus time are shown in Figure 1-B through 11-B for the various compositions of samples.

The durability factor was calculated according to the equation

$$DF = P_c N_c / M$$

Tabel 1-B. Results from Freeze-Thaw and Residual Flexure Strength Test.

SERIES NO.	COMPOSITION %		FREEZE-THAW RESULTS		RESIDUAL FLEXURAL STRENGTH RESULTS	
	Binder	Aggregate (Type)	Average Durability Factor (%)	Remarks	Average Flexural Strength (psi)	Modulus of Rupture (psi)
582 & 604	23 (75-25m)	77 (Quartz)	40		219	245
583 & 605	23 (65-35m)	77 (Quartz)	31	Spalling, Large Voids	248	204
585	23 (50-50m)	77 (Quartz)	25	Spalling, Large Voids	275	275
586	21 (75-25m)	79 (Limestone)	92		1453	1430
587	21 (65-35m)	79 (Limestone)	90	Spalling, Cracking	773	750
588	21 (50-50m)	79 (Limestone)	71	Spalling, Small Voids	758	863
625	23 (50-50m)	77 (Quartz)	41	Small Voids	303	303
526	23 (65-35m)	77 (Quartz)	61	Spalling	474	474
628	23 (75-25m)	77 (Quartz)	59	Spalling, Small Voids	422	416
629	23 (100PCPD)	77 (Quartz)	54	Spalling, Large Voids	342	328
630	23 (70-30m)	77 (Quartz)	42	Spalling	290	289

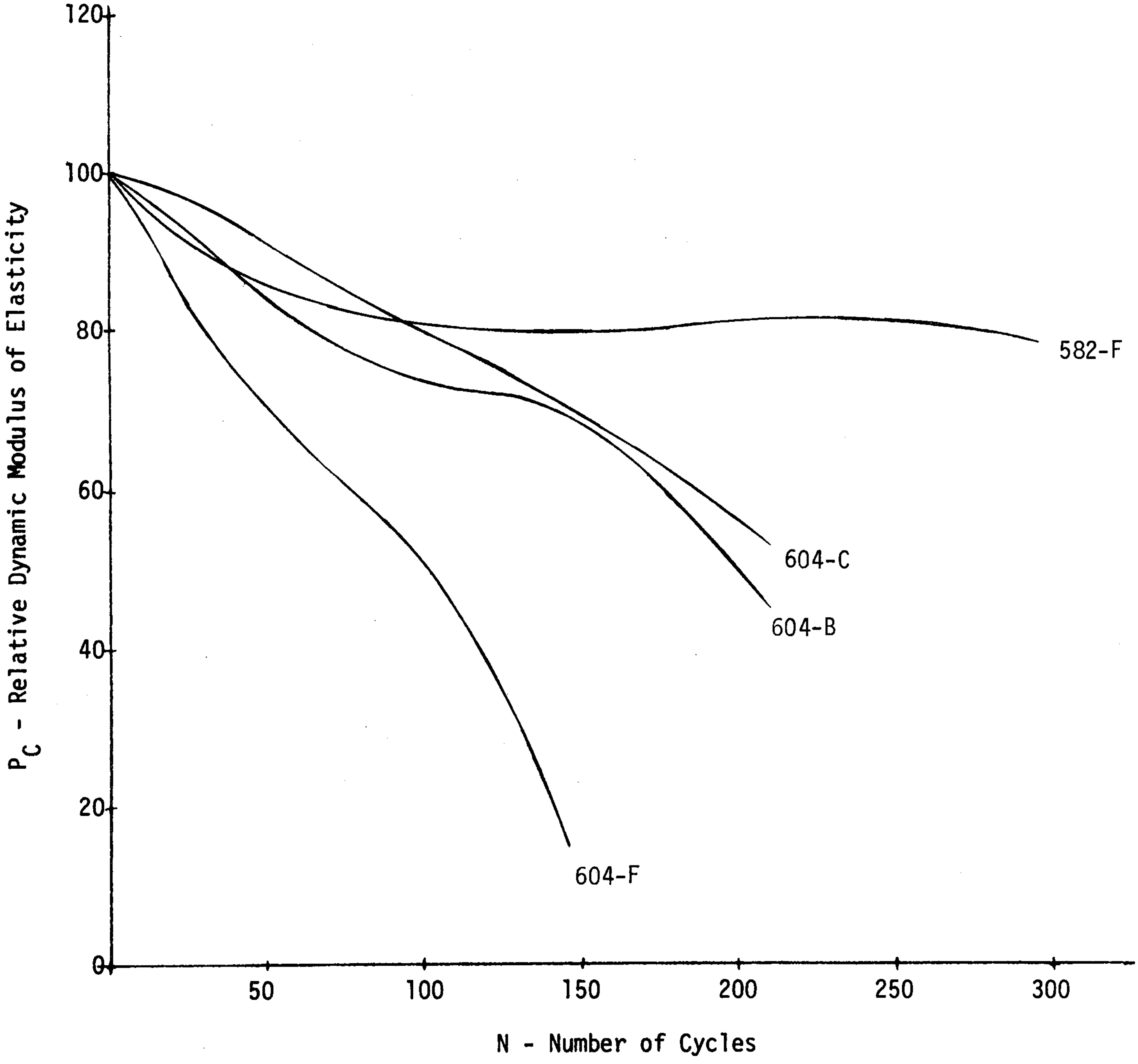


Figure 1-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 582-F & 604-B, C, F.

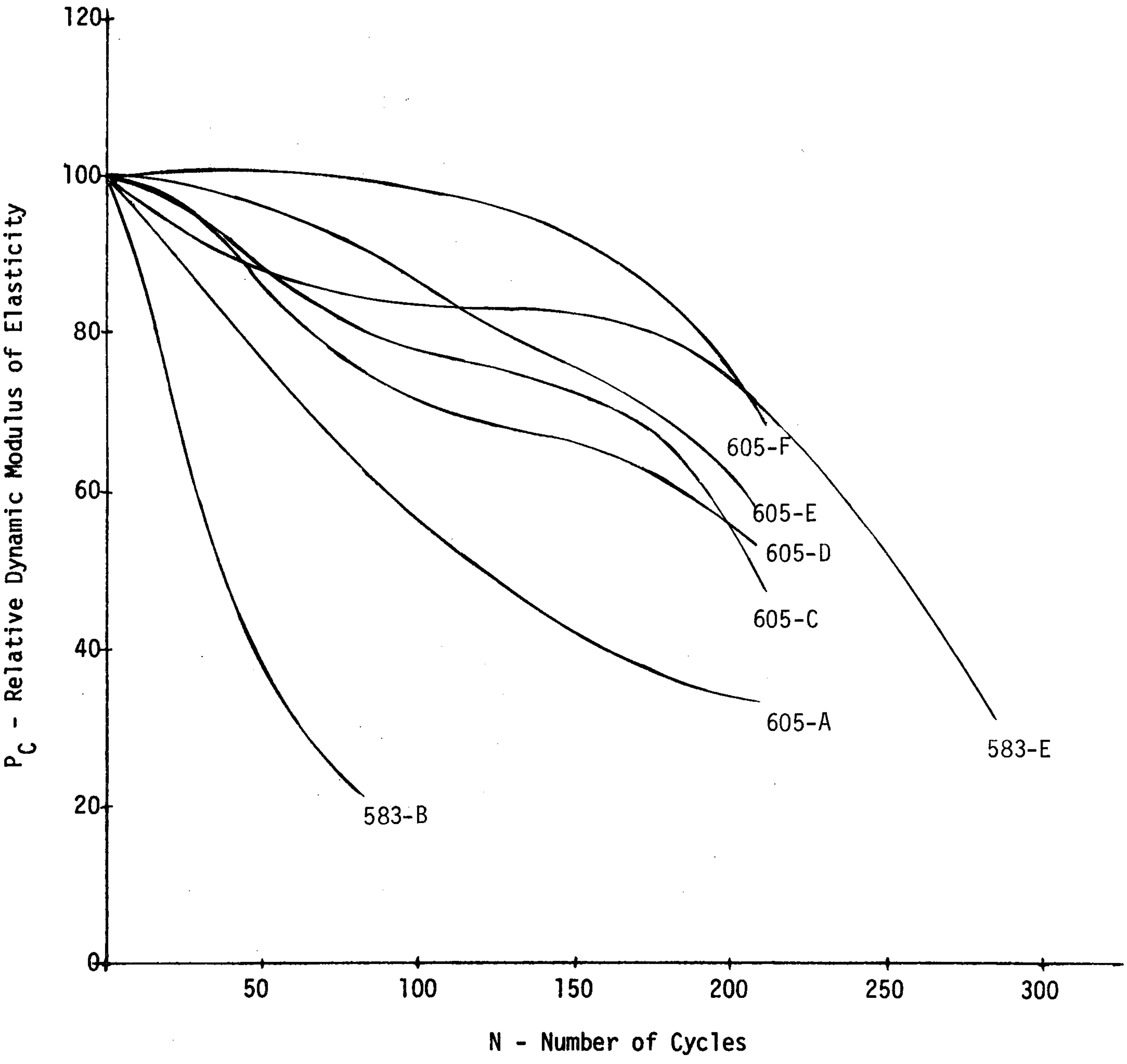


Figure 2-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 583-B, E & 605-A, C, D, E, F.

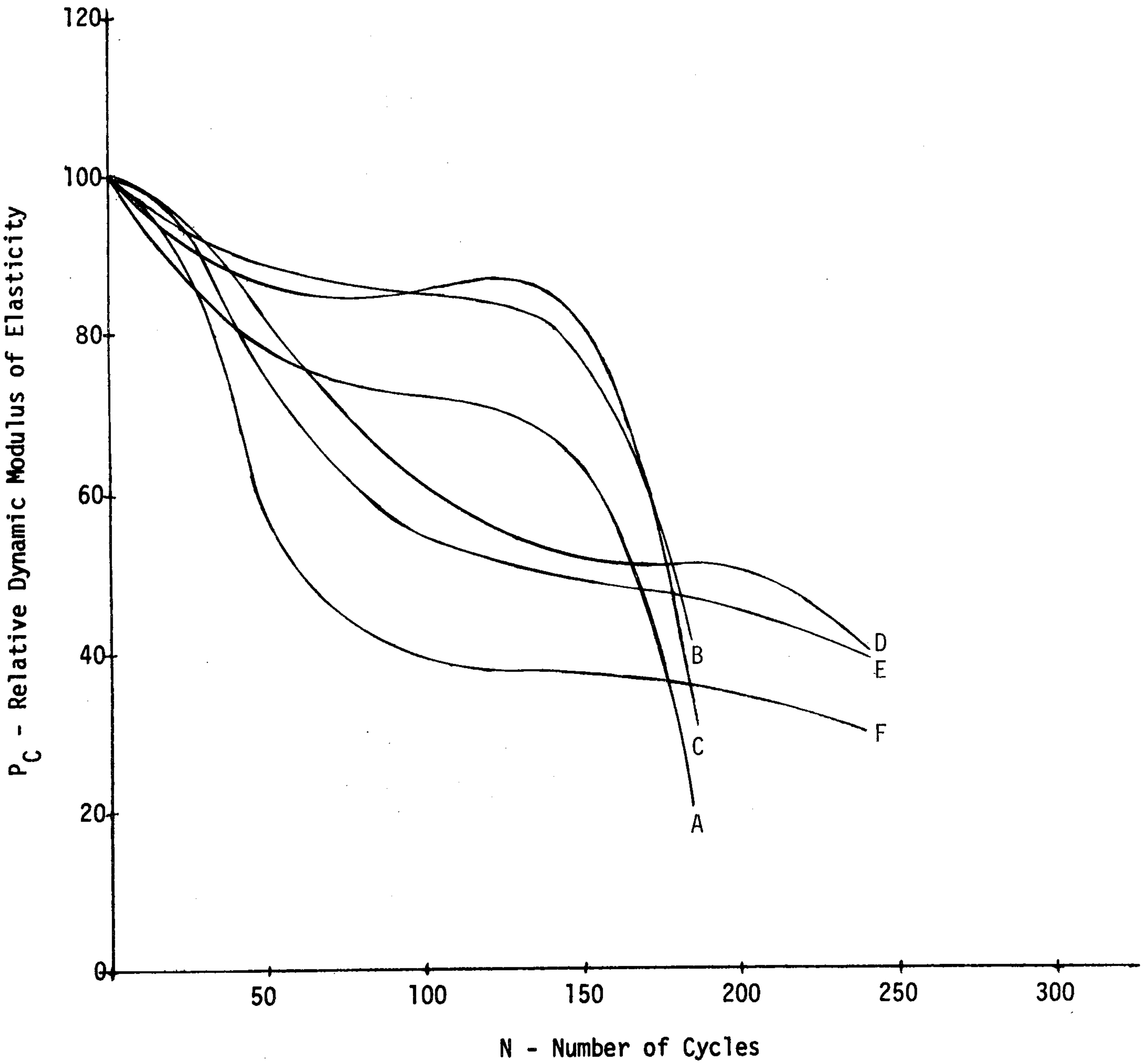


Figure 3-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 585-A, B, C, D, E, F.

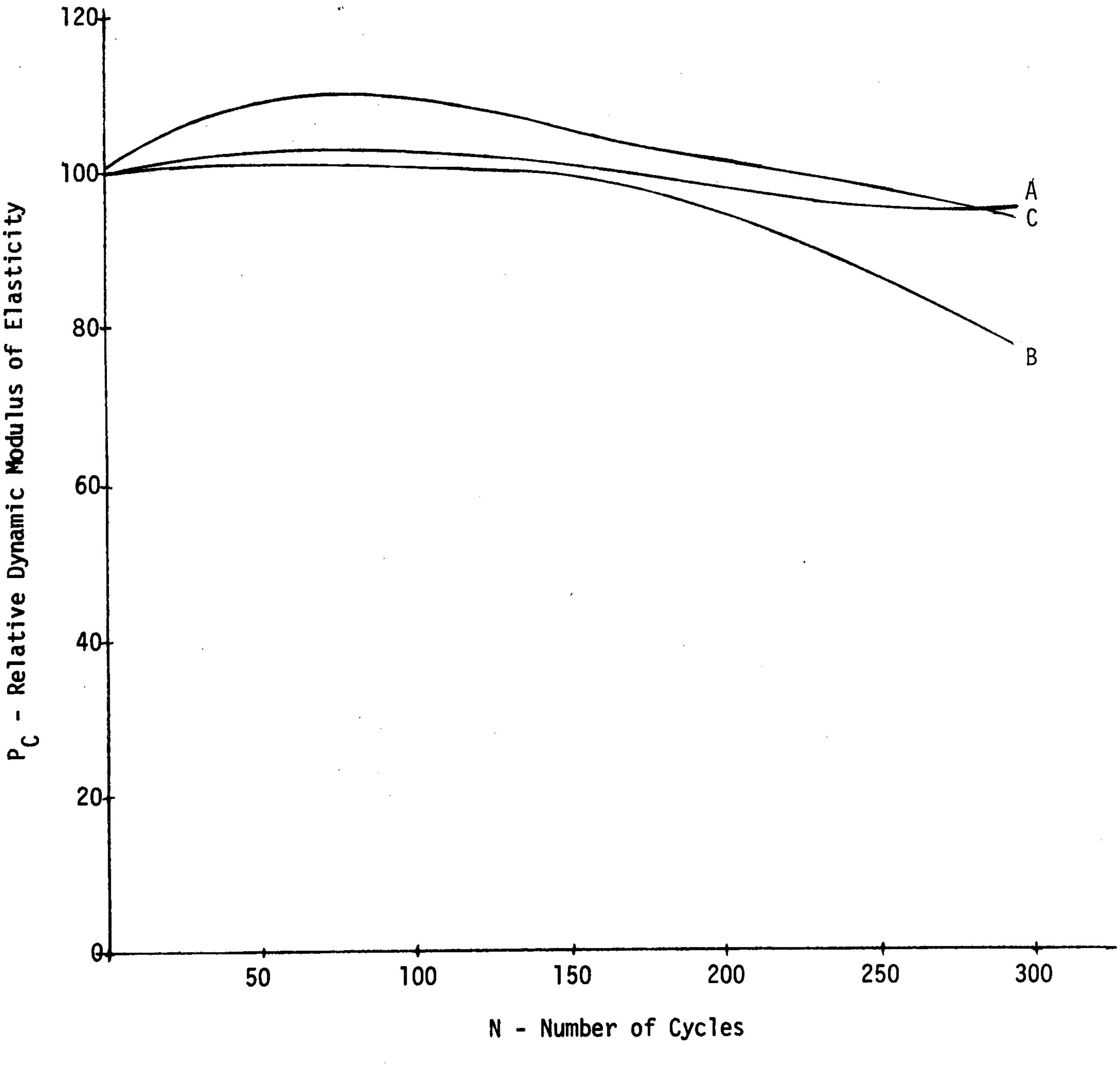


Figure 4-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 586-A, B, C.

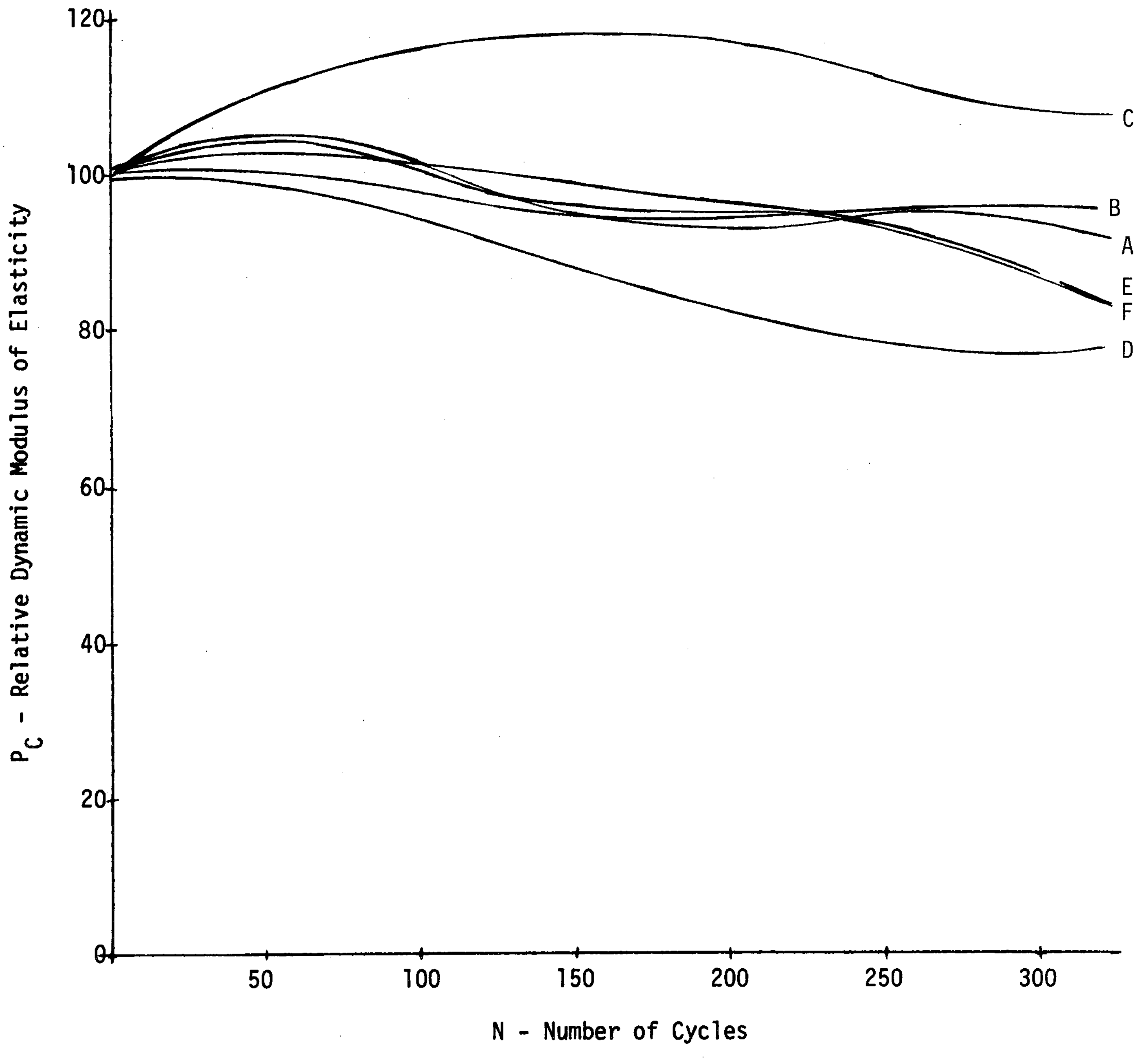


Figure 5-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 587-A, B, C, D, E, F.

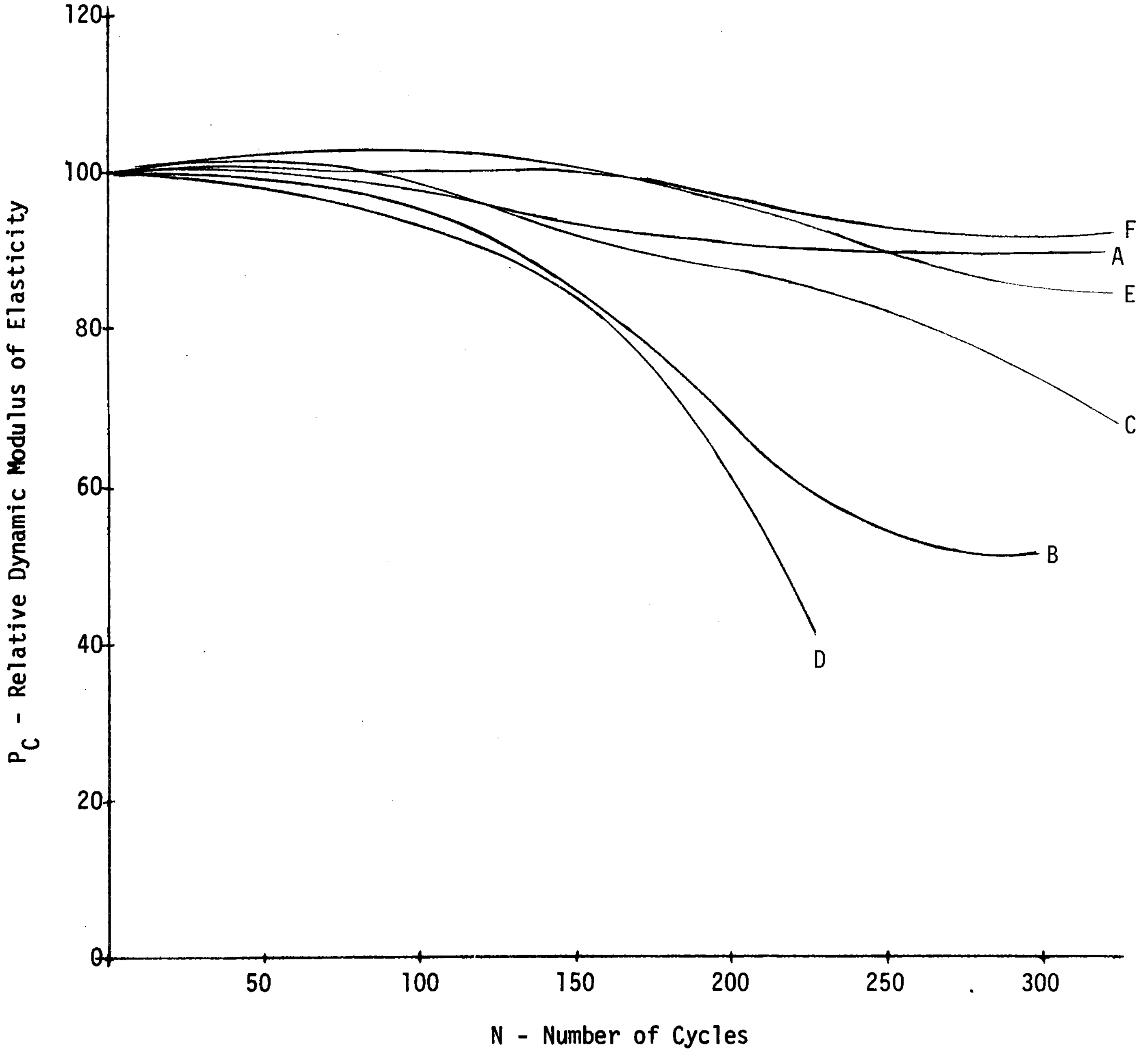


Figure 6-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 588-A, B, C, D, E, F.

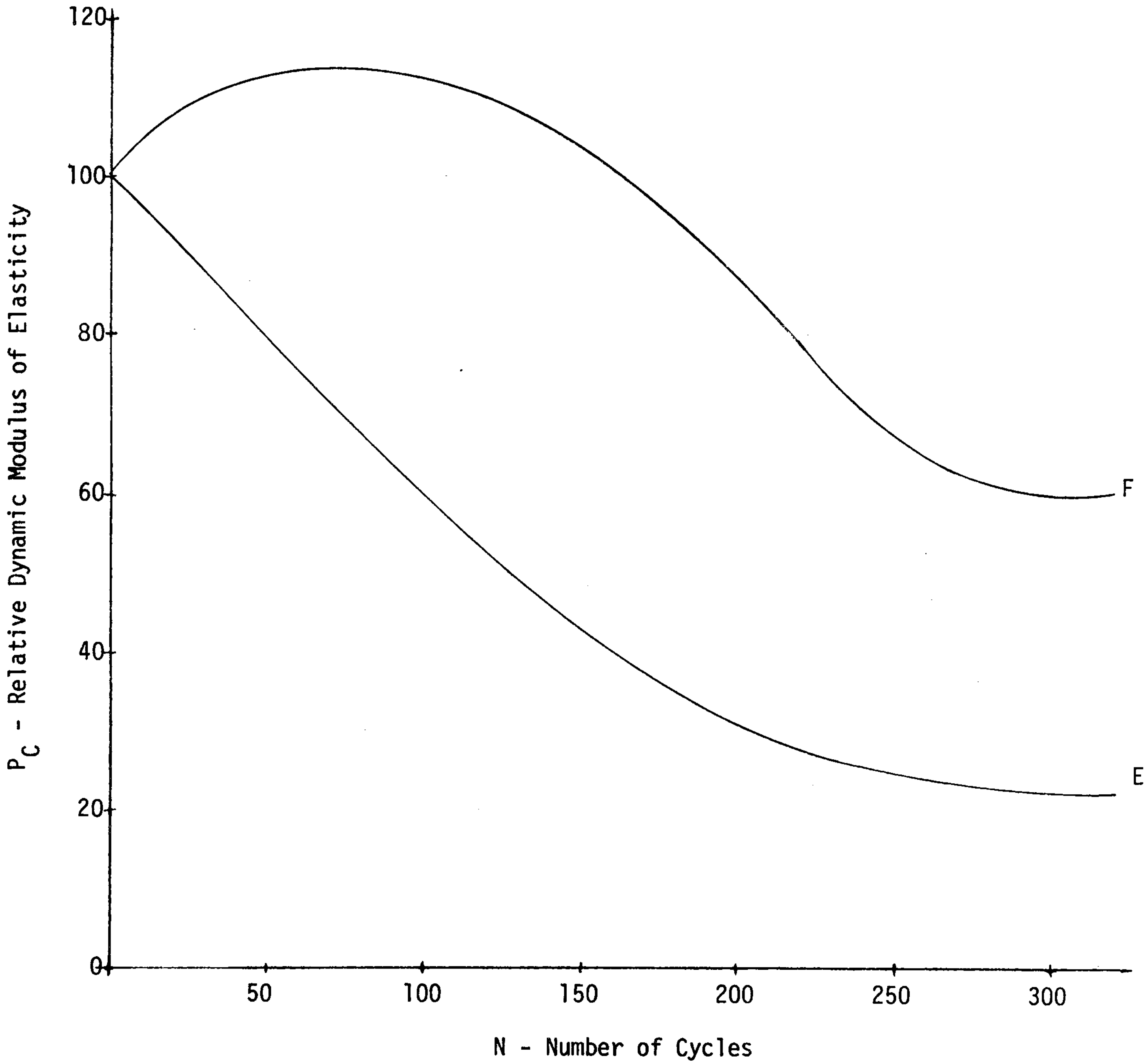


Figure 7-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 625-E, F.

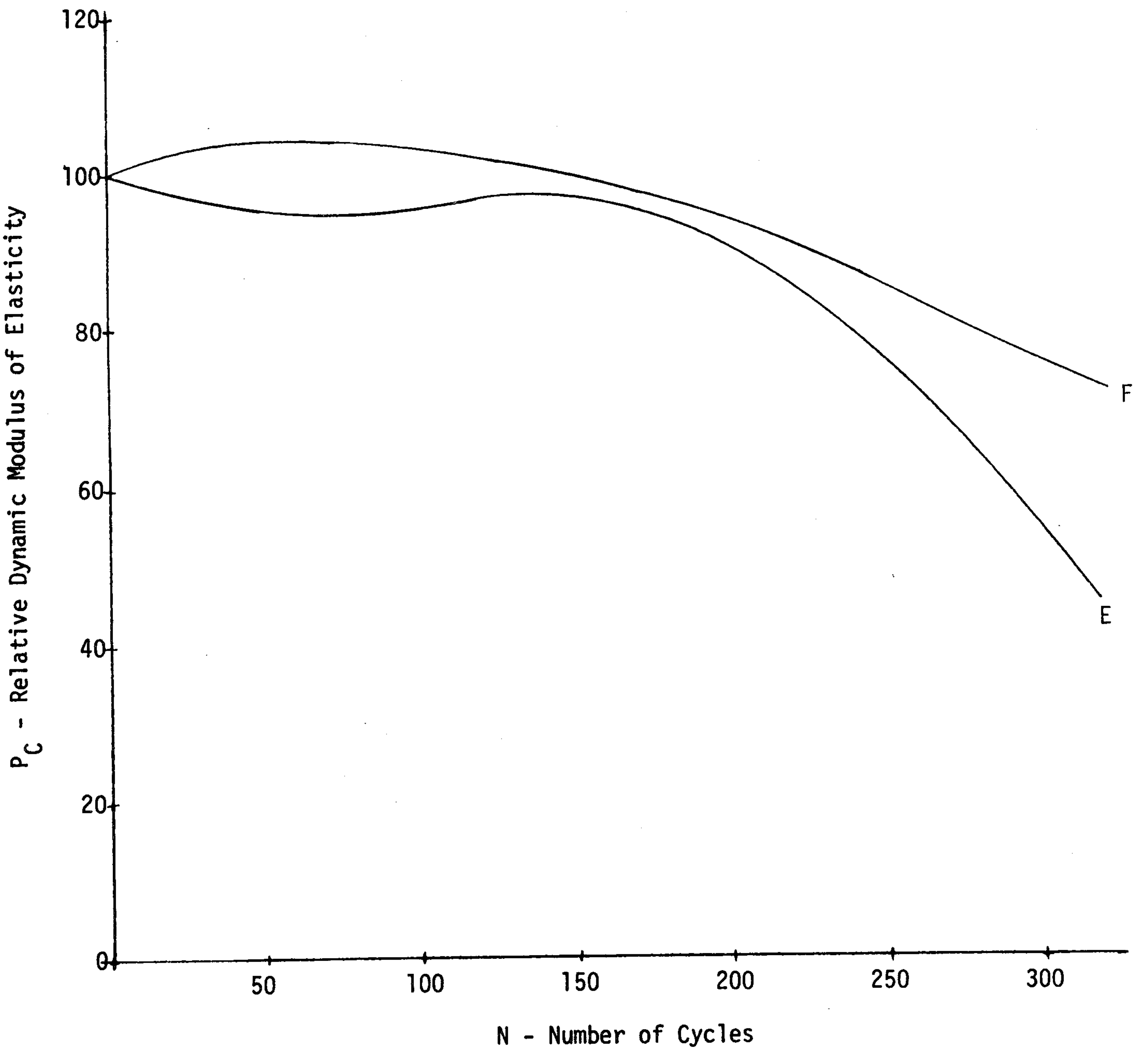


Figure 8-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 526-E, F.

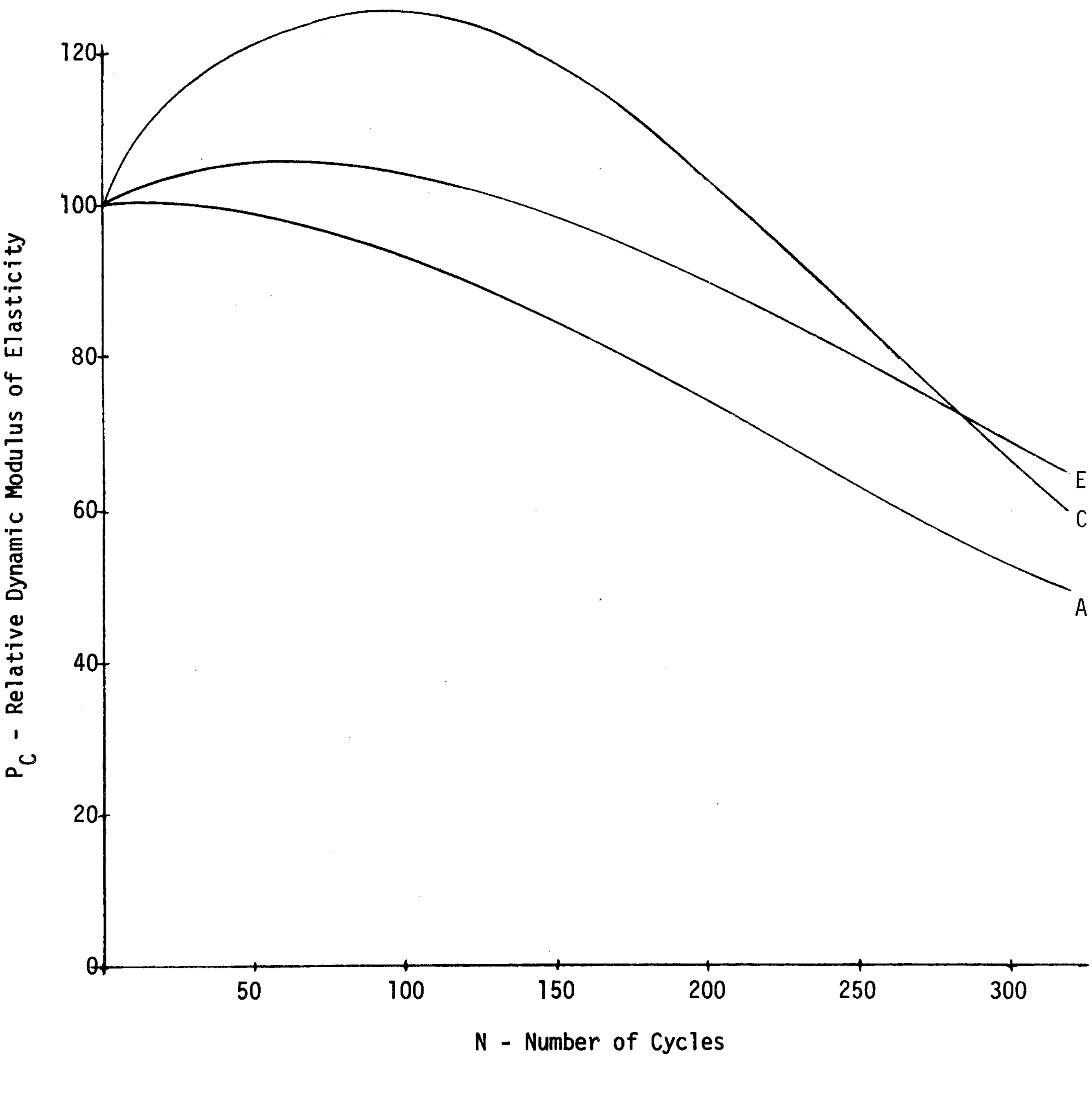


Figure 9-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 628-A, C, E.

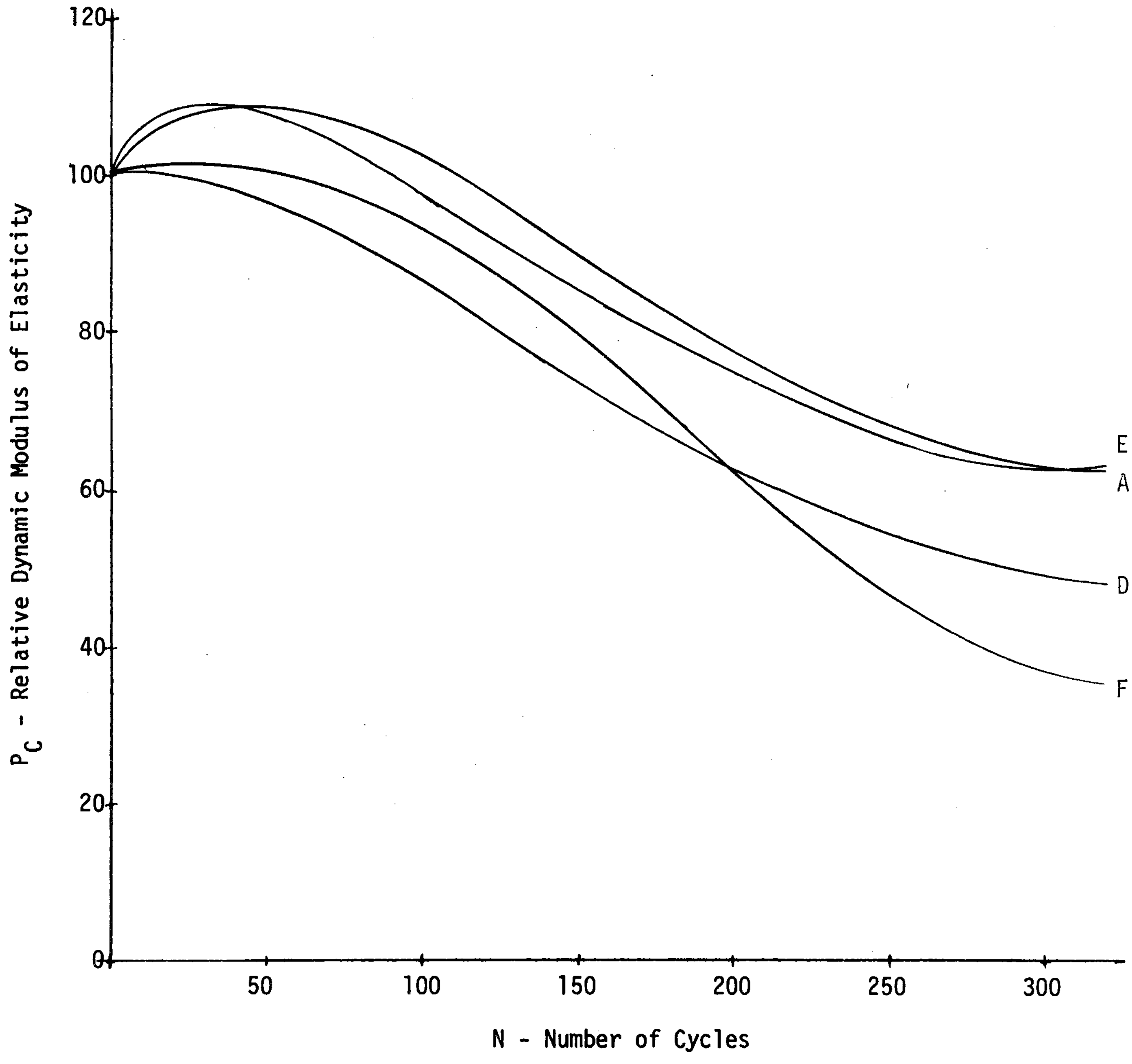


Figure 10-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 629-A, D, E, F.

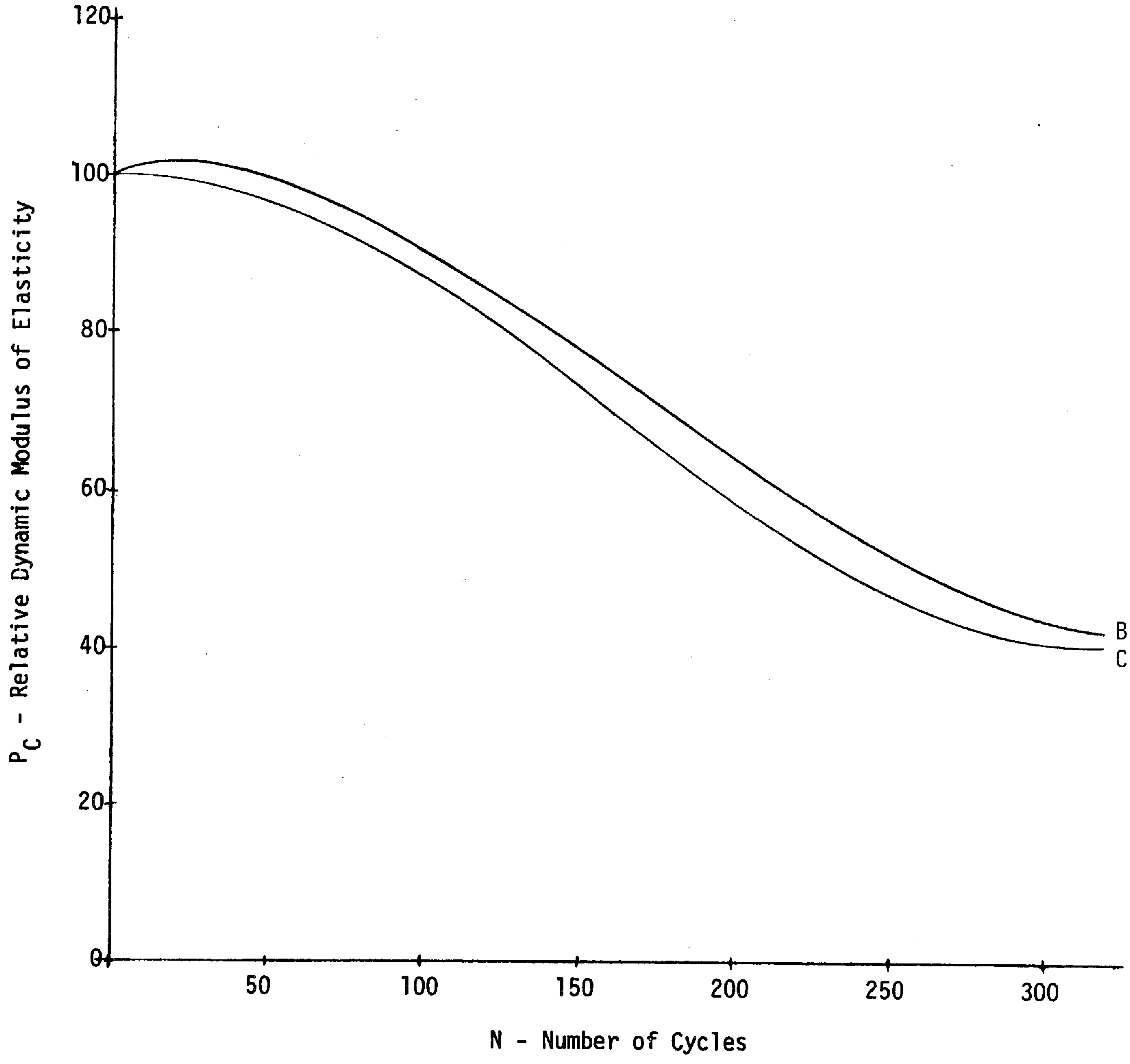


Figure 11-B. Relative Dynamic Modulus vs. Number of Freeze-Thaw Cycles for Sample Nos. 630-B, C.

where: DF = durability factor of the specimen (%),

P_c = relative dynamic modulus of elasticity at c cycles (%),

N_c = number of cycles at which P reaches the minimum value for discontinuing the test or the specified number of cycles at which the exposure is terminated, whichever is less, and

M = specified number of cycles at which the exposure was to be terminated.[9]

The following modifications were made in testing the sulfur concrete specimens:

1) regular tap water was used instead of lime water since these were not portland cement samples, and

2) failure was defined as being that point at which the samples reached 50% of their original dynamic modulus of elasticity as opposed to 60%, as prescribed by ASTM.

The flexure tests were conducted on the beams upon completion of the freeze-thaw tests. The beams, therefore, were in a deteriorated condition and were not the standard specimen length designated in ASTM C78-64. The residual flexural strengths of the beams were determined using third-point loading at a constant crosshead speed of 0.05 in./min.

The flexure stress was calculated by using the equation:

$$\delta = Mc/I$$

where: δ = flexural strength (psi)

M = maximum moment (in.-lbs.)

c = distance from neutral axis to the extreme fiber (inches)

I = moment of inertia (in.^{4})

The modulus of rupture was calculated using two separate equations:

1) If the fracture occurred within the middle third of the span length $R = Pl/bd^2$ was used where:

R = modulus of rupture (psi),

P = maximum applied load indicated by the testing machine (lbs.),

l = span length (gage length, inches),

b = average width of specimen (inches), and

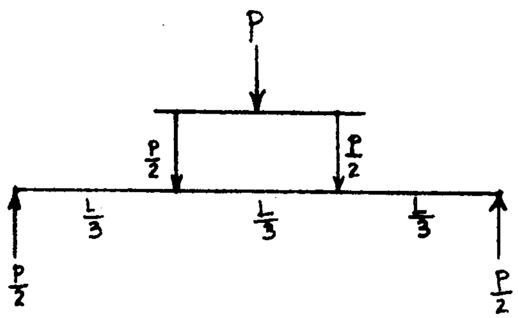
d = average depth of specimen (inches).

2) If the fracture occurred outside the middle third of the span length by not more than 5% of the span length $R = 3Pa/bd^2$ was used, where:

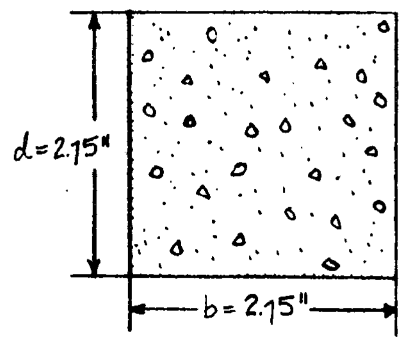
a = distance between the line of fracture and the nearest support measured along the center line of the bottom surface of the beam (inches).

Since fracture did not occur outside the middle third of the span length by more than 5% of span length, none of the samples were discarded.

A diagram of the third point loading and typical beam cross-section are shown in Figure 12-B.



Load application at the third points



Cross-section of beam

Figure 12-B. Thirdpoint Loading Diagram and Beam Cross-section.

Conclusions:

At this writing a series of freeze-thaw specemins are still under test. A proposal to continue the service effort into the next calender year was sent to the Bureau on 4 October 1978. This proposal also contained activity to further expand the data base and in-service performance predictions capability of sulfur-recycled asphalt pavements. The effort to date has been primarily directed to analyzing recycled materials taken from the Las Vegas area. The proposal task would evalute other materials and also examine the economics aspects of sulfur-recycling in the light of current materials cost trends and processing technology.

REFERENCES

1. Izatt, J. O., Gallaway, B.M., Saylak, D., Sand-Asphalt Pavement Experimental Project Highway U.S. 77, Kenedy County, Texas, "A Construction Report," April, 1977.

2. Saylak, D., Gallaway, B.M., "Post Construction Evaluation of U.S. 77 Kenedy County Sulphur-Asphalt-Sand Pavement Test Sections," Interim Report No. 1, October, 1977.

3. Schmidt, R.M., "A Practical Method for Determining the Resilient Modulus of Asphalt Treated Mixes," Chevron Research Company, Richmond, California, Highway Research Board Meeting, January 18, 1972.

4. Scrivner, F.H. and Moore, W.M., "An Electro-Machanical System for Measuring the Dynamic Deflection of a Road Surface Caused by an Oscillating Load," Research Report No. 32-4, Texas Transportation Institute, December, 1964.

5. Goss, C.L., Hawkins, K.D., and Hubbard, A.B., "Equipment for Collecting Pavement Roughness Information," Department Research Report No. 2-1, Texas State Department of Highways and Public Transportation, December, 1976.

6. Mahoney, J.P. and Lytton, R.L., "Measurements of Pavement Performance Using Statistical Sampling Techniques," Research Report No. 207-2, Texas Transportation Institute, Draft, March, 1978.

7. Epps, J.A., "Influences of Mixture Variables on the Flexural Fatigue and Properties of Asphaltic Concrete," Thesis, University of California, Berkeley, 1968.

8. McBee, W., Sullivan, T., and Saylak, D., "Recycling Old Asphaltic Pavements with Sulphur," a paper presented to the American Society for Testing Materials, Ottawa, September, 1978.

9. Annual ASTM Standards, Concrete and Mineral Aggregation; Manual of Concrete Testing, Part ID, November, 1973.