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J. M. HOOVER
L. D. SQUIER
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DECEMBER 1975

Progress Report 2
ISU-ERI-Ames-76202

EVALUATION OF CHEMICALLY STABILIZED SECONDARY ROADS—LINN COUNTY, IOWA

ERI Project 1049S

ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY
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PROGRESS REPORT 2

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ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY AMES

A cooperative research project in affilliation with:

Allis-Chalmers Construction Machinery Division
American Admixtures
American Can Company
Armak Highway Chemicals Department
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Linwood Stone Products Company, Inc.
Macklin Inc.
National Ash Association
National Chemical Stabilization Association
National Lime Association
Salt Institute
Sandar Inc.
Saunders Petroleum Company
Scott Paper Company

This project is also partially supported by the Engineering Research Institute at Iowa State University, Ames, Iowa 50011.

INTRODUCTION

This is the second Progress Report on the "Evaluation of Chemically Stabilized Secondary Roads," Linn County, Iowa. Progress Report 1, dated May 1974, described (a) the purpose, objectives, and phases of the project, (b) construction, (c) location and materials, (d) post-construction density and moisture contents, and (e) limited Benkelman Beam and Spherical Bearing Value (SBV) field tests. Only selected portions of Progress Report 1 will be included herein due to a two-fold effort of making this report as understandable as possible while conserving what little project funds are still available.

The report is divided into three parts. Part 1 presents field test data of the test and control sections, with some performance evaluation. Part 2 presents a major portion of the laboratory evaluations of the untreated and treated soils of each test section. Part 3 presents an overall discussion and summary of results, to date.

It should be clearly understood that the data, observations, and evaluations presented in this report, though now constituting a major part of the total project, are still limited to a representation of progress of the project only, and not as final objective results.

Table 1 presents data relative to sponsors, additives, and representative classification of soil for each test section.

Table 1. Test section data relative to sponsors, additives and classification of soil.

Section No.	Company	Material	AASHO Soil Classification	Mix Depth, in.	Unified Class	Application: Quantity or Rate, 1000 ft Section
T-2[a]	Scott, Flambeau, Rayonier, Macklin	Lignosulfonate	A-2-4(0)	6	SM	1 1/2 gal./sq yd
T-2A[a]	Same & Ciba-Geigy	Lignosulfonate & Pramitol 25	A-2-4(0)	6	SM	1 1/2 gal./sq yd & 20 gal./acre
T-3[a]	Ciba-Geigy	Pramitol 25	A-2-4(0)	3	SM	15 gal./acre-shoulder only
T-3A[a]	Same	Same	A-2-4(0)	3	SM	20 gal./acre-shoulder only
T-5	Salt Institute	Sodium Chloride	A-3	6	SM	2 lbs/sq yd/ inch of depth
T-6	Saunders Petroleum & Nat. Chem. Stab. Assoc.	Kelpak	A-2-4(0)	6	SM	50 gal. at 10 gal./ 1000 gal. H_2O
T-8AS[b]	Same as T-6	Clapak/Claset	Subgrade treated,	6		15 gal. Clapak/ 10 gal. Claset in 3000 gal. H_2O
T-8BS[b]			A-6(9) west		CL	
			A-4(3) east		ML	
T-8AB[b]	Same as T-6	SA-1	Base treated	6		10 gal. at 1 gal./ 1000 gal. H_2O
T-9			A-4(1) west		SM	
T-8BB[b]			A-2-4(0) middle		SM	
			A-1-b east			

Table 1. (continued)

T-10	Armak and Emulsified Asphalts	Asphalt emulsion	A-2-6(1)	4	SC	4+%
T-11	National Lime Assoc. & Linwood Stone Products	Hydrated Lime	A-6(5)	8	CL	4%
T-12	National Ash Assoc. & Chicago Flyash Co.	Hydrated Lime & Flyash	A-6(4)	6	SC	4% Lime, 12% Flyash
T-13	Dow Chemical Co.	Liquidow	A-2-6(0)	6	SC	1/3 gal./sq yd
T-14	Bitucote Products	Asphalt Emulsion	A-6(2)	6	SC	4%
T-16	Del Chemical Co.	Terra-Seal	A-6(1)	6	SC	6 gal. at 1 gal./ 1000 gal. H_2O
T-17	Dow Chemical Co.	Liquidow	(Surface application only)			1/3 gal./sq yd
T-19	Sandar, Inc.	Lignosulfonate & hydrated lime	A-7-6(12)	6	CL	1 gal./sq yd 2% lime

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[a] 500 ft. length sections.

[b] AS represents west half of section T-8, subgrade
AB represents west half of section T-8, base
BS represents east half of section T-8, subgrade
BB represents east half of section T-8, base

Table 1. Test section data relative to sponsors, additives and classification of soil.

Section No.	Company	Material	AASHO Soil Classification	Mix Depth, in.	Unified Class	Application: Quantity or Rate, 1000 ft Section
T-2[a]	Scott, Flambeau, Rayonier, Macklin	Lignosulfonate	A-2-4(0)	6	SM	1 1/2 gal./sq yd
T-2A[a]	Same & Ciba-Geigy	Lignosulfonate & Pramitol 25	A-2-4(0)	6	SM	1 1/2 gal./sq yd & 20 gal./acre
T-3[a]	Ciba-Geigy	Pramitol 25	A-2-4(0)	3	SM	15 gal./acre-shoulder only
T-3A[a]	Same	Same	A-2-4(0)	3	SM	20 gal./acre-shoulder only
T-5	Salt Institute	Sodium Chloride	A-3	6	SM	2 lbs/sq yd/inch of depth
T-6	Saunders Petroleum & Nat. Chem. Stab. Assoc.	Kelpak	A-2-4(0)	6	SM	50 gal. at 10 gal./1000 gal. H_2O
T-8AS[b]	Same as T-6	Clapak/Claset	Subgrade treated,	6		15 gal. Clapak/10 gal. Claset in 3000 gal. H_2O
T-8BS[b]			A-6(9) west		CL	
			A-4(3) east		ML	
T-8AB[b]	Same as T-6	SA-1	Base treated	6		10 gal. at 1 gal./1000 gal. H_2O
T-9			A-4(1) west		SM	
T-8BB[b]			A-2-4(0) middle		SM	
			A-1-b east			

Table 1. (continued)

T-10	Armak and Emulsified Asphalts	Asphalt emulsion	A-2-6(1)	4	SC	4+%
T-11	National Lime Assoc. & Linwood Stone Products	Hydrated Lime	A-6(5)	8	CL	4%
T-12	National Ash Assoc. & Chicago Flyash Co.	Hydrated Lime & Flyash	A-6(4)	6	SC	4% Lime, 12% Flyash
T-13	Dow Chemical Co.	Liquidow	A-2-6(0)	6	SC	1/3 gal./sq yd
T-14	Bitucote Products	Asphalt Emulsion	A-6(2)	6	SC	4%
T-16	Del Chemical Co.	Terra-Seal	A-6(1)	6	SC	6 gal. at 1 gal./ 1000 gal. H_2O
T-17	Dow Chemical Co.	Liquidow	(Surface application only)			1/3 gal./sq yd
T-19	Sandar, Inc.	Lignosulfonate & hydrated lime	A-7-6(12)	6	CL	1 gal./sq yd 2% lime

[a] 500 ft. length sections.

[b] AS represents west half of section T-8, subgrade
AB represents west half of section T-8, base
BS represents east half of section T-8, subgrade
BB represents east half of section T-8, base

PART 1. FIELD TESTS

Benkelman Beam

In order to analyze the flexural capabilities of the test sections, Benkelman Beam tests were used to measure deflection of the surface caused by a single rear axle load of 17,300 lb distributed on dual tires (8650 lbs/dual). Each rear tire of the ERI Soil Lab load test truck was maintained at 75 psi air pressure. Since the maximum allowable single axle in Iowa is 18,000 lb, deflections thus determined were near maximum values.

Six or more observations of maximum deflection were made for each test section, two at each of the section quarter points. At each point of testing, deflection measurements were made at both the inside wheel track (IWT) and outside wheel track (OWT) of the load truck travelling within the normal traffic lane. All deflection measurements for both IWT and OWT conditions were averaged and are presented in Table 2.

As a qualitative measure of the flexibility of each test section, a relative stiffness factor was computed by dividing the load/dual in thousands of pounds (kips) by the maximum deflection; the more flexible the material, the lower the relative stiffness factor. These results are presented in Table 3. Figures 1 through 14 present a plot of the relative stiffness values of each test and control section conducted to date. Each point is the summation of the OWT and IWT relative stiffness values from Table 3 and thus represents the stiffness of the section under the full axle load of 17,300 lbs.

Table 2. Benkelman Beam Field Test Deflections

Section	Average Maximum Deflections, in.									
	OWT[a]					IWT[a]				
	Pre-Const.	Post Const.	Fall 1973	Spring 1974	Fall 1975	Pre-Const.	Post Const.	Fall 1973	Spring 1974	Fall 1975
T-2 Control	.073	-	-	.207	-	.052	-	-	.061	-
T-2	.109	.175	.101	.240	-	.094	.092	.042	.219	-
T-2A	.116	.081	.052	.189	-	.076	.051	.043	.093	-
T-5 Control	-	-	-	.021	.038	-	-	-	.017	.049
T-5	.018	.019	.017	.025	.041	.014	.017	.016	.017	.038
T-6 Control	.036	-	-	.030	.068	.018	-	-	.024	.070
T-6 Seal	.021	.021	.018	.020	.049	.015	.014	.017	.019	.033
T-6 No Seal	.027	.019	.017	.023	.053	.015	.020	.015	.012	.022
T-8A Control	-	-	-	.038	.044	-	-	-	.031	.033
T-8A	.016	.017	.010	.052	.054	.010	.014	.014	.044	.044
T-9	.016	.013	.013	.022	.044	.011	.010	.012	.013	.035
T-8B Control	-	-	-	.012	.022	-	-	-	.011	.022
T-8B	.015	.015	.014	.019	.049	.015	.012	.014	.017	.048
T-10,11, 12,13 & 14 Control	.096	-	-	-	.186	.042	-	-	-	.091
T-10 Seal	.072	.054	.022	.098	.061	.043	.028	.020	.050	.064
T-10 No Seal	.044	.046	.030	.057		.021	.037	.033	.035	
T-11	.043	.034	.022	.042	.045	.027	.026	.020	.032	.057
T-12	.037	.028	.020	.034	.067	.021	.024	.019	.024	.041
T-13	.041	.041	.032	.095	.103	.038	.037	.034	.056	.065
T-14 Seal	.056	.100	.055	.086	.116	.038	.107	.044	.056	.077
T-14 No Seal	.063	.092	.036	.126		.038	.057	.030	.111	
T-16 Control	-	-	-	.070	.066	-	-	-	.043	.050
T-16	.036	.028	.028	.100	.051	.027	.038	.031	.052	.036
T-17 & 19 Control	-	-	-	.054	.064	-	-	-	.044	.054
T-17	-	-	-	-	.117	-	-	-	-	.117
T-19	.092	.079	.043	.082	.082	.050	.057	.042	.063	.091

[a] OWT = outside wheel track, IWT = inside wheel track.

Table 3. Benkelman Beam Field Test Relative Stiffness.

	Relative Stiffness, kips/inch									
	OWT					IWT				
	Pre-Const.	Post Const.	Fall 1973	Spring 1974	Fall 1975	Pre-Const.	Post Const.	Fall 1973	Spring 1974	Fall 1975
T-2 Control	118.5	-	-	41.8	-	166.3	-	-	141.8	-
T-2	79.4	49.4	85.6	36.0	-	92.0	94.0	206.0	39.5	-
T-2A	74.6	106.8	166.3	45.8	-	113.8	169.6	201.1	93.0	-
T-5 Control	-	-	-	411.9	227.6	-	-	-	508.8	176.5
T-5	480.6	455.3	508.8	346.0	211.0	617.9	508.8	540.6	508.8	227.6
T-6 Control	240.3	-	-	288.3	127.2	480.6	-	-	360.4	123.6
T-6 Seal	411.9	411.9	480.6	432.5	176.5	576.7	617.9	508.8	455.3	262.1
T-6 No Seal	320.4	455.3	508.8	376.1	163.2	576.7	432.5	576.7	720.8	393.2
T-8A Control	-	-	-	227.6	196.6	-	-	-	279.0	262.1
T-8A	540.6	508.8	865.0	166.3	160.2	865.0	617.9	617.9	196.6	196.6
T-9	540.6	665.4	665.4	393.2	196.6	786.4	865.0	720.8	665.4	247.1
T-8B Control	-	-	-	720.8	393.2	-	-	-	786.4	393.2
T-8B	576.7	576.7	617.9	455.3	176.5	576.7	720.8	617.9	508.8	180.2
T-10,11,12,13 & 14 Control	90.1	-	-	-	46.5	206.0	-	-	-	95.1
T-10 Seal	120.1	160.2	393.2	88.3	141.8	201.2	308.9	432.5	173.0	135.2
T-10 No Seal	196.6	188.0	288.3	151.8		411.9	233.8	262.1	247.1	
T-11	201.2	254.4	393.2	206.0	192.2	320.4	332.7	432.5	270.3	151.8
T-12	233.8	308.9	432.5	254.4	129.1	411.9	360.4	455.3	360.4	211.0
T-13	211.0	211.0	270.3	91.1	84.0	227.6	233.8	254.4	154.5	133.1
T-14 Seal	154.5	86.5	157.3	100.6	74.6	227.6	80.8	196.6	154.5	112.3
T-14 No Seal	137.3	94.0	240.3	68.7		227.6	151.8	288.3	77.9	
T-16 Control	-	-	-	123.6	131.1	-	-	-	201.2	173.0
T-16	240.3	308.9	308.9	86.5	169.6	320.4	277.6	279.0	166.3	240.3
T-17 & 19 Control	-	-	-	160.2	135.2	-	-	-	196.6	160.2
T-17	-	-	-	-	73.9	-	-	-	-	73.9
T-19	94.0	109.5	201.2	105.5	105.5	173.0	151.8	206.0	137.3	95.1

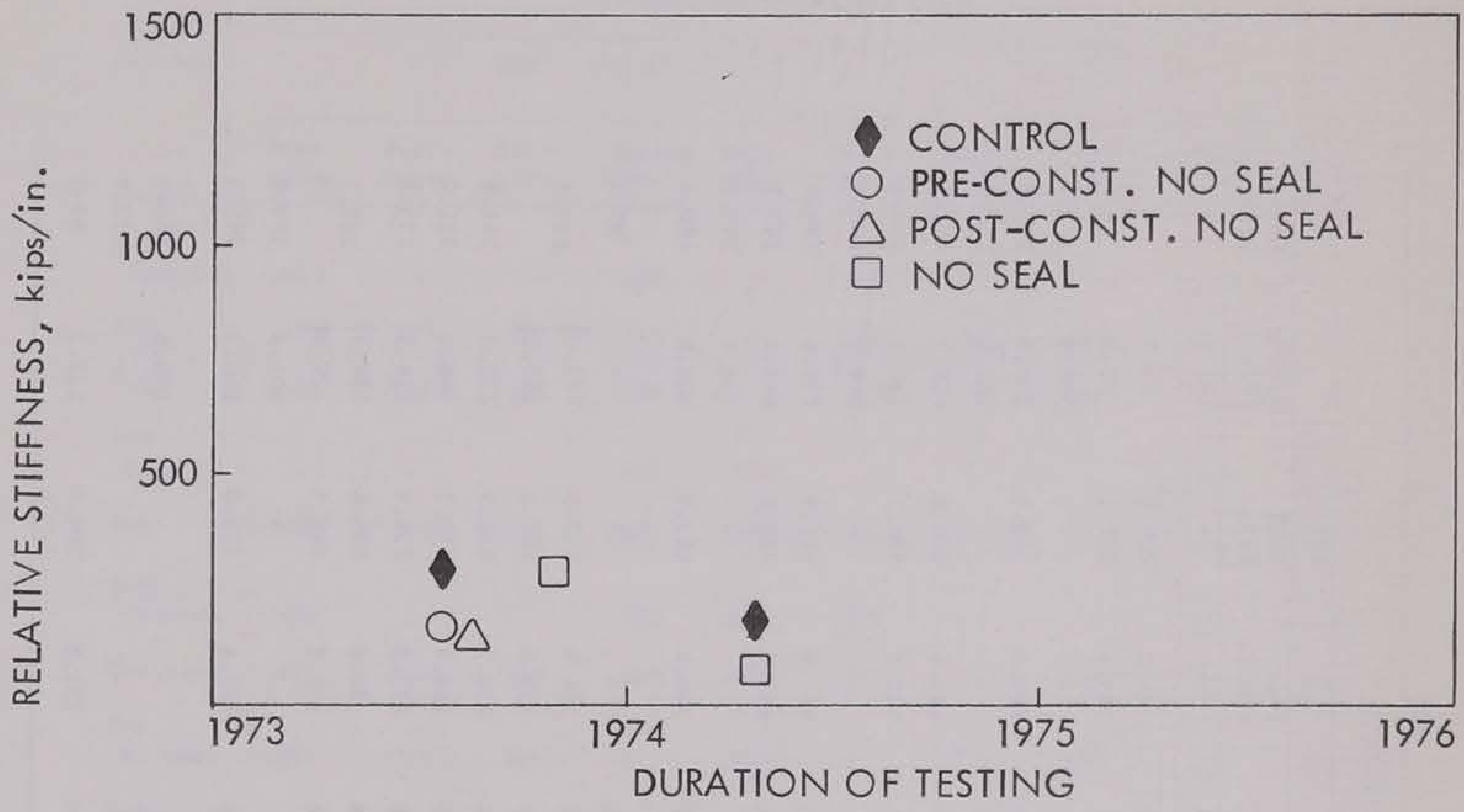

Figure 1. Benkelman Beam-relative stiffness vs. time, Test Section T-2.

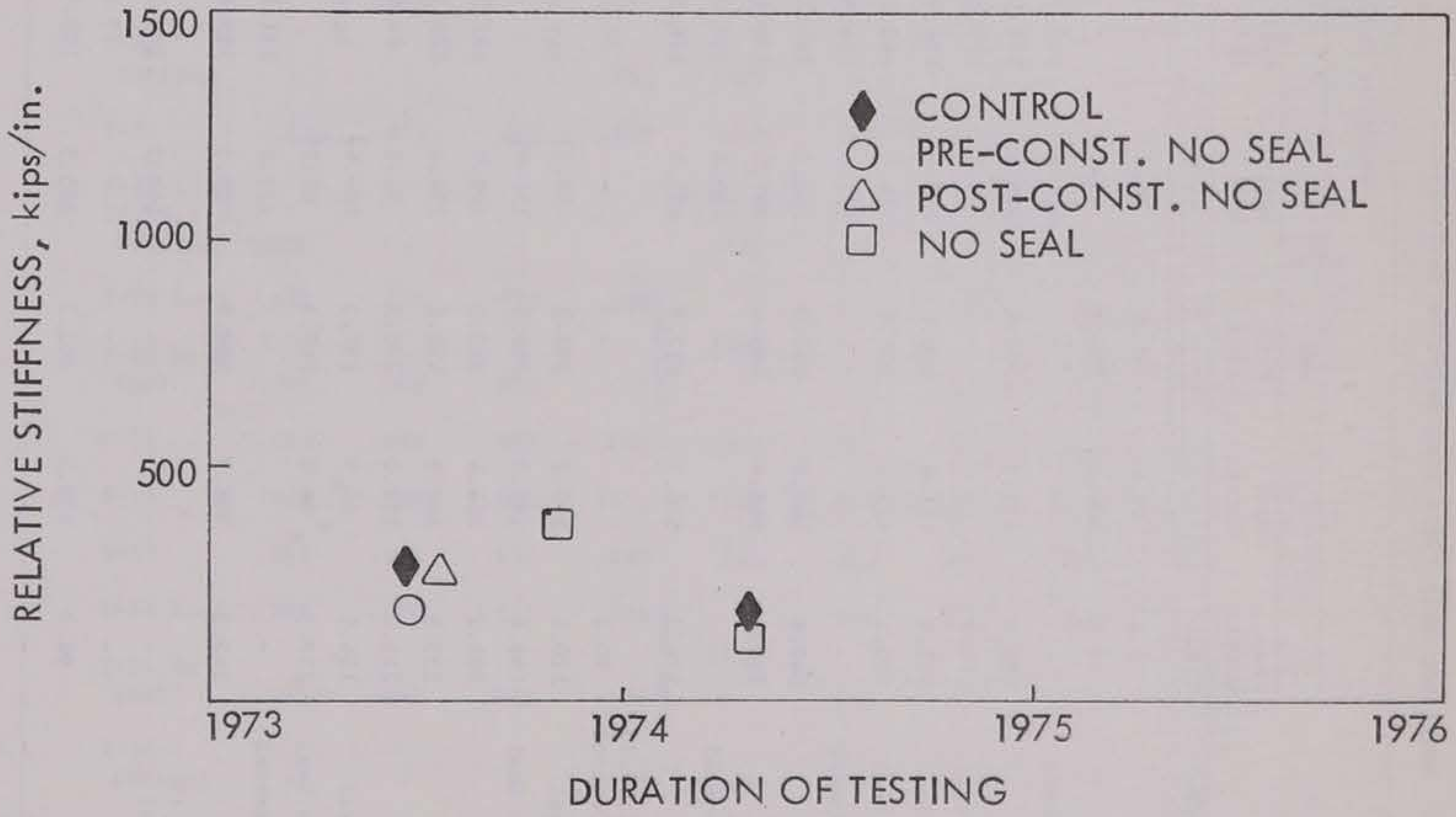

Figure 2. Benkelman Beam-relative stiffness vs. time, Test Section T-2A.

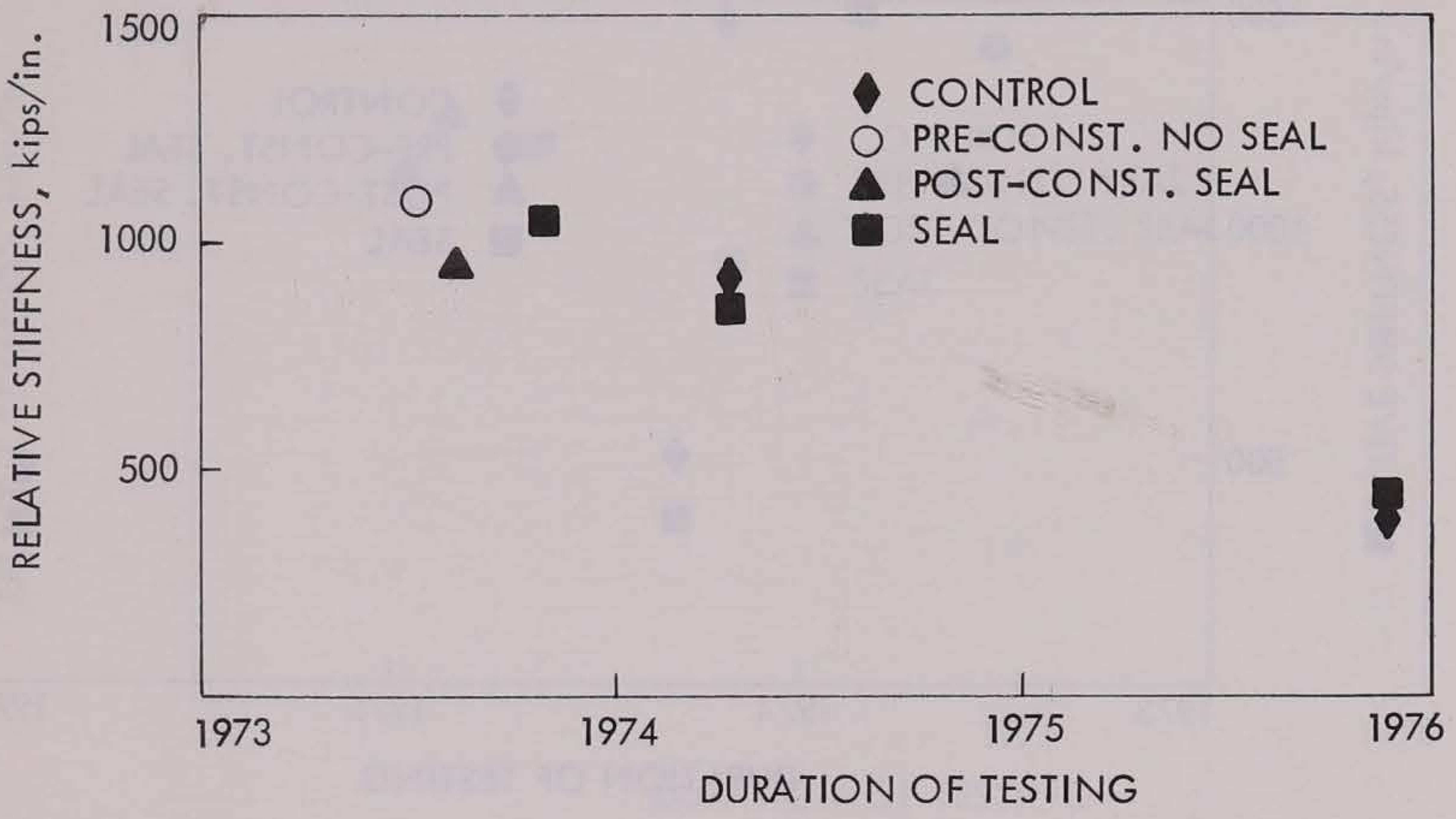

Figure 3. Benkelman Beam-relative stiffness vs. time, Test Section T-5.

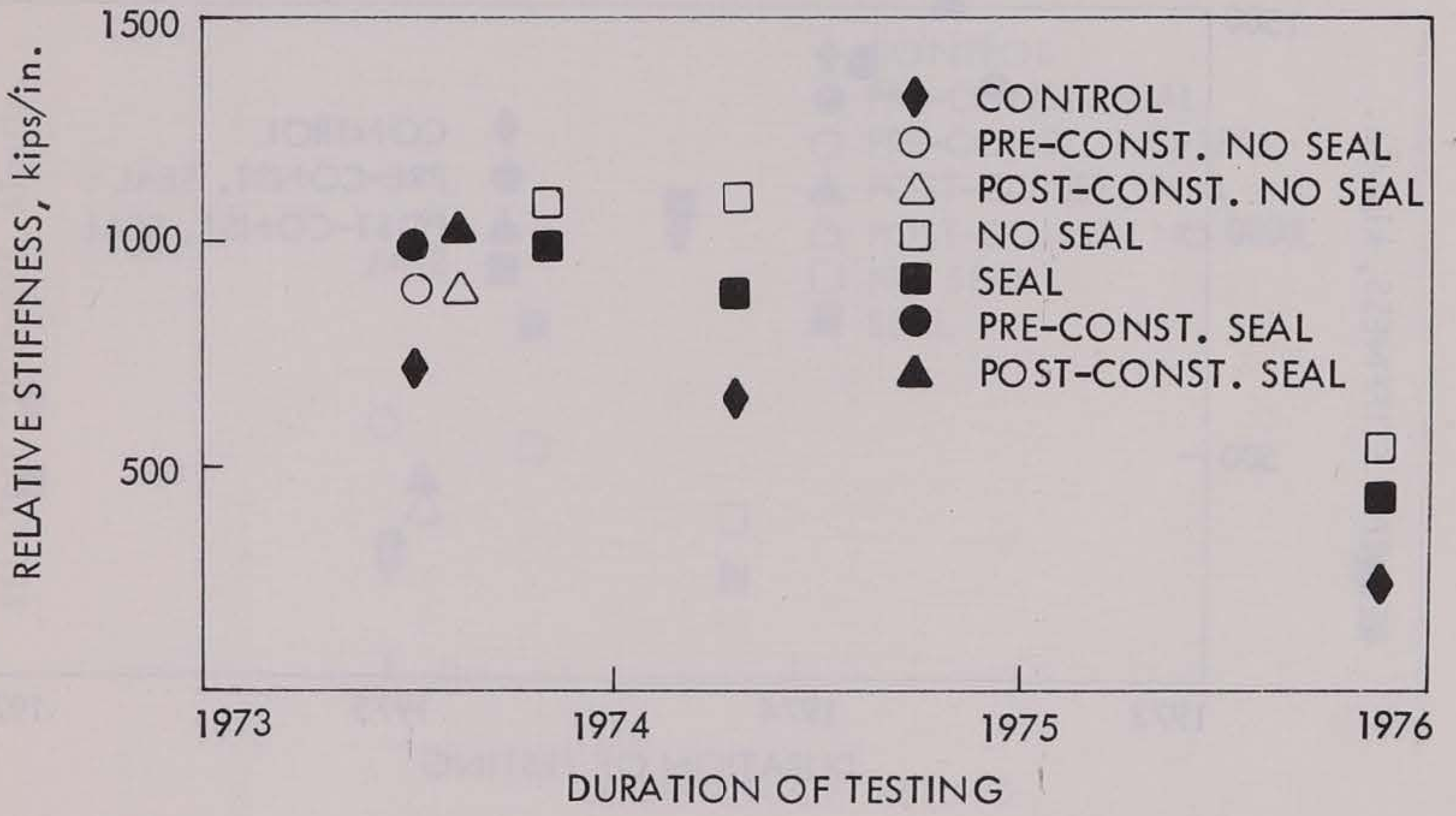

Figure 4. Benkelman Beam-relative stiffness vs. time, Test Section T-6.

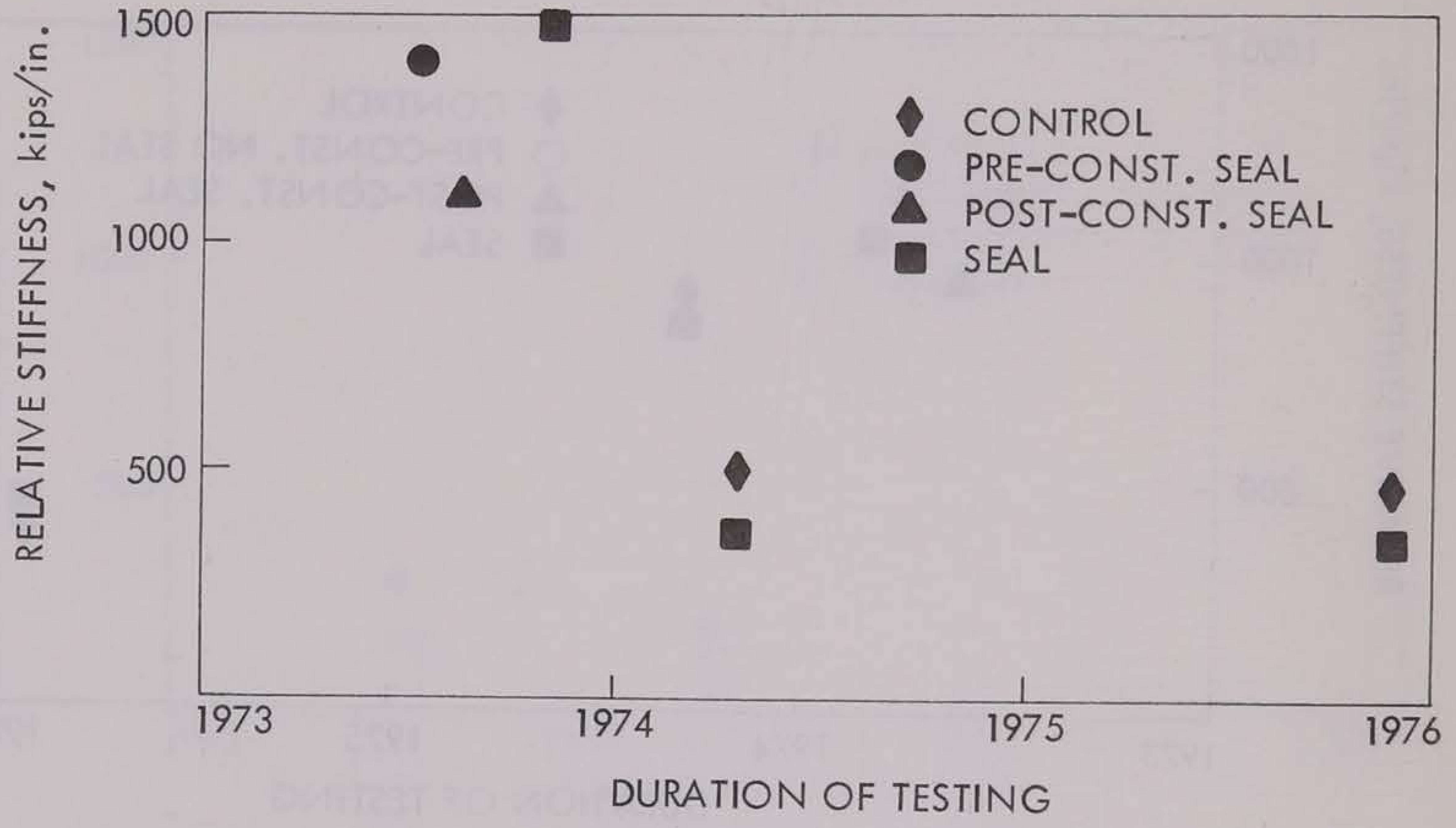

Figure 5. Benkelman Beam-relative stiffness vs. time, Test Section T-8A.

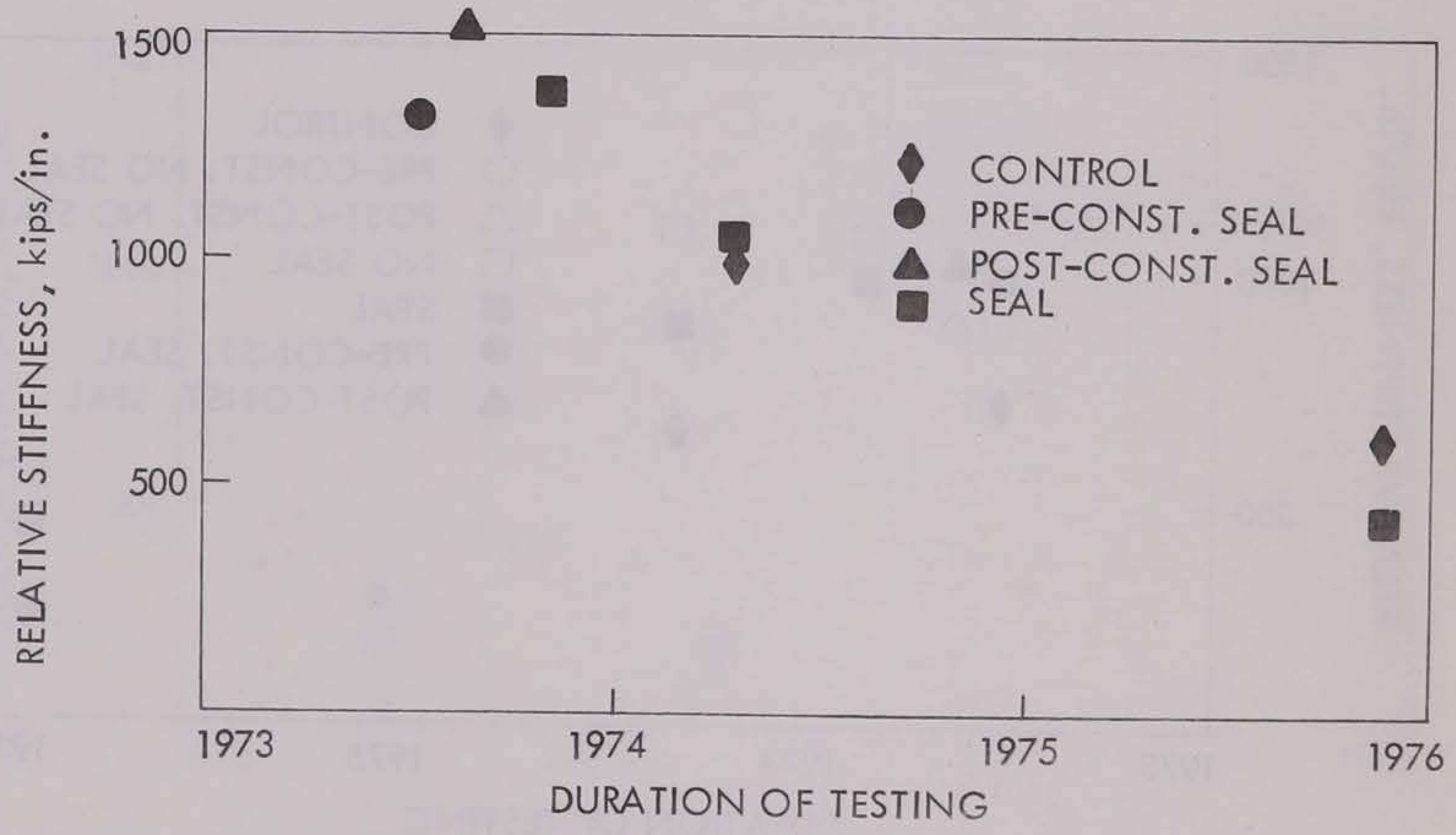

Figure 6. Benkelman Beam-relative stiffness vs. time, Test Section T-9.

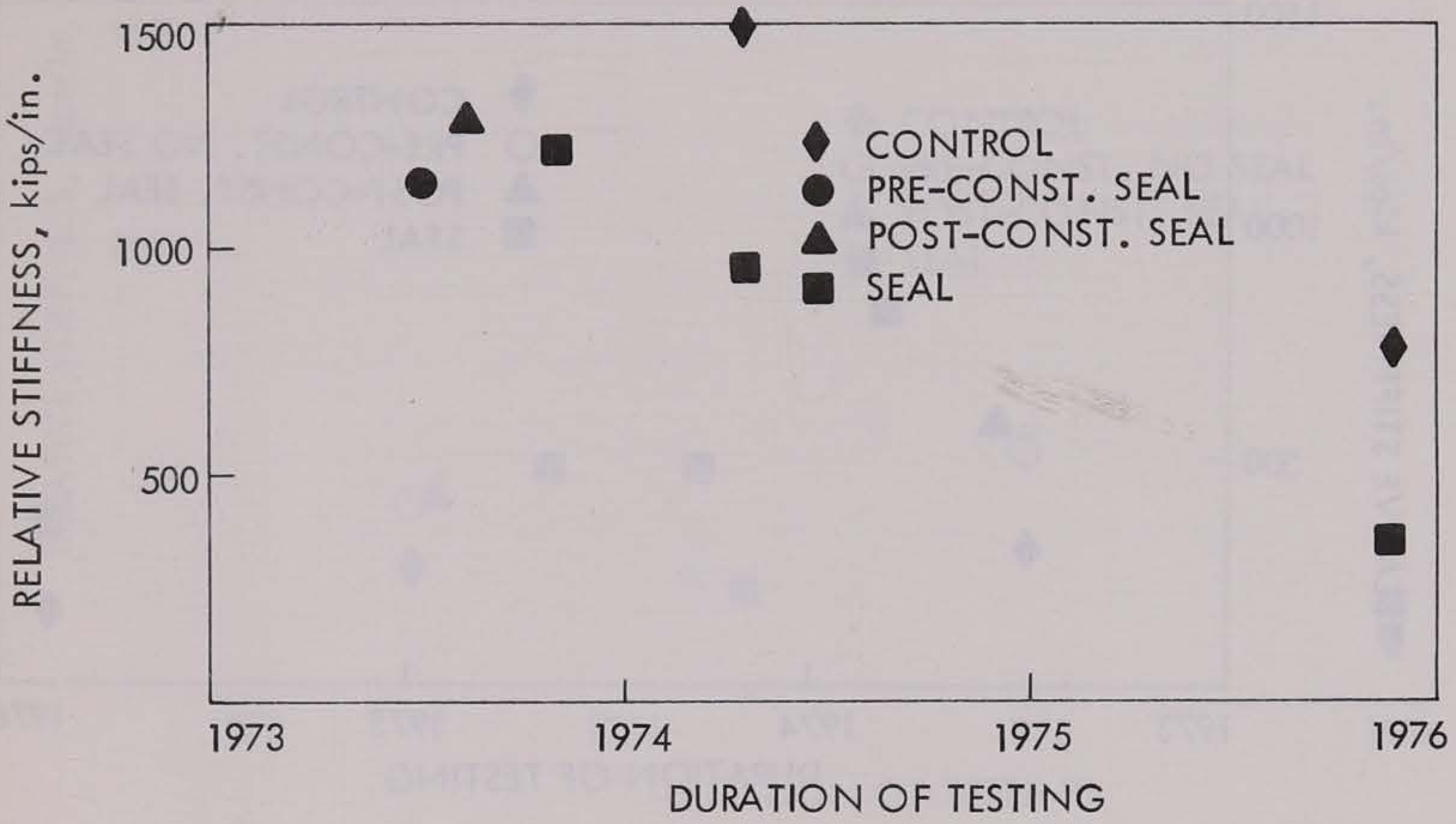

Figure 7. Benkelman Beam-relative stiffness vs. time, Test Section T-8B.

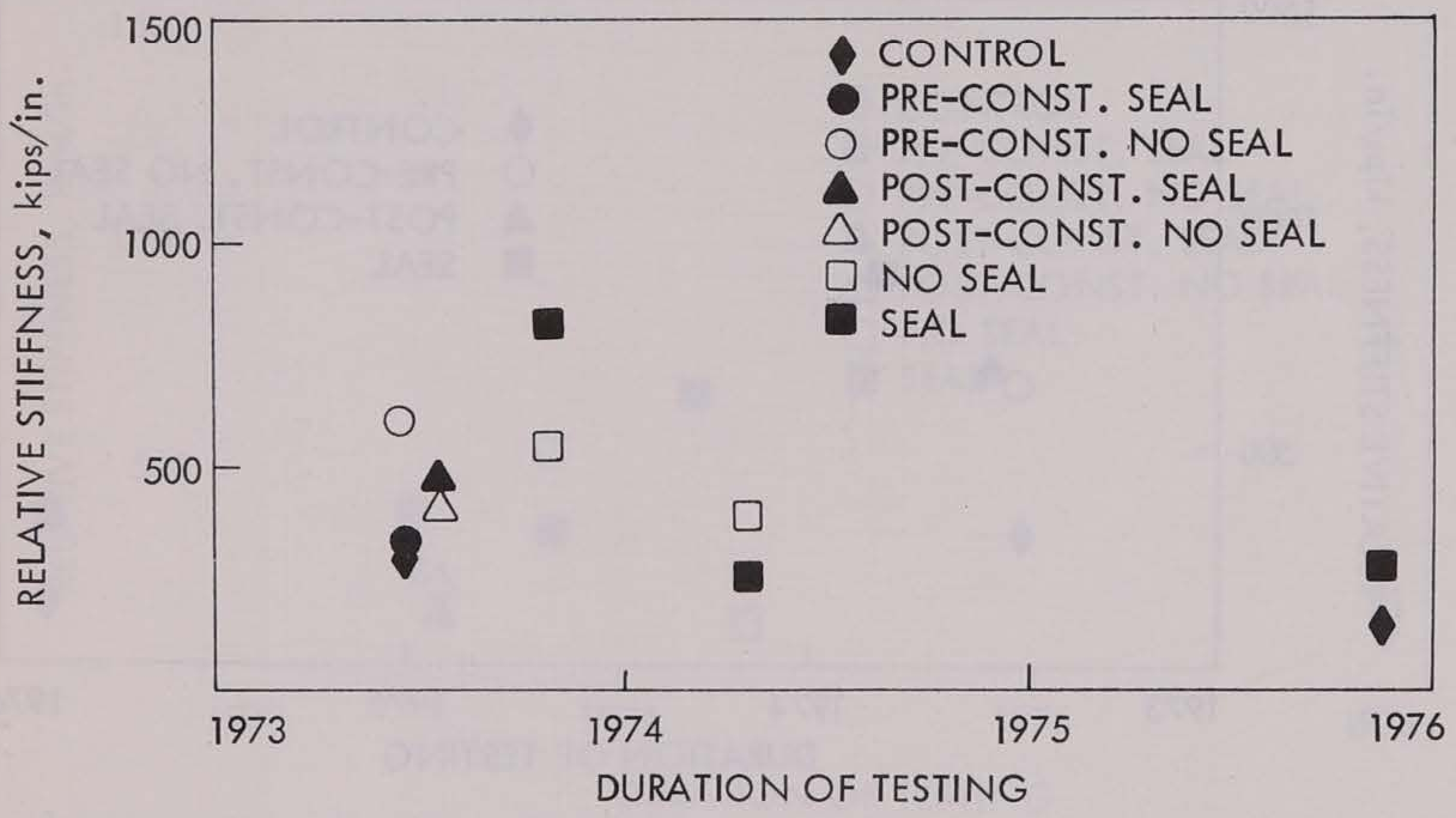

Figure 8. Benkelman Beam-relative stiffness vs. time, Test Section T-10.

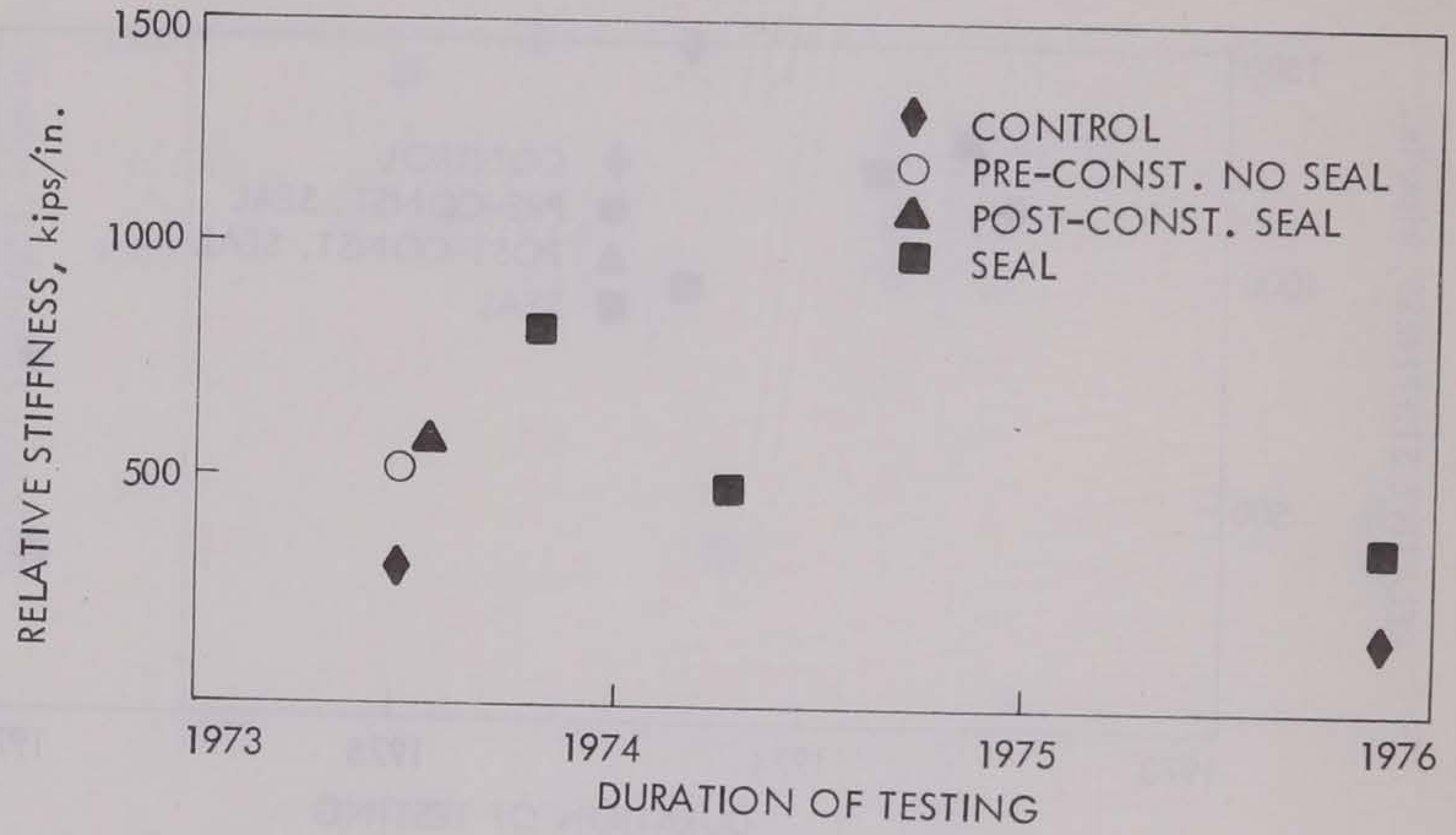

Figure 9. Benkelman Beam-relative stiffness vs. time, Test Section T-11.

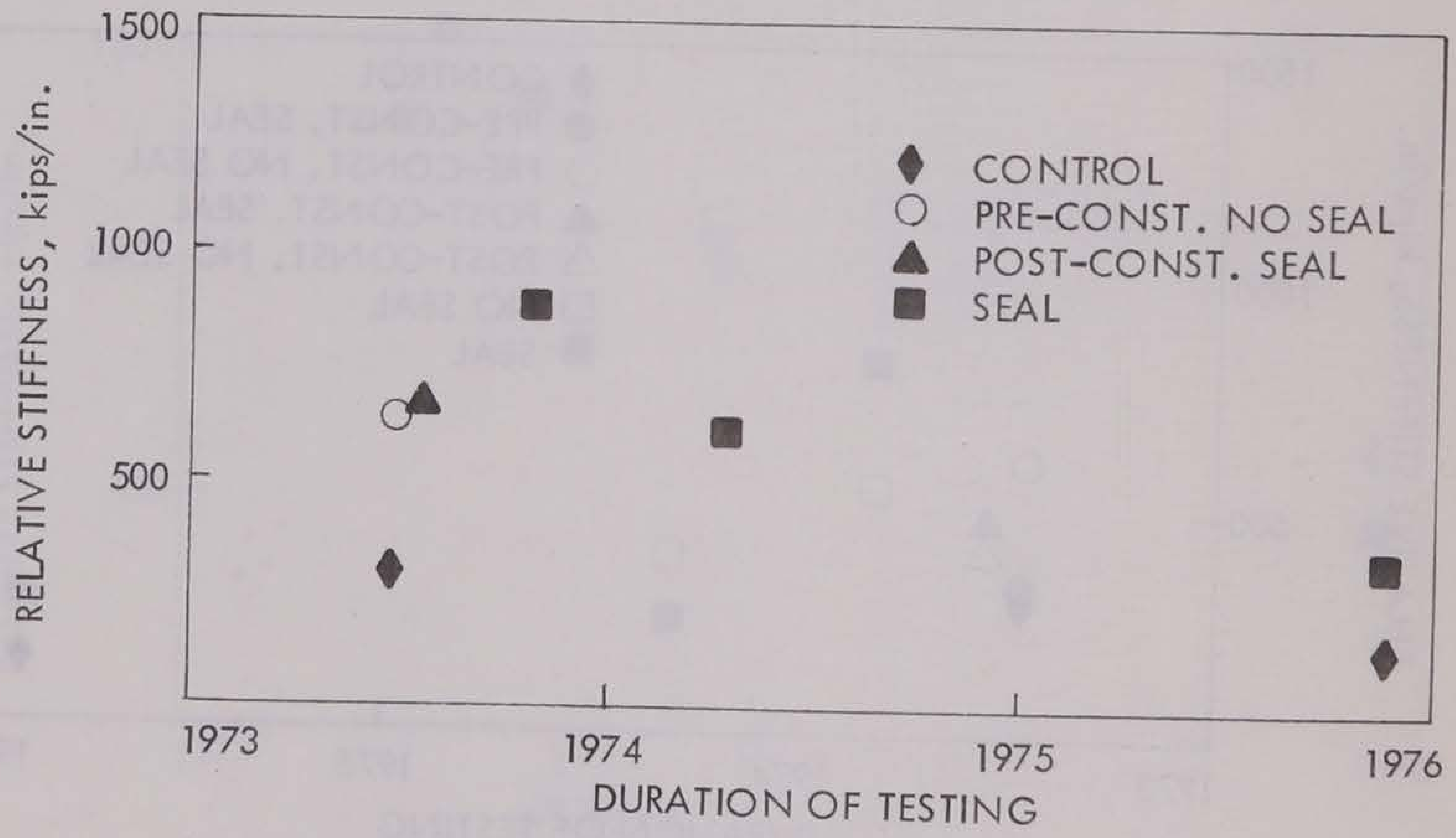

Figure 10. Benkelman Beam-relative stiffness vs. time, Test Section T-12.

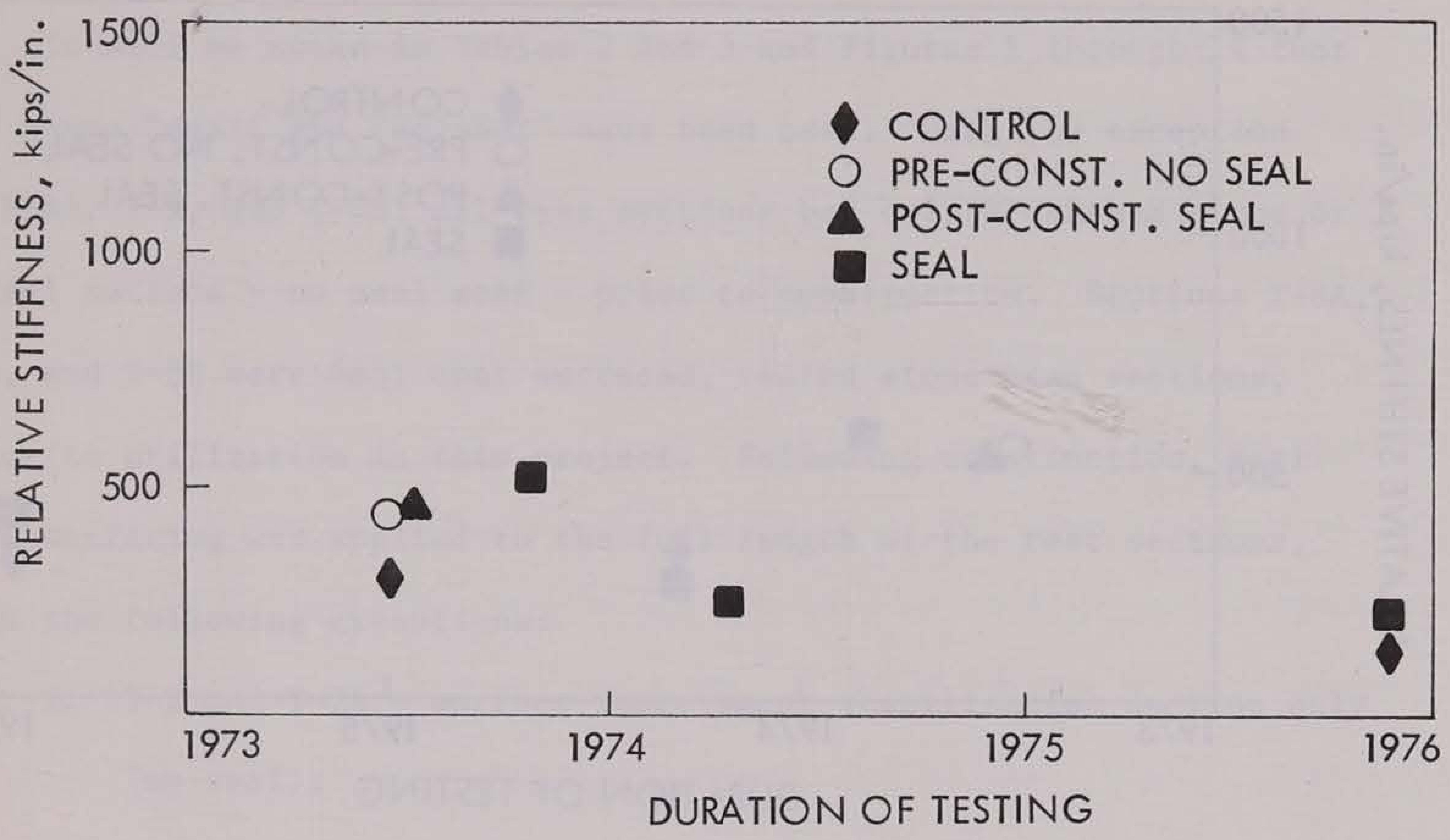

Figure 11. Benkelman Beam-relative stiffness vs. time, Test Section T-13.

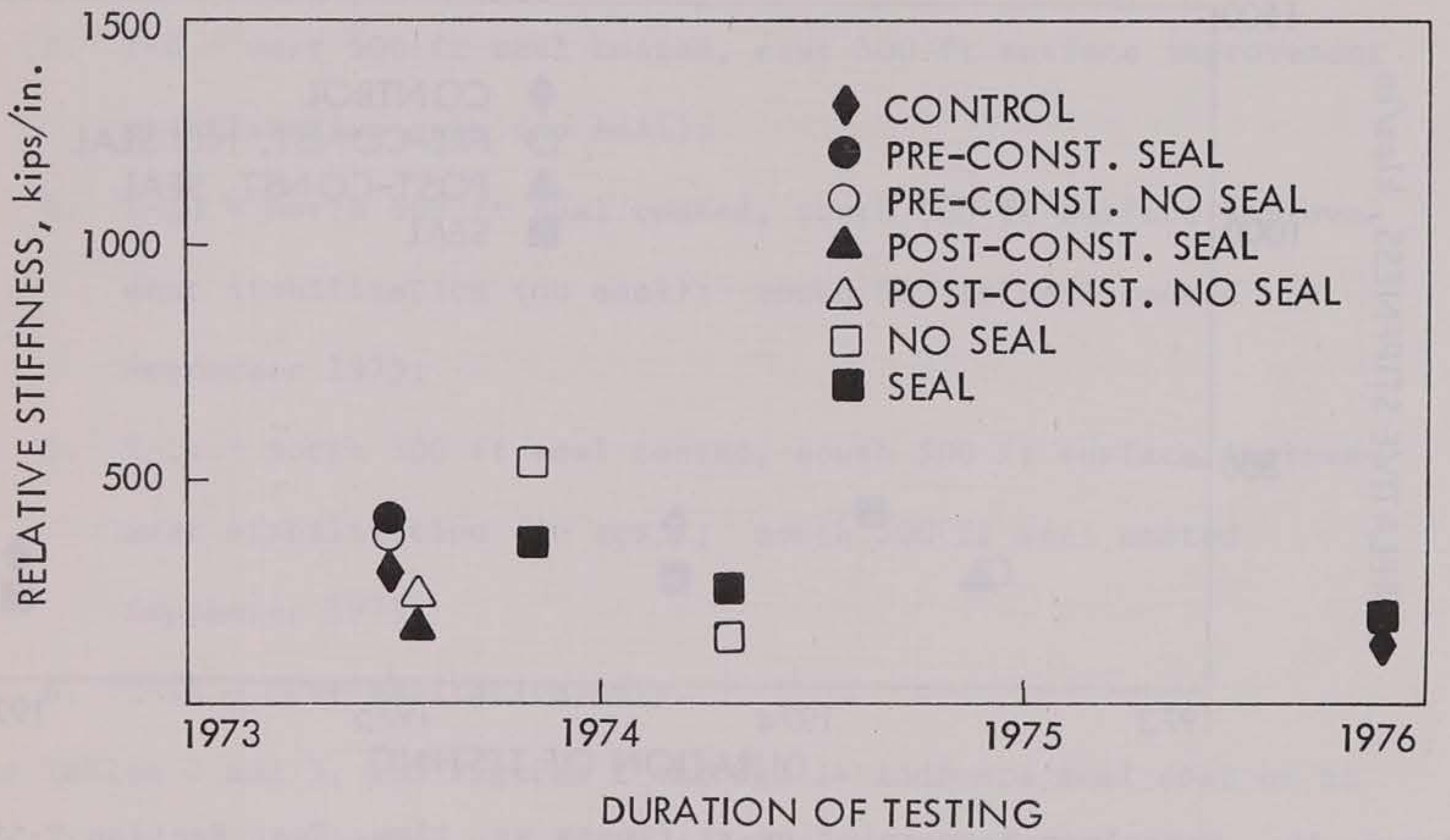

Figure 12. Benkelman Beam-relative stiffness vs. time, Test Section T-14.

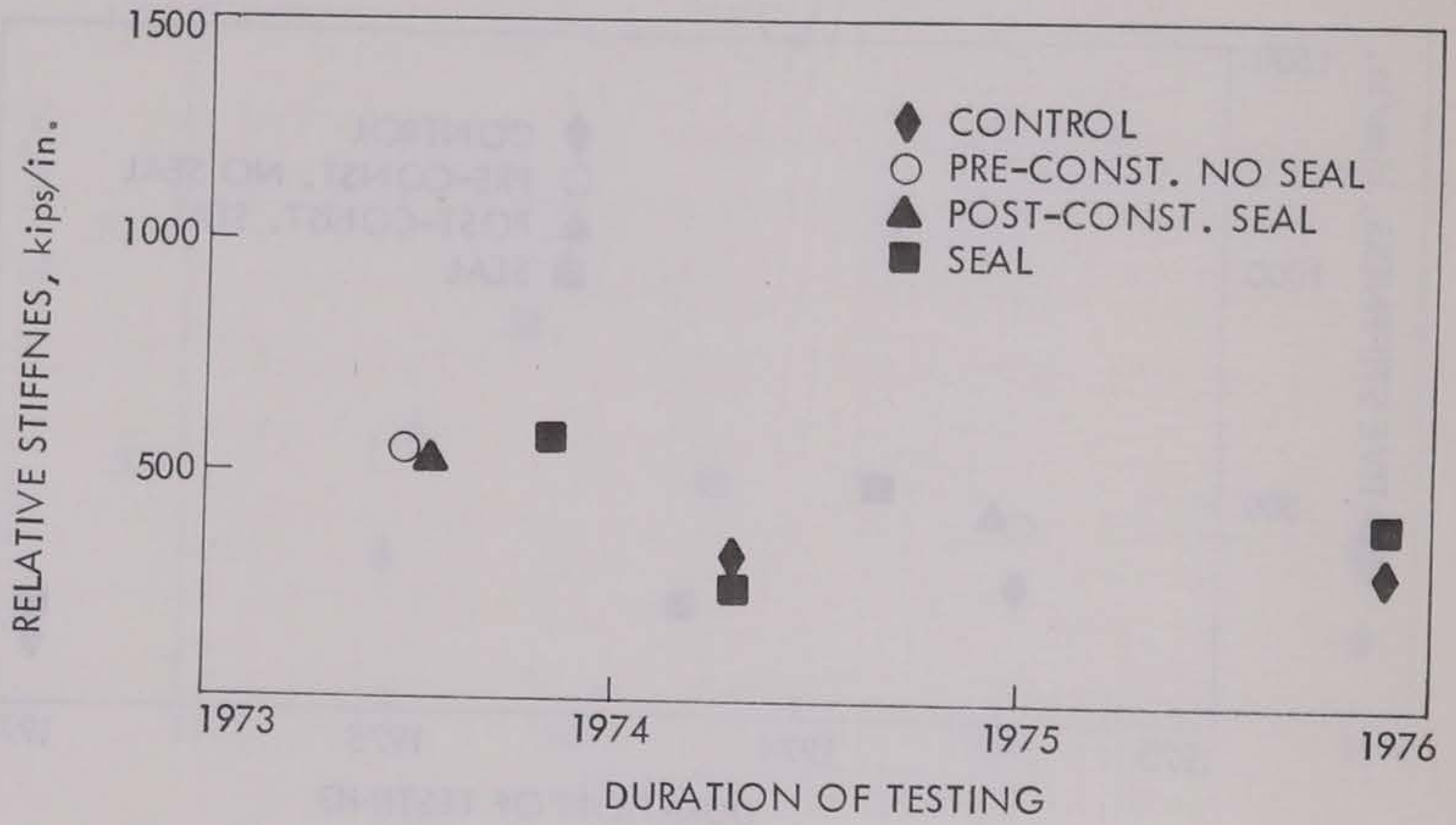

Figure 13. Benkelman Beam-relative stiffness vs. time, Test Section T-16.

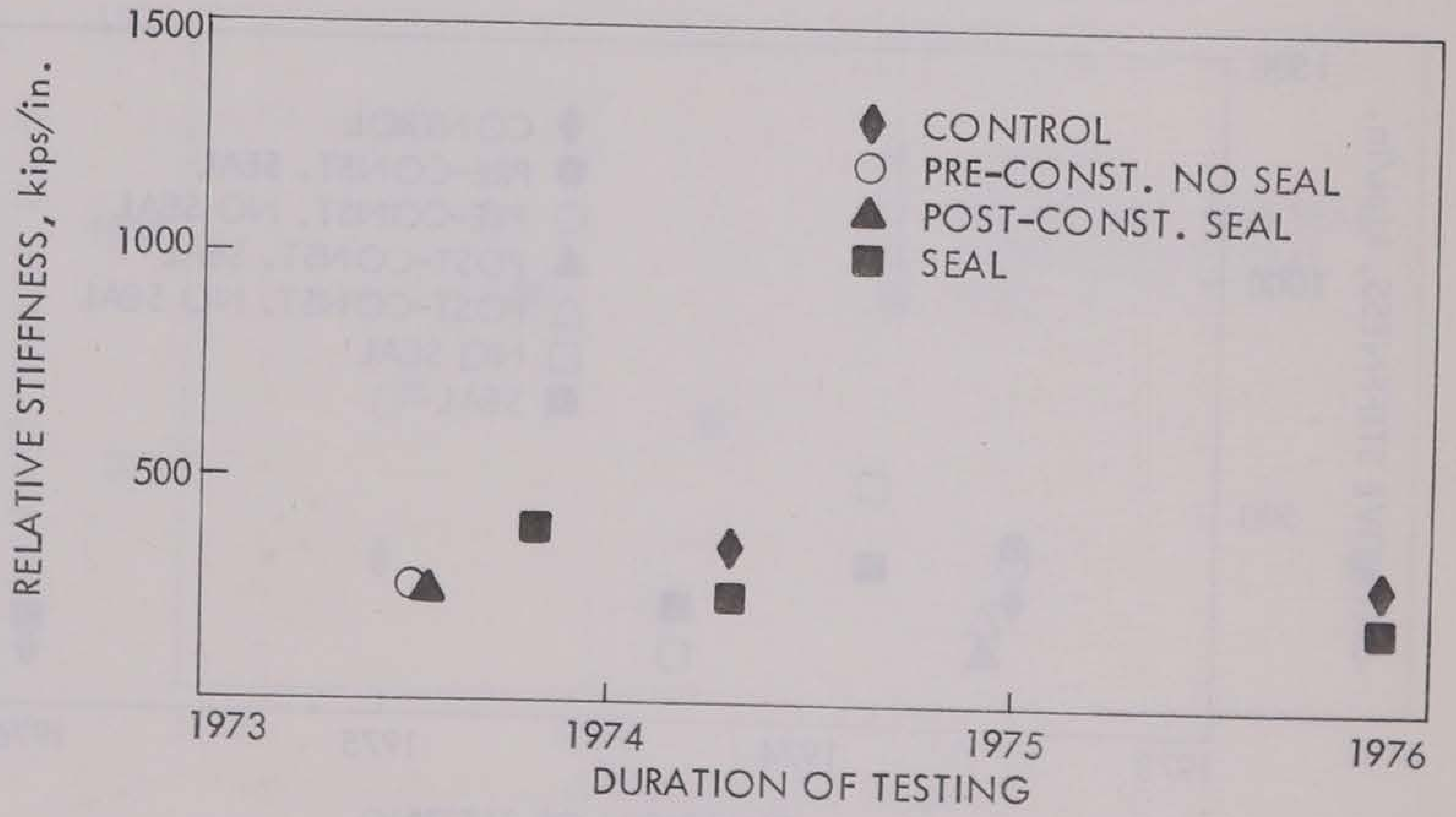

Figure 14. Benkelman Beam-relative stiffness vs. time, Test Section T-19.

It will be noted in Tables 2 and 3 and Figures 1 through 14 that the terms "seal" and "no seal" have been used. With the exception of T-8A, T-9, and T-8B, all test sections had only a crushed stone or gravel surface - no seal coat - prior to construction. Sections T-8A, T-9, and T-8B were seal coat surfaced, rolled stone base sections, prior to utilization in this project. Following construction, seal coat surfacing was applied to the full length of the test sections, with the following exceptions:

1. T-2 and T-2A - surface improvement stabilization section only (no seal);
2. T-3 and T-3A - shoulder treatment for weed encroachment control only;
3. T-6 - west 500 ft seal coated, east 500 ft surface improvement stabilization only (no seal);
4. T-10 - north 500 ft seal coated, south 500 ft surface improvement stabilization (no seal); south 500 ft seal coated September 1975;
5. T-14 - north 500 ft seal coated, south 500 ft surface improvement stabilization (no seal); south 500 ft seal coated September 1975;
6. T-17 - dust palliative only.

Thus Tables 2 and 3, and Figures 1 through 14 indicate seal coat or no seal coat surface conditions existing either prior to or following construction.

Sections T-2, T-2A, T-3, and T-3A became the subbase for a 4 in. maximum size macadam base and a 3 in. asphaltic concrete surface pavement during the summer and early fall 1975, and must thus be considered removed from further testing in this project. Sections T-8A, T-8B, T-9, T-10, T-11, T-12, T-13, T-14, and T-19 were re-sealed in September 1975.

As might be expected, most of the outside edges of the roadway test sections exhibited the greatest deflection and lowest relative stiffness values, Tables 2 and 3. This is a normal situation on secondary roads, due to lower lateral restraint at the edge of the geometric cross-section of the roadway.

Of the fourteen test sections on which the Benkelman Beam tests were conducted, comparison of post- and pre-construction relative stiffness values indicates a definite lowering in three and one half of the test sections, six remaining relatively unaffected, and four and one-half sections showing immediate improvement due to construction and addition of the stabilization additives. Sections showing a definite post-construction lowering of stiffness were T-5, T-8A, T-14 (each of which was constructed at somewhat above optimum moisture content), and T-10 no seal. T-10 seal showed a definite increase in stiffness. Variations in stiffness within T-10 are primarily attributed to a rather significant variation of soil within the length of the section, being fairly coarse grained at the south (no seal) and finer grained at the north (seal).

Comparison of Fall 1973 with pre-construction relative stiffness values indicates that only T-10 (no seal) and T-14 (seal) had lower stiffness values, T-5, T-6 (seal), and T-16 were approximately equal to pre-construction stiffness, and all remaining sections were definitely of greater stiffness. Sections T-5, T-10 (no seal), and T-14 (seal), however, showed a definite increase in stiffness in the approximate three months which had elapsed from post-construction testing to Fall 1973 testing.

All relative stiffness values for Spring 1974 were significantly lower than Fall 1973 values, with the exception of section T-6 (no seal). The fact that this section did not show a spring strength reduction was probably due to the nature of the soil rather than the action of the additive, since the sandy soil in this section had sufficient void size to prevent water from being drawn upward by capillary action.

It should be pointed out that spring is normally the most critical time for roads due to thawing and subsequent weakening of the roadway. At this time, water has easy access to the road via capillary action, and the freezing and thawing effects can quickly destroy a road.

Only section T-16 showed a slight improvement in overall stiffness from Spring 1974 to Fall 1975 testing. Sections T-8A, T-10, T-13, T-14, and T-19 remained about the same in stiffness values, whereas T-5, T-6, T-9, T-8B, T-11, and T-12 produced lower stiffness values for Fall 1975 than for Spring 1974.

An indication of benefits of treatment can be subjectively observed by comparing the relative stiffness values of the test sections at pre-construction and Spring 1974, plus control section values. Sections which showed a strength gain, or only minor strength losses, indicating good performance at a critical weathering cycle, are T-2A, T-6, T-10 seal, T-11, T-12, T-14 seal, and T-19. Sections T-6, T-11, T-12, and T-19 showed increasing stiffness in the OWT, an indicator of good improvement in overall road stability from pre-construction to Spring 1974.

Discussion.

Maximum deflection tests under a slow moving load, as in the Benkelman Beam test conducted in this study, are affected by the following variables:

1. base thickness, soil type, and moisture content,
2. subgrade soil type and moisture content,
3. stabilization additive utilized, i.e., cementing agent, binder, etc.,
4. surface course thickness, and
5. time of year.

In general, there is a direct relationship between Benkelman Beam deflections and the moisture contents of the base and subgrade of a flexible highway. Moisture contents and deflections are normally high in the spring immediately following thawing, while both reach their lowest values in the fall when the water table is at its lowest elevation.

The arbitrary limiting design deflections for flexible pavement base courses normally range from 0.05 to 0.2 in. Converted to relative stiffness, these limiting deflections thus range from 346.0 to 86.5 kips/in., respectively, under the axle load of 17,300 lbs. Using section T-2 as an example only, since its relative stiffness was among the lower values indicated, the pre-construction, post-construction, Fall 1973, and Spring 1974 values are 171.4, 143.3, 291.6, and 75.5 kips/in., respectively. These relative stiffness values indicate deflections of 0.10, 0.12, 0.06, and 0.23 in., respectively. These values should not, however, be construed as being within limiting design deflections for a high performance pavement: there are no such criteria for intermediate type secondary roads.

Spherical Bearing Value

The relative bearing capacity of each test section was analyzed in situ by the Spherical Bearing Value (SBV) test. This test has been shown to attain better reproducibility than either CBR or plate bearing tests.[1]

The SBV is the result of a stress-strain test in which hydraulic loads are applied to a 6 in. diameter, spherically shaped, loading head, and vertical deflections are recorded at various increments of load. Data obtained is plotted with load as ordinate, and a function of deflection and diameter of the sphere as abscissa. To simplify the calculations, hydraulic pressure was used instead of load, since the gauge readout was in pressure. The load varied from the pressure by a constant which was equal to the area of the piston in the cylinder. Slope of the plotted points was not affected by this difference and does not change. Slope of

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[1] Butt, G.S., Demirel, T., and Handy, R.L. Soil Bearing Test Using a Spherical Penetration Device. Highway Research Record No. 243, pp. 62-74, 1968.

the plotted line is defined as the Spherical Bearing Value (SBV), with units of psi. With the SBV data obtained on the test sections, a linear regression analysis was run on each data set in order to assure a "best fit" line and subsequent SBV.

Three or more SBV tests were conducted on each test section, with at least one at each of the section quarter points, alternating to the approximate center line of each traffic lane. All SBV values thus determined for each test section are presented in Table 4. As noted, the SBV tests were conducted at the same time as the Benkelman Beam tests through Spring 1974.

Table 4. Spherical Bearing Value field test results.

Section No.	Pre-Construction	Post-Construction	Fall 1973	Spring 1974
T-2	161.0	83.0	140.0	89.0
T-2A	217.5	126.0	140.0	97.0
T-5	535.0	194.3	230.0	225.2
T-6	320.0	417.3	266.2	485.6
T-8A	228.0	470.0	330.0	245.7
T-9	220.0	600.0	340.0	168.6
T-8B	190.0	140.0	230.0	98.8
T-10	406.7	86.3	260.0	172.5
T-11	206.7	244.0	313.3	193.7
T-12	193.3	307.0	483.3	337.0
T-13	160.0	146.7	146.7	97.0
T-14	393.3	63.3	136.7	69.2
T-16	246.7	183.3	130.0	105.7
T-19	270.0	103.3	130.0	66.0

Of the fourteen test sections, comparison of post- and pre-construction values indicates a definite lowering in eight of the test sections, while one section remained relatively unaffected, and five sections showed immediate bearing improvement due to construction and addition of the stabilization additives. Those sections showing a definite post-construction reduction in bearing were T-2, T-2A, T-5, T-8B, T-10, T-14, T-16, and T-19.

Comparison of Fall 1973 with pre-construction SBV's indicates an identical number of sections showing lower, relatively unaffected, and increased values. Those sections showing a reduction from pre-construction bearing capacity were T-2, T-2A, T-5, T-6, T-10, T-14, T-16, and T-19.

Comparison of Fall 1973 with post-construction SBV's indicates a lowering of four of the test sections, while one remained relatively unaffected, and nine showed bearing improvement. Those sections showing reduced bearing were T-6, T-8A, T-9, and T-16. During the approximate three months following construction, sections T-2, T-2A, T-5, T-8B, T-10, T-11, T-12, T-14, and T-19 showed definite increases in bearing capacity.

The bearing capacity of section T-13 was relatively unaffected between post- and pre-construction testing and remained the same approximately three months after construction. Section T-16 showed a continued decrease in bearing from pre- to post-construction to Spring 1974 values.

The Spring 1974 values for SBV showed the same general trend as the Benkelman Beam and relative stiffness values. All sections but T-5 and T-6 showed decreases in strength, with these two showing very little decrease and a large increase, respectively.

By comparing pre-construction SBV values to the values for Spring 1974 we get an idea of the spring reduction in strength and how the soil materials were affected by treatment. All sections but T-6, T-8A, and T-12 showed lower values for spring than for pre-construction, with T-11 showing only a small reduction. Sections T-6, T-11, and T-12 also showed good behavior in the Benkelman Beam tests, indicating benefits of treatment were becoming evident.

Field Density

Progress Report 1 presented methods and data on the series of post-construction moisture content and density (M-D) tests performed on each test section. Field densities were obtained with a Troxler nuclear M-D unit employing both back-scatter principle and direct transmission. This method derives its data from the hydrogen ion content in the combined soil/water mixture. As was indicated in Progress Report 1 for several sections, any soil having high organic content or any type of asphaltic mix produced high values.

Table 5 compares the average dry density for each test section obtained with the Troxler unit to average standard values of 95% and 100% of the dry densities from 2 in. diameter by 2 in. high laboratory specimens containing the same additive percentage as used in the field. It should be noted that in all but one case, the field densities were within 95% of the density achieved in the lab procedure, while T-11 achieved 94% of that figure. Sections T-5 and T-8A were in excess of the 100% laboratory value. Reliability of the Troxler data as noted above should be kept in mind when interpreting these results. In general, however, it appears that all test sections achieved a reasonable degree of densification during construction.

Table 5. Field densities as determined by Troxler nuclear unit vs 2 in. x 2 in. lab densities for same additive percentage.

Section	Field Density, pcf	Lab Density, pcf	
		100%	95%
T-2	128.6	132.5	125.9
T-2A	127.3	132.8	126.2
T-5	132.0	129.4	122.9
T-6	127.1	129.7	123.2
T-8AB	137.8	133.9	127.2
T-8BB	126.8	118.4	112.5
T-10	124.1	126.0	119.7
T-11	114.9	121.9	115.8
T-12	116.3	118.1	112.2
T-13	124.5	129.2	122.7
T-14	113.5	115.0	109.3
T-16	124.0	129.1	110.4
T-19	105.1	109.0	103.6

Dust

A volumetric dust sampling device was used to determine "dusting" on sections T-2, T-2A, T-10 no seal, T-14 prior to construction, T-14 no seal, T-16 control and prior to seal, and T-17 control and surface treated. This procedure utilizes a portable, battery operated vacuum pump system. A variable flow meter, calibrated in cubic feet per minute, is used to determine the volume of air passing through the system. An intake unit is placed in line with and behind the right rear tire of the test vehicle, in this case a van. A vehicle speed of 30 mph is used, with the intake 6 ft behind the tire and about 1 ft above the roadway. With the vehicle moving at 30 mph, a stopwatch is started and the vacuum pump activated as the rear wheels cross the beginning of a test section. Both are stopped as the vehicle crosses the end of the section. The weight of dust collected within the time period noted, coupled with the 0.5 cu ft/min setting, determines a weight of dust per million cubic feet of air. An average of three runs for each section were made to provide more dust and reduce weighing errors. Results are presented in Fig. 15.

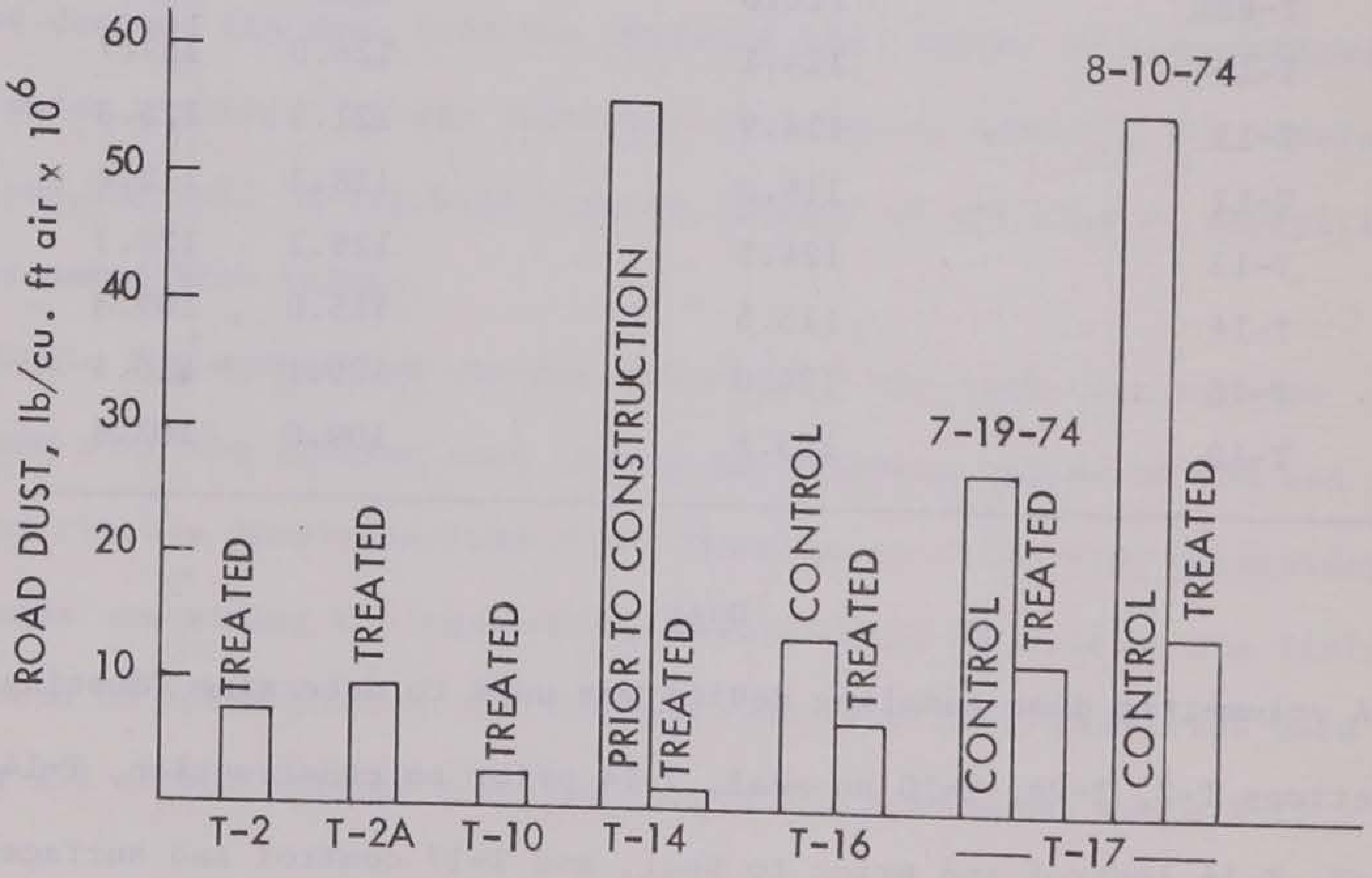

Figure 15. Results of volumetric dust sampling.

Section T-17 was primarily a dust palliative section, and dust measurements were the only method used to evaluate performance. Dust measurements were also taken using the adjacent control section as a comparison. It is apparent from Fig. 15 that each treatment was initially effective.

PART 2. LABORATORY EVALUATION

In addition to the various field tests discussed in the preceding sections and Progress Report 1, numerous laboratory investigations were begun in June 1973. Each of the laboratory investigations is designed to contribute information relative to analysis of the in-situ field tests and observations, with correlation of laboratory and field tests possibly contributing to mix and/or thickness designs of roadway soils stabilized with the various products used in the test sections. Each lab test is conducted on soil obtained from the test sections prior to construction and (a) utilized in an untreated condition, other than water, (b) treated at the same percentage of additive concentration used in the field construction as recommended by the participant, (c) treated at less percentage of additive than used during construction, or (d) treated at greater percentage of additive than used during construction.

In an attempt to achieve a percentage lower than that used in construction, many of the trace chemicals were mixed in a more diluted form than used in the field, but during determination of optimum moisture and maximum density this diluted solution was used in quantitites which resulted in the actual additive percentage being equal to or greater than that used during construction.

Only those laboratory tests considered to be completed on treated and untreated section soils are reported herein. These include:

1. Moisture-density under standard compaction.
2. Unconfined compressive strength following 24 hr air cure.

3. Freeze-thaw following 24 hr air cure.
4. Erosibility following 24 hr and 7 day air cure, plus 7 day moist cure.
5. Trafficability following 24 hr air cure.

In the presentation of test results, an asterisk (*) denotes the same additive percentage as used during field construction.

Laboratory testing still in process centers around the Iowa Continuous K-Test for determination of shear parameters c and ϕ, modulus of elasticity E, and lateral pressure ratio K of each section soil and treatment level.

Materials

Representative untreated soil samples were taken at various points within each test section after initial scarification and prior to any additive application. These samples were sent to the laboratory, air-dried, pulverized, and then mixed to obtain an average representative soil type for each particular test section. Samples were then subjected to lab tests for determination of particle size distribution, plasticity, and classification (see Table 1 and Progress Report 1), prior to preparation of specimens for tests noted above.

Specimen Preparation and Curing

Specimens used for moisture-density determination, unconfined compressive strength, freeze-thaw, and erosibility tests were 2 in. in diameter by 2 in. in height, molded using the drop hammer technique developed by Chu and Davidson.[2] Densities obtained from this method are comparable to those obtained from the standard proctor test. Specimens for the traffic simulation tests, however, were molded in a different manner and will be covered in that section.

Soil was passed through a 3/8 in. crusher, if necessary, then mixed in a table-top Hobart mixer with water, additive, or both, to give the desired moisture and additive contents. Further hand-mixing was done as required to assure even distribution of moisture and additive. A predetermined amount of soil-additive mixture was placed in the molding device and drop hammer-compacted to a height of 2 ± .05 in.

In several of the lab studies it should be noted that only a 24 hr air cure was used, because of its similarity to normal field conditions prior to seal coat surfacing. Previous studies have used many combinations of curing periods ranging from 0 to 28 days. The 0-day cure has proven to be of little value in relation to chemical reactions taking place or in showing strength gain upon drying. The 24 hr cure is sufficient to show trends that develop with different additive contents, although strengths are not as great as with longer cure periods. Due to the large number of specimens molded, the 24 hr cure was a practical compromise in terms of time and soil saved. It should be emphasized however, that many of the additives require a longer cure period to fully develop their strength and stability. Results will be discussed with this in mind, with the further studies more clearly defining trends in the next report.

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[2] Chu, T.Y., and Davidson, D.T. Some Laboratory Tests for the Evaluation of Stabilized Soils. Iowa Engineering Experiment Station Bulletin 21, pp. 243-248, 1960.

Amount of additive used in the lab studies for duplication of field quantities was determined by knowing the untreated optimum dry density of the soil obtained from lab tests, quantity of additive used in field construction, surface area of the test section, and depth of treatment. From this information an amount of chemical per unit dry weight of soil was calculated.

T-2. An ammonium lignosulfonate with a 53% solids content was used in the equivalent amounts of 1, 1 1/2*, and 2 gal./sq yd. This yielded a lignin solids content based on dry soil weight of 0.74%, 1.11%*, and 1.47%, respectively.

T-2A. Pramitol was used as an additive to the above lignin and tested in the following combinations: 1 gal./sq yd lignin + 20 gal./acre Pramitol, 1 1/2 gal./sq yd lignin* + 20 gal./acre Pramitol* and 1 gal./sq yd lignin + 25 gal./acre Pramitol. Solids percentages of lignin are the same as in T-2, and the percentages of Pramitol used, based on dry soil weight, for the 20 gal./acre and 25 gal./acre applications were .006%* and .008%, respectively.

T-5. NaCl was added in granular form, applied directly to the soil at the rates of 1 1/2%, 2%*, and 3% of the dry soil weight. This was followed by application of the required amount of water for compaction.

T-6. Kelpak used during construction was diluted 10/1000 in water, with the catalyst being added at the rate of 0.37% of the Kelpak. Based on the procedures described previously, this solution was duplicated for lab-treated specimens, further water being added as necessary to reach the desired moisture content. As a variation on the construction method, Kelpak was diluted 5/1000 and 20/1000 in water and added until proper moisture content was achieved, without addition of water. The resulting percentages of Kelpak used at the dilution rates of 5/1000, 10/1000*, and 20/1000 were .032%, .024%*, and .144%, respectively, based on dry soil weight.

T-8AS. Clapak and Claset were applied to the subgrade soil in amounts of 15 gal. and 10 gal., respectively, mixed into 3000 gal. of water. This proportionate amount was duplicated in the lab tests with further water added as required to reach optimum moisture content. In addition, ratios of 10 gal. Clapak to 6 2/3 gal. Claset, and 20 gal. Clapak to 13 1/3 gal. Claset were used and diluted in the equivalent of 3000 gal. of water. These solutions were added to the soil without supplemental water. The three equivalent amounts of Clapak, 10, 15* and 20, yielded .039%, .011%*, and .083% of the dry soil weight. Used in the respective combinations with Clapak, the Claset amounts of 6 2/3, 10*, and 13 1/3 yielded percentages of .026%, .007%*, and .055%, respectively, dry soil weight.

T-8BS. Fifteen gallons Clapak and 10 gal. Claset per 3000 gal. water were used on both T-8AS and T-8BS. Chemical dilution rates and amounts for T-8BS were the same as for T-8AS, but due to a different soil type, unit dry weight differed. The equivalent amounts of 10, 15*, and 20 gal. Clapak yielded .031%, .007%*, and .064%, respectively. Claset used at 6 2/3, 10*, and 13 1/3 gal. yielded .021%, .005%*, and .042%, respectively.

T-8AB. SA-1 was applied during construction of sections T-8AB and T-8BB at 1/1000 concentration, with 10 gal. of concentrate being used for both sections. Additional lab concentrations of 0.5/1000 and 2/1000 were also selected. With the additional solutions being used without supplemental water, the SA-1 percentages achieved for dilutions of 0.5/1000, 1/1000*, and 2/1000 were .004% , .004%*, and .039%, respectively, based on dry soil weight.

T-8BB. Based on procedures identical to T-8AB, the SA-1 dilutions of 0.5/1000, 1/1000*, and 2/1000 yielded SA-1 percentages of .005%, .004%*, and .040%, respectively.

T-10. Asphalt emulsion specimens were tested at 3%, 4%*, and 5% residual asphalt content based on dry soil weight. The emulsion was heated to approximately 35°C, and added to the soil, which was slightly above its optimum moisture content. After thorough mixing, the soil was air dried to optimum moisture content for compaction.

T-11. Hydrated lime was used in the lab studies at rates of 2%, 4%*, and 6%, dry soil weight.

T-12. Participants recommendations called for 4% lime* and 12% flyash* based on dry weight of soil. Since the cost of lime is about 4 times that of flyash, it was decided to choose over and under lab quantities in such a manner that total additive cost would not change. Combinations of 5% lime to 8% flyash and 3% lime to 16% flyash were thus used.

T-13. An aqueous solution of 35% $CaCl_2$ was added to the road surface at a rate of 1/3 gal/sq yd. This amount was duplicated in the lab, along with equivalent amounts of 1/5 gal./sq yd and 1/2 gal./sq yd. The $CaCl_2$ contents, based on dry soil weight, of the 1/5 gal./sq yd, 1/3 gal./sq yd* and 1/2 gal./sq yd applications were .099%, .166%*, and .249%, respectively.

T-14. Mixing procedures identical to those of T-10 were used with residual asphalt content being 3%, 4%*, and 5% of dry soil weight.

T-16. Six gallons of Terra-Seal were used at 1/1000 concentration for the 1000 ft test section. This amount was duplicated in the lab, with solutions of 0.5/1000 and 2/1000 also chosen for testing. These additional amounts were applied with no supplemental water. Based on dry soil weight, concentrations of 0.5/1000, 1/1000*, and 2/1000 yielded .004%, .003%*, and .017% Terra-Seal, respectively.

T-19. A calcium lignosulfonate with 63% solids was applied during construction at 1 gal./sq yd in combination with 2% lime*. Lignin solids content at 1 gal./sq yd* was 1.06%*, dry weight of soil. Additional amounts of 1/2 gal./sq yd lignin and 4% lime, 6% lime alone, and 1 1/2 gal./sq yd lignin and no lime, were used for the lab study. Lignin solids contents of the 1/2 gal./sq yd and 1 1/2 gal./sq yd amounts were .54% and 1.66% based on dry weight of soil.

Moisture-Density

Tests for determination of optimum moisture and density were begun at a moisture content lower than suspected optimum, and as each sample was molded, moisture was incremented until over optimum. Dry densities were calculated based on specimen height, weight, and moisture content.

These tests were run for every additive percentage to expose any trends of optimum moisture and maximum dry density which might develop.

Optimum moisture-maximum dry density values are presented in the Appendix and are compared with those actually achieved in molding of all test specimens.

Unconfined Compression Tests

A Soiltest AP-170 unconfined compression unit was used with a controlled strain rate of 0.1 in. per min. Load was applied through a calibrated proving ring with a ball and socket load head to minimize eccentricity. The maximum load which the specimen could withstand was recorded and converted to a psi value of stress. An average stress value for two identically mixed and molded specimens was determined, and is shown in Fig. 16 through 30. Note the tick mark on the right side of each bar on the graphs, indicating the lower of the averaged strengths, an indication of spread of the two values.

Figures 16 through 30 also present unconfined compressive strengths (q_u) of field mixed, field lab molded standard proctor size specimens determined in the same testing machine as the 2 in. by 2 in. cylinders, but approximately 10 months after molding. Representative samples of the treated materials were removed from each test section immediately after field mixing, molded in 1/30 cu ft molds mounted on a large concrete block, extruded, securely wrapped in Saranwrap, sealed, and taken to the laboratory for storage in a constant temperature and 100% relative humidity curing room. UCS of the field mixed and molded specimens thus represent about 10 months of moist curing.

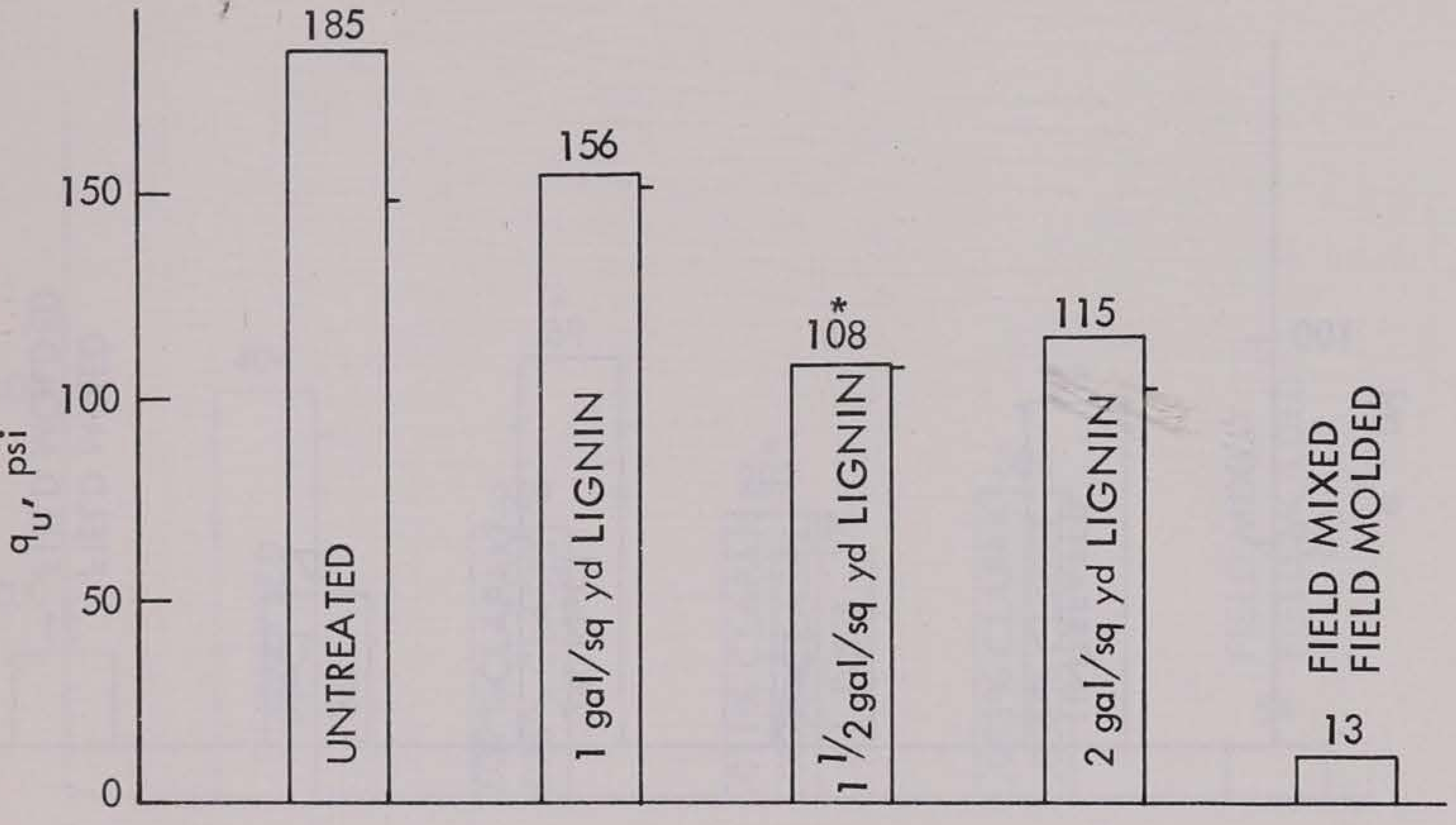

Figure 16. Unconfined compression results; section T-2.

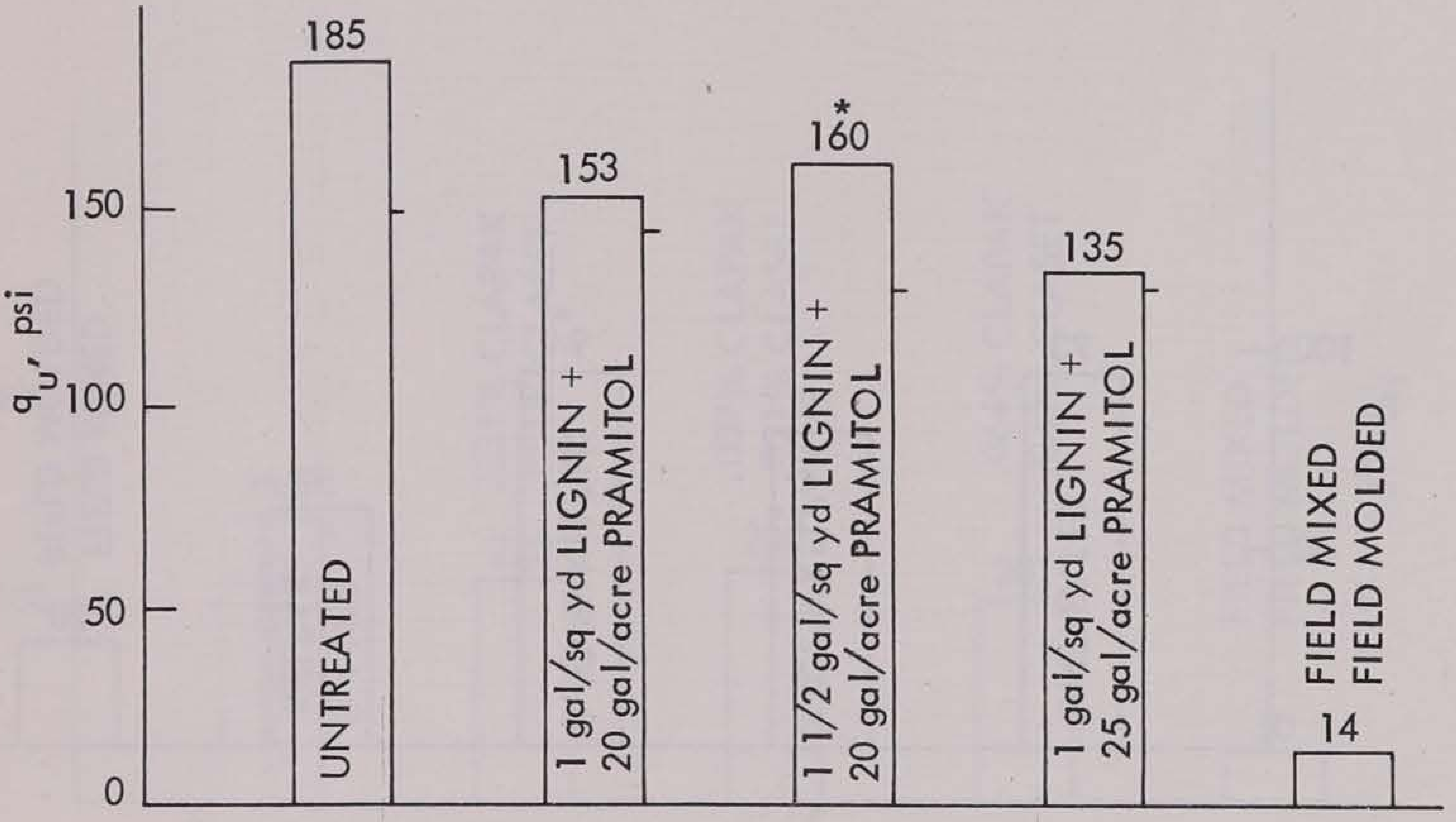

Figure 17. Unconfined compression results; section T-2A.

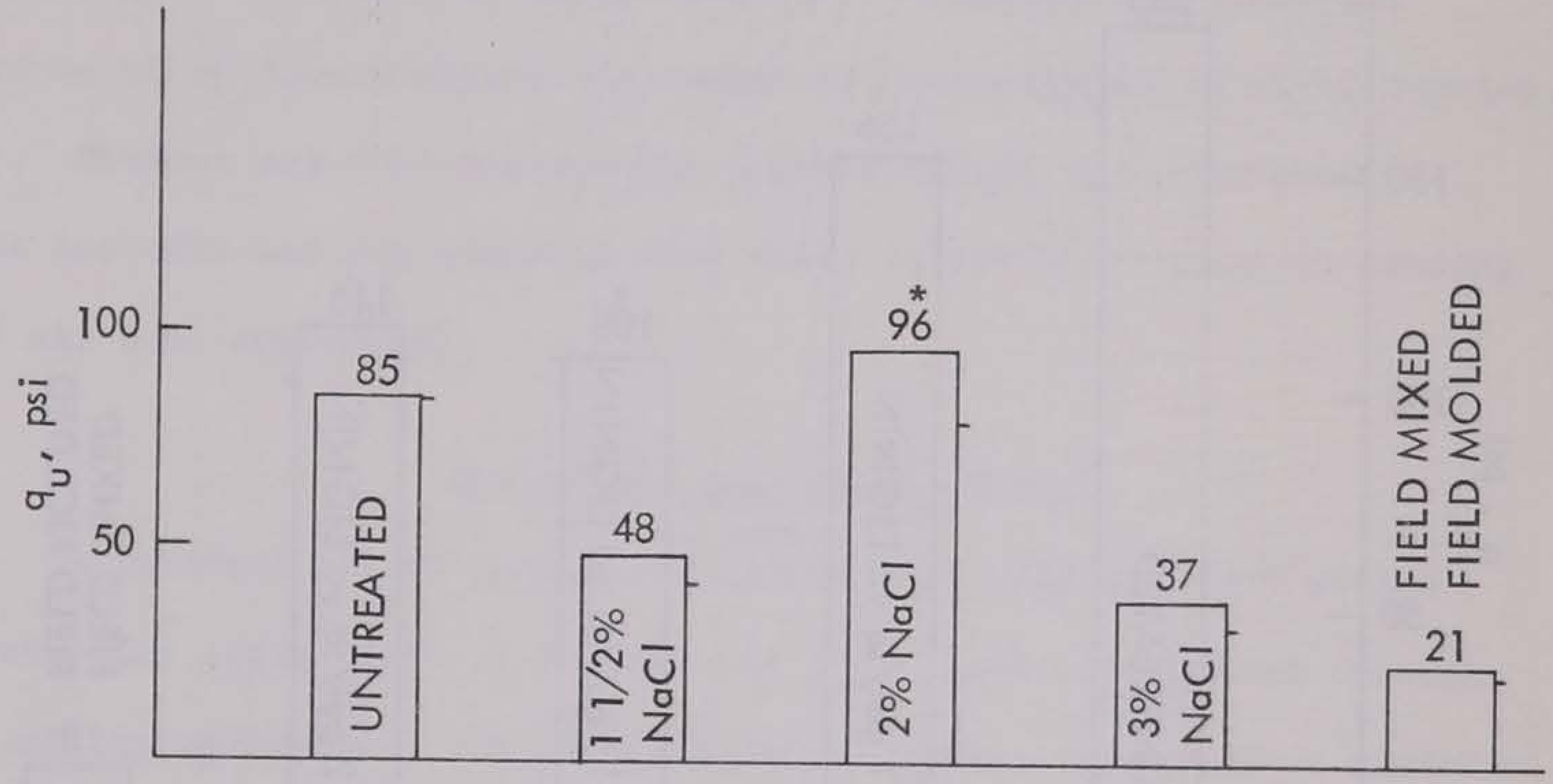

Figure 18. Unconfined compression results; section T-5.

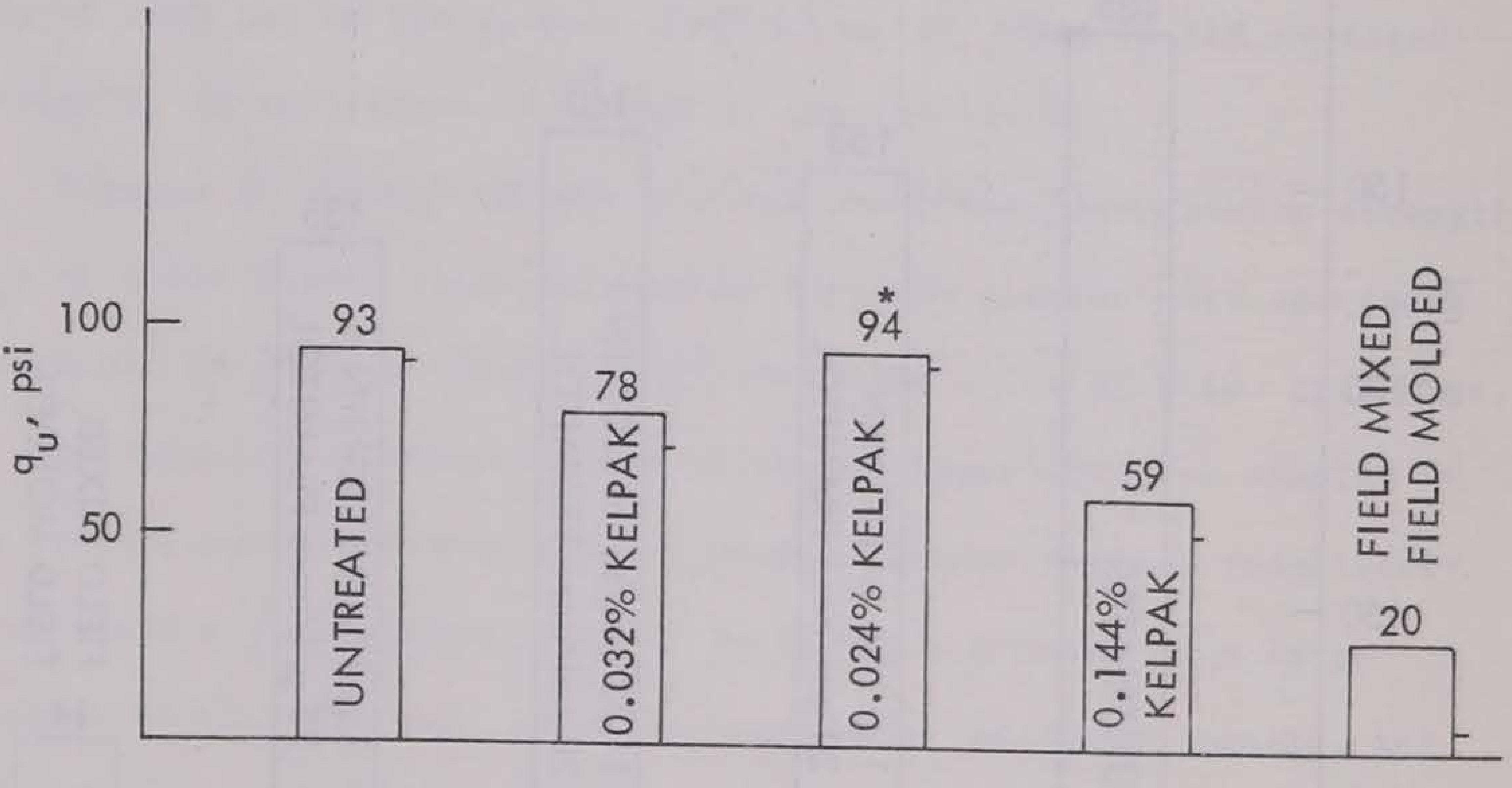

Figure 19. Unconfined compression results; section T-6.

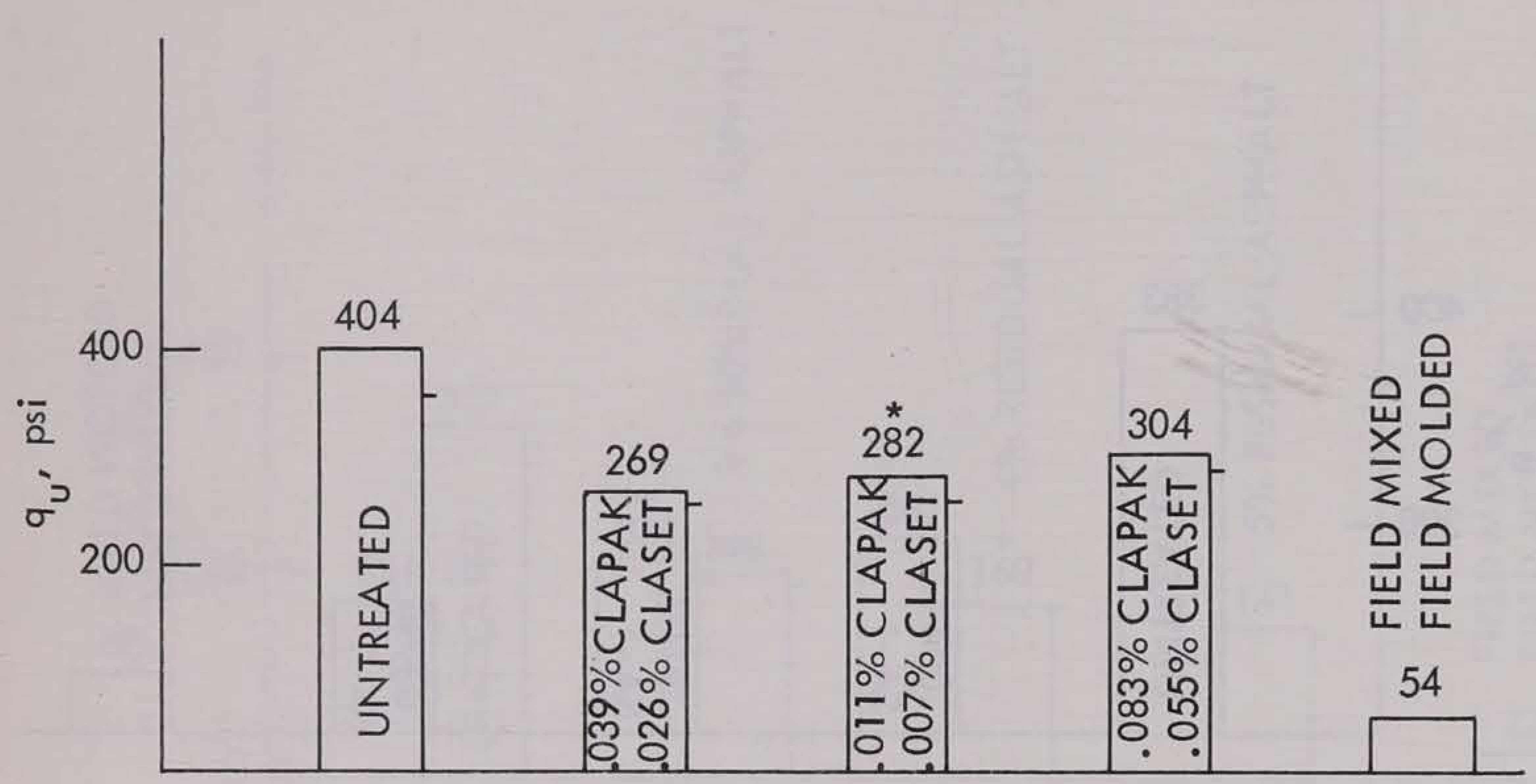

Figure 20. Unconfined compression results; section T-8AS.

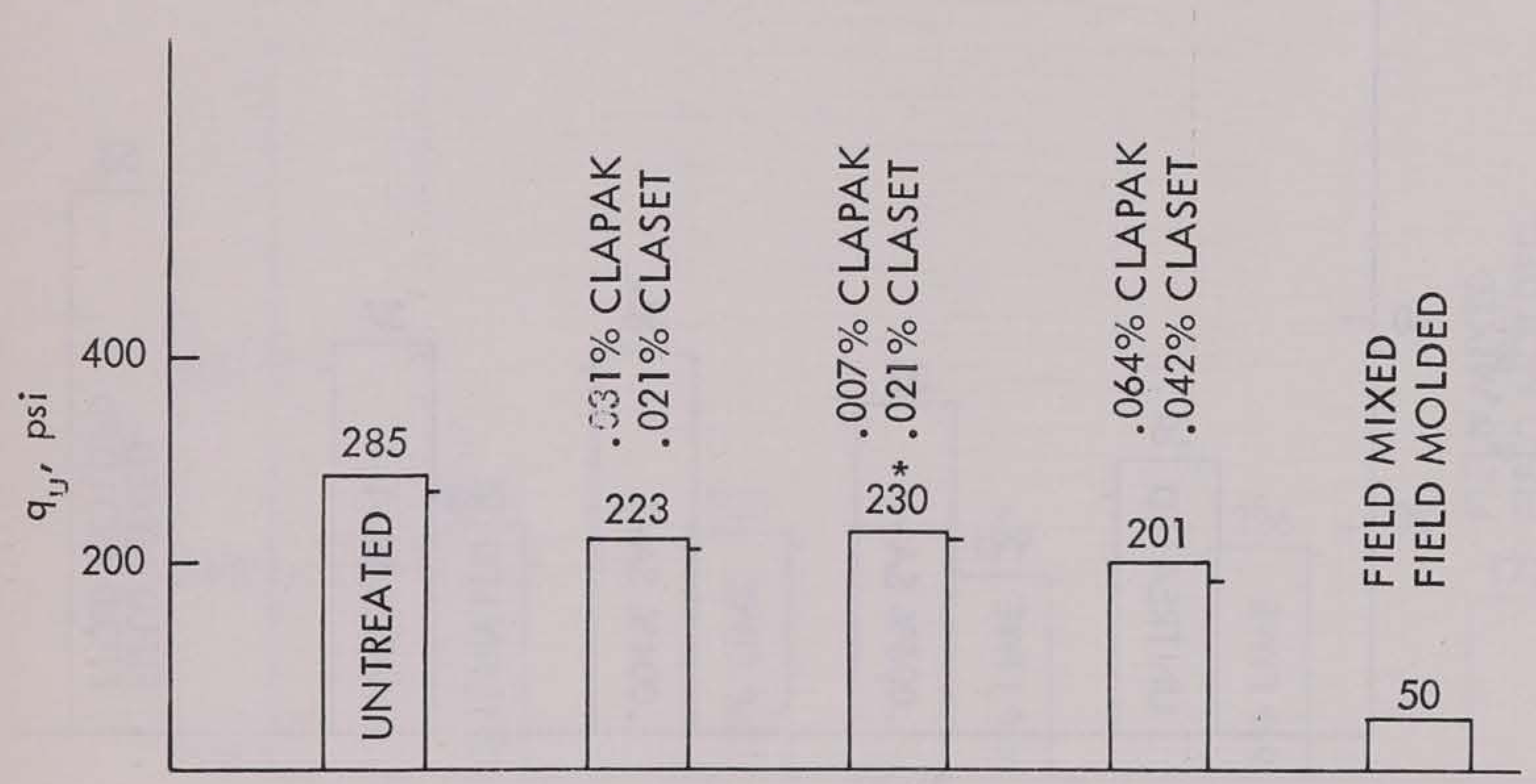

Figure 21. Unconfined compression results; section T-8BS.

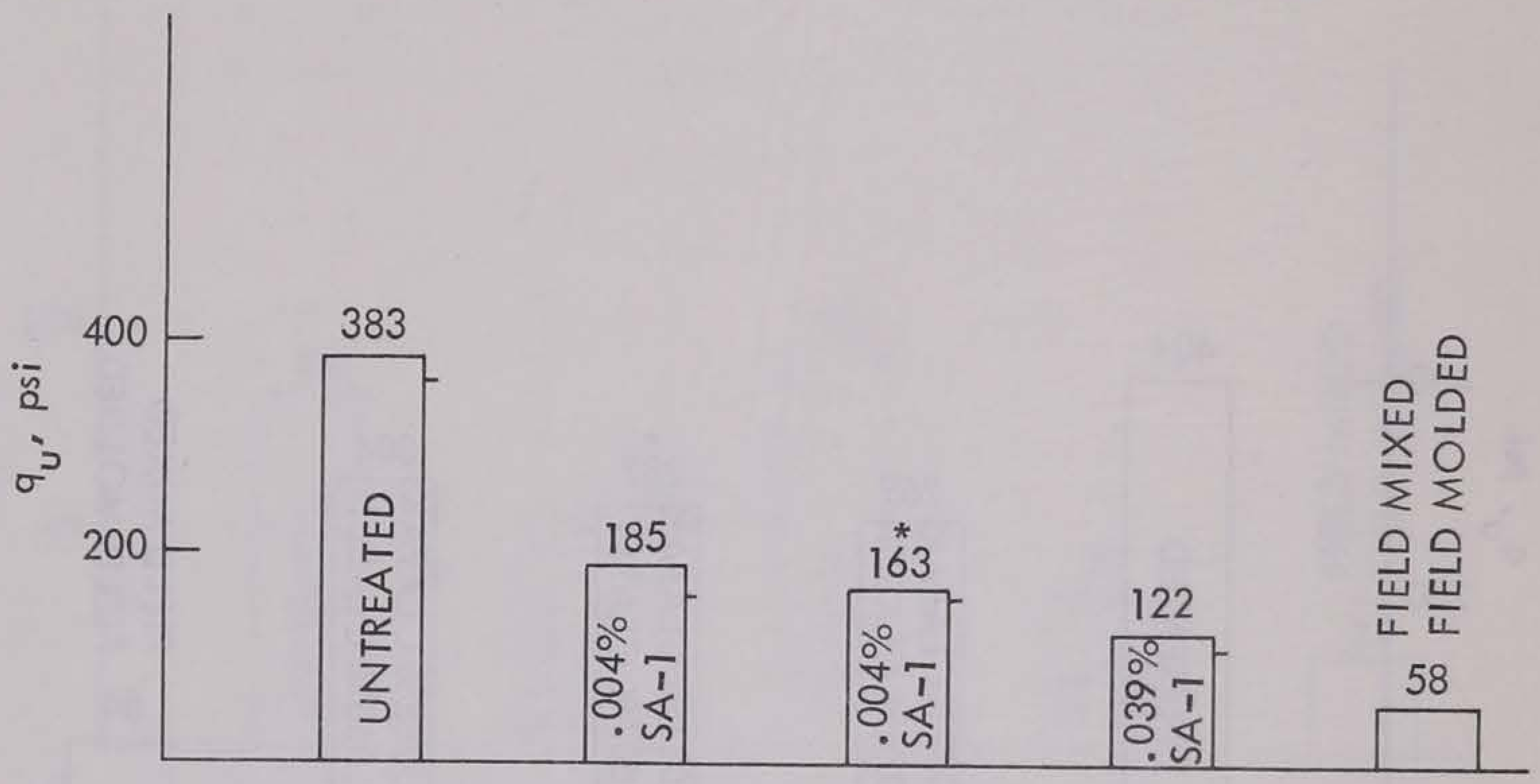

Figure 22. Unconfined compression results; section T-8AB.

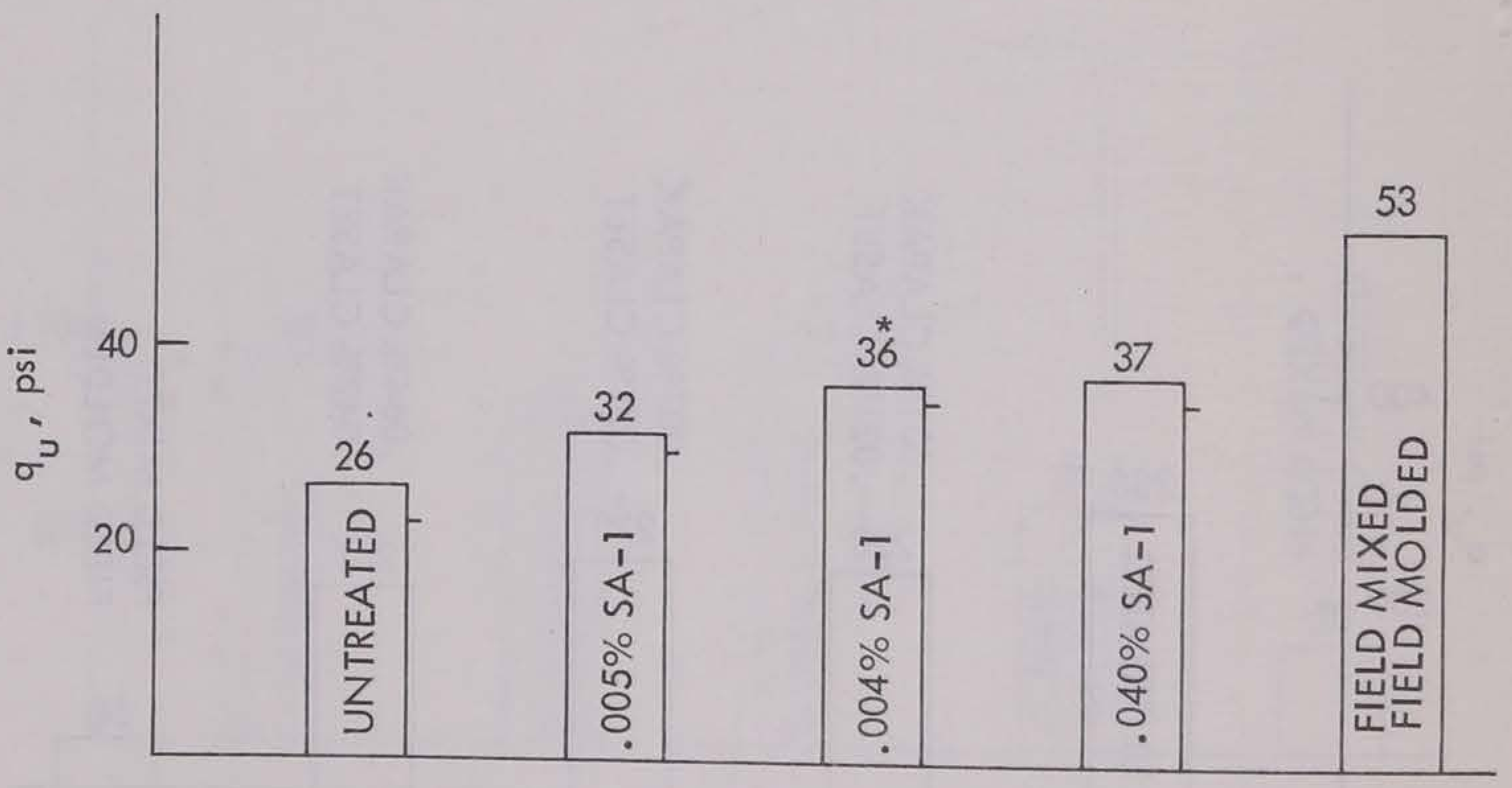

Figure 23. Unconfined compression results; section T-8BB.

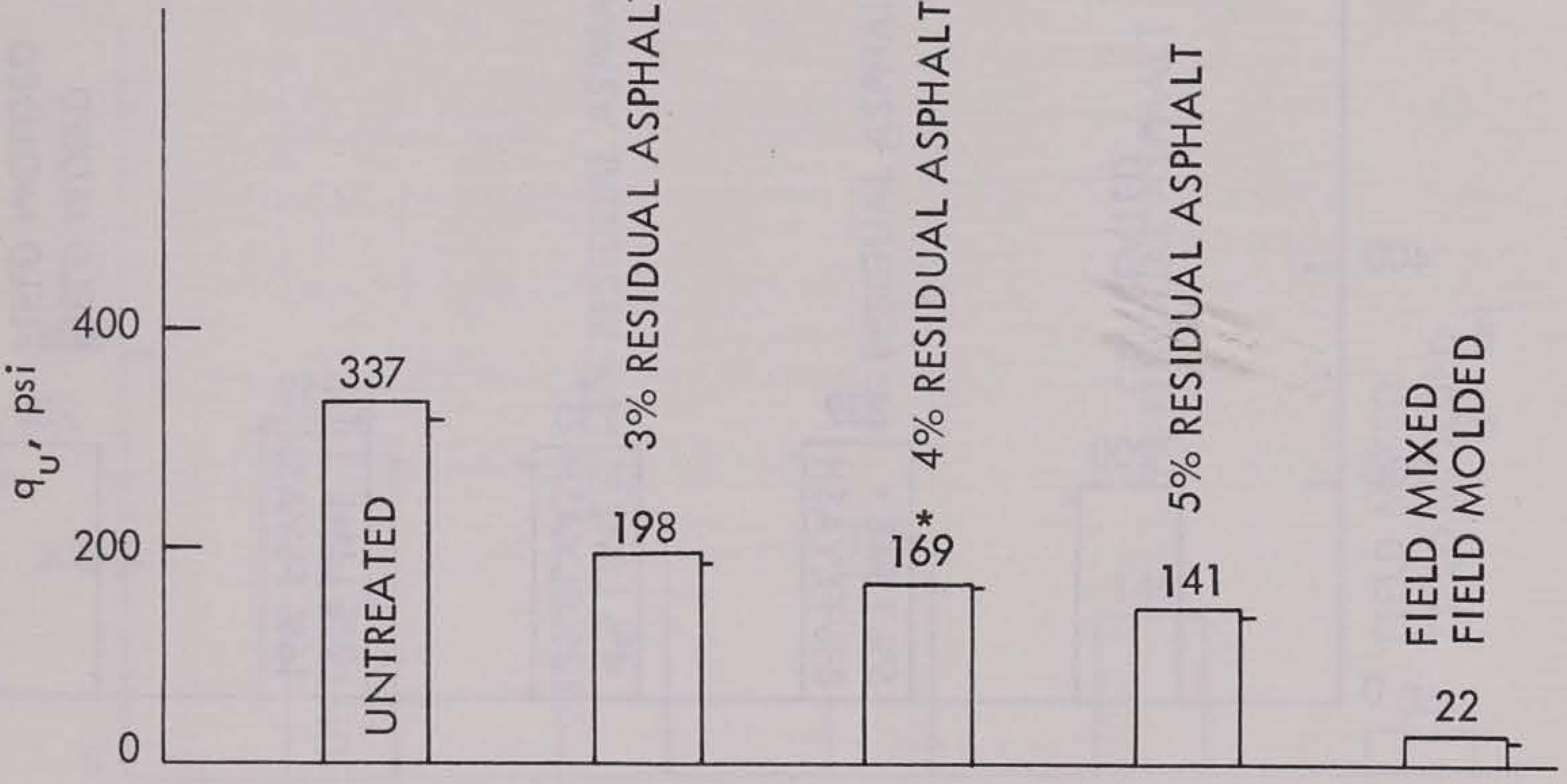

Figure 24. Unconfined compression results; section T-10.

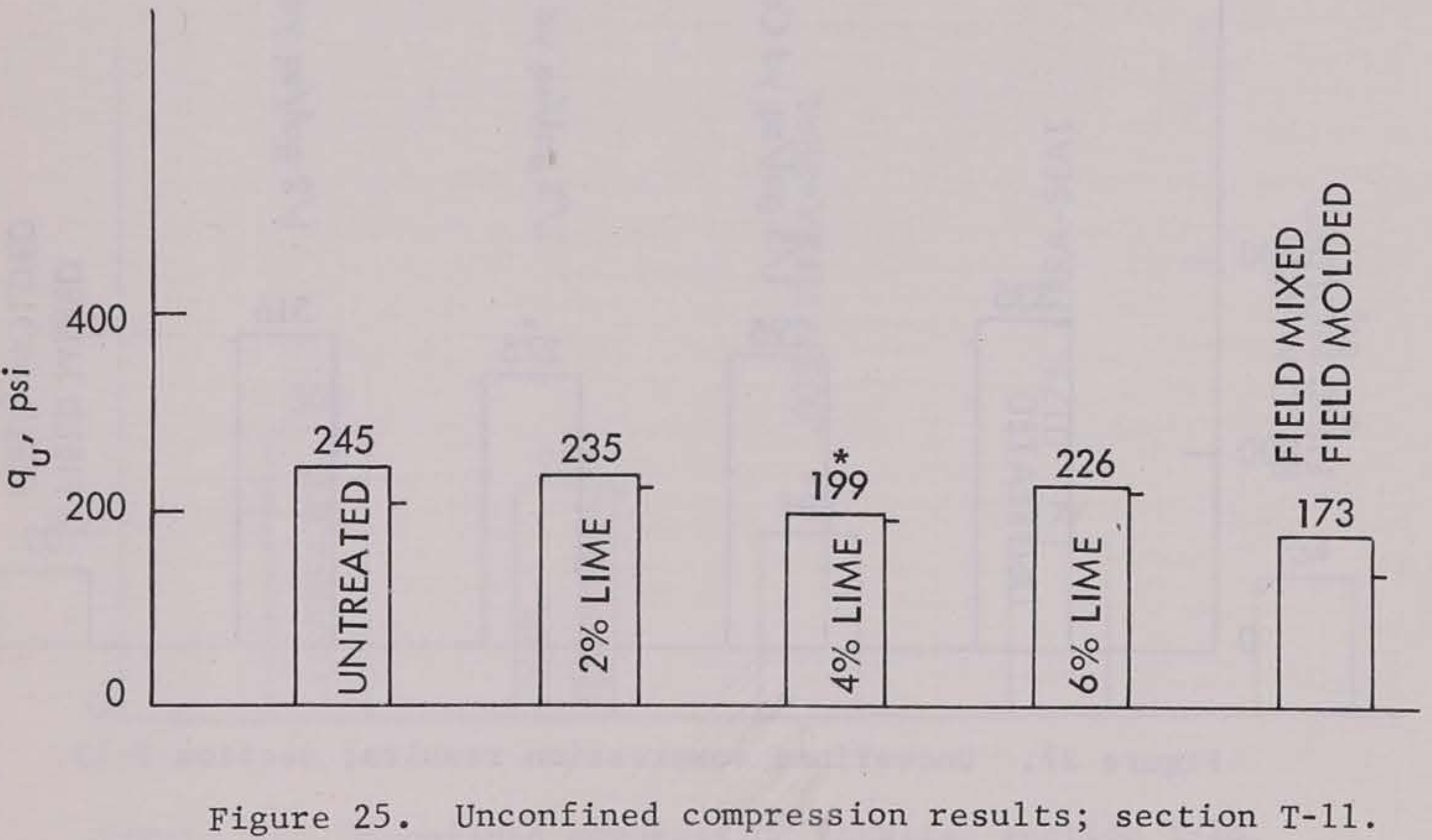

Figure 25. Unconfined compression results; section T-11.

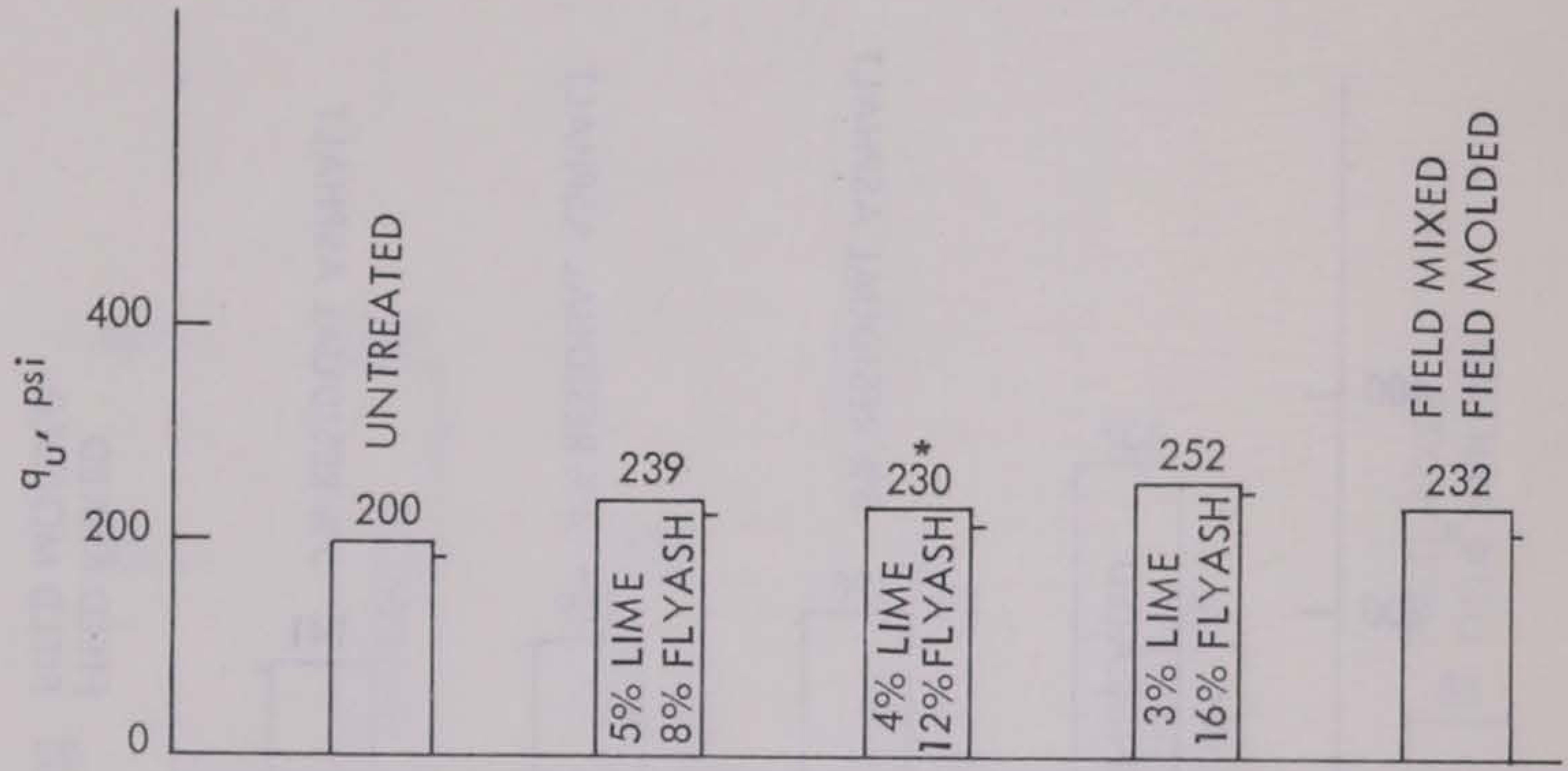

Figure 26. Unconfined compression results; section T-12.

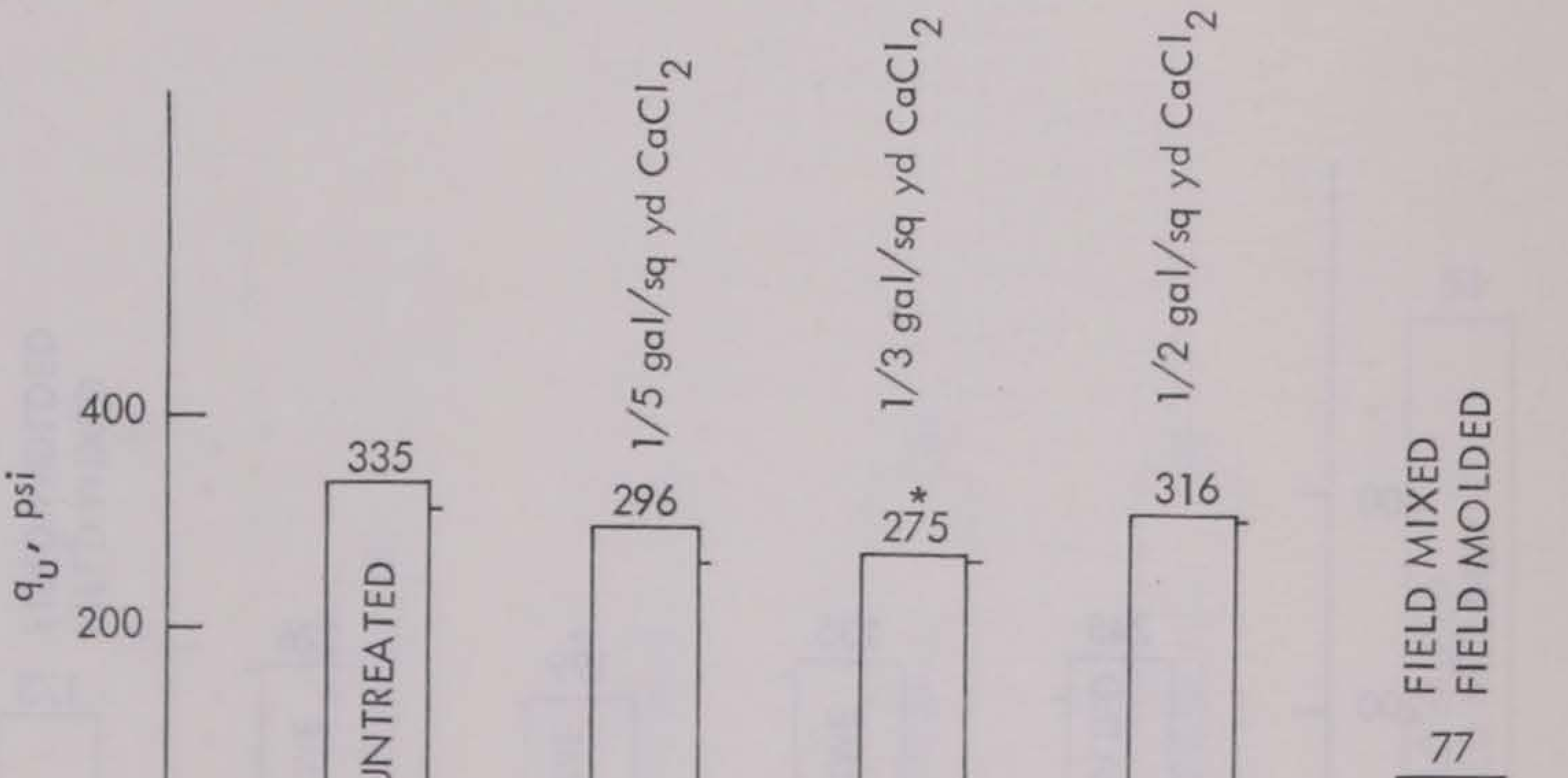

Figure 27. Unconfined compression results; section T-13.

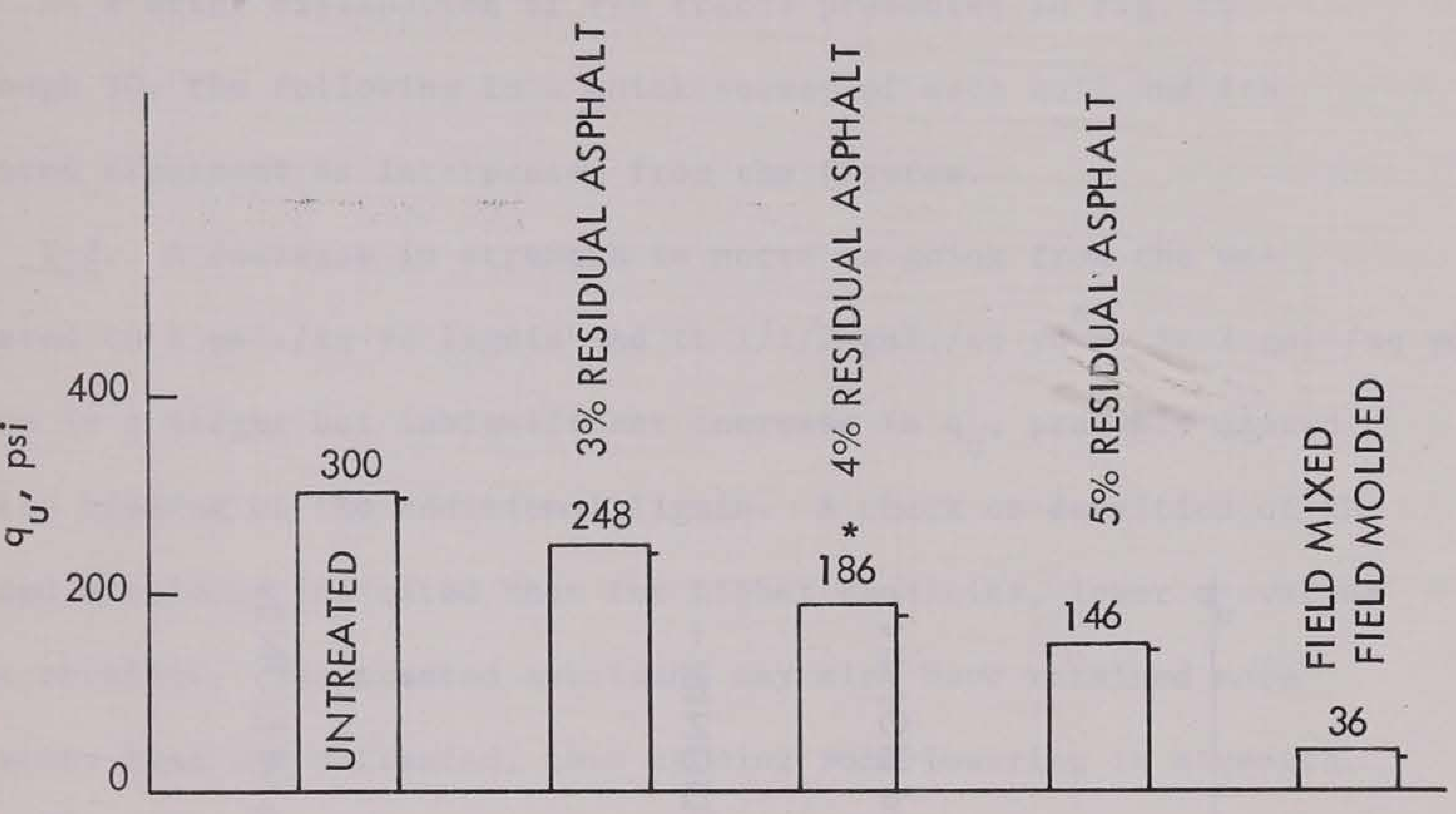

Figure 28. Unconfined compression results; section T-14.

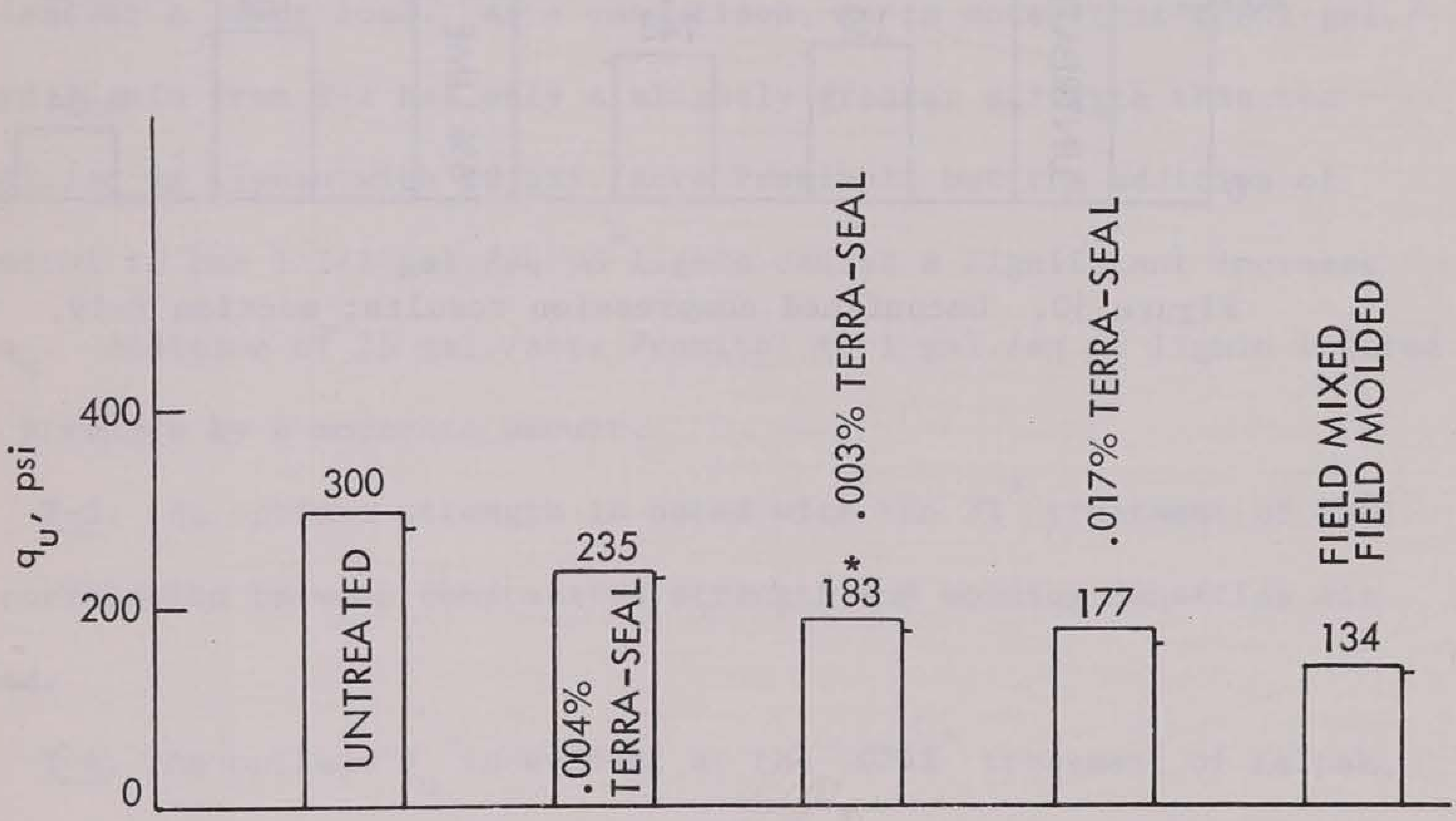

Figure 29. Unconfined compression results; section T-16.

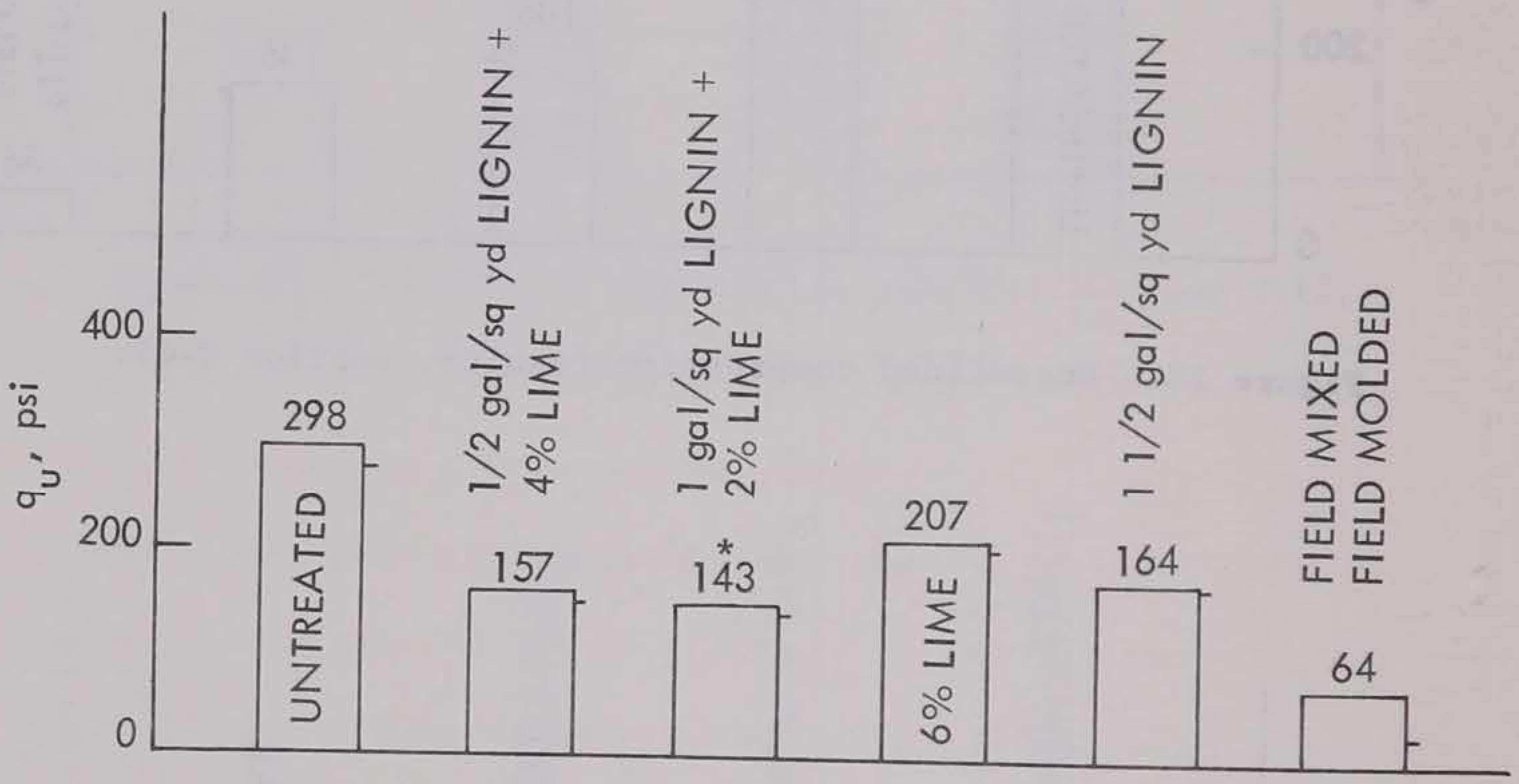

Figure 30. Unconfined compression results; section T-19.

As a brief explanation of the trends presented in Fig. 16 through 30, the following is a quick survey of each soil and its related treatment as interpreted from the figures.

T-2. A decrease in strength is noted in going from the untreated to 1 gal./sq yd lignin and to 1/1/2 gal./sq yd*. At 2 gal./sq yd there is a slight but insignificant increase in q_u, probably caused by the binding of the additional lignin. A check on densities of the molded specimens indicated that for higher densities, lower q_u values were obtained. The treated specimens may also have retained more moisture than the untreated, thus causing some lowering in strength.

T-2A. Again, all treated specimens had lower q_u values than the untreated, but with no apparent correlation with density. It is probable that the lignin retained enough moisture to cause the specimens to fail at a lower load. As a comparison, it is noted that the 1 gal./sq yd lignin from T-2 has only a slightly greater strength than the 1 gal./sq yd lignin with 20 gal./acre Pramitol, but the addition of Pramitol to the 1 1/2 gal./sq yd* lignin causes a significant increase in q_u. Addition of 25 gal./acre Pramitol to 1 gal./sq yd lignin lowered the strength by a moderate amount.

T-5. An optimum strength is noted with the 2%* treatment of NaCl. No correlation between compressive strength and molding densities was noted.

T-6. An optimum q_u is evident at the .024%* treatment of Kelpak, with a lowering of strength as the additive percentage was increased. A retention of moisture by the soil-chemical mix as well as a reduction in surface tension may be the cause of decreasing strengths with increasing additives. A relationship indicating somewhat lower strengths with lower densities was noted but was not consistent.

T-8AS. Lower strengths are achieved for treated than for untreated specimens. This was substantiated by Denny[3] in his work with the combinations of Clapak and Claset. Slightly higher q_u values are shown with the largest quantities of Clapak-Claset combination. No trends were noted with q_u versus molding densities.

T-8BS. A decrease in q_u with increasing additive percentage is noted, which may be attributed to a more silty nature of the soil and lower cohesion.

T-8AB. All treated specimens exhibited lower unconfined compressive strength values than the untreated. SA-1 is suspected to contain $CaCl_2$, which would retain more hygroscopic moisture and thus cause a reduction in strength.

T-8BB. An apparent increase in strength of the SA-1 treated specimens over the untreated was noted, although the difference was nominal. Low q_u values for the specimens should be noted and can be attributed to a lack of sufficient fines as binder material. The low densities achieved verify this observation.

T-10. A decreasing trend of q_u values as the residual asphalt content increased was noted and can be attributed to the higher plasticity of the treated mixture. A decrease in maximum density was noted as the additive percentage increased.

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[3] Denny, C.K. Soil Chemical Additives as Surface Improvement Agents for Unpaved Roads. Unpublished M.S. Thesis. Ames, Iowa: Iowa State University, Library, 1973.

T-11. Relatively little variation in strength was noted with the different percentages of lime. The untreated specimens were slightly higher in strength, but with a longer cure period this trend should reverse. Similarity of strength values indicate that even though lime may have reduced soil plasticity, cementing reactions had not yet added appreciable strength.

T-12. All treated specimens show slightly higher strengths than untreated specimens, yet have lower densities, indicating some pozzolanic reaction. With the 24 hr cure, the highest value of q_u was for the low lime, high flyash content specimens.

T-13. As compared to the untreated specimens, there was a slight decrease in strength for the treated specimens, probably attributable to the hygroscopic and deliquescent properties of $CaCl_2$, which tends to retain moisture.

T-14. A definite trend of decreasing strength with increasing residual asphalt percentage was noted and can be attributed to the higher plasticity which asphalt imparts to the soil.

T-16. All specimens treated with Terra-Seal exhibited lower strengths than untreated. A longer curing period may be necessary to detect a strength gain.

T-19. It was apparent that all specimens containing lignin exhibited lower strengths than the untreated specimens, substantiating data from sections T-2 and T-2A. The 6% lime treatment indicates a higher strength than the lignin/lime combinations or lignin only, which could be expected to increase with a longer cure period.

Field Mixed - Field Molded. Nearly all field mixed and molded specimens exhibited lower q_u values than the lab treated, lab molded specimens. Section T-8BB, however, showed a higher strength than lab values, which might be attributed to particle size breakdown due to the stabilizer mixer. Sections T-11 and T-12 had q_u values similar to the equivalent additive quantity lab values, but are the result of the 10 month humid cure period allowing for pozzolanic and/or cementing action to occur.

Table 6 presents a comparison of laboratory maximum dry densities and optimum moisture contents with field mixed and molded q_u specimens moisture and density, for equivalent additive contents. Also included are the average field test section densities and moisture contents as determined with the Troxler unit. It may be noted that with the exception of two of the section materials, all field mixed, field molded specimens had either similar (T-8BB) or higher moisture contents than the lab specimens; only T-5 and T-8AS were at less moisture content. This may have significantly contributed to the reduction in field mixed and molded q_u. In addition, it will be noted that the field T-8BB had a significantly higher dry density than its equivalent lab specimens, which may also have contributed to its having a higher q_u than the lab specimens.

Freeze-Thaw Tests

The problem of spring thaw loss of strength in a road surface has plagued road builders for many years, and full scale experimentation

Table 6. Density comparisons.

Section No.	Lab Mixed-Lab Molded		Field Mixed-Field Molded		Troxler Nuclear Unit	
	Dry Density, pcf	M.C., %	Dry Density, pcf	M.C., %	Dry Density, pcf	M.C., %
T-2	132.5	8.3	122.2	15.6	128.6	9.5
T-2A	132.8	8.6	119.9	16.1	127.3	8.4
T-5	129.4	8.4	125.8	5.5	132.0	4.1
T-6	129.7	8.8	127.2	11.2	127.1	6.4
T-8AS	119.3	12.8	125.4	8.1	-	-
T-8BS	127.7	8.8	120.3	15.3	-	-
T-8AB	133.9	8.0	129.8	9.3	137.8	6.9
T-8BB	118.4	8.7	129.2	8.6	126.8	8.4
T-10	126.0	8.4	119.4	12.7	124.1	9.7
T-11	121.9	10.5	112.5	15.3	114.9	8.9
T-12	118.1	13.1	112.9	17.7	116.3	7.9
T-13	129.2	9.9	120.9	11.3	124.5	8.7
T-14	115.0	12.5	97.5	22.6	113.5	14.1
T-16	129.1	8.9	122.2	10.0	124.0	7.3
T-19	109.0	16.1	108.7	20.2	105.1	11.5

with additives to minimize the problem has proven very expensive. A laboratory apparatus developed by George[4] has proven effective for determining the freeze-thaw durability of stabilized soil specimens, and is referred to as the Iowa Freeze-Thaw Test. Many other tests to determine the resistance of soil to damage by frost action have been tried, as discussed by George[4].

The Iowa Freeze-Thaw Test calls for unconfined compressive strengths to be determined on specimens subjected to various freeze-thaw cycles and compared to control specimens. Few of the 24 hr air cure specimens tested in this project could be extracted from the specimen holder in a manner useful for unconfined strength tests. A modified procedure[3] was therefore used which evaluated performance of the specimens on the basis of elongation only.

Following 24 hr air cure, duplicate specimens were placed in sample holders which fit inside standard Thermos flasks filled to a predetermined height with water in contact with the specimen base. Initial specimen height measurements were then taken to serve as datums for all measurements thereafter.

Flasks and specimens were placed in a freezer maintained at 20°F ± 2°F for 16 hr. Upon removal, height readings were taken, and the specimens were allowed to thaw for 8 hr, after which readings were again taken. This constituted one cycle, and the process was repeated for a total of ten cycles.

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[4] George, K.D. Development of Freeze-Thaw Test for Evaluating Stabilized Soil. Unpublished M.S. Thesis, Ames, Iowa: Iowa State University, Library, 1961.

To simulate actual field conditions, tops of the specimens were allowed to freeze while the water in contact with the bottoms was maintained at about 35°F. This is accomplished with small light bulbs plugged into a variable voltage source.

Evaluation for criteria was the net elongation of the specimens as a percentage of original height. Figures 31 through 45 present plots of percent elongation after each freeze and thaw period versus number of cycles. An average elongation for each treatment was calculated and is presented in Table 7. The reader is cautioned against using the average elongation as the sole evaluation of performance since such values give a quantitative comparison of the overall performance of each treatment, but do not reflect the many fluctuations which may occur during the course of a test. The following discussion of each soil and its treatment points out these occurances and also the trends which developed.

T-2. Although the average percent elongation does not show a significant difference with treatment, it should be pointed out that the untreated specimens fluctuated a great deal. The least F-T susceptible treatment appeared to be 1 1/2 gal./sq yd lignin.*

T-2A. All treated specimens showed similar patterns of behavior with no apparent optimum treatment. Addition of Pramitol did not significantly improve, nor was apparently detrimental, to the F-T performance of the lignin treated soil.

T-5. A shrinkage of all samples was noted, with the 2% NaCl* treatment having the least amount shrinkage.

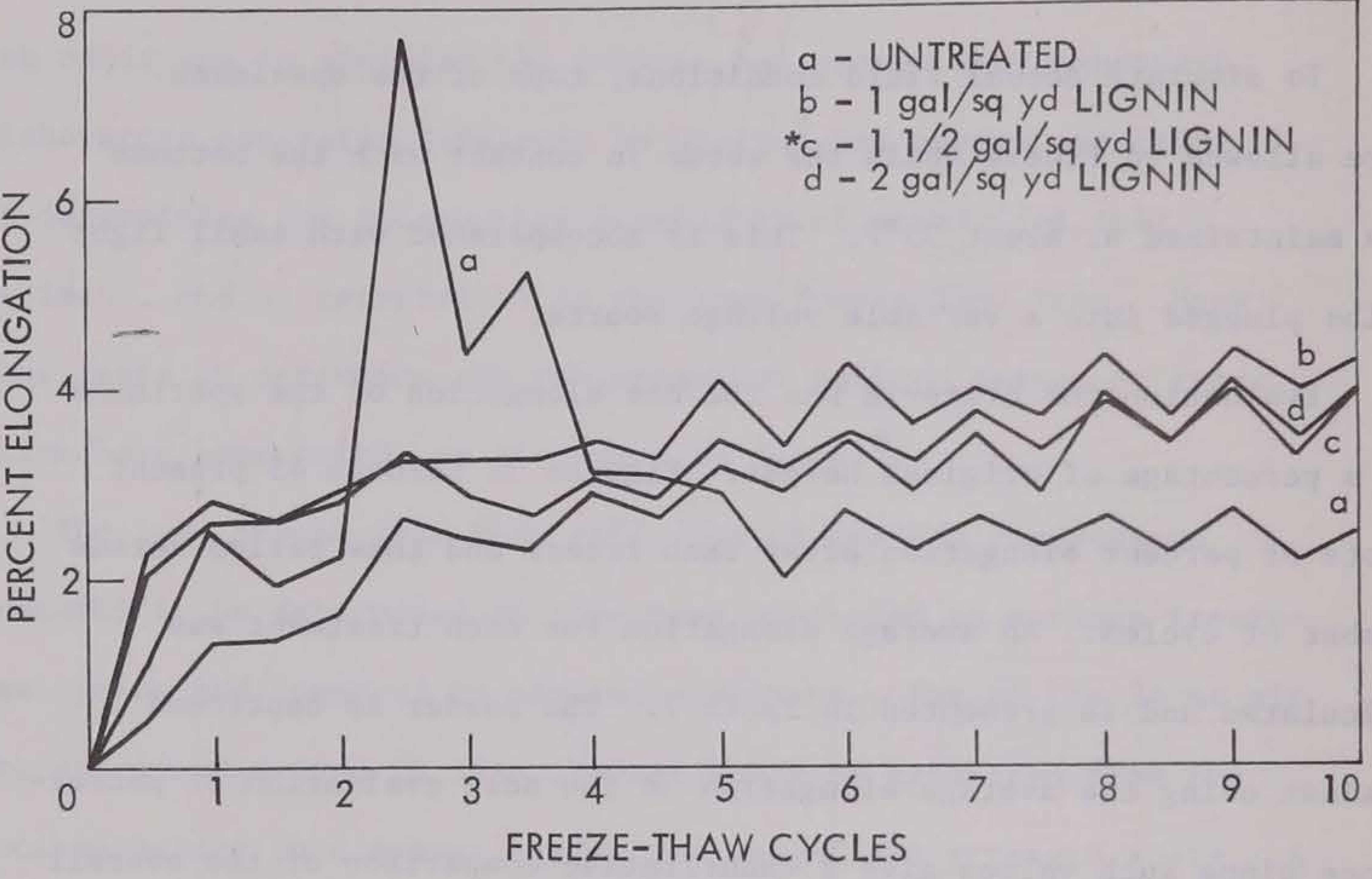

Figure 31. Freeze-Thaw results; section T-2.

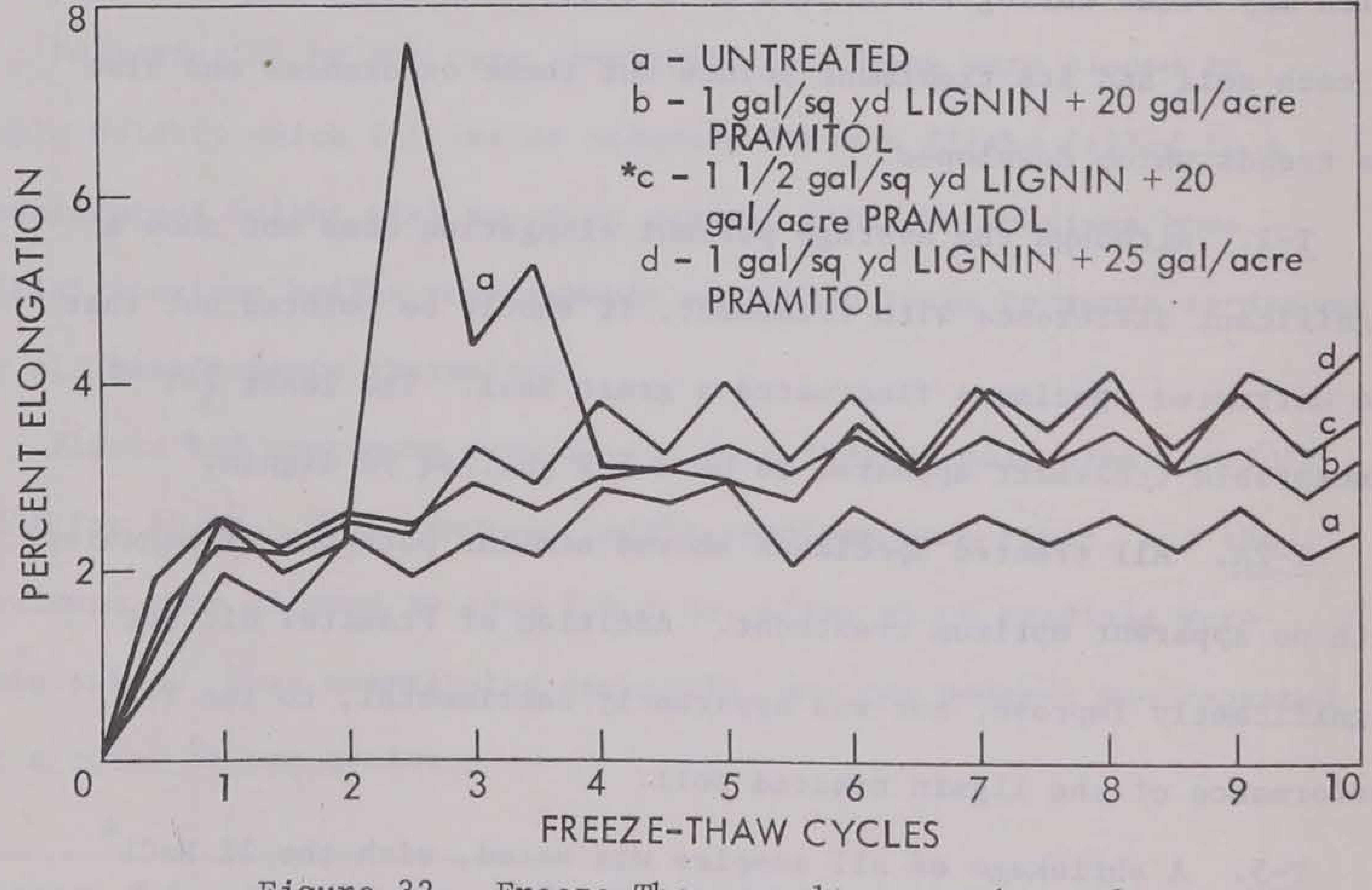

Figure 32. Freeze-Thaw results; section T-2A.

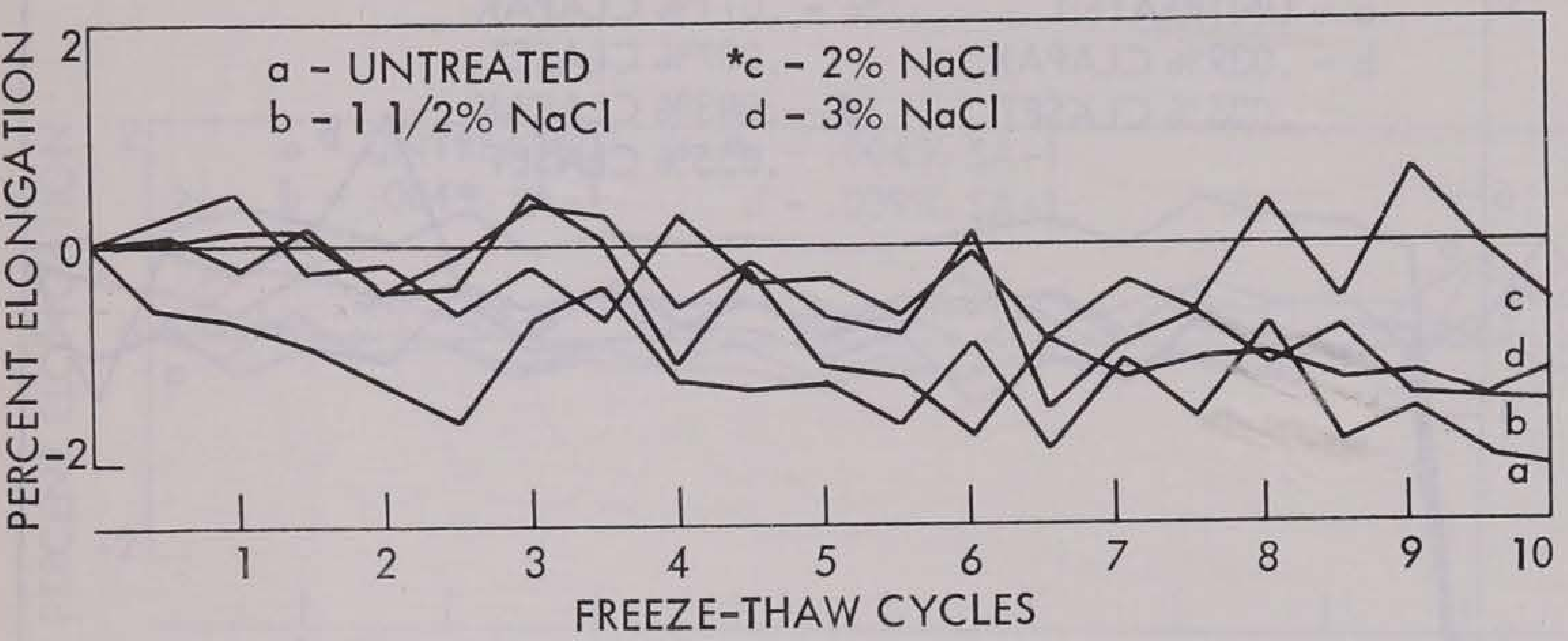

Figure 33. Freeze-Thaw results; section T-5.

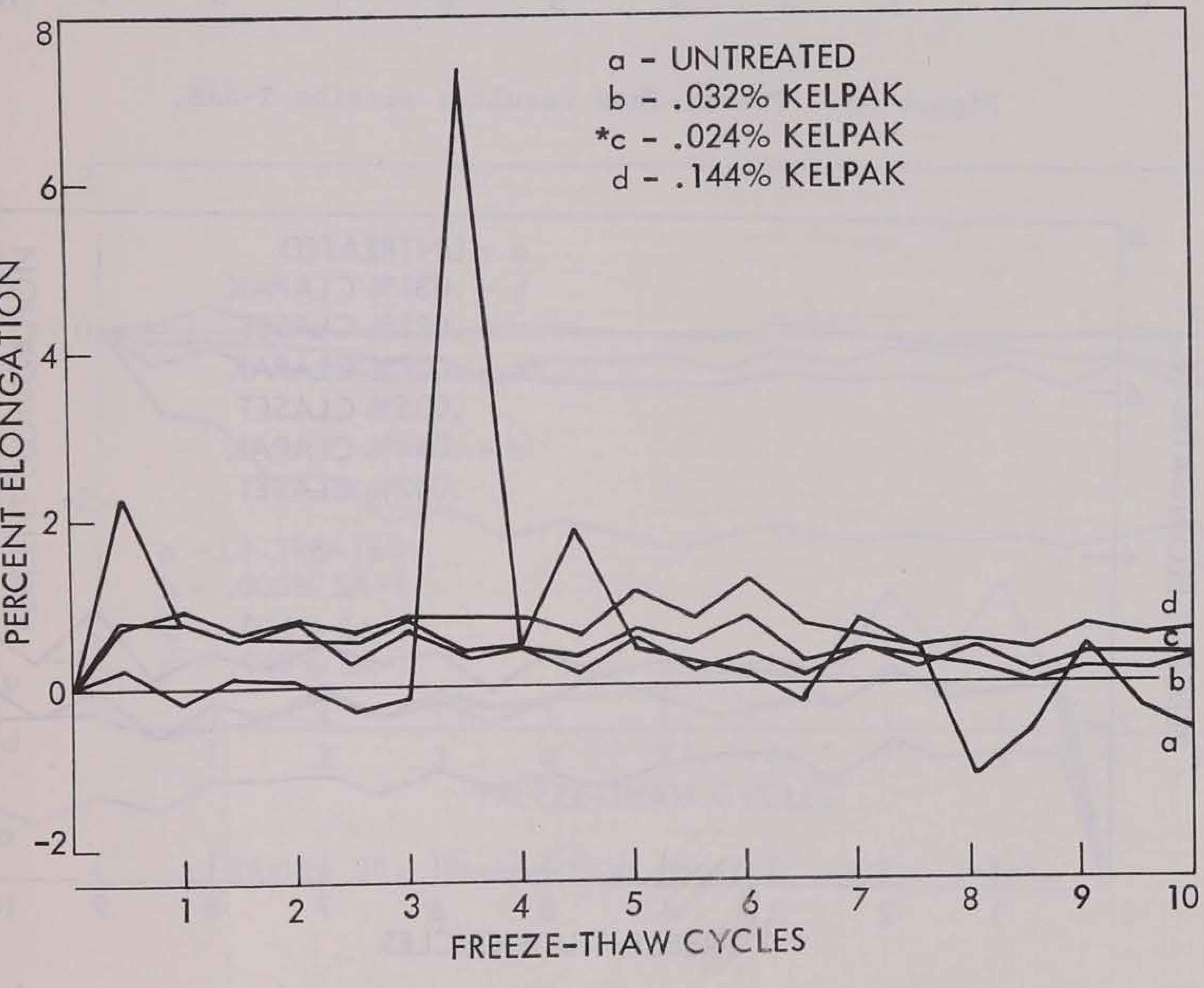

Figure 34. Freeze-Thaw results; section T-6.

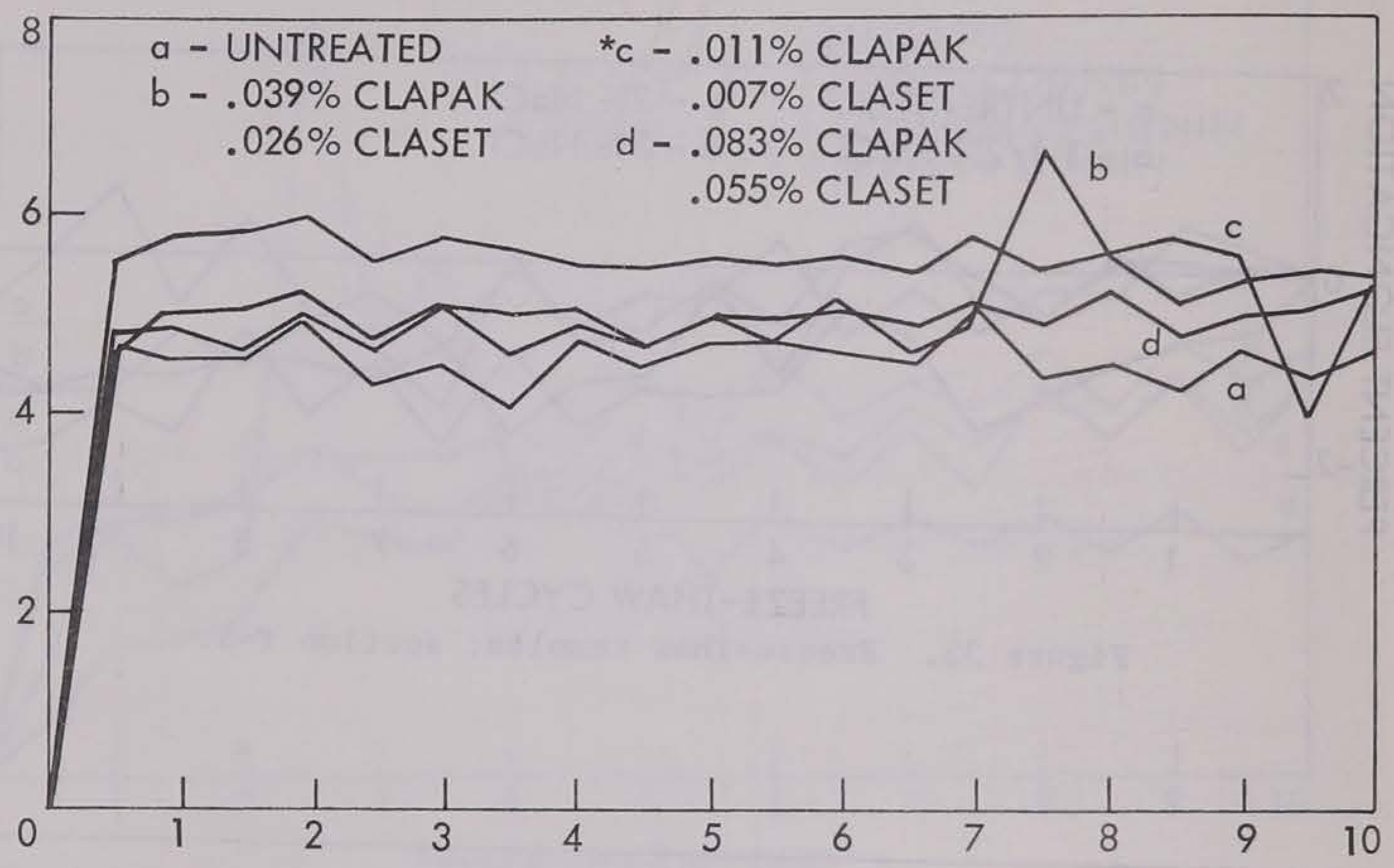

Figure 35. Freeze-Thaw results; section T-8AS.

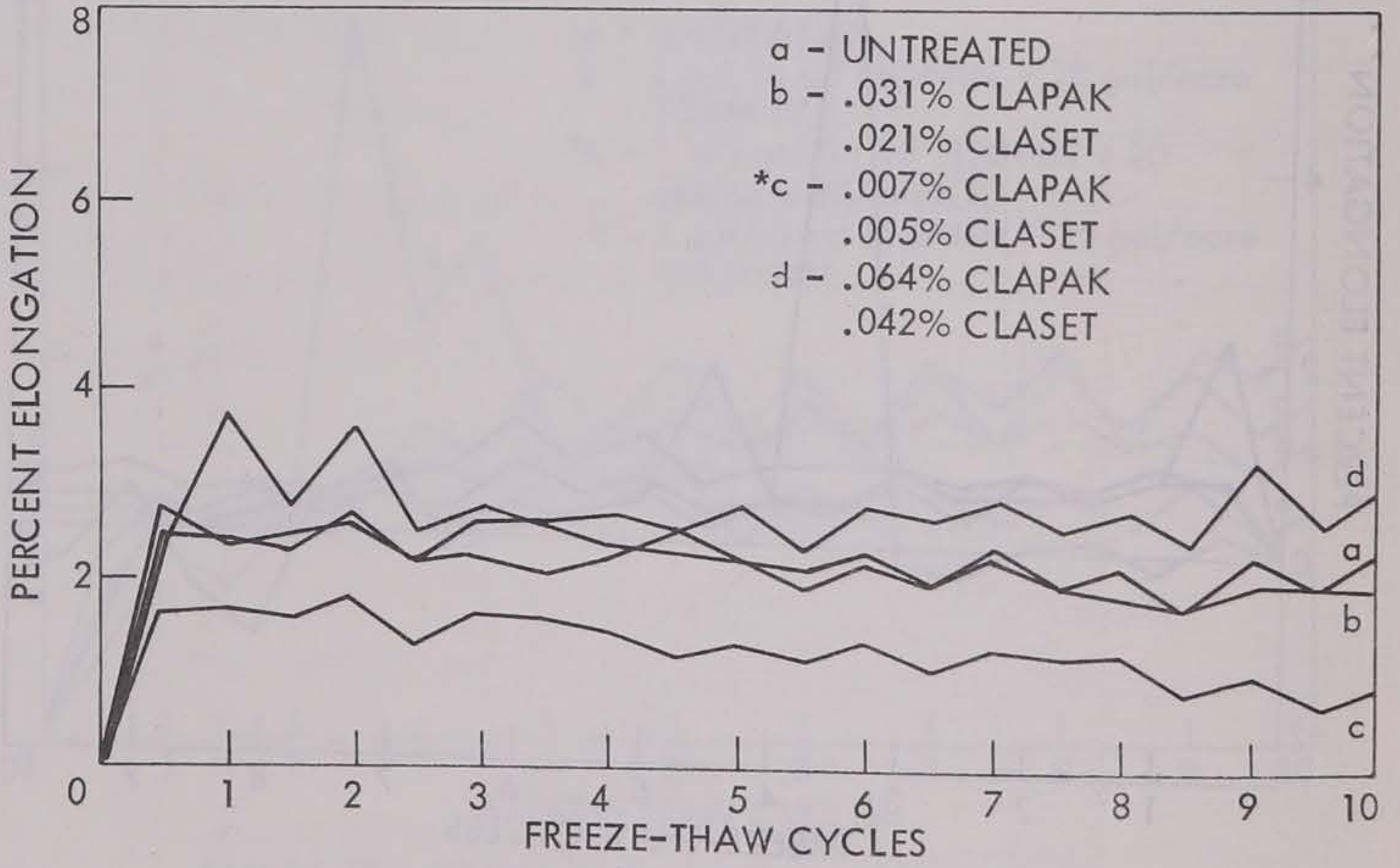

Figure 36. Freeze-Thaw results; section T-8BS.

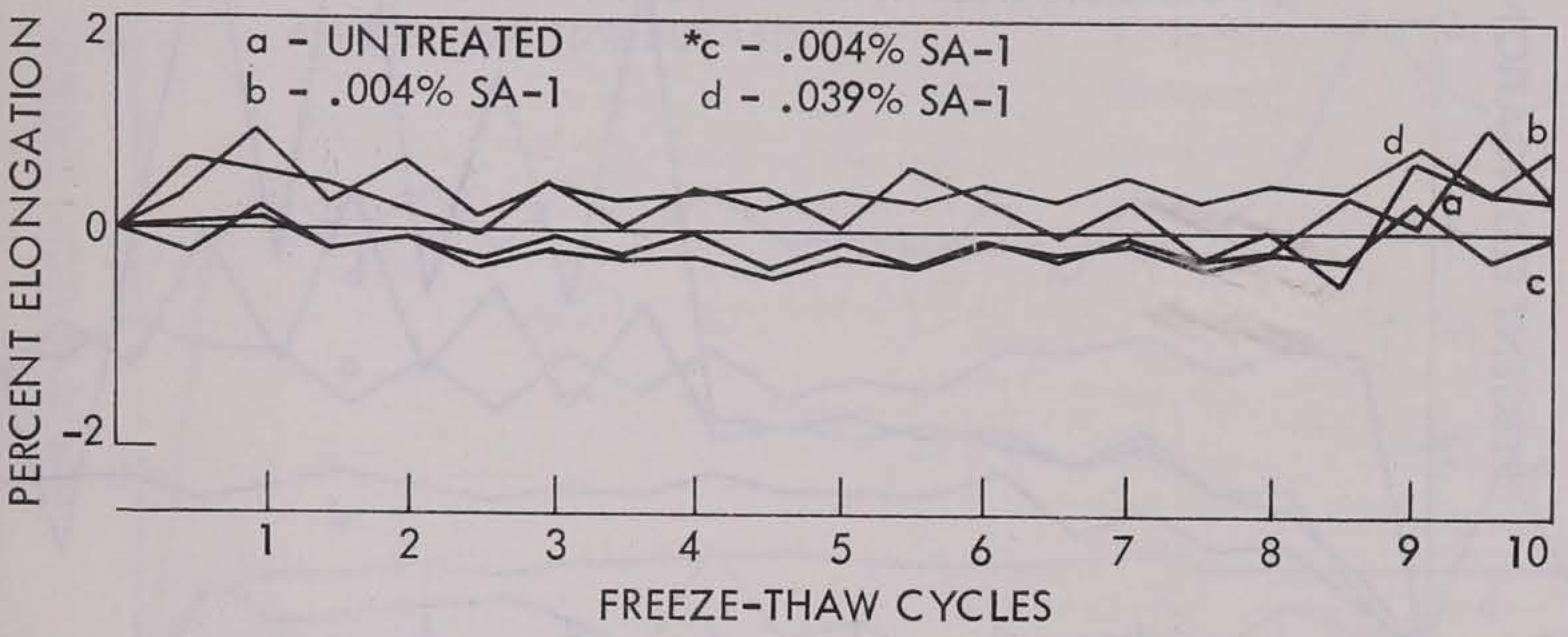

Figure 37. Freeze-Thaw results; section T-8AB.

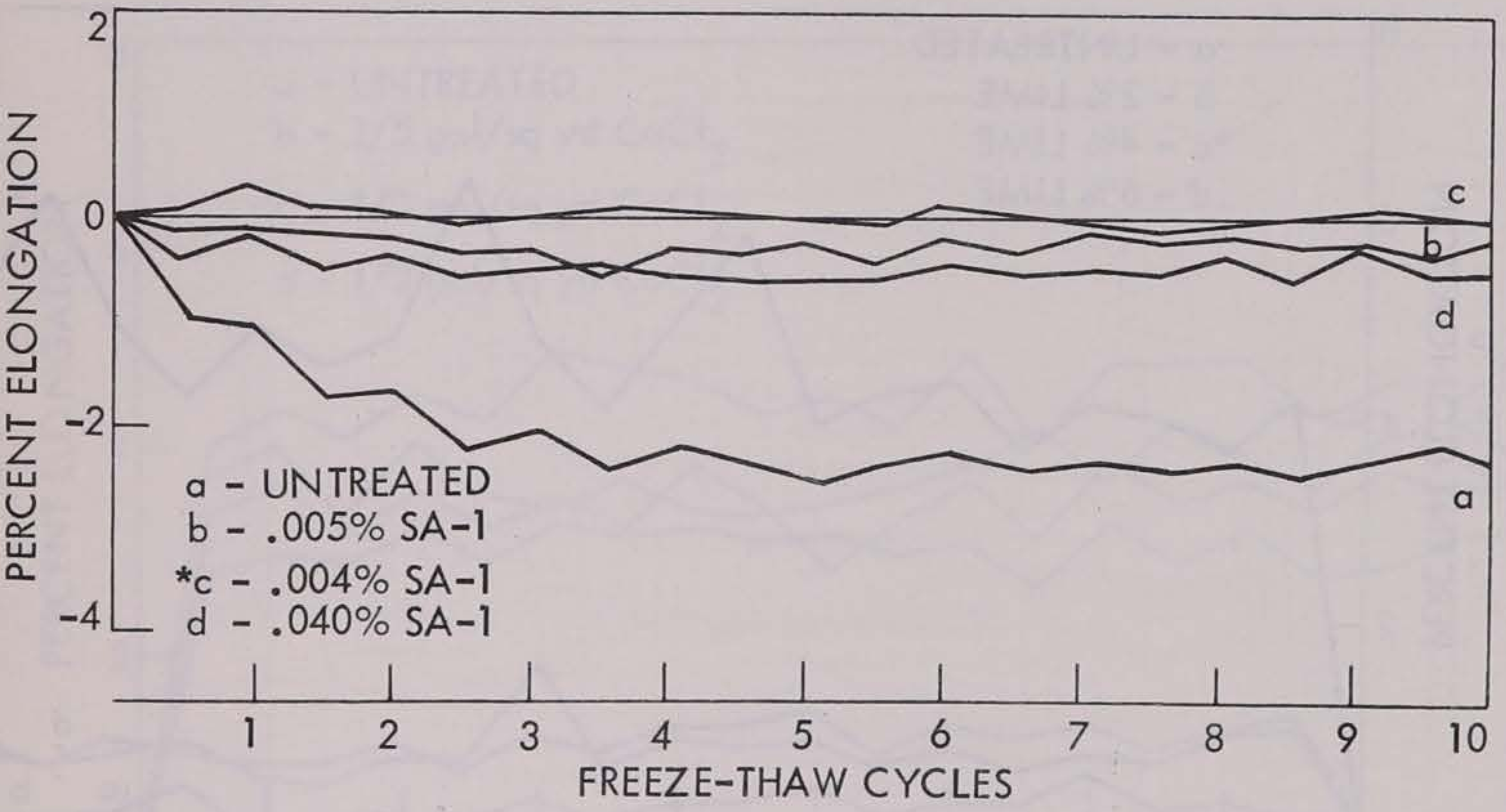

Figure 38. Freeze-Thaw results; section T-8BB.

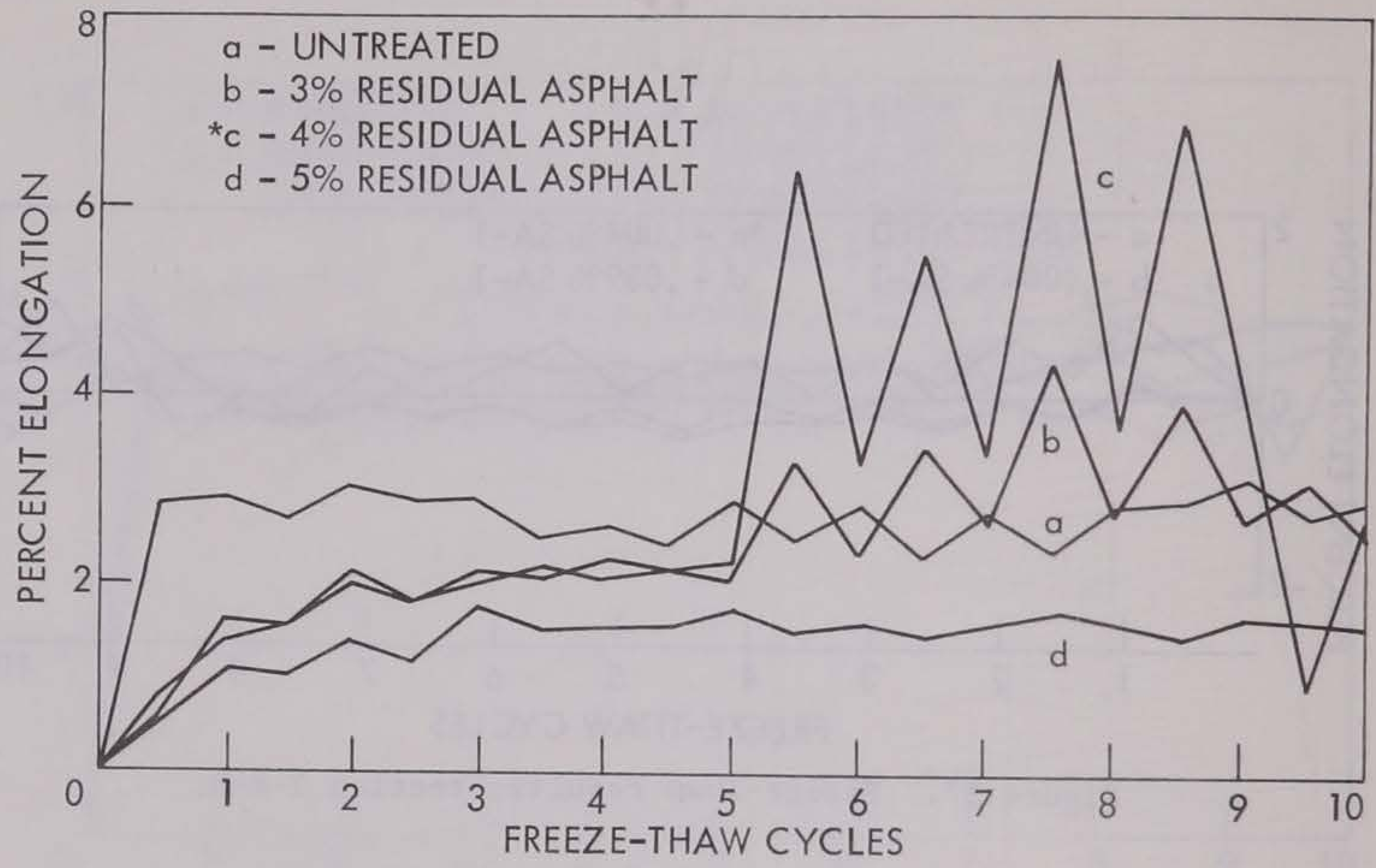

Figure 39. Freeze-Thaw results; section T-10.

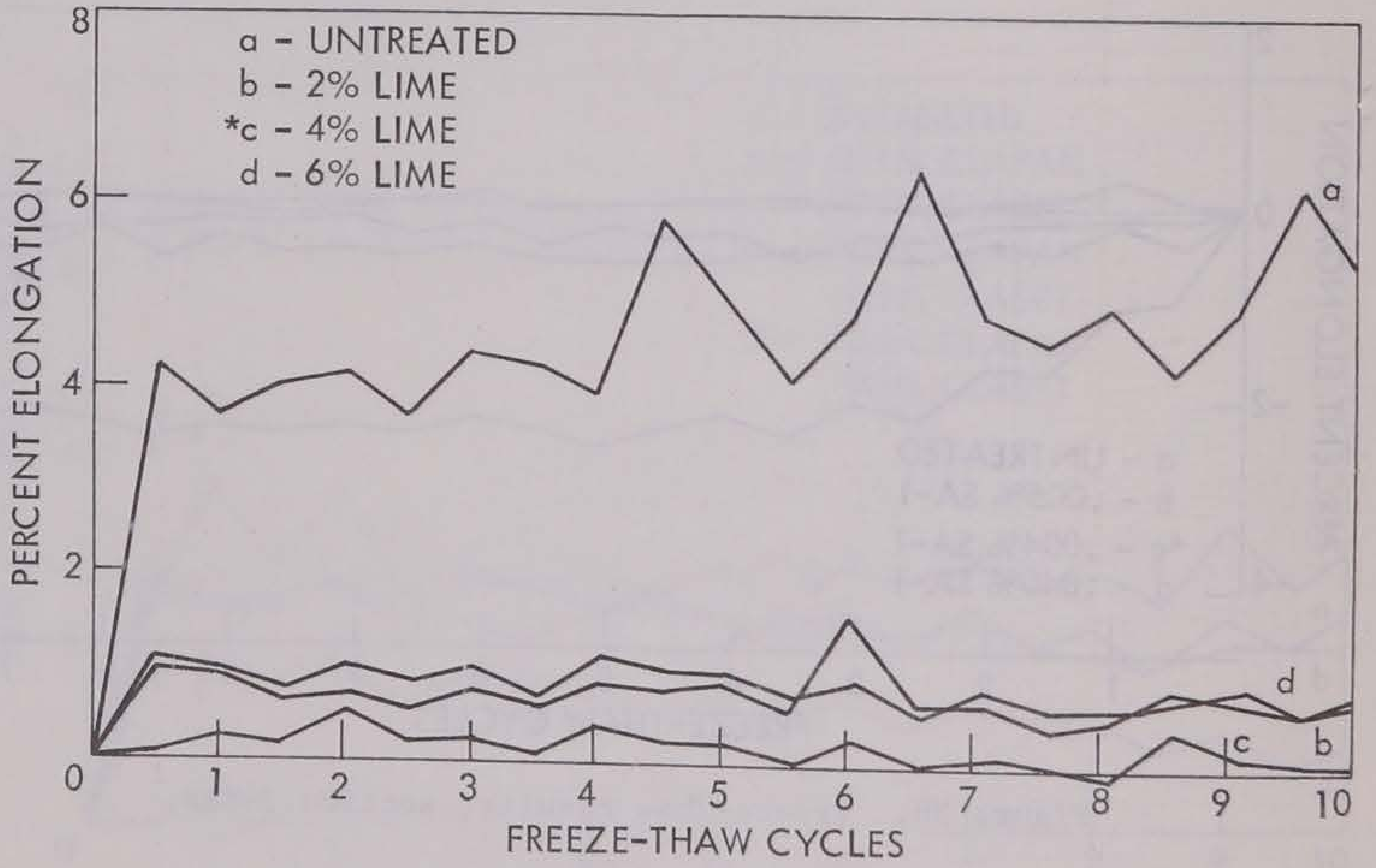

Figure 40. Freeze-Thaw results; section T-11.

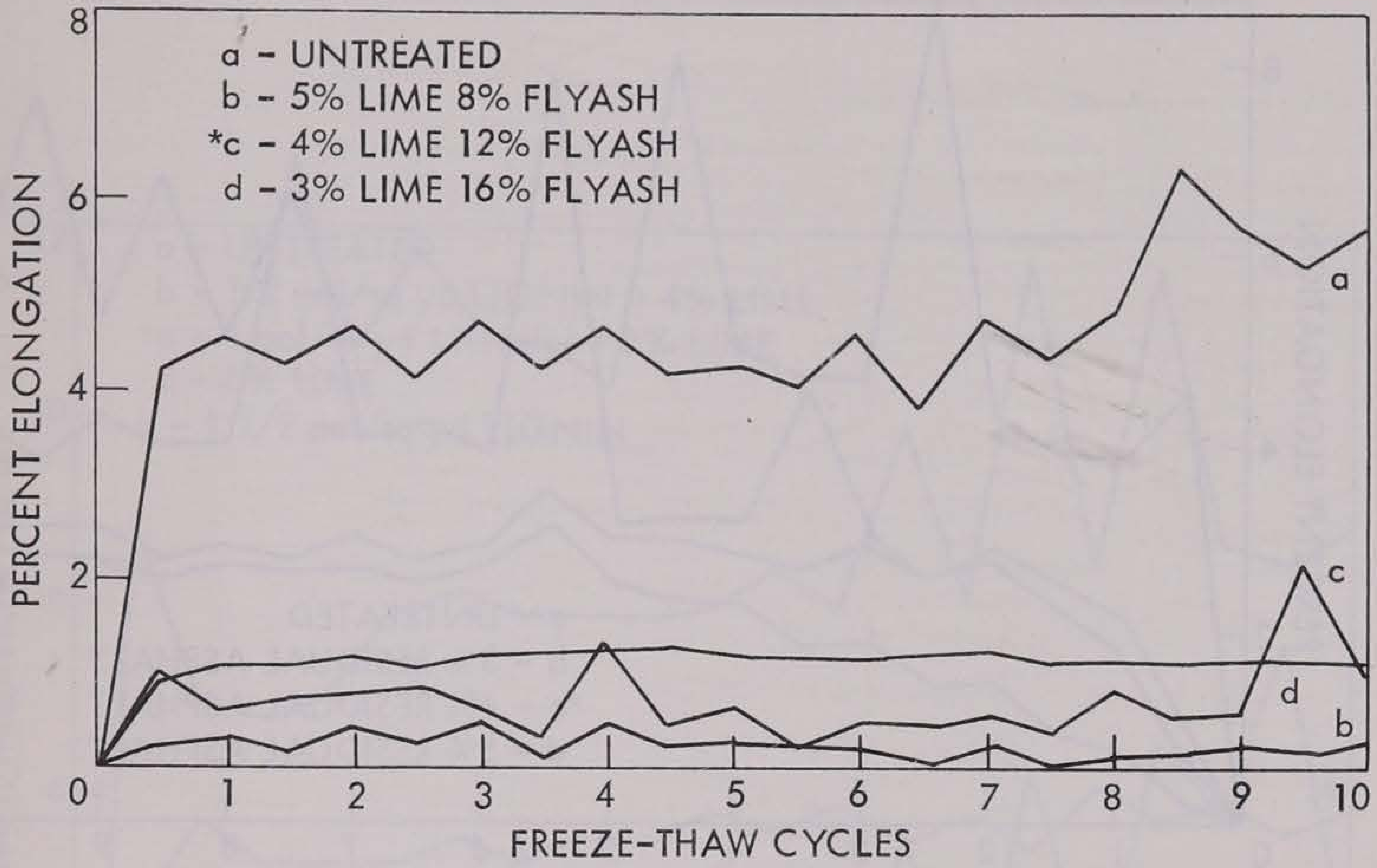

Figure 41. Freeze-Thaw results; section T-12.

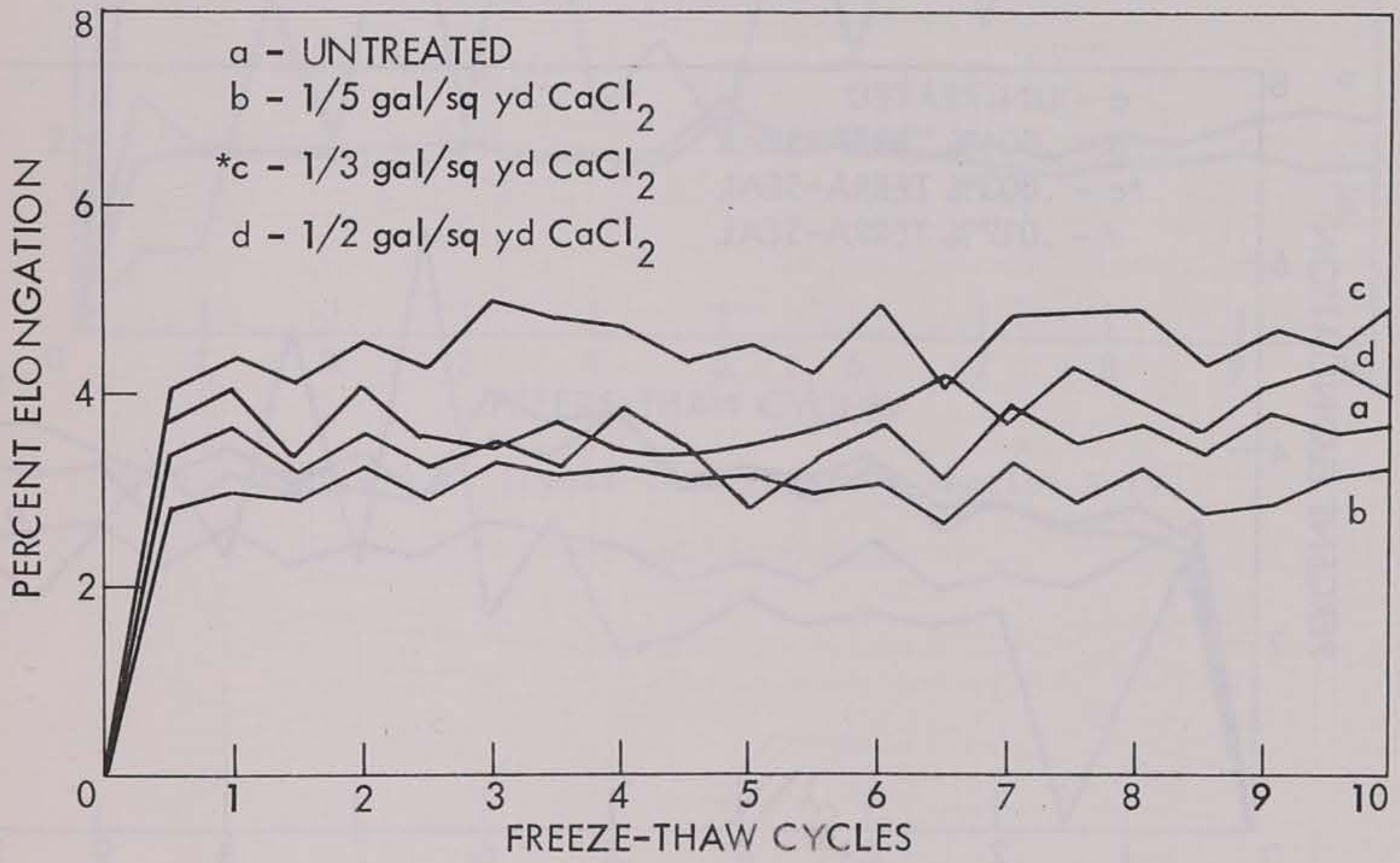

Figure 42. Freeze-Thaw results; section T-13.

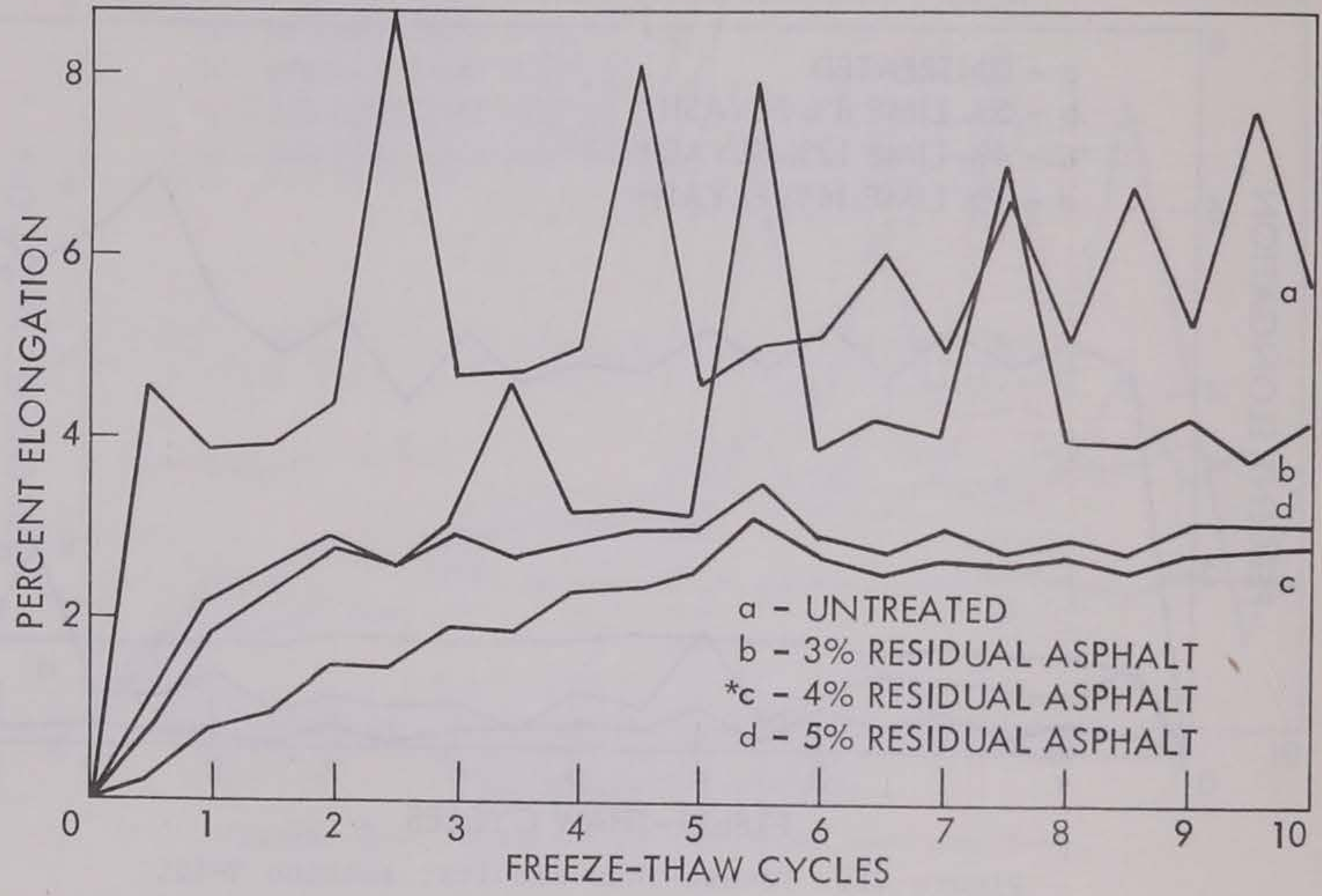

Figure 43. Freeze-Thaw results; section T-14.

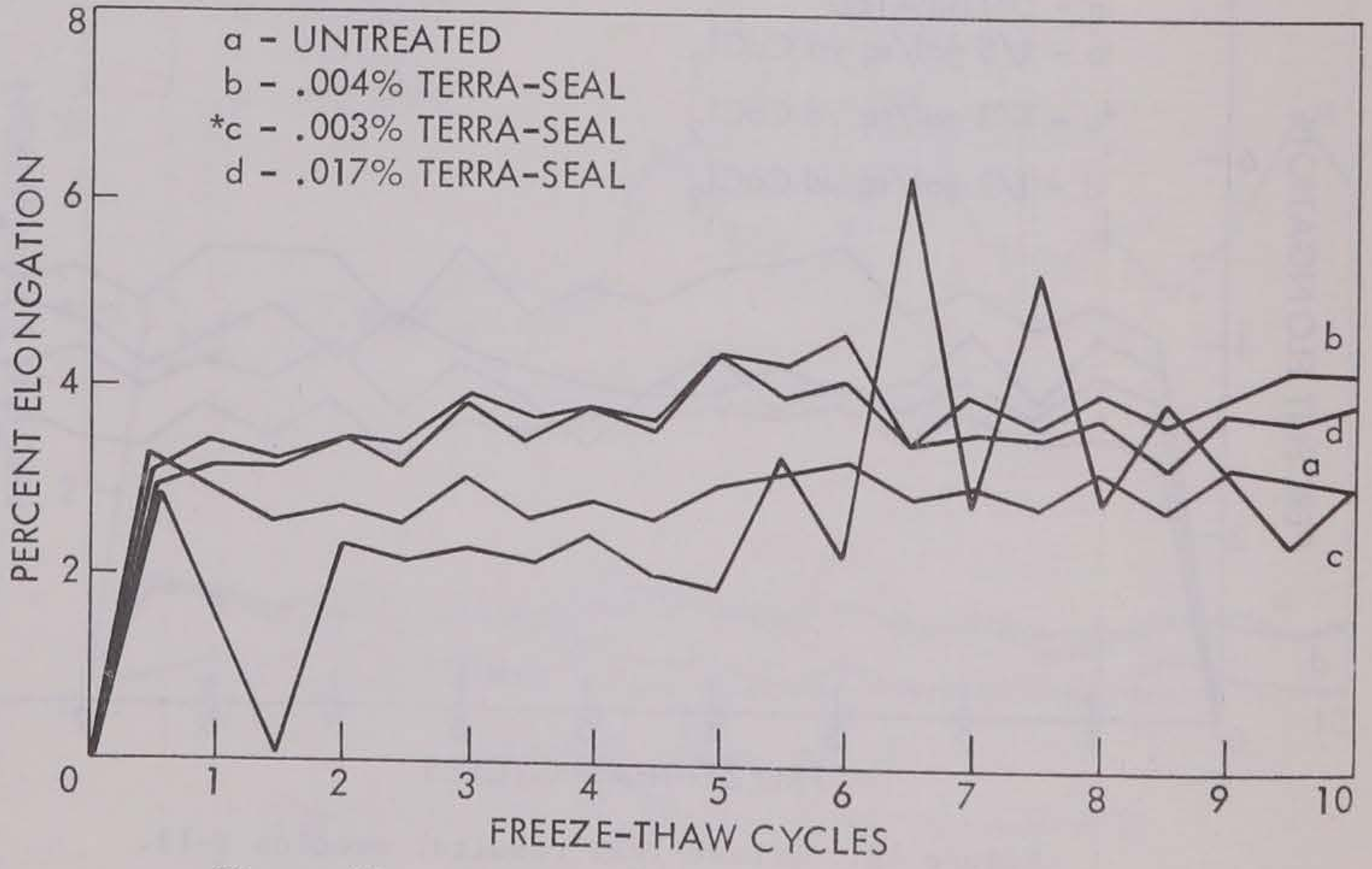

Figure 44. Freeze-Thaw results; section T-16.

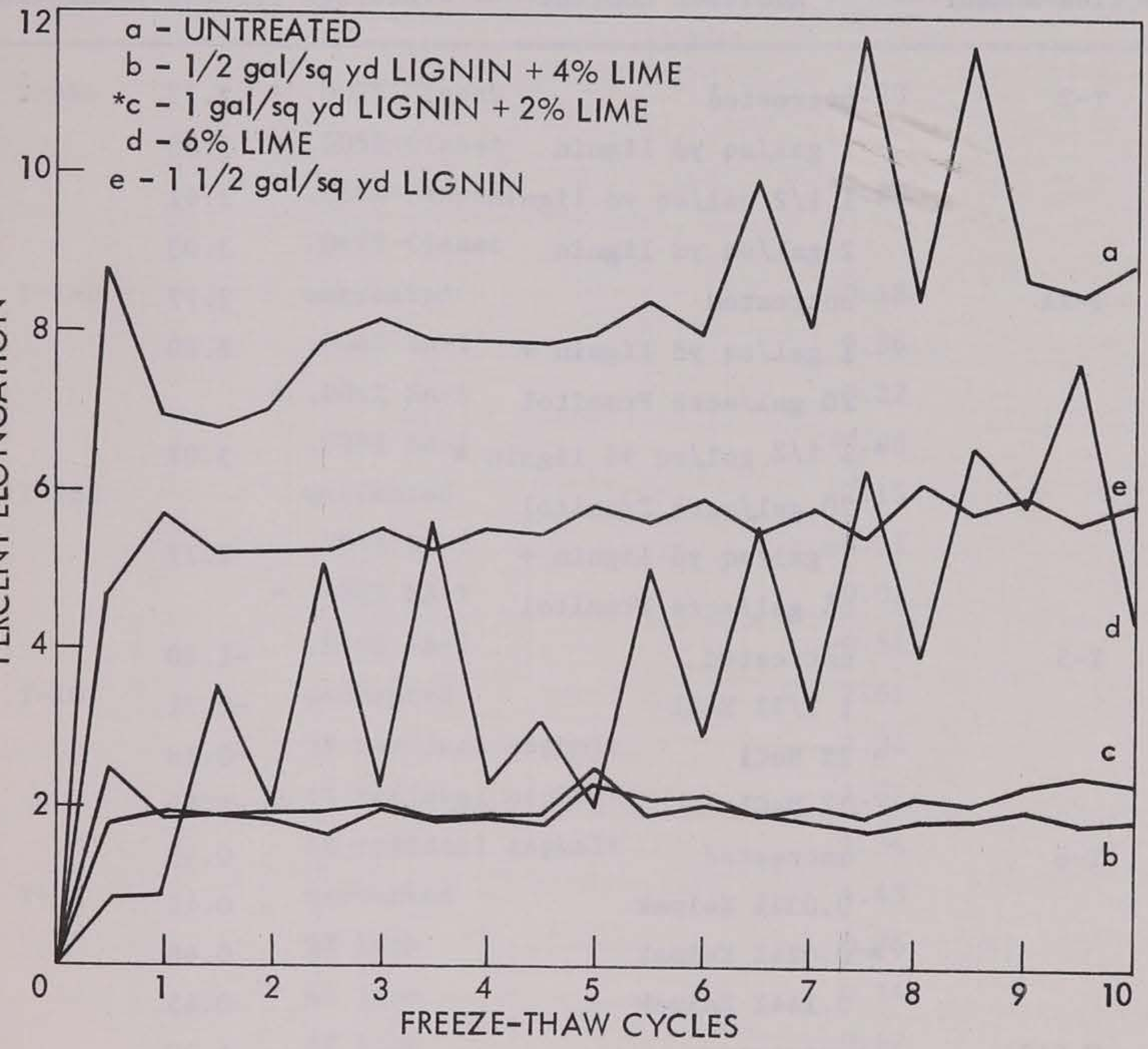

Figure 45. Freeze-Thaw results; section T-19.

Table 7. Average freeze-thaw elongation.

Section Number	Additive Content	Average Percent Elongation
T-2	untreated	2.77
	1 gal/sq yd lignin	3.35
	* 1 1/2 gal/sq yd lignin	2.61
	2 gal/sq yd lignin	3.03
T-2A	untreated	2.77
	1 gal/sq yd lignin + 20 gal/acre Pramitol	2.80
	* 1 1/2 gal/sq yd lignin + 20 gal/acre Pramitol	3.02
	1 gal/sq yd lignin + 25 gal/acre Pramitol	2.77
T-5	untreated	-1.20
	1 1/2% NaCl	-0.71
	* 2% NaCl	-0.18
	3% NaCl	-0.49
T-6	untreated	0.43
	0.032% Kelpak	0.42
	* 0.024% Kelpak	0.68
	0.144% Kelpak	0.45
T-8AS	untreated	4.30
	.039% Clapak .026% Claset	5.26
	* .011% Clapak * .007% Claset	4.76
	.083% Clapak .055% Claset	4.70
T-8BS	untreated	2.06
	.031% Clapak .021% Claset	2.13

Table 7. (continued)

Section Number	Additive Content	Average Percent Elongation
T-8BS	* .007% Clapak	1.23
	* .005% Claset	
	.064% Clapak	2.60
	.042% Claset	
T-8AB	untreated	0.18
	.004% SA-1	0.36
	* .004% SA-1	-0.22
	.039% SA-1	-0.08
T-8BB	untreated	-2.15
	.005% SA-1	-0.31
	* .004% SA-1	-0.02
	.040% SA-1	-0.51
T-10	untreated	2.61
	3% residual asphalt	2.34
	* 4% residual asphalt	2.97
	5% residual asphalt	1.34
T-11	untreated	4.43
	2% lime	0.76
	* 4% lime	0.14
	6% lime	0.67
T-12	untreated	4.43
	5% lime 8% flyash	0.21
	* 4% lime 12% flyash	0.66
	3% lime 16% flyash	1.09
T-13	untreated	3.29
	1/5 gal./sq yd $CaCl_2$	2.87
	* 1/3 gal./sq yd $CaCl_2$	4.30
	1/2 gal./sq yd $CaCl_2$	3.58
T-14	untreated	5.28
	3% residual asphalt	3.64

Table 7. (continued)

Section Number	Additive Content	Average Percent Elongation
T-14	* 4% residual asphalt	2.10
	5% residual asphalt	2.60
T-16	untreated	2.68
	.004% Terra-Seal	3.63
	* .003% Terra-Seal	2.78
	.017% Terra-Seal	3.44
T-19	untreated	8.01
	1/2 gal./sq yd lignin + 4% lime	1.83
	* 1 gal./sq yd lignin + 2% lime	1.89
	6% lime	3.69
	1 1/2 gal./sq yd lignin	5.20

T-6. The rather erratic behavior of the untreated soil should be noted (Fig. 34), even though the average percent elongation is nearly the same as for the treated specimens. All specimens performed rather well, with the .032% Kelpak treatment showing the best overall F-T behavior.

T-8AS. The untreated soil appeared to give the best F-T performance, with relatively little difference noted between treatments. It should be noted however, that 4-5% elongation was experienced for all treatment levels and is thus judged ineffective against freeze-thaw damage with this soil classification.

T-8BS. Optimum F-T performance was apparent with .007% Clapak* and .005% Claset*. Slightly higher densities and moisture contents of the other two treatments (Table 8, Appendix) appear to be associated with poorer F-T performance.

T-8AB. All SA-1 treated specimens showed good F-T behavior, which might be attributed to the non-frost susceptible soil (rolled stone) and high densities achieved.

T-8BB. F-T shrinkage of all specimens was noted, the untreated soil having a -2.15% average elongation. Treatment appeared to improve resistance to freezing and thawing, with the optimum at .004% SA-1*.

T-10. Data presented for the 3 and 4%* asphalt emulsion treatment appears indicative of a possible structural change in the soil during the fifth cycle. Bond breakdown between asphalt and aggregate could have occurred, thus allowing water to penetrate the soil. The 5% treatment showed superior F-T performance.

T-11. A very marked improvement in F-T durability was noted with each treatment level of lime, with the optimum amount at 4%*.

T-12. Significant F-T improvement was noted with the addition of lime and flyash; best overall performance being obtained at 5% lime and 8% flyash. The graph of 3% lime and 16% flyash (Fig. 41) appeared to indicate that the rather large quantity of flyash may have been filling the voids, creating a cutoff of most of the capillary moisture movement, since the lack of high and low points on the plot indicates little water in the specimens to cause swelling when frozen.

T-13. No significant improvement of F-T durability was apparent with the addition of $CaCl_2$. Due to the open gradation of the soil, it is suspected that at least a portion of the $CaCl_2$ leached out during thawing, causing little change in F-T behavior from the untreated.

T-14. A rather significant improvement was noted with the addition of 4^* and 5% residual asphalt, whereas 3% did not completely eliminate the large cyclic elongation variations of the untreated soil. Optimum treatment was at $4\%^*$.

T-16. No major reduction in resistance to freeze-thaw was noted, indicating either that a longer cure may be necessary, or that Terra-Seal may not affect the freezing resistance of the A-6 soil. A slight trend toward increasing density versus increased freeze-thaw elongation was noted.

T-19. A strong improvement was noted with addition of the combination lignin and lime, whereas lime or lignin alone did not improve the F-T durability of the A-7-6 soil nearly as much. The apparent success of the two different combinations of lignin and lime on improving F-T durability of the soil supports an hypothesized action of lime to insolubilize the lignin, creating a waterproof binder. The low position of the lignin-lime curves (Fig. 45) indicates the specimens are relatively unsusceptible to capillary moisture movement.

Erosibility Tests

A stabilized soil used as a surface course is often subjected to severe erosion from rain, and as a consequence may lose fine material or even aggregate. Denny[3] designed a test to determine erosion of a specimen under severe rain conditions.

The "rainmaker" consists of a distilled water source coupled with a pressurized air supply, fed through a spray nozzle. The 2 in. by 2 in. cylindrical specimen rests on a rack supported inside a receptacle having a siphon drain to handle excess water. Supply air is set at 20 psi, the nozzle placed 11 1/2 in. above the top of the specimen, and the spray applied at a constant rate of 150 ml/15 min. The eroded soil is trapped in the receptacle, oven-dried, and weighed to determine the percentage eroded based on the calculated oven-dry specimen weight at time of molding. This percentage is expressed as the Erosibility Index (EI). The higher the EI, the greater the susceptibility to erosion. By averaging the results from identical specimens a quantitative means of comparing stabilization behavior at different additive contents is obtained. This test cannot be construed to be a rain simulation, due to the number of variables under actual rain conditions, but serves only as a quick test for comparative stabilization purposes, surface durability, or erosibility, particularly with trace chemical treatments.

Figures 46 through 60 present the average EI values with the various additive contents for each test section. Three curing conditions were utilized with each treatment and level thereof, particularly for those soil-chemical combinations needing longer curing periods for reactivity effects: 24 hr air cure, 7 day air cure, and 7 day moist cure. With the two air cures, specimens were molded, weighed, and allowed to air dry for their respective periods on a lab bench at a near constant temperature of 72°F. Air dry weights achieved during the 7 day air cure were near

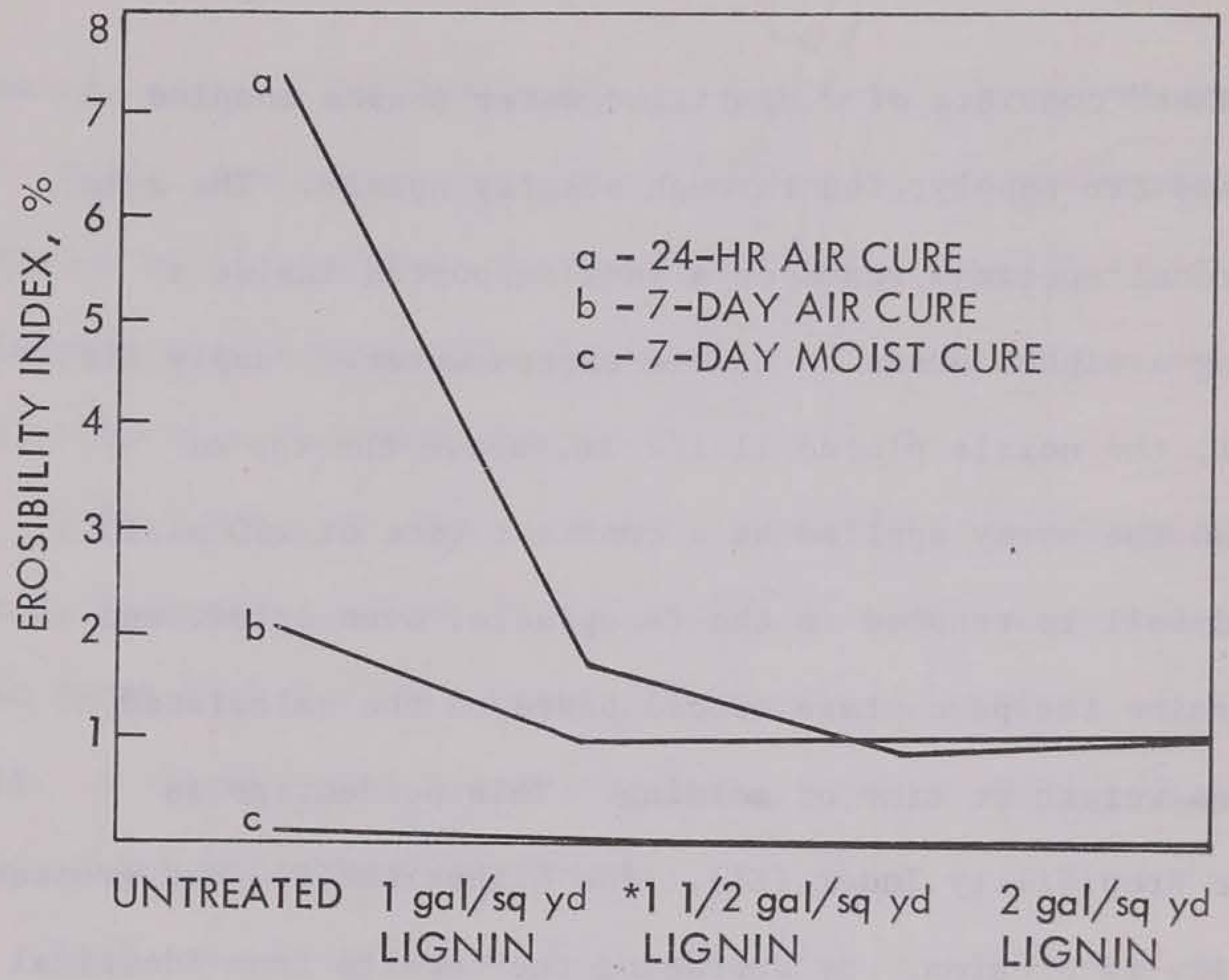

Figure 46. Erosibility results; section T-2.

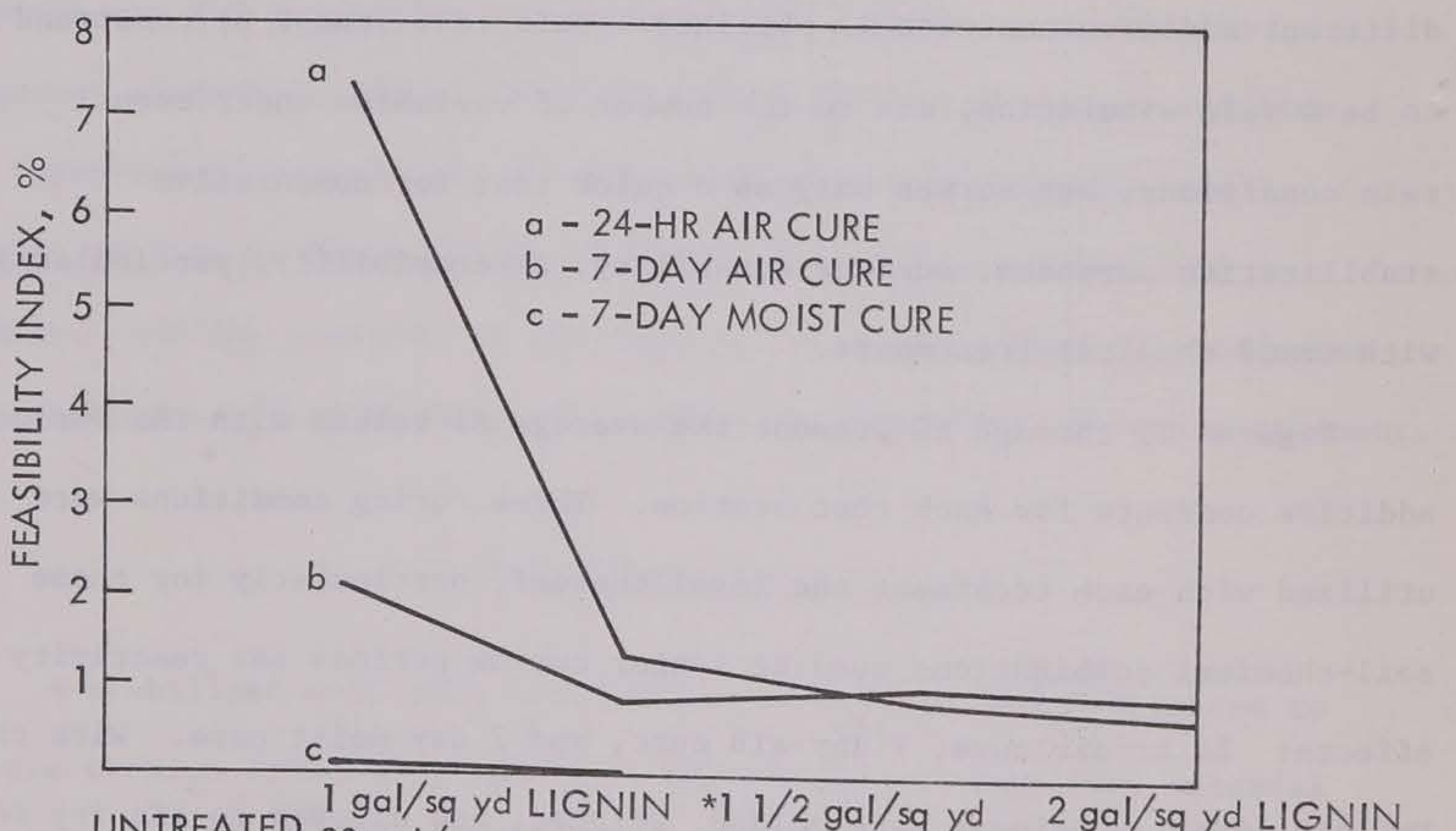

Figure 47. Erosibility results; section T-2A.

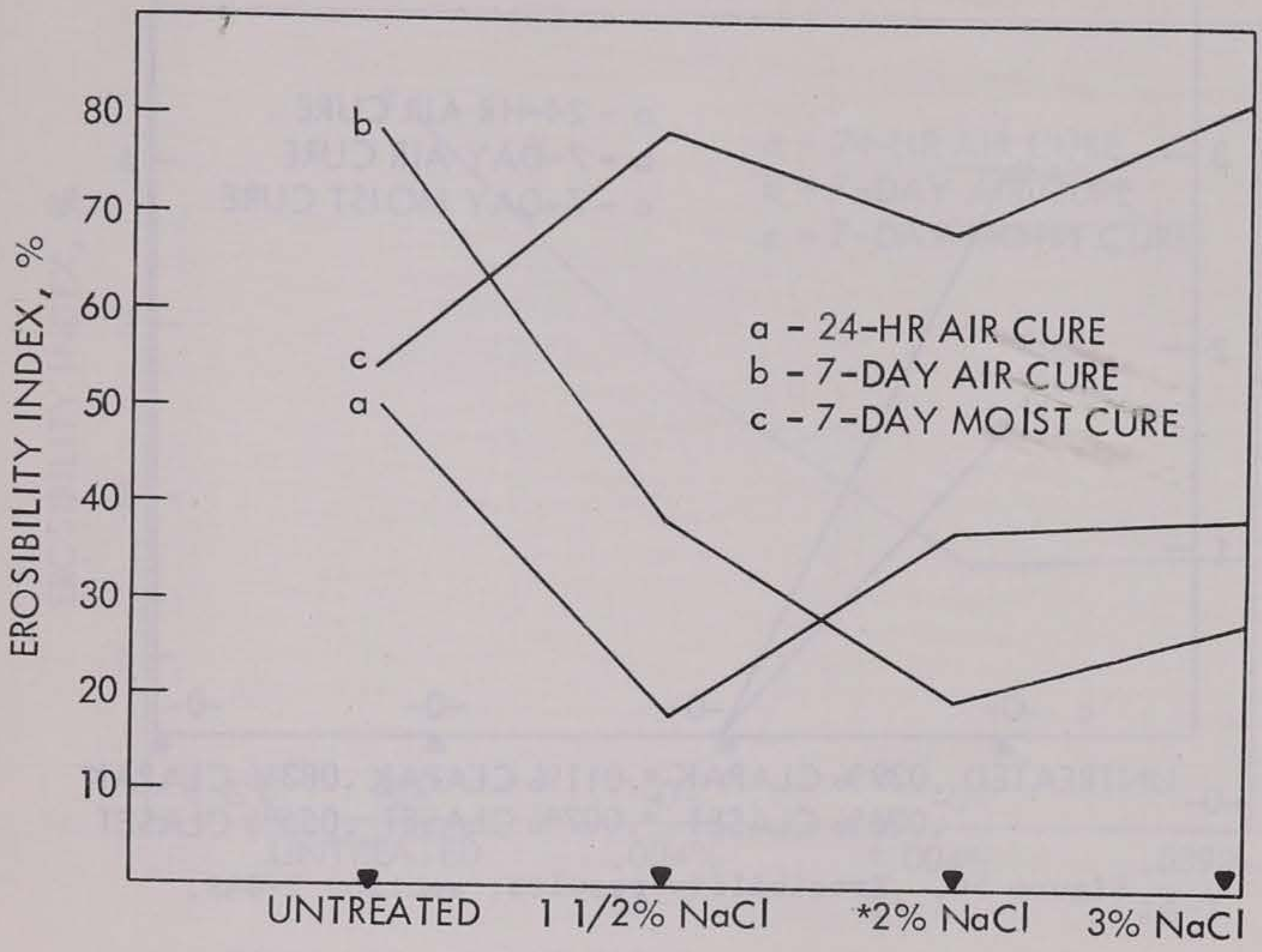

Figure 48. Erosibility results; section T-5.

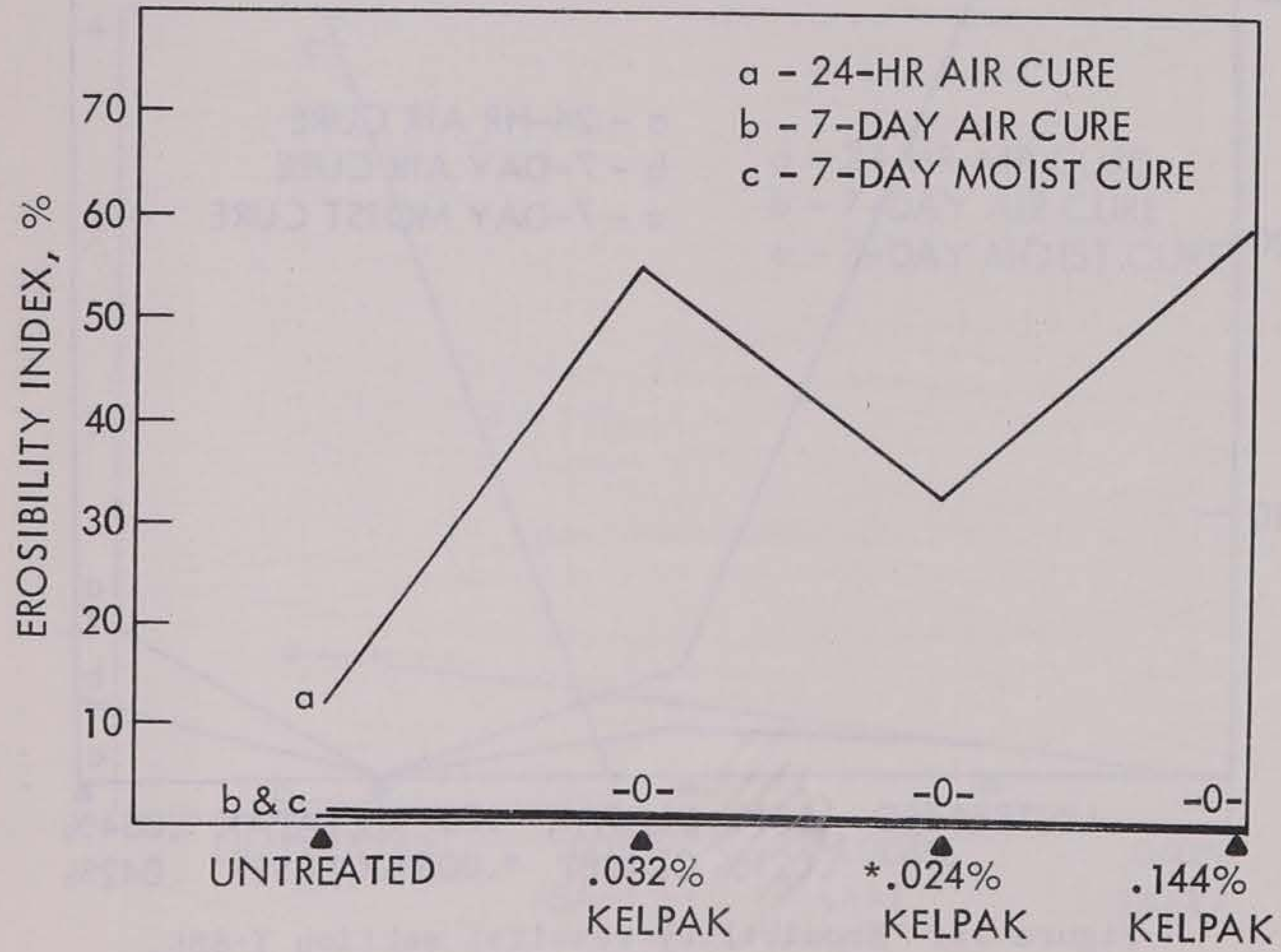

Figure 49. Erosibility results; section T-6.

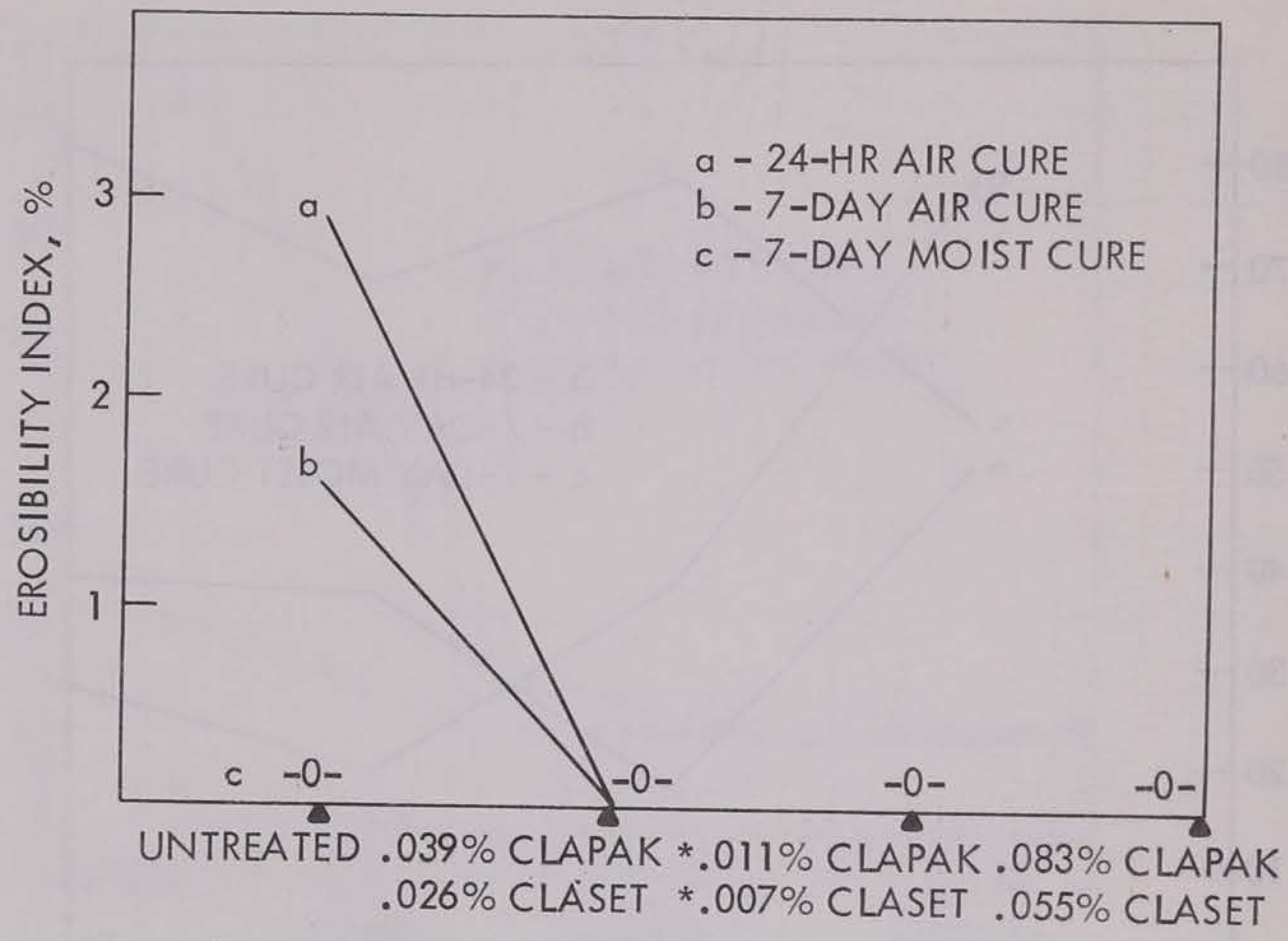

Figure 50. Erosibility results; section T-8AS.

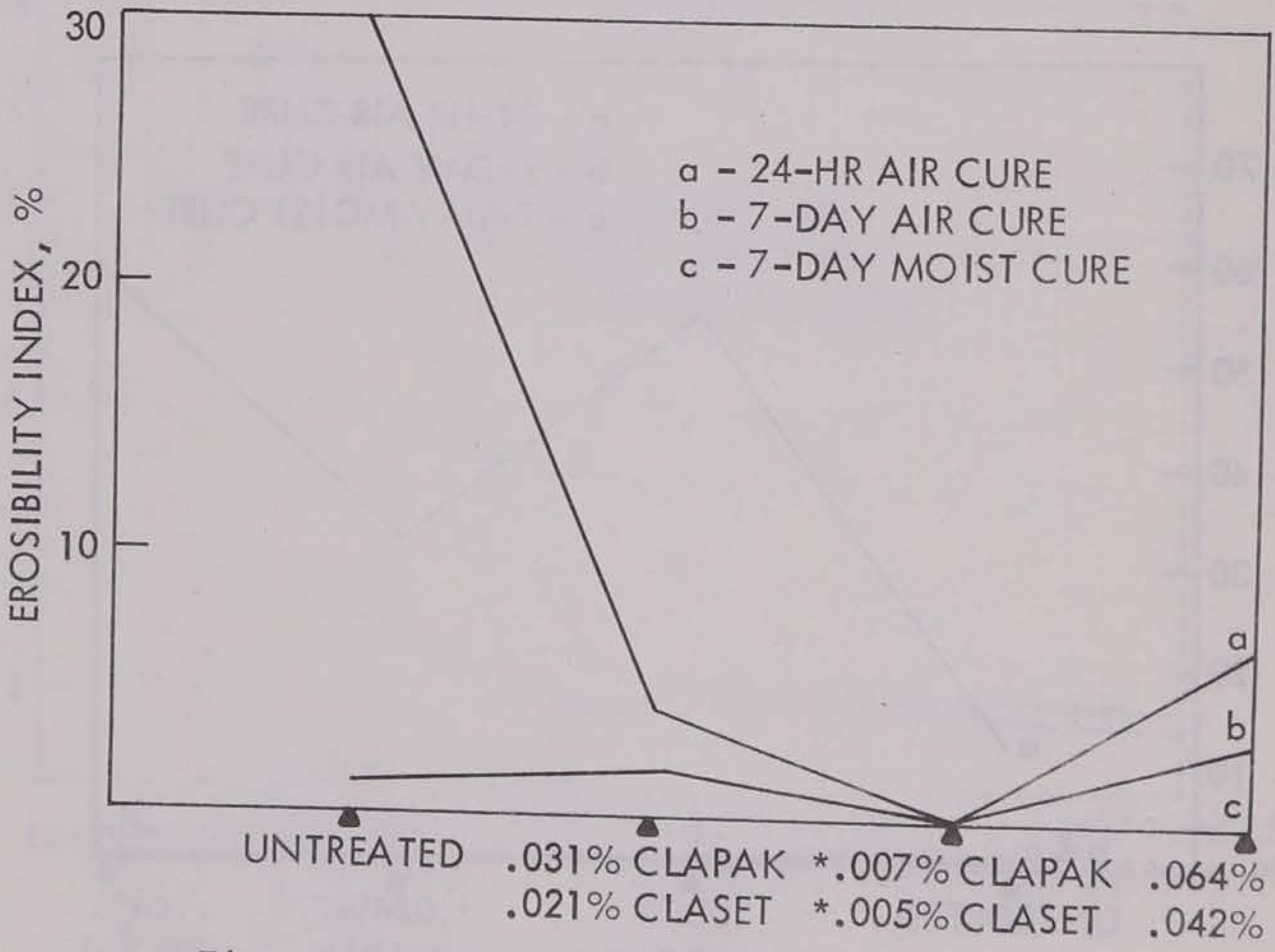

Figure 51. Erosibility results; section T-8BS.

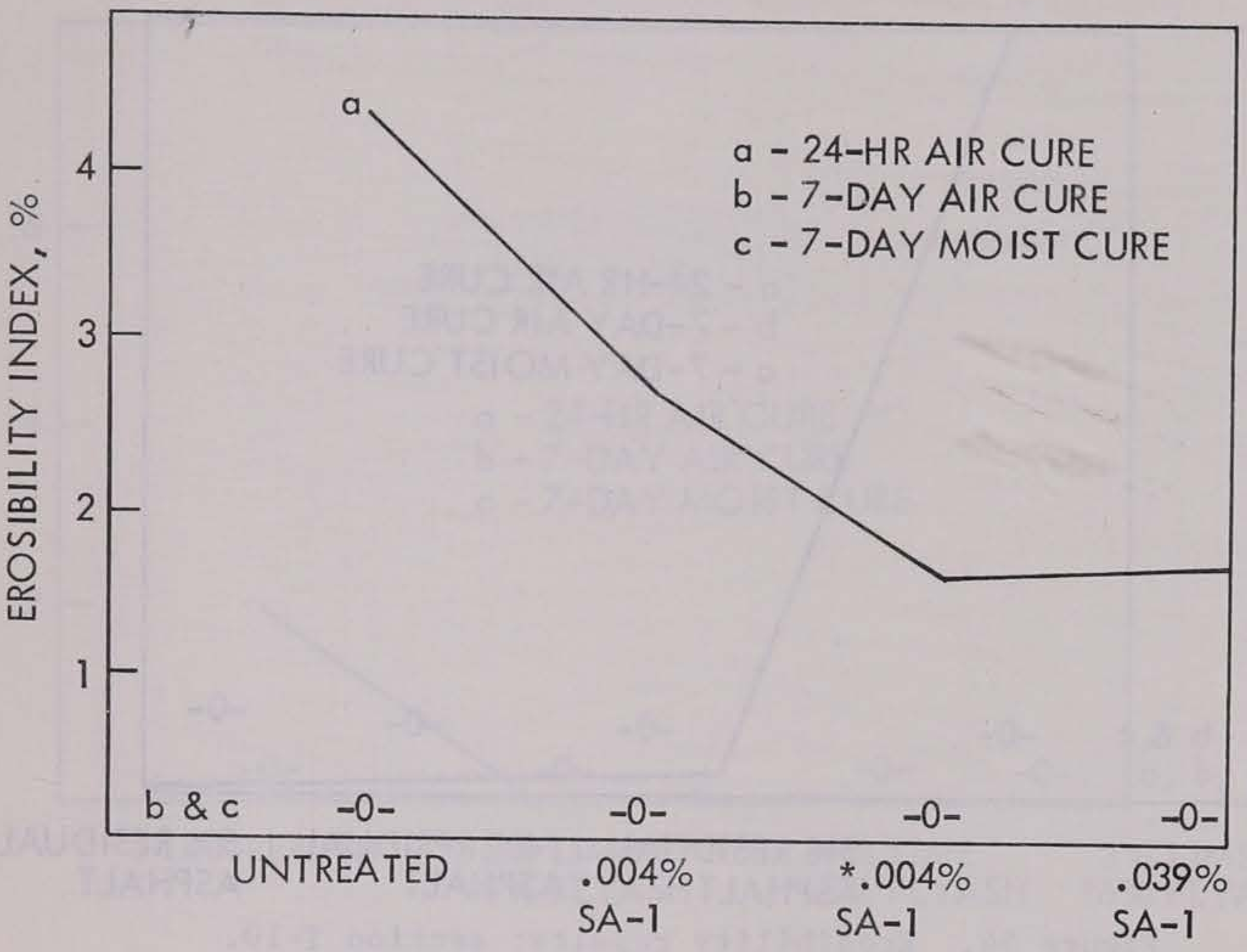

Figure 52. Erosibility results; section T-8AB.

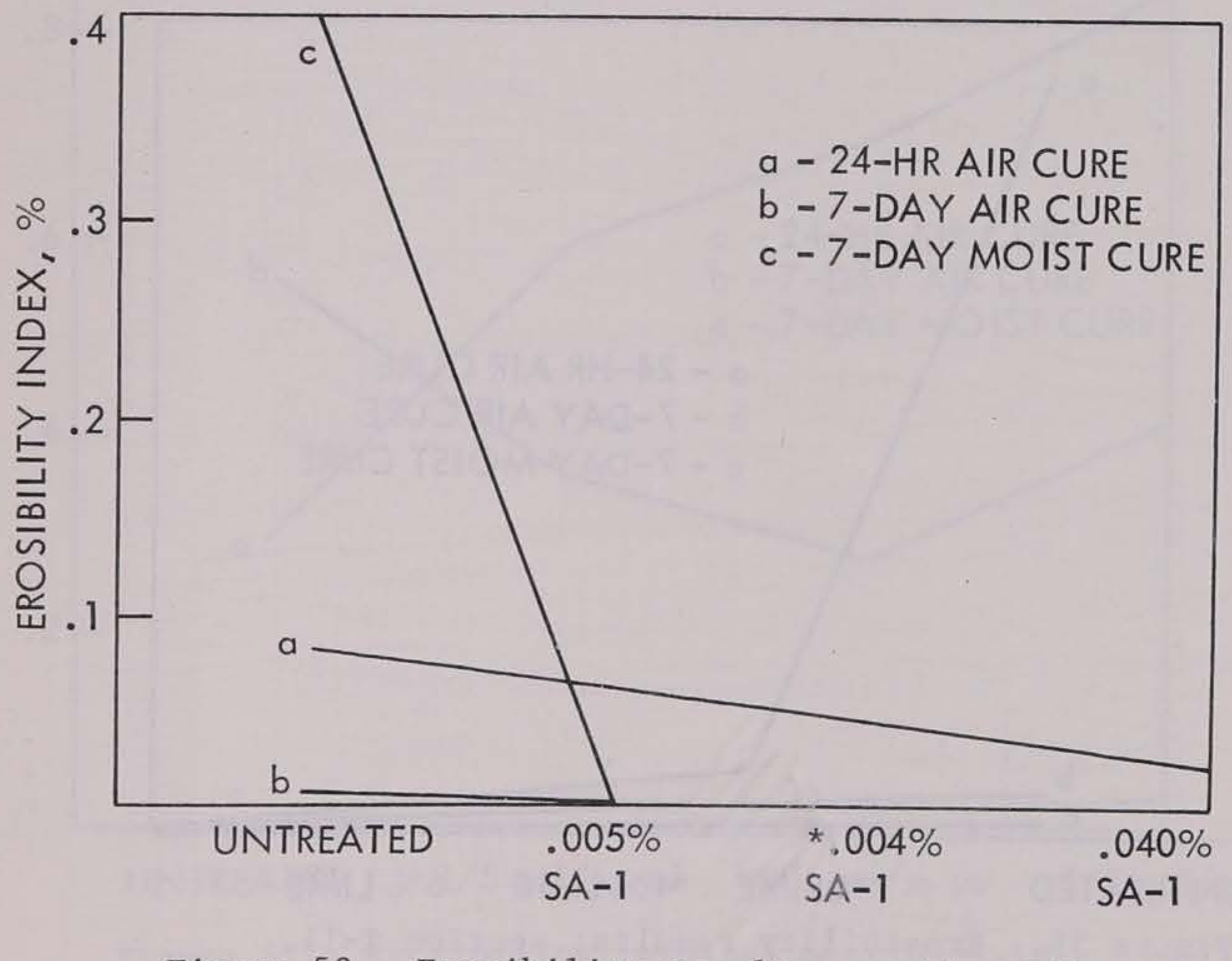

Figure 53. Erosibility results; section T-8BB.

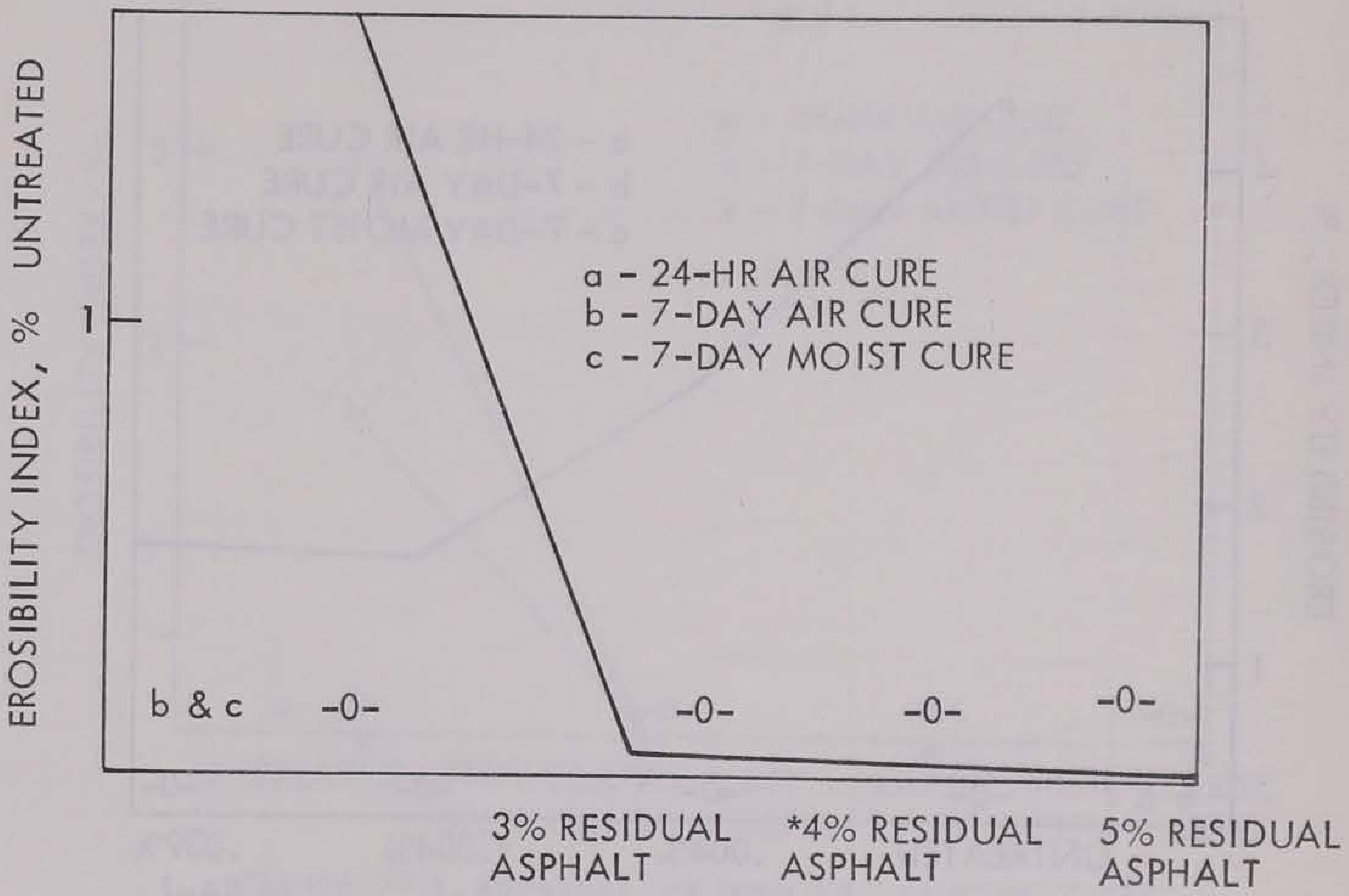

Figure 54. Erosibility results; section T-10.

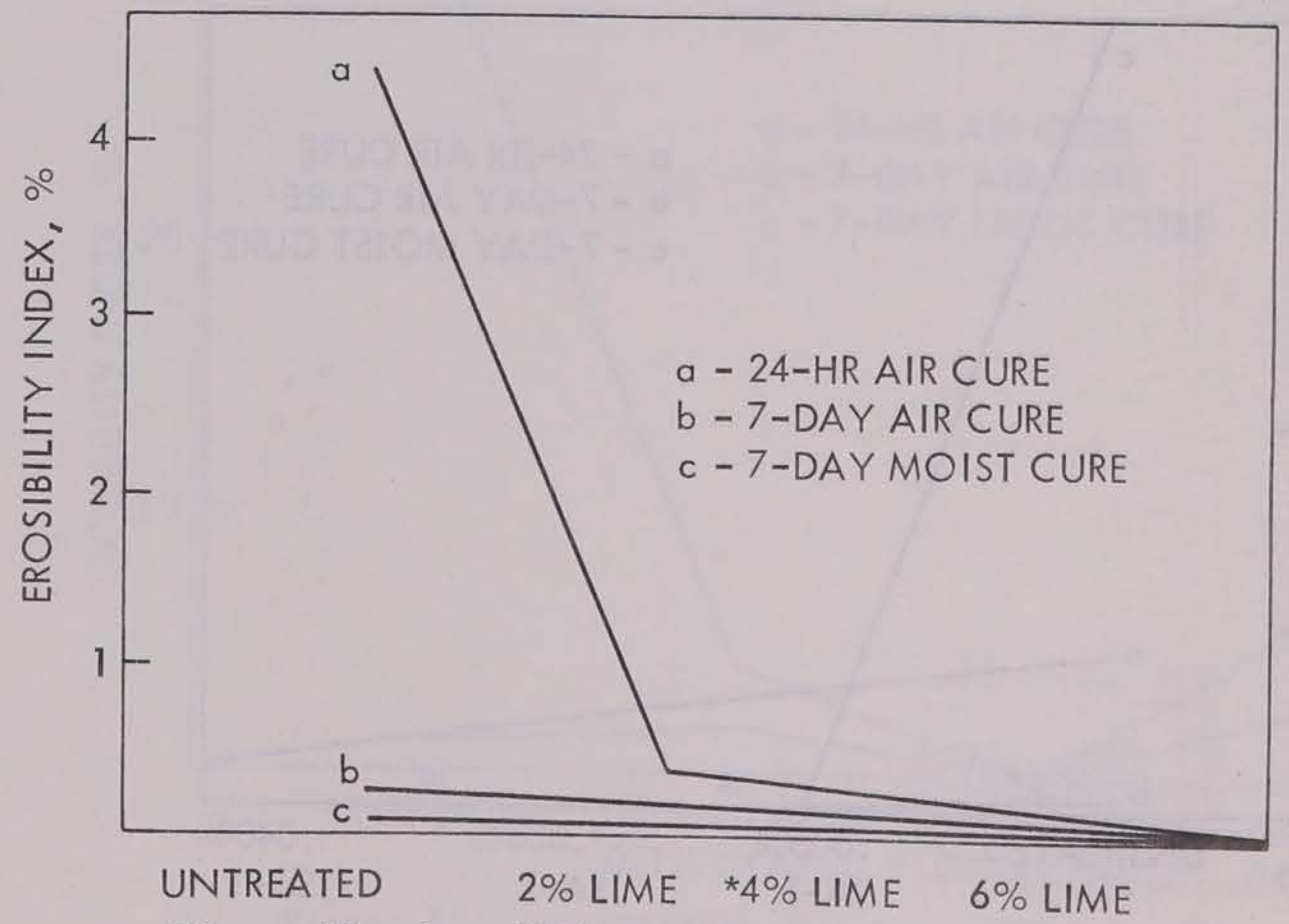

Figure 55. Erosibility results; section T-11.

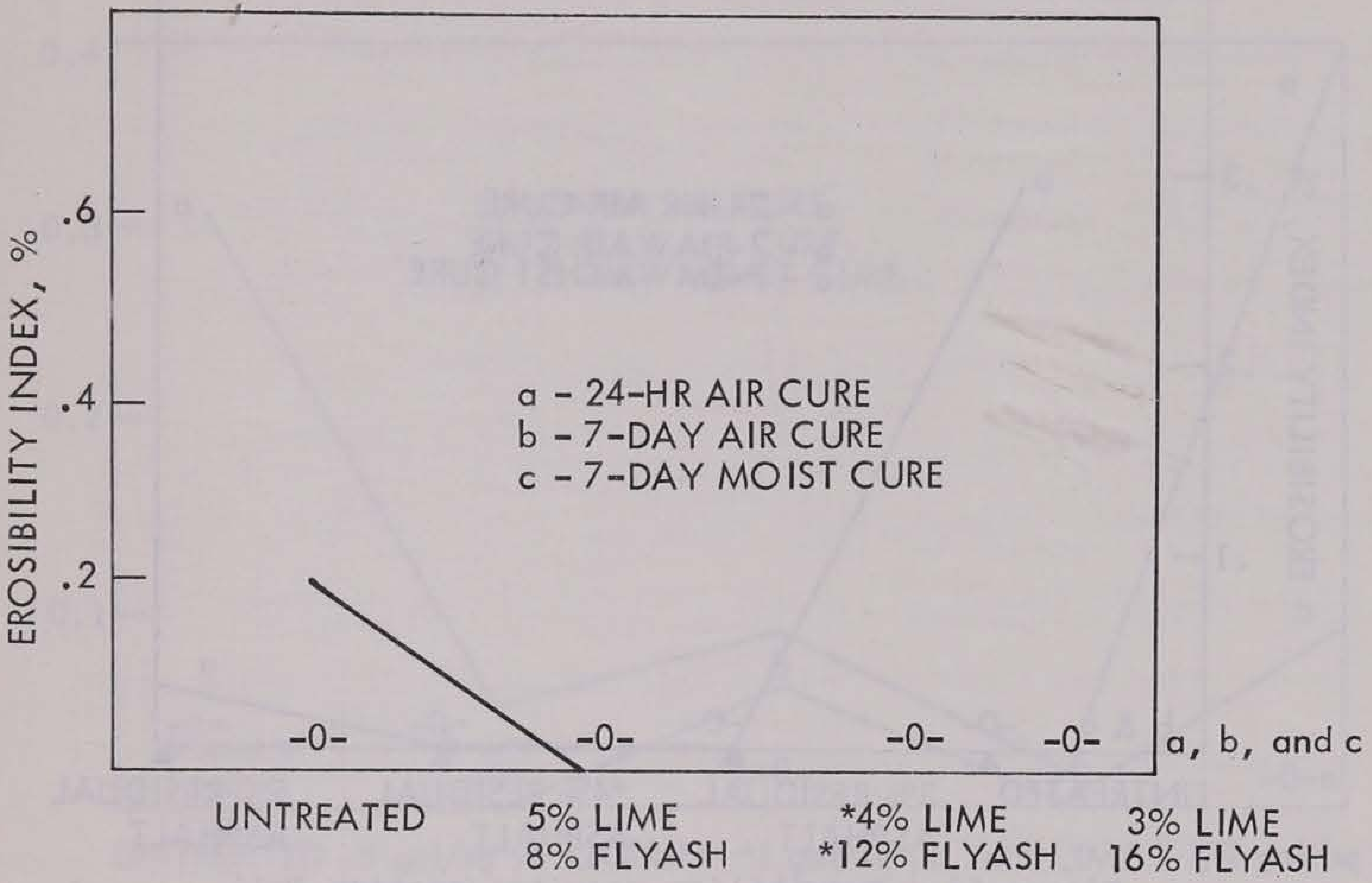

Figure 56. Erosibility results; section T-12.

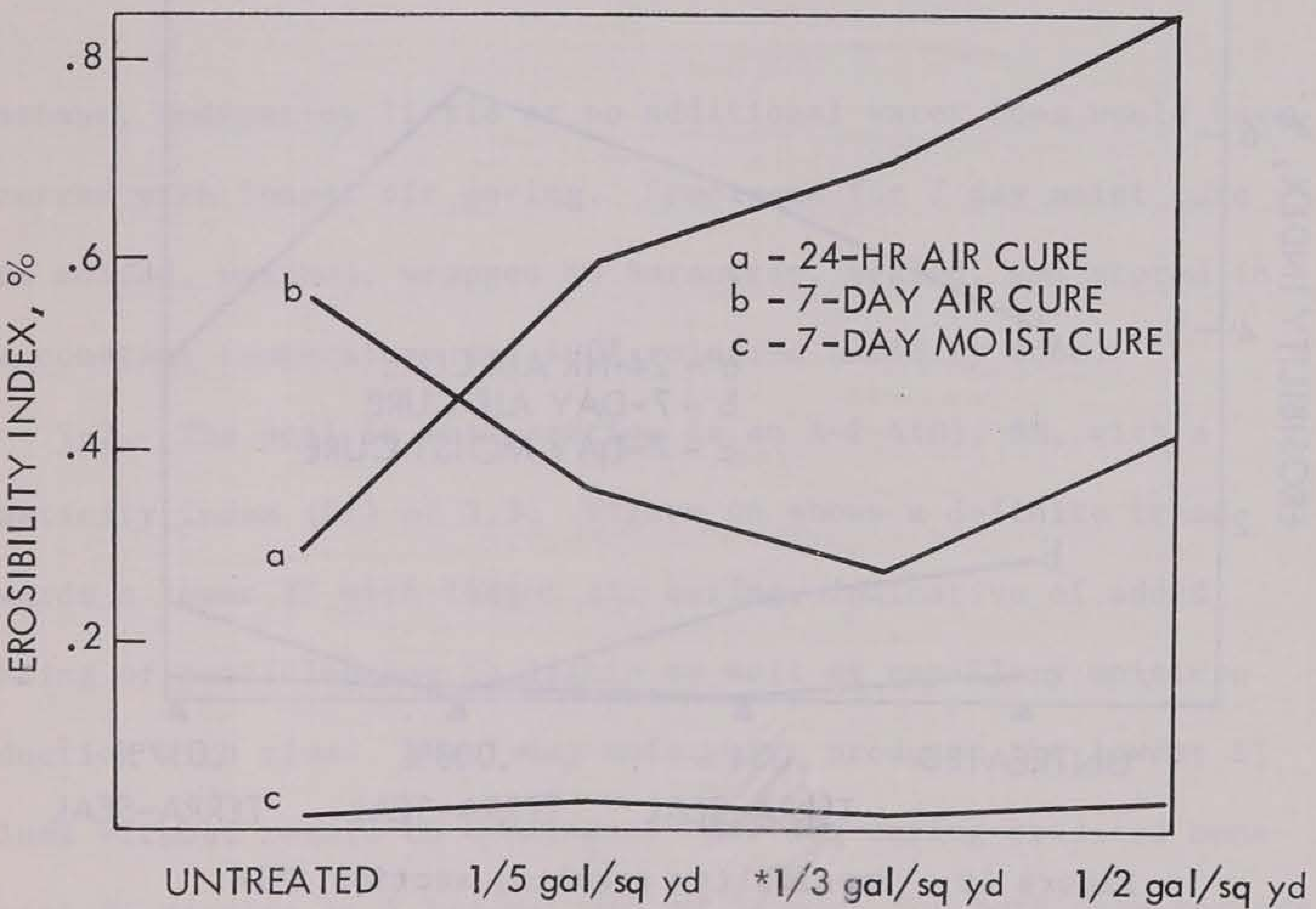

Figure 57. Erosibility results; section T-13.

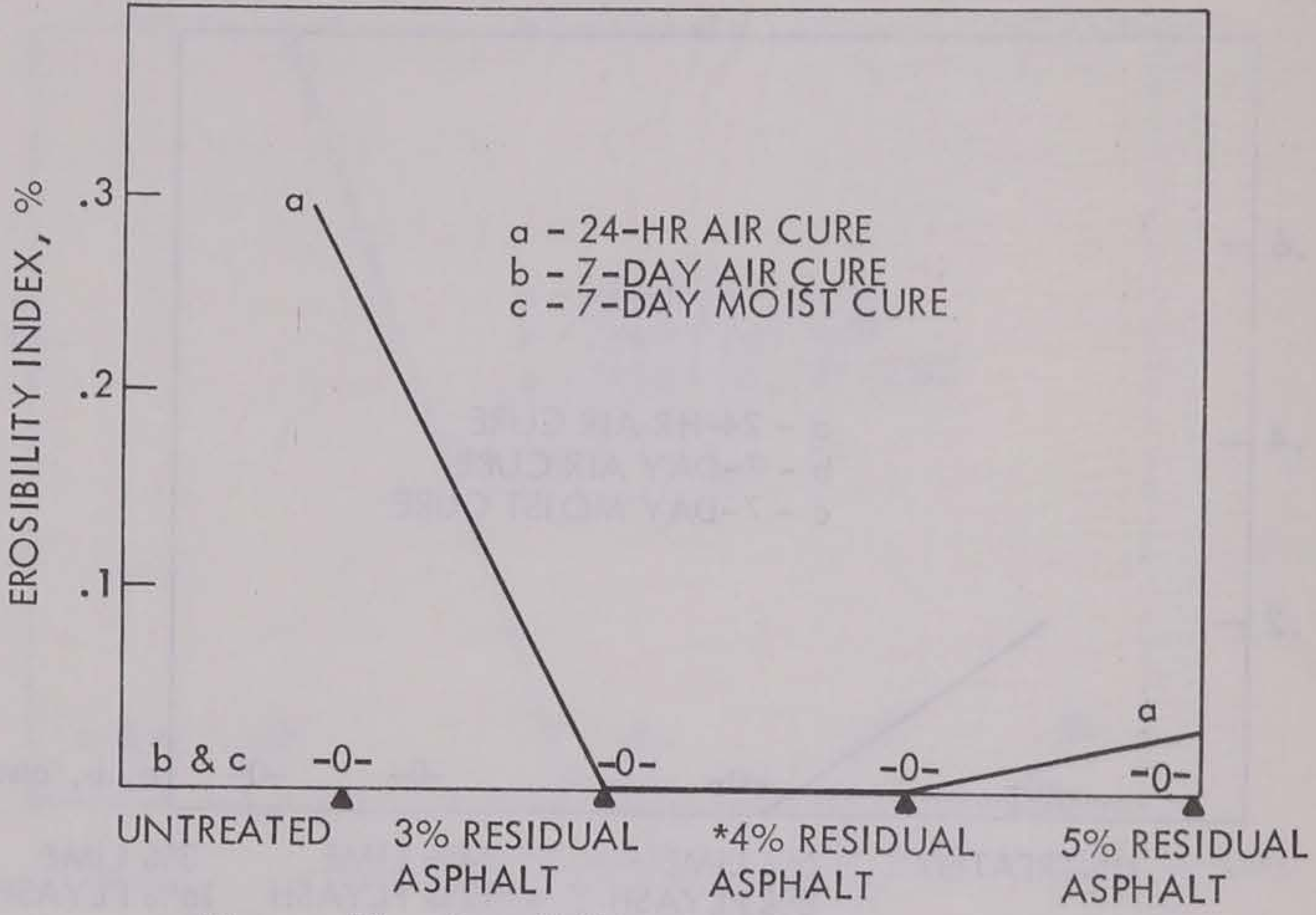

Figure 58. Erosibility results; section T-14.

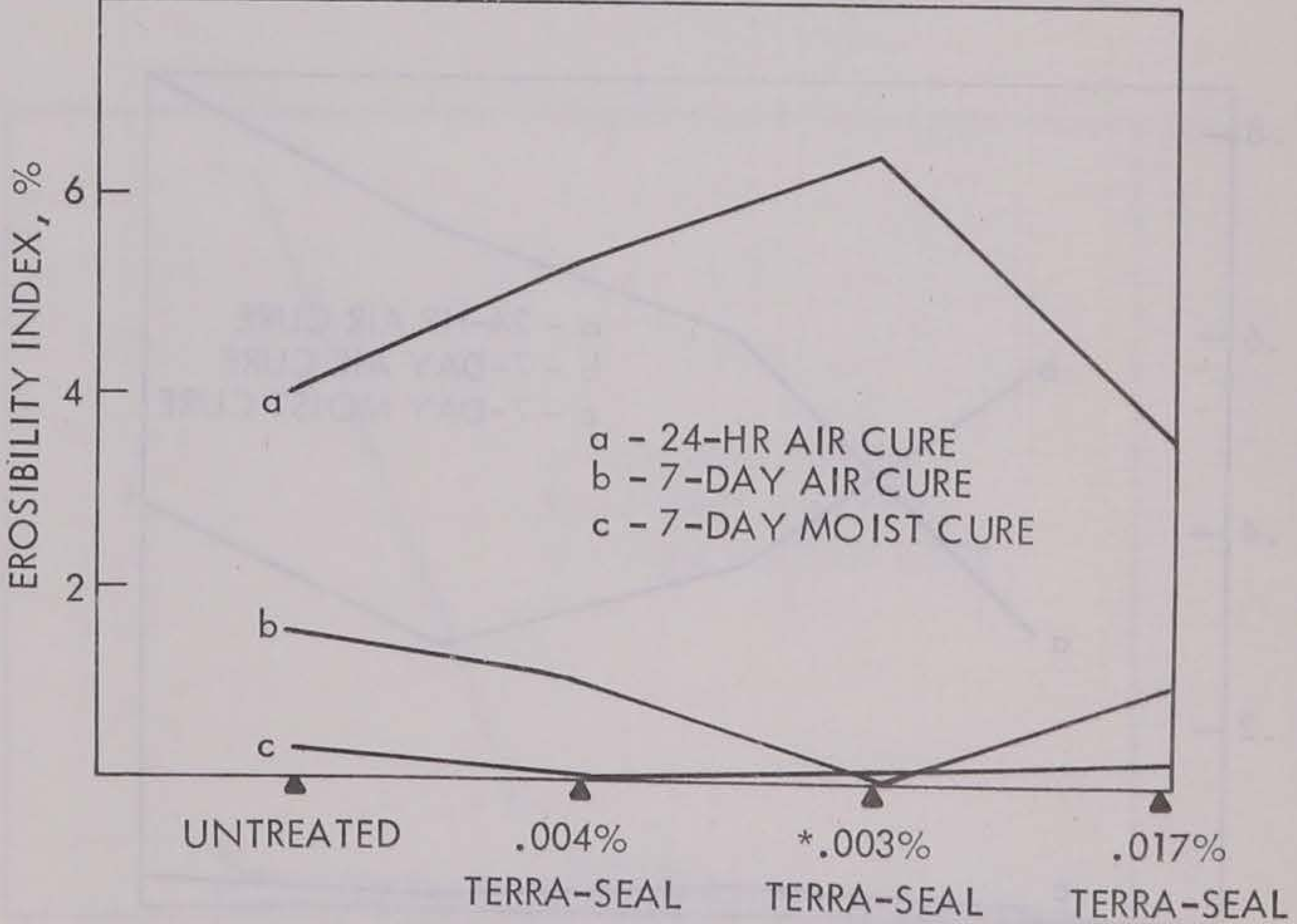

Figure 59. Erosibility results; section T-16.

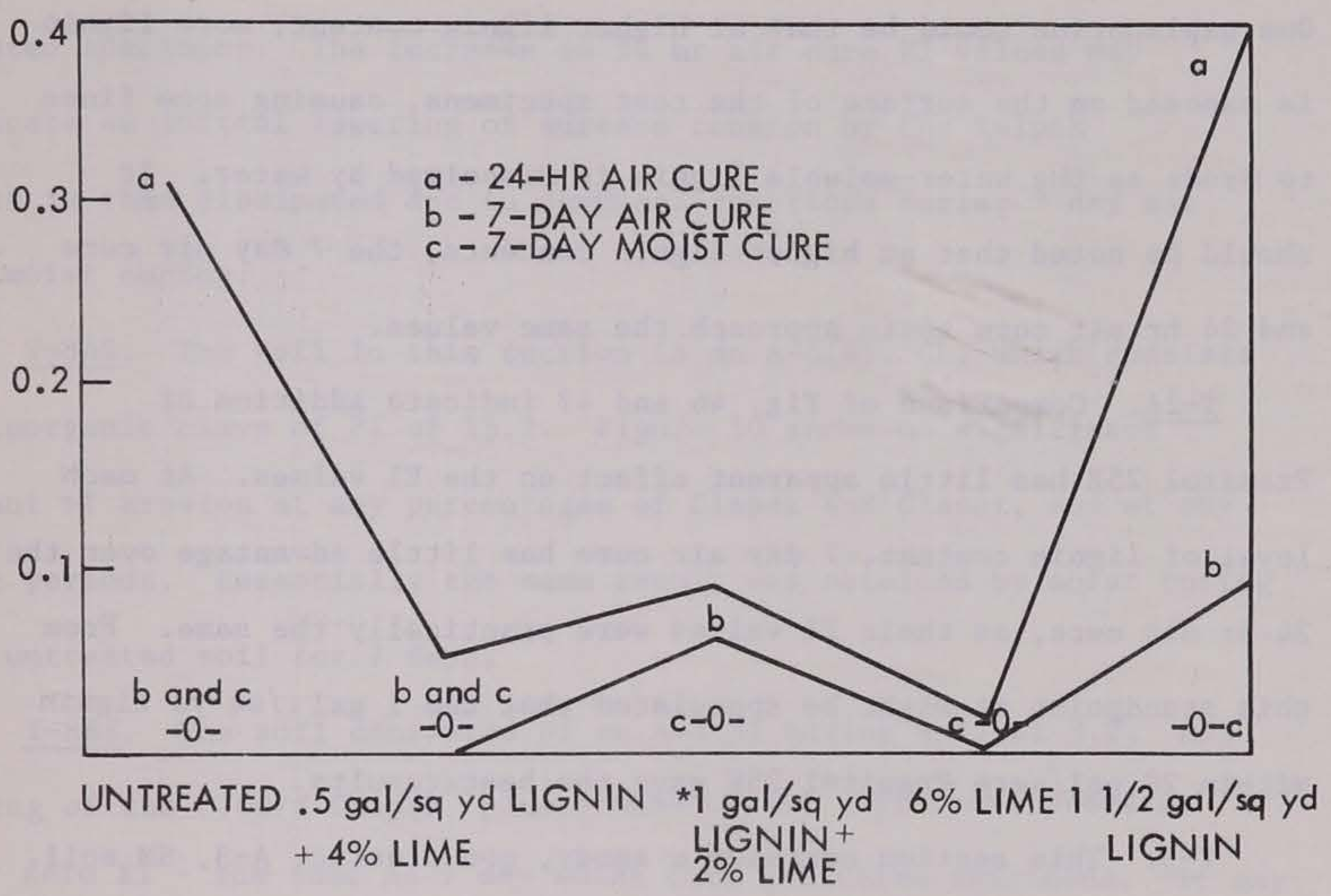

Figure 60. Erosibility results; section T-19.

constant, indicating little or no additional water loss would have occurred with longer air curing. Specimens for 7 day moist cure were molded, weighed, wrapped in Saranwrap, sealed, and stored in the constant temperature and 100% relative humidity room.

T-2. The soil in this section is an A-2-4(0), SM, with a plasticity index (PI) of 5.3. Figure 46 shows a definite trend towards a lower EI with longer air curing, indicative of added binding of particles due to lignin as well as capillary moisture reduction with time. The 7 day moist cure produced the lowest EI values without regard to treatment. Air dry curing produced beneficial EI results at 1 1/2 gal./sq yd lignin* for both cure periods.

One explanation would be that at higher lignin content, more lignin is exposed on the surface of the test specimens, causing some fines to erode as the water-soluble lignin is dissolved by water. It should be noted that at higher lignin contents, the 7 day air cure and 24 hr air cure tests approach the same values.

T-2A. Comparison of Fig. 46 and 47 indicate addition of Pramitol 25E has little apparent effect on the EI values. At each level of lignin content, 7 day air cure has little advantage over the 24 hr air cure, as their EI values were practically the same. From this standpoint it might be speculated that the 1 gal./sq yd lignin within 20 gal/acre Pramitol 25E gave the best results.

T-5. This section contains a sandy, non-plastic, A-3, SM soil. The EI method of test proved to be poor for this soil containing little or no cohesion, nor cementing agent, since most of the specimens failed prior to the end of the 15 min testing period. The 7 day moist cure showed the worst results, probably due to the sandy nature of the soil and the wet mode of curing. NaCl stabilization of soil arises from colloidal reactions and alteration of the characteristics of soil water. Due to the coarse nature of the soil, the NaCl would be unable to act as an effective soil flocculant, and the wet mode of curing would reduce the binding effect of crystalization. The 24 hr air cure showed considerable improvement in EI values, with best results occuring at 1 1/2% NaCl content.

T-6. Soil in this section is an A-2-4(0), SM, with a PI of 1.1. No significant amount of erosion occurred at the 7 day moist or air cures. The untreated 24 hr air cure had a lower EI value than the treated specimens. The increase in 24 hr air cure EI values may indicate an initial lowering of surface tension by the Kelpak which is then dissipated due to chemical reactions during 7 day air and moist curing.

T-8AS. The soil in this section is an A-6(9), CL, which consists of inorganic clays of PI of 15.2. Figure 50 shows no significant amount of erosion at any percentages of Clapak and Claset, and at any cure periods. Essentially the same result was obtained by moist curing the untreated soil for 7 days.

T-8BS. The soil consisted of an A-4(3) having a PI of 3.2. Air drying of the 0.007% Clapak* plus 0.005% Claset* specimens produced near zero EI - the same as 7 day moist cure untreated specimens. It may be hypothesized from both T-8AS and T-8BS that moist curing of the untreated soils, and Clapak-Claset treatment of the air dried soil specimens, retard evaporation, benefiting cohesion, which thus retards erosion.

T-8AB. The soil in this section was an A-4(1), SM, with PI of 6.6. Figure 52 shows zero EI value at 7 day air and moist cures for all percentages of the SA-1 additive as well as the untreated specimens. The lowest EI value at 24 hr air drying was produced with .004%* SA-1 content based on dry weight of soil, indicating a possible initial increase in surface tension due to the SA-1 treatment, which in effect would reduce the susceptibility of the fines to erosion.

T-8BB. This is an A-1-b, SM soil, at PI of 6. Figure 53 indicates nominal decreasing EI with increasing SA-1 contents. Compared with the untreated specimens, the maximum decrease in EI attained was 0.4%, hardly enough to justify treatment of this soil for control of surface erosion. With the 24 hr air cure specimens a direct relationship of EI versus density was noted; as the density decreased the EI also decreased, a trend in conflict with that of several other section materials.

T-10. An A-2-6(1), SC soil, with PI of 9.5, this material showed definite improvement in EI at 24 hr air curing, Fig. 54, regardless of asphalt content.

T-11. This soil is an A-6(5), CL, having a PI of 13.4. Figure 55 shows a definite improvement of the untreated samples at 7 day air and moist cures as compared to the 24 hr air cure, reflecting the high PI of the soil and improvement of the cohesive strength with cure time. The 7 day moist cure produce best overall EI results at all treatments, except at the 6% lime content, where all cures produced no appreciable EI values.

T-12. Lime-flyash treatment of this A-6(4), SC soil, produced a maximum decrease in EI of 0.2%, again not enough to justify treatment for erosion control only. The soil had a PI of 14.6.

T-13. The soil was an A-2-6(0), SC, with PI of 11.4. As indicated in Fig. 57, nominal erosibility benefits were acheived after 7 days air curing at 1/3 gal./sq yd* $CaCl_2$. Since the maximum erosibility effect with all treatment levels was less than 1%, the use of $CaCl_2$ as an erosion control agent would not be justifiable.

T-14. The soil consists of an A-6(2), SC, having a PI of 11.6. EI results are similar to those presented for section T-10, though lower, probably due to the increased PI of the soil. The 5%, 24 hr air cure specimens showed some minor erosion of fines but also were at a slightly lower density than all other specimens.

T-16. For this A-6(1), SC soil, with a PI of 11.7, .003%* Terra-Seal produced some 7 day air cure EI benefits while .004% showed very slight EI improvement of 7 day moist cure specimens. It is evident in Fig. 59 that 24 hr air cure does not allow adequate curing due to treatment, though the EI value decreased with increasing percentage additive. Densities of all treated specimens followed the same trend, in that higher densities corresponded to lower EI values. Decreases in surface tension may be the mechanism of this additive, and EI results tend to bear out this presumption.

T-19. The soil herein was an A-7-6(12), CL, of PI 18.7. Addition of lime tended to decrease erosibility of the soil at both air cures, while lignin alone yielded higher EI values.

Discussion

Resistance of soils to external forces is due to friction between solid particles and the cohesion furnished by films of moisture covering these particles. When such a film thickens, it performs as a lubricant, reducing the friction between adjacent particles and consequently diminishing the total resistance value. The plasticity index (PI) of a soil is the amount of water which must be added to change the soil from its plastic limit to its liquid limit. Thus, the PI is an indication of the range of moisture a soil can hold before its resistance value diminishes. Generally, during this investigation, it was found that the higher the PI the smaller the erosibility index (EI) of the untreated soils.

Table 8 presents the average EI values for various PI ranges of untreated soils. For each cure period it will be noted that these values decreased as the PI increased. As a consequence, unless the additive produced some means of stabilization of the lower PI soils within the 24 hr cure period, no major EI benefits would be shown regardless of the cure process. Thus the following sections may have achieved some immediate erosibility benefits due to addition of stabilizing additive: T-2, T-2A, T-5, T-8AS, T-8BS, T-8AB, T-10, T-11, T-12, T-14, and T-19.

An attempt was made to correlate weight loss of the samples (EI) to some function of their Atterberg limits. From reviewing the test data, it was found that due to the sensitivity of the erosibility method of testing, results of EI values greater than 2% were more reliable and the percent error minimal. After careful study, the Atterburg function

$$PI/(PL + LL)$$

(which could be termed the coefficient of erodible durability) was used in the correlation since it incorporates all plasticity properties of the soil. Between the reciprocal of the EI values and the coefficient of erodible durability, a coefficient of correlation of 0.941 was obtained. The EI value used for this correlation was at 24 hr air cure since 7 day air and moist cures generally produced EI values less than 2%.

Table 8. Comparison of Erosibility and Plasticity Indices

Plasticity Index	Average EI values for untreated soils,%		
	24 hr air cure	7 day air cure	7 day moist cure
0	50.9	80.2	55.4
0<PI<5	26.09	0.73	0.37
5<PI<10	13.38	0.67	0.13
10<PI<15	4.82	0.45	0.07
PI>15	1.50	0	0

The correlation coefficient was quite good, and the plot and equation are shown in Fig. 61. Further tests would have to be run before any major conclusions could be drawn from this analysis, but at least it illustrates the EI dependency on Atterburg limits.

As a potential stabilization tool however, consider the following illustration. The test data showed that soils with PI's greater than 7.5 had EI values at 24 hr cure of less than 2%, while at 7 day cure periods they had EI values of less than 0.6%. Thus, knowing the Atterberg limits of a soil and its expected cure period, a rough estimate could be made as to the erodible durability of the soil, and whether stabilization was or was not required. Atterburg limit tests of the treated soils at 24 hr air cure would further refine and verify this potential tool.

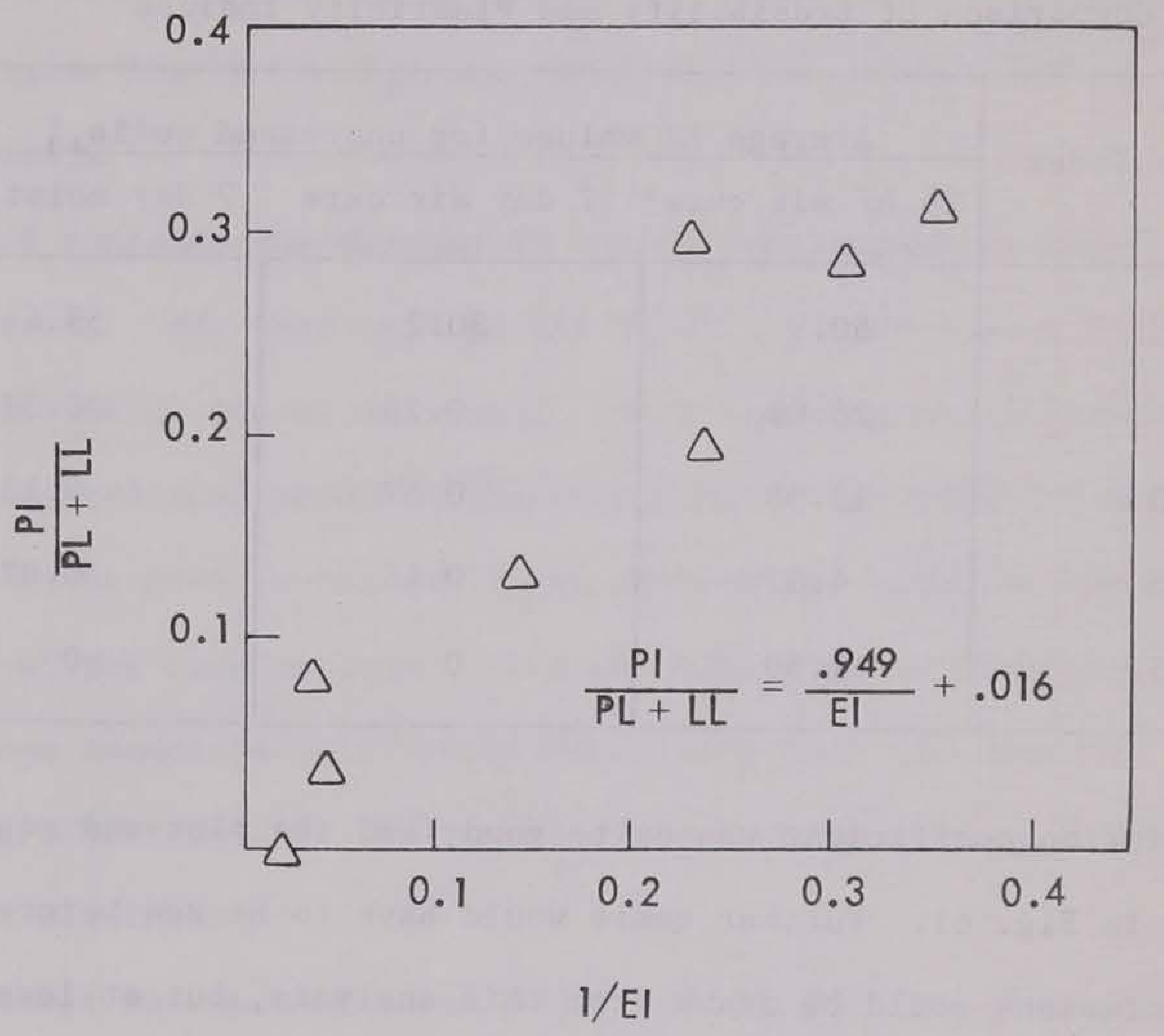

Figure 61. Correlation of 24-hr cure results.

Traffic Simulation Tests

Performance of a roadway during extreme conditions such as heavy wheel loading, rain, or a combination of both, is a good evaluation of its durability. Resistance to rutting is very important if a road is to continue to carry traffic in the manner intended, particularly such low volume roads as studied in this project.

Traffic simulation tests were used to evaluate the performance of unsurfaced treated and untreated specimens subjected to a simulated wheel load equivalent to that of a moderate to heavy truck. The test is run with a constant wheel load under both wet and dry conditions and in this manner a resistance to rutting can be determined. It is then possible to obtain data which may yield means for a comparative evaluation of different chemical treatments and soil types, and to predict performance under actual conditions when data is correlated with final field testing.

The traffic simulator apparatus was originally developed by the Bituminous Research Laboratory at Iowa State University and partially modified for use with stabilized base soils by the Soil Research Laboratory. Only a brief summary of the operation and a description of the apparatus will be presented here; a more complete description is given by Csanyi and Fung[5] and Bergeson[6].

There are three main components: (a) the main frame, (b) a horizontally oscillating carriage, and (c) a specimen retainer box. The main frame is about 11 ft long, 3 ft wide, and 2 ft high and is supported by rigid legs bolted to a concrete floor. The frame supports a travelling carriage and a specimen retainer box. The carriage operates in a to and fro manner with an 8 in. diameter, 1 1/4 in. wide, solid rubber tire applying the load and driving the carriage during its forward motion. A 1/2 hp motor connected to the loading wheel and auxiliary reverse drive wheel, through a reducing gear and belt drive, powers the carriage in such a manner that the wheels rotate in their respective directions continuously. During reverse motion the loading

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[5] Csanyi, L.H., and Fung, H.P. Traffic Simulator for Checking Mix Behavior. Highway Research Record 21, 1964, pp 57-58.

[6] Bergeson, K.L. Asphaltic Products and Elastomers as Dust Palliatives and Surface Improvement Agents for Unpaved Secondary Roads. Unpublished M.S. Thesis. Ames, Iowa: Iowa State University, Library, 1972.

wheel is retracted, and the auxiliary drive returns the carriage, thus simulating one-way traffic. Travel speed is somewhat less than 4 mph.

Contact wheel pressure is applied through a regulated compressed air ram and was maintained at 85 psi, or at a pressure approximately equal to that of a moderately heavy truck. Simulated rainfall was applied through a modified paint sprayer mounted in front and slightly above the carriage. An air pressure regulator connected to the sprayer provided a fine uniform spray of approximately 0.15 to 0.20 in./hr, spraying specimens mounted in the retainer box; the latter is mounted on the forward portion of the main frame with specimens aligned along the centerline path of the loading wheel.

All specimens for this test are molded in special 4 in. diameter rings which are then mounted directly in the retainer box without extrusion. Prior to mounting, each specimen, in its individual ring, was air cured 24 hr. During molding, the molding rings are secured to a Proctor stand, and a 4 in. diameter by 1/4 in. disc positioned in the bottom of the mold to allow for position adjustment within the retainer box. Following curing, the specimens are placed in the retainer box, secured with a cover plate, and positioned flush with the cover plate by use of adjusting screws against the discs.

Compaction of specimens is done in two layers on a predetermined quantity of soil, each layer rodded 25 times with a 5/8 in. diameter round-tipped rod, then subjected to 20 blows of a standard 5.5 lb

Proctor hammer. After leveling of minor surface irregularities, a 4 in. diameter by 1/4 in. disc is placed on top of the specimen, and 5 or more additional blows applied to the disc until desired density is achieved. The result is a specimen approximately 2.4 in. high with a smooth, partially sealed surface similar to what one might expect in the field following final rubber tire compaction.

Six specimens were molded for each test run, with duplicate specimens being used for each additive treatment. These duplicates were positioned to minimize position effects within the retainer box.

Under the applied pressure of 85 psi the loading wheel sequentially traversed each specimen for:

1. 1000 passes,
2. 1000 passes with simulated rain,
3. 2 hr water fogging period with no traffic application, and
4. 1000 passes (or until failure) with simulated rain. Failure of specimens was considered to be 0.5 in. average centerline rut depth.

To obtain average rut depths, three measurements were periodically taken along the track centerline at the quarter points of each specimen. For items 1, 2, and 4 above, measurements were made at 0, 50, and 200 passes, and each 250 passes thereafter until failure or a maximum of 3000 cycles. Readings taken at 50 passes were assumed to allow for initial seating and compaction effects.

Figures 62 through 74 compare the levels of treatment for each test section. Each data line is presented as the average of the duplicate specimens.

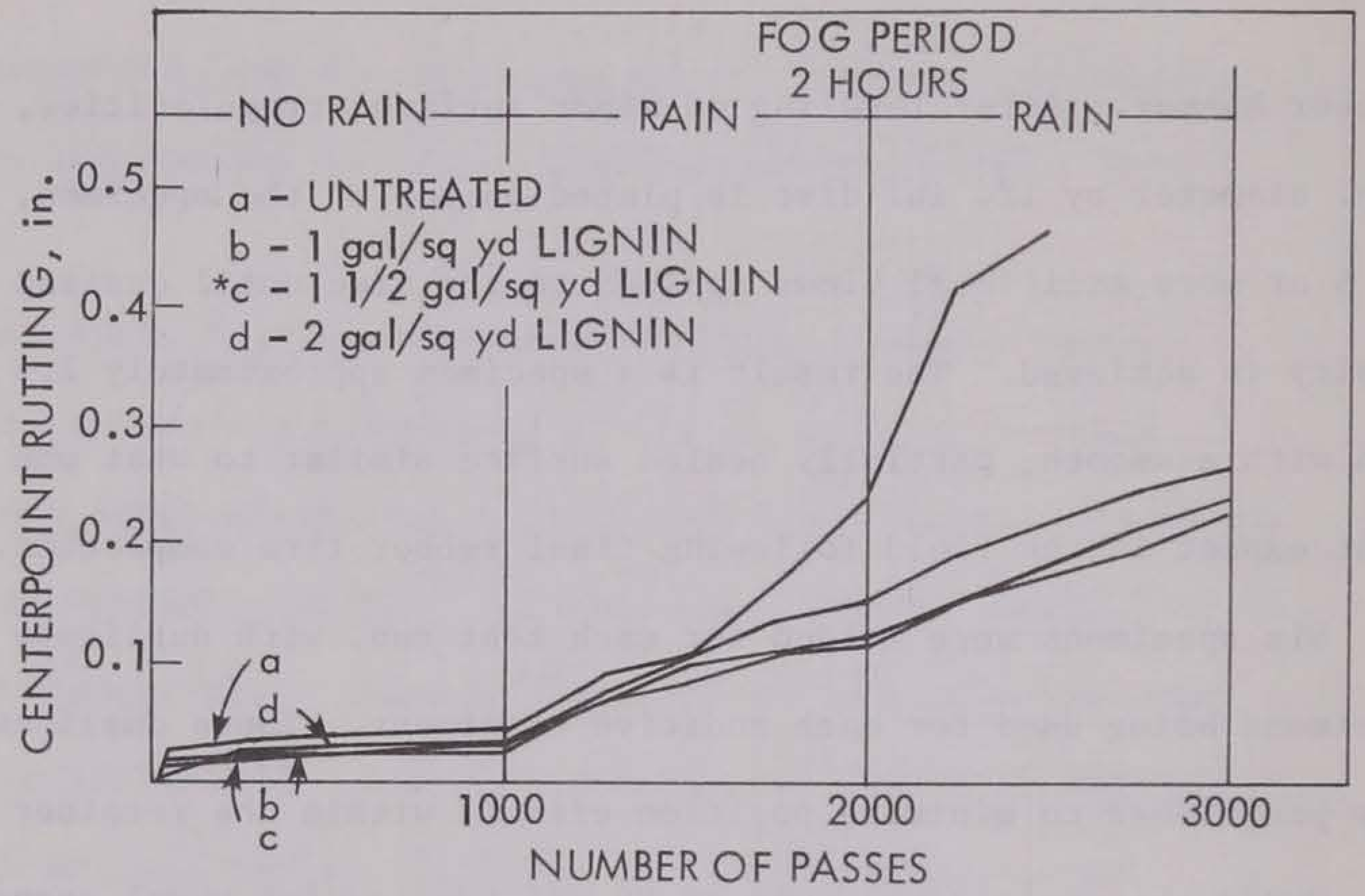

Figure 62. Traffic Simulation results; section T-2.

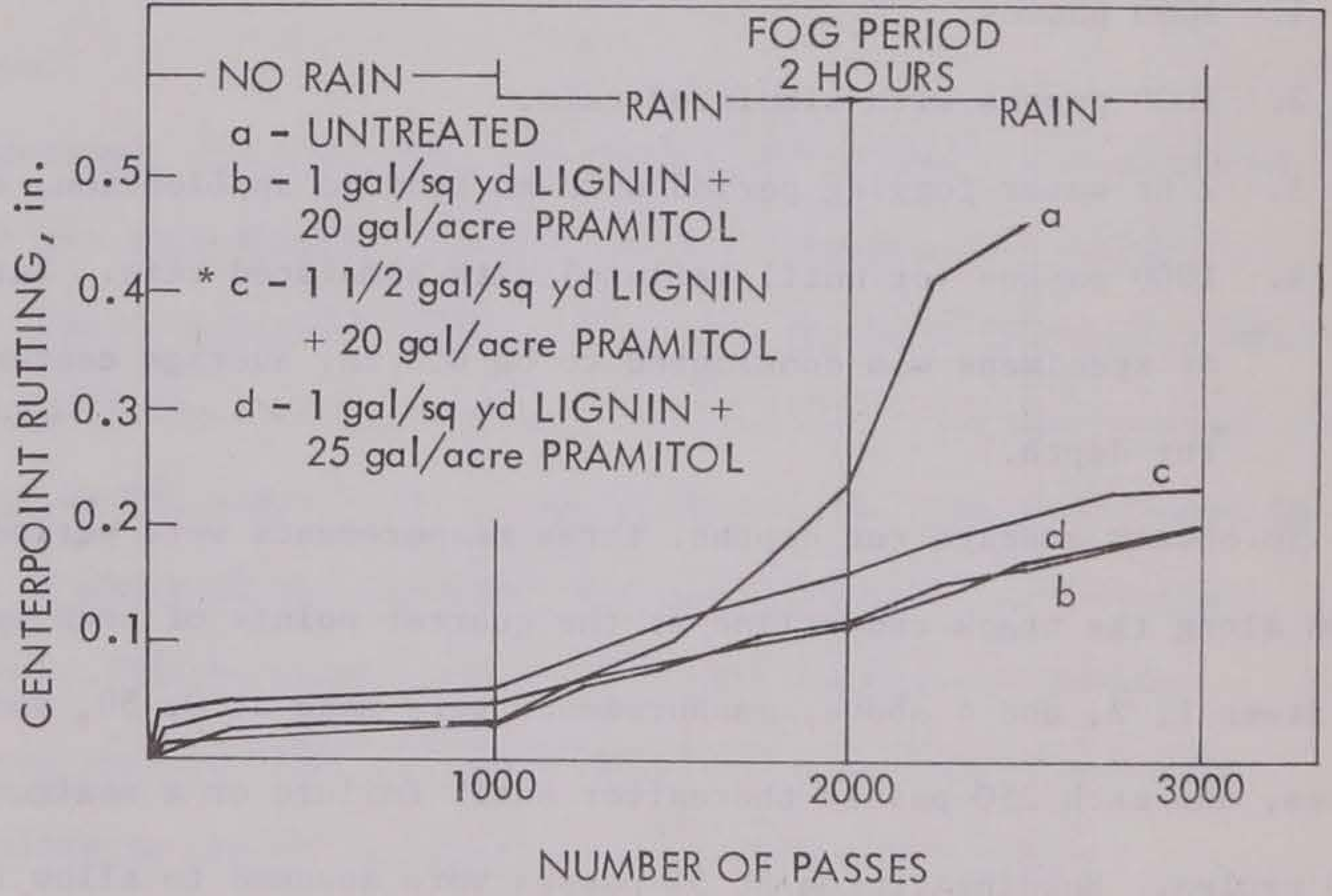

Figure 63. Traffic Simulation results; section T-2A.

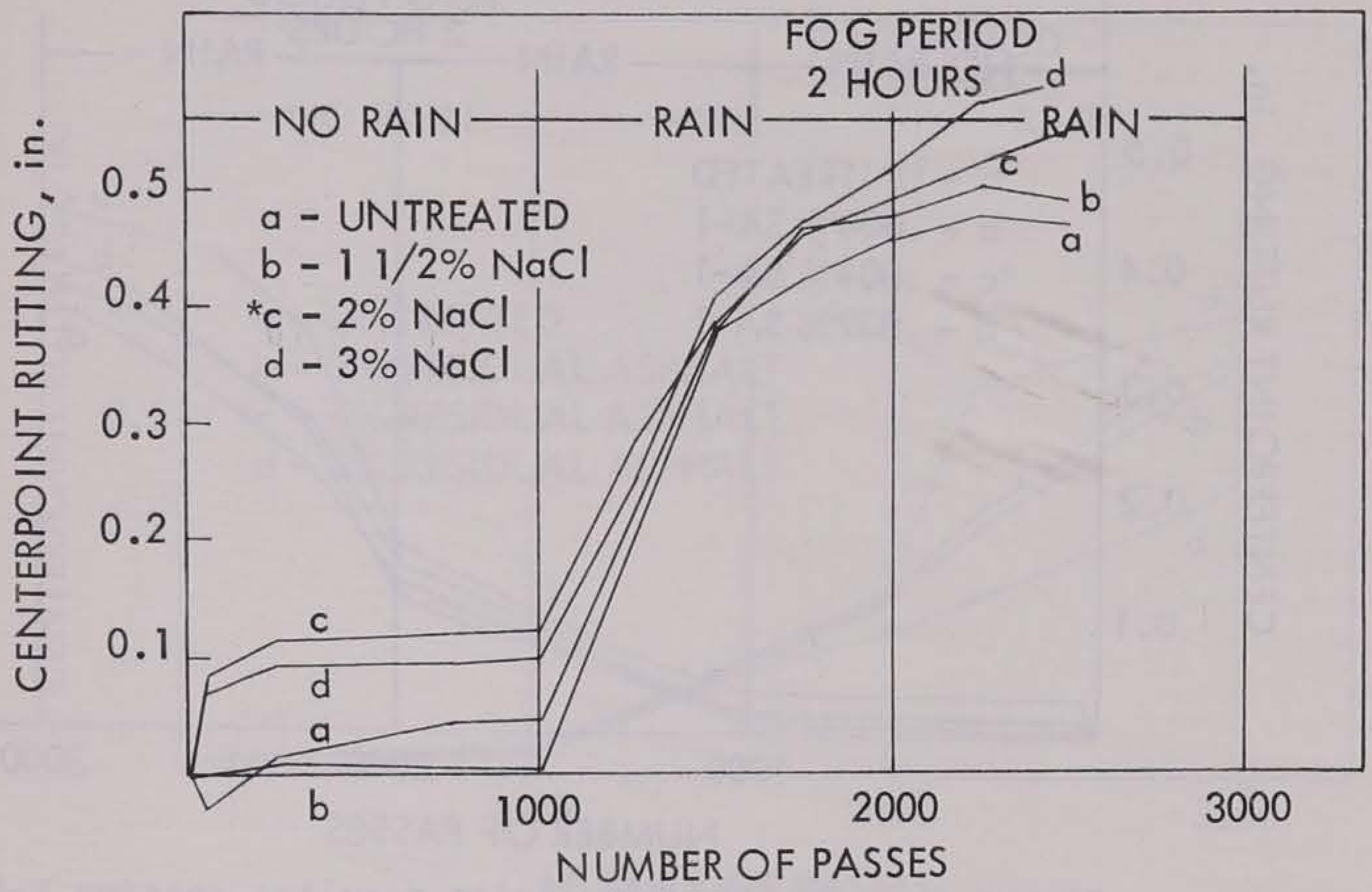

Figure 64. Traffic Simulation results; section T-5.

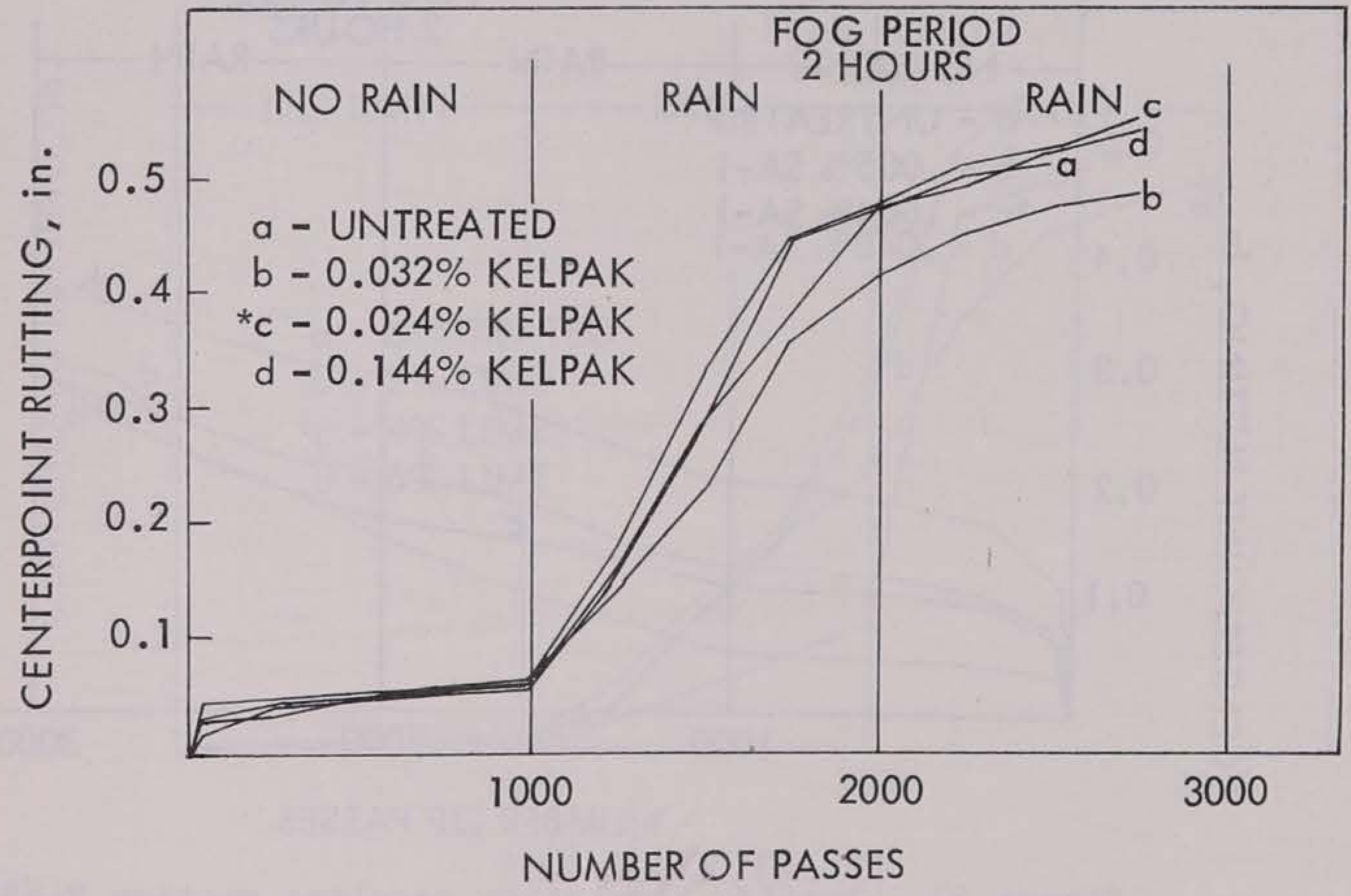

Figure 65. Traffic Simulation results; section T-6.

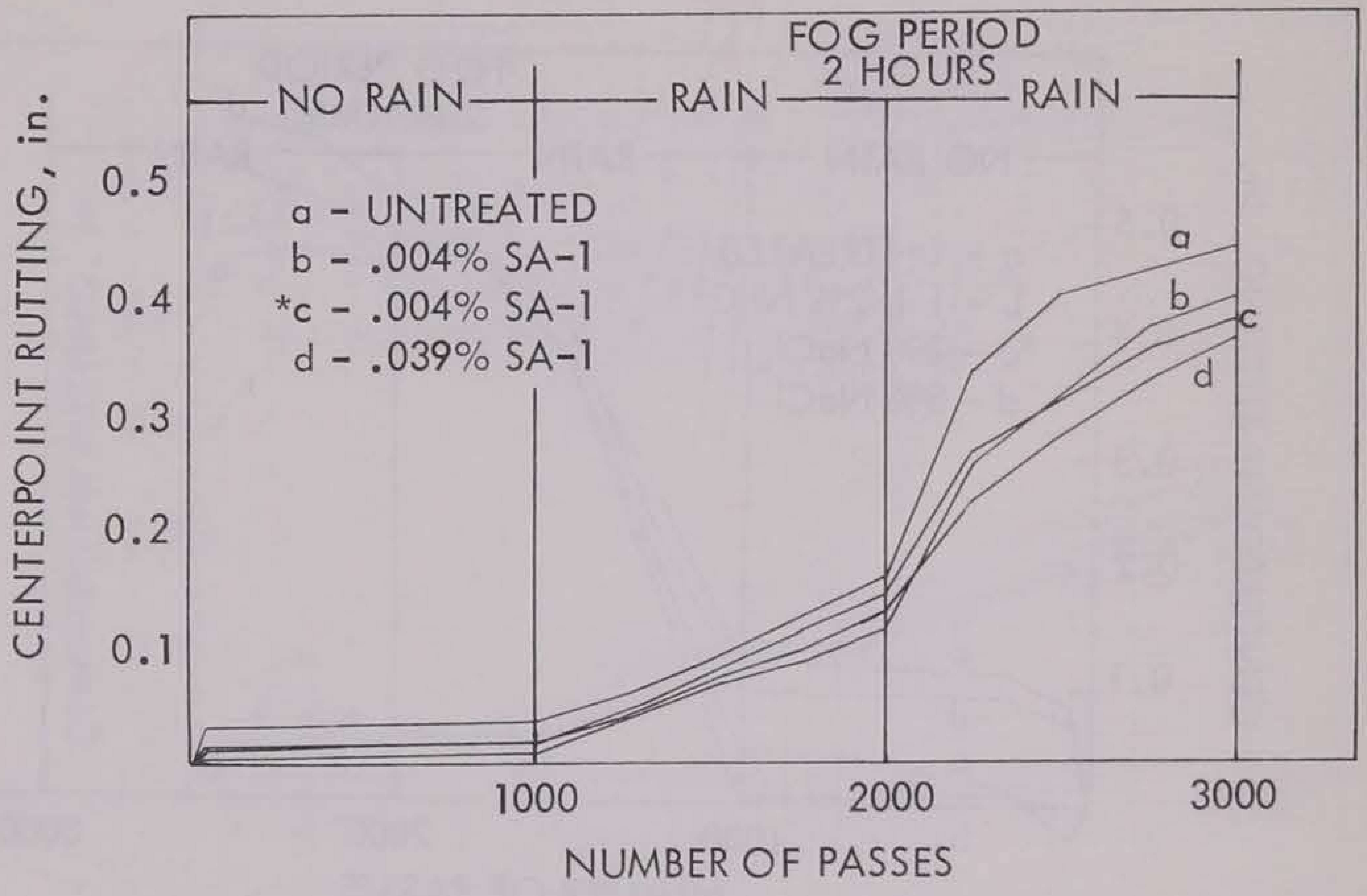

Figure 66. Traffic Simulation results; section T-8AB.

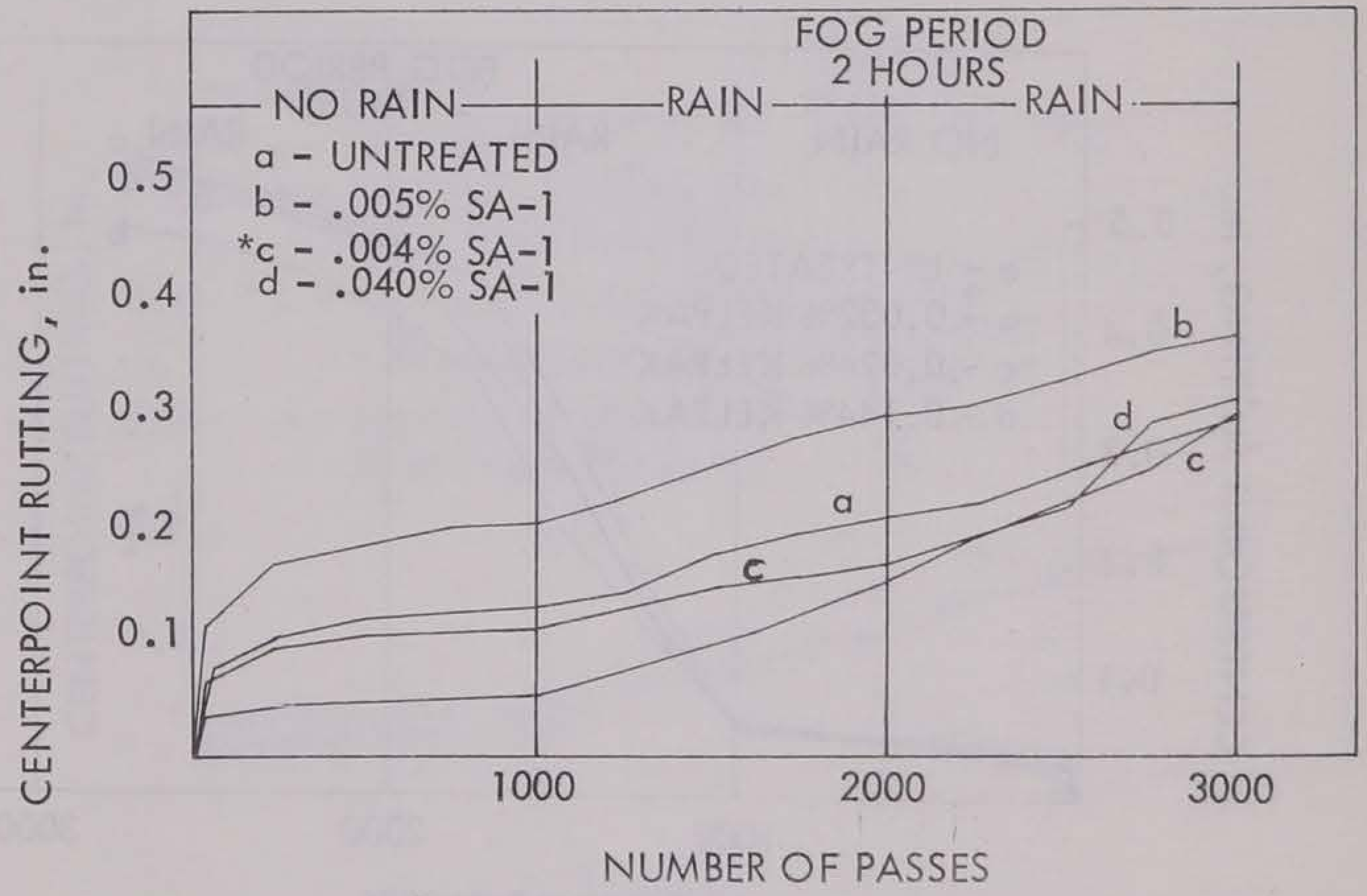

Figure 67. Traffic Simulation results; section T-8BB.

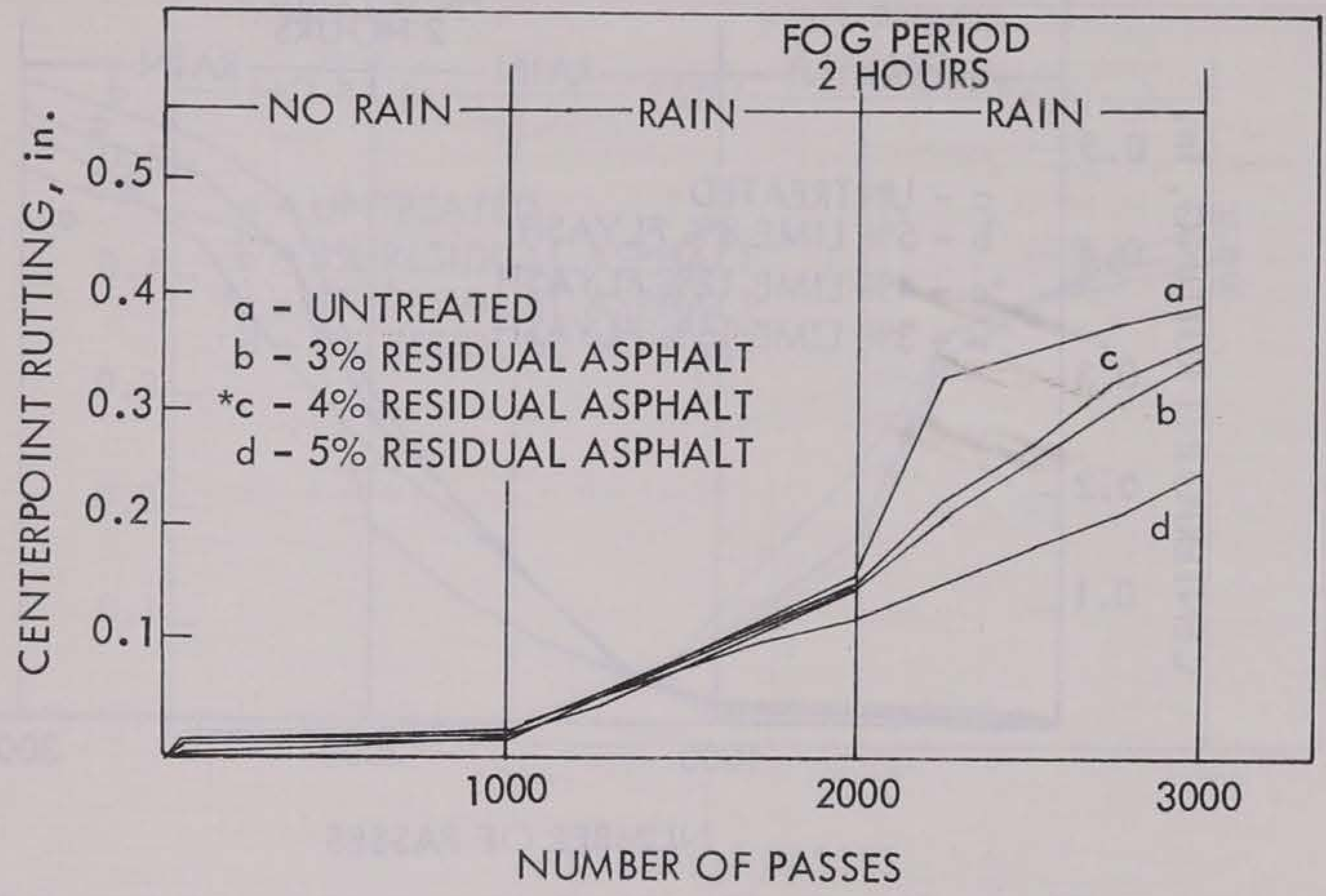

Figure 68. Traffic Simulation results; section T-10.

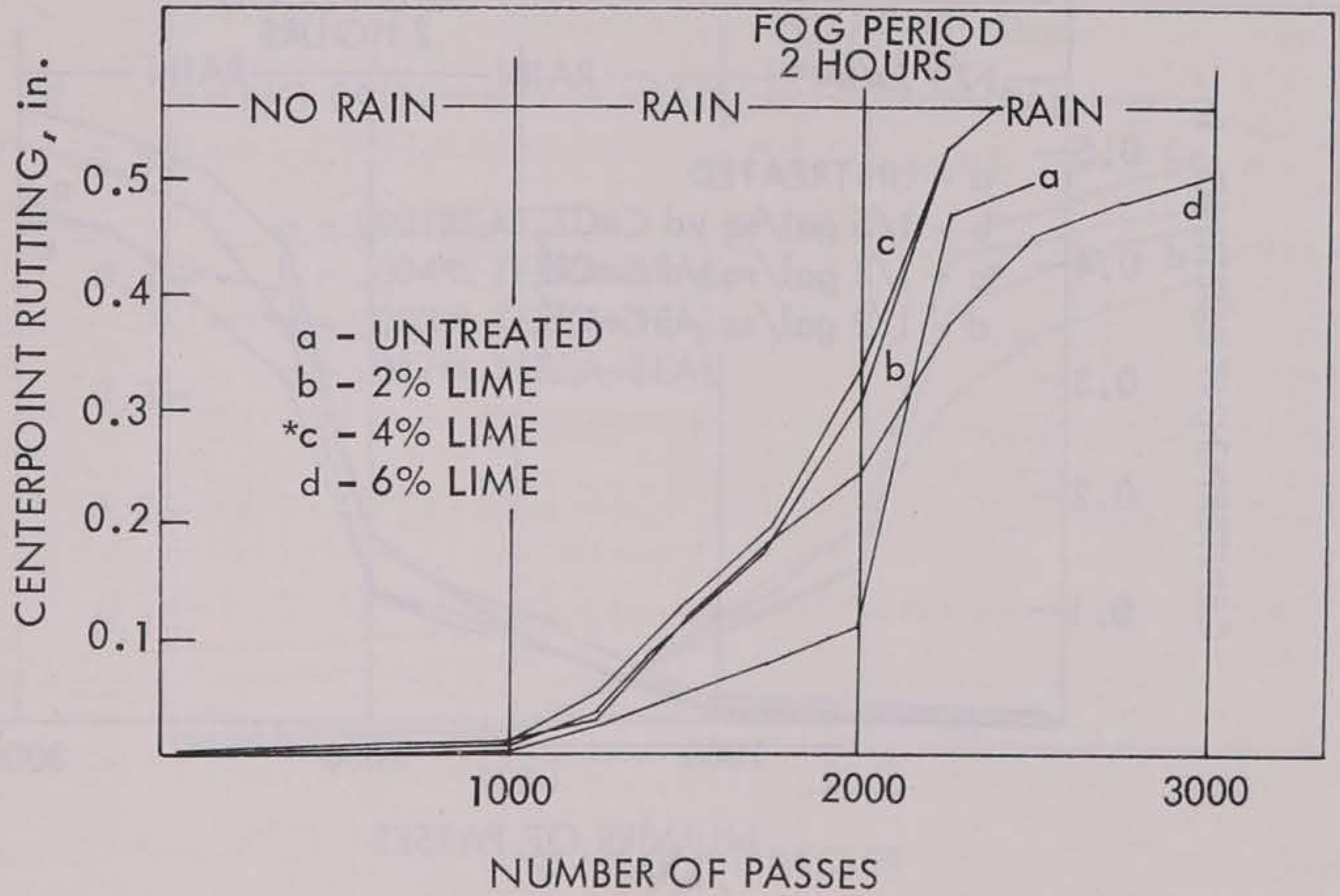

Figure 69. Traffic Simulation results; section T-11.

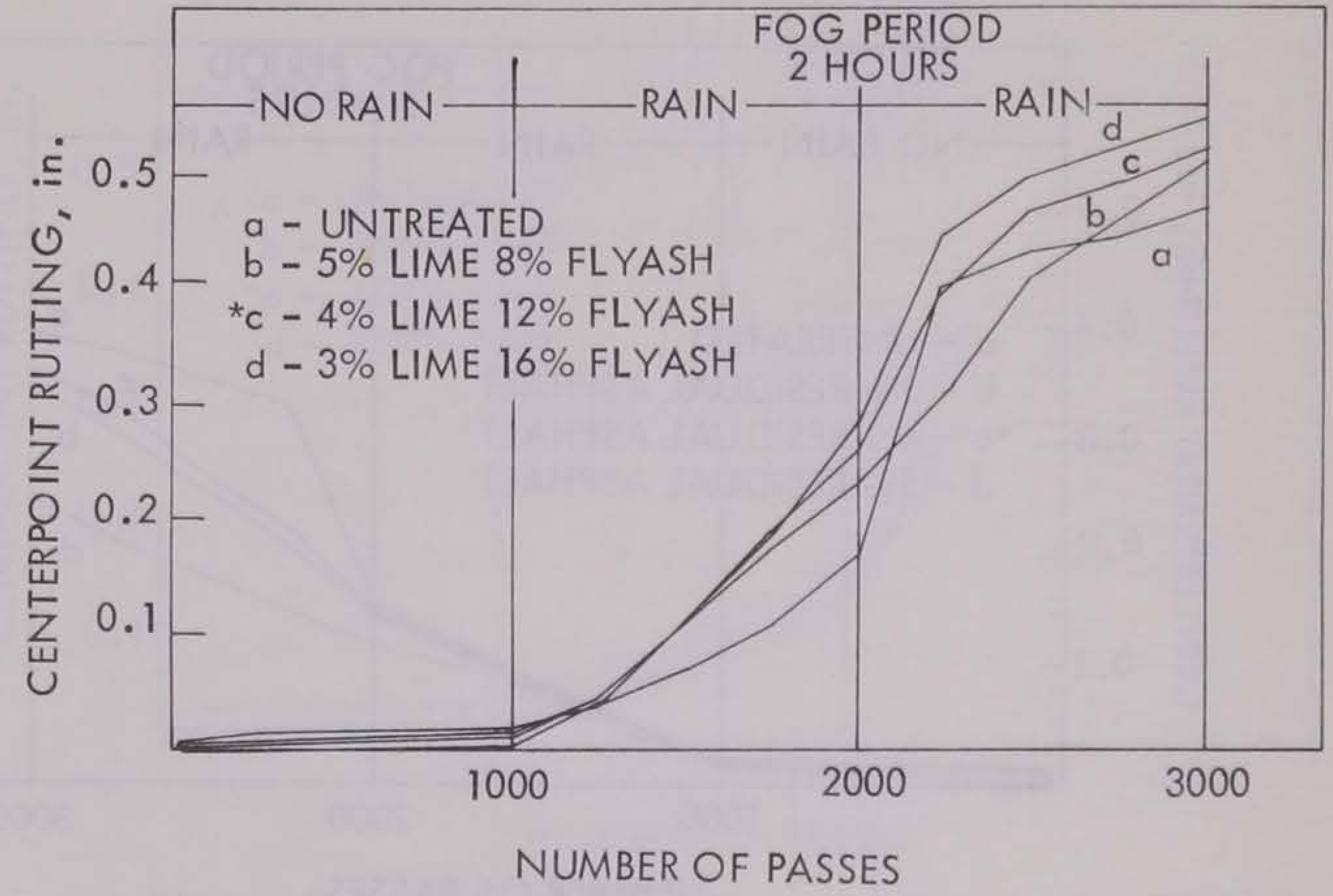

Figure 70. Traffic Simulation results; section T-12.

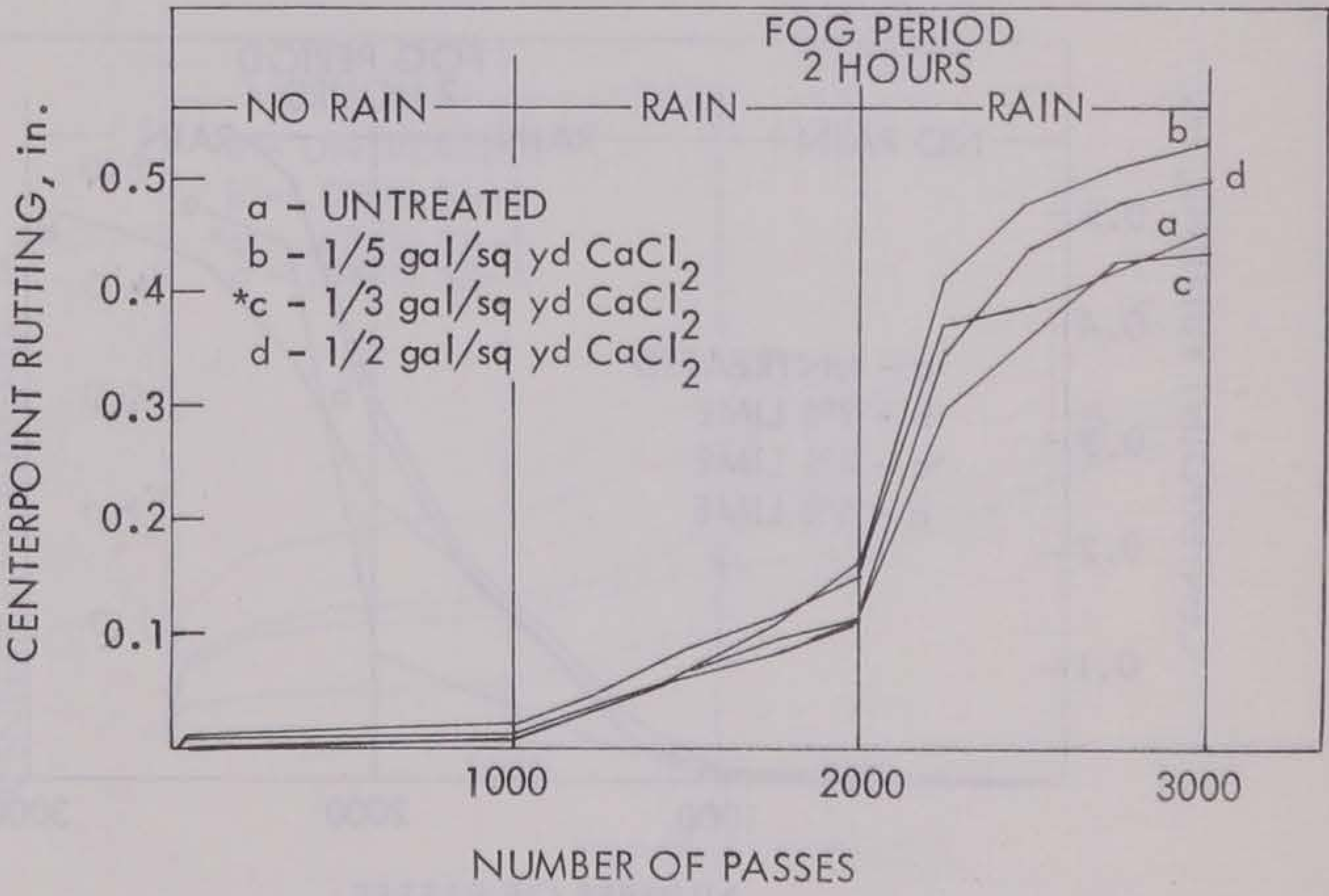

Figure 71. Traffic Simulation results; section T-13.

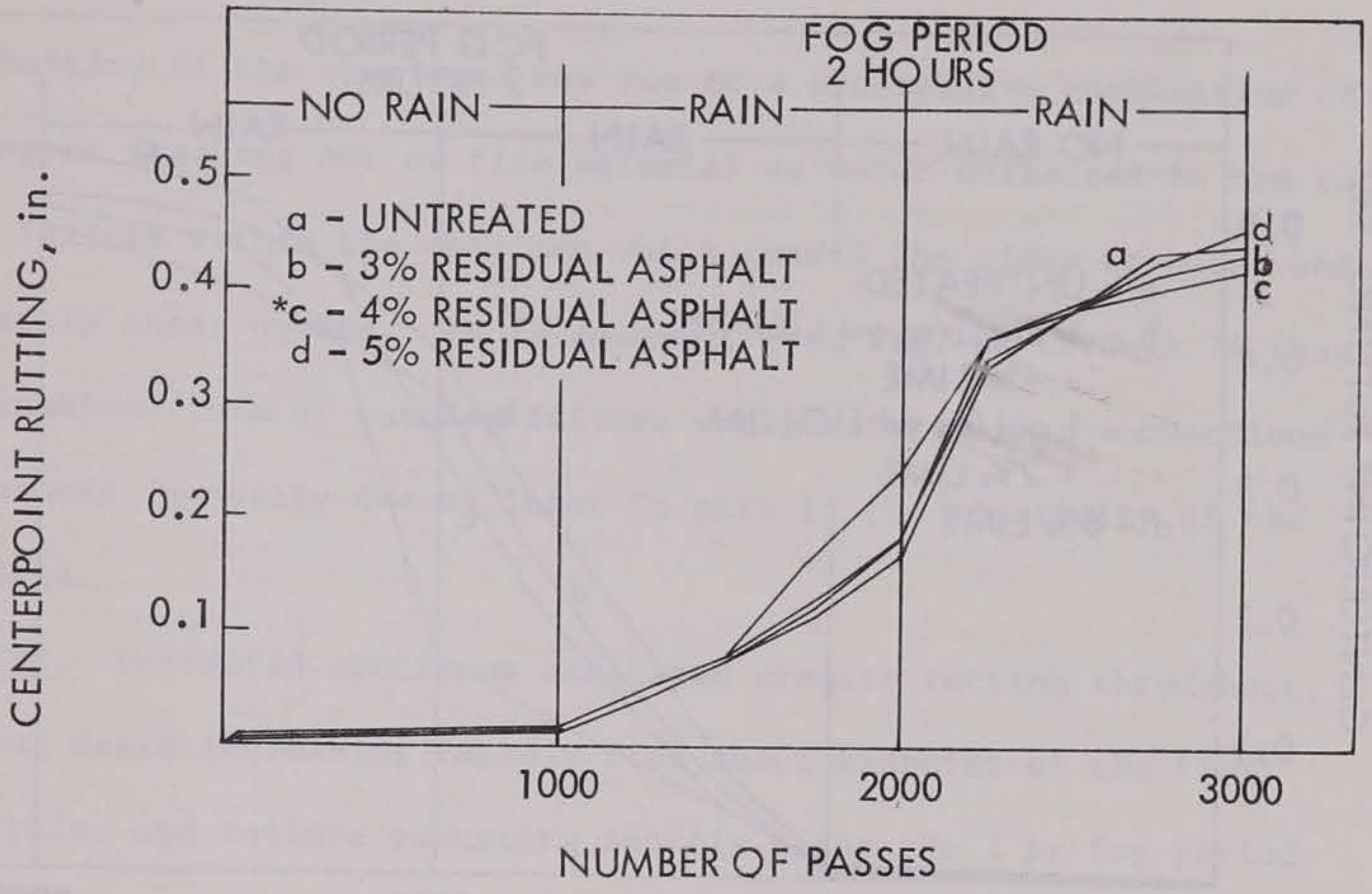

Figure 72. Traffic Simulation results; section T-14.

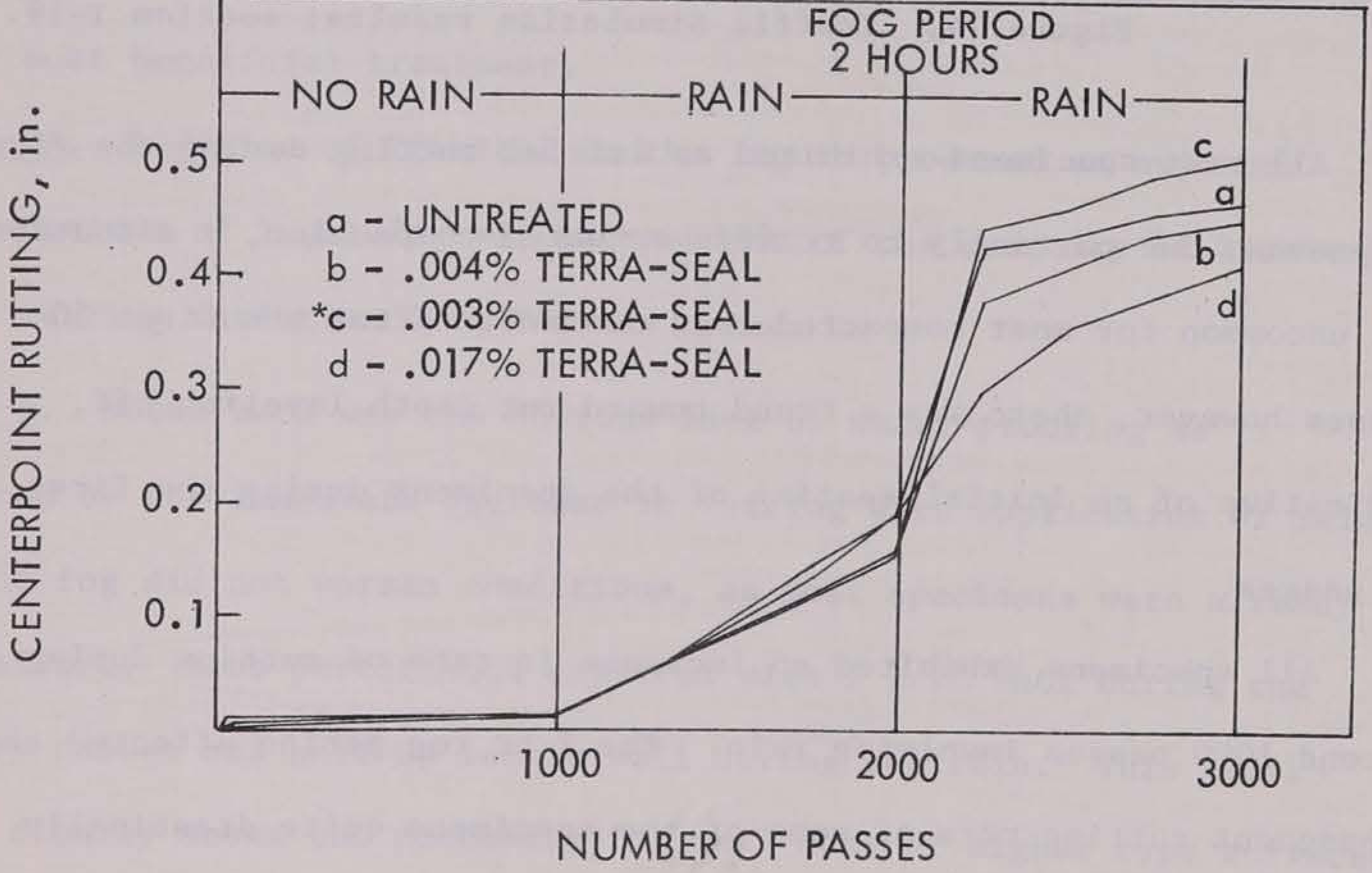

Figure 73. Traffic Simulation results; section T-16.

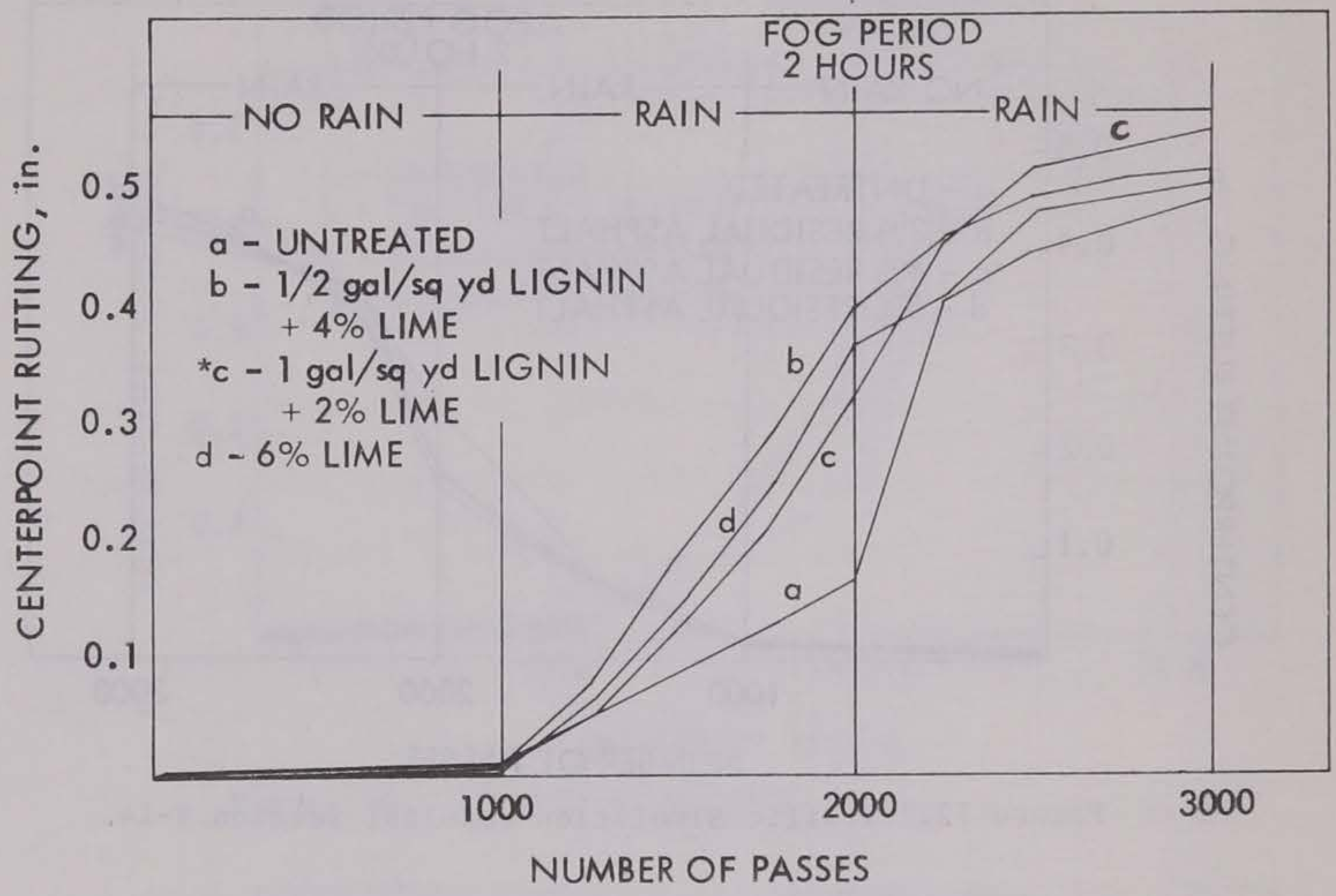

Figure 74. Traffic Simulation results; section T-19.

All test specimens exhibited an initial rutting during the first 50 passes, due partially to traffic actuated compaction, a situation not uncommon for most compacted road courses. After the first 50 passes however, there was a trend toward rut depth leveling off, indicative of an initial seating of the specimens during the first 50 passes.

All specimens exhibited an increase in rate of rutting during the second 1000 passes involving rain. The 2 hr fog period affected the subsequent rutting rate of some of the specimens quite drastically while others displayed little change.

Rutting of the specimens was due to a progressive combination of washing or tracking out of fine material as water collected in the rut, and a failure within the specimen which caused the sides to bulge and ultimately shear upward. It is apparent from Fig. 62 through 74 that this combined form of rutting failure was greater with some sections than others, possibly due at least in part to the plasticity of the materials.

T-2. Untreated specimens exhibited greater rutting throughout, with rut depth increasing rapidly from about midpoint of the first rain cycle, and failure occurring shortly after the 2 hr fog period. The water-proofing effects of lignin are apparent from the decreased rut depth and rate of rutting, with 1 1/2 gal./sq yd* lignin appearing as the most beneficial treatment.

T-2A. Addition of Pramitol to the lignin produced an apparent lignin optimum of 1 gal./sq yd, independent of the quantity of Pramitol. Little rutting variation from T-2 was noted.

T-5. Noted here was the obvious lack of water-proofing as evidenced by the immediate increase in rutting with application of rain. The 2 hr fog did not worsen conditions, as most specimens were already near failure. Best performance appeared with 1 1/2% NaCl during the 1000 dry passes and held up fairly well during the rain. This observation clearly shows the necessity for seal coat or higher type surfaces for this soil and stabilizer agent. Two* and 3% NaCl levels produced significant initial seating and compaction effects.

T-6. A very close grouping of all specimens during the first 1000 passes was noted, with all specimens then exhibiting a significant increased rate of rutting at the first application of rain. The fog appeared to have little effect on rate of failure of the specimens. Optimum treatment appeared to be .032% Kelpak.

T-8AB. Some improvement over the untreated specimens was noted, though all specimens exhibited similar rutting trends. A slight increase in the rate of rutting during the second 1000 passes was apparent, but the fog period caused a marked increase in rutting. Treatment at .004% SA-1 (line b, Fig. 66) showed low initial seating and compaction effects and low rutting during the 1000 no rain applications of traffic loading.

T-8BB. A wide range of rut depths was noted for the different treatment levels though little change in rate of rutting was noted with all specimens throughout the 3000 cycles. Susceptibility to rain was not significant for all specimens. This behavior was possibly due to the emulsion treatment, applied several years preceding this project, not allowing water to penetrate the compacted soil specimens. In general, the best performance was obtained from .040% SA-1 treatment.

T-10. All specimens exhibited similar behavior through the first 2000 passes. Widely varied behavior occurred thereafter, with the untreated specimens indicating a definite wetting and subsequent loss of stability after the fog period, while the 5% asphalt treatment displayed little change in rate of rutting, constituting the best treatment. Treatments at 3 and 4%* showed similar trends throughout the test but were not as effective as 5% following fogging.

T-11. All specimens exhibited very minor rutting during the initial 1000 passes. Untreated specimens exhibited less rutting than the treated during the second 1000 passes, but were noticeably affected by the fog period. An explanation for this is that during the second 1000 passes the clays in the untreated specimens plugged the voids, thus creating a temporary waterproof effect, while the treated soils contained larger void spaces and increased permeability due to particle aggregation brought about by action of the lime. For 24 hr air curing, 6% lime treatment produced the most stable effects against rutting, though it is apparent from the data that seal coating of this soil is required.

T-12. A similar occurrence was noted as with section T-11 where flocculation of clays caused the treated specimens to exhibit greater rutting during the second 1000 passes than the untreated. It was also apparent from 1500 to 3000 passes that rutting increased with flyash content. Specimen densities also decreased with increasing flyash content, reinforcing the latter rut depth measurements.

T-13. Only minor variations in rutting were noted for all specimens during the first 2000 passes. Following the fog period and an additional 250 passes, the untreated specimens tended to fail at a slower rate, indicating that treated specimens may have been retaining moisture. The 1/3 gal./sq yd* $CaCl_2$ produced best performance in this test, but it is apparent that seal coating or higher type surfacing would normally be required for this soil and stabilizer.

T-14. All specimens displayed similar rutting trends with only minor variations, indicating no obvious effect from the asphalt emulsion treatment of this soil.

T-16. The .017% Terra-Seal treatment showed a slower rate of rutting after fogging than did all other specimens. Rate of rutting for all specimens was markedly increased from 1000 to 2000 passes with little variation due to treatment.

T-19. The specimens again displayed the effects of lime causing flocculation of clays, increasing erosion and rutting. Initial seating and compaction was significantly low, with only very minor rutting increases during the first 1000 passes for all specimens.

PART 3. DISCUSSION AND SUMMARY

The following summation is a discussion of field and laboratory evaluations to date. Each test section is briefly discussed through the common denominator of completed laboratory tests and at least partially compared to field performance. Each participant must fully understand that the following discussions are not final conclusions and may be subject to minor to severe changes stemming from final Spring and Fall 1976 field observations, plus completion of all laboratory testing.

T-2. With the exception of the unconfined compressive strength, addition of lignin to the soil seemed to improve overall performance. Both the erosibility and traffic simulation tests appear to be a measure of the stability of the fines, and the use of lignin, which tends to glue or cement the fines, aided the performance. Although lignin tends to fill voids and decrease permeability, the freeze-thaw test indicated little or no improvement with treatment. It is suspected that moisture retained in the specimens through use of the lignin was responsible for reduction in q_u values. Benkelman Beam results indicate little strength gain upon addition of lignin, whereas the SBV test corresponds with unconfined compression results and indicates a lowering of strength. No marked improvements in either optimum moisture or maximum dry density were evident.

T-2A. The addition of Pramitol 25 to the lignin did not significantly alter the results of any of the lab tests in comparison with T-2, although unconfined compressive strengths were slightly higher. It was noted in the field and verified by Benkelman Beam and SBV tests, that addition of Pramitol to the lignin caused some improvement in the deflection, relative stiffness and SBV values when compared to section T-2. The mechanism by which this occurs is not known at this time. SBV results indicate a lowering of bearing capacity from pre-construction, but are consistently equal to or higher than T-2. Unconfined compressive strengths follow the SBV pattern from untreated to treated. Again, no marked improvement in optimum moisture-density were observed.

<u>T-3 & T-3A</u>. The evaluation of these shoulder treatments with Pramitol 25 consisted only of visual observations of weed growth. During 1973, 1974, and early 1975 the treatment was apparently performing quite well.

<u>T-5</u>. Addition of 2%* NaCl produced slight improvement in q_u and F-T elongation, while 1 1/2% NaCl produced minor erosibility and trafficability benefits. Results of the field tests indicate that deflection characteristics remained unchanged but SBV was lowered. At 2%* NaCl an increase in both optimum moisture content and maximum dry density was noted.

<u>T-6</u>. No increase in performance with the addition of Kelpak was noted in the lab studies, with the erosibility test indicating a poor performance of the chemical stabilizer. A very marked increase in erosion was noted with treatment. Due to the nature of this test, a decrease in surface tension would be suspected as the cause of the poor showing. Both Benkelman Beam and SBV results indicate a general

improvement in strength, however. Optimum moisture content and maximum dry density of the soil were not significantly altered through Kelpak treatment.

T-8AS. No improvement in performance was noted from Clapak-Claset with freeze-thaw, q_u, or erosibility tests. Since this was a subgrade soil and not directly subjected to traffic, traffic simulation tests were not run. A trend of decreasing maximum dry density and increasing optimum moisture content with increasing additive amount was noted.

T-8BS. Treatment with .007%* Clapak - .005%* Claset improved freeze-thaw and erosibility. Unconfined compressive strength was lowered from the untreated and was reasonably constant regardless of treatment level. No major benefits were apparent in optimum moisture and density due to treatments.

T-8AB. Some improvement in fines retention occurred with addition of SA-1 during the erosibility and traffic simulation tests. Little change was noted in freeze-thaw performance, with neither treated nor untreated soils showing any appreciable heave. A marked decrease in q_u values indicates a possible retention of hygroscopic moisture. A strength increase was apparent from field SBV values, while the Benkelman Beam tests showed no change in deflection characteristics. No trends in optimum moisture-density variation were apparent.

T-8BB. Addition of SA-1 produced minor reductions in erosibility of the specimens but failed to demonstrate much improvement in trafficability. Since this particular base material had prior asphalt emulsion treatment, it is speculated that dynamic loading of the traffic wheel during simulator tests broke down the asphalt-aggregate bonds allowing the fines to be washed out. A marked improvement was observed in the freeze-thaw test even though specimen shrinkage rather than swelling was the problem. The q_u values slightly improved with treatment, which indicates some possible weak bonding and adhesive interlocking. However, all q_u values were small. No demonstrable improvement in field values was apparent, though the SBV value was higher than for pre-construction testing in Fall 1973. Maximum dry density was improved, though optimum moisture remained the same as for the untreated samples, with .004% SA-1*.

<u>T-10</u>. Increased performance with both erosibility and traffic simulation tests indicate that the soil particles are bonded by the asphalt of the emulsion. Freeze-thaw results indicated some waterproofing of the soil, reducing capillarity. SBV and q_u values indicated lower strengths, probably due to the more plastic nature of the mix. Benkelman Beam tests illustrated some improvement but were not consistent. Maximum dry densities decreased while optimum moisture contents showed no trend with increasing emulsion contents.

<u>T-11</u>. Erosibility of the treated specimens was improved but may, at least in part, be attributed to carbonation, where a weak cementing action could not withstand effects of the loading wheel in the traffic simulation study; it should be noted that these latter specimens did in fact perform rather poorly. A rather obvious improvement was noted in freeze-thaw susceptibility while q_u values dropped slightly. An improvement was observed in the field, as noted by Benkelman Beam and SBV results.

As expected with increasing lime percentages, optimum moisture content increased while the maximum dry density reduced.

T-12. Reduction of Erosibility Index was the result of treatment with lime and flyash, whereas negligible improvement was apparent from the traffic simulation tests. Reasons for the above behavior are probably the same as for T-11. A marked improvement was observed in freeze-thaw results, the 3% lime and 16% flyash data indicating that voids were filling with large amounts of flyash, resulting in impermeable specimens. Increases in q_u and SBV values were noted with SBV showing some effects of curing time. Benkelman Beam deflections and stiffness were improved. Maximum densities were decreased and optimum moisture contents raised by the lime-flyash treatment.

T-13. Nominal erosibility benefits were noted with 1/3 gal./sq yd* $CaCl_2$, with only minor improvements in trafficability obtained at the same treatment level. No major improvement was noted in the freeze-thaw test. SBV and q_u values decreased slightly with treatment. No significant changes were obtained in deflections during Benkelman Beam testing. $CaCl_2$ treatment caused small increases in optimum moisture content and decreases in density.

T-14. As with section T-10 a reduction in EI was noted, but no apparent change was produced in trafficability results. Improvement was obvious during freeze-thaw testing, but q_u definitely decreased with increasing asphalt content. Figure 15 shows a significant reduction in dusting brought about by addition of the emulsion. Benkelman Beam deflections and stiffness were relatively unchanged while SBV values were significantly reduced from pre-construction levels. A decrease in maximum dry densities was indicated while optimum moisture content was increased then decreased with increasing asphalt content - 4%* treatment having the same OMC as the untreated.

T-16. Traffic simulation, freeze-thaw and erosibility tests indicated only minor improvements with treatment. The q_u values decreased with addition of Terra-Seal. Little is known about the mechanism of stabilization of this chemical, but a reduction in surface tension, allowing some improvement in density, is suspected. Maximum dry densities did in fact increase, though coupled with slight increases in optimum moisture content. Benkelman Beam and SBV tests indicated no improvement of the roadway deflection or bearing, although dust measurements indicated a modest improvement prior to seal coating.

T-17. The only evaluation of this test section was on the basis of dust measurements presented in Fig. 15. A marked decrease in dusting was noted.

T-19. Traffic simulation tests indicated best overall performance with untreated specimens. Erosibility was improved with combinations of lignin and lime, and lime only. Based on freeze-thaw tests, lignin plus lime produced very good reductions of elongation. Unconfined compressive strengths were reduced with addition of lignin and/or lime. No optimum treatment was indicated in all tests, though the combination of lignin and lime appears to perform fairly well. SBV and Benkelman Beam results indicated a decreased bearing and no change, respectively. Maximum dry densities decreased, but optimum moisture contents fluctuated with addition of lignin and/or lime.

In general, performance of all field sections, materials, and additives has not been as good, nor as poor in some cases, as initially expected. To date, however, all sections show varying degrees of performance. Completion of all field and lab tests during 1976 should provide data from which reasonably accurate and objective conclusions can be drawn as to benefits, or lack thereof, that were achieved with each additive within the confines of this project.

APPENDIX

Lab mixed, lab molded densities.

Section No.	Additive Content	Optimum Moisture-Density Tests		Traffic Simulator Specimens		Freeze-Thaw, Rainmaker, Unconfined Specimens	
		Dry Density, pcf	M.C. %	Dry Density, pcf	M.C. %	Dry Density, pcf	M.C. %
T-2	untreated	133.8	7.8	127.1	8.0	130.6	7.2
	1 gal./sq yd lignin	132.8	8.3	129.4	8.3	129.6	7.8
	1 1/2 gal./sq yd lignin*	132.5	8.0	127.9	8.6	132.1	7.4
	2 gal./sq yd lignin	133.8	8.0	127.4	8.7	130.3	7.6
T-2A	untreated	133.8	7.8	127.1	8.0	130.6	7.2
	1 gal. sq yd lignin + 20 gal./acre Pramitol	132.3	8.1	126.3	8.8	132.7	7.8
	1 1/2 gal./sq yd lignin* + 20 gal./acre Pramitol*	132.8	8.6	128.5	8.5	133.0	8.0
	1 gal./sq yd lignin + 25 gal./acre Pramitol	133.6	8.0	129.4	8.0	134.1	8.3
T-5	untreated	127.8	7.2	125.6	7.2	127.6	6.4
	1 1/2% NaCl	130.6	7.8	126.8	7.7	129.7	7.6
	2% NaCl*	129.4	8.4	127.0	8.2	128.9	8.2
	3% NaCl	130.6	7.7	127.3	7.1	128.1	7.2
T-6	untreated	128.8	9.3	128.0	9.0	129.8	8.6
	.032% Kelpak	128.8	8.5	127.2	8.4	125.4	7.7
	.024% Kelpak*	129.7	8.8	126.1	9.0	128.4	8.3

Lab mixed, lab molded densities. (continued)

Section No.	Additive Content	Optimum Moisture-Density Tests		Traffic Simulator Specimens		Freeze-Thaw, Rainmaker, Unconfined Specimens	
		Dry Density, pcf	M.C. %	Dry Density, pcf	M.C. %	Dry Density, pcf	M.C. %
	.144% Kelpak	127.7	9.1	125.3	8.8	126.4	8.4
T-8AS	untreated	119.5	12.9			118.0	13.8
	.039% Clapak	119.2	13.4			118.9	13.1
	.026% Claset						
	.011% Clapak*	119.3	12.8			117.7	12.7
	.007% Claset*						
	.083% Clapak	118.2	14.0			118.7	13.6
	.055% Claset						
T-8BS	untreated	127.5	9.5			127.6	9.0
	.031% Clapak	128.6	9.8			127.6	9.7
	.021% Claset						
	.007% Clapak*	127.7	8.8			125.9	8.7
	.005% Claset*						
	.064% Clapak	128.3	10.0			128.8	10.0
	.042% Claset						
T-8AB	untreated	133.4	8.1	131.0	8.4	133.2	7.5
	.004% SA-1	133.1	7.8	128.3	8.2	133.0	7.8
	.004% SA-1*	133.9	8.0	128.6	8.2	133.4	8.0
	.039% SA-1	134.2	8.1	130.0	8.3	133.6	8.1
T-8BB	untreated	116.1	8.6	121.6	8.6	116.6	7.5

Lab mixed, lab molded densities. (continued)

Section No.	Additive Content	Optimum Moisture-Density Tests		Traffic Simulator Specimens		Freeze-Thaw, Rainmaker Unconfined Specimens	
		Dry Density, pcf	M.C. %	Dry Density, pcf	M.C. %	Dry Density, pcf	M.C. %
	.005% SA-1	115.7	9.5	115.4	10.4	116.2	8.4
	.004% SA-1*	118.4	8.7	119.0	8.1	115.6	7.4
	.040% SA-1	117.4	8.4	116.7	7.7	115.4	7.9
T-10	untreated	132.5	7.9	127.1	8.4	131.5	7.7
	3% residual asphalt	128.7	8.2	123.4	8.7	126.1	8.0
	4% residual asphalt*	126.0	8.4	121.9	8.6	121.3	8.0
	5% residual asphalt	123.7	8.0	118.6	9.2	122.2	8.2
T-11	untreated	130.1	9.3	121.3	9.1	127.7	9.5
	2% lime	124.2	10.3	115.7	10.7	121.5	10.5
	4% lime*	121.9	10.5	113.6	11.2	120.2	10.5
	6% lime	119.4	11.6	117.9	10.9	117.8	11.9
T-12	untreated	124.5	11.1	118.0	11.1	124.8	10.6
	5% lime 8% flyash	119.4	12.7	110.2	13.0	117.0	11.6
	4% lime 12% flyash*	118.1	13.1	110.8	13.6	117.2	12.8
	3% lime 16% flyash	118.3	13.0	111.1	13.4	118.9	12.8
T-13	untreated	130.5	8.4	120.9	9.5	128.2	8.6
	1/5 gal./sq yd $CaCl_2$	129.1	9.5	122.1	9.8	129.1	9.3
	1/3 gal./sq yd $CaCl_2$*	129.2	9.9	122.9	11.0	128.9	9.5
	1/2 gal./sq yd $CaCl_2$	129.4	9.2	122.6	9.1	128.4	9.4
T-14	untreated	122.0	12.5	115.9	12.7	121.8	12.9

Lab mixed, lab molded densities. (continued)

Section No.	Additive Content	Optimum Moisture-Density Tests Dry Density, pcf	Optimum Moisture-Density Tests M.C. %	Traffic Simulator Specimens Dry Density, pcf	Traffic Simulator Specimens M.C. %	Freeze-Thaw Rainmaker Unconfined Specimens Dry Density, pcf	Freeze-Thaw Rainmaker Unconfined Specimens M.C. %
	3% residual asphalt	115.9	13.4	109.6	13.1	115.4	14.1
	4% residual asphalt*	115.0	12.5	106.8	13.5	115.4	12.9
	5% residual asphalt	115.2	11.6	106.0	12.0	113.2	12.3
T-16	untreated	128.1	8.8	122.0	8.7	127.6	9.7
	.004% Terra-Seal	129.6	9.2	122.6	9.5	129.4	9.5
	.003% Terra-Seal*	129.1	8.9	120.1	9.0	128.6	9.1
	.017% Terra-Seal	129.4	9.0	124.1	10.9	129.8	9.2
T-19	untreated	112.1	15.8	103.7	14.7	110.9	15.1
	1/2 gal./sq yd lignin + 4% lime	109.2	14.5	101.2	14.8	106.5	13.5
	1 gal./sq yd lignin* + 2% lime*	109.0	16.1	101.1	17.2	108.7	15.4
	6% lime	105.5	18.5	99.1	18.5	106.4	17.5
	1 1/2 gal./sq yd lignin	111.5	15.9			109.0	16.9

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