SOIL STABILIZATION FIELD TRIAL

INTERIM REPORT III

by

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16. Abstract

Shrinkage cracks in cement-stabilized bases/subbase can be alleviated by specifying the right cement dosage, or by other additives/procedures that suppress crack susceptibility. A field trial of six 1000 ft test sections to investigate several alternative techniques was initiated and constructed in August 2000. The following additives/procedures are included for investigation:

- 5.5% cement additive (control section); design based on a reduced strength criteria.
- 5.5% cement precracked while "young".
- 5.5% cement precut (grooved) every 3 m (10 ft).
- 3.5% cement with 8% fly ash.
- Ground granulated blast furnace slag (GGBFS) complemented by 2% lime.
- Three percent lime and 12% fly ash; the current favored stabilization technique of MDOT.

First interim report covering the first phase of investigation/monitoring during the 28-day period was submitted in April 21, 2001. Two layers of asphalt concrete – 11 cm (4.5 inches) base, 6 cm (2.25 inches) polymer modified binder – were placed over the stabilized layer beginning September 21, 2000, followed by the second field monitoring on November 13, 2001. Field tests included deflection tests employing Falling Weight Deflectometer (FWD), retrieval of 10-cm (4-inch) cores for compression tests, and a manual crack survey. The results were presented in Interim Report II. On June 16, 2003, (nominally 3 years) the test sections were monitored; this time again deflection test employing FWD, and a manual crack survey. Prior to the June 2003 survey, a 5 cm (2 inches) polymer modified surface course was placed, with the road opening to traffic on July 8, 2002. Presented in this report are the results of deflection analysis discussing comparative performance of various stabilizing agents or special crack mitigation techniques included in the test program.

Deflection data gathered are analyzed employing MODULUS 5.1 with the pavement sections modeled as a four- layer system, and in a few cases as a three-layer system. Whenever the results were inconclusive, ELMOD software was also employed to substantiate MODULUS outputs.

The backcalculated moduli results show that the moduli of the three cement-treated sections increased from 440 days to 1034 days. The results for two sections – cement-fly ash and lime-GGBFS-are not conclusive; the indications are they remain the same or slightly decreased. No doubt the lime-fly ash suffered loss of stiffness from 440 days to 1034 days. The lime-treated subgrade showed steady increase in modulus from 28 days to 440 days and again from 440 days to 1084 days as well. In the lime-fly ash section, the lime-treated subgrade suffered a loss in modulus relative to those of the cement sections. The subgrade modulus remains unchanged from 440 days, with an average value of 140 MPa. The asphalt concrete modulus, corrected to 22°C (72° F) was reasonably uniform from section 1 to 5, however, decreased significantly for sections 6 and 6 (alternate). With 22 cm (8.75 inches) of asphalt concrete, all of the sections remain crack-free at the time of the survey.

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DISCLAIMER

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CHAPTER 1

INTRODUCTION

1.1 Background

Stabilizing agents, for example, cement, lime, lime-fly ash and others have been successfully used in pavement base/subbase construction. There is concern, however, over possible shrinkage cracking due to drying and/or thermal contraction, especially in high-strength cement-stabilized soil. Recent studies suggest that crack-related degradation can be abated by adopting materials and/or methods that bring about a “desirable” crack pattern, “desirable” being defined as numerous fine cracks at close spacing, which ensures adequate load transfer across the cracks. It is not so much the number of cracks but the width of these cracks that has a significant influence on the long-term performance of the pavement since wider cracks have the tendency to reflect through the overlying pavement. Limiting/controlling drying shrinkage can effect the development of this “desirable” crack pattern in a stabilized layer. Several alternatives are available to control the drying shrinkage. These include: judiciously selecting the cement dosage, selecting a soil for stabilization having limited fines content and plasticity, and the use of a fly ash additive in conjunction with Portland cement, all of which promote development of a “desirable” crack pattern in a stabilized layer.

Controlling shrinkage cracking is another method to alleviate the detrimental affects of this cracking to pavement performance. This control can be effected by “precutting” to induce a weak plane in the stabilized layer or “precracking” at an early age (before 48 hours after construction) by several passes of a vibratory roller with 100% coverage.

1.2 Scope/Objective of the Study

Seeking for materials and methods to alleviate cracking in cement-treated soil, six field sections were constructed in August 17 and 18, 2000 incorporating the following material combinations or methods each in a separate but contiguous test section of 305m (1000 feet) long: cement, precracked cement layer, precut cement layer, cement-fly ash, lime-ground granulated blast furnace slag (GGBFS), and lime-fly ash (LFA).

1.3 Scope of this Interim Report

First interim report covering the first phase of investigation/monitoring during the 28-day period was submitted in April 21, 2001 (1). Two layers of asphalt concrete – 11cm (4.5 inches) base, 6cm (2.25 inches) polymer modified binder – were placed over the stabilized layer beginning September 21, 2000, followed by the second field monitoring on November 13, 2001. Field tests include deflection tests employing Falling Weight Deflectometer (FWD), retrieval of 10-cm (4-inch) cores for compression tests, and a manual crack survey. The results were presented in Interim Report II, which included a discussion as to possible changes (strength- and stiffness-gain, and crack reflection) over a fourteen-month period, since September 15, 2001 when the first monitoring was completed. On June 16, 2003, (nominally 3 years) the test sections were monitored; this time again deflection tests employing FWD, and a manual crack survey. Prior to the June 2003 survey, a 5 cm (2 inches) polymer modified surface course was placed, with the road opening to traffic on July 8, 2002. Presented in this report are the results of deflection analysis discussing comparative performance of various stabilizing agents or special crack mitigation techniques included in the test program.

Chapter 2

FIELD TEST RESULTS

2.1 Project Description

Six test sections were included in the westbound lane of Highway #302 in Marshall County, Mississippi. Each test section was 305 m (1000 ft) long and 8.5 m (28 ft) wide, though only the traffic lane 4.25 m (14 feet wide) was tested. A typical cross-section of the test pavement is presented in Figure 2.1, where 915 m (5000 ft) LFA base was replaced by five other stabilized layers, 305 m (1000 ft) each. With MDOT standard LFA base 305 m (1000 ft) at the east end included in the test program for comparison purposes, the field trial comprises the following six additives/procedures:

- 190+00 to 195+00: cement 5.5%, cement control – Section 1A
- 195+00 to 200+00: cement 5.5%, precut – Section 1B
- 200+00 to 210+00: cement 5.5%, precracked – Section 2
- 210+00 to 215+00: cement 5.5%, cement control - Section 3A
- 215+00 to 220+00: cement 5.5%, precut – Section 3B
- 220+00 to 230+00: cement 3.5% and fly ash 8% - Section 4
- 230+00 to 240+00: lime 2% and GGBFS 6% - Section 5
- 245+00 to 250+00: lime 3% and fly ash 12%, MDOT Standard – Section 6
- 250+00 to 255+00: lime 3% and fly ash 12% with 10-cm (4-inch) drainage layer – Section 6 (alternate)

In order to eliminate unforeseen variations while transitioning from one section to another, each end of a test section – 31 m (100 feet) in 305 m (1000 feet) long sections and 15 m

(50 feet) in 152 m (500 feet) sections – is not monitored leaving three 244 m (800-feet) test sections and six 122 m (400 feet) sections.

2.2 Field Evaluation Tests

2.2.1 Falling Weight Deflectometer Study

Assisted by MDOT Research Division, deflection measurements were conducted on the asphalt layer at every 31 m (100 feet) along each test section, thus gathering nine deflection test data in each 1000-feet section and five in each 500-feet section. The following test set-up was used: three seating drops followed by 40-kN (9000 lbs) and 76 kN (17000 lbs) load drops at each test location. For brevity, FWD deflection data will not be included in this report; however, the backcalculated modulus of each test section is reported and discussed in chapter 3.

2.2.2 Crack Mapping

Following the classification adopted in the first interim report (fine, low, medium, high severities) (1), a crack survey was conducted. The asphalt surface was completely crack-free, as expected.

Chapter 3

RESULTS AND DISCUSSION

3.1 Introduction

The purpose of the three-year investigation is to discern whether the stabilized layer has improved in stiffness as a result of continued pozzolonic reaction producing cementitious compounds. This investigation is particularly relevant as the early studies suggested slight degradation of stabilized layer from 7 to 28 days. The severe hot temperature that existed during and after construction could have caused this temporary setback in the strength gain. From 28 days to 440 days, however, all six stabilized bases improved so far as modulus is concerned. The issue addressed here is whether the stabilized layers continue to gain stiffness after the road is open to traffic on 5/6/2002.

3.2 Modulus of Stabilized Layer

Employing the deflection bowl obtained from FWD tests, moduli of the layers are backfigured. Backcalculation program MODULUS 5.1 is utilized, with the pavement modeled as a four layer system: 22 cm (8.75 inches) asphalt concrete, 15 cm (6 inches) of stabilized layer, 15 cm (6 inches) of lime-treated subgrade and the underlying subgrade. Whenever the results were inconclusive a three-layer analysis (with stabilized base and lime-treated subgrade clubbed together) was conducted to substantiate the four-layer analysis. Section #6 alternate of the LFA Section (Station 250+00 to 255+00) included a 10-cm (4-inch) drainage layer as well where, by necessity, the stabilized layer and the lime-treated subgrade were combined to form a 30-cm (12-inch) layer. Combining those two layers could be justified in view of close modulus values of LFA and lime-treated material.

The moduli results of 1034-day deflection studies are compared with those of the 440-day and 28-day FWD tests (see Tables 3.1 through 3.7). The modulus of the asphalt layer is corrected to 22°C (72°F) temperature, in accordance with BELLS3 method described in reference 3. In computing the average for each test section, outliers are detected by Chauvenet's criterion.

A brief discussion of the modulus of the stabilized layers is presented in two parts: first, how much increase is observed from 440-day to 1034-day, and second, a comparison of the four experimental sections with the cement control section followed by another comparison of LFA base again with cement control section.

Section #1A and #3A (cement control). In this section the 1034-day modulus of stabilized layer had increased by 10% from 440-day modulus, whereas the 28-day to 440-day increase was 47% (Table 3.1). Clearly the strength gain of the stabilized layer slowed down from 440 days to 1034 days. The modulus of the treated subgrade increased steadily (600 MPa to 1484 MPa), however (Figure 3.1). The same trend i.e. slightly more than two-fold increase in modulus of lime-treated subgrade is observed in other cement-treated sections as well, especially in precut and precracked sections.

Section #1B and # 3B (Precut). Modulus after 1034 days is 53% larger compared to that of 440-days (Table 3.2 and Figure 3.2). Initially due to the precuts the 440-day and 28–day modulus lagged behind that of the control section, however, at 1034 days the modulus is 20% larger than that of the control section.

Section #2 (precracked). The stabilized layer modulus at 1034 days is 13 % larger than the 440-day modulus (Table 3.3). It is observed that the cement stabilized layer gained its stiffness at a faster rate from 28 days to 440 days (57%), when compared to the gain from 440 days to 1034 days (13 %) (Figure 3.3). The 1034-day modulus of 2456 MPa is comparable to that of the control section, however.

Section #4 (cement-fly ash). The deflections in this section are relatively larger than in the previous sections. Both 9000-lb and 17000-lb load deflections are analyzed in MODULUS 5.1 backcalculation routine, but both analyses resulted in a very low modulus value (606 MPa) for the stabilized base, a 60% decrease from the 440-day moduli (Table 3.4). Not convinced by the modulus trend, ELMOD program is employed to analyze the deflection basins. Using deflection basin fit method the layer modulus values are obtained. Except for the subgrade, whose modulus, for unknown reasons decreased, the moduli of the top 3 layers are considered acceptable (see Table 3.4.a).

A question now arises as to why ELMOD solution is preferred over the MODULUS solution. First, the MODULUS routine results in E_3 value nearly four-fold compared to the 440-day modulus, which does not agree with the trend in other sections. Specifically, in the first three sections E_3 had more than doubled during the same period. Note that ELMOD, however, resulted in a two-fold increase from 440-day to 1034–day (510 MPa vs. 1083 MPa) which is consistent with other sections (Table 3.4.a). Second, MODULUS analysis resulted in E_2 modulus value only a third of that of the lime-treated subgrade, whereas ELMOD resulted in modulus at least equal to that of the treated subgrade, which is believed to be more reasonable. Variation of E2, E3 and E4 with time is plotted in Figure 3.4.

Section #5 (lime-GGBFS). It is noted that the lime-GGBFS modulus has decreased from 440 days to 1034 days, whereas the lime-treated subgrade showed an increase as expected, a 120% over the 440-day modulus (Figure 3.5). The trend in E_2 and E_3 of sections 4 and 5 are similar in that the stabilized bases in both sections decreased accompanied by a two-fold increase in E_3 values. It could be that with each layer (E_2 and E_3) showing comparable values, the ability of backcalculation routine to distinguish those layers is being stretched. With this in mind a three-layer analysis was conducted, where lime-GGBFS layer and lime-treated layer are combined together. It is observed that the composite modulus is 1960 MPa (Table 3.5.a). As both base and subbase moduli could not be estimated precisely, tentatively each layer is assigned a stiffness value of 1960 MPa.

Section #6 (lime-fly ash). Unexpected to say the least, the modulus of lime-fly ash had decreased from 380 MPa to 300 MPa in the interval 440-day to 1034-day (Table 3.6). No doubt, the deflections in this section are unusually large relative to those in other sections. Both 9000-lb load and 17000-lb load deflections are used in MODULUS, but none of the runs resulted in acceptable values. Apart from a four-layer analysis, a three-layer analysis is also performed as three-layer analysis is reported to be more reliable. The three-layer analysis confirmed that the composite modulus is low, as well (Table 3.6.a). ELMOD program is now employed, but this program also did not produce acceptable values, though it showed a very slight increase in lime-fly ash modulus value. From Figure 3.6 it is observed that from 28-day to 440-day the modulus of lime-fly ash increased and the modulus of lime-treated subgrade decreased, but from 440-day to 1034-day the modulus of lime-fly ash decreased and correspondingly modulus of lime-treated subgrade increased. Such moduli shift between adjacent layers is referred to as “compensating error”. It simply means that the backcalculated moduli of adjacent layers may, depending on sensor deflections, adjust each other; that is, if one modulus decreases, the modulus of adjacent layer shows corresponding increase. That the upper layer seemingly showing lesser stiffness than the underlying layer could bring in another problem, referred to as “inverted layer” effect. The outcome of four-layer analysis with both MODULUS and ELMOD, suggests that lime-fly ash layer is less stiff than lime treated subgrade. That a three-layer analysis (with lime-fly ash combined with lime treated subgrade) gives a composite modulus closer to E_2 seems to confirm that the base layer is less stiff than the lime-treated subgrade layer.

Section #6 (alternate). The presence of drainage layer necessitated, a four-layer analysis, with asphalt layer, drainage layer, combined lime-fly ash and lime treated subgrade, and subgrade layer. While comparing the 440-day modulus and 1034-day modulus, it is observed that the modulus of the composite layer decreased from 450 Mpa to 381 Mpa (Table 3.7). The results of this analysis is suspect because with the drainage layer above the base layer, the section is inverted, and therefore, back figured modulus values using MODULUS should be viewed with caution. The finding that the composite modulus had slightly decreased suggests degradation of one or both layers, needing more investigation to resolve the issue. The planned core strength evaluation during the fifth year investigation of the stabilized layers would help to assess the status of the lime-fly ash base.

A comparison of the composite modulus (lime-fly ash and lime-treated subgrade) between section 6 and section 6 (alternate) is presented in Table 3.8. Whether the drainage layer has any effect on material performance is sought here by comparing moduli of both sections. It is observed that the composite modulus of 6 (alternate) and that of 6 are statistically not different, which only suggests that the drainage layer at the top of the base has practically no effect. Improved drainage, however, may result in better pavement performance in the long run.

3.3 Lime-Treated Subgrade

Investigating the modulus of lime-treated subgrade from section 1 through section 6, two graphs are plotted with station-wise modulus (Figure 3.7), and section- wise modulus (Figure 8). In view of the same lime-treated subgrade in all of the sections, the variation observed from beginning to the end of the test road, is substantial, as per the 1034-day results (Figure 3.8). For example, the modulus of lime-treated subbase remained nearly constant for sections 1, 2 and 3, it decreased in sections 6 and 6 (alternate), however, it increased in section 5. Why the moduli values of section 6 and 6 (alternate) decreased drastically needs further investigation, for example, retrieving samples and testing. There is one trend though, that variation from the norm in the lime stabilized subgrade—both low and high values—is observed in sections where the stabilized base material showed degradation from 440-day to 1034-day. It could be that the backcalculation of sections 5, 6 and 6 (alternate) could have been affected by the inherent difficulties encountered with "compensating effect" of adjacent layers, and also the anomalies associated with an "inverted" pavement configuration.

3.4 Asphalt Concrete Surface

Making use of the backcalculation results, the spatial variation of the asphalt concrete (AC) modulus is also investigated. Though the moduli of AC and subgrade are obtained from four-layer analysis, the results obtained from three-layer analysis are preferred, as the latter is likely to give more reliable results than the former. As can be verified in Figure 3.9, AC modulus remains practically constant from section 1 through section 5, with substantial reduction in sections 6 and 6 (alternate). This decreasing tendency in the modulus can be attributed to the increased deflections/strains and accompanying nonlinear behavior of AC. On average a 70% increase in strain is observed from control section to lime-fly ash section for a typical FWD load of 17,000 lbs., owing primarily to decreased base support. This result is born out by comparing the AC modulus under 17000-lb load with 9000-lb load, where the lighter load (9000 lbs) resulted in only a minor change from section 1 to section 5, with the exception of sections 6 and 6 (alternate).

3.5 Subgrade

Figure 3.10 depicts the spatial variation of subgrade modulus. Discounting for one outlier, namely the subgrade modulus of section 4, the variability from section 1 to section 6 (alternate) is statistically not significant. An average value of subgrade modulus would be135 MPa (20,000 psi).

Chapter 4

SUMMARY AND CONCLUSIONS

Seeking for materials and methods to alleviate shrinkage cracking in cement-treated soil, seven test sections were constructed in August 2000. Extensive laboratory tests and field investigations were conducted during and after construction (for a period of 28 days) with the results reported in the second interim report dated April 21, 2001. After emplacement of 17cm (6.75 inches) of asphalt concrete beginning September 21, 2000, the sections, still not opened to traffic, were monitored on November 14, 2001. The third inspection and tests took place on June 16, 2003, which included deflection tests employing Falling Weight Deflectometer, and a crack survey.

The backcalculated results show that the moduli of the three cement-treated sections increased from 440 days to 1034 days. The results for two sections—cement-fly ash and lime-GGBFS- are not conclusive; the indications are they remain the same or slightly decreased. No doubt the lime-fly ash suffered loss of stiffness from 440 days to 1034 days. The lime-treated subgrade showed steady increase in modulus from 28 days to 440 days and again from 440 days to 1084 days as well (Figure 3.8). With the lime-fly ash base, the lime-treated subgrade underneath it also suffered a loss in modulus relative to those of the cement sections. The subgrade modulus remains unchanged from 440 days, with an average value of 140 MPa (Figure 3.10).

The asphalt concrete modulus, corrected to 22^{o} C (72^{o} F) was reasonably uniform from section 1 to 5, however, decreased significantly for sections 6 and 6 (alternate). With 22 cm (8.75 inches) of asphalt concrete, all of the sections remain crack free at the time of the survey.

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Table 3.1 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Cement control section

Section	Station	1034 - day Modulus, MPa[a]				440 - day Modulus, MPa				28 - day Modulus, MPa			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
	190+50	11533	1393[c]	4807[b]	159	6760	4780	890	160	—	2540	210	80
	191+50	9500	3517	1724	138	8540	2320	660	140	—	1380	260	90
1-A	192+50	9769	3138	1738	145	6590	2110	750	250[b]	—	190[d]	730[d]	120[b]
	193+50	10576	1379	1655	131	7090	2300	490	110	—	1450	1310[b]	90
	194+50	11587[b]	1117[c]	786[b]	97[b]	9970	850	390	100	—	810[c]	380[c]	80[c]
	210+50	8080[b]	2524[c]	814	159	10520	2940	440	180	—	1160	200	80
	211+50	8973	1159	676	159	7500	1680	570	180	—	980	230	90
3-A	212+50	10522	4807	1586	166	7900	2460	1030[b]	210	—	3270	100	70
	213+50	10920	4848	2034	131	15310[b]	4730	650	150	—	2570	740	80
	214+50	9252	2034	1641	145	12110	2960	550	160	—	1430	520	100
	Average	10131	2983	1484	148	8550	2710	600	150		1850	320	90

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[c] Not considered in the average calculation because of unsatisfactory deflection bowl
E1 Modulus of asphalt concrete
E2 Modulus of cement-treated soil (control section)
E3 Modulus of lime-treated subgrade
E4 Modulus of subgrade

Table 3.2 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Precut cement section

Section	Station	1034 - day Modulus, MPa[a]				440 - day Modulus, MPa				28 - day Modulus, MPa			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
1-B	195+50	10092	1924	793[c]	90	13250	1150	470	90	—	940	770	90
	196+50	11081	2979	1759	124	6990	3010	710	140	—	1340	890	130
	197+50	11415	4269	1331	97	7950	2070	380	120	—	2670	520	110
	198+50	12921	4366	1828	124	12990	2240	480	120	—	1660	170	160
	199+50	9629	3745[c]	1552[c]	117	10640	2210	420	100	—	600[c]	210[c]	160[c]
3-B	215+50	11275	1090[c]	2255[c]	131	7700	1810	840	140	—	1500	440	110
	217+50	11318	710[c]	1697	103	8720	2810	360	170	—	3430[b]	610	140
	218+50	9059	4428	1841	131	9830	3440	760	170	—	1060	320	110
	219+50	10242	2600	2559[b]	166	9420	9580[b]	210[b]	200	—	1520	190	140
	Average	10781	3428	1691	120	9560	2240	530	140		1470	540	120

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[c] Not considered in the average calculation because of unsatisfactory deflection bowl
E1 Modulus of asphalt concrete
E2 Modulus of precut cement-treated soil
E3 Modulus of lime-treated subgrade
E4 Modulus of subgrade

Table 3.3 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Precracked cement section

Section	Station	1034 - day Modulus, MPa[a]				440 - day Modulus, MPa				28 - day Modulus, MPa			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
2	201+00	11103	3752	1579	138	8580	2660	870	140	—	710[d]	1430[d]	140
	203+00	11662	4441	2517	200[b]	12940	2990	450	150	—	2160	460	170
	204+00	10974	3897	1807	131	13070	2540	620	150	—	290[d]	1870[d]	80
	205+00	8693	1738	1414	117	8930	3010	860	110	—	720[d]	940[d]	80
	206+00	9833	1097	641	131	6930	1250	560	130	—	480[d]	1800[d]	90
	208+00	8069	1503	1034	110	8730	1240	490	140	—	990	590	90
	209+00	8435	766	338[b]	131	8050	1060	480	120	—	1950	320	70
	Average	9824	2456	1499	126	9280	2170	640	140		1380	410	100

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[c] Not considered in the average calculation because of unsatisfactory deflection bowl
E1 Modulus of asphalt concrete
E2 Modulus of precracked cement-treated soil
E3 Modulus of lime-treated subgrade
E4 Modulus of subgrade

Table 3.4 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Cement-fly ash section

Section	Station	1034 - day Modulus, MPa[a]				440 - day Modulus, MPa				28 - day Modulus, MPa			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
	222+00	7097	586[c]	3621[c]	124	6310	1450	630	140	—	434[d]	2180[d]	80
	223+00	7717	462	1200	117	8190	1450	280	140	—	330[d]	2110[d]	80
	224+00	6779	2490[b]	1517	152	7560	1510	1360[b]	150	—	2760	170	70
4	225+00	6807	731	2697	159	5230	1540	540	150	—	920[c]	280[c]	90[c]
	226+00	7510	441	1310	159	5260	1690	290	170	—	480[c]	140[c]	100[c]
	227+00	5848	559	1386	159	4950	1460	570	150	—	810[c]	250[c]	100[c]
	228+00	6503	834	1434[c]	159	6960	360[d]	1140[d]	180	—	830[c]	250[c]	100[c]
	229+00	5669	428[c]	4945	159	6560	1580	660	160	—	2340	510[b]	130[b]
	Average	6741	606	2176	148	6380	1530	510	155		2380	215	70

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[c] Not considered in the average calculation because of unsatisfactory deflection bowl
E1 Modulus of asphalt concrete
E2 Modulus of cement-fly ash section
E3 Modulus of lime-treated subgrade
E4 Modulus of subgrade

Table 3.4.a Backcalculated moduli from 1034-day FWD deflection tests using ELMOD. Cement-fly ash section

Section	E1 (av), MPa[a]	E2 (av), MPa	E3 (av), MPa	E4 (av), MPa
4	5993	1014	1083	90

Table 3.5 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Lime-GGBFS section

Section	Station	1034 - day Modulus, MPa[a]				440 - day Modulus, MPa				28 - day Modulus, MPa			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
5	231+00	12017	1883	3159	164	6860	2270	1340	130	—	6900	200	100
	232+00	8607	779	2832	166	5170	2800	1300	130	—	4530[c]	40[c]	110[c]
	233+00	9037	2007	3628	140	8360	2780	1430	160	—	9960[b]	840[b]	90
	234+00	10597	917[c]	6993[c]	149	6890	2840	1330	130	—	1070	550	80
	235+00	9478	1228	1090	179	8630	1640	800	160	—	1900	210	70
	236+00	9285	2145	1579	159	7570	1800	470	170	—	1960	470	110
	237+00	10393	1028[c]	455[c]	159	10110	1040	310	130	—	1010[c]	130[c]	90[c]
	238+00	10866	855	566	172	12140	2080	760	180	—	1350	270	120
	239+00	11038	1448	1352	138	8980	4100[b]	470	150	—	3760[c]	100[c]	130[c]
	Average	10147	1478	2029	158	8300	2160	910	150		2640	340	100

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[c] Not considered in the average calculation because of unsatisfactory deflection bowl
E1 Modulus of asphalt concrete
E2 Modulus of lime-GGBFS soil
E3 Modulus of lime-treated subgrade
E4 Modulus of subgrade

Table 3.5.a Backcalculated moduli from 1034-day FWD deflection tests. Lime-GGBFS section. Three-layer analysis

Section	Station	1034 - day Modulus, MPa[a]		
		E1	Composite[f]	E4
5	231+00	11114	2672	172
	232+00	7628	1469	172
	233+00	8386	2934	145
	234+00	8381	2634	166
	235+00	8865	1517	138
	236+00	9468	1769	159
	237+00	11071	648	152
	238+00	9371	1310	145
	239+00	11350	1372	138
	Average	9515	1960	154

[a]1 MPa = 0.145 ksi
[f]Composite modulus of lime-GGBFS and lime-treated subgrade
E1 Modulus of asphalt concrete
E4 Modulus of subgrade

Table 3.6 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Lime-fly ash section without drainage layer

Section	Station	1034 - day Modulus, MPa[a]				440 - day Modulus, MPa				28 - day Modulus, MPa			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
	246+00	6606	138	676	145	5790	350	180	130	—	220	400	140
	247+00	6918	179	641	138	5700	420	210	140	—	370	270	120
6	248+00	6153[c]	103[c]	276[c]	97	4360[b]	350	230	80[b]	—	220	740	70
	249+00	6681	290	883	124	5340	400	340[b]	160	—	260	5240[b]	100
	249+50	6530	593	483[b]	124	5380	720[b]	220	160	—			
	Average	6684	300	733	126	5550	380	210	150		270	470	110

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[c] Not considered in the average calculation because of unsatisfactory deflection bowl
E1 Modulus of asphalt concrete
E2 Modulus of lime-fly ash soil
E3 Modulus of lime-treated subgrade
E4 Modulus of subgrade

Table 3.6.a. Backcalculated moduli from 1034-day FWD deflection tests. Lime-fly ash section without drainage layer. Three-layer analysis

Section	Station	1034 - day Modulus, MPa[a]		
		E1	Composite[f]	E4
6	246+00	6089	476	152
	247+00	6444	531	145
	248+00	5853	248	97
	249+00	5379	1379[c]	131
	249+50	5417	1693[c]	131
	Average	5837	418	131

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[f] Composite modulus of lime-fly ash and lime-treated subgrade
E1 Modulus of asphalt concrete
E4 Modulus of subgrade

Table 3.7 Comparison of backcalculated moduli from 28-day, 440-day and 1034-day FWD deflection tests. Lime-fly ash section with drainage layer. LFA and lime-treated subgrade combined

Section	Station	1034-day Modulus, MPa[a]				440-day Modulus, MPa				28-day Modulus, MPa			
		E1	Drainage layer[e]	Composite[f]	E4	E1	Drainage layer[e]	Composite[f]	E4	E1	E2	E3	E4
6 (alternate)	25100	7735	221	524	110	6790	160	540	120	—	—	—	—
	25200	7434	228	269	103	6430	130	410	90	—	—	—	—
	25300	7047	600[b]	234	110	8420	160	270	70	—	—	—	—
	25400	7714	166	497	166	8030	170	590	150	—	—	—	—
	Average	7483	205	381	122	7420	160	450	110				

[a] 1 MPa = 0.145 ksi
[b] Outlier tested according to Chauvenet's criterion
[e] Modulus of drainage layer
[f] Composite modulus of lime-fly ash and lime-treated subgrade
E1 Modulus of asphalt concrete
E4 Modulus of Subgrade

Table 3.8 Composite modulus comparison between sections 6 and 6 (alternate)

Section	Station	Composite Modulus[f], MPa[a]
6	246+00	476
	247+00	531
	248+00	248
	249+00	1379[b]
	249+50	1693[b]
	Average	418
6 (alternate)	251+00	524
	252+00	269
	253+00	234
	254+00	497
	Average	381

[a] 1 MPa = 0.145 ksi
[f] Composite modulus of lime-fly ash and lime-treated subgrade
[b] Outlier tested according to Chauvenet's criterion

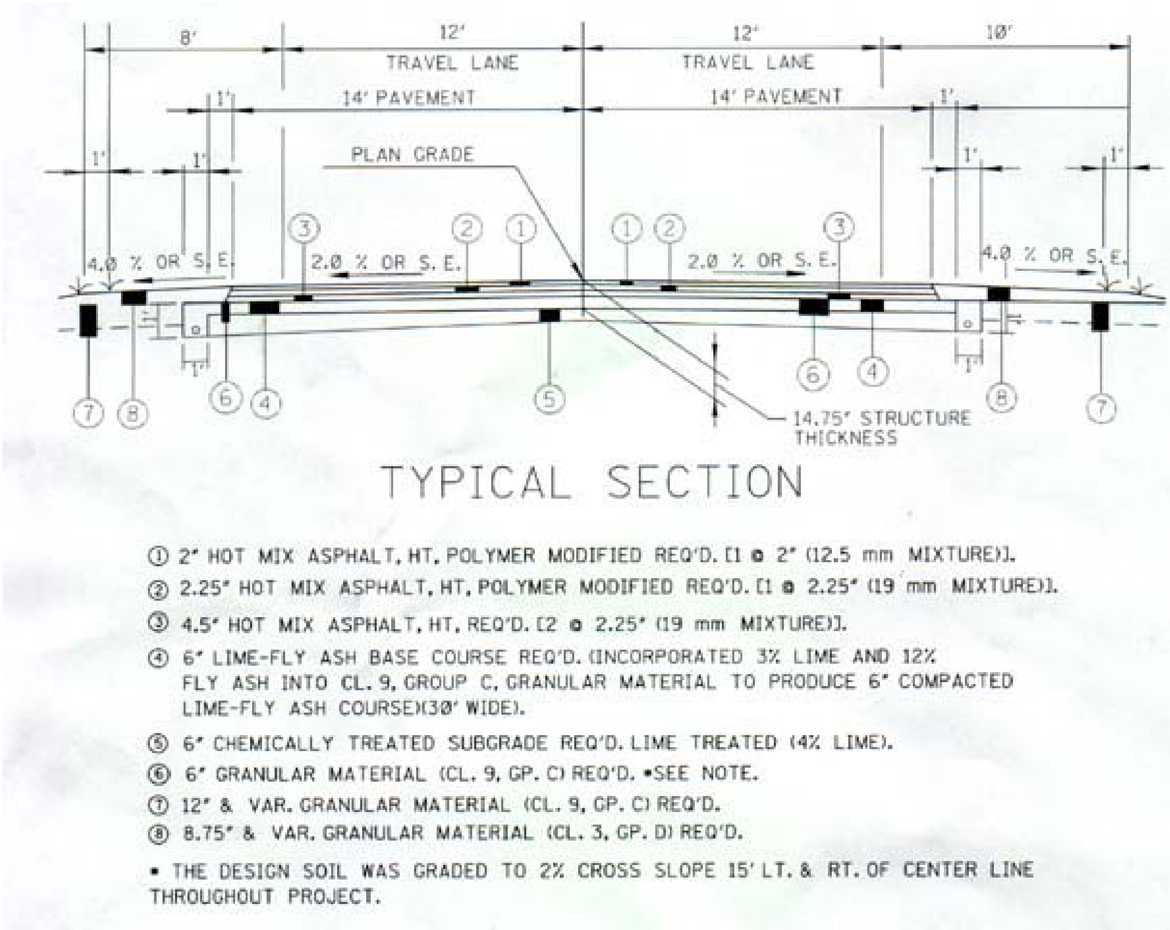

Figure 2.1 Typical test section x-section, Mississippi Highway #302, Marshall County

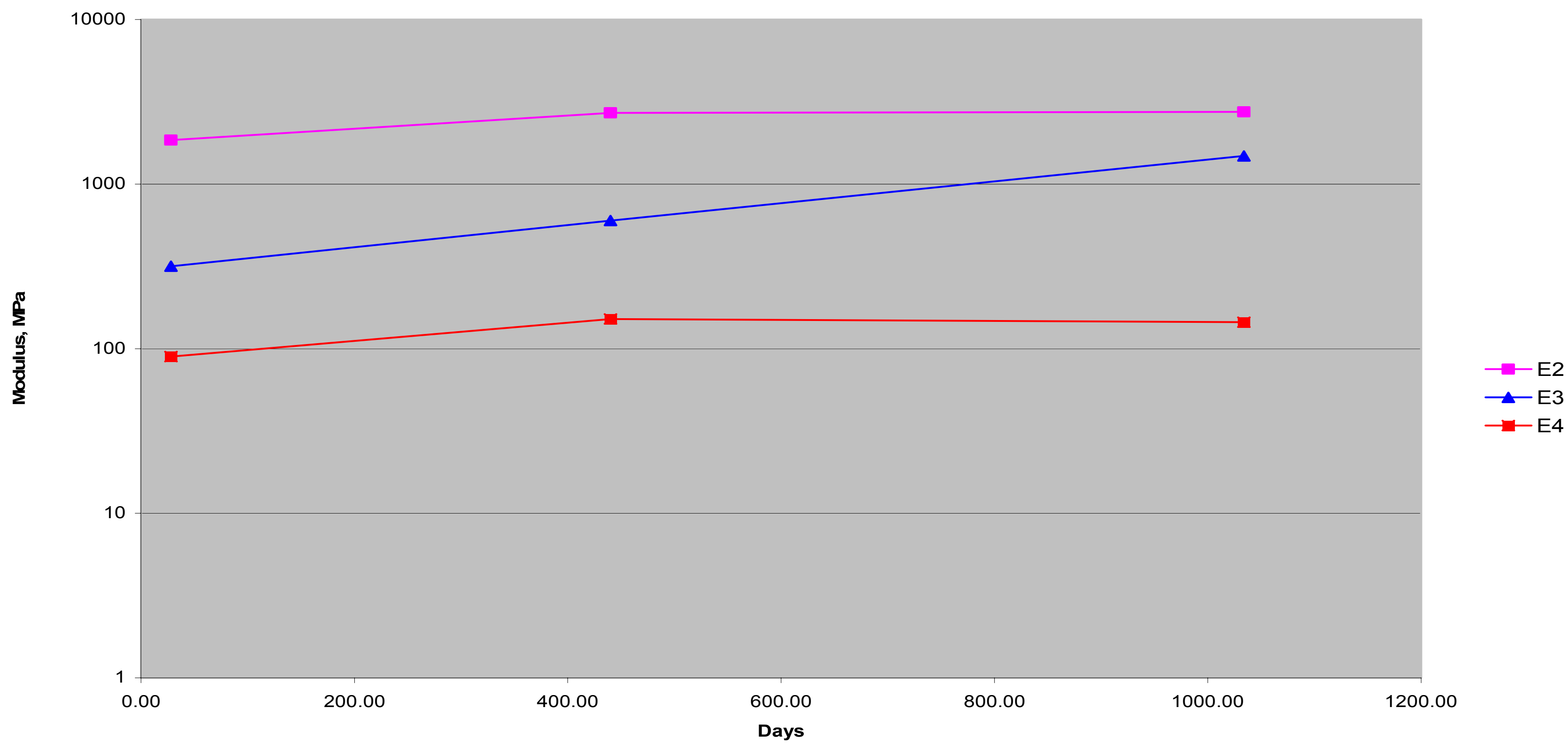

Figure 3.1 Modulus (backcalculated) increase with time of the control section. E_2 = Modulus of cement stabilized layer, E_3 = Modulus of lime-treated subgrade, E_4 = Modulus of subgrade

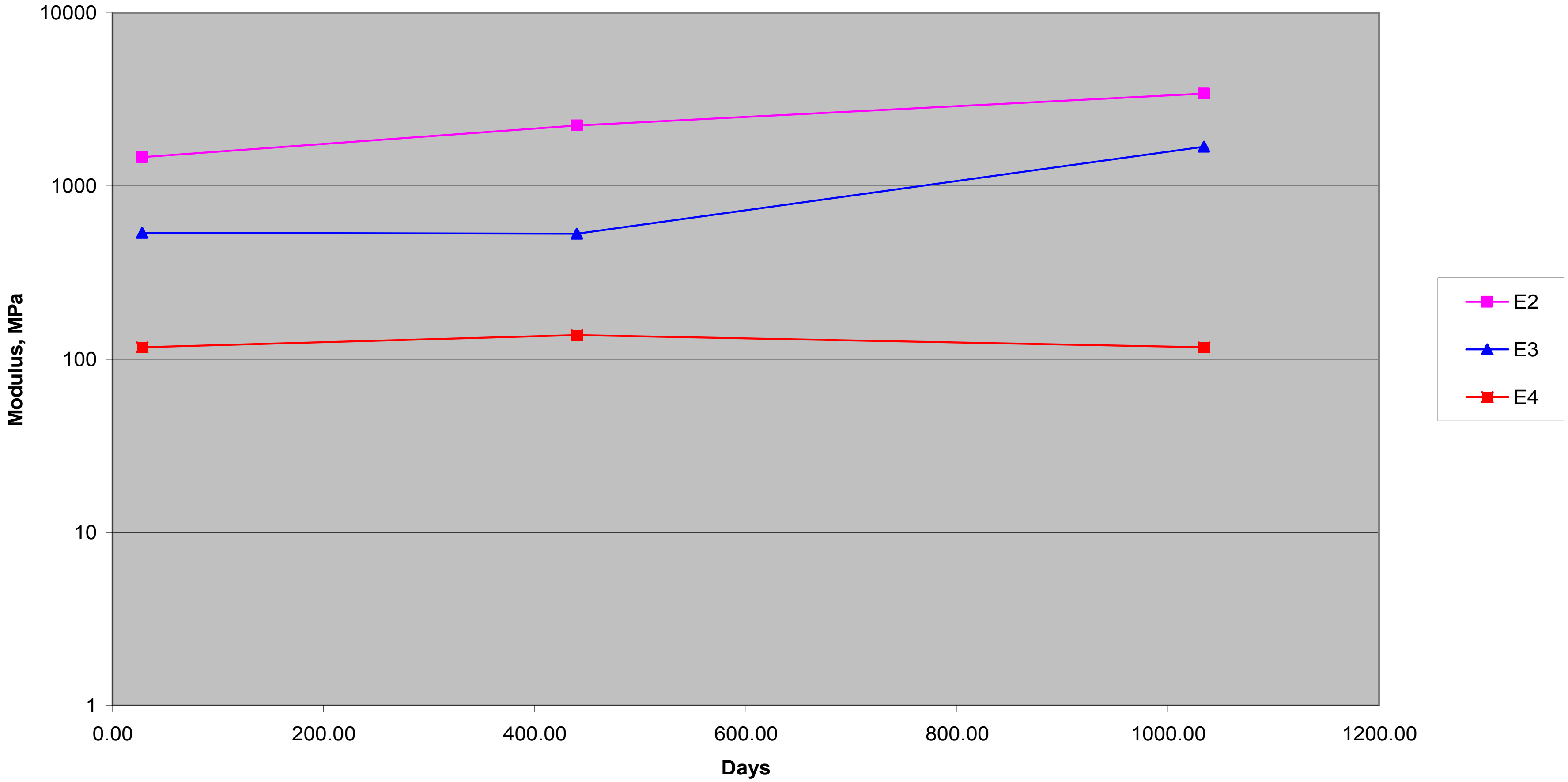

Figure 3.2 Modulus (backcalculated) increase with time of the precut section. E_2 = Modulus of cement stabilized layer, E_3 = Modulus of lime-treated subgrade, E_4 = Modulus of subgrade

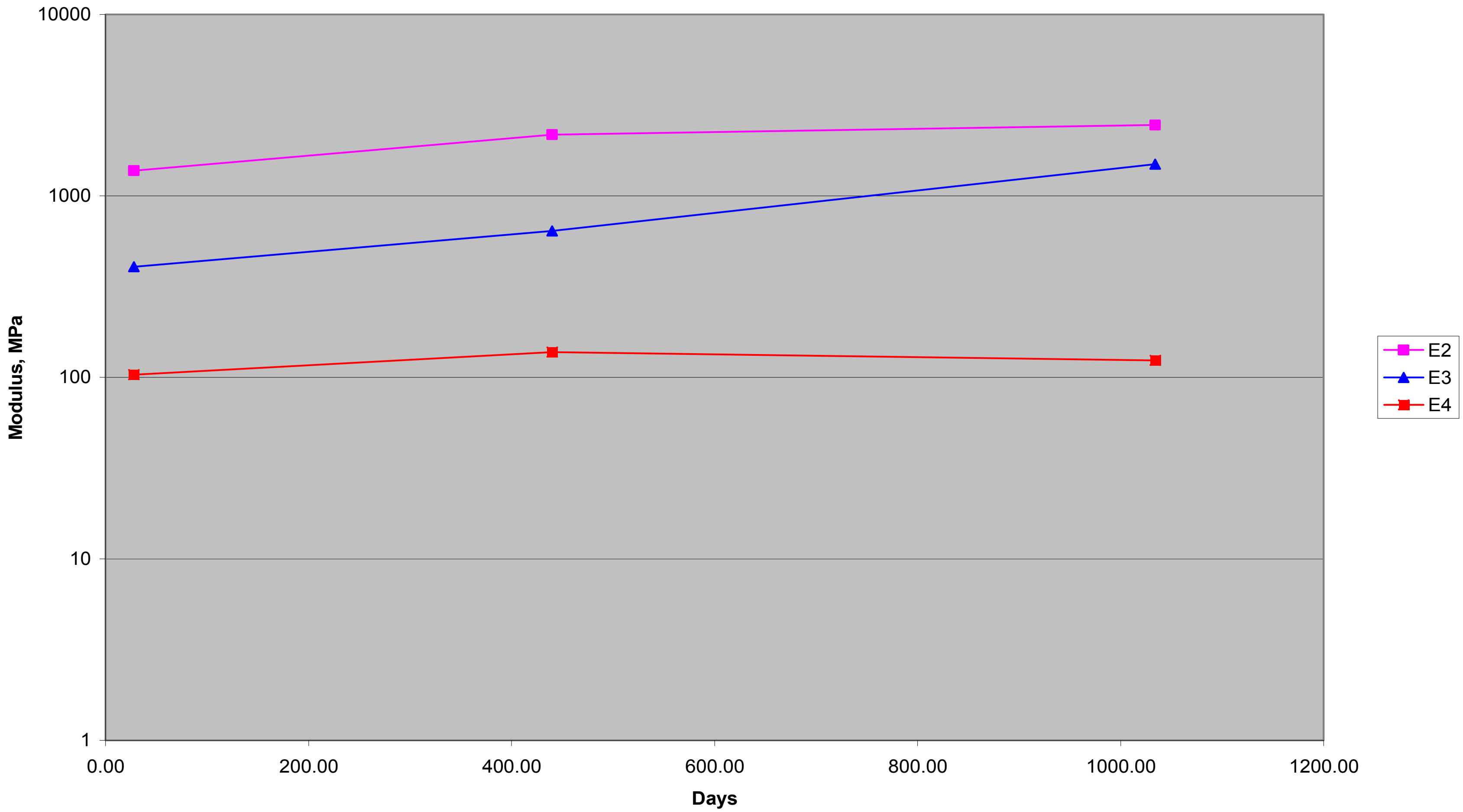

Figure 3.3 Modulus (backcalculated) increase with time of the precracked section. E_2 = Modulus of cement stabilized layer, E_3 = Modulus of lime-treated subgrade, E_4 = Modulus of subgrade

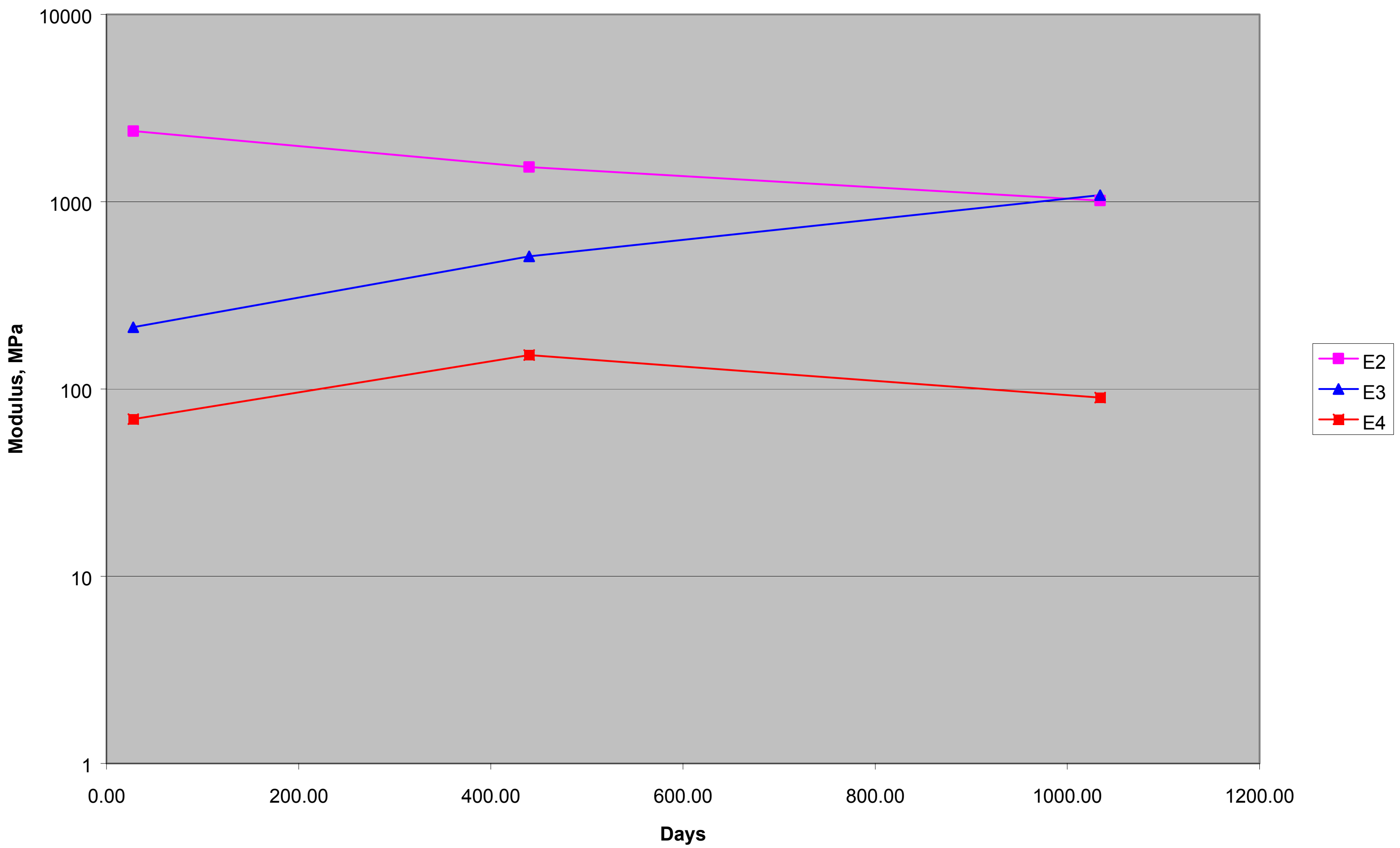

Figure 3.4 Modulus (backcalculated) increase with time of the cement-fly ash section. E_2 = Modulus of cement-fly ash soil, E_3 = Modulus of lime-treated subgrade, E_4 = Modulus of subgrade

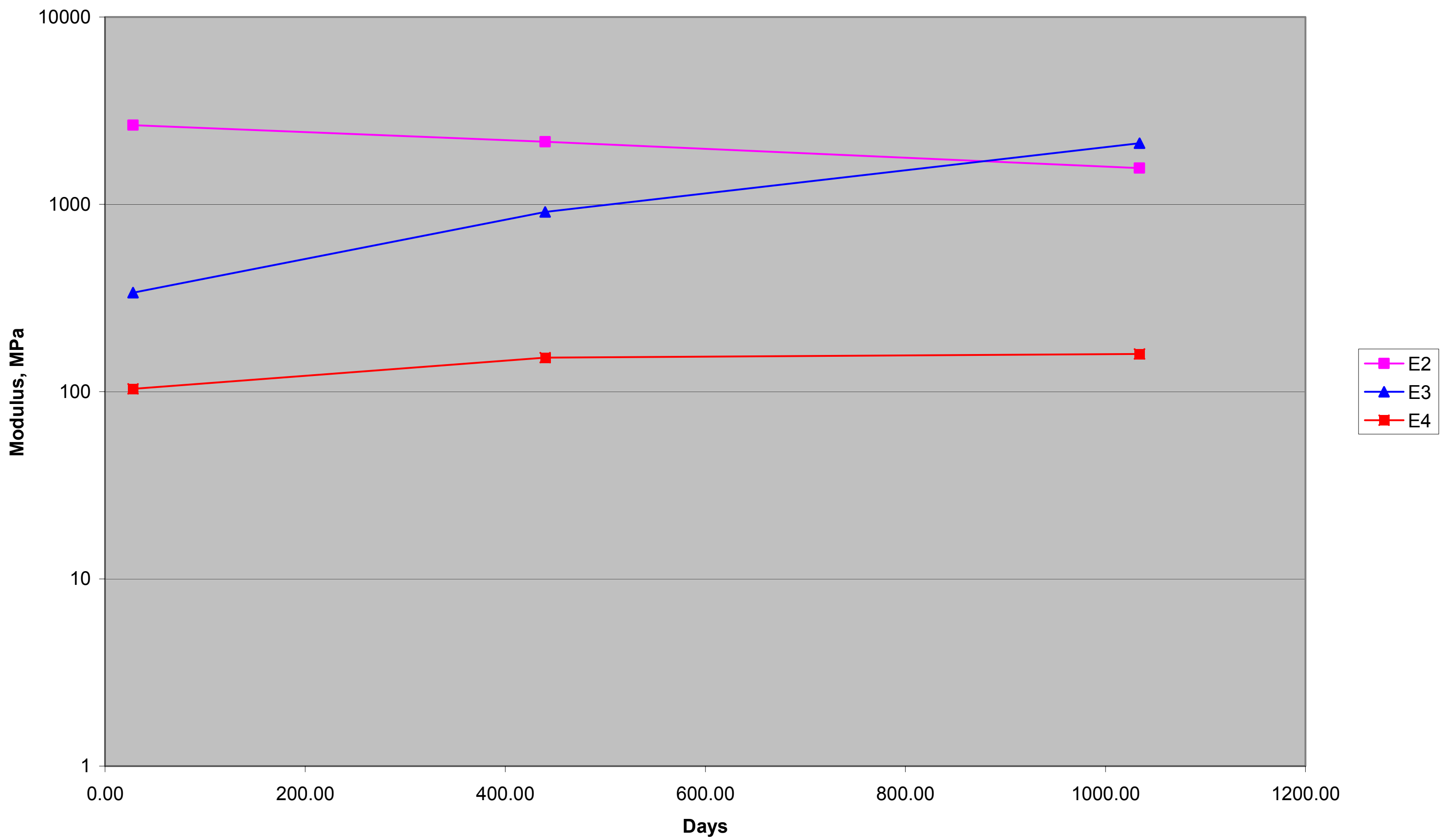

Figure 3.5 Modulus (backcalculated) increase with time of the lime-GGBFS section. E_2 = Modulus of lime-GGBFS soil, E_3 = Modulus of lime-treated subgrade, E_4 = Modulus of subgrade

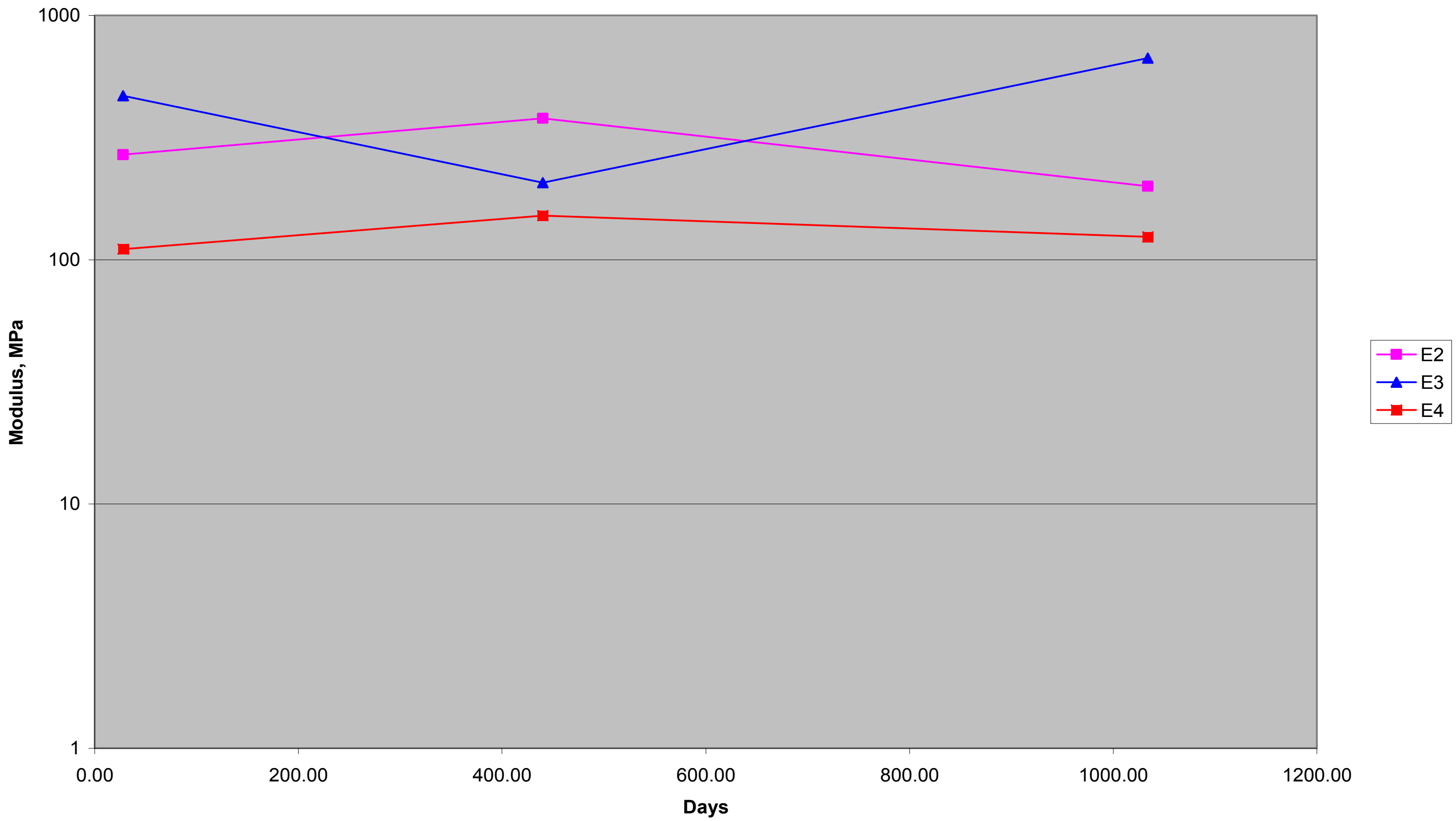

Figure 3.6 Modulus (backcalculated) change with time of the lime-fly ash section without drainage layer. E_2 = Modulus of lime-fly ash soil, E3 = Modulus of lime-treated subgrade, E_4 = Modulus of subgrade

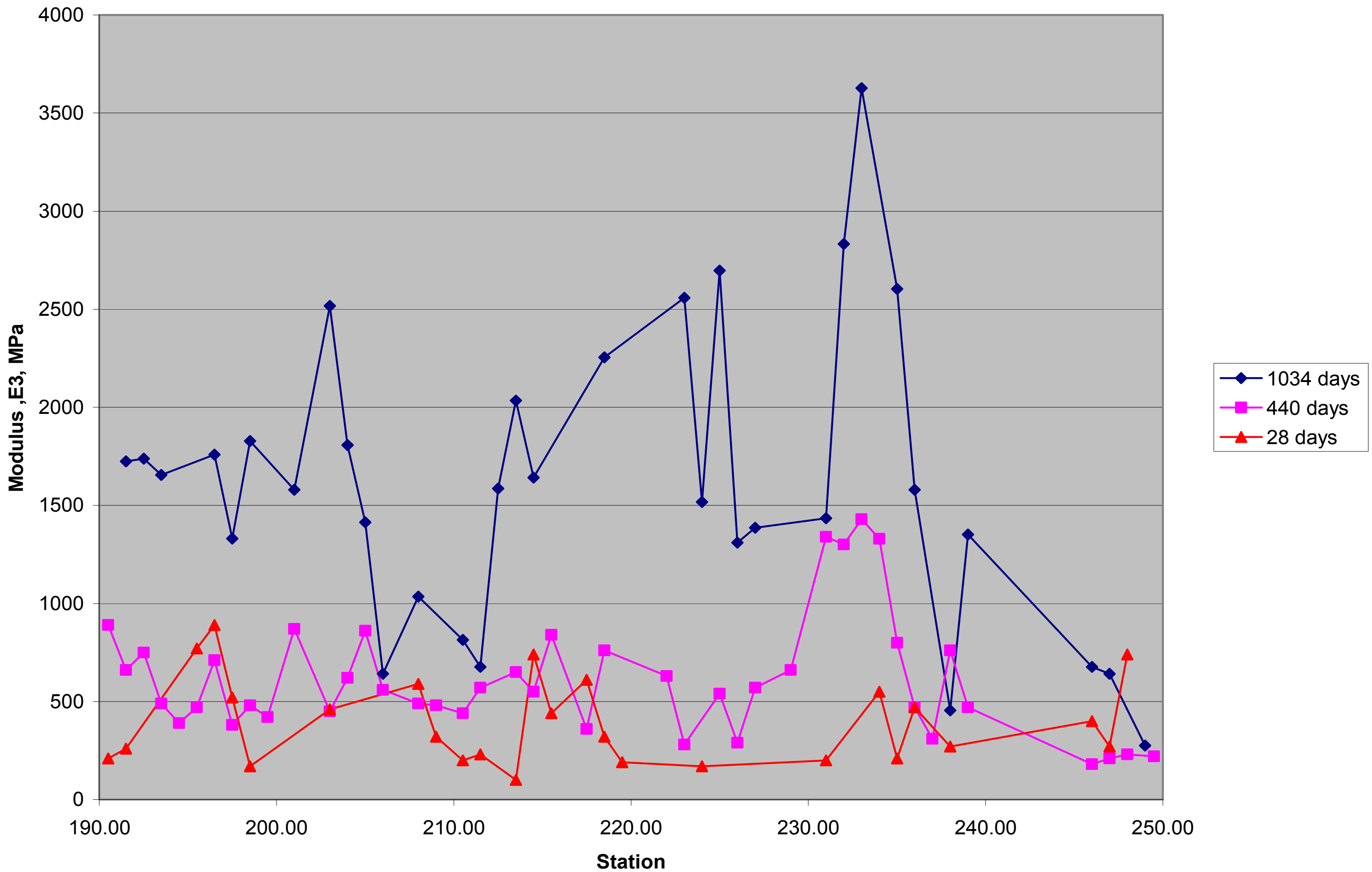

Figure 3.7 Modulus (backcalculated) variation of lime-treated subgrade along the road

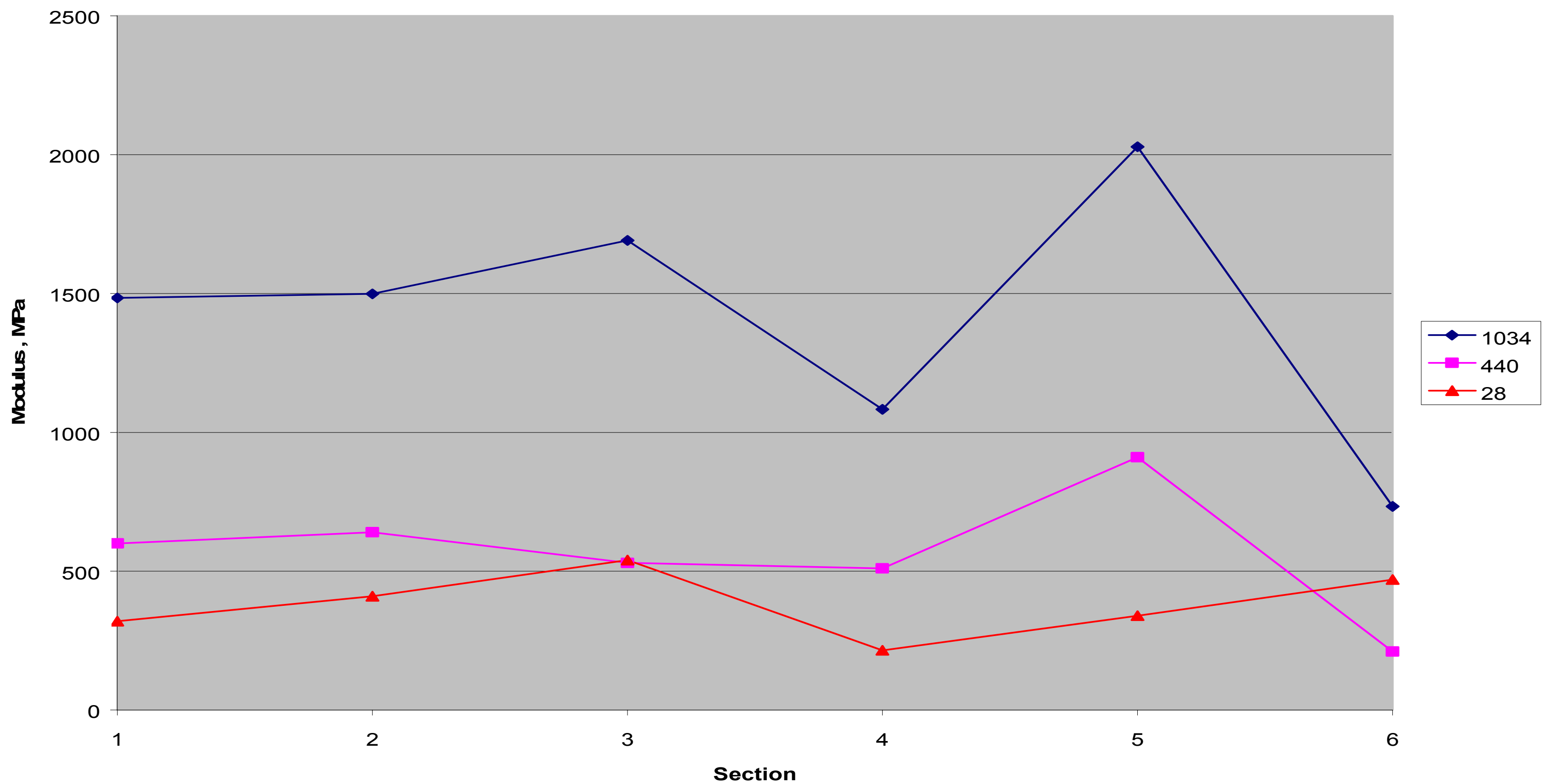

Figure 3.8 Modulus (backcalculated) variation of lime-treated subgrade (section average)

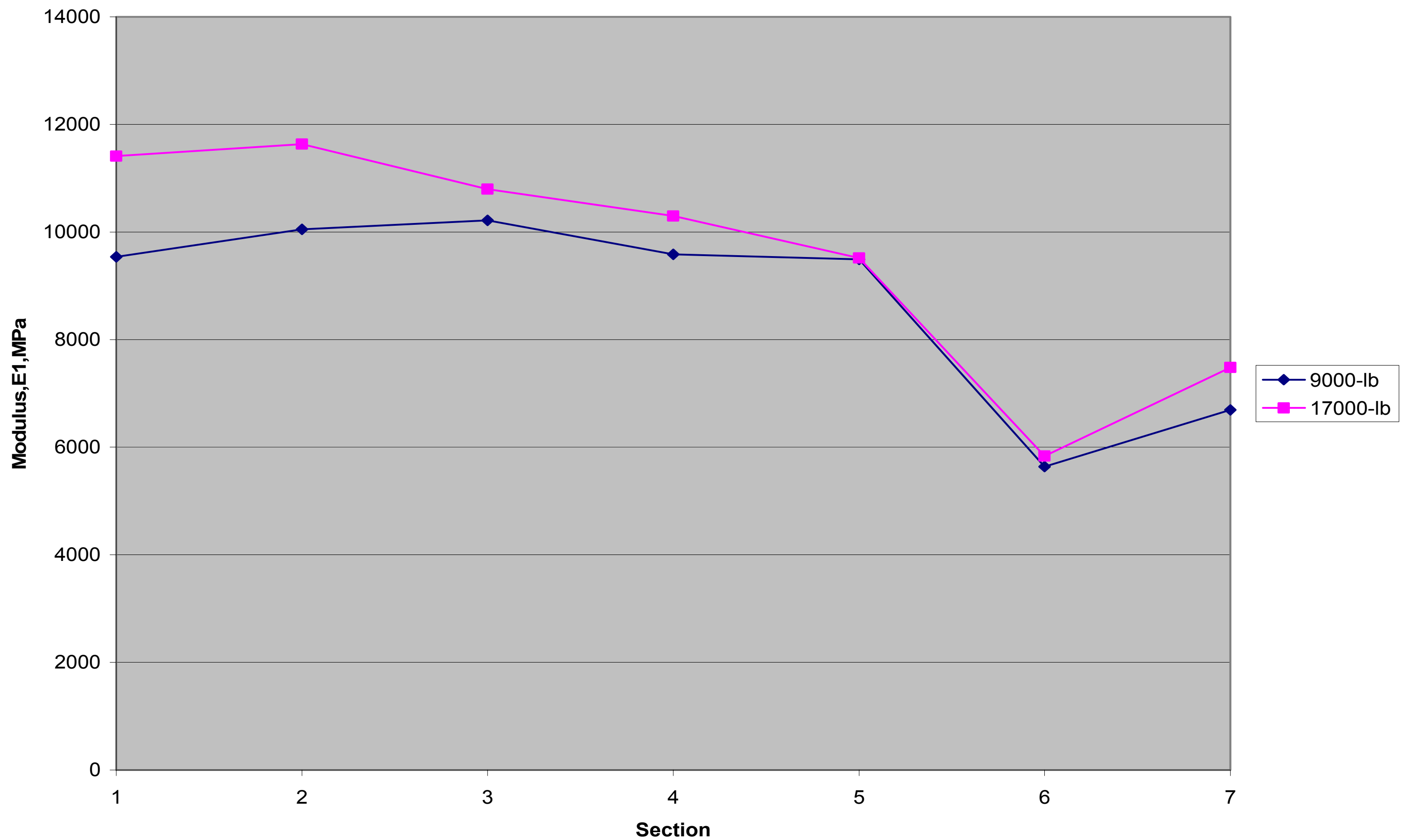

Figure 3.9 Modulus (backcalculated) variation of asphalt concrete surface (section average). (7 refers to section 6 (alternate))

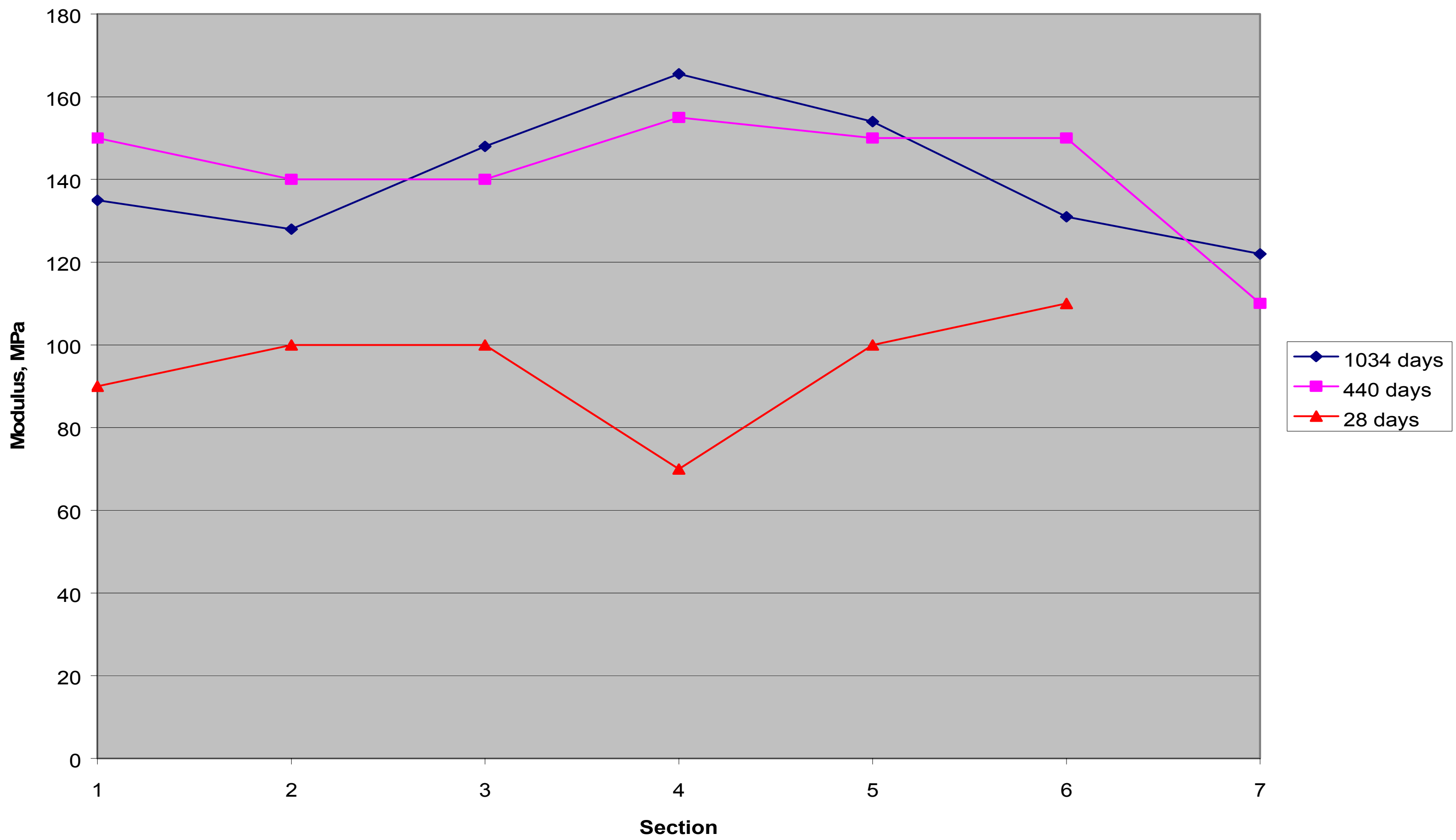

Figure 3.10 Modulus (backcalculated) variation of subgrade (section average). (7 refers to section 6 (alternate))