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PAVEMENT DAMAGE FACTORS DURING SPRING THAW IN ALASKA

BY

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CHAPTER

1. INTRODUCTION

It is generally accepted that the damage accumulated in pavement structures due to applied loads varies in a non-linear fashion with applied load level (1,2,3). Typically an exponential relationship is assumed, with "rule of thumb" applications usually involving a power of 4. As an example, the equation could take the form:

$$D.F. = \left(\frac{W}{W_{REF}}\right)^n$$

where

$D.F.$ = damage factor resulting from W
W = applied wheel load
W_{REF} = reference wheel load (usually 9 kip)
n = exponent (often 4)

In such a case, doubling the applied load from some standard load results in sixteen times as much damage as would be caused by the standard load. The exponent developed from AASHO road test data is 4.79 (1), and this has been used for most Alaskan applications.

In Alaska, however, as in other areas where pavement freezing occurs during winter, a question arises regarding damage levels that accumulate during the spring thaw period. Simple observation has made it obvious that pavement damage accumulates extremely rapidly during spring thaw conditions. This is usually considered to be the result of trapped moisture in the thawed zone between surface and thawing front which adversely affects pavement response to load. Alaska DOT&PF routinely monitors pavement surface deflections during spring thaw and applies load restrictions when these deflections indicate that excessive damage is likely to accumulate. It would be of interest to know the probable damage levels that occur during spring thaw and how this damage relates to measured deflections and load levels. As a result, Alaska DOT&PF

collected deflection data on selected in-service pavement sections at different times during the spring thaw for the purpose of determining damage factors related to load and deflection levels.

This report describes the deflection data collected and the mechanistic analysis procedures employed in developing damage factors for asphalt concrete (AC) and subgrade on these selected sections. In particular, Alaska DOT&PF personnel required the development of a damage factor relationship using maximum measured deflection, which was carried out. The relationship between load ratio (i.e. actual load divided by the standard 9000 lb load) and damage factor was also investigated.

2. TEST SECTION DATA

2.1 Deflections

Data from the eight pavement test sections listed in Table 2.1 were analyzed using the procedures described in Section 3. Test points are located at 0.1 mile spacing so that 10 or 11 points were tested within each section on the dates shown in Table 2.1. Since the objective of the research is to investigate load-related damage factors during the spring thaw period, non-destructive tests (NDT) were carried out using a Dynatest Model 8000 Falling Weight Deflectometer (FWD) to measure deflection basins. Each point was tested at approximately eight different load levels by performing three test sequences involving 4 tests each, as shown in Table 2.2. Certain load levels occurred during more than one test sequence. Actual applied load varies slightly as a result of differing pavement response characteristics, and for analysis purposes, deflections are normalized to the loads shown in Table 2.2. by assuming elastic behavior and multiplying the measured deflection by the ratio of normalized load to measured load. Pavement surface temperature was also monitored during testing and recorded with the deflection data.

All raw data is available on computer diskettes. Normalized center deflections are plotted in Figures 2.1 through 2.8 as a function of applied load and date. These are maximum deflections at the center of the load plate and are often used as the primary indicator of structural response. However, the shape of the deflection basin must be considered for a more realistic interpretation of pavement response. Only one data set shows a very marked thaw weakening effect, i.e. Figure 2.6 shows significantly increasing deflections during the period April 20 to April 30 for Elliot Highway 35 to 36, after which the deflections decrease to May 15. Table 2.3 lists 9 kip and 20 kip deflections for each section on the test dates, providing an indication of relative strength response if one assumes that at least one of the test dates represents a fully thawed condition. All sections except Parks 275-276 appear to show stress-stiffening response. For example, in Figure 2.2, a load of 5 kips results in approximately 10 mils of deflection, while, due to stress-stiffening, a load of 20 kips results in 30 to 35 mils, i.e. less than 40 mils (= 10 x 20/5) that would be expected from an elastic or nonstress-sensitive response. Figures 2.9 through 2.16 also show deflection trends with time for various load levels, and again, only Figure 2.14 (i.e. Elliott MP 35-36) exhibits a significant thaw weakening effect.

2.2 Structural Section and Materials

According to Alaska DOT&PF, layer thicknesses for all test sections are:

Surfacing	2" AC
Base Course	4"
Subbase	6"
Select	24" to 30"

The AC (asphalt concrete) typically involves about 6% AC 2.5 with 3% voids and 5% P_{200} (i.e. passing the #200 sieve).

Table 2.1 Test Sections

Roadway	Location (mile)	Test Dates	Relative Strength (see Table 2.3)
Alaska Highway	282.84 to 283.84	April 22, May 1 May 7	Very High
Elliott Highway	5.0 to 6.0	April 15, April 29 May 4, May 13	High
Elliott Highway	10.0 to 11.0	April 15, April 29 May 4, May 13	High
Elliott Highway	19.2 to 20.2	April 29, May 6 May 13	Moderate
Elliott Highway	27.1 to 28.1	April 30, May 6 May 15	Low
Elliott Highway	35.71 to 36.71	April 20, April 30 May 6, May 15	Low (Significant Thaw Weakening)
Goldstream Road	6.25 to 7.15	May 1, May 7 May 14	Moderate
Parks Highway	275.6 to 276.6	April 24, May 3 May 14	High

Table 2.2 Deflection test load data

Test Sequence	Indicator	Target Load (kips)
1	L1	9
	L2	7.5
	L3	5.5
	L4	3.5
2	L1	15.5
	L2	13
	L3	9
	L4	5.5
3	L1	24
	L2	20
	L3	13 or 15.5
	L4	9

Table 2.3 Test section average deflections

Test Section	Date	Normalized Maximum Deflections (mils) 9000 lb	20000 lb
Alaska 282-283	4/22	9.24	17.26
	5/1	10.24	19.66
	5/7	10.71	20.45
Elliott 5-6	4/15	14.48	29.55
	4/29	16.50	33.97
	5/4	17.12	34.86
	5/13	18.01	35.34
Elliott 10-11	4/15	17.86	31.56
	4/29	20.04	36.69
	5/4	20.53	37.83
	5/13	21.22	36.93
Elliott 19-20	4/29	25.62	51.10
	5/6	27.68	56.57
	5/13	28.60	55.64
Elliott 27-28	4/30	39.34	75.32
	5/6	37.03	69.99
	5/15	30.36	64.31
Elliott 35-36	4/20	27.13	50.98
	4/30	36.62	70.02
	5/6	30.57	60.84
	5/15	23.22	49.73
Goldstream 6-7	5/1	20.37	43.63
	5/7	23.29	50.27
	5/14	25.12	54.28
Parks 275-276	4/24	17.48	40.19
	5/3	18.71	44.89
	5/14	19.12	46.20

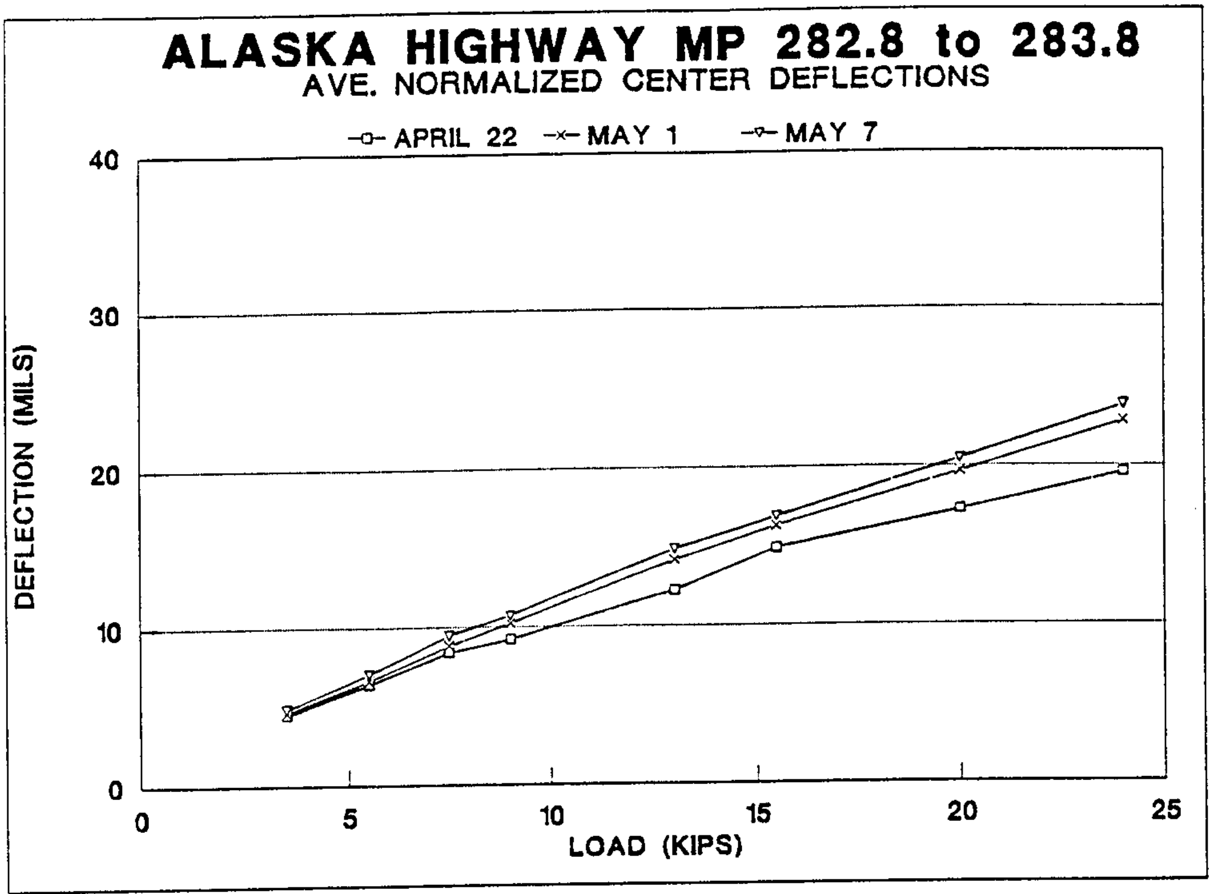


Figure 2.1

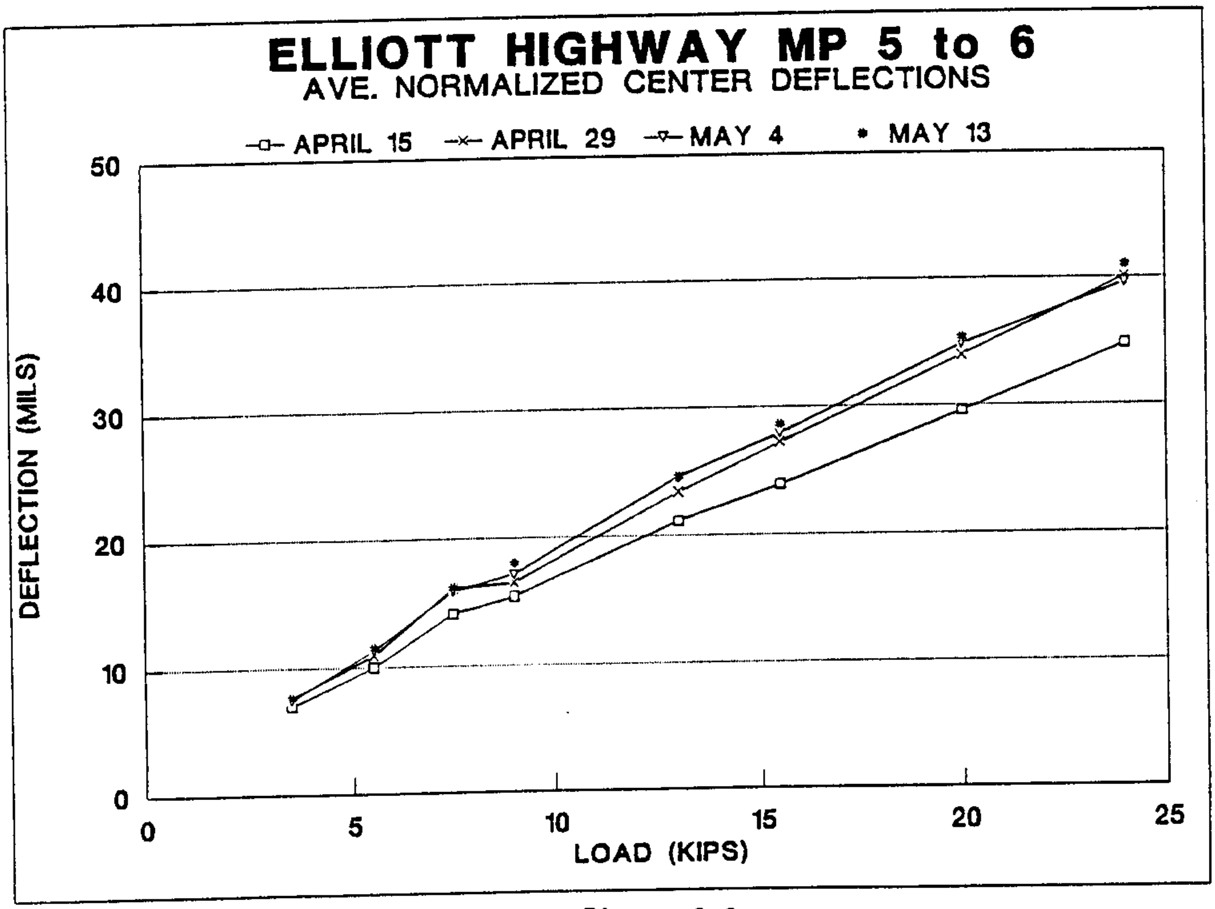


Figure 2.2

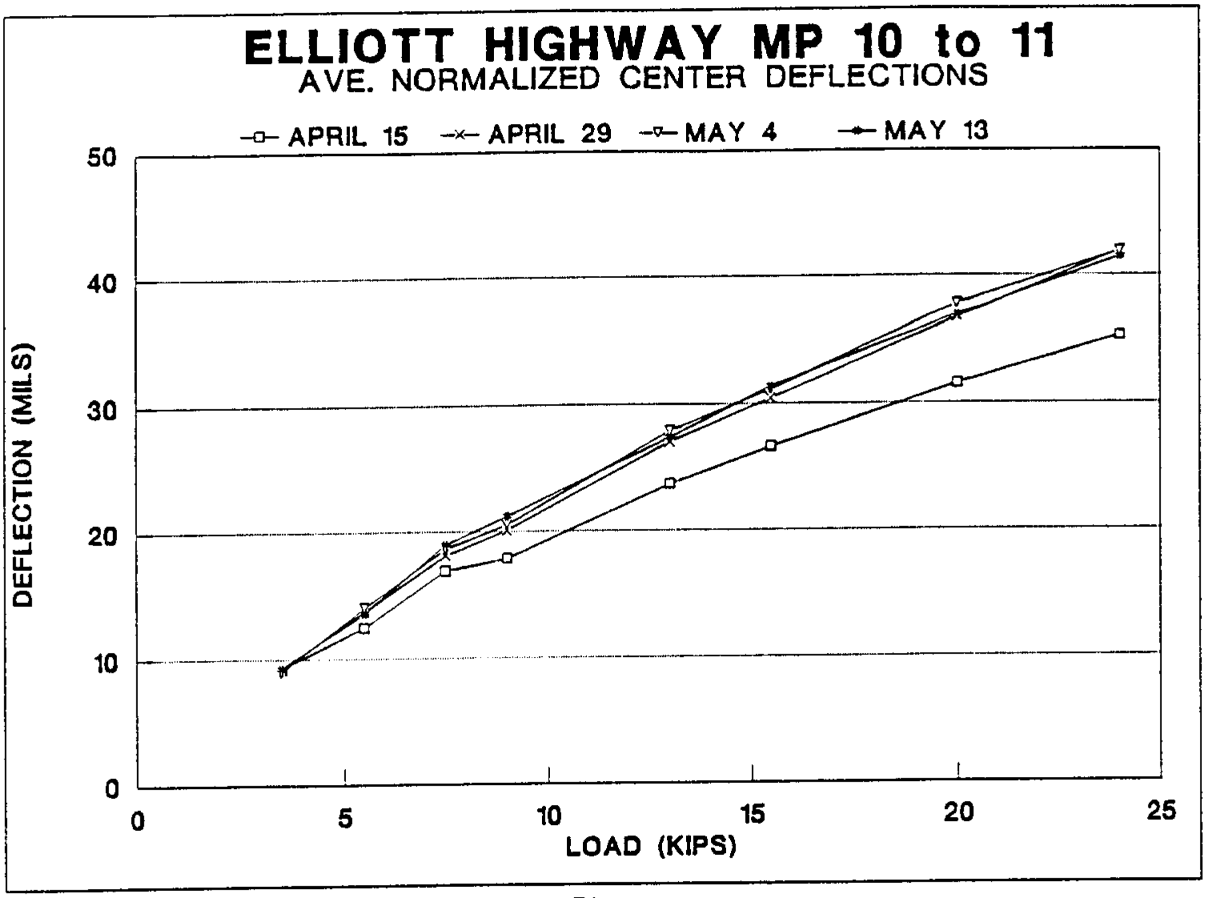


Figure 2.3

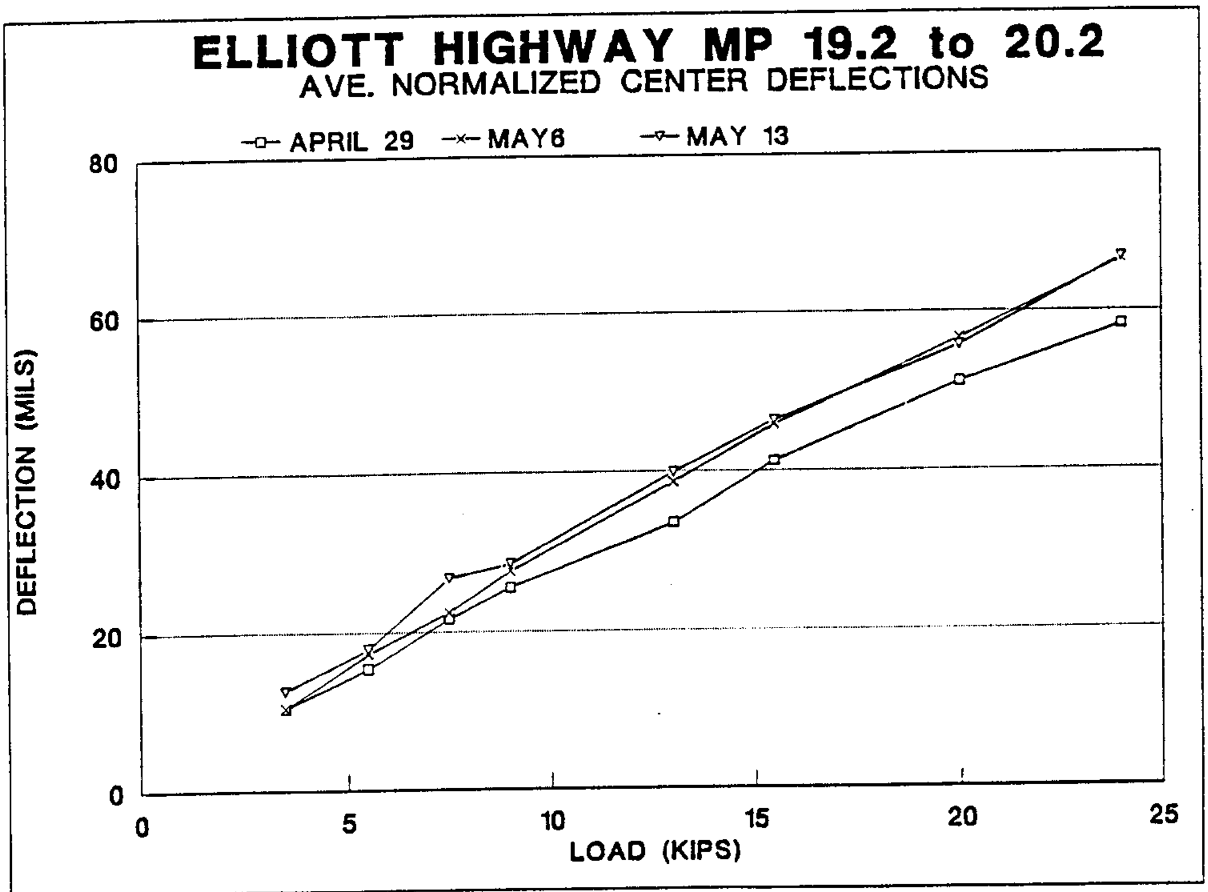


Figure 2.4

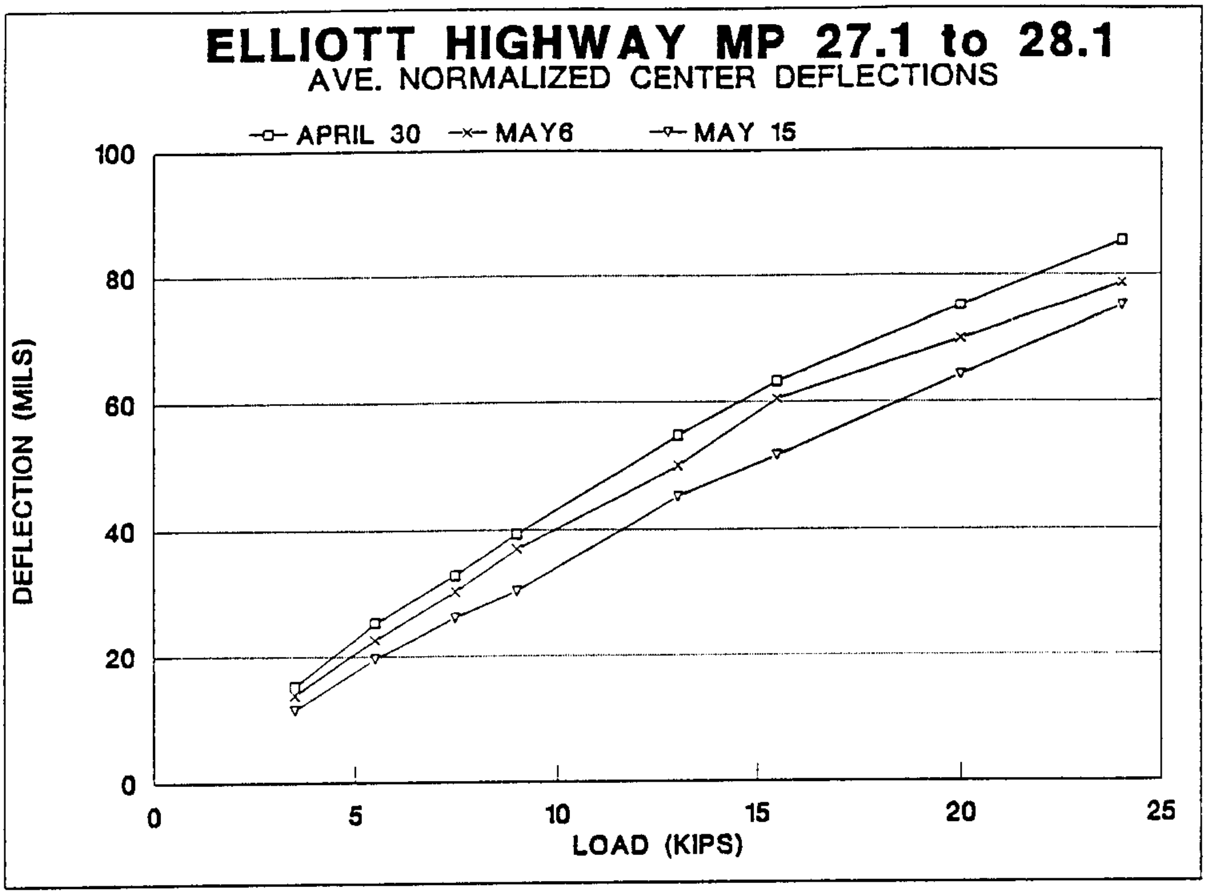


Figure 2.5

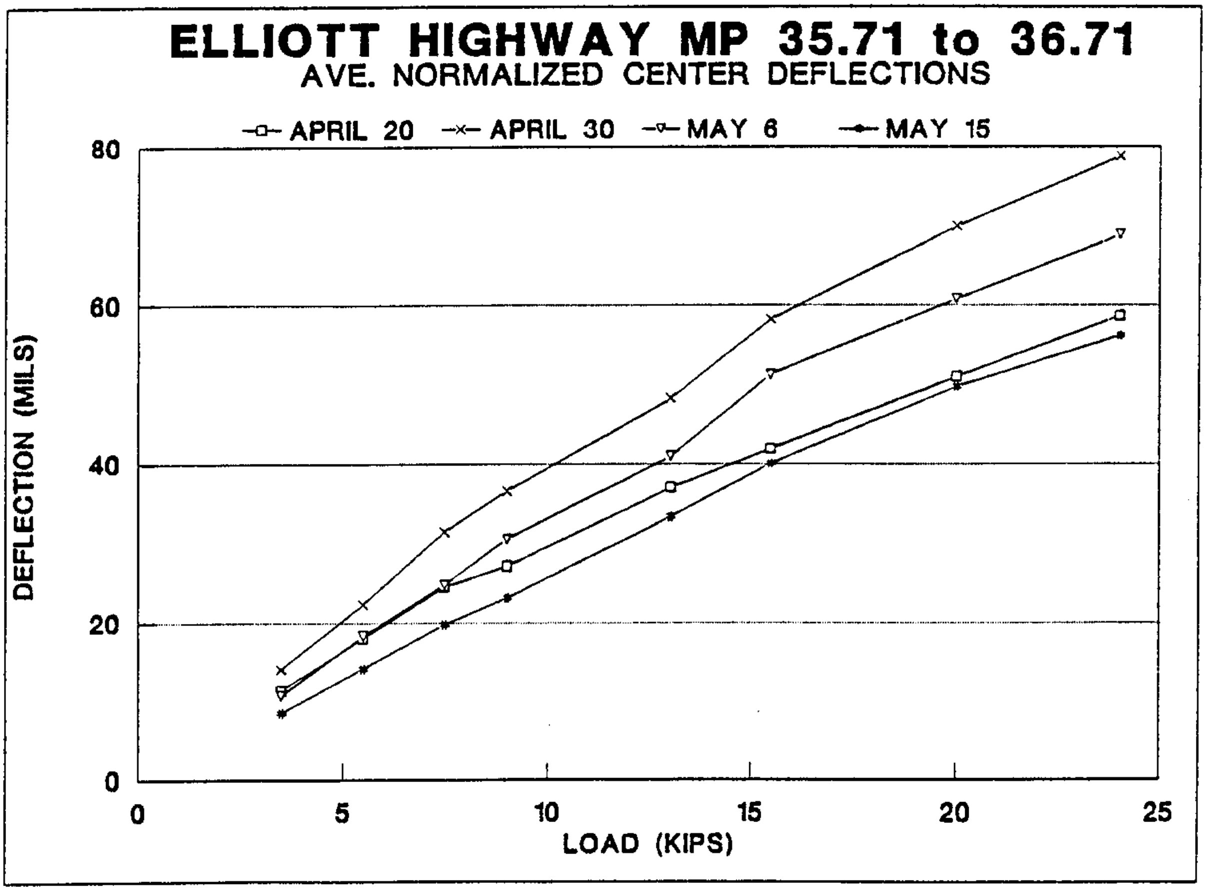


Figure 2.6

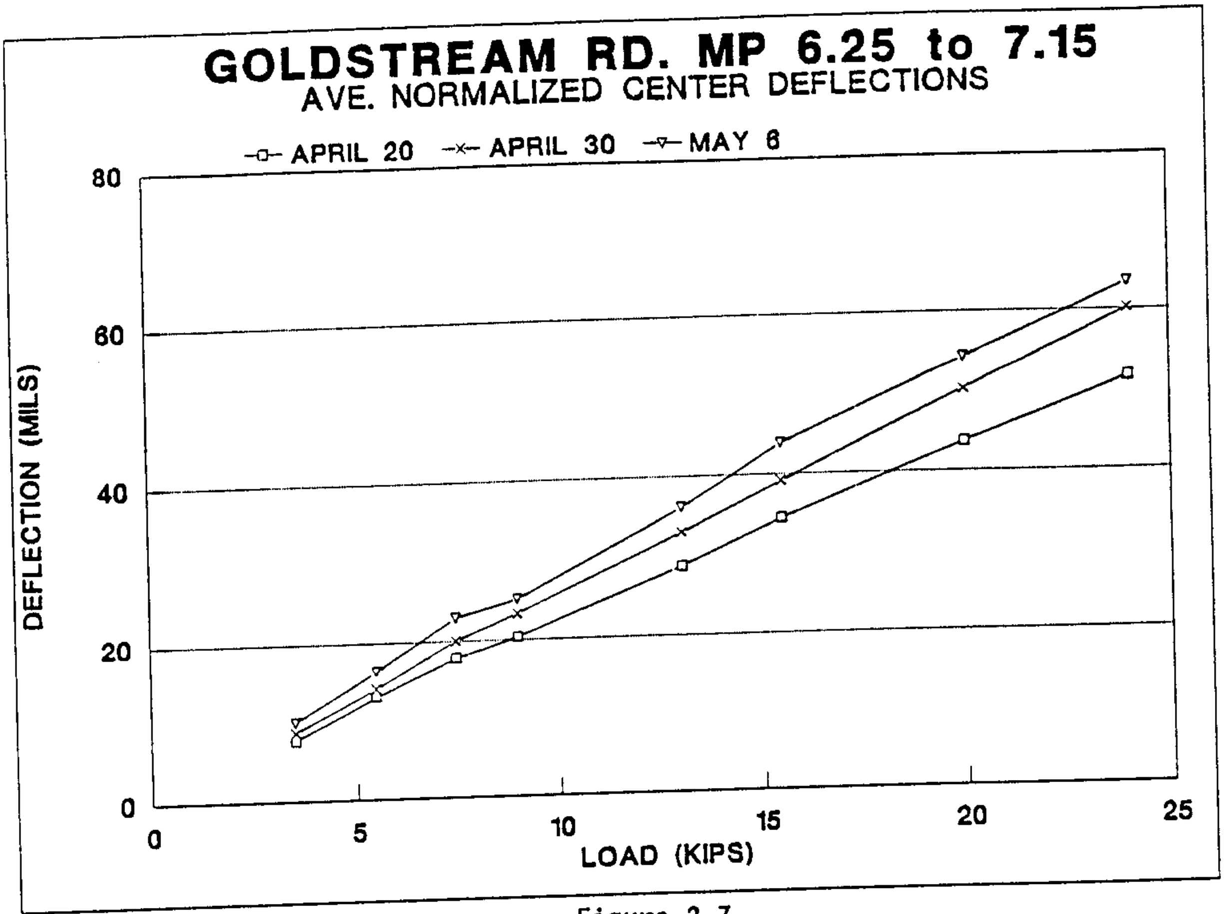


Figure 2.7

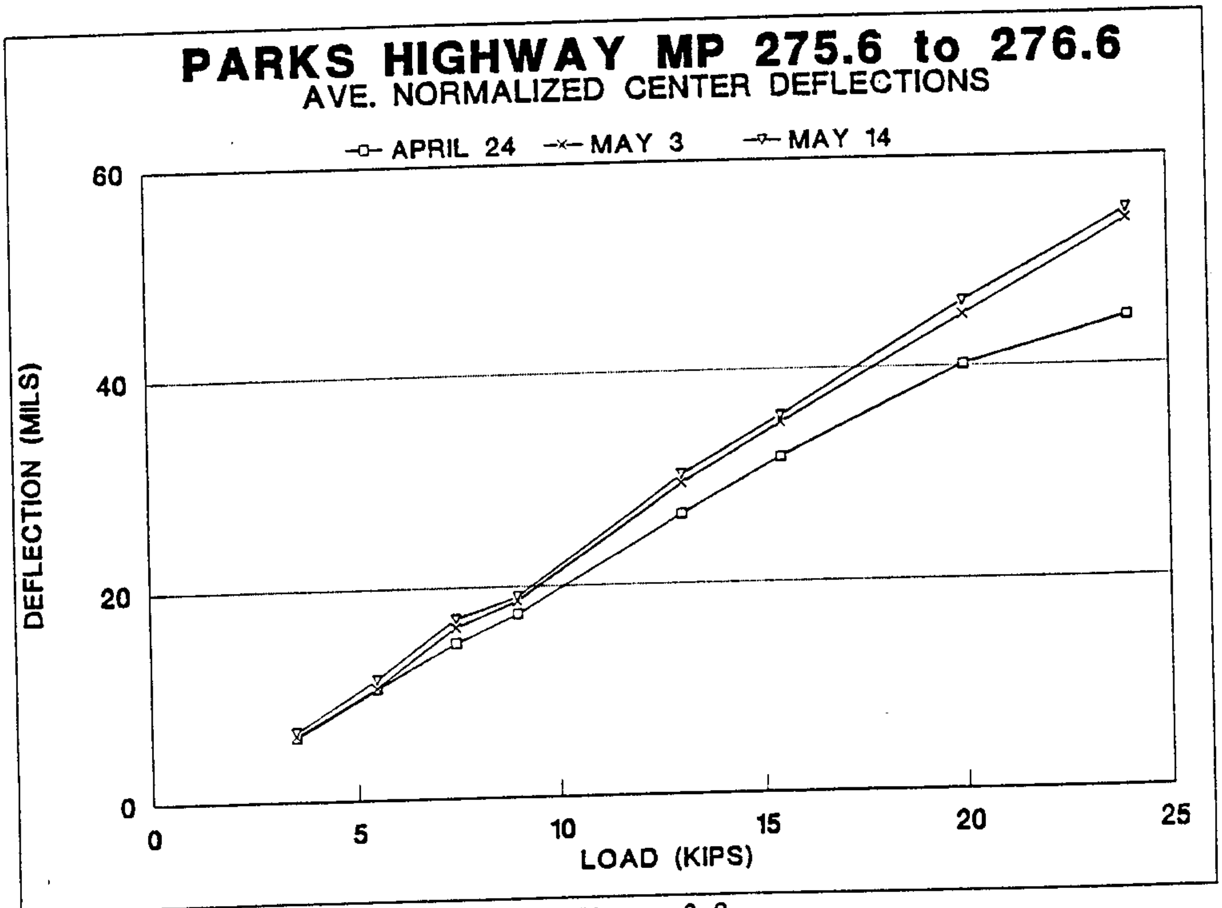
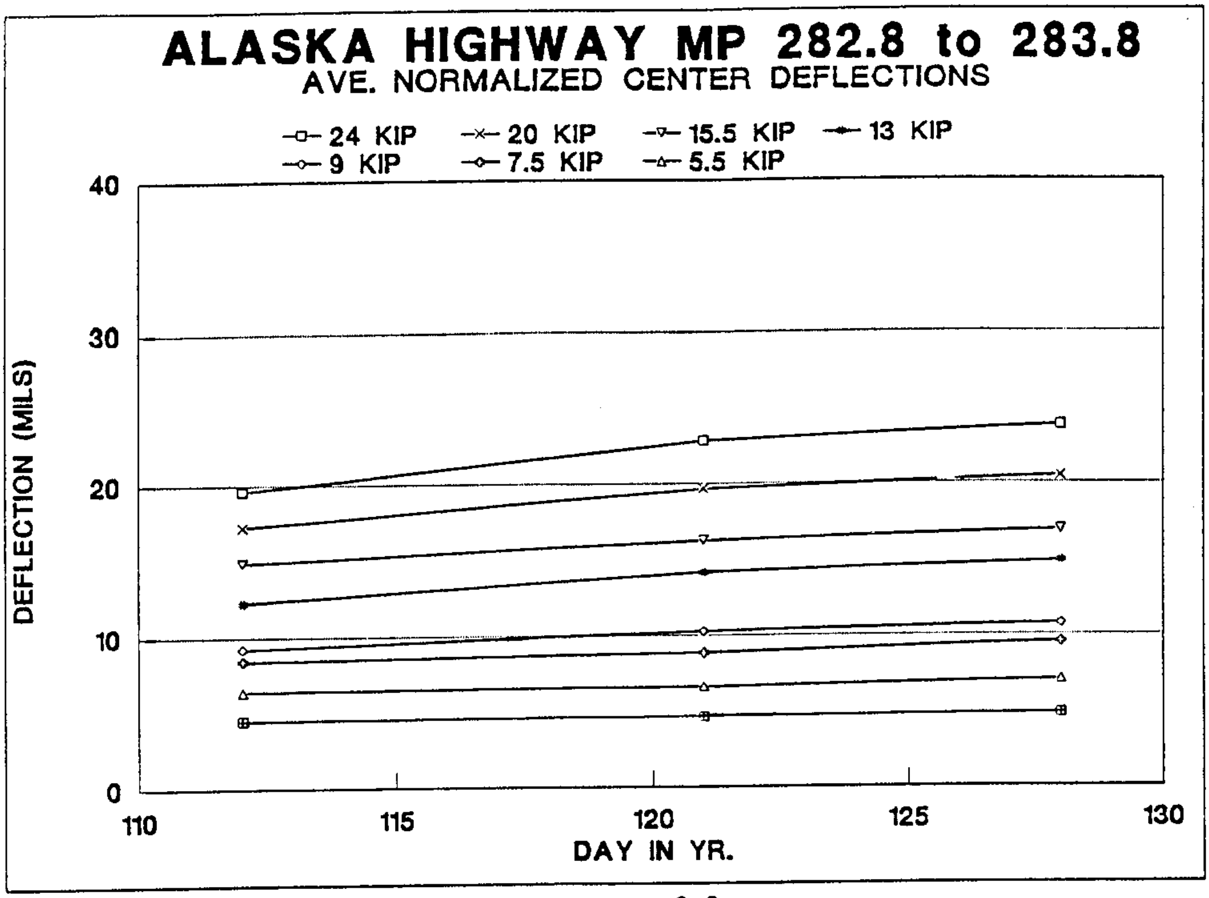


Figure 2.8



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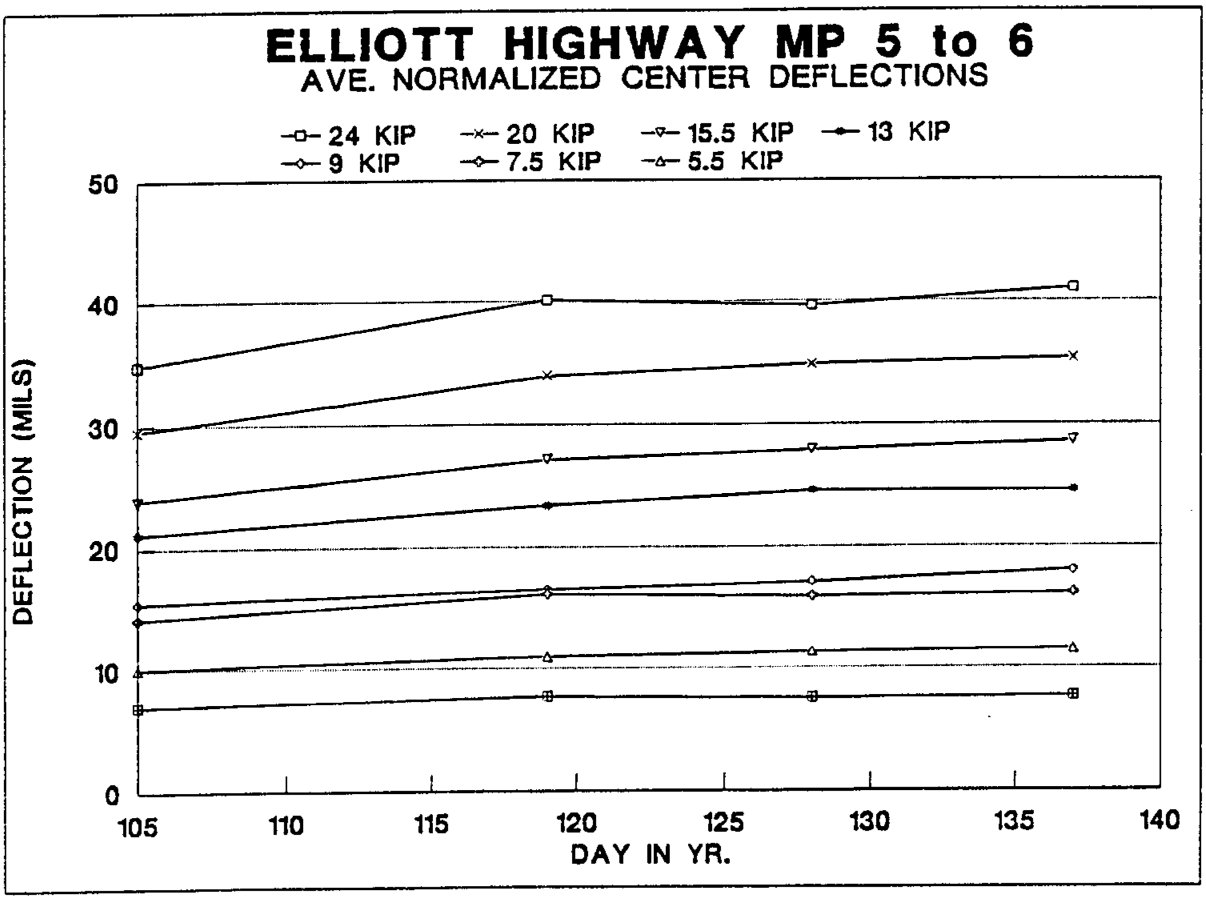

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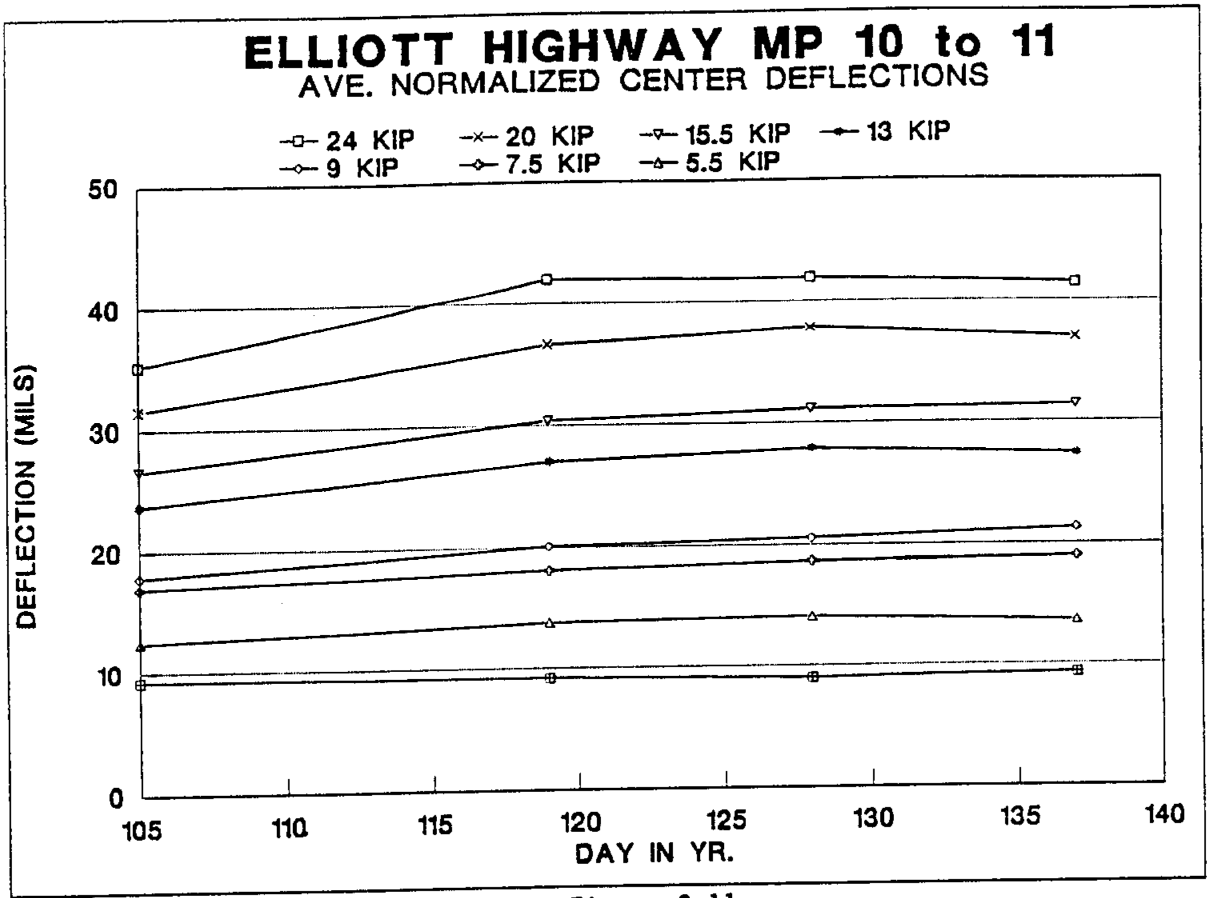

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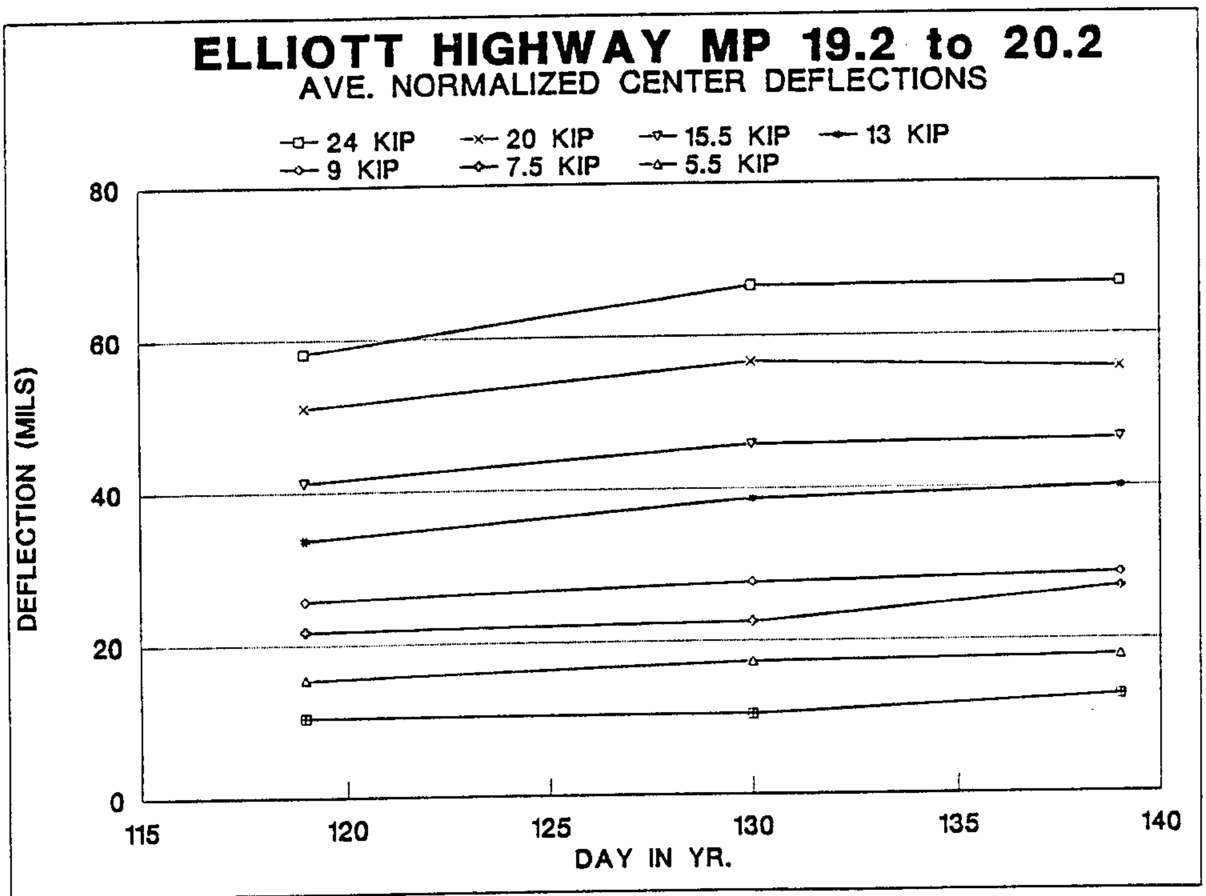

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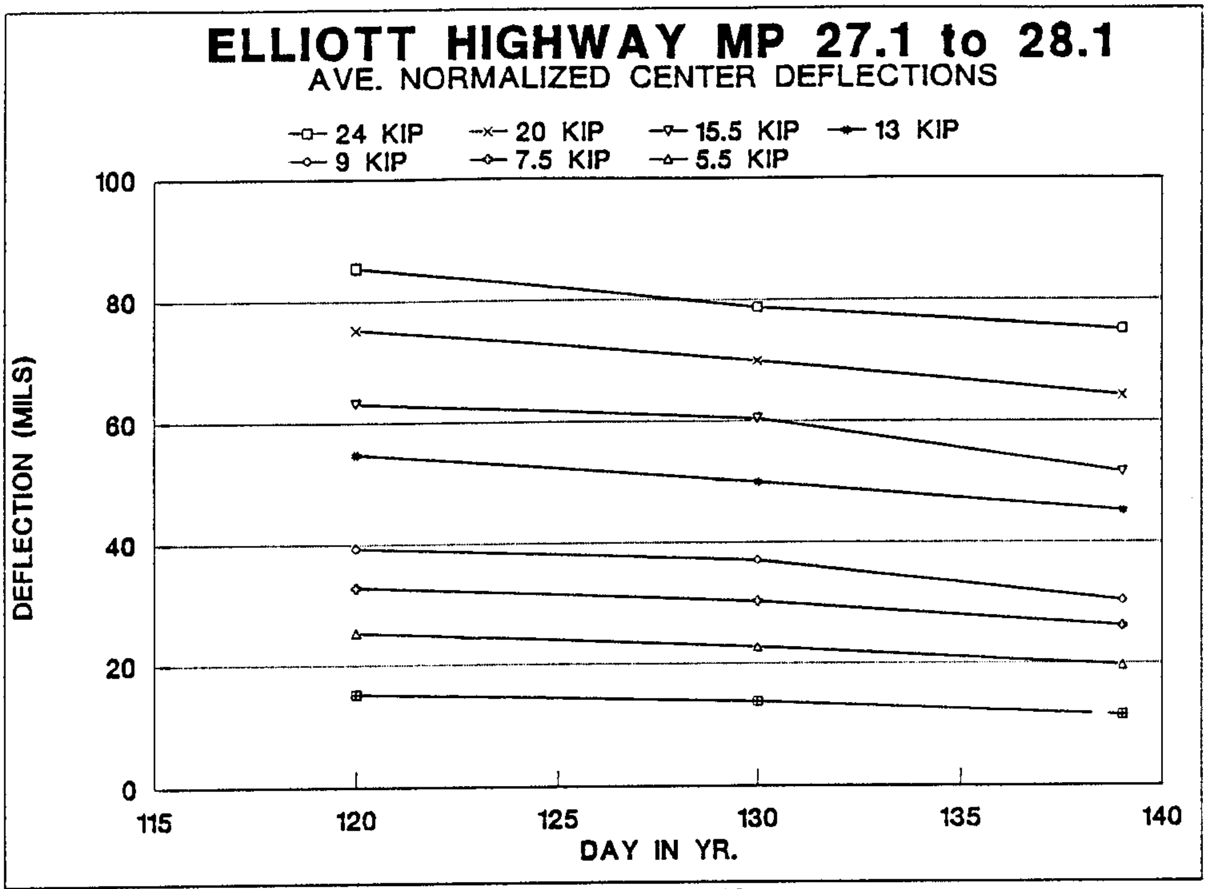


Figure 2.13

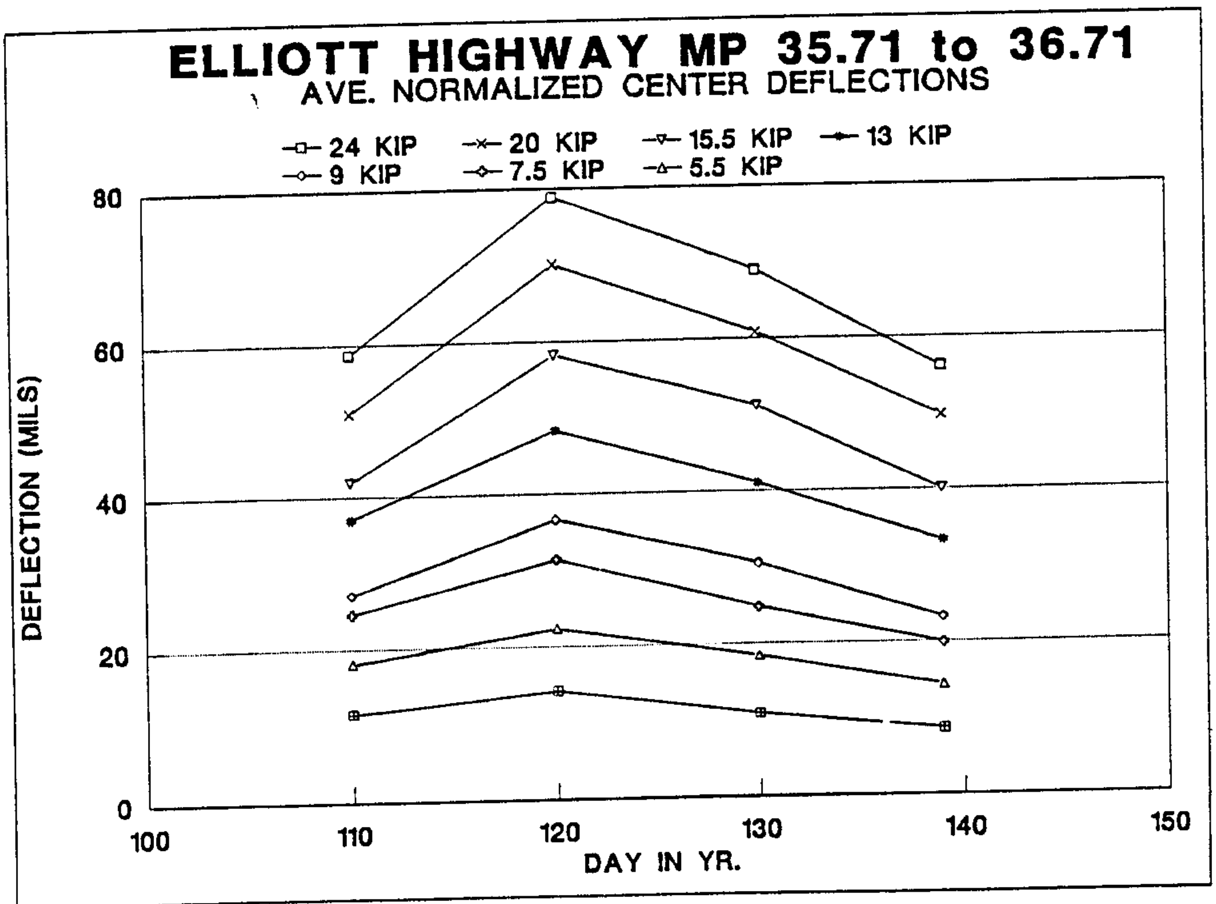


Figure 2.14

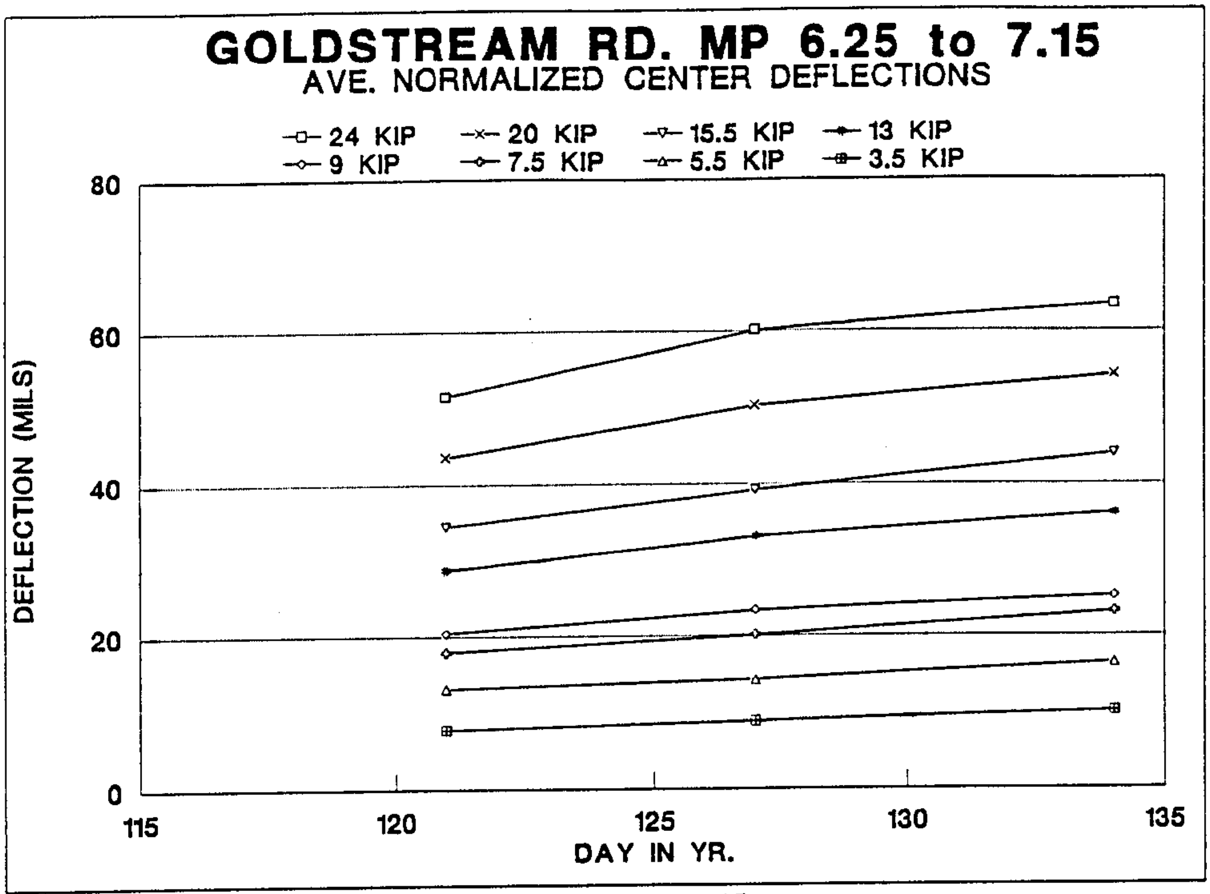


Figure 2.15

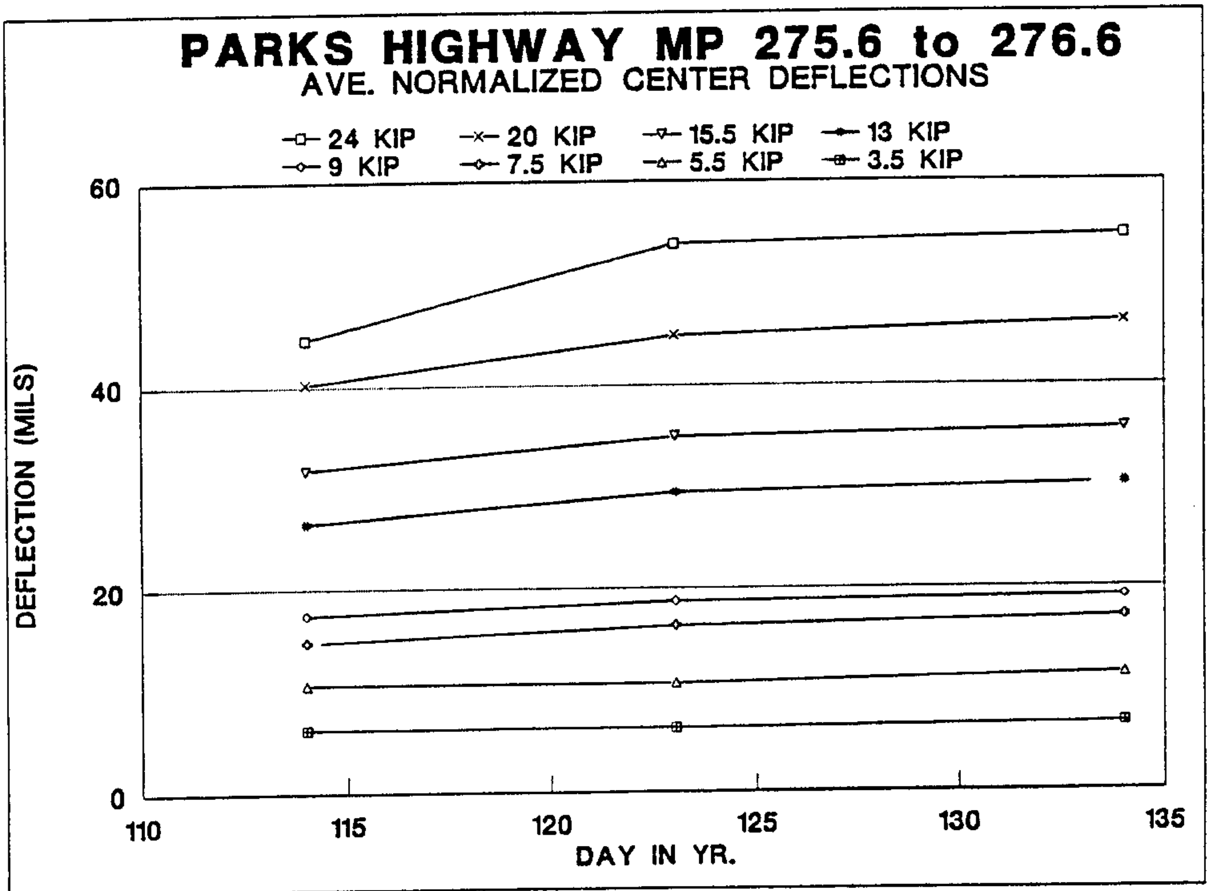


Figure 2.16

3. ANALYSIS APPROACH

3.1 General

In order to evaluate the load-related damage effects during spring thaw for the pavement test sections, the measured deflection basins for each load level were analyzed as follows:

a) Unbound material layer moduli were back calculated using ELMOD (3,4,5,6,7)

b) AC modulus was adjusted to 40°F using The Asphalt Institute (TAI) equation (8)

c) Stresses and strains were calculated at critical locations for each test point at each test date and each load level (i.e. bottom of AC layer, top of unbound layers) and averaged over each test section

d) TAI strain based fatigue equations were used to calculate average remaining life N_{ij} for each test section where

   i = load level

   j = test date

   and N = number of load repetitions

e) Damage factors (DF) were calculated relative to standard 9,000 lb wheel loads (i.e. one half of an equivalent axle load or EAL) by considering:

$$D.F. = \frac{N_{reference}}{N_{ij}}$$

where $N_{reference}$ was defined as

Nij with i = 9,000 lb and
j = actual test date for each test section in order to investigate load effects on a given date.
or j = latest test date in year for each test section to relate load effects to a (presumably) completely thawed pavement section

f) For the latter case in e), (i.e. latest test date) regression analyses were carried out to investigate the relationship between DF and center deflection as well as DF and load ratio (= Wx/Wg where Wx is the wheel load at load level X and Wg = 9,000 lb.)

3.2 Moduli and Stress-Strain Calculations

Originally, approximately 500 of these deflection basin analyses were envisaged. To date, in excess of 3,000 have been carried out with the ELMOD (3,4,5,6,7) program for this period. ELMOD was chosen to replace the ISSEM4 program for this project after discussion with Alaska DOT&PF personnel. Reasons for the change include the facts that results are similar, ELMOD is significantly faster, and ELMOD can provide an estimate of the depth to an apparent stiff layer in the pavement from the deflection basin. This stiff layer location is of particular interest in the thaw situation being investigated here. The ELMOD estimates, in terms of "equivalent" depth are plotted in Figures 3.1 through 3.8. The equivalent depth is the transformed section thickness relative to the subgrade modulus using Odemark's transformation (3). Actual depth is typically less than the equivalent depth, and is a function of layer thickness and modular ratio. The estimated depths plotted in Figures 3.1 through 3.8 generally show the expected trend of increasing depth to the stiff layer as thawing progresses. In all cases except Figure 3.6 (i.e. Elliott 35.7 to 36.7) it appears as if significant thawing may have occurred prior to testing, with estimated equivalent depths in excess of about 50 inches. For the Elliott 35.7 to 36.7 section, estimated thaw depths for the earliest FWD tests are less than an equivalent depth of 40 inches. It is interesting to note that the results discussed in Chapter 4 show maximum spring thaw damage occurring for this Elliott 35.7 to 36.7 section, i.e. load related damage levels are worse during the period when a limited portion (in this case less than 50 inches) of the pavement is thawed. Figures 3.1 through 3.8 generally appear to indicate that more consistent resolution in terms of the thaw depth estimate is obtained with higher load levels. This is probably related to the actual location of the stiff layer, i.e. lower loads may be adequate for cases where the stiff layer is close to the surface. For deeper stiff layer locations, a higher load level is probably necessary to sufficiently mobilize material response at that depth so that the surface deflections are affected by the stiff layer.

3.3 Asphalt Concrete Moduli

Moduli for the AC layer were based on The Asphalt Institute (TAI) equation (18) for a mix with 6% AC 2.5 asphalt cement, 3% air, P200 = 5% and a loading time of 25-35 milliseconds, corresponding to the FWD load pulse duration. The modulus relationship used by ELMOD is a function of temperature only, so a regression analysis of TAI moduli versus temperature was performed to calibrate the ELMOD equation between 35°F and 100°F, and a correlation coefficient of 0.975 was obtained. The ELMOD equation was used to perform the AC modulus adjustment from the as-measured temperature to 40°F. Both equations are shown in Figure 3.9. The variation between the two equations at 40°F is 9%, which would have a relatively minor effect on calculated stresses and strains for the AC material.

3.4 Fatigue Relationships

The numbers of load repetitions, N, discussed under 3.1 are based on TAI fatigue equations for both AC and subgrades. For AC, the equation related to fatigue cracking is:

$$N = 18.4\ C\ (4.325 \times 10^{-3})\ e_t^{\ -3.291}\ E^{\ -0.854} \qquad \text{Eq. 3.1}$$

where

N = allowable number of load repetitions

e_t = maximum horizontal tensile strain at base of AC

E = AC modulus (psi)

and

$$C = 10^M \qquad \text{Eq. 3.2}$$

$$M = 4.84 \left(\frac{V_b}{V_v+V_b} - 0.69\right) \qquad \text{Eq. 3.3}$$

where

V_b = volume % of asphalt cement

V_v = volume % of voids

For the AC mix in question, C = 4.17 and E = 1282600 psi at 40°F, resulting in

$$N = 2.016 \times 10^{-6}\ e_t^{\ -3.291} \qquad \text{Eq. 3.4}$$

The subgrade relationship related to rutting is:

$$N = 1.365 \times 10^{-9}\ e_c^{\ -4.477} \qquad \text{Eq. 3.5}$$

where

N = allowable number of load repetitions

e_c = vertical compressive strain at the top of the subgrade

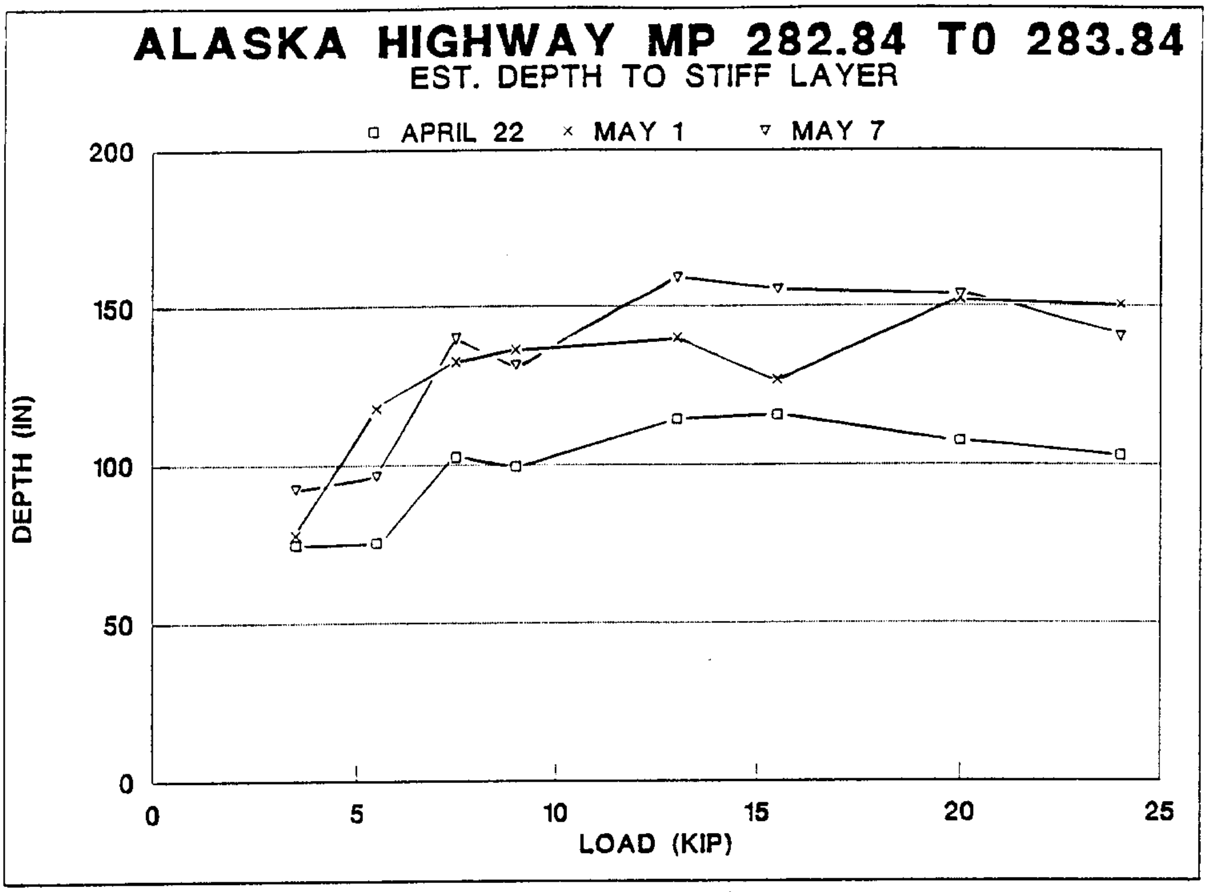


Figure 3.1

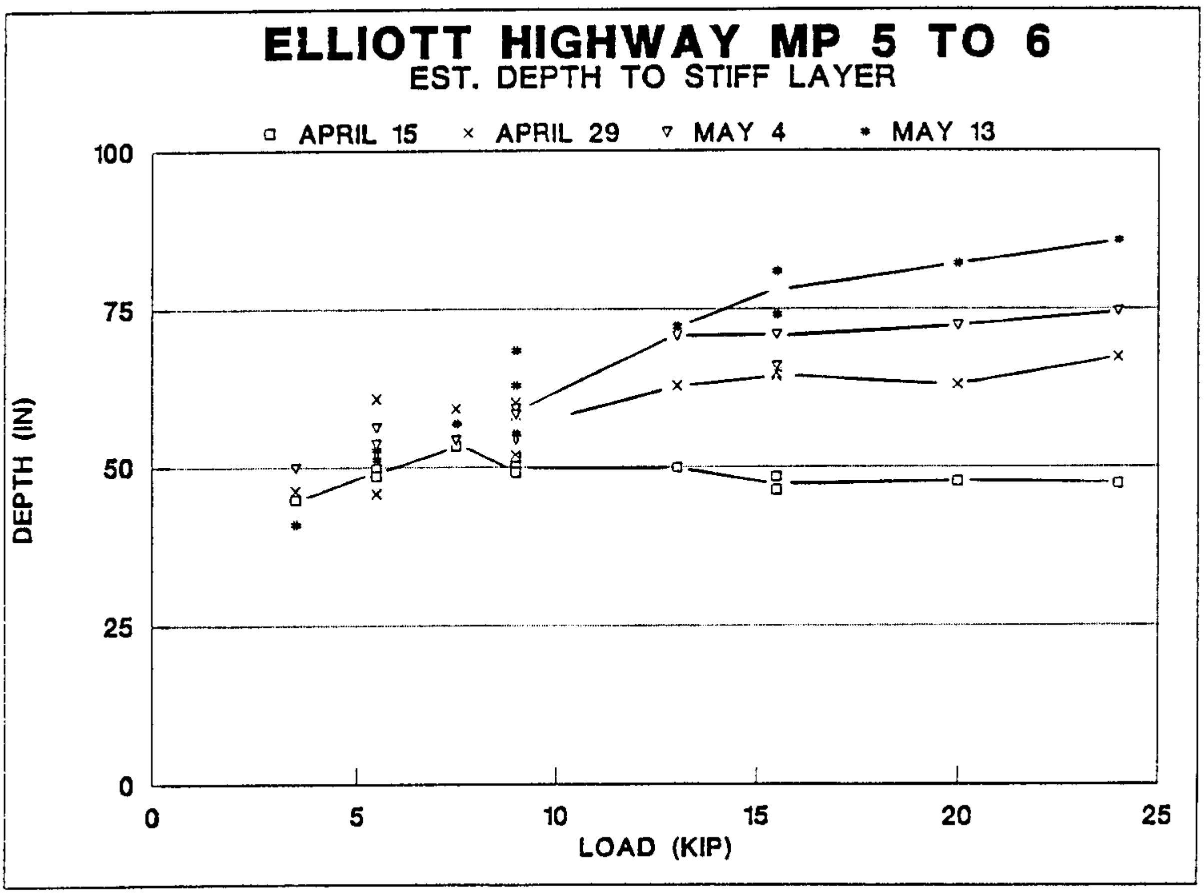


Figure 3.2

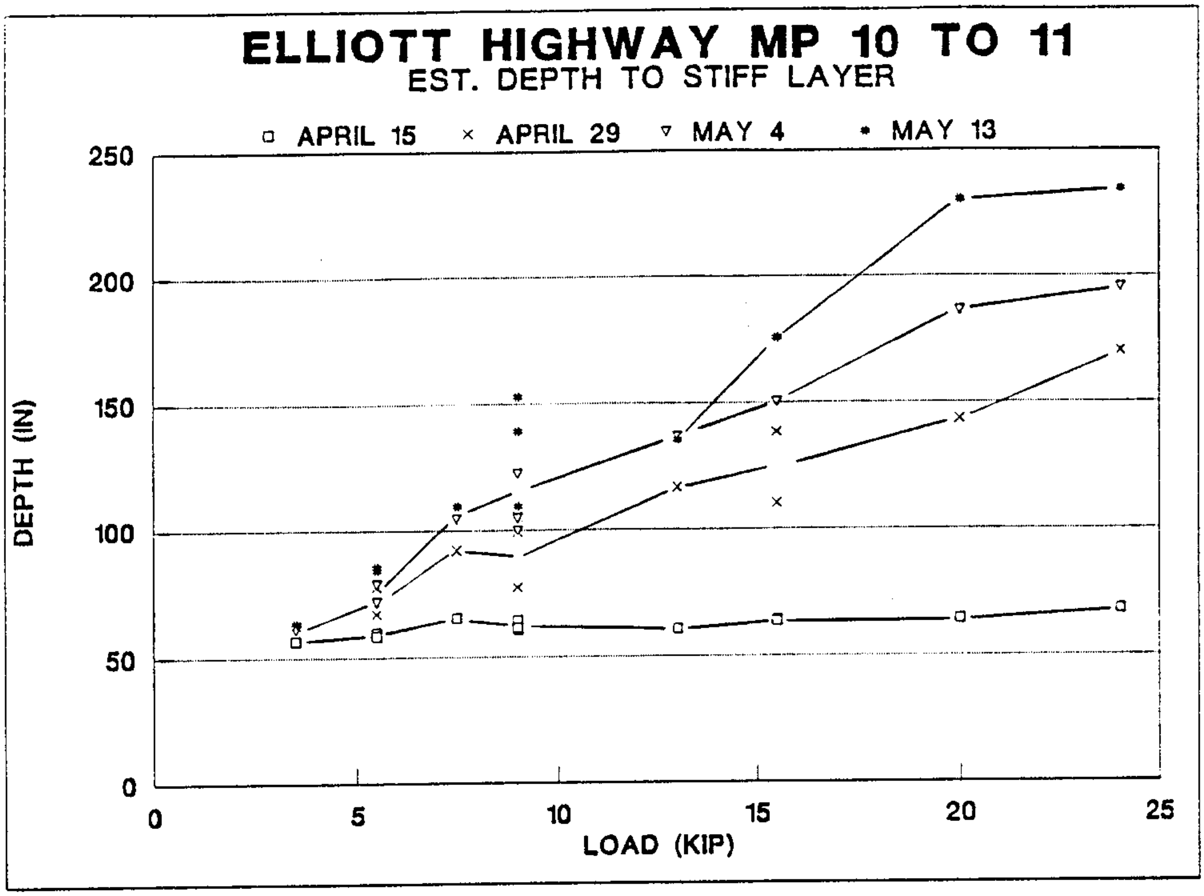
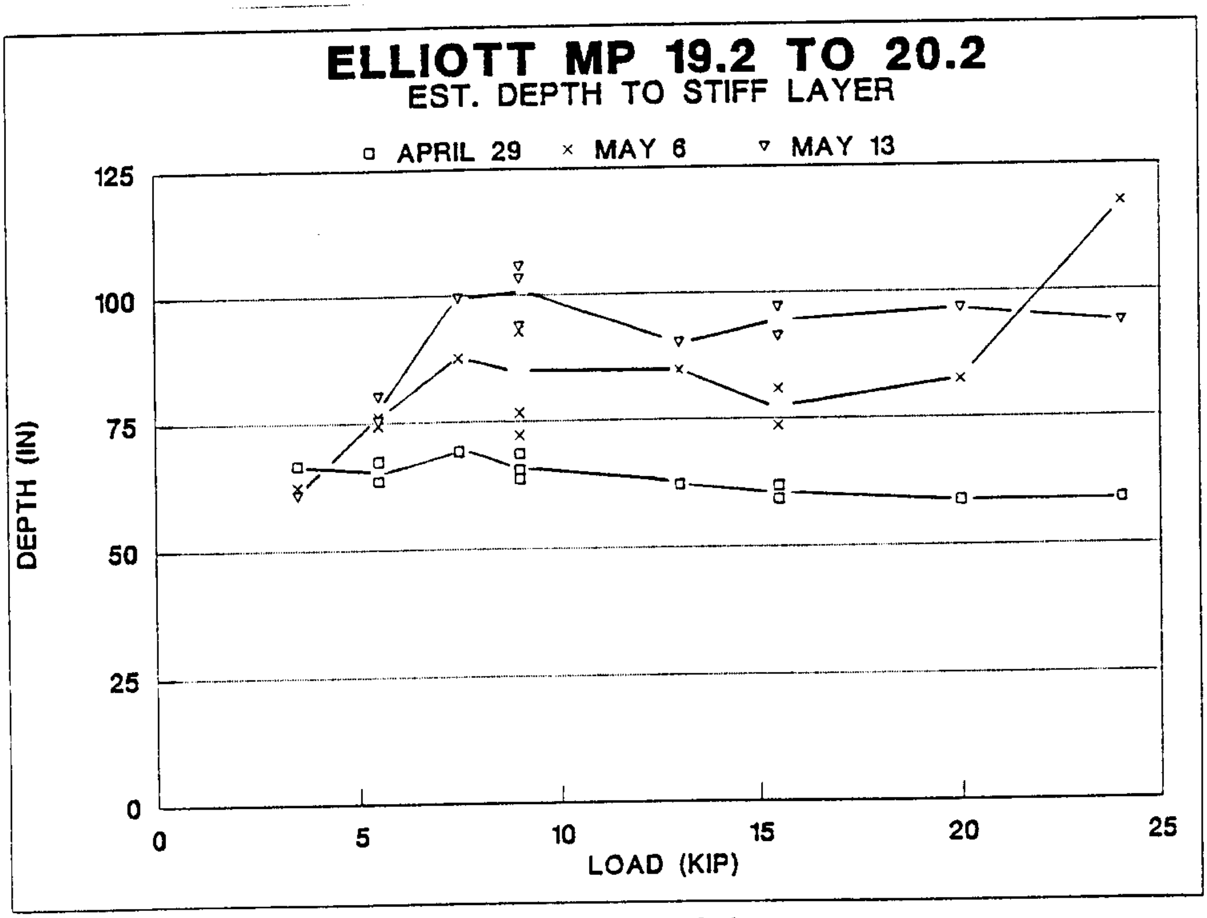


Figure 3.3



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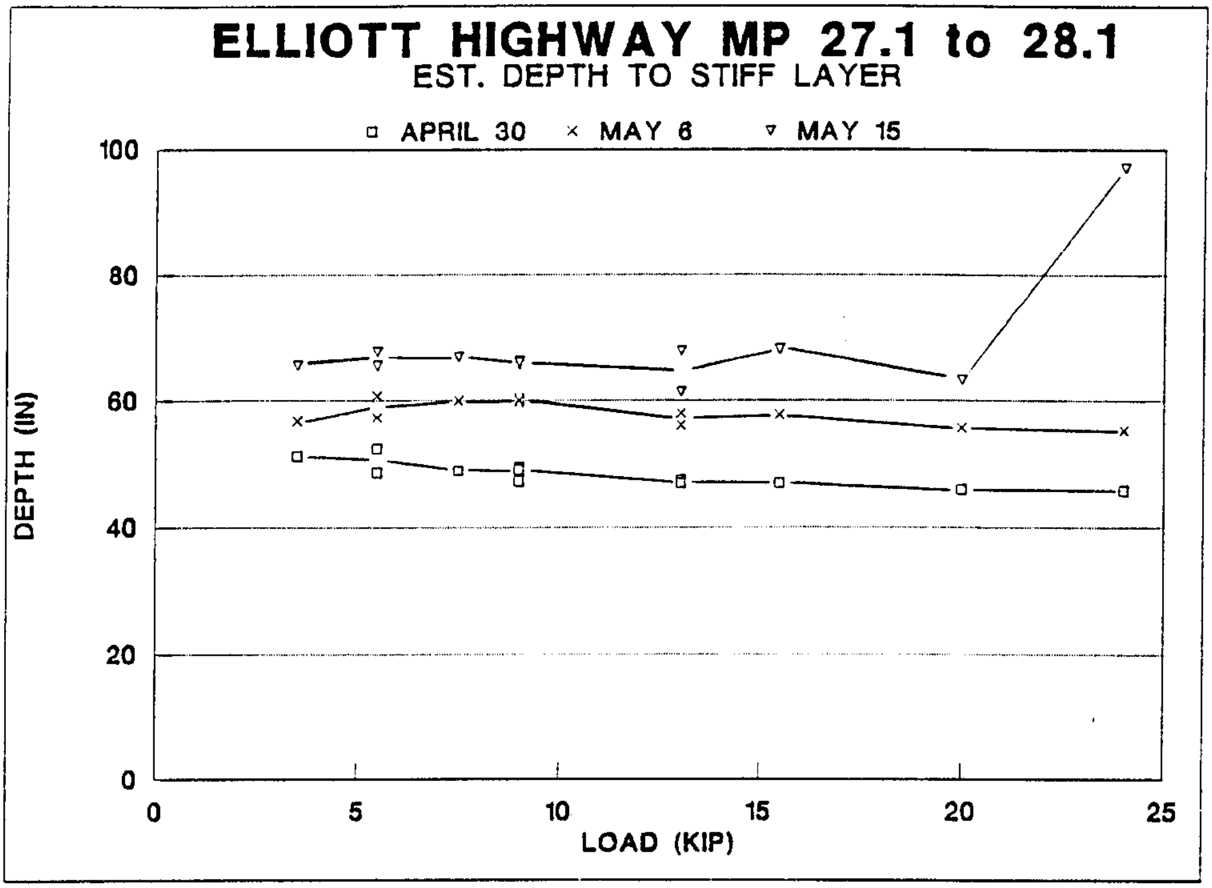

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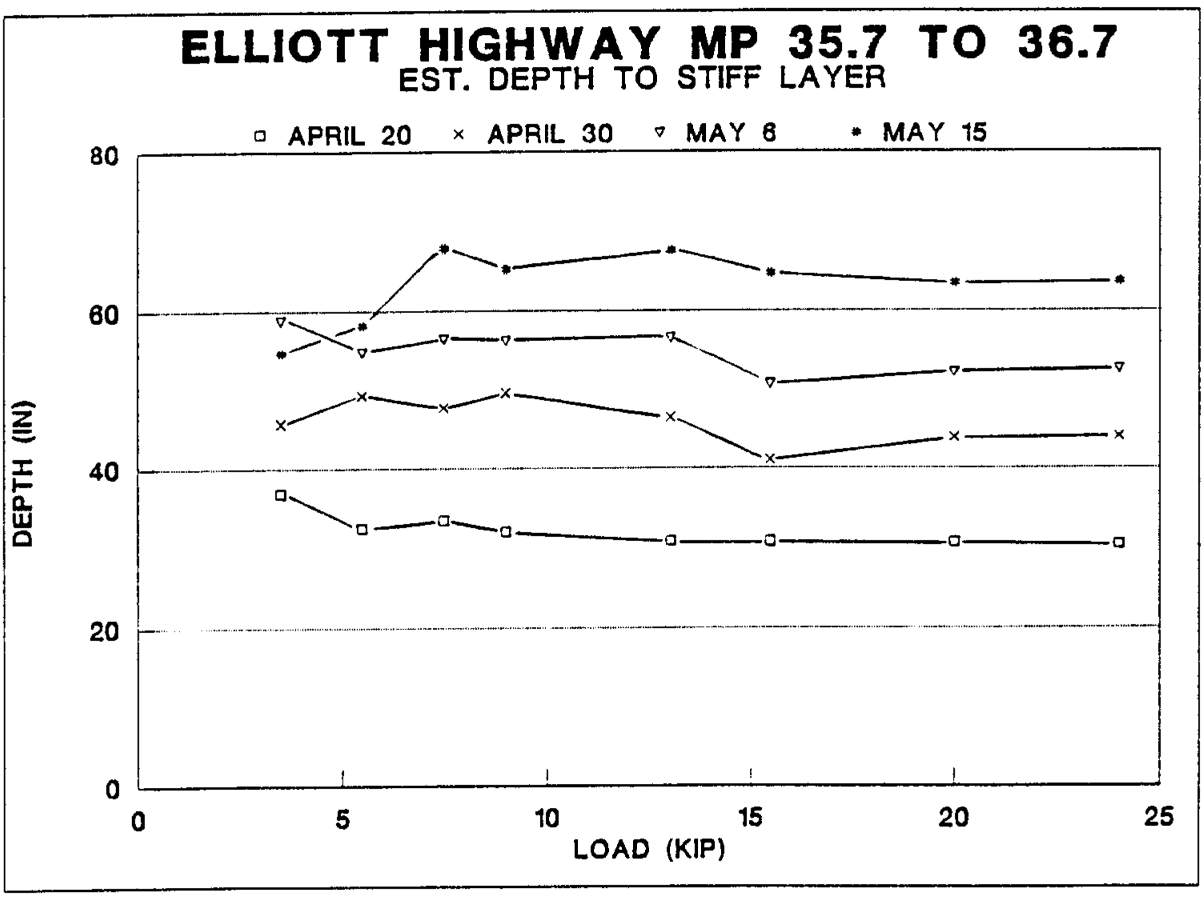


Figure 3.6

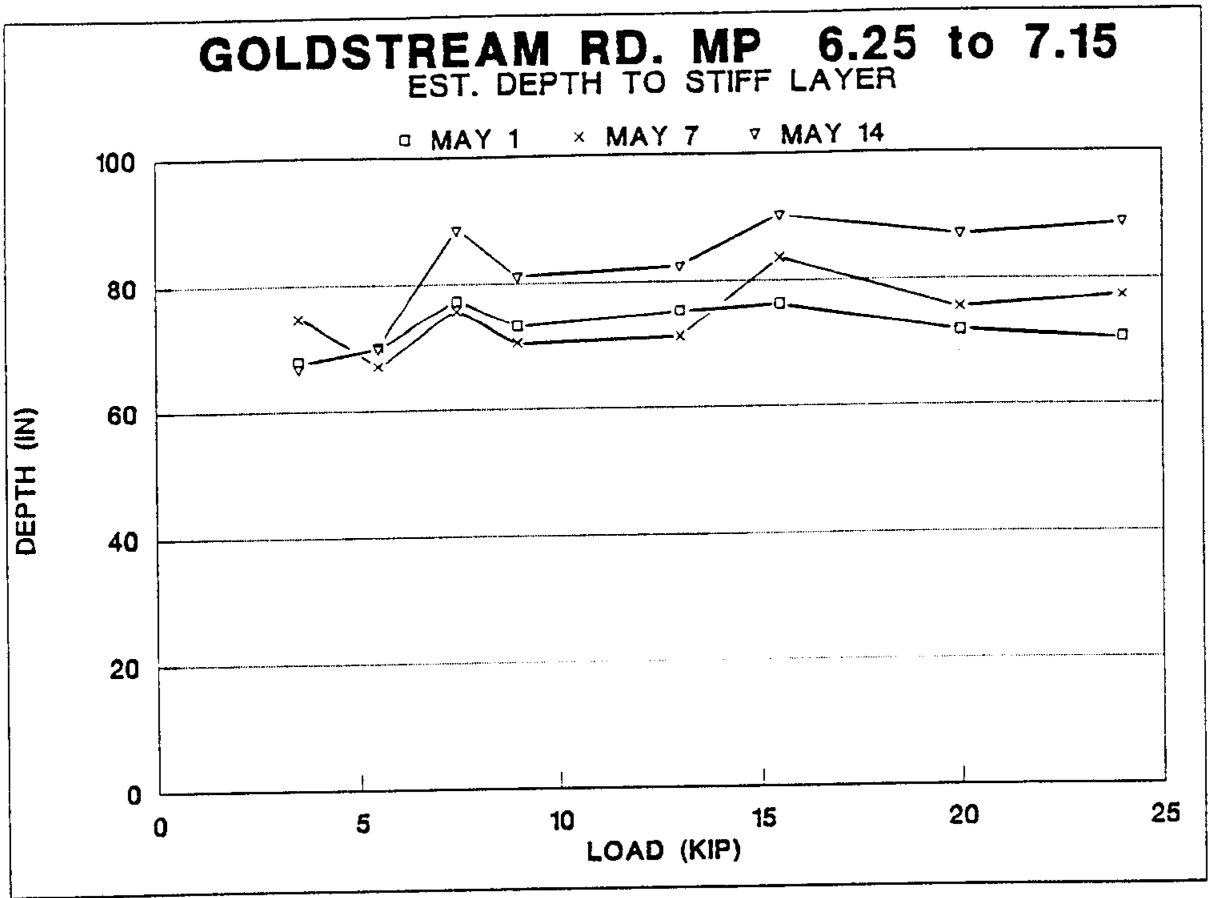


Figure 3.7

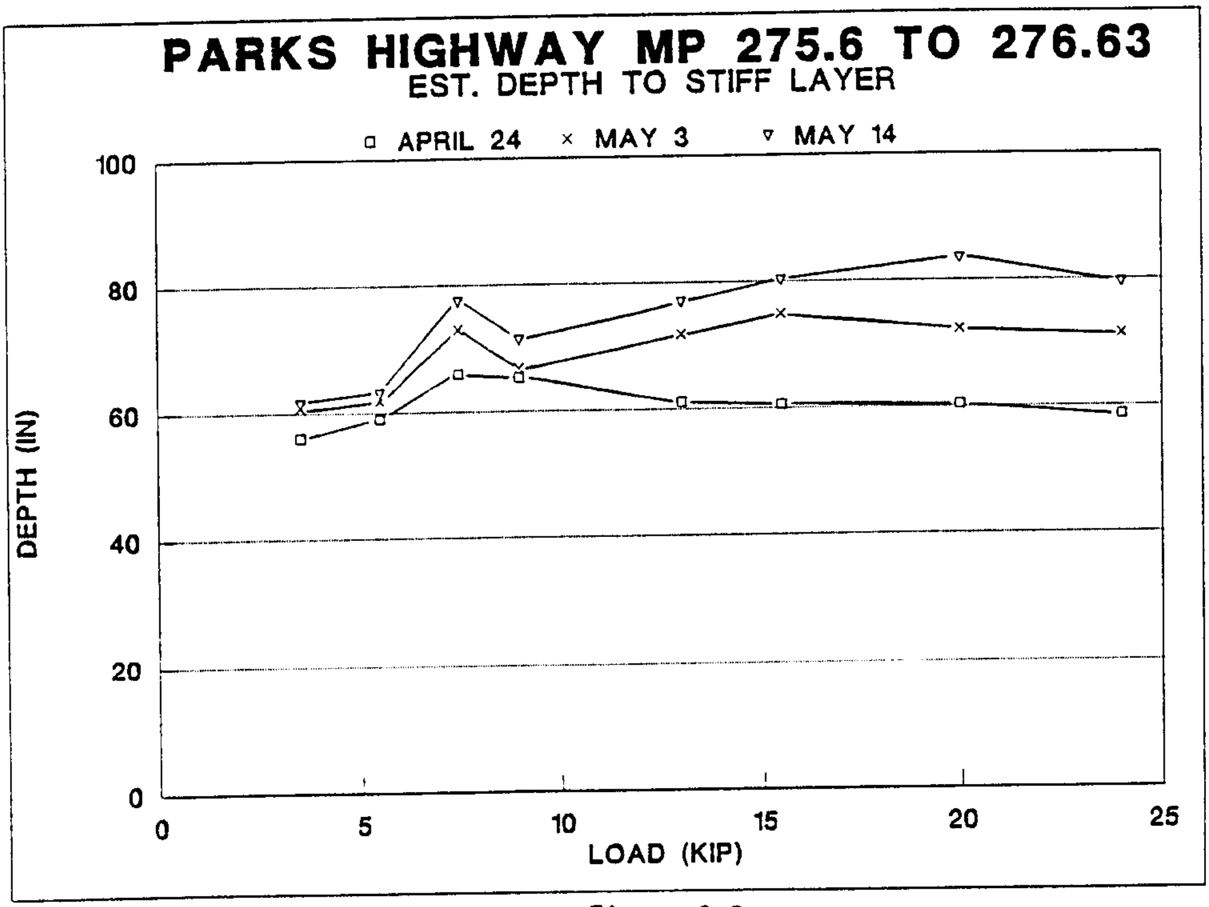


Figure 3.8

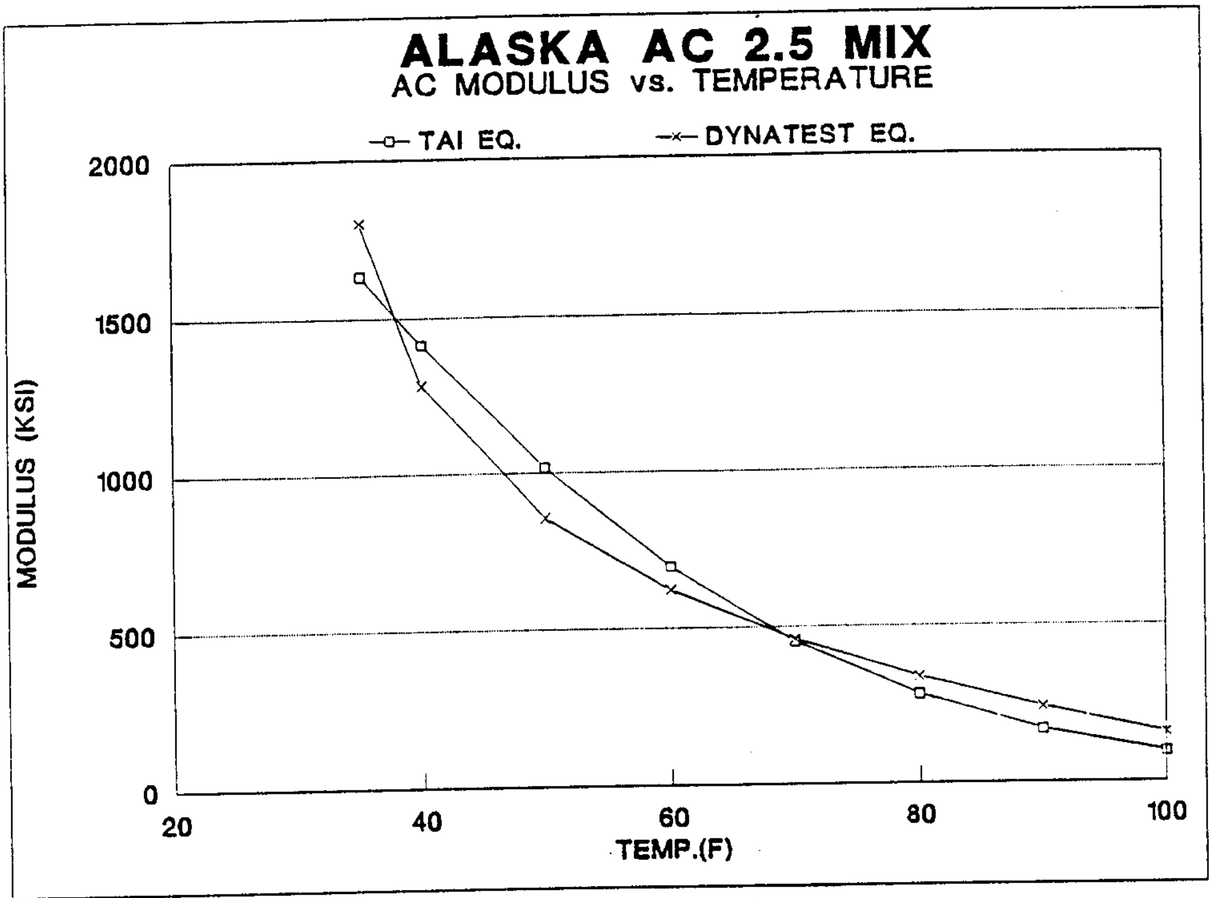

ALASKA AC 2.5 MIX
AC MODULUS vs. TEMPERATURE
TAI EQ.
DYNATEST EQ.
MODULUS (KSI)
2000
1500
1000
500
0
20
40
60
80
100
TEMP.(F)

Figure 3.9

4. ANALYSIS RESULTS

4.1 General

Stresses and strains in the AC, base and subgrade were calculated using the approaches outlined in Chapter 3. The intent of the analysis is to investigate the relationship between damage factor, as defined in Chapter 3, and maximum center deflection or applied load. Typically, damage considerations are limited to the surfacing (AC) layer and subgrade materials. This approach has been used for this particular project, primarily since there are no generally accepted distress (fatigue or rutting) relationships available for base materials. However, base damage is briefly discussed for one of the data sets and should be investigated further.

4.2 Asphalt Concrete Damage Factors

Calculated tensile strains in the AC layer, as a function of measured deflection, are plotted for each test date and section in Figures 4.1 through 4.8. In all cases, strain is strongly correlated with deflection, as expected. It should be noted that the deflection ranges shown in Figures 4.1 through 4.8 are all related to the same load range (3.5 to 24 kip), i.e. the 23.8 mil maximum deflection shown by the Alaska highway section in Figure 4.1 occurred under an approximate 24 kip load, while this load caused almost 80 mils of deflection on Elliott Highway MP 35.7 to 36.7 section on April 30 (Figure 4.6). These specific deflection range limits need to be considered when using the deflection based damage factor relationships described below. Maximum AC strain levels in Figures 4.1 through 4.8 vary from approximately 217 microstrain to 652 microstrain. The upper limiting value may be related to the bending geometry of the thin (2") AC surfacing itself. For instance, even the strongest pavement section (i.e. Figure 4.1, Alaska Highway MP 282.8 to 283.8) under the lowest load (3,500 lb) will show an increase in maximum tensile strain in the AC simply by increasing AC thickness from 2" to 3", everything else remaining constant. At some point, of course, this trend reverses itself and increasing AC thickness results in reduced maximum tensile strain. For the sections analyzed, all AC thicknesses were 2", so that base or subgrade strains are more critical than AC strain, resulting in higher damage factors than those calculated for the AC layer. This is evident from the data in the following section.

Damage factors (DF) were calculated as outlined in Chapter 3. Various relationships between DF and load or deflection were considered. As an example, Figure 4.9 illustrates an arithmetic plot of DF versus normalized load, for the Elliott 35.7 to 36.7 section. As expected, noting the apparent exponential relationship in Figure 4.9, the data appeared linearly related on a log-log scale for both normalized load and deflection versus damage factor. Load related damage factors for AC are plotted for all test sections in Figures 4.10 through 4.17 and deflection-based plots are shown in Figures 4.18 through 4.25. In all instances, the plotted data show relatively linear trends for specific test dates. The deflection-based plots in Figures 4.18 through 4.25 seem to more clearly delineate damage effects as a function of time of testing than do the load-based plots. For instance, Figure 4.20 shows significantly more damage occurring for April 15 than May 13 at any given deflection on Elliott Highway MP 10 to 11. The corresponding load plot in Figure 4.12 does not show as definite a variation for all load levels. Inspection of Figures 4.18 through 4.25 tends to reinforce the impression that significant thawing may have taken place prior to testing most of the sections. Figures 4.19, 4.20, 4.23 and 4.25 show evidence of thaw weakening (i.e. increased damage during thaw for a given deflection level). <u>All</u> of these sections were tested at least once before April 24. The remaining sections (Figures 4.18, 4.21, 4.22 and 4.24) show little or no evidence of thaw weakening. Only <u>one</u> (Figure 4.18, Alaska Highway MP 282.8 to 283.8) of these was tested prior to April 29 and it may be that this section of the Alaska Highway is not susceptible to thaw weakening.

Linear regression analyses were performed on the data plotted in Figures 4.10 through 4.25 to determine the regression constraints A, B, C and D in the relationships:

$$DF = A \left(\frac{LOAD}{9000}\right)^{B} \qquad \text{Eq. 4.1}$$

$$DF = C\ (Deflection)^{D} \qquad \text{Eq. 4.2}$$

where

Load = applied wheel load (lb)

Deflection = center deflection (mil)

Tables 4.1 and 4.2 list the regression results for AC damage based on equations 4.1 and 4.2 respectively. Extremely high correlation coefficients, generally in excess of 0.99, were calculated for each specific test section on any given date. Combined data for all test dates on a given section shows slightly lower correlation coefficients, all in excess of 0.91. The constants A, B, C and D from Tables 4.1 and 4.2 are plotted as a function of test date in Figures 4.26 through 4.29, which seem to indicate that the exponents B and D (Figures 4.27 and 4.29) remain relatively constant during the thaw period while the intercepts A and C introduce a multiplicative factor into the damage relationship. This factor appears to tend towards 1.0 for the load-related case (Figure 4.24) when no thaw weakening effects are present; and reaches a value of almost 3 for the section showing significant thaw weakening. There does not appear to be any such trend for the deflection-related plot in Figure 4.28. This is probably due to the fact that the load-related analyses involve a load parameter normalized relative to 9000 lb whereas the deflection analyses simply involve the actual deflection in mils. As such, the deflection related equations in Table 4.2 should probably be applied to similar pavements and deflection ranges only. Also, it is recommended that future analyses consider a normalized deflection parameter.

The damage factors are probably governed by the choice of fatigue equation (for example, Eq 3.4 for AC, where the exponent is 3.291). If this is the case, then the expected value of the exponent in the load-related equations would be approximately 3.291. However, the exponents are somewhat attenuated to a range of 2.4 to 3.1 in the load-related equations (Table 4.1). For the deflection-related equation, the range is 2.8 to 3.5 (Table 4.2).

4.3 Subgrade Damage Factors

The damage factor calculation procedure used for the subgrade was similar to the AC approach except that vertical compressive strain was used instead of horizontal tensile strain. Subgrade damage factors are substantially higher than the AC damage factors for the specific pavement sections studied, and maximum subgrade damage occurs later than maximum AC damage, as expected.

Figure 4.30 shows subgrade damage factors for Elliott 35.7 to 36.7, corresponding to the AC damage factors shown in Figure 4.9. Comparison of these two figures indicate that the subgrade damage factors are approximately 20 times higher than the AC damage factors and occurred on April 30 rather than April 20. The higher subgrade damage levels may be related to the fact that tensile strain levels generated in the thin (2") AC section are limited by geometry, as discussed in Section 4.2. Maximum subgrade damage levels are related to the time when the subgrade is partially thawed. The available data is insufficient to determine how much subgrade thaw has occurred when maximum damage occurs.

Load-related subgrade damage factors are plotted in Figures 4.31 through 4.38, and deflection-related damage factors are shown in Figures 4.39 through 4.46. Trends are similar to those for the AC damage factors except for absolute magnitude and date of maximum damage occurrence.

Regression analyses were carried out based on equations 4.1 and 4.2, and the results are listed in Tables 4.3 and 4.4. As for the AC analyses, extremely high correlation coefficients were found. The data in Tables 4.3 and 4.4 are plotted in Figures 4.47 through 4.50. Inspection of Tables 4.3 and 4.4 as well as Figures 4.47 through 4.50 seems to indicate similar relationships to those observed for the AC. Although there is a larger range in exponents (3.1 to 4.9 for load related and 4.1 to 5.0 for deflection-related factors) the major effect of thaw weakening again appears to be multiplicative in terms of intercepts A and C. For the load related case, intercept A reaches a maximum value of almost 14 and again appears to tend towards 1.0 in those cases where little or no thaw weakening occurs. This is expected since the load parameter is normalized relative to 9,000 lb. No such trend is evident for the deflection-based analyses, where the deflection parameter has not been normalized. Future analyses should involve a normalized deflection parameter.

The subgrade fatigue equation (Equation 3.5) exponent of 4.477 seems to be reflected by the deflection related exponents in Table 4.4 and Figure 4.50. Load related exponents in Table 4.3 appear to vary quite significantly from the value of 4.477. These variations may be related to non-linear response characteristics of the pavement structures. For instance, the Parks Highway exponents are the only ones in excess of the fatigue equation value, and this is the only section that appears to show a stress softening response in Table 2.3.

4.4 Base Course Damage

In typical analytical procedures, the response of unbound materials other than the subgrade to repeated loading is usually ignored. Very little data is available in terms of fatigue relationships for base and subbase materials, although it is expected that such relationships will be developed.

For this project, preliminary analyses of base damage for the section exhibiting significant thaw weakening (Elliott 35.7 to 36.7) was carried out since it was thought that base damage may in fact be more critical than AC damage in thin pavements. The subgrade vertical strain relationship (Eq 3.5) was applied to the base course calculated strains for illustrative purposes. Figure 4.51 shows the plotted base damage factors for the Elliott 35.7 to 36.7 section. Corresponding AC damages are shown in Figure 4.9, and subgrade damage in Figure 4.30. Comparison of these figures yields the following observations

i) Maximum AC damage and maximum base damage occurs at about the same time.

ii) For the thin section under consideration, base damage may be more critical than AC damage. This is certainly the case (by factor of about 4) if the subgrade fatigue equation (Eq. 3.5) is in fact applicable to base response. Actual base response would determine relative damage.

iii) Maximum subgrade damage may be greater than that shown by base, and occurs at a different time. A definitive base damage function is required before it can be reliably determined whether base damage is more severe than subgrade damage.

Based on this, it appears that further investigation is desirable to determine actual base damage factors, using a fatigue or performance relationship that is relevant to the base material. In general, however, it is apparent that base course damage should be considered since it may govern damage occurring near the pavement surface. Also, since subgrade damage occurs later than AC or base damage, a combination of surface (i.e. AC or base) damage and subgrade damage should be considered in evaluating traffic damage effects occurring during the thaw period.

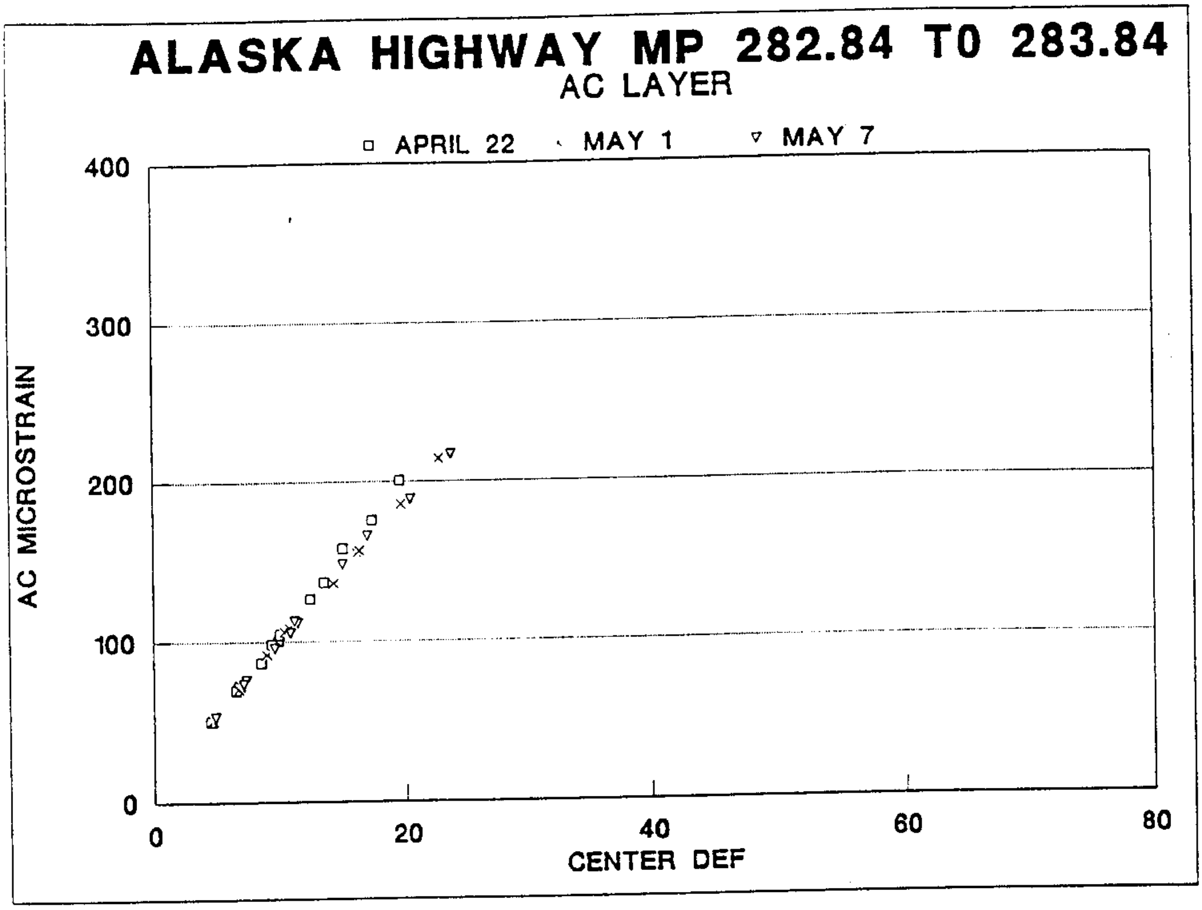


Figure 4.1

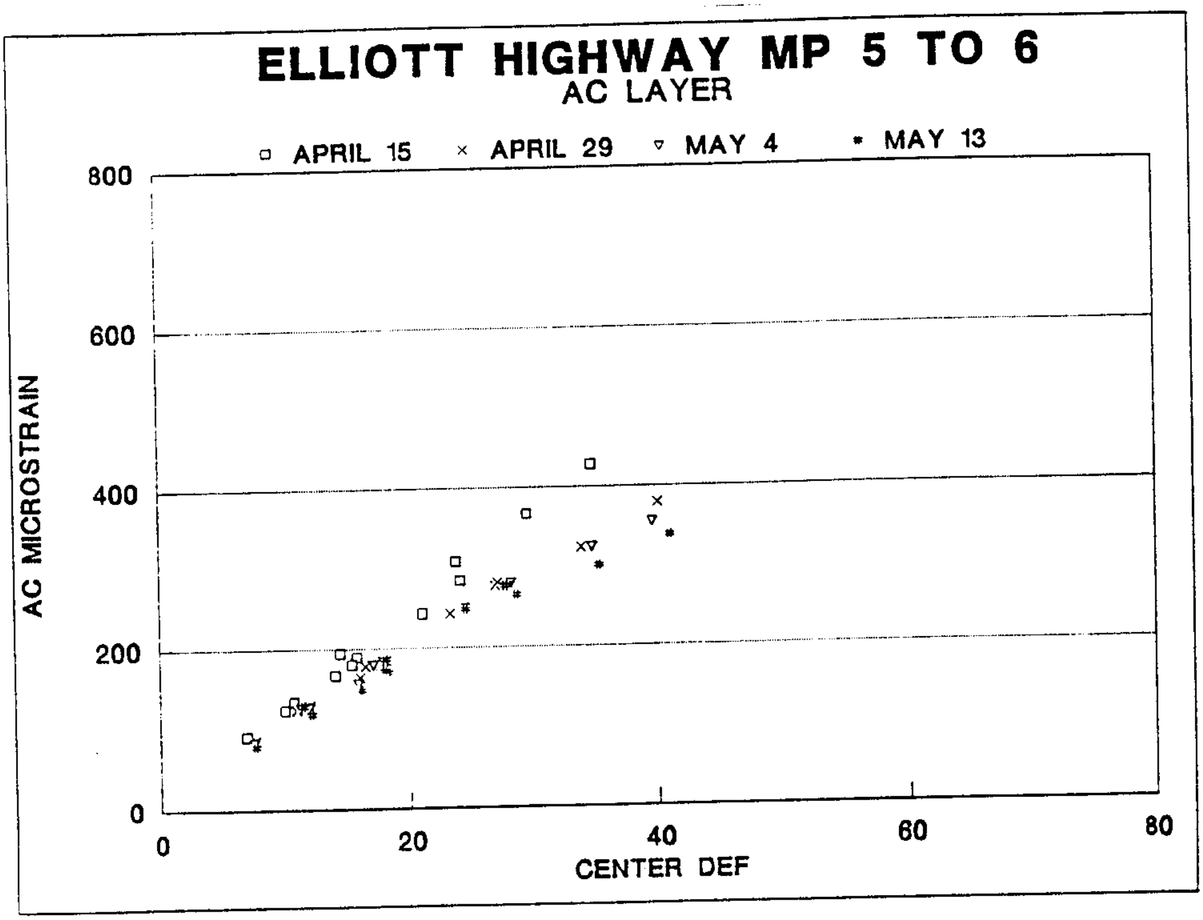


Figure 4.2

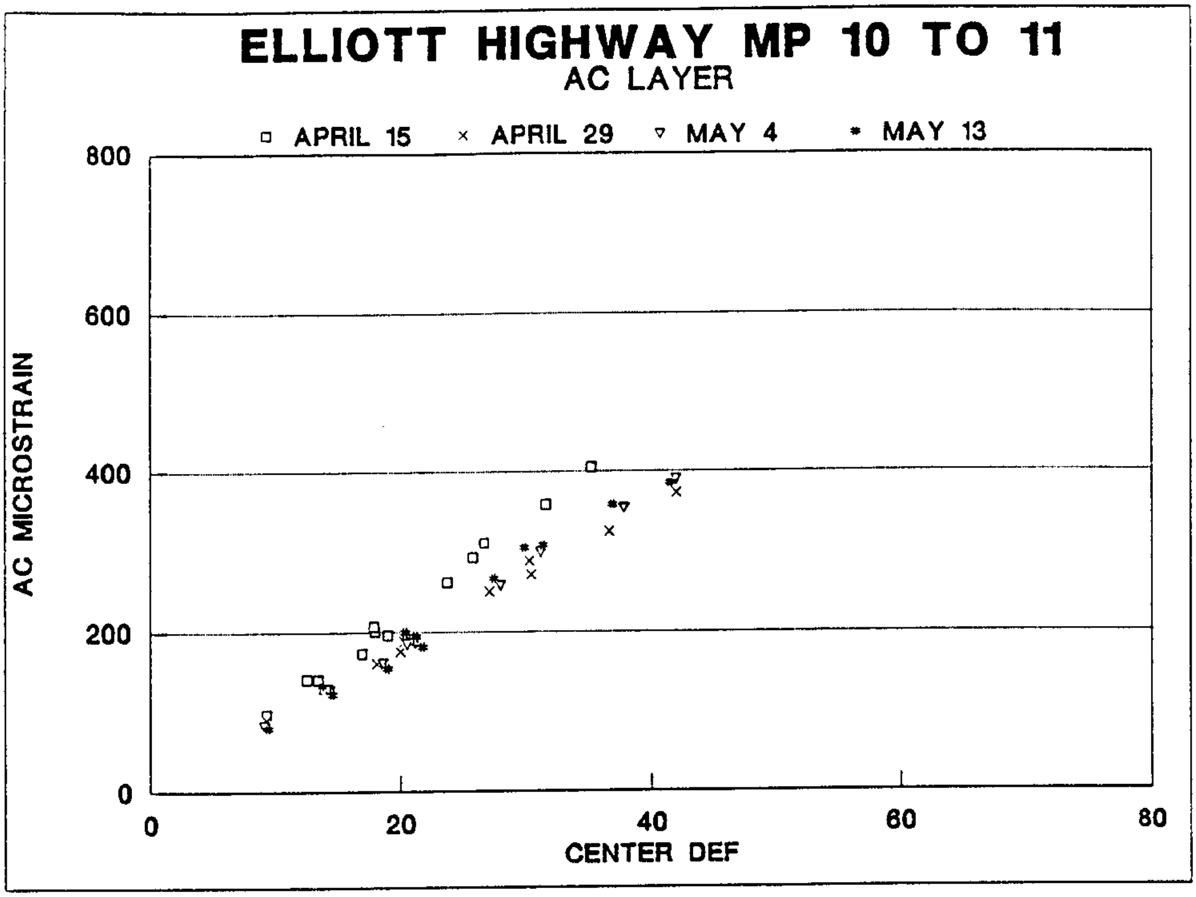


Figure 4.3

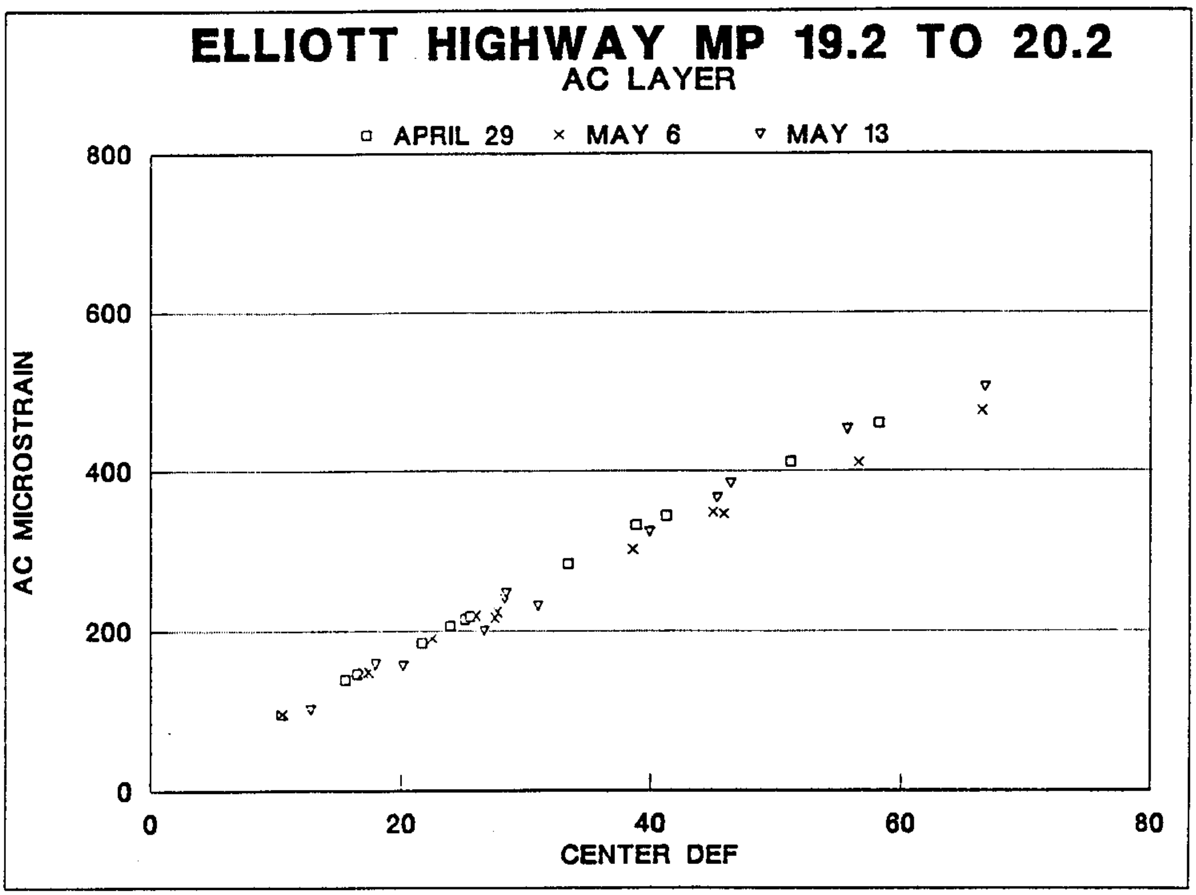


Figure 4.4

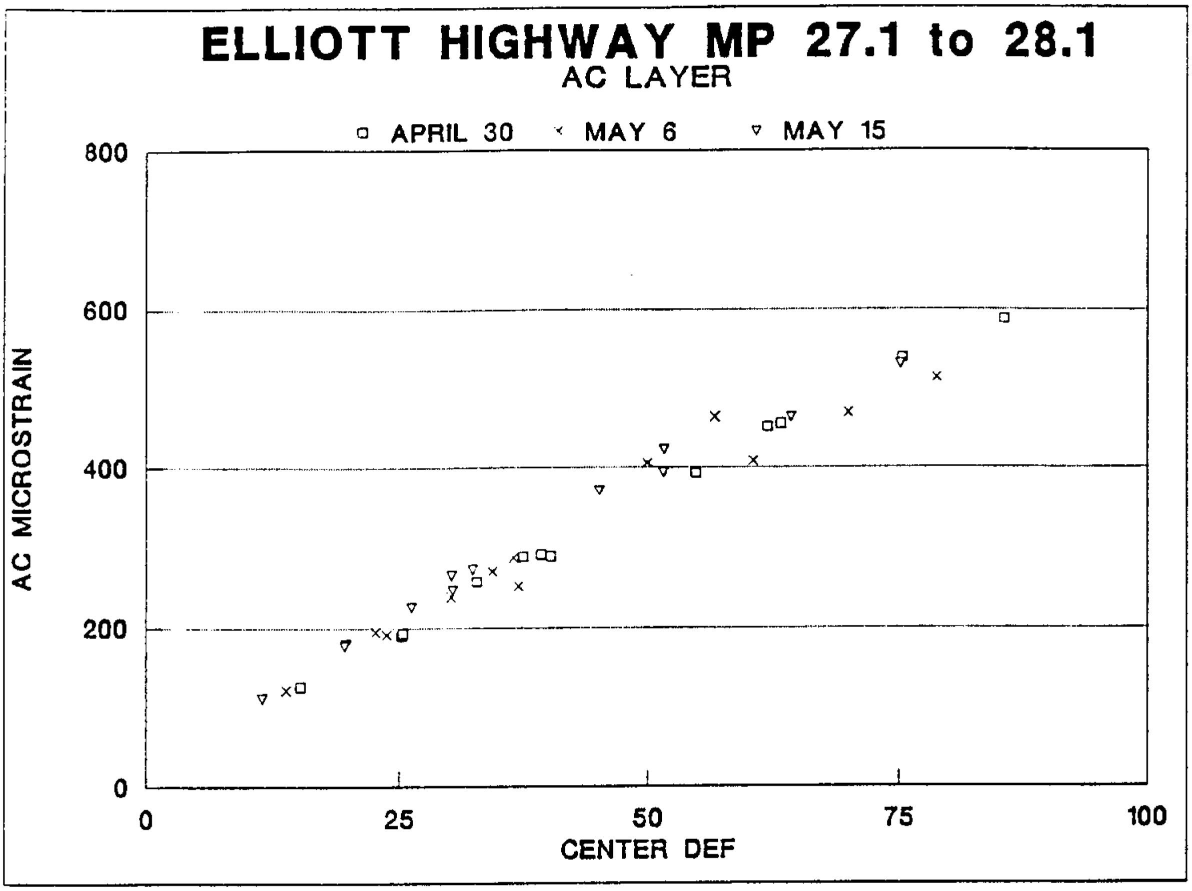


Figure 4.5

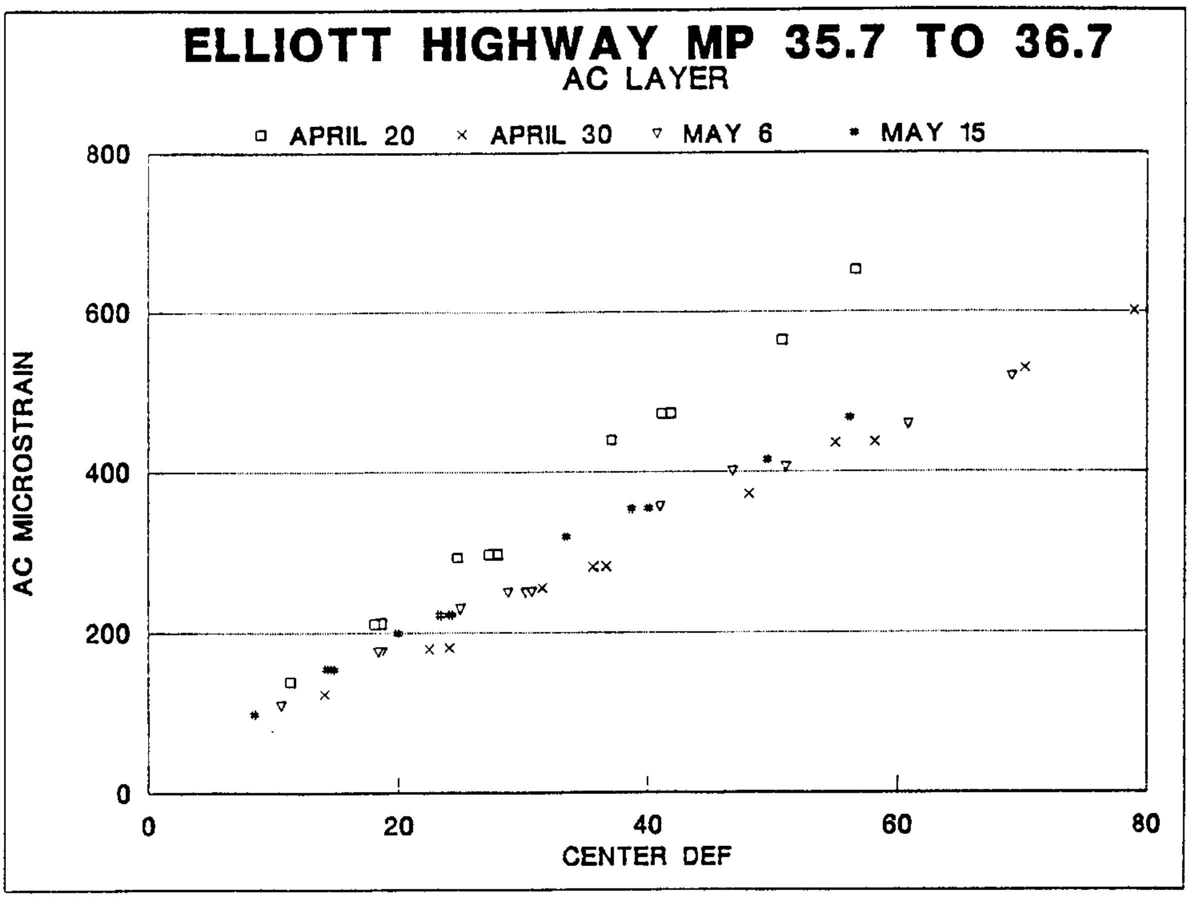


Figure 4.6

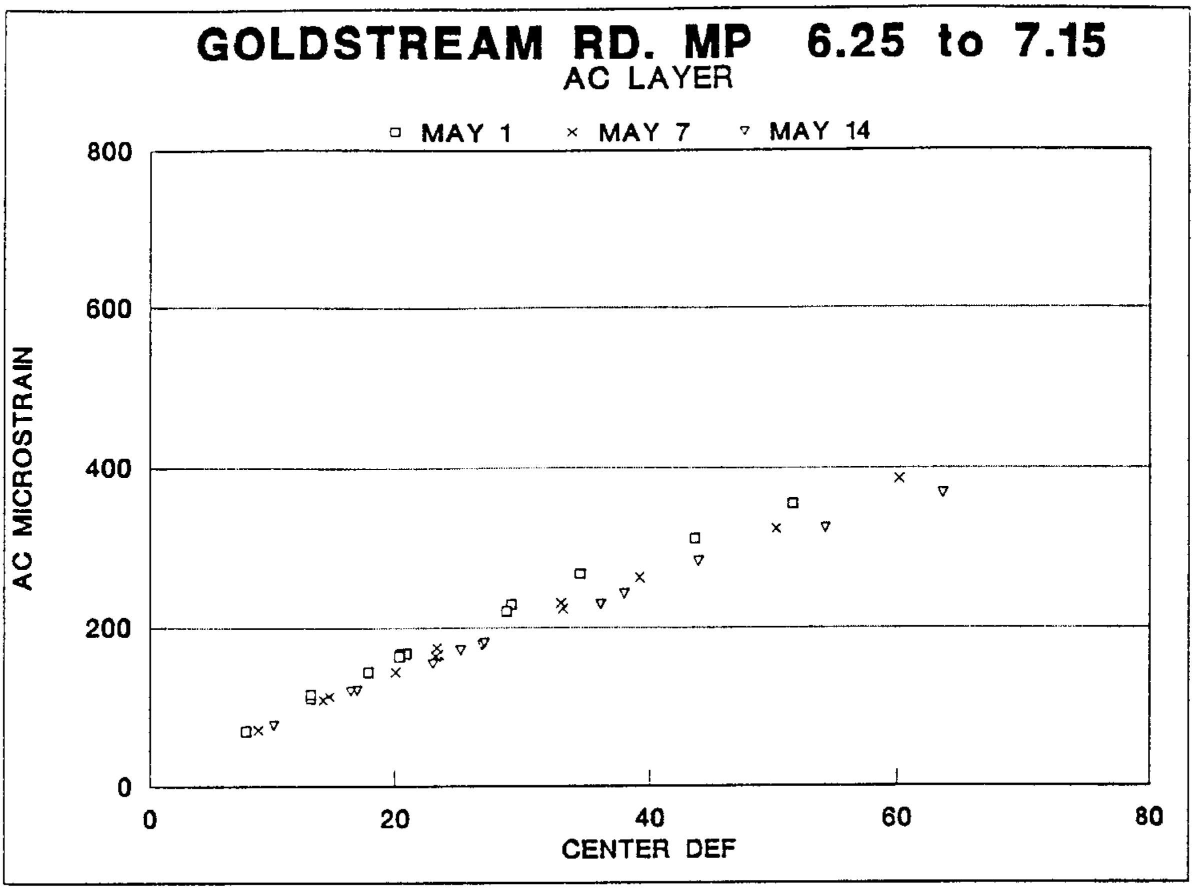


Figure 4.7

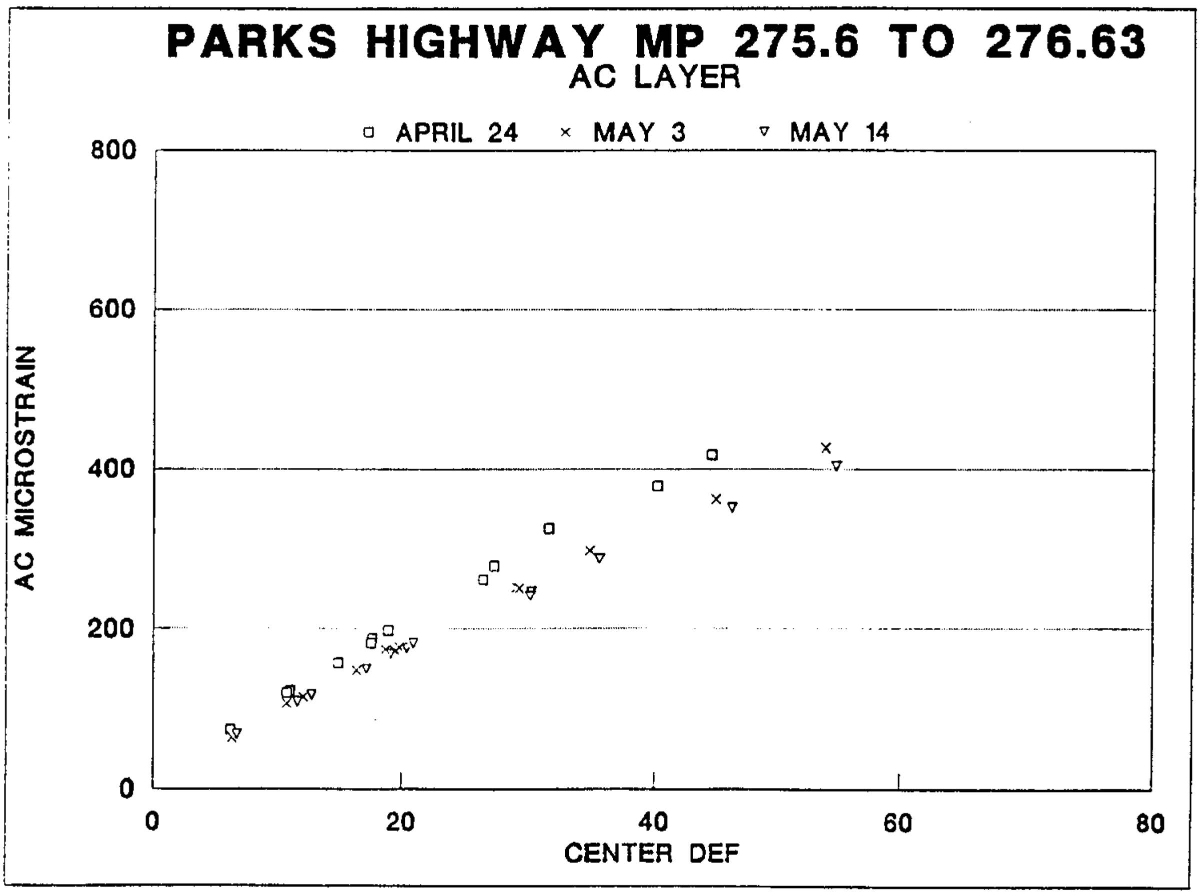


Figure 4.8

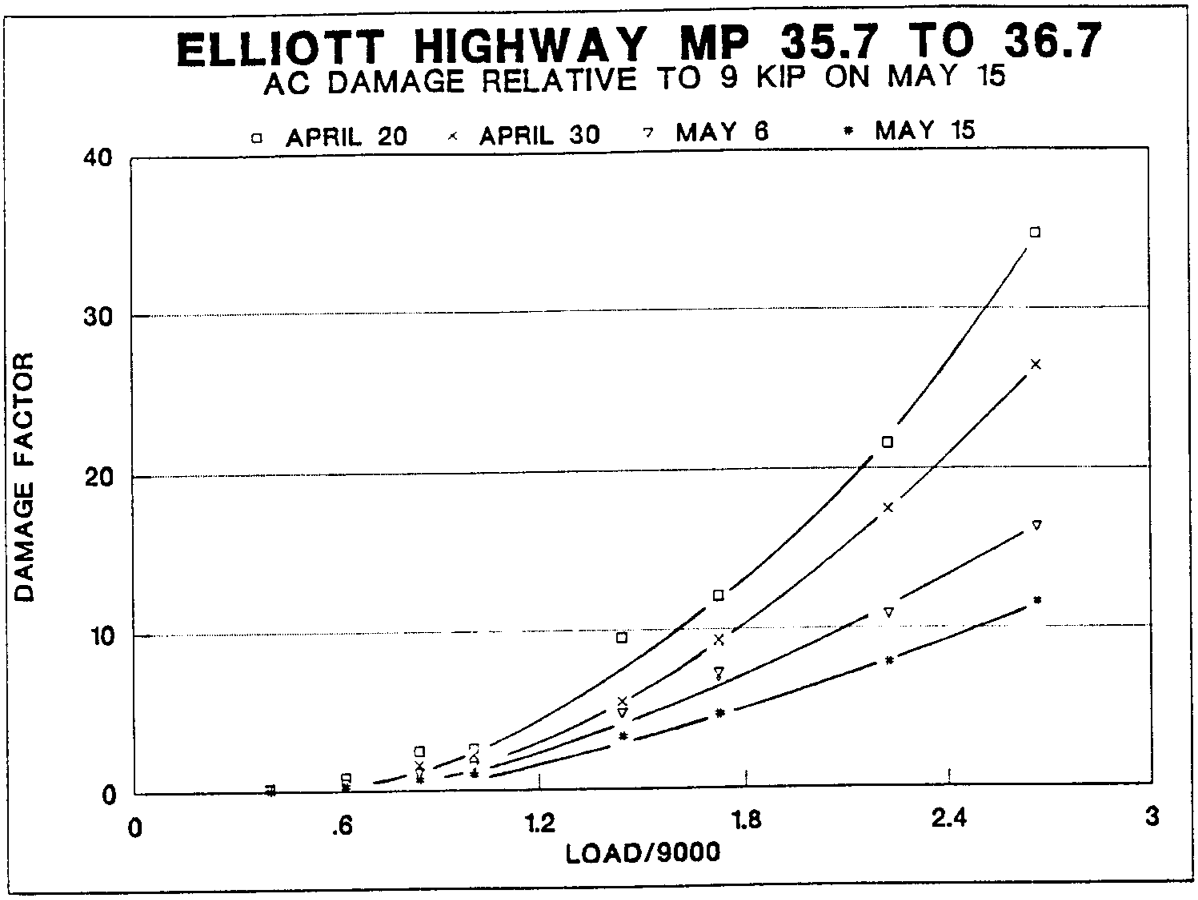


Figure 4.9

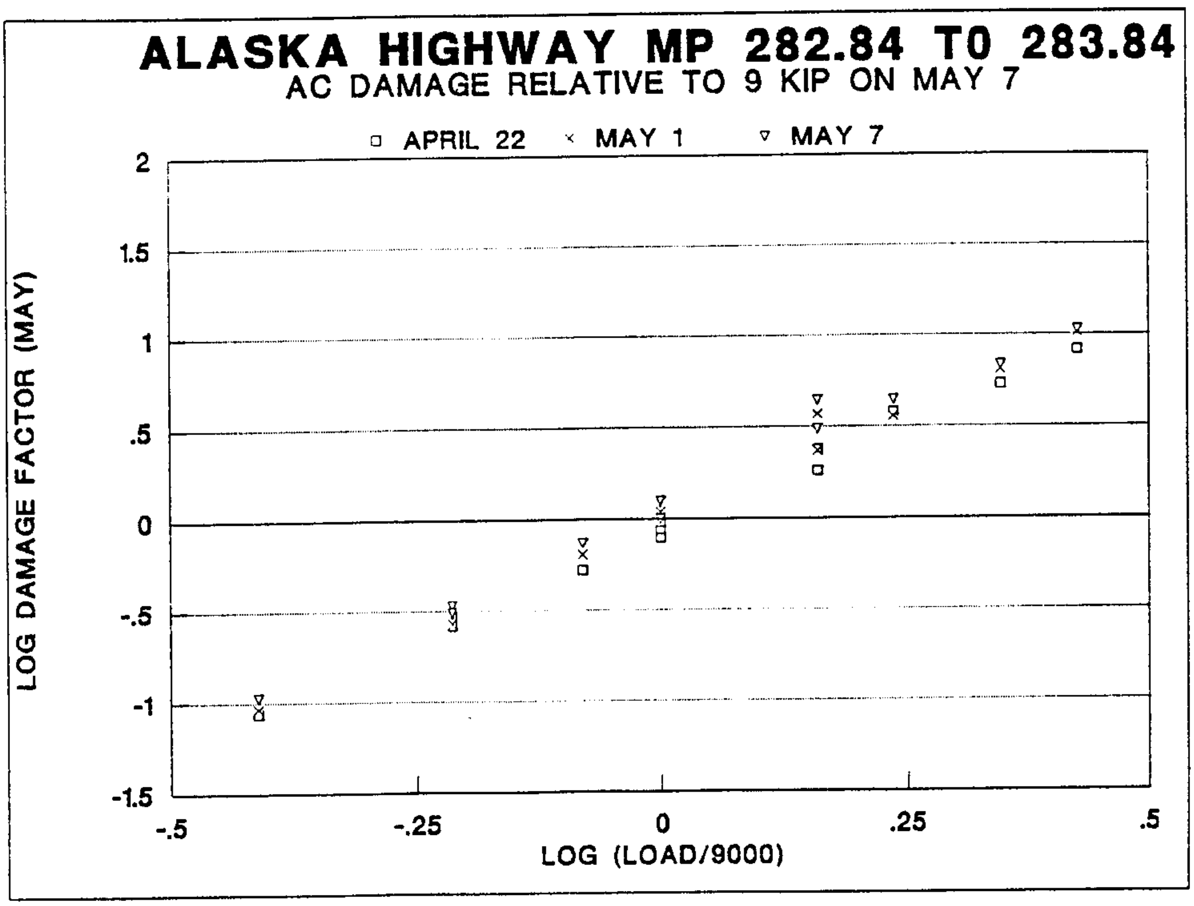


Figure 4.10

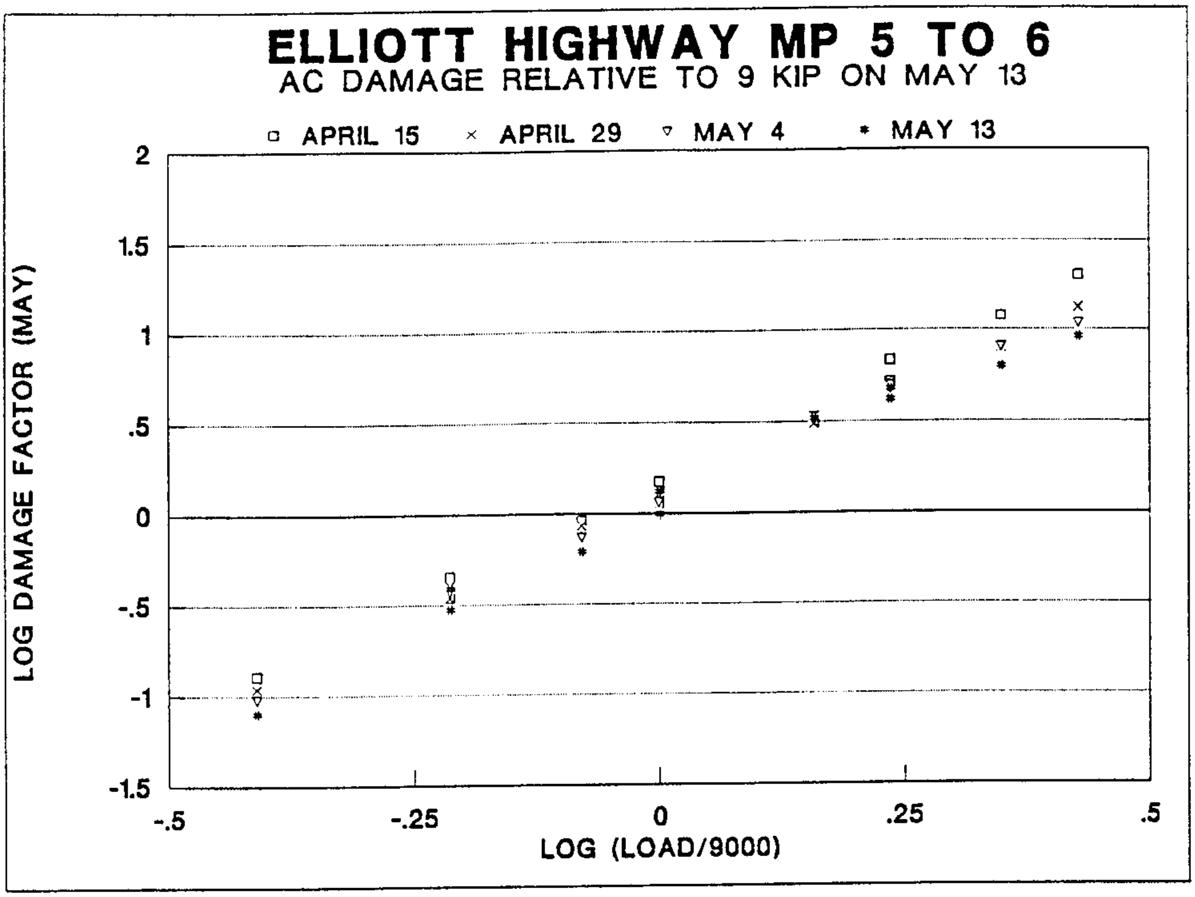


Figure 4.11

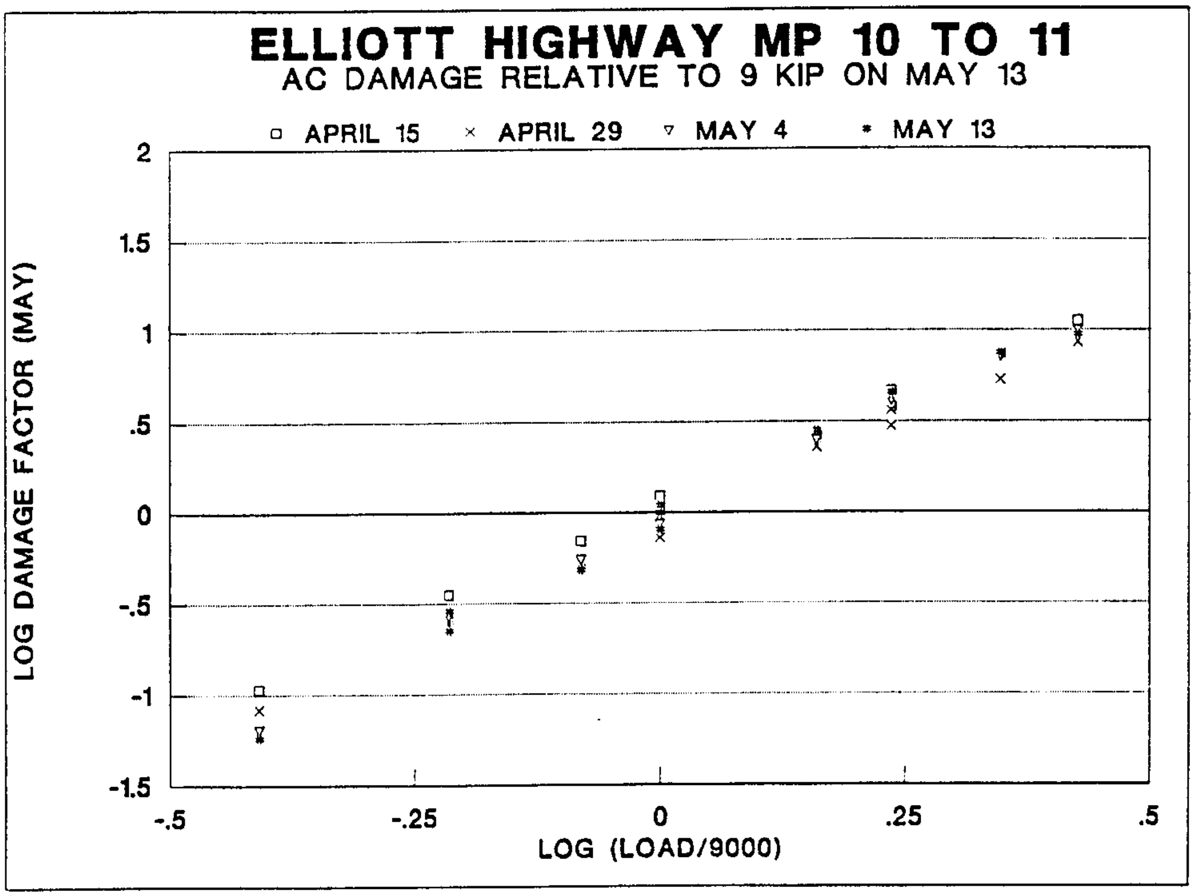


Figure 4.12

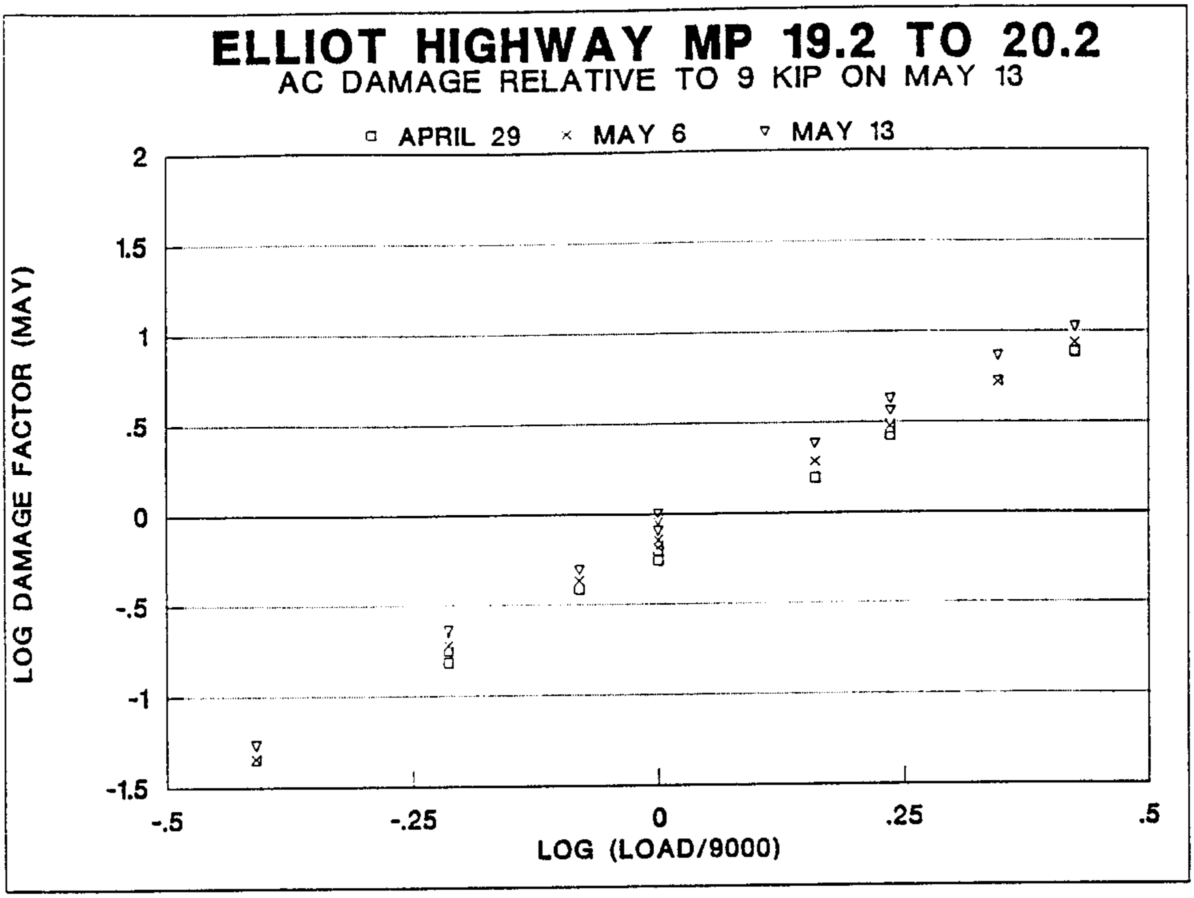


Figure 4.13

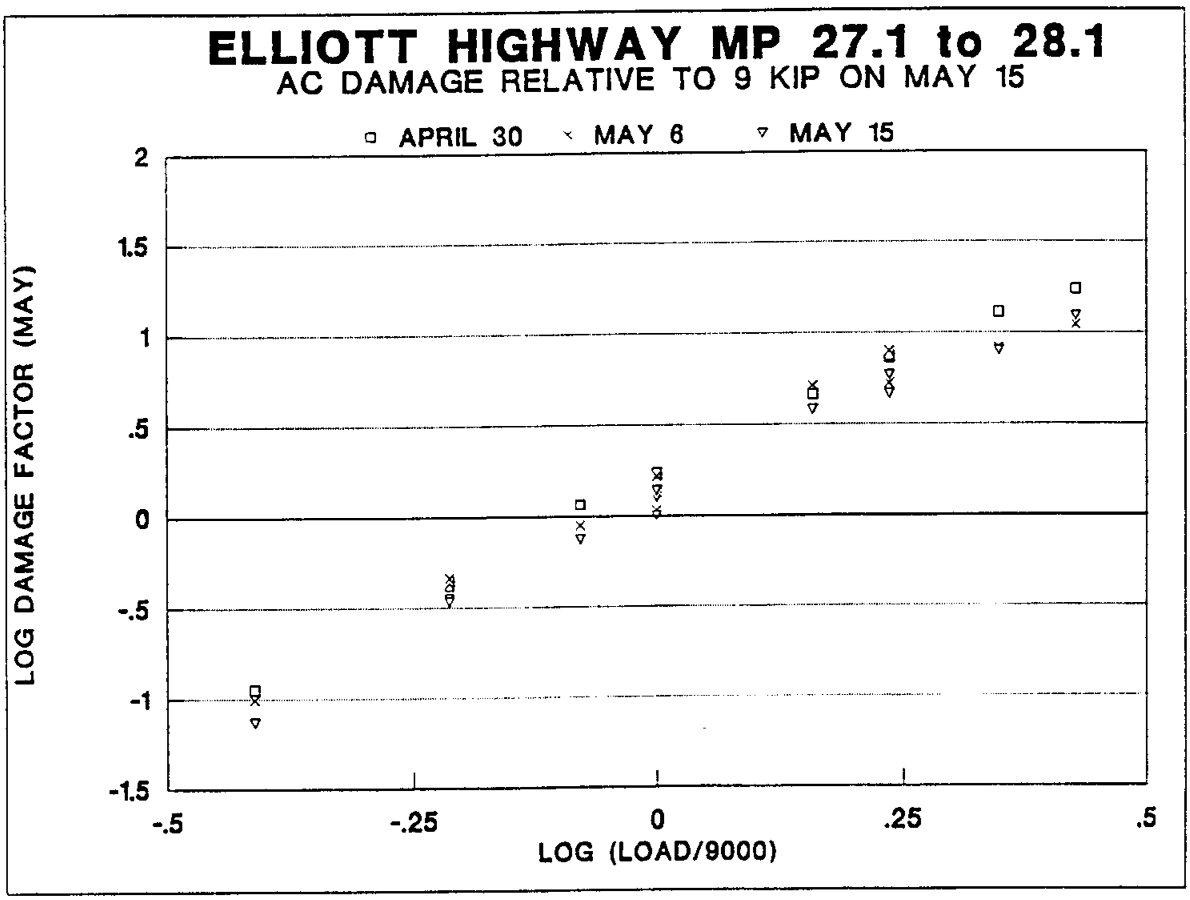


Figure 4.14

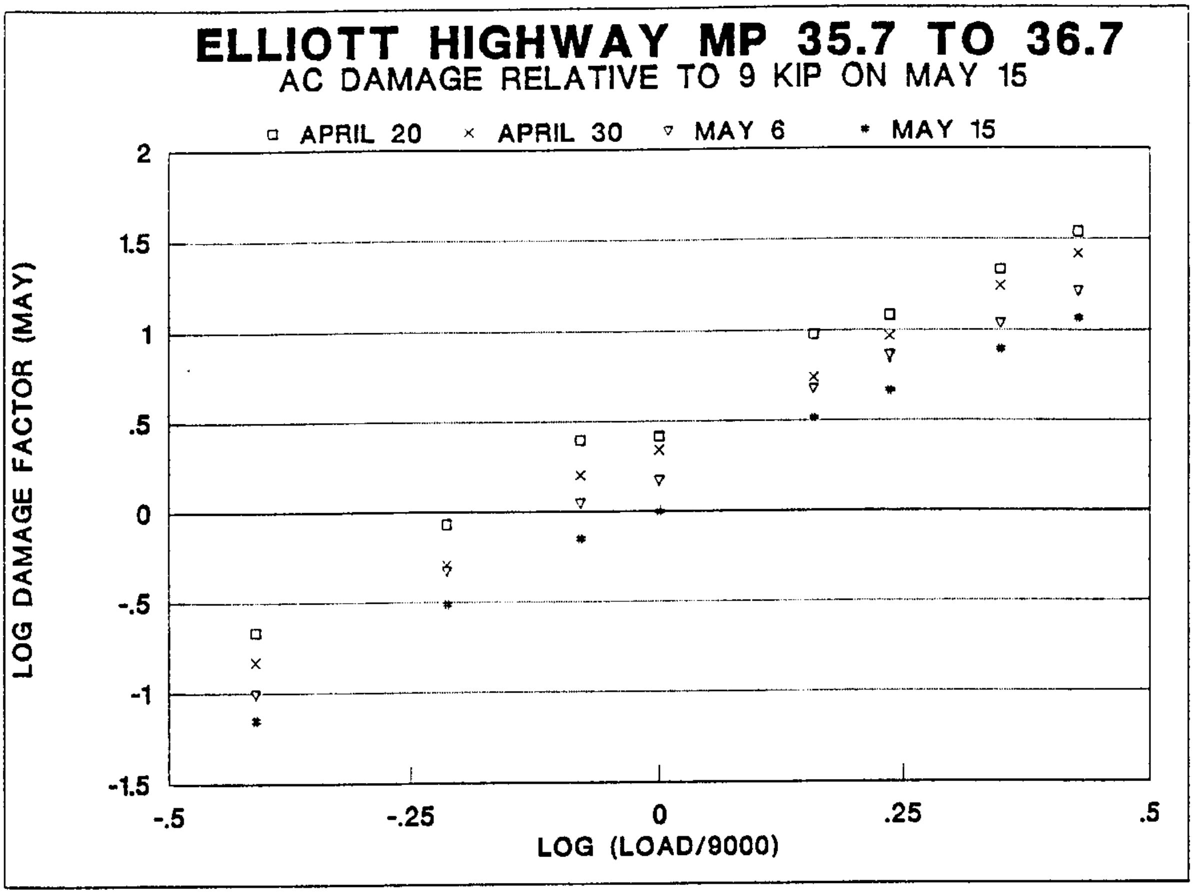


Figure 4.15

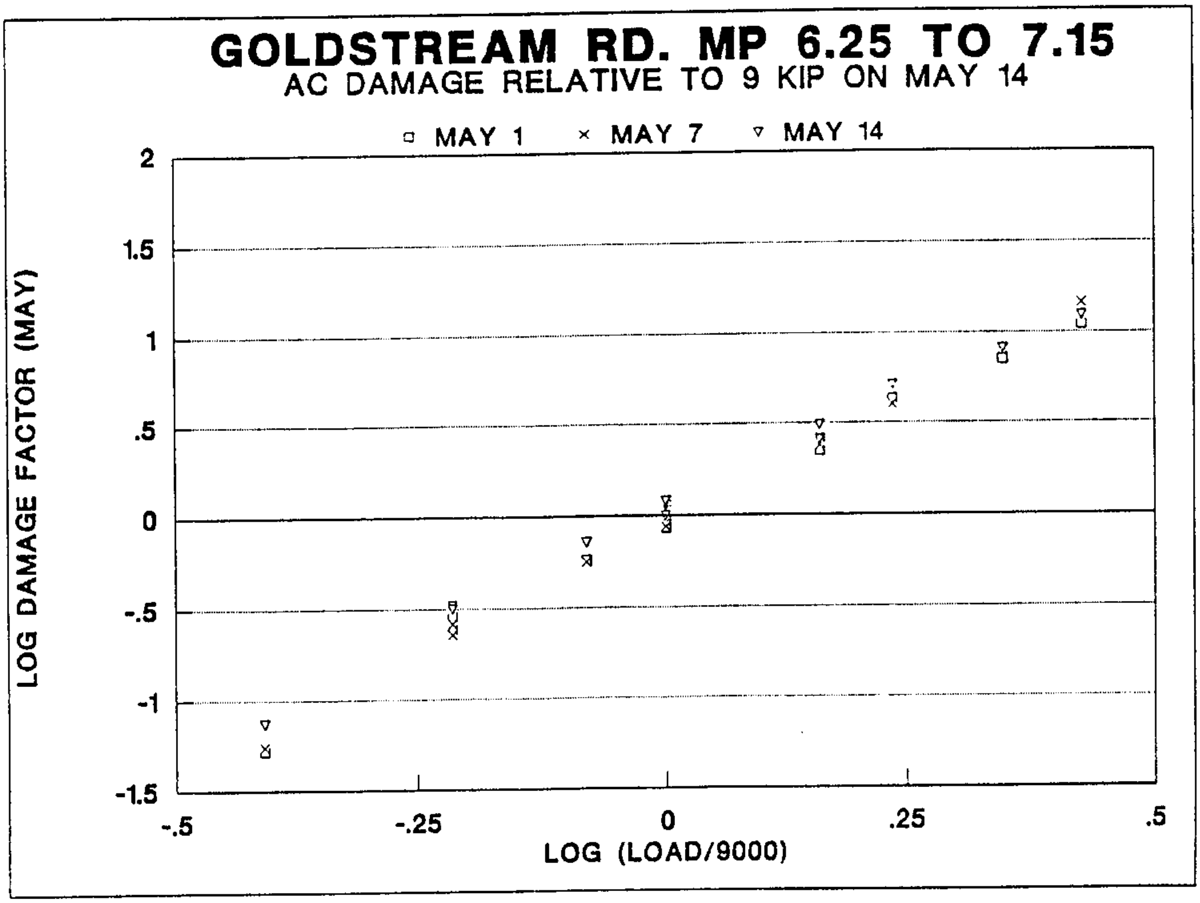


Figure 4.16

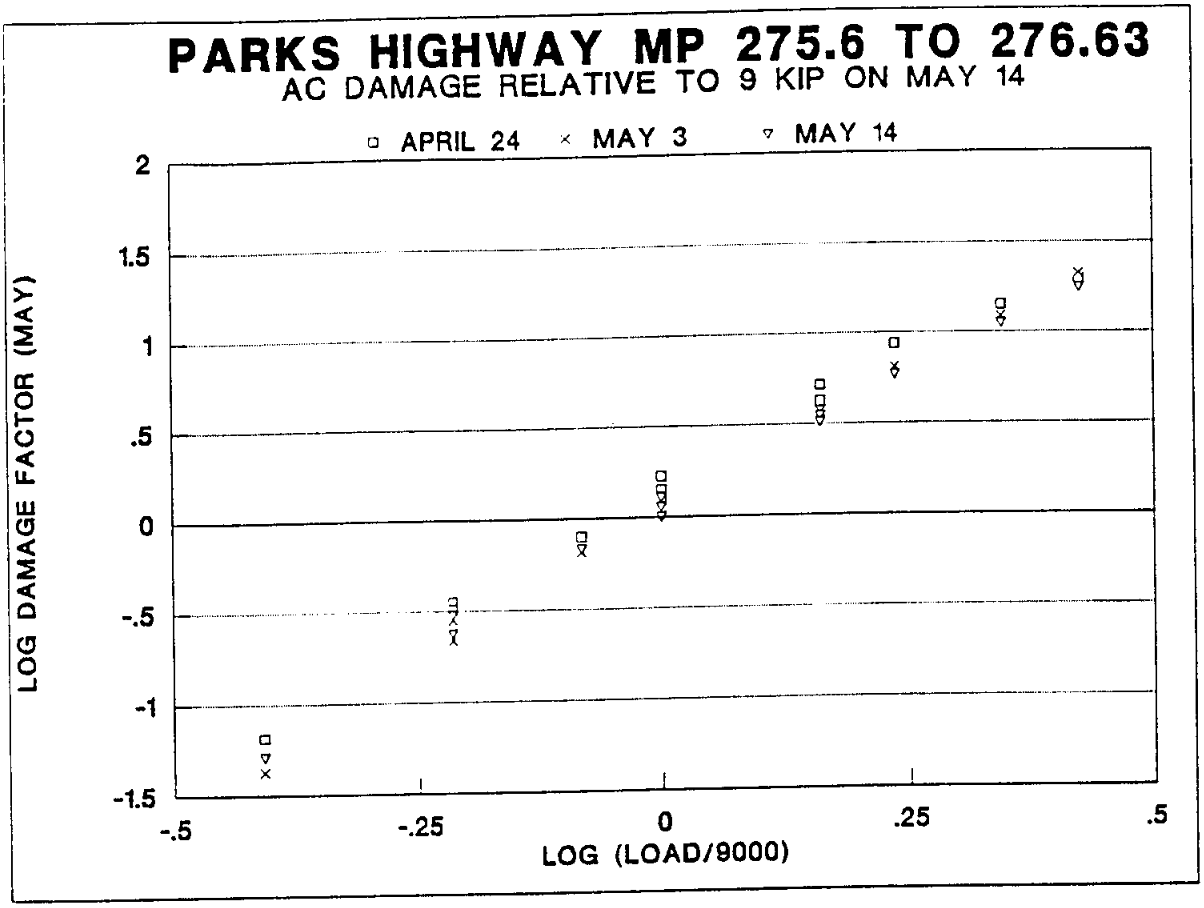


Figure 4.17

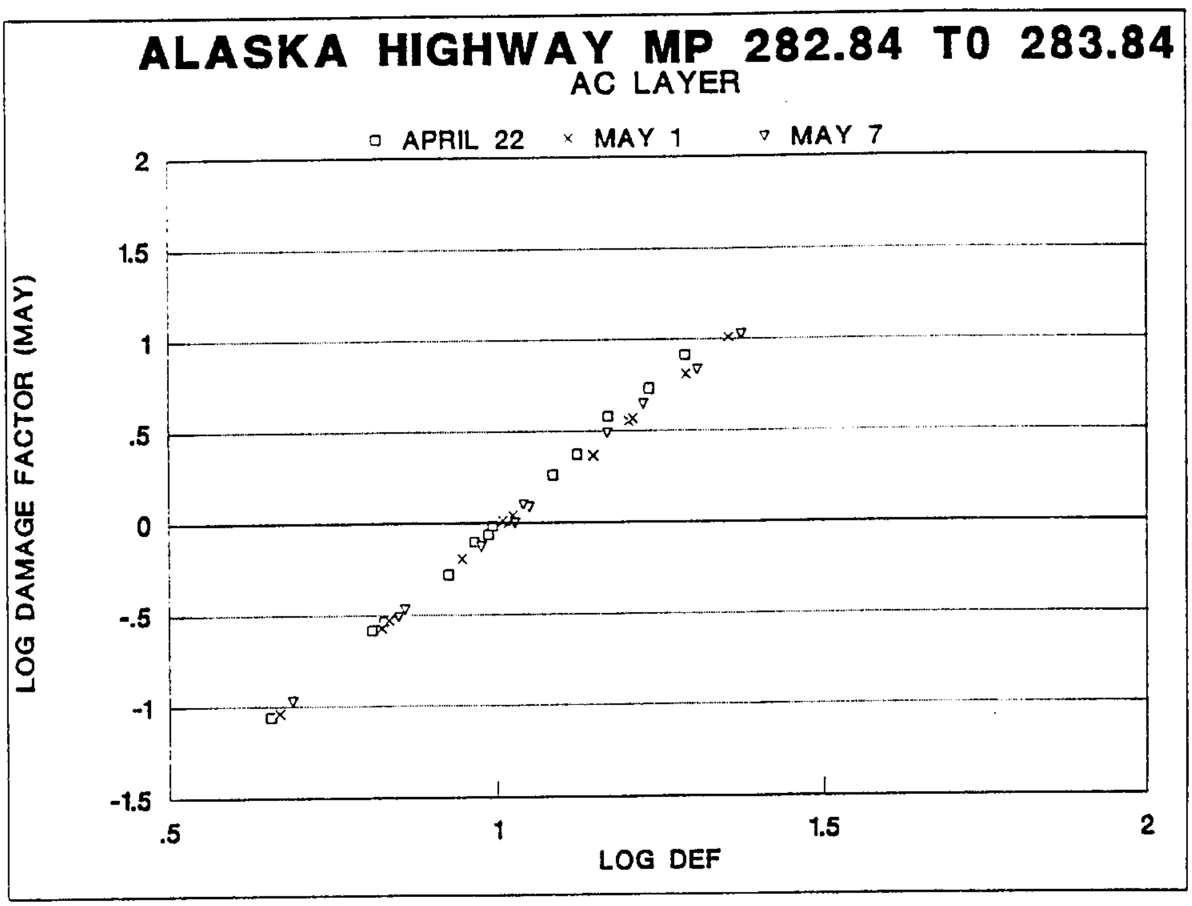


Figure 4.18

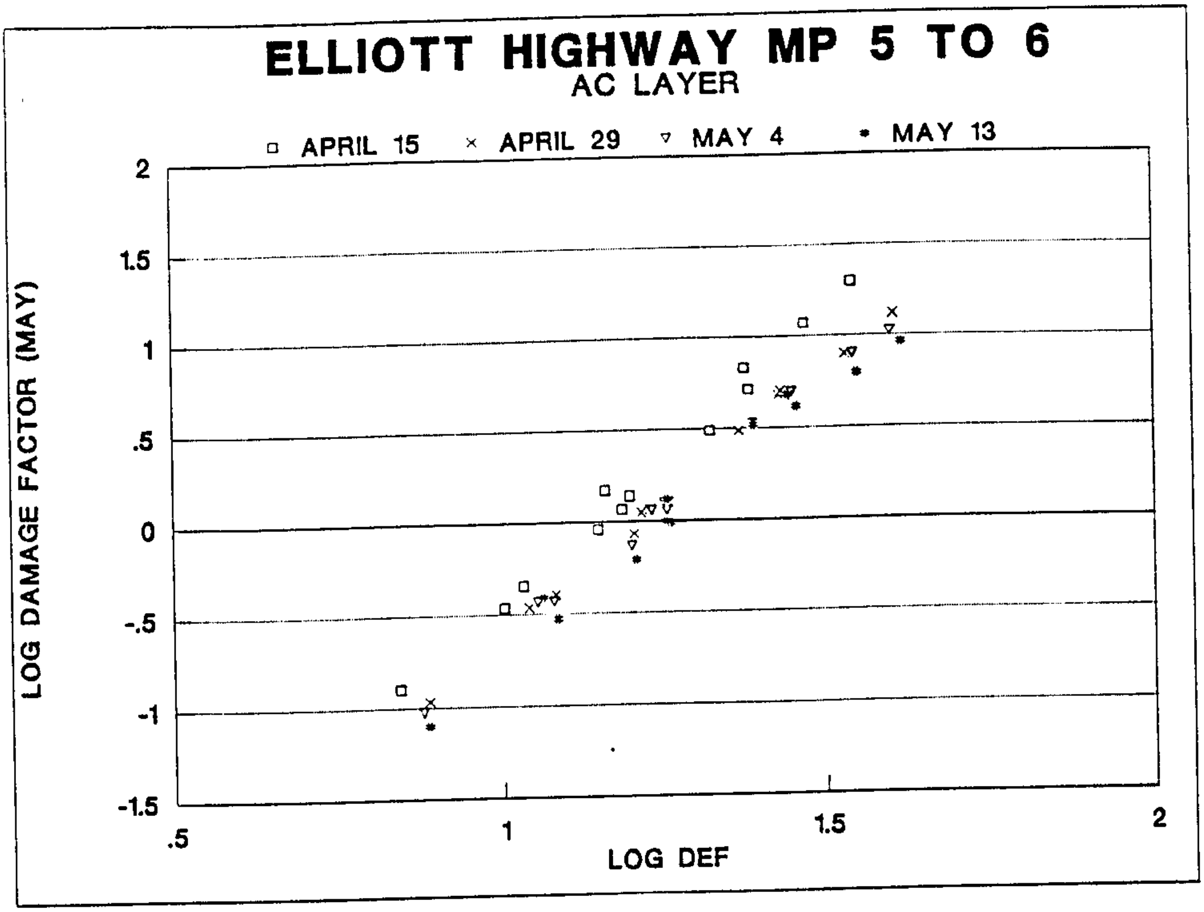


Figure 4.19

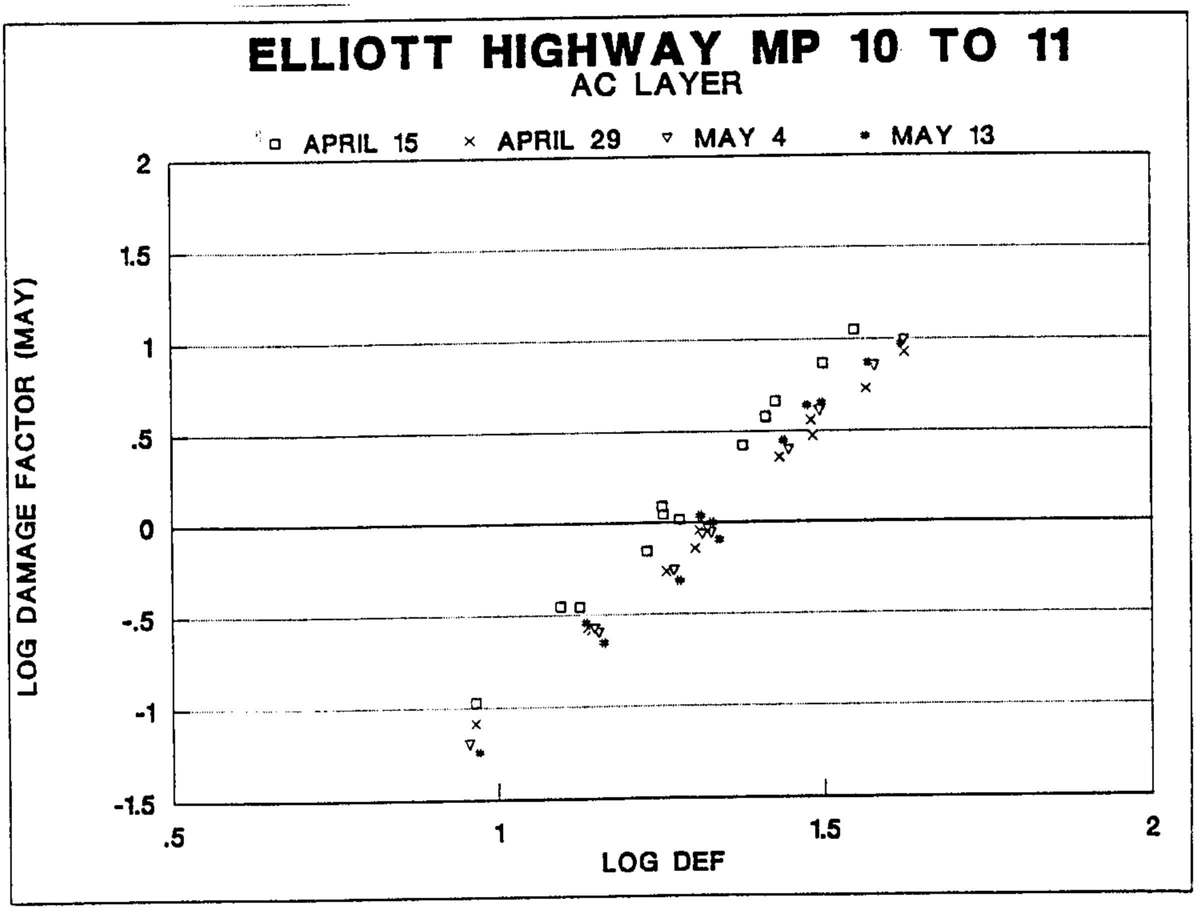


Figure 4.20

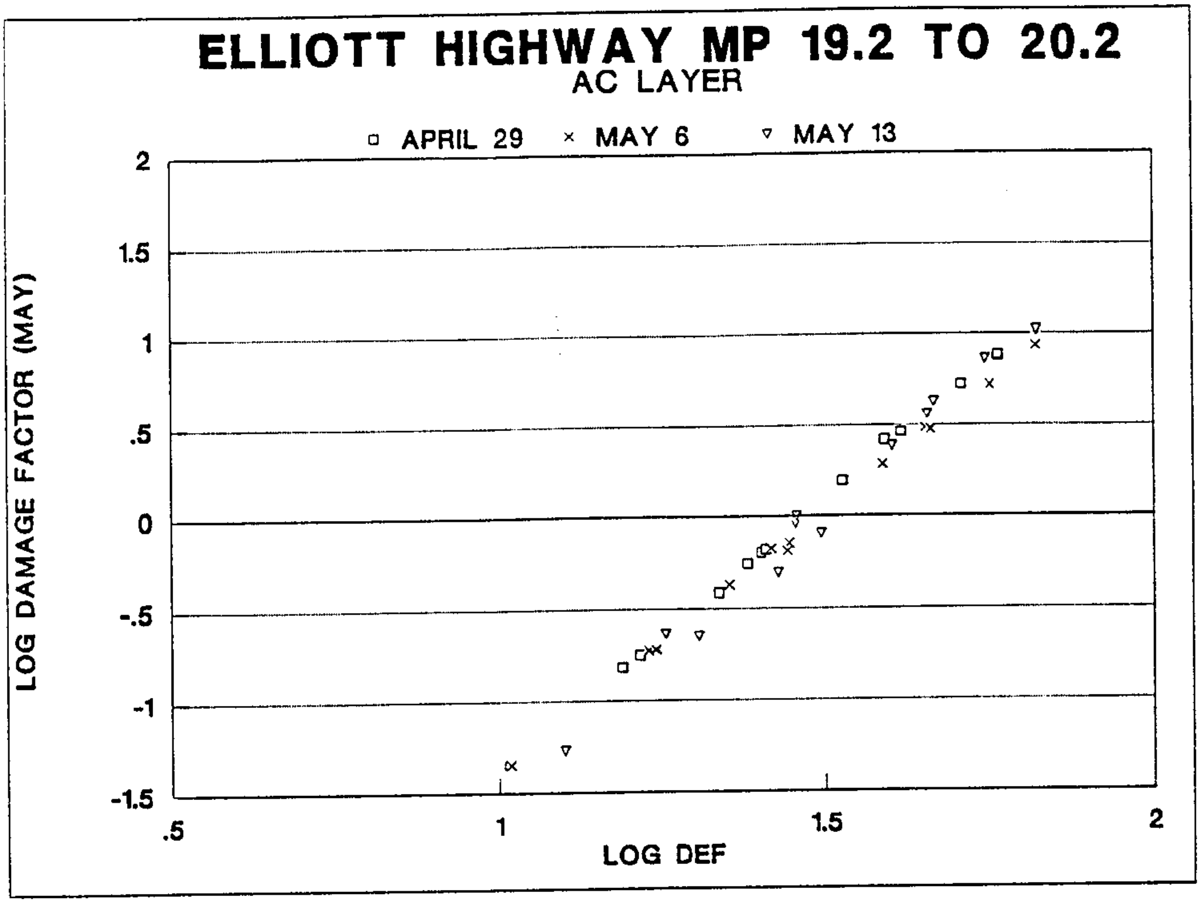


Figure 4.21

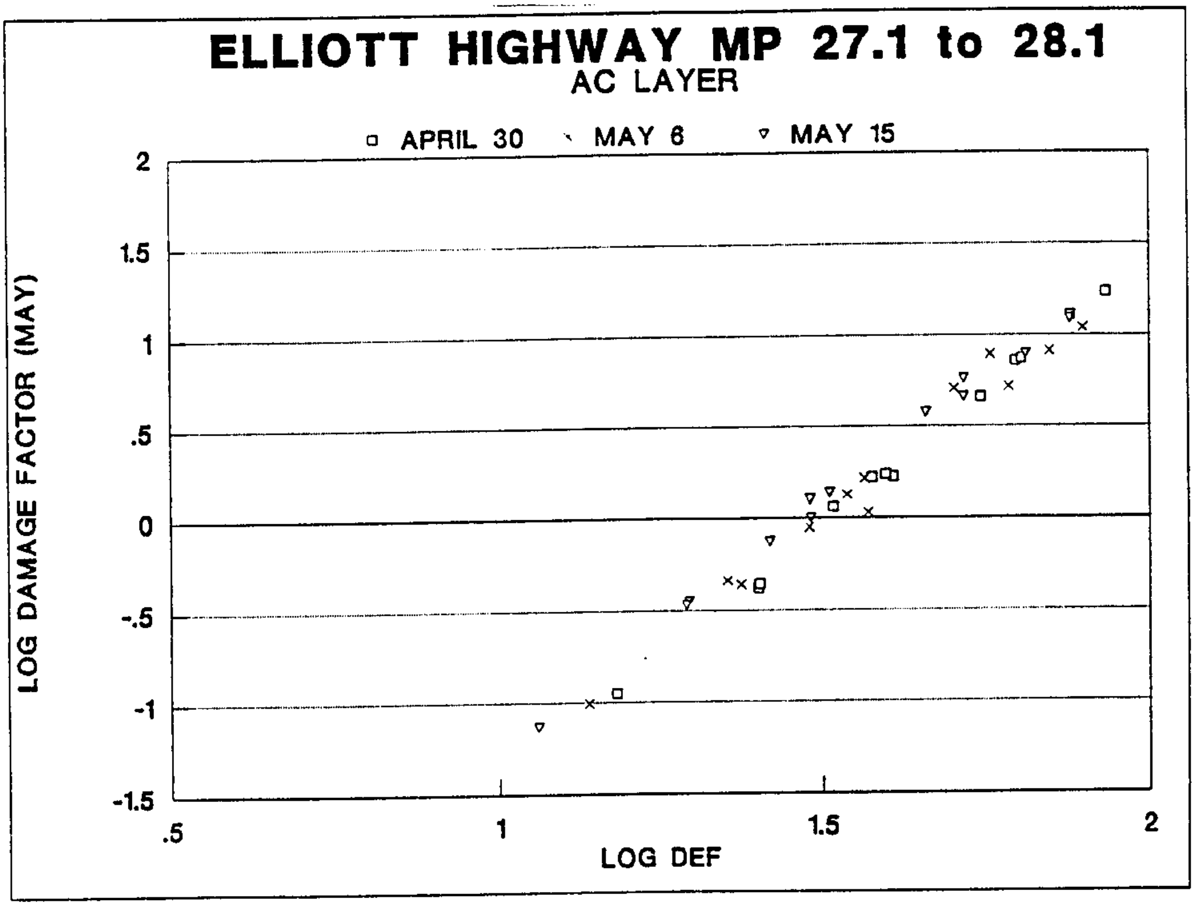


Figure 4.22

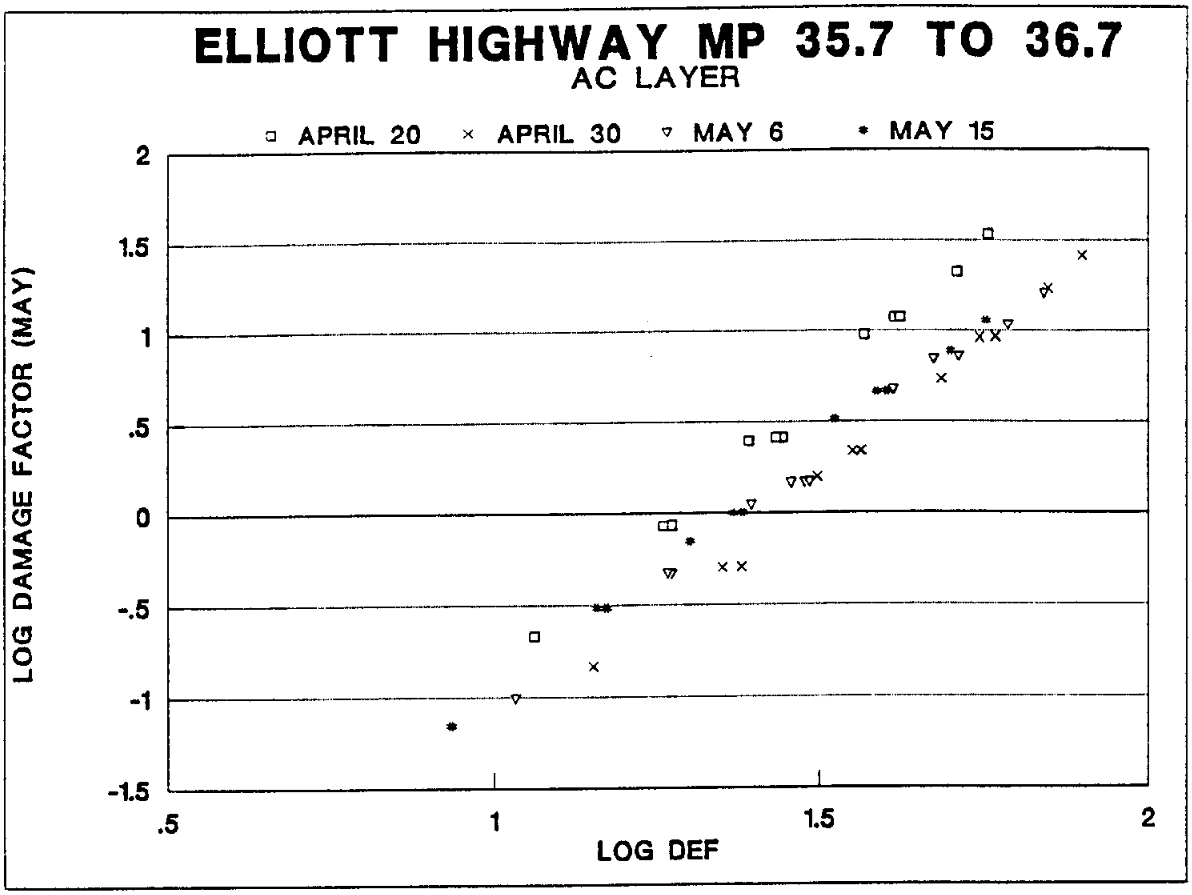


Figure 4.23

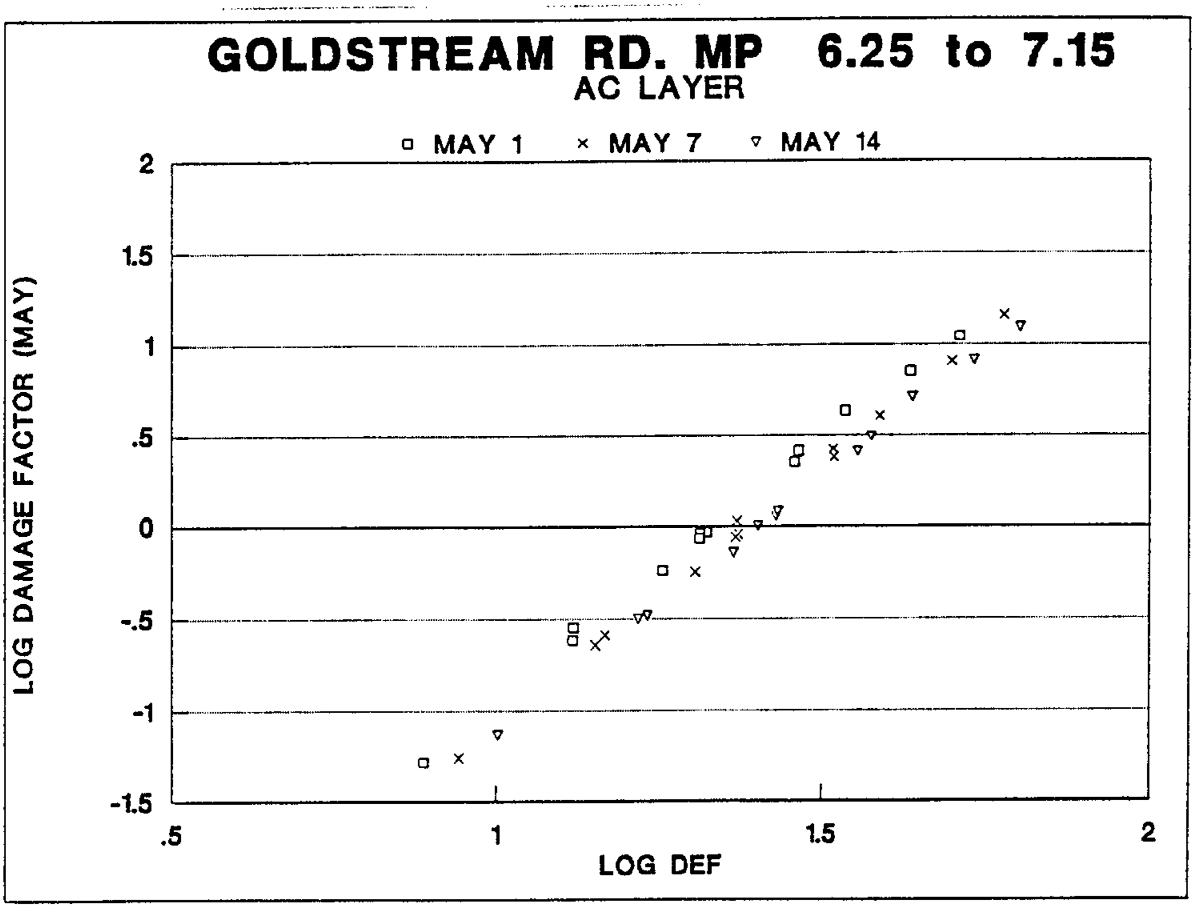


Figure 4.24

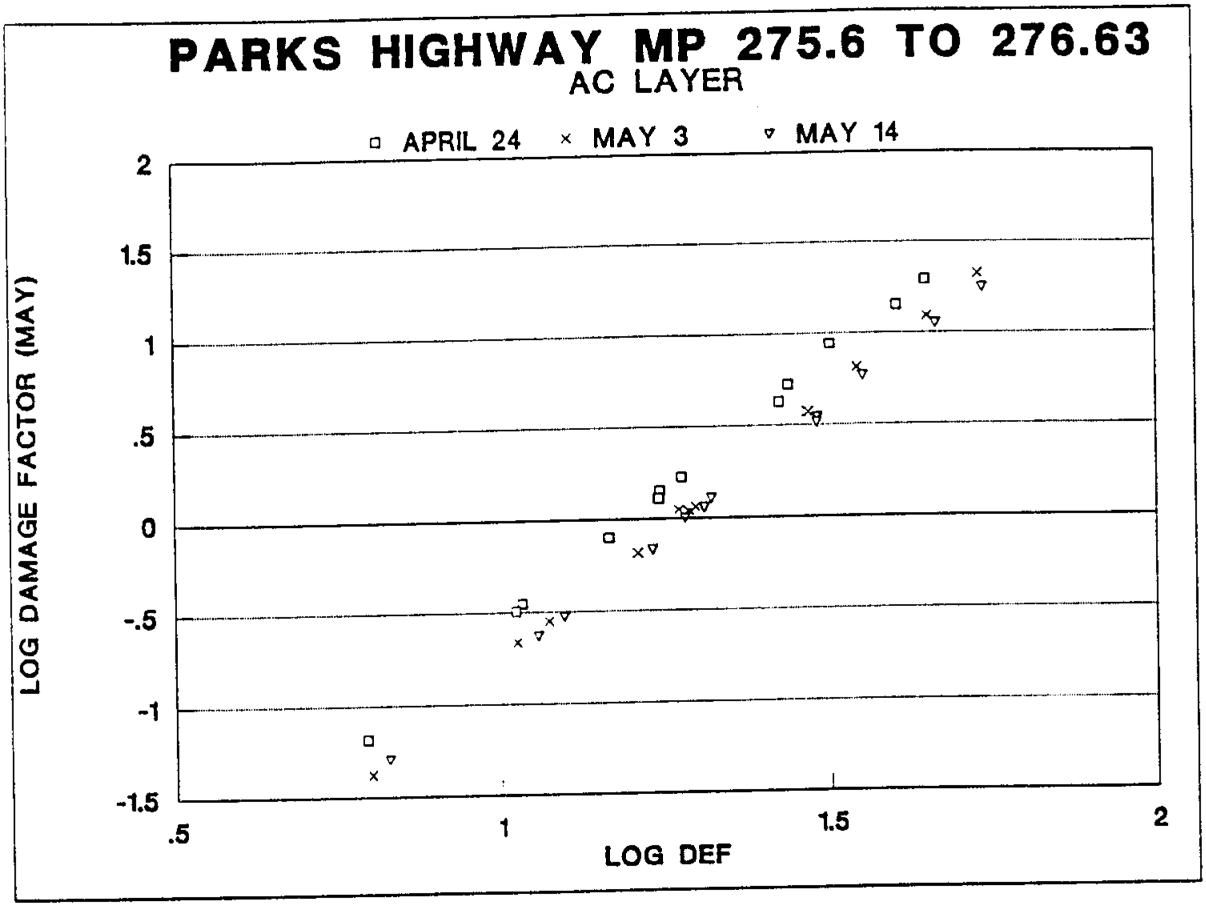

PARKS HIGHWAY MP 275.6 TO 276.63
AC LAYER
APRIL 24
MAY 3
MAY 14
LOG DAMAGE FACTOR (MAY)
2
1.5
1
.5
0
-.5
-1
-1.5
.5
1
1.5
2
LOG DEF

Figure 4.25

AC REGRESSION ANALYSES

DAMAGE FACTOR = A(LOAD/9000)^B

TEST SECTION	DATE	LOG A	A	B	R^2
ALASKA 282-283	4/22	-.062271	.8664211	2.374548	.994
	5/1	.0012966	1.002990	2.470944	.99
	5/7	.0621702	1.153905	2.448555	.985
	ALL	.0003985	1.000918	2.431349	.981
ELLIOTT 5-6	4/15	.1494997	1.410911	2.615317	.994
	4/29	.086209	1.219576	2.468605	.997
	5/4	.0699184	1.174677	2.472923	.994
	5/13	.0214992	1.050750	2.461262	.984
	ALL	.0817816	1.207207	2.504527	.985
ELLIOTT 10-11	4/15	.0464972	1.113005	2.403809	.998
	4/29	-.066958	.8571207	2.40578	.996
	5/4	-.04979	.8916820	2.63455	.996
	5/13	-.043016	.9056992	2.703269	.989
	ALL	-.028317	.9368779	2.536852	.987
ELLIOTT 19-20	4/29	-.2153	.6091160	2.681678	.998
	5/6	-.17325	.6710425	2.686696	.998
	5/13	-.073953	.8434260	2.735301	.996
	ALL	-.154168	.7011840	2.701225	.988
ELLIOTT 27-28	4/30	.2095827	1.620252	2.64658	.995
	5/6	.1405873	1.382252	2.486895	.971
	5/15	.065004	1.161459	2.616162	.988
	ALL	.13839	1.375276	2.583212	.975
ELLIOTT 35-36	4/20	.4664177	2.926966	2.593079	.991
	4/30	.3189949	2.084466	2.704545	.996
	5/6	.1856359	1.533331	2.618585	.991
	5/15	.0175673	1.041279	2.635107	.994
	ALL	.247154	1.766664	2.637829	.929
GOLDSTREAM 6-7	5/1	-.05394	.8832019	2.707415	.993
	5/7	-.041217	.9094587	2.81084	.997
	5/14	.03462	1.082979	2.61402	.994
	ALL	-.020179	.9545991	2.707159	.991
PARKS 275-276	4/24	.1469699	1.402716	3.00726	.991
	5/3	.0366547	1.088065	3.170414	.995
	5/14	.0361167	1.086718	2.991475	.995
	ALL	.073247	1.183715	3.054205	.988

Table 4.1

AC REGRESSION ANALYSES

DAMAGE FACTOR = C(DEFLECTION)^D

TEST SECTION	DATE	LOG C	C (X10^6)	D	R^2
ALASKA 282-283	4/22	-3.10508	785.0910	3.103967	.999
	5/1	-2.9812	1044.239	2.934118	.999
	5/7	-2.9928	1016.717	2.940426	.998
	ALL	-3.00449	989.7147	2.970055	.996
ELLIOTT 5-6	4/15	-3.63246	233.0988	3.179311	.99
	4/29	-3.55417	279.1451	2.935518	.997
	5/4	-3.5418	287.2103	2.89537	.995
	5/13	-3.59031	256.8562	2.879462	.981
	ALL	-3.47999	331.1387	2.891251	.948
ELLIOTT 10-11	4/15	-4.3343	46.31269	3.47696	.992
	4/29	-4.12982	74.16176	3.11731	.996
	5/4	-4.46368	34.38112	3.364651	.997
	5/13	-4.68651	20.58211	3.540595	.981
	ALL	-4.28916	51.38543	3.288002	.953
ELLIOTT 19-20	4/29	-4.395	40.27170	3.000955	.999
	5/6	-4.20355	62.58208	2.819589	.999
	5/13	-4.76479	17.18739	3.203991	.987
	ALL	-4.4061	39.25545	2.976612	.99
ELLIOTT 27-28	4/30	-4.5174	30.38086	2.987143	.997
	5/6	-4.15583	69.85058	2.777644	.976
	5/15	-4.01464	96.68520	2.743407	.996
	ALL	-4.15726	69.62096	2.792604	.983
ELLIOTT 35-36	4/20	-4.11411	76.89357	3.200358	.992
	4/30	-4.44633	35.78244	3.082525	.996
	5/6	-3.84408	143.1924	2.75677	.995
	5/15	-3.70232	198.4632	2.727593	.997
	ALL	-3.77453	168.0622	2.776105	.916
GOLDSTREAM 6-7	5/1	-3.76531	171.6683	2.830018	.998
	5/7	-3.94648	113.1149	2.862018	.998
	5/14	-3.9056	124.2796	2.781567	.999
	ALL	-3.77749	166.9206	2.755965	.98
PARKS 275-276	4/24	-3.45921	347.3682	2.890177	.999
	5/3	-3.64233	227.8610	2.871307	.999
	5/14	-3.5819	261.8786	2.78148	.999
	ALL	-3.50932	309.5138	2.807492	.974

Table 4.2

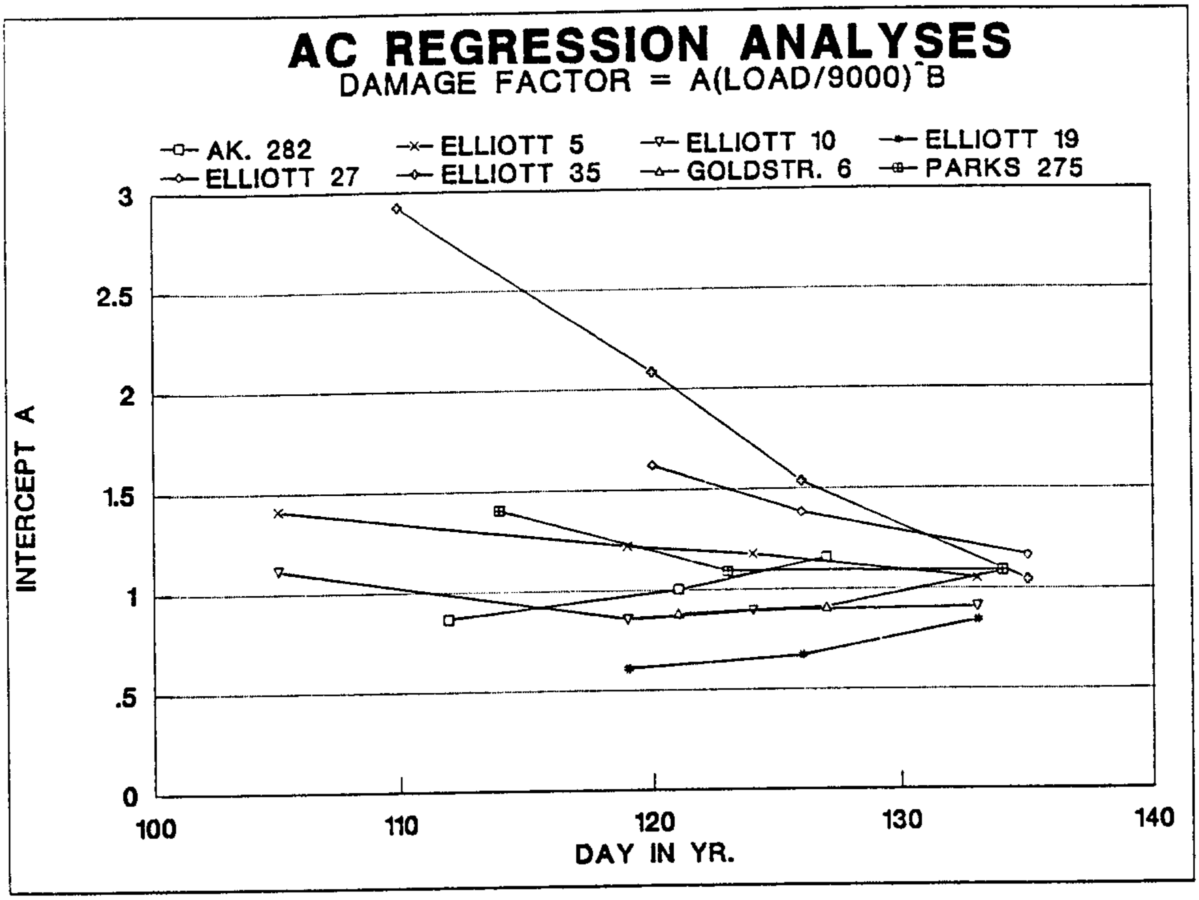


Figure 4.26

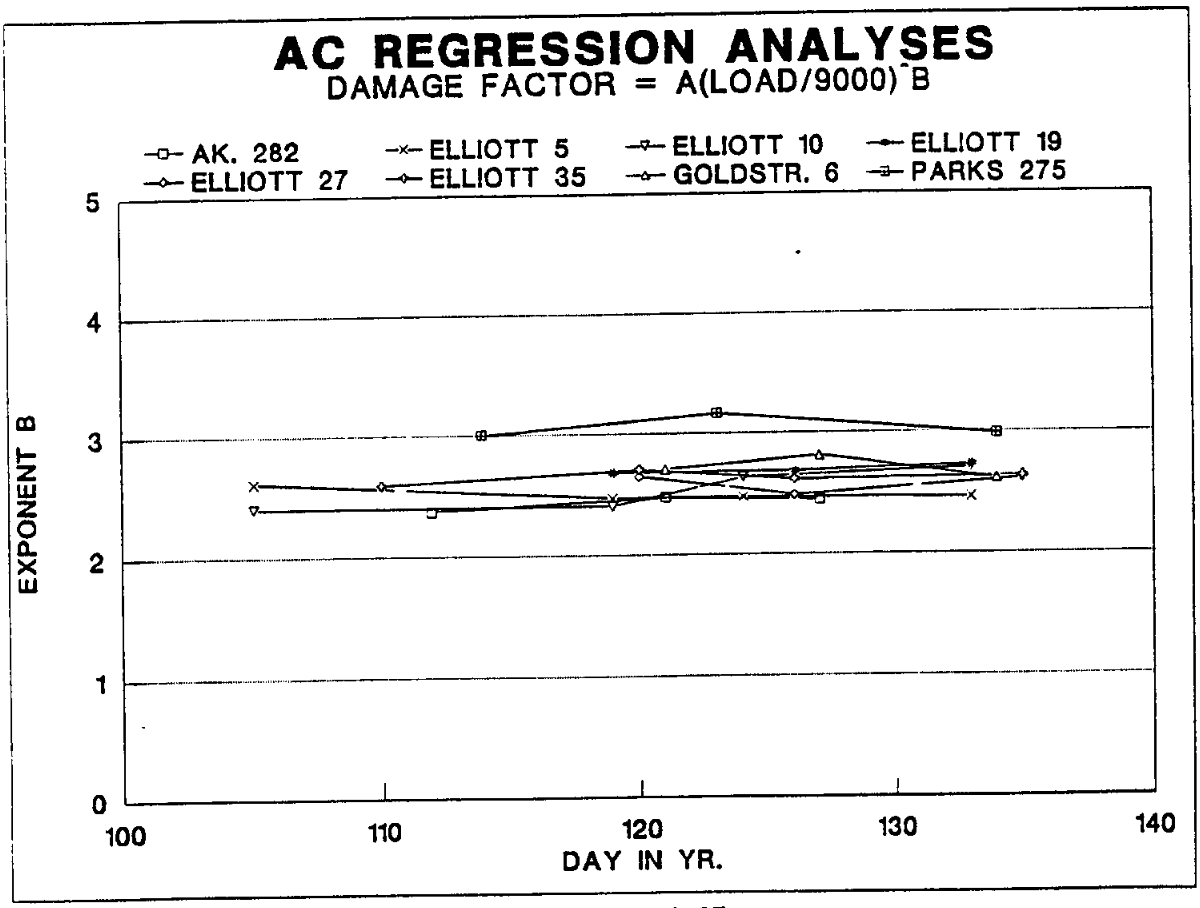
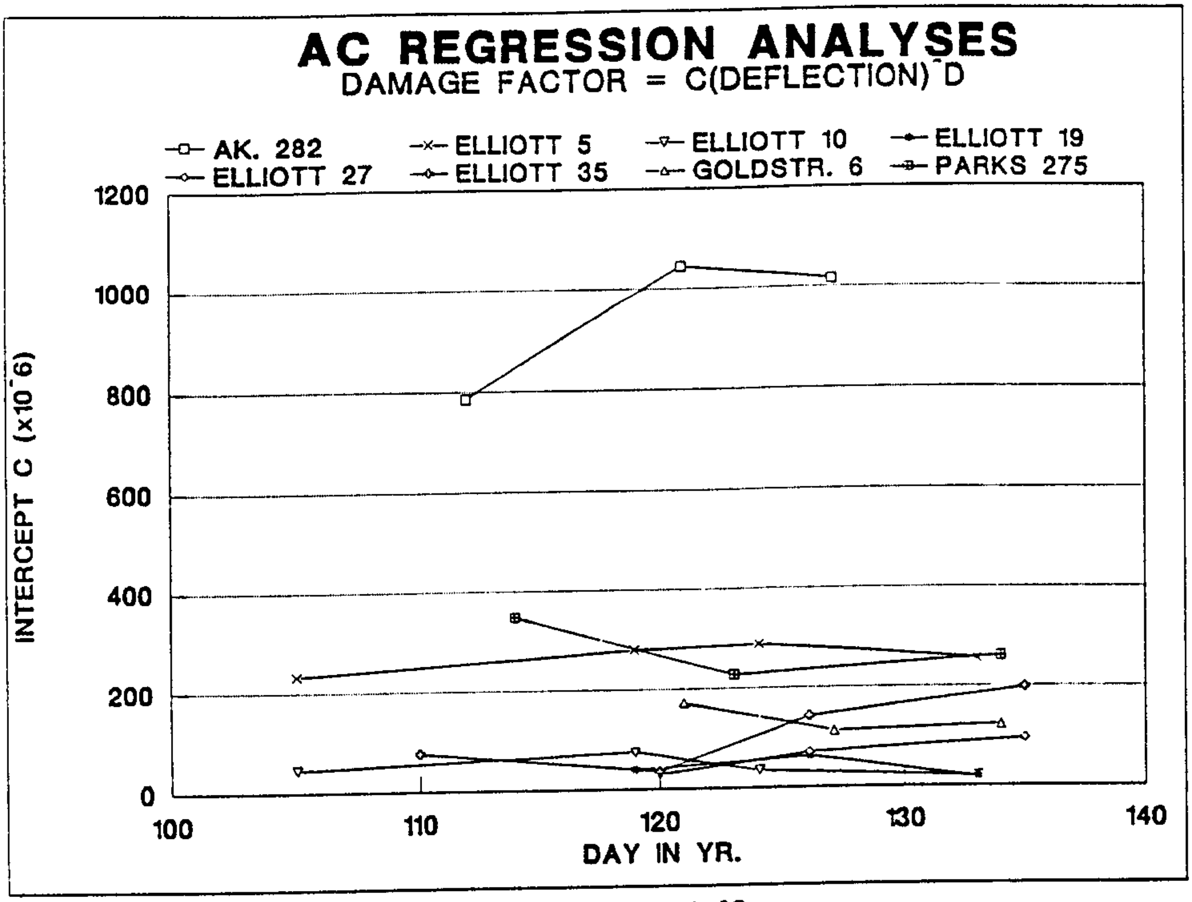


Figure 4.27



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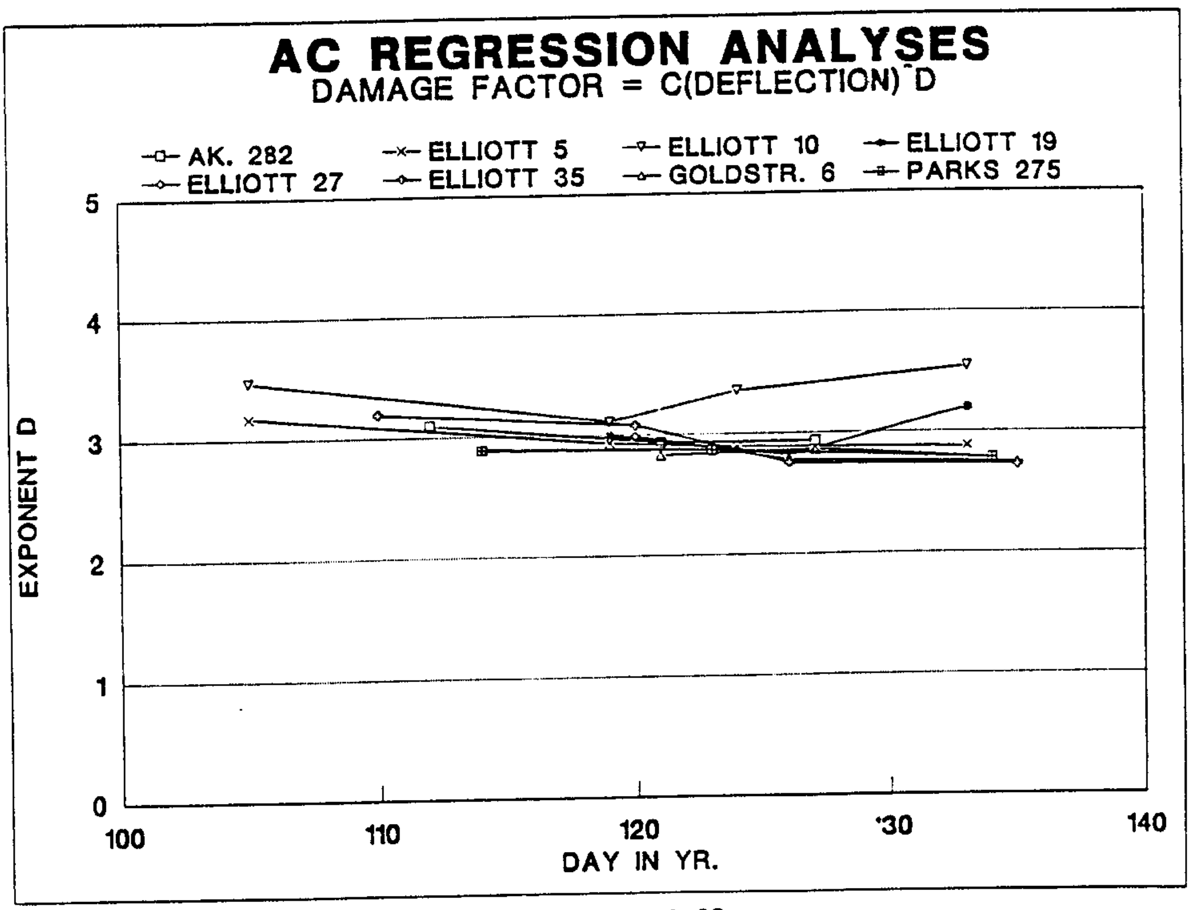

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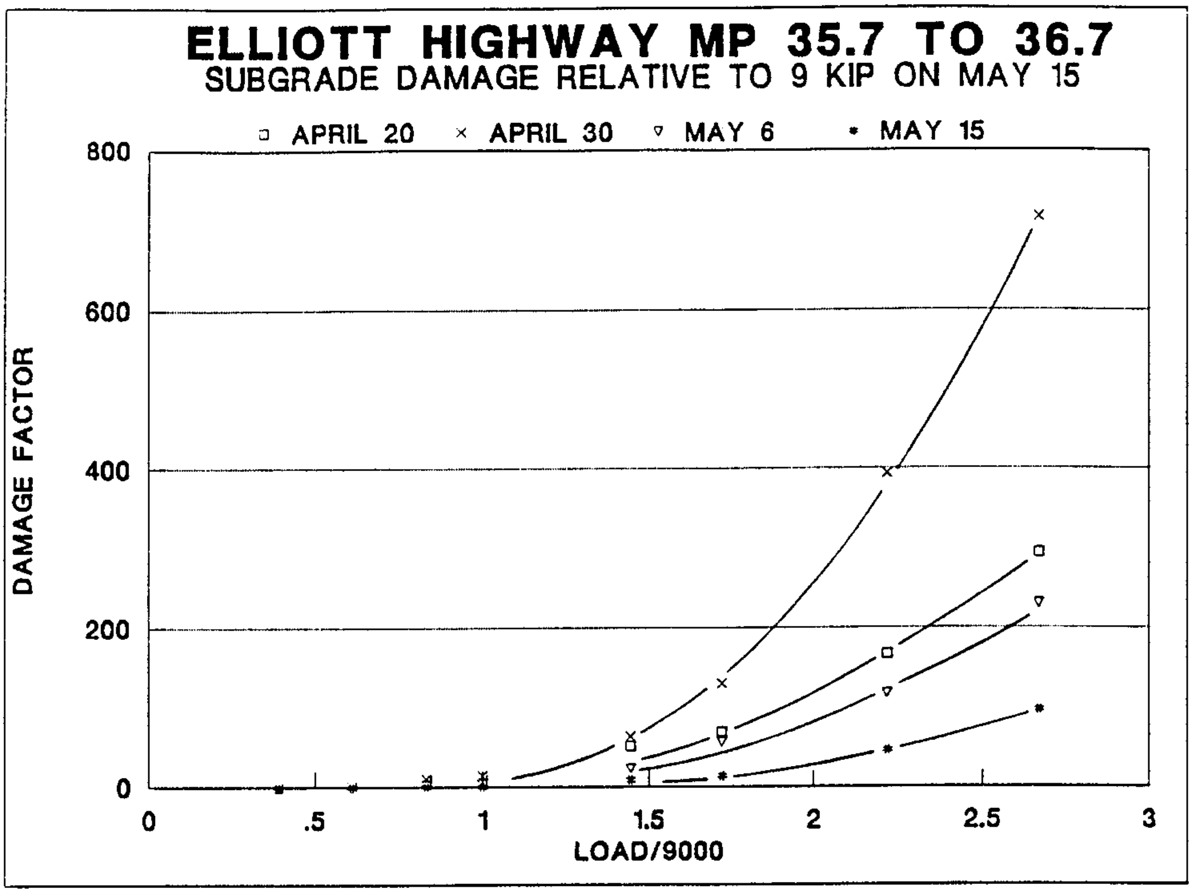

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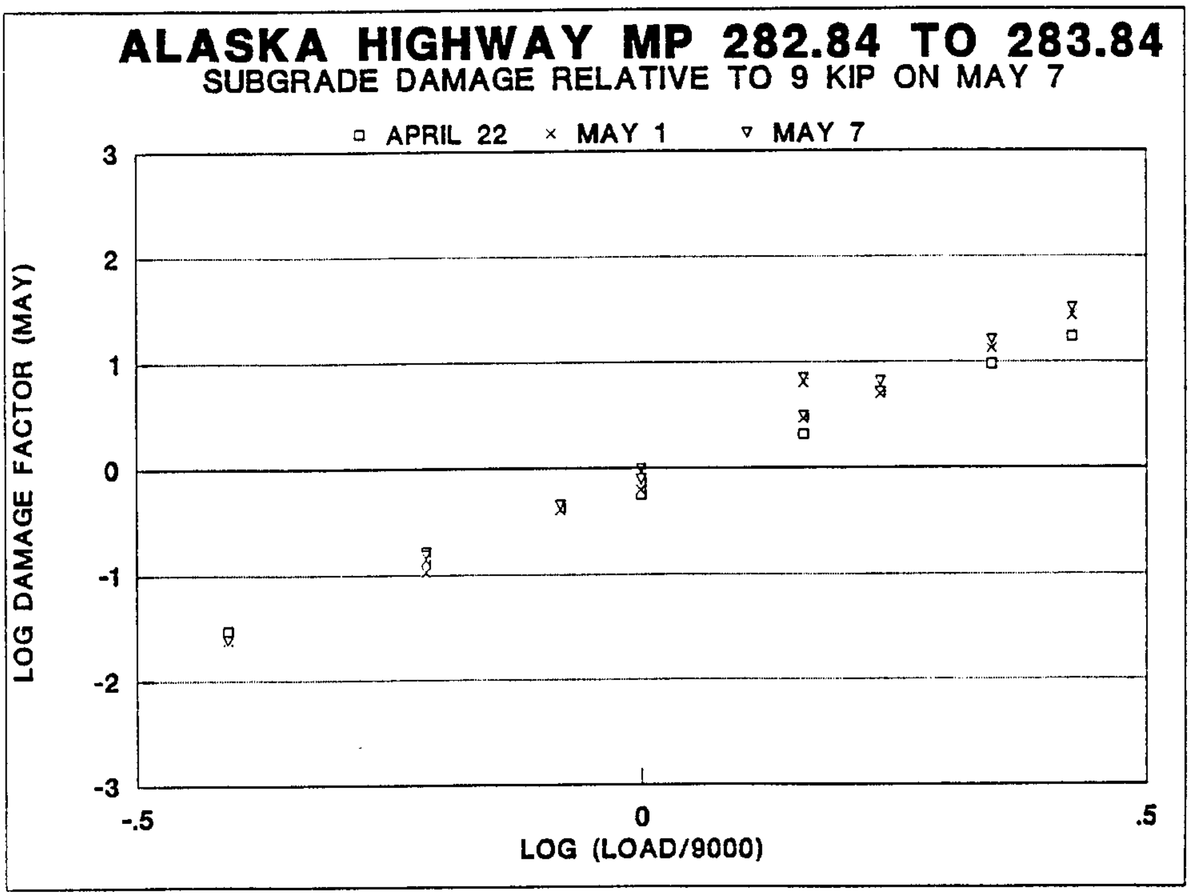

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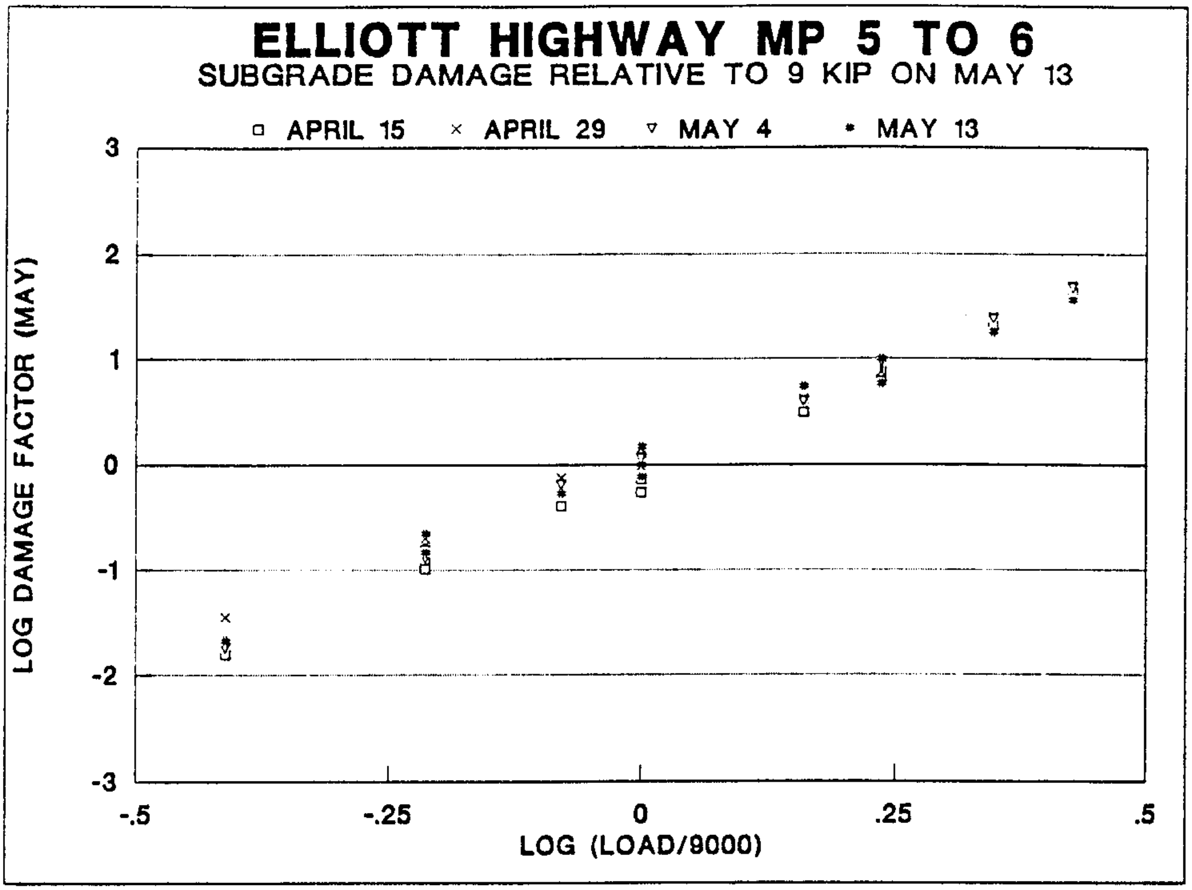

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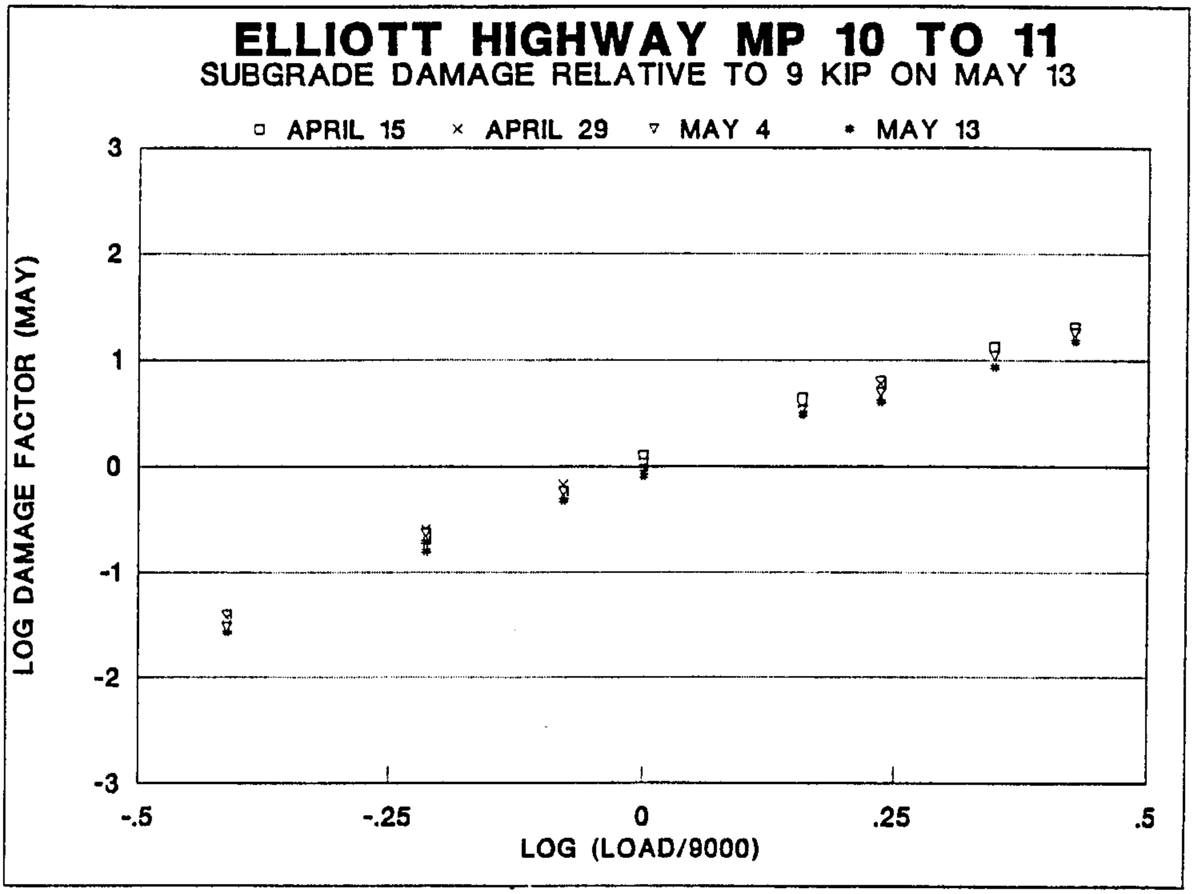
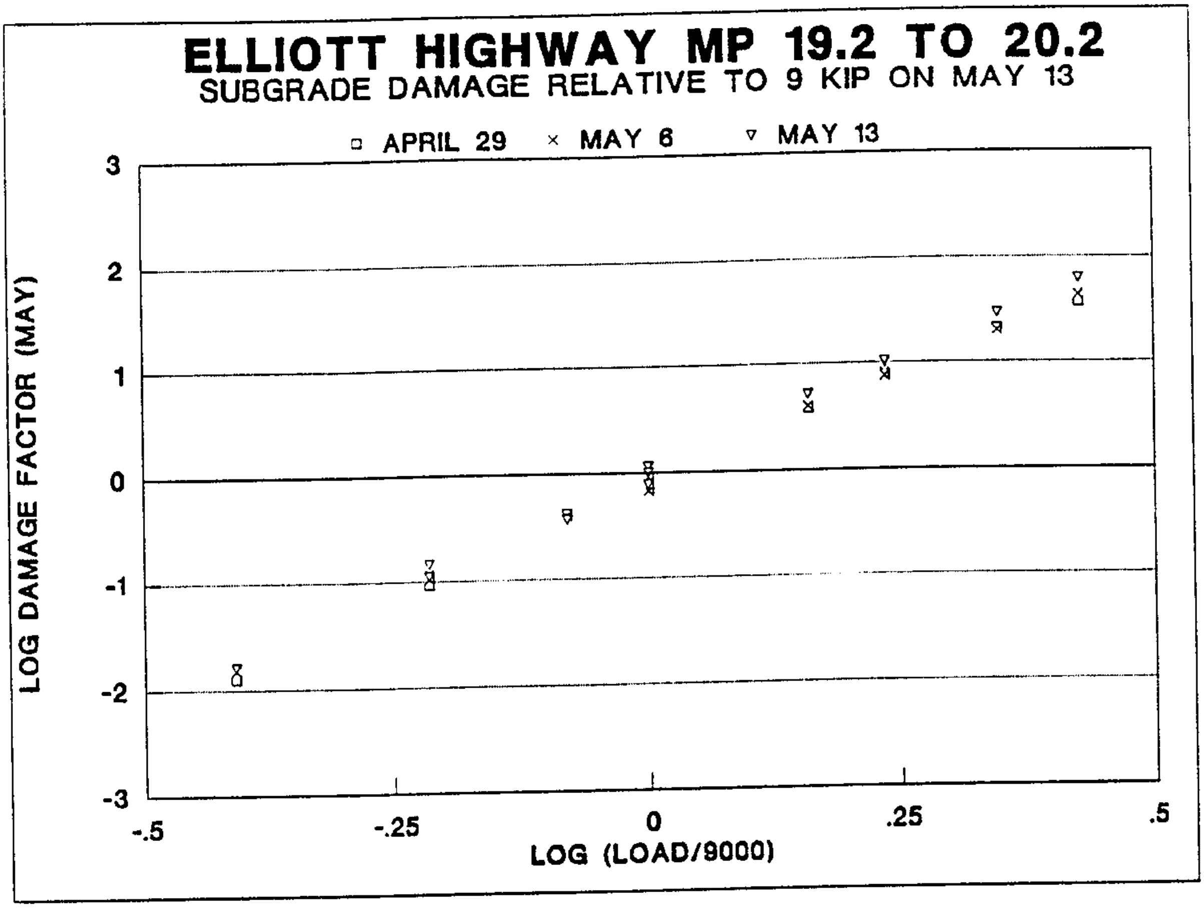


Figure 4.33



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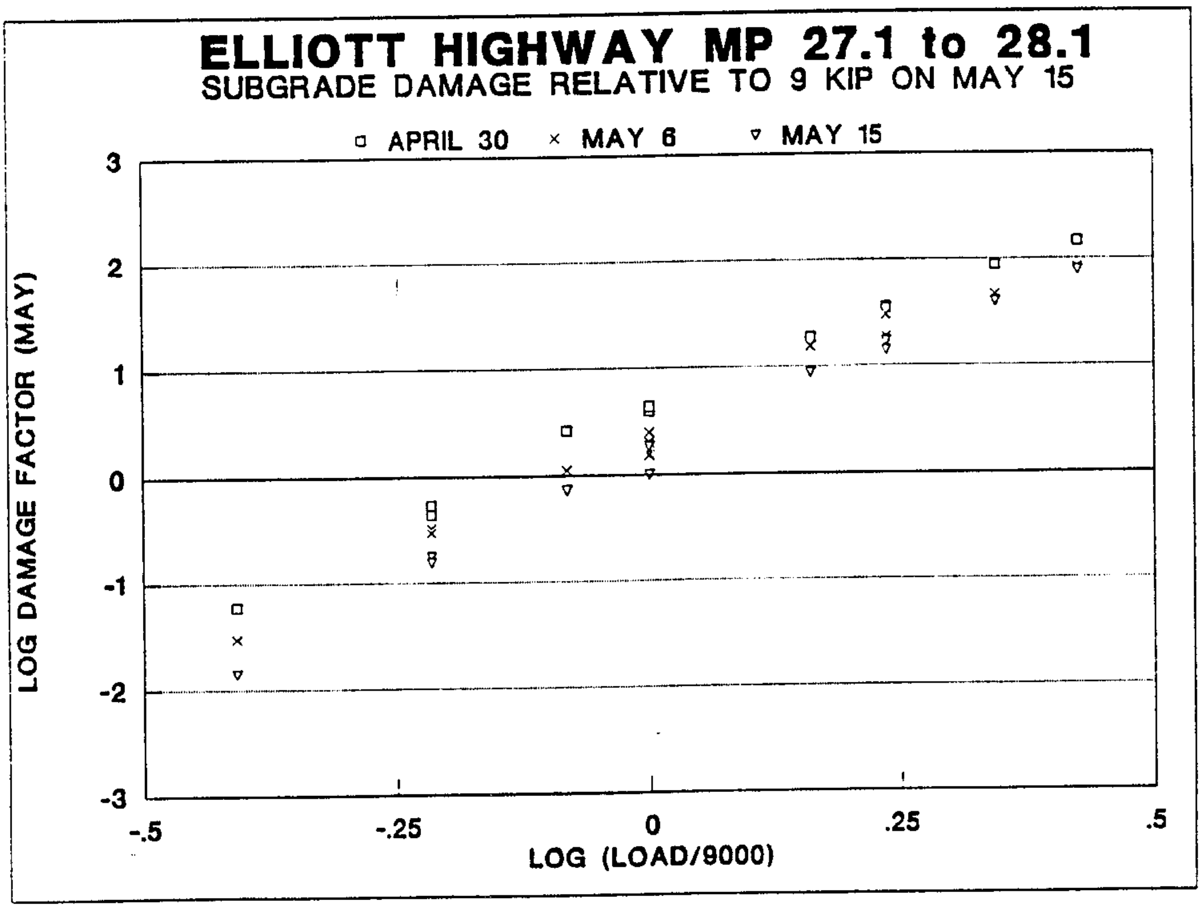
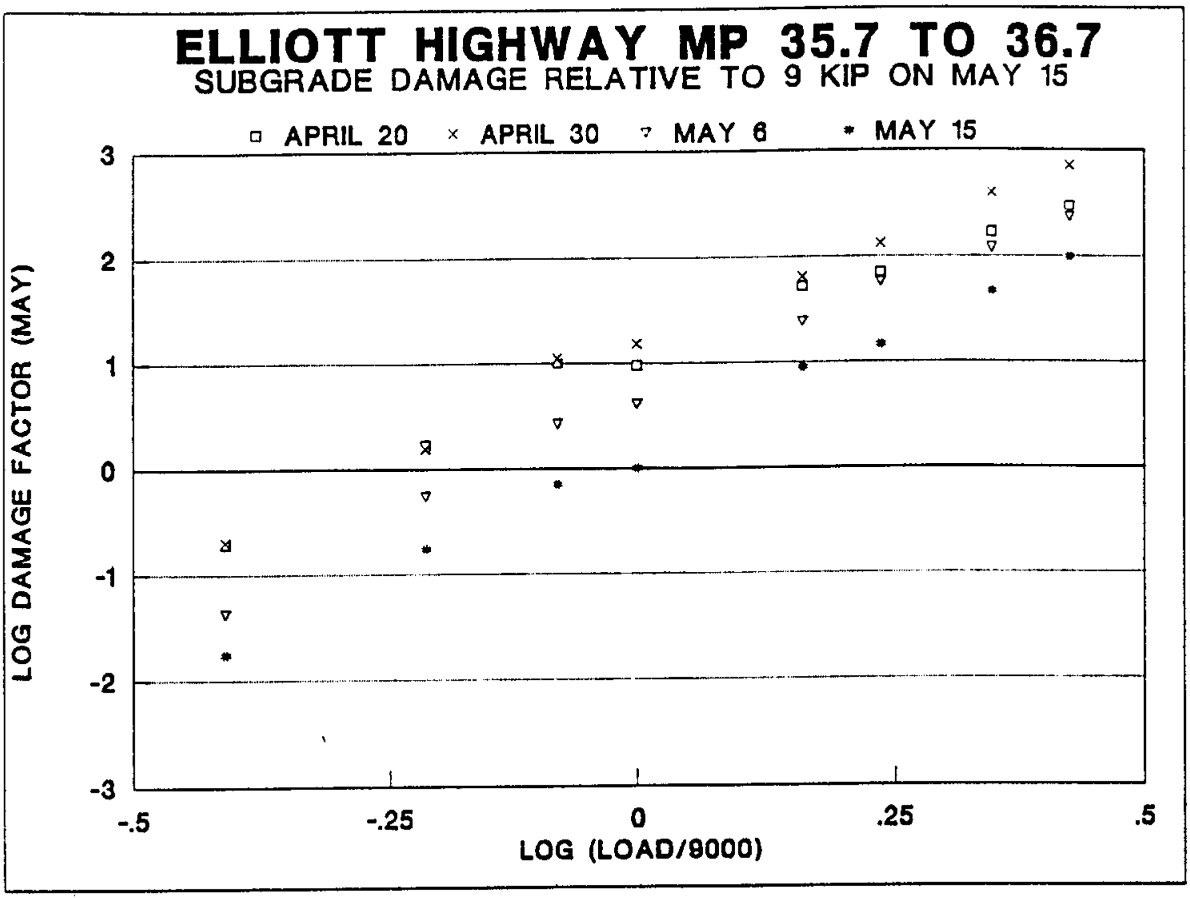


Figure 4.35



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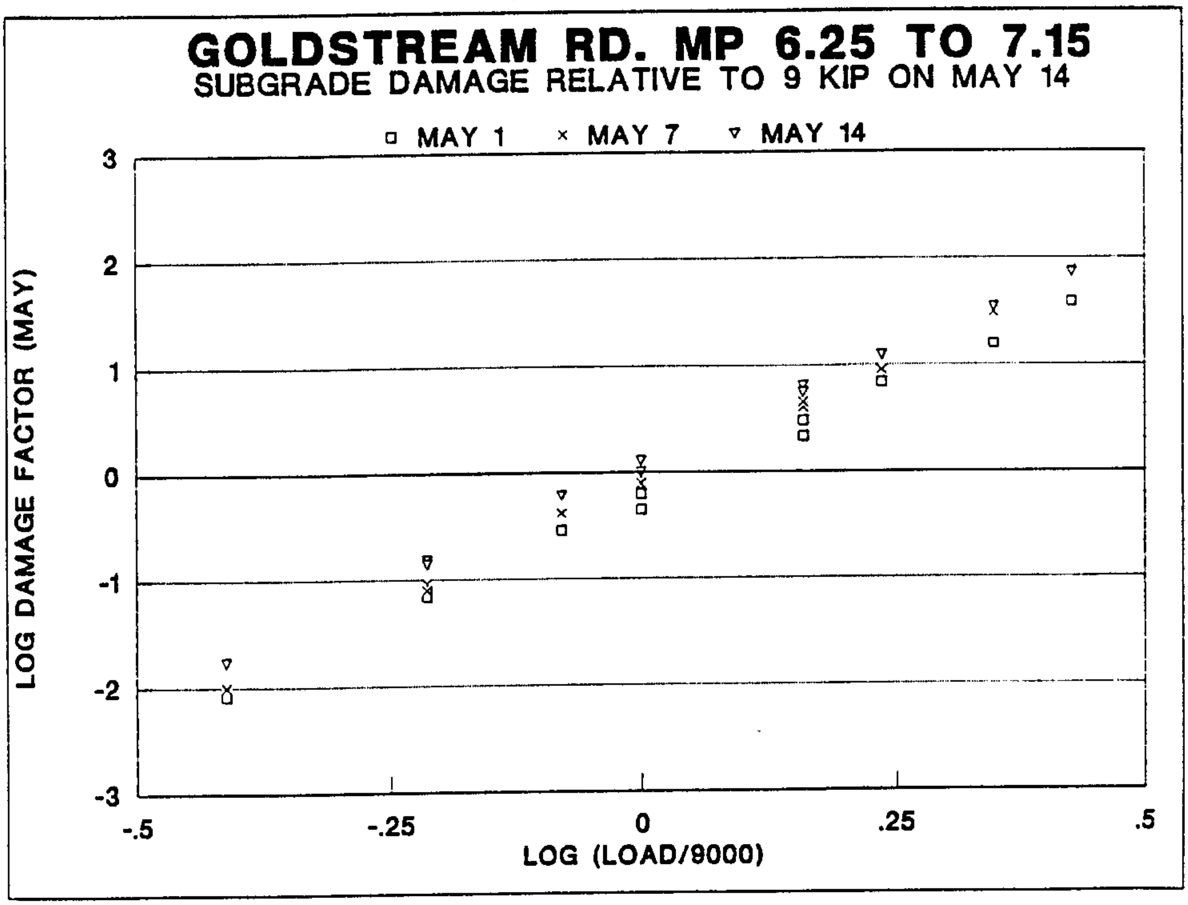

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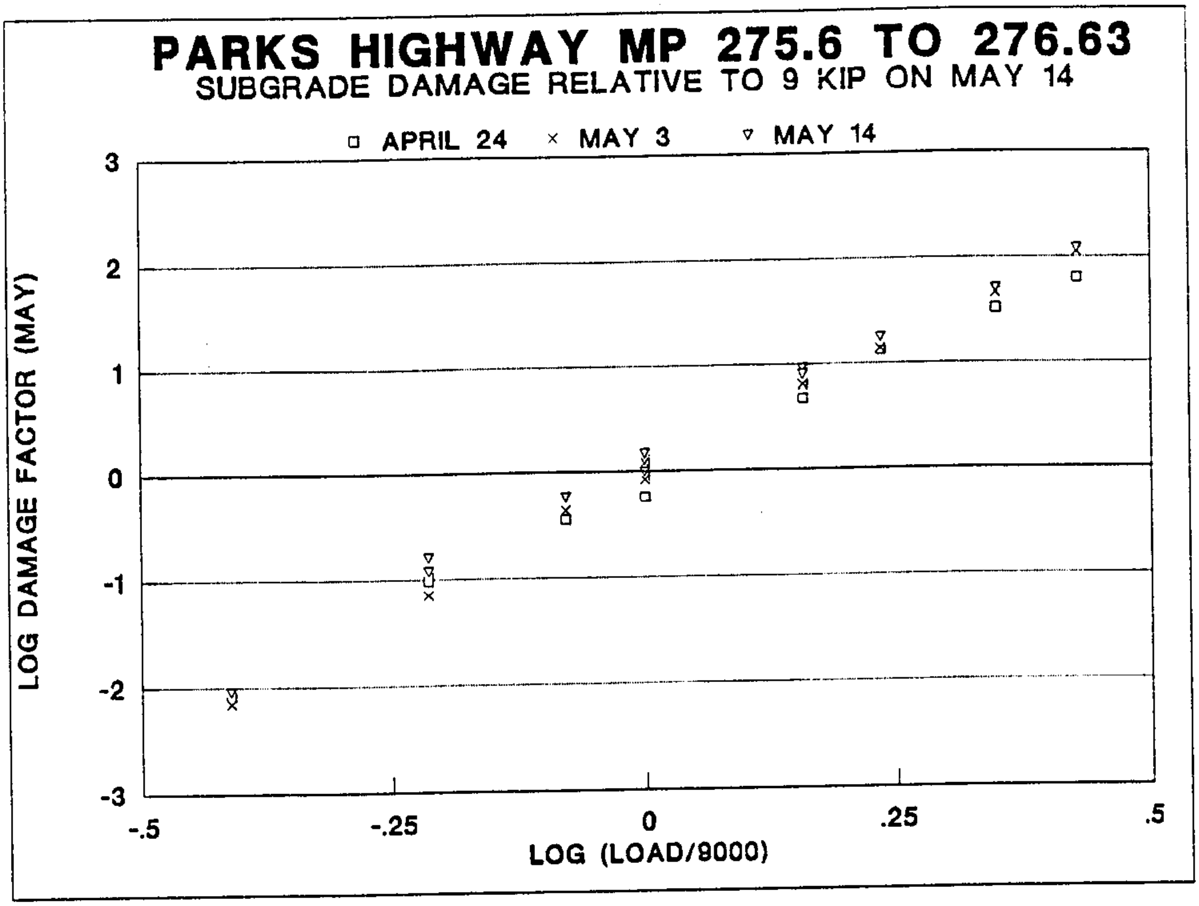

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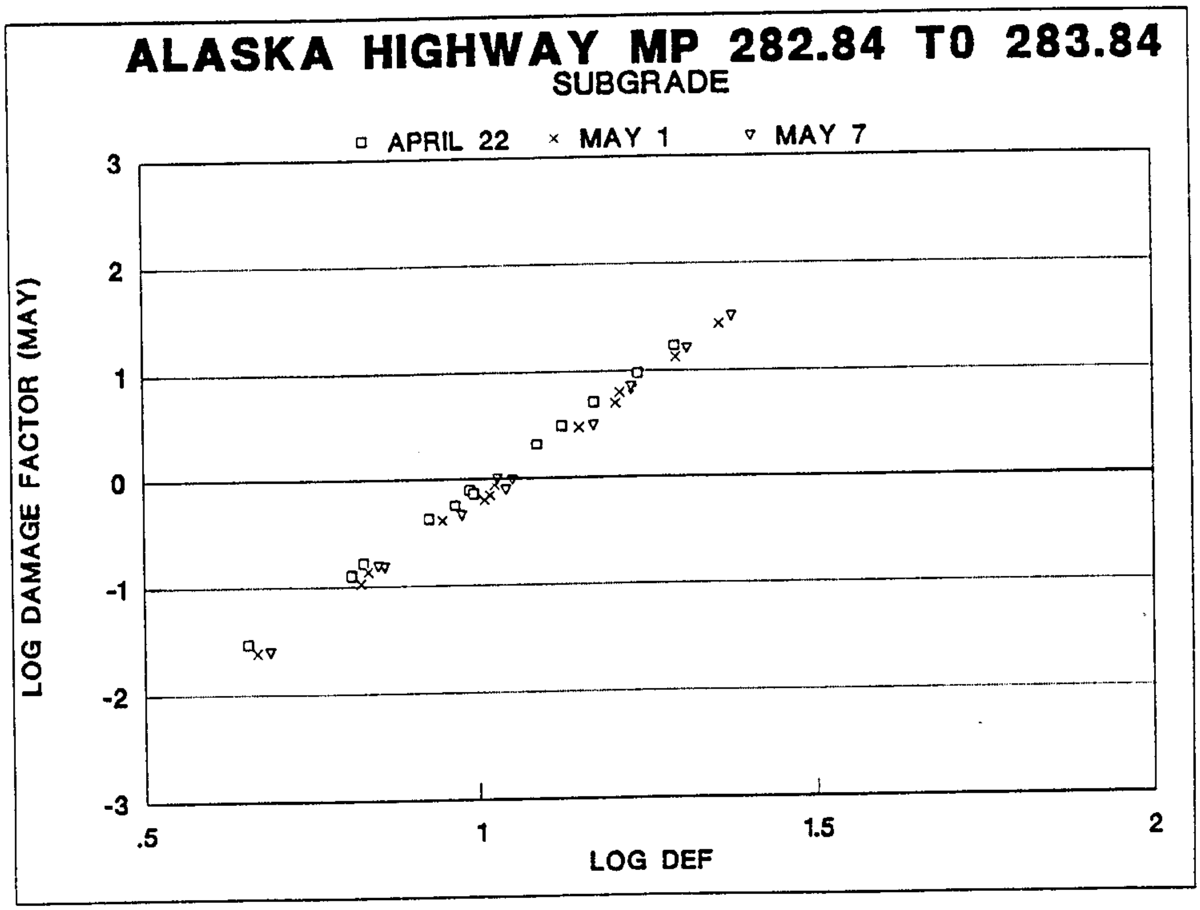


Figure 4.39

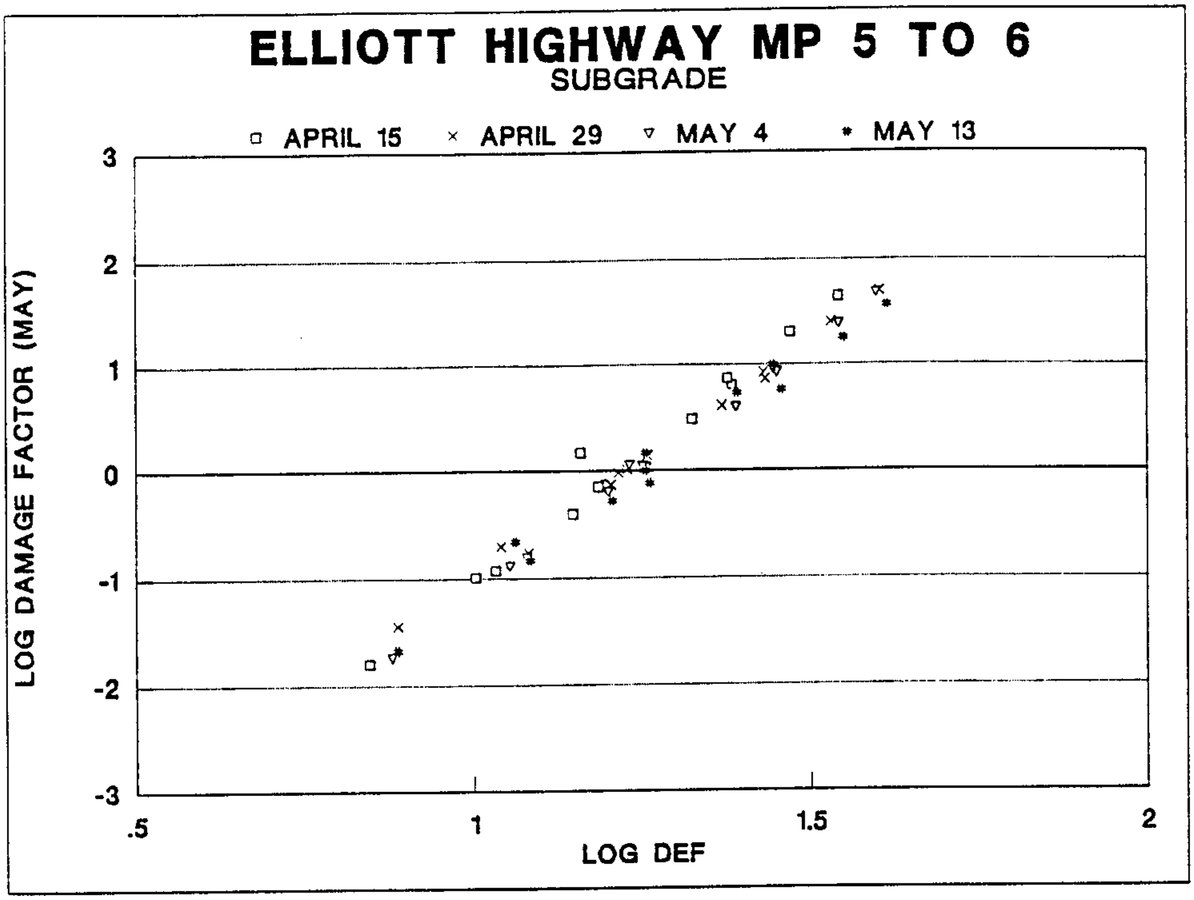
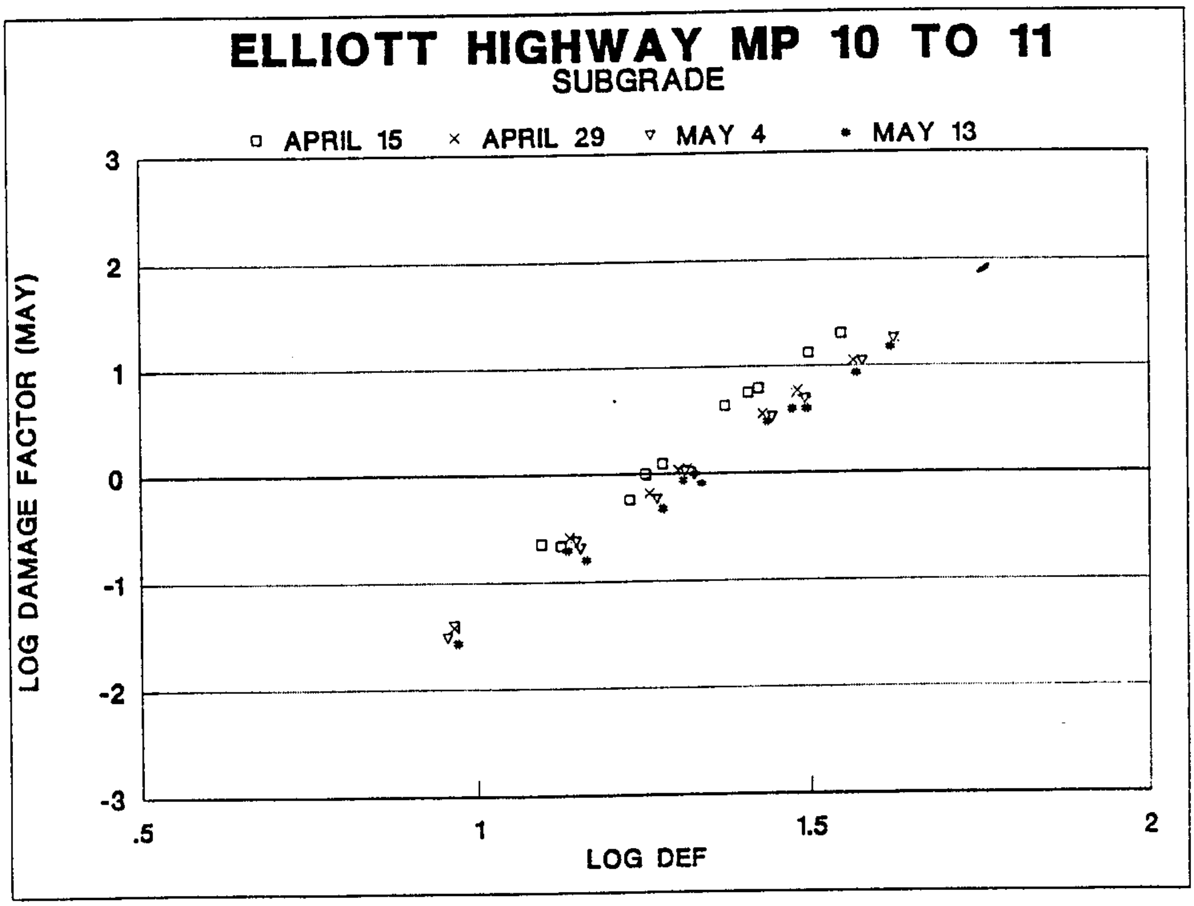


Figure 4.40



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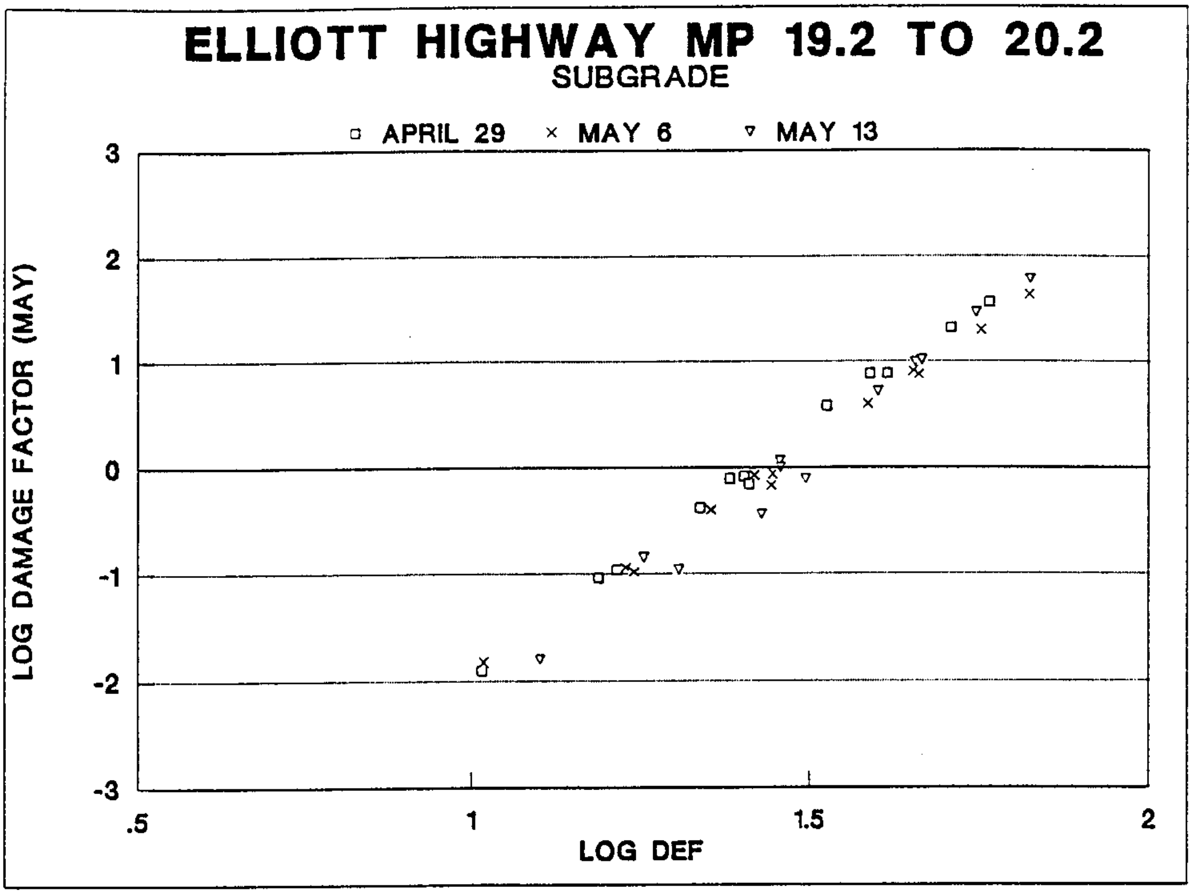

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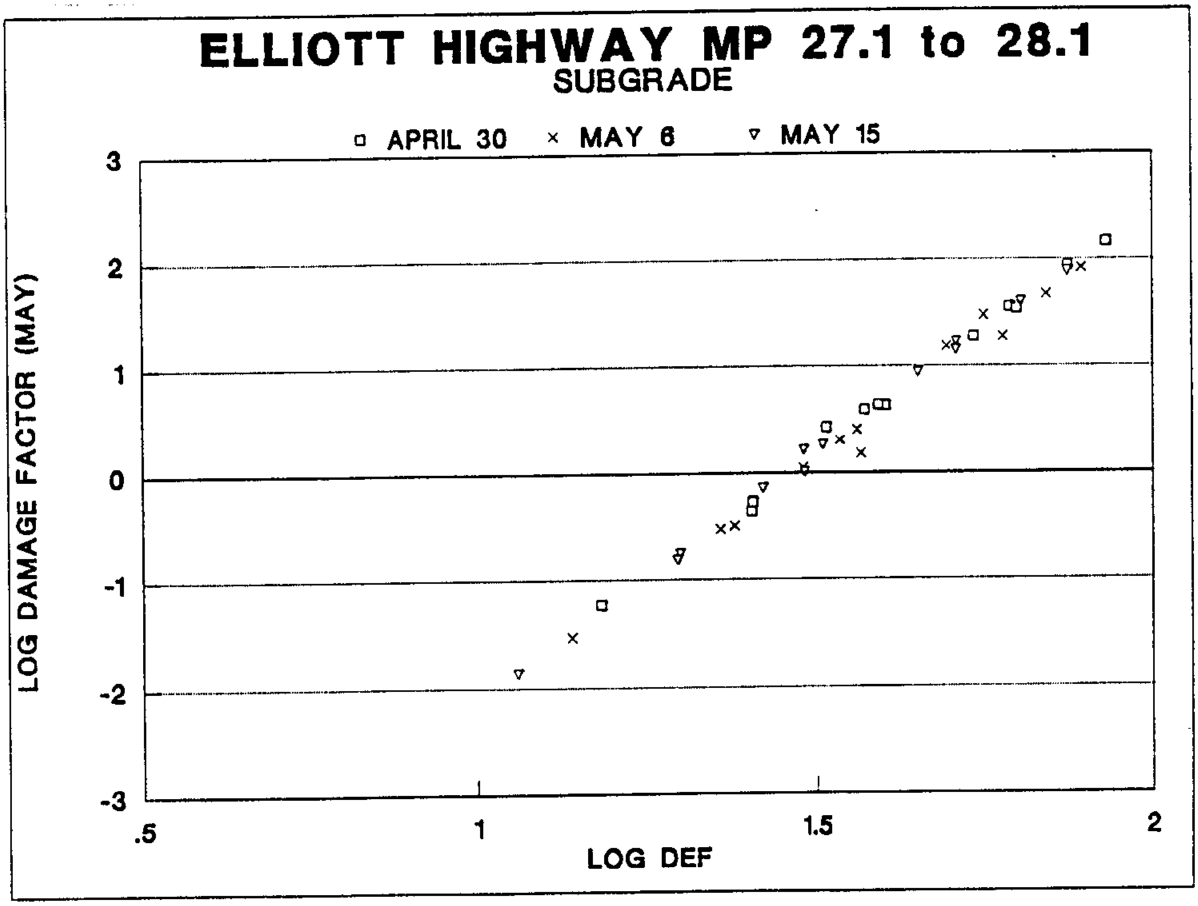

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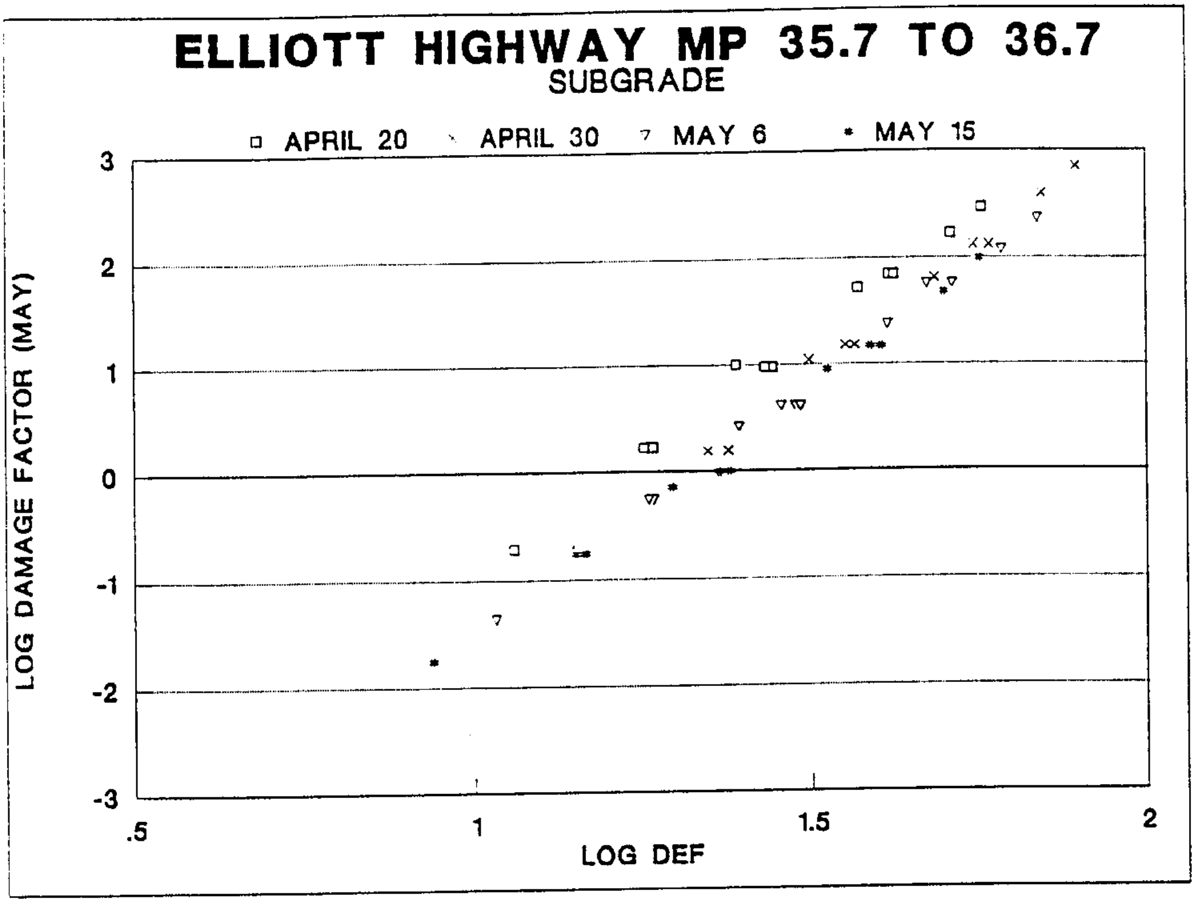

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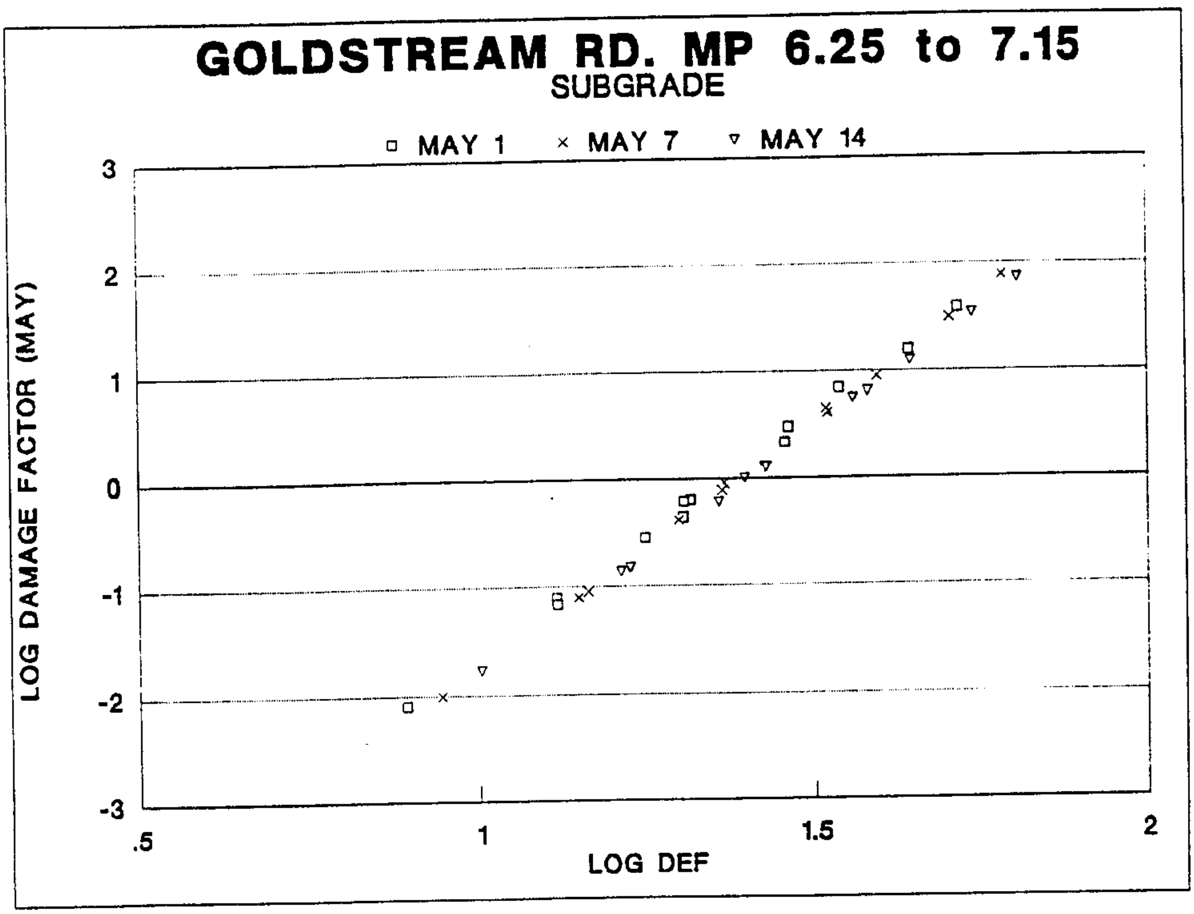

Figure 4.45

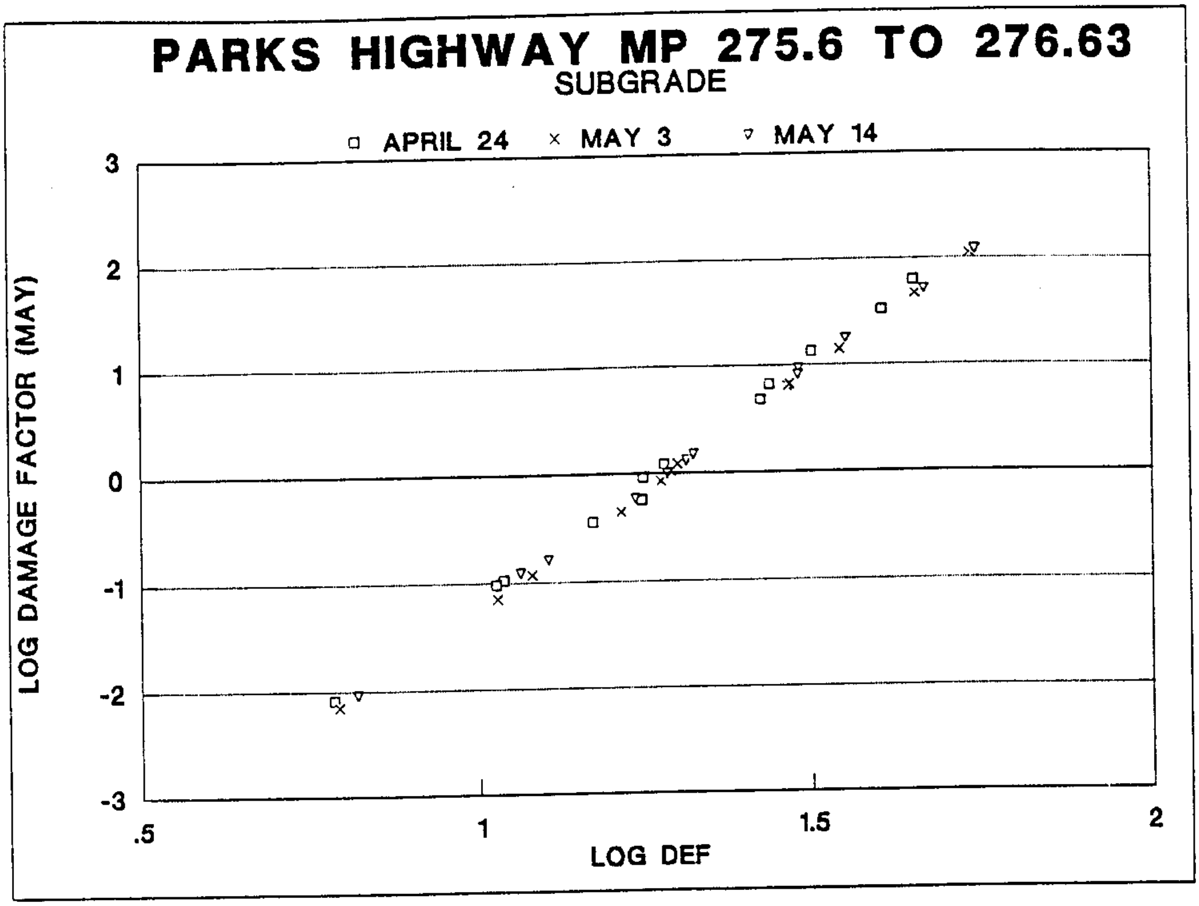
PARKS HIGHWAY MP 275.6 TO 276.63
SUBGRADE
APRIL 24
MAY 3
MAY 14
LOG DAMAGE FACTOR (MAY)
3
2
1
0
-1
-2
-3
.5
1
1.5
2
LOG DEF

Figure 4.46

SUBGRADE REGRESSION ANALYSES

DAMAGE FACTOR = A(LOAD/9000)^B

TEST SECTION	DATE	LOG A	A	B	R^2
ALASKA 282-283	4/22	-.141846	.7213632	3.313779	.994
	5/1	-.105916	.7835812	3.706525	.986
	5/7	-.029535	.9342541	3.727531	.989
	ALL	-.092432	.8082915	3.582611	.983
ELLIOTT 5-6	4/15	-.125737	.7486227	4.073115	.997
	4/29	.0687006	1.171388	3.713347	.996
	5/4	.0076506	1.017772	4.01462	.997
	5/13	.0088021	1.020474	3.769464	.987
	ALL	-.010051	.9771225	3.892637	.988
ELLIOTT 10-11	4/15	.0160282	1.037596	3.242831	.995
	4/29	.0119816	1.027973	3.137411	.993
	5/4	-.033587	.9255780	3.180133	.991
	5/13	-.107	.7816278	3.168684	.991
	ALL	-.028144	.9372512	3.182265	.988
ELLIOTT 19-20	4/29	-.115527	.7664309	4.161895	.998
	5/6	-.092678	.8078338	4.117458	.999
	5/13	-.015114	.9657973	4.293166	.997
	ALL	-.07444	.8424808	4.19084	.996
ELLIOTT 27-28	4/30	.57924	3.795247	4.048717	.993
	5/6	.3267477	2.122011	4.143432	.986
	5/15	.1314194	1.353379	4.421309	.991
	ALL	.3458024	2.217187	4.204486	.959
ELLIOTT 35-36	4/20	.9990758	9.978742	3.681724	.983
	4/30	1.143649	13.92031	4.210685	.993
	5/6	.6275212	4.241517	4.409949	.992
	5/15	.112101	1.294497	4.441216	.994
	ALL	.7205867	5.255169	4.185893	.857
GOLDSTREAM 6-7	5/1	-.249169	.5634184	4.306786	.996
	5/7	-.090895	.8111571	4.588281	.999
	5/14	.0672315	1.167432	4.308293	.998
	ALL	-.090944	.8110656	4.40112	.982
PARKS 275-276	4/24	-.056641	.8777261	4.650748	.992
	5/3	-.009851	.9775726	4.949168	.996
	5/14	.1029172	1.267410	4.815649	.995
	ALL	.012142	1.028352	4.805188	.99

Table 4.3

SUBGRADE REGRESSION ANALYSES

DAMAGE FACTOR = $C(\text{DEFLECTION})^{D}$

TEST SECTION	DATE	LOG C	C $(X10^{6})$	D	R^2
ALASKA 282-283	4/22	-4.39017	40.72208	4.333667	.999
	5/1	-4.58663	25.90419	4.407851	.998
	5/7	-4.66787	21.48473	4.464748	.997
	ALL	-4.50825	31.02773	4.364943	.992
ELLIOTT 5-6	4/15	-5.92057	1.200688	4.903792	.982
	4/29	-5.40822	3.906430	4.41644	.996
	5/4	-5.85584	1.393670	4.700525	.998
	5/13	-5.52204	3.005799	4.409395	.998
	ALL	-5.61309	2.437306	4.553931	.984
					.98
ELLIOTT 10-11	4/15	-5.91026	1.229532	4.70331	.994
	4/29	-5.29792	5.035934	4.073919	.998
	5/4	-5.37907	4.177630	4.074479	.998
	5/13	-5.57571	2.656379	4.169353	.992
	ALL	-5.39544	4.023092	4.141421	.962
ELLIOTT 19-20	4/29	-6.59409	.2546303	4.65165	.997
	5/6	-6.26037	.5490729	4.31507	.997
	5/13	-7.35551	.0441052	5.014071	.983
	ALL	-6.61378	.2433436	4.578951	.98
ELLIOTT 27-28	4/30	-6.65703	.2202774	4.572782	.996
	5/6	-6.81611	.1527179	4.618103	.988
	5/15	-6.75582	.1754608	4.631533	.997
	ALL	-6.74229	.1810131	4.606481	.992
ELLIOTT 35-36	4/20	-5.53343	2.927993	4.563728	.994
	4/30	-6.28541	.5183105	4.80546	.996
	5/6	-6.15677	.6969955	4.641239	.995
	5/15	-6.13968	.7249699	4.584455	.992
	ALL	-6.06427	.8624422	4.67626	.952
GOLDSTREAM 6-7	5/1	-6.14382	.7180919	4.495006	.997
	5/7	-6.46268	.3446038	4.699687	.999
	5/14	-6.41478	.3847867	4.576118	.999
	ALL	-6.26605	.5419385	4.528077	.995
PARKS 275-276	4/24	-5.63848	2.298900	4.473733	.997
	5/3	-5.75036	1.776806	4.480363	.999
	5/14	-5.72118	1.900291	4.477488	.999
	ALL	-5.68652	2.058164	4.464399	.997

Table 4.4

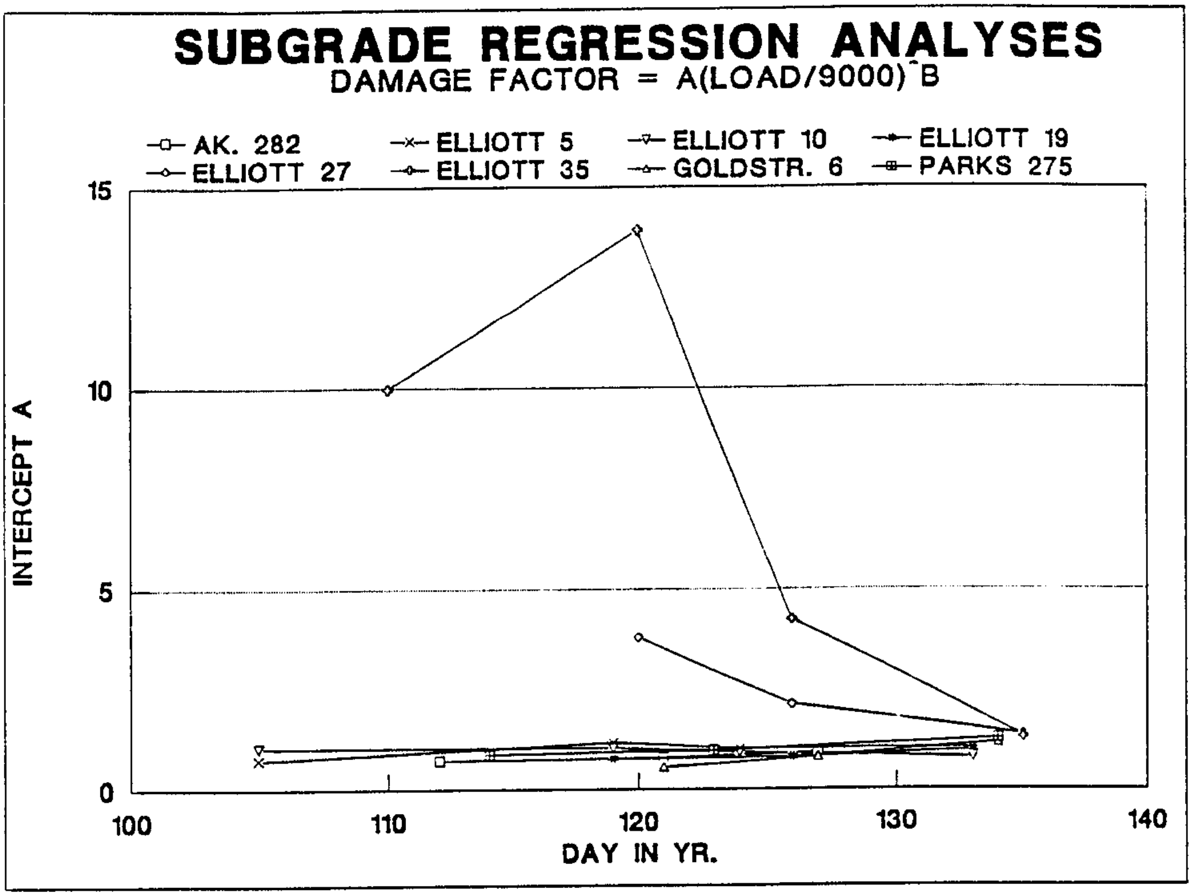

Figure 4.47

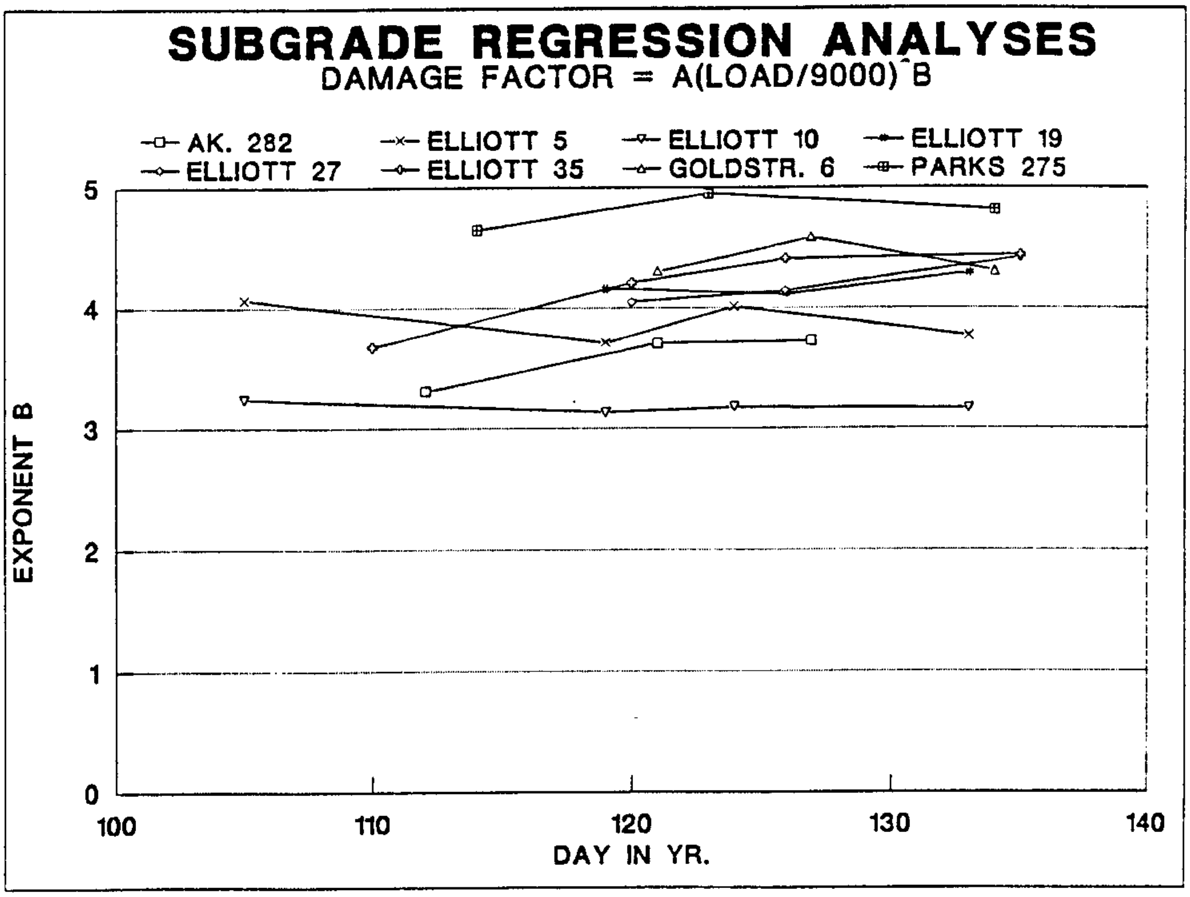

Figure 4.48

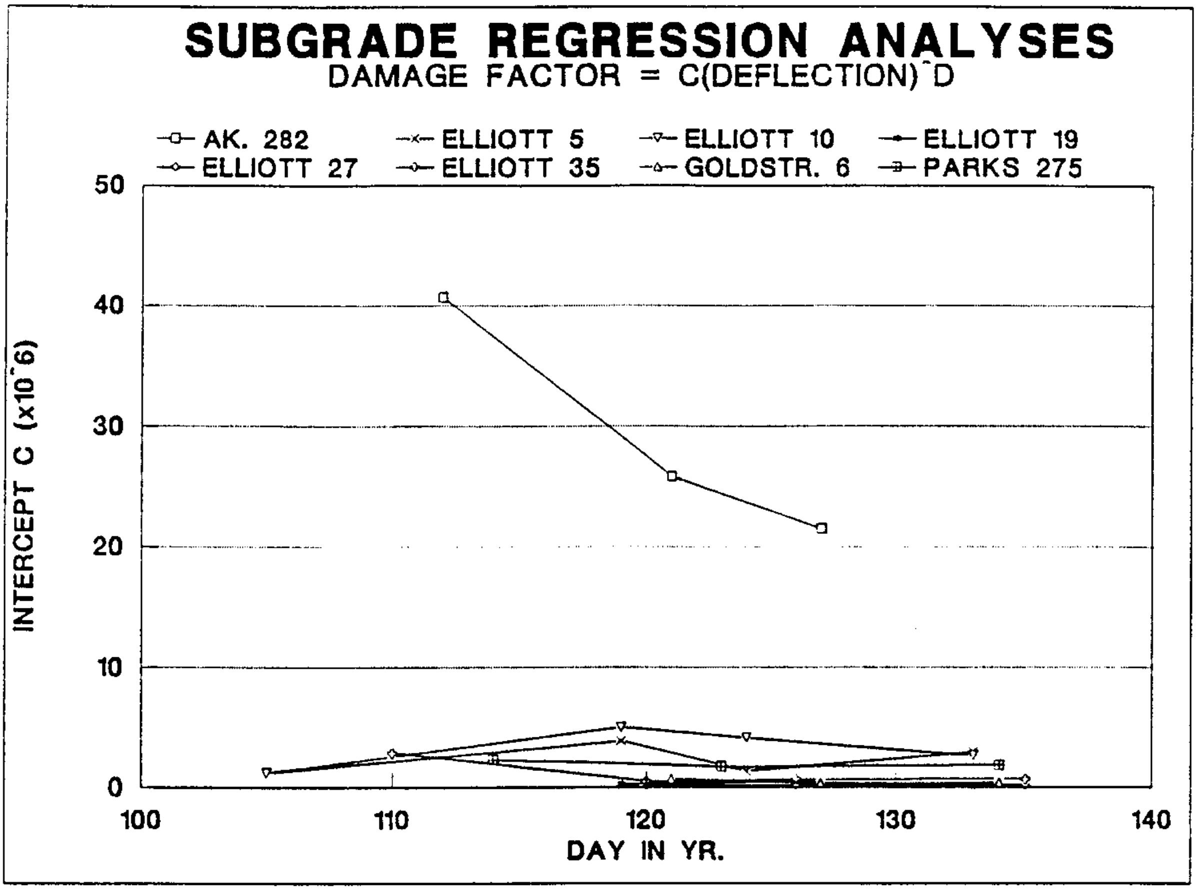

Figure 4.49

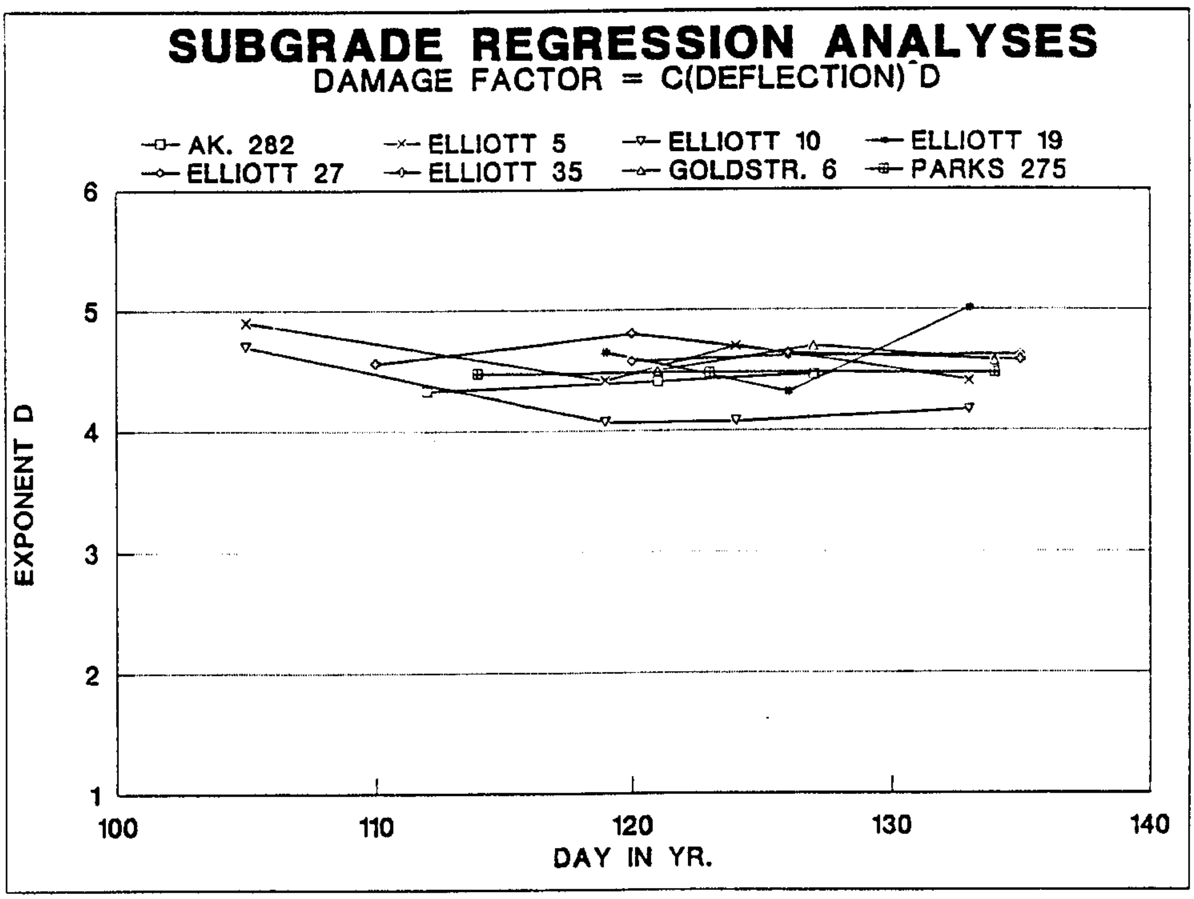

Figure 4.50

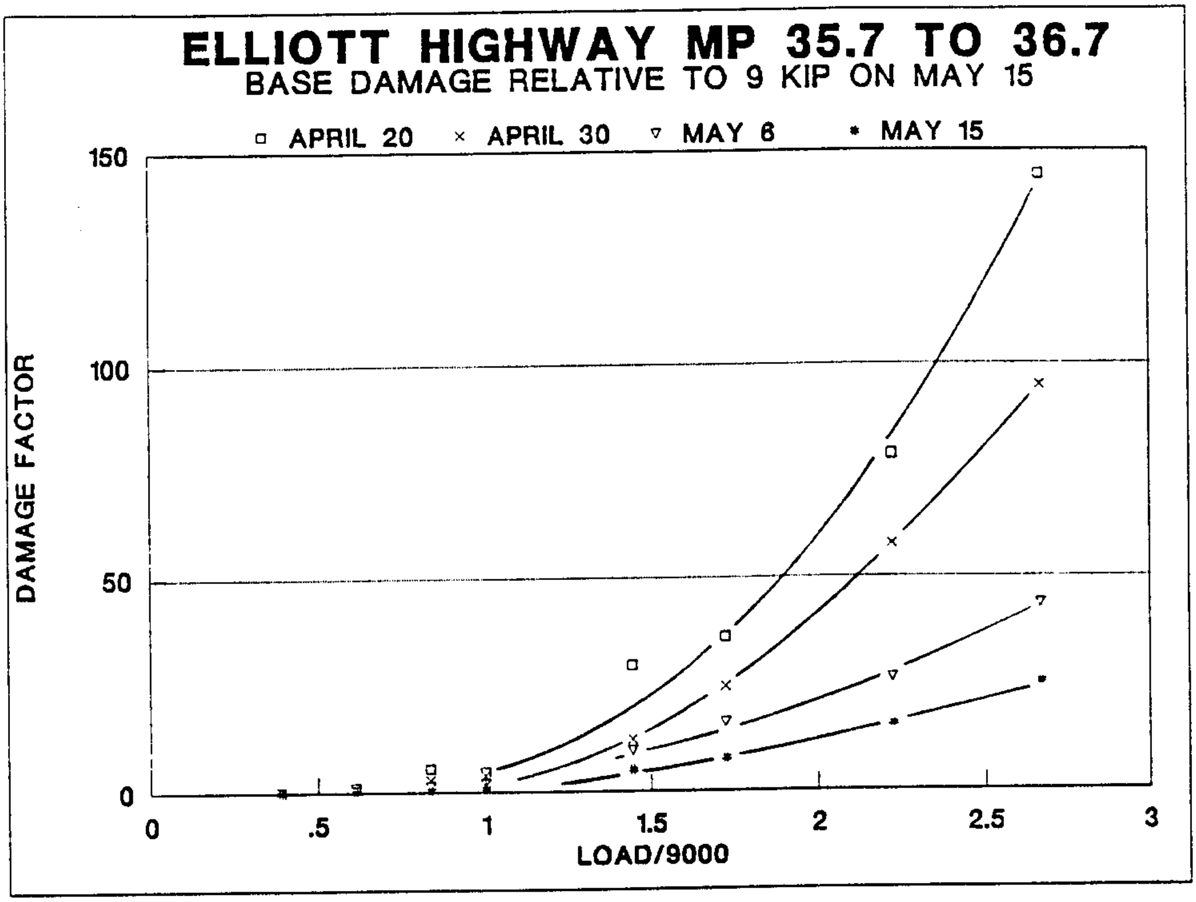
ELLIOTT HIGHWAY MP 35.7 TO 36.7
BASE DAMAGE RELATIVE TO 9 KIP ON MAY 15
APRIL 20
APRIL 30
MAY 6
MAY 15
DAMAGE FACTOR
150
100
50
0
0
.5
1
1.5
2
2.5
3
LOAD/9000

Figure 4.51

5. SUMMARY AND CONCLUSIONS

Damage factors were calculated for AC and subgrade strain conditions under varying loads for eight pavement sections during the spring thaw period. All eight sections consisted of thin pavement structures with only 2" AC surfacing. All eight sections exhibited non-linear deflection responses, of which seven exhibit stress stiffening characteristics. Regression analyses were performed to investigate the relationships between damage factors and normalized load (relative to nine kips) as well as maximum deflection (in mils). The following observations are based on these analyses.

i) Significant thawing may have occurred prior to any testing in all sections except Elliott 35.7 to 36.7.

ii) The effect of thaw weakening, where observed, appears primarily as a multiplicative effect in the load-related damage equations developed through regression analyses. This observation needs further verification using a wider data base (see (i) above) and it is recommended that this verification be carried out by Alaska DOT&PF. Particular attention should be paid to testing data to ensure that data is collected early during the spring thaw.

iii) The highest multiplier was approximately 3 for AC damage and 14 for subgrade damage. Both are developed from Elliott 35.7 to 36.7 data.

iv) A series of load related damage factor equations of the form

$$DF = A\ (Load/9000)^B \qquad \text{Eq. 5.1}$$

where

DF = damage factor
Load = applied load (lb) [Range 3,500 to 24,000]
A,B = regression coefficients

were developed. Excellent correlation coefficients were obtained. Ranges of A and B are:

	A	B
Asphalt Concrete	0.6 to 2.9	2.4 to 3.1
Subgrade	0.6 to 13.9	3.1 to 4.9

High values of A appear to be related to thaw weakening effects. If no thaw weakening is evident, the value of A falls in the range of 0.6 to 1.4 and appears to tend to 1.0. Specific pavement relationships and limits are provided in Chapters 2, 3 and 4. Fatigue equation choice probably governs the value of B.

v) A series of deflection-related damage factor equations of the form

$$DF = C\ (\text{Deflection})^{D} \qquad \text{Eq. 5.2}$$

where

DF = damage factor
Deflection = maximum measured deflection (mils)
C,D = regression coefficients

were developed. Excellent correlation coefficients were obtained. Actual values of C and D are listed in Chapter 4, and should be related to specific pavement sections and range limits since a normalized deflection parameter was <u>not</u> used. Ranges of C and D are as follows:

	$C(X10^{-6})$	D
Asphalt Concrete	20.5 to 1044.2	2.7 to 3.5
Subgrade	0.04 to 40.7	4.1 to 5.0

It is recommended that future analyses should use a normalized deflection parameter similar to that typically used for load. The value of C may then show similar trends to those found for A in the load-related equations. Exponent D is probably governed by the choice of subgrade fatigue equation, and may be affected by the non-linear pavement deflection response.

vi) Damage to AC is limited in thin sections due to limited tension development in the AC under load. In such cases, base response probably governs damage accumulation, as shown by the limited base damage calculations carried out for this project. A realistic base course fatigue equation is necessary in order to perform those analyses reliably.

vii) Base and AC damage appears to peak at about the same time during thaw. Subgrade maximum damage occurs later, so that both surface (i.e. AC (or base) and subgrade damage should be considered when evaluating damage caused by traffic loading during spring thaw.

viii) From an implementation point of view, results of the study may be applied to all mechanistic pavement designs, particularly those relating to the evaluation of existing pavement structures. Also, the damage relationships provide some insight to the effect of overloaded axles on existing pavement structures and may be useful in estimating increased costs related to overload permits. It should be noted that the following specific points are based on a limited data base which should be extended in order to evaluate the reliability of the estimated damage factors.

a) The deflection based damage equations should not be used except for the specific locations where developed, since these equations are not based on a normalized deflection indicator.

b) Load based damage relationships may be applicable to all similar pavement structures, i.e. thin AC surfacings in Alaska. Some pavements may not show thaw-weakening response.

c) Center deflections during spring thaw can be used to determine if a pavement exhibits significant thaw-weakening characteristics or not. It is possible that thaw-weakening is related to excess fines (as defined by Alaska DOT&PF procedures) in the unbound materials.

d) Equation 5.1 may be used directly to estimate load-related damage. Alternatively, damage may be evaluated using mechanistic analysis of the candidate pavement structure and relevant fatigue equations for AC and subgrade to calculate the allowable number of repetitions of an applied load on the pavement. If thaw weakening is expected, the higher values of A listed under (iv) above can be used to reduce the allowable repetitions to reflect the effect of damage during spring thaw. For instance, divide allowable repetitions for AC by approximately three and for subgrade by approximately 12. The combined damage effect can be evaluated using a cumulative linear damage hypothesis (Miner's Law).

6. REFERENCES

1) Yoder, E.J. and Witczak, M.W. "Principles of Pavement Design." 2nd edition. John Wiley & Sons. 1975.

2) Stubstad, R.N. and Connor, B. "Prediction of Damage Potential on Alaskan Highways During Spring Thaw Using the Falling Weight Deflectometer." Alaska DOT&PF. 1982.

3) Ullidtz, P. "Pavement Analysts." Elsevier Science Publishing Co. 1987.

4) Ullidtz, P. and Stubstad, R.N. "Analytical - Empirical Pavement Evaluation Using the Falling Weight Deflectometer." TRR 1022 Transportation Research Board. 1985.

5) Ullidtz, P., Battiato, G., Larson, B.K. and Stubstad, R.N. "Verification of the Analytical - Empirical Method of Pavement Evaluation Based on FWD Testing." Sixty International Conference on the Structural Design of Asphalt Pavements. 1987.

6) Ali, N.A. and Khosla, N.P. "Determination of Layer Moduli Using a Falling Weight Deflectometer." TRR 1117. Transportation Research Board. 1987.

7) Mahoney, J.P., Coetzee, N.F., Stubstad, R.N. and Lee, S.W. "A Performance Comparison of Selected Back Calculation Computer Programs." STP 1026 (Bush and Baladi, Editors). American Society for Testing Materials. 1989.

8) "Research and Development of The Asphalt Institute's Thickness Design Manual (MS-1) Ninth Edition." R.R.-82-2. The Asphalt Institute. 1982.