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A STUDY of PRESTRESS CHANGES in a POST-TENSIONED BRIDGE DURING the FIRST 30 MONTHS (FINAL REPORT)

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Prepared by Research Division
Nevada Department of Transportation
1263 South Stewart Street
Carson City, Nevada 89712

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16. Abstract

A post-tensioned, simply-supported, concrete bridge structure in northern Nevada was instrumented in 1988 during construction, and the variation of its response was monitored over a 30-month period. The measured data consisted of tendon strain on four strands, concrete surface strain on two girders, and the deflection of the mid span relative to the ends of the superstructure. The measured losses on the tendons were due to creep and shrinkage. The data showed that the actual total creep and shrinkage losses are 30 percent higher than those predicted using a time-step analysis and 60 percent higher than those predicted by AASHTO. The results also indicate that the prestress forces continue to change due to seasonal variation in temperature and humidity, but the average stress becomes nearly stable.

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ABSTRACT

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Chapter 1

INTRODUCTION

1.1 Background

The ambient relative humidity (RH) in most of the State of Nevada is low compared to the RH in the rest of the country [6]. In prestressed concrete bridges, a small RH could lead to excessive prestress losses, and could adversely affect the service performance of the bridge. Because current design guidelines are primarily based on data for RH which is higher than those experienced in Nevada, a study was undertaken to determine the actual prestress changes in a bridge. Accordingly, in September 1988, the Golden Valley Interchange, a 155 foot, simple span, post-tensioned box girder bridge located near Reno, Nevada was instrumented during construction. Electrical strain gages were bonded directly to post-tensioning cables in the bridge near midspan, along with mechanical strain gages which were attached to the concrete surface. The bridge's response was then monitored over a 15-month period. Data consisted of tendon strain measurements on four strands, the concrete surface strain on two girders, and the deflection of the mid span relative to the ends of the superstructure. From the strain data the actual time-dependent prestress losses due to creep and shrinkage were calculated. The strain data could not show the relaxation loss because this component of loss does not directly affect strains.

A theoretical analysis was made using the AASHTO (American Association of State and Transportation Officials) code specifications [6] and a time-step analysis proposed by Naaman [2].

A study was then done on the prestress changes that occurred by comparing the actual losses to predicted values. The measured and calculated data for the first 15 months after post-tensioning were presented and discussed in a previous report [5]. The report also included a state-of-the-art review of the available literature on the subject of prestress loss. Because prestress forces continued to decline and because there was evidence that seasonal changes may be affecting the losses, the project was extended for an additional 15 months, during which eight sets of new data were collected. The primary focus of this report is to present the measured and calculated results for project duration. Reference 5 contains information on the bridge geometry, materials, construction, equipment, and instrumentation.

1.2 Object and Scope

The main objective of the overall study was to measure prestress losses directly in a full-scale bridge and compare those values to the results from the available prediction methods. The purpose of the second 15-month period of the study was to capture the effects of seasonal changes and to determine if the prestress force is stabilizing. Furthermore, it was essential to determine how the stabilized stress compared to that predicted by AASHTO, based on which the bridge was designed. To determine the seasonal effects on the prestress and deflection, temperature and humidity data collected at the Reno-Cannon International Airport were assumed to represent the climatic condition that the bridge (located at about 5 miles north of the airport) experienced. To determine the stabilized prestress in 30 months, a logarithmic curve was fitted to the measured stresses.

The theoretical calculations of the prestress losses consisted of a time-step method and the AASHTO method. Unlike Ref. 5 which considered only the instrumented girders to determine the losses, the present report considered the entire bridge assuming that losses in all the girders are the same.

Chapter 2

MEASURED RESULTS

2.1 Introductory Remarks

During the 30 month period of this project, there were three types of data periodically collected. They were, (1) strains measured directly on the prestressing tendons, (2) strains measured on the concrete surface, and (3) bridge deflections. All of these measurements were taken at or near the center of the span for the Golden Valley bridge. These measurements, as well as the time schedule used to collect them, are presented in this chapter.

2.2 Measurement Schedule

Because the majority of prestress losses occur early in the life of a structure, the measurements were taken more frequently at first, and then at increasingly larger intervals for the rest of the project. Initially measurements were taken at 1 day, 2 days, 3 days, 7 days, and 14 days, then 4 weeks, 6 weeks, 13 weeks, 25 weeks, 12 months, 15 months, and 18 months from the day of initial prestressing (September 8, 1988). During the last year of the project, measurements were taken about every 2 months to capture the effect of seasonal changes on prestressing forces.

2.3 Strains Measured on Prestressing Tendons

A total of four tendons, two on the interior girder and two on the exterior girder, were instrumented with electrical resistance strain gages. Three strain gages were bonded to three different wires on one strand in each of the instrumented tendons. Therefore, the bridge was initially instrumented with 12 strain gages, during the grouting process, however, 3 of these were damaged.

About 20 strain gage data sets were obtained in one-hour intervals to eliminate the daily variation of prestress force due to temperature and humidity changes.

The prestress force at midspan of the bridge was then calculated using these average values and plotted in Fig. 2.1. Because the gages were attached to the wires in the direction of each wire axis, and because the wire axis is at approximately ten degrees relative to the axis of the tendon, the strain changes measured on the wires were amplified by a factor of 1.03. This figure was arrived at by considering a flat bar subjected to axial stress with a strain gage installed at an angle of ten degrees relative to the bar axis. The factor of 1.03 is necessary to convert the strain on the gage to the axial strain of the bar. Considering that strain gages generally are off by several degrees from the axis of the wires, the approximation was deemed to be appropriate. A similar but larger conversion factor was determined based on tests in Ref. 4.

It should be noted that only creep and shrinkage losses are reflected in the tendon strains. This is because relaxation losses are the changes in stress without any strain changes.

As expected, the majority of prestress losses occurred in the first 90 days from prestressing. Then the prestress force remained nearly constant for the next 3 months. However, between March 1989 and September 1989 (174 and 363 days from initial prestressing), there was a relatively large drop in prestress of nearly 12 ksi. The loss rate then slowed until May of the following year where there is another sharp drop. This is then reversed in the subsequent months until the last data set was taken.

The measured prestress forces for the period between the two drops appear to be stable and may represent the level of final prestress force around which seasonal variation in the force occur.

2.4 Mechanical Strain Gages

Six dial gage assemblies with a gage length of 30 inches were bonded to the concrete at three wall thicknesses away form the blockouts. This was to avoid any local influences of the blockout openings. The dial gage data were collected at mid-mourning on each day of data collection. The concrete strain data shown in Table 2.1 were converted to a prestress loss by first fitting a least-squares line to the measured strains and then finding the strain at the level of the tendon from this line. The prestress values are also shown in Table 2.1. Because the tendons are bonded, the strain change in the concrete at the level of the tendon was assumed to be the strain change in the tendon. Similar to tendon, the concrete surface strains reflect only creep and shrinkage losses, because relaxation losses are not associated with any strain changes.

Figure 2.1 compares the time-dependent prestress losses measured from concrete strain data with the losses from the electrical strain gage readings. As can be seen in Fig. 2.1, the strain measurements on the concrete surface during the first six months showed relatively small losses, with a trend much different from that of the electrical strain gage readings. The overall magnitude of prestress loss is typically lower for the concrete gages compared to the electrical gages by about 12 to 15 ksi. It should be noted that, at the time of dial gage readings, the tendon strains were near the average daily value.

The losses based on the concrete surface strain data may be unreliable because the majority of the measured strains were highly nonlinear with an inconsistent distribution. Some nonlinearity of strains is expected due to the variation of temperature and creep deformations along the depth of the girder. Detailed examination of these factors was beyond the scope of this study.

2.5 Center Span Deflections

The midspan deflection relative to the abutments was measured on each data collection day using a surveying level and a Philadelphia Rod with a sensitivity of 0.01 ft. The data, collected on the east and the west edge of the bridge and averaged, are presented in Table 2.2. A plot of these data can be seen in Fig. 2.2. A negative camber in this figure indicates a downward deflection. The slight increase in camber after the first month is attributed to the compaction of the backfill at the abutments. In the subsequent months, the bridge generally deflected downward. A comparison of Fig. 2.1 and 2.2 shows that, when the tendon force was nearly constant or on the rise, the bridge moved upward. The changes in the direction of the deflection is attributed to climatic variations.

Chapter 3

THEORETICAL ANALYSIS OF PRESTRESS LOSSES

3.1 Introductory Remarks

The theoretical analyses of prestress losses for the Golden Valley Interchange are presented in this chapter. Two common methods are utilized, the current AASHTO lump-sum estimate of separate losses [6], and the time-step method as presented in Naaman [2]. Each method assumes an average relative ambient humidity for calculation purposes, but because of the variations in prestress losses due to climatic variations, and because of the severe climate changes throughout the year in the Reno area, the effects of temperature and humidity are explored in the analysis of the actual data, and in the theoretical analysis.

3.2 AASHTO Prestress Losses

Six Components of prestress loss occur in post-tensioned bridges, namely, losses due to the anchorage set, friction, elastic shortening, relaxation, creep, and shrinkage.

The lump-sum estimate of separate losses, which is presented in AASHTO's Standard Specifications for Highway Bridges [6], is widely used because of the relatively small number of design parameters involved and because it is simple. The AASHTO procedure is specified to determine all but the first loss component, anchorage set. The procedure, as well as the numerical values used for different parameters are summarized here. For anchorage set losses Reference 5 may be used.

Friction Losses

Frictional Losses, FR, are calculated as follows:

$$FR = T_o - T_x$$

Where $T_o = T_x\, e^{(KL+\mu\alpha)}$

T_x = Initial prestress force (189 ksi)

K = Wobble coefficient (0.0002)

L = Length from jacking end to section of interest (77.5 ft)

μ = coefficient of angular friction (0.25)

α = change in angle between the anchorage and the section of interest (0.0753 radians)

When $(KL+\mu\alpha)$ is < 0.3, $T_o = T_x(1+KL+\mu\alpha)$

The parameters for the Golden Valley Interchange can be seen in parentheses after each variable. The values are determined at the midspan section of the bridge, near the strain gages. A value of 6.49 ksi was calculated for the frictional loss of prestress using the above specification.

AASHTO Total Losses Excluding Relaxation and Anchorage Set

The total loss in prestress is calculated as follows:

$$\Delta f_s = SH + ES + CR_c + CR_s$$

where:

Δf_s = total loss excluding friction and anchorage set in psi.

SH = loss due to concrete shrinkage in psi.

ES = loss due to elastic shortening in psi.

CR_c = loss due to creep of concrete in psi.

CR_s = loss due to relaxation of prestressing steel in psi.

Shrinkage loss, SH:

$SH = 0.80(17{,}000-150RH)$

Where:

RH = Mean annual ambient relative humidity in percent. (50% for Golden Valley)

$SH = 0.80(17{,}000-150(50)) = \underline{7.6 \text{ ksi}}$

Elastic Shortening loss, ES:

$ES = 0.5(E_s/E_{ci})f_{cir}$

Where:

E_s = Modulus of elasticity of prestressing steel strand. (29,000 ksi)

E_{ci} = Modulus of elasticity of concrete at transfer of stress. (3,668 ksi, based on measured cylinder data)

f_{cir} = Concrete stress at the center of gravity of the prestressing steel due to prestressing force and dead load of beam immediately after transfer, it was computed at the section of maximum moment. (At this stage, the initial stress in the tendon was reduced by tendon friction). (1.264)

$ES = 0.5\ (29{,}000/3668)0.660 = \underline{5.00 \text{ ksi}}$

The above values are based on an initial concrete compressive strength of 4,200 psi, a section moment of inertia of 11,924,900 in^4, a cross sectional area of 12,128 in^2, and a midspan eccentricity of 35 inches.

Creep of concrete, CR_c:

$CR_c = 12f_{cir} - 7f_{cds}$

Where:

f_{cir} = This is the stress at the center of gravity of the prestressing steel due to the prestressing force and dead load of the beam immediately after transfer. However at this stage, the initial stress in the tendon is reduced by tendon friction and elastic shortening. (1.199)

f_{cds} = Concrete stress at the center of gravity of the prestressing steel due to all dead loads except the dead load present at the time the prestressing force is applied. (For the Golden Valley Bridge this would be due only to bridge railing which was assumed to be negligible.)

$CR_c = 12(1.199) - 7(0.0) = \underline{14.38 \text{ ksi}}$

Relaxation of Prestressing Steel, CR_s:

$CR_s = 5{,}000 - 0.07FR - 0.1ES - 0.05(SH + CR_c)$
(for low relaxation strand)

$CR_s = 5{,}000-0.07(6{,}490)-0.1(5{,}000)-0.05(21{,}980)$

$= \underline{2.95 \text{ ksi}}$

Total lump-sum loss:

$\Delta f_s = SH + ES + CR_c + CR_s$

$= 7.6 + 5.00 + 2.95 + 14.38$

$= \underline{29.93 \text{ ksi}}$

3.3 Time-Step Prestress Losses

Time-step methods are used to determine the time-dependent prestress losses. The method presented in Naaman [2] is one of the more established procedures, and it was used in this study. Because the time-step method accounts for interaction among time-dependent losses, it is considered to be more accurate than the AASHTO method.

The time-dependent losses are calculated over a series of short time intervals. The time intervals used for the theoretical analysis were the same intervals used for the actual measurements of the data. Thus, actual measurements and theoretical measurements could be compared for each "time-step".

Since the time-step method involves repetitious computational effort, a program named PSLOSS was written to perform the calculations. Appendix A presents a description and listing of PSLOSS, as well as a sample data file and a sample output.

The time-dependent loss components are determined using the following procedure [2].

Relaxation Losses, Δf_{pR}:

$$\Delta f_{pR}(t_i, t_j) = ((f_{ps}t_i)/10)\ (f_{ps}(t_i)/f_{py} - 0.55)\ \log(t_i/t_j)$$

Where:

Δf_{pR} = relaxation loss from t_i to t_j (ksi)

$f_{ps}(t_i)$ = stress in prestressing steel at beginning of time interval (ksi)

f_{py} = yield strength of prestressing steel (ksi)

t_i and t_j are the time at the beginning and end of the interval, respectively, in hours (not less than 1 hour)

For low-relaxation prestressing steel a value of 45 is used in the denominator instead of the 10 shown. This was the case in the Golden Valley Interchange.

Shrinkage Losses, Δf_{pS}

The shrinkage losses of the concrete depend on many parameters, including composition of the concrete mix, characteristics of the aggregates, relative humidity of the environment, curing history, and the like. Therefore, the loss due to shrinkage in the time-step method has many variables.

$$\Delta f_{pS}(t_i, t_j) = E_{ps}\epsilon_{SU}K_{SH}K_{SS}b(t_j - t_i)/(b+t_i)(b+t_j)$$

Where:

Δf_{pS} = Shrinkage loss for time interval considered (ksi)

E_{ps} = Modulus of Elasticity of the prestressing steel (ksi)

ϵ_{SU} = Ultimate Shrinkage Strain (in/in)

K_{SH} = Correction factor which depends on the average relative humidity of the environment where the structure is built

K_{SS} = Correction factor which depends on the shape and size of the member

t_i, t_j = The time at the beginning and end of the interval respectively (not less than 1 hour)

The value for b is taken to be 35 for moist-cured concrete and 55 for steam-cured concrete. For Golden Valley b = 35.

Creep Losses, Δf_{pC}

As for shrinkage, creep losses depend on a variety of factors, such as time, age at loading, relative humidity, type of aggregates, etc. The general equation for time-step creep losses is:

$$\Delta f_{pC}(t_i, t_j) = E_{ps}[g(t_j) - g(t_i)] C_{CU} K_{CH} K_{CA} K_{CS} \epsilon_{ci}$$

Where:

Δf_{pC} = Creep loss over specified time interval

E_{ps} = Modulus of elasticity of prestressing steel (ksi)

C_{CU} = Ultimate creep coefficient

K_{CH}^* = Correction factor depending on the average relative humidity of the environment where the structure is built

K_{CA}^* = Age at loading factor

*Note:
Theoretical values for K_{CH} and K_{CA} are specified for

humidities 40 percent or greater, and for times greater than 7 days. Since no other data were available for humidities less than 40 percent, the equations for K_{CH} and K_{CA} were used for all values used in the time step computations.

K_{CS} = Shape and size factor

ϵ_{ci} = Instantaneous (initial) elastic strain, defined as follows:

$$\epsilon_{ci} = f_{cgs}(t_i)/E_c$$

Where f_{cgs} = stress in the concrete at the centroid of the steel at time t_i due to the prestressing force and dead load

E_c = Modulus of elasticity of concrete

$g(t)$ = Is a time function which is used by Naaman [2]. It is the time function suggested by ACI Committee 209 [1] and is given by:

$$g(t) = t^{0.60}/(10+t^{0.60})$$

For the above correction factor values used for the Golden Valley Bridge see Appendix A, Section A.4.

As can be seen, the time-step method requires the use of many variables, and without sufficient knowledge about certain design parameters, assumptions can sacrifice accuracy to the point where a less sophisticated method may be more accurate. In analyzing the Golden Valley Interchange, all of these variables were known and a very accurate analysis was made. An exception to this was with two variables; C_{CU} - the ultimate creep coefficient, and ϵ_{su} - the ultimate shrinkage strain, for which the ACI Committee 209 [1] suggested values were used. A value of 2.35 was used for C_{CU}, and a value of 550 μs was used for ϵ_{su}. (The value for the ultimate shrinkage strain was modified to take the time of prestressing into account. See Appendix A, section A.3)

3.4 Effect of Variable Humidity on Time-Step Results

Program PSLOSS was used to determine losses based on a constant mean ambient relative humidity (RH) of 50% which would be used for the normal analysis. However, because of the variable humidities throughout the project, the program PSLOSS was also run for different humidity values corresponding to the average humidity during each time-step measurement taken. The time-step results for the constant and variable humidities are shown in Table 3.1 and Fig. 3.1. It should be noted that relaxation losses are excluded in the plots to allow for direct comparison of stresses with the measured values. As it was mentioned in Chapter 2, the measured strains do not reflect the changes due to relaxation because relaxation losses are not associated with any strain changes.

From this figure a good correlation can be seen between the trends in the time-step losses with variable RH and the actual measurements. The concrete strain losses follow the modified curve very closely showing the direct correlation between humidity, and creep and shrinkage of the concrete. The tendon measurements follows the curve with a slight time lag. This shows that humidity and temperature are affecting the prestress losses greatly, and that they may need to be considered in the analysis of seasonal variation of the prestress losses. This is discussed further in Chapter 4.

3.5 Regression Analysis

To find a value of prestress loss for the entire life of the structure, a regression analysis was made of the measured tendon data. Several curve fitting techniques were used to find a relationship between the prestress loss and the time of measurement. These included an exponential curve fit which expresses the data in the form $y = Be^{Mx}$, a logarithmic curve fit to express the data in the form $y = B + M\ln x$, a power curve fit to express the data in the form $y = Bx^{M}$, and a regression analysis to linearize the data logarithmically in the form $\log y = B*\log x$. Table 3.2 presents the results of these analyses.

Since the logarithmic linearization gave the best approximation of the measured data, it was used to determine the value for prestress loss for the structure. From this graph the value of prestress in 30 months was found to be 148.1 ksi. The prestress loss was found by subtracting that value from the initial prestress of 183.1 ksi, or 35 ksi. A graph of the measured tendon data vs. the logarithmic linearization can be seen in Fig. 3.2.

A comparison of creep and shrinkage prestress losses over the life of the structure can be seen in Table 3.3. The table includes the AASHTO lump-sum method, the Naaman time-step method, and the regression analysis of the measured tendon data.

A comparison between stresses based on the logarithmic linearization and the Naaman time-step method using a relative annual humidity of 50% can be seen in Fig. 3.3.

3.6 Calculated Midspan Deflections

The long term deflection was found by using the creep coefficient and average prestress force. This is an approximate method for deflection calculation found in Nilson [3]. The long-term deflection due to self-weight is modified by creep, and may be obtained by applying the creep coefficient to the instantaneous value. Thus, the total (40 year) member deflection, Δ, after losses and creep deflections when effective prestress and self-weight act, is given by:

$$\Delta = -\Delta_{pc} - [(\Delta_{pi}+\Delta_{pc})/2]C_u + \Delta_o(1+C_u) \quad [3]$$

Where:

Δ_{pi} = The displacement due to prestress = $5Pel^2/48EI$

$\Delta_{pc} = \Delta_{pi}(P_c/P_i)$

Δ_o = The displacement due to dead load = $5wl^4/384EI$

C_u = Creep coefficient

To determine deflection during the life of the structure, Eq. 3 can be used with C_u modified by the time function of $[t^{0.6}/(10+t^{0.6})]$ which is presented in Ref. 2. For the Golden Valley Interchange, the calculated one-year deflection was 1.8 inches and the total deflection after 40 years was 2.2 inches.

Chapter 4

DESIGN IMPLICATIONS

4.1 Introductory Remarks

The measured tendon stresses and center span deflections of the bridge during its first 30 months after prestressing are compared with theoretical results in this chapter. Because the prestress losses based on the concrete surface strains did not appear to be reliable because of the observed nonlinearity of strain distribution along the girders. Therefore, the discussion presented in this chapter is based on tendon strain data. Also included in this chapter are the temperature and humidity data collected near the bridge site, and their effects of the stresses and deflection of the bridge.

4.2 Comparison of Measured and Calculated Losses

The electrical strain gage data indicate the total losses due to creep and shrinkage. The measured prestress history at the midspan of the bridge is shown in Fig. 3.1. A comparison of the time step results with those from the electrical gages, shows that the measured losses were higher than the theoretical results except for the first six months, during which the time-step results were up to 5 ksi higher than those measured. For the period of September '89 to May '90 during which the measured losses appeared to have stabilized, the time step results showed a creep and shrinkage loss of approximately 27 ksi, whereas the measured loss was 32 ksi, a difference of 5 ksi. An exponential least square fit of the measured losses (Fig. 3.2) led to a loss of 36 ksi in 30 months, whereas the time-step result in thirty months shows a loss of 29 ksi, a difference of 7 ksi. Note that all these losses are due to creep and shrinkage only.

The total creep and shrinkage losses using the AASHTO guidelines [6] are 22 ksi. This value is based on a mean relative humidity of 50 percent and a specified initial prestress of 189 ksi less a friction loss of 6.27 ksi at midspan. The smoothed measured data show a loss of 32 ksi and 36 ksi for one year and thirty months, respectively. The measured data suggest that an adjustment of AASHTO equation may be necessary. Because the difference is mainly attributed to the low relative humidity in the area and because only the shrinkage loss expression in the AASHTO guidelines depends on this factor, the adjustment may need to be made in the equation for shrinkage losses. More data will be needed before a reliable expression can be developed.

4.3 Comparison of Measured and Calculated Deflections

The deflection data were collected on the east and the west edge of the bridge and were averaged (Fig. 2.2). The structure appeared to have deformed upward or downward around an average midspan deflection of approximately 0.6 inch. The maximum deflection was measured on the west side of the structure one year after prestressing, and had a magnitude of 1.1 inch. Using routine methods of calculating deflection of prestressed members [3] and using the specified prestress forces, the computed deflection at midspan is 1.8 inch in one year and 2.2 inch during the life of the structure. The structure is treated as a simply-supported beam in these calculations. The abutments of the actual bridge, however, impose some constraints against rotation at the ends which reduce mid span deflection, and improve the rideability of the bridge.

4.4 Effects of Temperature and Humidity

Figure 4.1 shows the mean monthly temperature and the percentage of mean monthly relative humidity data for the duration of the project. The data were collected at the Reno-Cannon International Airport which is located at about 5 miles south of the Golden Valley Interchange. Both the temperature and the humidity data show considerable variation. It should be noted that even within any 24-hour period, temperature and humidity in the area typically vary substantially. As expected, the temperature and humidity data show opposite trends. The relative humidity over the 30-month duration of the project was about 30 percent in summer months and 60 to 70 percent in winter months. The mean annual relative humidity for the Reno area based on longer climatic data is 47 percent. The mean temperature was about 30°F in winter months and about 75°F during summer months.

The sensitivity of the measured tendon stresses to climatic data may be observed in Fig. 3.2 and Table 4.1. The fitted curve may be treated as an average curve around which climatic changes affect the tendon stresses. A comparison between the slope of the measured and fitted curves reveals the effect of seasonal changes. In segment AB, for example, the slope of the measured curve is larger than that of the fitted curve. The same is true for segments CD and EF. Table 4.1 shows that for all these segments, the average humidity was higher than 50 percent, and the temperature was below 50 °F. Segments BC and DE have opposite trends.

The variation in the direction of the deflection is attributed to climatic changes. A comparison of Figs. 2.2 and 4.1 shows that for the periods during which the monthly relative humidity exceeded 50 percent the bridge cambered. This trend was repeated consistently for three times during November '88 to March '89, October '89 to March '90, and November '90 to March '91. The camber is due to the absorption of the ambient moisture by the bridge and the recovery of some of the volume loss which occurred during the first few weeks after construction.

The effects of seasonal changes on the measured defection may be observed in Fig. 2.2 and Table 4.1. In segment AB, for example, the bridge shows relative camber. The same is true for segments CD and EF. Table 4.1 shows that for all these segments, the average humidity was higher than 50 percent, and the temperature was below 45 °F. Segments BC and DE show opposite trends.

Chapter 5

SUMMARY AND CONCLUSIONS

5.1 Summary

The variation of prestress forces and deflections in a post-tensioned concrete bridge was studied over a 30-month period from the time of stressing. The structure is a simply-supported multi-cell box girder bridge located north of Reno, Nevada. The objective of the study was to determine if the relatively low humidity in the area would lead to excessive losses beyond those predicted by the standards developed by the American Association of State Highway and Transportation Officials (AASHTO). The focus of the study was on time-dependent losses due to creep and shrinkage of concrete.

The measured data consisted of tendon strains, concrete surface strains, and center span deflection relative to the abutments. The strains were measured on an exterior and an interior girder. The time interval for data gathering was short during the first three months, but was increased afterward. During the last year of field measurements, data were collected on an average interval of approximately seven weeks to capture seasonal variations in tendon stresses.

The study also included a time-step analysis of prestress losses and a comparison of these losses with those observed and those predicted using the AASHTO method. To identify the effects of changes in the ambient relative humidity on the tendon stresses and deflection, the climatic data measured at the Reno-Cannon

International Airport were summarized and correlated with the measured stresses and deflections.

5.2 Conclusions

Based on the study presented in this report, the following conclusions may be drawn:

(1) The combined creep and shrinkage losses observed on the tendons were at least 30 percent higher than those predicted by a time-step method and more than sixty percent larger than the loss based on the AASHTO procedure.

(2) Seasonal climatic effects (temperature and relative humidity) influenced the prestress force and deflection through most of the 30-month period for which data were collected. These effects could not be observed during the first three months after stressing because the magnitude of losses was relatively large, and because the changes in climatic parameters were relatively small during this period.

(3) The tendon stresses during the latter two years seem to oscillate around an average curve that is fitted to the measured losses. Compared to the fitted curve, the rate of tendon stress loss slowed when the mean ambient relative humidity exceeded 50 percent. The reverse was true when humidity was below 50 percent.

(4) Similar to prestress forces, the mid span deflection of the bridge was affected by seasonal variation of temperature and humidity. During the last 18 months, the average deflection appeared to have stabilized.

(5) The maximum measured deflection was approximately one-

half of the predicted value. The partial fixity provided by the abutments, which is normally ignored in design, is believed to have contributed to the difference. There was a general agreement between the trend of the deflection data and the measured prestress forces.

(6) Nonlinear strain distribution was observed along the girder depths. To determine losses based on concrete surface strains, transducers need to be connected to the girder directly at the level of tendons.

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Days After Prestressing	Date	GAGE						Final Prestress
		1	2	3	4	5	6	
0	8-Aug-88	0.2096	0.2146	0.1485	0.2081	0.1919	0.215	183.8
7	8-Sep-88	0.2123	0.2158	0.1478	0.2107	0.1956	0.2164	183.1
14	22-Sep-88	0.2144	0.2172	0.1473	0.2126	0.1977	0.2179	182.4
28	6-Oct-88	0.217	0.2204	0.1438	0.2153	0.2006	0.2203	179.4
42	20-Oct-88	0.2182	0.2216	0.1426	0.2161	0.2019	0.2215	178.1
92	9-Dec-88	0.2173	0.2202	0.1432	0.2151	0.2009	0.2203	179.1
174	1-Mar-89	0.2175	0.2226	0.1419	0.2158	0.2023	0.222	177
364	7-Sep-89	0.2132	0.239	0.1204	0.2313	0.2181	0.2335	166.6
454	6-Dec-89	0.2299	0.2362	0.1318	0.2292	0.2162	0.2323	167.4
539	1-Mar-91	0.2289	0.2357	0.1319	0.2285	0.2156	0.2312	168
623	24-May-90	0.2314	0.2398	0.1296	0.2316	0.219	0.2345	164.9
665	5-Jul-90	0.2335	0.2429	0.1272	0.2337	0.2215	0.2363	162.7
714	23-Aug-90	0.2352	0.2442	0.1259	0.2353	0.2229	0.2375	161.7
756	4-Oct-90	0.236	0.2445	0.1254	0.236	0.2237	0.2381	161.2
819	6-Dec-90	0.2356	0.2432	0.1266	0.2353	0.2229	0.2373	162.4
855	11-Jan-91	0.234	0.2414	0.1277	0.2336	0.2213	0.2362	163.4
882	7-Feb-91	0.2343	0.2421	0.1271	0.2339	0.2218	0.2368	162.6
931	28-Mar-91	0.2336	0.2407	0.1277	0.2334	0.2214	0.2361	163.4
REFERENCE READING	——	0.2096	0.2146	0.1485	0.2081	0.1919	0.215	

Table 2.1 - Golden Valley Interchange Concrete Strain Gage Readings.

DAYS AFTER PRESTRESSING	DATE	EAST	WEST	AVERAGE
-1	7-Aug-88	-0.54	-0.84	-0.69
0	8-Aug-88	0.27	-0.04	0.12
1	9-Aug-88	0.18	-0.27	-0.05
3	11-Aug-88	-0.06	-0.18	-0.12
7	15-Aug-88	-0.48	-0.72	-0.6
14	22-Aug-88	-0.6	-0.66	-0.63
28	6-Oct-88	-0.24	-0.6	-0.42
56	20-Oct-88	-0.39	-0.81	-0.6
91	8-Dec-88	-0.12	-0.6	-0.36
106	23-Dec-88	-0.18	-0.6	-0.39
174	1-Mar-89	0	-0.3	-0.15
364	7-Sep-89	-0.6	-1.08	-0.84
454	6-Dec-89	-0.48	-1.02	-0.75
539	1-Mar-90	-0.3	-0.72	-0.51
623	24-May-90	-0.36	-0.96	-0.66
665	5-Jul-90	-0.42	-0.96	-0.69
714	23-Aug-90	-0.42	-1.02	-0.72
756	4-Oct-90	-0.54	-0.96	-0.75
819	6-Dec-90	-0.72	-0.84	-0.78
882	7-Feb-91	-0.54	-0.9	-0.72
931	28-Mar-91	-0.3	-0.66	-0.48

Table 2.2 - Golden Valley Interchange Time Dependent Deflections.

DAYS FROM PRESTRESSING	DATE	AVERAGE TIME-STEP HUMIDITY (%)	TENDON MEASUREMENT (ksi)	MODIFIED TENDON MEAS. (ksi)	CONCRETE STRAIN (ksi)	NAAMAN TIME-STEP PRESTRESS AT 50% HUMIDITY	MODIFIED THEORETICAL (ksi)
0	8-Sep-88	25.4	183.80	183.80	183.80	177.72	177.72
1	9-Sep-88	25.4	181.90	181.84	183.70	175.88	175.54
7	15-Sep-88	26.5	176.20	175.96	183.10	171.71	170.61
14	22-Sep-88	37.1	174.20	173.90	182.40	169.27	168.40
28	6-Oct-88	34.6	171.20	170.81	179.40	166.24	164.82
42	20-Oct-88	42.9	168.70	168.23	178.10	164.31	163.54
91	8-Dec-88	56.9	164.30	163.70	179.10	160.66	161.62
174	1-Mar-89	69	164.00	163.39	177.00	158.05	161.09
364	7-Sep-89	39.5	152.30	151.32	166.60	155.79	153.96
454	6-Dec-89	48.1	152.10	151.12	167.40	155.26	154.92
539	1-Mar-90	62.4	151.30	150.29	168.00	154.90	157.16
623	24-May-90	44.6	151.40	150.40	164.90	154.61	153.62
665	5-Jul-90	38.2	149.30	148.23	162.70	154.49	152.33
714	23-Aug-90	36.3	148.70	147.61	161.70	154.37	151.85
756	4-Oct-90	40.9	147.20	146.07	161.20	154.27	152.59
819	6-Dec-90	49.4	145.00	143.80	162.40	154.14	154.03
882	7-Feb-91	62.2	148.80	147.72	162.60	154.02	156.32
931	28-Mar-91	55.2	153.80	152.87	163.40	153.94	154.92

Table 3.1 - Golden Valley Interchange Prestress Loss Data.

Days from 100% Prestressing	Measured Prestress	Modified Prestress	Logarithmic Linearization	Inverse Linearization	2nd order Non-Linear	Exponential Curve Fit	Power Curve Fit
1	181.90	181.84	188.56	187.22	174.04	171.11	188.56
7	176.20	175.96	176.02	159.84	173.66	170.91	176.02
14	174.20	173.90	171.76	157.91	173.22	170.67	171.76
28	171.20	170.81	167.60	156.97	172.32	170.20	167.60
42	168.70	168.23	165.22	156.65	171.40	169.73	165.22
91	164.30	163.70	160.76	156.32	168.09	168.11	160.76
174	164.00	163.39	157.12	156.18	162.05	165.39	157.12
364	152.30	151.32	153.07	156.10	146.27	159.32	153.07
454	152.10	151.12	151.88	156.09	137.84	156.53	151.88
539	151.30	150.29	150.96	156.08	129.31	153.94	150.96
623	151.40	150.40	150.19	156.07	120.35	151.42	150.19
665	149.30	148.23	149.84	156.07	115.67	150.17	149.84
714	148.70	147.61	149.47	156.07	110.03	148.73	149.47
756	147.20	146.07	149.16	156.07	105.06	147.51	149.16
819	145.00	143.80	148.74	156.06	97.35	145.69	148.74
882	148.80	147.72	148.35	156.06	89.34	143.90	148.35
931	153.80	152.87	148.07	156.06	82.90	142.52	148.07
3650	***	***	141.09	156.04	-559.89	83.52	141.09
14600	***	***	134.34	156.03	-8825.73	9.71	134.34

Table 3.2 - Regression Analysis Data.

METHOD	CREEP AND SHRINKAGE LOSS IN 40 YEARS (KSI)
AASHTO	22
Time-Step Method, RH = 50%	25.8
Extrapolated Value From Measured Data	35

Table 3.3 - Comparison of AASHTO, Time-Step, and Extrapolated Measured Design Life Prestress Losses for the Golden Valley Interchange.

	TENDON STRESS		DEFLECTION	
SEGMENT	TEMPERATURE °F	HUMIDITY %	TEMPERATURE °F	HUMIDITY %
A-B	31	68	31	68
B-C	61	39	61	39
C-D	46	52	43	56
D-E	62	40	59	42
E-F	35	60	35	60

Table 4.1 - Effect of Climatic Data on Tendon Stress and Deflection.

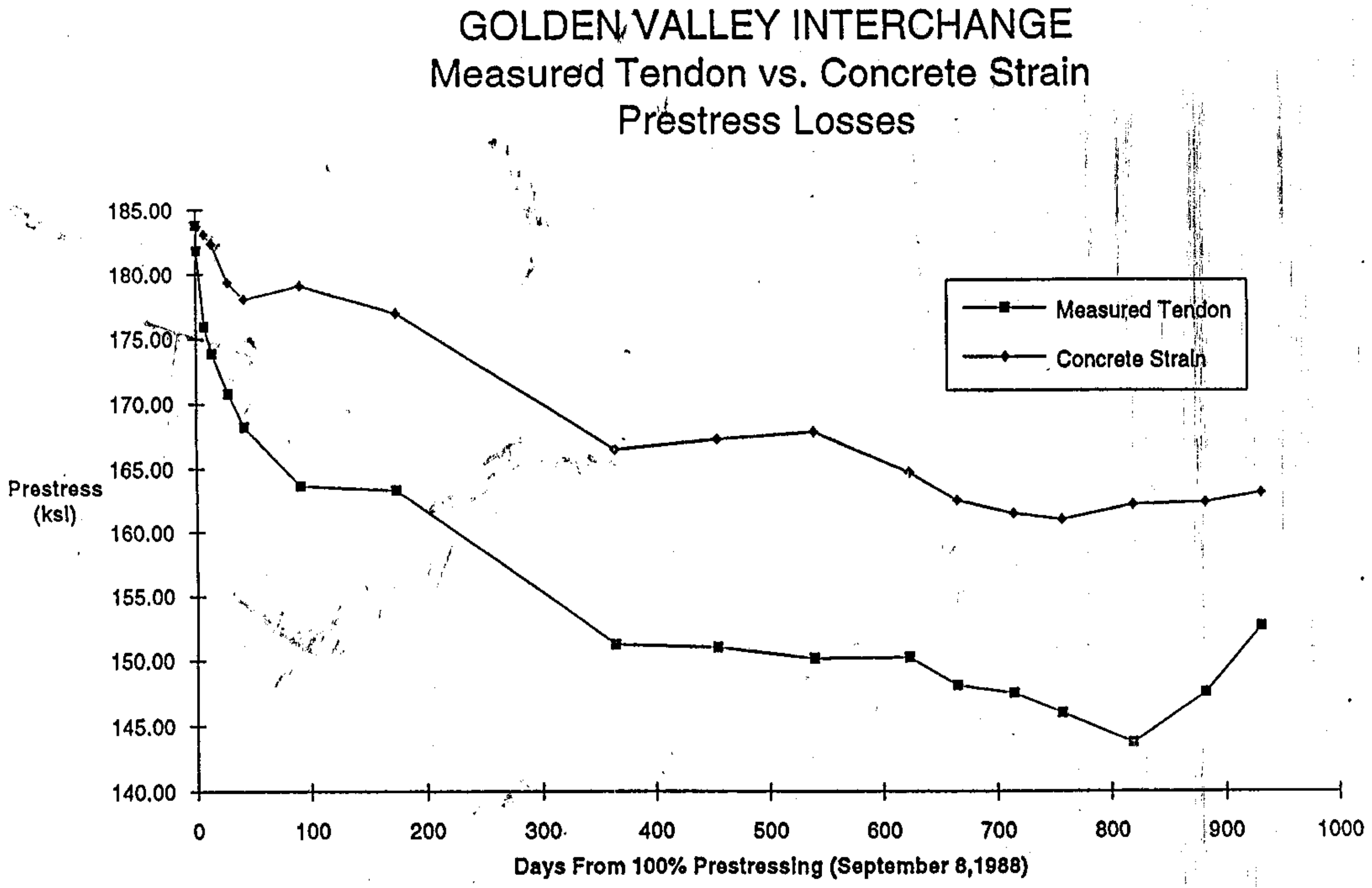

Figure 2.1 - Comparison Between Measured Tendon and Concrete Strain Prestress Losses.

GOLDEN VALLEY INTERCHANGE
Center Span Deflections

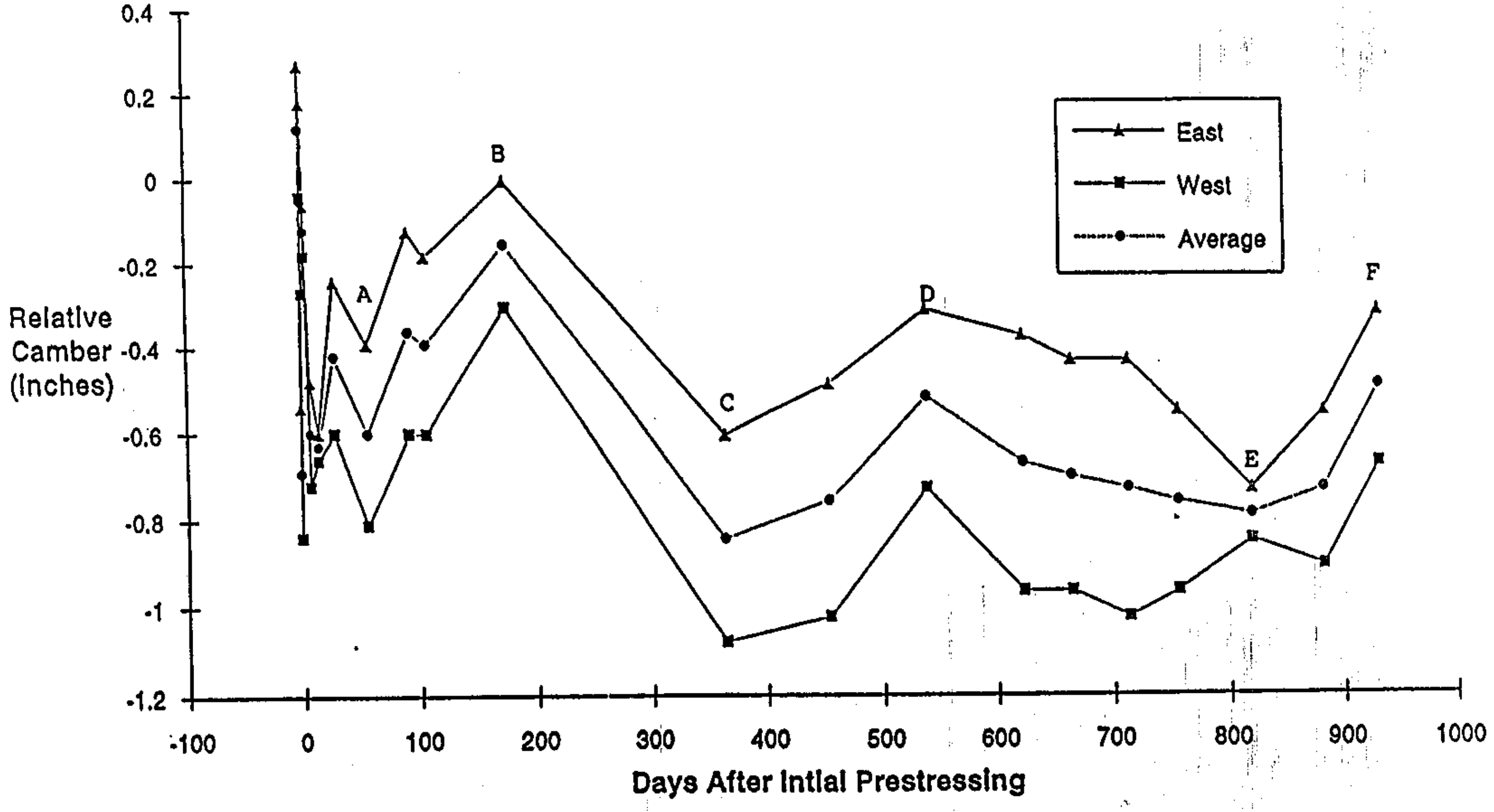

Figure 2.2 - Golden Valley Interchange Center Span Deflections.

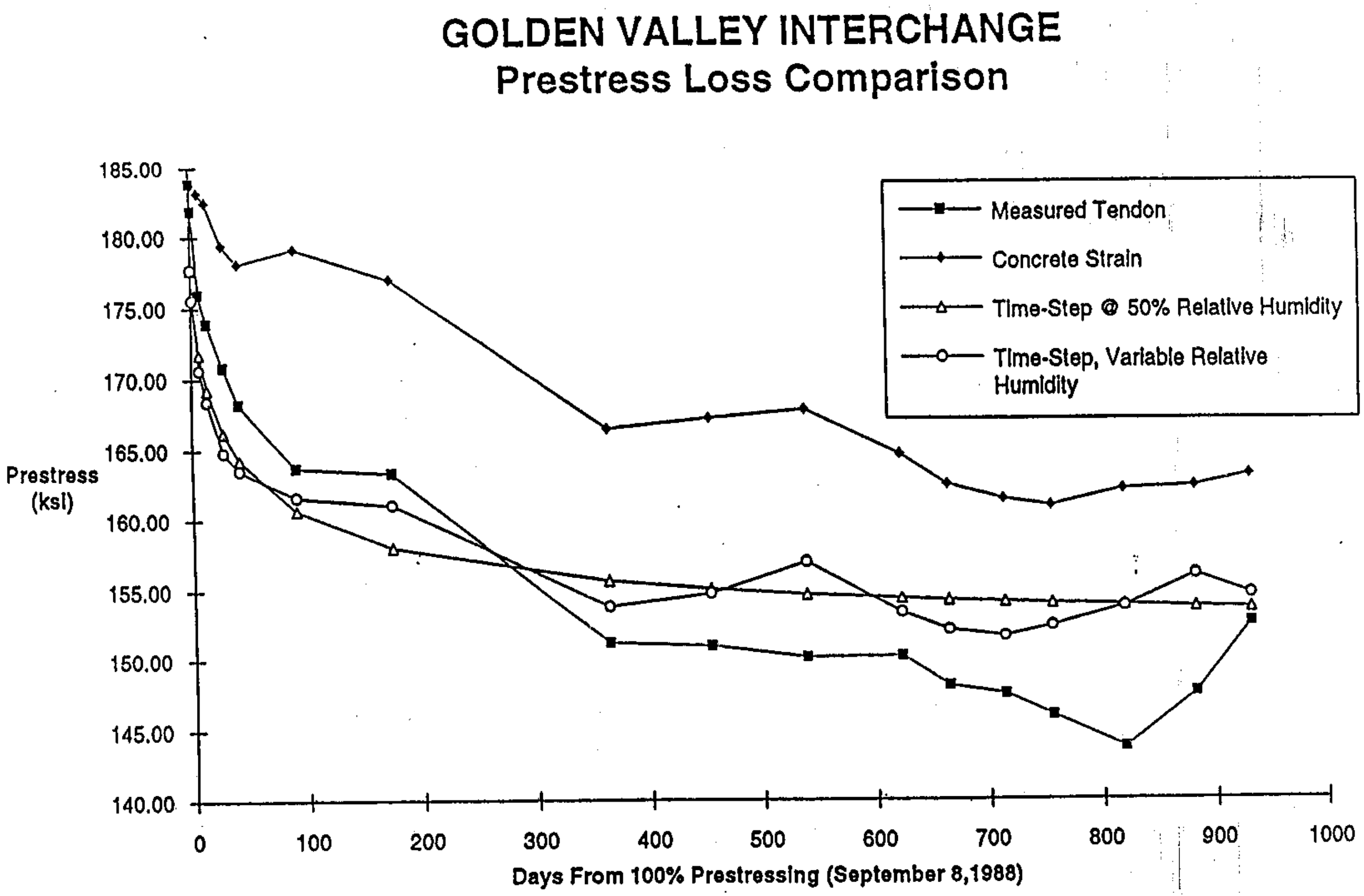

Figure 3.1 - Comparison Between Measured Tendon Prestress Losses, Concrete Strain Losses and Naaman Time-Step Theoretical Prestress Losses.

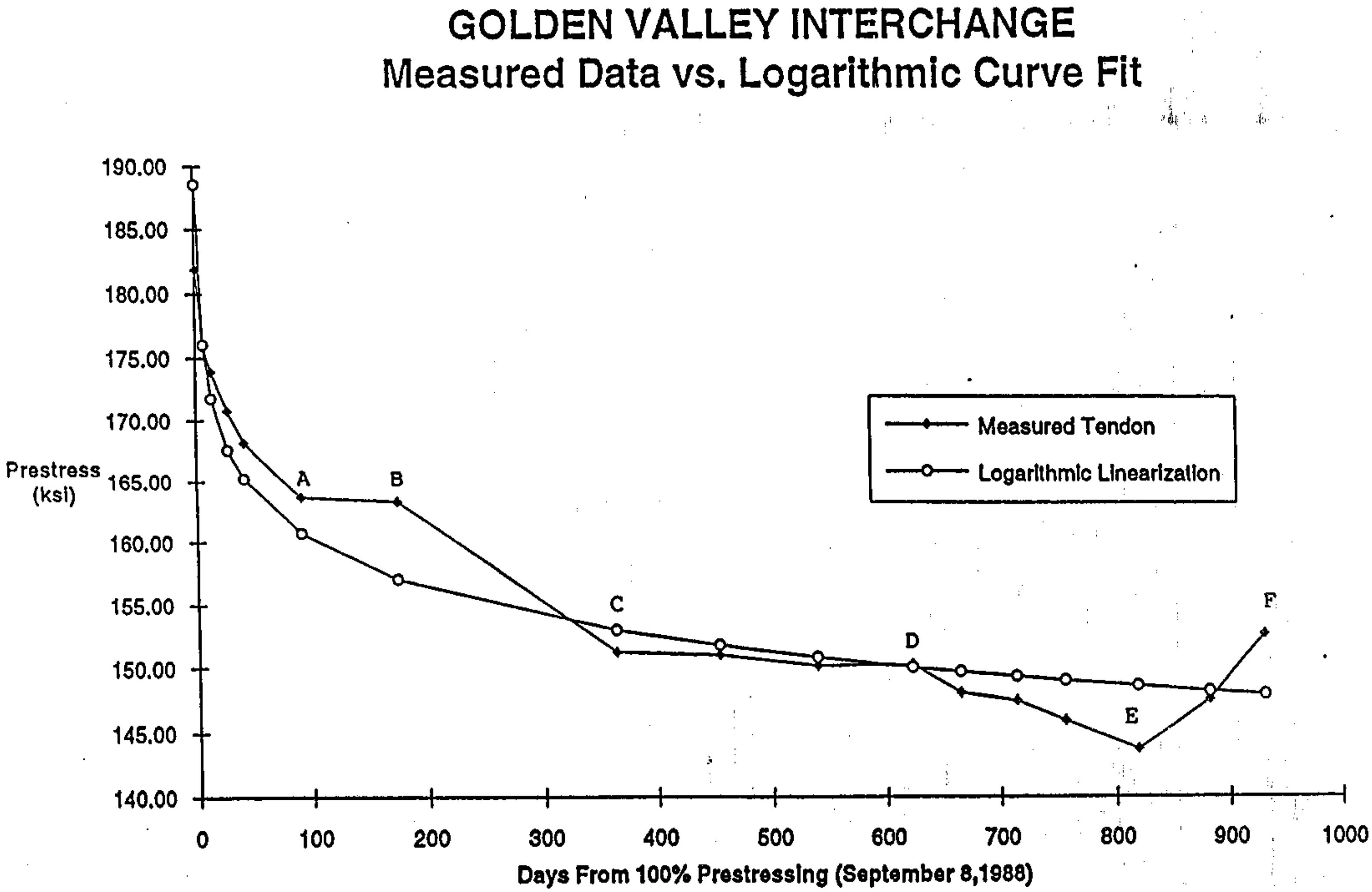

Figure 3.2 - Comparison Between Measured Tendon Prestress Losses and Logarithmic Linearization.

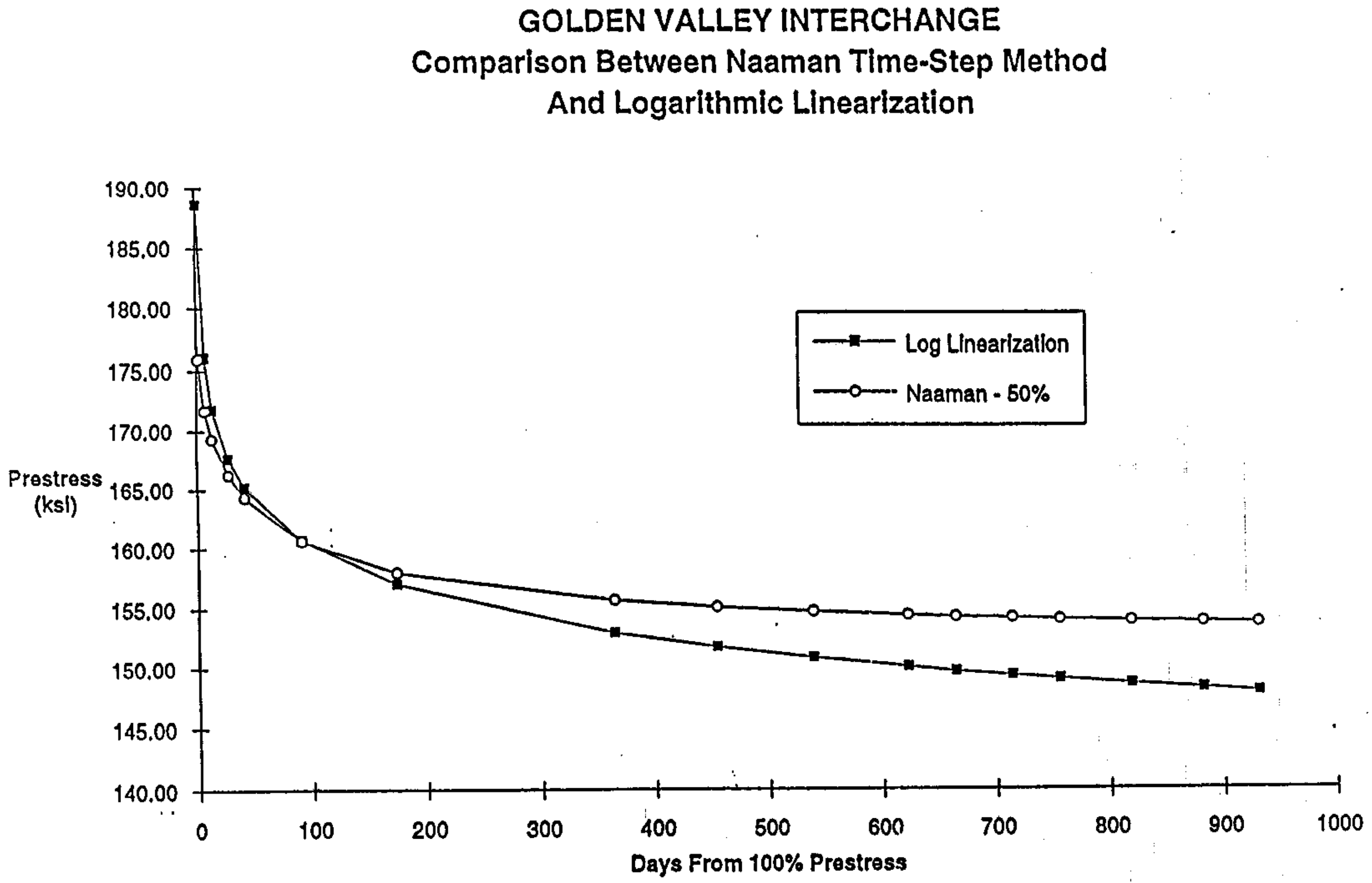

Figure 3.3 - Comparison Between Logarithmic Linearization and Naaman Time-Step Method at 50% Relative Humidity.

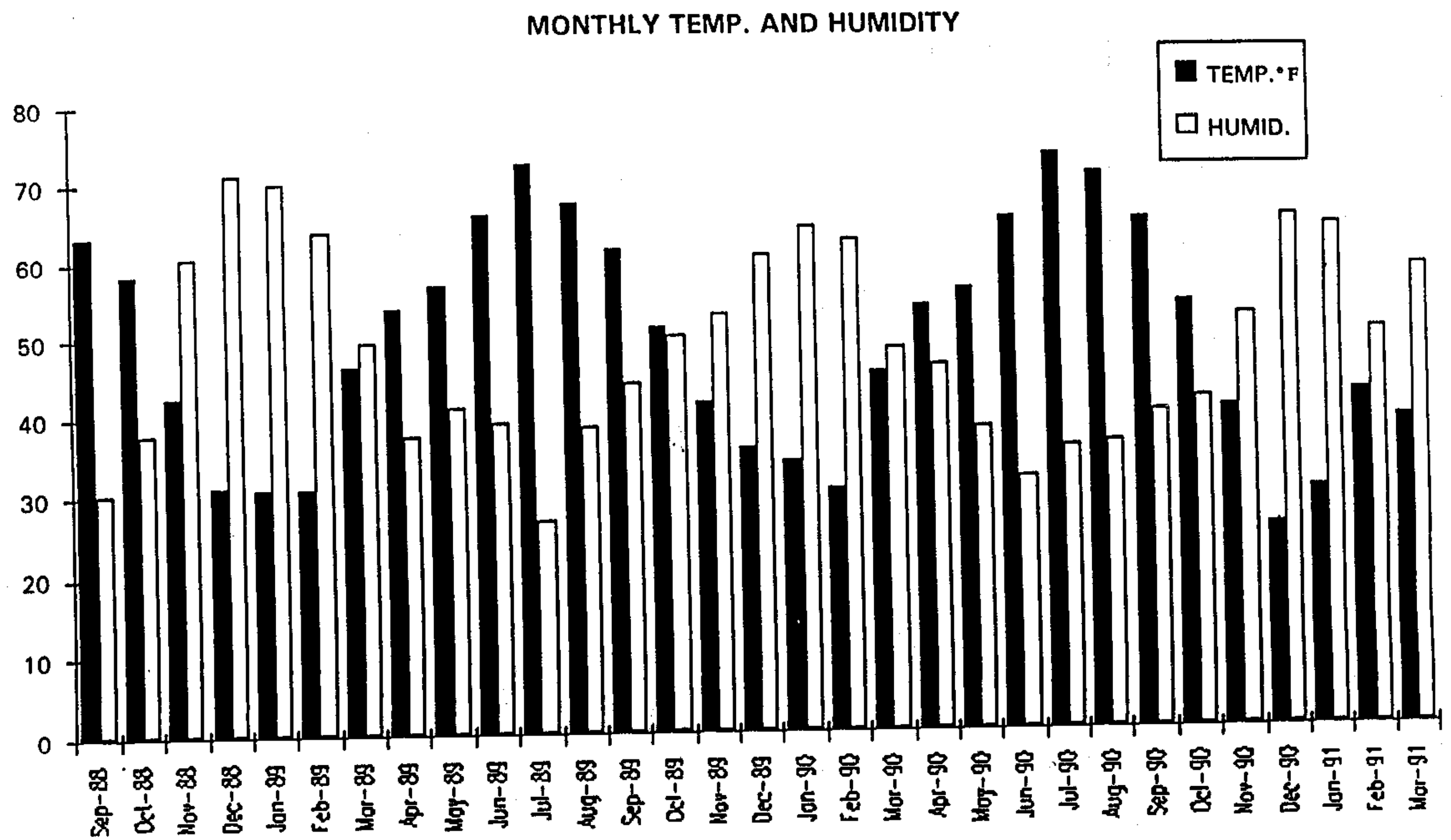

Figure 4.1 - Variation of Monthly Climatic Data in the Course of the Project.

APPENDIX A

Computer Program PSLOSS.BAS

A.1 Description

PSLOSS is a computer program that calculates the prestress losses in post-tensioned members using the time-step method by Naaman [2] and the AASHTO Method [6]. It is written in IBM BASIC A2.1. The program allows the user to input the rather large number of parameters used in time-step method computation from a data file. The general data file parameters, as well as the parameters used for the Golden Valley Interchange, can be seen in sections A.2 and A.3. The program outputs user-specified time step prestress loss and AASHTO prestress losses. There is also a subroutine in the program that allows the user to calculate time-step prestress losses that exclude relaxation. (Actual measurements to determine prestress losses for this bridge were taken from strain gages bonded directly to the prestressing tendons. Since the strain gages see no relaxation losses, those losses needed to be excluded so that a comparison could be made between actual losses and theoretical losses.) PSLOSS is ideal for the time-step method of analysis due to the rather large number of calculations involved.

The following is a line by line description of the program:

Lines 10-160

These lines contain a program heading and a brief explanation of the program itself.

Lines 170-260

All the variables used in PSLOSS are dimensioned and initialized here. Variables are currently dimensioned for use of up to 50 time-steps.

Lines 270-350

These lines interactively ask the user to supply the program with general information about the input data file, problem name, type of prestressing steel used, and the number of time intervals chosen in the data file.

Lines 360-440

This is the last portion of the main program. The data file is opened for input and all of the subroutines are called.

Lines 450-590

This is a data input subroutine that inputs all of the parameters used in the time-step calculations, as well as the AASHTO calculations. It inputs the data from the data file defined in line 280.

Lines 600-700

This subroutine calculates the prestress loss due to friction at midspan.

Lines 710-810

This subroutine calculates the instantaneous prestress loss due to elastic shortening. This loss and the frictional loss are then subtracted from the initial desired prestress, and the new value is used in the time-step loss calculations.

Lines 820-1150

This is the time-step loss subroutine. Within it, losses for relaxation, shrinkage and creep are calculated.

Lines 1160-1610

These lines contain the output subroutine for time-step losses according to Naaman. The losses are cumulated for each time-step as well as for the entire period. Losses due to friction and elastic shortening are printed along with total losses excluding friction and the final effective prestress.

Lines 1620-1970

If desired this subroutine calculates and accumulates the prestress losses excluding friction and then prints out the results. Again the results are cumulated for each time-step as well as for the entire period.

Lines 1980-2160

If AASHTO prestress losses are desired, this subroutine calculates the lump sum of prestress losses according to current AASHTO code specifications.

Lines 2170-2280

This is the final subroutine of the program. It prints out all of the AASHTO lump sum losses.

A.2 Complete Listing of Computer Program "PSLOSS"

```
10  REM ***************************************************************
20  REM *                                                             *
30  REM *                    COMPUTER PROGRAM PSLOSS.BAS              *
40  REM *                    VERSION 1.0                              *
50  REM *                    BY ERIC J. HUTCHENS                      *
60  REM *                    CIVIL ENGINEERING DEPARTMENT             *
70  REM *                    UNIVERSITY OF NEVADA, RENO               *
80  REM *                                                             *
90  REM *    This computer program was written by Eric J. Hutchens    *
100 REM *    by modifying version 1.0 of PLOSS written by Joseph F.   *
110 REM *    Shields.  It calculates prestress losses in post-        *
120 REM *    tensioned members using the time step method in          *
130 REM *    Naaman and by using AASHTO code standards.               *
140 REM *                                                             *
150 REM ***************************************************************
160 REM
170 REM
180 DIM TI(50),TJ(50),DFPR(50),DFPS(50),FCGS(50),DEFL(50),FT(50),FPS(50)
190 DIM EC(50),E(50),GTJ(50),GTI(50),DFPC(50),FC(50),ECE(50),KCA(50)
200 DIM CTOT(50),CMTOT(50)
210 SL=0
215 RL=0
220 CL=0
230 SHL = 0
240 CRL = 0
250 CTOT=0
260 CLS
270 COLOR 2
280 INPUT "ENTER DATA FILE NAME";F$
290 COLOR 3
300 INPUT "ENTER PROBLEM NAME";J$
310 COLOR 4
320 INPUT "ENTER 45 FOR LOW LAX OR 10 FOR STRESS RELIEVED";D
330 COLOR 5
340 INPUT "ENTER NUMBER OF TIME INTERVALS";N
350 COLOR 2
360 OPEN F$ FOR INPUT AS #1
370 GOSUB 460
380 GOSUB 610
390 GOSUB 720
400 GOSUB 830
410 GOSUB 1170
420 GOSUB 1630
430 END
440 REM
450 REM****************************************************************
460 REM*                    DATA INPUT SUBROUTINE                      *
470 REM****************************************************************
480 REM
490 INPUT #1 ,FP,U,A,K,S
500 INPUT #1 ,APS,EPS,FC,W,EO,IC,AC,MD,FPY
510 INPUT #1 ,ESU,KSS,B,CCU,KCA,KCS
520 FOR I=1 TO N
530 INPUT #1 ,TI(I),TJ(I),FC(I)
540 EC(I)=33*W^1.5*SQR(FC(I))/1000
550 NEXT I
```

```
560 INPUT #1,RH,MDN
570 CLOSE #1
580 RETURN
590 REM
600 REM***************************************************************
610 REM*           FRICTIONAL LOSS CALCULATION SUBROUTINE            *
620 REM***************************************************************
630 REM
640 Z=U*A+K*S
650 FPX=2.7183^(-Z)*FP
660 IF Z<=.3 THEN FPX=FP/(1+Z)
670 FPIN=FPX
680 XFPIN=FPX
690 RETURN
700 REM
710 REM***************************************************************
720 REM*              ELASTIC SHORTENING LOSS SUBROUTINE             *
730 REM***************************************************************
740 REM
750 FI=FPX*APS
760 FCIR=FI/AC+FI*EO^2/IC-MD*EO/IC
770 ECON=33*W^1.5*SQR(FC)/1000
780 DFPES=.5*EPS/ECON*FCIR
790 FPX=FPX-DFPES
800 RETURN
810 REM
820 REM****************************************************************
830 REM*                TIME-STEP LOSS SUBROUTINE                     *
840 REM****************************************************************
850 REM
860 KCH=1.27-.0067*RH
870 KSH=1.4-.01*RH
880 IF RH>80 THEN KSH=3-.03*RH
890 FOR I=1 TO N
900 REM        --------------------------------
910 REM        CALCULATION OF RELAXATION LOSSES
920 REM        --------------------------------
930 REM
940 DFPR(I)=(FPX/D)*(FPX/FPY-.55)*.4343*LOG(TJ(I)/TI(I))
950 IF DFPR(I)<0 THEN DFPR(I)=0
960 REM
970 REM        -------------------------------
980 REM        CALCULATION OF SHRINKAGE LOSSES
990 REM        -------------------------------
1000 REM
1010 DFPS (I)=EPS*ESU*KSH*KSS*B*(TJ(I)-TI(I))/(B+TI(I)+15)/(B+TJ(I)+15)
1020 REM
1030 REM        ---------------------------
1040 REM        CALCULATION OF CREEP LOSSES
1050 REM        ---------------------------
1060 REM
1070 FCGS(I) = (FPX*APS/AC)*(1+(EO^2*AC/IC))-(MD*EO/IC)
1080 E(I) = FCGS(I)/EC(I)
1090 GTJ(I) = TJ(I)^.6/(10+TJ(I)^.6)
1100 GTI(I) = TI(I)^.6/(10+TI(I)^.6)
1110 DFPC(I)=EPS*(GTJ(I)-GTI(I))*CCU*KCH*KCA*KCS*E(I)
1120 FPX=FPX-DFPR(I)-DFPS(I)-DFPC(I)
1130 NEXT I
1140 RETURN
1150 REM
```

```
1160 REM***************************************************************
1170 REM*      TIME-STEP PRESTRESS LOSS PRINTER OUTPUT SUBROUTINE      *
1180 REM***************************************************************
1190 REM
1200 P$="                                                      CUMMULATIVE    FINAL"
1210 X$="  TIME     RELAXATION   SHRINKAGE     CREEP       TOTAL      PRESTRESS"
1220 U$=" (DAYS)       (KSI)        (KSI)       (KSI)       (KSI)        (KSI)"
1230 Y$="  #####       ##.##        ##.##       ##.##       ##.##       ###.##"
1240 Z$="  SUM=        ##.##        ##.##       ##.##       ##.##"
1250 K$="###.##"
1260 PRINT
1270 PRINT
1280 PRINT
1290 PRINT J$
1300 PRINT
1310 PRINT"***************************************************"
1320 PRINT"*            TIME STEP PRESTRESS LOSSES          *"
1330 PRINT"***************************************************"
1340 PRINT
1350 PRINT P$
1360 PRINT X$
1370 PRINT U$
1380 PRINT"_____________________________________________________________________"
1390 PRINT USING Y$;0,0,0,0,0,FPIN-DFPES
1400 FOR I=1 TO N
1410 RL=RL+DFPR(I)
1420 SL=SL+DFPS(I)
1430 CL=CL+DFPC(I)
1440 TOT=DFPC(I)+DFPS(I)+DFPR(I)
1450 CTOT(I)=RL+SL+CL
1460 PRINT USING Y$;TJ(I),DFPR(I),DFPS(I),DFPC(I),CTOT(I),FPIN-DFPES-CTOT(I)
1470 NEXT I
1480 PRINT"_____________________________________________________________________"
1490 PRINT USING Z$;RL,SL,CL,RL+SL+CL
1500 PRINT
1510 PRINT
1520 PRINT
1530 PRINT "FRICTIONAL LOSSES="USING K$;FP-FPIN
1540 PRINT "ELASTIC SHORTENING LOSSES="USING K$;DFPES
1550 DT=FPIN-FPX
1560 PRINT "TOTAL LOSSES EXCLUDING FRICTION="USING K$;DT
1570 PRINT "EFFECTIVE PRESTRESS AFTER";TJ(N)/365;"YEARS=";USING K$;FPX
1580 PRINT
1590 PRINT
1600 RETURN
1610 REM
1620 REM *********************************************************
1630 REM *   TIME-STEP LOSSES EXCLUDING RELAXATION SUBROUTINE   *
1640 REM *********************************************************
1650 REM
1660 C$="                                          CUMMULATIVE          FINAL"
1670 A$="    TIME       SHRINKAGE       CREEP        TOTAL          PRESTRESS"
1680 B$="   (DAYS)        (KSI)         (KSI)        (KSI)            (KSI)"
1690 D$="   #####         ##.##         ##.##        ##.##           ###.##"
1700 E$="   SUM =         ##.##         ##.##        ##.##"
1710 PRINT
1720 PRINT
1730 PRINT  "FOR TIME-STEP LOSSES EXCLUDING FRICTION -- ENTER 1"
1740 INPUT  "OTHERWISE ENTER 0";A
1750 IF A = 0 GOTO 1990
```

```
1760 PRINT
1770 PRINT J$
1780 PRINT
1790 PRINT "********************************************"
1800 PRINT "*  TIME-STEP LOSSES EXCLUDING RELAXATION   *"
1810 PRINT "********************************************"
1820 PRINT
1830 PRINT C$
1840 PRINT A$
1850 PRINT B$
1860 PRINT"__________________________________________________________"
1870 PRINT USING D$;0,0,0,0,XFPIN-DFPES
1880 FOR I=1 TO N
1890 SHL=SHL+DFPS(I)
1900 CRL=CRL+DFPC(I)
1910 CMTOT(I)=SHL+CRL
1920 PRINT USING D$;TJ(I),DFPS(I),DFPC(I),CMTOT(I),FPIN-DFPES-CMTOT(I)
1930 NEXT I
1940 PRINT"_________________________________________________________"
1950 PRINT USING E$;SHL,CRL,SHL+CRL
1960 PRINT
1970 PRINT
1980 REM**********************************************************
1990 REM*        AASHTO PRESTRESS LOSS CALCULATION SUBROUTINE    *
2000 REM**********************************************************
2010 INPUT "FOR AASHTO PRESTRESS LOSSES ENTER 1, 0 OTHERWISE";G
2020 IF G = 0 GOTO 2280
2030 AF=2.7183^(Z)*FP
2040 IF (Z)<=.3 THEN AF= FP*(1+Z)
2050 FR=AF-FP
2060 FCDS=MDN*EO/IC
2070 SH=.8*(17-.15*RH)
2080 ES=.5*EPS*FCIR/ECON
2090 FCIR=(FP-FR-ES)*APS/AC+(FP-FR-ES)*APS*EO^2/IC-MD*EO/IC
2100 CRC=12*FCIR-7*FCDS
2110 CRS=20-.3*FR-.4*ES-.2*(SH+CRC)
2120 IF D=45 THEN CRS = 5-.07*FR-.1*ES -.05*(SH+CRC)
2130 IF CRS<0 THEN CRS=0
2140 TL=SH+ES+CRC+CRS
2150 PRINT
2160 PRINT
2170 PRINT"*********************************************************"
2180 PRINT"*            AASTHTO PRESTRESS LOSSES                   *"
2190 PRINT"*********************************************************"
2200 PRINT
2210 PRINT "   AASHTO FRICTIONAL LOSSES ="USING K$;FR
2220 PRINT "   AASHTO ELASTIC SHORTENING LOSSES ="USING K$;ES
2230 PRINT "   AASHTO SHRINKAGE LOSSES ="USING K$;SH
2240 PRINT "   AASHTO CREEP LOSSES ="USING K$;CRC
2250 PRINT "   AASHTO RELAXATION LOSSES ="USING K$;CRS
2260 PRINT "     TOTAL AASHTO LOSSES EXCLUDING FRICTION ="USING K$;TL
2270 PRINT "     AASHTO EFFECTIVE PRESTRESS ="USING K$;FP-TL
2280 RETURN
```

A.3 General Data File Parameters for "PSLOSS"

Line 1 Input: FP,U,A,K,S

FP - Desired initial prestress (ksi)
U - Coefficient of angular friction
A - Change in angle between force at the anchorage and the force at s (radians)
K - Wobble coefficient (ft^{-1})
S - Length from anchorage to any point x on beam (ft)

Line 2 Input: APS,EPS,FC,W,EO,IC,AC,MG,FPY

APS - Area of prestressing steel (in^{2})
EPS - Modulus of elasticity of steel (ksi)
FC - Initial concrete compressive strength (psi)
W - Unit weight of concrete (pcf)
EO - Eccentricity of prestressing steel (in)
IC - Section moment of inertia (in^{4})
AC - Section area (in^{2})
MD - Dead Load moment at time of transfer (k-in)
FPY - Yield stress of prestressing steel (ksi)

Line 3 Input: ESU,KSS,B,CCU,KCA,KCS

ESU - Ultimate shrinkage strain
KSS - Shrinkage size correction factor
B - 35 for moist cure, 55 for steam cure
CCU - Ultimate creep coefficient
KCA - Creep loading age correction factor
KCS - Creep size correction factor

Line (4 through n) Input: TI(I), TJ(I), FC(I)

n - number of time intervals used
TI(I) - Initial time (days)
TJ(I) - Time at end of interval (days)
FC(I) - Concrete compressive strength at TI(I)

Line n+1 Input: RH,MDN

RH - Mean annual ambient relative humidity (%)
MDN - Moment due to Dead Load not present at time of stressing (k-in)

A.4 Data File Parameters Used for the Golden Valley Interchange

Line 1

FP - Desired initial prestress. 189 ksi
U - Coefficient of angular friction. 0.25
A - Change in angle between force at anchorage and force at S. 0.0753 radians
K - Wobble coefficient. 0.0002 ft^{-1}
S - Length from anchorage to point of interest on girder. All measurements are at center span. 77.5 ft

Line 2

APS - Area of prestressing steel. There are 484, 0.5 inch diameter 7-wire strands of Grade 270, Low-Relaxation prestressing steel (ASTM A-416). 74.05 in^2
EPS - Modulus of elasticity of prestressing steel. 29,000 ksi
FC - Initial concrete compressive strength. 4600 psi
W - Unit weight of concrete. 139 pcf
EO - Eccentricity of prestressing steel. 35 in
IC - Section moment of inertia. 11,924,900 in^4
AC - Section Area. 12,128 in^2
MD - Dead Load moment at time of transfer. 422,000 k-in
FPY - Yield stress of prestressing steel. 252 ksi

Line 3

ESU - Ultimate shrinkage strain. ACI Committee 209 recommends a value of $780\mu s$ for the ultimate shrinkage strain. However, this value of strain is calculated from an initial time t=0. Prestressing on this bridge was done 15 days later, so the recommended value was modified to eliminate the strain that occurred during the first 15 days. The following relationship was used:

$$\epsilon_{sh,t} = [t/(35+t)]\epsilon_{sh,u}$$

Where $\epsilon_{sh,t}$ is the shrinkage strain at any time t after age 7 days. And $\epsilon_{sh,u}$ is the recommended ultimate shrinkage strain.

$$\epsilon_{sh,15} = [15/(35+15)]780 = 234\ \mu s$$

Therefore $\epsilon_{sh,u}$ used for this bridge =

$$780 - 234 = 550\ \mu s$$

KSS - Shrinkage size correction factor. This is calculated from the following equation:

$$K_{SS} = 1.2^{(-0.12V/S)}$$

Where V/S is the volume-surface ratio in inches.

$K_{SS} = 1.2^{(-0.12*4.644)} = \underline{0.9034}$

B - 35 for moist cured, 55 for steam cured. $\underline{B = 35}$

CCU - Ultimate creep strain. ACI Committee 209 recommended value was used. $C_{cu} = \underline{2.35}$

KCA - Creep loading age correction factor. This is calculated from the following equation:

$K_{ca} = 1.25t^{-0.118}$

Where t is in days ≥ 7 days.
Loading took place at t = 15 days.

$K_{ca} = 1.25(15^{-0.118}) = \underline{0.9081}$

KCS - Creep size correction factor. This is calculated from the following equation:

$K_{cs} = 0.667(1+1.13^{-0.54V\backslash S})$

Where V\S is again the volume to surface area in inches.

$K_{cs} = 0.667[1+1.13^{(-0.54*4.644)}] = \underline{1.1573}$

Lines (4 through n)

These lines represent the time-steps that are desired for calculation. They consist of time t_i--the initial time in days, t_j--the ending time in days, and the compressive strength of the concrete at time t_i. The time steps used for the Golden Valley bridge corresponded to the times of the actual measurements.

Line n+1

RH - Mean annual ambient relative humidity in percent. $\underline{RH = 50}$

MDN - Moment due to Dead Load not present at time of stressing. $\underline{MDN = 0.0 \text{ k-in}}$

A.5 PL50 - A Sample Data File Used for Program PSLOSS

This is the data file used for the Golden Valley Interchange using a relative annual ambient humidity of 50%.

```
189,.25,.0753,.0002,77.5                                    : line 1
74.05,29000,4600,139,35,11924900,12128,422000,252
.00055,.9034,35,2.35,.9081,1.1573
.04166,1,4600
1,7,4600
7,14,5300
14,28,5300
28,42,5300
42,91,5300
91,174,5300
174,364,5300
364,454,5300
454,539,5300
539,623,5300
623,665,5300
665,714,5300
714,756,5300
756,819,5300
819,882,5300
882,931,5300
931,1825,5300
1825,14600,5300
50,0.0
```

A.6 Sample Run of "PSLOSS" Using Above Data File PL50

```
RUN
ENTER DATA FILE NAME? a:pl50
ENTER PROBLEM NAME? Golden Valley 50% Humidity
ENTER 45 FOR LOW LAX OR 10 FOR STRESS RELIEVED? 45
ENTER NUMBER OF TIME INTERVALS? 19


Golden Valley 50% Humidity

**********************************************
*          TIME STEP PRESTRESS LOSSES        *
**********************************************

                                               CUMMULATIVE    FINAL
  TIME    RELAXATION   SHRINKAGE     CREEP       TOTAL      PRESTRESS
 (DAYS)     (KSI)        (KSI)       (KSI)       (KSI)        (KSI)
-----------------------------------------------------------------------
     0       0.00         0.00        0.00        0.00        177.72
     1       0.85         0.17        1.67        2.69        175.03
     7       0.48         0.94        3.23        7.33        170.39
    14       0.14         0.87        1.58        9.92        167.80
    28       0.13         1.27        1.76       13.08        164.64
    42       0.07         0.89        1.04       15.07        162.65
    91       0.12         1.71        1.93       18.84        158.88
   174       0.08         1.19        1.42       21.53        156.19
   364       0.08         0.93        1.33       23.86        153.85
   454       0.02         0.20        0.33       24.41        153.31
   539       0.01         0.13        0.24       24.79        152.93
   623       0.01         0.10        0.19       25.09        152.63
   665       0.01         0.04        0.08       25.21        152.50
   714       0.01         0.04        0.09       25.35        152.37
   756       0.00         0.03        0.07       25.45        152.27
   819       0.01         0.04        0.09       25.59        152.13
   882       0.01         0.04        0.08       25.71        152.01
   931       0.00         0.02        0.06       25.79        151.92
  1825       0.05         0.22        0.61       26.68        151.04
 14600       0.15         0.21        0.97       28.01        149.71
-----------------------------------------------------------------------
  SUM=       2.22         9.04       16.76       28.01


FRICTIONAL LOSSES=  6.27
ELASTIC SHORTENING LOSSES=  5.01
TOTAL LOSSES EXCLUDING FRICTION= 33.02
EFFECTIVE PRESTRESS AFTER 40 YEARS=149.71



FOR TIME-STEP LOSSES EXCLUDING FRICTION -- ENTER 1
OTHERWISE ENTER 0? 1
```

Golden Valley 50% Humidity

```
*****************************************
*  TIME-STEP LOSSES EXCLUDING RELAXATION  *
*****************************************

                                       CUMMULATIVE       FINAL
   TIME        SHRINKAGE     CREEP       TOTAL         PRESTRESS
  (DAYS)         (KSI)       (KSI)       (KSI)           (KSI)
 ---------------------------------------------------------------
     0           0.00         0.00        0.00          177.72
     1           0.17         1.67        1.84          175.88
     7           0.94         3.23        6.01          171.71
    14           0.87         1.58        8.45          169.27
    28           1.27         1.76       11.48          166.24
    42           0.89         1.04       13.41          164.31
    91           1.71         1.93       17.06          160.66
   174           1.19         1.42       19.67          158.05
   364           0.93         1.33       21.93          155.79
   454           0.20         0.33       22.46          155.26
   539           0.13         0.24       22.82          154.90
   623           0.10         0.19       23.11          154.61
   665           0.04         0.08       23.23          154.49
   714           0.04         0.09       23.35          154.37
   756           0.03         0.07       23.45          154.27
   819           0.04         0.09       23.58          154.14
   882           0.04         0.08       23.70          154.02
   931           0.02         0.06       23.78          153.94
  1825           0.22         0.61       24.61          153.11
 14600           0.21         0.97       25.80          151.92
 ---------------------------------------------------------------
 SUM =           9.04        16.76       25.80

FOR AASHTO PRESTRESS LOSSES ENTER 1, 0 OTHERWISE? 1

*******************************************************
*             AASTHTO PRESTRESS LOSSES                *
*******************************************************

   AASHTO FRICTIONAL LOSSES =  6.49
   AASHTO ELASTIC SHORTENING LOSSES =  5.01
   AASHTO SHRINKAGE LOSSES =  7.60
   AASHTO CREEP LOSSES = 14.35
   AASHTO RELAXATION LOSSES =  2.95
     TOTAL AASHTO LOSSES EXCLUDING FRICTION = 29.90
     AASHTO EFFECTIVE PRESTRESS =159.10
Ok
```

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Report No.	Publication
CCEER-84-1	Saiidi, Mehdi and Renee A. Lawver, "User's Manual for LZAK-C64, A Computer Program to Implement the Q-Model on Commodore 64," Civil Engineering Department, Report No. CCEER-84-1, University of Nevada, Reno, January 1984.
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CCEER-84-3	Saiidi, Mehdi, James D. Hart, and Bruce M. Douglas, "Inelastic Static and Dynamic Analysis of Short R/C Bridges Subjected to Lateral Loads," Civil Engineering Department, Report No. CCEER-84-3, University of Nevada, Reno, July 1984.
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Kenny C. Guinn, Governor

Nevada Department of Transportation
Tom Stephens, P.E. Director
Prepared by Research Division
Alan Hilton, Research Manager
(775) 888-7803
ahilton@dot.state.nv.us
1263 South Stewart Street
Carson City, Nevada 89712