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Measured Stress Ranges and Cross Frame Analysis of the Holston River Bridge

(June 1993 to November 1993)

A Thesis

Presented for the

Masters of Science

Degree

The University of Tennessee, Knoxville

Mark David Mayhew

May, 1994

ACKNOWLEDGMENT

I would first like to thank my major professor, James H. Deatherage for his guidance and patience. I would like to thank Dr. Goodpasture for his time he spent on helping me interpret and write the computer programs, as well as reviewing this document and sitting on my defence committee. I would also like to thank Dr. Edwin Burdette for his time spent both reviewing this document and sitting on my defence committee.

Special thanks is also given to my family, especially my brother and sister, Micheal Mayhew and Iwalani Adams for their encouragement and guidance. Also, I would like to offer thanks to my patents for their love and support and my nephew and niece, Josuha Adams and Jessica Mayhew for their love.

ABSTRACT

On January 1992, the Holston River Bridge experienced a "full height tear" through the flanges and web of the outside east bound girder. The girder underwent repairs. These repairs consisted of additional web and stiffener plates added to the outside girder. In addition, longitudinal stiffeners were installed between the cross-frames. After the repairs on the bridge, a research program was conducted by the University of Tennessee Civil Engineering Department to obtain the following information: a) determine the effectiveness of the repairs on the bridge, b) to estimate the portion of the bridge fatigue life expended at the time of the failure, and c) identify the limiting fatigue locations and estimate the remaining life of the bridge based on current and estimated future usage.

This objective of this research is to collate the field data, and analyze the number and magnitude of the stress on critical sections of the bridge. From this information, the "limiting fatigue locations" on the Cross Frame were determined, and an estimate the remaining life of the Cross Frame was calculated.

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LIST OF SYMBOLS

SYMBOL	DESCRIPTION
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic.
CB	Cross Brace
CF	Cross Frame
DOT	Department of Transportation
FB	Floor Beam
F_{sr}	Maximum stress range.
ksi	Thousand pounds per square inch
lb_f	Pound Force
MCP	Mean Crossing Peak cycle counting method
M & L	Middle and Left lane traffic
n_i	Number of stress cycles with range magnitude S_{ri}.
N_i	Fatigue life corresponding to constant stress range S_{ri}.
N_p	Number of stress cycles experienced to-date.
N_r	Remaining fatigue life.
N_t	Total Fatigue Life.
PADTT	Present Average Daily Truck Traffic.
psi	Pounds per square inch
psic	Pounds per square inch - compression
psit	Pounds per square inch - tension
RF	Rain Flow cycle counting method
RMC	Root Mean Cube - Miner's Rule
R & S	Right and shoulder lane traffic

LIST OF SYMBOLS

SYMBOL	DESCRIPTION
S-N	Stress - Number of cycles curve
S_{re}	Equivalent Stress Range.
S_{ri}	Constant Stress Range.
$S_{r,max}$	Maximum stress range.
S_{rs}	Root-mean-square value.
TCS	Test Control Software
γ_i	Fraction of occurrence of stress range S_{ri}.
π	Pi (3.1416).

Chapter 1

Introduction

Background history and information

The Holston River Bridge (Figure 1) is located outside of Knoxville on Interstate 40, two miles east of the I-640 interchange. It consists of eight spans built on four continuous longitudinal girders. It was designed and built in the early 1970's as a four lane bridge, two lanes east bound and two lanes west bound. However, after the piers were poured, the design changed to accommodate one more lane in each direction. To facilitate the extra width, cantilevers were installed to the exterior girders. These cantilevers were attached to the girders by braces that connected to the web and bottom flange of the girders. In January of 1992, the outside girder of the East bound lane experienced a "full height tear through the flanges and web"(1). This girder was jacked back into place and the tear welded. Additional web and stiffener plates were installed along with flange splice plates.

Purpose of Research

Because of the failure just discribed, a study was conducted by the University of Tennessee Civil Engineering Department to; (a) determine the effectiveness of the repairs on the bridge, (b) estimate the portion of the bridge fatigue life expended at the time of the failure, and (c) identify the limiting fatigue locations and estimate the remaining life of the bridge based on current and estimated future usage.

Methodology

The methodology to obtain and analyze this information was as follows:

(a) Review of pertinent literature:

A thorough review of the literature was performed. This review consisted of obtaining information that would help in predicting the percentage of the amount of life experienced to date by the bridge.

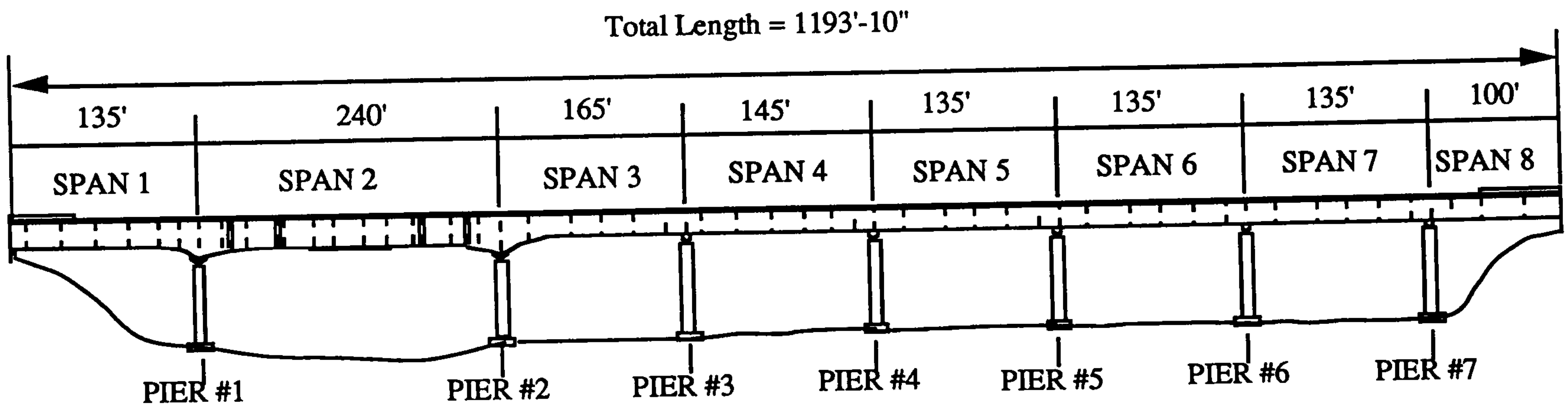


Figure1: Elevation of Holston River Bridge

b) Location and installation of the strain gages:

After reviewing the bridge plans and physically inspecting the bridge, and with input from Dr. John Fisher, the locations of the critical members were determined and the members were instrumented with strain gages. These strain gage locations were chosen to provide the stress history data relative to critical design details, the effectiveness of the repair of the previously existing fatigue crack, and to determine the dynamic response of the structure to significant loading conditions.

(c) Data Acquisition:

After the gages were installed, data were obtained during the months of August, September, and November. The data acquisition system used was the Optim Megadac data collection system. The Megadac system was connected to a Zenith personal computer that utilized the TCS 3000 software. Two other basic programs were created to separate and analyze the data. The results of these programs obtained categorized the stress loads for each strain gage.

(d) Final Report and analysis of data obtained during testing period:

The purpose of this report is to analyze the test data, calculate the equivalent stress, determine the critical members of the cross frame, and estimate the remaining life of the cross frame members.

Literature Review

Fatigue life is defined as "the length of time before an initially microscopic flaw in a critical structure detail develops into a crack of a certain length (typically about an inch or the thickness of the material) and becomes detectable by normal non-destructive inspection techniques" (4). This clearly indicates that the member is distressed, but catastrophic structural failure is not necessarily imminent. Further loading on the member would cause the crack to extend. The principal parameters that influence the fatigue life of a member are the nature of the structural detail, the stress range experienced by the detail, and the volume and variation of live load traffic on the bridge. Therefore, the fatigue evaluation of a bridge structure involves the establishment of the fatigue category, the calculation of the equivalent stress range, the estimation of the number of stress cycles experienced, and the calculation of the remaining fatigue life.

AASHTO specifications classify steel bridge structural details into a number of categories. The fatigue categories for structural details are found in Table 10.3.1B of the AASHTO Standard Specification for Highway Bridges (9).

Depending on the nature and fabrication of the detail, the fatigue category is represented by the stress range vs. cycle (S-N) curve (Figure 2, Category E). However, S-N curves are referenced to constant amplitude stress cycles. Because the actual stress cycles experienced by a bridge varies, an equivalent stress range (S_{re}), that equates variable stress range to a constant amplitude range, is needed.

There are three methods of obtaining the stress ranges of a bridge: the Single Truck method, the AASHTO Design Stress method, and the Direct Measurement of Stress range method.

The Single Truck method is based on the observation that most of the stress cycles in a bridge structure are caused by single vehicle passages (4). Based on this observation, a simple method for estimating the equivalent constant amplitude stress range is developed. Fisher (7,8) has proposed the use of a single HS-20 truck and the calculation of the equivalent stress range following the provisions of AASHTO specifications. Moses (10) proposed the use of a "fatigue truck" (similar to a HS-15 truck) with provisions regarding impact factor and lateral distribution factors (4). Both methods provide quick estimates of the equivalent stress range (S_{re}).

The AASHTO Design Stress method uses the AASHTO design live load and impact stress as the basis for fatigue evaluation. These AASHTO design provisions include various safety factors which are necessary to account for the variability of the traffic load, including loads that exceed the AASHTO standard vehicle (4). In general, the actual stress ranges are significantly lower than the live load and impact stresses predicted. Therefore, this method tends to yield very conservative estimates of fatigue life.

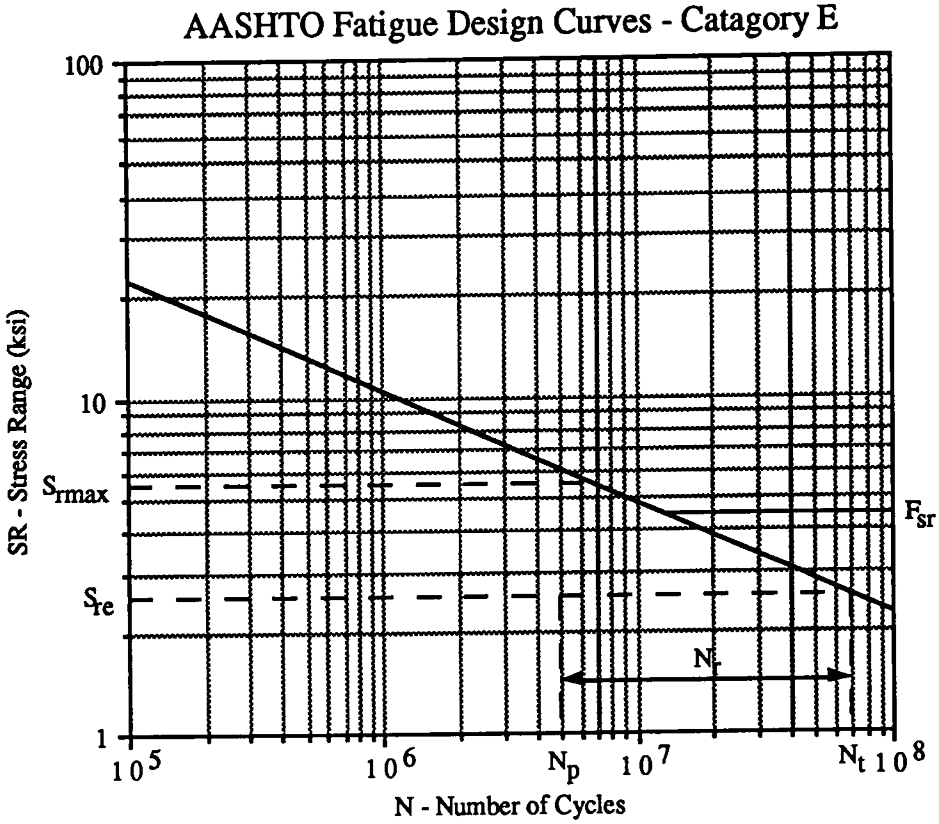


Figure 2: Estimate of Total Fatigue

The Direct Measurement of Stress Range method is the most site-specific and costly of the three methods. It requires the structure to be instrumented with strain gages. The strains are monitored and recorded over a time period that realistically represents the traffic pattern. Figure 3 shows a typical strain-time record. The shape of the curve resembles the influence line with superimposed strain fluctuation due to the vibrations of the structure (4) and noise. The strain-time record is reduced to determine the stress cycles and the frequency of occurrence. There are several methods used to count the number of cycles and they are discussed in Chapter 3. The simplest stress cycle counting method (used in this report) is the "Mean Crossing Peak Counting Method". In this method, a cycle is defined as the time segment where the strain starts from the zero axis to the positive strain region, through the axis to the negative strain region, and back to the zero axis. The stress range magnitude is taken as the difference between the maximum and minimum stress record during this cycle.

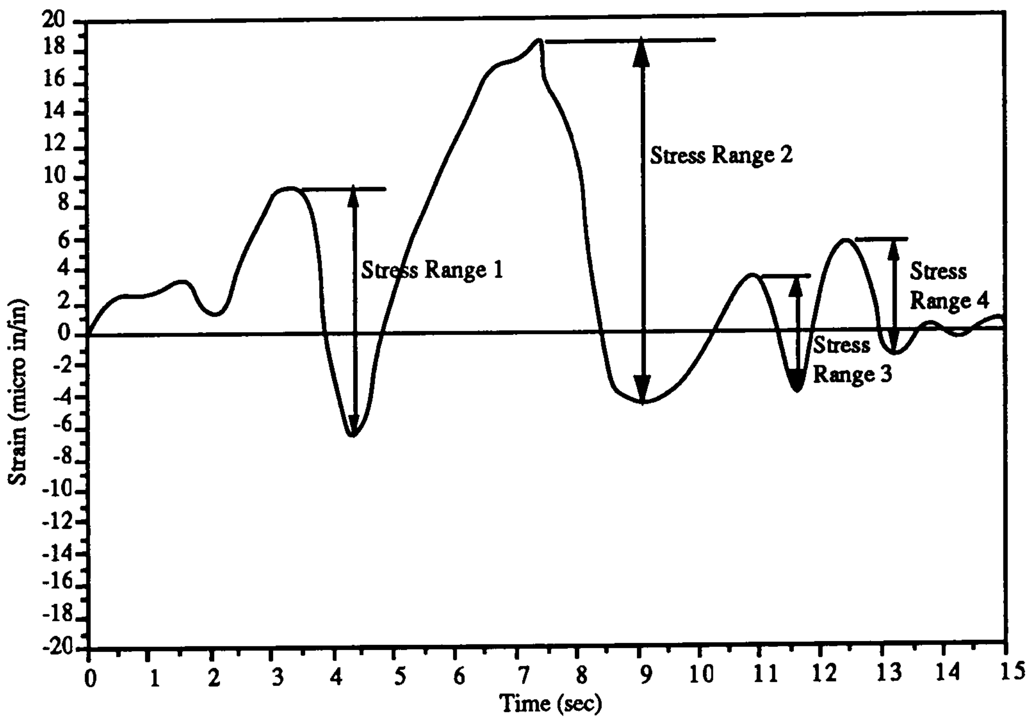


Figure 3: Typical Strain-Time Record

Tensile stress is regarded as positive and compressive stress as negative. The conversion from strain to stress is done by multiplying the strain difference by the modulus of elasticity. Tables A-1 through A-10 show the summarized stress frequency results from data taken for normal traffic during the months of June 1993 to November 1993. The equivalent constant amplitude range is commonly determined by invoking Miner's rule, which stipulates linear cumulation of fatigue:

$$\Sigma \frac{n_i}{N_i}$$

Where: n_i = number of stress cycles with range magnitude S_{ri}, and

N_i = fatigue life corresponding to constant stress range S_{ri}.

Since the typical S-N curve for steel has a one-third gradient, the equivalent constant amplitude stress range based on Miner's rule is the "root-mean-cube" value of the variable stress ranges (4). Therefore:

$$S_{re} = \sqrt[3]{\Sigma \gamma_i \; S_{ri}{}^3} \qquad \text{(Equation 1)}$$

γ_i = fraction of occurrence of stress range S_{ri}. or:

$$\gamma_i = \frac{n_i}{\Sigma \; n_i}$$

An alternate method of calculation uses the root-mean-square value for the equivalent stress range:

$$S_{rs} = \sqrt[2]{\Sigma \gamma_i \; S_{ri}{}^2} \qquad \text{(Equation 2)}$$

An examination of these equations reveals that the root-mean-square value (S_{rs}) will always be lower than the root-mean-cube value (S_{re}). Therefore, using the root-mean-square method will lead to a more conservative value.

Once the equivalent constant amplitude stress range (S_{re}) is calculated, the maximum stress range ($S_{r,max}$) is compared with the fatigue limit for that detail. Fatigue limit is defined as the "constant amplitude stress range, below which the detail will be able to endure unlimited number of cycles without developing fatigue cracks"(4). On a S-N diagram (Figure 2) the maximum stress range is represented as the horizontal threshold (F_{sr}). The fatigue limits for the various detail categories are found in Table 10.3.1A of AASHTO Bridge Specification (9).

Note, if the random variable stress ranges are below the fatigue limit, that is

$$S_{r,max} < F_{sr},$$

cumulative fatigue damage will not develop. However, if $S_{r,max}$ is greater than or equal to F_{sr} then fatigue cracking is expected. If the fatigue limit of the S-N diagram is not applicable, the total fatigue life (N_t) can be estimated by extending the descending segment of the S-N curve.

Once the maximum stress range ($S_{r,max}$) is compared to the fatigue limit and the equivalent stress range is calculated, the total fatigue life (N_t) can be obtained directly from the S-N curve. To calculate the remaining fatigue life an estimation of the number of stress cycles experienced to-date (N_p) is required. This can be ascertained by traffic volume counts or bridge traffic history data. The stress cycles experienced to-date can be calculated from a ADTT (average daily truck traffic) vs. time curve (Figure 4). The area under the ADTT curve represents the total number of vehicles passing over the bridge within a specified period of time. With these data and an estimate of the number of stress cycles per vehicle, the number of cycles to date (N_p) is calculated by:

$$N_p = \text{Area}\ (N_p) * \frac{\text{Cycles}}{\text{Vehicle}}$$

Therefore, the remaining fatigue life (N_r) can be calculated by:

$$N_r = N_t - N_p \qquad \text{(Equation 3)}$$

The conversion of remaining fatigue life into time requires the present average daily truck traffic (PADTT), average cycles per truck , and remaining fatigue life (N_r).

$$\text{Time(yr.)} = \frac{N_r}{\text{PADTT (Ave cycles/truck)365}} \qquad \text{(Equation 4)}$$

Where: $$\text{Ave. cycles/truck} = \frac{\Sigma n_i/\text{time(hr)}}{\text{\# trucks/time(hr)}}$$

$$\text{\# trucks daily} = \frac{\text{\# trucks}}{\text{time(hr)}} * 24\ \text{hr.}$$

Therefore: $$\text{Time (yr.)} = \frac{N_r * \text{time(hr)} * \text{\#trucks daily}}{\text{PADTT} * \Sigma n_i * 24\ \text{hr} * 365}$$

If it is assumed that the PADTT stays constant, then PADTT=#trucks daily and

$$\text{Time (yr.)} = \frac{N_r * time(hr)}{\Sigma n_i * 24 * 365} \qquad \text{(Equation 5)}$$

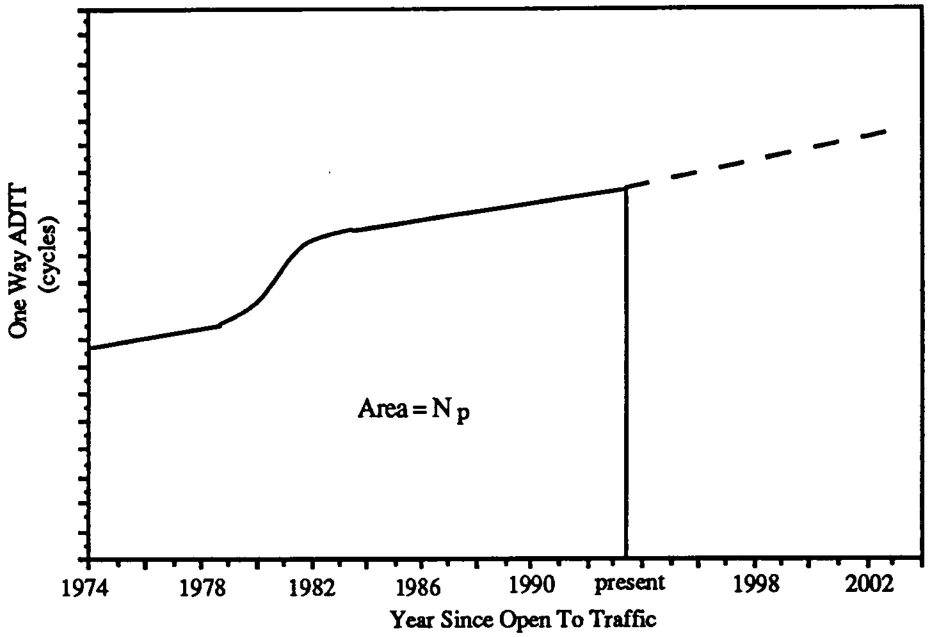


Figure 4: ADTT Variation with Time

Since this method is based on field measured stress ranges, the estimated remaining life is fairly accurate. If this estimated remaining life is judged to be inadequate, retrofitting and strengthening are required (4). When the cumulative cycles are 80-90% of the distance to the fatigue resistance curve, visible cracking should become apparent. If large cracks exist, the design fatigue resistance curves may not be applicable (5). In this case the Commonwealth of Pennsylvania DOT recommends that the residual fatigue resistance be analyzed by fracture mechanics models.

Chapter 2

Data Acquisition

Location of strain gages

After reviewing the bridge plans, physically inspecting the bridge, and with input from Dr. John Fisher, the locations of the strain gages were determined. These locations were chosen to determine the stresses at fatigue prone details as well as provide information on how the loads are transferred from one component to another.

The Holston River bridge (Figure 1) consists of 8 spans. Span one (135 ft.), located on the west end of the bridge, and span two (240 ft) were chosen to be instrumented for this study. Span one was chosen because its design was typical of other spans; and span two was chosen because it is the longest span as well as the location of the girder failure. The locations of these gages are shown in Appendix B, Figures B1-B12.

Two different lengths of 350 ohm resistance gages were used. The one-eighth inch gages were used in the web gap locations, and the one quarter inch gages were used in all other locations. Both of these gages were manufactured by Micro-Measurements.

Before these gages were installed, the surface was stripped of paint and mill scale with a grinder. The locations were then cleaned and the strain gages installed per the manufacturer's instructions.

Data Acquisition System (Megadac)

The Megadac system allows for the capture of dynamic analog data from the strain gages in real time. It has a sampling rate of 25,000 samples per second and a capacity of up to 128 channels of input (6). The Megadac system uses a data trigger function (6). This function, when unarmed, continuously reads and overwrites the data it scans. This feature allows for the observation of data prior to and during testing. When triggered, the function allows for the scanning and storage of data. During the bridge testing a sampling rate of 50 to 60 samples per second per gage was used. Data from thirty two strain gages could be recorded during any one test period. Each test period was for a period of 10 min. to 1 hour. The Megadac system and computer equipment were housed inside a van. This allowed for access to the bridge site as well as transportation of equipment.

TCS 3000 allows for the simple selection of a variety of unique programs and utilities while remaining within the TCS 3000/Megadac environment. The program allows for the selection of test parameters, definition of channels, the checking of test validity, calibration, recording, and reviewing of test data. However, the format in which the data are recorded is not compatible for analysis by other programs. TCS 3000 will allow for the conversion of data from a binary format into an ASCII file that contains the following information:

AT8593A.006	Test Name
08/05/93	Test Date
02:21:39	Test Time
32	Time + Number of gages
60	Readings per second
Time Sec G78 UE G79 UE...	Header telling the sequence of the gage readings.
+3.5000E+001 -1.1842E+000...	Actual data. Time is the first reading, G78 is the second reading.
+3.5017E+001 -1.1842E+000...	Next set of data. Time is the first reading, G78 is the second reading.

Because of the size and arrangement of the data, two other programs were created for analysis of the test data (DATAACQ.BAS and DATARED.BAS). DATAACQ.BAS (Appendix - C) separates the data to a specific gage files and DATARED.BAS (Appendix - D) analyzes and categorizes the stresses seen by each gage.

Chapter 3

Analysis of Data

Separation and Cycle counting methods

When the strain gage data is recorded it is stored as a binary file. TCS 3000 allows for the conversion of this data from a binary format into an ASCII file. The format of this ASCII file was too large to be manipulated by itself, therefore, two other programs were created for the separation and analysis of the test data (DATAACQ.BAS and DATARED.BAS). Users instructions for these programs are found in Appendix E.

DATAACQ.BAS (Appendix - C) separated the strain data from the ASCII file to specific gage files. The ASCII file was set up as a data matrix. The number of columns depended on the number of strain gages recorded and the length of the data acquired. The number of rows in the matrix was based on the test duration multiplied by the counts per second:

# of columns = 1 + # of gages

# of rows = test duration * counts/sec.

Therefore, DATAACQ.BAS separated the specific strain data by initially reading the time in each row of data then reading the strain data as a matrix (g(i,j)):

```
DO UNTIL EOF(1) = -1
FOR i = 1 TO l
    INPUT #1, T(i)
    FOR j = 1 TO N
        INPUT #1, g(i, j)
    NEXT j
NEXT i
```

where: *g(i,j)* =Strain data matrix

j =#of gages (# of columns)

i =# segment of time read

A test length of 15 minutes with 32 gages was approximately 250 kBit long. In the BASIC language, a matrix was limited to 16 k; therefore, this program read two seconds worth of data, separated the data into its separate gage files, then read two more seconds of data until the whole ASCII file was transferred.

Once the separation was completed, the program DATARED.BAS was used to count cycles for each gage data file. There are different methods of counting cycles: range pair counting, mean crossing peak counting, and rain flow. The method used in the program was mean crossing peak counting. Mean crossing peak counting produces a mean (zero) axis, then counts the number of predetermined cycles that go above and below the mean axis. During testing, gages drifted due to temperature changes or other problems in the data acquisition system (Figure 5). Therefore, as time passed during a test, some strain cycles did not fall below the zero level.

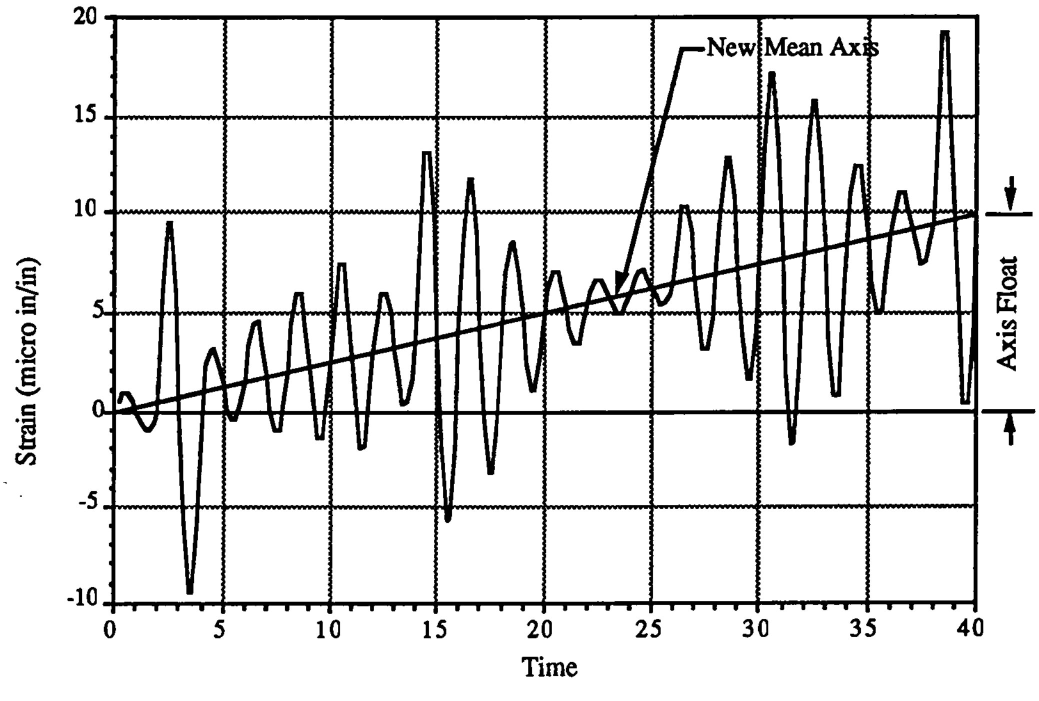


Figure 5: Data Float

DATARED.BAS corrected for this by calculating the average of the first 20 and last 20 data points; then it created a straight line between these two sets of twenty.

Correct1 = sum1 / 20: Correct2 = sum2 / 20	Averages the first & last 20 data points.
slope = (Correct2 - Correct1) / (T(31) - T(10))	Finds the slope between the two points.
*c = Correct1 - slope * T(10)*	Finds the x-axis zero point.
*Correct = slope * T(i) + c*	Creates a new Zero Axis.
g(i) = g(i) - Correct	Corrects the data.

DATARED.BAS corrected the data to the new mean axis, then counted the cycles that are created when a maximum positive and minimum negative strain value is obtained. There are tests to find the maximum and minimum strain points to complete a cycle. The first test was to check if the strain was greater than zero, greater than the previous strain reading and greater than the previous high strain reading (quadrant one - Figure 6). If these checks are true, a new high strain point is assigned. The next test was to see if the strain was less then zero, less than the previous strain reading and less than the previous low strain

```
FOR i = 1 TO L
    IF g(i) > 0 AND g(i) > g(i - 1) THEN
        IF g(i) >= Hg(j) THEN Hg(j) = g(i): Ht(j) = T(i)
    END IF
    IF g(i) < 0 AND g(i) <= g(i - 1) THEN
        IF g(i) < Lg(j) THEN Lg(j) = g(i): Lt(j) = T(i)
    END IF
    IF g(i) < 0 AND g(i + 1) > 0 THEN j = j + 1
NEXT i
```

reading (quadrant three - Figure 6). If this check was true, a new low strain point was assigned. The final test was to see if the previous data point was negative and if the new data point was positive (indicates crossing the mean axis and a completion of a cycle). When these tests are satisfied, the cycle is completed. The high and low strain data points and their respective times were recorded, and the strain difference was calculated. Stress was found by multiplying the strain difference by Young's Modulus for steel ($29x10^6$ psi). With the stress calculated, it was then categorized within the appropriate stress range.

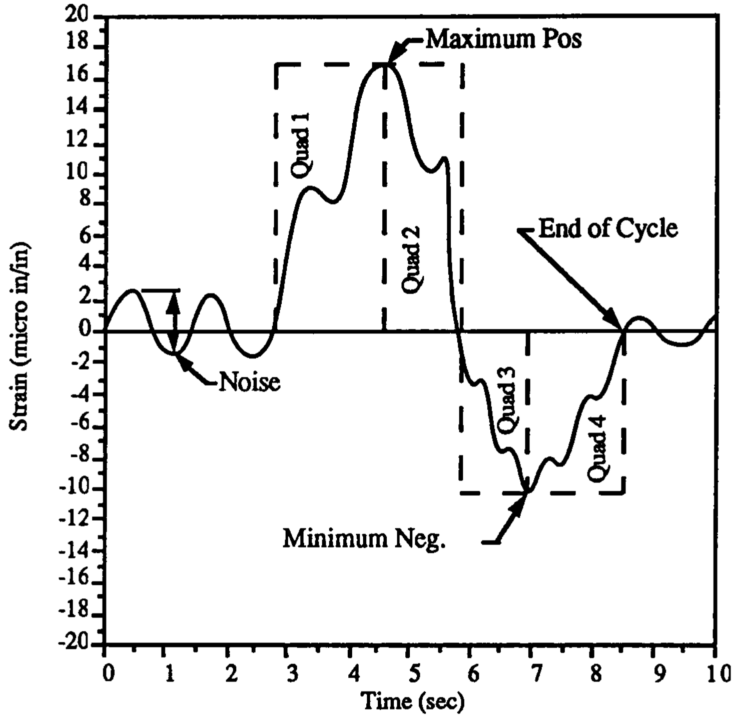


Figure 6: Definition of a Cycle

In addition to the strain data, some noise is also recorded during testing. In most cases the noise is easily defined by its magnitude and frequency of occurrence. Any stress cycle that has a magnitude of less then 500 psi was ignored by the program. Also if the frequency of occurrence was within the range of 5 to 50 cycles per second, then it was checked and possibly ignored. Occasionally a cycle of high magnitude (greater then 20-30,000 psi) was recorded. This behavior was infrequent and could be excluded in the cycle count. The frequency of occurrence and high magnitude recordings were checked through the use of a TCS 3000 graph package; then a decision was made to determine if the data was valid or should be removed from the cycle count.

With the cycles defined and categorized into specific stress ranges, the results for normal traffic conditions were summarized. There were three types of traffic flow seen during testing: normal traffic with three lanes open (Tables A-1 through A-10), middle lane and left lane open (Tables A11 through A19), and outside shoulder and right lane open (Tables A-20 through A-31). With the stresses categorized, the equivalent stress ranges could be calculated using the root-mean-cube equation.

Other Programs and their theory:

Besides the mean crossing peak counting method, the range pair counting method and rain flow counting methods can be used in counting cycles. The range pair counting method (Figure 7) counts a strain range as a cycle if it can be paired with a subsequent

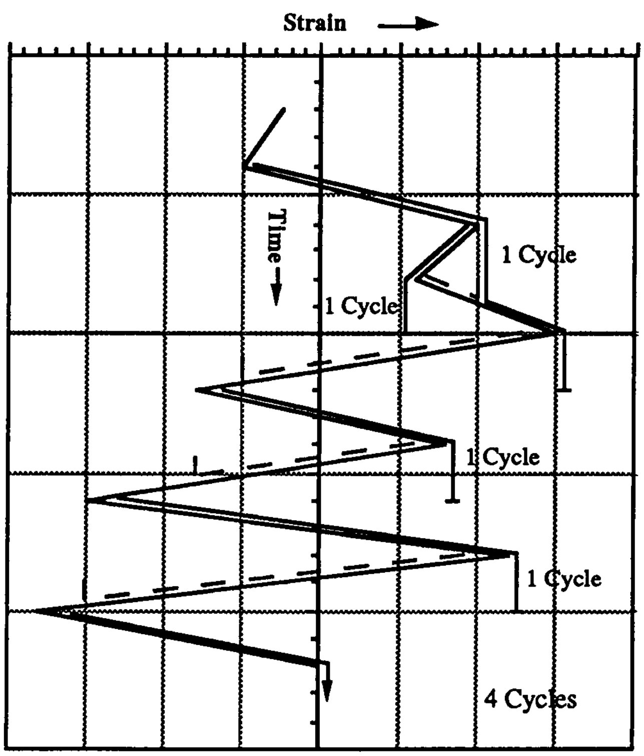


Figure 7: Example of Range Pair Cycle Counting Method

straining of equal magnitude in the opposite direction. The strain peak does not necessarily have to cross a mean. Therefore, cycles could be counted in which the strain does not change direction. Furthermore, if the initial peak of a range is a minimum, a cycle is counted between this minimum and the positive maximum which occurs before the strain/ becomes more negative than the initial strain peak (11).

The rain flow counting method (Figure 8) imagines the lines connecting the strain peaks as a series of "pagoda roofs" with rain flowing downward. This is why the strain time history plot is oriented with the time axis vertically downward. The rain flow methodology allows for cycles and half cycles to be counted. The rain flow initiates at each peak. It is then allowed to drip down and continue until it initiates a minimum, or when it comes opposite a minimum more negative than the minimum from which it initiated. Furthermore, if rain flow initiates at a maximum, it must end when it comes opposite a more positive maximum than the maximum from which it initiated. Also, rain flow must also

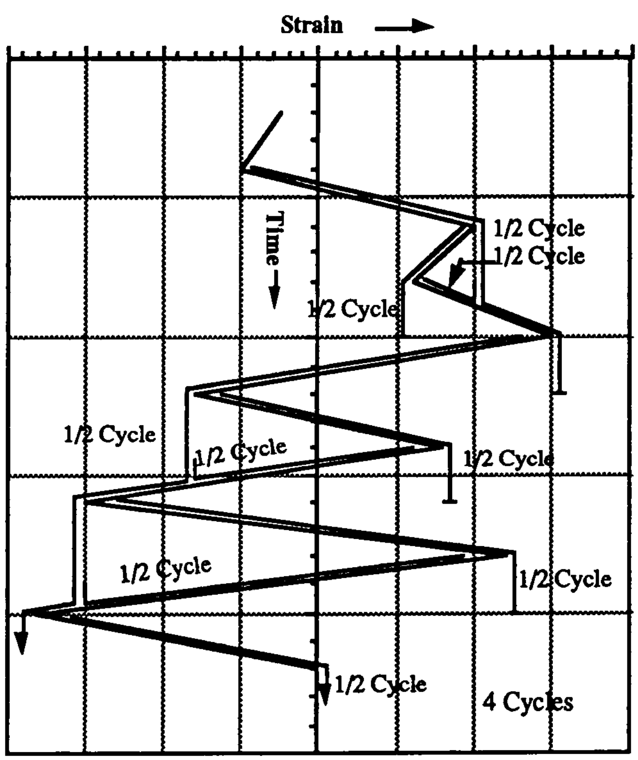


Figure 8: Example of Rain Flow Cycle Counting Method

stop if it meets the rain from a roof above. These count as a half cycle. Finally, half cycles are counted between the most positive maximum and the most negative minimum (if the most positive maximum occurs first) and between the most positive maximum and the most negative minimum that occurs before it in the history (11).

Because a half cycle is counted at the beginning of each peak and ends when it initiates a greater peak, and because a half cycle is also counted when it meets rain from the roof above, a rain flow cycle reduces to the range pair cycle. The difference would probably be the cycle counted in rain flow by the most positive maximum and minimum counted in rain flow.

Analysis of Cross Frame

With the stresses categorized, the equivalent stress range is calculated using the Root-Mean-Cube equation (Equation 1). Next the maximum stress of each gage was compared with the maximum stress range (F_{sr}) for its corresponding fatigue category. Two of the twelve Cross Frames (1A,1B,1C,1D, Figure B-1) between Piers 1 and 2 were instrumented. The gage locations are shown in Figures B1,B2,B4 through B9. All of the Cross Frames members that were instrumented are of AASTHO Category E details. Therefore, the maximum allowable stress range is 4500 psi. The Total Fatigue Life can be found from the Category E S-N curve (Figure 2), or the equation that defines the curve:

Total Fatigue Life =10^(3.012*(3.007-LOG(Sr(ksi))))

The Cross Frame consist of original members and members that had been retrofitted since the girder failure. For the original members, the number of stress cycles experienced to date (N_p) could be calculated using ADTT data (Figure 14). Furthermore, the Remaining Fatigue Life (N_r) is calculated using Equation 3 and the Remaining Time (yr.) is calculated using Equation 4. However, the retrofitted details are all located on the web gap. The stresses obtained are affected by the retrofits; therefore, no estimate of cycles to date (N_p) could be obtained from ADTT data. Therefore, for illustration, it was assumed that

50%, 70%, and 90% of the total fatigue life (N_t) was equal to the number of cycles to date (N_p). Therefore, the remaining fatigue life (N_r) was equal to 50%, 30%, and 10% of the total fatigue life. The remaining life in years was calculated using ADTT data (Figure 14).

Chapter 4

Presentation of Data

Cross Frame

Span two is the longest span on the Holston River bridge, and cross frames span between the four girders in this span. The cross frames run perpendicular to the four girders (Figure 9). They distribute the loads from the deck and stringers to the girders. Spanning diagonally between each cross frame are lateral braces. These lateral braces run from the outside of the cross frame to the inside of the next existing cross frame. These lateral braces help distribute the loads from one cross frame to another. Because the cross frames are located on the opposite side of the girders from the cantilevers, they also create a counter force from the loads applied to the girder from the cantilevers.

All cross frame members was made of double angles and gusset plates (3,12). Each cord of the cross frame is welded to gusset plates. The gusset plate detail (Figure B-2) dictated that the cross frames are Category E details. The cross fames and lateral braces are bolted to the girders through lateral gusset plates. The lateral gusset plate is bolted to tabs that are welded horizontally along the web of the girder on each side of the vertical stiffener. These tabs are four inches from the vertical stiffener, and create a four inch web gap on each side of the stiffener (12). At this location, forces introduced by the cross frame tend to pump the girder in and out. "When out of plane distortion occurs, this portion of the web behaves similarly to a beam with two fixed ends, put into double curvature, and having a length of four inches" (12). Small out of plane distortions over this short distance can result in high stress ranges within this gap. "This out of plane distortion within the web gap was determined to be the mostly likely cause of the girder failure" (12). Both the web gap locations and the cross frames were instrumented.

Comparison of Measured vs Calculated Loads on the Cross Frame

To determine if the strains measured during testing were within acceptable

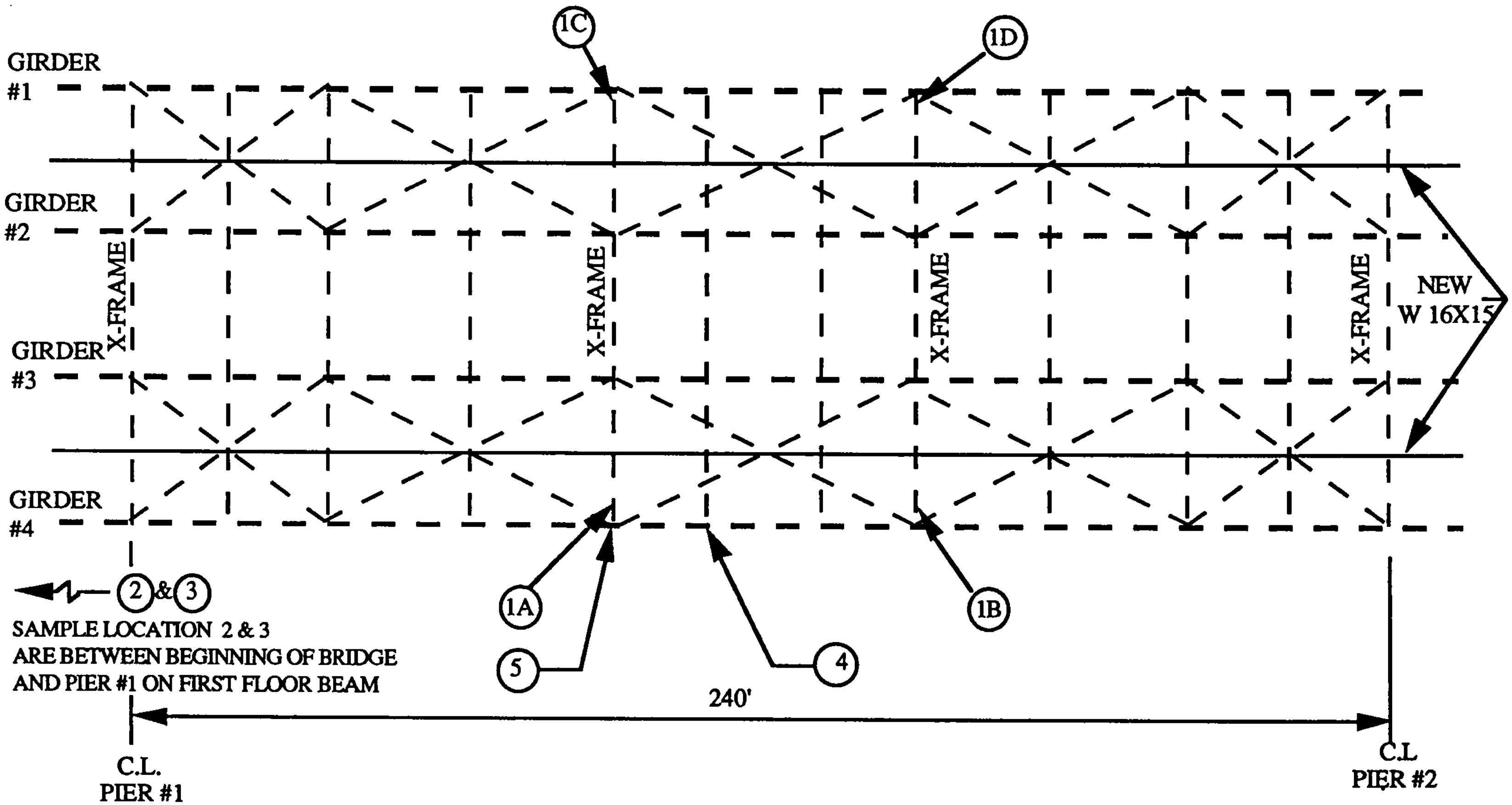


Figure 9: Plan of Span 2 on the Holston River Bridge

ranges, a comparison of the measured crawl test data was made with a simplified truss analysis. The crawl test was performed by driving a truck of known weight over the bridge and recording the strain at various gages. The truss analysis was performed by modeling the rear axle reactions in the middle lane (Figure 10). The bridge deck was assumed to be a stiff plate with the loads linearly distributed to the stringers and girder.

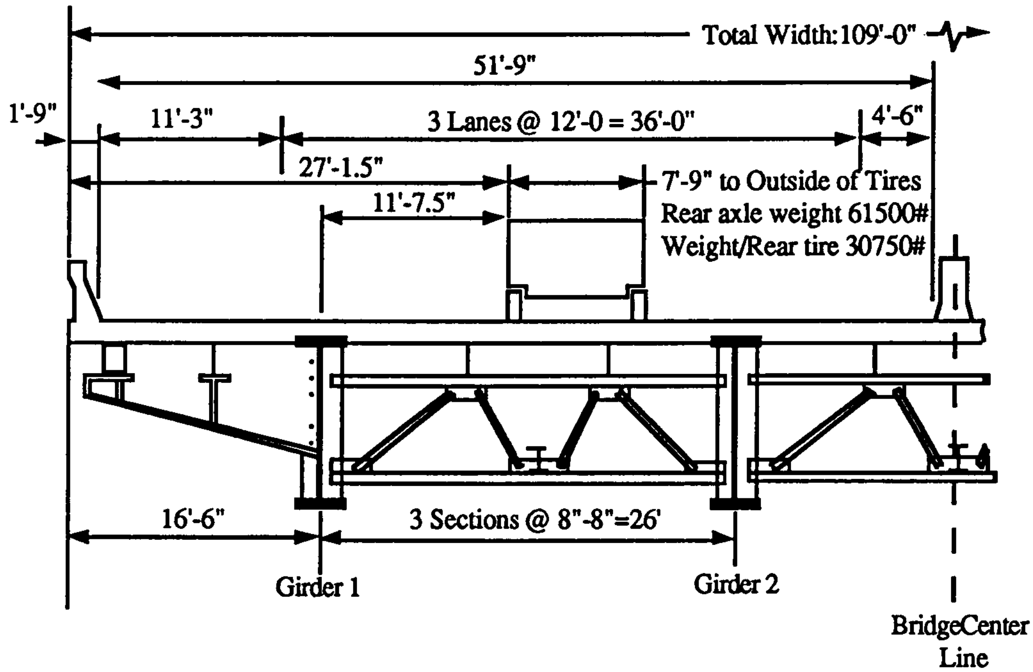


Figure 10: Typical section of bridge at Cross Frame with Truck Location

Figure 11 shows a comparison of the measured and computed data. The measured data is in parentheses.

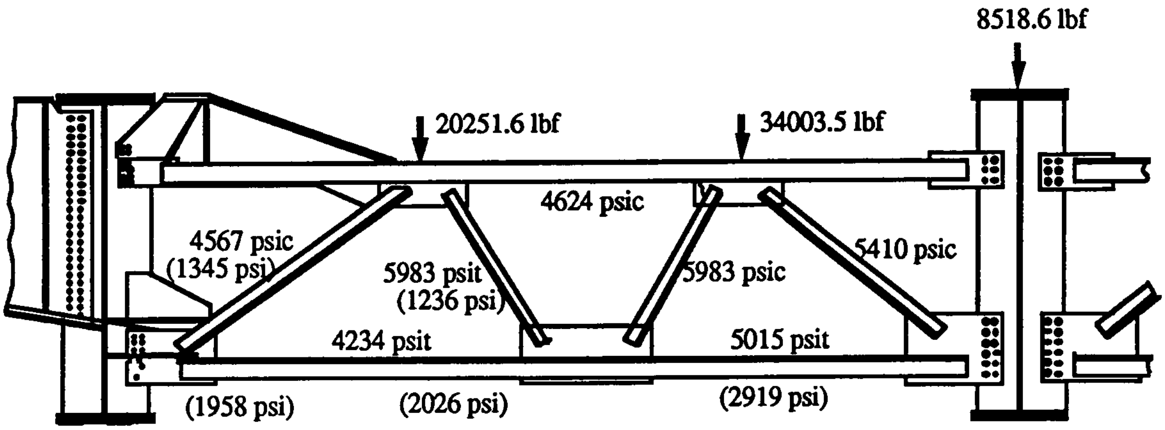


Figure 11: Comparison of Cross Frame Calculation and Crawl Test Data.

Stress cycles and Equivalent Stress Results

A total of 18.8 hours of testing was performed on the Holston River bridge. 5.6 hours were of normal traffic conditions, 4.7 hours were of traffic in the right lanes and outside shoulder, and 8.6 hours were on the middle and left lanes. The Holston River bridge had 133 strain gages installed, with data collected on 116 gages.

The results of normal traffic conditions as well as the equivalent stress ranges are summarized in Tables A-1 through A-10. The equivalent stress was calculated using the "Root-Mean-Cube" method (Miner's rule, Equation 1). Tables 1 and 2 summarize the strain gages with equivalent stresses between 500 to 1000 psi. Tables 3 and 4 summarize the strain gages with equivalent stresses between 1000 to 1500 psi, and Table 5 summarize the strain gages with equivalent stresses greater then 1500 psi.

Table 6 has the results of gages G111 through G118 using the Mean crossing peak cycle counting method. Table 7 has the results of gages G111 through G118, using the Rain Flow cycle counting method and a comparison of the equivalent stress with the Mean Crossing Peak cycle counting method. When compared with the Mean Crossing Peak counting method, the Rain Flow counting method yields higher results.

Table 1: Summary of Stress Ranges 500 to 1000 psi

Gage Number	Location	RMC (psi)	Traffic Flo w		
			Normal	M &L	R & S
G54	1-B web gap	992		*	*
G61	1-C CF bottom cord 1st dia.	988	*	*	
G33	1-B CF bottom cord 1st dia.	987		*	*
G7	1-A CF bottom cord 1st dia.	974	*		*
G55	1-C Cantilever top web	958	*		*
G91	1-D CF bottom cord 3rd dia.	937		*	
G104	2 FB bottom web	930	*		*
G70	1-C CF bottom cord 3rd dia.	928		*	
G60	1-C CF bottom cord 1st dia.	923	*	*	*
G41	1-B CF 2nd dia.	922		*	*
G24	Girder 4 web east side of ret	913	*		*
G8	1-A CF bottom cord 1st dia.	887	*		
G89	1-D CF 2nd dia.	882	*	*	*
G32	1-B CF bottom cord 1st dia.	874		*	*
G93	1-D CB next to CF	872	*	*	*
G72	1-C CB next to CF	871	*	*	*
G84	1-D CF 1st dia.	866	*	*	
G28	1-B Cantilever bottom web	851	*		*
G30	1-B Girder 4 bottom flange	851		*	
G63	1-C CF bottom cord 1st dia.	849	*	*	*
G53A	1B-Girder 4 web-vert	847			*
G13	1-A CF top cord rosette	836	*	*	
G18	1-A CB next to CF	834	*		*
G71	1-C CB next to CF	831	*	*	*
G14	1-A CF 2nd dia.	830	*	*	*

Table 2: Summary of Stress Ranges 500 to 1000 psi

Gage Number	Location	RMC (psi)	Traffic Flow		
			Normal	M &L	R & S
G6	1-A CF bottom cord 1st dia.	819	*		*
G88	1-D CF top cord rosette	801	*	*	*
G99	1-D Cantilever bottom flg.	800	*		*
G67	1-C CF top cord rosette	794	*	*	*
G94	1-D CB next to CF	791	*	*	*
G85	1-D CF knee brace flange	785			*
G101	2 Cantilever bottom web	785	*		*
G17	1-A CB next to CF	781	*		*
G2	1-A Cantilever bottom web	775			*
G50	1-B CB next to CF	775		*	*
G64	1-C CF knee brace flange	771			*
G44	1-B CB next to CF	770		*	*
G36	1-B CF knee brace flange	767			*
G34	1-B CF bottom cord 1st dia.	763		*	
G1	1-A Cantilever top web	759			*
G35	1-B CF 1st dia.	752		*	
G3	1-A Girder 4 top flange	750	*		*
G9	1-A CF 1st dia.	750	*		*
G40	1-B CF top cord opp. rosette	750	*		
G57	1-C Girder 4 top flange	750			*
G100		750			*
G102	2 Cantilever top web	750	*		
G103	2 FB top web	750	*		

Table 3: Summary of Stress Ranges 1000 to 1500 psi

Gage Number	Location	RMC (psi)	Traffic Flo w		
			Normal	M &L	R & S
G19	1-A web gap	1492			*
G25	4 Girder 4 web	1481	*		*
G58	1-C Girder 4 bottom flange	1461	*		*
G201		1458		*	*
G98	1-D web gap	1425	*	*	*
G47	5 Girder 4 web	1411			*
G59	1-C Girder 4 bottom flange	1359	*		
G106	2 FB bottom web	1351	*	*	*
G20	1-A web gap	1335			*
G12	1-A CF top cord rosette 45°	1331	*	*	
G82	1-D Girder 4 bottom flange	1326	*		*
G11	1-A CF top cord rosette	1284	*	*	*
G29	1-B Girder 4 top flange	1274			*
G113	2 FB Girder 3 rosette-vert	1262	*		
G56	1-C Cantilever bottom web	1250			*
G118	3 FB bottom flg GP	1250	*		
G16	1-A CF top cord 3nd dia.	1227		*	
G4	1-A Girder 4 bottom flange	1213	*		
G90	1-D CF bottom cord 2nd dia.	1213			*
G83	1-D Girder 4 bottom flange	1204	*		
G81	1-D CF bottom cord 1st dia.	1201			*
G117	3 FB bottom flg GP	1198	*		*
G116	2 FB Girder 3 web	1186	*	*	

Table 4: Summary of Stress Ranges 1000 to 1500 psi

Gage Number	Location	RMC (psi)	Traffic Flow		
			Normal	M &L	R & S
G108	2 FB web gap	1180	*	*	*
G109	2 FB web gap	1180	*	*	*
G112	2 FB bottom web	1166		*	
G46	5 Girder 4 web	1148			*
G10	1-A CF knee brace flange	1145		*	
G114	2 FB Girder 3 rosette-45°	1143		*	
G97	1-D web gap	1142	*		*
G42	1-B CF bottom cord 2nd dia.	1140			*
G49	5 Girder 4 web	1130			*
G69	1-C CF bottom cord 2nd dia.	1111			*
G23	4 Girder 4 web	1105			*
G80	1-D CF bottom cord 1st dia.	1105			*
G96	1-D web gap	1083	*		*
G62	1-C CF bottom cord 1st dia.	1073			*
G75	1-C web gap	1070		*	
G68	1-C CF 2nd dia.	1054		*	
G15	1-A CF top cord 2nd dia.	1052			*
G26	4 Girder 4 web	1050			*
G115	2 FB Girder 3 rosette-hor	1033			*
G45	5 Girder 4 web	1017			*
G111	2 FB top web	1013		*	
G79	1-D CF bottom cord 1st dia.	1009	*		
G43	1-B CF bottom cord 3nd dia.	1008		*	

Table 5: Summary of Stress Ranges Greater then 1500 psi

Gage Number	Location	RMC (psi)	Traffic Flow		
			Normal	M &L	R & S
G105	2 FB top web	2409	*	*	*
G52A	1-B Girder 4 web-horz	2179			*
G78	1-D Cantilever top web	2099			*
G37	1-A CF top cord rosette	2068			*
G52	1-B web gap	2038			*
G110	2 FB web gap	1893	*	*	
G95	1-D web gap	1861	*		*
G54A	1-B Girder 4-horz	1793			*
G76	1-C web gap	1761	*		*
G73	1-C web gap	1712			*
G51-A	1-B Girder 4 web-vert	1668			*
G51	1-B web gap	1654			*
G74	1-C web gap	1623	*		*
G107	2 FB web gap	1612		*	
G5	1-A Girder 4 bottom flange	1601			*
G48	5 Girder 4 web	1598			*
G27	1-B Cantilever top web	1597			*
G31	1-B Girder 4 bottom flange	1588			*
G53	1-B web gap	1536			*

TABLE 6: Normal Traffic results: Mean Crossing Peak Counting Method

	Gage No.							
Stress Range (psi)	G111	G112	G113	G114	G115	G116	G117	G118
500-1000	756	2109	6954	6956	3273	1320	764	925
1000-1500	94	195	1344	592	217	217	153	131
1500-2000	5	52	322	184	31	113	102	117
2000-2500	1	29	125	90	4	38	45	53
2500-3000		5	92	29		12	6	24
3000-3500		1	62	6		2	1	2
3500-4000			53					
4000-4500			17					
4500-5000			7					
5000-5500			3					
Time (Hr.)	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Eqv. Stress	858.02	945.02	1261.7	958.15	830.11	1111.5	1197.6	1250

Table 7 : Normal Traffic Results; Rain Flow Counting Methods and Comparison

	Gage No.							
Stress Range (psi)	G111	G112	G113	G114	G115	G116	G117	G118
500-1000	704	2412	9729	8311	3930	1541	1200	1408
1000-1500	136	255	1440	774	303	233	192	185
1500-2000	55	84	368	211	73	156	130	119
2000-2500	13	32	151	116	14	75	52	69
2500-3000	3	16	96	71	8	28	22	36
3000-3500	1	7	66	34	4	7	4	12
3500-4000			70	11	2	1	1	1
4000-4500			55	5				1
4500-5000			31	2				
5000-5500			17					
5500-6000			8					
6000-6500			7					
6500-7000			2					
Time (Hr.)	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Eqv. Stress (RF)	1065.2	1011.4	1391.1	1058.0	904.7	1216.1	1207.4	1260.7
% Difference	19.4	6.56	9.30	9.44	8.24	8.60	0.81	0.85

Figure 12 shows an example of how one cycle using the Mean Crossing Peak counting method could be counted as 5 cycles using the Rain Flow counting method. This inconsistency is due to the fact that the rain flow counting method counts half cycles. Some of these counting cycles may be eliminated due to the range criteria, but overall, the Rain Flow counting method produces greater results.

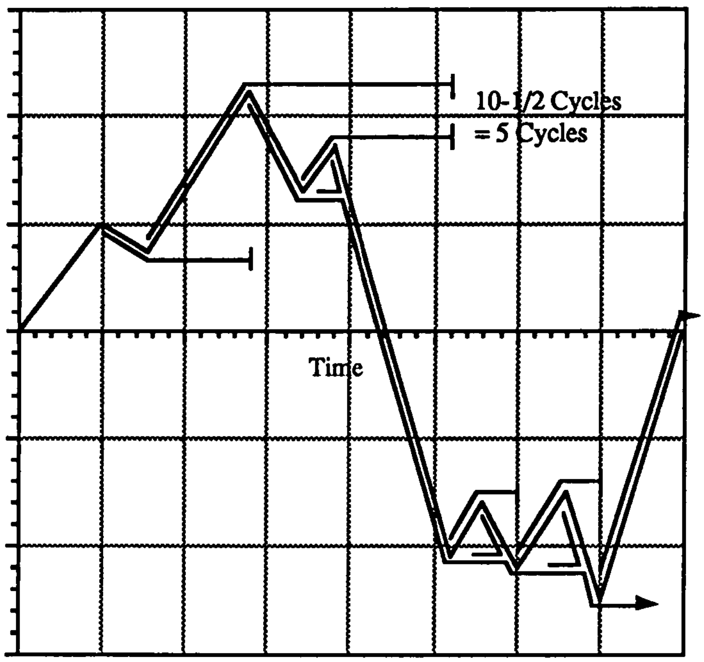


Figure 12: One cycle of Mean Crossing Peak vs. Rain Flow

Another reason that the Mean Crossing Peak counting method has lower results is due to the mean axis float. In some instances there were spontaneous axis shifts as shown in Figure 13. The axis shift would miss some of the acceptable cycles until the axis adjustment caught up to the new mean.

Overall the equivalent stress range using the Mean Crossing Peak counting method was relatively close to the Rain Flow counting method. Except for gage G111 (19.4% difference) the equivalent stress ranges had differences of less than 10%.

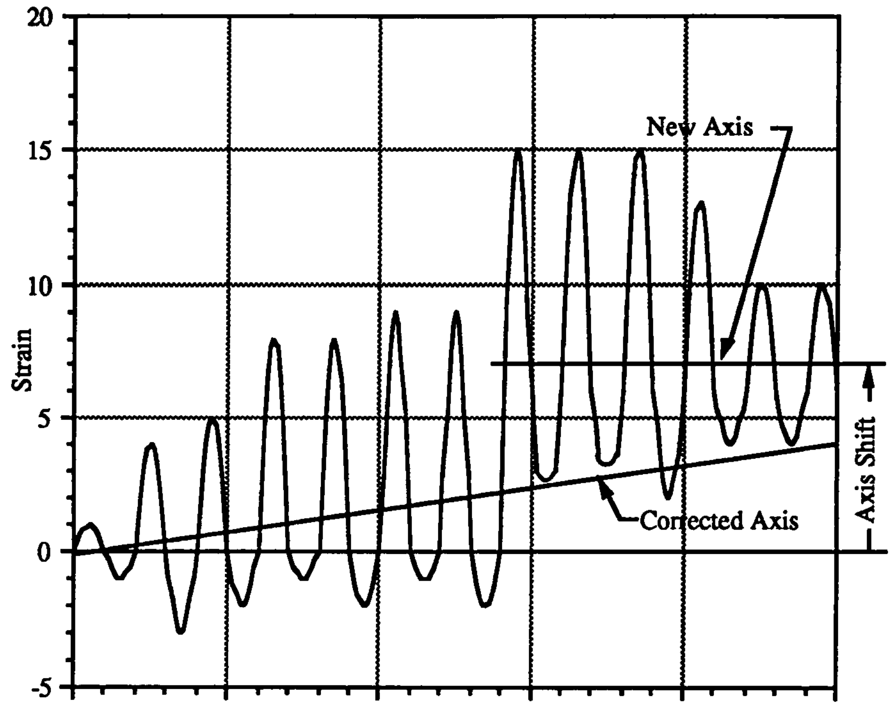


Figure 13: Example of Spontaneous Axis Drift.

Cross Frame Analysis

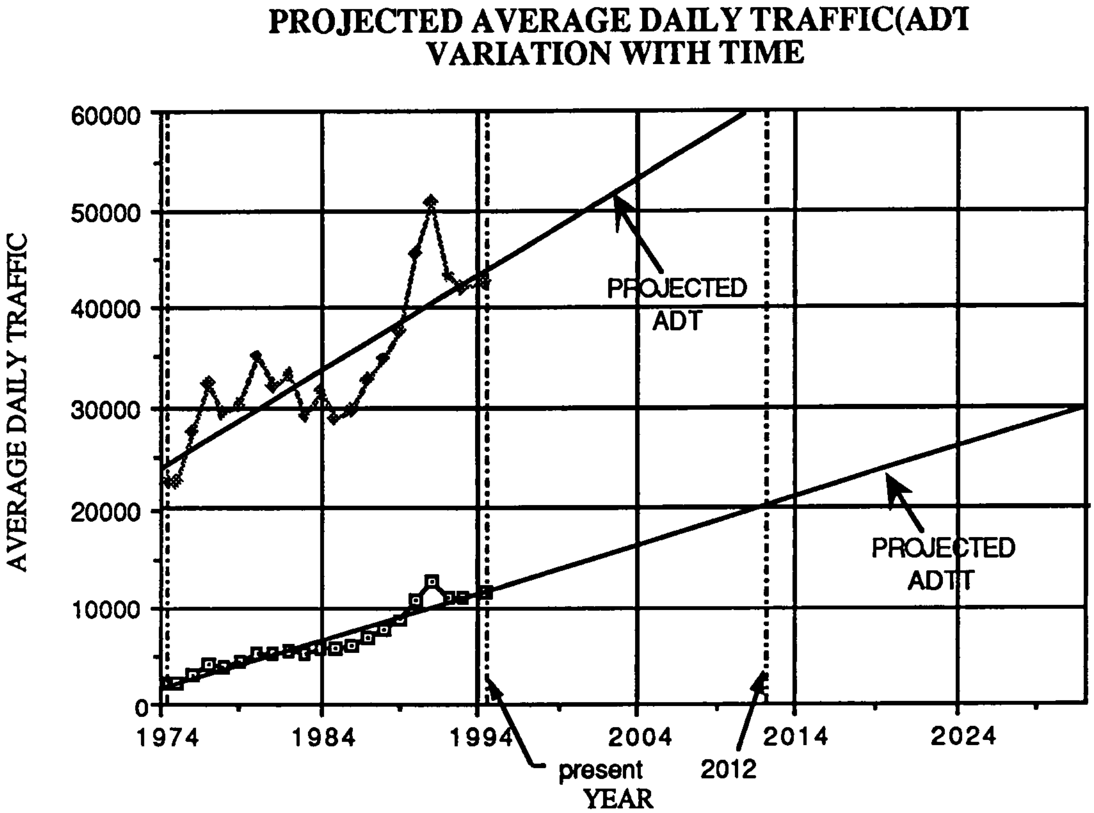
Two cross frames were instrumented with sixty-seven strain gages. Two of these gages (G76, G95) experienced stress ranges greater than the maximum stress range (4500 psi - Category E) for normal traffic conditions. Three strain gages (G43, G69, G75) experienced stress ranges greater than the maximum stress range for middle and left lane traffic. Five strain gages (G51, G52, G73, G76, G95) experienced stress ranges greater than the maximum stress range for right lane and shoulder traffic conditions. Table 8 lists these gages and notes whether the detail had been retrofitted or not.

Table 8: Traffic Conditions

Traffic Conditions:	Normal	Middle & Left Lane	Right Lane & Shoulder
Strain Gages on Retrofitted Details	G76, G95	G75	G51,G52,G73,G76,G95
Original Details		G43,G69	

For the un-retrofitted details, the remaining life could be calculated using Equation 3, with the assumption of one cycle per truck and the calculated number of cycles to date (N_p) of 35,972,210. The remaining life in years was calculated using projected ADTT data (Figure 14). Gage G43 is located on the 1-B cross frame and has a remaining life of 88.9 years. Gage G69 is located on the 1-C cross frame and has a remaining life of 130.1 years.

The retrofitted details are all located on the web gap. The stresses obtained are affected by the retrofits; therefore, no estimate of cycles to date (N_p) could be obtained from ADTT data. Therefore, it was assumed that 50%, 70%, and 90% of the total fatigue life (N_t) was equal to the number of cycles to date (N_p). Therefore, the remaining fatigue life (N_r) was equal to 50%, 30%, and 10% of the total fatigue life. The remaining life in years was calculated using ADTT data (Figure 14). Table 9 shows the results.



PROJECTED ADDITIONAL TRUCK CYCLE
PRESENT TO 2012 - 103,000,000
PRESENT TO 2032 - 282,000,000

Figure 14: ADTT and ADT Data

Table 9: Estimated Remaining Life of Retrofitted details

Normal Traffic							
Gage Number	Location	Max. Stress (ksi)	Equivalent Stress (psi)	Total Fatigue Life	Remaining Life (yrs)		
					50%	30%	10%
G76	1C-web gap	4.5-5	1550.2	304,522,421	24.0	16.1	3.4
G95	1D-web gap	5-5.5	1628.3	262,644,820	21.4	14.3	2.9
Left & Middle Lane Traffic							
Gage Number	Location	Max. Stress (ksi)	Equivalent Stress (psi)	Total Fatigue Life	Remaining Life (yrs)		
					50%	30%	10%
G75	1C-web gap	4.5-5	1070.1	929,823,169	52.4	37.1	9.2
Right Lan e & Shoulder Traffic							
Gage Number	Location	Max. Stress (ksi)	Equivalent Stress (psi)	Total Fatigue Life	Remaining Life (yrs)		
					50%	30%	10%
G51	1B-web gap	4.5-5	1654.3	250,386,837	20.7	13.8	2.8
G52	1B-web gap	7-7.5	2038.4	133,500,372	12.5	8.1	1.5
G73	1C-web gap	5-5.5	1711.8	225,887,484	19.1	12.7	2.5
G76	1C-web gap	5-5.5	1760.9	207,460,212	17.8	11.8	2.3
G95	1D-web gap	6-6.5	1861.3	175,548,195	15.6	10.3	2.0

Chapter 5

Conclusions and Recommendations

Stress Cycles and Equivalent Stress

A total of 18.82 hours of testing was performed from June to November 1993 on the Holston River bridge. The data were analyzed using the Mean Crossing Peak counting method and the results categorized in stress cycle tables (Tables 1 & A-1 through A-24). Furthermore, the equivalent stress range (S_{re}) was calculated for each gage. These results were compared with data analyzed using the Rain flow Cycle counting method (Table 8). Except for one gage, the comparison showed that the Mean Crossing Peak counting results were within 10% of the Rain Flow Analysis results. These differences could be due to the following reasons:

1. Rain Flow Cycle counting method counts half cycles. Some of these cycles may be eliminated due to the range criteria, but overall the Rain Flow Cycle counting method will have higher stress ranges.
2. Spontaneous axis drift. In some instances the mean axis drifted spontaneously (Figure 13). Depending on the magnitude of the spontaneous drift from the corrected axis, cycles using the Mean Crossing Peak counting method could be missed while cycles using the Rain Flow counting method would be counted.
3. Combination of noise and deviation from the mean axis. With the combination of noise and the deviation from the mean axis, the mean for a cycle could be increased so that the tension part of the cycle was greater than the corrected mean. Therefore, while this cycle was counted using the Rain Flow method, it would not be counted using the Mean Crossing Peak method.

Since the Rain Flow Cycle counting method is an acceptable standard in the automobile industry as well as with researchers associated with highway research projects, more programs have been developed for this cycle counting method. The MEGADAC acquisition system will incorporate the Rain Flow Cycle counting method in its future software package. It is therefore recommended that in future testing the Rain Flow Cycle counting method be used in conjunction with the Mean Crossing Peak Cycle counting method as a comparison.

Cross Frame Analysis

With the assumption that 50% of the stress cycles have been experienced to date, gages G52, G73, G76, G95 under right lane and shoulder traffic conditions have remaining life of less than 20 years. These four gages are located on the web gap where the cross frame mates with the girder. Furthermore, this is the same location where the cantilever attaches to the outside of the girder. Therefore, when the traffic is located in the right lane and shoulder, the cantilever and girder should experience more loads than during normal traffic conditions. However, results could be skewed by the limited amount of data collected to date. Since most of these gages only have 2 to 5 hours worth of data, more data are required to accurately describe the true total fatigue life of the members. From these results, it would appear that the stresses in the web gap have been significantly reduced. For a measured equivalent stress range of approximately 2000 psi, the predicted fatigue life of these details is approximately 38.1 years.

List of References

1. 8 Span Continuous Welded Steel Girder. I 40 over Holston River and SR168. Knox County (47): Inspection Report BR#47-I40-25.92.

2. Deatherage, J. Harold. Proposal for the Investigation of the Fatigue Life of the I-40 Bridge over the Holston River Proposal. Knox County. State of Tennessee Department of Transportation Planning Division, March 17,1993.

3. Layout of Bridge I-40 Over Holston River and Station 786+15 Knox County: Drawing K-100-119. State of Tennessee Department of Highways. 1970.

4. Fisher, John W., Ti Huang, Lung-Yang Lai, and Ben T. Yen., Manual for Inspecting Bridges for Fatigue Damage Conditions. Lehigh University: Dept. of Civil Engineering #511-1, Report #FHWA-PA-89-022+85-02, January 1990.

5. Fisher, John W.., Inspecting Steel Bridges for Fatigue Damage. Lehigh University: Fritz Engineering Laboratory #386-15(81), Report # 72-3 FHWA/PA-81/005, March 1981.

6. Optim Corporation, Technical Manual for the Megadac Series 3000. Optim Corporation, Release 1.0 May 1982.

7. Fisher, J.W..,B.T. Yen, D. Wang, and J.E. Mann. Fatigue and Fracture Evaluation for Rating Riveted Bridges. Fritz Engineering Laboratory #499.3, Bethlehem. PA 1988; NCHRP Report No. 302, Transportation Research Board, December 1987.

8. Fisher, J.W..,B.T. Yen, and D. Wang. Fatigue of Bridge Structures- A Commentary and Guide for Design. Evaluation and Investigation of Cracking. ATLSS Report No. 89-02, NSF-ERC Advanced Technology for Large Structural Systems, Lehigh University, Federal Highway Administration Research Report FHWA-RD-89-167.

9. American Association of State Highway and Transportation Officials, AASHTO Standard Specifications for Highway Bridges. 14th Edition, 1989.

10. Moses,F., C.G. Schilling, and K.S. Raju, Fatigue Evaluation Procedures for Steel Bridges. NCHRP Report No. 299, Transportation Research Board December 1987.

11. Dowling, N.E., Fatigue Failure Predictions for Complicated Stress-Strain Histories. Journal of Materials, JMLSA, Vol. 7, No 1 March 1972, pp71-87.

12. Sanders, M.D., "Controlled Load Tests on a Four Girder Steel Bridge". Masters Thesis, The University of Tennessee, Knoxville TN, May 1994.

APPENDIX-A

Stress/Cycle Data

TABLE A-1 : Normal Traffic results: Gages G1 to G8

	Gage No.							
Stress Range (psi)	G1	G2	G3	G4	G5	G6	G7	G8
500-1000			3	111	727	1	83	137
1000-1500				32	203		7	19
1500-2000				22	91			3
2000-2500				5	36			
2500-3000				1	10			
3000-3500					1			
Time (Hr.)	0.56	0.56	3.13	0.56	3.13	0.56	0.56	0.56
Eqv. Stress	0	0	750	1213	1200	750	814.8	887.1

TABLE A-2 : Normal Traffic results: Gages G9 to G15

	Gage No.							
Stress Range (psi)	G9	G10	G11	G12	G13	G13A	G14	G15
500-1000	39	123	78	94	237		58	144
1000-1500		7	32	38	12		5	18
1500-2000			20	25				
2000-2500			1	3				
Time (Hr.)	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Eqv. Stress	750	796	1178	1208	791.4	0	816	839.7

TABLE A-3 : Normal Traffic results: Gages G16 to G25

	Gage No.							
Stress Range (psi)	G16	G17	G18	G19	G20	G23	G24	G25
500-1000	603	54	68	521	181	299	168	436
1000-1500	41	1	1	49	40	75		162
1500-2000	13			23	12	12		67
2000-2500	0			5				26
2500-3000	1							5
3000-3500								2
Time (Hr.)	0.56	0.56	0.56	0.56	0.56	2.57	2.57	2.57
Eqv. Stress	864.4	766.1	762.9	939.4	979.3	955.7	750	1239

TABLE A-4 : Normal Traffic results: Gages G26 to G56

	Gage No.							
Stress Range (psi)	G26	G27	G28	G31	G40	G51	G55	G56
500-1000	302		2	167	17	40	19	1
1000-1500	48			38		4	0	
1500-2000	1			23		8	1	
2000-2500				6		3		
2500-3000						3		
Time (Hr.)	2.57	0.56	0.56	0.56	0.12	0.12	2.35	2.35
Eqv. Stress	864.2	0	750	1128	750	1414	874.5	750

TABLE A-5 : Normal Traffic results: Gages G57 to G68

	Gage No.							
Stress Range (psi)	G57	G58	G59	G60	G61	G63	G67	G68
500-1000		456	410	945	742	342	711	461
1000-1500		199	197	150	242	45	15	13
1500-2000		115	131	8	37	1	0	
2000-2500		32	37				0	
2500-3000		13	11				0	
3000-3500		2	2				1	
Time (Hr.)	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
Eqv. Stress	0	1325	1359	873.3	987.8	849.1	793.8	774.1

TABLE A-6 : Normal Traffic results: Gages G71 to G79

	Gage No.							
Stress Range (psi)	G71	G72	G73	G74	G75	G76	G78	G79
500-1000	450	205	534	425	138	779	1	609
1000-1500	3	2	93	181	42	149		238
1500-2000			82	153		167		32
2000-2500			55	64		112		1
2500-3000			20	34		48		
3000-3500			10	5		12		
3500-4000			3	1		7		
4000-4500			2			1		
4500-5000						1		
Time (Hr.)	2.35	2.35	1.08	2.35	1.27	2.35	2.35	2.35
Eqv. Stress	756	758.7	1471	1517	920.2	1550	750	1009

TABLE A-7 : Normal Traffic results: Gages G81 to G94

	Gage No.							
Stress Range (psi)	G81	G82	G83	G84	G88	G89	G93	G94
500-1000	3667	336	641	315	795	582	307	170
1000-1500	198	115	230	24	24	38	11	1
1500-2000	40	55	130			4		
2000-2500	3	17	21					
2500-3000	1	5	5					
3000-3500		1	1					
3500-4000								
4000-4500								
Time (Hr.)	2.35	1.08	2.35	2.35	2.35	2.35	2.35	2.35
Eqv. Stress	826	1234	1204	809.4	775.7	817.72	780.2	755.27

TABLE A-8 : Normal Traffic results: Gages G95 to G102

	Gage No.							
Stress Range (psi)	G95	G96	G97	G98	G99	G100	G101	G102
500-1000	1336	457	440	1467	6		487	6
1000-1500	252	140	168	252			10	
1500-2000	136	53	73	215			1	
2000-2500	136	5	9	86			1	
2500-3000	110		1	28				
3000-3500	37			8				
3500-4000	13			2				
4000-4500	11							
4500-5000	2							
5000-5500	1							
Time (Hr.)	2.35	2.35	2.35	2.35	2.35	2.35	2.57	2.57
Eqv. Stress	1628.3	1072.1	1141.7	1269	750	0	785.4	750

TABLE A-9 : Normal Traffic results: Gages G103 to G110

	Gage No.							
Stress Range (psi)	G103	G104	G105	G106	G107	G108	G109	G110
500-1000	15	1614	10071	5185	3285	2275	1850	4670
1000-1500		77	5120	769	578	356	319	733
1500-2000		4	2788	170	200	134	125	224
2000-2500			1116	47	100	62	47	80
2500-3000			471	30	69	19	19	71
3000-3500			238	17	60	2	3	72
3500-4000			160	7	24	1		68
4000-4500			112	2	9			55
4500-5000			76	1	5			16
5000-5500			84		1			11
5500-6000			81					5
6000-6500			57					5
6500-7000			47					1
7000-7500			48					1
7500-8000			26					
8000-8500			30					
8500-9000			27					
9000-9500			19					
9500-10000			27					
10000-10500			12					
10500-11000			7					
11000-11500			5					
11500-12000			3					
12000-12500			0					
12500-13000			3					
13000-13500			1					
Time (Hr.)	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Eqv. Stress	750	795.33	2409	1038.4	1358.5	1080.7	1095.5	1573.8

TABLE 10: Normal Traffic results: Gages G111 to G118

	Gage No.							
Stress Range (psi)	G111	G112	G113	G114	G115	G116	G117	G118
500-1000	756	2109	6954	6956	3273	1320	764	925
1000-1500	94	195	1344	592	217	217	153	131
1500-2000	5	52	322	184	31	113	102	117
2000-2500	1	29	125	90	4	38	45	53
2500-3000		5	92	29		12	6	24
3000-3500		1	62	6		2	1	2
3500-4000			53					
4000-4500			17					
4500-5000			7					
5000-5500			3					
Time (Hr.)	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Eqv. Stress	858.02	945.02	1261.7	958.15	830.11	1111.5	1197.6	1250

TABLE A-11 : Middle & Left Lane Traffic results: Gages G4 to G16

	Gage No.							
Stress Range (psi)	G4	G10	G11	G12	G13	G14	G15	G16
500-1000	730	197	581	106	185	74	155	344
1000-1500	102	17	18241	51	22	8	42	96
1500-2000	13	53	1108	54				22
2000-2500	0		25	5				23
2500-3000	1		8	1				8
3000-3500	1		1					1
Time (Hr.)	2.57	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Eqv. Stress	907	1144.6	1284.3	1330.8	836.16	829.75	907.89	1227.3

TABLE A-12 : Middle & Left Lane Traffic results: Gages G30 to G43

	Gage No.							
Stress Range (psi)	G30	G32	G33	G34	G35	G37	G41	G43
500-1000	2422	125	286	1372	364	1254	818	4240
1000-1500	241	1	0	13	1	222	207	458
1500-2000	24	2	1	2		17	7	292
2000-2500	0	0	0				2	59
2500-3000	0	1	0					5
3000-3500	1		1					0
3500-4000								1
4000-4500								0
4500-5000								1
Time (Hr.)	2.16	4.73	4.73	4.73	4.73	4.73	2.16	3.72
Eqv. Stress	850.8	874.3	822.66	762.51	752.48	890.34	921.72	1008.4

TABLE A-13 : Middle & Left Lane Traffic results: Gages G44 to G53

	Gage No.							
Stress Range (psi)	G44	G45	G50	G51	G51A	G52	G52A	G53
500-1000	799	174	317	2015	2213	3618	2248	1087
1000-1500	7	37	2	510	336	807	558	215
1500-2000		7	0	134	33	433	317	15
2000-2500			1	13	0	129	165	4
2500-3000				4	1	33	69	
3000-3500				0	2	5	9	
3500-4000				1	1	1	2	
4000-4500						1	1	
Time (Hr.)	4.73	0.71	4.73	4.73	4.73	4.73	4.73	4.73
Eqv. Stress	757.8	943.65	775.13	1020.9	903.76	1161.6	1308.2	912.7

TABLE A-14 : Middle & Left Lane Traffic results: Gages G54 to G67

	Gage No.							
Stress Range (psi)	G54	G54A	G58	G60	G61	G62	G63	G67
500-1000	466	945	1371	3735	1134	1573	559	2619
1000-1500	11	252	372	92	27	7	5	108
1500-2000	0	116	36	13	1	2	2	
2000-2500	1	47	2	0	0	1	1	
2500-3000	0	5	0	0	1	0	1	
3000-3500	0	2	1	0		0	1	
3500-4000	0	0	1	1		0		
4000-4500	2	0				1		
4500-5000		0						
5000-5500		0						
5500-6000		1						
Time (Hr.)	2.57	2.16	5.69	5.69	3.13	5.69	5.69	3.13
Eqv. Stress	927.51	1207.9	966.1	787.8	782.5	788.4	827.9	784.3

TABLE A-15 : Middle & Left Lane Traffic results: Gages G68 to G75

	Gage No.							
Stress Range (psi)	G68	G69	G70	G71	G72	G73	G74	G75
500-1000	708	2817	8660	742	307	2153	1189	2054
1000-1500	96	40	935	17		654	532	630
1500-2000	19	4	389			350	121	204
2000-2500	8	1	24			68	6	15
2500-3000	8	1	5			9	1	2
3000-3500	1	0	2					0
3500-4000	2	2						1
4000-4500		0						0
4500-5000		0						1
5000-5500		1						
Time (Hr.)	3.61	5.69	5.69	3.13	3.13	5.69	5.69	5.69
Eqv. Stress	1053.8	818.29	928.26	769.8	750	1158.1	1072.1	1070.1

TABLE A-16 : Middle & Left Lane Traffic results: Gages G76 to G89

	Gage No.							
Stress Range (psi)	G76	G79	G80	G81	G83	G84	G88	G89
500-1000	1714	1447	677	9469	763	153	2289	843
1000-1500	595	16	4	512	227	1	142	157
1500-2000	359	0		66	20	0	1	5
2000-2500	58	1		6	1	0		
2500-3000	8			4		0		
3000-3500	1					1		
3500-4000	1							
Time (Hr.)	5.69	3.13	3.13	2.08	3.13	2.08	3.06	3.06
Eqv. Stress	1199.6	764.09	755.29	817.77	956.18	866.46	800.68	881.79

TABLE A-17 : Middle & Left Lane Traffic results: Gages G90 to G98

	Gage No.							
Stress Range (psi)	G90	G91	G93	G94	G95	G96	G97	G98
500-1000	1564	5292	319	409	1285	533	563	1095
1000-1500	25	524	6	2	373	32	52	401
1500-2000		235	1	1	278		0	197
2000-2500		34			113		1	30
2500-3000		5			30			
3000-3500					2			
Time (Hr.)	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
Eqv. Stress	764.01	936.8	774.84	761.33	1315.8	798.23	828.62	1153.2

TABLE A-18 : Middle & Left Lane Traffic results: Gages G105 to G112

	Gage No.							
Stress Range (psi)	G105	G106	G107	G108	G109	G110	G111	G112
500-1000	9028	4603	2625	1979	2399	3587	763	2151
1000-1500	3339	621	822	504	614	929	234	339
1500-2000	1918	285	309	205	184	382	35	271
2000-2500	941	202	133	58	68	174	1	83
2500-3000	648	183	120	19	20	103	1	18
3000-3500	382	56	64	4	4	82	0	2
3500-4000	264	27	47		1	97	0	1
4000-4500	180	8	36			68	1	1
4500-5000	106		10			34		
5000-5500	95		4			32		
5500-6000	39					19		
6000-6500	33					9		
6500-7000	18					1		
7000-7500	6					1		
7500-8000	5							
8000-8500	3							
8500-9000	4							
9000-9500	4							
9500-10000	3							
10000-10500	1							
10500-11000	2							
11000-11500	1							
Time (Hr.)	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16
Eqv. Stress	2073.3	1350.7	1612	1140.8	1116.4	1892.8	1012.9	1165.7

TABLE A-19 : Middle & Left Lane Traffic results: Gages G114 to G201

	Gage No.							
Stress Range (psi)	G114	G115	G116	G117	G201			
500-1000	5476	2412	1781	1110	772			
1000-1500	523	426	314	244	232			
1500-2000	187	104	194	57	55			
2000-2500	165	19	57	1	7			
2500-3000	102	2	39		0			
3000-3500	24		2		1			
3500-4000	10		1					
Time (Hr.)	2.16	2.16	2.16	2.16	2.57			
Eqv. Stress	1143	965.28	1186.2	963.18	1036.4			

TABLE A-20 : Right Lane & Shoulder Traffic results: Gages G1 to G10

	Gage No.							
Stress Range (psi)	G1	G2	G3	G5	G6	G7	G9	G10
500-1000	101	135	1	479	38	344	53	194
1000-1500	1	4		131	0	113		1
1500-2000				126	1	8		
2000-2500				92		2		
2500-3000				34				
3000-3500				15				
3500-4000				4				
Time (Hr.)	1.58	1.58	1.58	1.58	1.58	1.58	1.58	0.92
Eqv. Stress	758.79	775.25	750	1600.8	818.56	973.98	750	754.62

TABLE A-21 : Right Lane & Shoulder Traffic results: Gages G11 to G23

	Gage No.							
Stress Range (psi)	G11	G14	G15	G17	G18	G19	G20	G23
500-1000	184	115	154	145	257	484	284	179
1000-1500	197	1	73	2	5	160	150	95
1500-2000	1		11	1	0	95	91	22
2000-2500			1		0	62	23	2
2500-3000					0	28	6	
3000-3500					1	11	1	
3500-4000						2		
Time (Hr.)	1.57	0.92	0.92	1.58	1.58	1.58	1.58	1.24
Eqv. Stress	1069.8	757.74	1051.5	780.75	833.91	1492.2	1335.4	1104.7

TABLE A-22 : Right Lane & Shoulder Traffic results: Gages G24 to G32

	Gage No.							
Stress Range (psi)	G24	G25	G26	G27	G28	G29	G31	G32
500-1000	140	295	165	4	104	2	430	451
1000-1500	32	71	82	1	0	0	154	65
1500-2000	2	67	11	0	0	1	186	4
2000-2500		37	1	0	0		93	
2500-3000		18		1	1		31	
3000-3500		3					5	
3500-4000		0					5	
4000-4500		1						
Time (Hr.)	1.24	1.24	1.24	2.16	2.16	2.16	2.16	2.16
Eqv. Stress	912.68	1480.9	1050.3	1597	850.83	1274	1587.7	866.8

TABLE A-23 : Right Lane & Shoulder Traffic results: Gages G33 to G46

	Gage No.							
Stress Range (psi)	G33	G36	G37	G41	G42	G44	G45	G46
500-1000	457	312	282	192	367	549	245	824
1000-1500	221	6	90	14	350	13	100	106
1500-2000	6		108		38		15	86
2000-2500			86		2			26
2500-3000			113		3			12
3000-3500			50					1
3500-4000			12					
Time (Hr.)	2.16	2.16	2.16	0.84	2.16	2.16	1.24	1.24
Eqv. Stress	986.5	766.74	2068	807.2.9	1140	770.4	1017.3	1147.9

TABLE A-24 : Right Lane & Shoulder Traffic results: Gages G47 to G52A

	Gage No.							
Stress Range (psi)	G47	G48	G49	G50	G51	G51A	G52	G52A
500-1000	399	590	181	348	687	521	1443	1013
1000-1500	73	85	104	3	191	93	235	205
1500-2000	63	57	26		165	38	139	94
2000-2500	41	49	3		111	40	97	69
2500-3000	14	37			67	37	94	65
3000-3500	4	17			27	15	42	57
3500-4000	1	7			2	12	45	50
4000-4500	1	2			3	4	43	37
4500-5000		1			2	1	29	24
5000-5500		0				1	8	9
5500-6000		1					4	4
6000-6500							2	2
6500-7000							2	0
7000-7500							1	1
7500-8000								1
Time (Hr.)	1.24	1.24	1.24	2.16	2.16	1.90	2.16	1.89
Eqv. Stress	1410.8	1597.9	1129.9	757.7	1654	1668	2038	2179

TABLE A-25 : Right Lane & Shoulder Traffic results: Gages G53 to G58

	Gage No.							
Stress Range (psi)	G53	G53A	G54	G54A	G55	G56	G57	G58
500-1000	349	210	291	1032	130	0	1	282
1000-1500	162	7	94	162	37	1		107
1500-2000	178	2	11	88	0			96
2000-2500	97	0	2	70	0			39
2500-3000	6	1		77	1			14
3000-3500	4			65				0
3500-4000	2			33				2
4000-4500				6				
4500-5000				4				
5000-5500				1				
5500-6000				0				
6000-6500				1				
Time (Hr.)	2.16	1.90	1.51	1.90	1.26	1.26	1.26	1.26
Eqv. Stress	1536	847.21	991.6	1793	958.43	1250	750	1461

TABLE A-26 : Right Lane & Shoulder Traffic results: Gages G60 to G71

	Gage No.							
Stress Range (psi)	G60	G62	G63	G64	G67	G68	G69	G71
500-1000	326	230	76	218	324	128	250	151
1000-1500	73	161		2	5	2	144	2
1500-2000	5	5		1	1	1	26	0
2000-2500	1	5		1		1	5	0
2500-3000								1
Time (Hr.)	1.26	1.26	1.26	1.05	1.26	0.61	1.26	1.26
Eqv. Stress	922.8	1073	750	770.9	772	827	1111	831.1

TABLE A-27 : Right Lane & Shoulder Traffic results: Gages G72 to G82

	Gage No.							
Stress Range (psi)	G72	G73	G74	G76	G78	G80	G81	G82
500-1000	95	528	117	478	9	331	948	574
1000-1500	2	110	73	90	3	246	177	186
1500-2000	0	75	69	77	1	20	143	166
2000-2500	0	65	40	61	0	4	47	46
2500-3000	1	49	10	60	1	2	7	10
3000-3500		31	0	25	2		3	2
3500-4000		9	2	8	1			
4000-4500		1		1				
4500-5000		0		0				
5000-5500		1		2				
Time (Hr.)	1.26	1.26	0.83	1.26	1.84	1.84	1.84	1.84
Eqv. Stress	871.1	1712	1623	1761	2099	1105	1201	1326.3

TABLE A-28 : Right Lane & Shoulder Traffic results: Gages G85 to G96

	Gage No.							
Stress Range (psi)	G85	G88	G89	G90	G93	G94	G95	G96
500-1000	343	491	357	340	216	281	944	403
1000-1500	8	14	38	179	7	14	210	208
1500-2000	2			52	2		110	39
2000-2500				9	0		102	4
2500-3000				5	0		107	
3000-3500				2	1		57	
3500-4000							25	
4000-4500							16	
4500-5000							6	
5000-5500							0	
5500-6000							0	
6000-6500							1	
Time (Hr.)	1.84	1.84	1.84	1.28	1.84	1.84	1.84	1.84
Eqv. Stress	785.44	774.4	828.7	1213	871.99	790.8	1861.3	1083

TABLE A-29 : Right Lane & Shoulder Traffic results: Gages G97 to G104

	Gage No.							
Stress Range (psi)	G97	G98	G99	G100	G101	G102	G103	G104
500-1000	422	988	190	4	149			222
1000-1500	140	215	12		4			53
1500-2000	72	168						3
2000-2500	4	121						1
2500-3000		37						
3000-3500		14						
3500-4000		2						
Time (Hr.)	1.84	1.84	1.84	1.84	1.24	1.24	1.24	1.24
Eqv. Stress	1114.4	1425	800.44	750	773	0	0	930.31

TABLE A-30 : Right Lane & Shoulder Traffic results: Gages G105 to G112

	Gage No.							
Stress Range (psi)	G105	G106	G107	G108	G109	G110	G111	G112
500-1000	4300	1091	1382	670	801	1915	36	369
1000-1500	1643	155	170	103	107	295		57
1500-2000	566	89	74	68	84	96		11
2000-2500	153	24	28	29	26	54		
2500-3000	45	5	8	7	13	31		
3000-3500	20	1	5	2	4	29		
3500-4000	18		1	1		26		
4000-4500	12					18		
4500-5000	12					4		
5000-5500	18					3		
5500-6000	17					0		
6000-6500	15					1		
6500-7000	12							
7000-7500	19							
7500-8000	9							
8000-8500	20							
8500-9000	12							
9000-9500	3							
9500-10000	7							
10000-10500	3							
10500-11000	0							
11000-11500	1							
Time (Hr.)	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Eqv. Stress	2184.5	1065.6	1066.1	1179.9	1180.1	1480	750	906.9

TABLE A-31 : Right Lane & Shoulder Traffic results: Gages G113 to G201

	Gage No.							
Stress Range (psi)	G113	G114	G115	G116	G117	G118	G201	
500-1000	2568	1858	674	530	190	272	437	
1000-1500	280	88	73	89	113	59	81	
1500-2000	67	5	38	19	26	3	47	
2000-2500	17	0	19	1	1		46	
2500-3000		0	2	1			21	
3000-3500							8	
3500-4000							1	
4000-4500							0	
4500-5000							1	
Time (Hr.)	1.24	1.24	1.24	1.24	1.24	1.24	1.24	
Eqv. Stress	906.35	795.6	1033.1	939.92	1110.2	903.16	1458	

APPENDIX-B
Location of Strain Gages

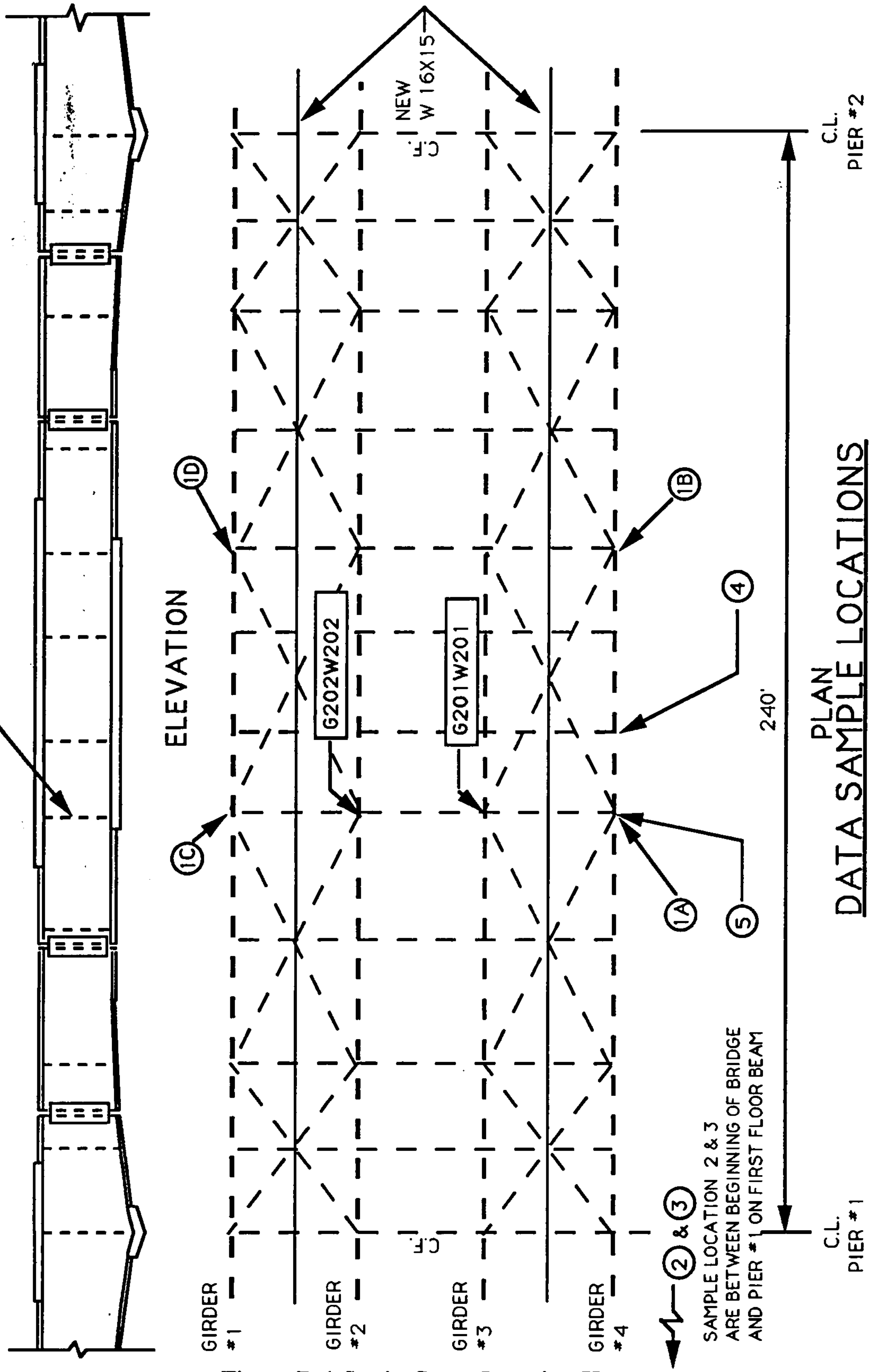


Figure B-1 Strain Gages Location Key

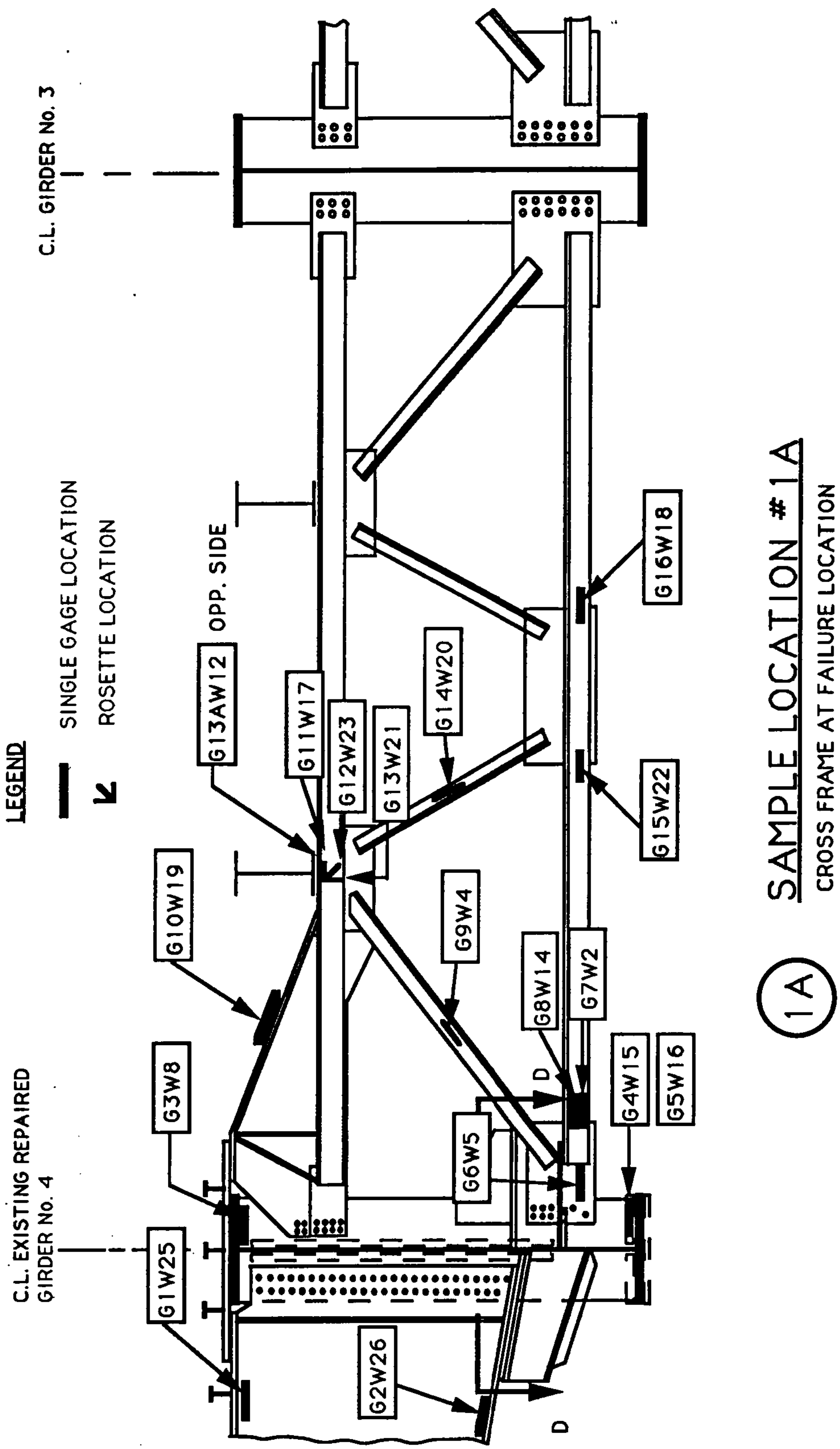


Figure B-2 Location of Strain Gages 1-16

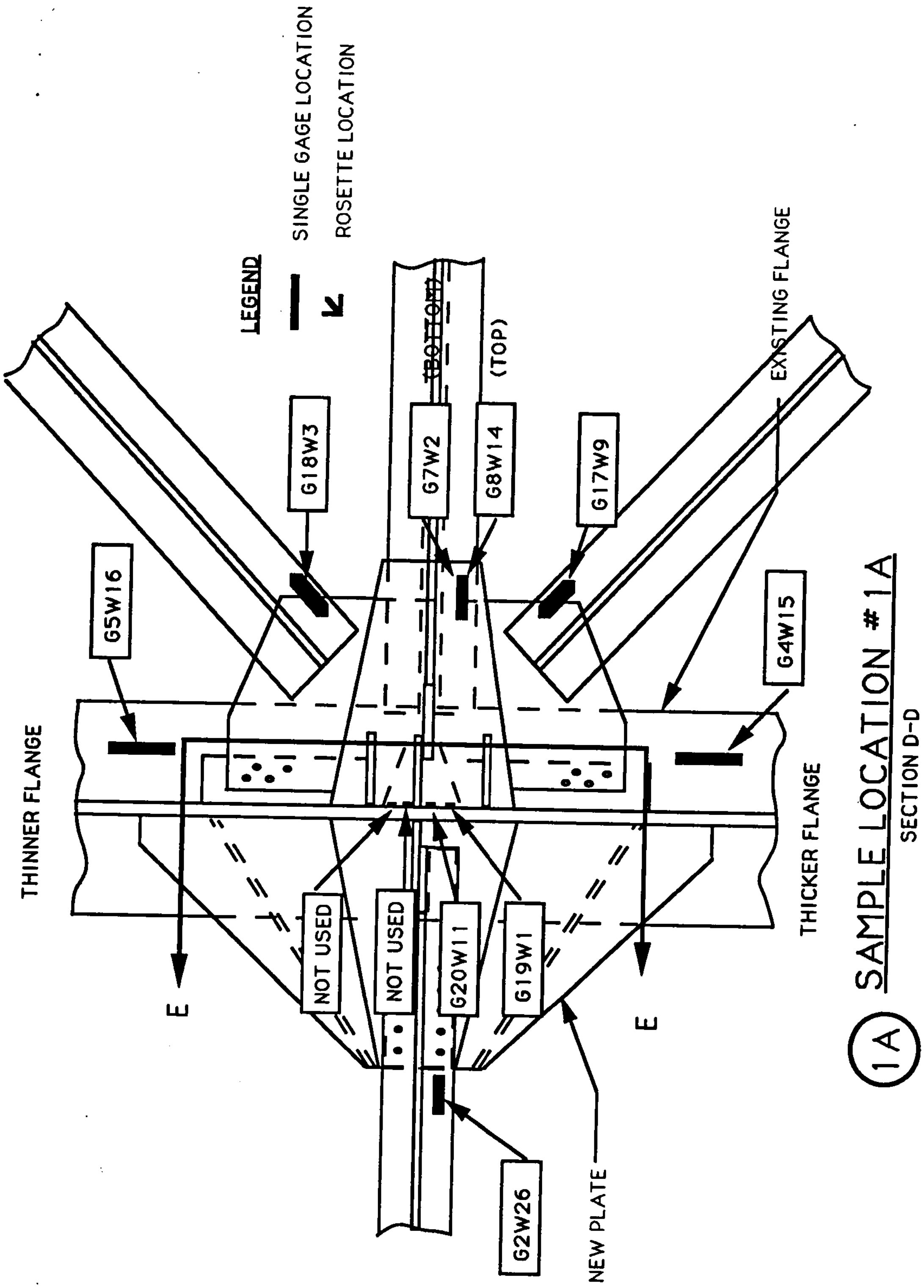


Figure B-3 Detail Location of Strain Gages 2-20

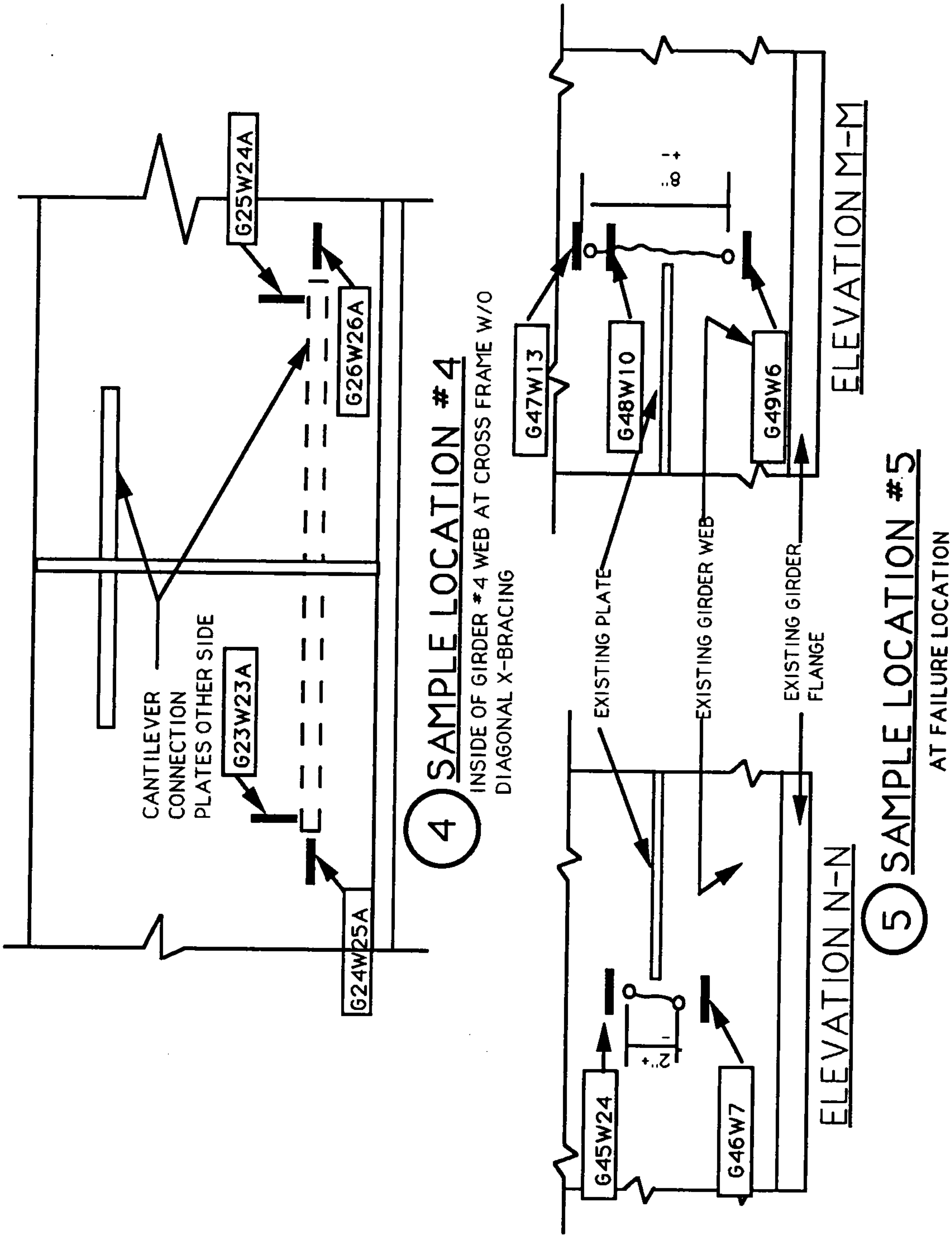


Figure B-4 Detail Location of Strain Gages 23-49

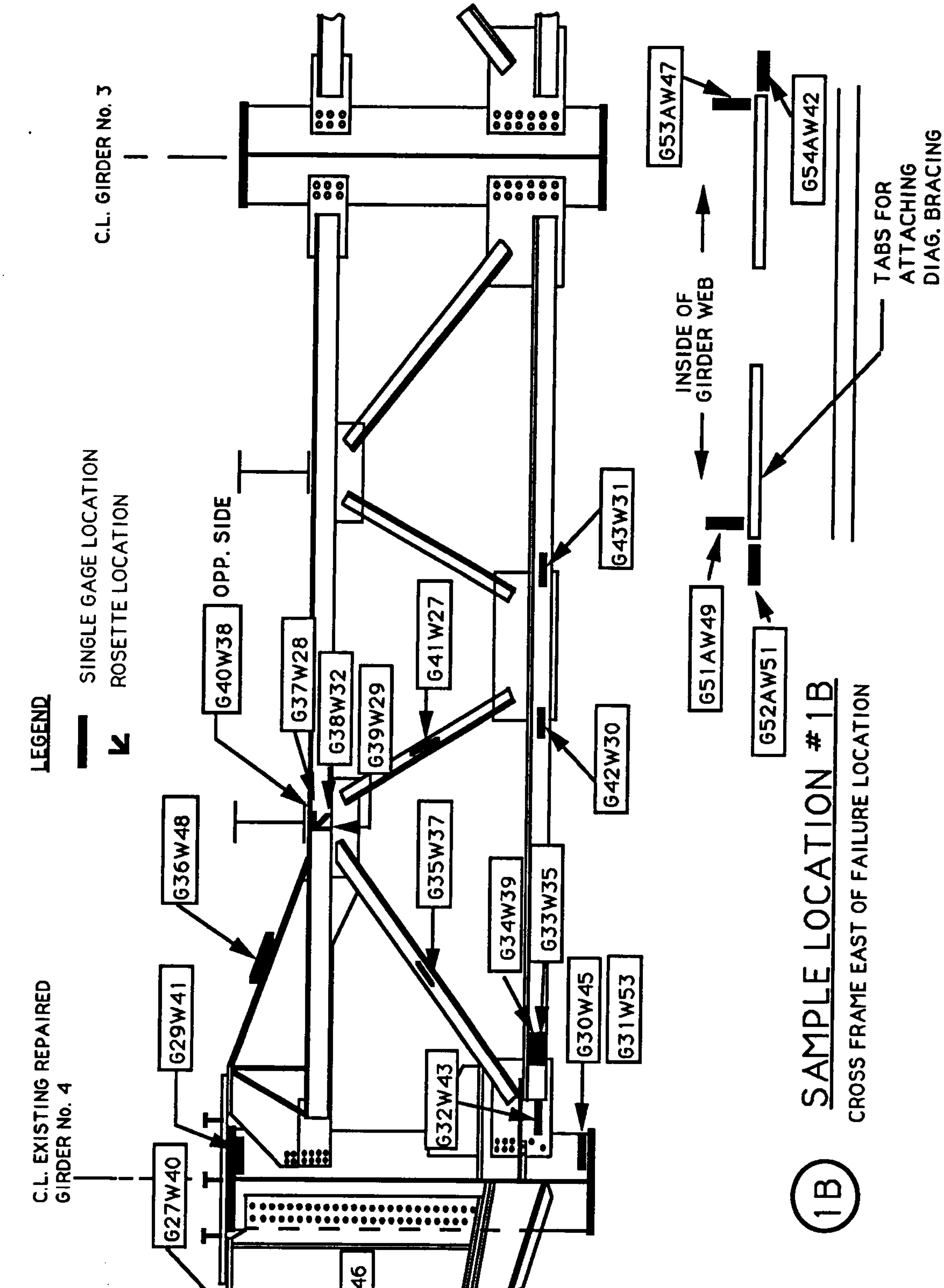


Figure B-5 Location of Strain Gages 27-54

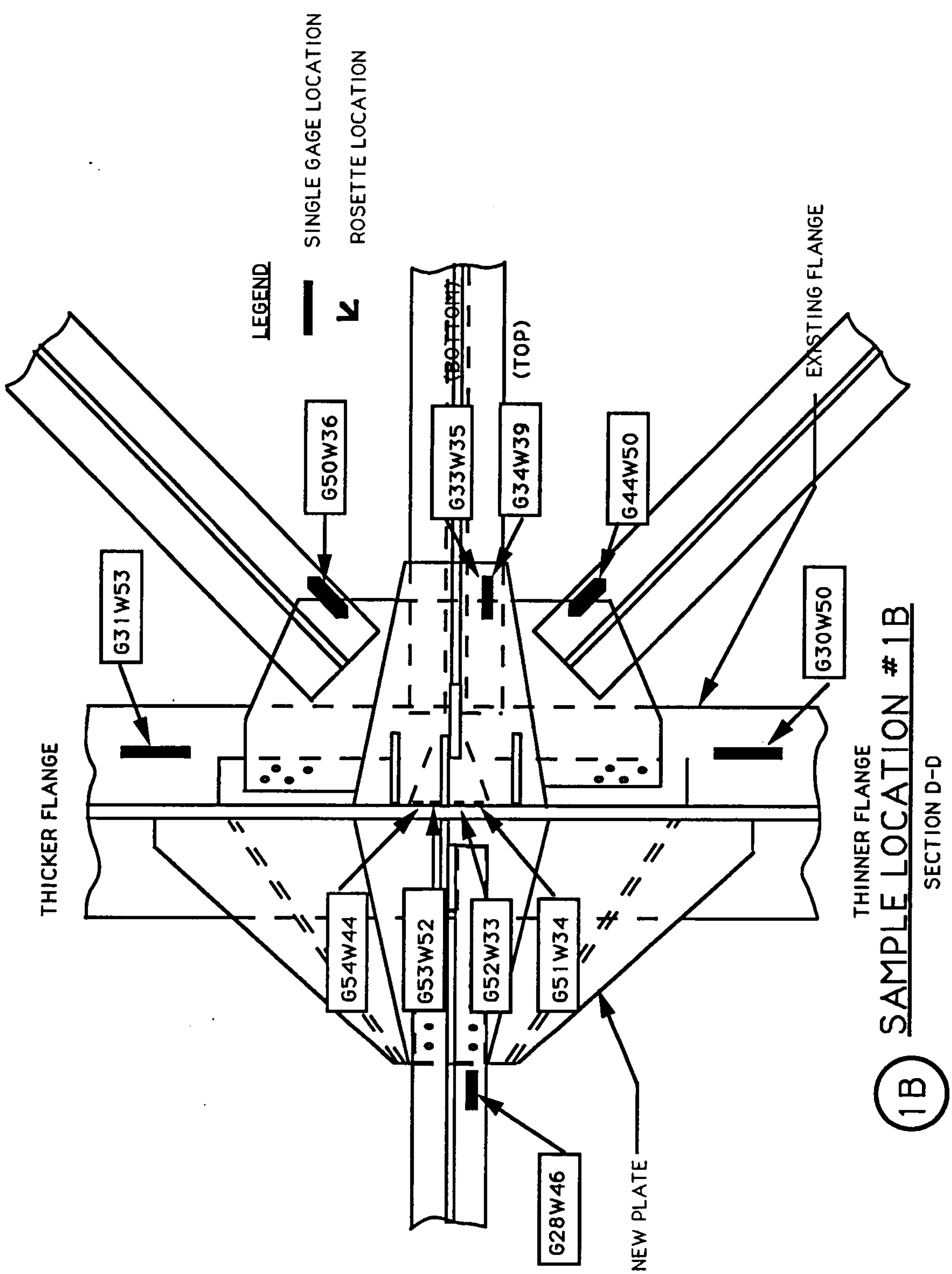


Figure B-6 Detail Location of Strain Gages 28-54

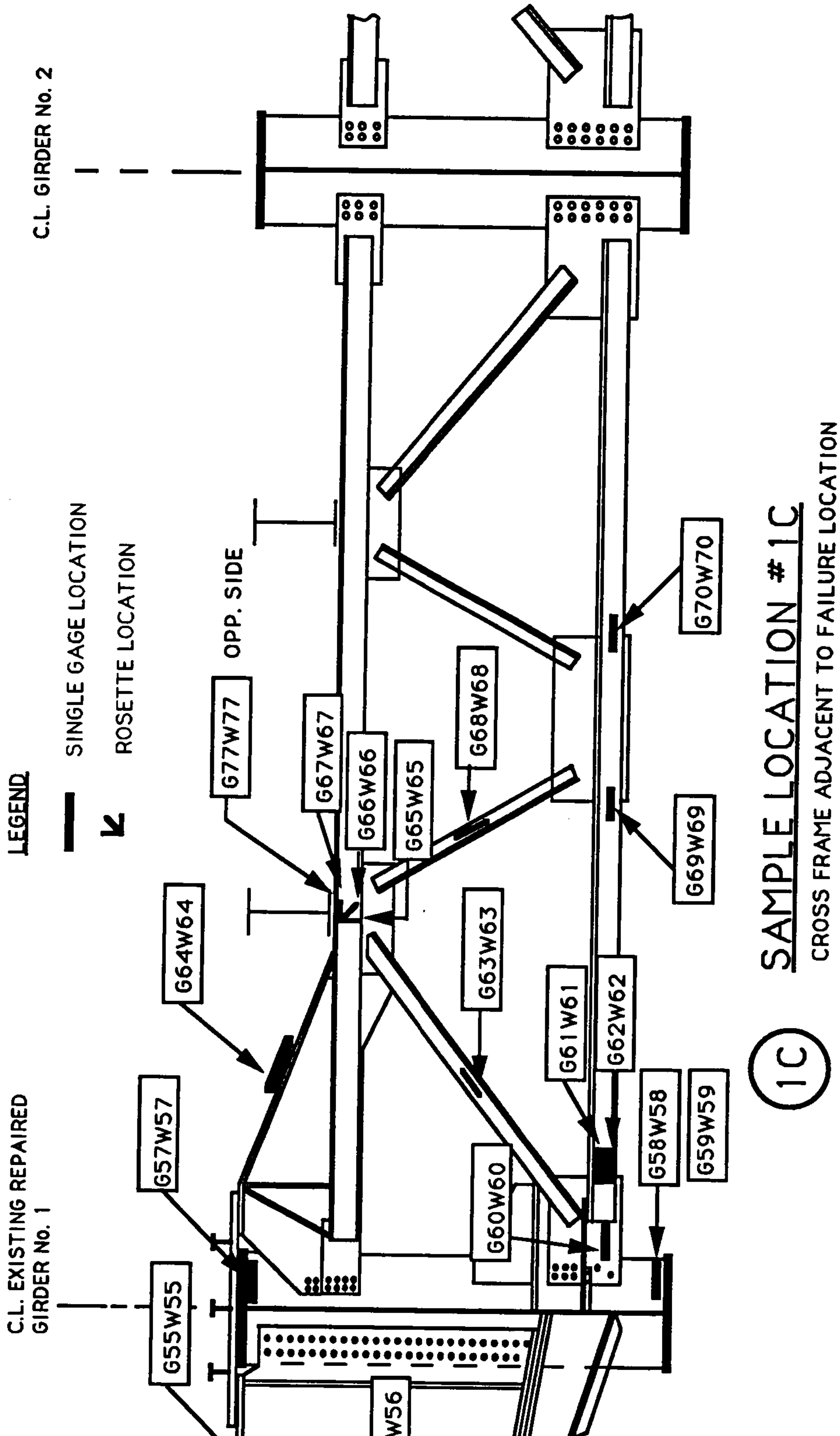


Figure B-7 Location of Strain Gages 55-70

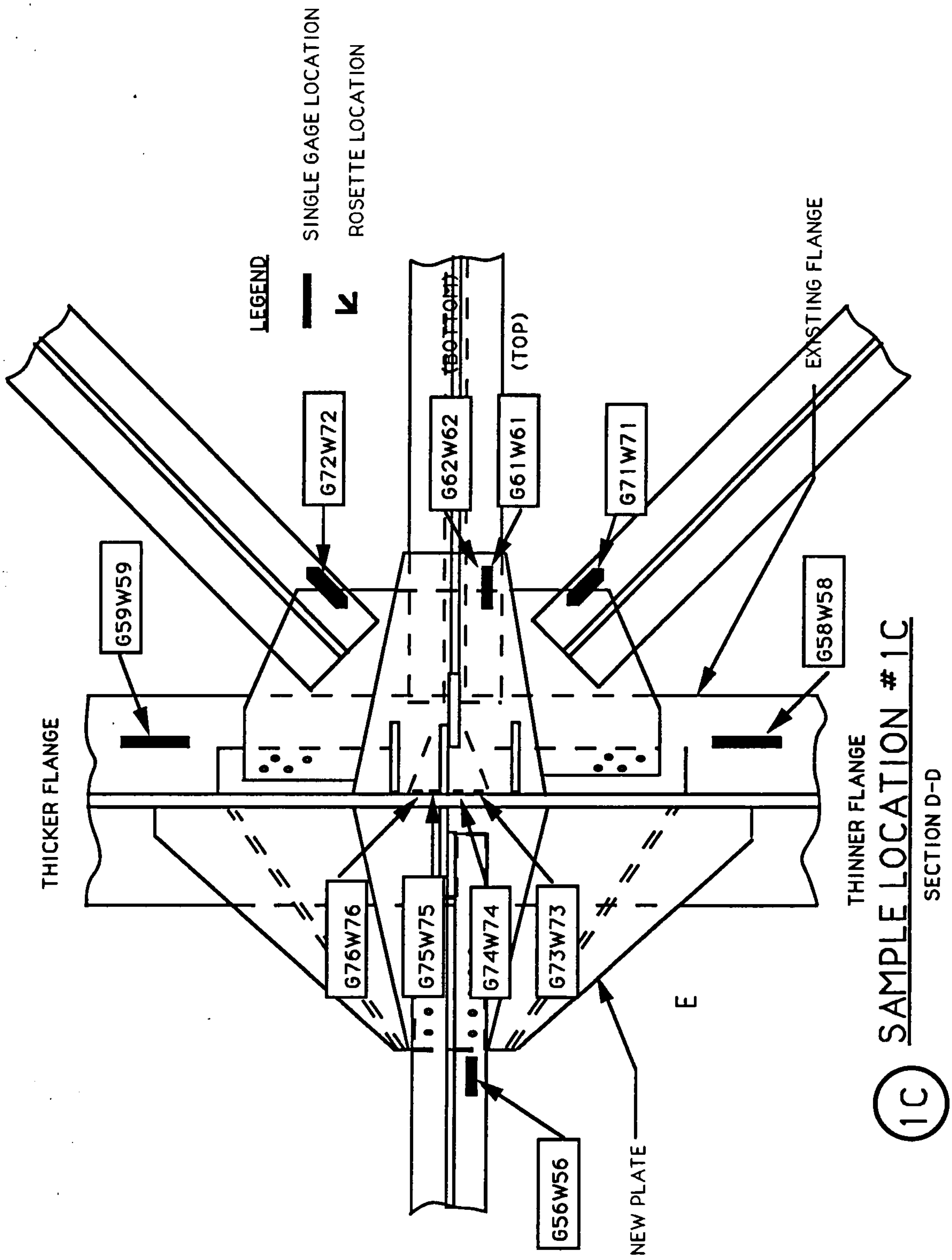


Figure B-8 Detail Location of Strain Gages 56-76

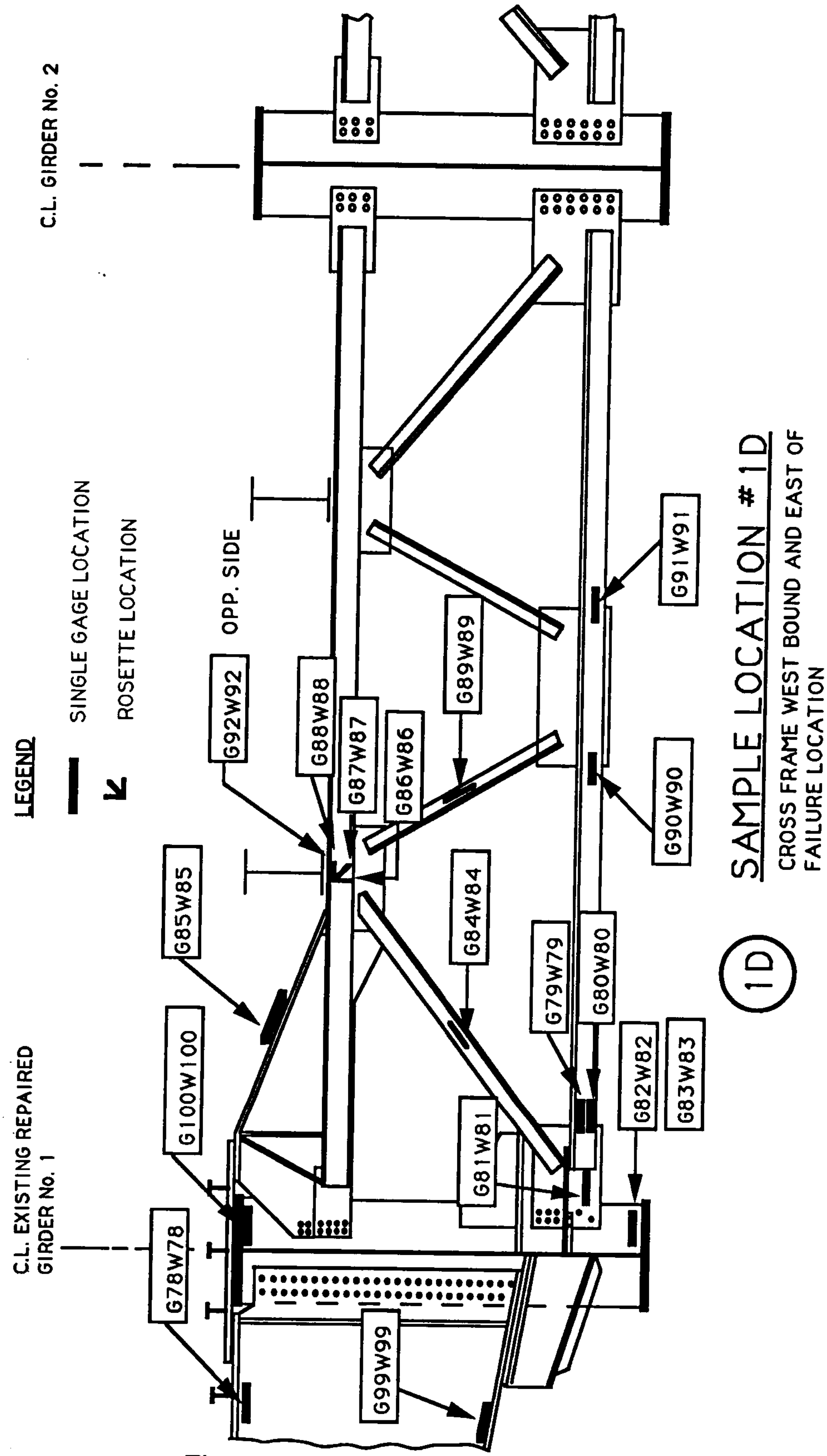


Figure B-9 Location of Strain Gages 78-100

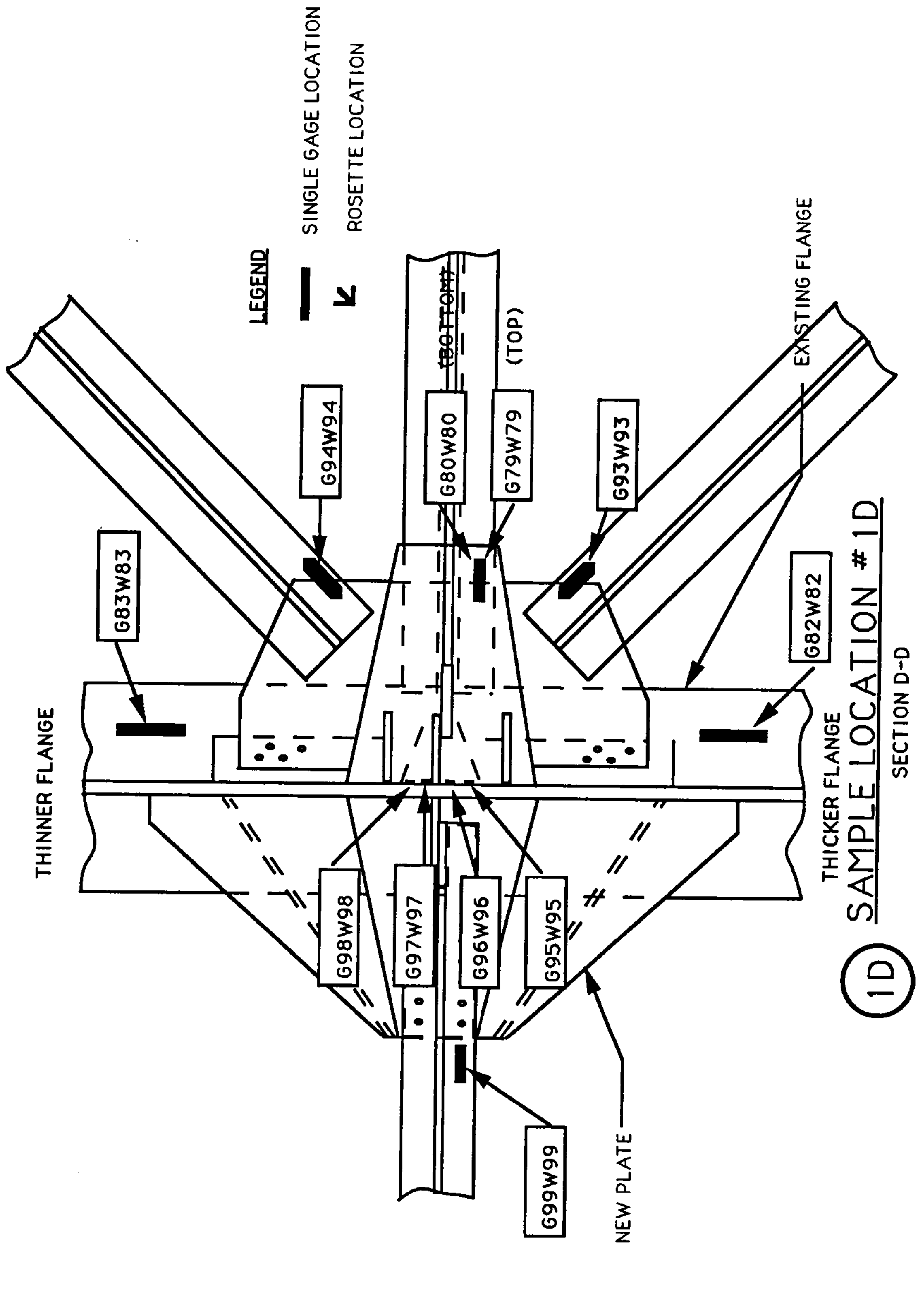


Figure B-10 Detail Location of Strain Gages 80-99

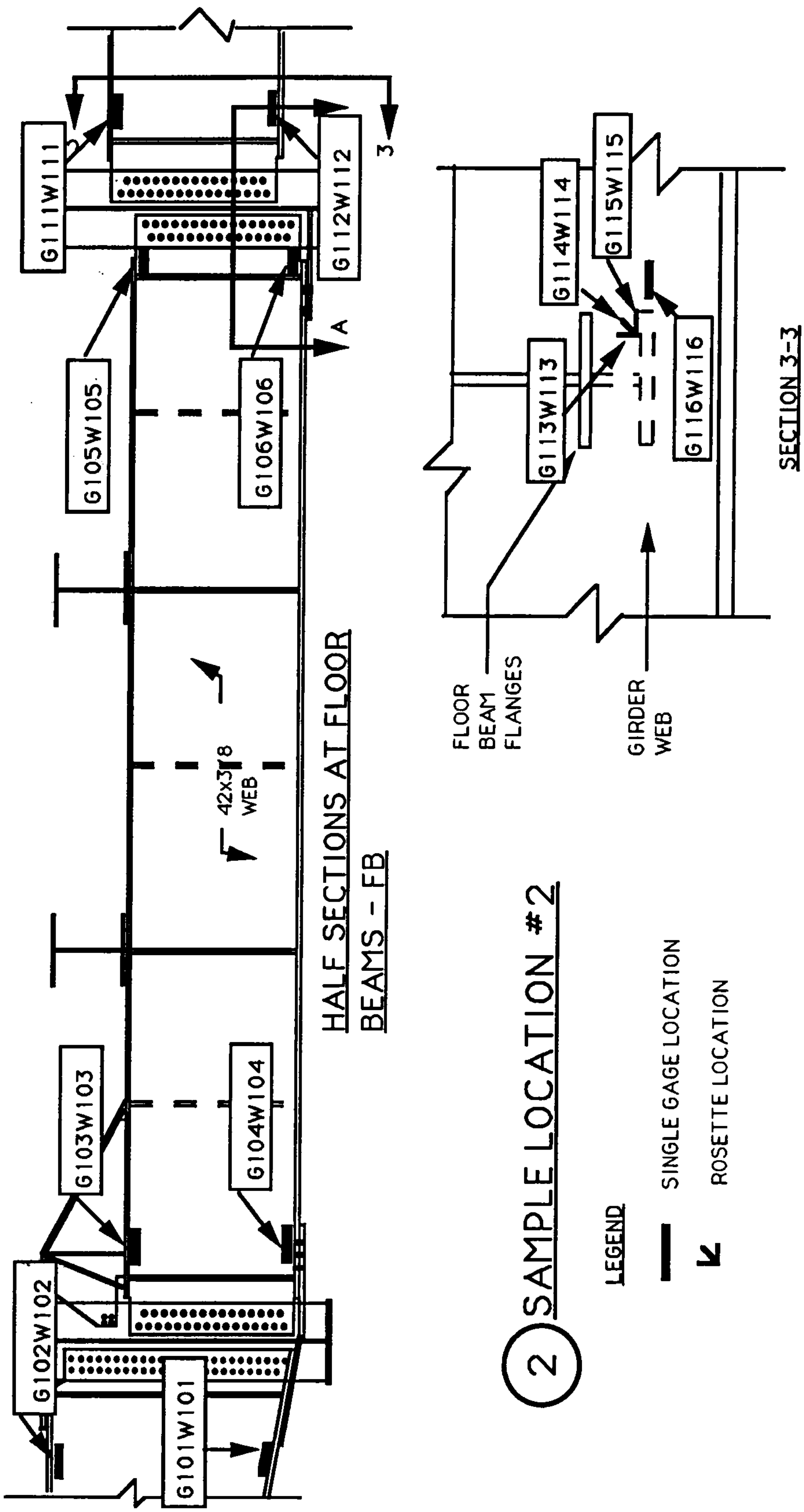


Figure B-11 Location of Strain Gages 101-116

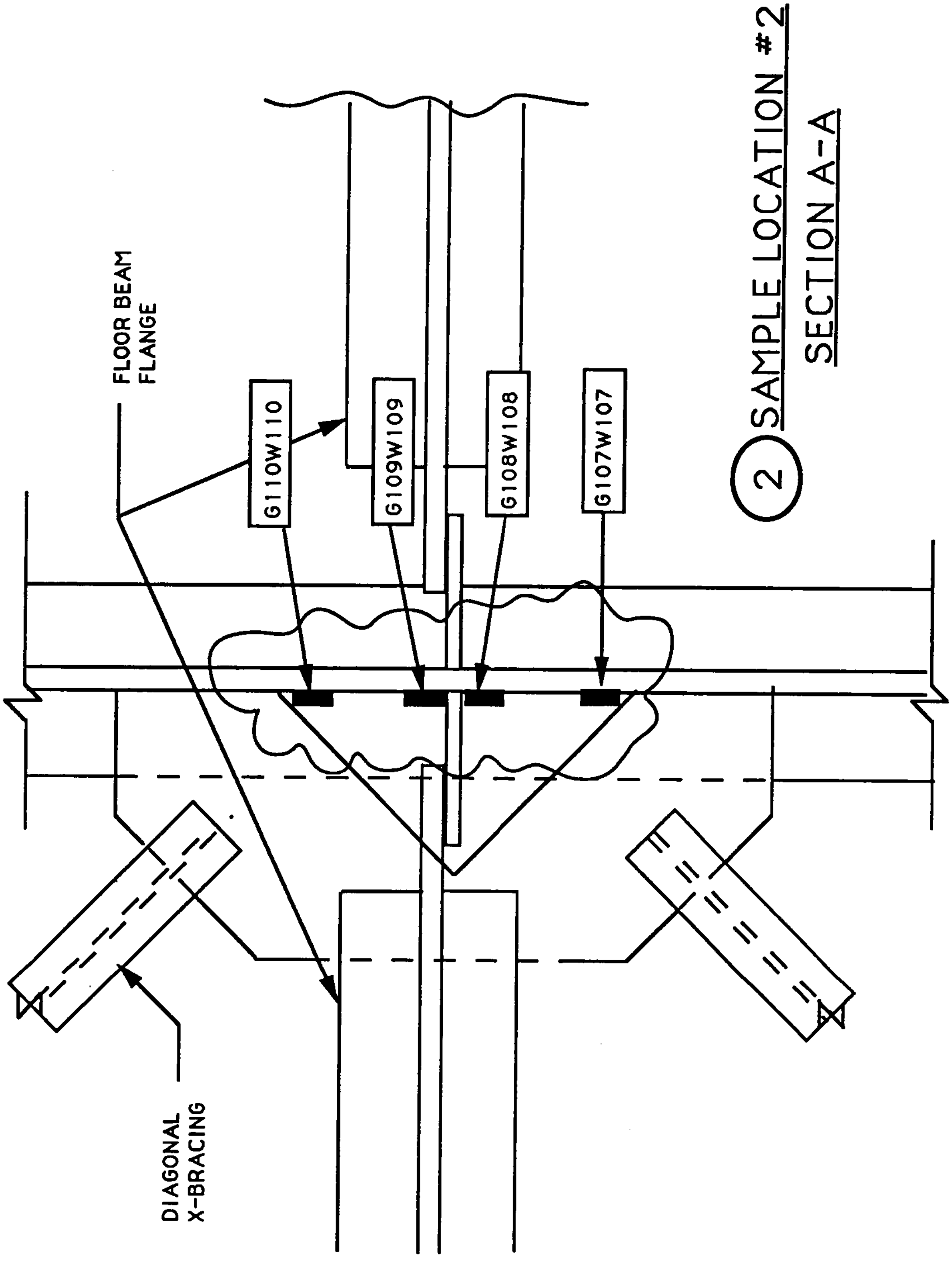


Figure B-12 Detail Location of Strain Gages 107-110

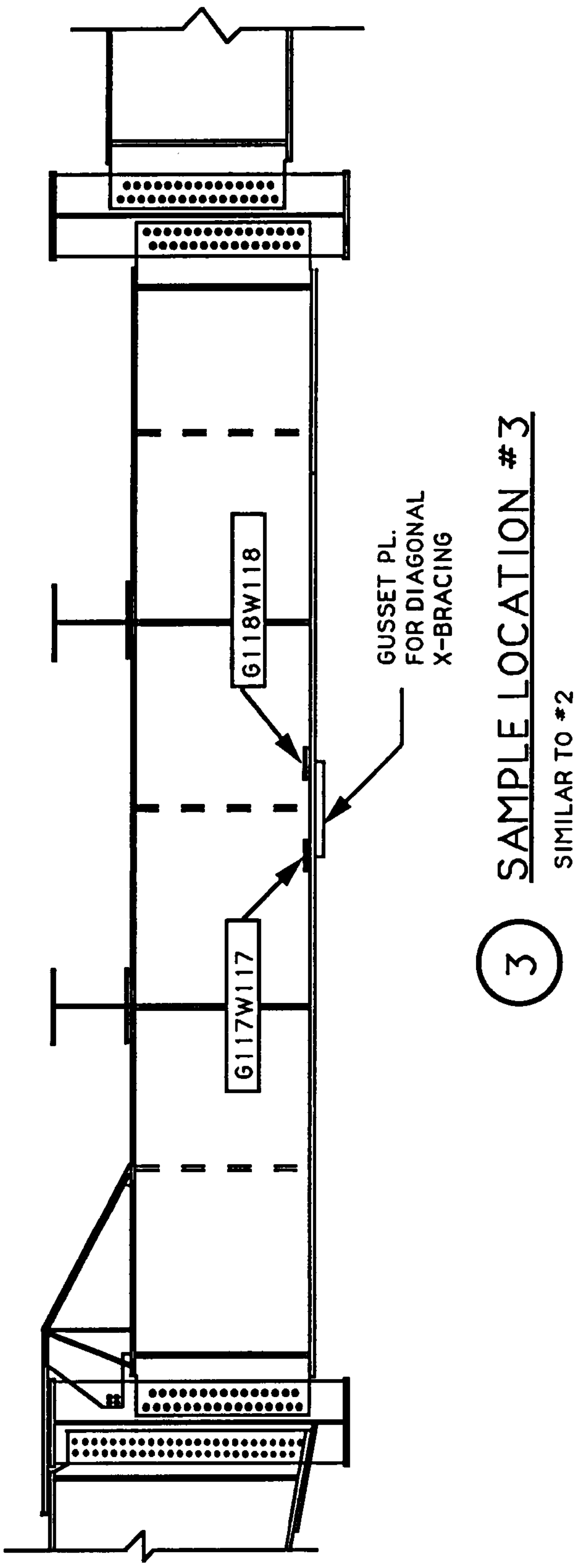


Figure B-13 Location of Strain Gages 117 &118

APPENDIX-C

Computer Program DATAACQ.BAS

```
REM ************************************************************
REM                         READ ME!
REM This is an interactive program; to run this program you just need to "Run"
REM basic.  You also need to know the following:
REM    1) The input file name.  Remember to include the Drive (A:file.name).
REM    2) The gage name and the location of the gage in the data string.
REM         Note: Time is the first location, the first gage is location 2.
REM  or 2) A data file with the gages and locations you want read
REM************************************************************
      DIM T(600), g(495, 32), gname$(32), location(33)
      CLS
      PRINT "Do you want to run this program interactive (Input:1),"
      PRINT "or through the use of an input file (Input:2)?"
50    INPUT "Input either 1 or 2:"; an
REM************************************************************
REM This section opens the input file and creates the output files.
      INPUT "Input the file you want read (Ex:\HRB1\SEPT\AT8593A.006):"; file$
      IF an = 1 THEN
        INPUT "Input the number of gages you want read:"; number
          FOR i = 1 TO number
            INPUT "Input the gage name (Ex:G78):"; gname$(i)
            INPUT "Input the gage location (3rd):"; location(i)
          NEXT i
        GOTO 100
      END IF
      IF an = 2 THEN
        INPUT "Input the Gage Location file name (Ex:A:AT8593A.DAT):"; Gfile$
        OPEN Gfile$ FOR INPUT AS #2
        INPUT #2, number
          FOR i = 1 TO number
            INPUT #2, gname$(i), location(i)
          NEXT i
        GOTO 100
      END IF

      PRINT "You didn't input either 1-interactive or 2-input file": GOTO 50

100   OPEN file$ FOR INPUT AS #1
      INPUT #1, H1$, H2$, H3$, H4$, H5$, head$
      INPUT "Input the test name (Ex:AT8593A):"; tname$
      PRINT "The name of your output files are:"
      FOR i = 1 TO number
        e$ = tname$ + "." + gname$(i)
        OPEN e$ FOR OUTPUT AS #(i + 2)
        WRITE #(i + 2), H1$, H5$
        PRINT e$
      NEXT i

REM************************************************************
REM This section reads the input file.
      PRINT H1$, H2$, H3$, H4$, H5$
      Csec = VAL(H5$)
      l = 2 * Csec
      m = VAL(H4$): N = m - 1
      IF m > 33 THEN PRINT "You have greater then 32 gage readings"

      DO UNTIL EOF(1) = -1
```

```
      FOR i = 1 TO l
       INPUT #1, T(i)
REM          PRINT T(i)
         FOR j = 1 TO N
           INPUT #1, g(i, j)
         NEXT j
      NEXT i

REM************************************************************
REM This section separates the gage readings & writes them to the output file.
      z = 0
      FOR i = 1 TO l
        FOR j = 1 TO number
        z = location(j) - 1
        WRITE #(j + 2), T(i), g(i, z)
        NEXT j
      NEXT i
REM        tsec = tsec + (i - 1) / Csec: PRINT "time (sec)="; tsec
      LOOP
      CLOSE #1, #2
      FOR i = 1 TO number
        CLOSE #(i + 2)
      NEXT i
      END
```

APPENDIX - D

Computer Program DATARED.BAS

```
DECLARE SUB CatS (DStress!,s1!,s2!,s3!,s4!,s5!,s6!,s7!,s8!,s9!,s10!,s11!,s12!,s13!,s14!)
    DIM g(16000), T(16000), Hg(5000), Lg(5000), Ht(5000), Lt(5000)
    DIM gname$(32), file$(32), outname$(32)
    CLS
    PRINT "Do you want to run this program interactive (Input:1),"
    PRINT "or through the use of an input file (Input:2)?"
10   INPUT "Input either 1 or 2:"; an
REM*************************************************************
REM This section opens the input file and creates the output files
    IF an = 1 THEN
     number = 1
     INPUT "Input the file you want read (ex:\TEMP\AT8593A.G1):"; file$(1)
     INPUT "Input the gage you want read (ex:G1):"; gname$(1)
     outname$(1) = "Reduced." + gname$(1)
    GOTO 20
    END IF
    IF an = 2 THEN
    INPUT "Input the test name (Ex:AT8593A):"; iname$
    INPUT "Input the Gage Location file name (Ex:\TEMP\AT8593A.DAT):"; Gfile$
     INPUT "Input the result file name (Ex:8593A7):"; ONAME$
     OPEN Gfile$ FOR INPUT AS #2
     INPUT #2, number
      FOR i = 1 TO number
       INPUT #2, gname$(i), location
       outname$(i) = ONAME$ + "." + gname$(i)
       file$(i) = iname$ + "." + gname$(i)
      NEXT i
     CLOSE #2
    GOTO 20
    END IF
    PRINT "You didn't input either 1-interactive or 2-input file": GOTO 10
REM*************************************************************
REM This section sets up the Printing format
20   A1$ = "  Stress  * Strain * High Strain * Time  * Low Strain * Time "
    A2$ = "   (psi)   (m-in)    (m-in)     (sec)    (m-in)    (sec)"
    A3$ = " ###,###.## ###.###    ###.###    ###.###   ###.###    ###.###"
    B1$ = "  Betwn  500-1000:    ##### "
    B2$ = "  Betwn 1000-1500:    #### "
    B3$ = "  Betwn 1500-2000:     ### "
    B4$ = "  Betwn 2000-2500:     ### "
    B5$ = "  Betwn 2500-3000:     ### "
    B6$ = "  Betwn 3000-3500:     ### "
    B7$ = "  Betwn 3500-4000:     ### "
    B8$ = "  Betwn 4000-4500:     ### "
    B9$ = "  Betwn 4500-5000:     ### "
    B8$ = "  Betwn 5000-5500:     ### "
    B9$ = "  Betwn 5500-6000:     ### "
    B8$ = "  Betwn 6000-6500:     ### "
    B9$ = "  Betwn 6500-7000:     ### "
    B10$ = "  Greater  7000  :    ### "
REM*************************************************************
REM This section reads the input file, finds out the length, then calculates
REM the correction factor.
    OPEN file$(1) FOR INPUT AS #1: INPUT #1, H1$, H5$
    DO UNTIL EOF(1) = -1
       INPUT #1, t1, g1
       Count = Count + 1
```

```
LOOP
Finish = Count - 19: Fin = Count - 20
Csec = VAL(H5$)
L = 15998: NLoop=INT(Count/L):Remain = Count - L * NLoop
E = 29
CLOSE #1

FOR N = 1 TO number
  OPEN file$(N) FOR INPUT AS #1: INPUT #1, H1$, H5$
  OPEN outname$(N) FOR OUTPUT AS #3
REM*********************************************************
  PRINT #3, "The ASCI file is:", H1$
  PRINT #3, "Data from gage file:", file$(N)
  PRINT #3, A1$
  PRINT #3, A2$
REM*********************************************************
  FOR i = 1 TO 20
   INPUT #1, T(i), g(i)
   sum1 = sum1 + g(i)
  NEXT i

  FOR i = 21 TO Fin
   INPUT #1, t1, g1
  NEXT i

  FOR i = 21 TO 40
   INPUT #1, T(i), g(i)
   sum2 = sum2 + g(i)
  NEXT i
  CLOSE #1: OPEN file$(N) FOR INPUT AS #1: INPUT #1, H1$, H5$

  Correct1 = sum1 / 20: Correct2 = sum2 / 20
  slope = (Correct2 - Correct1) / (T(31) - T(10))
  c = Correct1 - slope * T(10)
REM This section reads the input file then corrects the data using Correct.
REM  (For horizontal line correction activate next line deactivate slope cor)
REM       Correct = Correct1

  FOR m = 1 TO NLoop
  j = 1
   FOR i = 1 TO L
    INPUT #1, T(i), g(i)
REM       (For sloped straight line correction)
    Correct = slope * T(i) + c
    g(i) = g(i) - Correct
   NEXT i

REM      This section finds the high and low strain points
   IF g(0) < 0 AND g(1) >= 0 THEN j = j + 1
   FOR i = 1 TO L
    IF g(i) > 0 AND g(i) > g(i - 1) THEN
     IF g(i) >= Hg(j) THEN Hg(j) = g(i): Ht(j) = T(i)
    END IF
    IF g(i) < 0 AND g(i) <= g(i - 1) THEN
     IF g(i) < Lg(j) THEN Lg(j) = g(i): Lt(j) = T(i)
    END IF
    IF g(i) < 0 AND g(i + 1) > 0 THEN j = j + 1
```

```
         NEXT i

        g(0) = g(L): T(0) = T(L): k = j - 1
REM      This section calculates the delta-stresses and categorizes the data
         FOR i = 1 TO k
          DStrain = Hg(i) - Lg(i)
          DStress = E * DStrain
           IF DStress < 500 THEN GOTO 100
          PRINT #3, USING A3$; DStress; DStrain; Hg(i); Ht(i); Lg(i); Lt(i)
           CALL CatS(DStress, s1, s2, s3, s4, s5, s6, s7, s8, s9, s10,s11,s12,s13,s14)
100       NEXT i

        Hg(1) = Hg(j): Ht(1) = Ht(j): Lg(1) = Lg(j): Lt(1) = Lt(j)
         FOR i = 2 TO j
          Hg(i) = 0: Ht(i) = 0: Lg(i) = 0: Lt(i) = 0
         NEXT i
       NEXT m

       FOR i = 1 TO Remain
       j = 1
        INPUT #1, T(i), g(i)
REM        (For sloped straight line correction)
        Correct = slope * T(i) + c
        g(i) = g(i) - Correct
       NEXT i

REM      This section finds the high and low strain points
       IF g(0) < 0 AND g(1) >= 0 THEN j = j + 1
       FOR i = 1 TO Remain
        IF g(i) > 0 AND g(i) > g(i - 1) THEN
         IF g(i) >= Hg(j) THEN Hg(j) = g(i): Ht(j) = T(i)
        END IF
        IF g(i) < 0 AND g(i) <= g(i - 1) THEN
         IF g(i) < Lg(j) THEN Lg(j) = g(i): Lt(j) = T(i)
        END IF
        IF g(i) < 0 AND g(i + 1) > 0 THEN j = j + 1
       NEXT i

REM     This section calculates the delta-stresses and categorizes the data
       FOR i = 1 TO j
        DStrain = Hg(i) - Lg(i)
        DStress = E * DStrain
         IF DStress < 500 THEN GOTO 200
        PRINT #3, USING A3$; DStress; DStrain; Hg(i); Ht(i); Lg(i); Lt(i)
         CALL CatS(DStress, s1, s2, s3, s4, s5, s6, s7, s8, s9, s10,s11,s12,s13,s14)
200     NEXT i
       FOR i = 1 TO j
        Hg(i) = 0: Ht(i) = 0: Lg(i) = 0: Lt(i) = 0
       NEXT i
REM***********************************************************
REM This section prints out the results
       WRITE #3,
       PRINT #3, "    Stress Range  *  Times within"
       PRINT #3, "       (psi)          Range:"
       PRINT #3, USING B1$; s1
       PRINT #3, USING B2$; s2
       PRINT #3, USING B3$; s3
```

```
        PRINT #3, USING B4$; s4
        PRINT #3, USING B5$; s5
        PRINT #3, USING B6$; s6
        PRINT #3, USING B7$; s7
        PRINT #3, USING B8$; s8
        PRINT #3, USING B9$; s9
        PRINT #3, USING B10$; s10
        PRINT #3, USING B11 s11
        PRINT #3, USING B12$; s12
        PRINT #3, USING B13$; s13
        PRINT #3, USING B14$; s14
        PRINT "The name of your output file is:"; outname$(N)
        s1 = 0: s2 = 0: s3 = 0: s4 = 0: s5 = 0: s6 = 0: s7 = 0: s8 = 0
        s9 = 0: s10 = 0:s11 = 0:s12 = 0:s13 = 0:s14 = 0: j = 1: sum1 = 0: sum2 = 0
500      CLOSE #1, #3
      NEXT N
END

SUB CatS (DStress, s1, s2, s3, s4, s5, s6, s7, s8, s9, s10)
        IF DStress <= 1000 THEN s1 = s1 + 1: GOTO 300
        IF DStress <= 1500 THEN s2 = s2 + 1: GOTO 300
        IF DStress <= 2000 THEN s3 = s3 + 1: GOTO 300
        IF DStress <= 2500 THEN s4 = s4 + 1: GOTO 300
        IF DStress <= 3000 THEN s5 = s5 + 1: GOTO 300
        IF DStress <= 3500 THEN s6 = s6 + 1: GOTO 300
        IF DStress <= 4000 THEN s7 = s7 + 1: GOTO 300
        IF DStress <= 4500 THEN s8 = s8 + 1: GOTO 300
        IF DStress <= 5000 THEN s9 = s9 + 1: GOTO 300
        IF DStress <= 5500 THEN s10 = s10 + 1: GOTO 300
        IF DStress <= 6000 THEN s11 = s11 + 1: GOTO 300
        IF DStress <= 6500 THEN s12 = s12 + 1: GOTO 300
        IF DStress <= 7000 THEN s13 = s13 + 1: GOTO 300
        s14 = s14 + 1
300
END SUB
```

APPENDIX - E
Computer Program Users Guide

DATAACQ.BAS (Appendix - C) separates the TCS 3000 ASCII test data into specific gage files (Figure E-1). This gage file includes the test name and the number of readings per second in the first line. The remaining lines contain the time and strain data as illustrated below:

AT8593A.006, 60	Test Name, Reading per second
+3.500E+001 -1.1842E+000	Actual data. Time is the first reading, strain is the second reading.

Figure E-1: Output of DATAACQ.BAS Program

From the specific gage file, the program DATARED.BAS (Appendix - D) can analyze the data, and categorizes the stress ranges into a table as shown in Figure E-2.

Stress * (psi)	Strain * (m-in)	High Strain * (m-in)	Time * (sec)	Low Strain * (m-in)	Time " (sec)
#####	###	###	####	###	####
Stress Range * (psi)		Times within" Range:"			
Betwn 500-1000:		####			
Betwn 1000-1500:		####			
Betwn 1500-2000:		###			
Betwn 2000-2500:		###			
Betwn 2500-3000:		###			
Betwn 3000-3500:		###			
Betwn 3500-4000:		###			
Betwn 4000-4500:		###			
Betwn 4500-5000:		###			
Betwn 5000-5500:		###			
Betwn 5500-6000:		###			
Betwn 6000-6500:		###			
Betwn 6500-7000:		###			
Greater 7000 :		###			

Figure E-2: Output of DATARED.BAS Program

Both programs can either be run interactively (for the separation and analysis of a single gage) or through the use of a gage location file (for the separation and analysis of a group of gages). The gage location file tells DATAACQ.BAS and DATARED.BAS the number of gages you want separated/analyzed, the gage name, and gage location in the ASCII file (Figure E-3). The gage location file can be used when running either program, however when you run DATAACQ.BAS, you are limited to separating only 13 gages at a time. Therefore, if you want to separate an ASCII file with 32 gages, then you will need to create 3 gage input files (file 1: first 13 gages and locations, file 2: next 13 gages and location, file 3 last 6 gages and locations). When you run DATARED.BAS, you may analyze as many gage file as you want.

13	:Number of gage you want read
G10, 2,G11,3,G12,4,G13,5,...	:Gage name, Location in ASCII file, etc.
	Note: Time is the first location

Figure E-3: Gage Location File Description

Both programs can be run either through "QBasic" or "QB45". Once initiated the programs will initially ask you if you would like to run interactively or through an input gage location file:

```
Do you want to run this program interactive (Input:1)
or through the use of an input file (Input:2)?
Input either 1 or 2:" "
```

Figure E-4: Initial Request

If you run DATAACQ.BAS interactively, the program will request (Figure E-5) the ASCII file you want separated, then the number of gages you want separated. Next the program will ask the gage name and specific location in the ASCII file for each gage you want separated.

```
Input the file you want read (Ex:\HRB1\SEPT\AT8593A.006):" "
Input the number of gages you want read:" "
Input the gage name (Ex:G78):" "
Input the gage location (3rd):" "
```

Figure E-5: File Request

If you run DATAACQ.BAS through the use of a gage data file, the program (Figure E-6) will request the ASCII file you want separated, then the name of the gage location file:

```
Input the file you want read (Ex:\HRB1\SEPT\AT8593A.006):" "
Input the Gage Location file name (Ex:A:AT8593A.DAT):" "
```

Figure E-6: ASCII & Gage Data File Request

Finally, in both methods, the program will request the test name, and print out each gage file name:

```
Input the test name (Ex:AT8593A):" "
The name of your output files are:  AT8593A.G10
```

Figure E-7: Test Name & Output File Request

You will notice that the Gage output file name is created by taking the test name and combining it with the gage name ("test name"+"."+"gage name").

Similar to running DATAACQ.BAS, If you run DATARED.BAS interactively, the program will request (Figure E-8) the separated strain gage data file you want analyzed, then the gage name you want analyzed.

```
Input the file you want read (ex:\TEMP\AT8593A.G1):" "
Input the gage you want read (ex:G1):" "
```

Figure E-8: DATARED.BAS Request

If you run DATARED.BAS through the use of a gage location file, the program (Figure E-9) will request the test name, strain gage data file, and the results file name:

```
Input the test name (Ex:AT8593A):" "
Input the Gage Location file name (Ex:\TEMP\AT8593A.DAT):" "
Input the result file name (Ex:8593A7):" "
```

Figure E-9: Test Name & Output File Request

You will notice that the results file name is created by taking the result file name and combining it with the gage name ("result name"+"."+"gage name"=8593A7.G#).

VITA

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The following September he entered the University of Hawaii and in January of 1981 he transferred to the University of Tennessee at Knoxville. In June of 1984 he received his degree of Bachelor of Science in Mechanical Engineering.

He reentered The University of Tennessee at Knoxville in the Fall of 1990, where he obtained a minor in Architecture in August of 1991. Fall 1992, he reentered The University of Tennessee as a graduate assistant in Civil Engineering. Approximately two and a half years later he graduated with a Masters of Science degree in Civil Engineering in the Spring of 1994.