



**SCHOOL OF CIVIL AND
ENVIRONMENTAL ENGINEERING
OKLAHOMA STATE UNIVERSITY**

**FATIGUE ASSESSMENT OF BRIDGE MEMBERS
BASED ON IN-SERVICE STRESSES**

By

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**INTERIM REPORT NO. 2:
DATA ACQUISITION
SYSTEM FOR
STRAIN MEASUREMENTS**

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16. ABSTRACT <p>When a bridge is designed, conservative assumptions are made with regard to load distribution and structural continuity. Simple support is assumed when rotational restraint exists, deck girders are assumed noncomposite when significant shear transfer occurs at service loads, haunch is ignored, and elements such as railing are treated as nonstructural dead load rather than as stiffening elements. As a result of these and other conservative assumptions, stresses calculated for design may be well above stresses computed on the basis of strains measured while the bridge is in service.</p> <p>The magnitude of the stress fluctuations under service load determines the fatigue life of the bridge. The accuracy of remaining fatigue life estimates can be improved if these estimates can be based on measured rather than computed strains, typically resulting in a significant increase in projected bridge life. A more accurate fatigue life estimate leads to fewer negative fatigue life computations for operating, undamaged bridges. The result is an overall reduction in retrofit and replacement costs.</p> <p>To take advantage of this cost savings, a data acquisition system has been constructed for use by the Oklahoma Department of Transportation in measuring strains on in-service bridges. Construction of the system involved the development of hardware and software to facilitate interaction with a general-purpose commercial datalogger. Application of the system requires the user to install strain gages on the structure of interest, extend leadwires from the gages to a junction box containing bridge completion circuitry, connect the junction box to a battery-powered datalogger, and connect the datalogger to an on-site computer. The computer is loaded with software to assist the user in setting up the datalogger and downloading collected data.</p> <p>This report contains information regarding construction of the data acquisition system which may be useful for system maintenance and operation. This report also contains a set of general guidelines for conducting a bridge test and applying the test results. It is recommended that a complete bridge evaluation include a thorough visual inspection, an analysis of the structure, and a load test. The load test should include both a series of short-term tests in which stresses are recorded as a truck of known weight passes over the bridge, and at least one long-term test in which the number and magnitude of stress cycles are recorded under normal traffic.</p> <p>Data collected using the data acquisition system can be used to estimate remaining fatigue life and set inspection intervals. The recommended procedure for estimating remaining fatigue life follows NCHRP Report 299, taking full advantage of the fact that stresses are measured rather than computed. The procedure for setting inspection intervals is based on a fracture mechanics estimate of the time required for a crack of an assumed initial length to grow to a critical length when driven by the measured stress cycles.</p>			
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Approximate Conversions to SI Units				Approximate Conversions from SI Units					
Symbol	When You Know	Multiply by	To Find	Symbol	Symbol	When You Know	Multiply by	To Find	Symbol
<u>Length</u>				<u>Length</u>					
in.	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in.
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yd
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
<u>Area</u>				<u>Area</u>					
in. ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.00155	square inches	in. ²
ft ²	square feet	0.0929	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.8361	square meters	m ²	m ²	square meters	1.196	square yards	yd ²
ac	acres	0.4047	hectares	ha	ha	hectares	2.471	acres	ac
mi ²	square miles	2.590	square kilometers	km ²	km ²	square kilometers	0.3861	square miles	mi ²
<u>Volume</u>				<u>Volume</u>					
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.2642	gallons	gal
ft ³	cubic feet	0.0283	cubic meters	m ³	m ³	cubic meters	35.315	cubic feet	ft ³
yd ³	cubic yards	0.7645	cubic meters	m ³	m ³	cubic meters	1.308	cubic yards	yd ³
<u>Mass</u>				<u>Mass</u>					
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
<u>Temperature (exact)</u>				<u>Temperature (exact)</u>					
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
<u>Force and Pressure or Stress</u>				<u>Force and Pressure or Stress</u>					
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in. ²	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in. ²

**FATIGUE ASSESSMENT OF BRIDGE MEMBERS
BASED ON IN-SERVICE STRESSES**

State Study No. 2196

Interim Report No. 2:
Data Acquisition System for Strain Measurements

By

Farrel J. Zwememan
John W. Kelly
and
Orin A. Johnston

Prepared as part of an investigation
conducted by the
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Oklahoma State University
sponsored by
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Oklahoma Department of Transportation
State of Oklahoma
and the Federal Highway Administration
June, 1997

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Oklahoma Department of Transportation or the Federal Highway Administration. The report does not constitute a standard, specification, or regulation. While equipment and contractor names are used in this report, it is not intended as an endorsement of any machine, contractor, or product.

EXECUTIVE SUMMARY

When a bridge is designed, conservative assumptions are made with regard to load distribution and structural continuity. Simple support is assumed when rotational restraint exists, deck girders are assumed noncomposite when significant shear transfer occurs at service loads, haunch is ignored, and elements such as railing are treated as nonstructural dead load rather than as stiffening elements. As a result of these and other conservative assumptions, stresses calculated for design may be well above stresses computed on the basis of strains measured while the bridge is in service.

The magnitude of the stress fluctuations under service load determines the fatigue life of the bridge. The accuracy of remaining fatigue life estimates can be improved if these estimates can be based on measured rather than computed strains, typically resulting in a significant increase in projected bridge life. A more accurate fatigue life estimate leads to fewer negative fatigue life computations for operating, undamaged bridges. The result is an overall reduction in retrofit and replacement costs.

To take advantage of this cost savings, a data acquisition system has been constructed for use by the Oklahoma Department of Transportation in measuring strains on in-service bridges. Construction of the system involved the development of hardware and software to facilitate interaction with a general-purpose commercial datalogger. Application of the system requires the user to install strain gages on the structure of interest, extend leadwires from the gages to a junction box containing bridge completion circuitry, connect the junction box to a battery-powered datalogger, and connect the datalogger to an on-site computer. The computer is loaded with software to assist the user in setting up the datalogger and downloading collected data.

This report contains information regarding construction of the data acquisition system which may be useful for system maintenance and operation. This report also contains a set of general guidelines for conducting a bridge test and applying the test results. It is recommended that a complete bridge evaluation include a thorough visual inspection, an analysis of the structure, and a load test. The load test should include both a series of short-term tests in which stresses are recorded as a truck of known weight passes over the bridge, and at least one long-term test in which the number and magnitude of stress cycles are recorded under normal traffic.

Data collected using the data acquisition system can be used to estimate remaining fatigue life and set inspection intervals. The recommended procedure for estimating remaining fatigue life follows NCHRP Report 299, taking full advantage of the fact that stresses are measured rather than computed. The procedure for setting inspection intervals is based on a fracture mechanics estimate of the time required for a crack of an assumed initial length to grow to a critical length when driven by the measured stress cycles.

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The data acquisition system constructed as a part of this project is modeled after a system built by researchers at The University of Texas at Austin for the Texas Department of Transportation, as described in the report number FHWA/TX+464-1F, "Estimating Residual Fatigue Life of Bridges." The authors of the TxDOT report are G. F. Post, K. H. Frank, and B. Tahmassebi.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

When a bridge is designed, conservative assumptions are made with regard to load distribution and structural continuity [Burdette et al., 1988]. Simple support is assumed when rotational restraint exists, deck girders are assumed noncomposite when significant shear transfer occurs at service loads, haunch is ignored, and elements such as railing are treated as nonstructural dead loads rather than as stiffening elements. As a result of these and other conservative assumptions, stresses calculated for design may be well above stresses computed on the basis of strains measured while the bridge is in service [Moses et al., 1987].

The magnitude of stress fluctuations under service load determines the fatigue life of the bridge. The accuracy of remaining fatigue life estimates can be improved if these estimates can be based on measured rather than computed strains, typically resulting in a significant increase in projected bridge life. A more accurate fatigue life estimate leads to fewer negative fatigue life computations for operating, undamaged bridges. The result is an overall reduction in retrofit and replacement costs.

1.2 Objective of Study

The objective of the portion of the project covered by this report is the development of equipment and procedures for fatigue assessment of bridge members based on in-service stresses. A data acquisition system has been constructed for use by the Oklahoma Department of Transportation (ODOT) in measuring strains on in-service bridges. The construction and operation of this system are described in the following chapters, along with procedures for using the acquired data to estimate remaining fatigue life. A photograph of the complete data acquisition system constructed for this project is provided in Figure 1.

1.3 Scope of Report

This report is the second of two interim reports describing the results of the project "Fatigue Assessment of Bridge Members Based on In-Service Stresses." The first interim report covered load tests and analyses of the U.S. 69 bridge over the South Canadian River, as well as the results of laboratory fatigue tests. This second interim report covers construction, operation, and application of a system for measuring and recording strains on an in-service bridge.

The following chapters of this interim report are written as reference documents for system maintenance and operation, and to serve as a guideline for using collected data. Chapter 2 describes system hardware to the extent necessary for maintenance, repair, or replacement of



Figure 1. Data Acquisition System

system components. Chapter 3 provides a general description of system software to establish the relationship between the software components. A complete program listing is provided in the Appendix. Chapter 4 is a set of stand-alone operating instructions for the data acquisition system. Recommended procedures for load testing, fatigue life estimating, and setting inspection intervals are provided in Chapter 5.

CHAPTER 2

DATA ACQUISITION HARDWARE

2.1 Datalogger

A datalogger (DL) is a programmable device that is capable of performing numerous electrical measurements, such as strain gage readings, and storing the data in memory for further processing. The datalogger used for this project is the Campbell Scientific 21X model. The 21X, shown in Figure 2, has four excitation channels capable of supplying ± 5 volts DC and 8 differential input channels. It may be powered by either 12 D cell batteries or a 12V marine battery, and has a final storage capacity of 19,296 locations.

There are two ways to program the DL: (1) enter coded instructions through the keypad located on the DL's control panel, or (2) download a coded instruction program via computer through the serial port. Entering a program with the keypad is quite tedious. DL programs are written in a terse code comprised of numbers and letters which correspond to commands listed in the Campbell operation manual. Coded programs can be long and difficult to debug for even simple tests such as the ones used for this project. To overcome the difficulties associated with keypad input, computer software was written to drive the datalogger.

The software written for this project allows the user to create DL tests without encountering the terse code. The main program, discussed below, generates the downloading files once the user has provided the appropriate parameters. This software was written with the user in mind, intent on minimizing user knowledge of a strict protocol of any kind.

2.2 Interface Box

The Interface Box is a circuitry junction box for all DL input channels. Figures 3 and 4 provide a photograph and a sketch of the front and back faces of the box. The input channels are the 8 receptacles on the front face and will be referred to as Inputs for the remainder of this report. The Inputs may be used in any order and any combination. Each Input is equipped to process either a strain gage or a transducer (strain gages and transducers are described in Section 2.3), but only one device per Input. There are no restrictions on the mixing of these two types of devices within a test. Refer to Figure 5 for an example of Input configuration.

Figures 6 and 7 provide a layout of the inside of the Interface Box. Note the 8 Inputs on the front face and the 8 Bridge Completion Module (BCM) chips, one per Input, located on the inside panel of the box. Symmetry was implemented as much as possible to simplify the wiring. The two terminal strips at the top of the box are divided into two sections each. The left sides of each



Figure 2. Datalogger

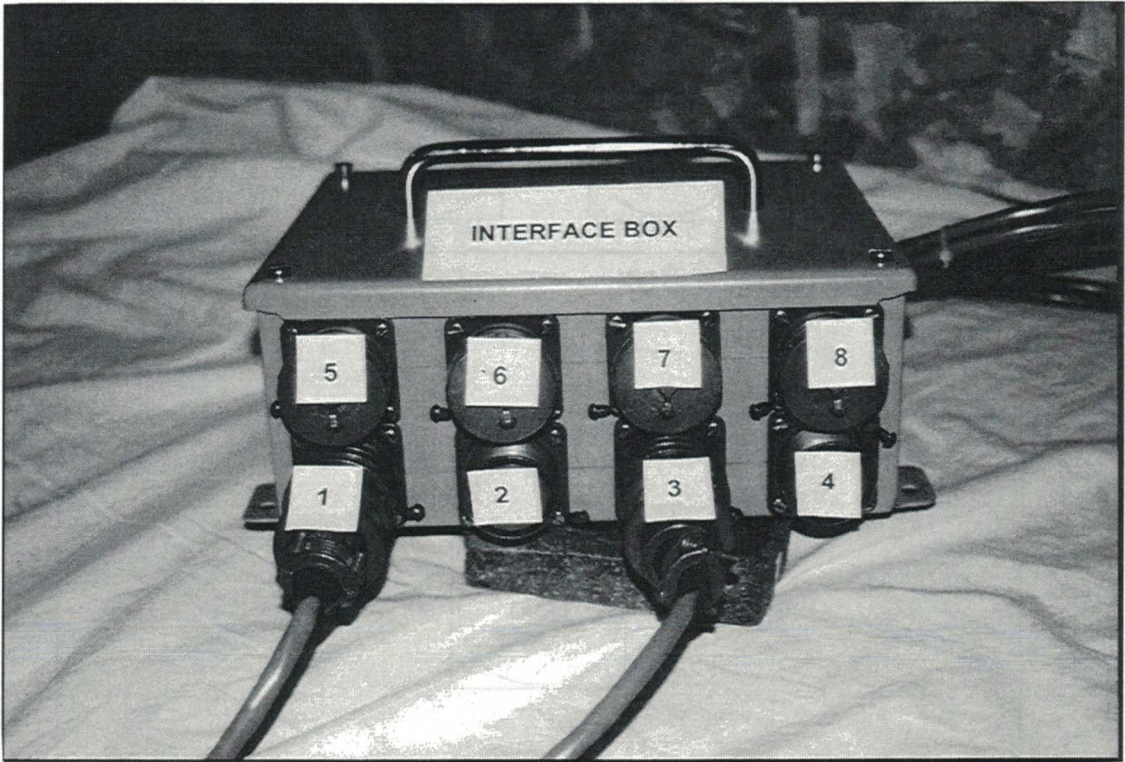
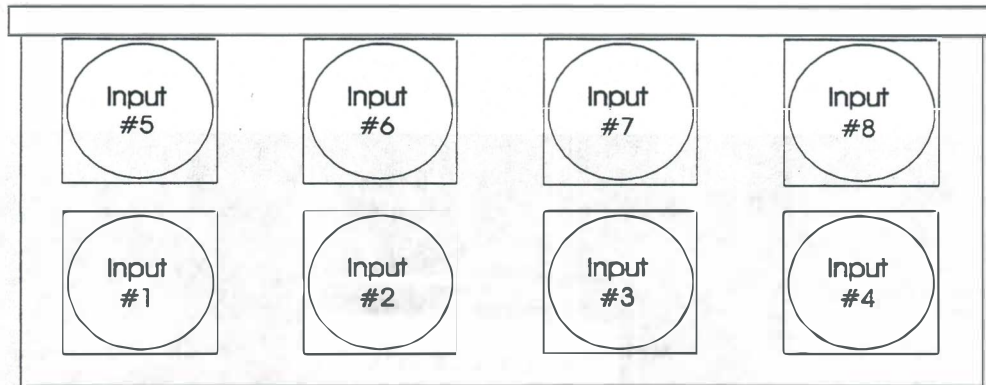
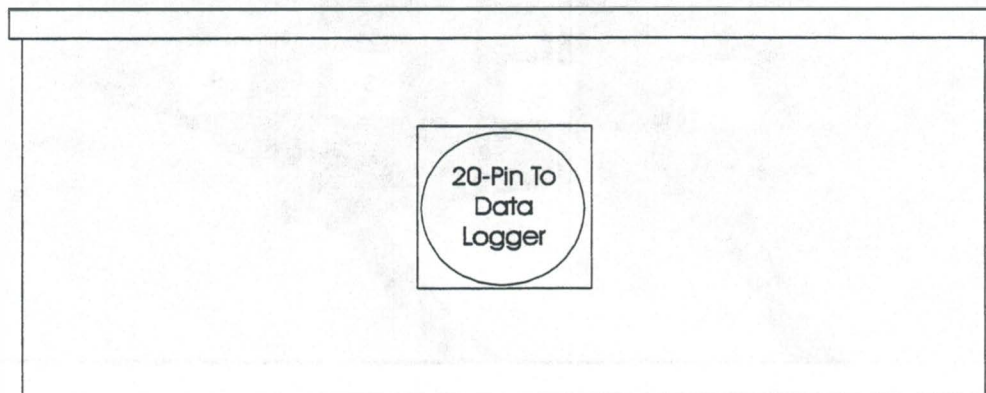


Figure 3. Interface Box



Front of Interface Box.



Back of Interface Box.

Figure 4. Sketch of Interface Box. The 8 Input channels are 16-pin “cannon plugs.” All circuitry from the inputs are routed through the 20-pin “cannon plug” to the datalogger (DL).

Input #5 Transducer	Input #6 Vacant	Input #7 Vacant	Input #8 Strain Gage
Input #1 Vacant	Input #2 Strain Gage	Input #3 Vacant	Input #4 Transducer

Figure 5. Input Example. Inputs are not used in sequential order, and there is a mix of strain gages and transducers.

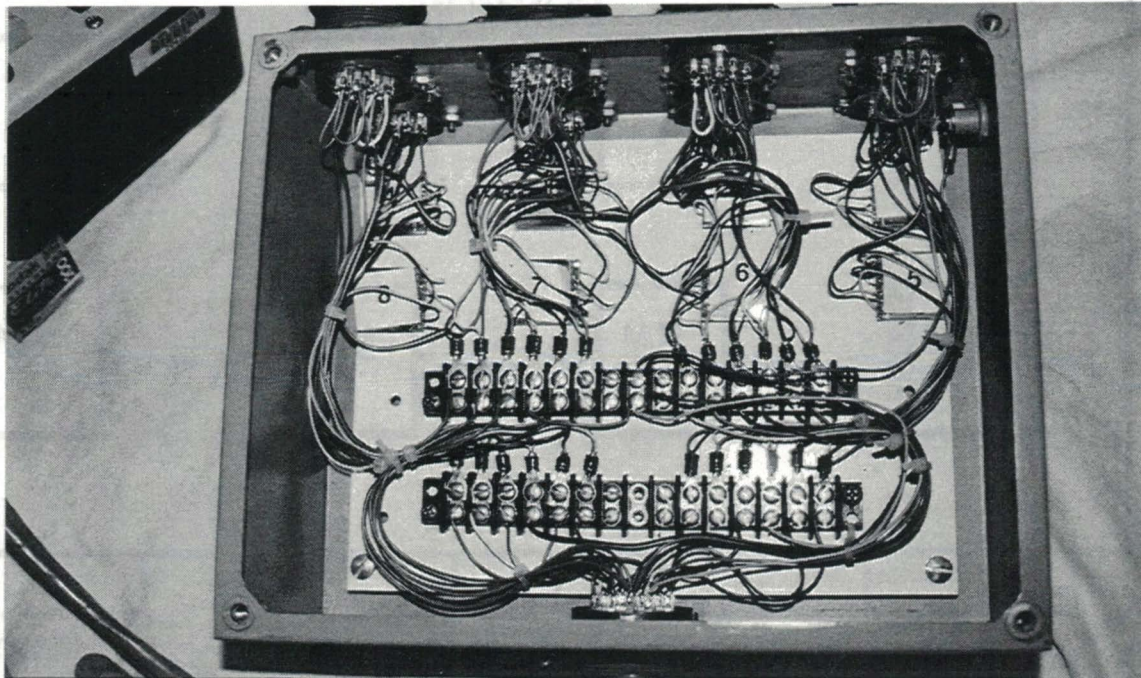


Figure 6. Interface Box Interior

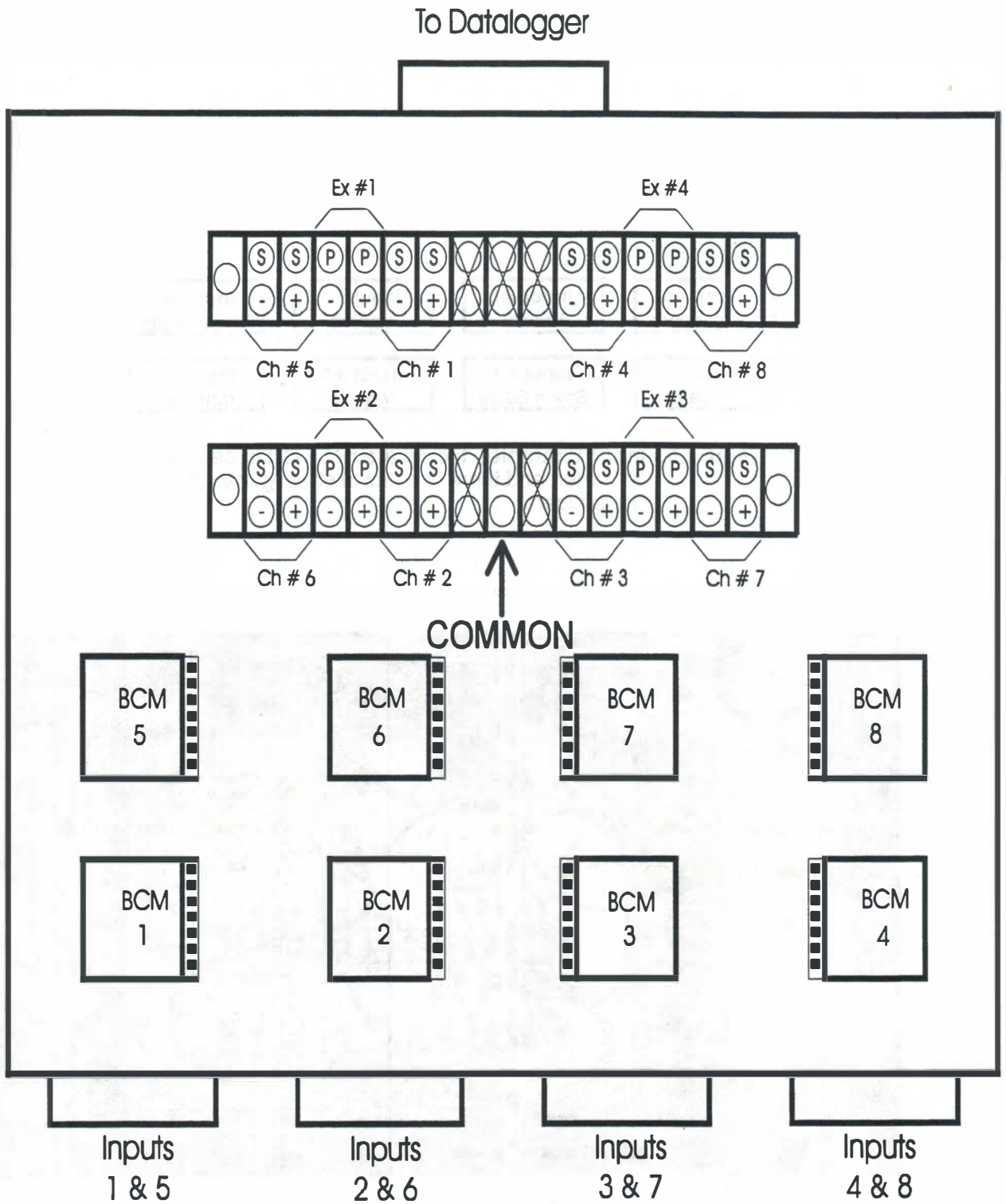


Figure 7. Plan View of the Interface Box. The terminal strips are partitioned by brackets to designate the divisions of the excitation channels and the Input channels. Refer to Figures 8 and 9 for a more detailed sketch of a typical excitation channel branch.

terminal strip service the four Inputs on the left side of the box face (Inputs #1, #2, #5, and #6), and the right sides service the four on the right. The terminal strip closest to the BCM chips services the four channels located on the center of the box face (Inputs #2, #3, #6, and #7) and the other strip services the other four Inputs. The Common for the excitation circuits passes through the middle pair of poles of one of the terminal strips connecting the P- poles of each excitation channel to the Interface Box casing. Figures 8 and 9 may be helpful in visualizing the circuitry layout.

2.2.1 Excitation

There are only four excitation channels to supply eight Inputs. Therefore, each excitation channel is connected to two Inputs in parallel and actually excites both simultaneously. The ordering of the Input channels, shown in Figure 10, is to convey the orientation of the Inputs on the front face of the Interface Box. Note that Inputs #1 through #4 make up the bottom row on the Interface Box and Inputs #5 through #8 make up the top row.

Each channel has a circuit for a transducer and a strain gage. This circuit is shown in Figure 11. The P+ and P- connections in Figures 7, 8, and 9 are the excitation poles in Figure 11, and the S+ and S- are the measurement poles. Although all Inputs share an excitation channel with another Input, each must have a separate set of measurement poles.

The excitation and measurement poles (P+, P-, S+, S-) make up an ensemble of leads for a Wheatstone Bridge, or a *full bridge*. Refer to Figure 12 for full bridge schematics of measurement devices. A full bridge is a configuration of four resistors of equal resistance. In the case of a transducer, all four resistors are 350 Ω strain gages. If an individual strain gage is the measurement device, the full bridge is composed of one 350 Ω strain gage and three 350 Ω resistors, provided by the Bridge Completion Modules (BCM).

Since both devices are full bridges, the DL operates individual strain gage circuits and transducer circuits identically. There is no need for “switching” mechanisms or program logic to select the appropriate circuit. Instead, the circuitry is mechanically controlled by the Input connection. When an Input connector is plugged into the socket, the correct circuit will be activated while the other circuit remains open. Connections were fabricated so that individual strain gages and transducer circuits would not share any common pins. If a transducer is installed, leads from the four strain gages configure a full bridge inside the box. If a strain gage is installed, the leads from the gage are connected to the BCM.

Each BCM may be configured for a 120 Ω gage or a 350 Ω gage. The distinction is made within the Interface Box wiring. Refer to Figure 8 and note the solder tab labels on the BCM sketches. The tab with label D is the wire leg for 350 Ω gages and the tab with label X is the wire leg for 120 Ω gages. As shown in the schematic of Figure 8, the DAS is currently restricted to

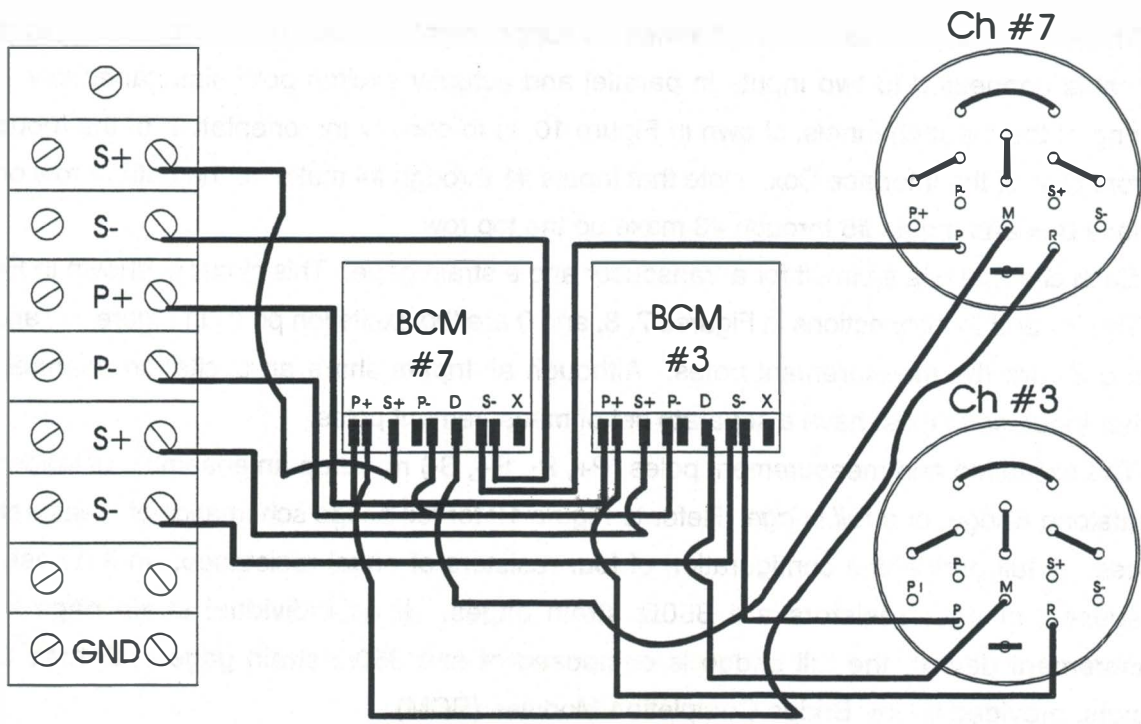


Figure 8. Strain Gage Circuit. Single strain gage circuit diagram for Excitation Channel #3 and associated Input Channels #3 and #7. Only pins P, M, and R of the channel plugs are used for the single strain gage. The 8 unlabeled pins that are joined in pairs are for the transducer circuit as are the four pins labeled P-, P+, S-, and S+. The bottom pin with the dash through it is unused.

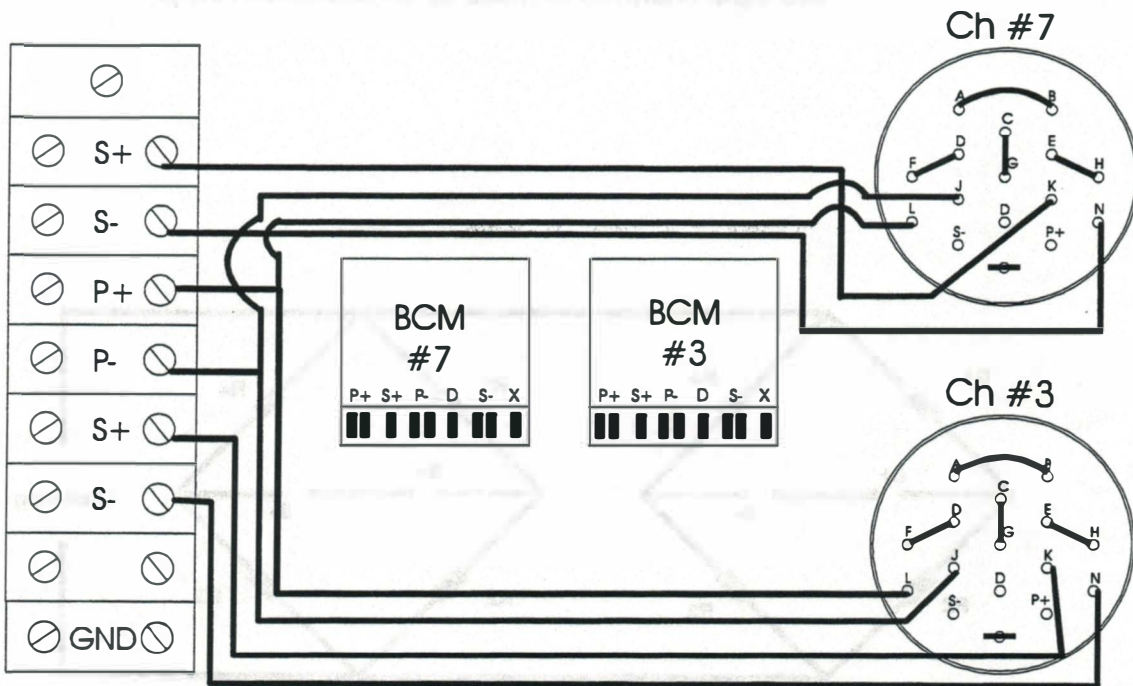


Figure 9. Transducer Circuit. Transducer circuit diagram for Excitation Channel #3 and associated Input Channels #3 and #7. All lines for single strain gage are omitted to increase legibility. Pins A through H adjoin the four strain gages into the bridge configuration. Pins L, J, K, and N are the excitation poles and measurement poles, respectively. The bottom pin with the dash through it is unused.



Figure 10. Excitation Arrays. Each excitation channel services two Input channels to make up an Excitation Array.

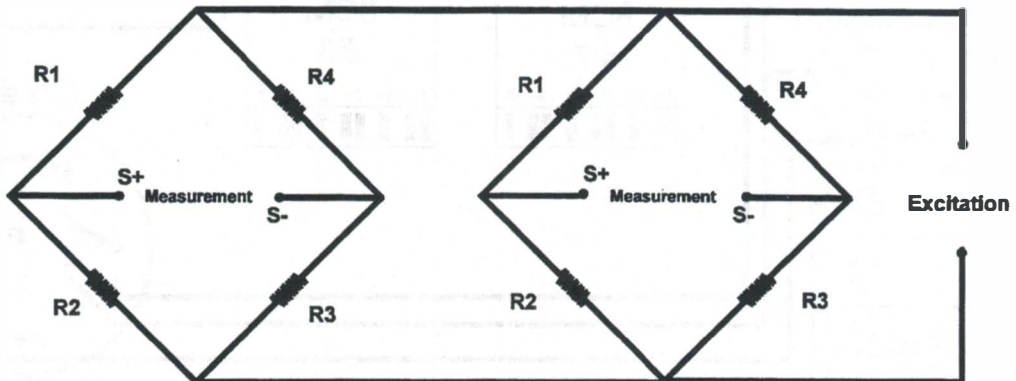


Figure 11. Schematic of a Single Excitation Array. Each bridge represents one Input which could be a strain gage circuit or a transducer. Since both bridges are parallel with each other and the excitation, the same voltage will be applied to either one for any scenario. This will also be true if one of the channels is vacant.

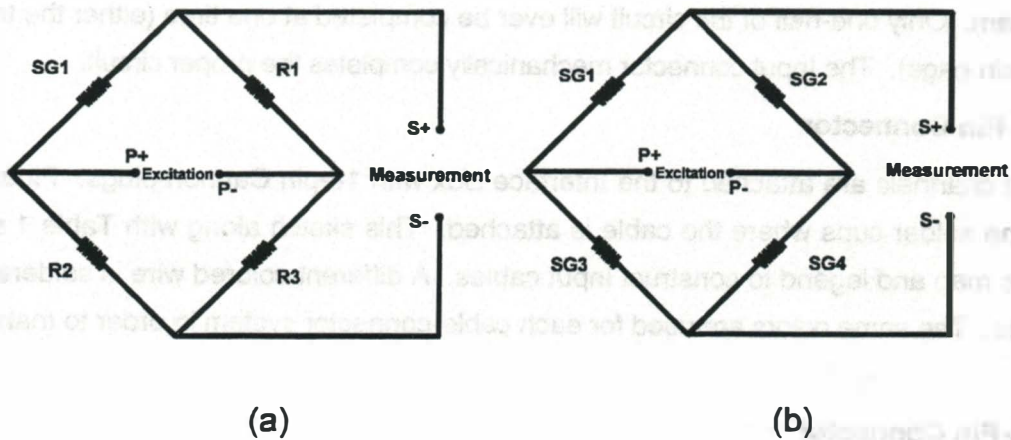


Figure 12. Full Bridge Circuits. Configurations of (a) a single strain gage (SG1) and a Bridge Completion Module (R1, R2, and R3), and (b) a transducer with 4 strain gages. Both circuits are equivalent.

350 Ω gages. In order to expand the system to accept 120 Ω gages, a wire connection must be made between the X tab on each BCM and the respective unused pin (pin S) of each Input connector (the dashed pin in Figure 8). Once this has been done, 120 Ω gages may be employed only if the strain gage wire connection is modified. Instead of connecting the strain gage wires to pins P, M, and R, the wires should be connected to pins P, the dashed pin, and R. Further details on strain gage connections are discussed in Section 2.3.

2.2.2 Measurement Readings

The measurement circuits are much simpler than the excitation circuits. Each Input is equipped with a set of measurement poles notated as S+ and S-. Figure 7 shows the terminal locations for each of the Input measurement poles. Figures 8 and 9 provide circuit diagrams for the transducer and strain gage of an Excitation Array; the S+ and S- poles can be traced out in this diagram. Only one-half of the circuit will ever be completed at one time (either the transducer or the strain gage). The Input connector mechanically completes the proper circuit.

2.2.3 16-Pin Connector

Input channels are attached to the Interface Box with 16-pin Cannon plugs. Figure 13 is a view of the solder cups where the cable is attached. This sketch along with Table 1 should be used as a map and legend to construct Input cables. A different colored wire is soldered to each of the pins. The same colors are used for each cable-connector system in order to make them all uniform.

2.2.4 20-Pin Connector

A double cable fixed to a 20-pin cannon plug runs from the Interface Box to the DL. Two 15-conductor cables are used to service the pins. A view of the 20-pin plug is sketched in Figure 14. Table 2 lists each pin letter, the respective wire color, and a description of its function. All four excitation channels have a common pole (P-). The Common for the circuit is labeled on the terminal strip shown in Figure 7. From this terminal, the Common is carried to the casing of the Interface Box through a grounding screw which is mounted on the inside. The circuit is completed through the 20-pin plug casing and a wire which links the casing to the DL. The 20 pins of the plugs service the eight measurement poles (16 pins) and the four excitation P+ poles (4 pins). Since there are not 20 unique wire colors, the same 10 colors were used from each cable. Although this could be confusing, it is not likely to cause problems since complete disassembly of the cable should not be necessary. If there is ever a need to repair the cable, a simple system of wire labeling prior to any wire disconnecting should prevent problems. In Table 2, annotations of 1 and 2 are employed to differentiate the wires into the two groups from which they originate.

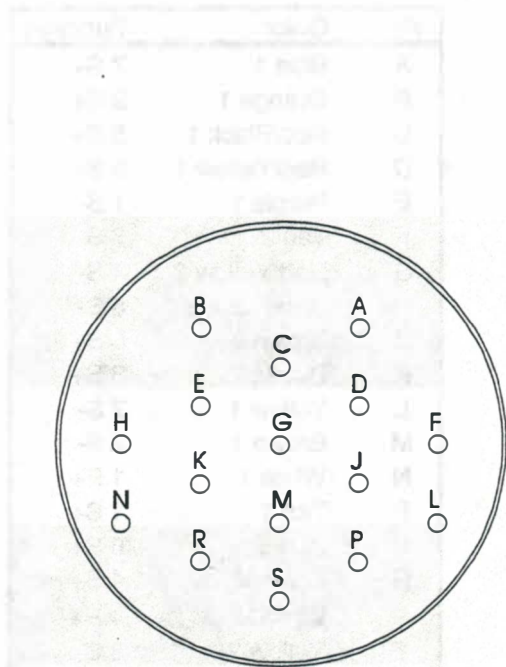


Figure 13. 16-Pin Connector. The display above is shown from an inside view of a connector plug where the solder cups are located. This is the same view that would be needed to construct a new cable.

Pin	Color	Function
A	Gray	Gage 1R
B	Yellow	Gage 3W
C	Purple	Gage 1W
D	Pink	Gage 2W
E	Brown	Gage 3R
F	Black	Gage 4R
G	Green	Gage 2R
H	Blue	Gage 4W
J	Red	Gage 1B (P+)
K	White	Gage 3B (S-)
L	Tan	Gage 4B (P-)
M	Red/Yellow	Strain Gage D
N	Orange	Gage 2B (S+)
P	Red/Green	Strain Gage S-
R	Red/Black	Strain Gage P+
S	Vacant	N/A

Table 1. Wire Color Legend for 16-Pin. The table above is a legend for pin assignments. The colors are those of the wires in the 15-conductor cable. The highlighted lines are for strain gages; all other pins (except pin S) are used for the transducer. The letters R, W, and B are the colors red, white, and black, respectively. These are the colors of strain gage leadwires.

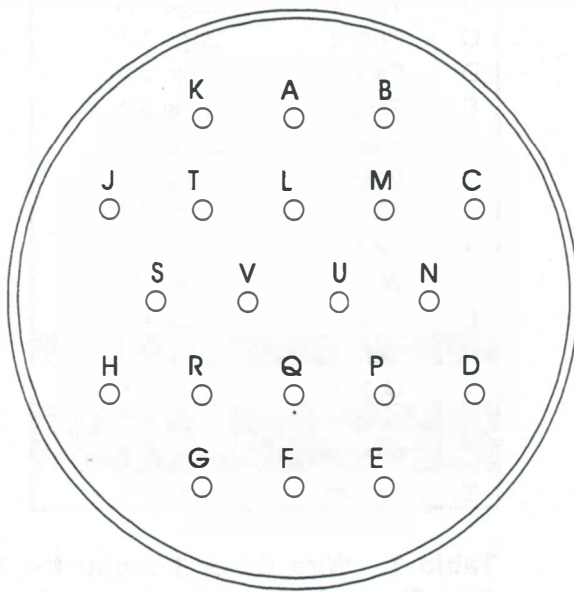


Figure 14. 20-Pin Connector. The Schematic above represents the inside of the cable connector that is attached to the interface box. This is the view that would be needed to repair or reconstruct a cable.

Pin	Color	Function
A	Blue 1	7 S+
B	Orange 1	2 S+
C	Red/Black 1	5 S+
D	Red/Yellow 1	5 S-
E	Purple 1	1 S-
F	Tan 2	6 S-
G	Red/Yellow 2	4 S-
H	Red/Black 2	8 S-
J	Brown 2	8 S+
K	Purple 2	3 S+
L	Yellow 1	7 S-
M	Brown 1	2 S-
N	White 1	1 P+
P	Tan 1	1 S+
Q	Blue 2	6 S+
R	Green 2	4 S+
S	White 2	4 P+
T	Yellow 2	3 S-
U	Green 1	2 P+
V	Orange 2	3 P+
Case	Bare 1 & 2	Common

Table 2. Wire Color Legend for 20-Pin. Each pin of the connector services a colored wire. The numbers 1 or 2 after each color indicate from which cable the wire originates. All of the wires for cable 2 are shaded. The numbers in the Function column are associated with either the Excitation or Measurement Channels.

2.3 Measurement Devices

Stress cannot be directly measured by any practical means. Strain, however, can be measured quite easily. Strain gages and transducers operate very similarly to measure the strain of the surface with which they are in contact. When a member, say a steel beam, is subjected to a load, the length of the member changes. The measurement device attached to the member must undergo the same change, allowing the DL to determine the strain. The stress is calculated from the strain measurement by Hooke's Law (Stress = Strain x Modulus of Elasticity). The Modulus of Elasticity, often referred to as E, is a material property and is equal to 29,000 ksi for structural steel. All calculations for obtaining the stress values are performed by the computer and the DL during the test.

2.3.1 Single Strain Gage

A single strain gage can be quite useful for taking measurements in space-limiting locations on the bridge. The disadvantage of the strain gage is that more time is required for proper bonding to the testing surface. A picture of a gage bonded to a steel bar is shown in Figure 15.

Compensation for leadwires should not be necessary. An 80-foot cable was measured to have a resistance of about 2.0Ω. The impact of this increased resistance for a 350Ω gage is shown in the following equation for the adjusted gage factor [Measurements, 1993]:

$$GF' = GF \times \frac{350\Omega}{350\Omega + 2 \times 2\Omega} = 98.9\% GF$$

which will result in increased strain reading of approximately 1.1%. For most applications, this will be an acceptable range of error; but if leadwire compensation is desired, the correction to the gage factor may be made using the above equation. The resistance for the leadwire may be estimated from the linear relationship of 1Ω per 40 feet of cable; the multiplier of 2 is in the equation to account for the fact that each strain gage has two leadwires that run the length of the cable.

If the Interface Box is expanded to accept 120Ω gages, it is possible that leadwire resistance could become an important contributor of error. Examination of the above equation will show that as resistance of the strain gage decreases, the effect of leadwire resistance on gage factor increases.

All gages shall be bonded to steel surfaces according to the manufacturer's specifications. Some additional suggestions and requirements regarding gages are:

- Use only 350Ω gages—120Ω gages are not compatible with the BCMS.
- Properly align the gage in the direction of measurement. Great care should be taken to avoid skewing which will cause inaccuracy.
- Protect all gages with a polysulfide protective coating system. Refer to manufacturer's instructions for application.

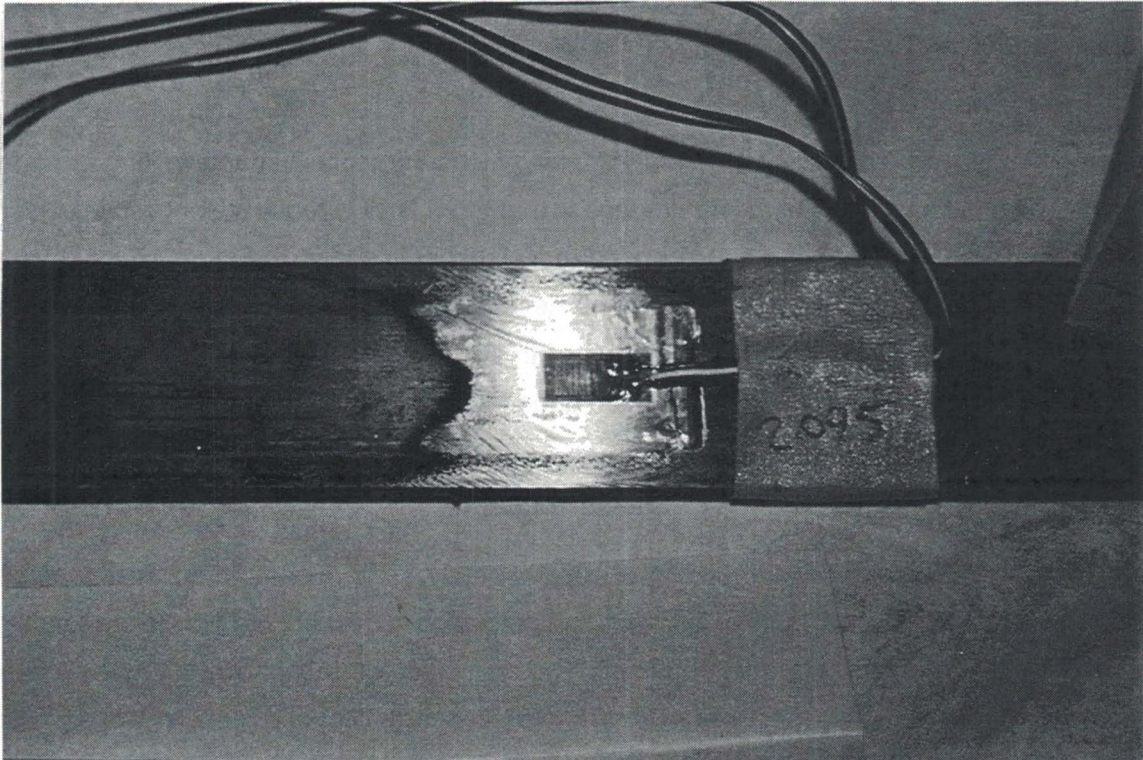


Figure 15. Strain Gage

- Use strain relief in leadwires and sufficient tape to prevent gage damage.
- Keep documentation on gage factors (GF) for each strain gage. Many gages with different GFs look exactly alike. For example, tape a label of the GF next to the bonded strain gage.

Any strain gage of any gage factor (GF) may be used provided that the gage resistance is 350Ω . The system is compatible with 350Ω gages only.

2.3.2 Transducer

Manufactured strain transducers are typically clamped directly to a beam flange or plate—no adhesive bonding is required. Additionally, transducers amplify the strain which can enhance small strain readings. Unfortunately, this can also be a disadvantage; transducers must be calibrated, so the stress is only as accurate as the calibration. After extended use, transducers require recalibration to ensure proper readings. Transducers that are not properly or frequently calibrated will produce bad results. Other disadvantages of transducers include:

- Limited use. Only on flat surfaces large enough for a transducer to be clamped flush, such as beam flanges.
- Proper care and handling. Strain gages must be protected against damage; bars must be protected against disfigurement and yielding.

The connection of strain gages to the transducer is very critical. The transducer will appear to operate properly even if gages are improperly sequenced. The color chart in Table 2 should be followed carefully to ensure that the colored wires are correctly coordinated with the pin letters.

Figure 16 shows how the transducer strain gages are to be connected to one another and to the connector. Two of the gages will always measure the same sign, i.e. two gages will be in tension when the other pair is in compression. These pairs are indicated in the sketch with T1, T2, C1, and C2. This does not mean that T1 and T2 will always be in tension; it is used as a labeling system to show how the gages are to be oriented with respect to one another. Depending on the type of transducer used, all four gages may measure the same magnitude of strain, while for other transducers, one pair will measure the primary strain of the transducer and the other pair will measure the Poisson strain. For the latter case, the primary pair will be labeled as the “tension” gages and the Poisson pair will be labeled as the “compression” gages.

Transducers are very simple to use in a testing situation, but great care must be taken to ensure that no errors are made during construction. Calibration will be the true test of proper wiring of the transducer.

Strain transducers are not supplied with the data acquisition system constructed for this project. Transducers may be purchased from manufacturers of data acquisition equipment or they may be constructed in-house.

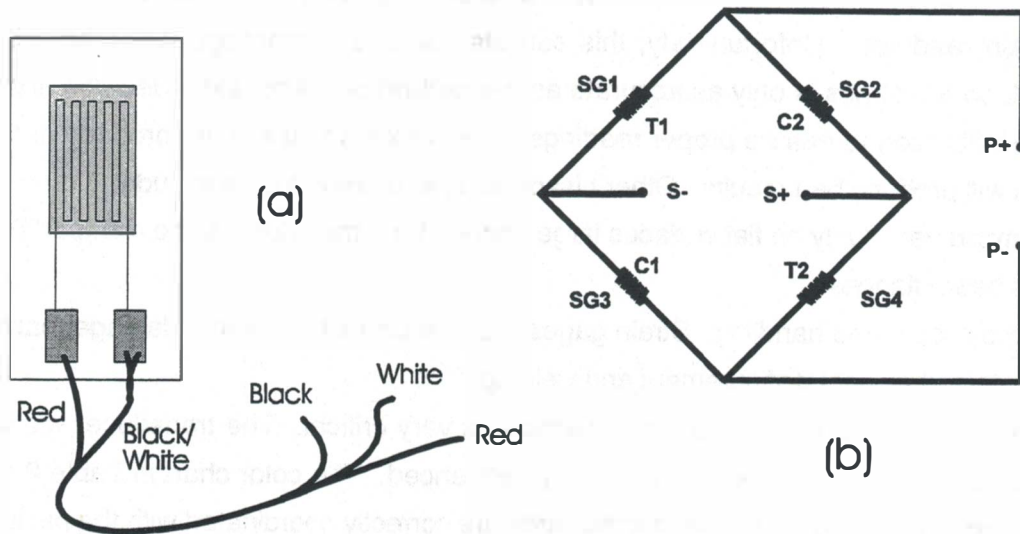


Figure 16. Strain Gage Wiring. (a) Strain gages have leadwires composed of three conductors. Leadwire assembly is identical for individual strain gages and for gages of transducers. (b) The full bridge schematic for transducers is shown once again. Reference the SG numbers with Table 1 and Figure 13 for cable construction. The labels C1, C2, T1, and T2 are given to indicate tension and compression.

2.4 Portable Computer System

All software necessary to conduct tests and operate the DL is installed on the portable computer system (PCS). The computer is a Gateway Colorbook 486 with a microprocessor speed of 66 MHz and a memory capacity of 250 megabytes of hard disk space and 4 megabytes of RAM. The power cord and power transforming unit for battery recharging are pictured with the computer in Figure 17. All system disks and operation manuals are delivered with the computer. Information regarding the care and use of the PCS may be found in the manufacturer's operation manuals.

The computer is supplied with two batteries, with a total operating time of approximately five hours. To conserve power the PCS may be plugged into a portable generator at the test site. However, the PCS should not be plugged into any external power source while in communication with the DL. The electrical noise generated by the power transmission will alter the signals to and from the datalogger. Since the PCS will be powered primarily by battery during testing, both batteries should be fully charged prior to field excursions. Batteries will charge only when the PCS is turned off and can take up to 2 hours to become fully charged.

2.5 SC32A

The SC32A (Figure 18) is provided by Campbell Scientific and is required for direct link communications between the DL and the PCS. The SC32A manages file transfers from the computer to the DL and converts 21X logic to logic compatible with the computer [Campbell Scientific, Inc., 1992]. Refer to the Campbell Scientific manual for more information regarding the SC32A unit.



Figure 17. Portable Computer System (PCS)

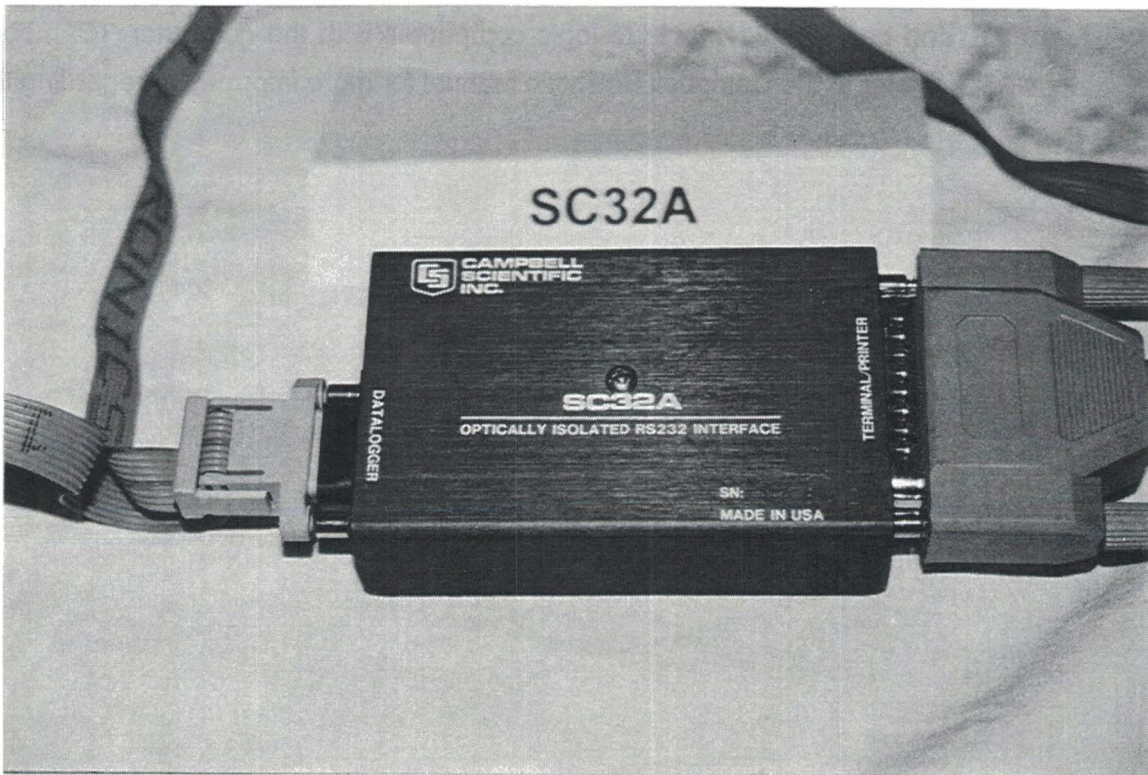


Figure 18. SC32A

CHAPTER 3

DATA ACQUISITION SOFTWARE

The seven executable programs listed below are used to conduct a test. All of the programs except GT.EXE and TELCOM.EXE were written specifically for this project. GT and TELCOM are input/output programs provided with the DL by Campbell Scientific.

1. FRAME.BAT. A batch program that manages and executes all other programs in this package.
2. PROG.EXE. The main program for user interaction and test management.
3. GT.EXE. Campbell Scientific program called Graphterm. GT downloads files to the DL, sends the computer time, and monitors inputs.
4. TELCOM.EXE. Campbell Scientific program for collecting data from the DL.
5. COLLECT.BAT. A short batch program used to execute TELCOM. Also used as a Boolean expression within FRAME.
6. RESET.BAT. A batch program that restores program variables.
7. PLOT.EXE. Program used to plot the results of a truck test to the screen.

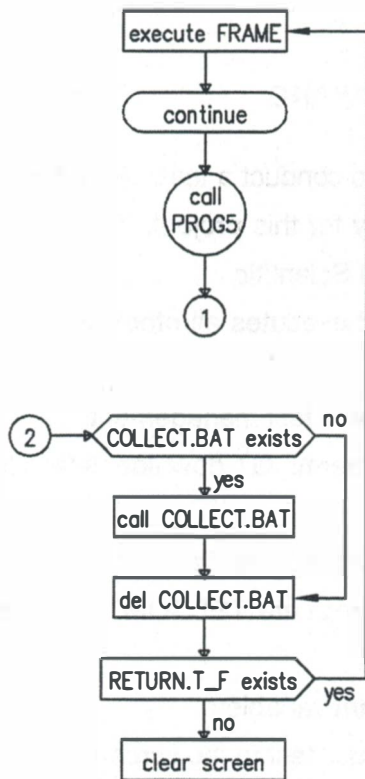
In addition to the programs listed above, six files are created for data management. More detailed information regarding the programs listed above and the data files is provided in the following sections.

A flowchart for the complete software package is shown in Figure 19. The flowchart is written in sufficient detail to allow the reader to follow the interconnection of the programs, subroutines, and files. A list of every variable assignment is not provided within the flowchart. Variable assignments may be found in the fully commented source code provided in the Appendix.

3.1 FRAME.BAT

All data acquisition sessions are started from the batch program FRAME, and control is immediately passed to PROG. Beginning the session in a batch program was made necessary by a software conflict that can occur when collecting data. In the first versions of the software, sessions were started from PROG, and data collection was initiated by a DOS SHELL command calling GT. This procedure resulted in two files being opened simultaneously. Conducting data collection in this way produced a conflict in the connection link between the computer and the DL. This conflict does not occur when data collection is accomplished by calling TELCOM from a batch program. When a software user requests a data collection, PROG returns control to FRAME, where commands for data collection are executed.

Following data collection, FRAME requires a loop to return to PROG so that the user may provide additional instructions. A condition statement loops control back to the line in the batch



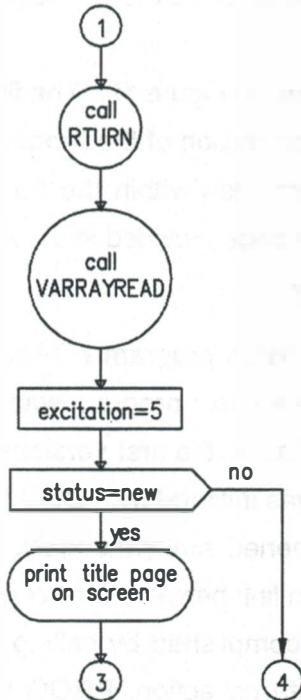
FRAME is a DOS program that calls the quickbasic programs which set up the files used to drive the datalogger. FRAME also calls the batch files which issue the commands to the datalogger. Communication problems develop when datalogger commands are issued from within a quickbasic program.

PROG5 is the quickbasic program used to set up the files used to drive the datalogger.

Control is passed to location 1 below, which is the beginning of PROG5.

Location 2 is within PROG5. Control passes back to this point when the user issues the command to collect data. COLLECT is a batch program created by PROG5 to collect data from the datalogger.

RETURN.T_F is an empty file created by PROG5 to set up a loop within FRAME. If RETURN.T_F exists, the user has not selected the quit option in PROG5.



Beginning of PROG5.

Creates the file RETURN.T_F.

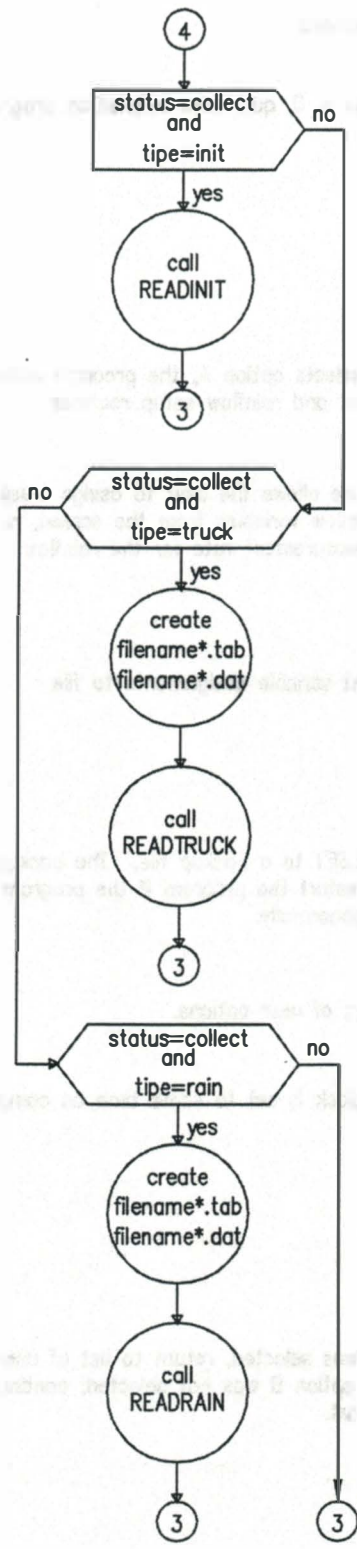
Reads default values for variables from VARS.SET.

Sets excitation voltage for the datalogger.

Status must equal new on the first loop through the program. If status is not equal to new, the user has been working with the program and the title page is not printed.

Location 4 is at the top of the next page. Location 3 begins the user selected options.

Figure 19. Flowchart for FRAME.BAT



If both equalities are satisfied, data has been collected for the purpose of initializing the all output to a constant reference value.

Subroutine used to read the collected data and compute the required offset for each channel.

Moves ahead to user selected options.

If both equalities are satisfied, data has been collected for a truck test.

Files are created to store the truck test data. The * takes the place of a letter used to differentiate each different set of data.

Formats and stores truck test data.

Moves ahead to user selected options.

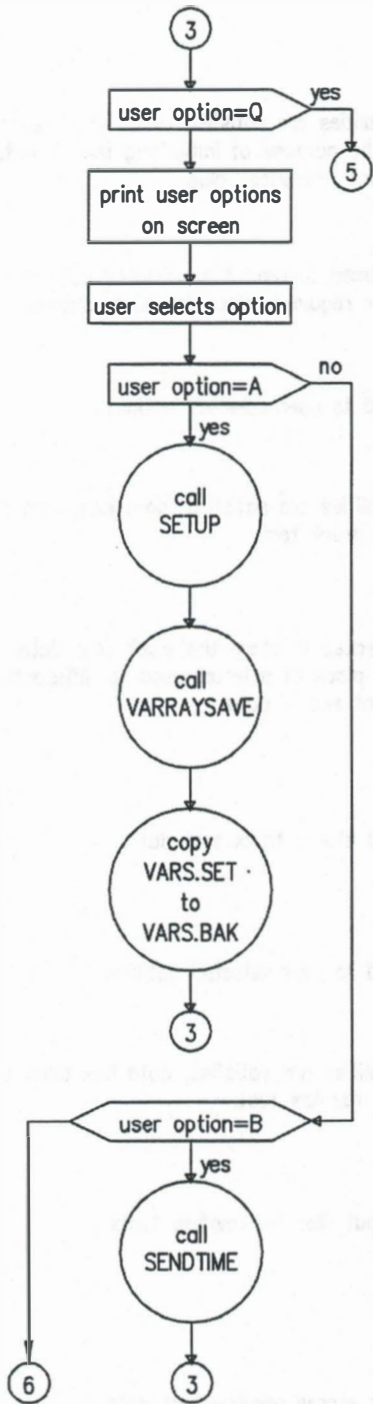
If both equalities are satisfied, data has been collected for a rainflow test.

Creates output files for rainflow tests.

Formats and stores rainflow test data.

Moves ahead to user selected options.

Figure 19. Continued



Start user options

If user option = Q, quit data acquisition program.

If the user selects option A, the program enters the truck test and rainflow setup routines.

This subroutine allows the user to assign truck test and rainflow variables from the screen, and computes measurement rate for the rainflow test.

Prints current variable assignments to file VARS.SET

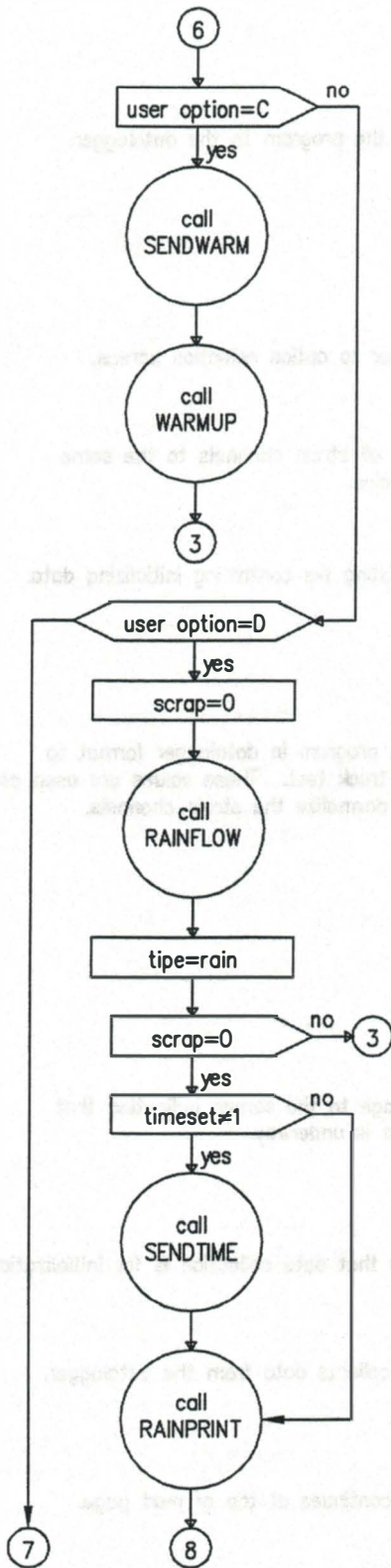
Copies VARS.SET to a backup file. The backup file is used to restart the program if the program terminates abnormally.

Return to list of user options.

Datalogger clock is set to same time as computer.

If option B was selected, return to list of user options. If option B was not selected, continue down flowchart.

Figure 19. Continued



Continue from preceding page.

Selection of option C puts datalogger in warmup/standby mode.

This subroutine starts a current running through strain gage circuits.

Prints page to screen indicating that warmup is underway.

Returns user to option selection screen.

Option D initiates the rainflow test.

Prints page to screen showing variables to be used in rainflow test.

The type of test being conducted is set of rainflow.

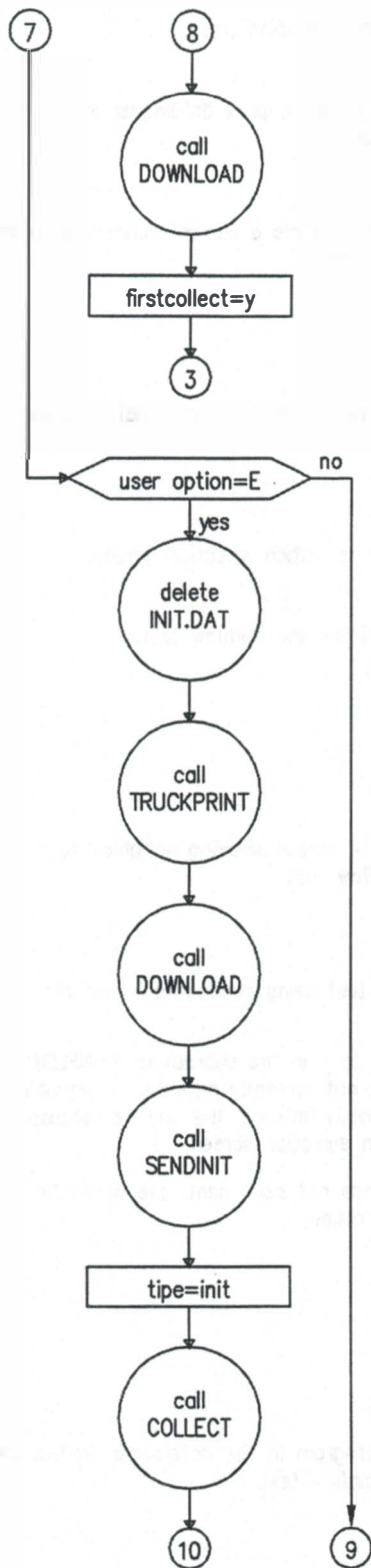
Scrap is set to 1 in the subroutine RAINFLOW if variables are not correctly entered. If variables are not correctly entered, the user is returned to the option selection screen.

If the time has not been sent, the subroutine SENDTIME is called.

Prepares a program in the datalogger format to conduct a rainflow test.

Flowchart continues at top of next page.

Figure 19. Continued



Downloads the program to the datalogger.

Returns user to option selection screen.

Normalizes all strain channels to the same constant value.

Deletes existing file containing initializing data.

Prepares a program in datalogger format to perform a truck test. These values are used as offsets to normalize the strain channels.

Prints a page to the screen indicating that initialization is underway.

Establishes that data collection is for initialization purposes.

Computer collects data from the datalogger.

Flowchart continues at top of next page.

Figure 19. Continued

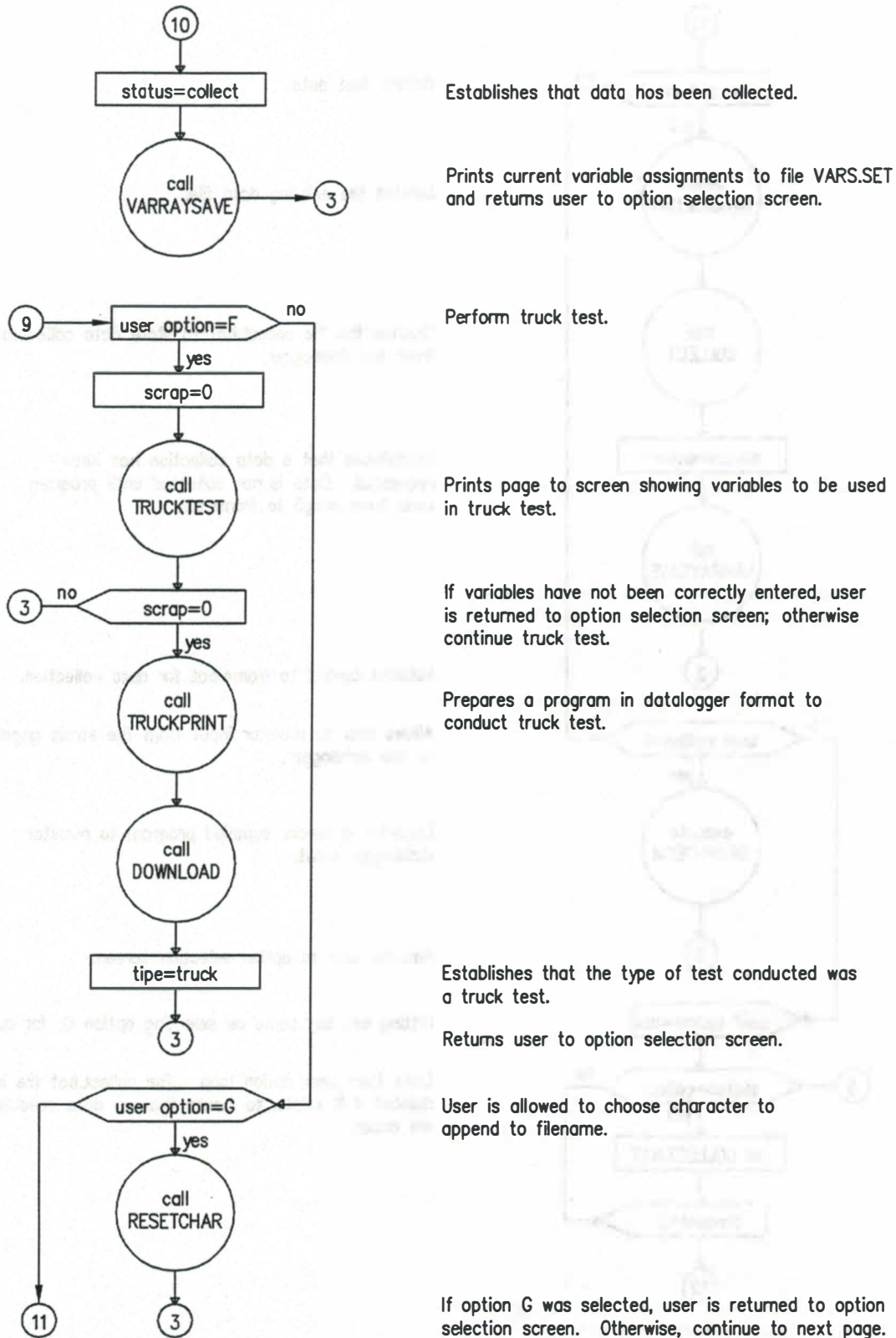


Figure 19. Continued

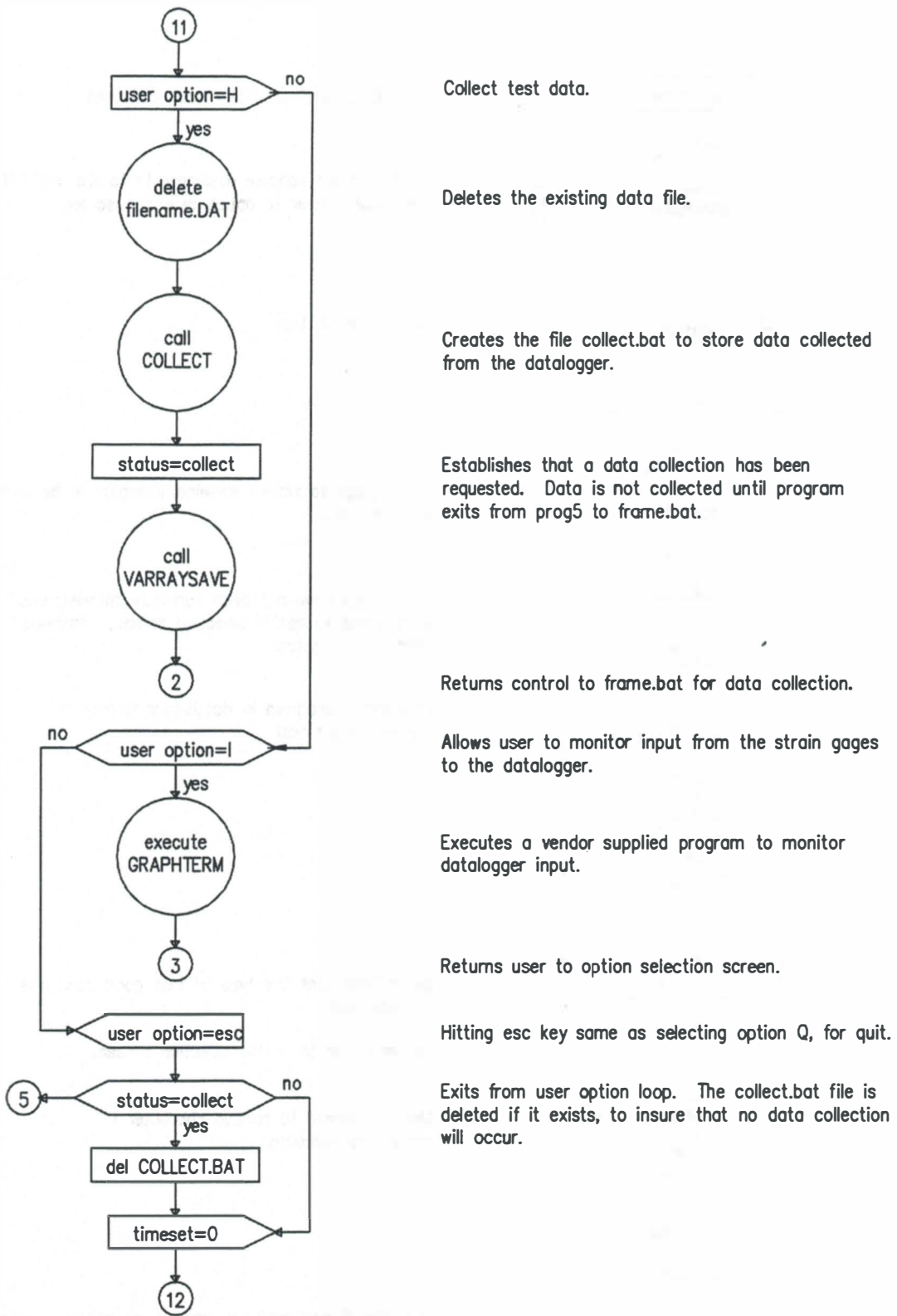
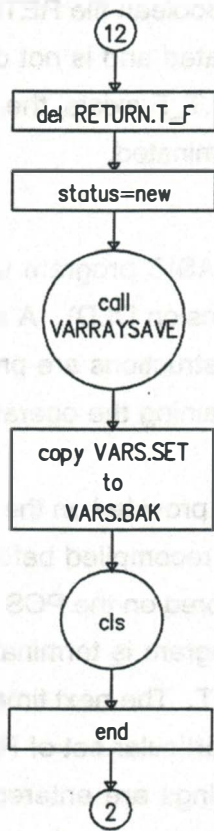


Figure 19. Continued



The file RETURN.T_F is deleted to end the loop in FRAME.BAT.

Status is set to new in preparation for the next execution of FRAME.BAT. Status must equal new for the first loop in FRAME.BAT.

Copies existing variable assignments, including status=new, to VARS.SET.

Copies VARS.SET to a backup file for use if the program terminates abnormally.

Clear the screen.

Ending PROC5 automatically returns the user to FRAME.BAT.

Figure 19. Continued

program which executes PROG. The condition is met with the Boolean file RETURN.T_F. This dummy file is created by PROG.EXE when the program is initiated and is not deleted until the user exits the program with the Quit option. If the file RETURN.T_F exists, the batch file loops back to the beginning; if the file does not exist, the batch file is terminated.

3.2 PROG.EXE

The main program, PROG, is a compiled stand-alone QBASIC program which translates user input parameters into datalogger downloadable files (extension DLD). A series of menus presents options and requests parameter inputs. On-screen instructions are provided for most menu functions and options. Chapter 4 is devoted to fully explaining the operation of the main program.

If it becomes necessary to modify the source code, which is provided on the PCS hard drive and listed in the appendix to this report, the program must be recompiled before the modified version will run. Software for compiling a QBASIC program is stored on the PCS hard drive.

PROG has automatic default settings. Every time the program is terminated, the current values of all global variables are saved to the data file VARS.SET. The next time the program is activated, these same settings are restored. For example, a particular set of Rainflow settings may be adopted as a standard for all tests. Once these settings are entered for a test, the values will remain as defaults for subsequent test Setups, until changed by the user.

3.3 GT.EXE

GraphTerm is one of two programs provided by Campbell Scientific to access the DL. GT is used to download files and, unlike TELCOM, is executed from PROG with a DOS SHELL command. There are no connection problems associated with downloading programs in this manner.

GT requires a station file with interfacing parameters. The station file for the current application, entitled OSU.STN, is installed on the hard drive of the computer. Users should not encounter the station file unless the file is accidentally erased or new parameters are required. Instructions for creating or editing the station file are found in the Campbell Scientific Manual. The parameters for this file are listed in Table 3.

The three functions with which GT is employed are (1) sending the computer time to the datalogger, (2) downloading a datalogger program, and (3) monitoring input channels. The program GT is always run in the background of PROG. The user will only see the screen switch to different menus and displays. Knowledge of GraphTerm operations are not necessary except for occasional use of the ESC key to return to PROG. Additional information regarding use of GraphTerm to monitor input channels is provided in Chapter 4.

3.4 TELCOM.EXE

TELCOM is another program provided by Campbell Scientific, and is the collection counterpart to GraphTerm. Although GT will perform data collections, a representative from Campbell Scientific recommended using TELCOM for the particular application of interest here. In the current application, TELCOM is used exclusively for data collection. A station file is required to provide for the computer the necessary information to connect to the DL. The same file, OSU.STN, is used by TELCOM and GT. When a collection is completed, all data are saved to a file with the extension DAT. The name for this file is derived from the Maintitle parameter which is provided by the user in PROG.

3.5 COLLECT.BAT

The batch program COLLECT is created by PROG when the user issues the Collect Test Data command. PROG then exits to FRAME, where COLLECT is executed. COLLECT contains a single line which calls TELCOM and provides necessary parameters. COLLECT is deleted by FRAME immediately after TELCOM is called.

3.6 RESET.BAT

If FRAME is terminated manually (CTRL-C or CTRL-ALT-DEL), the program variables may not be properly saved. An attempt to reboot FRAME may result in an error loop that can only be exited by resetting the computer. RESET is a short program that restores a version of VARS.SET to one that will disengage the loop.

3.7 PLOT.EXE

This program is used to plot the results of truck tests immediately after the tests are conducted. Test personnel can visually examine the data to ensure that the test and data collection are proceeding as expected. The executable program is stored as compiled QBASIC.

3.8 Files

3.8.1 VARS.SET

As discussed above, PROG must be terminated and control returned to FRAME to collect data. When PROG is terminated, all variable assignments previously made in PROG are lost. If the user wishes to continue working with the software, it would be necessary to re-enter all of the variable assignments. To avoid this time-consuming process, a file entitled VARS.SET is used to store the values and settings of all program variables. When PROG is re-entered, all variables are restored from this file through a subroutine. This feature was extended to encompass every startup. Since many variables remain unchanged, the user is able to implement automatic default settings. The parameters which remain the same from test to test will be saved and restored automatically. If the user wishes to change a variable, the Setup option is selected and the new value is entered manually. When PROG is terminated, the new value becomes the default value.

3.8.2 RETURN.T_F

RETURN.T_F is a dummy file created by PROG to control a loop within FRAME. RETURN.T_F is created early in PROG. While in PROG, if the user issues the Collect Test Data command, PROG terminates and control passes to FRAME. After data are collected, FRAME determines whether or not RETURN.T_F exists. If RETURN.T_F exists, PROG is again executed from within FRAME and the user can issue another command. If the user issues the Quit command, RETURN.T_F is deleted, PROG is terminated, and control passes back to FRAME. FRAME again determines if RETURN.T_F exists. If the file does not exist, FRAME terminates and the session is ended.

3.8.3 OSU.STN

As discussed in Sections 3.3 and 3.4 above, GT and TELCOM require access to a station file which contains the parameters necessary for the computer to communicate with the datalogger. For the current application this station file has been named OSU.STN and parameters are listed in Table 3.

3.8.4 FILENAME.DLD

FILENAME is a name provided by the user when the Setup command is issued. The name must conform to DOS restrictions. The DLD extension indicates that the file contains information to be downloaded to the datalogger. The file is a list of datalogger instructions prepared by PROG on the basis of commands issued by the user.

3.8.5 FILENAME.DAT

FILENAME is again the name provided by the user during Setup. This file exists in two forms: FILENAME.DAT and FILENAME*.DAT. FILENAME contains data directly downloaded from the DL. FILENAME* contains data that has been reformatted by PROG into a more readable form. The * in FILENAME* represents a letter that is assigned by PROG. The letter advances in the alphabet each time a test is run. This allows the user to enter only one FILENAME when a series of tests is run. The FILENAME* increments by one letter for each test so that the data files are not overwritten. In other words, the data files stored after a series of three tests could be named TESTA.DAT, TESTB.DAT, TESTC.DAT. The file TEST.DAT would be overwritten by each subsequent test.

3.8.6 FILENAME*.TAB

As discussed in the two preceding sections, FILENAME is the name provided by the user during Setup. The * represents a letter appended to FILENAME to differentiate data files saved for a series of different tests conducted at the same location. FILENAME*.TAB contains data from the DL which has been reformatted into a tabular form for easier interpretation by the reader.

CHAPTER 4

OPERATING INSTRUCTIONS

Software is provided with the DAS to facilitate communication between the engineer conducting the test and the Campbell Scientific datalogger. The following sections describe the user selectable menus and options available from the menus. To execute the data acquisition software, the user must enter the DOS mode, change to directory FRAME, and type "frame." The title screen will appear and the user is instructed to press return to begin.

The first menu available to the user is the Main Menu which is presented in Figure 20. The menu items are listed in the order of sequential execution. This does not imply, however, that all tests must be performed in this order or that all tests must include each of the steps A through I; the menu was designed to guide the user through the typical sequence of steps that most tests will follow. Menu selections are made by typing the letter which appears in parentheses.

4.1 Option A—Setup

To begin a new test or a new series of tests, Setup must be run. All tests require information from the user pertaining to the configuration of the measurement devices, gage factors, and Rainflow Settings. This information is entered through two menu screens. The first screen is presented in Figure 21 which requests the title and the channel status for all 8 inputs. The second screen is the "Rainflow Settings" Screen. This menu (Figure 22) allows the user to set parameters for the Rainflow Histogram. These settings are based on command 81 from the 21X Datalogger user's manual. If the Setup is for a Truck Test, the Rainflow Settings are irrelevant and may be bypassed by typing ENTER for each prompt. It is not permissible to set any of the numerical values equal to zero on these two screens.

Once all information is entered, it is saved to a file to be accessed each time the main program (PROG) is reactivated. Note that any previous entries appear as defaults (see menu in Figure 21). This is helpful if the same or nearly the same set of information is required for consecutive tests. The user may keep any or all of the default settings by typing the ENTER key with no entry change at each prompt.

4.1.1 Title and Initializing Time

Every test requires a title for file assignments. Any 6-character name may be used, provided that it conforms to the normal DOS file name rules. Useful titles contain some significant information related to the structure and/or the test. A counting character, which is appended to all output files, provides a labeling system for output files of multiple tests with the same title (see Section 4.7).

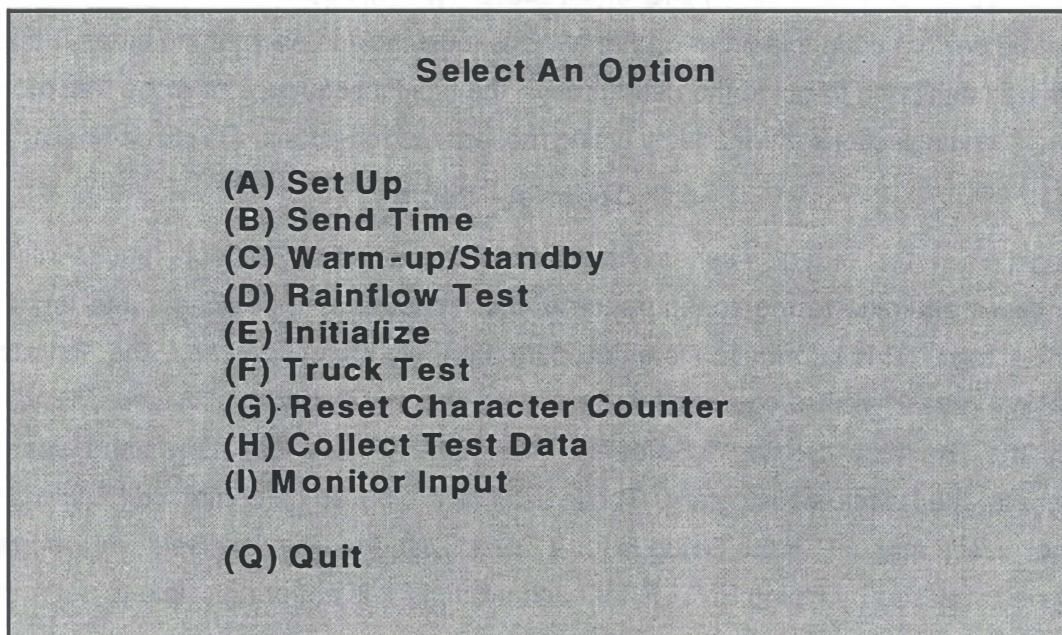


Figure 20. Main Menu Screen. User enters the letter corresponding to the desired function. Typing Q or the ESC key will exit the program to DOS.

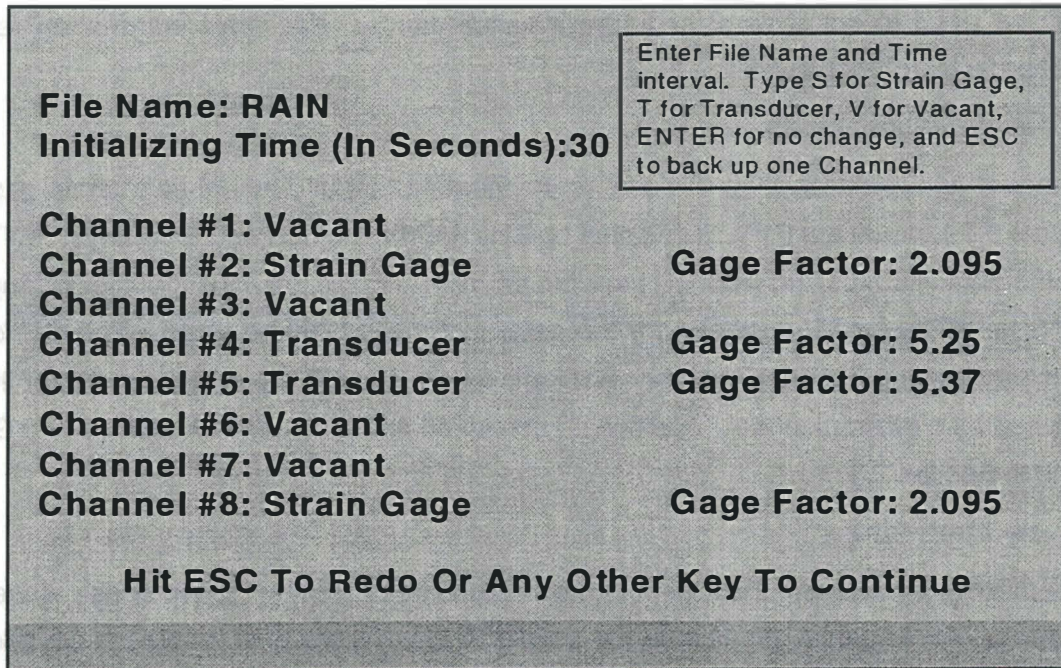


Figure 21. Setup Menu. This menu is used for both Rainflow and Truck Tests.

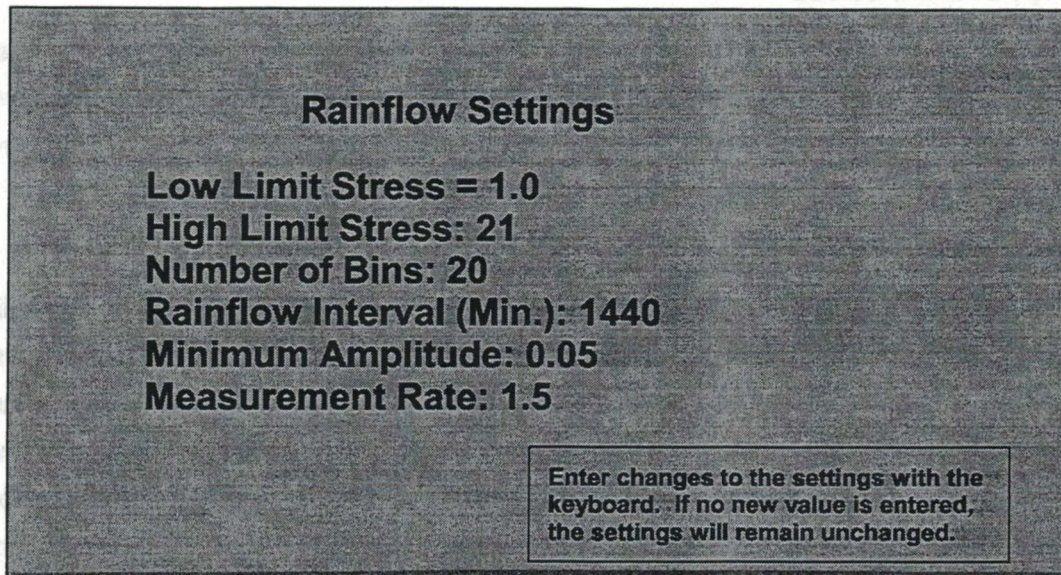


Figure 22. Rainflow Settings Menu

The initializing time is the duration of the initializing or zeroing test. The data collected for this test will be used to set a zero for future measurements. For more information regarding initialization, refer to Section 4.5.

4.1.2 Channel Assignments

Channel Assignments allow the user to designate an Input channel as a strain gage (“S”), transducer (“T”), or vacant (“V”). Additional options are the ENTER and ESC keys. ENTER will accept the default status and ESC will back the prompt up to the previous Input for editing.

If “S” or “T” is typed, a prompt for the gage factor (GF) will be given. The GF for strain gages is provided by the manufacturer. For transducers, the GF is a calibration factor that must be obtained by a calibration test. Additional information on measurement devices and GFs may be found in Section 2.3.

4.1.3 Low Limit Stress

The user must estimate the lowest future live load stress relative to the stress at the time of initialization. For instance, if stresses are initialized when there is no traffic on the bridge, the stresses at this time become zero to the data acquisition system. If it is expected that traffic will only cause tensile stresses, the Low Limit should be input as some small number such as 0.1. However, if traffic is expected to cause a decrease in stress or a compressive stress of 10 ksi, -10 should be input as the Low Limit. This limit is used as a lower boundary for computing the size of the divisions (bins) in the Rainflow histogram.

4.1.4 Upper Limit Stress

This limit is used as an upper boundary for computing the size of the Rainflow histogram. The Upper Limit should be greater than the largest stress value expected. The effectiveness of the histogram may be optimized by choosing a value close to the actual maximum stress. Results from a Truck Test can be helpful in selecting both the lower and the upper limits.

4.1.5 Number of Bins

A “counting matrix” is established by the datalogger based on the upper limit, lower limit, and number of amplitude bins. The user should be selective in choosing each of these parameters to obtain optimum output form. The amplitude range is the difference between the upper and lower limits, and the number of amplitude bins (maximum of 50 allowed by datalogger, maximum of 20 recommended for satisfactory performance—see Section 4.1.8 for additional information) is the number of histogram divisions the DL will use to count cycles. The size of each bin is calculated by dividing the amplitude range by the number of amplitude bins. Cycles which have an amplitude greater than the Upper Limit are counted in the last bin.

4.1.6 Rainflow Interval

Rainflow Tests are divided into test intervals. Data points are maintained in intermediate storage during the interval. At the end of the interval, the data are transferred to final storage until data are collected from the DL. It is recommended that multi-day tests have a test interval of 24 hours (1440 minutes). This will encompass the majority of Rainflow Tests.

4.1.7 Minimum Amplitude

Very small cycle amplitudes due to vibrations are of little consequence to fatigue life prediction and may be viewed as noise. Counting such cycles will do nothing more than occupy memory in the DL final storage. The Minimum Amplitude parameter is used to eliminate these small cycles which will distort the effective stress range calculation and quickly consume the DL memory during testing. This setting is a way of informing the DL of the triviality threshold. A quick view of Monitor Input (Option I) while no traffic is on the bridge is a good way to determine the order of magnitude of the minimum peak-valley distance. Values must be less than the bin width (see calculation example in Figure 23).

4.1.8 Measurement Rate

During a Rainflow test, the DL reads and stores strain data at a set rate. The rate at which data can be acquired and stored decreases as the number of active channels and number of bins increases. If the measurement rate is set too low, the DL cannot complete one set of readings before another starts. When this occurs, errors are generated in the output. To arrive at a reasonable measurement rate for the user provided number of channels and number of bins, the measurement rate is computed internally. The result of this internal computation is shown on the computer monitor as the measurement rate.

4.1.9 Input Summary

The last screen of Setup displays the Input information. The graphic, which may be seen in Figure 24, resembles the front of the interface box with Input 1 in the lower left corner and Input 8 in the upper right corner. Typing Y or ENTER will accept the test parameters, ESC will abort Setup, and any other key will allow the user to redo Setup.

4.2 Option B—Send Time

The second option from the Main Menu (see Figure 20) is Send Time. The internal clock of the DL may be synchronized with the computer clock using this command. Before the time is sent to the DL, the user is given the option to change the time and date of the computer clock. Once the time is sent, an internal flag is set high. Both the Rainflow and Truck Test subprograms include an algorithm to determine whether the time has been sent. If the flag is low, the computer will automatically download the time with the test program. Because of this feature, the Send

Lower Limit = 1 ksi

Upper Limit = 21 ksi

Amp Bins = 20

Bin width = $(21 - 1) / 20 = 1.0$ ksi

Figure 23. Bin Calculation Example. Each bin will have a width of 1.0 ksi. A cycle with an amplitude of 16.8 ksi will fall into bin number 17 which counts amplitude cycles between 16.0 and 17.0.

Rainflow Settings

Low Limit Stress: 0
High Limit Stress: 25
Number of Bins: 25
Rainflow Interval (min): 1440
Minimum Amplitude: 0.05

5 Txdcer GF = 5.37	6 Vacant	7 Vacant	8 StrGge GF = 2.095
1 Vacant	2 StrGge GF = 2.095	3 Vacant	4 Txdcer GF = 5.25

Is This Information Correct ('Y' To Proceed)
('Esc' To Abort)
(Any Other Key To Redo)

Figure 24. Input Summary Screen

Time option must only be selected if the DL is powered off and on during a test session. It is particularly important that time be sent before Rainflow tests since the DL clock controls the Rainflow Interval start and stop times.

4.3 Option C—Warm-Up/Standby

Strain values will tend to drift for about the first 20 minutes of excitation. To avoid this drift, it is recommended that gages be activated for a period of time to allow the circuitry to warm up to a steady-state condition where readings will be more reliable. The amount of time required for this warm-up period may vary, but is usually 10 to 20 minutes. This option allows the user to select the time interval and immediately begin the warm-up period. A dummy program is sent to the DL to activate the strain gages with excitation voltage only; no readings are stored in memory, which will help conserve battery life. The computer will notify the user with an on-screen message when the warm-up time has elapsed.

The amount of drift decreases as the gages warm up. If time does not permit a full 20 minutes to properly prepare the gages, a shorter period of time (5 to 10 minutes) can still help reduce drift errors.

Option C can also be used to maintain a current through the gages between tests, allowing the gages to remain active. The Standby option is similar to the Warm-Up option, except the time interval is indefinite. Pressing ESC will return the user to the Main Menu. The gages will remain in Standby mode until a test is initiated.

4.4 Option D—Rainflow Test

In order to calculate fatigue life, an effective stress range must be determined. This stress range is best computed from a histogram of stress cycles collected over a period of time, usually days. The DL has a Rainflow Histogram algorithm that will collect data to calculate the effective stress range.

To perform this test, the user must first run Setup. When Setup is complete, selecting D from the Main Menu will begin the Rainflow Test. An Input Summary Diagram will be displayed to allow verification of the test parameters. If no corrections are necessary, the test will begin when the operator selects the option to proceed.

It is recommended that tests extend for a duration of several days with 24-hour (1440-minute) intervals. The maximum test duration is dependent on number of bins, number of channels, interval lapse, and battery life. The rate of the DL memory consumption is increased with number of bins, number of channels, and interval lapse; increasing each of these will increase the number of data locations that must be saved in final storage. If all memory locations are filled, the DL will overwrite the data beginning with the first set. For a rainflow interval of 24 hours, test duration will be restricted by the battery life which is approximately four weeks. To

calculate the amount of memory consumed by a test, the following formula derived from the memory capacity of the DL and the memory used by a Rainflow Test may be used:

$$\overset{14,556}{\text{Integer}} \quad 16,926 - [4 + (2 \times \text{no. of bins}) \times \text{no. of channels} \times \text{no. of intervals}]$$

The value of 16,926 is the final storage capacity; the remaining numbers and variables are the amount of memory used. The integer 4 accounts for a labeling value and the time the data record was made. Information on DL memory capacity may be found in the Campbell Scientific Inc. 21X Operator's Manual.

Once the test parameters have been sent to the DL and the Main Menu returns to the screen, the Monitor Inputs option (see Section 4.9) may be selected to verify that all channels are functioning properly. If any entry registers ± 9999 , there is an open circuit on that Input. All connections should be checked until the short is located and mended. When the test is satisfactorily in progress, the program may be exited and the computer powered down and disconnected.

Although the DL immediately begins reading measurement devices and recording data, the first saved 24-hour interval will not begin until 12:00 midnight. The data collected between the time the test is initiated and midnight is a partial interval, and all data collected during this time will be dismissed.

The data that are collected are processed into two forms of output. Files with the TAB extension include the calculated value of the effective stress range for each channel interval. Files with the DAT extension contain data useful for plotting.

4.5 Option E—Initialize

Accurate interpretation of the data requires that all inputs be initialized to a common value. All traffic should be blocked from the structure during this process. The initialization creates a reference which is the basis of all measurements. For a truck test, this reference is always zero. Therefore, a recorded truck test stress of 3.5 ksi is actually a stress change of 3.5 ksi from the initialized state. For a rainflow test, the reference is the absolute value of the Low Limit stress. This shift was necessary for the Rainflow Test because the DL does not include negative stresses in the rainflow count.

INIT time, which is specified during Setup, can range from 10 seconds to 5 minutes. Factors to consider when determining the INIT time are bridge component sensitivity, wind effects, and previous experience. Initialization is essentially a Truck Test with no loads applied. The data values collected over the INIT time are averaged and incorporated into the Truck and Rainflow Tests as offsets. A longer period of time is required if the INIT measurements fluctuate widely. Monitoring the inputs immediately after initialization is one way to evaluate measurement stability.

Collection for the INIT process is automatically executed after the initialization time has elapsed. Once a message appears on the screen indicating initialization is complete, the load testing may proceed.

4.6 Option F—Truck Test

When option F is selected, an Input Summary diagram will be displayed (similar to Figure 24). A prompt will be given to allow the user to abort the test if corrections to the Inputs need to be made. If none are required, the test may begin by pressing any key. The computer downloads the program to the DL and returns the user to the Main Menu. When the user is returned to the Main Menu, the actual Test Truck should be driven over the bridge at a constant speed. As the truck moves over the bridge, the DL is collecting data at a rate of 40 samples per second. On the Truck Test Input Summary diagram, the indicated interval rate is the number of active channels multiplied by forty samples per second. When the truck has moved off the bridge, the Collect Data option (Option H) should be selected immediately. This option actually stops the DL from collecting data and transfers the data in the DL memory to the computer hard drive. Delay in selecting the Collect Data option may cause the first blocks of data to be overwritten by new data.

4.7 Option G—Reset Character Counter

Character counters are used for data collection files. These files are named after the test Maintitle with extensions TAB and DAT. The character counter creates a distinction between different tests on the same bridge, without requiring a new title for each test. Option G will reset the counter to the character A, which will increment alphabetically until it is reset again or until the letter Z is reached.

4.8 Option H—Collect Test Data

Once a test has been activated, it is no longer necessary for the computer to be connected to the DL. Any time the program is terminated, all parameters of the program are saved to a file. This is analogous to a bookmark in a novel; when the program is reactivated, it returns to the Main Menu as if it had never been terminated. This allows the user to run a long test (usually a Rainflow Test) without the computer present. When a test is completed, the computer may be returned to the DL ready to collect the test data.

To collect data after the computer has been reconnected to the DL, execute the program FRAME as described at the beginning of this chapter, then select option H, Collect Data. Both Rainflow and Truck Tests generate two files when the data are collected. For a Rainflow Test, tabular files are given the extension TAB and raw data files are given the extension DAT. Tabular files contain information on effective stress range and average number of cycles per interval. For a Truck Test the information in the two files is basically the same, but the data in the

DAT file are easier to export to a plotting program. The titles for these files will be the same as the MainTitle provided by the user in the Setup mode. Since more than one collection may be necessary on a project, a counter character is added to each pair of collection files. For example, if the MainTitle were "US177", the first collection files might be "US177A.TAB" and "US177A.DAT". The letter A is the counter character and will automatically increment alphabetically with subsequent collections. The user may reset this value to A with the Reset Counter Character option. This is only a bookkeeping parameter to aid in data file organization, and it is up to the user to decide when and if the counter should be reset. If the counter reaches the letter Z, it will roll over to the letter A on the next collection.

4.9 Option I—Monitor Input

Once a test has been initiated, the Monitor Input option is a good way to verify that all equipment is properly connected. Monitor Input is a function available through the GT program. When this option is selected, the user may be asked to enter a file name that contains the labels. Press the ENTER key to accept the default name. The Monitor screen will display 11 channels with values to the right. The Input numbers which are being used by the test do not necessarily directly correspond to the channel numbers on the screen. For example, if Inputs #2, #4, #5 and #8 are being used, channels 1 through 4, respectively, will show the stress readings, and channels 5 through 11 will be blank. An open circuit will display a ± 9999 .

To return to the Main Menu, hit the ESC key followed by Q.

4.10 Option Q—Quit

Typing Q or ESC will terminate the program. All variable settings are saved to a data file. When the program is reactivated for the next session, these settings will be restored as though the program had never been terminated.

4.11 Plot

After a truck test is complete and the data have been saved on the hard drive, it is recommended that a plot of the data be examined to ensure that the test and data collection are proceeding as expected. To generate a plot of stored data, exit the data collection portion of the software by selecting the Q option as described above. A normal exit from data collection returns the user to the FRAME subdirectory. At the C:\FRAME> prompt, type "plot" and press return. The message "ENTER THE NAME OF THE FILE TO BE PLOTTED INCLUDING THE EXTENSION?" will appear on the screen. At this point enter the name of the file plus the extension (i.e. testa.dat) if the file is stored in the FRAME subdirectory. If the file is not stored in FRAME, the name of the directory containing the file must precede the file name (i.e. C:\data\testa.dat).

Once a data file is selected, the new message "ENTER THE TIME TO START PLOTTING (in sec)?" should appear on the screen. Any time (in seconds) can be entered providing it does not exceed the maximum time of the data. The maximum time of the data can be determined by examining the ASCII data file. When the start time has been keyed in, press the enter key. The message "ENTER THE TIME TO STOP PLOTTING (in sec)?" should next appear on the screen. The user must enter a stop time greater than the start time and press enter.

The next questions which appear on the screen determine which channels are plotted. The message "WOULD YOU LIKE TO PLOT CHANNEL 1 (y or n)?" will be repeated for channels 1 through 8. After y or n has been selected for each channel, the plot will be generated. Axes on the plot will be labeled with minimum and maximum values for time and stress. The axes will appear as solid black lines. Data for each channel are color coded as 1-blue, 2-green, 3-cyan (light blue), 4-red, 5-magenta (purple), 6-brown, 7-dark gray, and 8-yellow.

Note that the colors will not correspond to the DL channel numbers if not all of the channels are plotted. For example, if the DL has recorded data for three channels, and only channels 1 and 3 are selected for plotting, channel 1 will plot as blue and channel 3 will plot as green (the second color). To exit the plotting program and return to the subdirectory FRAME, press the spacebar twice.

CHAPTER 5

BRIDGE EVALUATION PROCEDURE

A complete bridge evaluation should include a thorough visual inspection, an analysis of the structure, and a load test. It is preferable that all three tasks be performed by the same engineer or team of engineers. If all three tasks are performed by the same individuals, irregularities identified in the inspection can be more accurately incorporated in the structural model, and load tests can be organized to focus on expected problem areas.

An initial inspection of the structure can be performed from the ground. The purpose of this initial inspection is to locate any gross irregularities in the structure that are not shown on plans or inspection reports, and identify any access problems that must be solved prior to the test date. A detailed visual inspection can be conducted when equipment is available (such as a snoopers or a pole truck) for installation of load testing instrumentation. Complete guidelines for visual inspection are not included in this report. Guidelines for visual inspection are available in other publications [Federal Highway Administration, 1986; Federal Highway Administration, 1995; Parsons Brinckerhoff, 1993].

5.1 Structural Analysis

A structural analysis should be conducted prior to the load tests, with the analytical model constructed on the basis of as-built drawings and information collected in the initial inspection. Generally, a model including the superstructure, deck, and integral railings is adequate; it is not necessary to include the substructure and foundation. The level of sophistication of the model may range from a two-dimensional grid to a three-dimensional finite element mesh.

If a grid model is used, it must include both longitudinal elements (such as girders) and rigidly connected transverse elements (such as floorbeams or diaphragms). In a first analysis, the deck should be treated as fully composite with both the longitudinal and transverse elements, even if it is constructed noncomposite. Any haunch existing above the girders may be incorporated in the model, but this is not required for a first analysis. The deck and integral railing are included in the model by computing elastic transformed section properties of the composite beams. Also in a first analysis, supports should restrain translation but not rotation.

If a three-dimensional finite element model is used, comments in the preceding paragraph with regard to haunch and supports remain applicable. The primary advantage to using a three-dimensional model is that all elements of the model—including the deck, railing, and beam flanges and webs—can be modeled at their true relative elevations. The three-dimensional finite element model provides a more accurate representation of the actual structure. The disadvantages to a three-dimensional finite element analysis are the increased level of technical sophistication

required to properly construct the model and interpret the results, and the large amounts of computer time and storage required to complete the analysis.

Once the model is constructed, the structure should be analyzed under two different sets of loads to serve two different purposes. One purpose of the analysis is to determine critical locations on the superstructure during normal operations. For fatigue life estimates, critical locations are points where weak fatigue details experience high stress ranges, and normal traffic is taken to be the AASHTO fatigue truck. The other purpose of the analysis is to compute stresses at planned strain gage locations when the test truck passes over the bridge. The weight and configuration of the test truck may be selected by the engineer, but a fully loaded dump truck with tandem rear axles provides a heavy concentrated load.

Results of the analyses under the test truck load are then available for comparison to stresses measured during the load test. If measured and computed stresses differ by no more than 20 percent, refinement of the model is not necessary. If the stresses differ by more than 20 percent, but both are below a critical limit (such as the infinite life fatigue limit if fatigue is a concern), refinement is again unnecessary.

If the stresses differ by more than 20 percent and there is a concern that the stresses are too high, or there is a need to compute stresses in another part of the structure, the model may be improved in several ways. One approach would involve adjusting the level of composite action based on a study of measured stresses. If the stress is near zero in the top flange of a girder carrying positive moment and the bottom flange is carrying a relatively high tensile stress, a high level of composite action exists. If the compressive stress in the top flange is approximately equal to the tensile stress in the bottom flange, little or no composite action exists. Another possible improvement in the model could be made by increasing the level of rotational restraint if computed center-of-span positive moments are too high and end-of-span negative moments are too low. Rotational restraint can be incorporated in the model by installing rotational springs.

5.2 Load Testing

Load testing involves the measurement of strains at selected locations on the bridge while the bridge supports traffic. Measured strains are converted to stresses and stored in the DL memory for downloading to the PCS. Traffic supported by the bridge may be a test truck of known weight or normal traffic. Duration of load tests ranges from seconds for test truck loading to weeks for Rainflow cycle counting under normal traffic.

5.2.1 Equipment and Supplies

The data acquisition hardware including the datalogger, interface box, portable computer system, and SC32A are described in Chapter 2 of this report. These items represent the primary nonconsumable components of the data acquisition system. In addition to these items, there are

a number of minor equipment items and consumable supplies which must be available at the test site. Minor equipment items are listed in Table 4 and consumable supplies are listed in Table 5. Brief explanatory notes are provided alongside some of the items in the list. Tables 4 and 5 may be photocopied and used as checklists in preparing for a test.

5.2.2 Strain Gage Installation

The system constructed as a part of this project is capable of acquiring data from eight strain gages or transducers. If information is needed at more than eight locations, it will be necessary to conduct a series of loadings for each set of gage locations. It is common to install two to three sets of eight gages, connect to the first set and apply the load series, connect to the second set and repeat the load series, continuing in this manner until measurements have been made for all sets of gages.

Test personnel should determine where strain gages are to be installed prior to arriving at the test site. In general, strain gages should be installed at expected high strain locations in both positive and negative moment regions. At a given cross section, gages should be installed on both the top and bottom flanges to provide information about composite action. A structural analysis as discussed in Section 5.1 above should be conducted to provide guidance on strain gage location.

Equipment is provided for either adhesive or weldable strain gage installation. The gages function in the same way; the only significant difference is the method of installation. The time required to install adhesive and weldable gages is approximately the same when both techniques have been practiced. Adhesive strain gages are less expensive than weldable gages, so are preferred from an economic standpoint. However, weldable gages must be used if the temperature at the test site falls below 65°F because the strain gage adhesive becomes unreliable below this temperature. The weldable gages can be used at any temperature. There should be no concern over damage to the bridge due to welding; the depth of penetration of the weld is extremely small.

There is a wide variety of strain gage sizes and styles available from several different manufacturers. The data acquisition system constructed for this project will work with any 350 ohm strain gage. Therefore, the choice of size and style is dependent on the application. The strain measured by a gage is the average strain under the gage, so smaller gages will provide a more accurate measure of strain at a point. This accuracy is important if the gage is placed in a region where there is a large variation of stress with position, such as at a point of stress concentration. This accuracy is not important if the gage is placed in a region of uniform stress. The disadvantage to using small gages is in handling. It is more difficult to align the small gages and much more difficult to attach leadwires to solder tabs. It is strongly recommended that short

Table 4. Minor Equipment

- Computer
- Cable connecting PCS and DL (1)
- Cable connecting DL and Interface Box (1)
- Cables connecting Interface Box and strain gages (9)
- 12-volt marine battery—used to power the DL during unattended operation (should be fully charged prior to a test; the battery has been used to power the DL for as long as four weeks without charging; exercise caution in setting the length of the test time period, since loss of power to the DL will cause all stored data to be lost)
- C-clamps—used to clamp the DL and Interface Box to the bridge, and to support the cables extending from the strain gages to the Interface Box (4 @ 2.5 in., 4 @ 3 in., 5 @ 4 in.)
- D-rings (5)
- Chain—used with D-rings as a backup attachment between DL/Interface Box and bridge
- Reflective vests (2)
- Safety glasses (3)
- Electric drill—outfitted with a sanding wheel for cleaning paint and scale from bridge steel in preparation for strain gage installation
- Sanding wheel for electric drill
- Extension cord
- Wire cutters
- Pliers
- Tape measure (25 ft, 30 ft)
- Flashlight
- Strain gage welder/soldering iron—used to attach strain gages to bridge if weldable gages are used and to attach short leadwires to strain gages
- Tweezers (blunt nose)—used for handling strain gages and leadwires
- Tweezers (sharp nose)—used for handling strain gages and leadwires
- Dental probe—used to lift and separate leadwires
- Magnifying glass—used to inspect strain gage installation
- Multimeter—used to test strain gage for open circuits or shorts to ground
- Camera (not provided in kit but should be taken to test site)
- Rope
- Crescent wrench (10 in.)
- Screwdrivers (3)
- Grinding wheel
- Wire wheel
- Caliper micrometer set
- Tiedowns
- Pulley hoist—hooks over beam flange and may be used for lifting

Table 5. Consumable Supplies

- ___ Isopropyl alcohol
- ___ Paper towels
- ___ Sanding disks
- ___ Degreaser
- ___ Gauze pads
- ___ Surface conditioner
- ___ Surface neutralizer
- ___ 400 grit sandpaper
- ___ 220 grit sandpaper
- ___ Cotton swabs
- ___ Weldable strain gages
- ___ Adhesive strain gages
- ___ Strain gage adhesive and catalyst
- ___ Cellophane tape
- ___ Drafting tape
- ___ Solder
- ___ Rosin flux
- ___ Rosin solvent
- ___ Leadwire -- a short length of insulated light gage strain gage wire should be available in case it is needed to prepare additional strain gages
- ___ Protective coating
- ___ Plexiglass plate (4 in. x 4 in.) -- strain gages are taped to this thin plate in preparation for installation
- ___ Steel plate (4 in. x 4 in.) -- strain gages may be taped to this thin plate in order to solder short leadwires to solder tabs
- ___ Duct tape
- ___ Computer disks
- ___ Heat shrink tubing

pieces of leadwire be soldered to the gages before traveling to the test site. These short leadwires can be clamped to the cable extending to the junction box after the gages are installed. It is extremely difficult to apply solder after the gage is attached to the bridge when the bridge is carrying traffic. Two good general purpose gages for bridge test applications are models CEA-06-250UW-350 (adhesive) and CEA-06-W250A-350 (weldable) supplied by Measurements Group Inc. of Raleigh, North Carolina.

Detailed step-by-step instructions on strain gage installation are available from numerous sources and will not be repeated here. In addition to supplying strain gages and strain gaging accessories, the Measurements Group Inc. can provide instruction manuals and technical notes addressing the complete range of strain gage application procedures.

5.2.3 Loading and Measurement

Bridge loads can be of any form desired by test personnel. Generally, the loads used in a test program will be a test truck and normal traffic. Data from the test truck loading are useful for calibrating the analytical model. Data collected under normal traffic provide an indication of the range and number of stress cycles to which the bridge is subjected in regular service.

The test truck should be heavy and have a short axle spacing in order to produce a high moment. A fully loaded dump truck with dual rear axles is suitable. The truck should be driven across the bridge at constant speeds ranging from 5 mph to the maximum possible safe speed (expect 50 mph as a maximum for a fully loaded dump truck) to assess the effect of speed on impact. The truck should also be driven across the bridge at different transverse positions (such as the outside shoulder, outside lane, inside lane, and inside shoulder) to evaluate lateral load distribution characteristics. While data are being collected for the test truck loading, no other traffic should be on the bridge. If traffic is light, this may be accomplished by watching the traffic and moving the test truck only during open periods; if traffic is heavy, it may be necessary to close the bridge for brief periods.

A typical test truck loading begins by choosing the Test Truck option on the computer. The test truck is then signaled to cross the bridge. Once the truck has crossed the bridge, the data collected by the DL are downloaded to the computer hard drive by selecting the Collect Test Data option. The test truck then returns to the bridge approach and the sequence is repeated for a different speed or transverse position. The computer must not be powered through an extension cord while communicating with the DL; power must come from the computer's internal battery. Electrical noise generated by the outside power source will corrupt the data transmission from the DL to the computer.

Data collected during normal traffic operation are manipulated using a rainflow algorithm to arrive at an estimate of the number and range of stress cycles applied to the bridge. These data

are typically collected with the computer disconnected from the DL and the DL operating unattended. Data are collected in user selected intervals of up to 24 hours for periods of up to three weeks.

5.3 Sample Test Sequence

In this section of the report, a sample Test Form is presented and a typical sequence of software commands is described. In the sample test sequence which follows, it is assumed that a total of four measuring devices will be used—two Transducers and two Strain Gages. The sample will include both a Rainflow Test and a Truck Test. All commands to be issued by the user are set in bold type to aid the reader in performing the proper key strokes.

5.3.1 Test Form

Before initiating a test or a series of tests, a Fatigue Life Estimation Sheet (FLES) should be completed. In some cases, the entire sheet may be completed before leaving for the bridge site. In other cases, it may be appropriate to complete the sheet at the site. Regardless of how or when the sheet is filled out, it should be completed in order to maintain a record of the test. This sheet is intended to be used as a bookkeeping tool. Comments at the bottom of the FLES will be beneficial when test results are analyzed and may prevent trips back to the bridge for re-tests. Most items on the sheet are self-explanatory. Figure 25 shows an FLES that has been filled out for the sample test.

5.3.2 Test Setup

Power up the PCS and type FRAME at the C:> prompt. Follow the instructions to the Main Menu. At some point before the test begins, the time must be downloaded to the DL. If the Setup is completed ahead of time in the office, there is no need to send the time. This example, however, will assume the test is conducted in the field immediately following the Setup routine.

Type B to send the time. The next screen will display the computer time and date. If corrections are necessary, **type T** and enter the time in the same format as seen on the screen (only hour and minute required). Follow with the **ENTER** key and enter the correct date. If the **ENTER** key is depressed with no entry at all for time or date, no changes will be made. **Press Y** to continue.

The screen should quickly change to the GT program. The time send is completely automatic, but the user should watch to verify the connection. If time does not send, a message will be displayed to this effect. If a problem is indicated, check all connections to ensure the DL is properly connected.

Refer to the FLES and note that the letter "A" is written in the Test No. blank. This is an indication that reset must be selected to begin counting at "A". Once the screen has returned to the Main Menu, **type G**, then **A**, and hit **ENTER** to reset the character counter. This will ensure the first data collection will be entitled HWY177A.

**OKLAHOMA DEPARTMENT OF TRANSPORTATION
Fatigue Life Estimation Sheet**

Date: 11-18-95

Project No.: 95-07221-08

Time: 4:00 pm

Bridge: Boomer Creek

Maintitle: HWY177

Highway: US177

Test No.: A,B,C (A - Z)

Rainflow Test: yes (Yes/No)

Truck Test: yes (Yes/No)

Stress Range: 20 (ksi)

Initialization Time: 20 (sec.)

Number of Bins: 20

Truck Weight: 25 (tons)

Minimum Amplitude: 1.0 (ksi)

Truck Path: See Below

Duration of Test: 7 (days)

Test Interval: 1440 (min.--1 day = 1440)

Channel #1: V Gage Factor: _____ Location: _____

Channel #2: S Gage Factor: 2.095 Location: Plate #1

Channel #3: V Gage Factor: _____ Location: _____

Channel #4: T Gage Factor: 5.25 Location: Top flange Mid Span #1

Channel #5: T Gage Factor: 5.37 Location: Bot flange Mid Span #1

Channel #6: V Gage Factor: _____ Location: _____

Channel #7: V Gage Factor: _____ Location: _____

Channel #8: S Gage Factor: 2.095 Location: Plate #2

Comments: Test A is a truck test with truck in right shoulder 1' from parapet.

Test B is a truck test with truck in middle of bridge over centerline

Test C is a rainflow test from midnight 11-19-95 to midnight 11-25-95.

High winds today

(10/95)

Test Supervisor: J. Kelly

Figure 25. Fatigue Life Estimation Sheet (FLES)

To begin the Setup, **type A**. The Setup screen will appear and await the Maintitle entry. **Type HWY177** in this blank and press **ENTER**. This title was chosen since the bridge for this sample is located on U.S. Highway 177. The next prompt is for the Initialization Time. This test will use a time period of 1 minute, so **enter 60** seconds.

The next eight prompts are for the Inputs. The FLES shows that Inputs #2, #4, #5, and #8 will be used. These were chosen randomly to show that Inputs do not need to be used in any order. The prompt will move down the screen after each Input. **Type V** for each of the vacant inputs, **type S** for Inputs #2 and #8 followed by GF 2.095, and **type T** for Inputs #4 and #5 followed by GF 5.25 and 5.37. If any errors are made in the parameter input, the **ESC** key will move the prompt back up the screen. For example, if the prompt is at Input #8 and there is a mistake on Input #2, type the **ESC** key six times until the prompt reaches Input #2 and make the necessary corrections. Type **ENTER** six times to move the prompt back to Input #8. Notice that the parameters for Inputs #3 through #7 remain unchanged when the **ENTER** key is used.

Experiment with the **ESC** key, **ENTER** key and other commands for the Setup menu to learn the operation of each edit command. After all information has been correctly entered, move on to the Rainflow Settings Menu. The Low Limit Stress is 1.0 ksi, the High Limit Stress is 21 ksi, and the Number of Bins is 20. This will create a histogram with a bin width of 1.0 ksi. The Rainflow Interval is 1440 minutes, which corresponds to one 24-hour day, and is the maximum allowed. The Minimum Peak-Valley Amplitude is 0.05 ksi which is 5 percent of the bin width. This is a good estimate, but it should be checked with Monitor Input (see Section 5.3.3) prior to the test. These settings apply only to Rainflow Tests and will not affect the Truck Test in any way. The user may wish to do the Setup for both tests at one time (as shown above) or to do a separate Setup for the Rainflow Test; either way is acceptable. It is not permissible to set any of the numerical values equal to zero on either of the two Setup screens.

Once the Rainflow settings have been entered, the display screen will reproduce the Setup parameters. If all information is correct, **type Y**, or press the **ENTER** or **ESC** key to continue, or type any other key to redo the Setup.

5.3.3 Truck Test

The comments line of the FLES states that the first Truck Test (A) will be a 25-ton truck driven along the right shoulder one foot from the parapet wall. Once the truck is in place above the bridge abutment and traffic is closed off from the bridge, initialization may begin. From the Main Menu, **type E**. The initialization program will be downloaded and executed automatically by the computer program. A timer will be displayed to count off initializing time.

When this time has elapsed, the Main Menu will return to the screen. **Type I** to Monitor the Inputs. If a prompt appears to input a file name for labels, **press the ENTER** key and proceed.

Verify that all 4 inputs are reading stresses properly. The numbers should not necessarily read zero values since they have yet to be zeroed, nor should the readings necessarily be equal to each other. A properly functioning measurement device will display some value and fluctuate within a reasonable stress range. If a measurement device is malfunctioning, a value of ± 99999 will be shown. This is an indication of an open circuit and the test should be aborted to repair the device. To exit the Monitor option, **press the ESC** key followed by **Q**. The Main Menu should appear on the screen.

Before the Truck Test begins, it is important that the truck be ready to move. **Type F** and then **Y** or **ENTER** to proceed. As soon as the Main Menu reappears on the screen, **signal the driver of the truck** to begin driving. As soon as the truck has traversed the test length, **type H** to collect the data.

It is recommended that after each Truck Test the stored data be visually examined. To create a plot of the data, **type Q** to exit to the subdirectory FRAME, then **type PLOT** and **press ENTER** to execute the plotting program. In response to the message on the screen, **type** the filename **HWY177A.dat** and **press ENTER**. In response to the next message on the screen, enter the time to start plotting in seconds. For this example, **type 0** and **press enter**. In response to the next message, enter the time to stop plotting in seconds. This time would depend on the duration of the Truck Test; for this example, **type 15** and **press enter**. The next series of questions will ask which channels should be plotted. **Type Y** in response to each of the eight questions (one for each possible channel). When the last "y" is entered, the plot will appear. See Section 4.11 of this report for a discussion of the color coding for the plotted data.

Continue with each Truck Test until all tests are complete. Note that the counting character automatically increases alphabetically after each collection. This is reflected by tests outlined on the FLES. Resetting the counting character will erase the data files from the first test. If the counter must be reset, back up all previous test files to another directory. This must be done in the DOS environment.

5.3.4 Rainflow Test

The Rainflow test will generally be initiated after the Truck Tests are completed. Unless there has been a change to the test system, there should be no need to enter Setup. To start the Rainflow test, **type D** from the Main Menu. Verify that the test parameters are correct and proceed. The program will download automatically and the test will begin. The first interval of the test will not begin until midnight (12:00 A.M.) the next day. Data will be collected from the onset of the test, but all data collected before midnight of the first interval will be dismissed since it will not represent a complete interval.

When the Main Menu returns to the screen, select Monitor Input to verify that all channels are reading properly. If the test is running satisfactorily, **type Q** to exit the program and **power down the PCS**. The PCS may be disconnected until data are to be retrieved.

5.3.5 Collect Data

From the Main Menu, **type H** to collect the data. When the connection link is complete, there should be a long pause. During this pause, the data are being retrieved and the display will post the size of each data block that is received. There should be a list of the repeated expression "512F" in the left column of the screen. After a successful collection, this process will be quite evident. If the collection is not successful, select the collection option from the Main Menu again, and make note of the incident on the FLES comment line along with the new character counter associated with the collection. Although such a failure is infrequent, it does occur due to communication misses between the PCS and the DL.

An unsuccessful collection may be indicated by an error message during the DL connection routine. Either the CTRL-C key combination or a warm boot (CTRL-ALT-DEL) will end the collection routine. To prevent a repeated collection error, it will be necessary to run the RESET file before restarting FRAME. RESET will remove the collection parameters from the variables file, VARS.SET. When this step has been completed, a second attempt to collect the data may be carried out.

5.4 Fatigue Life Estimation

It is recommended that separate and independent estimates of remaining fatigue life be computed using Test Truck data and Rainflow data. Computing remaining fatigue life using two independent approaches and data sets provides a wider range of information for use in maintenance and upgrade decisions.

5.4.1 Test Truck Data

Data from a truck test are stored in files labeled with DAT and TAB extensions. Both files contain the same basic information, but the TAB files are better formatted for readability. The leftmost column in the file indicates the time in seconds at which the stress data was recorded relative to the time the test was started. Columns to the right of the time column contain stress data for all active gages. The file will contain hundreds of lines of data, with each line listing the relative time and stress at gaged locations.

The large volume of data makes it difficult to identify trends by simply examining the numbers. To appreciate the significance of the data, it is recommended that stress for each gage be plotted versus time. Plots can best be constructed by copying the ASCII data from the TAB file to a spreadsheet program such as EXCEL. In the spreadsheet program, the data can be organized and edited (such as deleting data collected before and after the truck is on the bridge) to

draw attention to significant information. The data can then be plotted in the spreadsheet program or exported to a more versatile graphics software package.

Once plots of stress versus time are available, the stress range at a gage location can be determined by subtracting the minimum plotted stress from the maximum plotted stress for that gage. In evaluating these stress ranges, recall that stresses from the DL are measured relative to the stress state at the time the gages were initialized. The measured stresses are superimposed on any existing dead load stresses. If the gaged location is in tension under dead load, a negative stress is a reduction in tension rather than an actual compressive stress. For this reason, it is recommended that the full stress range from minimum (even if negative) to maximum be treated as the stress range for fatigue life estimates.

Measured stresses are best used to calibrate the analytical model. The analytical model must be loaded with the same moving live load applied to the bridge during the test. Computed stresses can then be plotted to the same scale as measured stresses for comparison. If the computed and measured stresses are significantly different, the model can be modified by changing the composite beam stiffness or attaching rotational springs at supports.

When the analyst is confident that the model accurately represents the structure behavior under live load, loads representing normal traffic can be analytically applied to the bridge. The characteristics of this normal traffic can be determined from traffic counts or weigh-in-motion studies. Once stress ranges under normal traffic are computed, AASHTO fatigue curves can be used to estimate number of cycles to failure and remaining fatigue life. An example of the procedure is available in Zwememan et al. [1996].

5.4.2 Rainflow Data

Data collected during a Rainflow test are made available in the form of stress range histograms. Separate histograms are formed for each complete interval (typically a 24-hour period) between the time the test was started and the time data were collected. The histograms are saved in files with the TAB extension.

For each interval, the number of cycles and average stress range for each bin (see Section 4.1.5) is tabulated separately for each active gage. In other words, examination of the tabulated data could show that on the third day of data collection, at strain gage four, there were 10,000 cycles with stress ranges between 1 and 2 ksi, 8000 cycles with stress ranges between 2 and 3 ksi, 1400 cycles with stress ranges between 3 and 4 ksi, and 300 cycles with stress ranges between 4 and 5 ksi. The histogram data are used to compute an effective stress range and an average number of cycles per hour for each interval and each gage. The effective stress range is computed using Miner's Rule [Miner, 1945]. Similar to the Test Truck data, it is difficult to

completely appreciate the significance of the information collected until it has been exported to a spreadsheet program, edited, and plotted.

It should be recognized that the effective stress range is computed from all of the stress cycles applied at a point on the bridge, including minor vibration cycles. Therefore, it is likely that the cycle count will exceed the vehicle count by a considerable margin. While the high number of small cycles inflates the cycle count, it also reduces the effective stress range. In estimating remaining fatigue life, the high cycle count and low effective stress range from the Rainflow histogram should be used together; do not use the Rainflow effective stress range with the average daily traffic count or the Rainflow cycle count with the stress range computed for the AASHTO fatigue truck.

It should also be recognized that for purposes of Rainflow counting, the DL is not storing a complete stress-time history, similar to a test truck stress-time history, for each test interval. The Rainflow count is computed from the measured maximum and minimum stresses along the stress-time history.

The collection of strain data from strain gages by the DL is much slower for the Rainflow count than for the Truck Test. As a result, some maximums and minimums may be missed and the reported effective stress range will be less than the actual effective stress range. The amount less is dependent on the speed of the traffic, the length of the bridge span, the number of active gages, and the number of bins. If eight gages are active and twenty bins are desired, data are recorded for each gage every 1.3 seconds. Since a truck traveling at 60 mph can cross a 100-ft span in 1.13 seconds, it is possible that the truck could cross over the bridge between data recordings. If only four gages are active and the number of bins is set at 20, the collection rate drops to 0.6 seconds per gage. The operator should experiment with the number of active gages and the number of bins to arrive at an acceptable collection rate for each test application.

Based on the effective stress range and number of cycles from the Rainflow count, remaining fatigue life can be estimated. An example of the procedure is available in Zwememan et al., 1996.

5.5 Inspection Interval

5.5.1 Inspection Interval Equation

The inspection interval is computed by determining the time required for a crack of a given initial length to increase in length a specified amount. This calculation will be performed using the principles of linear elastic fracture mechanics.

Crack growth rate is typically modeled using the Paris equation [Paris and Erdogan, 1963] as shown below:

$$\frac{da}{dN} = C(\Delta K)^m \quad (1)$$

where a = crack length; N = number of cycles; C = fracture mechanics material constant; m = fracture mechanics material exponent; and ΔK = stress intensity factor range. To compute the number of cycles required to extend the crack a specified increment, the Paris equation is rearranged for integration

$$N_f = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m} \quad (2)$$

where N_f = number of cycles to final crack length; a_i = initial crack length; and a_f = final crack length.

The stress intensity factor describes the stress state near the tip of an infinitely sharp crack. The stress intensity factor is calculated as [Tada et al., 1985]

$$\Delta K = F(a, Y) \Delta \sigma \sqrt{\pi a} \quad (3)$$

where $F(a, Y)$ = a factor to account for crack length, crack shape, and member geometry; and $\Delta \sigma$ = stress range. The factor $F(a, Y)$ is difficult to determine for most practical applications, so it is necessary to approximate the solution for a specific application with a known solution for a simple geometry.

Two available solutions have been selected to encompass most highway bridge applications. A solution which is expected to be conservative treats the crack as an edge crack in a uniformly stressed plate. A crack completely through a beam flange, starting at the flange tip and extending toward the web is an example of this type of crack. The stress intensity factor for an edge crack is computed as [Gallagher et al., 1984]

$$\Delta K = 1.12 \Delta \sigma \sqrt{\pi a} \quad (4)$$

The second crack type, which is expected to better model a crack early in life, is a semi-elliptical crack. This crack could be embedded in a beam flange, with the major axis of the ellipse transverse to the beam and exposed to the surface of the flange. The stress intensity factor for a semi-elliptical crack is computed as [Gallagher et al., 1984]

$$\Delta K = \Delta \sigma \sqrt{\frac{\pi a}{Q}} M_F M_K \quad (5)$$

where Q = flaw shape factor (recommend $Q = 1.47$); $M_F = 1 + 0.12 (1 - a/2c)^2$; M_K = back surface correction factor (recommend $M_K = 1.0$); a = crack depth into plate; and c = crack length on surface of plate.

To compute the inspection interval assuming an edge crack, Equation 4 is substituted into Equation 2 and the integration is performed. The result is

$$N_f = \left(\frac{1}{1.12^m C \sigma^m \pi^{m/2}} \right) \left(\frac{-2}{m-2} \right) (a_f^{1-m/2} - a_i^{1-m/2}) \quad (6)$$

If a semi-elliptical crack is assumed, Equation 5 is substituted into Equation 2 and the result is

$$N_f = \left(\frac{m/2}{1.0675^m C \sigma^m \pi^{m/2}} \right) \left(\frac{-2}{m-2} \right) (a_f^{1-m/2} - a_i^{1-m/2}) \quad (7)$$

To arrive at numerical values for the inspection interval, it is necessary to select values for the variables in Equations 6 and 7 and to estimate the number of cycles applied to the bridge in a year.

5.5.2 Assignment of Variables

Assignment of numerical values to variables is based both on a literature review and on engineering judgment. If the engineer computing the inspection interval has available more accurate values for a specific application, the more accurate values should be used.

Values of material constants C and m reported in the literature [Barsom and Rolfe, 1987] for ferrite-pearlite steels are $C = 3.6 \times 10^{-10}$ and $m = 3.0$. These values are based on a best fit line through data points on a graph plotting stress intensity factor range versus crack growth rate. The line is constructed on the lower bound of the data points to provide the highest crack growth rate for a given stress intensity factor. Using these constants a conservative estimate of inspection interval, similar to a "safe" remaining fatigue life estimate, is computed.

The initial crack size to be used in computations is either the largest crack that could be missed in an inspection or the largest crack found in the structure, whichever is larger. The size of the largest crack that could be missed in an inspection is dependent on both the ability of the inspection method to detect a small crack and the reliability of the method not to miss a large crack. It is assumed here that the inspection method will be visual. It is reported in the literature [Fisher et al., 1979] that a trained inspector using 10x magnification can detect a surface crack approximately 0.25 in. long under good conditions. Since this report assumes visual inspection with the naked eye under field conditions, the initial crack length is taken to be 1 in. In the same literature it is reported that the depth of a semi-elliptical crack is usually less than one-half the surface crack length; therefore, the initial crack depth is conservatively taken as one-half the surface length.

The final crack length is the length which, when combined with the maximum stress applied to the structure, causes the member to fracture. It is suggested that a value of 2 in. be used for the final crack length. Substituting a crack length of 2 in. and a critical stress intensity factor of 35 ksi $\sqrt{\text{in.}}$ into Equation 4, results in a critical stress of 12.5 ksi. Substituting the same values into Equation 5 along with $Q = 1.47$, $M_K = 1.0$, and M_F based on $a/c = 0.5$, results in a critical stress of

15.9 ksi. The value of $K = 35 \text{ ksi}\sqrt{\text{in.}}$ is reported in the literature [Barsom and Rolfe, 1987] for a mild steel at a temperature of 0°F under a dynamic load.

The above calculations indicate that if a crack 2 in. long is present in a mild steel bridge girder on a cold winter day, a maximum stress of between 12.5 and 15.9 ksi could cause fracture. If the engineer determines that these values are either too high or too low for a particular application, or if the critical stress intensity factor for the steel differs from that assumed, different values of σ and K can be inserted into Equations 4 and 5, and a better estimate of final crack length can be computed.

If a final crack length is computed to be less than the initial crack length, the structure is not inspectable. In other words, the member will fracture with a smaller crack than an inspection can be expected to detect. Such a member must be redundant with other members in the structure so that fracture of the single member does not cause collapse of the structure. The load originally carried by the fractured member must be distributed to other members in the structure until the fractured member can be repaired or replaced.

5.5.3 Example Calculation

The procedure described above for computing a safe inspection interval is demonstrated in the following example. After calculation of the number of cycles to failure, a conversion is made to inspection interval in years. To perform this conversion, it is necessary to know the number of cycles per year applied to the bridge. Number of cycles per year can be extrapolated from a rainflow count of cycles per day obtained from the data acquisition system, or from a traffic count. In this example, the number of cycles per day is taken to be 3000.

It is assumed that a visual inspection has been performed and no cracks were found; therefore, the largest initial crack size which could exist in the structure is taken to be 1 in. Numerical values for variables in addition to the initial crack length are listed below:

cycles per day = 3000

$a_i = 1 \text{ in.}$

$a_f = 2 \text{ in.}$

$\Delta\sigma = 3 \text{ ksi}$ (effective stress range obtained from datalogger output)

$C = 3.6 \times 10^{-10}$

$m = 3$

$Q = 1.47$

Assuming an edge crack:

$$N_f = \frac{1}{1.12^m C \sigma^m \pi^{m/2}} \frac{-2}{m-2} \left[a_f^{1-m/2} - a_i^{1-m/2} \right]$$

$$N_f = \frac{1}{1.12^3 3.6 \times 10^{-10} 3^3 \pi^{3/2}} \frac{-2}{3-2} \left[2^{1-3/2} - 1^{1-3/2} \right]$$

$$N_f = 7703608 \text{ cycles}$$

$$\text{Inspection Interval} = \frac{7703608 \text{ cycles}}{3000 \frac{\text{cycles}}{\text{day}}} = \frac{2568 \text{ days}}{365 \frac{\text{days}}{\text{year}}} = 7.04 \text{ years}$$

Assuming a semi-elliptical crack:

$$N_f = \frac{Q^{m/2}}{C \sigma^m \pi^{m/2} 1.0675^m} \frac{-2}{m-2} \left[a_f^{1-m/2} - a_i^{1-m/2} \right]$$

$$N_f = \frac{1.47^{3/2}}{3.6 \times 10^{-10} 3^3 \pi^{3/2} 1.0675^3} \frac{-2}{3-2} \left[2^{1-3/2} - 1^{1-3/2} \right]$$

$$N_f = 15856984 \text{ cycles}$$

$$\text{Inspection Interval} = \frac{15856984 \text{ cycles}}{3000 \frac{\text{cycles}}{\text{day}}} = \frac{5285 \text{ days}}{365 \frac{\text{days}}{\text{year}}} = 14.5 \text{ years}$$

Providing all of the assumptions are satisfied, the inspection interval for this structure could safely be set at seven years. No currently existing crack could grow to the critical size in less than seven years.

CHAPTER 6

SUMMARY AND CONCLUSIONS

A data acquisition system has been constructed for use by the Oklahoma Department of Transportation in measuring strains on in-service bridges. Construction of the system involved the development of hardware and software to facilitate interaction with a general-purpose commercial datalogger. Application of the system requires the user to install strain gages on the structure of interest, extend leadwires from the gages to a junction box containing bridge completion circuitry, connect the junction box to a battery-powered datalogger, and connect the datalogger to an on-site computer. The computer is loaded with software to assist the user in setting up the datalogger and downloading collected data.

This report contains information regarding construction of the data acquisition system which may be useful for system maintenance and operation. Chapter 2 of the report serves as a reference document for maintenance or repair of hardware components. Chapter 3 provides a general description of system software to establish the relationship between software components; a complete program listing is provided in the Appendix. Chapter 4 contains operating instructions for the software developed to communicate with the datalogger.

This report also contains, in Chapter 5, a set of general guidelines for conducting a bridge test and applying the test results. It is recommended that a complete bridge evaluation include a thorough visual inspection, an analysis of the structure, and a load test. The load test should include both a series of short-term tests in which stresses are recorded as a truck of known weight passes over the bridge, and at least one long-term test in which the number and magnitude of stress cycles are recorded under normal traffic. The short-term tests can be used to calibrate the analytical model. Once the analytical model provides results in agreement with measured results, it can be used to study the effects of varying wheel loads and positions. Results of both the short-term and long-term tests should be considered in evaluating bridge maintenance and replacement options.

Data collected using the data acquisition system can be used to estimate remaining fatigue life and set inspection intervals. The recommended procedure for estimating remaining fatigue life follows NCHRP Report 299 [Moses et al., 1987], taking full advantage of the fact that stresses are measured rather than computed. Sample calculations are provided in Zwerneman et al., 1996. The procedure for setting inspection intervals is based on a fracture mechanics estimate of the time required for a crack of an assumed initial length to grow to a critical length when driven by the measured stress cycles. A sample calculation is provided at the end of Chapter 5.

The results of this research provide the Oklahoma Department of Transportation with equipment and procedures for accurately estimating remaining fatigue life and setting inspection intervals. These tools should help the Department to more effectively allocate funds for bridge maintenance, repair, and replacement.

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FRAME.BAT

```
@echo off
REM
REM
REM PC208 SOFTWARE IS NOT DESIGNED TO WORK SIMULTANEOUSLY WITH
REM OTHER PROGRAMS SUCH AS QBASIC PROGRAMS. THE RESULT IS
INTERMITTTENT
REM DATA RETRIEVALS - SOMETIMES DATA WILL COLLECT, AND OTHER TIMES
REM IT WILL NOT.
REM THIS BATCH FILE RUNS THE QBASIC PROGRAM AND THE PC208 SOFTWARE TO
REM AVOID THE COLLECTION PROBLEM. THE QBASIC PROGRAM WILL CREATE
REM AND/OR DELETE CERTAIN BATCH FILES. THESE ARE USED AS CONDITIONAL
REM STATEMENTS TO DETERMINE IF DATA IS TO BE COLLECTED OR IF THE USER
REM IS ENDING THE SESSION.
REM
REM
REM AGAIN IS A LABEL FOR THE PROGRAM LOOP.
:again
call prog5.exe
REM
REM
REM IF A COLLECTION IS TO BE MADE, THE QBASIC PROGRAM WILL CREATE THE
REM COLLECTION AND RETURN BATCH FILES. IF THE COLLECTION FILE EXISTS,
REM DATA WILL BE COLLECTED, AND THIS BATCH FILE WILL LOOP TO THE AGAIN
REM LABEL.
if exist collect.bat call collect.bat
del collect.bat
if exist return.t_f goto again
cls
REM
REM
REM IF THE USER EXITS THE QBASIC PROGRAM TO END THE SESSION, THE
REM COLLECTION AND RETURN BATCH FILES ARE DELETED. THE ABSENCE OF
REM THESE FILES WILL RESULT IN THE TERMINATION OF THE BATCH FILE.
```


RESET

```
echo off
IF EXIST COLLECT.BAT DEL RETURN.T_F
COPY VARS.BAK VARS.SET
IF EXIST COLLECT.BAT DEL COLLECT.BAT
```

PROG.BAS

```
DECLARE SUB BeginTest (Alarm$, Day$, MainTitle$)
DECLARE SUB Collect (Tipe$, Title$)
DECLARE SUB Download (MainTitle$)
DECLARE SUB Rainflow (Channel$(), MainTitle$, Factor#(), Excit%, Delay#, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Rate!, Hue%(), Ch%, Scrap%)
DECLARE SUB RainPrint (MainTitle$, Factor#(), LowLim!, HighLim!, RnTime#, PvDist!, Rate!,
Excit%, AmpBins%, INIT#(), INITA#())
DECLARE SUB ReadInIt (Factor#(), INIT#())
DECLARE SUB ReadRain (MainTitle$, Runner1$, Runner2$, Ch%, HighLim!, LowLim!,
RnTime#, FirstCollect$, Factor#(), AmpBins%)
DECLARE SUB ReadTruck (MainTitle$, Runner1$, Runner2$, Counter#, Factor#(), INIT#(),
Ch%)
DECLARE SUB ResetChar (Count%)
DECLARE SUB Rturn (Null$)
DECLARE SUB SendInIt (Delay#)
DECLARE SUB SendTime (TimeSet%)
DECLARE SUB SendWarm (Rate!, MainTitle$, Factor#(), Scrap%, Channel$(), Hue%(), Ch%,
Excit%, Delay#)
DECLARE SUB SetAlarm (Alarm$, Day$)
DECLARE SUB Setup (Channel$(), MainTitle$, Factor#(), Excit%, Delay#, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Rate!, Hue%(), Ch%, Scrap%)
DECLARE SUB TruckPrint (Rate!, MainTitle$, Factor#(), INIT#(), Excit%)
DECLARE SUB TruckTest (Rate!, MainTitle$, Factor#(), Scrap%, Channel$(), Hue%(), Ch%,
Delay#)
DECLARE SUB VarrayRead (TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!,
HighLim!, RnTime#, PvDist!, AmpBins%, Status$, Channel$(), Ch%, Count%, Counter#, Delay#,
INIT#(), OtherTitle$, FirstCollect$, Tipe$)
DECLARE SUB VarraySave (TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!,
HighLim!, RnTime#, PvDist!, AmpBins%, Status$, Channel$(), Ch%, Count%, Counter#, Delay#,
INIT#(), OtherTitle$, FirstCollect$, Tipe$)
DECLARE SUB WarmUp (Null$)
```

```
*****
```

```
!* PROGRAM SECTION ALPHA-1 *
!* THIS SECTION ALLOWS THE USER TO SELECT *
!* THE TYPE OF TEST THAT IS TO BE RUN. *
```

```
*****
```

```
DIM INIT#(8), INITA#(8), Factor#(8), Channel$(8), Ch%(8), Hue%(8)
```

```
*****
```

```
!*THE FOLLOWING SUBROUTINE CREATES A FILE CALLED RETURN.T_F. TO INITIATE
*
```

```
!*A LOOP IN FRAME.BAT. IT WILL BE DELETED WHEN THE QUIT COMMAND IS
SELECTED *
```

```
!*FROM THE MAIN MENU. *
```

```
*****
```

```
CALL Rturn(Null$)
```

```
*****
```

```
!*THE FOLLOWING SUBROUTINE INPUTS THE SETTINGS THAT WERE USED LAST TIME
THE *
```

```
!*PROGRAM WAS RUN. *
```

```
*****
```

```
CALL VarrayRead(TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!, HighLim!,  
RnTime#, PvDist!, AmpBins%, Status$, Channel$(), Ch%, Count%, Counter#, Delay#, INIT#(),  
OtherTitle$, FirstCollect$, Tipe$)
```

```
Excit% = 5  
COLOR 7
```

```
IF Status$ = "New" THEN  
CLS
```

```
*****
```

```
* THIS MAKES A TITLE BOX *
```

```
*****
```

```
LOCATE 3, 12: PRINT CHR$(218); STRING$(53, 196); CHR$(191);  
LOCATE 13, 12: PRINT CHR$(192); STRING$(53, 196); CHR$(217);  
FOR Row = 4 TO 12  
LOCATE Row, 12: PRINT CHR$(179);  
LOCATE Row, 66: PRINT CHR$(179);  
NEXT Row
```

```
*****
```

```
*THE FOLLOWING IS THE INITIAL SCREEN BROUGHT UP WHEN THE PROGRAM  
STARTS *
```

```
*****
```

```
LOCATE 5, 21  
COLOR 4: PRINT "OKLAHOMA DEPARTMENT OF TRANSPORTATION"  
LOCATE 8, 14  
PRINT "DATA ACQUISITION SYSTEM FOR FATIGUE LIFE ESTIMATION"  
LOCATE 11, 16  
COLOR 5: PRINT "By Oklahoma State University Civil Engineering"  
LOCATE 20, 30  
PRINT "Hit Return To Begin"  
P$ = INPUT$(1) ***** FUNCTION KEY. WILL CONTINUE WHEN # OF CHARACTERS *****  
***** IN PARENTHESES ARE PUSHED ON KEYBOARD. *****
```

```
*****
```

```
*  
* THIS IS A SIEVE FOR THE COLLECTION TYPE THAT HAS JUST BEEN *  
* OBTAINED FROM THE BATCH FILE. THE 'TIPE$' VARIABLE WILL *  
* DICTATE WHICH COLLECTION WAS MADE: INIT, TRUCK, or RAIN. *  
* IF INIT COLLECTION WAS MADE, PROGRAM WILL AUTOMATICALLY *  
* PROCESS THE DATA AND BEGIN THE REQUIRED TEST. IF TRUCK OR *  
* RAIN COLLECTION WAS MADE, DATA PROCESSING WILL BEGIN. *  
*
```

```
*****
```

```
ELSEIF Status$ = "Collect" AND Tipe$ = "Init" THEN  
CALL ReadInit(Factor#(), INIT#())  
CLS  
LOCATE 15, 20: PRINT "Initialization Complete. Truck Test Ready."  
LOCATE 16, 22: PRINT "(Press Any Key To Continue To Main Menu)"  
Q$ = INPUT$(1)  
MainTitle$ = OtherTitle$  
CALL VarraySave(TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!, HighLim!,  
RnTime#, PvDist!, AmpBins%, Status$, Channel$(), Ch%, Count%, Counter#, Delay#, INIT#(),  
OtherTitle$, FirstCollect$, Tipe$)
```

```

ELSEIF Status$ = "Collect" AND Tipe$ = "Truck" THEN
  Runner1$ = MainTitle$ + CHR$(65 + Count%) + ".TAB"
  Runner2$ = MainTitle$ + CHR$(65 + Count%) + ".DAT"
  Count% = Count% + 1
  IF Count% = 26 THEN Count% = 0
  CALL ReadTruck(MainTitle$, Runner1$, Runner2$, Counter#, Factor#(), INIT#(), Ch%)
  CLS
  LOCATE 10, 15: PRINT "Your Data Files Are Titled:"
  LOCATE 12, 20: PRINT Runner1$
  LOCATE 13, 20: PRINT Runner2$
  LOCATE 15, 10: PRINT "Please Make Note Of These Assignments!"
  LOCATE 16, 10: PRINT "(Press ESC To Continue)"
  DO WHILE Q$ <> CHR$(27)
    Q$ = INPUT$(1)
  LOOP
ELSEIF Status$ = "Collect" AND Tipe$ = "Rain" THEN
  Runner1$ = MainTitle$ + CHR$(65 + Count%) + ".TAB"
  Runner2$ = MainTitle$ + CHR$(65 + Count%) + ".DAT"
  Count% = Count% + 1
  IF Count% = 26 THEN Count% = 0
  CALL ReadRain(MainTitle$, Runner1$, Runner2$, Ch%, HighLim!, LowLim!, RnTime#,
FirstCollect$, Factor#(), AmpBins%)
  CLS
  LOCATE 10, 15: PRINT "Your Data Files Are Titled:"
  LOCATE 12, 20: PRINT Runner1$
  LOCATE 13, 20: PRINT Runner2$
  LOCATE 15, 10: PRINT "Please Make Note Of These Assignments!"
  LOCATE 16, 10: PRINT "(Press ESC To Continue)"
  DO WHILE Q$ <> CHR$(27)
    Q$ = INPUT$(1)
  LOOP
END IF

WHILE Q$ <> "Q"
  CLS

  *****
  '*   THIS MAKES A LIST OF OPTIONS   *
  *****

  LOCATE 8, 25
  COLOR 2: PRINT "Select An Option"
  LOCATE 12, 10: PRINT "(A)  Setup"
  LOCATE 13, 10: PRINT "(B)  Send Time"
  LOCATE 14, 10: PRINT "(C)  Warm-Up/Standby"
  LOCATE 15, 10: PRINT "(D)  Rainflow Test"
  LOCATE 16, 10: PRINT "(E)  Initialize"
  LOCATE 17, 10: PRINT "(F)  Truck Test"
  LOCATE 18, 10: PRINT "(G)  Reset Character Counter"
  LOCATE 19, 10: PRINT "(H)  Collect Test Data"
  LOCATE 20, 10: PRINT "(I)  Monitor Input"
  LOCATE 22, 10: PRINT "(Q)  Quit"
  *****

  '**THE FOLLOWING LINES OVERWRITE THE A-Q SHOWN ABOVE IN A DIFFERENT
  COLOR. *
  *****

```



```

COLOR 14
LOCATE 12, 11: PRINT "A"
LOCATE 13, 11: PRINT "B"
LOCATE 14, 11: PRINT "C"
LOCATE 15, 11: PRINT "D"
LOCATE 16, 11: PRINT "E"
LOCATE 17, 11: PRINT "F"
LOCATE 18, 11: PRINT "G"
LOCATE 19, 11: PRINT "H"
LOCATE 20, 11: PRINT "I"
LOCATE 22, 11: PRINT "Q"
DEFINT A-Z
Q$ = " "
WHILE INSTR("ABCDEFGHIQ" + CHR$(27), Q$) = 0
  Q$ = UCASE$(INPUT$(1))
WEND

*****
!*  OPTION A ALLOWS USER TO INPUT TEST PARAMETERS. THIS  *
!*  MODULE WILL PERFORM SETUP FOR BOTH RAINFLOW AND TRUCK  *
!*  TESTS. *
*****

IF Q$ = "A" THEN
  CALL Setup(Channel$, MainTitle$, Factor#(), Excit%, Delay#, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Rate!, Hue%(), Ch%, Scrap%)

*****
!*  FOLLOWING SUBROUTINE COPIES INFO. FROM SETUP TO VARS.SET. *
*****

  CALL VarraySave(TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Status$, Channel$, Ch%, Count%, Counter#, Delay#, INIT#(),
OtherTitle$, FirstCollect$, Tipe$)
  SHELL "COPY VARS.SET VARS.BAK" '***** GOES TO DOS MOMENTARILY AND DOES
COMMAND **

*****
!*  OPTION B SENDS COMPUTER TIME TO DATA LOGGER  *
!*  TO SYCRONIZE COMOPUTER AND DATA LOGGER  *
!*  USER IS GIVEN OPTION TO ADJUST COMPUTER TIME IF  *
!*  NECESSARY *
*****

ELSEIF Q$ = "B" THEN
  CALL SendTime(TimeSet%)

*****
!*  OPTION C IS USED TO ACTIVATE THE INSTRUMENTAION WITH AN *
!*  EXCITATION VOLTAGE TO ALLOW THEM TO WARM-UP. THIS WILL *
!*  REDUCE THE AMOUNT OF DRIFT IN READINGS GIVEN BY THE  *
!*  INSTRUMENTATION. *
*****

ELSEIF Q$ = "C" THEN
  CALL SendWarm(Rate!, MainTitle$, Factor#(), Scrap%, Channel$(), Hue%(), Ch%, Excit%,
Delay#)
  CALL WarmUp(Null$)

```

```

*****
!*  OPTION D INITIATES A RAINFLOW TEST *
!*  RAINFLOW TEST WILL COLLECT MANY DATA POINTS OVER A LONG *
!*  PERIOD OF TIME (1 TO 14 DAYS) WHILE AMBIENT TRAFFIC *
!*  CROSSES BRIDGE. *
*****

ELSEIF Q$ = "D" THEN
  Scrap% = 0
  CALL Rainflow(Channel$, MainTitle$, Factor#(), Excit%, Delay#, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Rate!, Hue%(), Ch%, Scrap%)
  Tipe$ = "Rain"
  IF Scrap% = 0 THEN
    IF TimeSet% <> 1 THEN
      CALL SendTime(TimeSet%)
    END IF
    CALL RainPrint(MainTitle$, Factor#(), LowLim!, HighLim!, RnTime#, PvDist!, Rate!, Excit%,
AmpBins%, INIT#(), INITA#())
    CALL Download(MainTitle$)
    FirstCollect$ = "Y"
  END IF

*****
!*  OPTION E INITIALIZES THE INPUTS FOR A TRUCK TEST. THE *
!*  SET UP MUST BE RUN BEFORE INITIALIZING. *
*****

ELSEIF Q$ = "E" THEN
  FOR I = 1 TO 8
    INIT#(I) = 0
  NEXT I
  SHELL "DEL INIT.DAT"
  OtherTitle$ = MainTitle$
  MainTitle$ = "INIT"
  CALL TruckPrint(Rate!, MainTitle$, Factor#(), INIT#(), Excit%)
  CALL Download(MainTitle$)
  CALL SendInit(Delay#)
  Title$ = MainTitle$ + ".DAT"
  Tipe$ = "Init"
  CALL Collect(Tipe$, Title$)
  Status$ = "Collect"
  CALL VarraySave(TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Status$, Channel$, Ch%, Count%, Counter#, Delay#, INIT#(),
OtherTitle$, FirstCollect$, Tipe$)
  END

*****
!*  OPTION F INITIATES A TRUCK TEST *
!*  TRUCK TEST WILL COLLECT MANY DATA POINTS OVER A SHORT *
!*  PERIOD OF TIME (1 TO 5 MIN) WHILE A TRUCK IS DRIVEN *
!*  OVER THE BRIDGE *
*****

ELSEIF Q$ = "F" THEN
  Scrap% = 0
  CALL TruckTest(Rate!, MainTitle$, Factor#(), Scrap%, Channel$(), Hue%(), Ch%, Delay#)
  IF Scrap% = 0 THEN
    CALL TruckPrint(Rate!, MainTitle$, Factor#(), INIT#(), Excit%)

```

```

CALL Download(MainTitle$)
Counter# = Delay# / Rate!
Title$ = MainTitle$ + ".DAT"
Tipe$ = "Truck"
END IF

ELSEIF Q$ = "G" THEN
CALL ResetChar(Count%)

*****
!* OPTION H COLLECTS THE DATA FOR THE APPROPRIATE TEST. *
!* COLLECTION IS MADE BY USER INPUT, BUT MODIFICATIONS *
!* COULD EASILY BE MADE TO EXECUTE AN AUTOMATIC TIMED *
!* COLLECTION. THE PROGRAM DETERMINES WHICH TYPE OF COL- *
!* LECTION IS TO BE MADE WITHOUT USER PROMPT. *
*****

ELSEIF Q$ = "H" THEN
Title$ = MainTitle$ + ".DAT"
SHELL "DEL " + Title$
CALL Collect(Tipe$, Title$)
Status$ = "Collect"
CALL VarraySave(TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!, HighLim!,
RnTime#, PvDist!, AmpBins%, Status$, Channel$(), Ch%, Count%, Counter#, Delay#, INIT#(),
OtherTitle$, FirstCollect$, Tipe$)
END

ELSEIF Q$ = "I" THEN
*****
!*FOLLOWING LINE CALLS GRAPHTERM PROGRAM, THEN SELECTS STATION OSU, *
!*THEN SELECTS MONITOR, AND THEN ENTER. *
*****
SHELL "GT OSU M" + CHR$(13)'*** COMMAND FOR MONITOR INPUT IN GT.EXE

ELSEIF Q$ = CHR$(27) THEN ***** ESC *****
Q$ = "Q"
END IF

WEND

IF Status$ = "Collect" THEN
SHELL "DEL COLLECT.BAT"
END IF

TimeSet% = 0
SHELL "DEL RETURN.T_F" ***** DELETES FILE SO LOOP IS NOT CONT. IN FRAME.BAT ***
Status$ = "New"

*****
!* FOLLOWING SUB PUTS VALUES FROM SETUP INTO VARS.SET *
*****

CALL VarraySave(TimeSet%, Rate!, MainTitle$, Factor#(), Excit%, LowLim!, HighLim!, RnTime#,
PvDist!, AmpBins%, Status$, Channel$(), Ch%, Count%, Counter#, Delay#, INIT#(), OtherTitle$,
FirstCollect$, Tipe$)

SHELL "COPY VARS.SET VARS.BAK"

```

```
COLOR 7
CLS
END
```

```
DEFSNG A-Z
```

```
SUB BeginTest (Alarm$, Day$, MainTitle$)
```

```
*****
```

```
* This sub will begin a test at a specific time. The *
* starting time is set with the SetAlarm Sub. *
* The Download Sub will begin a test immediately. *
```

```
*****
```

```
CLS
```

```
*****
```

```
* If no alarm time has been set, the test will begin *
* immediately. *
* If alarm time is the actual time (which is highly *
* unlikely), the test will begin immediately. *
* If the time is not the same as the alarm time, the *
* display clock will countdown the time until the test *
* begins. *
```

```
*****
```

```
IF Alarm$ = "" THEN
  continue = 1
ELSEIF TIME$ <> Alarm$ THEN
  continue = 0
ELSE
  continue = 2
END IF
```

```
DO WHILE continue = 0
  LOCATE 10, 25: COLOR 14: PRINT "Test Will Begin Momentarily"
  LOCATE 12, 10: COLOR 4: PRINT "Current Time"
  LOCATE 12, 50: COLOR 13: PRINT "Alarm Time"
  LOCATE 13, 12: COLOR 15: PRINT TIME$
  LOCATE 13, 51: PRINT Alarm$
  IF TIME$ = Alarm$ THEN
    continue = 2
    Alarm$ = ""
  END IF
LOOP
```

```
IF Alarm$ = "" AND continue = 1 THEN
  DO WHILE continue = 1
    CLS
    LOCATE 10, 25: COLOR 12: PRINT "No Alarm Has Been Set. Do You Wish To Set It?"
    LOCATE 12, 25: PRINT "(Please Type 'Y' To Set The Alarm Or 'N' To Begin Test
Immediately)."
    INPUT Cont$
    IF UCASE$(Cont$) = "Y" THEN
```



```

        continue = 3
        ELSEIF Cont$ = "N" OR Cont$ = "n" THEN
            continue = 2
        END IF
    LOOP
END IF

IF Cont = 2 THEN
    SendLine$ = "GT OSU K Y D " + MainTitle$
    PRINT SendLine$
END IF

IF Cont = 3 THEN
    Q$ = "E"
END IF

COLOR 5: LOCATE 23, 23: PRINT "Hit Return To Continue ....."
Q$ = INPUT$(1)
Alarm$ = ""
END SUB

-----

DEFINT A-Z
SUB Collect (Type$, Title$)
OPEN "COLLECT.BAT" FOR OUTPUT AS #1

*****
!* FOLLOWING STARTS TELCOM PROGRAM, THEN SELECTS STATION OSU, *
!* THEN SELECTS CALL DATALOGGER, THEN GIVES THE ALTERNATE NAME OF *
!* "Title$" TO THE SAVED FILE. *
*****

PRINT #1, "TELCOM OSU/C/F " + Title$
CLOSE #1
END SUB

DEFNSNG A-Z
SUB Download (MainTitle$)

*****
!* This sub will send the download file to the Datalogger *
*****

CLS

**** STARTS GRAPHTERM, STATION OSU, OPTION DOWNLOAD, FILENAME, THEN QUIT.
***

Phrase$ = "GT OSU D " + MainTitle$ + " Q"
SHELL Phrase$ '***** EXITS TO DOS AND EXECUTES Phrase$ *****
END SUB

```

```
DEFINT A-Z
SUB Rainflow (Channel$(), MainTitle$, Factor#(), Excit%, Delay#, LowLim!, HighLim!, RnTime#,
PvDist!, AmpBins%, Rate!, Hue%(), Ch%, Scrap%)
CLS
I = 3
LOCATE I, 10: PRINT "Main Title: "; MainTitle$
COLOR 2: LOCATE 4, 10: PRINT "Low Limit Stress: "; LowLim!
COLOR 2: LOCATE 5, 10: PRINT "High Limit Stress: "; HighLim!
COLOR 2: LOCATE 6, 10: PRINT "Number of Bins: "; AmpBins%
COLOR 2: LOCATE 7, 10: PRINT "Rainflow Interval: "; RnTime#
COLOR 2: LOCATE 8, 10: PRINT "Minimum Amplitude: "; PvDist!
RateMax# = .5
RateMin# = .2
LOCATE 9, 10: PRINT "Interval Rate: "; Rate!
```

```
*****
```

```
'* THE FOLLOWING LINES PRINT THE DATA AND BOXES TO VERIFY INPUT FROM SETUP
```

```
*
```