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INSTRUMENTATION REPORT
PROJECT CONCRETE SKY
PHASE VIII

Robert Geminder

TECHNICAL REPORT NO. AFWL-TR-69-181

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
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PHASE VIII

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FOREWORD

This report was prepared by the Mechanics Research, Inc., Los Angeles, California, under Contract F42650-69-C-0657. The program was performed under Requisition Number O/A 280520 from the Directorate of Procurement and Production, OOAMA, Hill AFB, Utah.

Inclusive dates of research were April 1969 through November 1969. The report was submitted 4 March 1970 by the Air Force Weapons Laboratory Project Officer, Captain Jacob C. Armstrong (WLCT).

Information in this report is embargoed under the Department of State ITIARs. This report may be released to foreign governments by departments or agencies of the US Government subject to approval of AFWL (WLCT), Kirtland AFB, NM, 87117.

All test data and gage locations are presented in a supplement that can be obtained from AFWL (WLCT), Kirtland AFB, NM, 87117.

The author wishes to express his appreciation to Captain Jacob C. Armstrong and Major Anthony Stephenson for their contributions and constructive criticism throughout the program.

This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement No. 2)

Three aircraft shelters, constructed of corrugated steel and concrete, were tested by various conventional weapons. The shelters were instrumented with strain gages, accelerometers, thermocouples, and pressure transducers. This report describes the instrumentation system used, the exact locations of the transducers, the calibration procedures used, and the data reduction system. All test data and the gage locations are presented in the supplement. The data are not analyzed in this report. However, the quality of the data is briefly discussed.

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SECTION I

INTRODUCTION

This report describes the Concrete Sky, Phase VIII, Instrumentation Program conducted at Hill Air Force Test Range, Utah. Three aircraft shelters were tested by subjecting the shelters to blasts from various conventional weapons. The shelters were instrumented to measure air pressure, air temperature, strain of the arch shell and doors; vibration of the arch shell, foundation, backwall and doors.

The structures were made from double corrugated, 10-gauge metal arches with 24-foot radii. Each shelter was covered with a different thickness of concrete and had a different design and a different material for the door. Each shelter had a different thickness of endwall. The shelters were designated in the following manner:

Shelter A: 14-inch Minimum Concrete Cover, Nylon Door,
24-inch Endwall

Shelter B: 18-inch Minimum Concrete Cover, Aluminum Door,
30-inch Endwall

Shelter C: 24-inch Minimum Concrete Cover, Steel Door,
36-inch Endwall

Figure 1 shows the layout of the shelters and the revetments. Figures 2, 3, and 4 show the shelters as seen from the front.

The shelters were subjected to blast pressure and shrapnel effects of 250 pound, 500 pound, and 1000 pound general purpose bombs, of 122 mm rockets, and to napalm. The weapons were aerially delivered and statically detonated.

A multichannel instrumentation system (shown in Figure 5) was used to record the data from the instrumented shelters. The outputs from the measuring transducers were transmitted by cable to a data acquisition system and recorded on magnetic tape. These data were played back to an oscillograph for final data presentation. All the data are presented in the supplement. This final data package presents each trace as a function of time with the vertical scale in engineering units and with the horizontal scale in seconds.

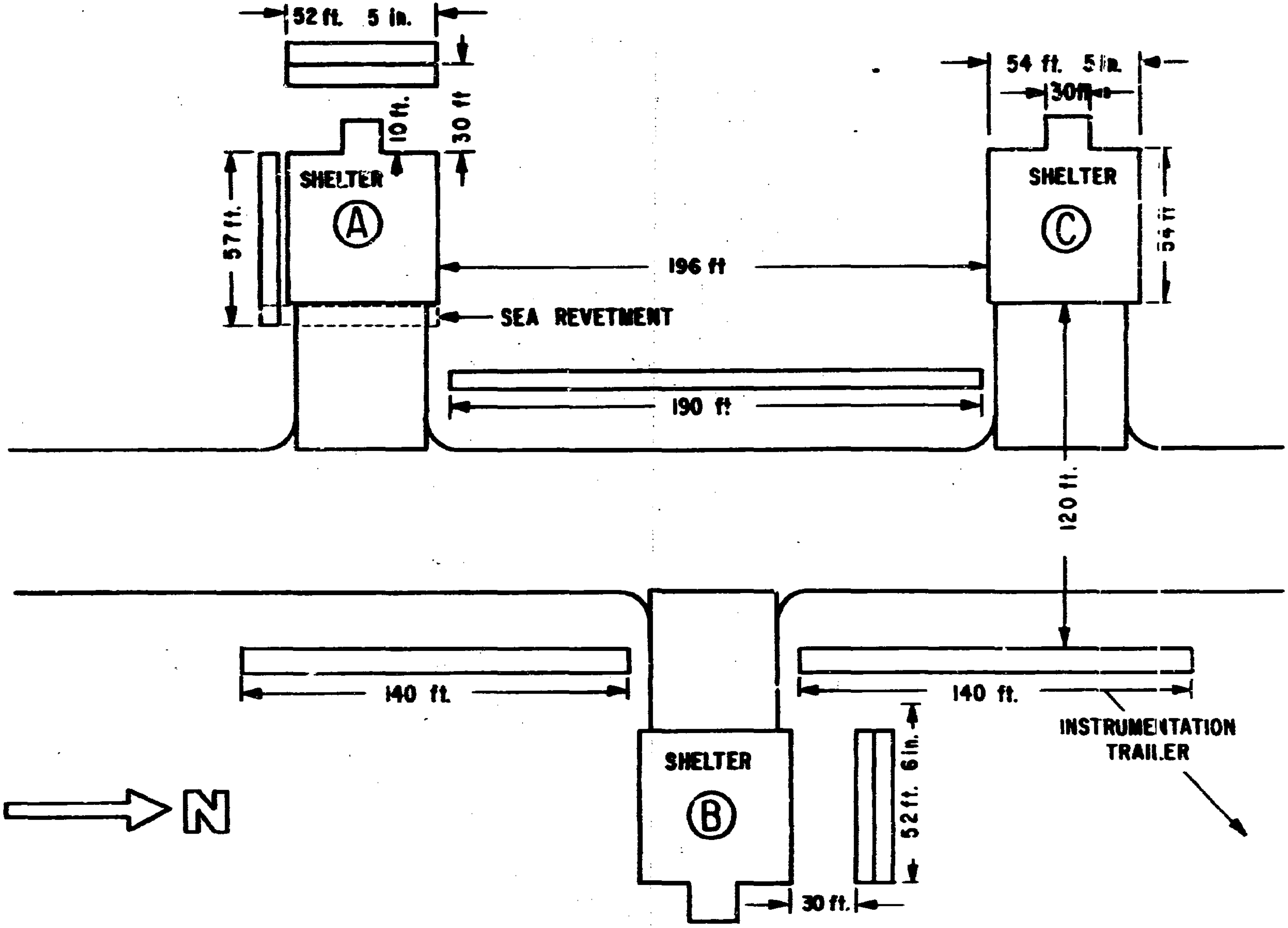

Figure 1. Concrete Sky Shelter Locations

Figure 2. Front View of Shelter A.
Note: 12 in. Concrete Caps and Nylon Curtain Door.

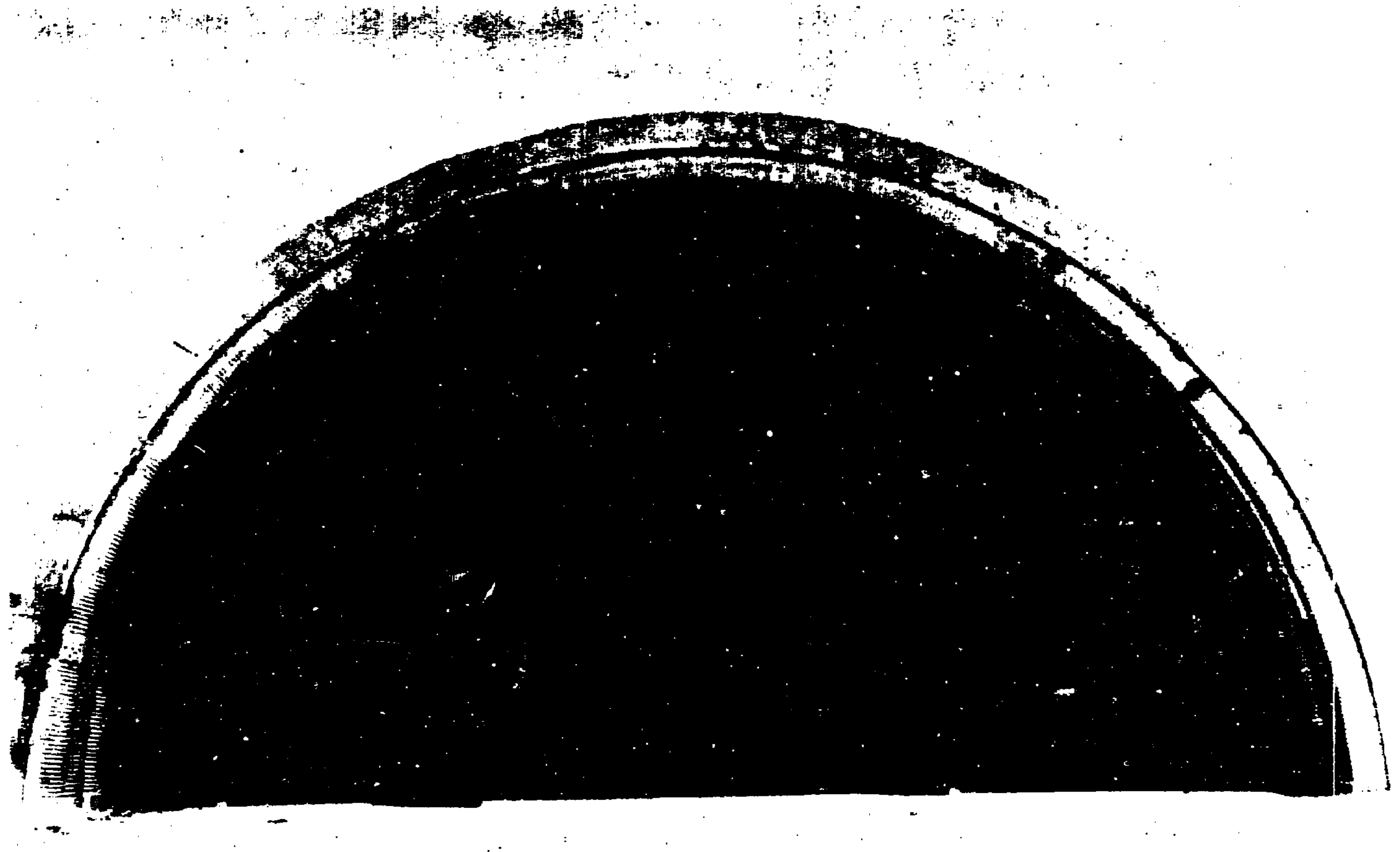

Figure 3. Front View of Shelter B.
Note: 18 in. of Concrete Cap and Aluminum Door.

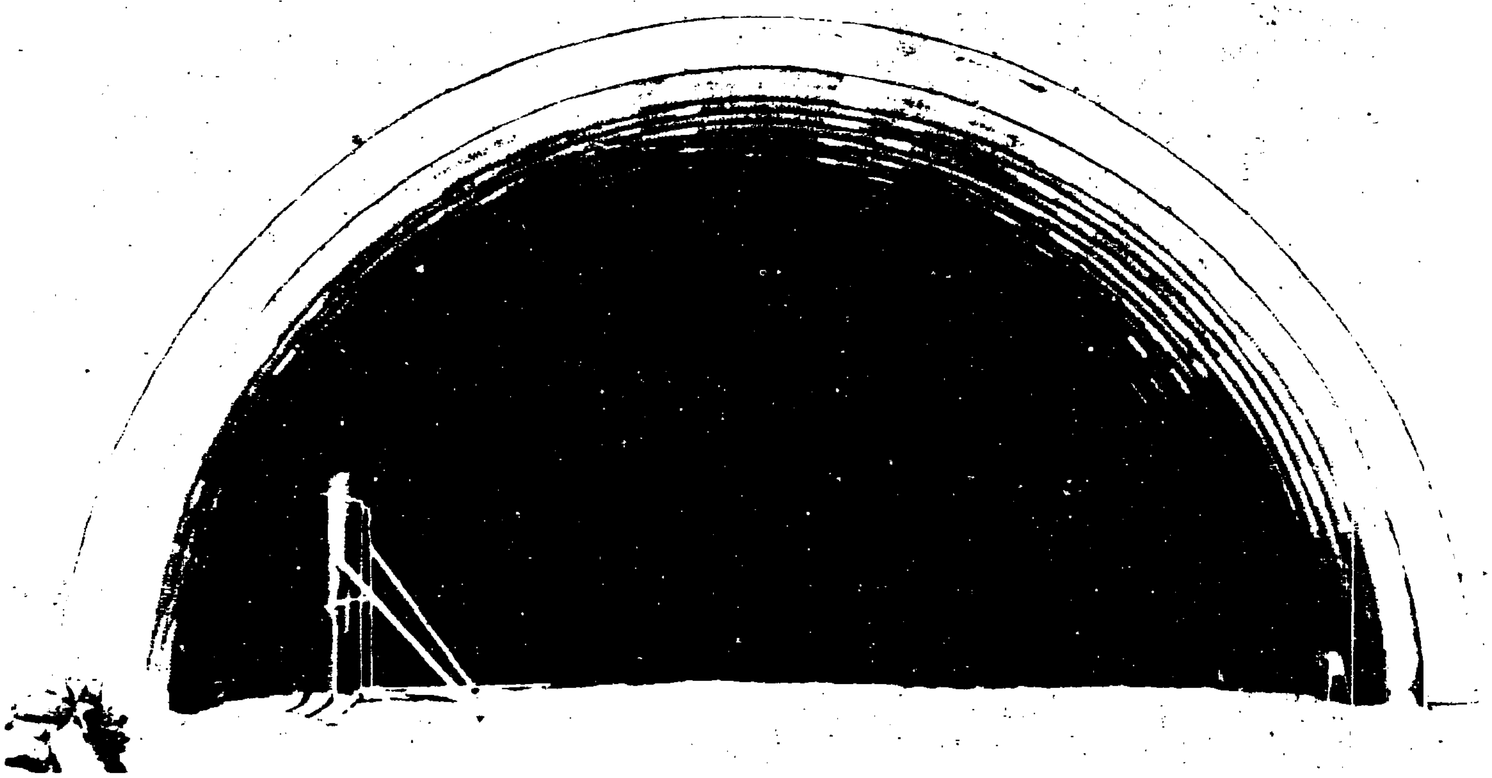

Figure 4. Front View of Shelter C.
Note: 24 in. of Concrete Cap and Steel Door.

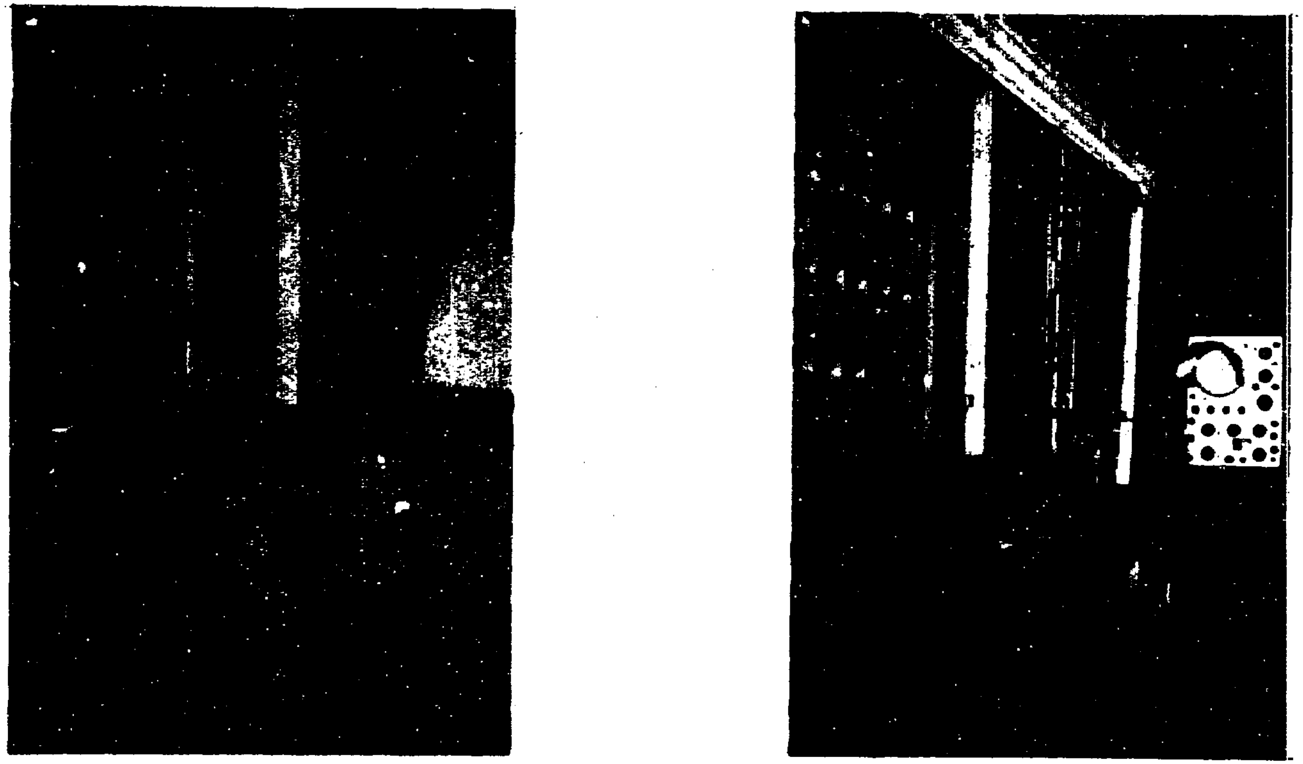

Figure 5. Concrete Sky Data Acquisition System.

A data package is presented for each test. The package includes the time histories of each transducer and a plan showing the location of all measuring sensors. Thus, the exact location of measuring sensors is presented for each test. The data are filtered, amplified or attenuated, and the arch accelerations are double integrated. Detailed description of the data reduction is presented later in this report.

In this report there will be no analyses of the data. The report covers the instrumentation system, the calibrations of the measuring systems, and the data reduction system.

SECTION II

INSTRUMENTATION SYSTEM

The Concrete Sky instrumentation system consisted of transducers which measured pressure, vibration, strain, and temperature. Each transducer provided an electrical output proportional to the measured parameter. This electrical signal was transmitted by cable to the data acquisition system. Each of the measuring systems will now be discussed.

1. Pressure Measuring System

The pressure measuring system consisted of a pressure transducer[1], a line drive amplifier[2], a 28-volt direct current power supply, and a magnetic tape recorder. Figure 6 shows a block diagram of the pressure system.

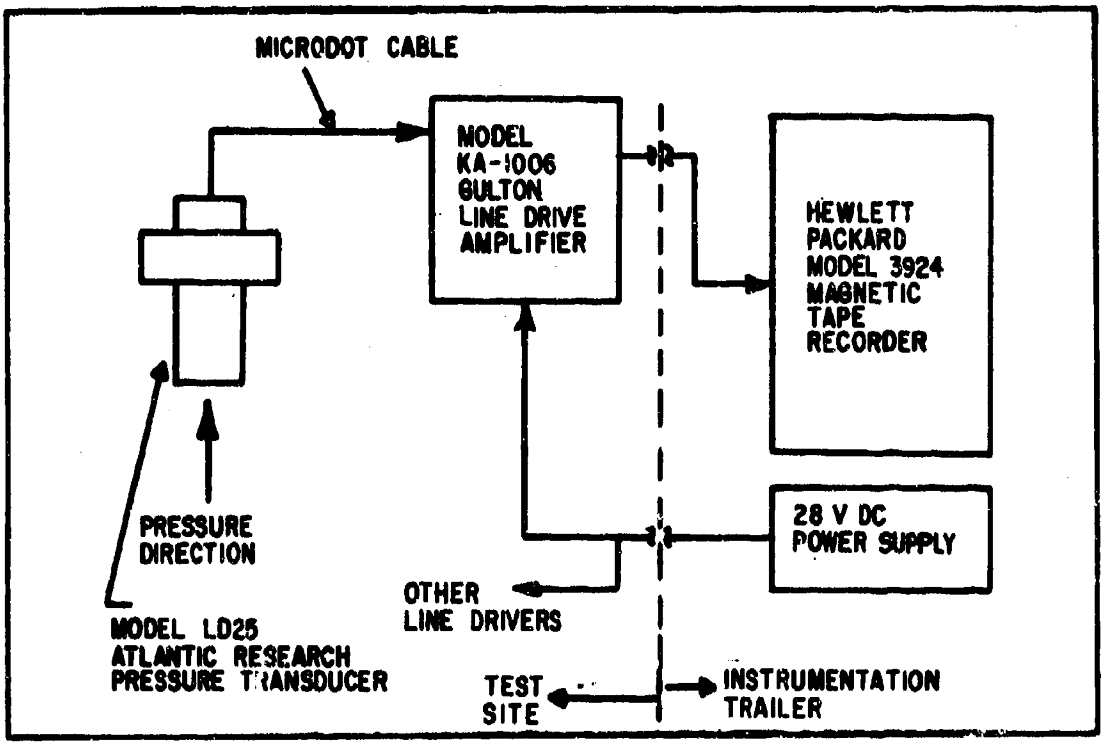

Figure 6
Block Diagram of the Pressure Measuring System

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(1) Atlantic Research, Model LD-25
(2) Gulton, Model KA-1006

The pressure transducer has a piezoelectric crystal sensing element which provides an electrical output proportional to the pressure on the face of the crystal. When mounted flush, the transducer will respond to transient pressures. The transducer has a flat frequency response through the range of 20 Hz to 10,000 Hz. The transducer measures pressure in the direction that it is mounted, as shown in Figure 7. Thus, the mounting of the transducer determines the type of pressure that will be measured. When the transducer is mounted so that its face is directly in line with the blast, the output voltage is proportional to the reflected pressure. When the transducer is rotated 90°, it is measuring the blast overpressure. Figure 7 shows the two basic mounting configurations.

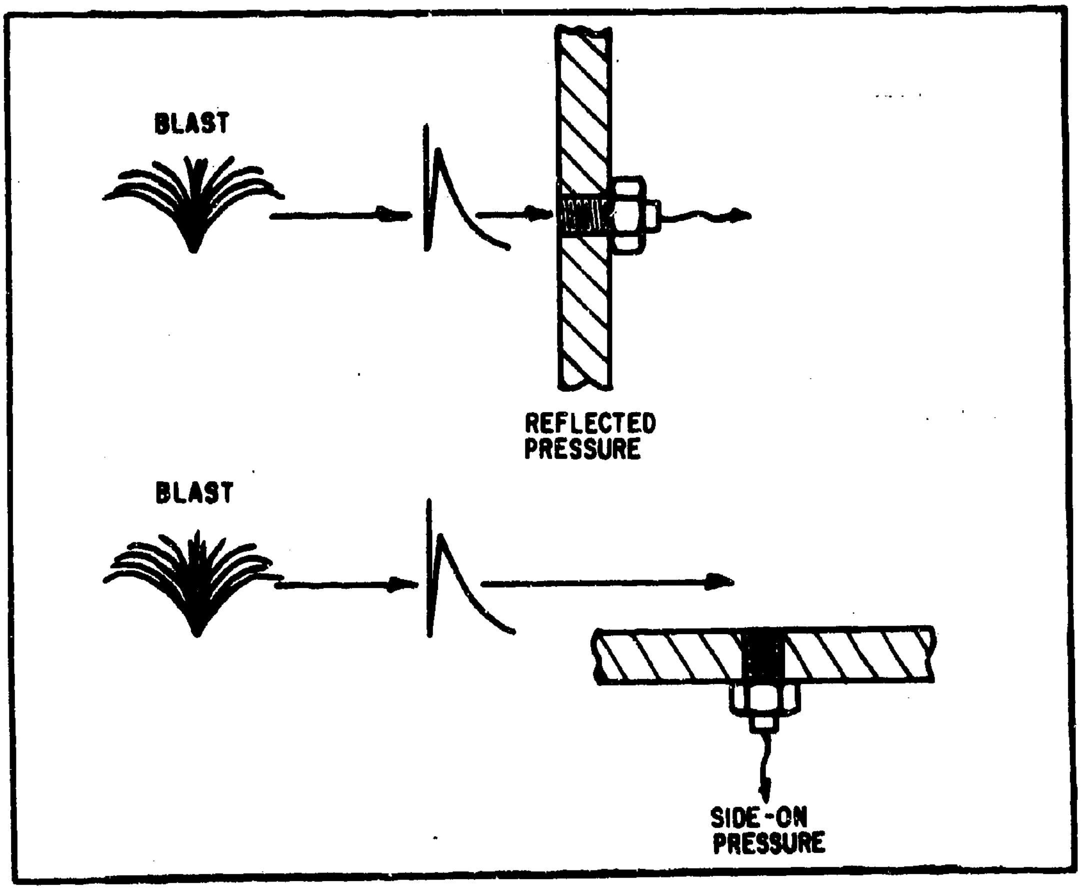


Figure 7
Mounting Configurations for the Pressure Transducers

Figures 8 through 12 show the actual mounting configuration. Figure 8 shows the mounting plate for pressure measurements on the inside of the shelters on the arch wall (P-15). Figure 9 shows the plate on the backwall (P-13) for inside pressure measurements. In each case, the pressure transducer was threaded into the plate so that the transducer face was flush with the plate. In these configurations, the reflected pressure is obtained.

Figure 8. Inside Pressure Transducer Side Wall Mounting Plate.

Figure 9. Inside Pressure Transducer Back Wall Mounting Plate.

Figures 10 and 11 show the mounting configuration for outside pressure measurements. Holes were drilled through the arch shell and then through the back wall, so that the transducer cable could be routed to the inside. The transducer was threaded through a mount face plate, and the plate was bolted to the arch shell mount. Both the transducer and the face plate were flush with the outside concrete of the arch shell or the backwall. These transducers were mounted at incident angles of 0°, 45°, and 90° with the blast.

Figure 10. Outside Pressure Transducer Arch Shell Mount

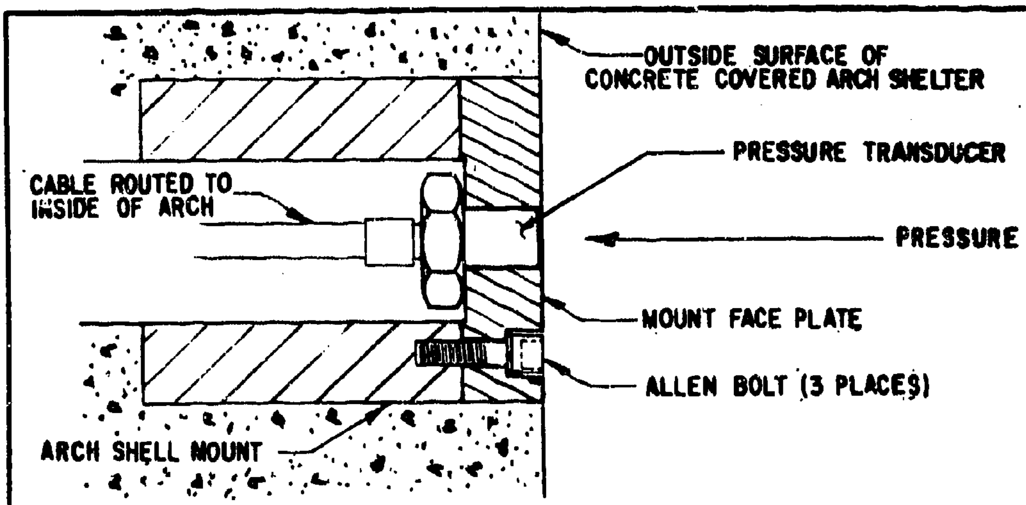


Figure 11. Complete Outside Pressure Transducer Mounting System.

Figure 12 shows the pressure transducer mounting configuration for all ground pressure measurements, both inside the shelter and outside the shelter. Again, the transducer was threaded into a plate so that the face of the transducer was flush with the plate. The plate was then placed at ground level. The overpressure was measured in this configuration.

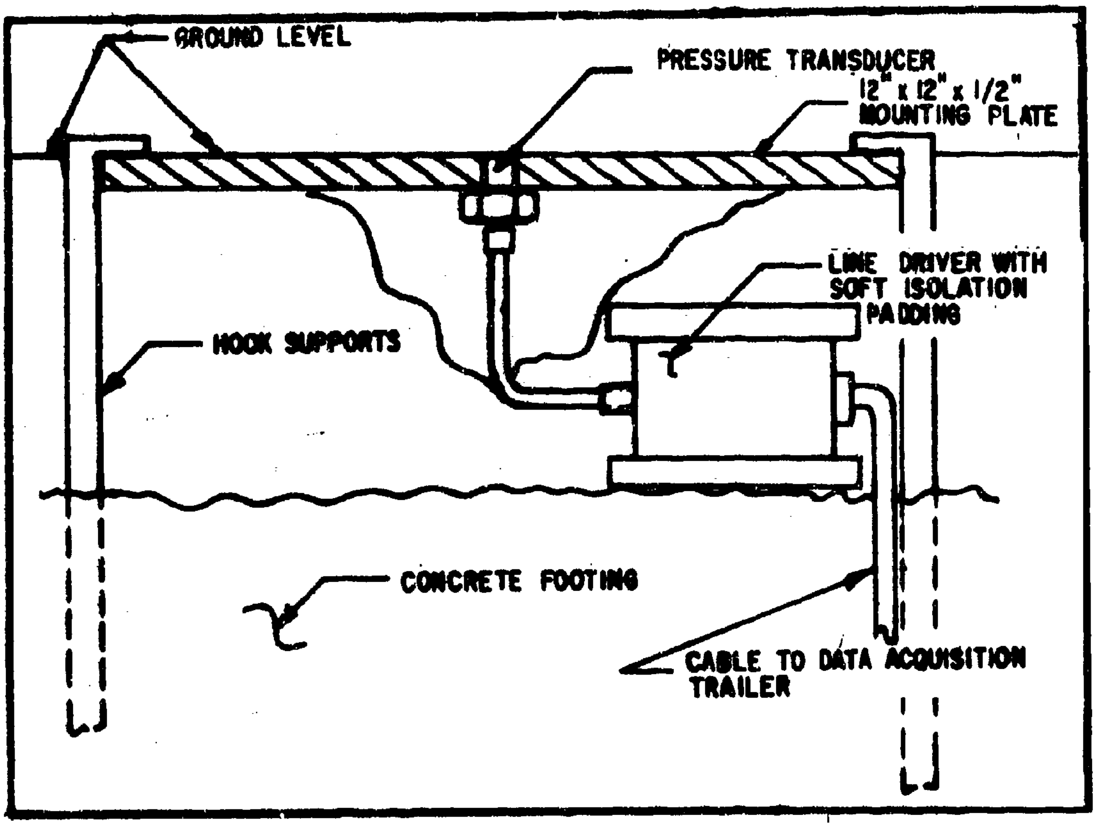


Figure 12. Outside and Inside Ground Pressure Transducer Mounts

To measure outside and inside door pressures, the transducers were mounted directly to the doors. The transducers were threaded into the steel and into the aluminum doors so that the transducer faces were flush with the surfaces of the doors.

The electrical output of the pressure transducer is approximately 80 millivolts per psi, and the capacitance of the crystal is approximately 260 pico farads. As a long cable was required between the shelters and the data acquisition trailer, a preamplifier was required near the transducers. The preamplifier, or the line drive amplifier, was a low-noise, high-input impedance, and a high gain amplifier. The preamplifiers were placed within 10 feet from the transducers and were wrapped in a soft insulation material. The transducer output was transmitted through a low-noise, low-capacitance Microdot cable to the line driver. The line driver output was transmitted through a cable[1] of approximately 1500 feet to the tape recorder. The line driver used has the specifications shown in Table I.

Table I Line Drive Amplifier Specifications

Frequency Response:	5 Hz to 12K Hz (± 5%)
Adjustable Gain:	-40 DB to Output Voltage of 6.5 Volts
Power Supply Voltage:	28 Volts
Noise Level:	5 Millivolts

The units were tested and evaluated by MRI. The specifications of Table 1 are the results obtained. The gain of the line drivers was adjusted during the calibration. The 28 volt direct current power for the line drive amplifiers was transmitted by one cable to each shelter from the data acquisition trailer.

The output from the line drivers was recorded on a magnetic tape recorder. The recording system will be discussed in Section 5.

---

(1) Belden Shielded Instrumentation Cable, Type Mohawk 1661

2. Vibration Measuring System

The vibration measuring system consisted of a vibration isolation mount[1], an accelerometer[2], a gage control unit[3], a low-pass filter, a data amplifier[4], and a magnetic tape recorder[5]. A block diagram of the system is shown in Figure 13.

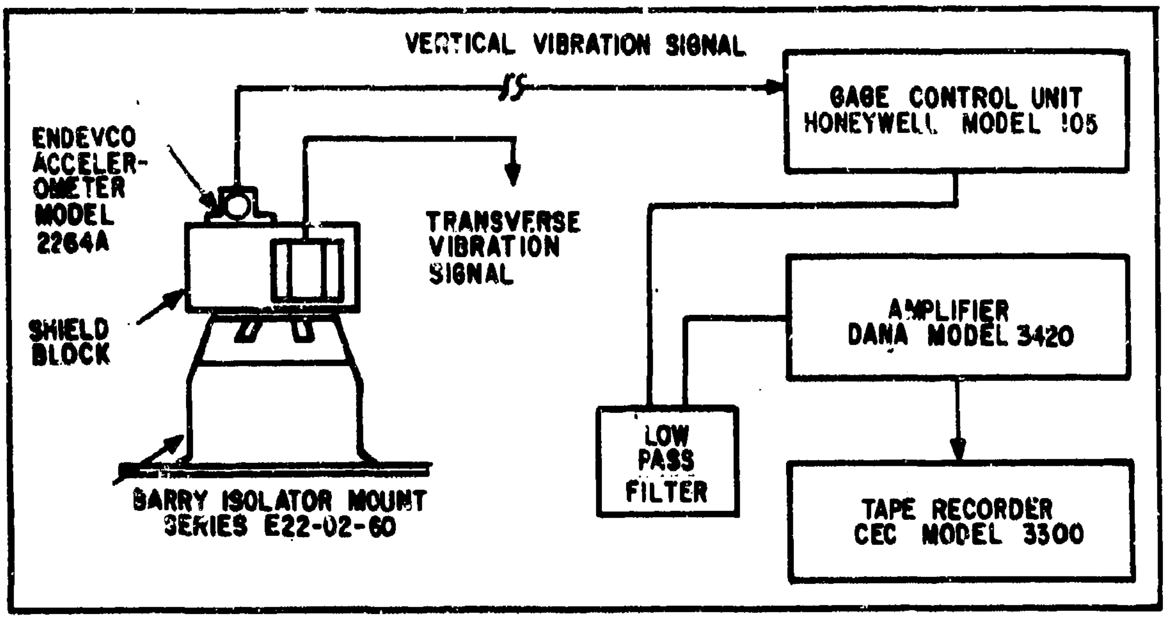


Figure 13. Block Diagram of the Vibration Measuring System

The accelerometers were a strain gage type using semiconductor gages for the sensing elements. These units are referred to as piezo-resistive accelerometers. The sensing elements provide electrical outputs which are proportional to the G to which the transducers are subjected.

---

(1) Barry, Series E22-02-60
(2) Endevco, Model 2264A
(3) Honeywell, Model 105
(4) Dana 3420
(5) Consolidated Electrodynamics Corp., Model 3300

In this particular program the accelerometer measurements were to be used to obtain the structural response of the arches and their foundations. The analytical studies performed prior to the measurements program showed that the structural modes which contributed significantly to the displacement response were in the frequency band from zero to 10 Hz. Thus, the acceleration response contributions from higher frequency components were not desired in the measured response. Two corrective measures were taken to reduce the higher frequency components from the acceleration measurements: electronic filtering of the accelerometer signal and mechanical isolation of the accelerometer body. The filter was a low pass 10 Hz filter with the components and frequency response shown in Figure 14.

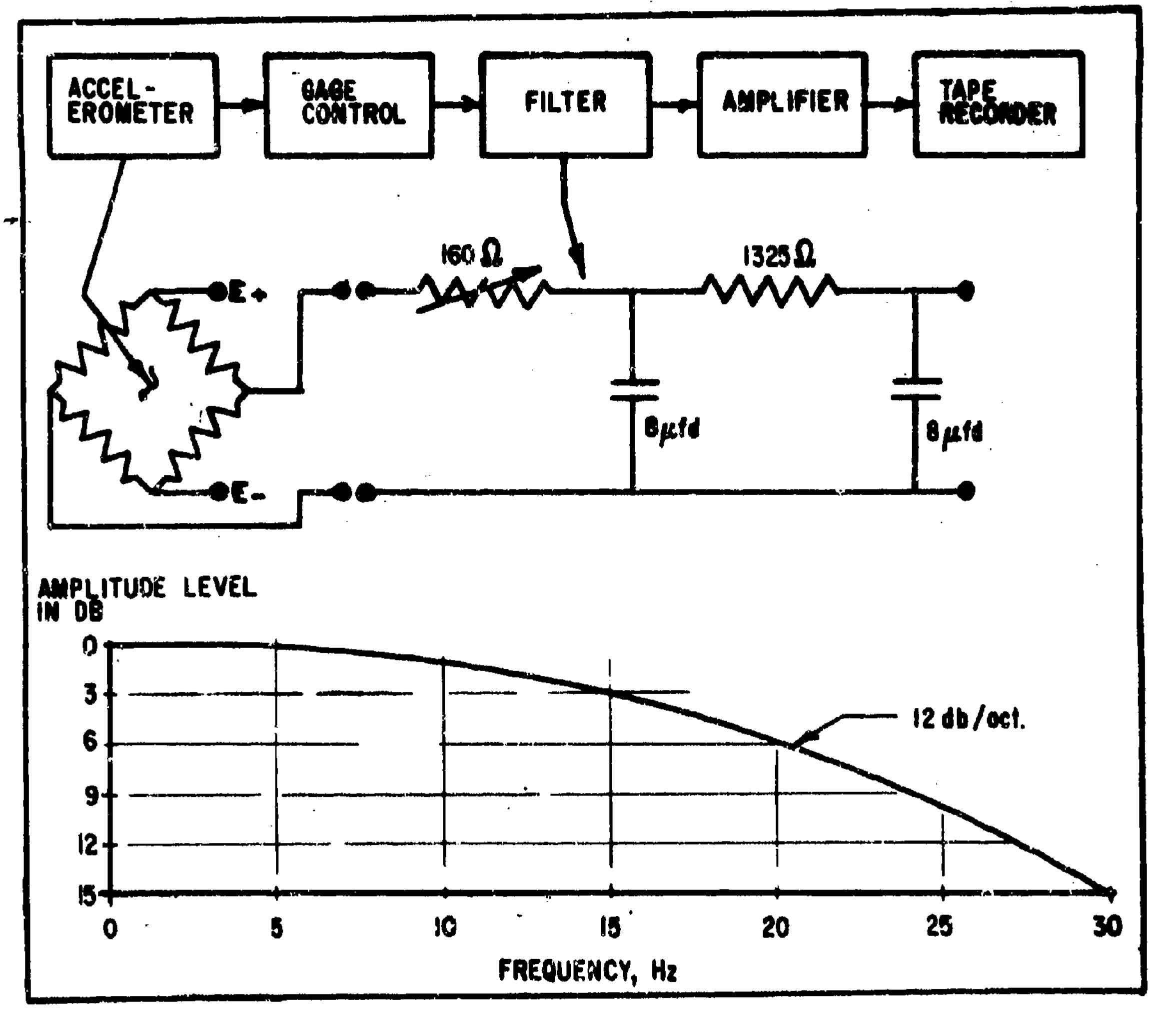


Figure 14. Electrical Filter Used in the Vibration Measuring System.

In addition to the electrical filter, a vibration isolation mount was used. A steel block was placed on the mount, and the accelerometers were placed on the steel block. The mount isolated the block and the accelerometers from the high-frequency vibrations. Thus, the isolation mount provided mechanical protection for the accelerometers. The three mounts were tested in the laboratory to determine the frequency spectrum of the mount-bloc-accelerometer system. Figure 15 shows the laboratory test setup. Frequencies above 1000 Hz were attenuated at a rate of 20 Db/octave.

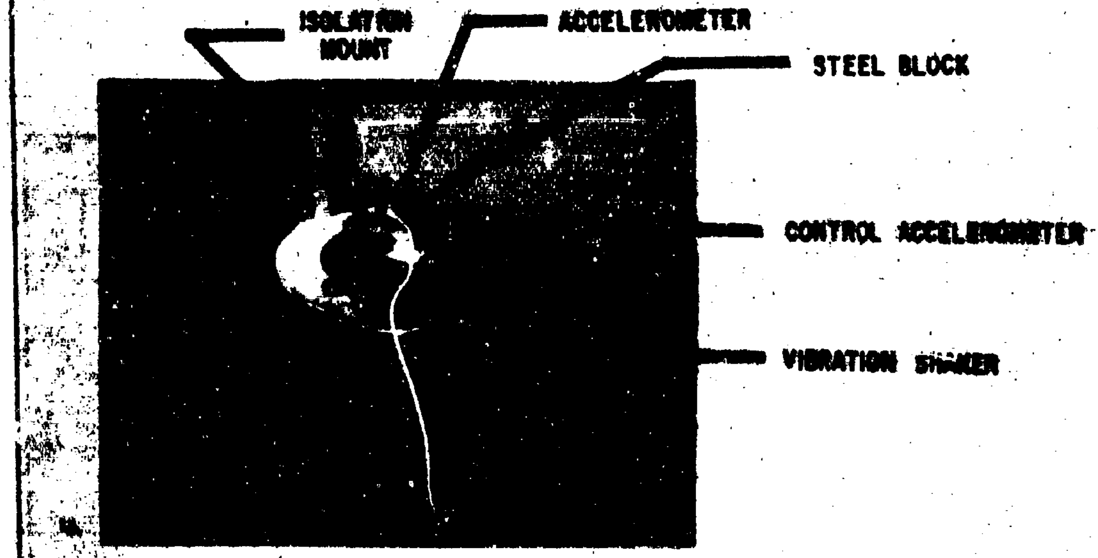
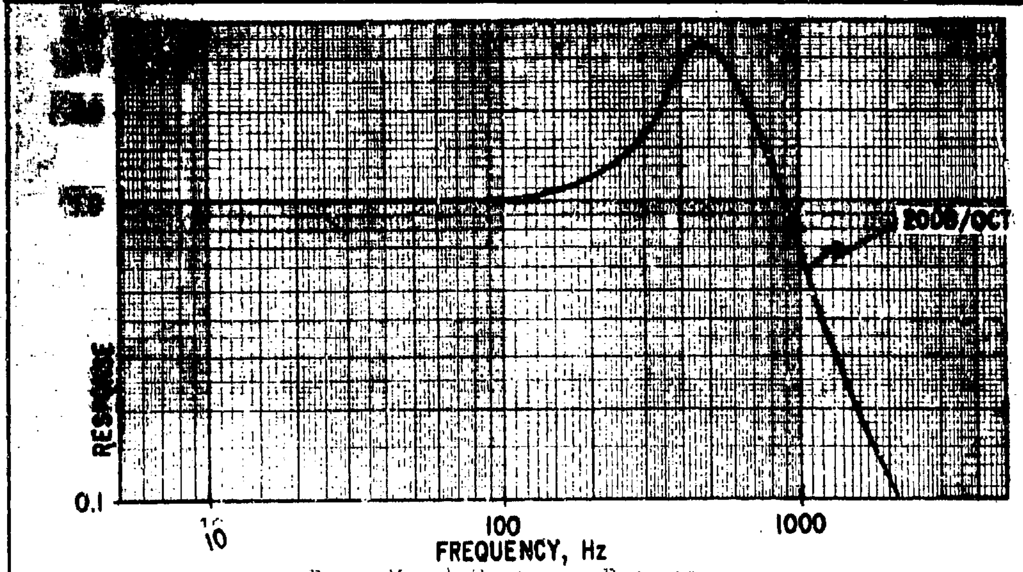


Figure 15. Evaluation of the Barry Mount.



Barry Mount Frequency Response.

The accelerometer assembly was protected from the blast environment by a metal shield, as shown in Figure 16.

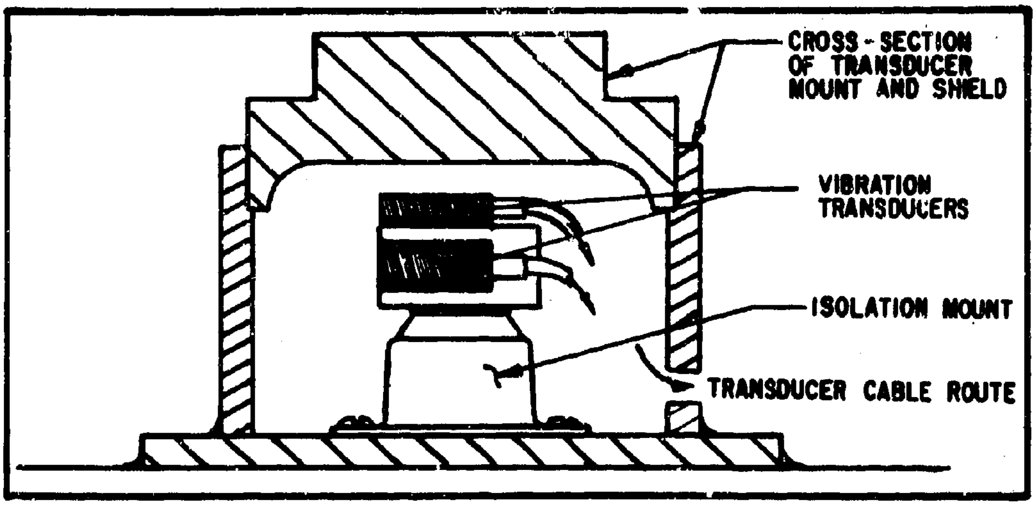


Figure 16. Sketch of Vibration Transducer System

These shields were welded to the arch and to the foundation, as shown in Figures 17 and 18.

Figure 17. Foundation Vibration Mounts

Figure 18. Arch Vibration Mounts

The output from the accelerometer was transmitted through a three-conductor shielded cable (approximately 1500 feet long) to the signal conditioning equipment in the data acquisition trailer. The signal conditioning equipment consisted of a gage control unit, a low-pass electrical filter, and a data amplifier for each accelerometer.

The gage control unit provided the Wheatstone bridge completion resistors, the bridge balancing circuit, the calibration resistors, and the DC power supply. The accelerometers consisted of a half-bridge circuit; thus, the gage control unit provided two precision resistors to complete the bridge. The balancing circuit rebalanced the measuring system for a zero voltage output. A 114-K ohm calibration resistor was used to obtain a known equivalent strain value. The gage control unit provided a switch so that this resistor could be placed across one of the legs of the Wheatstone bridge. The power for the bridge circuit was provided by the gage control unit. A voltage variation from 3 to 12 volts was available for each of the circuits.

The output of the gage control unit was routed through the low-pass filter to a D.C. data amplifier. The amplifiers were wired in a differential mode to minimize system noise. A gain range of 1 to 1000 was available for each channel.

The output of the amplifiers was recorded on magnetic tape.

3. Strain Measuring System

The strain measuring system consisted of a strain gage, a gage control unit, a data amplifier, and a magnetic tape recorder. A block diagram of the system is shown below in Figure 19.

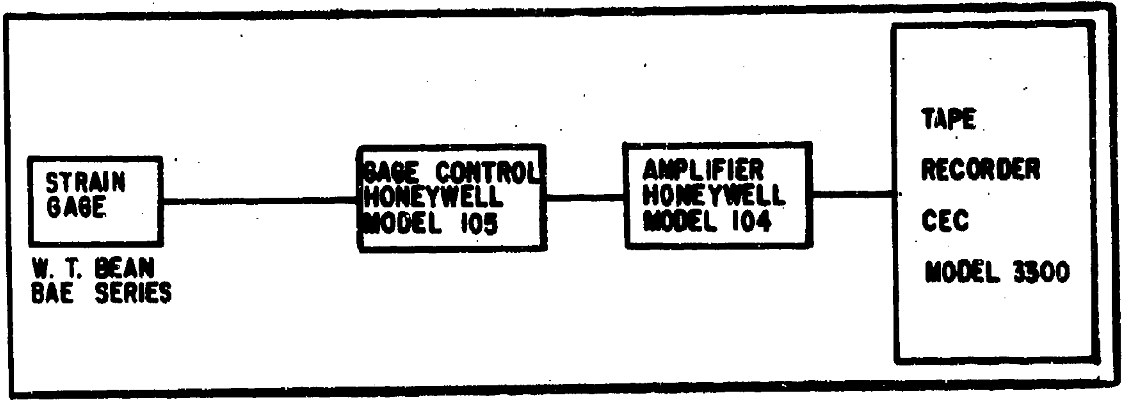


Figure 19. Block Diagram of the Strain Gage Measuring System

Two types of gages were used for strain measurement. Gages placed on steel were Model BAE-06-250 BB-120 TE[1] and gages placed on aluminum were Model BAE-12-250 BB-120 TE[1]. These gages have a nominal resistance of 120 ohms and a gage factor of approximately 2.0. Each of the gages consisted of a single element mounted along the axis of strain. The gages were mounted by using a BR-600[1] adhesive for steel and Eastman 910 for aluminum. The gages were weatherproofed by placing Gagecoat #1 over the top of the gage-wire installation.

---

(1) Bean Manufacturing Co.

Figures 20 and 21 show a typical strain gage installation.

Figure 20. Door Strain Gage Installation.

Figure 21. Door Strain Gage Installation with Protective Coating.

The strain gages were placed on the inside of the arch shells, the steel door and the aluminum door. Four additional gages were placed in the large corrugations of the arch shell, as shown in Figure 22. These gages, placed in Shelter B (S_b-40, 50, 90, 100), were installed to measure the strain distribution in the cross section of the arch.

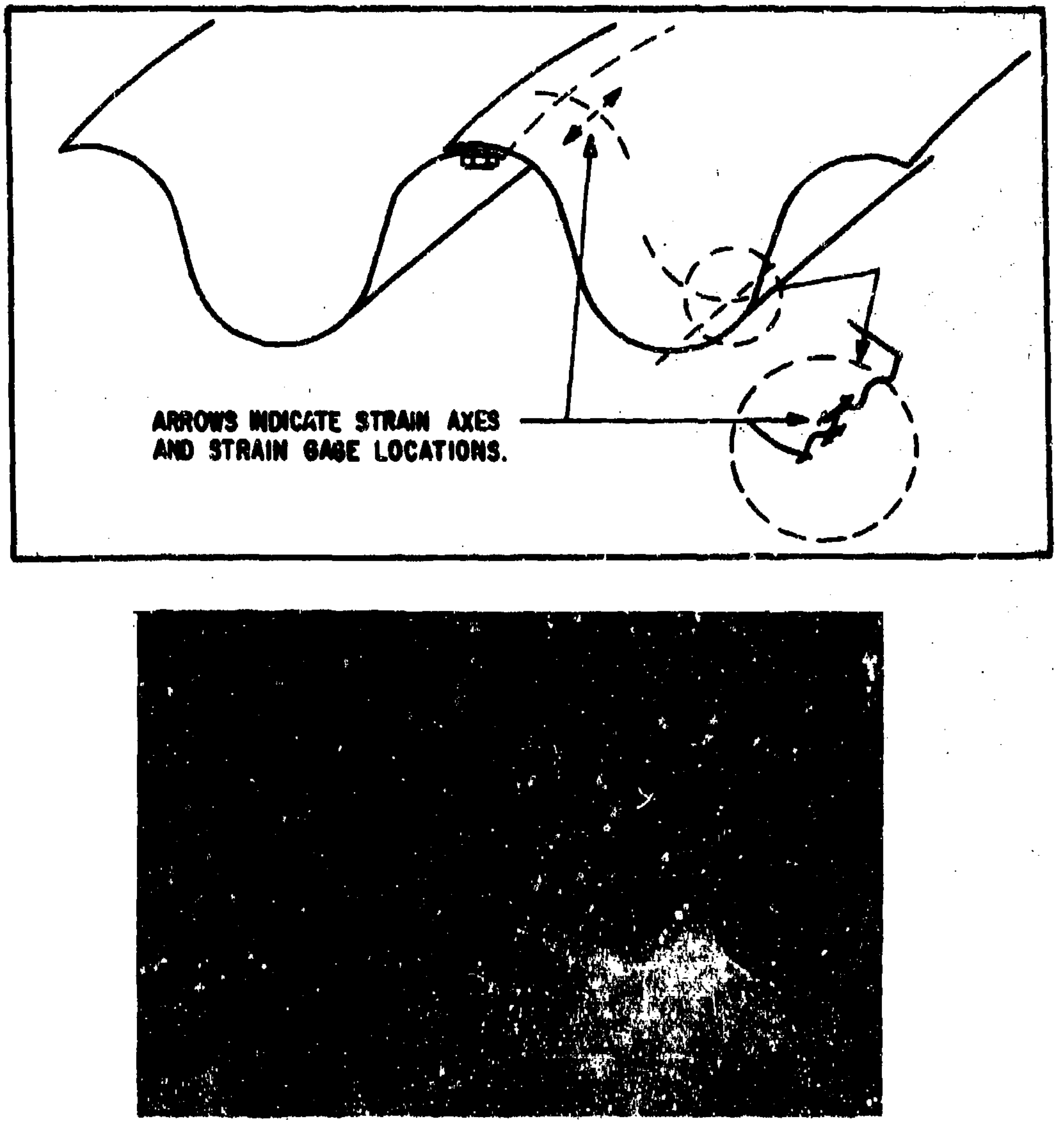


Figure 22. Arch Strain Gage Installation

A three-wire cable was used from each gage to the data acquisition trailer. The three-wire system minimized the effects of temperature changes on the strain measurement system. However, temperature effects were not a primary concern, as dynamic strain data were desired.

The cables from the strain gages were terminated in gage control units. These units were similar to the gage control units used in the vibration measuring system. They completed the Wheatstone bridge circuit and provided the calibration circuit, the balancing circuit, and the power supply.

The output from the gage control unit was transmitted through a D.C. data amplifier to a magnetic tape recorder.

4. Temperature Measuring System

The temperature measuring system consisted of a thermocouple, an ice junction, a data amplifier, and a magnetic tape recorder. A system block diagram is shown in Figure 23.

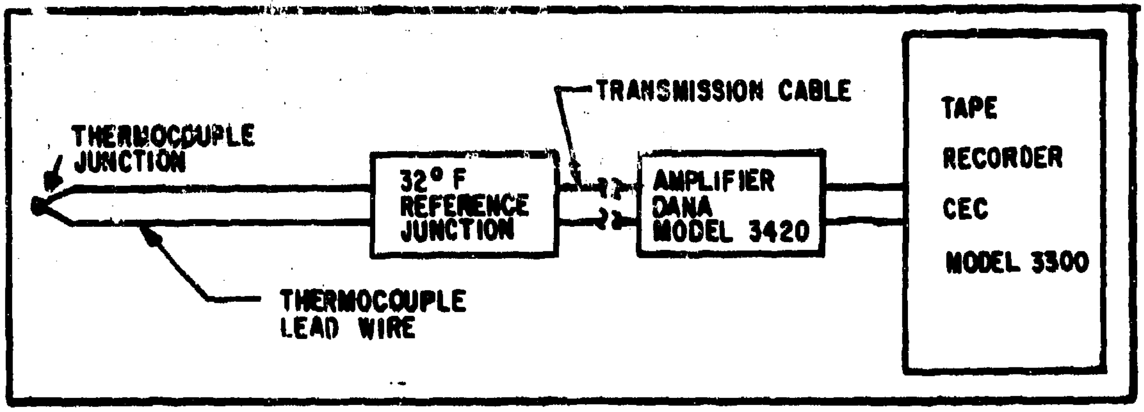


Figure 23. Block Diagram of the Temperature Measuring System

The thermocouples used were made of chromel vs. alumel wire. This type of thermocouple can measure temperatures to 2500° F. and yields an output of approximately 10 millivolts for every 500° F. Three configurations of thermocouples were used: two for air temperatures inside the shelters and one for the nylon door temperature. Figure 24 shows the configurations used for inside shelter temperatures, and Figure 25 shows the configuration used for the nylon door temperature. The exact location of the thermocouples is shown in the data book prior to each test.

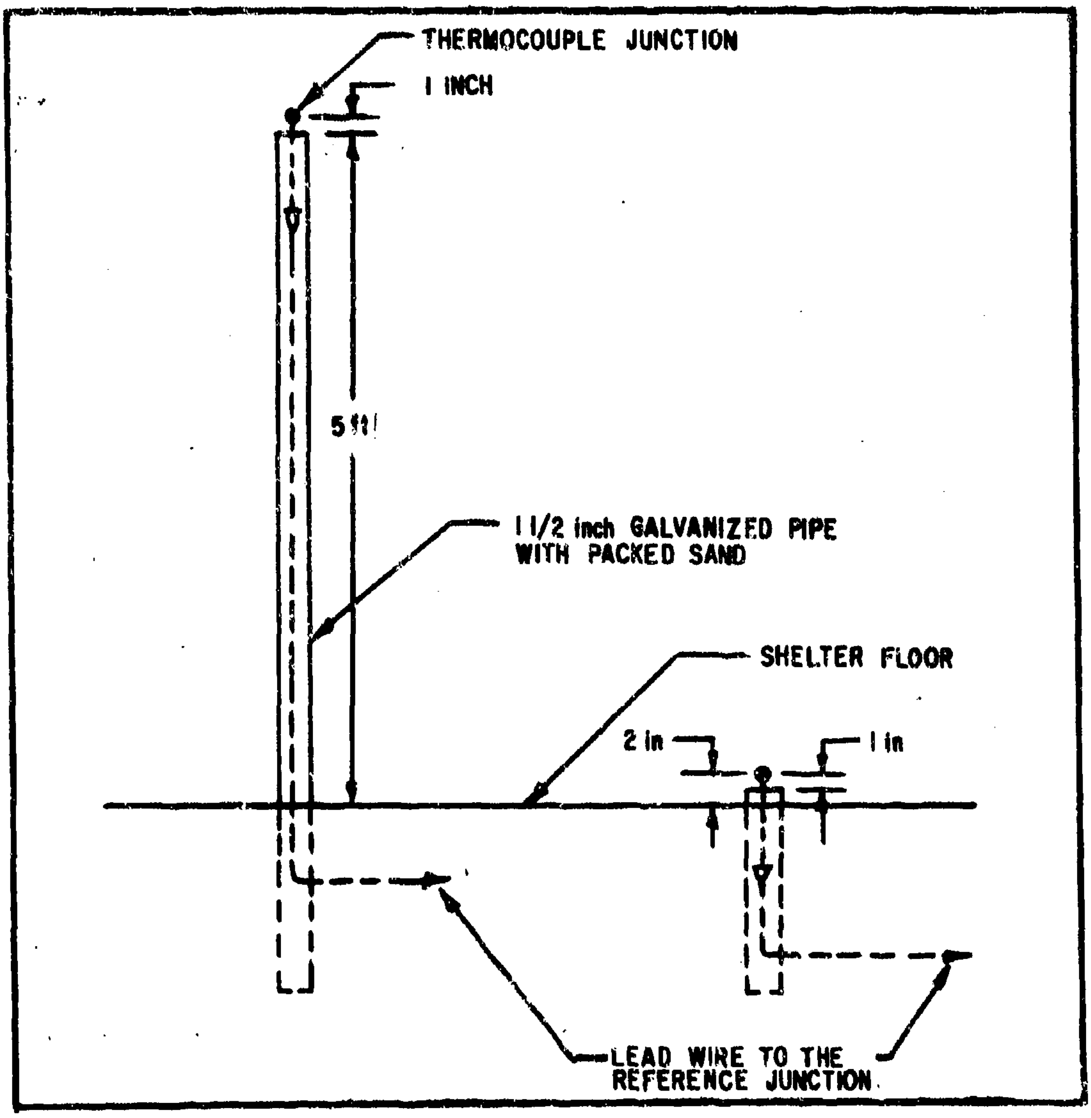


Figure 24. Inside Temperature Transducer Installation

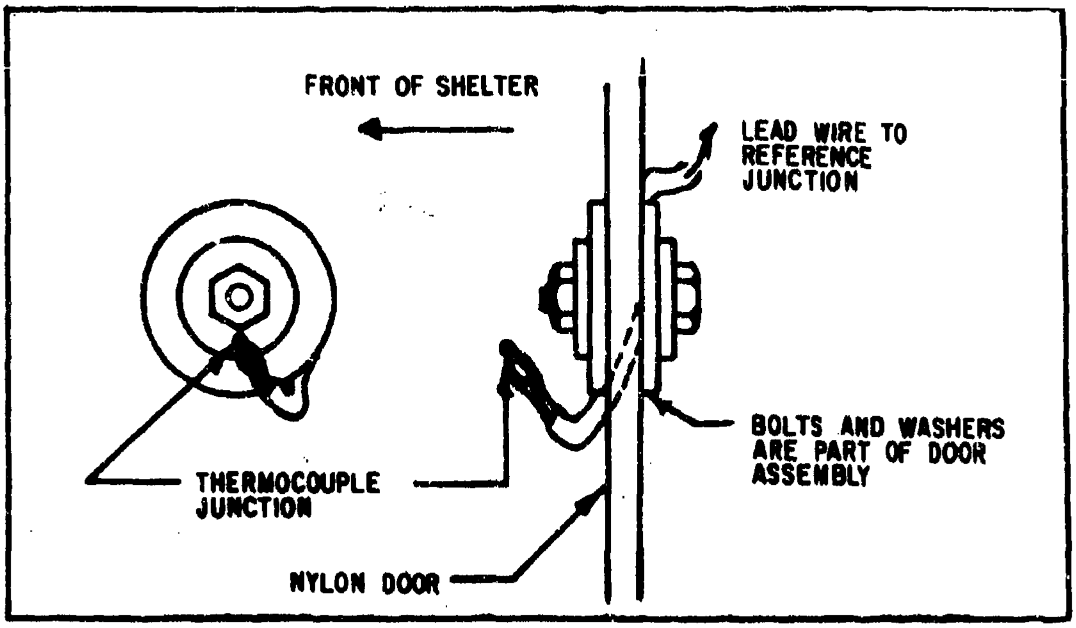


Figure 25. Nylon Door Temperature Transducer Installation

The thermocouples were routed to an ice junction located in the shelters. This junction provided a known reference for all temperature measurements. From the ice junction to the trailer, a standard two-conductor cable was utilized. A D.C. data amplifier was used to amplify the millivolt signals prior to recording them on a magnetic tape recorder.

5. Data Acquisition System

The data acquisition system consisted of four tape recorders (Figure 26). These magnetic tape recorders were used for all test data collection. The tape units were standard IRIG, 1 inch tape units. The high-frequency pressure data were recorded at 61 inches per second and at a center frequency of 54 K Hz, while all the other data were recorded at 15 inches per second and at a center frequency of 13.5 K Hz. All the data were recorded with FM electronics using a deviation of ± 40%.

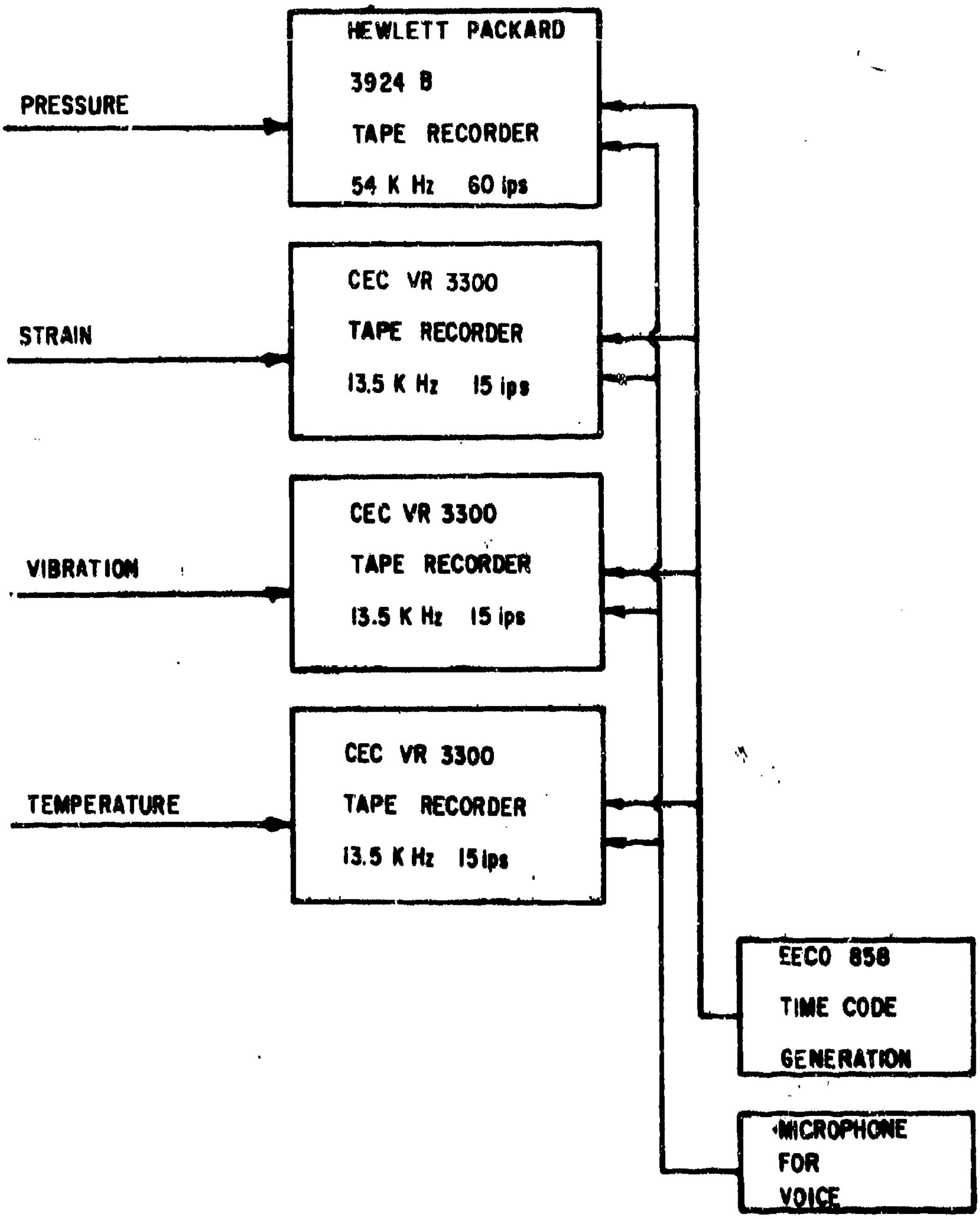


Figure 26. Data Recording System

The 40% deviation enabled the pressure data to be recorded with a frequency response of 0 to 10,000 Hz. These data were deviated through a carrier range of 32,400 Hz to 75,600 Hz at ± 2.5 volts. (Thus, a pressure equivalent to + 2.5 volts was recorded on magnetic tape as 75,600 Hz, and a negative pressure equivalent to − 2.5 volts was recorded at 32,400 Hz.)

All data, except the pressure data, were recorded with a frequency response of 0 to 2,500 Hz. These data were deviated ± 40% from the center frequency of 13.5 K Hz at ± 5 volts.

The four tape recorders were time correlated with a time code generator[1]. The output of the time code generator was recorded on Track 13 of all four tape recorders in an IRIG B format. This format is a 100-pulse-per-second signal yielding the exact time of occurrence.

Voice annotation was recorded on all tape units on Track 14. The voice track identified each event on the tapes.

---

(1) EECO 858

SECTION III

CALIBRATION OF INSTRUMENTATION SYSTEMS

Dynamic and electrical calibrations were performed on all measuring systems. Known pressure and vibration levels were applied to the pressure transducers and to the accelerometers. Electrical values simulating strain and temperature were applied to the strain gages and to the thermocouples. In this section detailed discussions are presented for the calibration methods that were utilized.

1. Pressure System Calibrations

Each pressure transducer used on the Concrete Sky Project was new and had a manufacturer's calibration certificate. A typical certificate is shown in Enclosure 1. This vendor calibration yielded the sensitivity and the linearity of the transducers. Thus, each transducer obtained was verified prior to actual installation.

Prior to each test and following each test, a dynamic pressure calibration was performed. The purpose of the calibration was to adjust the gain of line drive amplifiers and to calibrate the total end-to-end system. The pressure calibration system is shown in Figure 27.

The calibration pressure was obtained by using a microphone[1]. This unit was calibrated in an acoustical laboratory, so that a specified voltage produced a decibel level at a given frequency. From this calibration the following was obtained:

A voltage signal of 7.42 volts (RMS) at 400 Hz applied to the calibrator produces an output of 160 DB, which is equivalent to 0.29 psi (RMS). Therefore, the field calibrations performed on each pressure transducer yielded an output equivalent to 0.29 psi. This transducer output was observed on an oscilloscope in the instrumentation trailer, and the exact voltage was tabulated on a data sheet.

---

(1) Whittaker Photocon Dynamic Pressure microphone, Model PC-120

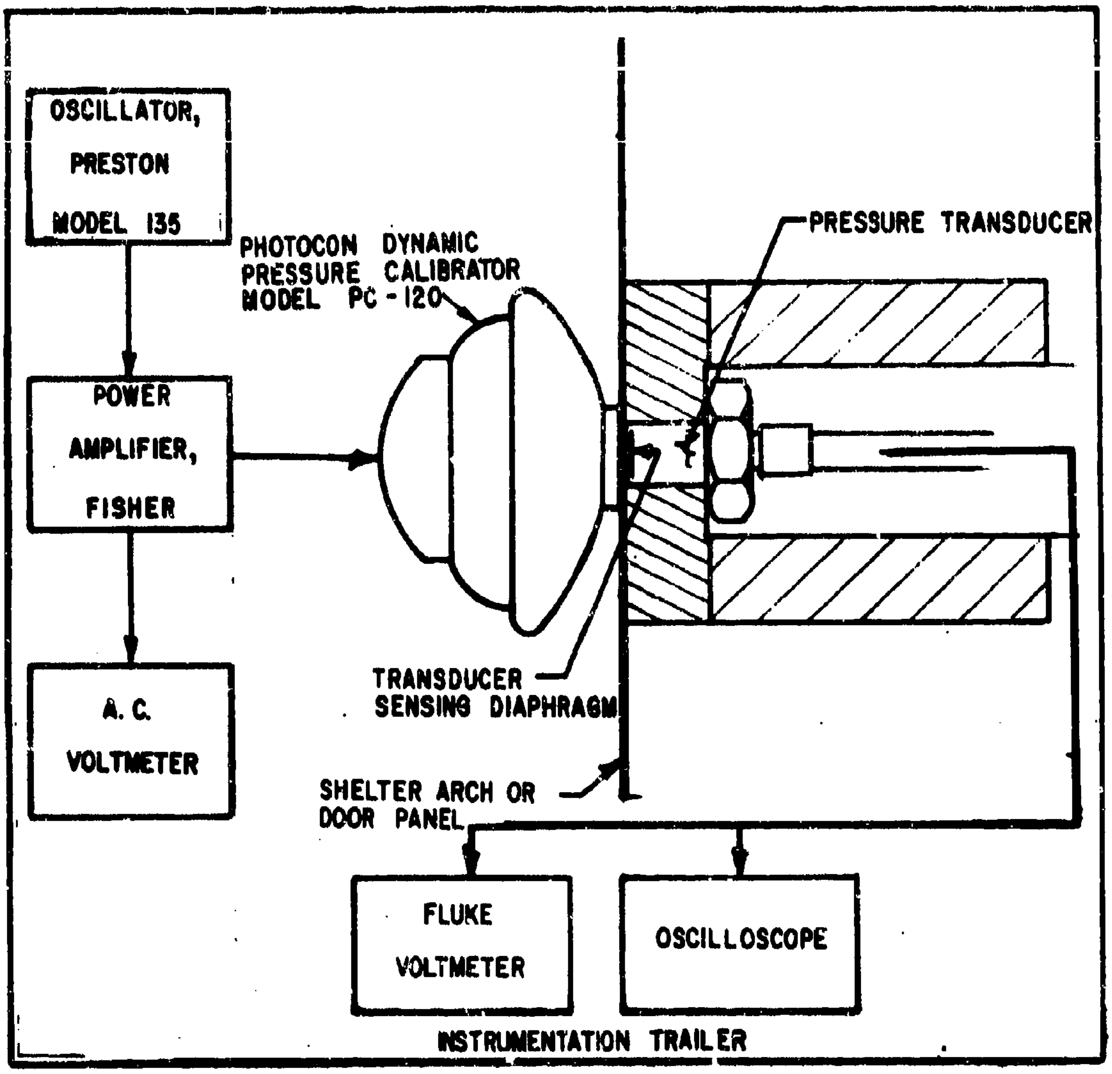


Figure 27. Dynamic Pressure Transducer Calibration System

All dynamic pressure calibrations were performed by placing the calibrator over the face of the transducer, as shown in Figure 27. The transducers were mounted in place prior to the calibrations, and the calibrator was moved to each location.

2. Vibration System Calibration

A laboratory calibration was performed on each accelerometer. Figure 28 shows a block diagram of the laboratory calibration system.

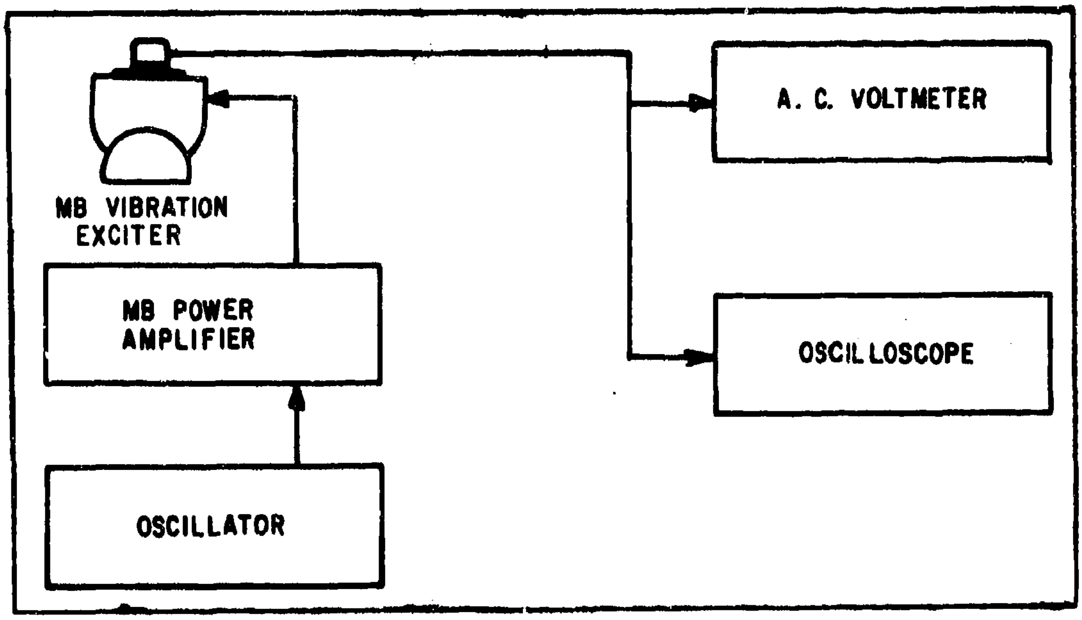


Figure 28. Laboratory Vibration Transducer Calibration System

A transducer calibration certificate was obtained for each accelerometer, a sample copy of which is shown in Enclosure 2. This calibration verified the frequency response of the accelerometer and established the sensitivity and linearity of the accelerometer.

Prior to each series of tests, a one g calibration was performed by rotating the accelerometer 90°, (Figure 29). This calibration was performed with the total vibration measuring system connected. The output voltage from the data amplifiers was recorded on a test data sheet.

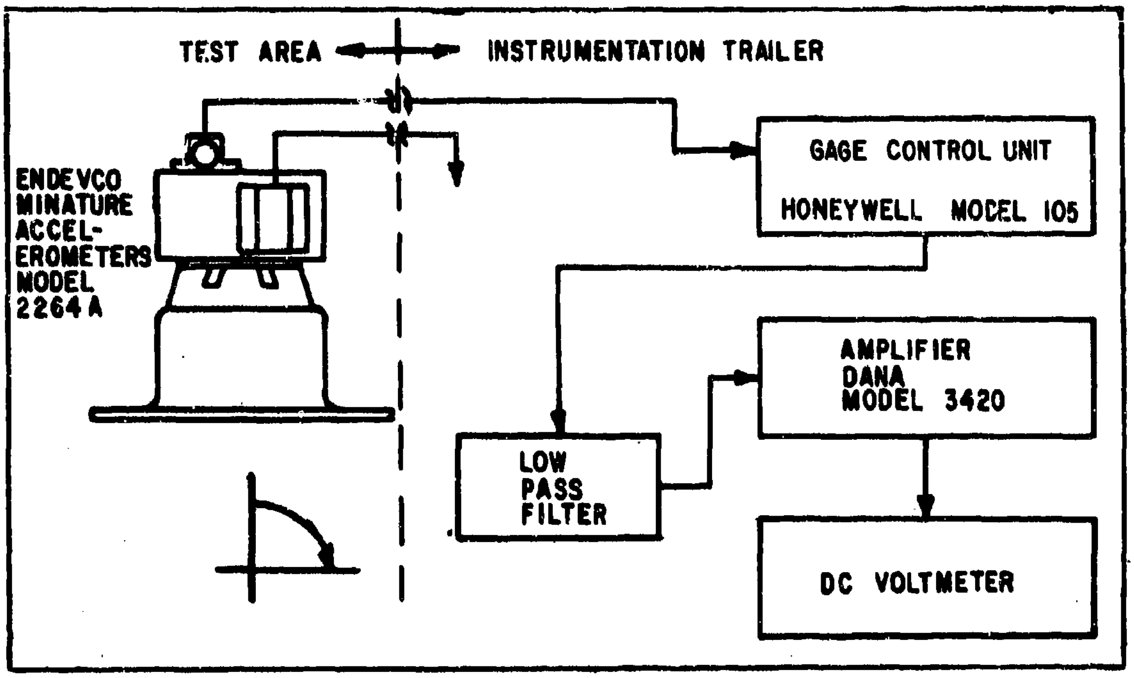


Figure 29. Field Vibration Transducer Calibration System

3. Strain Calibration System

The strain gage measuring system was calibrated electrically by placing a known precision resistor across the electrical circuit. This calibration method is shown in Figure 30. The resistor calibration value, R_{calib}, was selected at 114 K ohms. By closing switch S, the circuit was unbalanced and an output was obtained. This output was recorded on the tape recorder prior to each test.

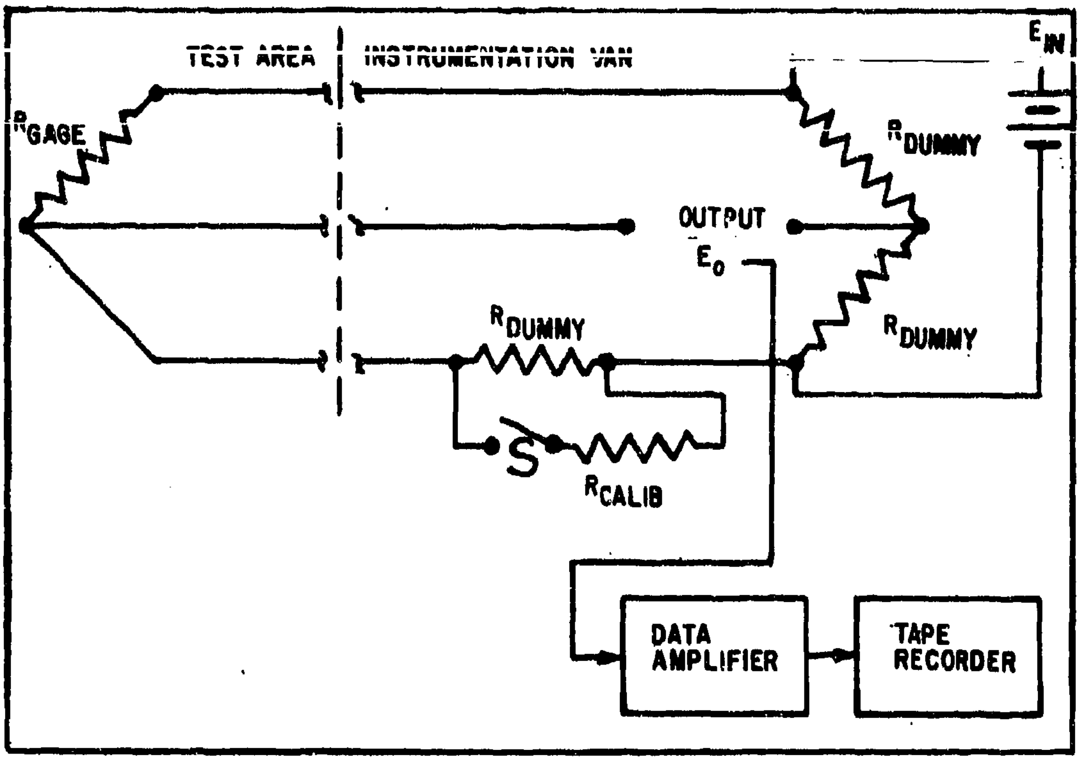


Figure 30. Schematic for the Strain Gage Calibration System

The resistor calibration value was equivalent to 518 μin/in as shown below:

$$\epsilon = \frac{R}{KN(R_{calib} + R)}$$

where ϵ = strain value in μin/in

R = strain gage resistance in ohms

K = manufacturers gage factor

N = number of active gages

R_{calib} = calibration resistance value in ohms

$$\epsilon = \frac{R}{(2.03)\ (1)\ (114{,}000 + 120)} = 518\ \mu\text{in/in}$$

4. Temperature Calibration System

The temperature measuring system was calibrated electrically by inserting a known voltage into the circuit as shown in Figure 31. The precision voltage was recorded on tape and used for data reduction.

Standard conversion tables for thermocouples were used to establish an equivalent temperature for a given voltage. All thermocouples were calibrated with a 15 millivolt signal equivalent to 692° F. for the chromel vs. alumel thermocouples used and with an ice reference junction.

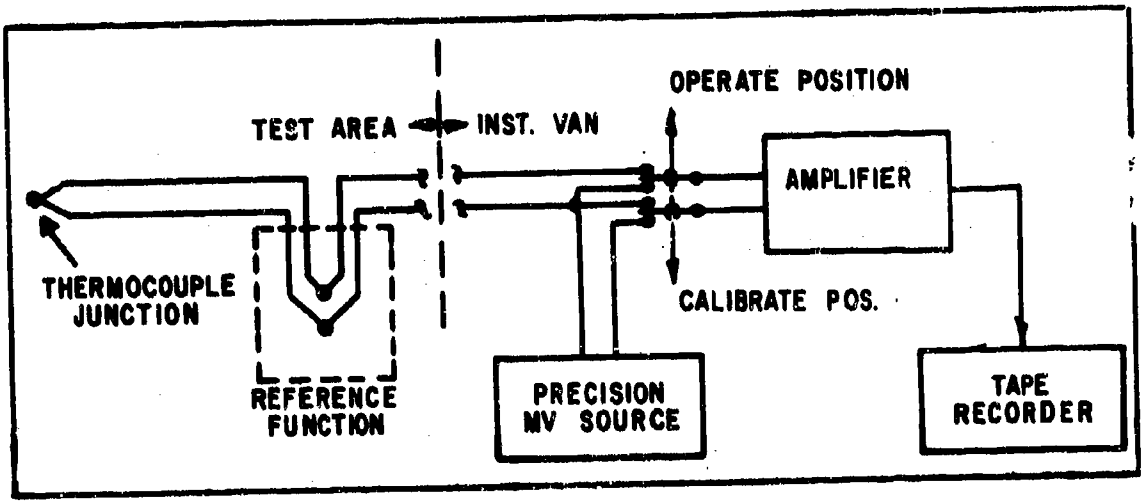


Figure 31. Block Diagram of the Temperature Calibration System

5. Tape Recorder Calibration

The four tape recorders were set up for the correct carrier frequencies and ± 40% deviation prior to each series of tests. After they were set up, a known precise voltage was recorded on each channel of the tape recorders. This voltage of 0.50 or 1.00 volt was simultaneously recorded on each channel. These recorded voltage calibrations were later used in the reduction of data.

SECTION IV

DATA REDUCTION

An analogue and a digital data reduction system were used to reduce the data. The pressure, the strain, the temperature, and the foundation vibration data recorded on magnetic tape were played back to an oscillograph and to a plotter. Scales in engineering units were placed on the data. The arch vibration data were digitized and double integrated by a computer, so that arch displacements were obtained on a Calcomp plotter. All the data are presented in data books under a separate cover. In this section the data reduction techniques are discussed.

1. Analogue Reduction System

The analogue reduction system consisted of a tape recorder, variable filter, amplifiers, a time code reader, an oscillograph, and an X-Y plotter. This system is shown in Figure 32.

In order to obtain the desired oscillograph presentation, the tape recorder speeds were reduced. The pressure data were played back at 1-7/8 ips, the strain and vibration data at 3-3/4 ips, and the temperature data at 7-1/2 ips. The data were filtered when necessary by a Rockland variable filter which alternates at 24 DB/octave. The output of the filter was amplified by a wide band amplifier[1]. The output of the amplifier was recorded on an oscillograph[2]. The temperature data were recorded on an X-Y recorder[3] because the changes in temperature occurred very slowly. The X-Y recorder provided a more desirable presentation of the temperature data than did the oscillograph.

The oscillograph data were reduced by utilizing the calibration data and field calibration notes. Each oscillograph trace was scaled for amplitude in engineering units and was scaled for time in seconds. All time scales for a given test had the same reference point. The procedures used in scaling the data to engineering units are presented in Enclosure 3.

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(1) Preston, 8300
(2) Honeywell, 1508
(3) Mosley, 7004A

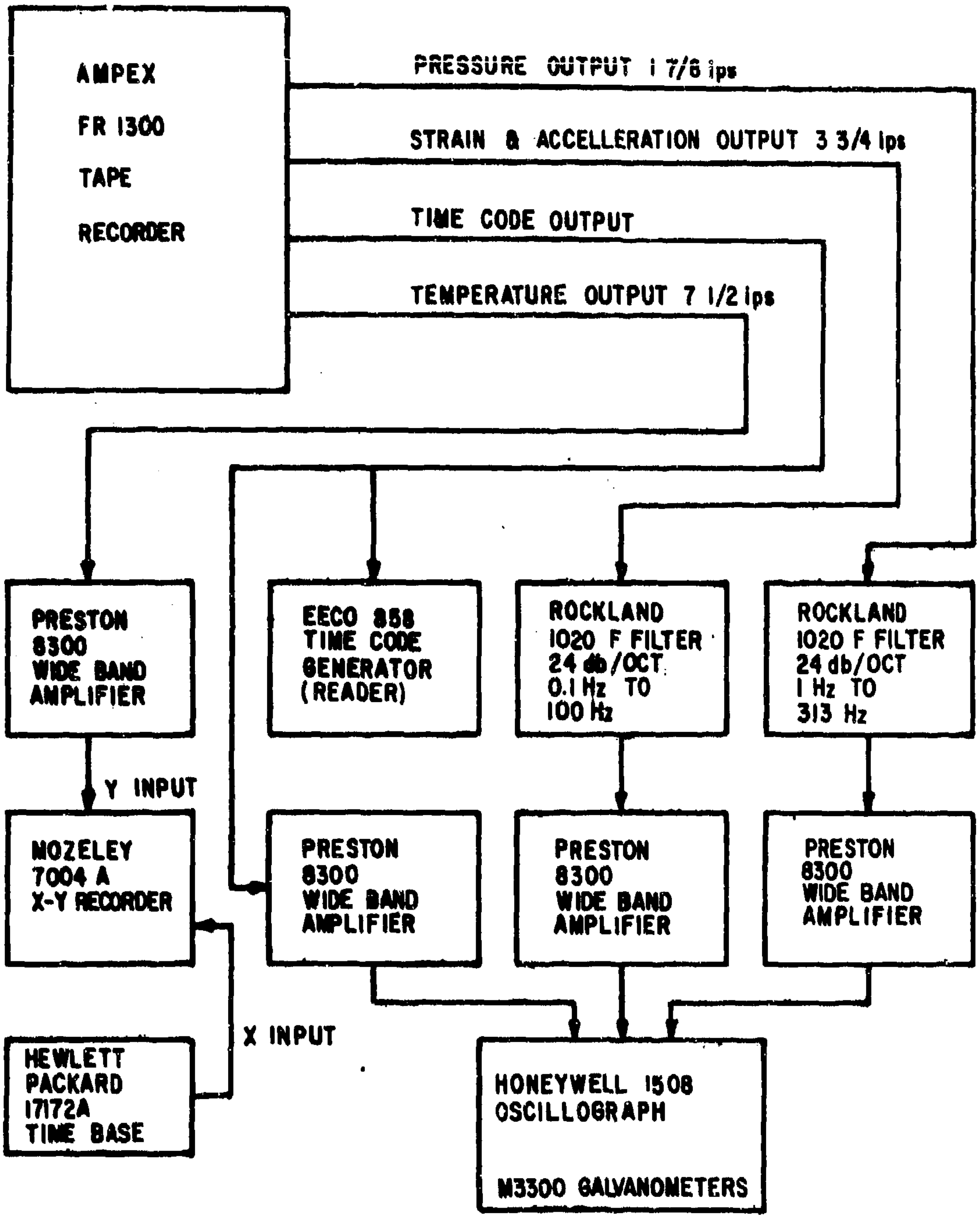

Figure 32
Analogue Data Reduction System

2. Digital Reduction System

Shelter arch deflections were desired. Direct deflection measurements could not be made; thus, the accelerometer data were utilized to obtain deflections. This data had to be double integrated to obtain displacement data. The best method for double integration of data is by means of a computer. The Kirtland AFB computer facility was used to reduce the acceleration time histories to displacement time histories. The method used to obtain the displacement data is discussed below:

The data tapes were played back on an Ampex FR-1300 tape recorder. The data were converted four channels at a time from analogue data to digital data by means of a EDCOMP 8032C A/D converter. A digital multiplexed tape was obtained (Figure 33). A CDC 8090 computer was used to de-multiplex the

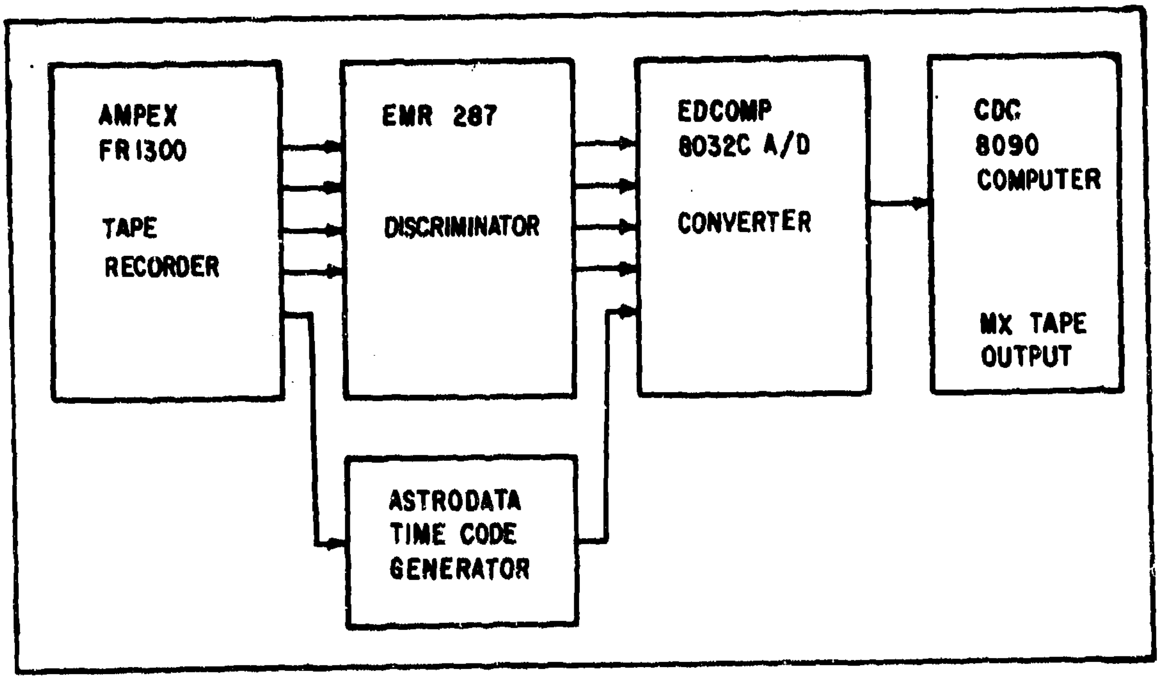

Figure 33. Digital Reduction System

tape and produce a stripped digital tape. This tape was checked on a display unit and on a plotter. Figure 34 shows a block diagram of this procedure.

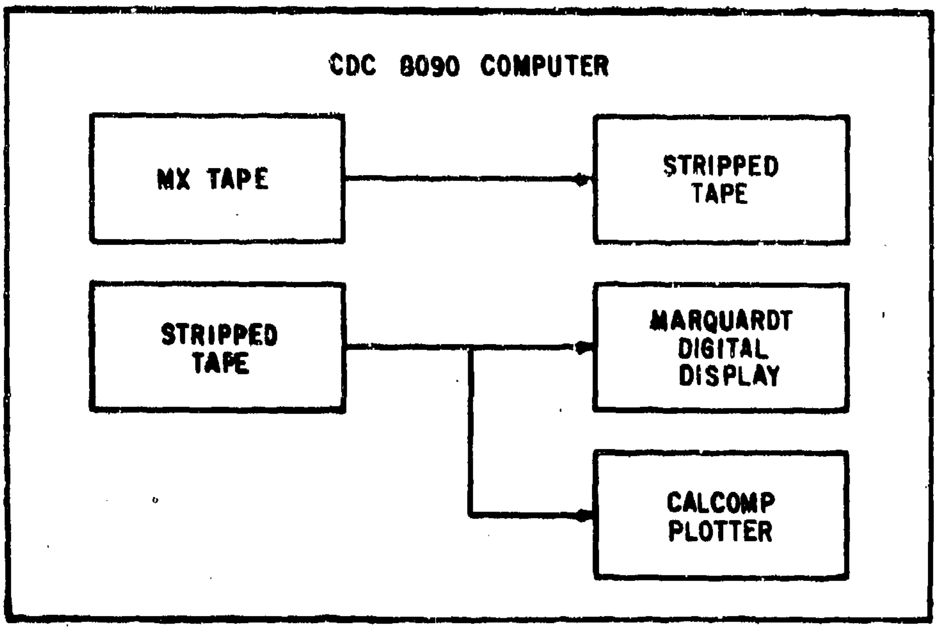

Figure 34. Procedure Used to De-Multiplex and Check the Digital Tape

The digital stripped tape consisted of the acceleration time history data. This tape was then placed in a CDC 1604-B computer system to obtain a plot tape which yielded displacement time history data.

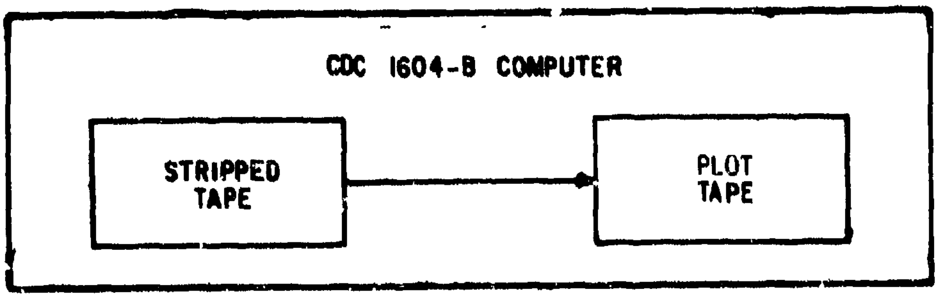

Figure 35. Conversion of Stripped Tape to Plot Tape

The plot tape was then placed in a CDC 160-A computer system to obtain the final data. A Calcomp plotter was used to reproduce the final data. Both the acceleration and displacement time histories are presented.

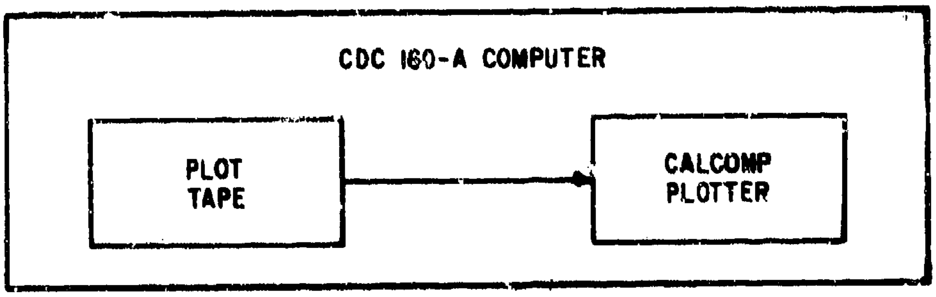

Figure 36. Displacement Data Presentation

SECTION V

DISCUSSION OF DATA

The test data are presented in three supplementary books:

Book I	Data for Tests:	7-B-1 (b)
		3-B-1 (a)
		14-A-2
		14-A-1
		7-A-3
		3-A-2
		8-A-1 (b)
		8-A-2
Book II	Data for Tests:	7-A-2
		8-A-1 (a)
		8-C-1
		7-C-4
		6-C-1
		8-C-2
		7-C-3
		7-C-2
Book III	Data for Tests:	8-B-3
		8-B-2
		8-B-1
		7-B-4
		7-B-3
		7-B-2
		10-C-2
		10-A-1
		10-C-1
		7-B-1 (a)
		7-A-1
		7-C-1
		3-C-2

The test numbers shown above were new numbers used after completion of the test programs. Table II shows the original and new numbers. The original numbers were used for voice annotation on the tapes. The test numbers were changed to establish meaning to the numbers. The following information can be noted from the test number:

1st Digit: 6 = 250 lb. G. P. Bomb
7 = 500 lb. G. P. Bomb
8 = 1000 lb. G. P. Bomb
3 = 122 mm Rocket (warhead)
10 = Napalm

Letters indicate shelters: Shelters A, B, and C.

Last digit indicates test number on a shelter.

Example: Test 8-A-3
1000 lb. G. P. Bomb detonated at Shelter A.
It is the third test of the series performed on Shelter A.

Table II Test Numbering System

Date of Test	Original Test Number	New Test Number	
July 16, 1969	Test #2 Door of #2	7-B-1 (b)	Data Book 1
July 16, 1969	Test #1 Door of #2	3-B-1 (a)	
July 11, 1969	Failure #2-1	14-A-2	
July 10, 1969	Failure #1-1	14-A-1	
July 10, 1969	Revet. 2-1	7-A-3	
July 10, 1969	Revet. 1-1	3-A-2	
July 10, 1969	9-A-1 Repeat N	8-A-1 (b)	
July 10, 1969	9-B-1	8-A-2	
July 9, 1969	8-D-1	7-A-2	Data Book 2
July 9, 1969	9-A-1	8-A-1 (a)	
July 8, 1969	9-A-3	8-C-1	
July 8, 1969	8-D-3	7-C-3	
July 7, 1969	8-E-3N	6-C-1	
July 7, 1969	9-B-3	8-C-2	
July 7, 1969	8-B-3	7-C-3	
July 7, 1969	8-A-3N	7-C-2	
July 2, 1969	9-A-2S	8-B-3	Data Book 3
July 2, 1969	9-B-2	8-B-2	
July 2, 1969	9-A-2N	8-B-1	
June 30, 1969	8-A-2S	7-B-4	
June 30, 1969	8-B-2	7-B-3	
June 30, 1969	8-A-2N	7-B-2	
June 26, 1969	6-B-3	10-C-2	
June 26, 1969	6-A-1	10-A-1	
June 26, 1969	6-A-3	10-C-1	
June 25, 1969	8-C-2	7-B-1 (a)	
June 25, 1969	8-C-1	7-A-1	
June 24, 1969	8-C-3	7-C-1	
June 24, 1969	1-C-3	3-C-2	

The test data were recorded on four tape recorders, identified as Tape Recorder 1, 2, 3, and 5. The first set of tests recorded on these tapes are identified by a -1 (i.e., first tape of tape recorder no. 1 is identified 1-1). When this tape was full, the next tape of the recorder was identified 1-2. Each tape recorder had a recording capacity of fourteen channels. The functions recorded on each channel are identified by using the first letter of each function, the shelter letter, and a number which identifies the exact location. Examples are given below:

V_a - 10: Vibration, Shelter A, Location 10

S_b - 6: Strain, Shelter B, Location 6

P_c - 4: Pressure, Shelter C, Location 4

T_a - 1: Temperature, Shelter A, Location 1

The test data will now be discussed for validity, and any questionable data will be pointed out. For exact gage location and the actual time histories obtained, refer to the data book supplements. Table III on the following pages gives explanations regarding the data validity.

Table III

Comments Regarding the Following Data

New Test Number	Strain Data	Vibration Data	Pressure Data
Data Book 1 7-B-1 (b)	S_b-14, S_b-15: Noisy signal	V_b-22, V_b-23: Inoperative V_b-17, V_b-18, V_b-19, V_b-20: Not reduced, not required	P_b-17 was not recorded. Door modifications eliminated this pressure
3-B-1 (a)	S_b-1, S_b-2: Saturated the tape channel	V_b-8: Inoperative V_b-17, V_b-18, V_b-19, V_b-20: Not reduced, not required	P_b-17 was not recorded. Door modifications eliminated this pressure
14-A-2	S_a-7: Inoperative S_a-10: Low level signal	V_a-17, V_a-18: Inoperative	P_a-2: Inoperative
14-A-1	S_b-1, S_b-2, S_b-7, S_b-10: Low level signal		
7-A-3	No strain data desired for this test	No vibration data desired for this test	
3-A-2	No strain data desired for this test	No vibration data desired for this test	

Comments Regarding the Following Data (Continued)

New Test Number	Strain Data	Vibration Data	Pressure Data
8-A-1 (b)		V_a-2: Inoperative V_a-7: Noisy signal	P_a-13: Inoperative
8-A-2	S_a-1, S_a-2, S_a-7: Low level signal	V_a-7: Noisy signal V_a-10: Low level signal	
Data Book 2 7-A-2	S_a-1, S_a-2: Low level signal	V_a-18: Noisy signal, Low level signal	
8-A-1 (b)	S_a-1, S_a-2: Low level signal	V_a-10: Low level signal	All pressures were lost due to the loss of the 28 volt power line. This test was repeated, Test 8-A-1a
8-C-1	S_c-2: Noisy signal S_c-8: Low level signal	V_c-2, V_c-10, V_c-14: Low level signal V_c-19: Noisy signal	P_a-5: Signal level saturated the tape

Comments Regarding the Following Data (Continued)

New Test Number	Strain Data	Vibration Data	Pressure Data
7-C-3	S_c-5, S_c-7, S_c-10: Low level signal	V_c-2, V_c-8, V_c-10: Low level signal V_c-13: Noisy signal V_c-14: Low level signal	P_c-5: Low level signal
6-C-1		V_c-10: Low level signal	
8-C-2			
7-C-3		V_c-10: Low level signal	
7-C-2			-1, P_c-3, P_c-5, P_c-13, P_b-12: were the odd tracks of tape recorder no. 2. The odd track record head malfunctioned during the test, thus, all channels were lost.
<u>Data Book 3</u> 8-B-3	S_b-40: Noisy signal S_b-50: Noisy signal S_b-100: Noisy signal	V_b-10: Low level signal V_b-17: Accelerometer inoperative	

Comments Regarding the Following Data (Continued)

New Test Number	Strain Data	Vibration Data	Pressure Data
8-B-2	S_b-9, S_b-10, S_b-100: Low signal level S_b-40, S_b-50: Noisy signal	V_b-8: Noisy signal V_b-9, V_b-10: Low level signal	
8-B-1	S_b-1, S_b-2: Low level signal S_b-40, S_b-50, S_b-100: Noisy signal	V_b-2: Noisy signal V_b-8, V_b-10, V_b-13, V_b-14, V_b-15, V_b-17: Low level signal	P_b-5, P_b-6, P_b-7: Low level signal
7-B-4	S_b-7, S_b-8: Low level signal	V_b-2, V_b-10, V_b-13: Low level signal V_b-14, V_b-15: Accelerometer Inoperative V_b-17, V_b-20: Noisy signal	All pressure data lost
7-B-3	S_b-7, S_b-8, S_b-9, S_b-10: Low level signal	V_b-2: Noisy signal V_b-8, V_b-10: Low level signal	

Comments Regarding the Following Data (Continued)

New Test Number	Strain Data	Vibration Data	Pressure Data
7-B-2	S_b-8, S_b-10, S_b-100: Low level signal	V_b-2, V_b-5, V_b-8: Low level signal V_b-20: Noisy signal	P_b-6: Low level signal

Comments Regarding the Following Data (Continued)

New Test Number	Temperature Data	Strain Data	Vibration Data	Pressure Data
10-C-2	Only temperature data was recorded. All data is presented.			
10-A-1	T-12 not operational			
10-C-1	All temperature data lost as all channels were overranged.			
7-B-1 (a)				All pressure data was lost.
7-A-1				
7-C-1		S_c-11: Noisy signal S_c-17: Low level signal		All pressure data was lost. Wiring error in instrumentation trailer.
3-C-2		S_c-17: Low level signal		Pressure data is suspect. Waveforms look similar.

SECTION VI

SUMMARY

This report presents discussions of the instrumentation system, the calibration system, and the data reduction system of the Concrete Sky Instrumentation Program. These systems are reviewed in great detail so that future data evaluations and analyses can be performed. The reduced data is presented under separate cover; however, comments concerning data validity are presented in Section V. Many of the reduced traces indicated that the signals recorded were very low level signals. These signals when reproduced on an oscillograph were in the noise level of the recorded signal levels. The signal to noise ratio for the instrumentation systems was approximately 40 decibels or 100 to 1. Therefore, a good detectable signal had to be at least 1% of the full scale level. For example, an accelerometer set for a 10 G full scale level yielded data to a minimum level of 0.1 G. Many signals were below this level; thus, the comment used in Section V for these channels is: Noisy signal.

The shelter response data for the tests conducted is of a high quality. This data clearly indicates the peak levels and the natural frequencies of the structures. The pressure data is extremely high frequency data and is a very difficult parameter to measure. This data is affected by items such as the placement of the bomb on the ground and the shrapnel effects. These types of variables make the data inconsistent. Thus, some of the pressure traces are suspect. A considerable amount of time is still required to evaluate the validity of the pressure traces.

APPENDIX I

PRESSURE TRANSDUCER CALIBRATION CERTIFICATE

Date June 2, 1969

CALIBRATION CERTIFICATE

Transducer Flush Mounting No. LD-25 Serial No. 458

CALIBRATION METHOD

Atlantic Research pressure transducers are calibrated by a pulse technique. The transducer is mounted in a vessel filled with nitrogen and the pressure pumped up to the desired value. The sudden release of pressure by means of a quick-acting valve results in a pressure step function being applied to the transducer. The response is observed on an oscilloscope.

This method is simple, unambiguous, and lends itself to absolute calibration through the use of a standard cell, standard capacitances, and a standard bourdon tube.

The results of the calibration of the transducer with the above Serial Number are given below. The calibration data are reproducible within ±1%. For accurate measurements, it is suggested that a calibration curve be used.

CALIBRATION RESULTS

Temperature 26 °C.

Capacitance 259 μμf

DC Input Resistance 10,000 megohms

Leakage Resistance* ----- megohms

Average Sensitivity

21.5 μμC/psi

0.083 volts/psi (open circuit)

-118 db ref 1 volt/dyne/cm^2 (open circuit)

Detailed Calibration Data

Pressure (psi)	Charge (μμ Coulombs)
25	505
50	1090
75	1650
100	2210

*Resistance from the transducer mounting sleeve or housing to the transducer output terminal(s); given where applicable.

Measurements made and certified by

APPENDIX II

ACCELERATION CALIBRATION

Model No. 2264A Serial No. 0995

Range ±150 g Manufacturer ENDEVCO

Max. Excitation Voltage 10 V DC AC

Terminals No. R g Restance 1723 Ω

Terminals No. B g Resistance 1726 Ω

SENSITIVITY:

Millivolts 2.78/g Excitation 10 VDC Applied Load 90 g

LINEARITY & HYSTERESIS: Temperature 80°F

Units (g)	Millivolts (up)	Millivolts (down)
0	0	0
10	27.82	28.49
30	83.28	83.67
50	138.73	139.01
70	196.63	196.36
90	253.66	

Linearity 0.6 %

Hysteresis 0.3 %

PSID:

Millivolt Shift

At Line Pressure of

CALIBRATION FACTOR:

Resistance	Millivolts	Units (g)
250 k	9.86	3.52
100 k	24.75	8.81
50 k	49.29	17.55
25 k	97.50	34.70

Tested by H. Shah Approved by R Weinstein

Date 6-6-69

APPENDIX III

Procedure Used in Scaling the Amplitude of Reduced Data to Engineering Units

A. Vibration in G

B. Pressure in PSI

C. Strain in μ IN/IN

D. Temperature in °F

A. VIBRATION

The following procedure was used in obtaining the amplitude scale for all vibration channels:

Data Acquisition

1. The dynamic calibration value was: 1G = 1.60* volts at an amplifier gain of $A_R = 1000$.

2. The test was conducted at an amplifier gain of $A_R = 300$.

3. A 0.5 volt calibration was recorded on tape.

Data Playback

4. The calibration value of No. 3 (0.5 volts) was played back to an oscillograph with a playback amplifier gain of $A_p = 20$.

5. The test data were played back to an oscillograph with a playback amplifier gain of $A_p = 10$.

Calculations

a) From No. 1, 1.60 volts = 1 G at A = 1000

b) The test run gain was changed (No. 2), thus

$$1.60 \text{ volts} = 1 \text{ G at } A = 1000$$

or

$$1.60 \times \frac{300}{1000} \text{ volts} = 1 \text{ G at } A = 300$$

$$0.48 \text{ volts} = 1 \text{ G}$$

c) The voltage calibration level of 0.5 volts (No. 3) is equivalent to

$$0.48 \text{ volts} = 1 \text{ G}$$

$$0.50 \text{ volts} = 1 \left(\frac{.50}{.48}\right) \text{ G}$$

$$0.50 \text{ volts} = 1.04 \text{ G}$$

d) Therefore, the calibration value played back in No. 4 is equal to:

$$1.04 \text{ G at } A_p = 20$$

---

* Representative numbers are used in these procedures for clearer understanding.

e) The calibration value of No. 4 is reduced from the oscillograph and it is equal to 0.77 inches of deflection. Thus,

$$1.04\ \text{G} = 0.77\ \text{in. at}\ A_p = 20$$

or

$$1.0\ \text{G} = \frac{.77}{1.04} = 0.74\ \text{in.}$$

f) The test data was played back (No. 5) with an amplifier gain of 10, thus

$$1.0\ \text{G} = 0.74\ \text{in. at}\ A = 20$$

$$1.0\ \text{G} = 0.74\ \left(\frac{10}{20}\right)\ \text{at}\ A = 10$$

or

$$\underline{1.0\ \text{G} = 0.37\ \text{in.}}$$

B. PRESSURE

The following procedure was used in obtaining the amplitude scale for all pressure channels.

Data Acquisition

1. The dynamic calibration value was: 160 DB (0.41 psi) = 34 millivolts.

2. A 1.0 volt calibration was recorded on tape.

Data Playback

3. The calibration value of 1.0 volts was played back to an oscillograph with a playback amplifier gain of $A_p = 20$.

4. The test data was played back to oscillograph with a playback amplifier gain of $A_p = 10$.

Calculations

a) From No. 1 we have 0.41 psi = .034 volts, thus the equivalent psi level for the recorded voltage calibration of No. 2 is:

$$.034\ \text{volts} = 0.41\ \text{psi}$$

and

$$1.00\ \text{volts} = \frac{1.00\ (.41)}{.034} = 12.05\ \text{psi}$$

b) The calibration value played back in No. [illegible] is equal to 12.05 psi at $A_p = 20$. This calibration played to an oscillograph is equal to 1.43 inches. Thus,

$$12.05 \text{ psi} = 1.43 \text{ in. of deflection}$$

or

$$1 \text{ psi} = \frac{1.43 \text{ in.}}{12.05} = 0.119 \text{ in. at } A_p = 20$$

c) The test data was played back at a lower gain (No. 4) than the calibration, $A_p = 10$. Therefore,

$$1 \text{ psi} = \frac{10}{20} (0.119 \text{ in}) = \underline{0.059 \text{ inch}}$$

C. STRAIN

The following procedure was used in obtaining the amplitude scale for all strain channels.

Data Acquisition

1. A calibration resistor was placed across one of the legs of the strain gage bridge circuit. The value of the resistor was:

$$R_c = 114{,}000\ \Omega$$

This value of resistance is equivalent to a strain value of 520 μin/in. For gages S-40, S-50, S-90 and S-100, two gages were connected in series, thus the equivalent strain for $R_c = 114{,}000\ \Omega$ is 1040 μin/in.

2. When the calibration resistor was placed across the circuit, the output voltage was recorded on the tape recorders.

3. Step No. 2 above was always performed at the same amplifier gain as the test run gain.

Data Playback

4. The R_c values were played back to an oscillograph with a playback gain of $A_p = 5$.

5. The test data was played back to an oscillograph with a playback amplifier gain of $A_p = 10$.

Calculations

a) From No. 1, the value of the calibration is 520 μin/in.

b) The calibration value played back to an oscillograph is equal to

$$520 \ \mu\text{in/in} = 0.92 \text{ inch of deflection at } A_p = 5$$

c) The test data (No. 5) is played back at $A_p = 10$, thus,

$$520 \ \mu\text{in/in} = 0.92 \left(\frac{10}{5}\right) \text{ inch of deflection}$$

$$520 \ \mu\text{in/in} = 1.84 \text{ in.}$$

or

$$\underline{100 \ \mu\text{in/in} = 0.354 \text{ inch}}$$

D. TEMPERATURE

The following procedure was used in obtaining the amplitude scale for all temperature data.

Data Acquisition

1. A 15 millivolt signal was recorded on all channels of the tape recorder. This signal is equivalent to 692° F.

Data Playback

2. The 15 millivolt signal was played back to the X-Y recorder with a playback amplifier gain of $A_p = 5$.

3. The test data was played back to the X-Y recorder with a playback amplifier gain of $A_p = 25$.

Calculations

a) The calibration value (No. 1) played back to the plotter was equal to 1.7 inches. Thus

$$15 \text{ mv} = 692° \text{ F} = 1.7 \text{ in.}$$

or

$$100° \text{ F} = 0.246 \text{ in. at } A_p = 5$$

b) The test data (No. 3) was played back at a gain of 25, therefore,

$$100° \text{ F} = 0.246 \text{ in} \times \frac{25}{5}$$

$$\underline{100° \text{ F} = 1.23 \text{ inches}} \text{ at } A_p = 25$$

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13. ABSTRACT

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Three aircraft shelters, constructed of corrugated steel and concrete, were tested by various conventional weapons. The shelters were instrumented with strain gages, accelerometers, thermocouples, and pressure transducers. This report describes the instrumentation system used, the exact locations of the transducers, the calibration procedures used, and the data reduction system. All test data and the gage locations are presented in the supplement. The data are not analyzed in this report. However, the quality of the data is briefly discussed.

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