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by
P. V. NAU and B. E. OLSEN

Work supported in part by
Contract EY-76-C-03-0167
Project Agreement No. 65
for the San Francisco Operations Office
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**GENERAL ATOMIC COMPANY**

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# ABSTRACT

Using 1/5-scale and 1/1-scale (prototype H451) fuel elements, one, two, or three stacked elements on a clamped base element were rocked from an initial release position. Relative displacement, rock-down loads, and dowel pin shear forces were measured. A scaled comparison between 1/5-scale and 1/1-scale results was made to evaluate the model scaling laws, and an error analysis was performed to assess the accuracy and usefulness of the test data.

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# 1. SUMMARY AND CONCLUSIONS

Rocking tests with 1/5-scale and 1/1-scale (prototype H451) fuel elements were carried out by rocking one, two, or three stacked elements on a clamped base element from an initial release position. The elements were instrumented to measure relative displacement (rocking angle), rock-down load and dowel pin shear force. Total force as well as discrete forces on the three dowels were obtained. Maximum peak values of rock-down load and dowel force were observed during the period of free rocking. A scaled comparison between 1/5- and 1/1-scale results was made to evaluate the model scaling laws. Finally, an error analysis was performed to assess the accuracy and usefulness of the test data.

The following main conclusions were derived from the tests;

1. The element rocking motion decays rapidly from initial release and increases in frequency at smaller angles.

2. Maximum rock-down forces and dowel forces are generally observed on the first rock-down after release, and they occur for zero rocking angle.

3. Only small variations in rocking motion and total forces result from rocking about different element axes (X, Y, and Z).

4. Rock-down load and dowel force do not increase appreciably with an increase in initial release angle above 5°.

5. In multiblock configurations (three or more stacked elements) the initially displaced elements at the top of the stack practically

transfer all their angular momentum on first rock-down to the block next to the base block. The elements then rock together as a rigid column.

6. Scaled comparisons between 1/5- and 1/1-scale rocking motion show good agreement particularly for small rocking angles (<5°). Rock-down loads and dowel forces do not agree very well. This shows that the rocking motion (displacement) is little dependent on the distortions incurred in the scaling of $\rho/E$ for the 1/5-scale element whereas the forces are largely affected.

7. Total random errors in the rocking displacement (angle) for two-block configurations are relatively small (maximum 7.2% representing one standard deviation). Larger errors exist in the force data (maximum 15.3%).

8. Test data from multiblock rocking configurations contain large errors (exceeding 24% for dowel forces) due to deviations in test array configuration and element geometry.

# 2. INTRODUCTION

Rocking tests were performed on 1/5- and 1/1-scale HTGR fuel elements to obtain a better computer model representation of the core structural behavior under seismic conditions. The basic properties obtained from these tests included element rocking angle, rock down force, and dowel pin shear force. This was achieved by tilting one element or several elements placed on top of each other to some initial relative position and releasing them. The required properties were then measured by strategically located instrumentation.

This report describes the results of 50 such tests with 1/5-scale model blocks and 22 tests with 1/1-scale prototype fuel elements. The tests were performed by Approved Engineering Test Laboratories (AETL), Los Angeles. AETL was primarily responsible for the instrumentation development and testing phase. Data reduction and analysis were the responsibility of General Atomic personnel. The bulk of the reduced data for the 1/5-scale and 1/1-scale rocking tests are contained in Refs. 1 and 2, respectively. A description of the methods used in data acquisition and reduction is given in this report's appendix.

## 3. OBJECTIVES

The specific objectives of the rocking tests were:

1. To establish the characteristics of the one-dimensional rocking motion of stacks of 1/5- and 1/1-scale graphite fuel elements subjected to various initial angular displacements. These characteristics include rocking motion, vertical rock-down load, and dowel shear force obtained as time histories.
2. To use the data to establish input parameters to analytical models including collision spring rates and damping values.
3. Within the scope of the test, to establish the dynamic scaling relationship between 1/5- and 1/1-scale elements.

# 4. ONE-FIFTH-SCALE ROCKING TESTS

## 4.1. DESCRIPTION OF TEST APPARATUS

### 4.1.1. Test Rig

The test fixture, shown in Fig. 4-1, consisted of a base slab to which one 1/5-scale element was rigidly clamped in an upright position such that the top surface of the block deviated no more than ±1/4° from the horizontal. The rig was capable of supporting three graphite blocks (excluding the clamped block) one on top of another, each tilted at an angle to the block below. A quick-release device was incorporated to release the blocks from the initial tilted configuration. The blocks were free to rock about one axis (described in Section 4.1.3) upon their release, with no interference from the fixture. A detailed layout of the test fixture is shown in AETL Drawing No. 5430-5845-5-1.* The test procedure is detailed in Ref. 3.

### 4.1.2. Graphite Elements

The 1/5-scale block was a scaled version of the prototype HTGR fuel element. Prior to these and other tests with 1/5-scale elements, a scaling analysis was performed that resulted in a set of scaling laws, which are given in Table 4-1. The dimensional analysis and assumptions made are discussed in Ref. 4. The scale factor $\lambda$ is a constant, and for the 1/5-scale test model $\lambda = 1/5$.

Exact similitude in the 1/5 scale block design was not attained due to (1) the practical difficulty and cost of attempting to simulate 208 prototype fuel and gas cooling holes in a 1/5-scale block, and (2) the selection of graphite as the structural material. The 1/5-scale graphite blocks were

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*These drawings are General Atomic proprietary information.

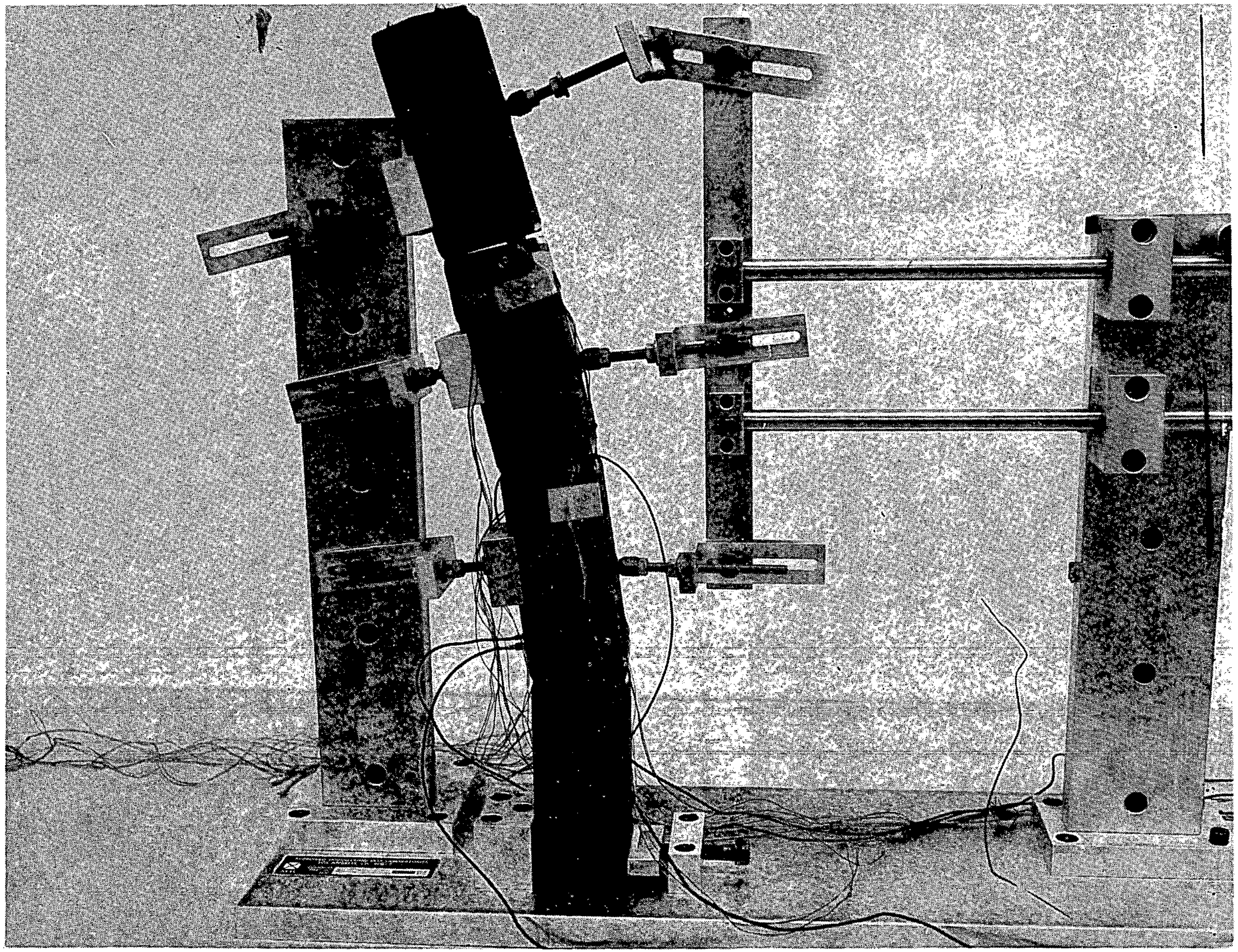

Fig. 4-1. One-fifth-scale rocking test assembly

## TABLE 4-1
## SCALING LAWS FOR TEST MODEL

| | |
|---|---|
| Length | $X_m = \lambda X_p$ |
| Velocity | $\dot{X}_m = \sqrt{\lambda}\dot{X}_p$ |
| Acceleration | $\ddot{X}_m = \ddot{X}_p$ |
| Time | $t_m = \sqrt{\lambda} t_p$ |
| Force | $F_m = \lambda^3 \left(\frac{\rho_m}{\rho_p}\right) F_p$ |
| Stiffness | $K_m = \lambda^2 \left(\frac{\rho_m}{\rho_p}\right) K_p$ |
| Modulus[a] of elasticity | $E_m = \lambda \left(\frac{\rho_m}{\rho_p}\right) E_p$ |
| Coefficient of restitution | $e_m = e_p$ |
| Coefficient of friction | $\mu_m \quad \mu_p$ |

where $\lambda$ = scale factor,

m = model,

p = prototype HTGR.

---

[a] Related to across-the-flats stiffness of a block.

designed with an arbitrary hole pattern made to match the scaled mass and coefficient of restitution. It was determined that by obtaining the correct scaled down values for these two parameters, the distortion in the dynamic characteristics of the test model would be small. However, this resulted in a 1/5-scale block that was too stiff and tended to produce dynamic loads that were too large on a true scale basis. The dowel pin stiffness, on the other hand, was scaled down correctly since they were made from steel as described in Ref. 3.

Each block measured 2.81 in. across the flats, stood 6.24 in. high, and weighed 2.07 lb. The steel dowel has a diameter of 0.31 and a bending stiffness of 3800 ±950 lb/in. The blocks used in these tests were designated A, B, C, and D, depending on the instrumentation configuration as described in Section 4.3.

### 4.1.3. Rocking Axis

The column was rocked about any one of three different axes, corresponding to three edges as specified for the hexagonal block, shown in Fig. 4-2.

## 4.2. INSTRUMENTATION

### 4.2.1. General

A detailed description of the instrumentation used in the 1/5-scale tests, including instrument type, manufacturer, model number, range, and accuracy, is given in Table 4-2. These instruments included transducers, signal conditioning instrumentation, and data recording equipment. The response from each transducer was an analog signal voltage, which could either be output to an oscillograph recorder or converted to a digital equivalent by a computer and put on magnetic tape. The tape was then used as input to data reduction software for further data analysis. Data acquisition and data reduction are further described in the appendix.

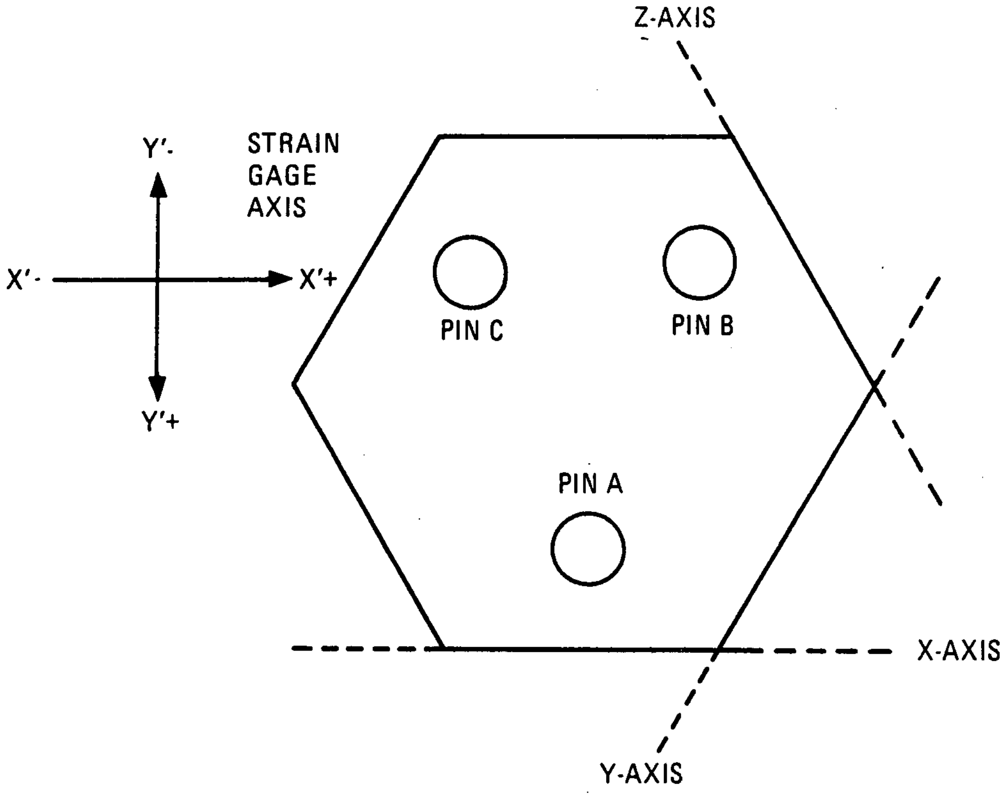

Fig. 4-2. Identification of rocking axes

## TABLE 4-2
## TEST INSTRUMENTATION - 1/5-SCALE AND 1/1-SCALE ROCKING TESTS

| Instrument | Manufacturer | Model | Range | Identification Number | Accuracy (%) |
|---|---|---|---|---|---|
| Galvanometer amplifier | Honeywell, Inc. | T6GA-500 | dc to 50 kHz | E1267S | ±2 |
| Charge amplifier | Kistler Instruments | 504 | 100,000 pcb | D730V | ±0.8 |
| Charge amplifier | Kistler Instruments | 568 | 100,000 pcb | D729V | ±0.5 |
| Charge amplifier | Kistler Instruments | 568 | 10,000 pcb | None | ±0.5 |
| Charge amplifier | Kistler Instruments | 568 | 10,000 pcb | None | ±0.5 |
| Digital volt-ohmmeter | Dana Electronics | 2000 | ±200 Vdc | E1065V | ±0.01 |
| DC power supply | Power Design Inc. | TW5005 | ±30 Vdc | E553V | ±1.0 |
| Strain gages (36) | J. P. Semiconductor | JP-090-500 | ±2000 μin./in. | None | ±1.0 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D897V | ±0.5 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D895V | ±0.5 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D893V | ±0.5 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D894V | ±0.5 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D896V | ±0.5 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D898V | ±0.5 |
| Load cell | Kistler Instruments | 9011 | +3500 lb | D775V | ±0.5 |
| LVDT | G. L. Collins | SS109 | ±1.5 in. | E107V | ±0.5 |
| LVDT | G. L. Collins | SS109 | ±1.5 in. | E108V | ±0.5 |
| Tape recorder | Wangco Inc. | 10 | 45 ips | D804V | N/A |
| Power supply | Varian Data Machines | 620/L-95-5 | ±5, +12 Vdc | D805V | -- |
| Power supply | Varian Data Machines | 03-950085-01 | ±5, +24 Vdc | D806V | -- |

TABLE 4-2 (Continued)

| Instrument | Manufacturer | Model | Range | Identification Number | Accuracy (%) |
|---|---|---|---|---|---|
| Power supply | Lambda | None | ±15 Vdc | D807V | ±0.5 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D809V | 5.0 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D810V | 5.0 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D811V | 5.0 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D812V | 5.0 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D813V | 5.0 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D814V | 5.0 |
| Dual peakholder | Sine Engineering | 05-10344 | 0.5 to 10 V | D815V | 5.0 |
| Strain gages (36) | J. P. Semiconductor | JP-090-500 | 2000 μin./in. | None | 1.0 |
| Oscilloscope | Tektronix | 545A | 0.1 μs to 5 s/cm | E940V | ±3.0 |
| Eddy probe driver | Spectral Dyn. Corp. | M600 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe driver | Spectral Dyn. Corp. | M600 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe driver | Spectral Dyn. Corp. | M600 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe driver | Spectral Dyn. Corp. | M600 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe | Spectral Dyn. Corp. | M60 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe | Spectral Dyn. Corp. | M60 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe | Spectral Dyn. Corp. | M60 | 0 to 0.2 in. | None | ±0.5 |
| Eddy probe | Spectral Dyn. Corp. | M60 | 0 to 0.2 in. | None | ±0.5 |
| DC amplifier | CIC | 3101-D3P | X1000 | D781V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D783V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D776V | ±0.1 |

TABLE 4-2 (Continued)

| Instrument | Manufacturer | Model | Range | Identification Number | Accuracy (%) |
|---|---|---|---|---|---|
| DC amplifier | CIC | 3101-D3P | X1000 | D778V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D780V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D786V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D791V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D782V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D784V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D785V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D779V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D792V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D793V | ±0.1 |
| DC amplifier | CIC | 3101-D3P | X1000 | D777V | ±0.1 |
| Recording oscillograph | CEC | 5-124 | 18 channels | E570V | -- |
| Data computer | Varian Data Machines | 620/L-100 | 8000 core | D802V | N/A |
| Magnetic tape system | PICO Periph. Inter. Corp. | MT-62 | 9 track | D803V | N/A |

### 4.2.2. Instrument Development Program

Prior to the 1/5-scale rocking tests, an instrument development program known as the Basic Rocking Test Study was conducted. This program included the design of a 1/5-scale steel dowel with JP-090-500 strain gages for measuring dowel forces, Kistler load washers Model 901A for the measurement of vertical rock-down forces, and the use of eddy current probes (Dymac Model M61) for measuring the rocking angle between elements. These designs were incorporated in two 1/5-scale elements (Figs. 4-3 and 4-4) and tested. The tests, reported in Ref. 5, showed very good instrumentation performance.

The tested stiffness value of the dowel pins after installation was within 14% of the design value. Static and dynamic calibrations of the attached strain gages showed approximately the same values, and small variations in the position of the application of the dowel load did not produce any significant changes in the strain gage reading.

The eddy current probes provided accurate measurements in a narrow gap range from 0.0 to 0.1 in. Outside this range, measurements were obtained using the nonlinear portion of the calibration curve. The two probes installed allowed angles up to 15° to be measured, which is above the maximum value of 6° obtained from HTGR fuel element design data.

Since the rock-down load is virtually impossible to measure with strain gages, load cells were the best alternative. Four load cells were embedded near the element edges and capped with graphite buttons which protruded slightly from the element surface. The element rock-down force would then only be transmitted through the load cells. For best results, the load cells were preloaded as recommended by the manufacturer. Since the stiffness of the load cell itself is much larger than the stiffness of the graphite element, reliable rock-down load could be obtained this way and no calibration would be necessary. A problem, however, was to adjust the protrusion of the load cell assembly above the graphite surface accurately enough such that element wobbling could be kept to a minimum.

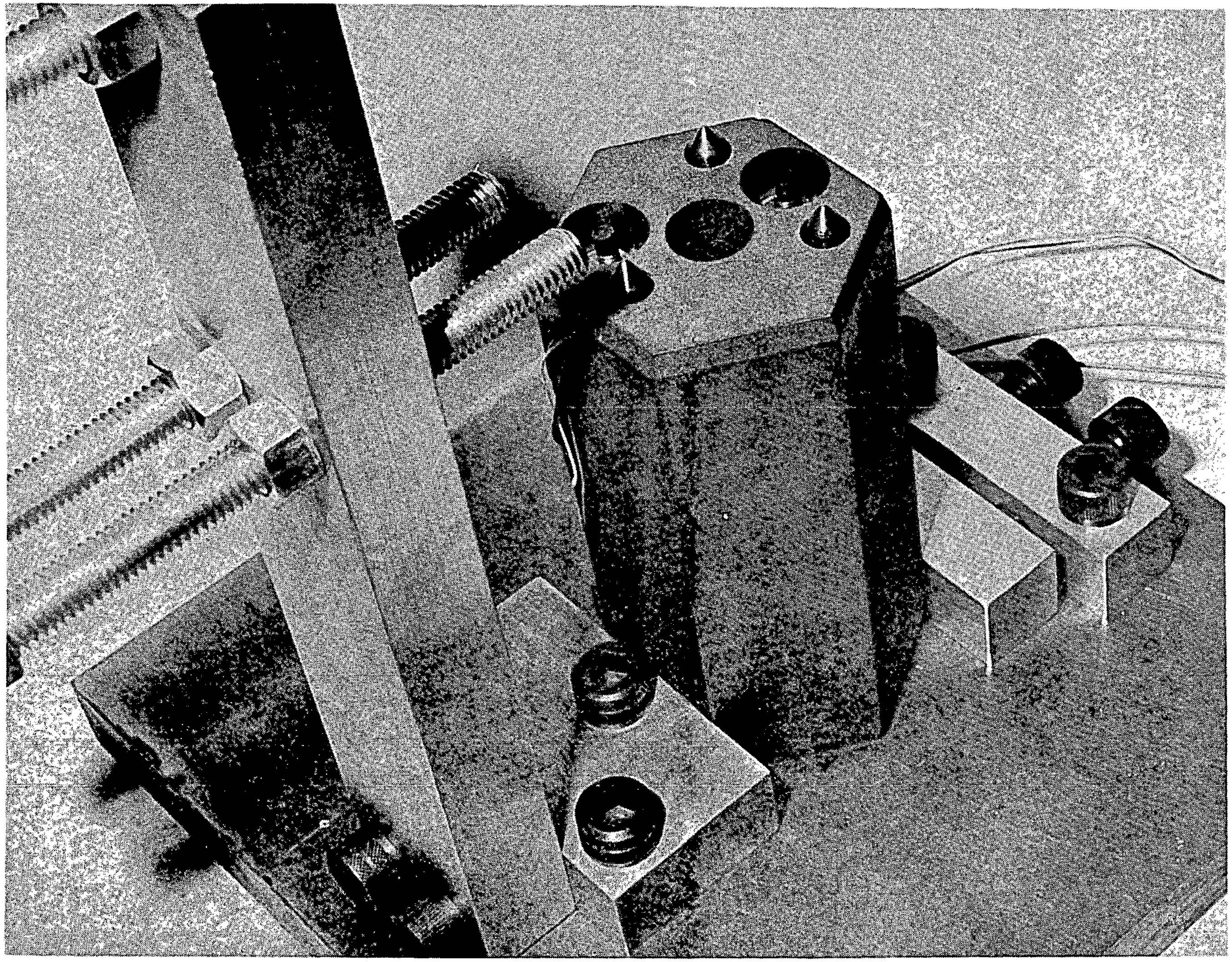

Fig. 4-3. Instrumented dowels and eddy current probes in a 1/5-scale element

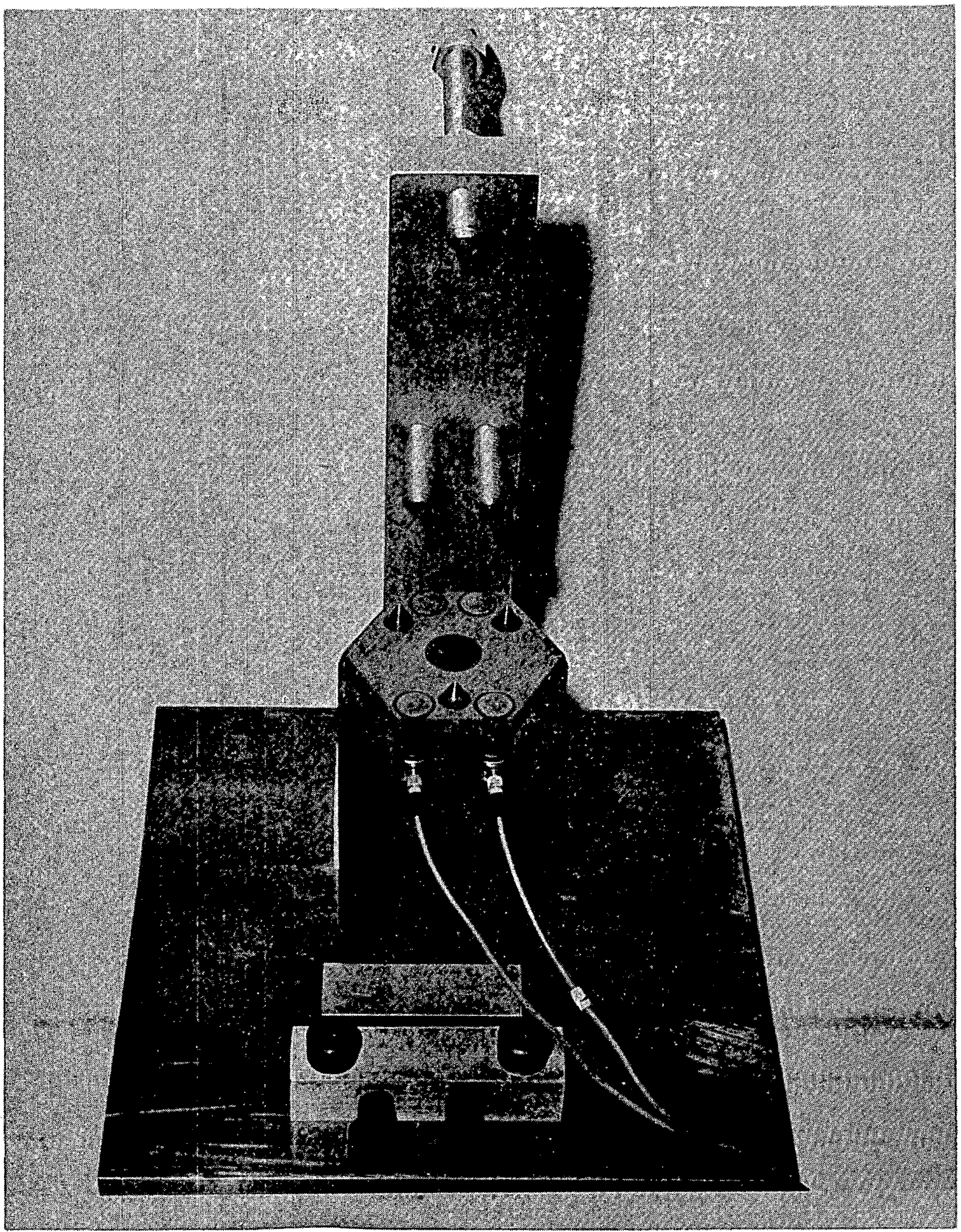

Fig. 4-4. Instrumented dowels and load cells in a 1/5-scale element

### 4.2.3. Element Instrumentation

The four blocks employed in the 1/5-scale rocking tests were instrumented as follows:

| | |
|---|---|
| Block A: | Dummy block - no instrumentation. See Fig. 4-5. |
| Block B: | Top - Strain gages on all three dowels located in the rocking direction and normal to the rocking direction.<br>Bottom - Four load cells, two on each side of the rocking axis. See Fig. 4-6. |
| Block C: | Top - Two eddy current probes, one on each side of the rocking axis. See Fig. 4-7. |
| Block D: | Top - Strain gages on all three dowels both parallel to the rocking axis and normal to the rocking axis; two eddy current probes, one on each side of the rocking axis. See Fig. 4-8. |

The strain gages were calibrated to measure dowel shear force on individual dowel pins. The load cells measured directly the rock-down load, and the eddy current probes measured the angular displacement of one rocking block relative to the other. Each instrument was calibrated both before the first test on a given day and after all tests were completed that day, except in the event that a change was made to that instrument. Transducer details and calibration factors are given in Table 4-3; the exact location of each transducer in the graphite elements is shown in Fig. 4-9.

### 4.2.4. Data Acquisition Instrumentation

A description of the data acquisition system showing the measurement circuits for all transducer types is given in Figs. 4-10 through 4-13.

The strain gages (Fig. 4-10), which were of the semiconductor type, were installed on the dowel pins to measure shear force. The circuit

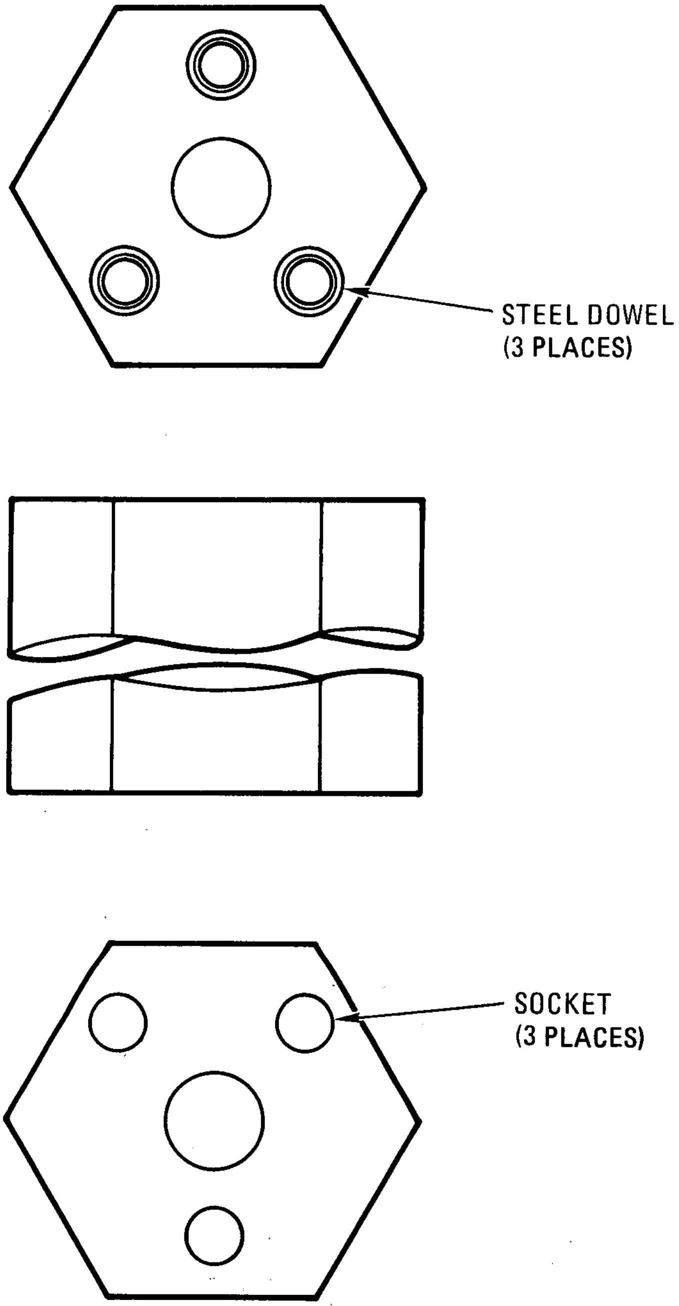

Fig. 4-5. One-fifth-scale element A

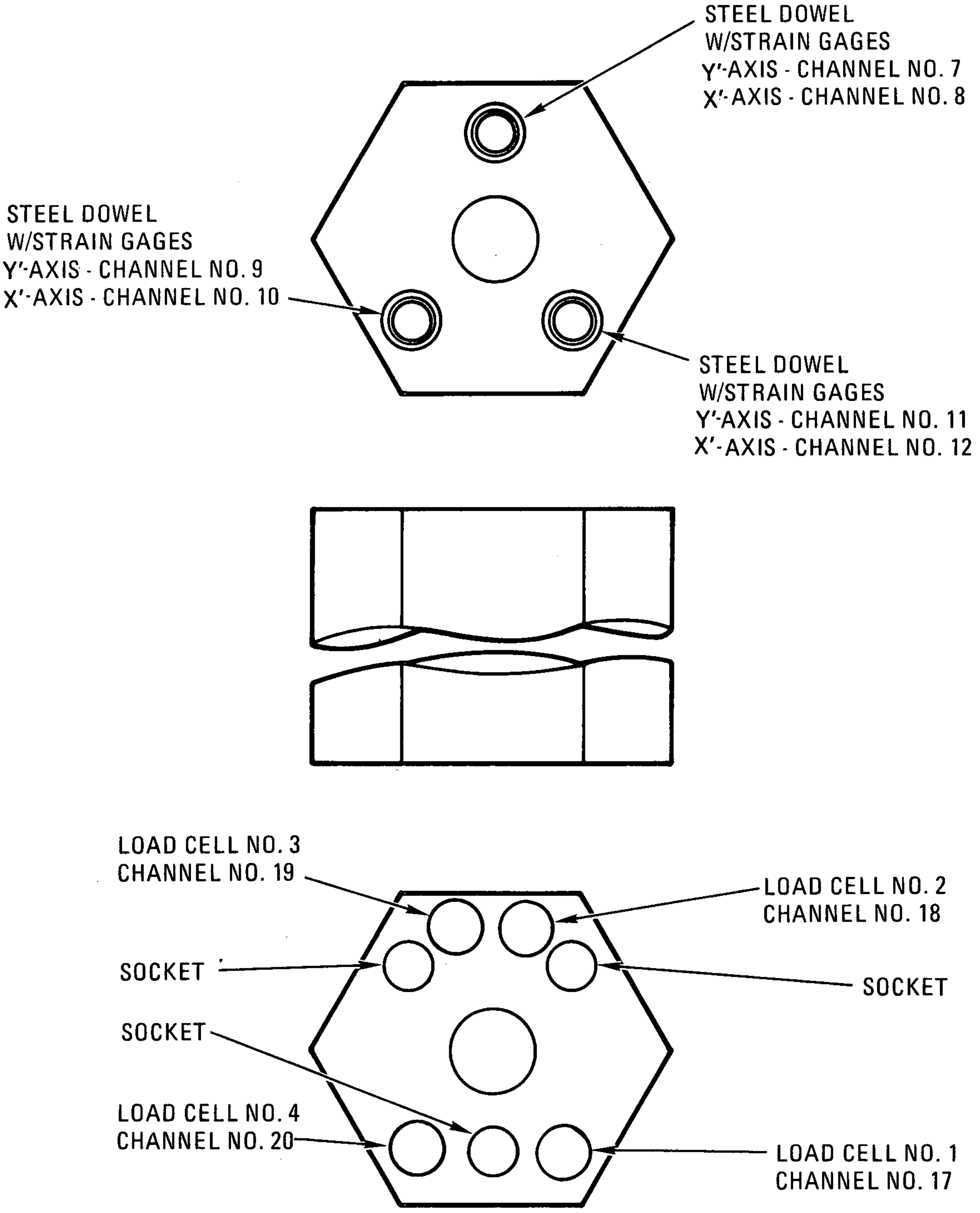

Fig. 4-6. One-fifth-scale element B

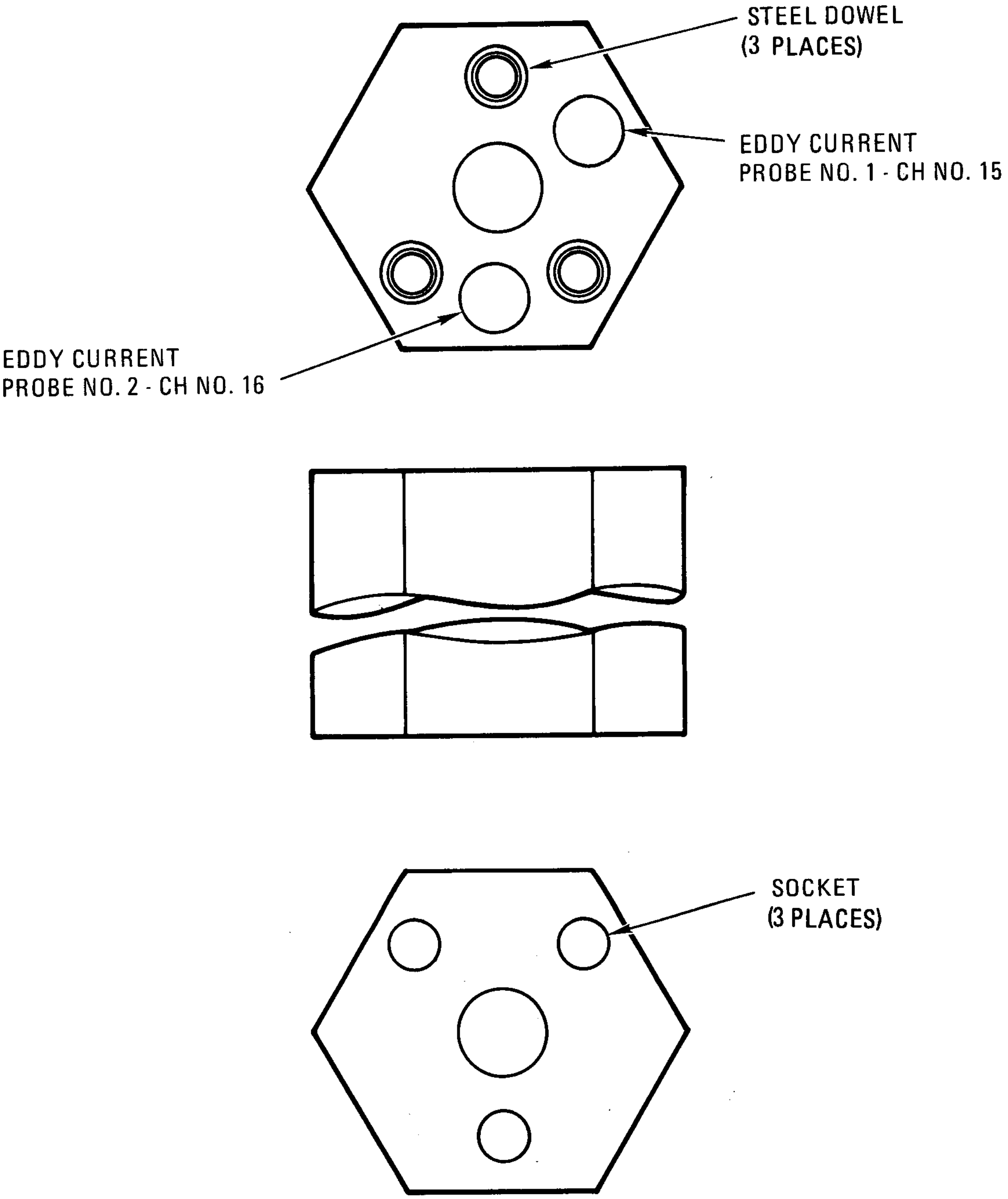

Fig. 4-7. One-fifth-scale element C

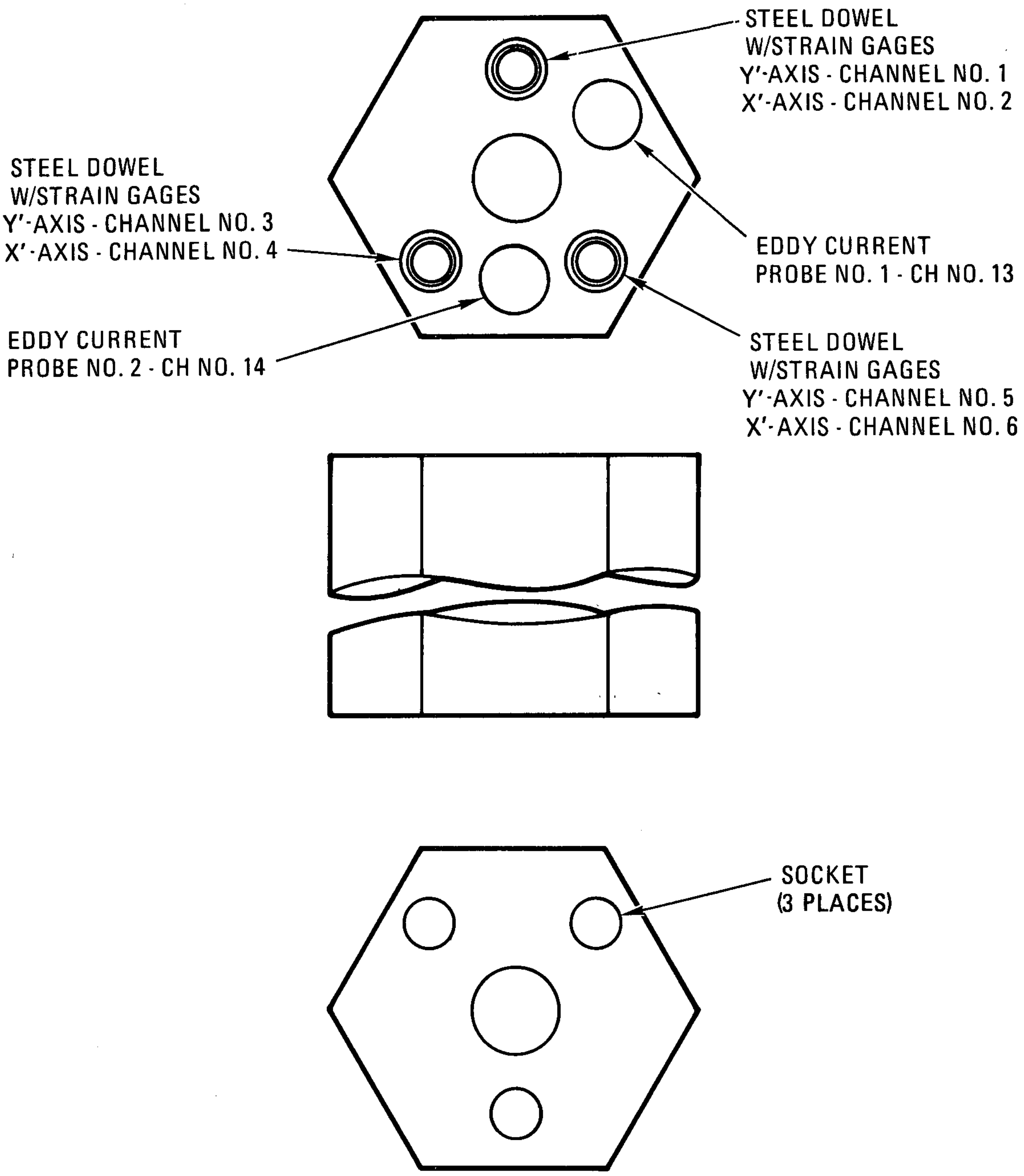

Fig. 4-8. One-fifth-scale element D

## TABLE 4-3
## INSTRUMENTATION AND MEASURED CALIBRATION FACTORS FOR 1/5-SCALE ROCKING TEST

| Transducer | Transducer Number | Associated Block | Sensitive Axis | Multiplexer Channel Numbers | Calibration Factor | |
|---|---|---|---|---|---|---|
| | | | | | Sequence A[a] | Sequence B[a] |
| Load cell | 1 | B | -- | 1, 41 | 0.01800 | 0.02440 |
| Load cell | 2 | B | -- | 2, 42 | 0.01800 | 0.02440 |
| Load cell | 3 | B | -- | 3, 43 | 0.01220 | 0.02440 |
| Load cell | 4 | B | -- | 4, 44 | 0.01220 | 0.02440 |
| Strain gage | 5 | D | A | 5, 45 | 0.07382 | 0.07413 |
| Strain gage | 6 | D | B' | 6, 46 | 0.08405 | 0.08384 |
| Strain gage | 8 | D | A' | 8, 48 | 0.08751 | 0.09176 |
| Strain gage | 9 | D | B' | 9, 49 | 0.09130 | 0.08217 |
| Strain gage | 10 | D | A | 10, 50 | 0.09590 | 0.09874 |
| Strain gage | 11 | D | B' | 11, 51 | 0.09328 | 0.09457 |
| Eddy probe | 13 | D | -- | 13, 53 | Nonlinear | Nonlinear |
| Eddy probe | 14 | D | -- | 14, 54 | Nonlinear | Nonlinear |
| Eddy probe | 15 | C | -- | 15, 55 | Nonlinear | Nonlinear |
| Eddy probe | 16 | C | -- | 16, 56 | Nonlinear | Nonlinear |
| Strain gage | 18 | B | A | 18, 58 | 0.09499 | 0.08933 |
| Strain gage | 19 | B | B' | 19, 59 | 0.08001 | 0.07993 |
| Strain gage | 22 | B | A | 22, 62 | 0.08275 | 0.09744 |
| Strain gage | 23 | B | B' | 23, 63 | 0.09779 | 0.10247 |
| Strain gage | 25 | B | A | 25, 65 | 0.08768 | 0.06809 |
| Strain gage | 26 | B | B' | 26, 66 | 0.08457 | 0.07743 |

(a) Test sequence A consists of tests 1 through 21, 23, and 24. Test sequence B consists of test 22 and tests 25 through 50. Factors are shown in volts/digital count.

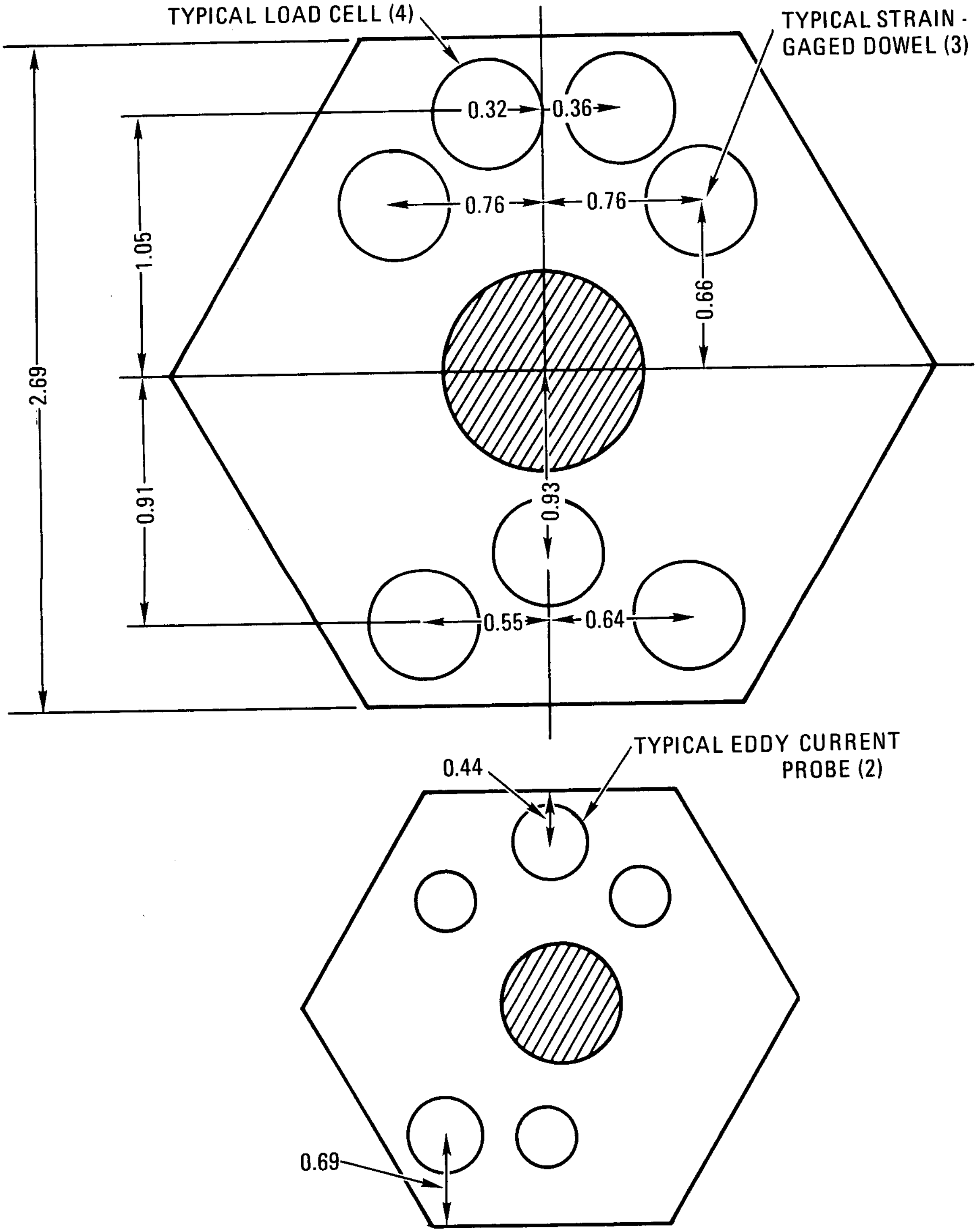

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Fig. 4-9. Transducer locations in the 1/5-scale element

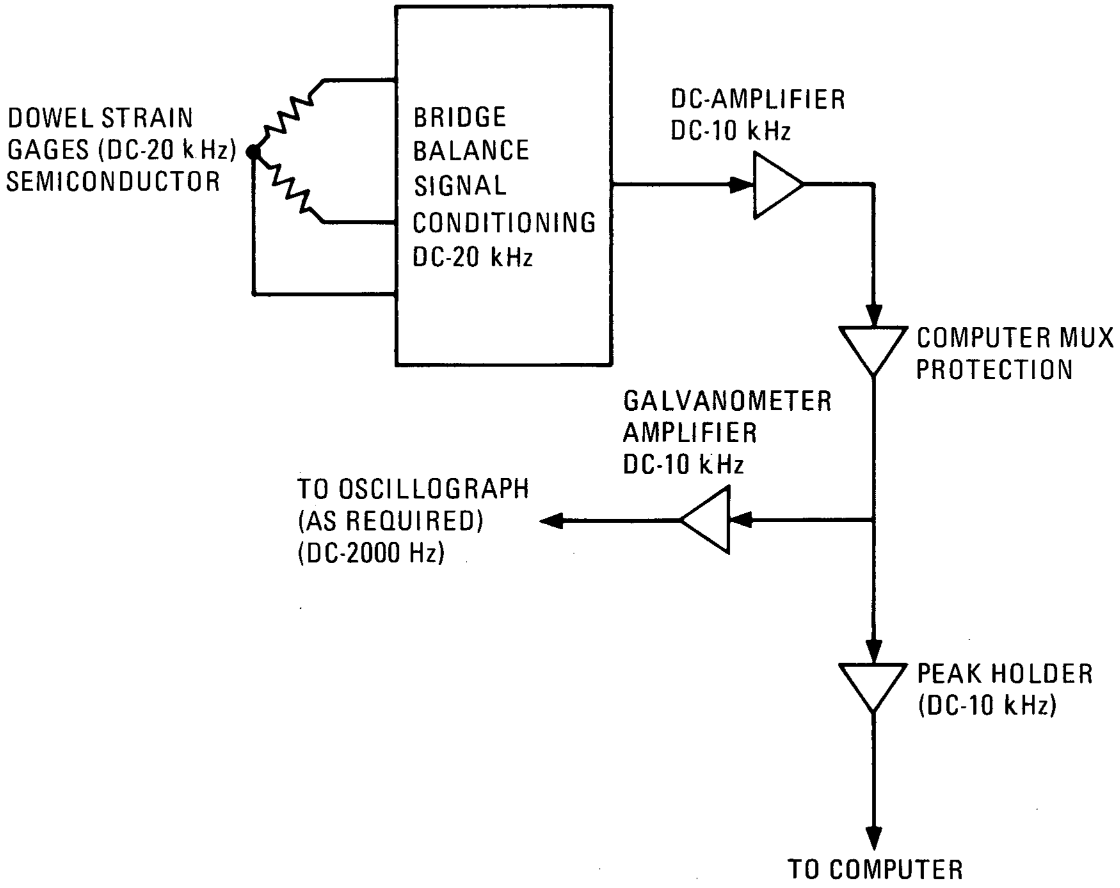


Fig. 4-10. Dowel force measurement system (strain gages)

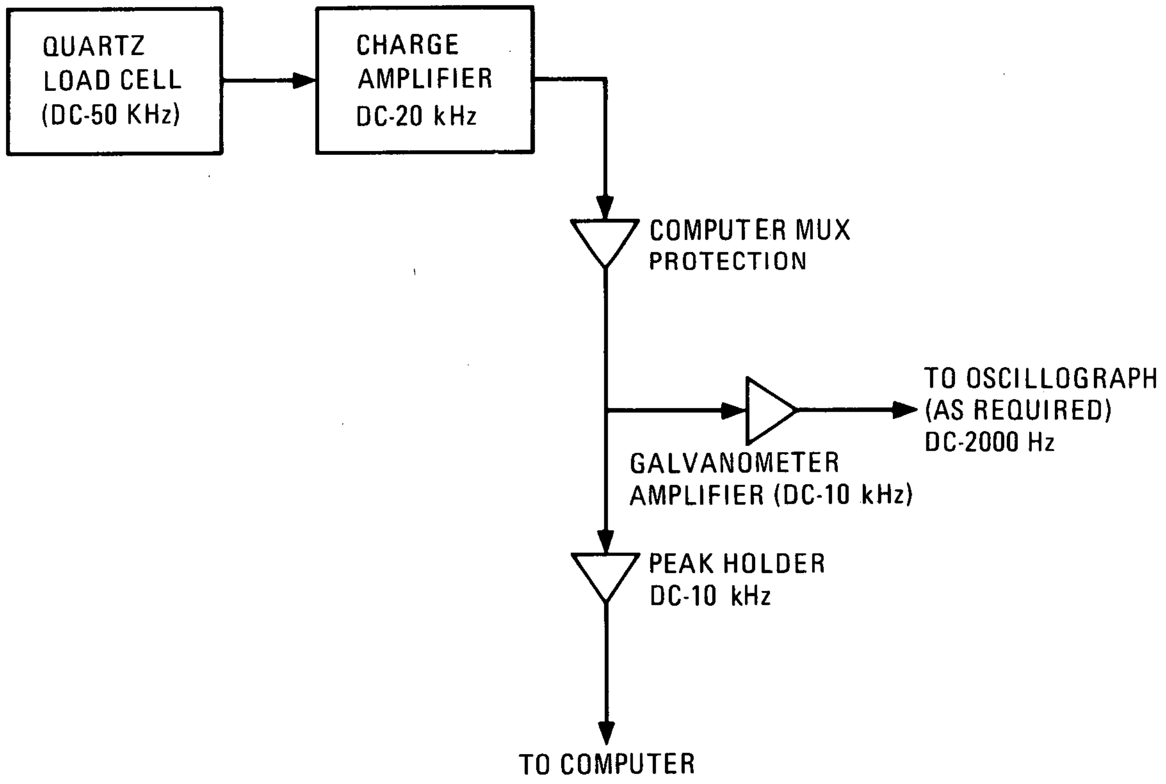


Fig. 4-11. Rock-down load measuring system (quartz load cells)

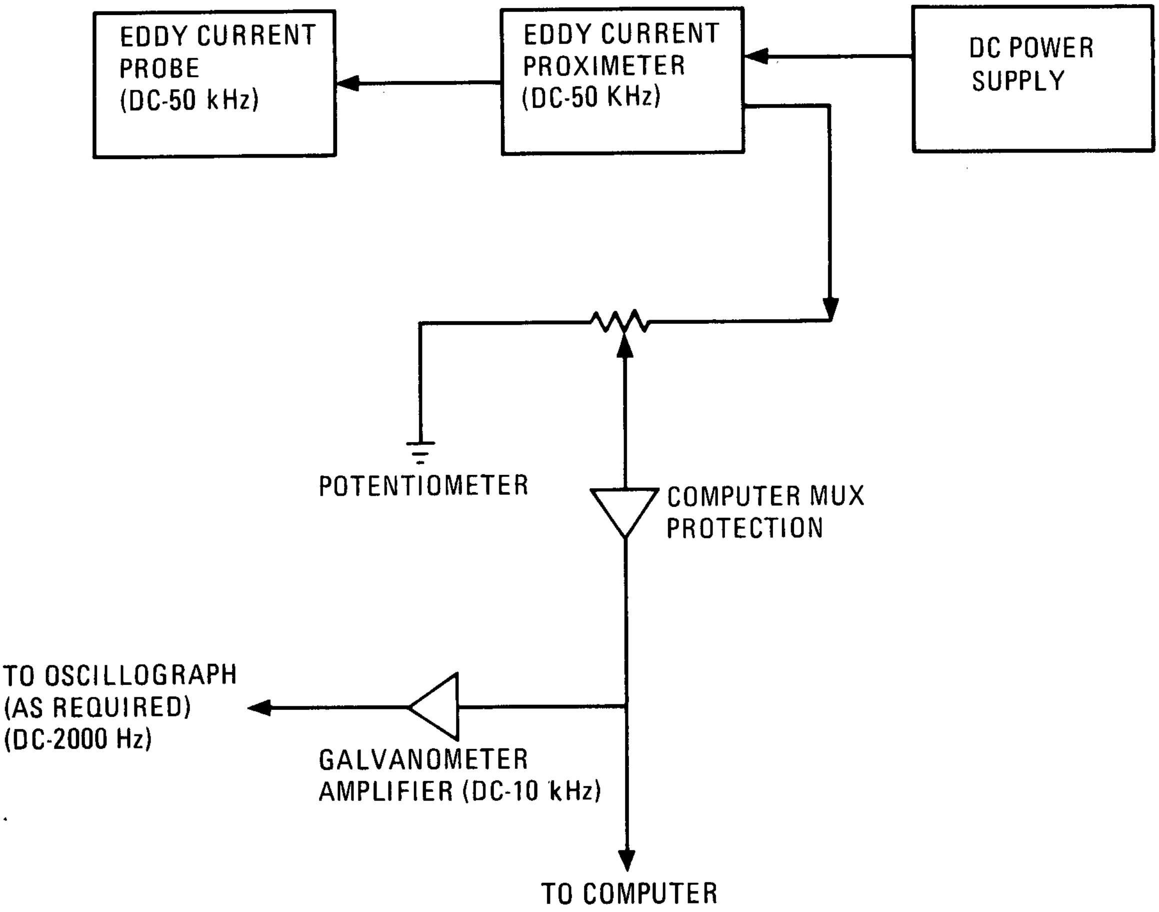


Fig. 4-12. Element displacement measuring system (eddy current probes)

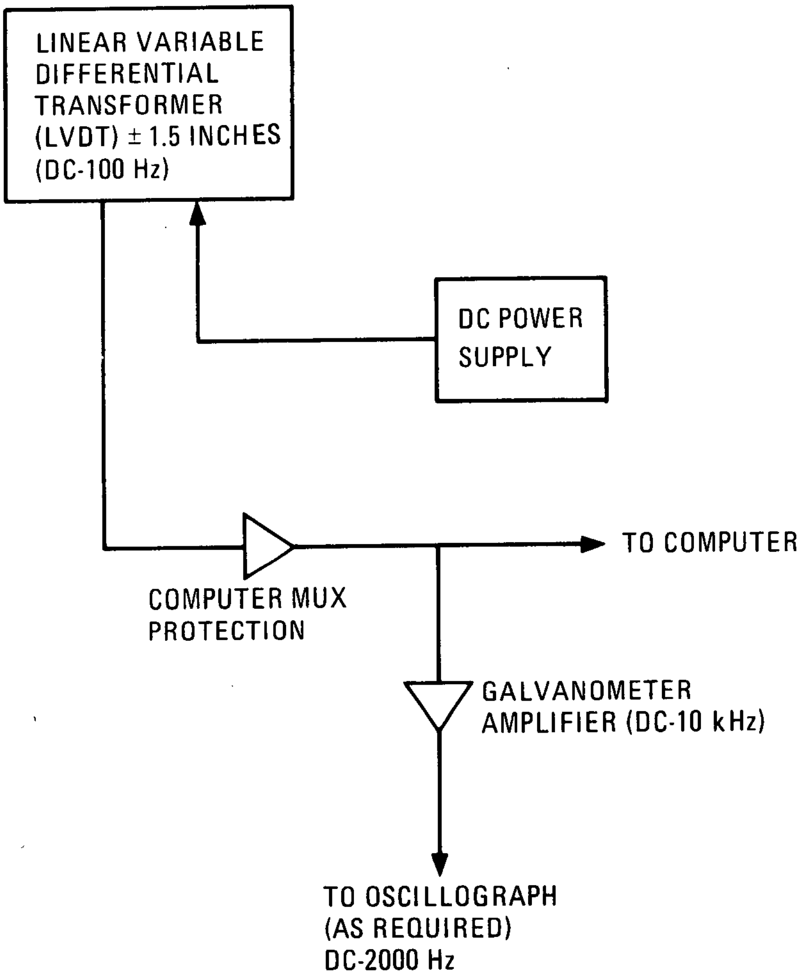


Fig. 4-13. Element displacement measuring system (LVDTs)

notably contained a peak holder. The function of this instrument was to record and hold the maximum value between digital time intervals in the event the time interval was large in comparison with the pulse duration of the maximum. Figure 4-11 shows the measurement system for the load cells, which measured the impact load of an element rocking down on another element. These were piezoelectric crystal washers, which measured the load directly. Two displacement measuring systems (Figs 4-12 and 4-13) monitored the angle of rocking between two blocks. The figures show an eddy current probe and a linear variable differential transducer (LVDT), respectively. The eddy current probe, which is an electromagnetic device, measured accurately in the range up to 0.2 in.; it was used in the 1/5-scale tests only.

## 4.3. TEST SCOPE

Table 4-4 gives a description of all 1/5-scale tests. The testing was conducted in the following sequence:

| | |
|---|---|
| Tests 1 through 10: | Verification of the system and instrumentation. |
| Tests 11 through 25: | Determination of the effects of instrumentation on block dynamics. |
| Tests 26 through 50: | Obtain data to meet the test objectives as stated in Section 2. |

The table also identifies the tests according to block configuration, initial angle, and rocking axis.

Block configuration B/C/D means block D is the clamped base block, C is on top of D, and B on top of C. The initial angle represents the relative tilt between blocks stacked on top of each other. (B/C/D at angles 8°/20° means B tilts 8° with respect to C and C tilts 20° with respect to D.) The rocking axes, denoted as X, Y, or Z, are defined in Fig. 4-9.

## TABLE 4-4
## ONE-FIFTH-SCALE TEST PLAN

| | Description | | | |
|---|---|---|---|---|
| Test | Configuration | Angle | Rocking Axis | Remarks |
| 1 | A/B | 5° | X | Load cell 3 (A-01-5)(a) never recorded above the electronic noise level. No time history available. |
| 2 | A/B | 20° | X | Load cell 3 (A-02-5) never recorded above the electronic noise level. No time history available. |
| 3 | A/C | 5° | X | |
| 4 | A/C | 20° | X | |
| 5 | A/D | 5° | X | |
| 6 | A/D | 20° | X | |
| 7 | B/C | 5° | X | Load cell 1 (A-07-3) saturated on three rocking events. Load cell 3 never recorded any data above the noise level (A-07-5). |
| 8R(b) | A/D | 20° | Y | |
| 9R | A/D | 20° | Y | Repeat of test 8. |
| 10 | A/D | 20° | Z | |
| 11 | C/D | 5° | X | |
| 12 | C/D | 20° | X | |
| 13 | B/C/D | 20°/0° | X | Load cell 3 (A-13-6) never recorded any data above the noise level. Load cell 2 saturated on two separate rocking events (maximum load = 73.6 lb at 10 volts) (A-13-5). |
| 14 | -- | -- | -- | Data from this test was not recoverable. |
| 15 | B/C/D | 8°/20° | X | Same comments as for test 13. |
| 16 | B/C/D | 8°/20° | X | Repeat of test 15. Load cell 2 not functioning (no load readings). Load cell 3 saturated at one point (A-16-4,5). |

TABLE 4-4 (Continued)

| Test | Description | | | Remarks |
|---|---|---|---|---|
| | Configuration | Angle | Rocking Axis | |
| 17 | A/C/D | 20°/0° | X | |
| 18 | A/C/D | 0°/10° | X | |
| 19 | A/C/D | 8°/20° | X | |
| 20 | A/B/C/D | 20°/0°/0° | X | Load cell 2 (A-20-5)[a] saturated on one rocking event. Load cell 3 (A-20-6) not functioning. |
| 21 | -- | -- | -- | Data from this test was not recoverable. |
| 22 | -- | -- | -- | Data from this test was not recoverable. |
| 23 | B/A/C/D | 20°/0°/0° | X | Load cell 2 (A-23-4) saturated on one rocking event. Load cell 3 (A-23-5) not functioning. |
| 24 | B/A/C/D | 0°/0°/8° | X | Load cell 3 (A-24-5) not functioning. |
| 25 | B/A/C/D | 20°/8°/5° | X | DC bias on strain gages 5 and 6 (A-25-7 and A-25-8). Load cell 3 (A-25-5) never records any data above the noise level. |
| 26 | B/C/D | 20°/0° | Y | |
| 27 | B/C/D | 0°/10° | Y | |
| 28 | B/C/D | 20°/8° | Y | |
| 29 | A/B/D | 20°/0° | X | |
| 30 | A/B/D | 0°/10° | X | |
| 31R | A/B/D | 20°/8° | X | |
| 32 | A/B/D | 20°/8° | X | Repeat of test 31. |
| 33 | A/B/D | 20°/8° | Y | |
| 34 | A/B/D | 0°/10° | Y | |
| 35 | A/B/D | 20°/8° | Y | DC bias, load cell 3 (A-35-5). |
| 36 | A/B/C/D | 20°/0°/0° | Y | |
| 37 | A/B/C/D | 0°/0°/2° | Y | |
| 38 | A/B/C/D | 0°/0°/8° | Y | |
| 39 | A/B/C/D | 5°/5°/2° | Y | DC bias, load cell 2 (A-39-5). |

TABLE 4-4 (Continued)

| Test | Description |  |  | Remarks |
|---|---|---|---|---|
|  | Configuration | Angle | Rocking Axis |  |
| 40 | A/B/C/D | 20°/8°/5° | Y | DC bias, load cell 2 (A-39-5). |
| 41 | A/C/B/D | 20°/0°/0° | X |  |
| 42 | A/C/B/D | 0°/0°/2° | X | Strain gage 18 (A-42-14) may not have been functioning. |
| 43 | -- | -- | -- | Data from this test was not recoverable. |
| 44 | A/C/B/D | 5°/5°/2° | X |  |
| 45 | A/C/B/D | 20°/8°/5° | X |  |
| 46 | A/C/B/D | 20°/0°/0° | Y | DC bias, load cell 1 (A-46-4). |
| 47 | A/C/B/D | 0°/0°/2° | Y |  |
| 48 | A/C/B/D | 0°/0°/8° | Y |  |
| 49 | A/B/C/D | 5°/5°/2° | Y |  |
| 50R | A/B/C/D | 20°/8°/5° | Y |  |

(a) Refers to a figure in Ref. 1; i.e., A-39-5 means test 39, figure 5.

(b) The letter R suffixed to a test number indicates that the test was repeated due to problems or discrepancies. One-fifth-scale tests that were repeated include 8, 9, 31, and 50.

## 4.4. TEST RESULTS

### 4.4.1. General

This section presents the results and briefly discusses the 1/5-scale results. Typical results only are presented; the bulk of the data is located in Ref. 1.

Unfortunately, the usefulness of the 1/5-scale test data has proved somewhat limited since either an apparent instrument malfunction or a problem in the data transmission went undetected for the duration of the testing. The instrument in question was Kistler Load Cell No. 3, which never gave a load reading above the general noise level. Hence, the total rock-down load, which is obtained by adding the response from all four load cells, may not be correct. Furthermore, from the strain gage data it may be concluded that, in some cases, the blocks were not rocking plainly about the rocking axis but showing considerable random wobbling motion. This was detected by the dowel strain gages located normal to the direction of rocking, which recorded substantial loads. This phenomenon can be expected since the 1/5-scale blocks are very light and easily affected by slight "binding" of the dowels due to small clearances between the dowel pins and the dowel pin sockets. These problems were investigated and are described in more detail in Ref. 6.

The total dowel pin shear load was obtained from the instantaneous vector sum of the three in-line strain gages ($X_1$, $X_2$, and $X_3$), and the three normal strain gages ($Y_1$, $Y_2$, and $Y_3$) as follows (Fig. 4-2):

$$\text{Total Shear Force} = \sqrt{X_1'^2 + Y_1'^2} + \sqrt{X_2'^2 + Y_2'^2} + \sqrt{X_3'^2 + Y_3'^2} \quad ,$$

### 4.4.2. Rocking Angle

Typical rocking angle decay time histories for one block rocking on top of another block are presented in Figs. 4-14 and 4-15. Figure 4-14 shows rocking about the X-axis at a 5° initial release angle, and Fig. 4-15 at a 20° initial angle. The frequency of rocking is shown to decrease with an increase in initial angle; at 5° the frequency is about 3.5 Hz, while at 20° the frequency is about 2.5 Hz. The logarithmic decrements, also calculated, corresponded to an average viscous damping factor of about 12% of critical.

Rocking about the Y and the Z axes is shown in Figs. 4-16 and 4-17. These figures can be compared with Fig. 4-15 since all represent the 20° initial rocking angle. The curves show very little difference in rocking behavior, as expected, except that rocking about the X-axis seemed to give somewhat higher amplitude response. This could be due to the geometrical arrangement of the dowels in the block, which is not the same with respect to the X, Y, and Z axes.

### 4.4.3. Dowel Force

A typical dowel pin shear force time history is presented in Fig. 4-18. This trace represents the vector sum of all six strain gages mounted on the three dowels. In most cases, the peak load occurs upon block impact; i.e., at zero rocking angle. This may be seen by superimposing the rocking angle and dowel force time history plots, Figs. 4-14 and 4-18.

### 4.4.4. Rock-Down Force

Figure 4-19 shows a typical load cell measurement of rock-down force (load cell No. 1). It is observed that the maximum load does not always occur on the first impact. The reason for this is that the dowels themselves take some of the rock-down load by interfering with the block rocking motion. This is a random occurrence and depends only on how the blocks are aligned initially.

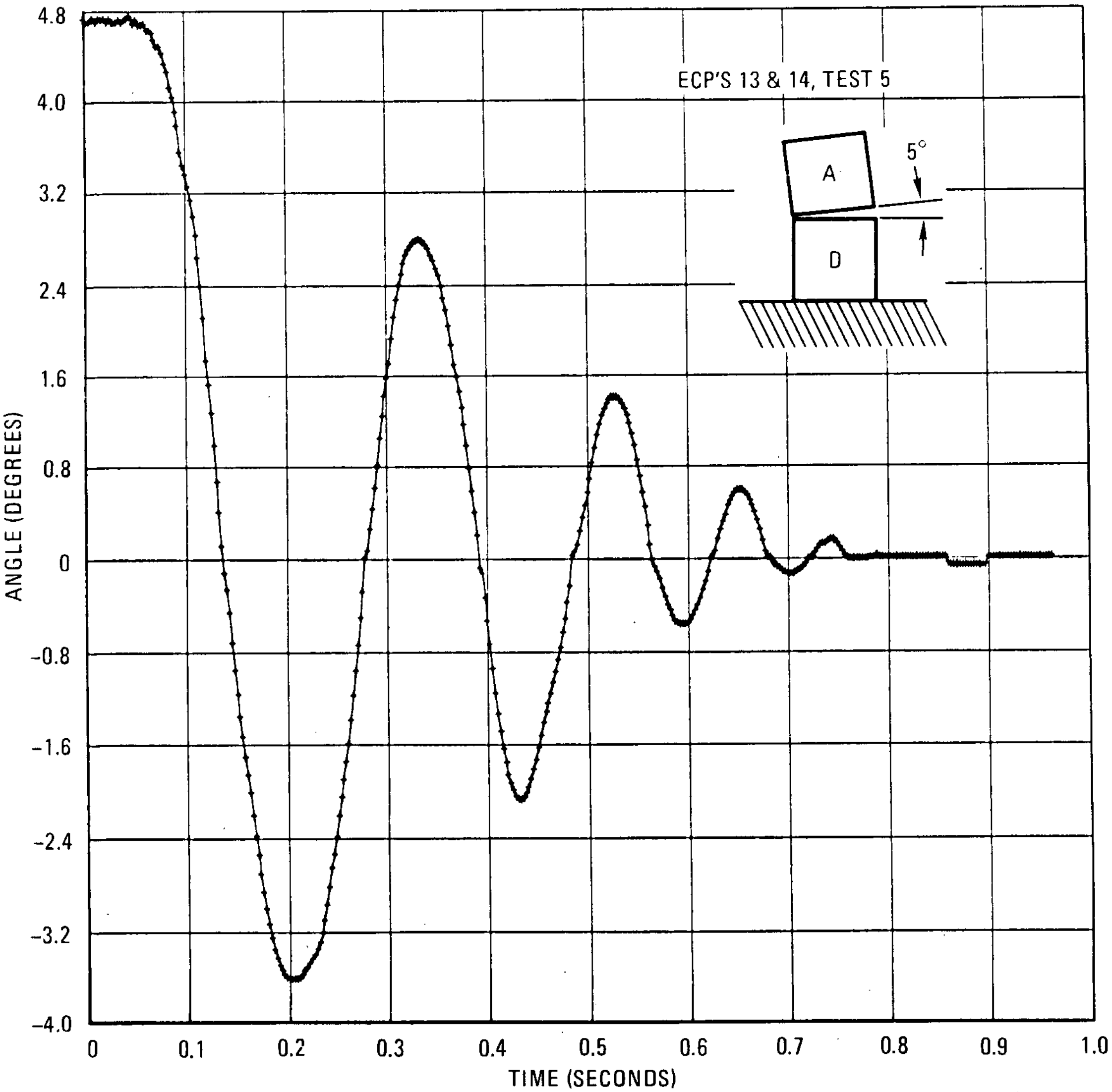


Fig. 4-14. Rocking Motion - 1/5-scale, two-block configuration, 5° initial angle, X-axis

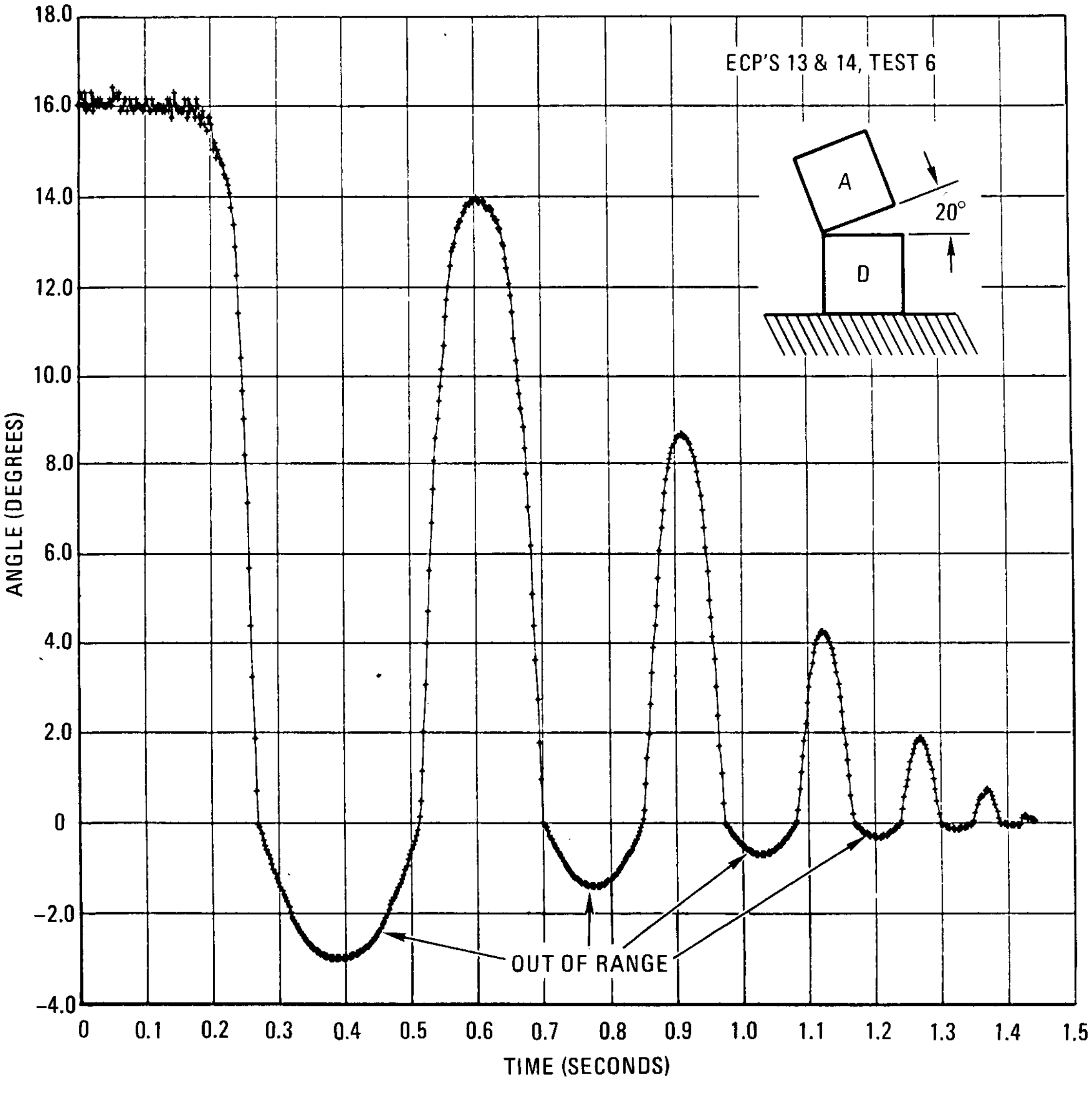


Fig. 4-15. Rocking motion - 1/5-scale, two-block configuration, 20° initial angle, X-axis

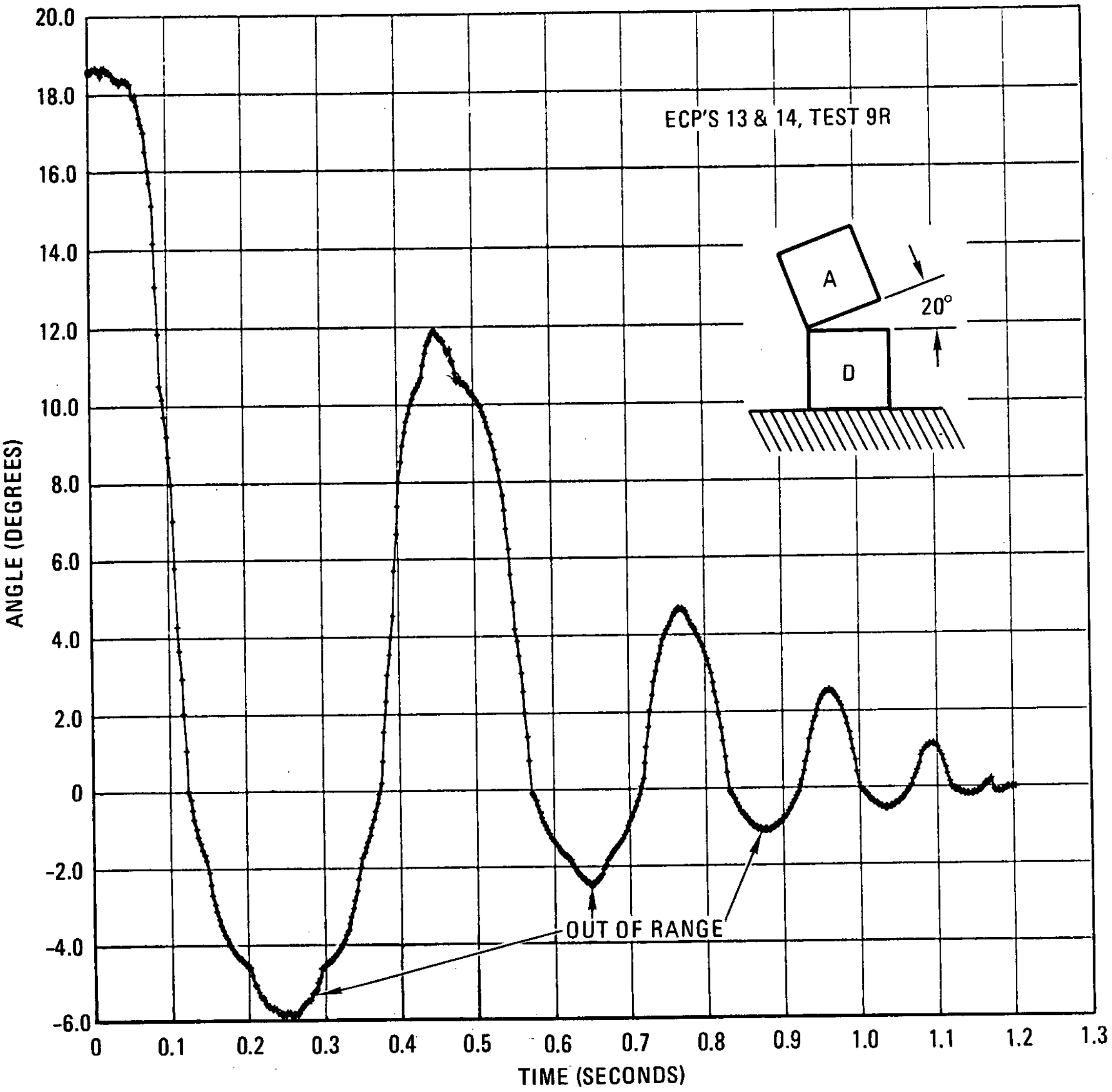


Fig. 4-16. Rocking motion - 1/5-scale, two block configuration, 20° initial angle, Y-axis

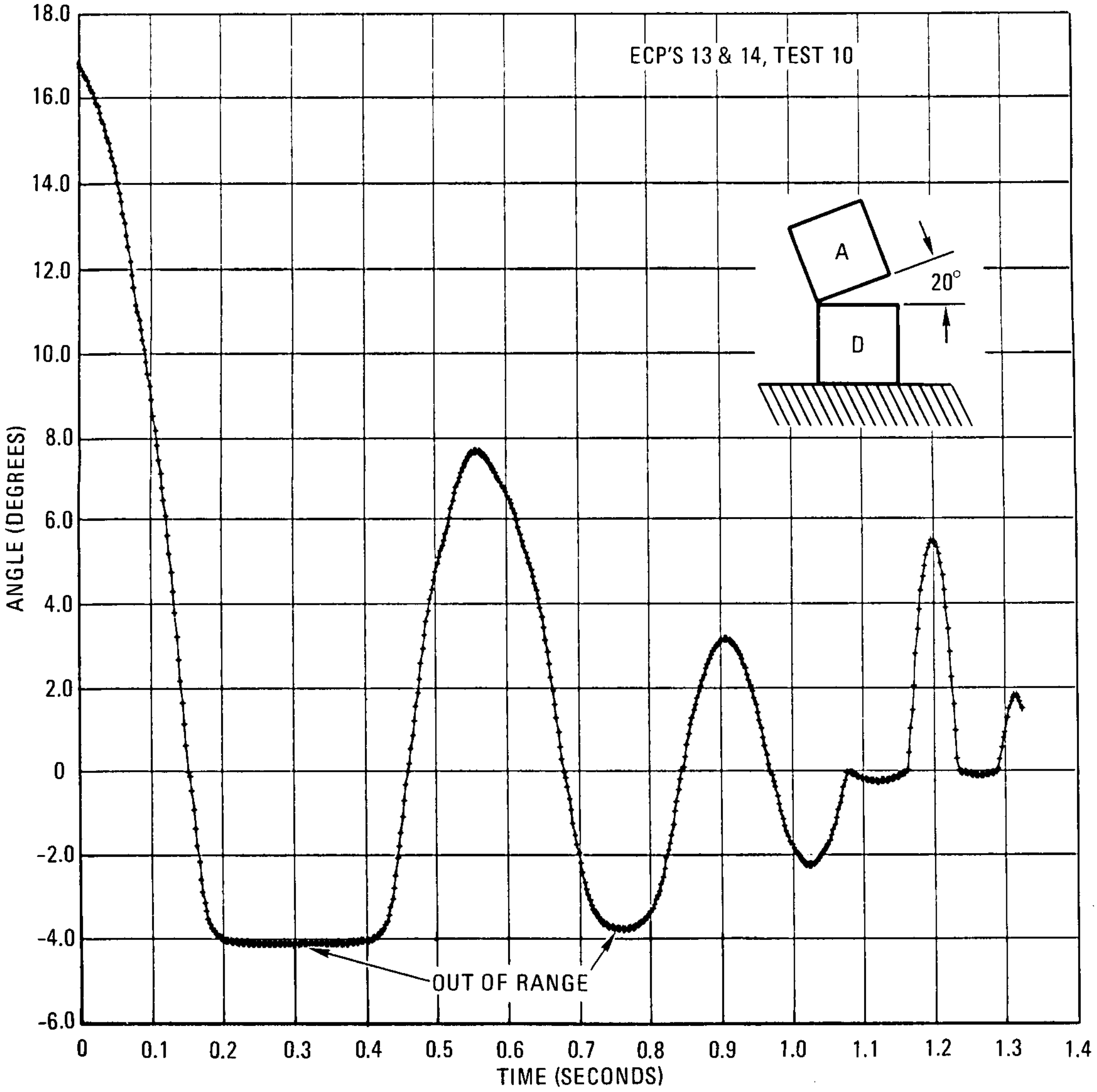


Fig. 4-17. Rocking motion - 1/5-scale, two-block configuration, 20° initial angle, Z-axis

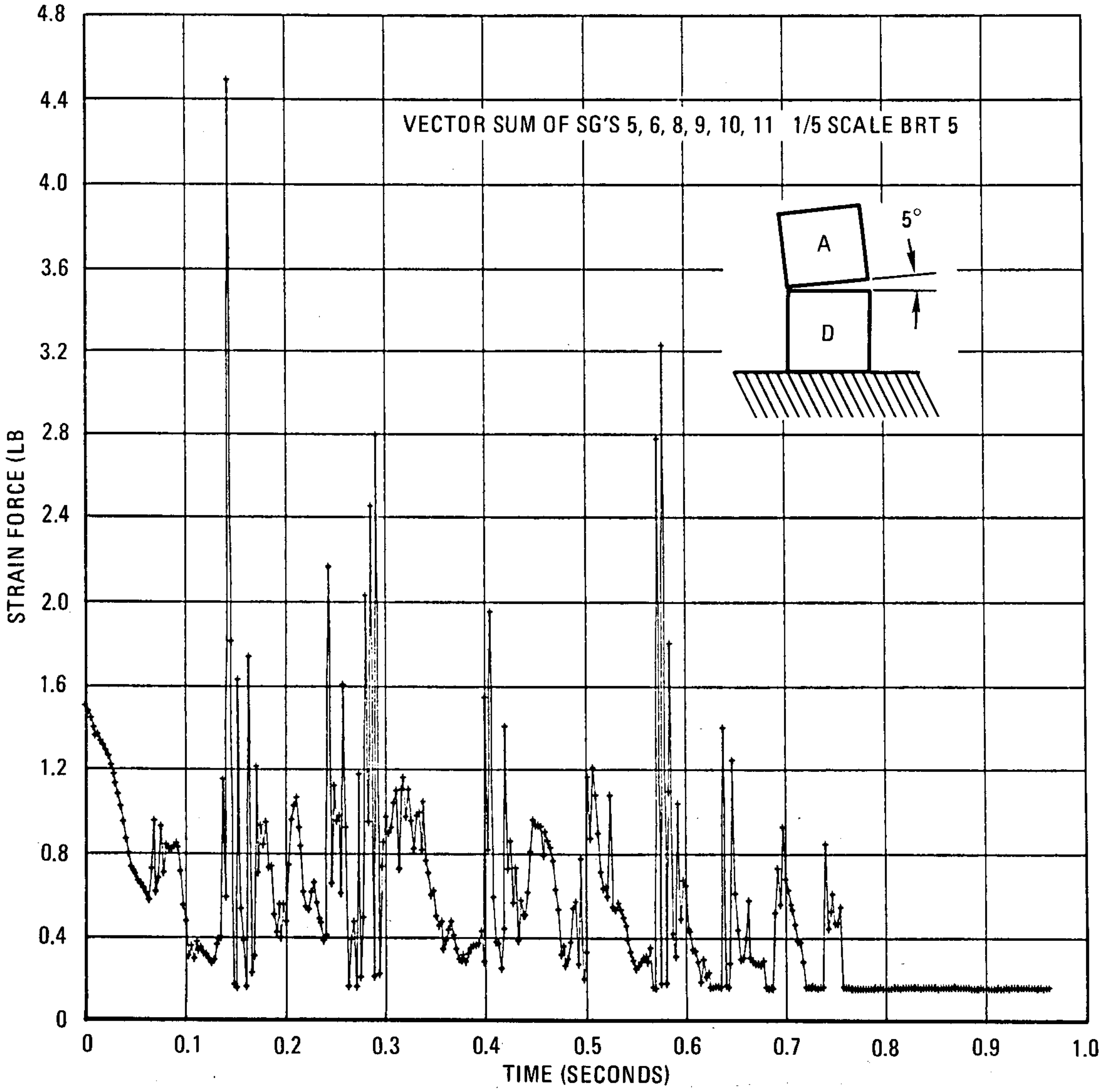


Fig. 4-18. Dowel shear force - 1/5-scale, two-block configuration, 5° initial angle, X-axis

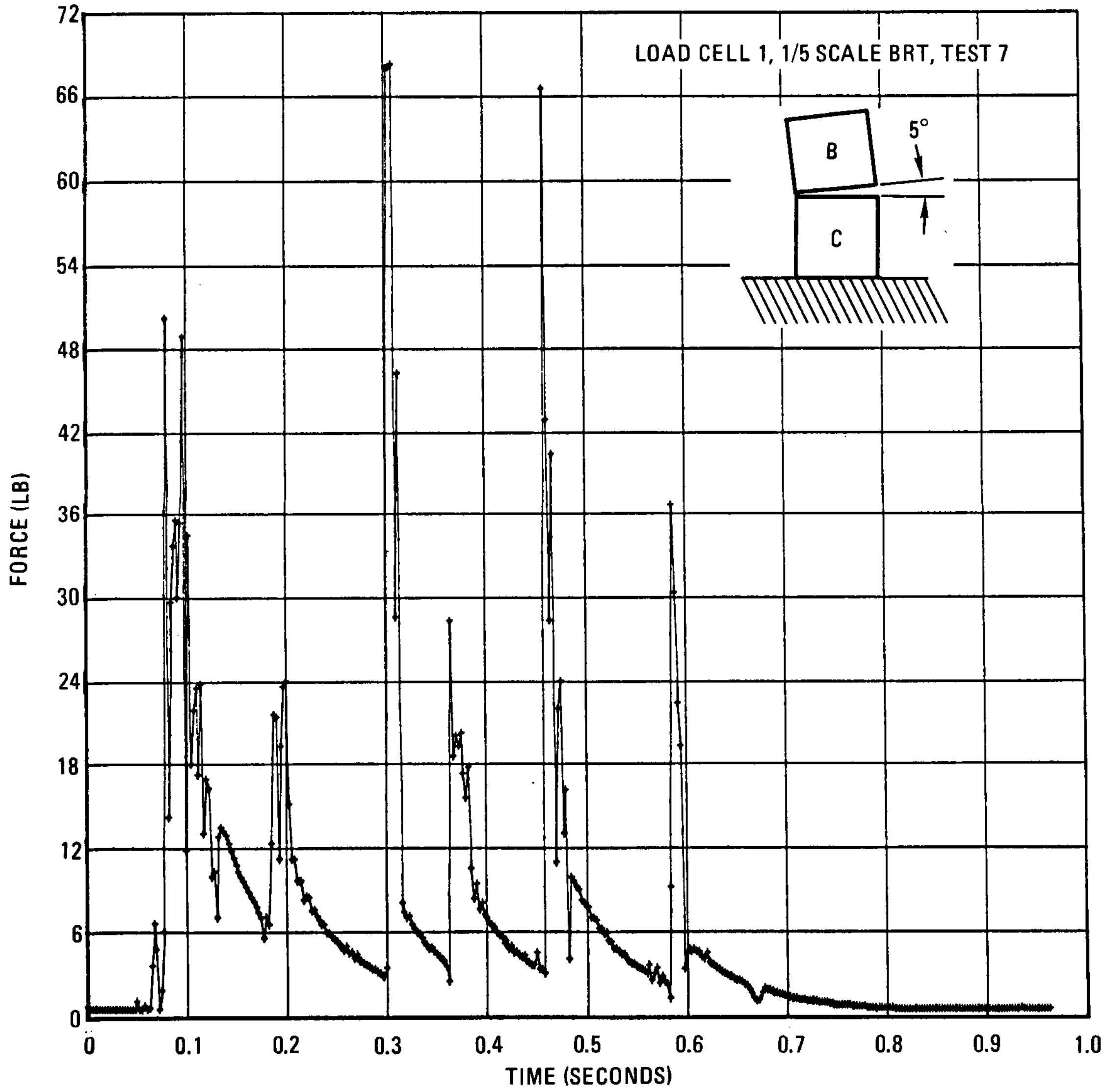


Fig. 4-19. Rock-down force - 1/5-scale, two-block configuration, 5° initial angle, X-axis

A summary of the results from the 1/5-scale tests is given in Table 4-5. The table includes the maximum total rock-down loads and dowel loads where applicable. These loads were not necessarily recorded on the first rock-down as mentioned above.

## TABLE 4-5
## ONE-FIFTH-SCALE MAXIMUM ROCK-DOWN AND DOWEL LOADS

| Test | Initial Conditions | | | Total Maximum Rocking Load(a,b) (lb) | Total Maximum Dowel Load(a) (lb) |
|---|---|---|---|---|---|
| | Configuration | Angle | Rocking Axis | | |
| 1 | A/B | 5° | X | N/A | 4.5 |
| 2 | A/B | 20° | X | N/A | 6.6 |
| 5 | A/D | 5° | X | N/A | 4.5 |
| 6 | A/D | 20° | X | N/A | 7.7 |
| 7 | B/C | 5° | X | 90 | N/A |
| 8R | A/D | 20° | Y | N/A | 6.8 |
| 9R | A/D | 20° | Y | N/A | 5.2 |
| 10 | A/D | 20° | Z | N/A | 6.4 |
| 11 | C/D | 5° | X | N/A | 4.8 |
| 12 | C/D | 20° | X | N/A | 6.8 |
| 13 | B/C/D | 20°/0° | X | 85 | 3.1 |
| 15 | B/C/D | 8°/20° | X | 88 | 2.5 |
| 16 | B/C/D | 8°/20° | X | 86 | 2.3 |
| 17 | A/C/D | 20°/0° | X | N/A | 6.8 |
| 18 | A/C/D | 0°/10° | X | N/A | 3.8 |
| 19 | A/C/D | 8°/20° | X | N/A | 3.9 |
| 20 | A/B/C/D | 20°/0°/0° | X | 108 | 5.3(B), 3.9(D) |
| 23 | B/A/C/D | 20°/0°/0° | X | 92 | 3.3 |
| 24 | B/A/C/D | 0°/0°/8° | X | 90 | 2.6 |
| 25 | B/A/C/D | 20°/8°/5° | X | 21 | 5.0 |
| 26 | B/C/D | 20°/0° | Y | 28 | 7.7 |
| 27 | B/C/D | 0°/10° | Y | 23 | 2.1 |
| 28 | B/C/D | 20°/8° | Y | 19 | 2.2 |
| 29 | A/B/D | 20°/0° | X | 41 | 7.4(b), 4.4(D) |
| 30 | A/B/D | 0°/10° | X | 51 | 4.6(B), 4.5(D) |
| 31R | A/B/D | 20°/8° | X | 52 | 3.8(B), 6.7(D) |
| 32 | A/B/D | 20°/8° | X | 51 | 3.6(B), 7.3(D) |
| 33 | A/B/D | 20°/0° | Y | 25 | 3.0(B), 5.2(D) |
| 34 | A/B/D | 0°/10° | Y | 37 | 3.4(B), 3.2(D) |
| 35 | A/B/D | 20°/8° | Y | 34 | 3.0(B), 3.8(D) |

TABLE 4-5 (Continued)

| Test | Initial Conditions | | | Total Maximum Rocking Load$^{(a,b)}$ (lb) | Total Maximum Dowel Load$^{(a)}$ (lb) |
|---|---|---|---|---|---|
| | Configuration | Angle | Rocking Axis | | |
| 36 | A/B/C/D | 20°/0°/0° | Y | 32 | 5.2(D), 4.2(B) |
| 37 | A/B/C/D | 0°/0°/2° | Y | 17 | 3.3(D), 3.1(B) |
| 38 | A/B/C/D | 0°/0°/8° | Y | 20 | 2.5(D), 2.6(B) |
| 39 | A/B/C/D | 5°/5°/2° | Y | 21 | 4.2(D), 2.8(B) |
| 40 | A/B/C/D | 20°/8°/5° | Y | 18 | 3.0(D), 2.4(B) |
| 41 | A/C/B/D | 20°/0°/0° | X | 60 | 3.9(D), 5.4(B) |
| 42 | A/C/B/D | 0°/0°/2° | X | 22 | 1.9(D), 1.4(B) |
| 44 | A/C/B/D | 5°/5°/2° | X | 34 | 4.8(D), 2.7(B) |
| 45 | A/C/B/D | 20°/8°/5° | X | 32 | 3.3(D), 3.8(B) |
| 46 | A/C/B/D | 20°/0°/0° | Y | 21 | 5.6(D), 7.9(B) |
| 47 | A/C/B/D | 0°/0°/2° | Y | 18 | 2.0(D), 1.0(B) |
| 48 | A/C/B/D | 0°/0°/8° | Y | 23 | 1.9(D), 1.2(B) |
| 49 | A/B/C/D | 5°/5°/2° | Y | 19 | 2.6(D), 3.0(B) |
| 50R | A/B/C/D | 20°/8°/5° | Y | 17 | 2.7(D), 2.8(B) |

(a) Does not necessarily represent first rock-down after initial release.

(b) Load component from load cell No. 3 not included.

# 5. FULL-SCALE ROCKING TESTS

## 5.1. DESCRIPTION OF TEST APPARATUS

A detailed description of the 1/1-scale test design and instrumentation is given in Ref. 7.

### 5.1.1. Test Rig

The test fixture for the 1/1-scale rocking test was designed to the same principles as the 1/5-scale test fixture, but the design permitted only two elements rocking on the base element as compared to three in the 1/5-scale test. The test fixture is shown in Fig. 5-1.

### 5.1.2. Graphite Elements

Each graphite block used in the 1/1-scale tests was an accurate reproduction of an HTGR fuel element, with the following exceptions: (1) steel rods were inserted in the block to compensate for the weight of fuel particles, and (2) instrumented aluminum dowels were provided in two of the elements. Each block stood approximately 31.2 in. high, weighed 275 lb, and measured 14.2 in. across the flats. The dowel design is shown in Fig. 5-2. These were strain gaged and epoxyed into the fuel elements in locations 180° to the original graphite dowels, which were removed. Each dowel was designed to a stiffness of 95,000 lb/in. ±25%. The actual stiffness values are discussed in Section 5.1.4.

The blocks used in the test are designated A, B, and C, having the instrumentation configurations described in Section 5.2.2. Drawings showing details of the test rig and fuel element designs are listed in Table 5-1.

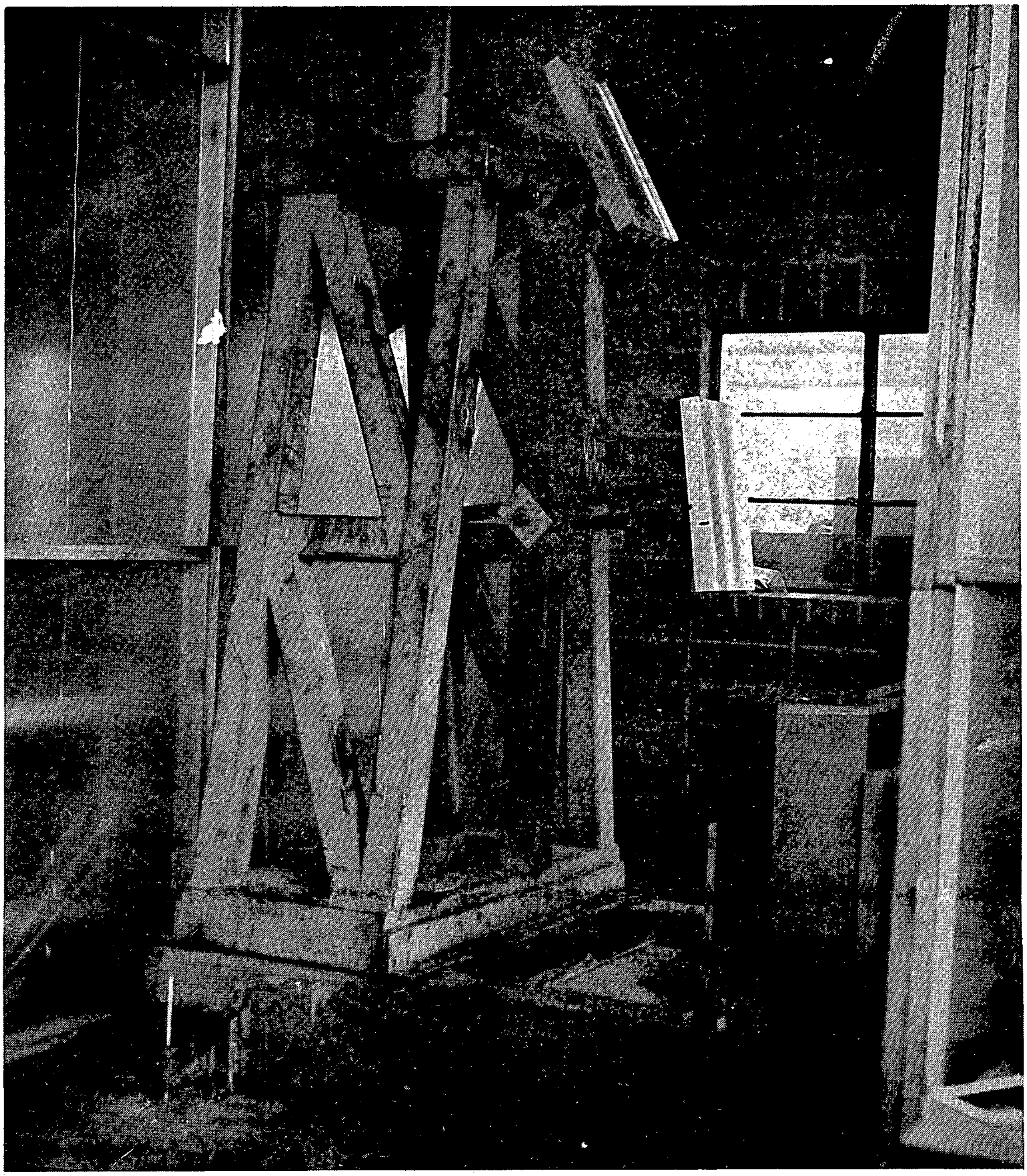


Fig. 5-1. Full-scale rocking test assembly

## TABLE 5-1
## DRAWINGS FOR 1/1-SCALE ROCKING TEST FIXTURE AND ELEMENTS

| Description | Drawing Number |
|---|---|
| 1/1 Fuel Element Rocking Test Fixture | 5430-5845-1-1 |
| Standard Fuel Element Plugged Hole Locations | 5430-5845-1 |
| Standard Fuel Element Instrumentation details | 5430-5845-1-3 (Sheets 1-3) |

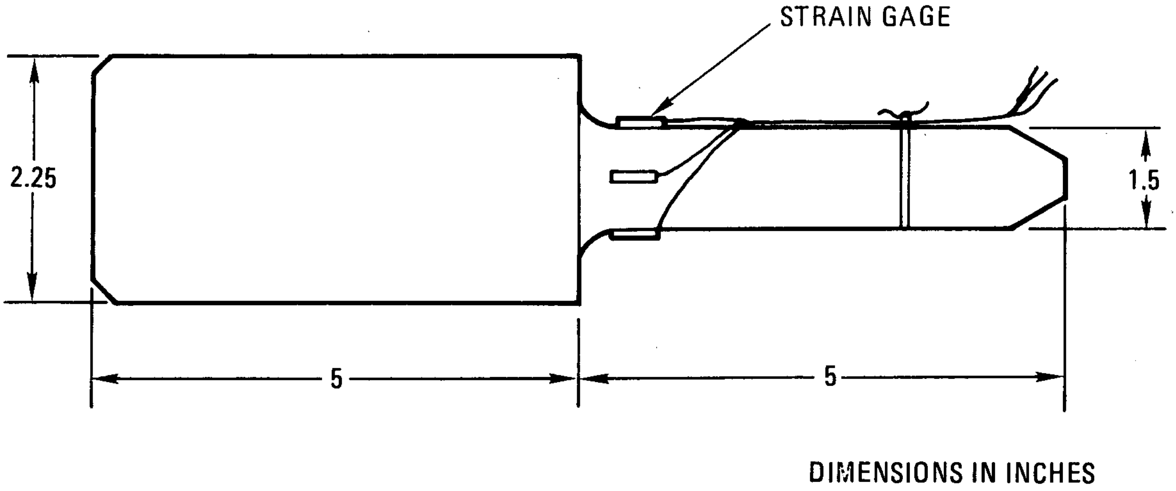


Fig. 5-2. Full-scale dowel dimensions for rocking test

### 5.1.3. Rocking Axes

The rocking axes corresponded to those in the 1/5-scale tests and are given in Fig. 5-3.

### 5.1.4. Dowel Stiffness Measurements

A summary of the dowel stiffness values obtained from the tests is presented in Table 5-2 for each dowel on two different blocks. The table gives a resulting dowel bending stiffness obtained by dividing the force by the deflection and averaging the results over three separate measurements. Figure 5-3 illustrates the dowel pin notation used in Table 5-2.

## 5.2. INSTRUMENTATION

### 5.2.1. General

A detailed description of the instrumentation used in the 1/1-scale test, including instrument type, manufacturer, model and serial numbers, calibration period, range, and accuracy, is given in Table 4-2. The data acquisition systems and data reduction methods were the same as for the 1/5-scale tests and are described in Section 4 and the appendix.

### 5.2.2. Fuel Element Instrumentation

A summary of the fuel element transducers used follows:

1. Linear variable differential transformers (LVDT) measured the vertical separation between blocks. One LVDT was located between each pair of blocks used in a given test.

2. Load cells measured vertical impact between blocks. Six load cells were located, one in each hexagonal corner.

## TABLE 5-2
## FULL-SCALE DOWEL THICKNESS VALUES

| Axis | Pin A | Pin B | Pin C |
|---|---|---|---|
| | Element A (lb/in.) | | |
| Y'+ | 83,026 ± 4,900 | 82,150 ± 2,360 | 84,645 ± 3,120 |
| Y'- | 82,374 ± 3,830 | 79,274 ± 2,740 | 81,172 ± 3,570 |
| X'+ | 80,433 ± 2,900 | 85,463 ± 3,800 | 81,378 ± 730 |
| X'- | 81,712 ± 7,550 | 81,833 ± 1,500 | 82,495 ± 5,960 |
| Average | 81,886 ± 1,450 | 82,180 ± 3,280 | 82,512 ± 2,130 |
| | Element B (lb/in.) | | |
| Y'+ | 79,346 ± 3,990 | 86,396 ± 1,840 | 81,871 ± 2,920 |
| Y'- | 83,333 ± 0 | 87,233 ± 2,050 | 84,291 ± 1,920 |
| X'+ | 80,975 ± 2,030 | 81,909 ± 3,780 | 83,333 ± 0 |
| X'- | 82,878 ± 910 | 84,291 ± 1,920 | 79,767 ± 9,520 |
| Average | 81,633 ± 2,290 | 84,957 ± 3,050 | 82,315 ± 2,550 |

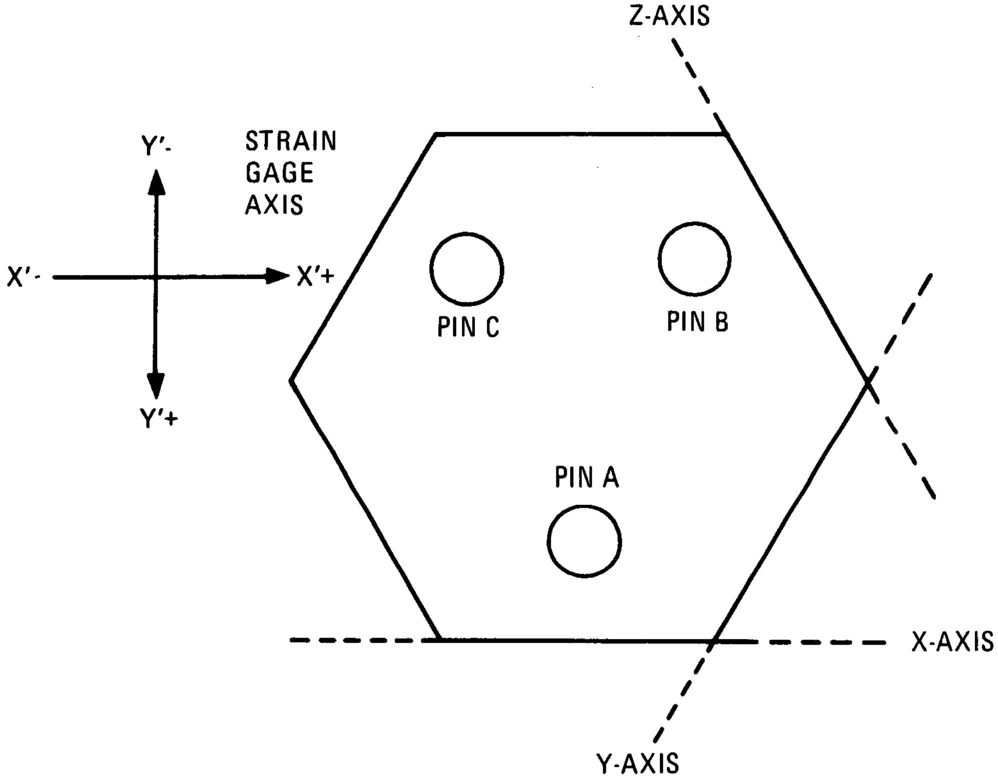


Fig. 5-3. Full-scale dowel pin notation

3. Strain gages measured shear loading across the base of the dowel pins. Two gages were attached to each pin, one in the direction of the rocking, the other normal to this direction.

The blocks were instrumented as follows:

Block A: Top - Six load cells, one in each hexagonal corner;
strain gages on all three dowels, both parallel
and normal to the rocking direction.
Bottom - One LVDT

Block B: Bottom - One LVDT

Block C: Bottom - One LVDT

Block D: Bottom - One LVDT

The locations of these transducers in each element are shown in Figs. 5-4 through 5-8. The data acquisition circuits for each transducer were the same as for the 1/5-scale instruments; they are shown in Figs. 4-10 through 4-13. All calibration procedures were the same as for the 1/5-scale tests. Table 5-3 contains all instrument calibration factors.

## 5.3. TEST SCOPE

As for the 1/5-scale test, the tests were aimed at obtaining dowel shear loads, rock-down impact forces, and rocking angle decay time histories. Table 5-4 gives a summary of the test procedures and explains any anomalies or apparent problems associated with a particular test.

## 5.4. TEST RESULTS

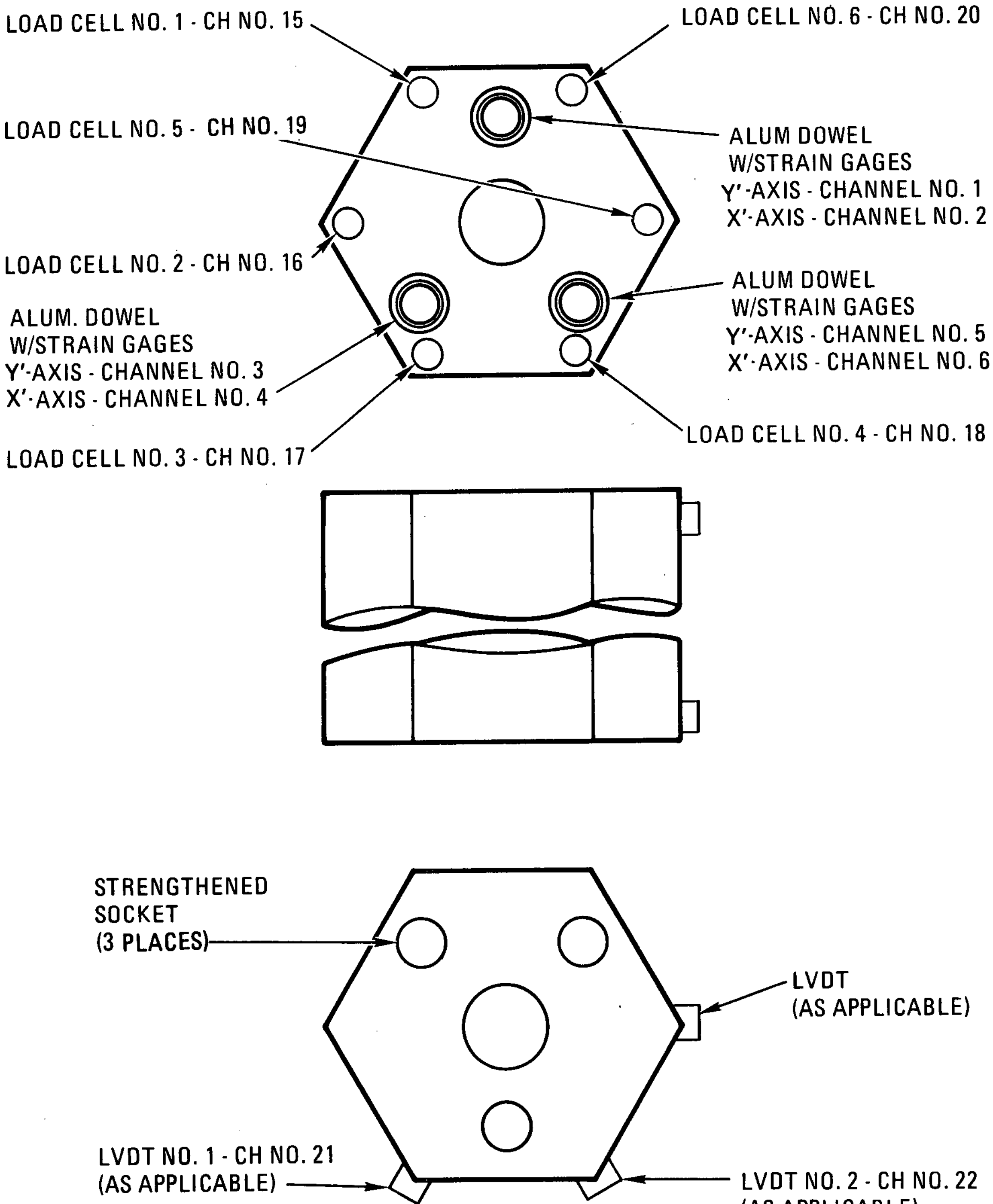


Fig. 5-4. Full-scale element A

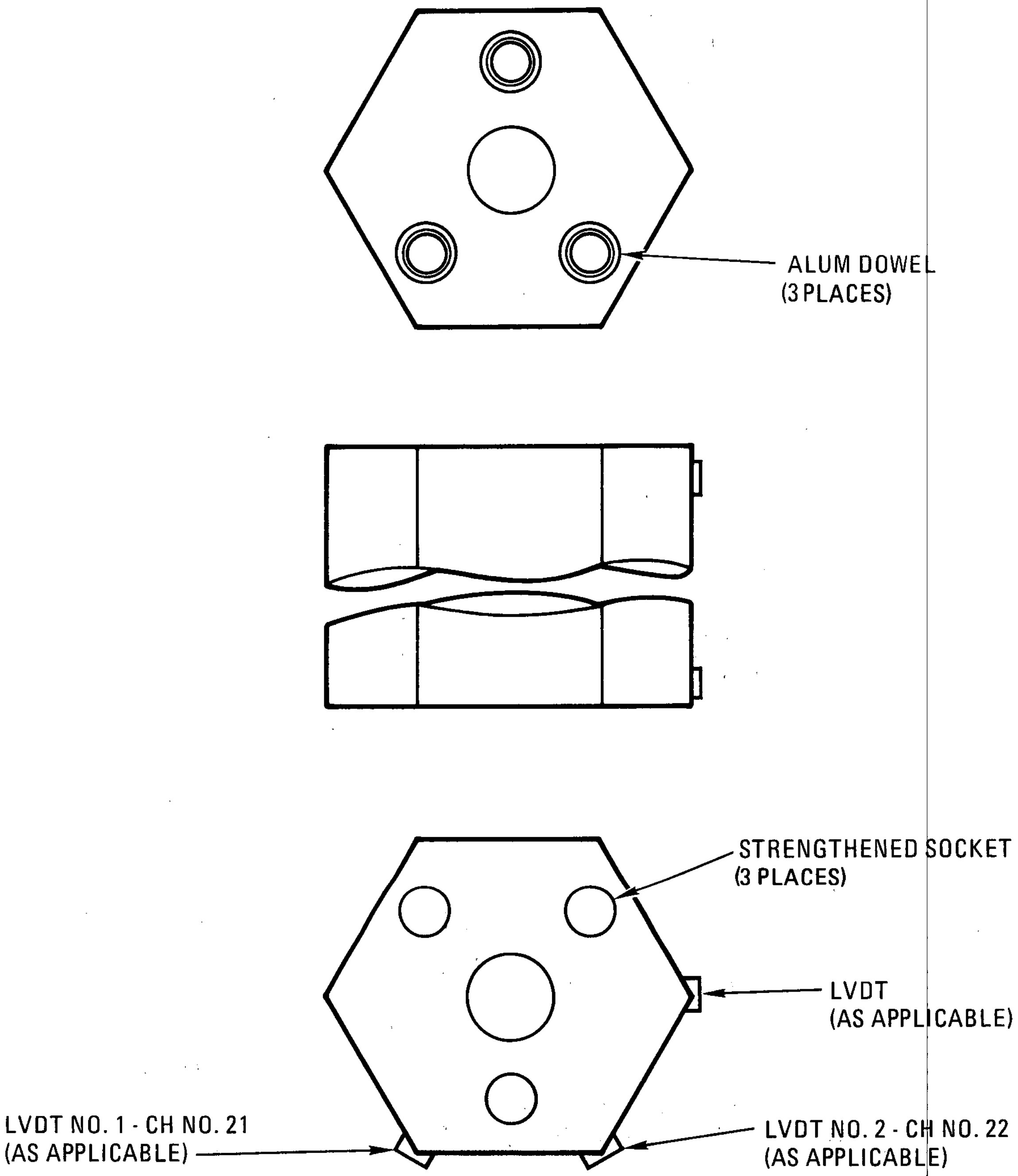


Fig. 5-5. Full-scale element B

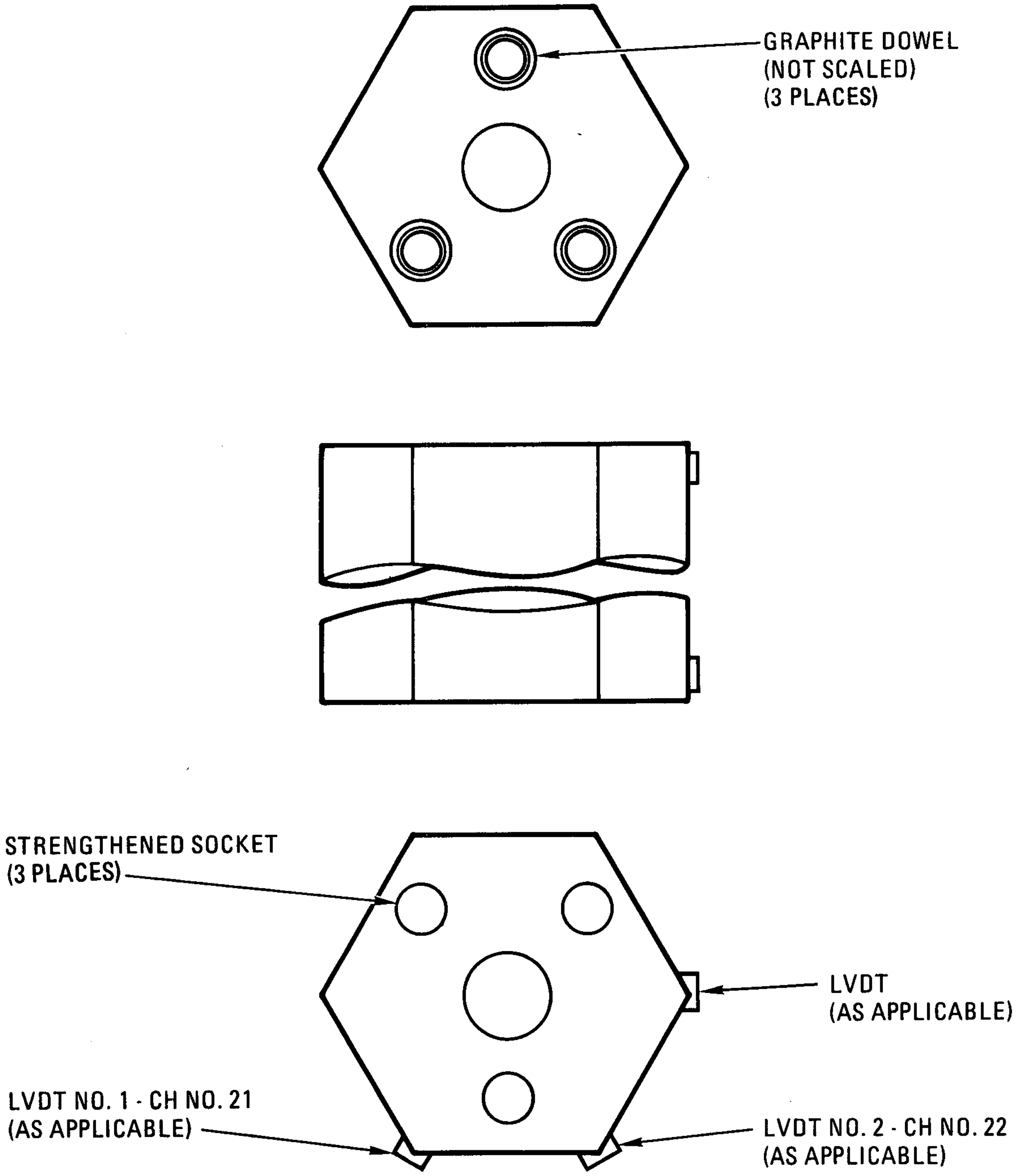


Fig. 5-6. Full-scale element C

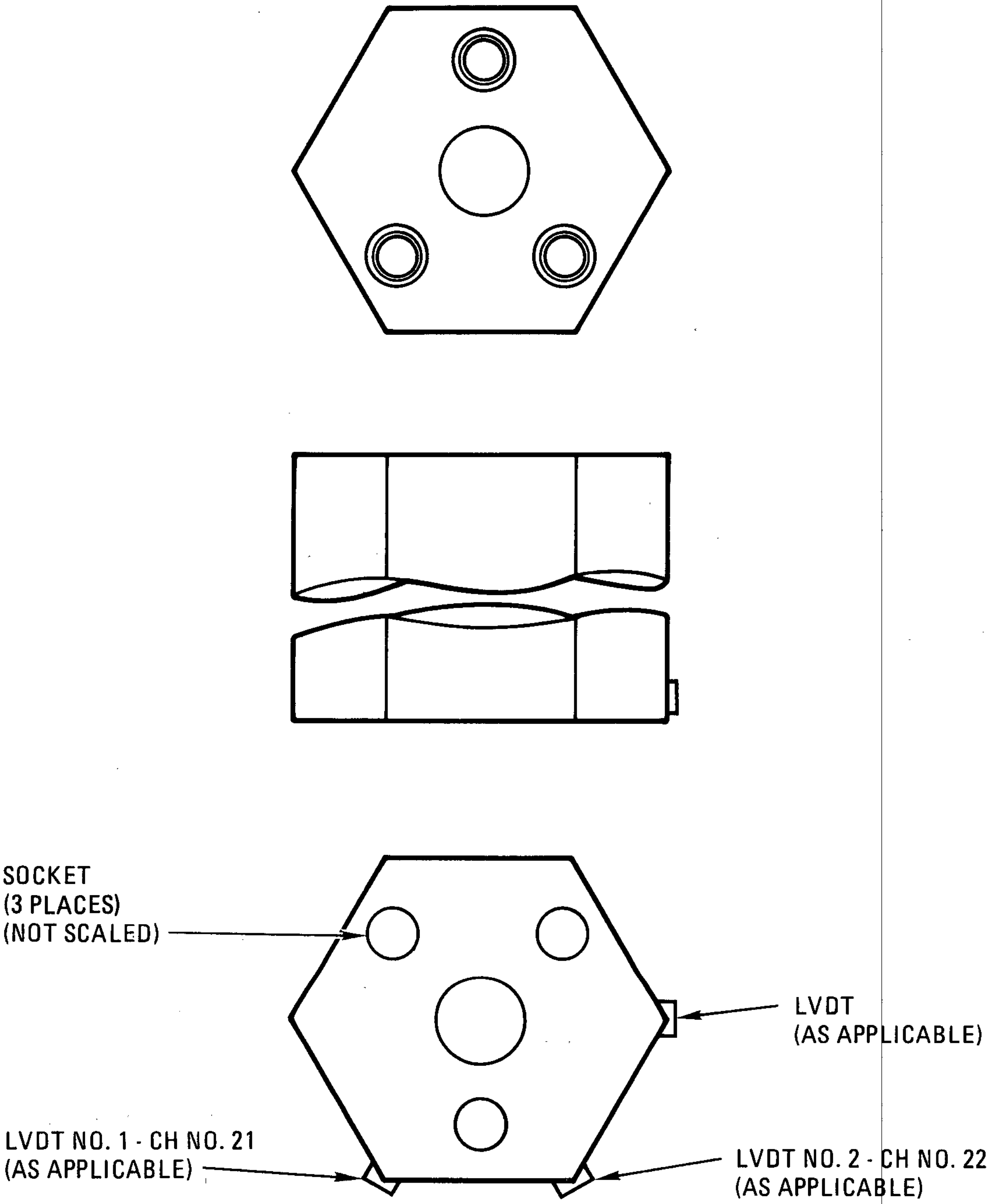


Fig. 5-7. Full-scale element D

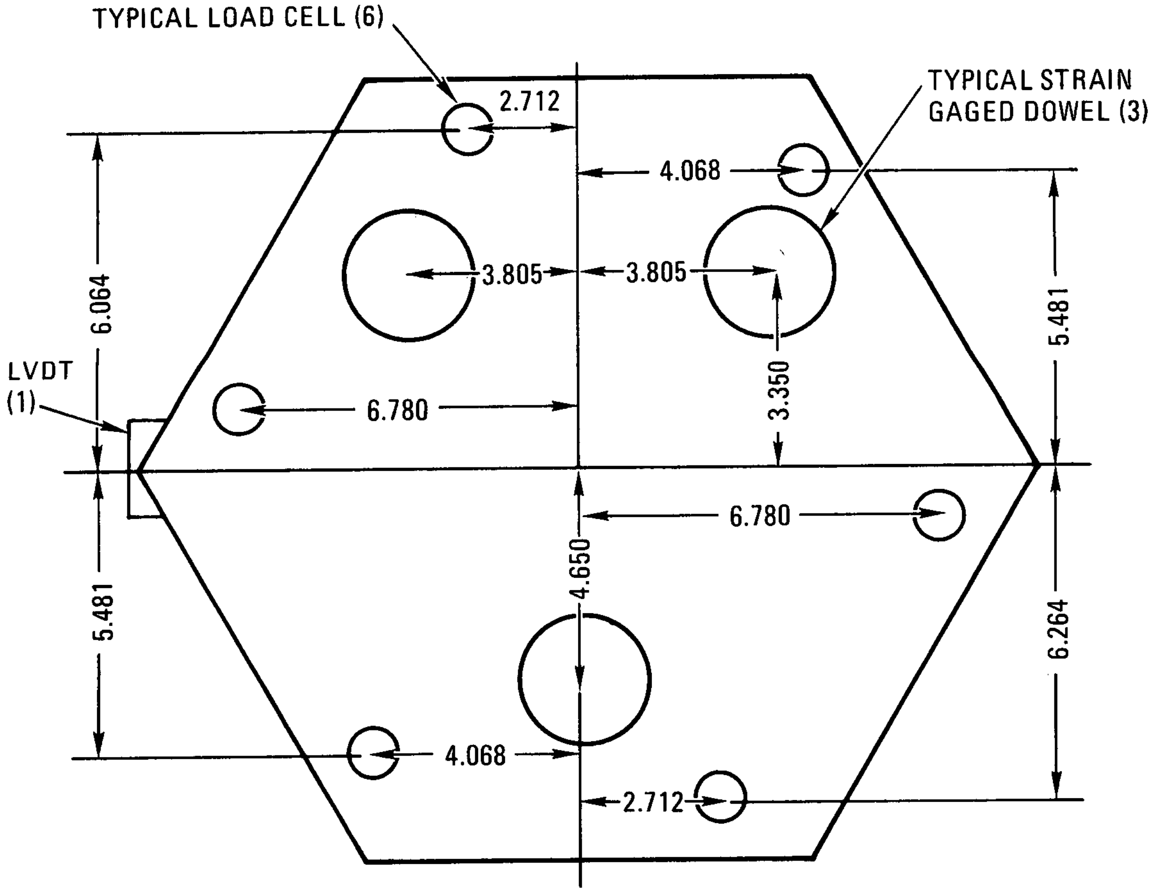


Fig. 5-8. Location of 1/1-scale fuel element instrumentation

## TABLE 5-3
## CALIBRATION FACTORS FOR 1/1 SCALE ELEMENT TRANSDUCERS

| Transducer | Transducer Number | Associated Block | Sensitive Axis | Multiplexer Channel Numbers | Calibration Factors[a] |
|---|---|---|---|---|---|
| Load cell | 1 | A | -- | 1, 41 | 0.24450 |
| Load cell | 2 | A | -- | 2, 42 | 0.24450 |
| Load cell | 3 | A | -- | 3, 43 | 0.24390 |
| Load cell | 4 | A | -- | 4, 44 | 0.24390 |
| Load cell | 5 | A | -- | 5, 45 | 0.24450 |
| Load cell | 6 | A | -- | 6, 46 | 0.24450 |
| LVDT | 13 | -- | -- | 13, 53 | 0.00244 |
| LVDT | 14 | -- | -- | 14, 54 | 0.00244 |
| Strain gage | 18 | A | Y' | 18, 58 | 3.9806 |
| Strain gage | 19 | A | X' | 19, 59 | 2.0802 |
| Strain gage | 22 | A | Y' | 22, 62 | 1.5615 |
| Strain gage | 23 | A | X' | 23, 63 | 1.3320 |
| Strain gage | 25 | A | Y' | 25, 65 | 1.9892 |
| Strain gage | 26 | A | X' | 26, 66 | 2.3791 |

(a)Units are volts/digital count.

## TABLE 5-4
## FULL-SCALE TEST PLAN

| | Description | | | |
|---|---|---|---|---|
| Test | Configuration | Angle | Rocking Axis | Remarks |
| 1R | B/A | 5° | X | |
| 2R | B/A | 15° | X | |
| 3 | B/A | 5° | Y | |
| 4R | B/A | 10° | Y | |
| 5 | B/A | 15° | Z | Load cell 2 may have saturated at one point (B-05-5)(a); maximum load = 1000 lb. |
| 6 | D/C | 5° | X | These tests were instrumented with LVDTs only. |
| 7 | D/C | 15° | X | |
| 8 | D/C/A | 15°/0° | X | Some dc bias on load cells 2 through 5 (B-08-6 through B-08-9). |
| 9 | D/C/A | 0°/10° | X | Load cell 1 saturated at one point (B-09-5); maximum load = 1000 lb. DC bias on load cell 2 (B-09-6). |
| 10 | C/B/A | 15°/0° | X | DC bias on load cells 2, 3, and 5 (B-10-6, B-10-7, and B-10-9). |
| 11 | C/B/A | 0°/10° | X | DC bias, load cell 2 (B-11-6). |
| 12R | C/B/A | 10°/6° | X | DC bias, load cell 2 (B-12-6). |
| 13 | C/B/A | 10°/6° | X | Repeat of test 12; dc bias, load cell 2 (B-13-6). |
| 14 | C/B/A | 10°/0° | X | DC bias on all load cells (B-14-5 through B-14-10). |
| 15 | -- | -- | -- | Data from this test were not recoverable. |
| 16 | C/B/A | 6°/10° | X | Load cells 1, 2, and 6 have dc bias (B-14-5, B-14-6, and B-14-10). |
| 17 | C/A/B | 17-1/2°/10° | X | |
| 18 | C/A/B | 0°/10° | X | |
| 19 | C/A/B | 6-1/2°/10° | X | |
| 20 | C/A/B | 17-1/2°/10° | Y | |
| 21 | C/A/B | 0°/10° | Y | |
| 22 | C/A/B | 6-1/2°/10° | Y | |

(a) Refers to a figure in Ref. 2, i.e., B-05-5 means test 05, Fig. 5.

### 5.4.1. General

Some preliminary test results are reported in Ref. 8. The bulk of the results and plotted data are contained in Ref. 2.

The total rock-down load on a given block was obtained by summing the instantaneous individual loads from each of the six load cells. The total dowel pin shear load was obtained from the instantaneous vector sum of the three in-line strain gages and the three nominal strain gages as shown in Section 4.4.1 for the 1/5-scale tests.

### 5.4.2. Two-Block Configuration

Figures 5-9 through 5-11 show the results from one fuel element rocking on another element with an initial release angle of 5°. The rocking angle decay time history (Fig. 5-9) shows a rocking behavior almost identical to that observed for the 1/5-scale blocks. (The spikes in these tracers are caused by noise in the data acquisition system.) However, log decrement in the 1/1-scale system is lower, corresponding to an average damping factor of about 6% of critical. As in earlier observations, the peak rock-down loads (Fig. 5-10) and dowel forces (Fig. 5-11) occur at zero rocking angle. In contrast to the 1/5-scale results the 1/1-scale data show that the maximum loads consistently occur at the time of the first rock-down.

Comparing the rocking behavior about the X, Y, and Z axes, similar observations were made from the 1/1-scale data as for 1/5-scale data, which showed slightly larger rocking angle amplitudes about the X-axis. Rock-down loads and dowel pin shear loads were also compared for these rocking axes; they are shown in Figs. 5-12, 5-13, and 5-14. It is seen that the maximum loads are approximately of the same magnitude; only the distribution of the loads is different. A maximum dowel shear load of 660 lb was recorded for rocking about the Z-axis. This indicates that a large percentage of the total dowel load from seismically induced forces may be due to element rocking action alone.

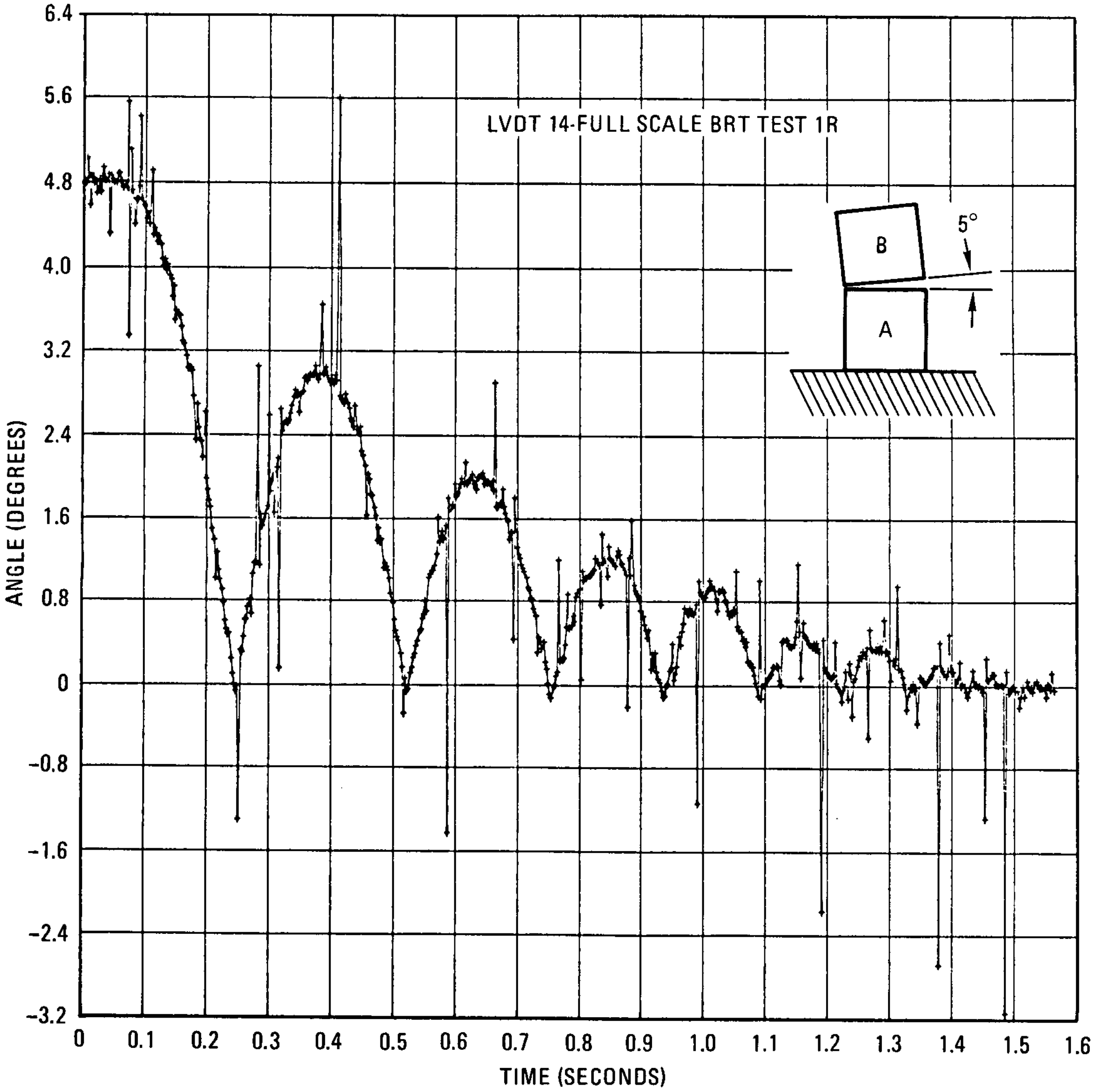


Fig. 5-9. Rocking motion - 1/1-scale, two-block configuration, 5° initial angle, X-axis

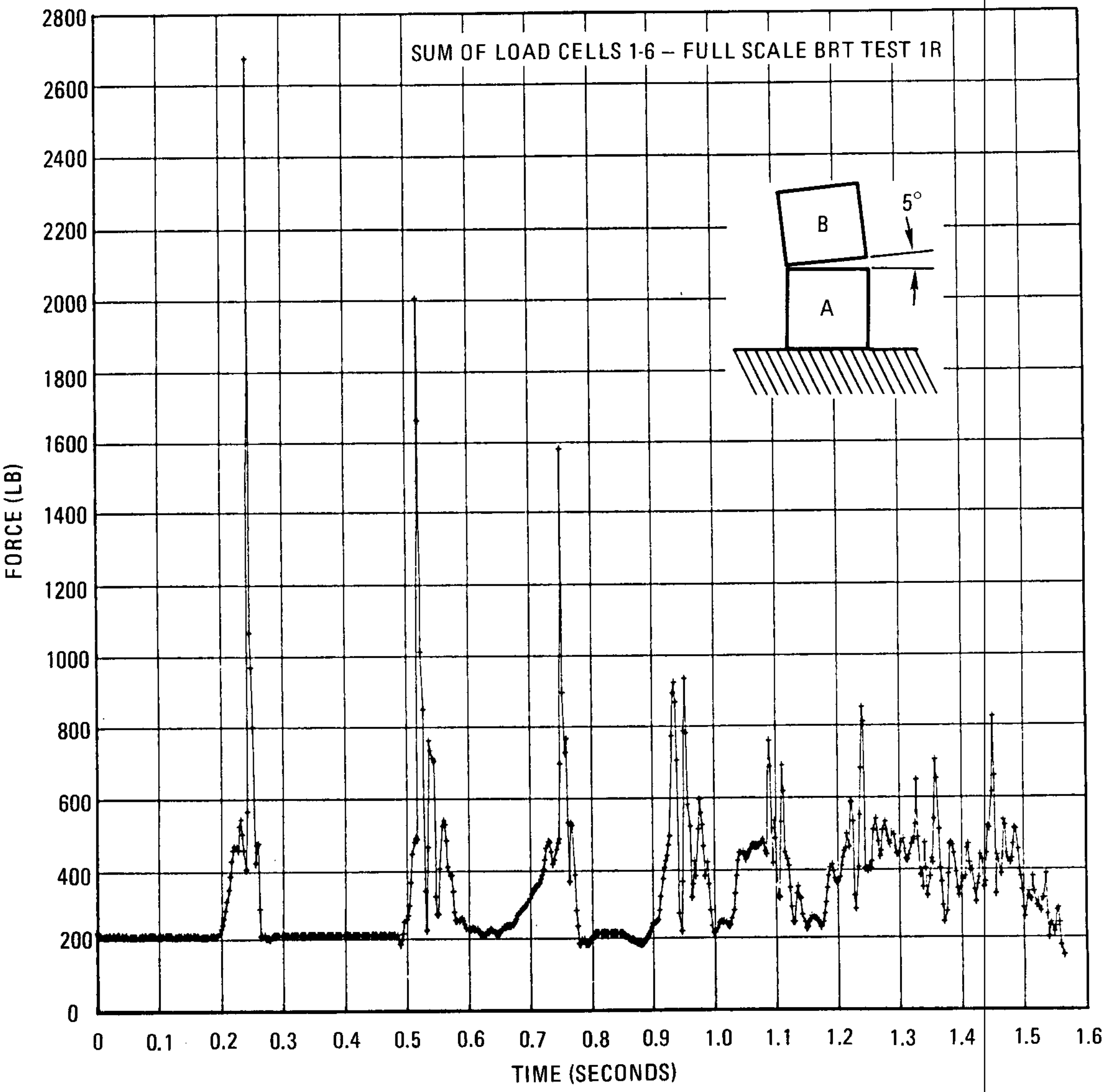


Fig. 5-10. Rock-down force - 1/1-scale, two-block configuration, 5° initial angle, X-axis

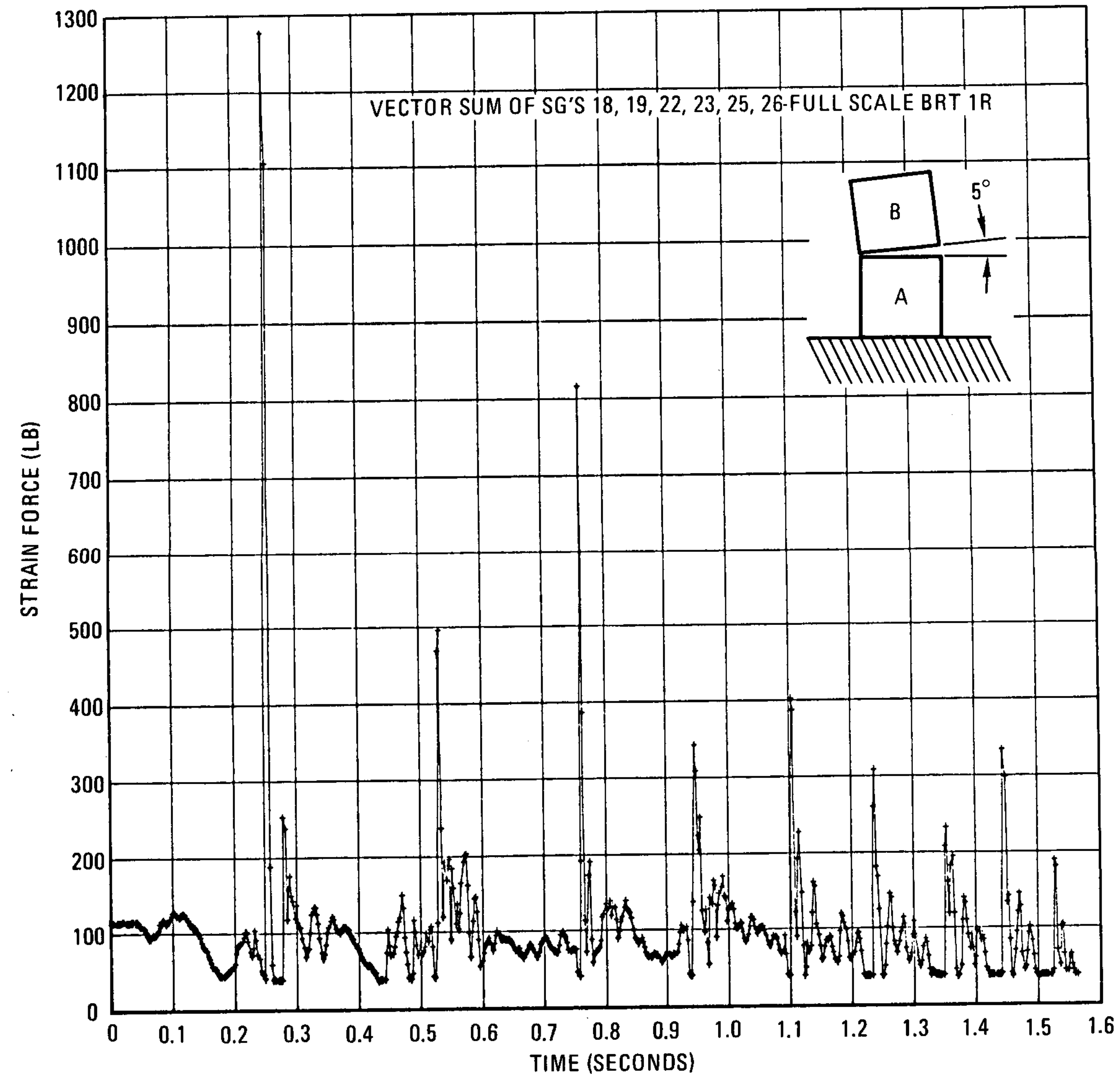
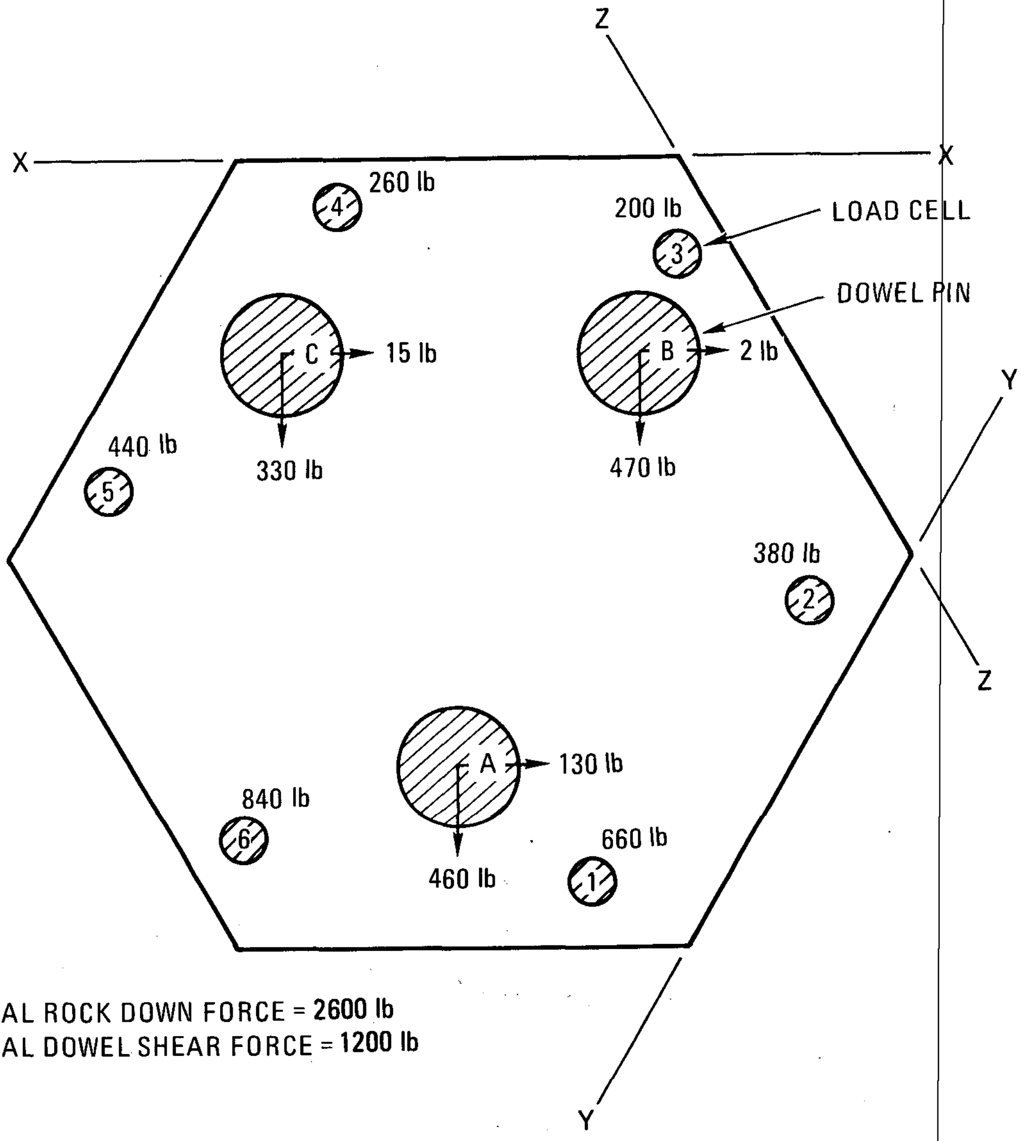


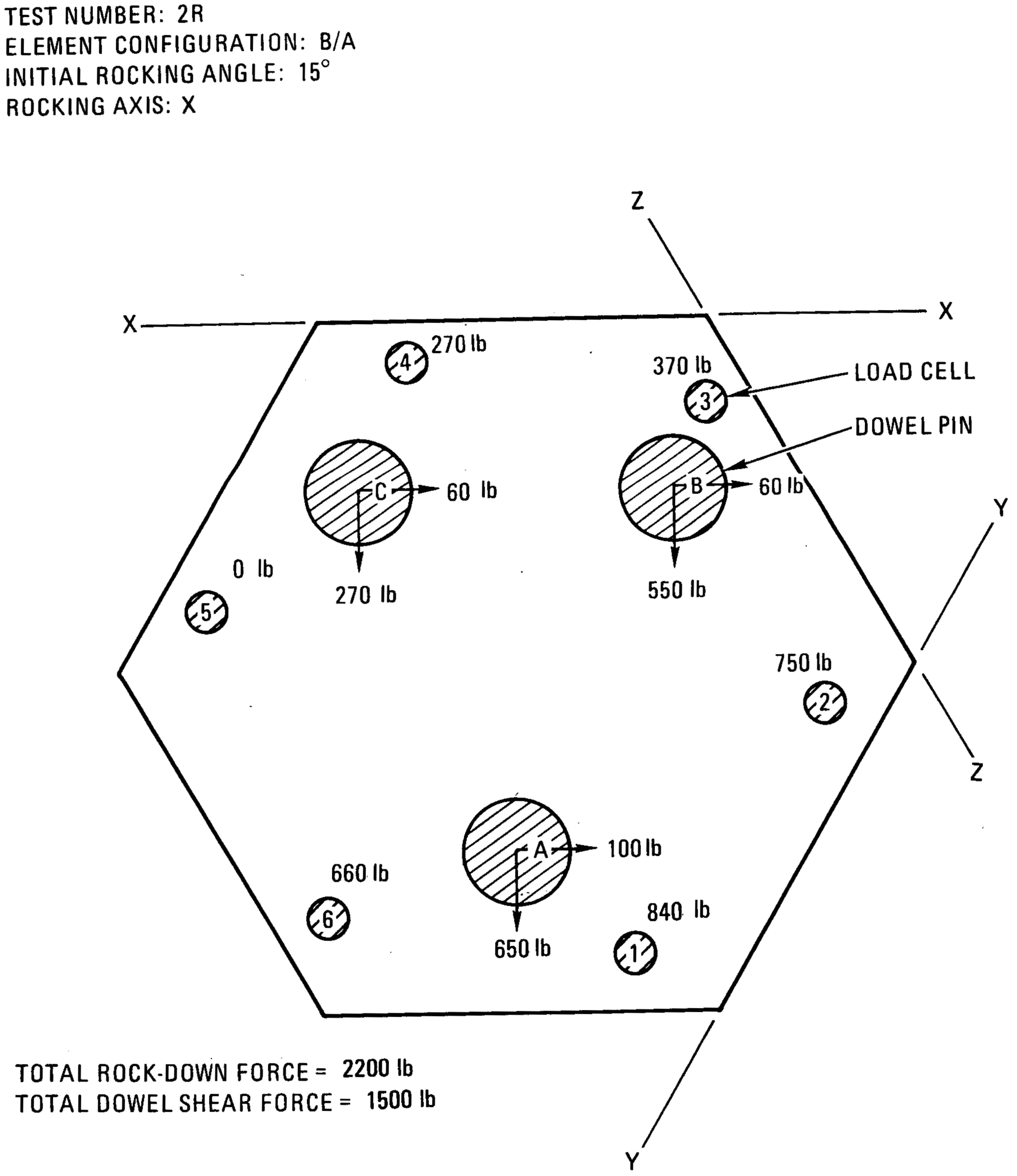
Fig. 5-11. Dowel force - 1/1-scale, two-block configuration, 5° initial angle, X-axis

TEST NUMBER: 1R
ELEMENT CONFIGURATION: B/A
INITIAL ROCKING ANGLE: 5°
ROCKING AXIS: X



TOTAL ROCK DOWN FORCE = 2600 lb
TOTAL DOWEL SHEAR FORCE = 1200 lb

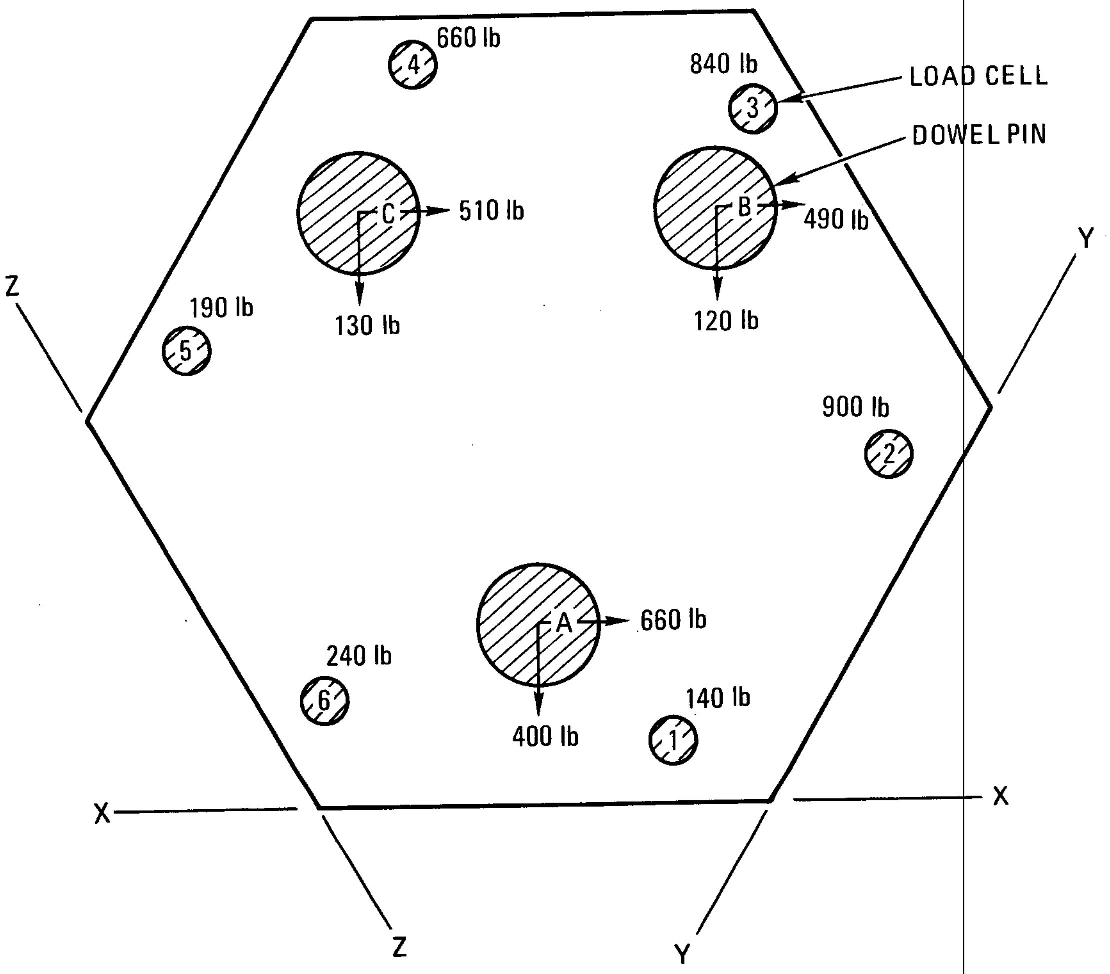
Fig. 5-12. Distribution of maximum rock-down load and dowel forces - 1/1-scale, two-block configuration, 5° initial angle, X-axis


TEST NUMBER: 2R
ELEMENT CONFIGURATION: B/A
INITIAL ROCKING ANGLE: 15°
ROCKING AXIS: X

TOTAL ROCK-DOWN FORCE = 2200 lb
TOTAL DOWEL SHEAR FORCE = 1500 lb

Fig. 5-13. Distribution of maximum rock-down load and dowel forces - 1/1-scale, two-block configuration, 15° initial angle, X-axis

TEST NUMBER: 5
ELEMENT CONFIGURATION: B/A
INITIAL ROCKING ANGLE: 15°
ROCKING AXIS: Z



TOTAL ROCK-DOWN FORCE = **2500 lb**
TOTAL DOWEL SHEAR FORCE = **1790 lb**

Fig. 5-14. Distribution of maximum rock-down load and dowel forces - 1/1-scale, two-block configuration, 15° initial angle, Z-axis

In order to check the influence of the load cell instrumentation on element rocking behavior and hence the validity of the measured rock-down loads, identical tests (tests 1R and 6) were performed with and without load cells. Figures 5-9 and 5-15 show the rocking behavior during two tests for a 5° release angle; there is practically no difference in the rocking amplitude and frequency characteristics. This behavior was confirmed for a 15° release angle (tests 2R and 7).

### 5.4.3. Multiblock Configurations

Several multiblock configurations were tested consisting of two blocks stacked on top of one clamped block. When the top block was initially tilted (test 10), the rocking phenomenon was as shown in Figs. 5-16 and 5-17. After release, the top block rocks down and practically transfers all its angular momentum to the middle block on initial impact. The two blocks then rock together on the base block in the same manner as described for two-block rocking. Identical behavior was exhibited when both the two top blocks were initially displaced (test 12R) as shown in Figs. 5-18 and 5-19. The maximum rock-down loads and dowel shear forces are shown in Fig. 5-20; they represent the interface between the base block and the middle block.

A summary of total rocking loads and dowel shear forces for all rocking configurations is given in Table 5-5.

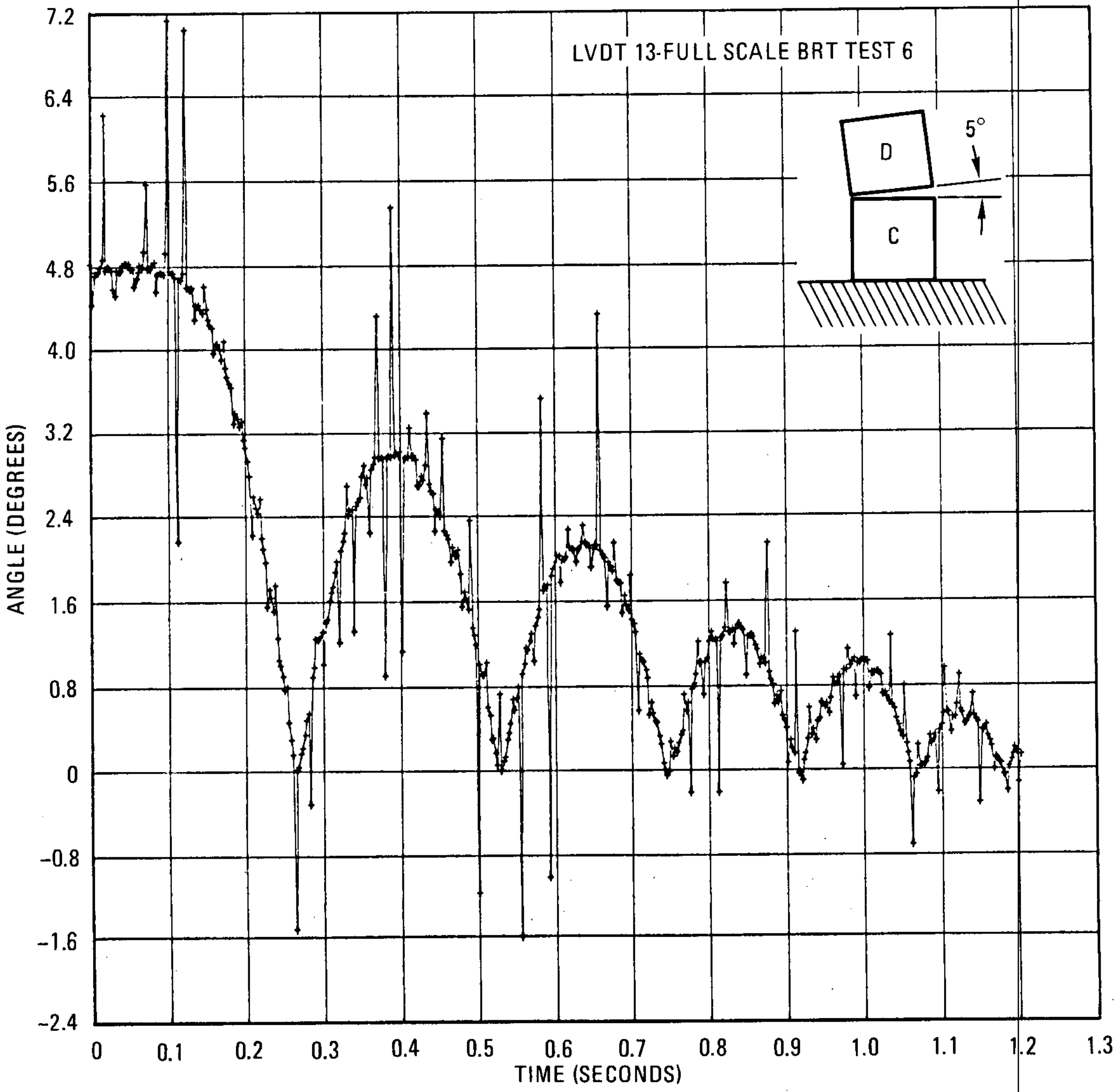


Fig. 5-15. Rocking motion (no-load cell instrumentation) - 1/1-scale, two-block configuration, 5° initial angle, X-axis

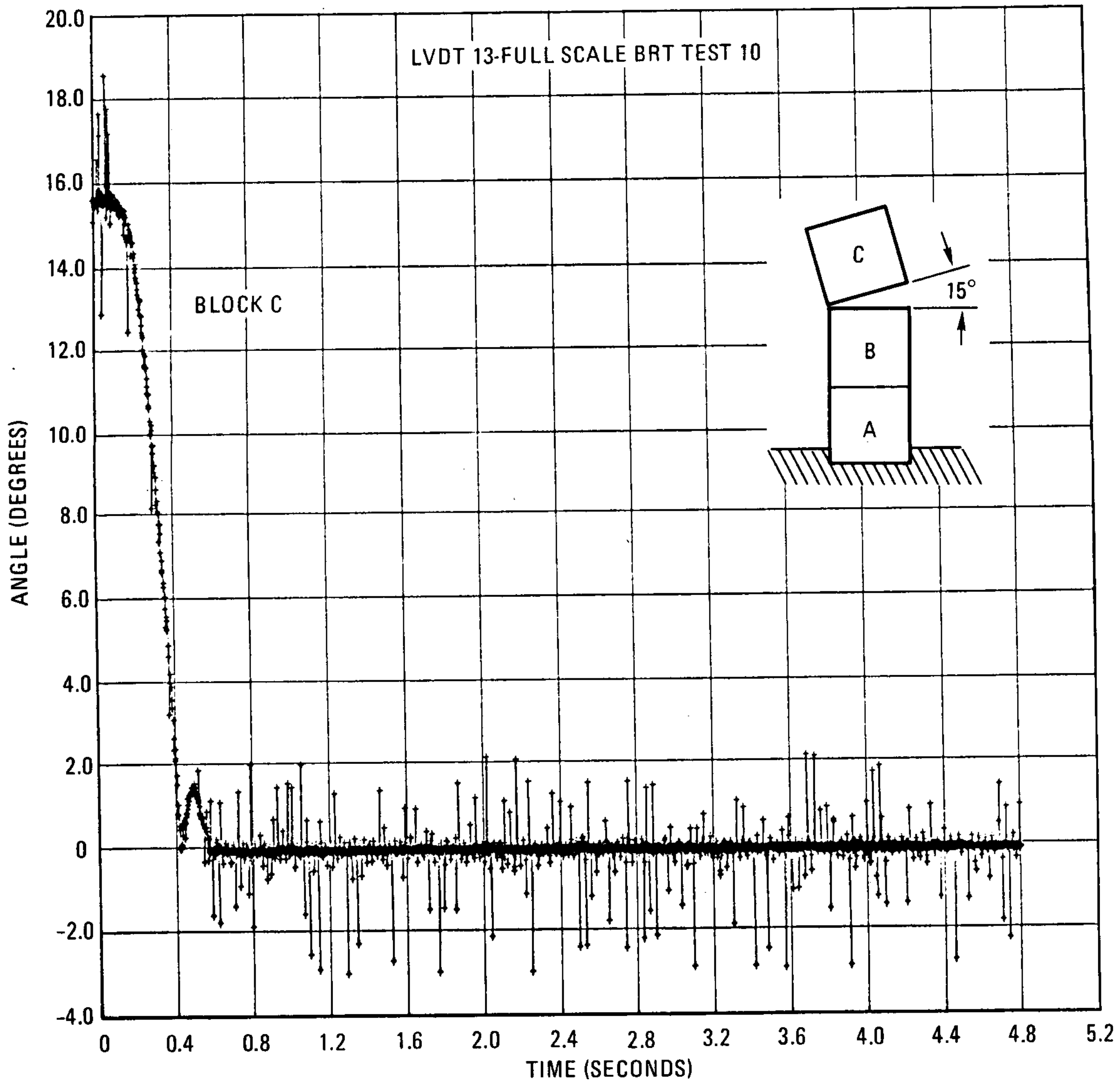


Fig. 5-16. Rocking motion (Block C) - 1/1-scale, three-block configuration, 15°/0° initial angle, X-axis

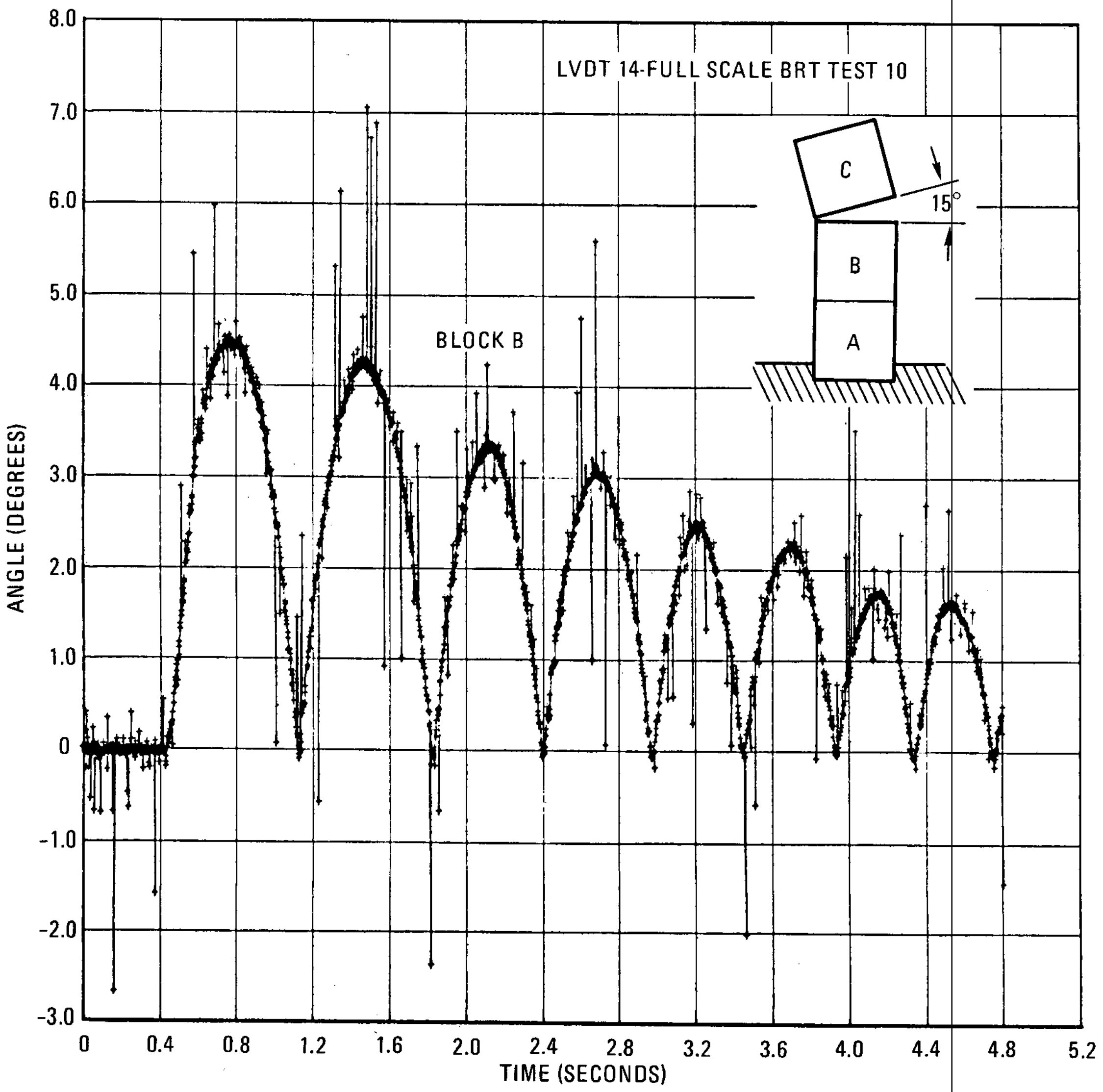


Fig. 5-17. Rocking motion (Block B) - 1/1-scale, three-block configuration, 15°/0° initial angle, X-axis

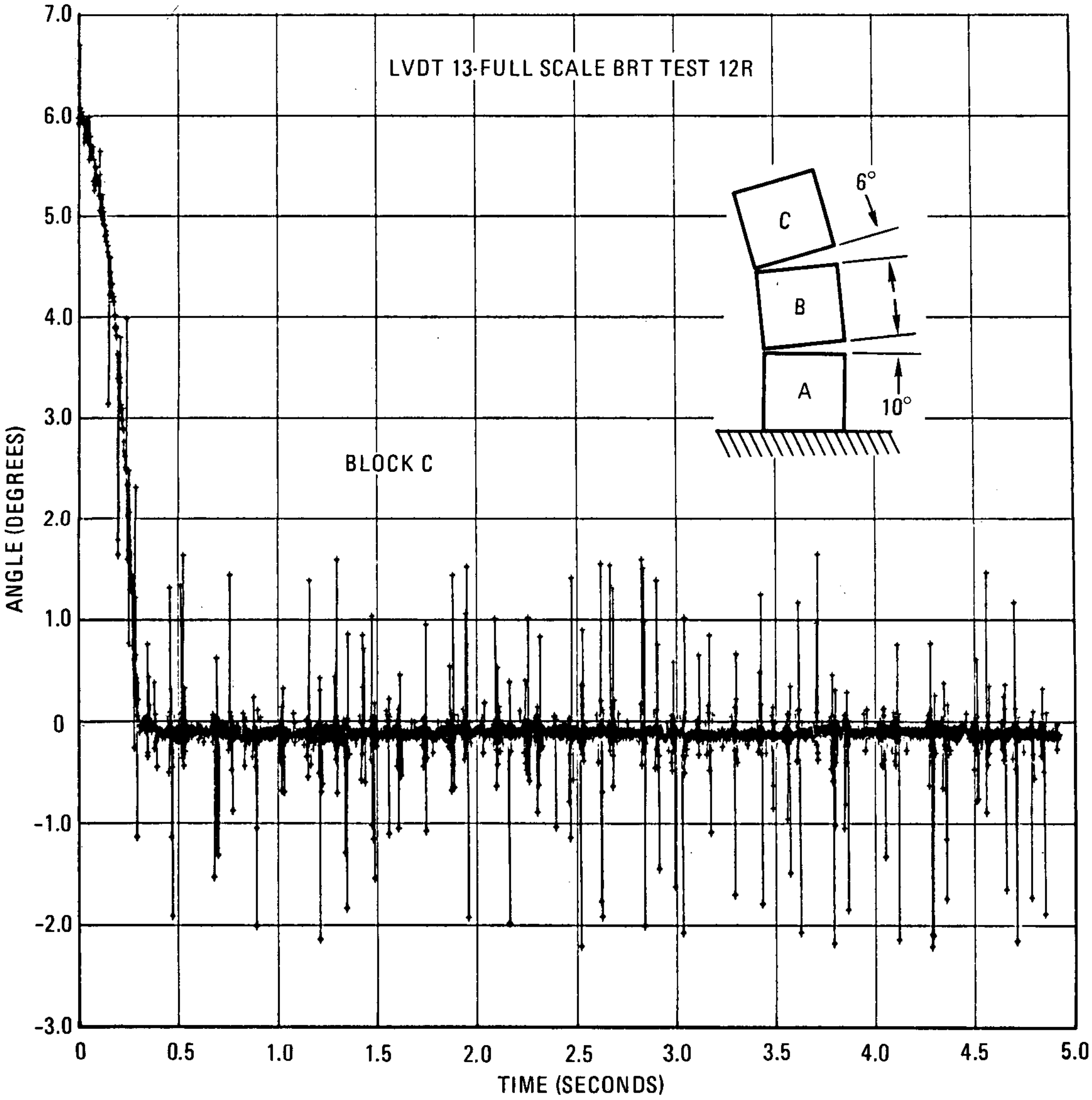


Fig. 5-18. Rocking motion (Block C) - 1/1-scale, three-block configuration, 10°/6° initial angle, X-axis

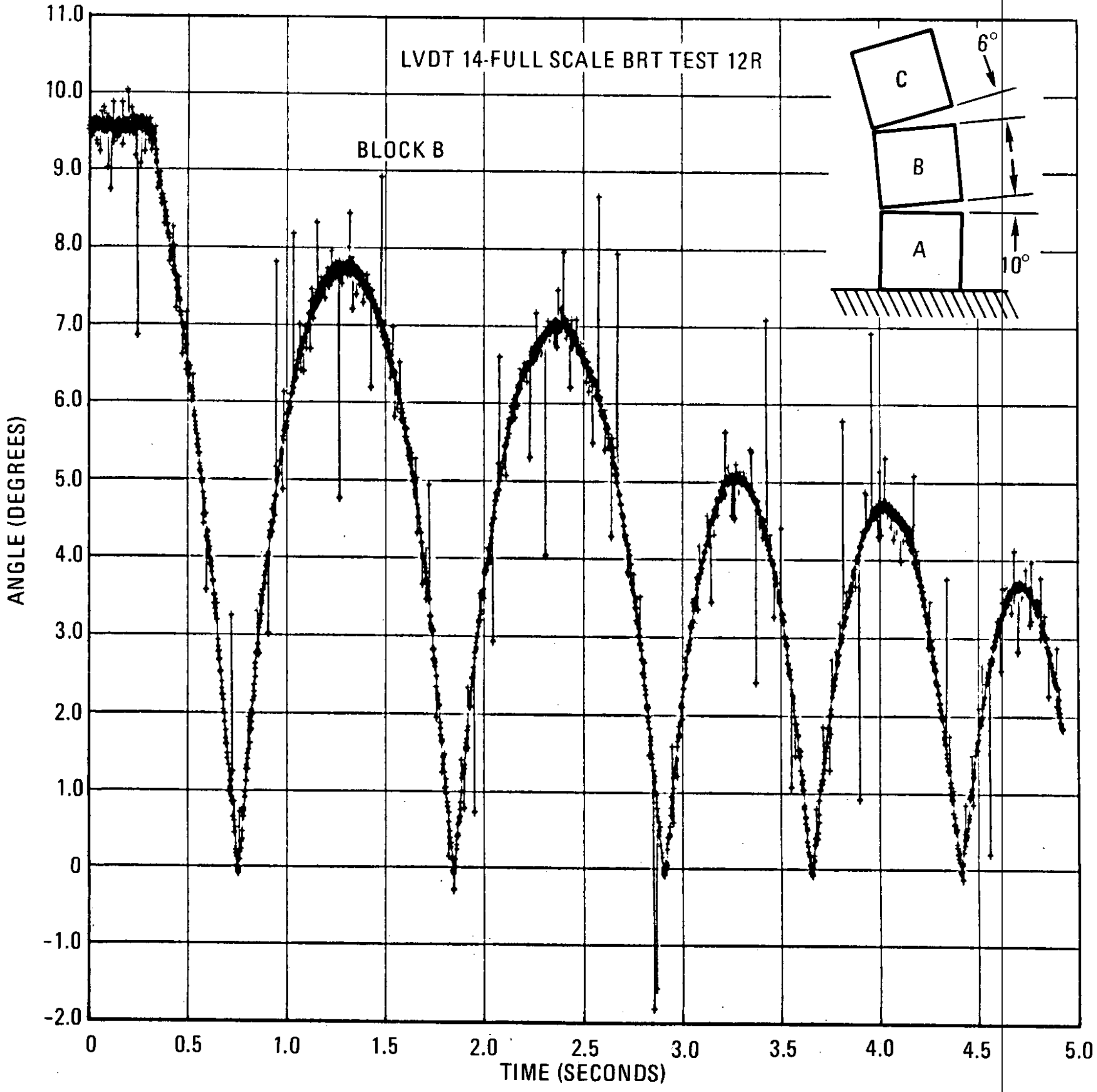


Fig. 5-19. Rocking motion (Block B) - 1/1-scale, three-block configuration, 10°/6° initial angle, X-axis

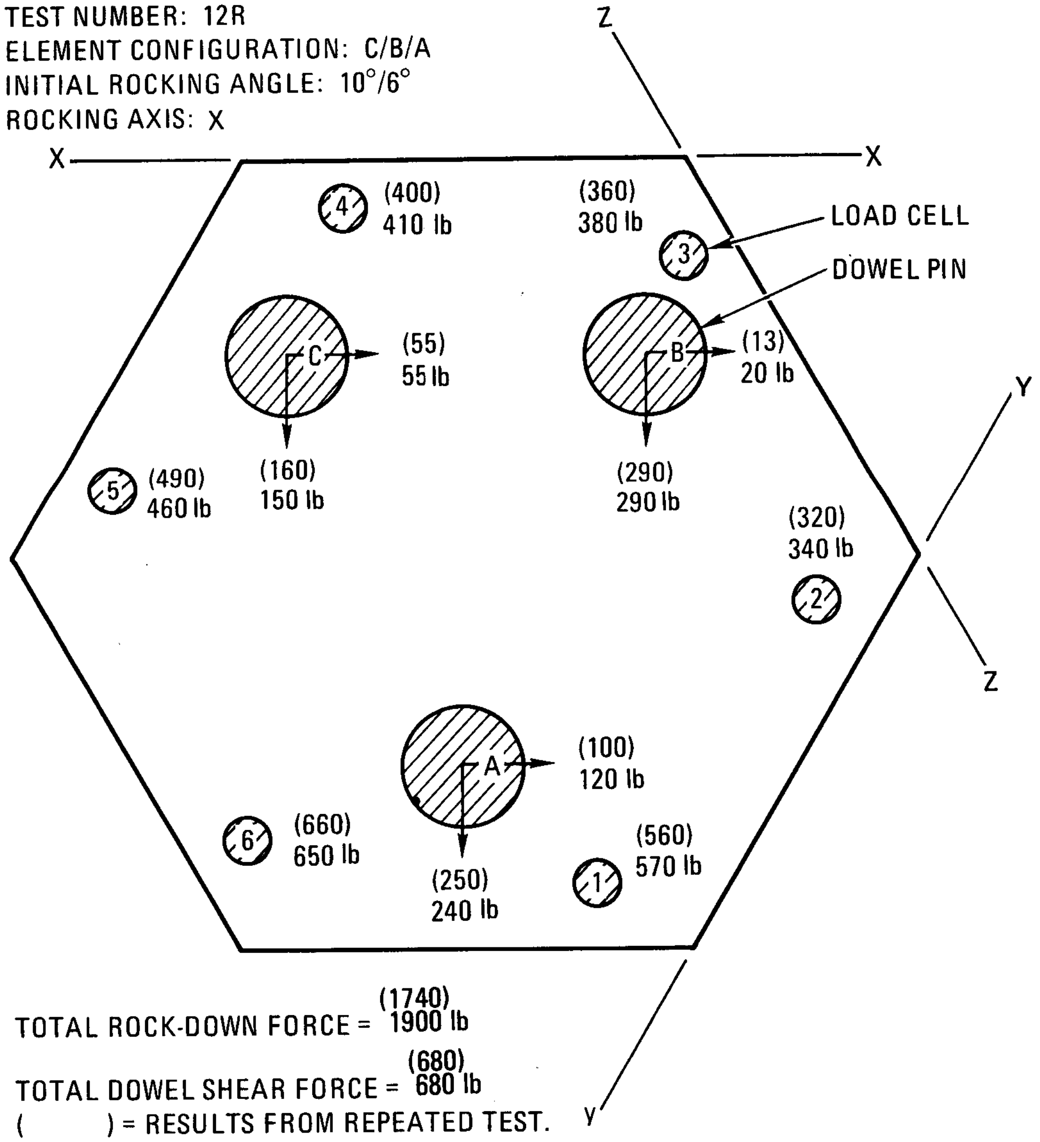


Fig. 5-20. Distribution of maximum rock-down load and dowel forces (Block A) - 1/1-scale, three-block configuration, 10°/6° initial angle, X-axis

TABLE 5-5
FULL-SCALE MAXIMUM ROCK-DOWN AND DOWEL LOADS

| Test | Initial Conditions | | | Peak Rocking Load Sum (lb) | Peak Dowel Shear Force Vector Sum (lb) |
|---|---|---|---|---|---|
| | Configuration | Angle | Rocking Axis | | |
| 1R | B/A | 5° | X | 2600 | 1200 |
| 2R | B/A | 15° | X | 2200 | 1500 |
| 3 | B/A | 5° | Y | 1600 | 1240 |
| 4R | B/A | 15° | Y | 1980 | 510 |
| 5 | B/A | 15° | Z | 2500 | 1790 |
| 8 | D/C/A | 15°/0° | X | 3450 | 660 |
| 9 | D/C/A | 0°/10° | X | 2420 | 640 |
| 10 | C/B/A | 15°/0° | X | 3700 | 1120 |
| 11 | C/B/A | 0°/10° | X | 1930 | 1930 |
| 12R | C/B/A | 10°/6° | X | 1900 | 680 |
| 13 | C/B/A | 10°/6° | X | 1740 | 680 |
| 14 | C/B/A | 10°/0° | Y | 2900 | 660 |
| 16 | C/B/A | 6°/10° | Y | 2170 | 600 |
| 17 | C/A/B | 17-1/2°/0° | X | 3050 | 920 |
| 18 | C/A/B | 0°/10° | X | 1530 | 930 |
| 19 | C/A/B | 6-1/2°/10° | X | 1800 | 980 |
| 20 | C/A/B | 17-1/2°/0° | Y | 2680 | 990 |
| 21 | C/A/B | 0°/10° | Y | 1600 | 710 |
| 22 | C/A/B | 5°/10° | Y | 1880 | 540 |

# 6. COMPARISON BETWEEN 1/5-SCALE AND 1/1-SCALE TESTS

An effort was made to compare 1/5-scale and 1/1-scale test results in order to establish the scaling relationships for angular displacement and forces. The model scaling laws were previously discussed in Section 4.1, where it was established that similitude was not obtained in the modeling of the 1/5-scale blocks and therefore the relationship between the 1/5- and 1/1-scale responses might be distorted.

It was difficult to compare test results directly since the initial conditions (release angle) did not always correspond (1/1 scale release angles were reduced when it was found that the blocks would rock over too far and overturn). However, by plotting angular displacement as a function of rocking frequency, a comparison independent of initial conditions and time was achieved. Such a plot representing two-block rocking is shown in Fig. 6-1. By normalizing the 1/1-scale data to 1/5 scale using the scaling ratios established in Table 4-1, the 1/5- and 1/1-scale data can be compared directly. The figure shows an agreement between 1/5- and 1/1-scale rocking motion within 25% in the range tested. This means that the distortions in the 1/5-scale block modeling, such as that caused by the incorrect $\rho/E$ ratio may have some effect on the block rocking motion. It is seen that the relatively stiffer 1/5-scale block tends to produce a higher rocking frequency, as would be expected.

The effect on rock-down loads and dowel shear forces was considerably more pronounced. This is shown in Table 6-1 even though exact initial conditions were not compared. The table shows that the 1/5-scale rock-down loads were largely overestimated, which was expected since the 1/5-scale block is too stiff. The dowel shear forces were much closer since care was taken to model the dowel pin stiffnesses more accurately. Since the 1/5-scale dowel forces were underestimated, it is suggested that the 1/5-scale dowel was not stiff enough or that a larger portion of the 1/5-scale

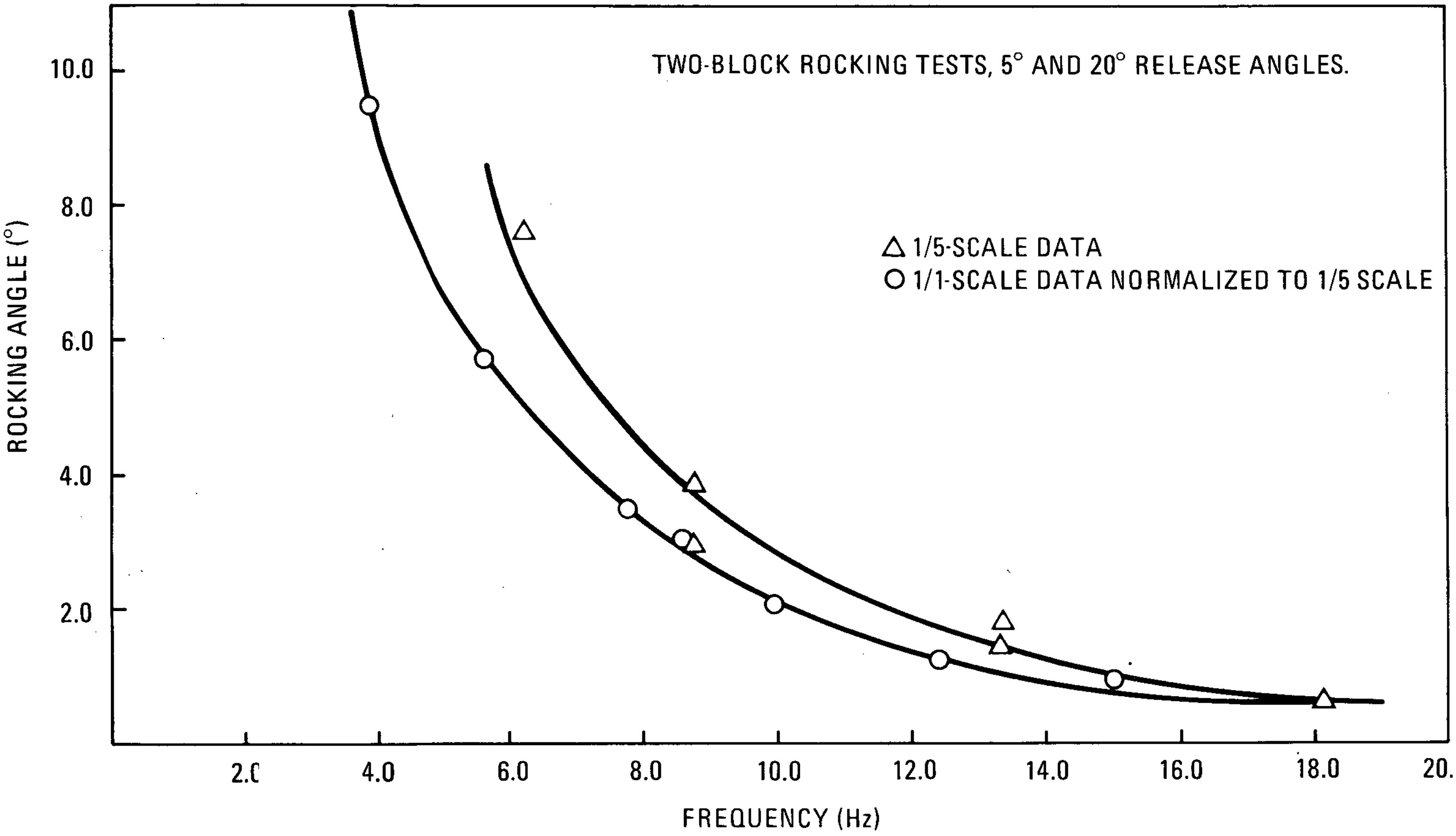


Fig. 6-1. Comparison between 1/5-scale and 1/1-scale rocking motion.

## TABLE 6-1
## COMPARISON BETWEEN 1/5- AND 1/1-SCALE MAXIMUM ROCK-DOWN LOADS AND DOWEL SHEAR FORCES

| Block Configuration | Net Rock-Down Load (lb) | | Net Dowel Shear Force (lb) | |
|---|---|---|---|---|
| | 1/5[a] | 1/1[b] | 1/5 | 1/1[b] |
| Two-block, 5° | 90 ± 0.5 | 20 | $5.1\,^{+1.5}_{-0.6}$ | 9.4 |
| Two-block, 15° to 20° | 116 | 17.6 | 6.5 ± 0.3 | 11.7 |
| Three-block, 15° to 20° | 40 | 25 ± 0.8 | $4.5\,^{+2.2}_{-1.5}$ | 6.8 ± 1.8 |

(a) On the low side since one load cell did not function.

(b) Normalized to 1/5 scale.

shear force was taken up by block-to-block friction. The latter is a real possibility since it was established from the results that the 1/5-scale rocking motion showed much larger logarithmic decay.

# 7. TEST DATA ERROR ANALYSIS

An estimate of errors in the 1/5- and 1/1-scale tests was made in order to obtain the expected accuracy of the presented data. This is particularly important where the data are used for correlation with results from analysis.

In general, the test data contain both random and systematic errors. If data from repeated tests are available in a sample of reasonable size, statistical analysis of the measurements can be employed to estimate the total random error involved. If repeated tests are not available, the random errors in the test system components must be obtained separately and compounded to obtain the total (random) error in the data.

On the other hand, systematic errors that tend to have the same algebraic sign are not amenable to statistical treatment. In most instances, however, they are easily obtained from the raw data plots. The data reduction codes can assess this error and automatically adjust the data point. If not, the systematic error is added algebraically to the random error to obtain the overall total error.

## 7.1. ERROR SOURCES

The commonly known sources of error in these tests are as follows:

1. Element configuration and initial conditions
2. Core element properties
3. Data acquisition system

4. Instrument calibration or verification

5. Extraneous errors

### 7.1.1. Element Configuration and Initial Conditions

Element configuration errors arise from core element dimensional tolerances, dowel pin and socket location, and dimensional tolerances. The rock-down loads and dowel forces are extremely sensitive to variations in these parameters. Angular velocities and displacements are presumed less sensitive.

The random configuration errors can only be estimated from a set of controlled parameter tests or from repeated tests with different elements. Although repeated tests with different elements were performed to a limited extent, the configuration error could not be singled out because the error contained components from all the other sources as well.

The error due to initial conditions, such as the initial release angle, could not be estimated either for the same reasons given above. Indications are, however, that the rocking response was not sensitive to small deviations in this parameter since only moderate changes in response (about 30% increase in rock-down load and dowel force) occurred when the release angle was changed from 5° to 20°. In any case, the release angle can be set quite accurately with the vernier angle gage to within ±0.5°.

### 7.1.2. Element Properties

Changes in element properties that can affect the core response are deviations in graphite density (block weight), Young's modulus (block stiffness), and coefficient of friction. The random error in the response as a result of expected deviations in these quantities has not been derived experimentally. The error assessment has therefore been made on a theoretical basis. From code sensitivity studies (Ref. 9) the effects of element density and friction changes are small in comparison with a change in Young's modulus. The mean element modulus for H451 graphite in the radial direction has been experimentally determined as $E = 1.07 \times 10^6$ lb/in.$^2$ with a standard deviation ($\pm 1\sigma$) of $0.06 \times 10^6$ lb/in.$^2$. The modulus only affects the rock-down loads since displacement and velocity are virtually independent of stiffness. Thus, assuming $F \alpha \sqrt{K}$, the error in the response becomes 2.8%.

### 7.1.3. Data Acquisition System

The data acquisition system errors include transducer sensitivity errors and errors in the signal conditioning, filtering, amplification, and recording stages of the system. These component errors, specified by the manufacturers, are given in Table 7-1. They are $\pm 3\sigma$ values. The estimation of the total system error for each instrument is therefore obtained from schematic diagrams such as that for the eddy current probe, shown in Fig. 7-1. The total error in each transducer circuit is given in Table 7-1 for both 1/5-scale and 1/1-scale test transducers.

### 7.1.4. Transducer Calibration or Verification

Transducer application errors are usually large as determined from calibration curves or verification data. In the rocking test, application errors occur in the following transducers: (1) LVDTs and eddy current probes measuring deflection, (2) strain gages measuring dowel forces, and (3) load washers measuring rock-down loads.

Although extensive calibrations and random error studies were not performed for these tests, except as described in Ref. 3, error assessments can be made based on the results obtained from other tests utilizing the same instrumentation and where such studies were conducted. Typical transducer application errors are given in Table 7-1.

## TABLE 7-1
## DATA ACQUISITION SYSTEM ERRORS AND INSTRUMENT APPLICATION ERRORS

| Instrument | Total Circuit Error[a] (%) | | Calibration and Verification Error[a] (%) | |
|---|---|---|---|---|
| | 1/5 Scale | 1/1 Scale | 1/5 Scale | 1/1 Scale |
| Strain gage | 5.1 | 5.1 | 26.0 | 26.0 |
| Eddy current probe | 1.3 | -- | 5.0 | -- |
| LVDT | -- | 0.6 | -- | 0 |
| Load cell | 5.0 | 5.0 | 2.0 | 2.0 |

[a] All errors represent ±3σ values.

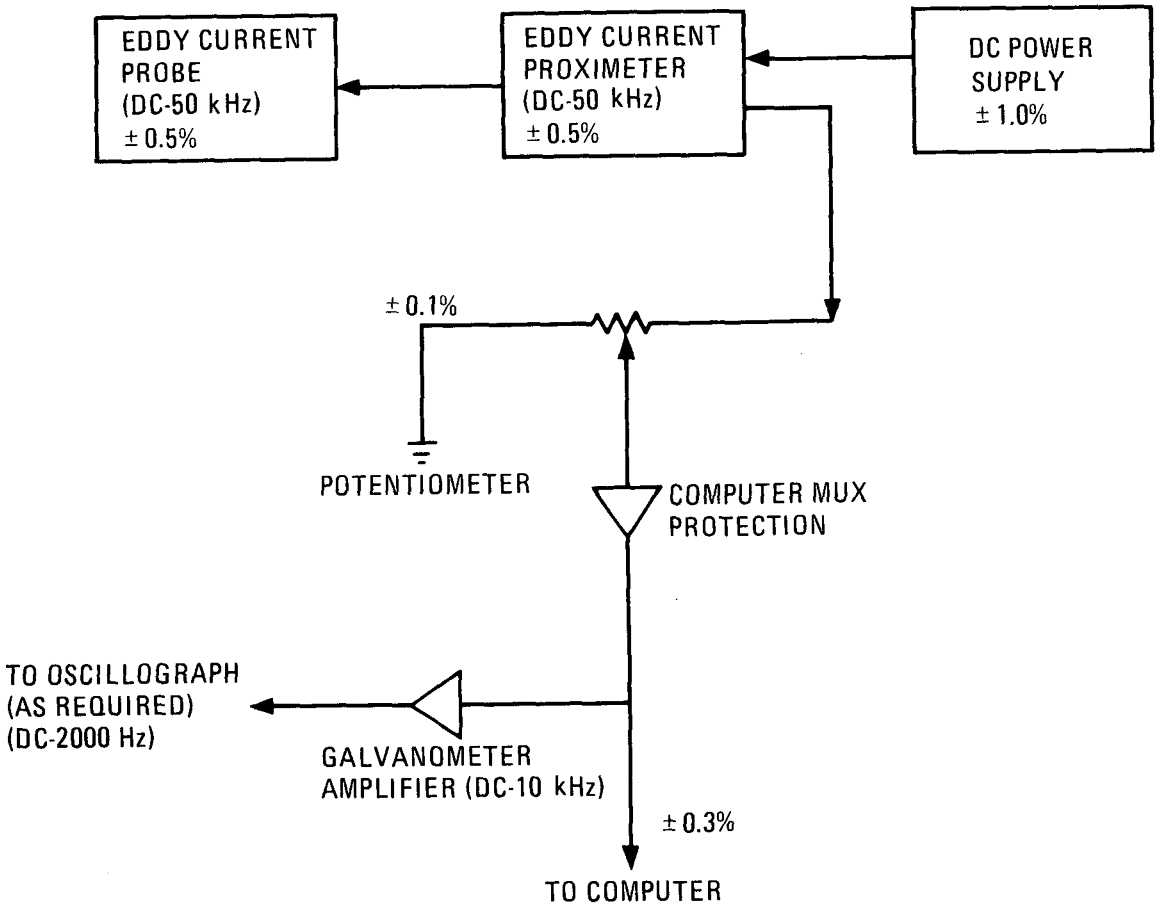


Fig. 7-1. Errors in element displacement measuring system

The LVDT calibration curves show no significant data point scatter, and the random error, therefore, is practically zero. The eddy current probe calibration curves also show very little scatter, and a typical maximum calibration error (±3σ) is estimated as 5.0% (Ref. 10).

Only static calibration curves for the strain gages were obtained in these tests. Since such calibration tests are very controlled, insignificant data scatter results. However, dynamic calibrations performed in other tests (Ref. 11) show considerable scatter equivalent to 26% on a 3σ basis.

All load washer applications produced accurate results. Since these transducers were already precalibrated by the manufacturer, a verification test was only necessary to measure the application error. This is described in Ref. 3; a maximum error of 2.0% resulted.

### 7.1.5. Extraneous Errors

Extraneous errors are somewhat ambiguous in nature. For example, a dc shift (drift) sometimes appears on the data plots. It could have originated in the bridge amplifier or it could have been caused by temperature changes in other components. In the strain gage data, this is a common occurrence, and drifts from 20% to 35% have been observed. Such systematic errors are generally compensated for test by test. Apart from drift, there is usually a random noise level associated with the output signal. This error, however, is only of the order of 1% to 2%.

## 7.2. TOTAL ERRORS

Since all the error components are not known, the total random errors in the test data cannot be obtained by compounding error components. However, some tests were repeated and a measure of the total system error can be determined. Statistically, based on N data points, the total error in the measurements is determined by the standard deviation with respect to the mean value of these data points:

$$\hat{S} = \frac{\left[\frac{1}{N}\sum_{i-1}^{N}\left(X_i - X_m\right)\right]^{1/2}}{\bar{X}_m} ,$$

where $X_i$ = ith data point,

$X_m$ = mean value at time t,

$\bar{X}_m$ = overall mean for distribution

The tests that were repeated are shown in Table 7-2. These represent 1/5- and 1/1-scale two-block and three-block tests. As seen, some tests were repeated with the blocks in the same relative position and with the same initial release angle; others had interchanged block positions but the same initial angle. The latter tests truely form the basis for evaluating the total error since variations in element properties and geometry configuration are accounted for. However, only a few tests were repeated in this manner.

Error calculations were usually based on comparisons of four consecutive peak values of rocking angle, rock-down load, and dowel shear force from two or three tests. The total errors in these data expressed to one standard deviation are given in Table 7-3. It is therefore a probability that 68.3% of the response data will contain errors within the tabulated error bounds.

The table shows that the errors in the rocking angle and frequency data are relatively small for two-block 1/5-scale and 1/1-scale tests. Such data therefore are useful to correlate analytical computer models with. One exception is the data from the 1/5-scale tests obtained for large initial release angles (20°), which were considerably affected by

## TABLE 7-2
## REPEATED TESTS EMPLOYED IN THE ERROR EVALUATION

| Test | Two-Block (Test No.) | Initial Release Angle | Three-Block (Test No.) | Initial Release Angle |
|---|---|---|---|---|
| 1/5 scale | 1, 3, 5, 7, 11 | 5° | 15, 16(a) | 8°/20° |
|  | 2, 4, 6 | 20° | 13, 17, 29 | 20°/0° |
| 1/1 scale | 1R, 6 | 5° | 12, 13(a) | 10°/6° |
|  | 2R, 7 | 15° | 8, 10 | 15°/0° |
|  |  |  | 9, 11 | 0°/10° |

(a) Repeated test with the same blocks in the same relative positions.

## TABLE 7-3
## TOTAL ERRORS[a] IN THE 1/5- AND 1/1-SCALE TEST DATA

| | 1/5 Scale (%) | | 1/1 Scale (%) | |
|---|---|---|---|---|
| Parameter | Two-Block | Three-Block | Two-Block | Three-Block |
| Frequency | 0.5 | (4.0)[b] | 0.5 | 15.3 (1.8)[b] |
| Rocking angle | 7.2 (37)[c] | -- | 3.3 | 26.0 (0.8)[b] |
| Rock-down load | 11.4 | (6.4)[b] | -- | 7.3 (1.9)[b] |
| Dowel shear force | 15.3 | 24 (8.3)[b] | -- | 25.0 (4.1)[b] |

[a] All errors are expressed as $\pm 1\sigma$ values.

[b] Repeated test with the blocks in the same relative positions.

[c] Large initial release angle (20°).

wobbling motion. The total errors in the rock-down loads and the dowel forces are somewhat higher compared to the errors in the displacement data. The two-block data, however, are considered useful data.

A marked increase in the error values, evident for three-block data, is probably due to the fact that these tests were difficult to control. These data, both 1/5 and 1/1 scale, are not recommended for use in code correlation.

It is also seen from Table 7-3 that total error values obtained from repeated tests without change in element position are much lower. This means that the error components due to variations in element geometry values are large compared to errors from other sources.

# 8. REFERENCES

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2. Olsen, B. E., General Atomic Company, "Full-Scale Rocking Test Data," unpublished data, 1977.

3.* "Test Procedure for Fuel Element Basic Rocking Test," Approved Engineering Test Laboratories Report 5430-5845, January 20, 1975.

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9. "HTGR Core Seismic Model Analysis," Energy Incorporated, December 1975.

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*General Atomic Company proprietary data.

10. Peterson, D., and B. E. Olsen, General Atomic Company, "One-Fifth and One-Half-Scale Two-Dimensional Tests," to be published.

11. Rakowski, J., General Atomic Company, "One-Fifth-Scale Dowel Force Test Final Report," to be published.

# APPENDIX

# DATA ACQUISITION AND REDUCTION

This appendix outlines the procedure used to obtain data output from the Basic Rocking Test. Software programs used in the data reduction effort are also described.

## A.1. DATA ACQUISITION

A block diagram of the data acquisition system is shown in Fig. A-1. Each transducer in the basic rocking test, load cell, strain gage, etc., converts a given dynamic reaction to a dc voltage. Calibration of the instrument establishes its range of response from zero up to ±10 volts, in terms of engineering units; load cells are calibrated in pounds. The signal from each instrument can follow two separate paths. One is to an anolog signal recorder (oscillograph), which plots voltage versus time. The other is through a multiplexer to the Varian 620/L-100 computer for conversion to a digital equivalent. The multiplexer serves to monitor all incoming instrument signals at intervals of 0.005 second. This constitutes a pass. The computer converts the data in each pass to an equivalent integer value represented as "counts." The conversion factor is always constant at 409.6 counts per volt. Since response may vary from zero to ±10 volts, the range of these integer values is zero to ±4096 counts. Response greater than 10 volts is still output at 10 volts, and the instrument is saturated.

The computer writes the digital equivalent counts on tape in the form of logical records. An end of file mark separates each test. This tape, together with a complete record of the test, the calibration factors associated with each instrument, and documented disparities between the performance of the test and the formally written procedure, constitute a "test package."

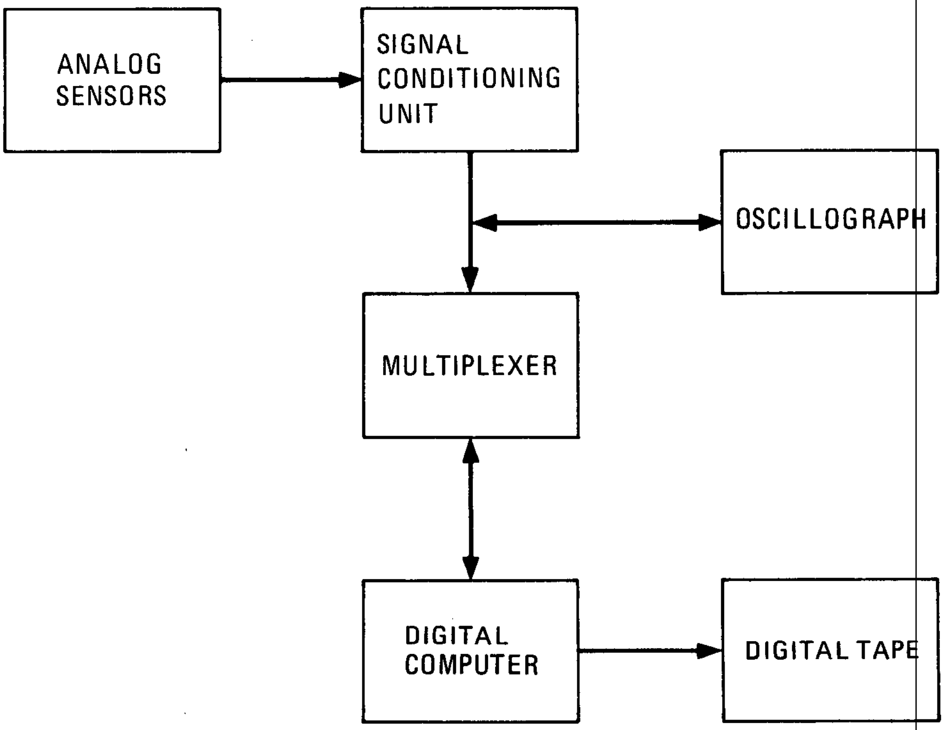

Fig. A-1. Data acquisition system

## A.2. DATA REDUCTION

The Varian computer uses nine-track tape drives. In order to make the Varian tape compatible with the Univac 1110 equipment at General Atomic Company, it is necessary to convert this nine-track tape to one with seven tracks. The seven-track tape, called the "translated" tape, contains the raw computer count data as explained above. Historically, the logical unit number associated with this tape has been nine; hence, it is referred to as Tape 9. The format of Tape 9 is as follows. Data is packed into logical records of 652 words each. The first 60 words of the first record contain information on the test number, the date it was conducted, the initial block configuration, and the rocking axis. The second 60 words of the first record contain information on the instrumentation used in the test. Thereafter, data follows in sequential fashion.

It has been customary, for the purposes of record keeping, to translate Tape 9 data to engineering units, which means taking the value in counts, multiplying by the appropriate calibration factor, and writing these values, now in pounds, inches, and seconds, to a new tape, which being historically associated with logical unit number 10 in the software routines, is called Tape 10. The format of Tape 10 shows the first two physical records to be the two 60-word records of header information explained above. Thereafter, data are broken up into physical records, each consisting of 96 consecutive multiplexer passes of data recorded in 81 channels. A minimum of 40 instrument channels are required for the basic rocking test, but 2 channels are employed for each of the 4 load cells, 12 strain gages, and 4 eddy current probes or LVDTs. These instruments are therefore recorded at half the nominal time intervals. Since the multiplexer pass is 0.005 second long, each record is 0.48 second of test time. Thus a physical record is 96 x 81 = 7776 words in length. Physical records are always separated on the magnetic tape by inter-record gaps, and individual tests are separated by end-of-file marks.

## A.3. DATA REDUCTION CODES

Data reduction codes generally operate on Tape 10, although a fundamental data dump program operates on Tape 9. The software processes are described as follows.

1. BRDUMP - a basic dump of the raw digitized data after translation of the test tape. BRDUMP unpacks the data via subroutine CONST on a word-by-word basis. For Basic Rocking Test data reduction, calibration factors were applied to the counts, and the resulting time histories were plotted via the SC4020 Datagraphics system. A listing of this program is given in Table A-1.

   Input to BRDUMP is:

   | | | |
   |---|---|---|
   | Card 1: | Title | , 12A6 |
   | Card 2: | File number of test | , 4I6 |
   | | Beginning record | |
   | | Ending record | |
   | | Number of channels to be converted | |

   Cards 3 to 6 are for each channel:

   | | | |
   |---|---|---|
   | Card 3: | Channel number | , 2I6, 6X, F12.6 |
   | | Plot option | (0 = no plot, 1 = plot) |
   | | Calibration factor | |

   Cards 4, 5, and 6 only if using the plot option

   | | | |
   |---|---|---|
   | Card 4: | Title of plot | , 10A6 |
   | Card 5: | Abscissa title | , 10A6 |
   | Card 6: | Ordinate title | , 10A6 |

2. PROBE - a subroutine of BRDUMP written to determine angular separation as measured by the eddy current probes in the 1/5-scale test. A listing is given in Table A-2.

Input to PROBE is:

Cards 1 to 6, same as for BRDUMP, except:

fifth field of card 2; number of eddy probes, I6
Card 7: Channel 1 associated with eddy probe, 4I6
Channel 2 associated with eddy probe
Number of points in separation vs. voltage table (card 9)
Plot option (0 = no plot, 1 = plot)

Card 8: Distance between center of probe and rocking edge (first channel) , 3E12.6
Distance between center of probe and rocking edge (second channel)
Initial angular displacement

There will be as many card 9s as specified on card 7:

Card 9: Calibrated displacement of channel 1 , 4F12.0
Voltage corresponding to this displacement
Calibrated displacement of channel 2
Voltage corresponding to this displacement

Cards 10, 11, and 12 only if using the plot option:

Card 10: Title of plot , 10A6
Card 11: Abscissa title , 10A6
Card 12: Ordinate title , 10A6

3. FSCOMP - a modification of BRDUMP which gives the component sum of several transducers for obtaining total rock-down load and dowel shear force. For load cells, the component sum is a summation of the magnitudes of each of the individual cells; for strain gages, it is a vector sum of on-axis and off-axis gages, as explained in Section 4.4. A listing of the changes to BRDUMP is given in Table A-3.

Input to FSCOMP:

Cards 1 and 2: same as BRDUMP

Card 3: Number of channels in component sum , 2I6
Type code (1 = load cells, 2 = strain gages)

Card 4: Channel number and
Calibration factor of each component , 6(I3,F6.3)

Card 5,6,7: Same as cards 4, 5, and 6 of BRDUMP.

## TABLE A-1
## LISTING OF BRDUMP PROGRAM

```
@FOR,SU    BRDUMP,BRDUMP,BRDUMP
FOR SE1B-02/05/76-08:57:44 (0,1)

   MAIN PROGRAM

   STORAGE USED: CODE(1) 000706; DATA(0) 064316; BLANK COMMON(2) 001774

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NTRAN
    0004   CONST
    0005   WARN
    0006   SETUP
    0007   FORMIT
    0010   GRAFIT
    0011   FINISH
    0012   EXIT
    0013   NINTR$
    0014   NRDU$
    0015   NIO3$
    0016   NIO2$
    0017   NIO1$
    0020   NPRT$
    0021   NSTOP$

   STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000   064243 1F      0001   000002 10L     0001   000367 100L    0000   064252 101F    0000   064255 102F
    0000   064261 103F    0001   000130 11L     0001   000030 121G    0001   000062 134G    0001   000447 135L
    0001   000502 140L    0001   000075 142G    0001   000103 146G    0001   000116 154G    0001   000124 160G
    0001   000521 190L    0000   064244 2F      0001   000150 200L    0001   000177 210L    0001   000322 235G
    0001   000342 241G    0001   000403 263G    0000   064245 3F      0001   000522 300L    0001   000533 323G
    0001   000561 334G    0001   000576 343G    0001   000616 352G    0000   064250 4F      0001   000543 460L
    0001   000673 500L    0001   000415 78L     0001   000527 998L    0001   000702 999L    0000 R 000404 A
    0000 R 000264 CALIB   0000 R 000524 CH      0000 I 064221 I       0000 I 064226 IDAT    0000 I 064200 IPLOT
    0000 I 064234 IT      0000 I 064222 J       0000 I 064230 JT      0000 I 064235 K       0000 I 064227 LC
    0000 I 000144 LL      0000 I 064225 LMN     0000 I 064233 MT      0002 I 000500 NARY    0002 I 000000 NARYS
    0000 I 064237 NARYT   0000 I 000024 NCH     0000 I 064224 NF      0000 I 064215 NFILE   0000 I 064216 NREC1
    0000 I 064217 NREC2   0000 I 064223 NREC21  0000 I 064220 NTOT    0000 I 064214 NW      0000 I 064236 NY
    0000 I 064240 N7      0000 I 064231 N1      0000 I 064232 N2      0000 R 064174 SIZE    0000 R 060174 T
    0000 R 000000 TITLE   0000 R 057424 TTL     0005 R 000000 WARN    0000 R 057614 XNA     0000 R 064114 XUNITS
    0000 R 064242 YMAX    0000 R 064241 YMIN    0000 R 060004 YNA     0000 R 064144 YUNITS


00100      1*     C     ********************************************************************    NEW000000
00100      2*     C                                                                             NEW000000
00100      3*     C     THIS PROGRAM UNPACKS RAW DATA AS TRANSMITTED BY THE TEST LAB            NEW000000
00100      4*     C     AND CONVERTS IT TO COUNTS VIA SUBROUTINE CONST.  CALIBRATION            NEW000000
00100      5*     C     FACTORS MAY THEN BE APPLIED TO TRANSLATE TO ENGINEERING UNITS.          NEW000000
00100      6*     C                                                                             NEW000000
00100      7*     C     ********************************************************************    NEW000000
00101      8*                                                                                      000000
00101      9*           COMMON NARYS(320),NARY(700)                                                000000
```

TABLE A-1 (continued)

```
00103                                                                              000002
00103              DIMENSION        TITLE(20),NCH(80),LL(80),CALIB(80),A(80)       000002
00104              DIMENSION CH(2000,12),TTL(10,12),XNA(10,12),YNA(10,12),T(2000), 000002
00104             .          XUNITS(2,12),YUNITS(2,12),SIZE(4),IPLOT(12)           000002
00105                                                                              000002
00105              DATA NW/652/                                                    000002
00107                                                                              000002
00107                                                                              000002
00107        C                                                                  NEW000002
00107        C     READ THE TITLE (TITLE), FILE NUMBER FOR THIS TEST (NFILE), AND   NEW000002
00107        C     THE BEGINNING AND ENDING RECORDS (NREC1,NREC2), AND NUMBER OF    NEW000002
00107        C     CHANNELS TO BE CONVERTED (NTOT)                                  NEW000002
00107        C                                                                  NEW000002
00107           10 READ (5,1,END=998) TITLE                                        000002
00112              READ (5,2) NFILE,NREC1,NREC2,NTOT                               000012
00120                                                                              000023
00120        C                                                                  NEW000023
00120        C     FOR EACH CHANNEL, READ THE CALIBRATION FACTOR, AND IF APPROPRIATE, NEW000023
00120        C     READ THE TITLE, X- AND Y-COORDINATE INFORMATION FOR USE BY THE   NEW000023
00120        C     SC4020 PLOTTING ROUTINES.  THIS LATTER DATA IS READ ONLY IF THE  NEW000023
00120        C     FLAG IPLOT IS SET TO NON-ZERO FOR THIS CHANNEL.                  NEW000023
00120        C                                                                  NEW000023
00120              DO 11 I=1,NTOT                                                  000023
00123              READ (5,3) NCH(I),IPLOT(I),CALIB(I)                             000040
00130              IF (IPLOT(I).EQ.0) GO TO 11                                     000050
00132              READ (5,4) (TTL(J,I),J=1,10)                                    000052
00140              READ (5,4) (XNA(J,I),J=1,10),(XUNITS(J,I),J=1,2)                000065
00152              READ (5,4) (YNA(J,I),J=1,10),(YUNITS(J,I),J=1,2)                000106
00164           11 CONTINUE                                                        000131
00166                                                                              000131
00166              NREC2=NREC2+1                                                   000131
00167              NF=NFILE-1                                                      000134
00167        C                                                                  NEW000134
00167        C     POSITION TAPE BY FILES                                           NEW000134
00167        C                                                                  NEW000134
00170              CALL NTRAN(9,10,8,NF)                                           000137
00171              LMN=0                                                           000145
00172              IDAT=0                                                          000146
00173                                                                              000150
00173          200 CONTINUE                                                        000150
00174                                                                              000150
00174        C                                                                  NEW000150
00174        C     READ IN A  652 WORD ARRAY OF PACKED DATA INTO THE NARY MATRIX    NEW000150
00174        C     CHECK THE TRANSMISSION STATUS: LC SHOULD BE 652.                 NEW000150
00174        C                                                                  NEW000150
00174          201 CALL NTRAN(9,2,NW,NARY,LC,22)                                   000150
00175              IF (LC.EQ.-2) GO TO 300                                         000157
00177                                                                              000163
00177              FLD(20,16,JT)=FLD(0,16,NARY(1))                                 000163
00200              N1=1                                                            000171
00201              N2=16                                                           000173
00202              NT=0                                                            000175
00203                                                                              000177
00203          210 CONTINUE                                                        000177
00204                                                                              000177
00204              NT=NT+1                                                         000177
00205              IF (NT.EQ.25) LMN=LMN+1                                         000201
```

## TABLE A-1 (continued)

```
00207    67*         IF (MT.EQ.25) GO TO 200                                                  000210
00211    68*                                                                               000216
00211    69*   C                                                                        NEW000216
00211    70*   C     SUBROUTINE CONST UNPACKS THE DATA IN THE NARY ARRAY                NEW000216
00211    71*   C                                                                        NEW000216
00211    72*         CALL CONST(N1,N2)                                                     000216
00212    73*                                                                               000223
00212    74*               IF (JT.EQ.NREC1) LMN=0                                          000223
00212    75*   C                                                                        NEW000223
00212    76*   C     JT IS A COUNTER FOR THE NUMBER OF RECORDS DUMPED                   NEW000223
00212    77*   C     MT IS A COUNTER FOR THE NUMBER OF MULTIPLEXER PASSES (MAX OF 24)   NEW000223
00212    78*   C     THE VARIABLE IT IS A FLAG WHICH IS 1 WHEN JT IS BETWEEN NREC1 AND  NEW000223
00212    79*   C     NREC2, AND IS ZERO OTHERWISE.                                      NEW000223
00212    80*   C                                                                           000230
00214    81*               IF (JT.EQ.NREC2.AND.MT.EQ.2) GO TO 10                           000244
00216    82*               IF (JT.GE.NREC1.AND.JT.LT.NREC21) IT=1                          000264
00220    83*               IF (JT.EQ.NREC21) IT=0                                          000271
00222    84*               IF (JT.EQ.NREC21) GO TO 10                                      000275
00224    85*               IF (IT.EQ.0) GO TO 78                                           000277
00226    86*                                                                            NEW000277
00226    87*   C                                                                        NEW000277
00226    88*   C     LMN IS A COUNTER FOR THE NUMBER OF PRINTED PASSES PER PAGE...      NEW000277
00226    89*   C     IT IS STRICTLY FOR OUTPUT CONTROL...IT ALLOWS 2 PASSES PER PAGE    NEW000277
00226    90*   C                                                                           000277
00226    91*         IF (LMN.EQ.2) PRINT 102, TITLE                                        000312
00232    92*         IF (LMN.EQ.2) LMN=0                                                   000322
00234    93*                                                                            NEW000322
00234    94*   C                                                                        NEW000322
00234    95*   C     THE FOLLOWING LOOP CONVERTS THE RAW DATA TO ENGINEERING UNITS,     NEW000322
00234    96*   C     AND INSERTS THEM INTO ARRAY CH, FOR PLOTTING PURPOSES.             NEW000322
00234    97*   C                                                                           000322
00234    98*         DO 100 J=1,2                                                          000326
00237    99*         IDAT=IDAT+1                                                           000331
00240   100*         DO 100 I=1,NTOT                                                       000342
00243   101*         K=NCH(I)+40*(J-1)                                                     000345
00244   102*         LL(I)=NARYS(K)                                                        000350
00245   103*         A(I)=LL(I)*CALIB(I)                                                   000355
00246   104*         IF (IPLOT(I).EQ.0) GO TO 100                                          000357
00250   105*         IF (IDAT.GT.2000) GO TO 100                                           000361
00252   106*         CH(IDAT,I)=A(I)                                                       000372
00253   107*     100 CONTINUE                                                              000372
00256   108*                                                                            NEW000372
00256   109*   C                                                                        NEW000372
00256   110*   C     PRINT RECORD NUMBER, COUNT OF PASSES, RAW DATA, AND CONVERTED DATA NEW000372
00256   111*   C                                                                           000372
00256   112*         PRINT 101, JT,MT,LL(1),(A(I),I=1,NTOT)                                000406
00267   113*         IF (WARN(15).GE.0) GO TO 998                                          000415
00271   114*                                                                               000415
00271   115*      78 CONTINUE                                                              000415
00272   116*                                                                               000415
00272   117*              IF (N2.LE.20) GO TO 140                                          000421
00274   118*              NY=36-N2                                                         000424
00275   119*              IF (NY.EQ.0) GO TO 135                                           000430
00277   120*              IF (IT.NE.0) FLD(0,NY,NARYT)=FLD(N2,NY,NARY(N1))                 000447
00301   121*     135 CONTINUE                                                              000447
00302   122*              N1=N1+1                                                          000451
00303   123*              N7=16-NY
```

## TABLE A-1 (continued)

```
00304     124*           IF (IT.NE.0) FLD(NY,NZ,NARYT)=FLD(0,NZ,NARY(N1))                 000454
00306     125*           N2=NZ                                                             000476
00307     126*           GO TO 190                                                         000500
00310     127*     140 CONTINUE                                                            000502
00311     128*           IF (IT.NE.0) FLD(0,16,NARYT)=FLD(N2,16,NARY(N1))                  000502
00313     129*           N2=N2+16                                                          000515
00314     130*     190 CONTINUE                                                            000521
00314     131*  C                                                                       NEW000521
00314     132*  C        A COMPLETE RECORD HAS BEEN TRANSLATED. RETURN TO BEGINNING OF LOOP NEW000521
00314     133*  C                                                                       NEW000521
00315     134*         GO TO 210                                                           000521
00316     135*                                                                             000522
00316     136*     300 CONTINUE                                                            000522
00317     137*         PRINT 103                                                           000522
00321     138*         GO TO 10                                                            000525
00322     139*     998 DO 450 I=1,NTOT                                                     000527
00325     140*     450 IF (IPLOT(I).GT.0) GO TO 460                                        000533
00330     141*         GO TO 999                                                           000541
00331     142*                                                                             000543
00331     143*  C                                                                       NEW000543
00331     144*  C        DO THE PLOTTING. FIRST, CALL THE SETUP ROUTINES.( SC4020 PLOTTER)  NEW000543
00331     145*  C                                                                       NEW000543
00331     146*     460 CALL SETUP(0,0,16)                                                  000543
00332     147*                                                                             000547
00332     148*  C                                                                       NEW000547
00332     149*  C        DEFINE THE TIME (ABCISSA) ARRAY (HERE CALLED T)                    NEW000547
00332     150*  C                                                                       NEW000547
00332     151*         T(1)=0.                                                             000547
00333     152*         DO 400 I=2,IDAT                                                     000561
00336     153*     400 T(I)=T(I-1)+.0025                                                   000561
00340     154*         SIZE(1)=T(1)                                                        000564
00341     155*         SIZE(2)=T(IDAT)                                                     000566
00342     156*                                                                             000576
00342     157*         DO 500 I=1,NTOT                                                     000576
00345     158*         IF(IPLOT(I).EQ.0) GO TO 500                                         000605
00347     159*         YMIN=1.E30                                                          000607
00350     160*         YMAX=-1.E30                                                         000611
00351     161*                                                                             000616
00351     162*  C                                                                       NEW000616
00351     163*  C        SELECT ORDINATE MINIMA AND MAXIMA FOR DEFINING FRAME LIMITS        NEW000616
00351     164*  C                                                                       NEW000616
00351     165*         DO 510 J=1,IDAT                                                     000616
00354     166*         YMIN=AMIN1(CH(J,I),YMIN)                                            000616
00355     167*         YMAX=AMAX1(CH(J,I),YMAX)                                            000623
00356     168*     510 CONTINUE                                                            000632
00360     169*         SIZE(3)=YMIN                                                        000632
00361     170*         SIZE(4)=YMAX                                                        000633
00362     171*                                                                             000634
00362     172*  C                                                                       NEW000634
00362     173*  C        FORMIT SETS UP THE FRAME LIMITS, SCALES THE AXES, AND WRITES THE   NEW000634
00362     174*  C        TITLE, X- AND Y- AXIS INFORMATION.  GRAFIT PLOTS THE POINTS, AND   NEW000634
00362     175*  C        DRAWS THE VECTORS BETWEEN THEM.                                    NEW000634
00362     176*  C                                                                       NEW000634
00362     177*         CALL FORMIT(SIZE,TTL(1,I),XNA(1,I),XUNITS(1,I),1,YNA(1,I),          000634
00362     178*                    YUNITS(1,I),1)                                           000634
00363     179*         CALL GRAFIT(IDAT,T(1),CH(1,I),1,16,1)                               000660
00364     180*     500 CONTINUE                                                            000677
```

## TABLE A-1 (continued)

```
00366     181*                                                                  000677
00366     182*            CALL FINISH                                           000677
00367     183*                                                                  000702
00367     184*                                                                  000702
00367     185*        999 CONTINUE                                              000702
00370     186*                                                                  000702
00370     187*          1 FORMAT (20A4)                                         000702
00371     188*          2 FORMAT (12I6)                                         000702
00372     189*          3 FORMAT (2I6,6X,E12.0)                                 000702
00373     190*          4 FORMAT (I6,9A6,2A6)                                   000702
00374     191*        101 FORMAT (I4,I4,I4,20F6.2)                              000702
00375     192*        102 FORMAT ('1',//,20X,20A4//)                            000702
00376     193*        103 FORMAT ('PROGRAM ENCOUNTERED EOF.  FILE TRANSLATION HALTED'/)  000702
00377     194*            CALL EXIT                                             000702
00400     195*            END                                                   000705

     END OF COMPILATION:        NO DIAGNOSTICS.
```

```
FOR,S     CONST,CONST
FOR SE1B-02/05/76-08:57:52 (0,)
```

## TABLE A-1 (continued) SUBROUTINE CONST

```
SUBROUTINE CONST      ENTRY POINT 000164

STORAGE USED: CODE(1) 000221; DATA(0) 000025; BLANK COMMON(2) 001774

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000150 110L      0001   000013 111G      0001   000043 30L       0001   000117 40L       0001   000133 45L
 0001   000146 50L       0000   000006 INJP$     0000 I 000002 J         0002 I 000500 NARY      0002 I 000000 NARYS
 0000 I 000003 NX        0000 I 000004 NY        0000 I 000001 N3        0000 I 000000 N7


00101       1*            SUBROUTINE  CONST(N1,N2)                                    000002
00103       2*            COMMON NARYS(320),NARY(700)                                 000002
00104       3*            DATA N7/077777777777777/                                    000002
00106       4*            DATA N3/80/                                                 000002
00110       5*            DO 100 J=1,N3                                               000002
00113       6*            NARYS(J)=0                                                  000013
00114       7*            IF(J.GT.N3)GO TO 110                                        000014
00116       8*            NX=N2+12                                                    000021
00117       9*            IF(NX.LE.36)GO TO 40                                        000024
00121      10*            NX=36-N2                                                    000030
00122      11*            IF(NX.NE.0)GO TO 30                                         000033
00124      12*            N2=0                                                        000035
00125      13*            N1=N1+1                                                     000036
00126      14*            GO TO 40                                                    000041
00127      15*         30 CONTINUE                                                    000043
00130      16*            FLD(23,NX,NARYS(J))=FLD(N2,NX,NARY(N1))                     000045
00131      17*            N2=0                                                        000061
00132      18*            N1=N1+1                                                     000062
00133      19*            NY=23+NX                                                    000066
00134      20*            NX=12-NX                                                    000071
00135      21*            FLD(NY,NX,NARYS(J))=FLD(N2,NX,NARY(N1))                     000075
00136      22*            N2=NX                                                       000113
00137      23*            GO TO 45                                                    000115
00140      24*         40 CONTINUE                                                    000117
00141      25*            FLD(23,12,NARYS(J))=FLD(N2,12,NARY(N1))                     000117
00142      26*            N2=N2+12                                                    000127
00143      27*         45 CONTINUE                                                    000133
00144      28*            IF(FLD(23,1,NARYS(J)).EQ.FLD(0,1,4))GO TO 50                000133
00146      29*            FLD(0,23,NARYS(J))=FLD(0,23,N7)                             000140
00147      30*         50 CONTINUE                                                    000150
00150      31*        100 CONTINUE                                                    000150
00152      32*        110 CONTINUE                                                    000150
00153      33*            RETURN                                                      000150
```

```
@FOR,S      BRDUMP,BRDUMP
FOR SE1B-02/06/76-14:23:46 (0,)
```

## TABLE A-2
## REVISED BRDUMP PROGRAM WITH SUBROUTINE PROBE

```
 MAIN PROGRAM

  STORAGE USED: CODE(1) 001176; DATA(0) 005432; BLANK COMMON(2) 001774

   COMMON BLOCKS:

   0003   ECP    000257
   0004   EXX    033260

  EXTERNAL REFERENCES (BLOCK, NAME)

   0005   NTRAN
   0006   CONST
   0007   WARN
   0010   PROBE
   0011   SETUP
   0012   FORMIT
   0013   GRAFIT
   0014   FINISH
   0015   EXIT
   0016   NINTR$
   0017   NRDU$
   0020   NIO3$
   0021   NIO2$
   0022   NIO1$
   0023   NPRT$
   0024   NSTOP$

  STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

   0000     005354 1F       0001     000002 10L      0001     000553 100L     0000     005363 101F     0000     005366 102F
   0000     005372 103F     0001     000133 11L      0001     000662 110L     0001     000135 12L      0001     000033 126G
   0001     000722 135L     0001     000755 140L     0001     000065 141G     0001     000100 147G     0001     000106 153G
   0001     000121 161G     0001     000127 165G     0001     000143 176G     0001     000774 190L     0000     005355 2F
   0001     000314 20L      0001     000332 200L     0001     000361 210L     0001     000213 220G     0001     000244 234G
   0001     000257 242G     0001     000265 246G     0001     000300 254G     0001     000306 260G     0000     005356 3F
   0001     000312 30L      0001     000775 300L     0001     000506 340G     0001     000526 344G     0001     000567 366G
   0001     000602 375G     0000     005361 4F       0001     000615 401G     0001     000573 411L     0001     001016 457G
   0001     001026 460L     0001     001051 471G     0000     005352 5F       0001     001066 500G     0001     001163 500L
   0001     001106 507G     0001     000670 78L      0001     001002 998L     0001     001172 999L     0000 R 000404 A
   0003 R 000255 ANGLE      0000 R 000264 CALIB     0004 R 000000 CH        0004 R 027340 CMK       0003 R 000004 D1
   0003 R 000054 D2         0000 I 005320 I         0000 I 005327 IDAT      0000 I 005347 IDMAX     0000 I 005300 IPLOT
   0000 I 005335 IT         0000 I 005321 J         0003 I 000251 JDAT      0000 I 005331 JT        0000 I 005323 K
   0003 I 000000 KECP1      0003 I 000002 KECP2     0000 I 005336 K1        0000 I 005337 K2        0000 I 005330 LC
   0000 I 000144 LL         0000 I 005326 LMN       0000 I 005340 L1        0000 I 005341 L2        0000 I 005342 M
   0000 I 005334 MT         0002 I 000500 NARY      0002 I 000000 NARYS     0000 I 005344 NARYT     0000 I 000024 NCH
   0003 I 000250 NECP       0000 I 005325 NF        0000 I 005315 NFILE     0000 I 005316 NREC1     0000 I 005317 NREC2
   0000 I 005324 NREC21     0003 I 000252 NTOT      0000 I 005346 NTOT1     0000 I 005322 NUM       0003 I 000253 NUMPTS
   0000 I 005314 NW         0000 I 005343 NY        0000 I 005345 NZ        0000 I 005332 N1        0000 I 005333 N2
   0000 R 005274 SIZE       0000 R 001274 T         0000 R 000000 TITLE     0000 R 000524 TTL       0003 R 000124 V1
   0003 R 000174 V2         0007 R 000000 WARN      0000 R 000714 XNA       0000 R 005214 XUNITS    0000 R 005351 YMAX
   0000 R 005350 YMIN       0000 R 001104 YNA       0000 R 005244 YUNITS    0003 R 000244 Z1        0003 R 000246 Z2
```

TABLE A-2 (continued)

```
00101      1*                                                                         000000
00101      2*        COMMON NARYS(320),NARY(700)                                      000000
00103      3*        COMMON/ECR/KECP1(2),KECP2(2),D1(2,20),D2(2,20),V1(2,20),V2(2,20),  NEW000002
00103      4*       *            Z1(2),Z2(2),NECP,JDAT,NTOT,NUMPTS(2),ANGLE(2)         NEW000002
00104      5*        COMMON /EXX/ CH(1000,12),CHK(1000,2)                             NEW000002
00105      6*                                                                         000002
00105      7*        DIMENSION        TITLE(20),NCH(80),LL(80),CALIB(80),A(80)        000002
00106      8*        DIMENSION           TIL(10,12),XNA(10,12),YNA(10,12),T(2000),    NEW000002
00106      9*       *        XUNITS(2,12),YUNITS(2,12),SIZE(4),IPLOT(12)              *01000002
00107     10*                                                                         000002
00107     11*        DATA NW/652/                                                     000002
00111     12*                                                                         000002
00111     13*                                                                         000002
00111     14*     10 READ (5,1,END=998) TITLE                                         000002
00114     15*        READ (5,2) NFILE,NREC1,NREC2,NTUT,NECP                           NEW000012
00123     16*        IF (NTOT.EQ.0) GO TO 12                                          NEW000024
00125     17*                                                                         *01000026
00125     18*        DO 11 I=1,NTOT                                                   000026
00130     19*        READ (5,3) NCH(I),IPLOT(I),CALIB(I)                              000043
00135     20*        IF (IPLOT(I).EQ.0) GO TO 11                                      000053
00137     21*        READ (5,4) (TIL(J,I),J=1,10)                                     000055
00145     22*        READ (5,4) (XNA(J,I),J=1,10),(XUNITS(J,I),J=1,2)                 000070
00157     23*        READ (5,4) (YNA(J,I),J=1,10),(YUNITS(J,I),J=1,2)                 000111
00171     24*     11 CONTINUE                                                         000135
00171     25*  C                                                                    NEW000135
00173     26*     12 IF (NECP.EQ.0) GO TO 20                                         NEW000135
00175     27*        DO 30 I=1,NECP                                                 NEW000136
00200     28*        J=NTOT+I                                                       NEW000146
00201     29*        READ (5,2) KECP1(I),KECP2(I),NUMPTS(I),IPLOT(J)                NEW000151
00207     30*        READ (5,5) Z1(I),Z2(I),ANGLE(I)                                NEW000163
00214     31*        ANGLE(I)=ANGLE(I)*3.141593/180.                                NEW000173
00215     32*        NUM=NUMPTS(I)                                                  NEW000177
00216     33*        READ (5,5) (D1(I,J),V1(I,J),D2(I,J),V2(I,J),J=1,NUM)           NEW000201
00227     34*      5 FORMAT (4E12.0)                                                NEW000221
00230     35*        IF (IPLOT(J).EQ.0) GO TO 30                                    NEW000221
00232     36*        READ (5,4) (TIL(K,J),K=1,10)                                   NEW000224
00240     37*        READ (5,4) (XNA(K,J),K=1,10),(XUNITS(K,J),K=1,2)               NEW000247
00252     38*        READ (5,4) (YNA(K,J),K=1,10),(YUNITS(K,J),K=1,2)               NEW000270
00264     39*     30 CONTINUE                                                       NEW000314
00266     40*     20 CONTINUE                                                       NEW000314
00267     41*                                                                         000314
00267     42*        NREC21=NREC2+1                                                   000314
00270     43*        NF=NFILE-1                                                       000316
00271     44*        CALL NTRAN(9,10,8,NF)                                            000321
00272     45*        LMN=0                                                            000327
00273     46*        IDAT=0                                                           000330
00274     47*                                                                         000332
00274     48*    200 CONTINUE                                                         000332
00275     49*                                                                         000332
00275     50*    201 CALL NTRAN(9,2,NW,NARY,LC,22)                                    000332
00276     51*        IF (LC.EQ.-2) GO TO 300                                          000341
00300     52*                                                                         000345
00300     53*        FLD(20,16,JT)=FLD(0,16,NARY(1))                                  000345
00301     54*        N1=1                                                             000353
00302     55*        N2=16                                                            000355
00303     56*        MI=0                                                             000357
```

## TABLE A-2 (continued)

```
00304     57*                                                      000361
00304     58*      210 CONTINUE                                    000361
00305     59*                                                      000361
00305     60*          MI=MI+1                                     000361
00306     61*          IF (MT.EQ.25) LMN=LMN+1                     000363
00310     62*          IF (MT.EQ.25) GO TO 200                     000372
00312     63*                                                      000376
00312     64*          CALL CONST(N1,N2)                           000376
00313     65*                                                      000402
00313     66*                IF (JT.EQ.NREC1) LMN=0                000402
00315     67*                IF (JT.EQ.NREC2.AND.MT.EQ.2) GO TO 10 000407
00317     68*                IF (JT.GE.NREC1.AND.JT.LT.NREC21) IT=1 000423
00321     69*                IF (JT.EQ.NREC21) IT=0                000443
00323     70*                IF (JT.EQ.NREC21) GO TO 10            000450
00325     71*                IF (IT.EQ.0) GO TO 78                 000454
00327     72*                                                      000456
00327     73*          IF (LMN.EQ.2) PRINT 102, TITLE              000456
00333     74*          IF (LMN.EQ.2) LMN=0                         000471
00335     75*                                                      000476
00335     76*          IF (NTOT.EQ.0) GO TO 411                 NE*000476
00337     77*          DO 100 J=1,2                                000500
00342     78*          IDAT=IDAT+1                                 000512
00343     79*          DO 100 I=1,NTOT                             000515
00346     80*          K=NCH(I)+40*(J-1)                           000520
00347     81*          LL(I)=NARYS(K)                              000531
00350     82*          A(I)=LL(I)*CALIB(I)                         000534
00351     83*          IF (IPLOT(I).EQ.0) GO TO 100                000541
00353     84*          IF (IDAT.GT.2000) GO TO 100                 000543
00355     85*          CH(IDAT,I)=A(I)                             000545
00356     86*      100 CONTINUE                                    000556
00361     87*                                                      000556
00361     88*          PRINT 101, JT,MT,LL(1),(A(I),I=1,NTOT)      000556
00372     89*      411 IF (NECP.EQ.0) GO TO 110                 NE*000573
00374     90*          DO 120 J=1,2                             NE*000574
00377     91*          JDAT=JDAT+1                              NE*000606
00400     92*          DO 120 I=1,NECP                          NE*000611
00403     93*          K1=KECP1(I)+40*(J-1)                     NE*000615
00404     94*          K2=KECP2(I)+40*(J-1)                     NE*000620
00405     95*          L1=NARYS(K1)                             NE*000625
00406     96*          L2=NARYS(K2)                             NE*000627
00407     97*          M=NTOT+2*I-1                             NE*000631
00410     98*          CH(JDAT,M)=L1                            NE*000640
00411     99*          CH(JDAT,M+1)=L2                          NE*000644
00412    100*          CHK(JDAT,1)=L1                           NE*000647
00413    101*          CHK(JDAT,2)=L2                           NE*000652
00414    102*      120 CONTINUE                                 NE*000662
00417    103*      110 CONTINUE                                 NE*000662
00420    104*          IF (WARN(15).GE.0) GO TO 998                000662
00422    105*                                                      000670
00422    106*       78 CONTINUE                                    000670
00423    107*                                                      000670
00423    108*              IF (N2.LE.20) GO TO 140                 000670
00425    109*              NY=36-N2                                000674
00426    110*              IF (NY.EQ.0) GO TO 135                  000677
00430    111*              IF (IT.NE.0) FLD(0,NY,NARYT)=FLD(N2,NY,NARY(N1))  000703
00432    112*      135 CONTINUE                                    000722
00433    113*              N1=N1+1                                 000722
```

## TABLE A-2 (continued)

```
00434    114*          NZ=16-NY                                                          000724
00435    115*          IF (IT.NE.0) FLD(NY,NZ,NARYT)=FLD(0,NZ,NARY(N1))                  000727
00437    116*          N2=NZ                                                             000751
00440    117*          GO TO 190                                                         000753
00441    118*      140 CONTINUE                                                          000755
00442    119*          IF (IT.NE.0) FLD(0,16,NARYT)=FLD(N2,16,NARY(N1))                  000755
00444    120*          N2=N2+16                                                          000770
00445    121*      190 CONTINUE                                                          000774
00446    122*          GO TO 210                                                         000774
00447    123*                                                                            000775
00447    124*      300 CONTINUE                                                          000775
00450    125*          PRINT 103                                                         000775
00452    126*          GO TO 10                                                          001000
00453    127*      998 IF (NECP.GT.0) CALL PROBE                                      NEW001002
00455    128*          NTOT1=NTOT+NECP                                                NEW001007
00456    129*          DO 450 I=1,NTOT1                                               NEW001012
00461    130*      450 IF (IPLOT(I).GT.0) GO TO 460                                   -01001016
00464    131*          GO TO 999                                                         001024
00465    132*                                                                            001026
00465    133*      460 CALL SETUP(0,0,16)                                                001026
00466    134*                                                                            001032
00466    135*          T(1)=0.                                                           001032
00467    136*          IDMAX=AMAX0(IDAT,JDAT)                                         NEW001033
00470    137*          DO 400 I=2,IDMAX                                               NEW001043
00473    138*      400 T(I)=T(I-1)+.0025                                              -01001051
00475    139*          SIZE(1)=T(1)                                                      001054
00476    140*          SIZE(2)=T(IDMAX)                                               NEW001056
00477    141*                                                                         -01001066
00477    142*          DO 500 I=1,NTOT1                                               NEW001066
00502    143*          IF(IPLOT(I).EQ.0) GO TO 500                                    -01001075
00504    144*          YMIN=1.E30                                                        001077
00505    145*          YMAX=-1.E30                                                       001101
00506    146*                                                                            001106
00506    147*          DO 510 J=1,IDMAX                                               NEW001106
00511    148*          YMIN=AMIN1(CH(J,I),YMIN)                                       -01001106
00512    149*          YMAX=AMAX1(CH(J,I),YMAX)                                          001113
00513    150*      510 CONTINUE                                                          001122
00515    151*          SIZE(3)=YMIN                                                      001122
00516    152*          SIZE(4)=YMAX                                                      001123
00517    153*                                                                            001124
00517    154*          CALL FORMIT(SIZE,TTL(1,I),XNA(1,I),XUNITS(1,I),1,YNA(1,I),        001124
00517    155*                       YUNITS(1,I),1)                                       001124
00520    156*          CALL GRAFIT(IDMAX,T(1),CH(1,I),1,16,1)                         NEW001150
00521    157*      500 CONTINUE                                                       -01001167
00523    158*                                                                            001167
00523    159*          CALL FINISH                                                       001167
00524    160*                                                                            001172
00524    161*                                                                            001172
00524    162*      999 CONTINUE                                                          001172
00525    163*                                                                            001172
00525    164*        1 FORMAT (20A4)                                                     001172
00526    165*        2 FORMAT (12I6)                                                     001172
00527    166*        3 FORMAT (2I6,6X,E12.0)                                             001172
00530    167*        4 FORMAT (I6,9A6,2A6)                                            NEW001172
00531    168*      101 FORMAT (I4,I4,I4,20F6.2)                                       -01001172
00532    169*      102 FORMAT ('1',//,20X,20A4//)                                        001172
00533    170*      103 FORMAT ('PROGRAM ENCOUNTERED EOF.  FILE TRANSLATION HALTED'/)     001172
```

TABLE A-2 (continued)

```
00534    171*          CALL EXIT                                              001172
00535    172*          END                                                    001175

      END OF COMPILATION:        NO  DIAGNOSTICS.
```

## TABLE A-2 (continued) SUBROUTINE PROBE

```
#FOR,SI      PROBE,PROBE
FOR SE1B-02/06/76-14:24:23 (,0)

   SUBROUTINE PROBE       ENTRY POINT 000640

   STORAGE USED: CODE(1) 000652; DATA(0) 004006; BLANK COMMON(2) 000000

    COMMON BLOCKS:

    0003   ECP     000257
    0004   EXX     027340

   EXTERNAL REFERENCES (BLOCK, NAME)

    0005   NERR2$
    0006   ATAN
    0007   NWDU$
    0010   NIO2$
    0011   NERR3$

   STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000017 114G     0001     000030 120G     0001     000054 131G     0001     000124 147G     0001     000140 153G
    0001     000156 160G     0001     000210 170G     0001     000244 202G     0001     000276 212G     0001     000335 225G
    0001     000435 245G     0001     000544 271G     0001     000555 275G     0001     000323 30L      0001     000571 304G
    0001     000150 31L      0001     000605 310G     0001     000236 32L      0001     000167 37L      0001     000221 39L
    0001     000255 42L      0001     000307 44L      0000     003751 51F      0001     000500 61L      0001     000510 62L
    0001     000513 63L      0001     000513 69L      0000 R 000010 A        0003 R 000255 ANGLE    0000 R 003742 ANG1
    0000 R 003743 ANG2     0004 R 000000 CH       0000 R 000004 CHMAX    0000 R 000000 CHMIN    0000 R 003732 CT
    0000 R 003744 DA       0000 R 003745 DE       0003 R 000004 D1       0003 R 000054 D2       0000 I 003736 I
    0000     003763 INJP$    0000 I 003734 J        0003 I 000251 JDAT     0000 I 003735 K        0003     000000 KECP1
    0003     000002 KECP2    0000 I 003741 L        0000 I 003746 LIM1     0003 I 000250 NECP     0000 I 003733 NECP2
    0000 I 003740 NPT      0003 I 000252 NTOT     0000 I 003737 NUM      0003 I 000253 NUMPTS   0000 R 003730 S
    0003 R 000124 V1       0003 R 000174 V2       0000 R 003747 Z        0000 R 003750 ZC       0003 R 000244 Z1
    0003 R 000246 Z2


 00101        1*               SUBROUTINE PROBE                                                          000010
 00103        2*               COMMON/ECP/KECP1(2),KECP2(2),D1(2,20),D2(2,20),V1(2,20),V2(2,20),         000010
 00103        3*              *            Z1(2),Z2(2),NECP,JDAT,NTOT,NUMPTS(2),ANGLE(2)                 000010
 00104        4*               COMMON /EXX/ CH(1000,12)                                                  000010
 00105        5*               DIMENSION CHMIN(4),CHMAX(4),A(1000,2),S(2)                                000010
 00106        6*               DATA CT/409.6/                                                            000010
 00110        7*               DATA CHMIN/4*1.E10/                                                       000010
 00112        8*               NECP2=2*NECP                                                              000010
 00113        9*               DO 10 J=1,NECP2                                                           000013
 00115       10*               K=NTOT+J                                                                  000017
 00117       11*               DO 10 I=1,JDAT                                                            000022
 00122       12*               CH(I,K)=ABS(CH(I,K))/CT                                                   000030
 00123       13*               CHMIN(J)=AMIN1(CHMIN(J),CH(I,K))                                          000032
 00124       14*               CHMAX(J)=AMAX1(CHMAX(J),CH(I,K))                                          000037
```

TABLE A-2 (continued)

```
00125      15*      10 CONTINUE                                                            000054
00130      16*         DO 20 J=1,NECP                                                      000054
00133      17*         IF (CHMIN(J).LT.V1(J,1)) V1(J,1)=CHMIN(J)                           000054
00135      18*         IF (CHMIN(J+1).LT.V2(J,1)) V2(J,1)=CHMIN(J+1)                       000063
00137      19*         NUM=NUMPTS(J)                                                       000072
00140      20*         IF (CHMAX(J).GT.V1(J,NUM))V1(J,NUM)=CHMAX(J)                        000077
00142      21*         IF(CHMAX(J+1).GT.V2(J,NUM))V2(J,NUM)=CHMAX(J+1)                     000107
00144      22*      20 CONTINUE                                                            000124
00146      23*         DO 30 J=1,NECP                                                      000124
00151      24*         K=NTOT+2*J-1                                                        000124
00152      25*         DO 30 I=1,JDAT                                                      000131
00155      26*         GO TO (31,32),J                                                     000140
00156      27*      31 NPT=NUMPTS(J)                                                       000150
00157      28*         DO 36 L=2,NPT                                                       000151
00162      29*         IF (CH(I,K).LE.V1(1,L)) GO TO 37                                    000156
00164      30*      36 CONTINUE                                                            000167
00166      31*      37 CH(I,K)=D1(1,L)-(D1(1,L)-D1(1,L-1))*(V1(1,L)-CH(I,K))               000167
00166      32*        ./(V1(1,L)-V1(1,L-1))                                                000167
00167      33*         DO 38 L=2,NPT                                                       000202
00172      34*         IF (CH(I,K+1).LE.V2(1,L)) GO TO 39                                  000210
00174      35*      38 CONTINUE                                                            000221
00176      36*      39 CH(I,K+1)=D2(1,L)-(D2(1,L)-D2(1,L-1))*(V2(1,L)-CH(I,K+1))           000221
00176      37*        ./(V2(1,L)-V2(1,L-1))                                                000221
00177      38*         GO TO 30                                                            000234
00200      39*      32 NPT=NUMPTS(J)                                                       000236
00201      40*         DO 41 L=2,NPT                                                       000237
00204      41*         IF (CH(I,K).LE.V1(2,L)) GO TO 42                                    000244
00206      42*      41 CONTINUE                                                            000255
00210      43*      42 CH(I,K)=D1(2,L)-(D1(2,L)-D1(2,L-1))*(V1(2,L)-CH(I,K))               000255
00210      44*        ./(V1(2,L)-V1(2,L-1))                                                000255
00211      45*         DO 43 L=2,NPT                                                       000270
00214      46*         IF (CH(I,K+1).LE.V2(2,L)) GO TO 44                                  000276
00216      47*      43 CONTINUE                                                            000307
00220      48*      44 CH(I,K+1)=D2(2,L)-(D2(2,L)-D2(2,L-1))*(V2(2,L)-CH(I,K+1))           000307
00220      49*        ./(V2(2,L)-V2(2,L-1))                                                000307
00221      50*      30 CONTINUE                                                            000335
00224      51*         DO 60 I=1,NECP                                                      000335
00227      52*         K=NTOT+2*I-1                                                        000340
00230      53*         ANG1=ATAN(CH(1,K)/Z1(I))                                            000346
00231      54*         ANG2=ATAN(CH(1,K+1)/Z2(I))                                          000356
00232      55*         DA=ABS(ANG1-ANGLE(I))                                               000366
00233      56*         DB=ABS(ANG2-ANGLE(I))                                               000372
00234      57*         LIM1=K                                                              000375
00235      58*         IF (DB.LT.DA) LIM1=K+1                                              000377
00237      59*         Z=Z1(I)                                                             000407
00240      60*         IF (DB.LT.DA) Z=Z2(I)                                               000415
00242      61*         ZC=Z                                                                000424
00243      62*         S(I)=1                                                              000426
00244      63*         DO 60 J=1,JDAT                                                      000435
00247      64*         IF (J.EQ.1.OR.J.EQ.JDAT) GO TO 69                                   000435
00251      65*         IF (CH(J-1,LIM1).GT.CH(J,LIM1).AND.CH(J+1,LIM1).GT.CH(J,LIM1)       000451
00251      66*        *.AND.CH(J,LIM1).LT..1*ANGLE(I)) GO TO 61                            000451
00253      67*         GO TO 69                                                            000476
00254      68*      61 S(I)=-S(I)                                                          000500
00255      69*         IF (Z-ZC) 65,62,65                                                  000501
00260      70*      65 Z=ZC                                                                000504
00261      71*         GO TO 63                                                            000506
```

## TABLE A-2 (continued)

```
00262     72*     62 Z=2.69*ZC                                     000510
00263     73*     63 CONTINUE                                      000513
00264     74*     69 A(J,I)=S(I)*ATAN(CH(J,LIM1)/Z)                000513
00265     75*     60 CONTINUE                                      000532
00270     76*        DO 70 I=1,NECP                                000532
00273     77*        K=NTOT+I                                      000544
00274     78*        DO 70 J=1,JDAT                                000547
00277     79*        CH(J,K)=A(J,I)*180./3.141593                  000555
00300     80*     70 CONTINUE                                      000571
00303     81*        DO 50 J=1,NECP                                000571
00306     82*        K=NTOT+2*J-1                                  000571
00307     83*        DO 50 I=1,JDAT                                000576
00312     84*        WRITE (6,51) I,CH(I,K)                        000605
00316     85*     50 CONTINUE                                      000620
00321     86*     51 FORMAT (I12, F15.6)                           000620
00322     87*        RETURN                                        000620
00323     88*        END                                           000651

     END OF COMPILATION:          NO  DIAGNOSTICS.
```

# TABLE A-3
# FSCOMP PROGRAM (MODIFIED BRDUMP)

```
@DATA,IL      PVN*FSCOMP.
DATA 7 GAC RL70-5 01/23-10:11:00
        @PLTREG,B
        @ASG,T      9,U,1732
        @ASG,AX       PVN*BRDUMP
        @COPY       PVN*BRDUMP.,TPFS.
        @FREE       PVN*BRDUMP.
        @FOR,S        BRDUMP,BRDUMP,BRDUMP
        -4,4
              DIMENSION TITLE(20),NCH(4,80),LL(80),CALIB(4,80),ISUM(6),B(6,6)
              DIMENSION A(80), ICODE(6)
        -15,16
        C     *****LOAD CELL CODE=1
        C     *****STRAIN GAGE CODE=2
              READ (5,2) ISUM(I),ICODE(I)
              ISM=ISUM(I)
              READ (5,5) (NCH(I,J),CALIB(I,J),J=1,ISM)
            5 FORMAT (6(I3,F9.0))
              IPLOT(I)=1
        -59,61
              A(I)=0.
              ISM=ISUM(I)
              ICOD=ICODE(I)
              GO TO (800,900), ICOD
          800 DO 810 JJ=1,ISM
              K=NCH(I,JJ)+40*(J-1)
              LL(I)=NARYS(K)
              A(I)=LL(I)*CALIB(I,JJ)+A(I)
          810 CONTINUE
              GO TO 850
          900 DO 910 JJ=1,ISM
              K=NCH(I,JJ)+40*(J-1)
              LL(I)=NARY3(K)
              B(I,JJ)=LL(I)*CALIB(I,JJ)
          910 CONTINUE
              A(I)=SQRT(B(I,1)**2+B(I,2)**2)+SQRT(B(I,3)**2+B(I,4)**2)+
             ,SQRT(B(I,5)**2+B(I,6)**2)
          850 CONTINUE
        @MAP
        LIB     CSD*PLOT
        @XQT
END DATA.

@FIN                                                                    CR
```

GENERAL ATOMIC COMPANY
P. O. BOX 81608
SAN DIEGO, CALIFORNIA 92138