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The John A. Blume Earthquake Engineering Center

Department of Civil Engineering

Stanford University

FACILITIES MANUAL

Prepared by

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and

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Earthquake Engineering Center

Department of Civil Engineering

Stanford University

Stanford, California 94305

March 1978

The John A. Blume Earthquake Engineering Center was established to promote research and education in earthquake engineering. Through its activities our understanding of earthquakes and their effects on mankind's facilities and structures is improving. The Center conducts research, provides instruction, publishes reports and articles, conducts seminars and conferences, and provides financial support for students. The Center is named for Dr. John A. Blume, a well-known consulting engineer and Stanford alumnus.

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The central computer system located in the Data Processing Laboratory of the John A. Blume Earthquake Engineering Center can perform the following functions: (1) Digitization of strong motion accelerograms obtained either from earthquakes or from tests of buildings can be performed. The accelerographs are traced on the digitizing table, which automatically records X and Y coordinates of points on the accelerograms. The coordinates are sent to the main computer, where the earthquake record is analyzed. (2) The computer controls the operation of the dynamic testing equipment and the shake table. The shake table can be vibrated to simulate any past earthquake or postulated future earthquake. (3) Measurements obtained dynamically from experiments run on the shake table or on the dynamic testing equipment are converted automatically from analog to digital form. The data is stored on disk or magnetic tape for further analysis. Signal generation and data acquisition can operate simultaneously. (4) The computer combined with the disk and magnetic tape allows for large programming capabilities. Earthquake records are analyzed routinely by programs which compute response spectra, RMS values, and response time histories. Static and dynamic structural analyses also can be performed. Test data or calculated results can be displayed graphically on a Calcomp plotter, a Tektronix graphics terminal, or a hard copy unit.

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Earthquakes	Digital techniques	Dyanmic structural analysis
		Computer programming

b. Identifiers/Open-Ended Terms

Shake table
Dynamic testing equipment

c. COSATI Field/Group

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(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

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Abstract to the Data Processing Laboratory

The processing of data for The John A. Blume Earthquake Engineering Center is carried out in the Data Processing Laboratory. The central computer system located in this lab can perform the following functions:

1. Digitization

   Digitization of strong motion accelerograms obtained either from earthquakes or from tests of buildings can be performed. The accelerograms are traced on the digitizing table, which automatically records x and y coordinates of points on the accelerograms. The coordinates are sent to the main computer, where the earthquake record is analyzed.

2. Signal Generation

   The computer controls the operation of the dynamic testing equipment and the shake table. The shake table can be vibrated to simulate any past earthquake or postulated future earthquake.

3. Data Acquisition

   Measurements obtained dynamically from experiments run on the shake table or on the dynamic testing equipment are converted automatically from analog to digital form. The data is stored on disk or magnetic tape for further analysis. Signal generation and data acquisition can operate simultaneously.

4. Data Analysis

   The computer combined with the disk and magnetic tape allows for large programming capabilities. Earthquake records are analyzed routinely by programs which compute response spectra, RMS values, and response time histories. Static and dynamic structural analyses also can be performed.

5. Plotting and Graphic Capabilities

   Test data or calculated results can be displayed graphically on a Calcomp plotter, a Tektronix graphics terminal, or a hard copy unit.

SECTION I. DIGITIZING SYSTEM

Introduction

This report is intended as an introduction to the earthquake ditizing system available at the John A. Blume Earthquake Engineering Center. The digitizing program at the Blume Center is utilized by the Engineering Branch of the U.S. Geological Survey as a part of their continuing effort to make available accurate digitized data for all recorded strong-motion earthquakes.

The digitizing system is an independent subsystem of the computer facility at the Blume Center. It entails specialized electronics hardware, a small programmable calculator with cassette storage capability and software developed for the digitizing of strong motion records. It is hoped that this report will provide an insight into the digitizing system at the Blume Center.

Digitizing System: An Overview

The digitization of strong-motion recordings requires specialized electronics hardware and computer software necessary for data acquisition and processing. Figure I gives an overview of the computation facility at the Blume Center, of which one of the parts is the digitizing subsystem. This system is an independent entity, operating free of the main system, but hardwired to the main computer for data transfer where the record is processed and plotted.

The digitizing subsystem consists of four main components: the programmable calculator, digitizer, digitizing table, and the cursor or transmitter connected to the table. The concept of digitization is

March 1978

JOHN A. BLUME EARTHQUAKE ENGINEERING CENTER

COMPUTATION FACILITIES

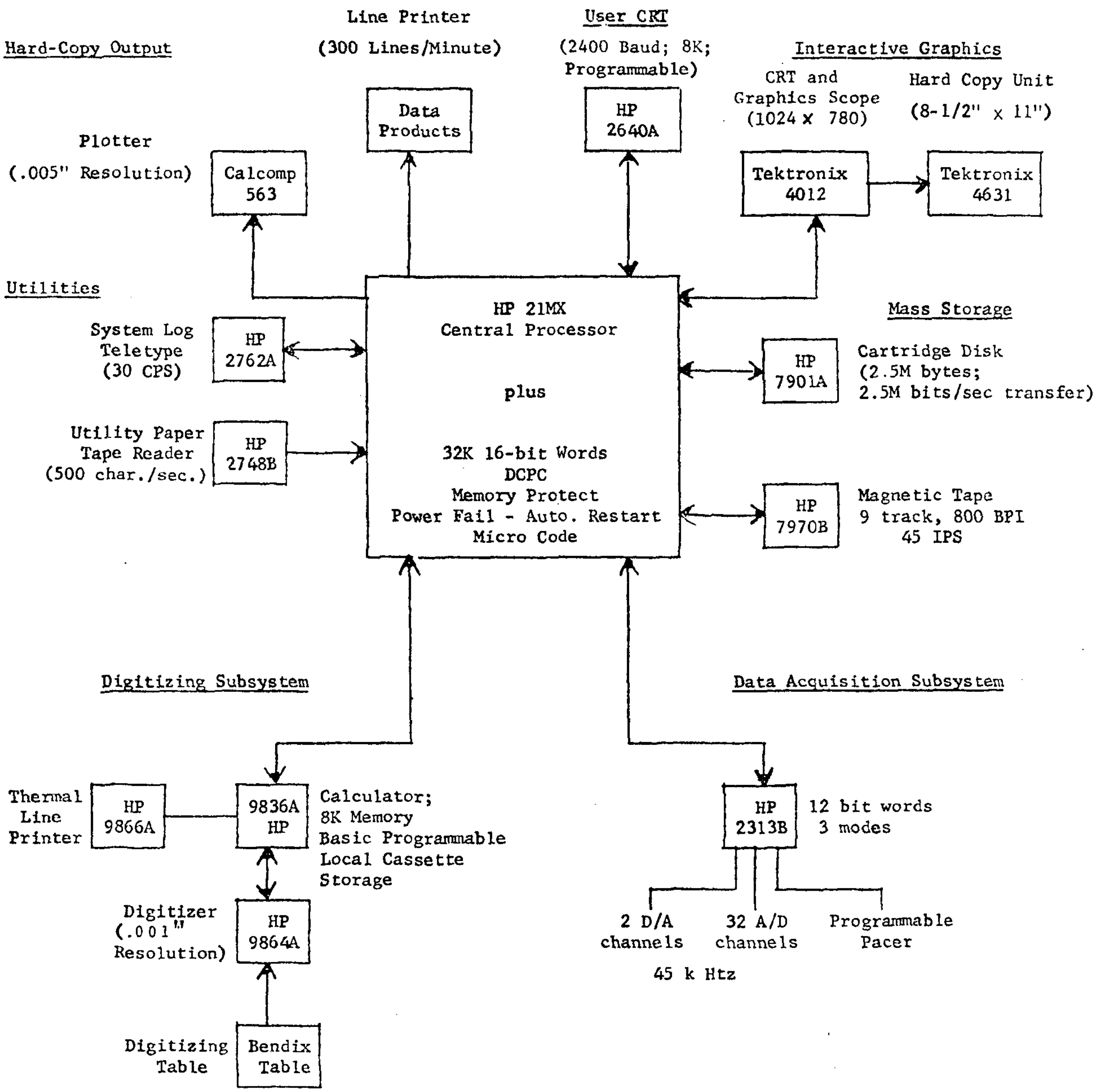


Figure 1

basically a simple one. The cursor is an electro-magnetic transmitter that produces signals received by the digitizing table, which in turn relays the signal to the digitizer. The digitizer converts the information into coordinates describing the position of the cursor's cross hairs (see Figure 2). These coordinates are determined, relative to an origin set by the user. The calculator which has been programmed to receive the coordinates evaluates the data and stores the results on cassettes for future use.

When the ground motion record has been completed, the data is transferred from cassette to the main computer for further processing. The analysis of data on the main computer provides greater versatility in terms of available memory, 32K; storage options, disc or magnetic tape; graphic displays, CRT graphics terminal or Calcomp plots; hardcopy availability, line printer or graphics terminal hard copy unit.

System Hardware

As was mentioned previously, there are four main hardware components which make up the digitizing system. These are a programmable calculator, digitizer, digitizing table and cursor. Each component will be described briefly in terms of its functions and capabilities.

The calculator or buffer computer is a Hewlett-Packard 9830A (HP9830A) with 8K memory and local cassette storage. The calculator is programmable in BASIC, thus making the system self-containing in terms of storage and computations capabilities. For the digitizing of strong-motion records the calculator is programmed to direct the user through the digitizing process, with the use of a 32-character display. The calculator is hardwired to the central computer where the data is later transferred for processing.

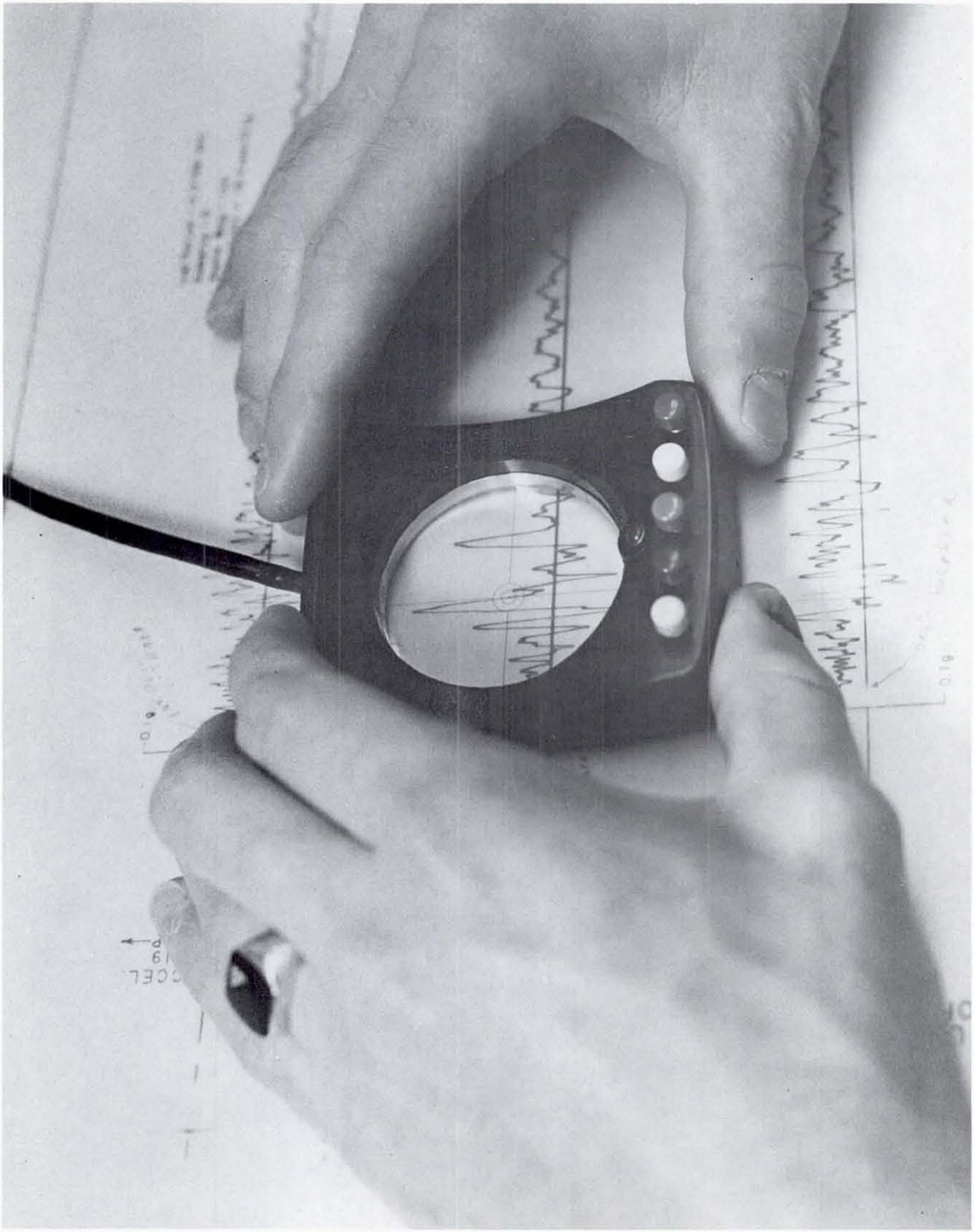


Figure 2

The digitizer, digitizing table and cursor represent the heart of the digitizing system. The digitizer is a Hewlett-Packard 9864A which has a resolution to the nearest 0.001 inches, and a maximum sampling rate of approximately 50 points per second. The digitizing surface is a 40 by 60 inch table which operates as a receiver of transmissions sent by the cursor. The cursor, through the use of four buttons, sends various signals received by the table and interpreted by the digitizer. These buttons correspond to specific operations performed by the digitizer. In particular, the setting of the origin, discrete point entry, continuous point entry and a hold feature which keeps the digitizer active but allows the user to remove the cursor from the table which would lose the origin if the hold feature was not activated.

The digitizer operates in conjunction with the calculator as a data entry device. The data input to the calculator is similar to a computer program requesting data from a deck of cards. The data is not read until the program makes a specific data request. Such a condition makes programming and interaction with the digitizer no problem.

The following is a complete list of the hardware employed at the Blume Center used specifically in the digitizing system.

HARDWARE LISTING

1. Hewlett-Packard 9830A Calculator
2. Hewlett-Packard 9866A Printer
3. Hewlett-Packard 9864A Digitizer
4. Hewlett-Packard 9162-0050 Digital Cassette
5. Hewlett-Packard Matrix Operations ROM, Option 270
6. Hewlett-Packard String Variables ROM, Option 274
7. Hewlett-Packard Calculator 11202A I/O Interface
8. Bendex 40" × 60" Digitizing Table and Cursor

The time histories on the following pages are:

i. an original ground acceleration recording.

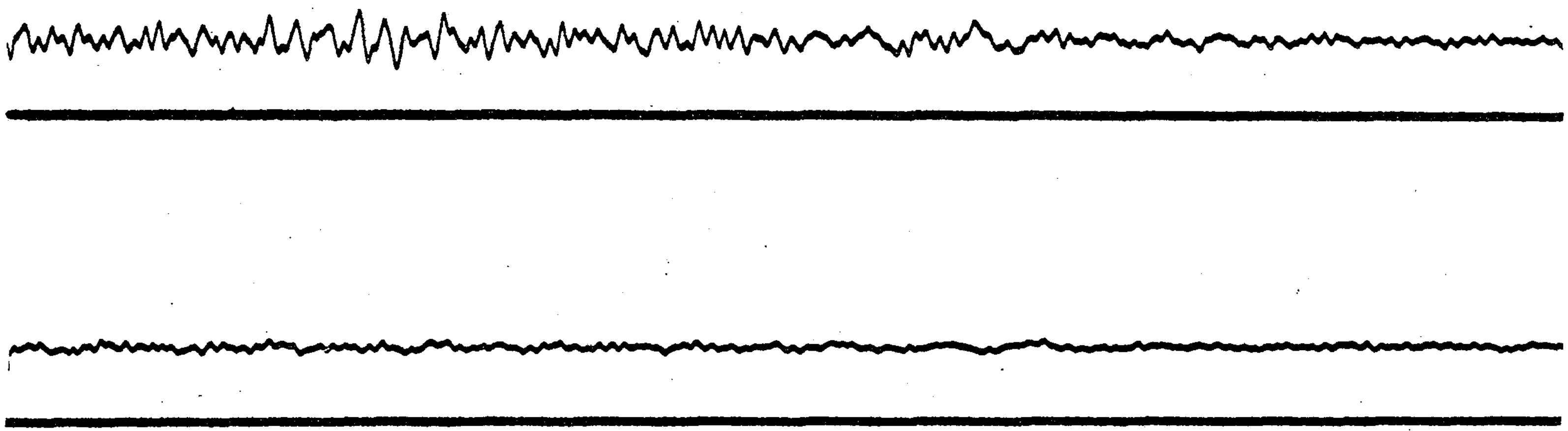
ii. a hardcopy of a tektronix plot of the digitized record approximately to scale.

iii. a five times blow up of the digitized record, useful for visual verification of two trials of the same record.

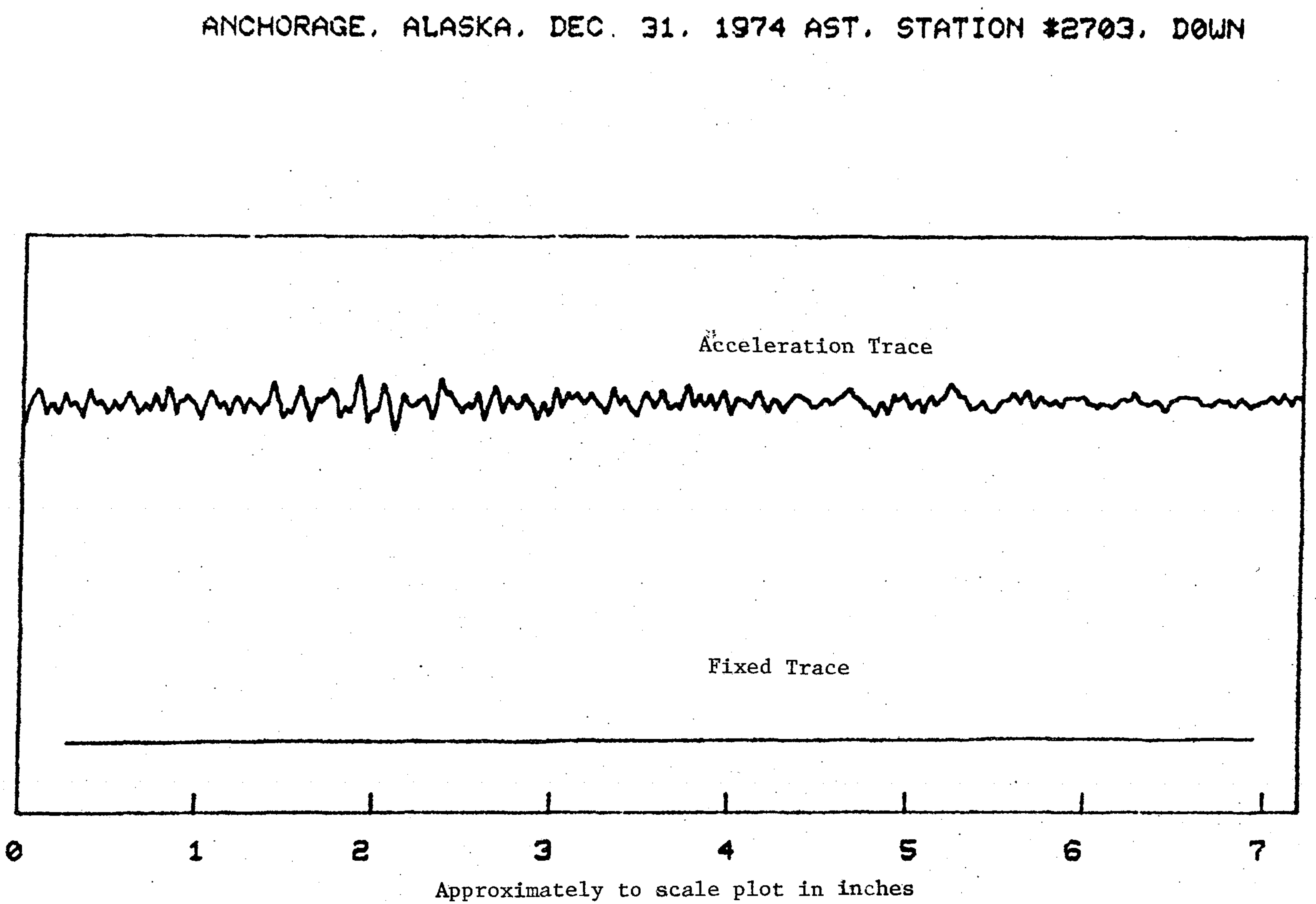
iv. a Calcomp plot of the digitized record.

U.S. STRONG-MOTION NETWORK
STATION NO. 2703 61019N 149.89W
ANCHORAGE, THIRD AND GAMBEL (GOVT. HOSP.)
AR-240, NO. 127 BASEMENT
EARTHQUAKE OF 31 DECEMBER 1974, 1755 AST
1 JANUARY 1975, 0355 GMT

Down Sens. = 7.60 cm/g
Per. = .051 sec
Damp. = 0.59 crit

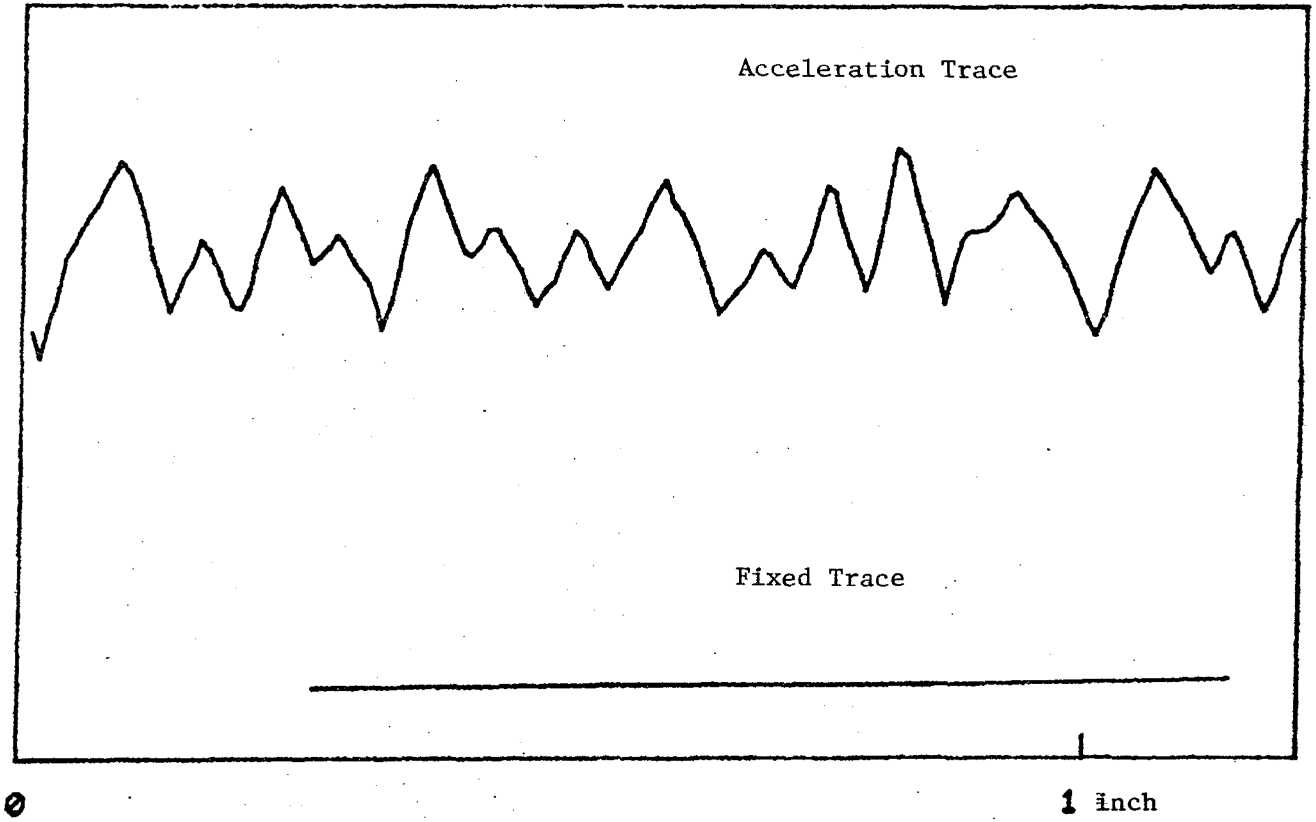


ORIGINAL GROUND ACCELERATION RECORDING



TEKTRONIX PLOT

ANCHORAGE, ALASKA, DEC. 31, 1974 AST, STATION #2703, DOWN

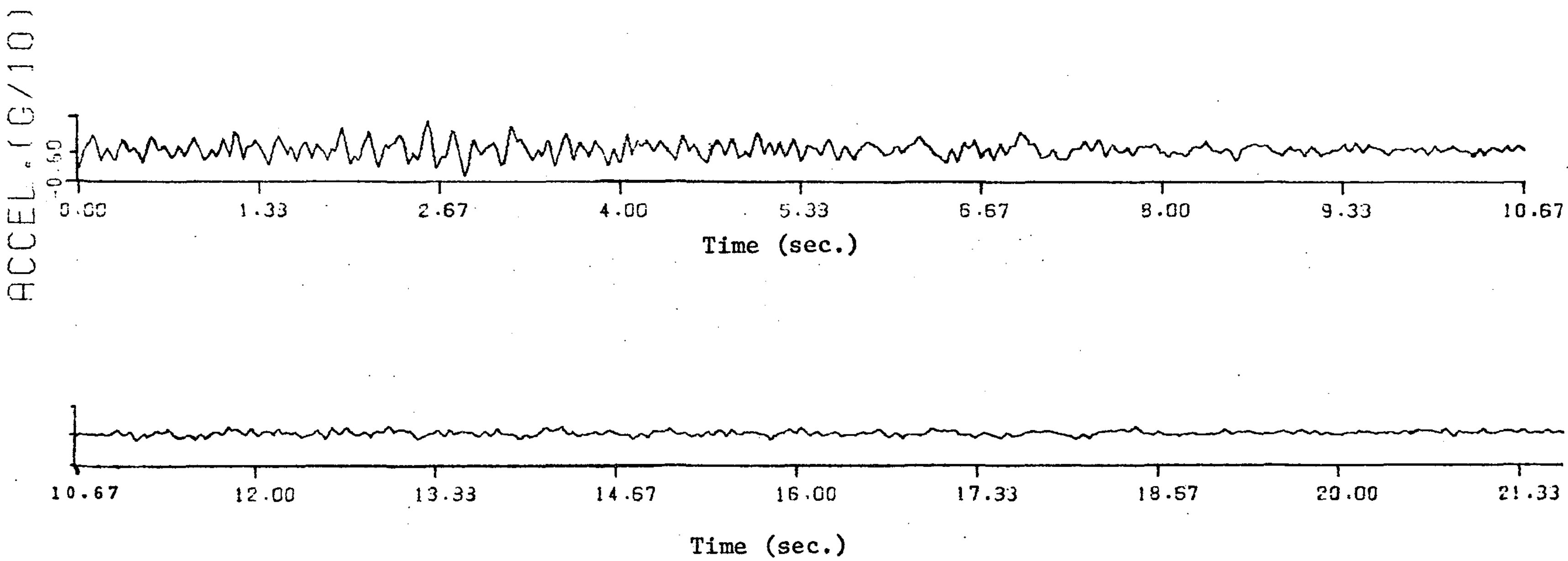


5X

5× the Original Scale

TEKTRONIX PLOT

Anchorage, Alaska Earthquake
31 December, 1974   1755 AST
Station No. 2703
Vertical



CALCOMP Plot of Digitized Record

The form on the following page is used by the operator during the digitizing process. The user provides information regarding the quality of the record for digitizing, instrument parameters which are not available on the record and any other information which he feels pertinent.

BLUME CENTER EARTHQUAKE DIGITIZATION		
name:	date:	project:

Code Number	Type of Trace	Comments: Label, Transformation Points I.D. Parameters, Sampling Procedure

SECTION II. SHAKE TABLE, DATA ACQUISITION AND SIGNAL GENERATION

Introduction

A schematic of the Earthquake Simulator and Data Collection System is shown in Figure 1. This system is used primarily for the dynamic testing of small components and scale models of full-scale structures subjected to unilateral vibrations. Not shown is a cyclic material testing apparatus which is used to determine specimen material properties and to test small-scale structural components, such as beam-column subassemblages, under cyclic loading conditions.

Following is a brief overview of this system with emphasis on the shake table and data acquisition system.

Shake Table

The shake table is used for dynamic testing by the application of unilateral vibrations. A vibration time history is input to the shake table as an analog voltage signal and is interpreted as either a displacement, velocity or acceleration command. Since the shake table is actually displacement controlled, appropriate circuits are activated to perform analog integration, if necessary, to produce the required displacement control signal.

The shake table measures 5 ft × 5 ft and is hydraulically driven under closed-loop servo control to a maximum force capacity of 11,000 lbs. Limits on displacement, velocity and acceleration are ± 2.5 in., 24 in./sec and 5 g respectively for the unloaded table. Tests have been performed to verify the shake table performance spectrum, as shown in Figure 2. Any additional mass added to the 2000 lb table weight will decrease the acceleration limit proportionally. Frequencies can be

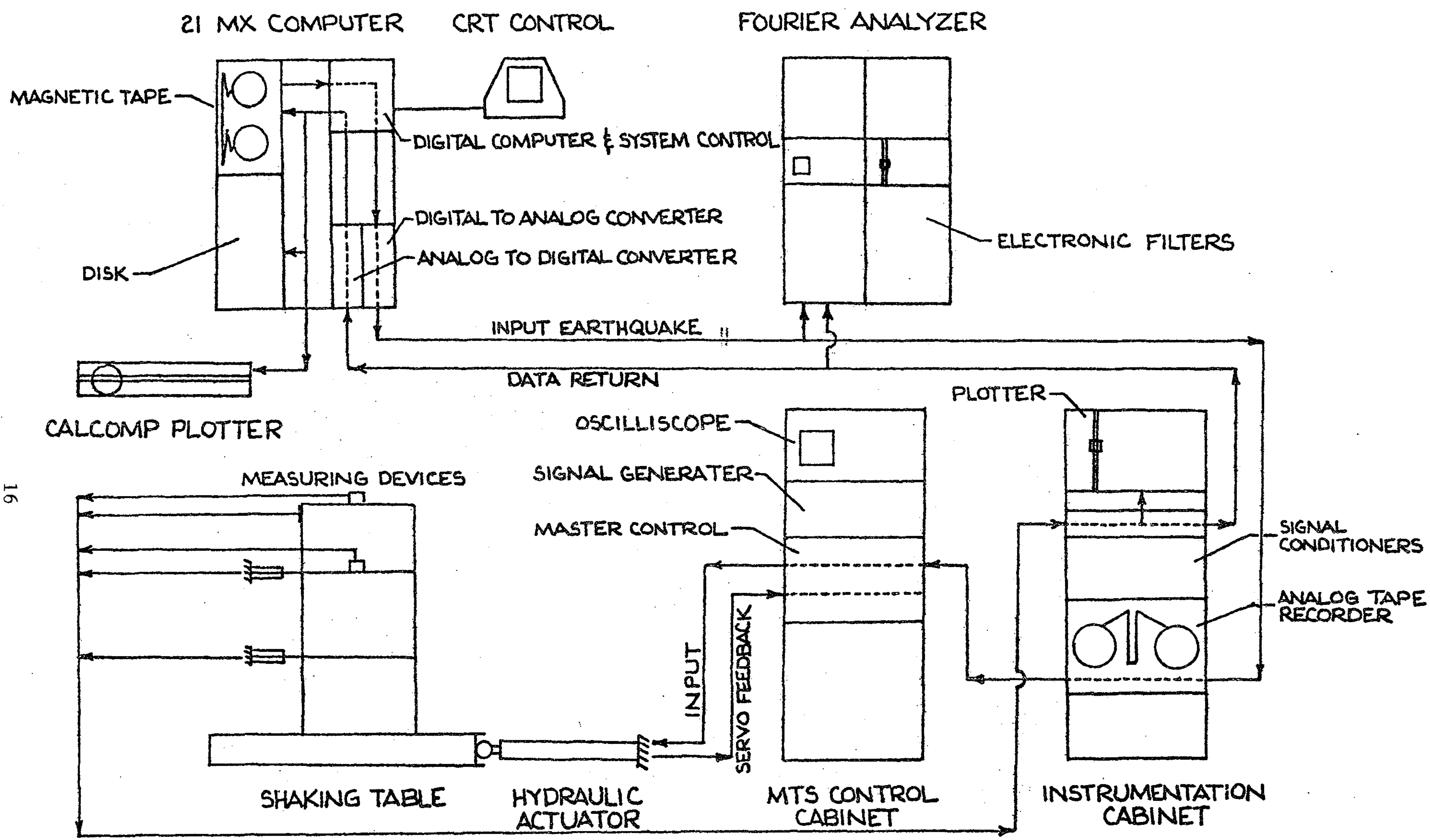


Fig. 1. Earthquake Simulator and Data Collection System

reproduced from virtually 0 Hz (D.C.) to approximately 70 Hz, where resonance occurs in the hydraulic lines. The table is supported on rails capable of sustaining vertical payloads up to 4000 lbs enabling testing of relatively heavy structures, such as those encountered in soil-structure interaction studies.

The possible types of motion available for input to the shake table fall into two basic categories: wave forms from analog signal generators and digitized time history records.

Signal generators are available in the laboratory to generate a variety of input motions including sinusoidal wave forms and white noise. Virtually any analog signal generator can be interfaced directly with the shake table input control.

Digitized time history records can be used to drive the shake table when processed by the in-house Hewlett-Packard 21 MX computer system. A computer program is available to utilize the digital to analog conversion capabilities of the computer to produce the desired control signal. This program could be modified to accept any digitized record, for instance a postulated future earthquake, but was written primarily for reproduction of digitized time histories of actual past earthquakes available on magnetic tape. Though the program is capable of producing either displacement or acceleration time histories, displacement records give better shake table control. The generated earthquake time history can be input directly to the shake table or stored on an analog tape recorder for later experimental studies.

Tests of shake table performance were made using these actual earthquake time histories, with various displacement and time scaling factors as required by model tests. The displacement time history from the El Centro record of the Imperial Valley, 1940 earthquake was input to the

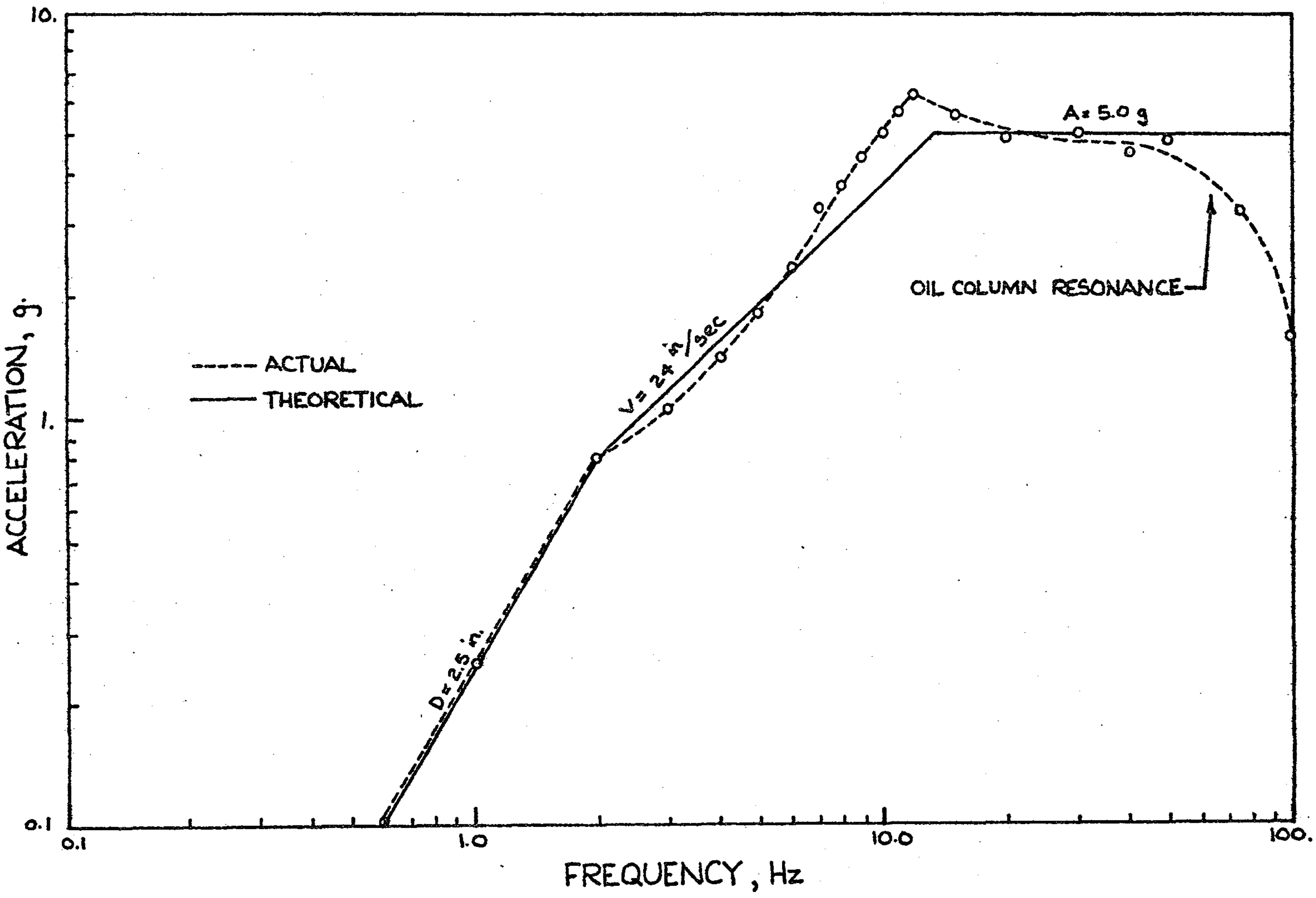


Fig. 2. Shake Table Performance Spectrum

shake table, producing the acceleration response shown in Figure 3. The response was then compared to the original acceleration time history in both the time and frequency domains. It can be seen that the table response agrees favorably with the original record, especially in the lower frequency range where most of the energy is released.

Data Acquisition

Data acquisition is performed through the analog to digital conversion capabilities of the Hewlett-Packard 21 MX computer system. A computer program is available to perform the sampling and digital conversion of up to 32 data channels. The data channels consist of a block of electronic transducers such as accelerometers, LVDT's (displacement transducers), load cells, strain gages and potentiometers. Data channels are sampled in a sequential block scan, from channel number one to the end channel, at discrete intervals of time. In a single block scan the computer samples the voltages of each successive channel at a rate of 45,000 reads per second. These block scans are then performed at equal steps in time with a minimum allowable pace period of approximately 500 microseconds between scans.

These voltage samples are interpreted by the computer as 16-bit integer words within a maximum voltage range of ±10.235 volts at a resolution of 0.005 volts, and are stored in core memory as the test progresses. However, since core memory is limited to about 10,000 integer values auxiliary storage must be utilized. A class input/output statement is used to transfer data from memory to magnetic tape with interruption in data acquisition minimized to approximately 0.05 sec, permitting the storage of virtually unlimited experimental data.

The computer system also has the capacity to perform simultaneous data acquisition and signal generation for control of testing apparatus,

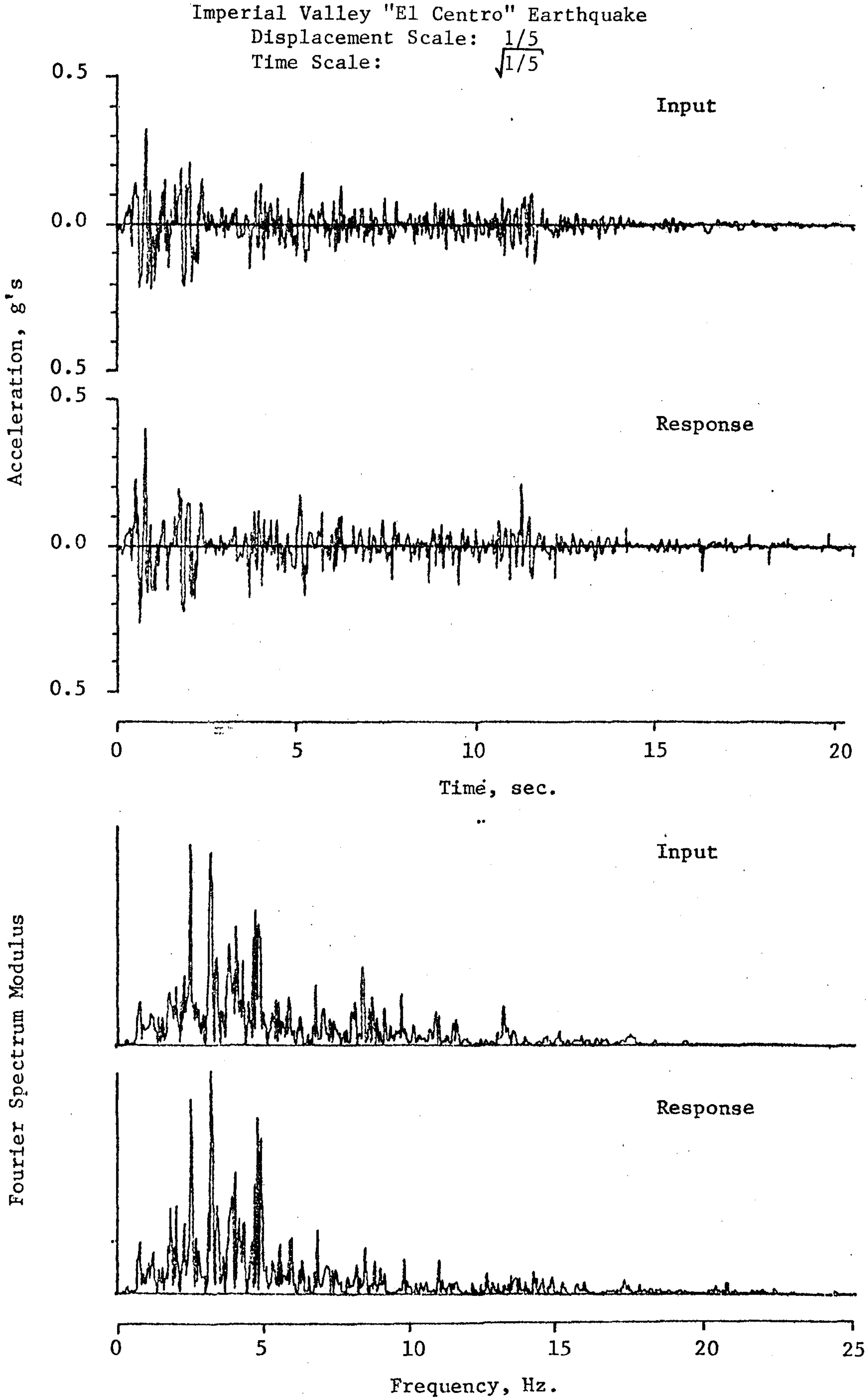


Fig. 3. Reproduction of Earthquake Records

such as the shake table. However, the computer sampling efficiency will be considerably reduced.

A second computer program is used to sort and convert each sequential block of raw data. Each 16-bit integer word is converted to the actual physical measurement, sorted by channel to construct a time history of response, and stored on magnetic tape. Cubic interpolation may also be performed at locations of data interruption where core to magnetic tape transfer occurred during data acquisition. A segment of this program can be utilized to store individual channel time history records in permanent magnetic disc files. Additional programs access these disc files to perform plotting and additional data reduction to extract desired quantities such as response spectra and energy dissipation. An annotated partial list of programs related to experimental data analysis are given below. These programs permit extraction of most of the important response characteristics.

1. TKPLT--plot on the Tektronixs graphic display and hardcopy unit, time history or X, Y data files.
2. MATH--perform addition, subtraction, multiplication, division of time history data files.
3. CALC--perform derivation, integration with base line correction of time history data files.
4. SMOTH--digital low-pass filtering of time history or X-Y data files (weighted mean averaging, 5 points).
5. JOIN--combine two time history data files into a single X,Y data file.
6. RSPA--calculation of response spectra, S_d, S_r, S_a from displacement or acceleration forcing function, damping included.

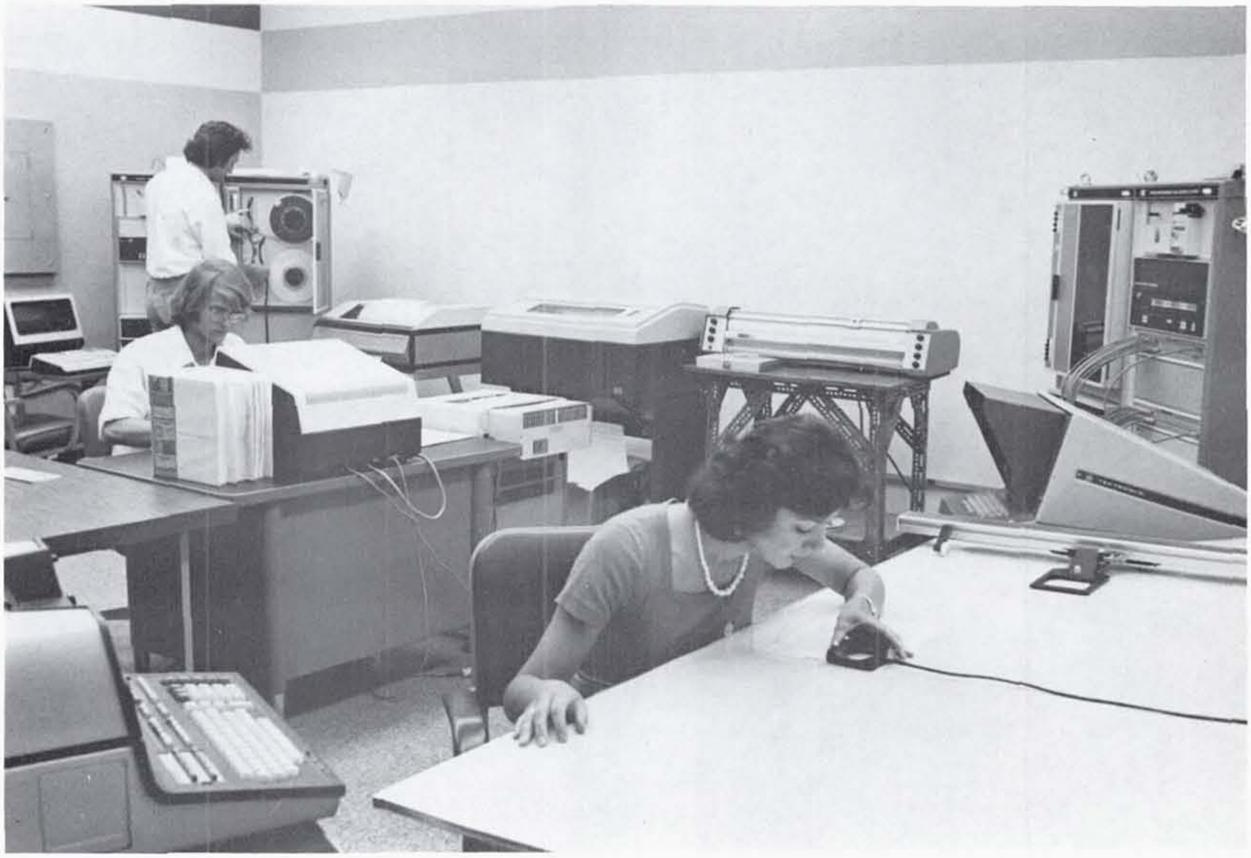


FIGURE 4 DATA PROCESSING CENTER

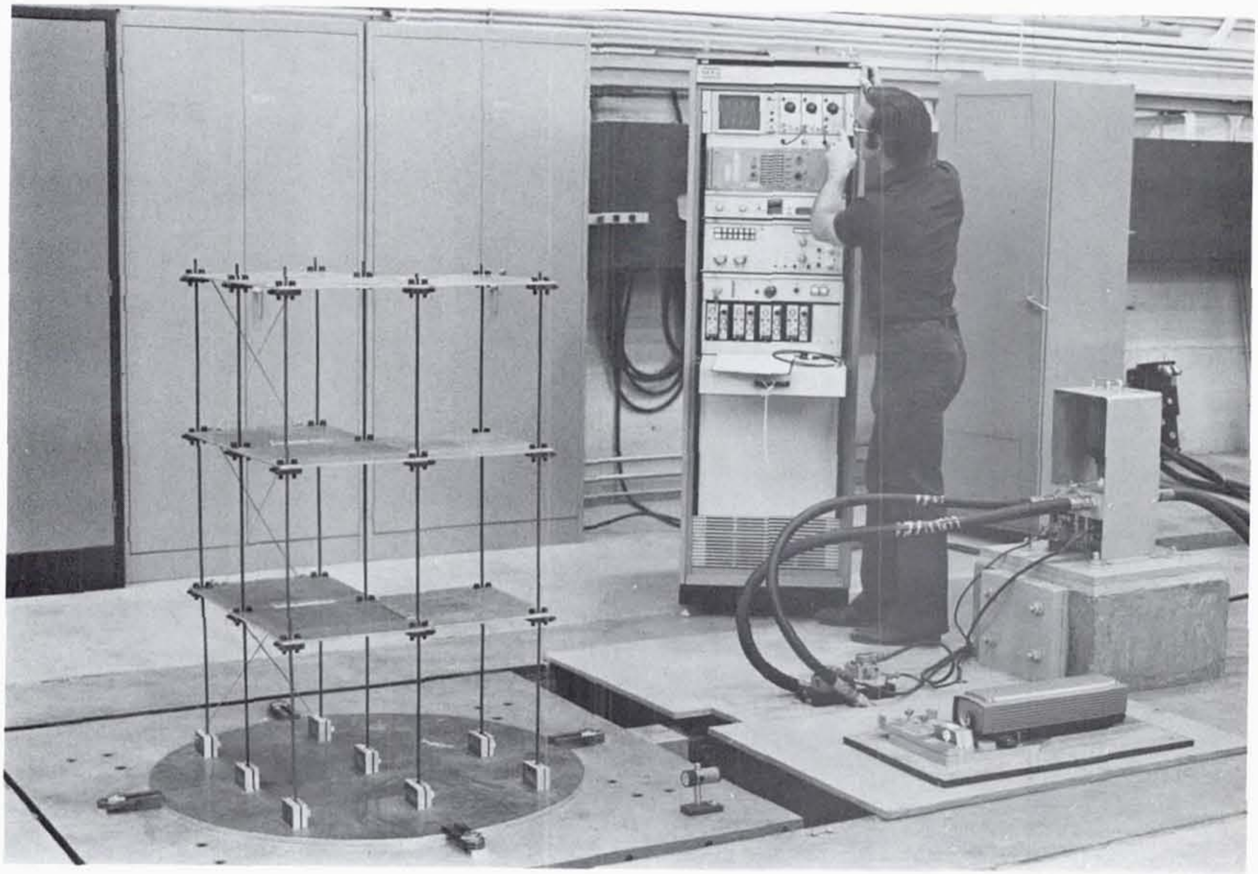


FIGURE 5 SHAKE TABLE AND CONTROL UNIT

SECTION III. FOURIER ANALYZER SYSTEM

The Fourier Analyzer is a portable, mini-computer system particularly useful for the on-site forced and ambient vibration analysis of structural systems. Essentially, the Fourier System is used to decompose sampled acceleration vs. time (or displacement vs. time) records into their respective frequency components. The result of this frequency decomposition permits the user to identify modal resonances and the associated damping parameters. Frequency decomposition may be performed on records obtained simultaneously at different points on the structure. The relative participation of each mode in any two records may be determined by the comparison of the magnitude and phase associated with each resonance. In this way mode shapes may be calculated as well as the modal frequencies and damping values.

The Fourier System has been used successfully to analyze many different types of structures including high-rise buildings, bridges, and electrical switchyard equipment. In most cases the analysis procedure has involved the determination of the power spectral density function from ambient vibration acceleration records. An important aspect of the determination of the power spectral density function is that of spectrum averaging. This technique is employed by averaging together individually calculated power spectral density functions. In this way the spectral peaks associated with structural resonances are more easily identified and the natural frequencies and associated damping values more accurately measured.

On the following pages is a list of the structures which have been tested, and a list of the Fourier Analyzer System Equipment.

STRUCTURES WHICH HAVE BEEN USED IN VIBRATION STUDIES

1. Embarcadero Trade Center Building, San Francisco, CA (45 stories)--May 1971
2. 533 South Freemont Building, Los Angeles, CA (8 stories)--August 1971
3. 5900 Wilshire Boulevard Building, Los Angeles, CA (32 stories)--August 1971
4. 15250 Ventura Boulevard Building, Sherman Oaks, CA (13 stories)--August 1971
5. I.E.D. Systems Building, Berkeley, CA (12 stories)--October 1971
6. Guy West Suspension Bridge, Sacramento, CA--January 1972
7. Hoover Tower, Stanford, CA (175 feet)--May 1972
8. Devil's Canyon Power Plant, CA--July 1972
9. Pearblossom Pumping Plant, CA--July 1972
10. Oso Pumping Plant, CA--July 1972
11. Wheeler Ridge Pumping Plant, CA--August 1972
12. Edmonston Pumping Plant, CA--August 1972
13. Windgap Pumping Plant, CA--August 1972
14. 975 California Avenue Building, Palo Alto, CA--September 1972
15. Industrial Storage Racks, located at: 3101 Kifer Road, Santa Clara, CA--Spring 1973; 579 Eccles Road, South San Francisco, CA--Spring 1973
16. Banco Central Building, Managua, Nicaragua--May 1973
17. Banco de America Building, Managua, Nicaragua--May 1973
18. Teatro Nacional Building, Managua, Nicaragua--May 1973
19. Enaluf Building, Managua, Nicaragua--May 1973
20. Sherman Building, San Jose, CA--May 1974
21. I.E.D. Systems Building, Mountain View, CA--May 1974
22. Blackwelder Building, Stanford, CA (12 stories)--May 1974

23. Quillen Building, Stanford, CA (12 stories)--June 1974

24. McFarland Building, Stanford, CA (8 stories)--June 1974

25. Hoskins Building, Stanford, CA (8 stories)--June 1974

26. Hulme Building, Stanford, CA (8 stories)--June 1974

27. Barnes Building, Stanford, CA (8 stories)--June 1974

28. Abrahms Building, Stanford, CA (8 stories)--June 1974

29. Circuit Breakers (Air Blast Type BX2) located at A.D. Edmonston Pumping Plant, CA--August 1974

30. Commodore Berry Bridge, Philadelphia, PA--February 1975

31. Circuit Breakers (Air Blast Type BX2) located at A.D. Edmonston Pumping Plant, CA--August 1975

32. Banco de America Building, Managua, Nicaragua--March 1976

33. Instituto Nacional de Seguros Building, San Jose, Costa Rica--March 1976

34. I.C.E. Building, San Jose, Costa Rica--March 1976

35. Condominio Las Americas Building, San Jose, Costa Rica-- March 1976

36. La Llacuna Building, San Jose, Costa Rica--March 1976

37. Caja del Seguro Social Buiding, San Jose, Costa Rica--March 1976

38. The Medical Building, Guatemala City, Guatemala--March 1976

39. F.I.A.S.A. Building, Guatemala City, Guatemala--March 1976

40. Free Press Building, Guatemala City, Guatemala--March 1976

41. Refinery tall columns, Richmond, CA--December 1977

FOURIER ANALYZER SYSTEM EQUIPMENT

Data Sampling and Analysis Equipment

1.	Analog to Digital Converter	(HP 5465A)
2.	Display Oscilloscope	(HP H51-180A)
3.	Display Unit	(HP 5460A)
4.	Control Unit	(HP 5475A)
5.	Computer	(HP 2115A)
6.	Power Supply	(HP 2161A)
7.	Filters	(Krohn-Hite 3323R)

Input/Output Equipment

1.	Teleprinter	(2752A)
2.	Paper Tape Reader	(2748A)
3.	Paper Tape Tunch	(2753A)
4.	X-Y Recorder	(7004B)

SHAKER SYSTEM EQUIPMENT

1.	Low Frequency Oscillator	(HP 202B)
2.	Noise Generator	(HP 3722A)
3.	Filters	(Krohn-Hite 3323R)
4.	Thruster & Air Blower	(Ling 370)
5.	Field Power Supply	(Ling PS-370)
6.	Power Amplifier	(Ling TP-850)

DISPLACEMENT MONITORING SYSTEM EQUIPMENT

1.	Laser Interferometer	(HP 5500A)
2.	Laser Reflector	(HP 10550A)
3.	Display Unit	(HP 5505A)
4.	Digital to Analog Converter	(HP 6933B)
5.	Directional Beam Bender	(Sanmac)

ADDITIONAL EQUIPMENT

1.	Instrumentation Tape Recorder	(HP 3960A)
2.	Servo Accelerometers	(Kistler 305T)
3.	Servo Amplifiers	(Kistler 515T)

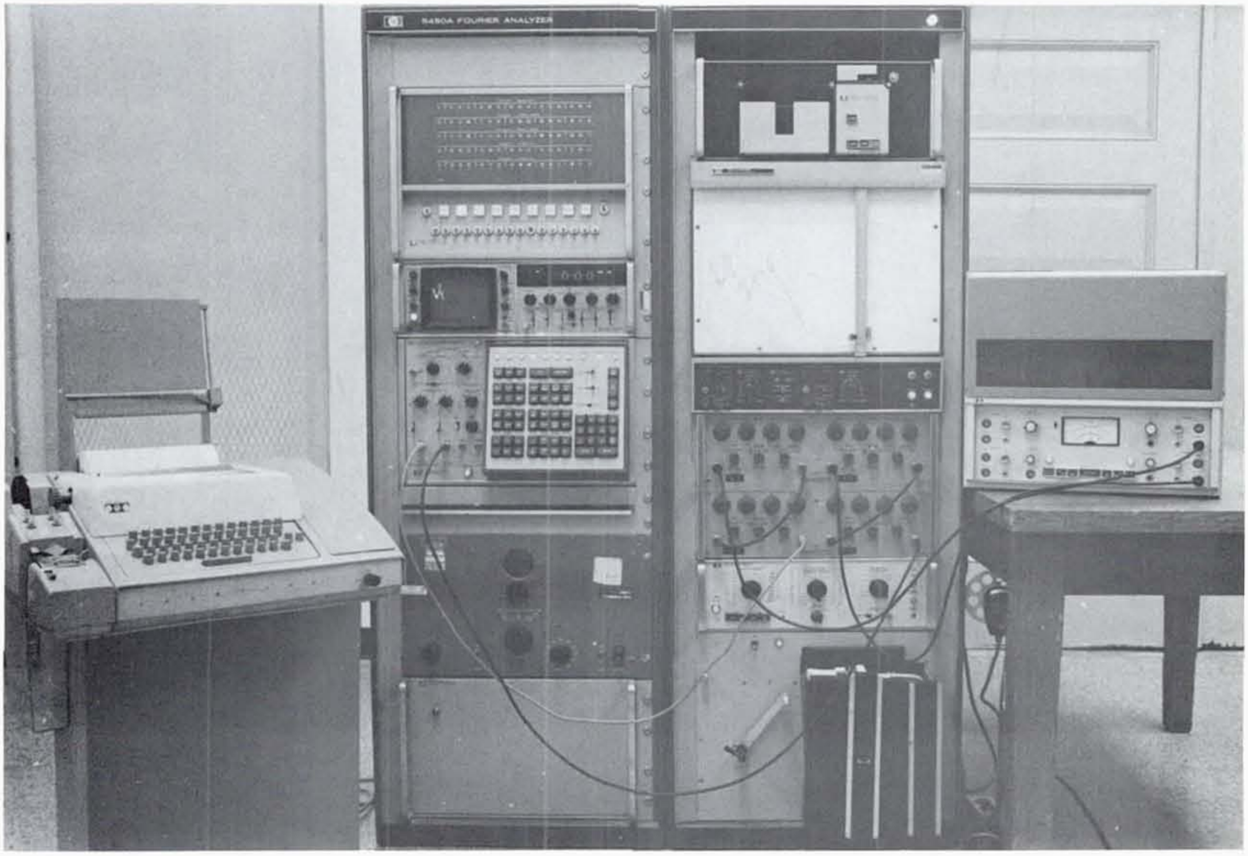


Figure 1

Fourier Analyzer System

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2. Hewlett-Packard 9864A Digitizer-Peripheral Manual; Hewlett-Packard Calculator Products Division; Loveland, Colorado, 1972.

3. Hewlett-Packard 9866A Printer-Peripheral Manual; Hewlett-Packard Calculator Products Division; Loveland, Colorado, 1972.

4. Hewlett-Packard 9830A Calculator 11270B Matrix Operations ROM Operating Manual; Hewlett-Packard Calculator Products Division; Loveland, Colorado, 1972.

5. Hewlett-Packard Calculator 11202A I/O Interface Installation and Service Manual; Hewlett-Packard Calculator Products Division; Loveland, Colorado, 1974.

6. Hewlett-Packard 9830A Calculator String Variables ROM Operating Manual for 11274B and Option 274; Hewlett-Packard Calculator Product Division; Loveland, Colorado, 1974.

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4. Hudson, D.E., N.C. Nigam, and M.D. Trifunac, "Analysis of Strong-Motion Accelerograph Records," Proc. Fourth World Conference on Earthquake Engineering, Santiago, Chile, 1969.

5. Nigam, N.D., and P.C. Jennings, "Calculation of Response Spectra from Strong-Motion Earthquake Records," Bull. Seism. Soc. Amer., vol 59, no. 2, 1969.

6. Trifunac, M.D., Low Frequency Digitization Errors and a New Method for Zero Baseline Correction of Strong-Motion Accelerograms, Earthquake Engineering Research Laboratory Report No. 70-07, California Institute of Technology, Pasadena, 1970.

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9. Trifunac, M.D., and V. Lee, Routine Computer Processing of Strong-Motion Accelerograms, Earthquake Engineering Research Laboratory Report No. 73-03, California Institute of Technology, Pasadena, 1973.

10. Trifunac, M.D., and V.W. Lee, "A Note on the Accuracy of Computed Ground Displacements from Strong-Motion Accelerograms," Bull. Seism. Soc. Amer., vol. 64, no. 4, 1974.

11. Trifunac, M.D., F.E. Udwadia, and A.G. Brady, High Frequency Errors and Instrument Corrections of Strong-Motion Accelerograms, Earthquake Engineering Research Laboratory Report No. 71-05, California Institute of Technology, Pasadena, 1971.

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