AMBIENT VIBRATION TESTING OF STRUCTURES

A DISSERTATION
Submitted in Partial Fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
EARTHQUAKE ENGINEERING
with
Specialization
in
STRUCTURAL DYNAMICS

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled, "Ambient Vibration Testing of Structures", in partial fulfillment of the requirements for the award of the degree of MASTER OF ENGINEERING IN EARTHQUAKE ENGINEERING with specialization in STRUCTURAL DYNAMICS, submitted in the Department of Earthquake Engineering, University of Roorkee, Roorkee, is an authentic record of my own work carried out for a period of about six months from August, 1993 to January, 1994 under the supervision of Dr.S.K.Thakkar, Professor and Head, Dr.N.C.Singhal, Reader, Mr.A.D.Pandey, Reader, and Mr.R.N.Dubey, Lecturer, Department of Earthquake Engineering, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

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Dated: January, 29, 1994

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Ambient Vibration testing of structures is a experimental method of determining the periods, damping ratios, mode-shape coefficients of the structures. These values can be used to validate/calibrate the mathematical model of the structure. This method does not require artificial excitation of the structures. Only natural excitation mechanisms are used. These are natural micro-tremors, wind or traffic induced excitations, shortly known as "Environmental Noise" or "Ambient Vibration".

This thesis deals with Ambient Vibration measurements and analytical studies of structures. The recently procured instruments, Solid State Recorder (SSR-1), Ranger seismometer (SS-1) and the associated software SWS has been used for analysis of data.

Two typical structures were chosen for Ambient Vibration testing namely (i) the Building of the Department of Earthquake Engineering, and (ii) Communication Tower of the Electronics Engineering Department. Observations were taken with suitable positioning of the sensors.

Natural frequencies, damping ratios upto some extent and the response spectra (floor spectra) were obtained from the analysis of experimental data.

These two buildings were also modelled mathematically for determining dynamic characteristics. The comparison between experimentally measured time periods and analytically computed values have also been made. The analytically obtained values of natural time periods are found to be about 10% higher than experimentally measured values.

CHAPTER-I

NTRODUCTION

1.1 BACKGROUND

Today, the method of finding the response of the structure experimentally has become an accepted one for determining its dynamic characteristics. The most important information of the structure is essentially its natural frequency, mode shapes and damping of the structure. Since these properties belong to the mathematical modeling of the structure rather than the structure itself, they can not be measured directly. Usually the structure is excited at certain points and its dynamic response is observed. The frequency response functions are calculated by means of Fast Fourier Transform techniques and parameters of an associated mathematical model (natural frequencies and response of the structure) are estimated. Although this method has been strongly advanced over the years, it has a serious drawback which becomes obvious when the large-scale structures such as high-rise buildings or bridges are to be analyzed. The artificial excitation of the structure by means of shaking or impact is often not appropriate for large-scale structures. The huge amount of energy necessary to induce structural vibrations may cause local damage and the measurement of the exciting forces usually is not a simple task.

Because of this problem Civil Engineers become interested in experimental techniques, which do not require artificial excitation. The method of Ambient Vibration Testing of structures use excitation by natural micro tremors, wind or traffic loads, which are available every where at any time. Of course, no quantitative information about the exciting forces can be used in this case.

The Ambient Vibration Testing of structures is carried out to determine the dynamic characteristics of prototype structures. The prototype structures are known to vibrate with low amplitude

Building and (ii) Communication Tower of Electronics Engineering Department.

* To analyze the data obtained experimentally.

* To carry out analytical studies using mathematical model for determining dynamic characteristics of the structures.

* To compare the experimental and analytical results.

1.4 SCOPE OF INVESTIGATION

The ambient vibration testing was done for two typical structures namely (i) Department of Earthquake Engineering Building and (ii) Communication Tower of Electronics Engineering Department. The (i) was tested in transverse direction while (ii) was tested in transverse and longitudinal directions. The recording was done in SSR-1 (Solid State Recorder) through SS-1 (Ranger Seismometer). Both the buildings was tested for wind induced vibration, the building (i) was also tested for exciting force (generator started in the ground floor of the building).

1.5 COMPOSITION OF THESIS

Chapter 1 describes the introduction to ambient vibration testing of two structures under consideration.

Chapter 2 describes the review of literature in which a case for ambient vibration testing of Golden Gate Suspension Bridge is also discussed.

Chapter 3 describes the different features of the measuring equipment.

Chapter 4 describes the use vibration survey software used for the analysis of the recorded data.

Chapter 5 describes the analytical techniques for analyzing the recorded data.

Chapter 6 describes the steps followed for the ambient vibration testing of two typical structures.

Chapter 7 describes the steps followed for analytically investigating the two structures under consideration.

Chapter 8 describes the conclusions drawn.

CHAPTER II

REVIEW OF LITERATURE

2.1 PROTOTYPE TESTING OF STRUCTURES

Dynamic tests of full-scale structures provide a unique opportunity to verify the validity of analytical models used in the analysis for design and to build a body of information on dynamic characteristics and behavior that could be used in design of future structures. Because of some limitations of model tests, the prototype tests provide additional information on dynamic behavior. Full-scale testing involves a means for applying a force and a method of measuring the resulting response. A lot of useful data on natural periods, mode-shapes, damping and earthquake behavior is obtained from tests. Earthquakes have provided full-scale tests on structures in many places in the world.

2.11 Types of Tests In Prototype

1. AMBIENT VIBRATION TESTS : These include the wind- induced and traffic-induced vibrations. These tests provide basic information on natural frequencies, mode shapes and damping of structures.

2. STEADY STATE VIBRATION TESTS : In these tests, the structures are excited into sinusoidal vibration by powerful electro-hydraulic vibrators or counter-rotating type weight exciter. These tests provide information on natural frequencies, mode shapes and damping in different modes of vibration. The frequency of excitation could vary from 1 to 20 Hz and load intensity may range from 1 to 20t.

3. RANDOM VIBRATION TEST : The excitation in these types of tests is random and is controlled through servo-hydraulic actuators. These tests provide information on earthquake response

and behavior.

4. PSEDODYNAMIC TEST : The computer-actuator on-line system as employed for models has been successfully employed for determining earthquake response of some full-scale structures.

5. EARTHQUAKE WITHSTAND TESTS ON PROTOTYPE EQUIPMENT AND SYSTEMS : Certain prototype electrical equipmant and systems are tested on shake table for seismic qualification purposes.

6. OBSERVATION IN EARTHQUAKES ON PROTOTYPE : Certain structures are instrumented to study its performance and behavior in real earthquakes.

The tests 1 to 6 has been largely carried out so far in Japan, U.S.A., Yugoslavia. The multistoried buildings, suspension bridges, towers and dams have been tested in large numbers in these countries.

In India very few attempts have been made to test prototypes. Attempts have also been made in the past to obtain vibration characteristics of water tower structures. The earthquake withstand tests on prototype equipment have been successfully conducted in the laboratories of Department of Earthquake Engineering, Roorkee.

2.2 AMBIENT VIBRATION MEASUREMENTS OF THE GOLDEN GATE SUSPENSION BRIDGE : A CASE STUDY

The Golden Gate Bridge lies across the entrance to the San Francisco Bay and joins the northern and southern peninsulas. Construction began in 1933, and in 1937 the bridge was opened to traffic. In 1952, the additional modifications were made to the lateral bracing system to increase the rigidity of the roadway after a strong wind storm in 1951 caused some structural damage to the bridge.

2.21 Description of Bridge

The bridge consists of a main span of 4,200 ft (1280.5 m) and two side spans of 1,125 ft (342.9 m) each. The spans are suspended from the main cable, which is supported by the two towers. Both towers are 690 ft (210.36 m) high from the pier to the base of the saddle castings and rise 746 ft (227.43 m) above water. An elevation is presented in figure 2. figure 3 shows a typical span cross-section, and figure 4 details one of the towers. Except for anchorages approaches and tower footings, the bridge is symmetrical about mid-span.

Extensive measurements were made of the wind and traffic induced vibrations of the main span, one side span and one tower. the purpose of these measurements was to experimentally determine modal parameters of the structure.

The wind traffic induced ambient vibrations were measured by a team from both the Princeton University Civil Engineering Department and Kinemetrics, Inc. Observation for vibrations were made at 18 stations on the main span and side span and 10 stations on one of the two towers. Wind speed was also measured concurrently with the vibration data. Analog data recorded on magnetic tape were later digitized for computer analysis.

2.22 Instrumentation of Bridge

Most seismometers have flat response down to only one or two hertz, limiting their usefulness at low frequencies. Large flexible structures often have modal frequencies below one hertz. Also the long cables can attenuate the seismometer outputs and increase the noise level, as the voltage output is very low.

Servo accelerometers were chosen for use in this project, as modal frequencies well below one hertz and several thousand foot cable were expected.

Bridge response was measured using Kinemetrics Model FBA-1 and FBA-11 force balance accelerometers. The site where the seismometers were to be installed was almost always wet because of the salt-laden fog, therefore plaster of paris was used for fixing up the seismometers, and this way no damage was done to the paints and metal of the bridge as well.

Wind speed was measured simultaneously with the bridge response using an R.M.Young UVW anemometer system. Only two axes of this triaxial device were used; these were oriented horizontally.

If individual cables had been used to connect each of the 12 accelerometers to its control/power panel in the recording station, over 18,000 ft.(5487.8 m) of cable would have been required for the main and the side span measurements. Using the cabling system as shown in figure :5 only slightly more than 4,000 ft.(1219.5 m) of cable was required for the accelerometers. For tower measurements, a combination of this cable system and individual sensor cables was used.

2.23 Signal Conditioning

Signals from the accelerometers were amplified and filtered using Kinemetrics Model SC-1 signal-conditioners. The wind speed data were not conditioned, as both the signal level and frequency content were adequate for direct recording.

2.24 Data Recording

Because of the extreme environmental conditions and the need for on site data review, an analog recording system was chosen over an equivalent digital system. Up to 12 channels of data were recorded simultaneously on a honey well Model 5600E 14-channels FM tape recorder.

2.25 Field Program for Data Recording

The field work began on June 14, 1982 and during the next ten days measurements were made of both span and tower vibrations. In order to reduce the amount of data required symmetry of the bridge response was assumed. Only the South half of the bridoe was studied.

The bridge was analyzed using 12 channel accelerometers, at each of the 18 stations shown in figure :2 six accelerometers were installed. The positions and sensitive directions of these accelerometers are shown in figure :3.

Station 8 was the reference station for all the span measurements. One hour of ambient vibration data were recorded at each of the main span stations. Thirty minutes of data were recorded at each of the side span stations except station 17, for which one hour of recording was done.

The motion of the San Francisco (south) tower of the Golden Gate Bridge was measured using 9 channel of accelerometers and thirty minutes of data recording was done.

The anemometer was then moved to the highest point of the west saddle on the tower. These wind sensors were now the highest objects on the bridge. The two wind speed signals were moved to channels 10 and 11 of the 14-channel recorder.

Accelerometers 1 through 6 were then moved to the various locations on the tower. Three or four tower stations were included in each of the four data run; in all 25 components of tower motion were measured. Thirty minutes of data were recorded for each run.

2.26 Digitization of Data

To facilitate computer processing of the vibration data, the analog data recorded on the two tape recorder were digitized at Kinemetrics following the field program.

During field portion of the Ambient Vibration measurements of the Golden Gate Bridge, many problems were encountered in the design of the instrumentation and in the data acquisition. These included sensor choice, sensor mounting, cable design, and protection from the environment. The solution of these problems have already been discussed.

Extensive, high-quality data were acquired during the field measurements. These data are expected to provide researchers and analysts with information of exceptional quality for years to come.

CHAPTER III

DESCRIPTION OF VIBRATION MEASURING EQUIPMENT

3.1 ACCELERATION LEVEL IN STRUCTURES

Stiff structures such as masonry buildings and concrete dams (f>5Hz), experience accelerations on the oder of 10^{-5} g to 10^{-3} g due to wind and micro seismic activity. Flexible structures, such as multi-storied buildings offshore structures (f<1Hz), experience accelerations on the oder of 10^{-4} g to 10^{-2} g under wind and wave forces.

3.2 DOMINANT FREQUENCIES IN STRUCTURES

Seismometers with high sensitivity and 1 to 100 Hz frequency response, is used to measure the response of stiff structures. The force balance accelerometers with DC to 50Hz frequency response is used on flexible structures.

During Ambient Vibration Survey, these sensitive transducers are positioned at numerous locations on the structure and connected to a portable recorder through a multi-channel signal conditioner. The signal conditioner applies low-pass filtering and amplification to the signals.

3.3 AMPLIFICATION-FILTERING OF SIGNALS

A key element for successful Ambient Vibration measurement is an amplifier/filter module with sufficient flexibility to meet differing field conditions of structure type and ambient forces. The ability to reject high frequency vibrations beyond the interest of structures is necessary. Sometimes an amplifier capable of 30,000 gain is necessary to obtain signals suitable for recording. Also, the ability to integrate the transducer output to enhance lower modes is very useful. These features can be used in the amplifier filter modules. Multi-channel systems can be constructed using amplifier panel.

A suitable recording system must have sufficient dynamic range to capture the structural response of modes with small participation. Other important features include: multiple recording speeds or sample rates, visual data monitoring capacity and event identifications, field portability, and rugged construction. Four channels FM record/reproduce is a normal minimum.

3.4 OPERATING INSTRUCTIONS FOR SOLID STATE RECORDER (MODEL SSR-1)

3.41 Brief Description of SSR-1

Modern digital 16-bit recorders, such as Kinemetrics, Model SSR-1, permit very high dynamic range (96 db) triggered event recording or continuous recording with high speed interface to a lap-top PC.

The SSR-1 offers additional features such as pre-programmed window turn-on for unattended operation, triggered event turn-on for event related response measurements, battery operation for remote applications, and time tagging and labelling of files for easy identification. Best of all, the data is acquired and stored digitally for the ease of analysis, field evaluation of data, as well as control over the SSR-1, is accomplished using a portable lap-top PC.

The SSR-1 is a good choice for measuring Dense Arrays: local effects and excellent choice in case of Dense Arrays: source mechanism and wave propagation as well as for after shocks.

3.42 Specifications of SSR-1

Recorder :Solid State 4MB memory RAM

Processor :1MB RAM, 3.5 inches floppy drive and 20MB memory hard disk with EGA

Features :Dynamic range 96dB with 16 bit accuracy
Provides pre-programmed window
Battery operation for remote applications
Time tagging and labelling of files
Data acquired stored digitally

3.5 OPERATING INSTRUCTIONS FOR RANGER SEIMOMETER (MODEL SS-1)

3.51 Brief Description of SS-1

The SS-1 Ranger Seismometer is a versatile, high-sensitivity, portable seismometer specifically designed for a variety of seismic field applications under adverse environmental conditions, Figure :6 shows the seismometer and case assembly. The Ranger combines high sensitivity, field selectable mode and rugged water-tight construction, in a package measuring only 5 inches in diameter by 12 inches long and weighing only 10.9 pounds. A separate calibration coil in the base provides a sample means of field calibrating the Ranger using only a known-voltage battery and a fixed precision resistor.

The Ranger is a spring-mass instrument with electromagnetic transduction. Its permanent magnet assembly is the seismic mass while the coil is attached to the frame.

The Ranger can be used either horizontally or vertically and is well suited to field or laboratory use. The relationship between major parts is shown schematically in Figure 7. The mass is supported by two circular flexures which constrain it to a single degree of freedom. A helical spring is used to suspend the mass. When the seismometer is used vertically, the suspension spring is fully extended, when used horizontally, the spring is unstressed. The force of suspension spring is controlled by positioning a hanger rod attached to the spring. The basic natural period of the mass, flexures, and suspension spring is extended by the addition of small rod-magnets installed around the mass. These period-extending magnets interact with the magnetic field of the mass, effectively producing a negative restoring force. In order to achieve the desired period, the field strength and position of the period-extending magnets are carefully adjusted at the factory.

3.52 Specifications of SS-1

Natural Period, Tn	=	1 second
Coil Resistance, Rc	=	5500 ohms
Critical Damping Resistance	=	6500 ohms
Generator Constant, G	=	340 volts/meter/sec
Total Mass Travel	=	2mm
Weight	=	1.45 Kg
Motor Constant of the Calibration Coil	=	0.4 newtons/amp

The SS-1 Ranger Seismometer may be used either vertically or horizontally. The seismometer should not be installed within six inches of any steel or magnetic object. To unclamp the mass, turn the lock fully counterclockwise.

3.53 Adjustments of SS-1

Mass centering is required while changing the position of SS-1 Ranger Seismometer from vertical to horizontal or otherwise. For mass centering the mass is brought to the center of its span of travel by means of the spring hanger rod at the top of the instrument shown in figure :7, after unclamping make this adjustment as follows:

1. Unscrew and remove the access cover/handle.
2. While holding the spring hanger knob with one hand, loosen the collet nut with the other hand.
3. Move the spring hanger-rod until the mass is fairly near center. Centering is determined by the coincidence of two lines, visible through the viewing port. With the mass reasonably centered, tighten the collet nut.
4. Fine centering of the mass is now achieved by means of the

mass centering nut. Turn this nut until the two lines as seen through the viewing port, coincide.

Since the mass of the sensors does not changes with time, the natural frequency and damping measured from this record can be used to assure that the essential sensor characteristics determined at the time of calibration remain unchanged.

CHAPTER IV

VIBRATION SURVEY SOFTWARE

4.1 BACKGROUND

The Kinemetrics Seismic Workstation Vibration Survey Software is a set of programs designed to aid the scientist or engineers in processing data recorded by Kinemetrics vibration recording systems. This application program package is intended to supplement the general purpose time series processing utilities provided in the basic Seismic Workstation software package.

4.11 Time Series File Processing

The first step in data processing on the Seismic Workstation is to acquire raw instrument data and convert it to the Workstation common data format (CDF). This stage of processing is handled by the Instrument Interface Software, as shown on the block diagram in figure :8.

Once the raw instrument data has been covered to a CDF file (with default file extension ".DAT"), the next few processing steps are to decode the serial time code (if necessary), and to edit the raw data down to a subset for processing by the Vibration Survey programs.

Time code decoding is accomplished using one of the decoding programs TSTCG or TSDATUM which decode the Kinemetrics TCG-1A or TCG-1B time code and the Datum bi-level slow code.

Each converted time series (CDF file) may be edited using the program TSEDIT. This allows the user to mark channels for removal from the file as well as to mark the beginning and end of a segment of the file for later processing steps.

If it is desired to reduce the size of the edited file by actually removing channels marked for deletion and discarding data beyond the beginning and end markers set by TSEDIT, the program XEDIT may be used.

4.12 Spectral Analysis of Recorded Data

The program for spectral analysis include FFT and QFFT. Both programs perform non-averaged fast Fourier transforms on up to four channels of data from CDF files. The program FFT differs from QFFT only in the respect that FFT allows 4 times larger transforms (8K transform, single-channel mode) to be computed compared to QFFT. However, FFT utilizes disk files for storage of intermediate results, thus slowing down processing. FFT is best used with a winchester disk or RAM disk.

The QFFT program is described in the following sections. However, the command descriptions are equally applicable to the FFT program commands.

4.13 QFFT of Data

The interactive spectral analysis program QFFT provides the user with the ability to view pre-recorded data graphically in the frequency domain. QFFT gives the user the option of processing the data with a power-of-two fast fourier transform up to order 11 (1024 point spectrum output) for single-channel mode, or trading resolution for multi-channel processing capability (up to 4 channels with 256 point spectra). In addition, rectangular, Hanning, or Hamming windows may be selected.

QFFT also provides the user with the capability for graphically zooming displays for detailed viewing, and producing labeled hard-copy output on the optional pen plotter. Detailed frequency auto-plots are scaled both horizontally and vertically. Time series plots have units of Volts and seconds. Frequency amplitude plots have units of Fourier amplitude and Hertz.

4.14 Starting Analysis Session for QFFT

QFFT is started with a command of the film :

QFFT Filename

where "filename" is the name of the CDF time series data file to be processed. The program then responds with a series of questions to determine the processing parameters which are to be used in processing the file. An example of this is shown in figure :8.

As indicated in figure :9, the first question requests the user to enter the number of channels to be analyzed. The acceptable range of values are shown in square brackets, and the user response must be typed in integer format (no decimal point is allowed). In the example, the acceptable range is 1 through 4 channels, and the user has elected single-channel processing mode. Note that the larger the number of channels to be processed, the smaller the allowable transform size. This is due to data array space limitations of QFFT.

The second question pointed by QFFT requests the transform order (size) to be entered. This is the power of two of the number of input data points which will be used in the FFT computation. Thus, a selection of 11 means that 2048 data points will be processed, yielding an output spectrum with 1024 points from 0 Hz (DC) to the Nyquist frequency (1/2 x sampling rate). Note that the upper limit of the acceptable range which is displayed is adjusted for the number of channels which has been selected in the preceding question.

The third question requests the user to select the transform window desired.

At this point, QFFT searches for the specified data file, reads the header information, and displays the comment, sample rate used, and the assigned channel names.

Next, QFFT request the number of the data file channel to be processed for each of the QFFT analyzer channels selected. In the example above, since only 1 analyzer channel was selected, only one date channel needed to be entered (channel 2, "AIDL", was entered.

The final question is used by QFFT to determine the point within the data file at which processing is to begin. This is useful for comparing transforms of data at different points within a given file, as well as for skipping past a bad section of the file. The maximum time offset which QFFT will accept is 30.0 seconds, and the user input may contain a decimal point.

At this point the initial dialog is complete, and QFFT proceeds to read the input data file and to execute the operations specified. The progress of the computations are indicated as shown in figure :9. Note that a transform of order 10 (1024 input points) will take approximately 20 seconds. After FFT calculations are complete, the Seismic Workstation screen is cleared, and the initial plot is displayed as shown in figure :10.

The initial QFFT plot consists of two "frames" in which functions are displayed. The upper frame (frame #1) is a linear-linear auto-scaled plot of the input time series for analyzer channel 1, while the lower frame (frame #2) contains on auto-scaled semi-log plot of the amplitude spectrum of the data. In the case of frame #1, the horizontal axis (time) is scaled in seconds, while the amplitude is normalized to full-scale. For frame #2, the horizontal axis is frequency in Hertz. Note that the top of the plot is also labeled (from left to right) with the data file name, the comment found in the header of the file, and the analyzer channel number.

When the initial plot is complete, the terminal cross-hairs appear, signaling that QFFT is now at the second input phase. This is described in the sections which follow.

4.15 Interrupting and Terminating QFFT

The analysis session is terminated by two methods, depending on the current input mode of QFFT. When QFFT is requesting input during the initial dialog, the program may be aborted by typing a <control -c> as the first character of the input. If QFFT is requesting input via the graphics cross-hairs, typing the character <Q> will "quit" the analysis session.

During actual plotting of data, whether the plotting is on the console terminal screen or on the plotter, the plotting of the current trace may be interrupted by depressing the <esc> (escape) key. If further plotting was pending, the program will immediately continue with the axis labeling and plotting of the next frame. Thus, plots in progress may not be completely aborted, but may be shortened by using the <esc> key. When the plotting finally comes to a halt, the <Q> command may be used to terminate QFFT execution.

4.2 INTRODUCTION TO QUICKTALK (SSR-1 Communications Program)

QuickTalk, QT, is an integrated environment for communicating with the Kinemetrics SSR-1 Solid State Recorder using an IBM or 100% compatible computer. It provides for direct communication as well as remote access over telephone lines and modems. A spread sheet-like parameter Work sheet is built into the program to ease the setup of experiments which require periodic changes in the configuration of the recorder. QuickLook, is also available from within QuickTalk to provide graphical display of received event files. Also, parameters can be readily loaded into the SSR-1 by sending them as a standard ASCII file. Parameters can also be transferred to the user's PC as an ASCII file which can later be edited using a word processor or text editor.

What QuickTalk really does that standard PC communications programs don't, mainly "insulate" the user from the simple SSR-1 two-character commands and 187 numeric parameters. Many of these commands are accessed from the "user friendly" pop up Work sheet complete with context-sensitive help in many areas.

Since QuickTalk directly accesses the PC's serial port, interrupt controller, and display screen memory, 100% hardware compatibility with the IBM PC is absolutely required. Also, the Bios (Basic Input Output System) ROM must be compatible. QuickTalk supports color display adapters, monochrome adapters and monitors as well as the Liquid Crystal and Plasma displays used on many Lap top computers. Communications at speeds up to 115.2 kilobaud are supported on faster computers.

4.3 INTRODUCTION TO QUICKLOOK (12/16 Bit SSR-1 Display Utility)

QuickLook (ql16) gives the field user a quick visual presentation of seismic waveform data recorded on Kinemetrics SSR-1 recorders. Maximum amplitude, event duration and predominant frequencies call all be readily determined.

It provides an immediate visual presentation of the data with no additional processing. It is also especially helpful in quickly determining which records require further analysis. Finally, ql16 can be used during periodic inspections to display functional test records to verify proper operation on-the-spot.

The program ql16 is provided with Kinemetrics SSR-1 digital seismic recording instruments. The program allows seismic records to be displayed graphically on the screen of an IBM PC (or 100% compatible) computer. The program is compatible with 16 bit (SSR-1) data. The events can be viewed as soon as they are transferred to the PC.

ql16 automatically scales the event to fit on the screen in both x and y axes. Once initially displayed, channels which are temporarily not wanted can be removed from the display and areas of interest can be quickly examined in greater detail by marking with the cursor and zooming in.

RAM memory is dynamically allocated to the program and all that is available will be used for data. If the event will not fit in the available memory, it is truncated.

4.4 INTRODUCTION TO MAC/RAN SOFTWARE

4.41 Time Series Analysis

A group of data values that are compiled with respect to their chronological occurrences can be considered a time series.

More often, one is concerned with a transformation of time series data into another domain so that a more involved investigation can be made. The most common of these transformation is the Fourier transform which computes a function in the frequency domain corresponding to the time series that it operated upon. The transformation is a very powerful tool and is used extensively for many purposes, including power estimation, spectral display and analysis, certain types of correlation, and even mathematical integration and differentiation, among many others. Thus, time series analysis is a very broad term that includes many frequency domain techniques to deal with a wide spectrum of phenomena. These techniques are also applicable to situations that do not involve a time basis, if an analogy can be made with a time series.

4.42 MAC/RAN as a Time Series Tool

MAC/RAN incorporates sophisticated algorithms and data preparation techniques in its processors. This minimizes the signal processing expertise and computer coding necessary to analyze data correctly. All data entered into MAC/RAN remains in a standard data format that allows continuous processing through various modules or selective output at any time during a program run. In addition MAC/RAN processes multiple channels simultaneously for greater throughput.

MAC/RAN allows any one, several, or all of its state-of-the-art processing procedures to be specified within the same program run. MAC/RAN driver and management software handle the delegation of tasks and data to the necessary modules by way of a control language. Thus, a control file stored on disk can be easily edited to after existing sequences of procedures, parameters, or input data. This avoids the rewriting of special software that is required to accommodate any adjustments needed to obtain the desired results.

MAC/RAN is not a programming language nor a set of subroutines from which one constructs his own data reduction system ; instead, it is a self-contained data reduction system that provides flexibility in the choice of any specific processing procedures required at any given time.

CHAPTER V

ANALYTICAL TECHNIQUES OF ANALYZING THE RECORDED DATA

5.1 THEORY FOR ANALYSIS OF DATA

The acceleration response of a physical structure can nearly always be characterized as a mixed random process, a composite of a random process and a deterministic shaping function. The deterministic shaping function results from the response of the structure in its normal modes to the random input provided by the natural processes of wind and micro-tremor. The random portion results from the nature of the input, as well as extraneous noise present in the measurement.

One property of the spectrum of a random process is that each segment of the infinite-duration time history, being different from any other segment, makes a unique contribution to the spectrum. Thus, the spectrum resulting from any finite time measurement is only an approximation to the true spectrum of the complete random process. The property presents the greatest problem in measuring the spectrum of a random process. The solution is accomplished by spectrum averaging. The average of many independent measurements is a better statistical estimate of the true value than any single measurement. In the process of averaging, the random components of the signal are diminished and the systematic components are enhanced.

During the field program, measurements are taken at several different positions on the structure in several different orientations. These data are analyzed by determining the relation between each signal and a reference signal. The reference location is chosen so that it contains information for all the modes of interest. Consider the generalized measurement situation shown in Figure :11, with two accessible points on the structure X and Y.

X and Y are related by some linear transfer quantity H, and Y is contaminated by some uncorrected noise source N.

The recorded time-function signals $x(t)$, $y(t)$ are Fourier transformed into linear spectra :

$$S_x = F\{x(t)\} \ ... \qquad (1)$$

$$S_y = F\{y(T)\} ... \qquad (2)$$

From these linear spectra, three power spectra can be computed. These are the "input" power spectrum,

$$G_{xx} = S_x S_x^*, ... \qquad (3)$$

and "output" power spectrum,

$$G_{yy} = S_y S_y^*, . \qquad ..(4)$$

and the cross power spectrum,

$$G_{yx} = S_y S_x^*, ... \qquad (5)$$

Where the asterisk in these equations indicates a complex conjugate. The output power spectrum can be expressed with two parts, one due to the input and one due to the uncorrected noise source :

$$S_y = HS_x + S_n ... \qquad (6)$$

Substituting (6) into (5), the cross power spectrum can be written

$$G_{yx} = HG_{xx} + G_{nx} ... \qquad (7)$$

After signal averaging, these terms become.

$$\bar{G}_{yx} = H\bar{G}_{xx} + \bar{G}_{nx} ... \qquad (8)$$

Assuming either that S_n is small or that $\bar{G}_{yx}$ has been sufficiently smoothed through averaging to make $\bar{G}_{nx}$ negligible, the cross spectrum terms are given by

$$\bar{G}_{yx} = H\bar{G}_{xx} ... \qquad (9)$$

The transfer function is then directly calculated :

$$H = \frac{\bar{G}_{yx}}{\bar{G}_{xx}} \qquad \ldots(10)$$

To measure the degree to which one signal is dependent on the other instead of another uncorrected source, the coherence function is evaluated. The coherence function is defined by

$$\gamma^2 = \frac{\left|\bar{G}_{yx}\right|^2}{\bar{G}_{xx}\bar{G}_{yy}} \qquad \ldots(11)$$

Equation (11) can be rewritten in a more convenient form :

$$\gamma^2 = \frac{\left|H\right| G_{xx}}{\left|H\right| \bar{G}_{xx} + \bar{G}_{nn}} \qquad \ldots(12)$$

At a given frequency, γ is the fraction of power at the system output that is due to the input. If $\bar{G}_{nn}$ is zero, $\gamma^2 = 1$. This indicates a perfect linear, non-noise contaminated relation between input and output. If $\left|H\right|^2 G_{xx}$ (the output term due to the input) is small compared with the noise, γ^2 will be close to zero. γ^2 is a value lying between 0.0 and 1.0 that gives a positive indication of the relationship between input and output.

Consider the structure shown in Figure :12. representing the plan view of the crest of a concrete arch dam. Structural coordinates are indicated for radial vibration of the arch. The set of time-series $x_1(t)$, $x_2(t)$, ...$x_i(t)$, ...$x_n(t)$ is transformed to the frequency domain:

$$S_1(f) = F\left\{x_1(t)\right\}$$

$$S_2(f) = F\left\{x_2(t)\right\}$$

$$S_i(f) = G\left\{x_i(t)\right\} \quad \ldots(13)$$

$$\begin{matrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{matrix}$$

$$S_n(f) = F\left\{x_n(t)\right\}$$

Modal frequencies of the structure appear as peaks in the amplitude spectra $|S_n(f)|$. The amplitude spectra of Figure :13 shows the three lowest modal frequencies.

The i^{th} mode shape coefficient H_{ij} at each natural frequency f_j, normalized to the value at coordinate 1, is simply

$$H_{ij} = \frac{\bar{G}_{ij}\ (f_j)}{\bar{G}_{11}\ (f_j)} \quad \ldots(14)$$

The relative phase of the complex product $S_1(f)\ \ S_i(f)$ gives the mode shape direction.

Damping estimates are obtained from the width of the peak corresponding to the modal frequency of interest :

$$\xi = 1/2\ \frac{BW}{f_i} \quad \ldots(15)$$

Where ξ is the critical damping ratio and BW is the peak width (bandwidth in, Hz) measured at $1/\sqrt{2}$ of the amplitude spectrum value $S(f_i)$.

It can be shown that the length of time-series required to give reasonable estimates of damping is

$$T_\sigma = \frac{2n}{\xi_1 f_1} \quad \ldots(16)$$

Where T is the length of record in seconds, ξ_1 is the damping ratio in the lowest mode of interest, f_1 is the corresponding frequency and n is the number of averages required for a sufficiently smooth spectrum. Experience has shown that a minimum of 32 averages are required for most civil structure.

5.2 FIELD PROCEDURE DATA ANALYSIS AND INTERPRETATION

Most ambient or shaker excited building vibration tests assume that the structure can be approximated by a damped, linear, discrete or continuous system whose properties varies with reference to a line. Two simultaneous velocity recordings are made in each run. One of the transducer (the reference instrument) is left in place while the other is shifted up and down or sideways along a line suitable for the defining of mode-shape that is to be measured. All the transducers are oriented parallel at the same location on the structure to record identical structural motion. This measurement provides a relative calibration between channels of the entire transducer amplifier, filter, recorder and analog to digital conversion system.

5.21 Selection of Time for Recording

The length of recording for each measurement is very important. Too short a period of time will result in unreliable spectra, and thus limit the usefulness of mode-shape and damping estimates. Too long of a recording increases project effort and cost. As a rule of thumb one hour of recording time is required for each second natural period corresponding to the lowest mode of interest.

CHAPTER VI

AMBIENT VIBRATION TESTING OF STRUCTURES

6.1 AMBIENT VIBRATION TESTING OF DEPARTMENT OF EARTHQUAKE ENGINEERING

6.11 Description of the Building

The Three storied building (ht. 11.8m) was tested for Ambient Vibrations on 11thSept., 1993. Figure :14 shows the front elevation of Department of Earthquake Engineering Building. The building is a framed structure building with reinforced brick columns and reinforced cement concrete beams. There are two stair cases in the building. One expansion joint is also provided in the building as shown in figure :28 (first floor plan of the building).

6.12 Instrumentation of Building

Six Kinemetrics 1-sec (natural period) seismometers SS-1 and a Kinemetrics SSR-1 portable digital event recorder was used in the study. The six channels scanned data were sampled at a rate of 200 SPS (Samples per second) per channel with 16-bit accuracy to provide 96 dB of dynamic range. A PC-XT was used to display and process the data.

6.13 Excitations in Building

Wind induced vibrations were recorded, additional measurements were made to study the response of the structure by starting the generator in the ground floor of the building, several times during the recording a below was also given in the vicinity of the sensors.

6.14 Description of Tests

The limited number of instruments available dictated an experimental scheme in which simulations measurements were made at few locations at a time. During the test of 11th Sept 1993 SS-1 (Ranger Seismometer) were placed at different floor levels (ie) 1st, 2nd and at the roof level as shown in figure :15 and recording was done simultaneously. The placement of seismometers during the tests conducted is listed in table :2.

Post processing of data included instrument corrections, transformation from velocity to acceleration and calculation of discrete fourier transform from long samples of the recorded motion.

6.2 AMBIENT VIBRATION TESTING OF COMMUNICATION TOWER OF ELECTRONICS ENGINEERING DEPARTMENT

6.21 Description of the Building

The Thirteen storied building (ht. 42.60m) was tested for Ambient Vibrations. Figure :16 shows the front elevation of Communication Tower of Electronics Engineering Department Building. The tower is having a coupled shear wall in longitudinal direction and is provided with a lift and a stair case. The foundation of tower is consisting of a raft supported by piles (26 numbers).

6.22 Instrumentation of Tower

Six Kinemetrics 1-sec (natural period) seismometers SS-1 and a Kinemetrics SSR-1 portable digital event recorder was used in the study. The six channels scanned data were sampled at a rate of 200 SPS (Samples per second) per channel with 16-bit accuracy to provide 96 dB of dynamic range. A Lap-Top PC was used to display the records, these data were stored in SSR-1 (Solid State Recorder) and latter transferred to a PC-XT for processing.

NAME OF THE BUILDING	TIME PERIOD (second)
Department of Earthquake Engineering	
(i) Transverse Direction	0.308
Communication Tower of Electronics Engineering Department	
(i) Longitudinal Direction	0.685
(ii) Transverse Direction	0.795

Using option qL16(exe) the plot shown in figure :18 is obtained. It gives information about the event time, plot parameter shown in figure :19 can also be obtained. For getting natural time period of structure the record of one channel a as shown in figure :18 is selected and the portion of interest is magnified by zooming the plot as shown in figure :18(a).

6.32 Damping and Natural Frequencies of Building

Using option fd(exe), natural frequency and damping ratio were found out. To find natural frequency two points were selected on the plot as shown in figure :20 then program asks for number of cycles chosen, count the number of cycles and put,for finding out the damping ratio three points are chosen on a plot. Then on asking for the information of the plot the figure :21 is obtained which gives values of frequencies and damping ratio's.

6.33 Vibration Recording of Different Floors

For getting uncorrected accelerogram make use of SWS main menu option 4 (ie) Strong motion data analysis, and then choose option 1 (VOL1DS) of this menu, this will convert .D16 file to .v1 and then making use of option 4 V1PLOT uncorrected accelerograph shown in figure :22 is obtained here acceleration on y-axis in terms of G and on x-axis is time in seconds.

For getting the plots shown in figure :23 which gives acceleration v_s time, velocity v_s time and displacement v_s time as well as the peak values are also written is the top. Using option 2 (VOL2DS) which convert file with $.v_1$ extension to file with $.v_2$ extension which is required for getting this plot. Here, we have corrected acceleration, velocity and displacement on Y-axis in cm^2/sec, cm/sec and cm resp. v_s time (sec) on X-axis we can also have quick look on peak values of acceleration, velocity and displacement with respect to time. And these positions are significantly marked on the plots shown in figure :23.

The results obtained for both the buildings are tabulated as shown in table 2 & 3. In these tables peak values of acceleration, velocity, and displacement Vs time are presented which may be of great use to identify the structural behavior.

6.34 Response Spectra of Floors

For getting response spectra (floor spectra) use option 3 of Strong motion data analysis menu this will convert file with $.v_2$ extension to file with $.v_3$ extension which is required for calculating the response spectra. Then choose option 6 for getting spectra. This is a plot as shown in figure :24 on log-log scale. On Y-axis is PSV (Power Spectral Velocity) in (inches/sec) and on X-axis is time (sec). As seen from the plot two more axis are there, on one is SD (Spectral displacement) in inches and an another is PSA (power spectral acceleration) in terms of g. This types of plot is very useful for finding SD, PSV and PSA at a given time for a known value of damping using the plot accordingly. Such plot are of great significance in structures like nuclear power plants where the response of a floor is required for validating with that of the instruments to be placed at that floor level.

CHAPTER VII

ANALYTICAL INVESTIGATION OF STRUCTURES

7.1 BACKGROUND

The two structures namely (i) Department of Earthquake Engineering and (ii) Communication Tower of Electronics Engineering Department, were considered as planner structures and analyzed by plane frame program. Both the building tested experimentally were modeled for analytical analysis as shown in figures :25-27, Figure :25 shows the mathematical model of Earthquake Engineering Department Building in transverse direction. Figure :26 & 27 shows the mathematical models of communication tower of Electronics Engineering Department in longitudinal and transverse directions respectively. As shown in figure :26 & 27 the foundation of the tower is replaced by two springs (ie) horizontal K_x and rotational K_0, the values of these spring constants was calculated by considering elastic half space.

7.2 MATHEMATICAL MODELLING

Mathematical models of the two structures studied namely (i)Department of Earthquake Engineering Building and (ii) Communication Tower of Electronics Engineering Department are shown in figure :25-27. Figure :25 shows the mathematical model for the department of earthquake engineering in transverse direction in which the wall has been replaced by strut (diagonal) members. Figure :26 & 27 shows the mathematical models of communication tower of electronics engineering department in longitudinal and transverse directions respectively, the beams were considered with rigid ends for modelling.

7.3 PLANE FRAME PROGRAM

Free vibration characteristics, that is, the natural frequencies and corresponding mode shapes of the system are determined as described in the following steps :

$$[M]_n \{\ddot{x}\}_n + [k]_n \{x\}_n = 0$$

$[M]$ = mass matrix

$[K]$ = stiffness matrix

$\{\ddot{x}\}$ = acceleration vector

$\{x\}$ = displacement vector

n = order of matrices and vectors

If the solution of the above equation is assumed as X = XSinpt, the above equation is converted into

(i) $K_n X_n = P^2 m_n x_n$

(ii) $K_n^{-1} M_n X_n = \frac{1}{p^2} X_n$

The above equations are the forms of standard eigen value problem whose solution leads to evaluation of natural frequencies and corresponding mode shapes. There are several methods of solving the eigen value problem. The inverse iteration method with shift of origin was employed in this study.

The mode participation factor is given as,

$$C_j^{(r)} = \frac{\{\phi\}^T \{M\} \{L_j\}}{\{\phi\}^T [M] \{\phi\}}$$

where $\{L_j\}^T = \{1,0,0\}$ for $j = 1$

7.4 COMPARISON OF ANALYTICAL AND EXPERIMENTAL RESULTS

The experimentally and theoretical values of time periods are :

NAME OF THE BUILDING	EXPERIMENTAL TIME PERIOD (second)	THEORETICAL TIME PERIOD (second)		
		1^{st}MODE	2^{nd}MODE	3^{rd}MODE
Department of Earthquake Engineering				
(i) Transverse Direction	0.308	0.34	0.12	0.08
Communication Tower of Electronics Engineering Department				
(i) Longitudinal Direction	0.685	0.81	0.17	0.07
(ii) Transverse Direction	0.795	0.97	0.21	0.09

On comparing the results obtained from experimental and analytical analysis it seen that the values of time period obtained from analytical analysis are of the order of 10 to 15% higher than those of experimentally obtained. This may be due to crude modelling of the structures, aimed only to compare/validate the results obtained experimentally.

The mode shape coefficients were also obtained from analytical analysis and are shown in table :4.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8.1 SUMMARY

Study have been made for Ambient Vibration testing of twostructures studied namely (i) Department of Earthquake Engineering and (ii) Communication Tower of Electronics Engineering Department, Ranger Seismometers SS-1 (velocity pick-up) were used and recording was done in Solid State Recorder SSR-1 RAM memory, recorded data were latter transferred to PC and were analyzed using SWS software.

To validate/compare the experimentally obtained results analytical analysis was done for both structures using suitable mathematical models.

8.2 CONCLUSIONS

Ambient Vibration testing was done for two structures and the results obtained are :

1) Time period of Earthquake Engineering Department in transverse direction is 0.308 seconds.

2) Values of peak acceleration, velocity and displacement for wind induced vibrations in Earthquake Engineering Department were obtained as shown in table :2 for event 1 & 2.

3) Values of peak acceleration, velocity and displacement for generator induced vibration (placed in the ground floor of the building) in Earthquake Engineering Department were obtained as shown in table :2 for event 3.

4) From analytical analysis of Earthquake Engineering Department the time period was found 0.34 seconds.

5) Time period of Communication Tower of Electronics Engineering Department in transverse direction is 0.795 seconds and in longitudinal direction is 0.685 seconds.

6) Values of peak acceleration, velocity and displacement for

wind induced vibrations in Communication Tower of Electronics Engineering Department were obtained as shown in table :3 for event 1 & 2.

7) From analytical analysis of Communication Tower of Electronics Engineering Department the time period in 1^{st} mode in transverse direction is 0.97 seconds and in longitudinal direction is 0.81 seconds.

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TABLE :1

ELEVATION OF STORIES

FLOOR	ELEVATION IN METERS
GROUND	0.00
1	2.35
2	5.53
3	8.89
4	12.24
5	15.59
6	18.94
7	22.29
8	25.65
9	29.00
10	32.35
11	35.70
12	40.30
13	42.60

TABLE :2

AMBIENT VIBRATION RESPONSE OF DIFFERENT FLOOR LEVELS (Peak values) for Department of Earthquake Engineering Building in transverse direction :

EVENT 1 (File Name AD500005)

Date	Channel No.	Acceleration (cm/sec^2)	Velocity cm/sec	disp cm	Sensor Position	Floor Level
11/9/93	2	7.88	-0.09	0.01	V	3
	3	-4.89	-0.22	-0.02	H	3
	4	-7.10	0.08	-0.01	V	1
	5	7.14	-0.08	0.01	V	2
	6	-3.57	-0.17	-0.02	H	2
	7	-3.08	-0.14	-0.01	H	1

EVENT 2 (File Name AD400006)

Date	Channel No.	Acceleration (cm/sec^2)	Velocity cm/sec	disp cm	Sensor Position	Floor Level
11/9/93	2	-6.90	-0.21	-0.02	V	3
	3	-6.57	-0.21	-0.01	H	3
	4	-5.10	-0.19	0.02	V	1
	5	-4.76	0.12	0.01	V	2
	6	-4.85	-0.19	0.02	H	2
	7	-4.91	-0.12	0.01	H	1

EVENT 3 (File Name AD400003)

Date	Channel No.	Acceleration (cm/sec^2)	Velocity cm/sec	disp cm	Sensor Position	Floor Level
11/9/93	2	-3.35	-0.17	-0.02	V	3
	3	-3.22	-0.17	-0.02	H	3
	4	-2.34	-0.14	-0.01	V	1
	5	-2.10	-0.09	-0.01	V	2
	6	-2.36	-0.13	-0.01	H	2
	7	-2.10	-0.09	-0.01	H	1

TABLE :3

AMBIENT VIBRATION RESPONSE OF DIFFERENT FLOOR LEVELS (Peak Values)
For Communication Tower of Department of Electronics Engineering

EVENT 1 (File Name AD600001)

Date	Channel No.	Acceleration (cm/sec^2)	Velocity cm/sec	disp cm	Sensor Position	Floor Level
11/9/93	2	5.17	0.50	0.06	T	7
	3	2.58	-0.14	0.01	L	6-7
	4	3.93	-0.29	0.03	L	5-6
	5	5.11	-0.43	-0.06	T	5
	6	3.09	-0.21	-0.02	L	4
	7	4.32	-0.36	-0.05	T	3

EVENT 2 (File Name AD600011)

Date	Channel No.	Acceleration (cm/sec^2)	Velocity cm/sec	disp cm	Sensor Position	Floor Level
11/9/93	2	-2.65	0.26	0.03	T	7
	3	-1.73	-0.08	0.01	L	6-7
	4	-2.20	0.14	-0.02	L	5-6
	5	-3.42	-0.30	0.04	T	5
	6	-1.99	-0.13	-0.02	L	4
	7	-3.00	-0.24	0.03	T	3

TABLE : 4

Dimensions of various elements of E & C Tower

Member	Breadth M	Depth M	Area M^2	Moment of Inertia M^4
Wall 1	0.3937	2.7813	1.095	0.7058
Wall 2	0.3937	3.6576	1.440	1.6053
Beam	0.2286	0.4572	0.1045	0.00182

Modulus of Elasticity — 2110000.00 T/m^2

Shear Modulus — 879166.0 T/m^2

Shape Factor — 1.2

Value of Soil Springs —

Horizontal Spring — 29770.0 T/m

Rotational Spring — 145000.0 T-m/radian

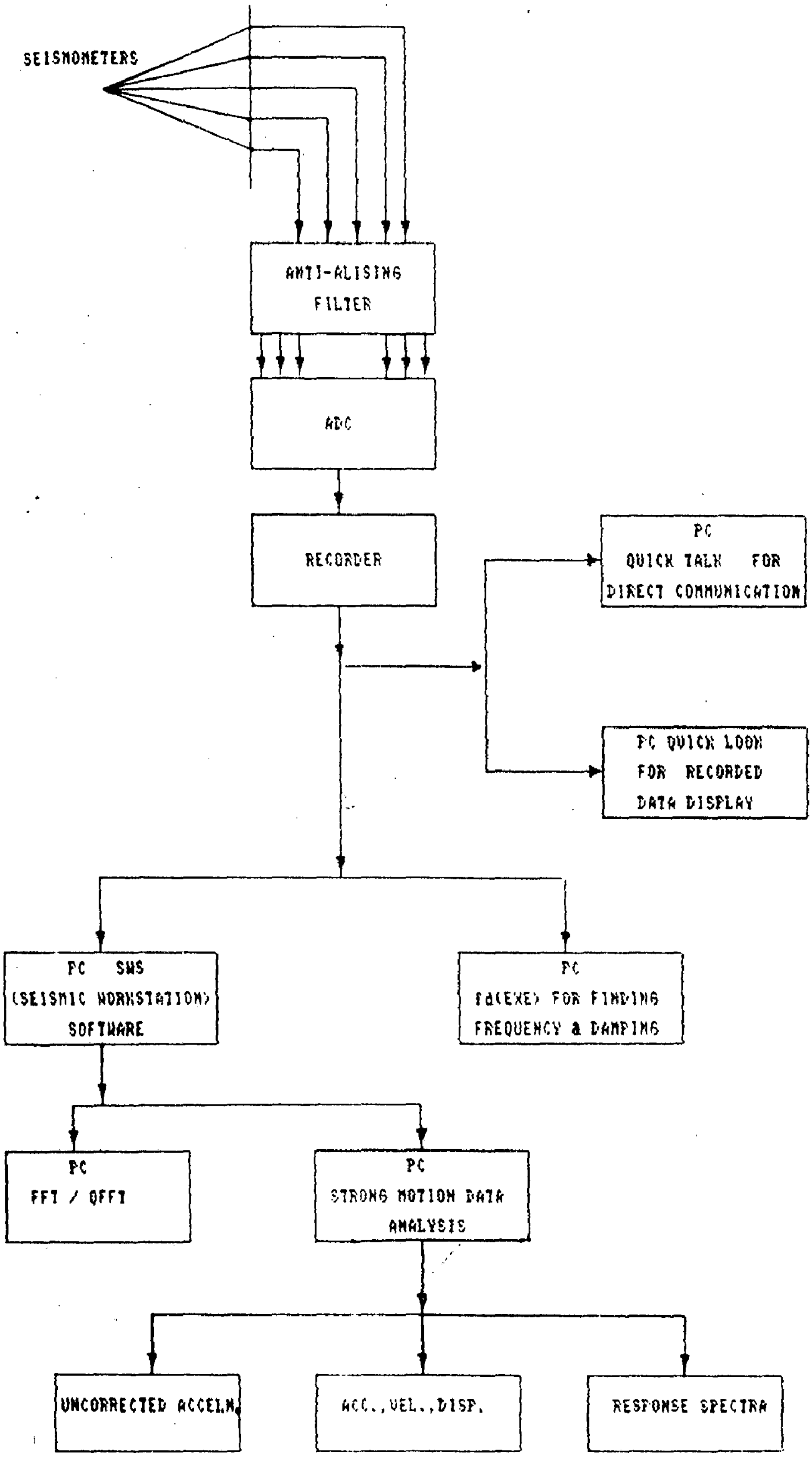


Fig:1 AMBIENT VIBRATION TESTING SET UP

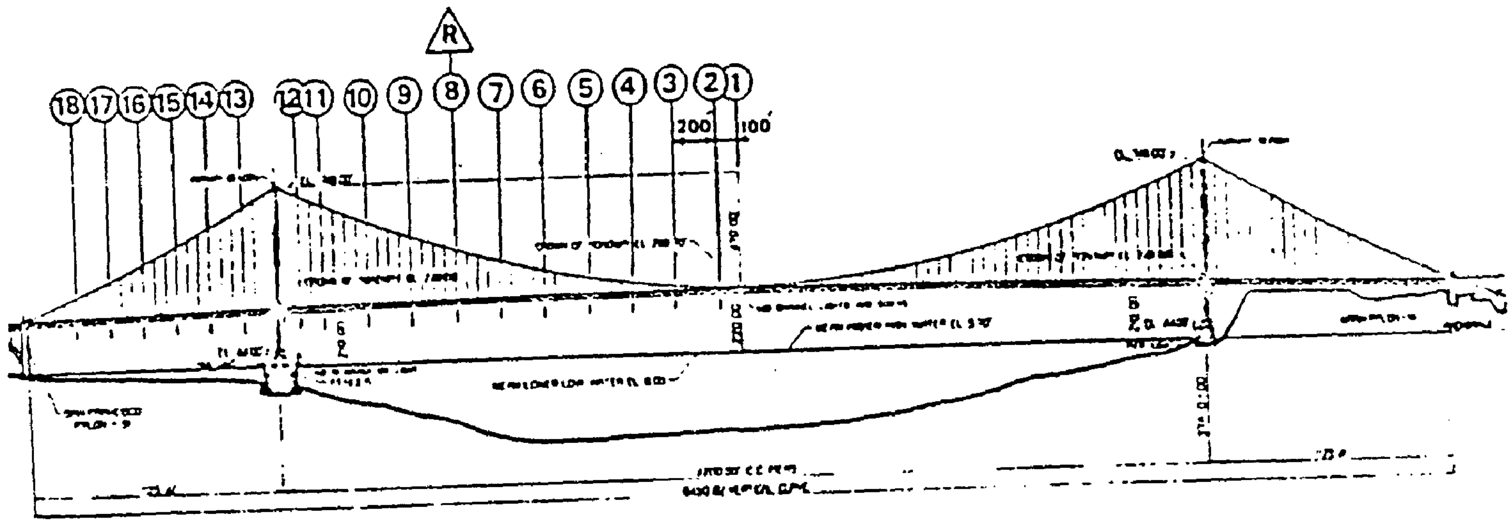


FIG :2 Elevation of Golden Gate Suspension Bridge showing span measurement location

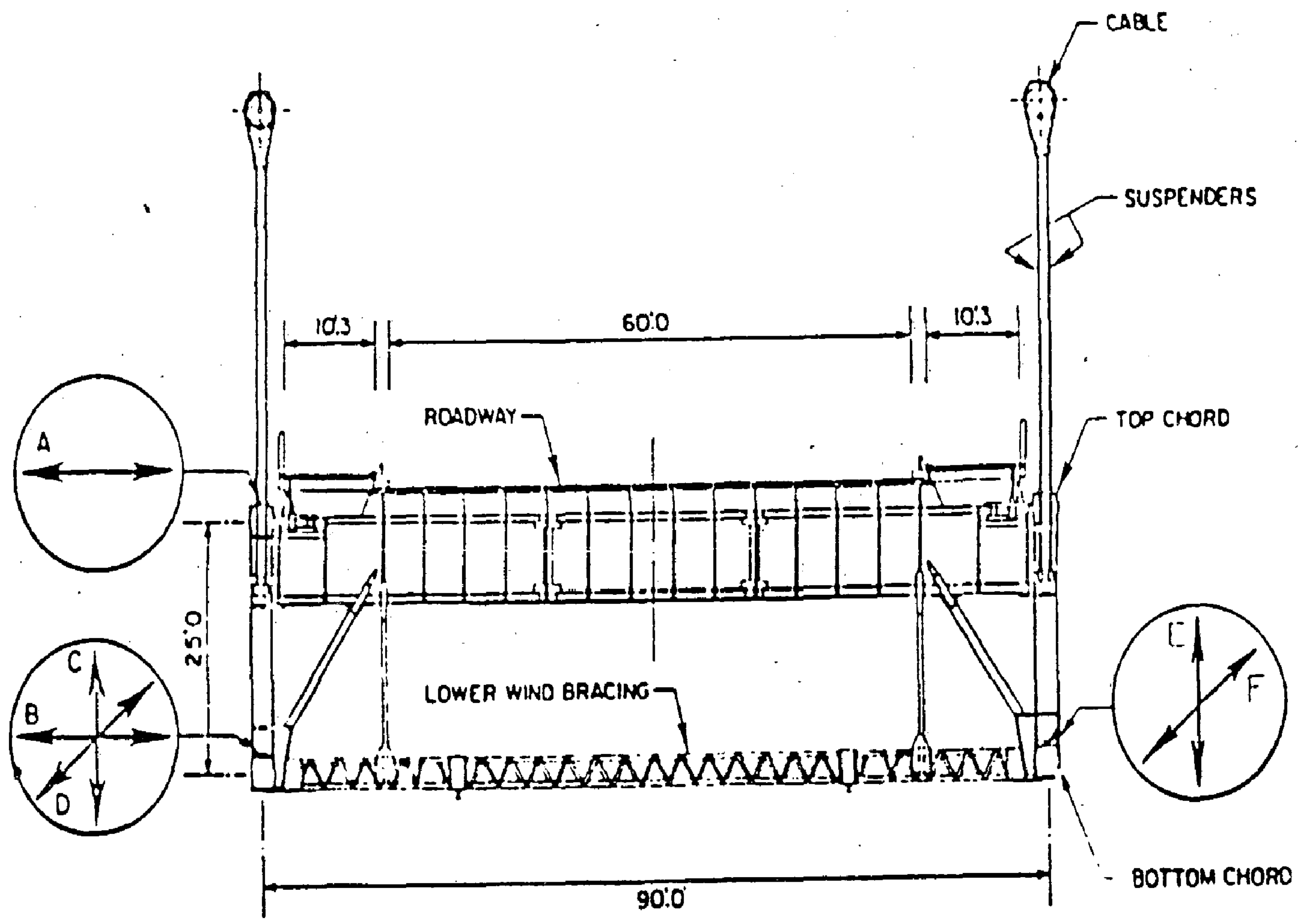


FIG :3 Typical span cross section showing sensor placement

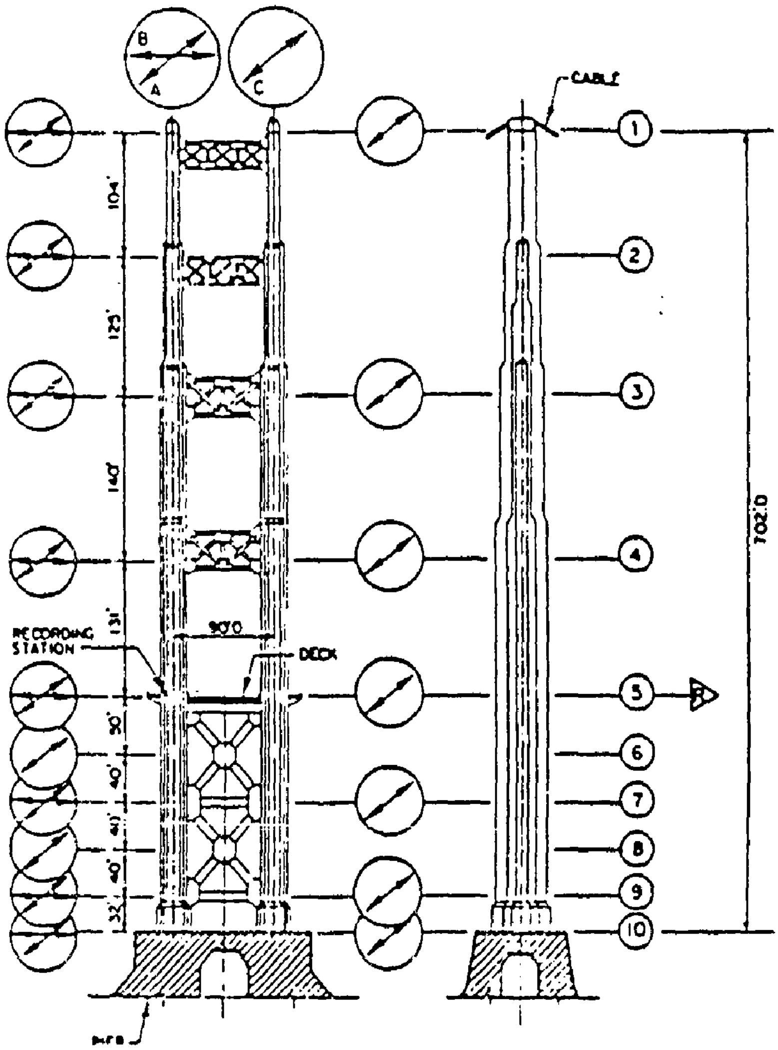


FIG :4 San Francisco tower with measurement station shown

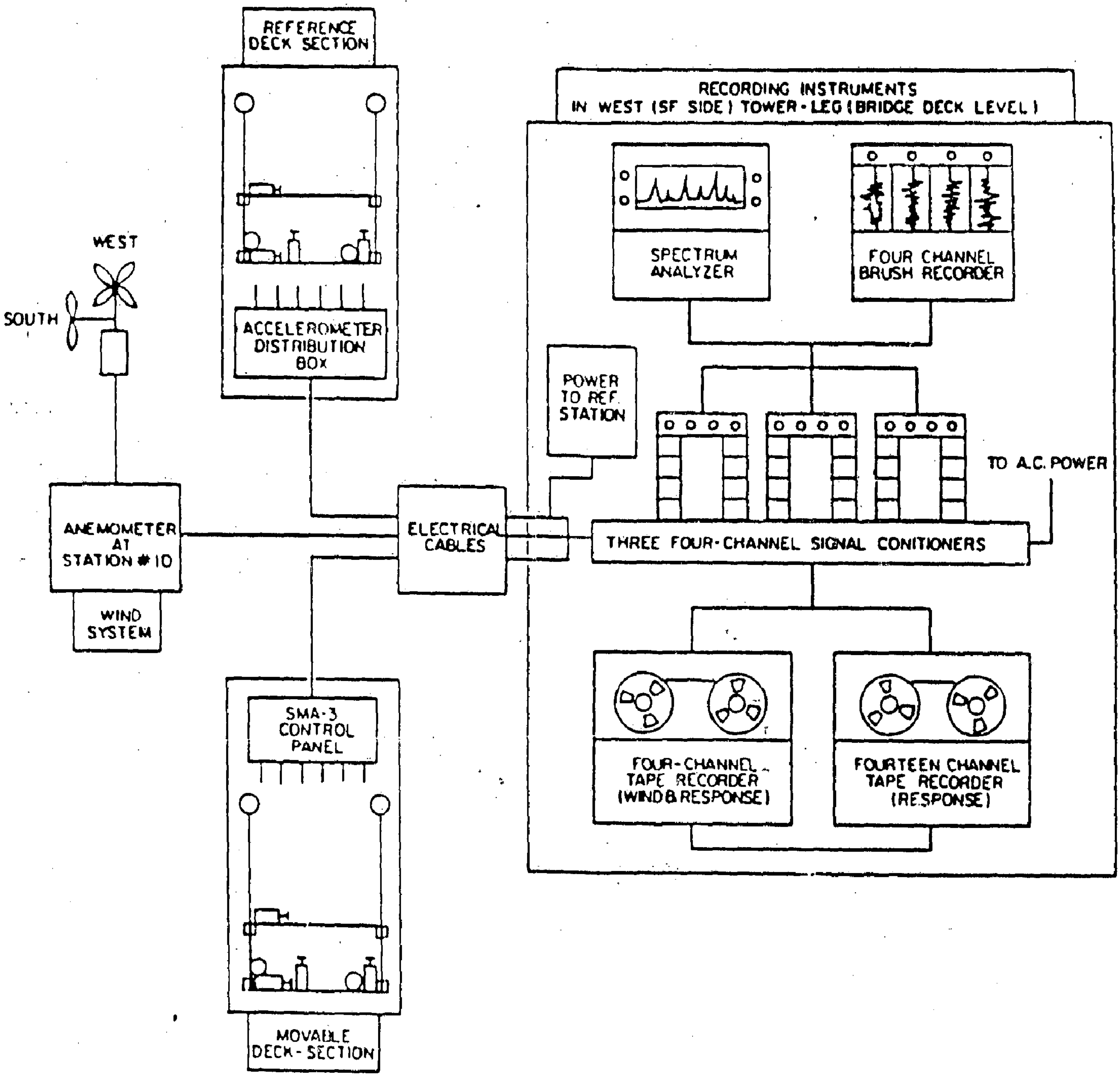


FIG :5 Ambient Vibration measurement system

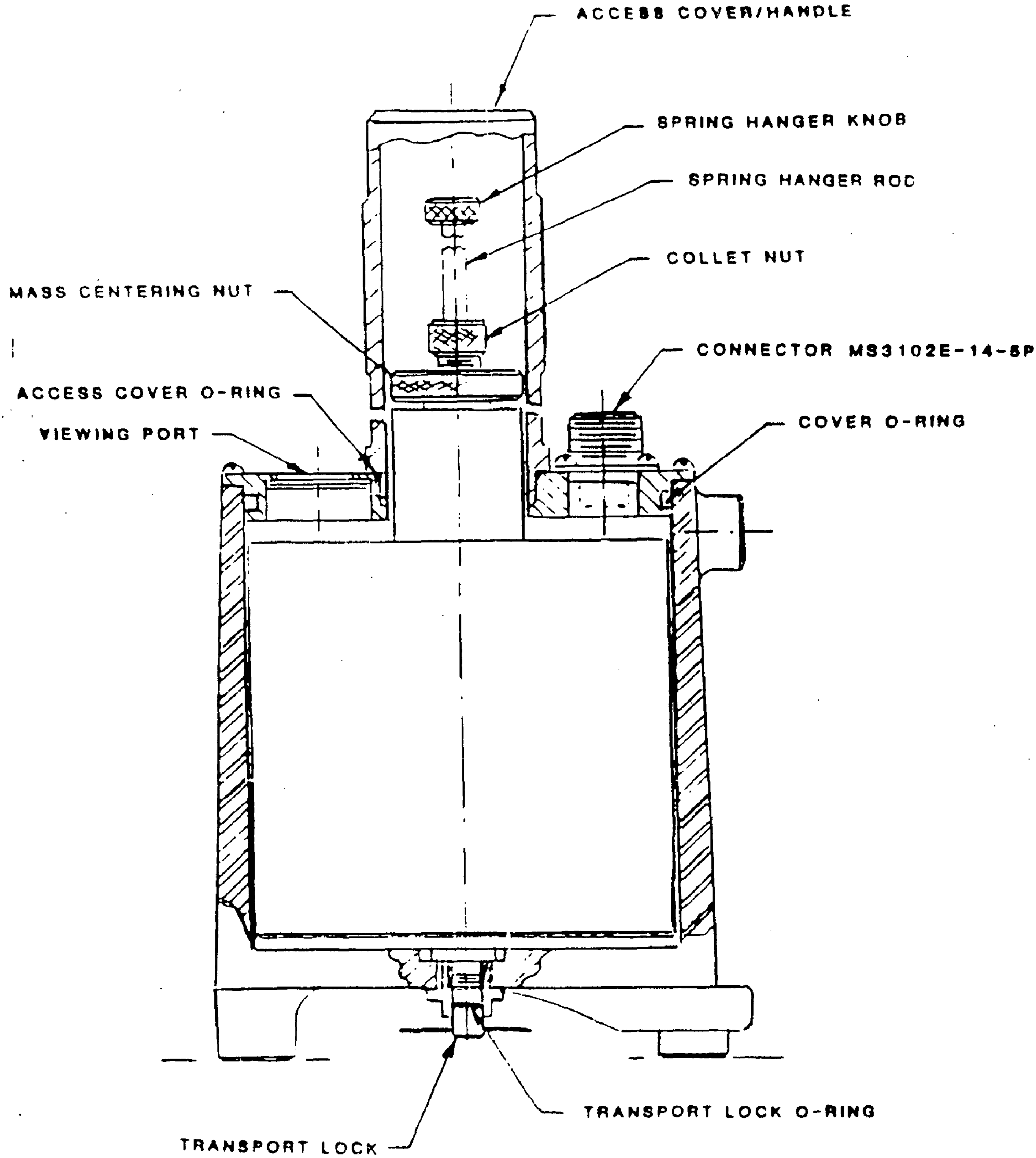


FIG :6 Seismometer and case assembly

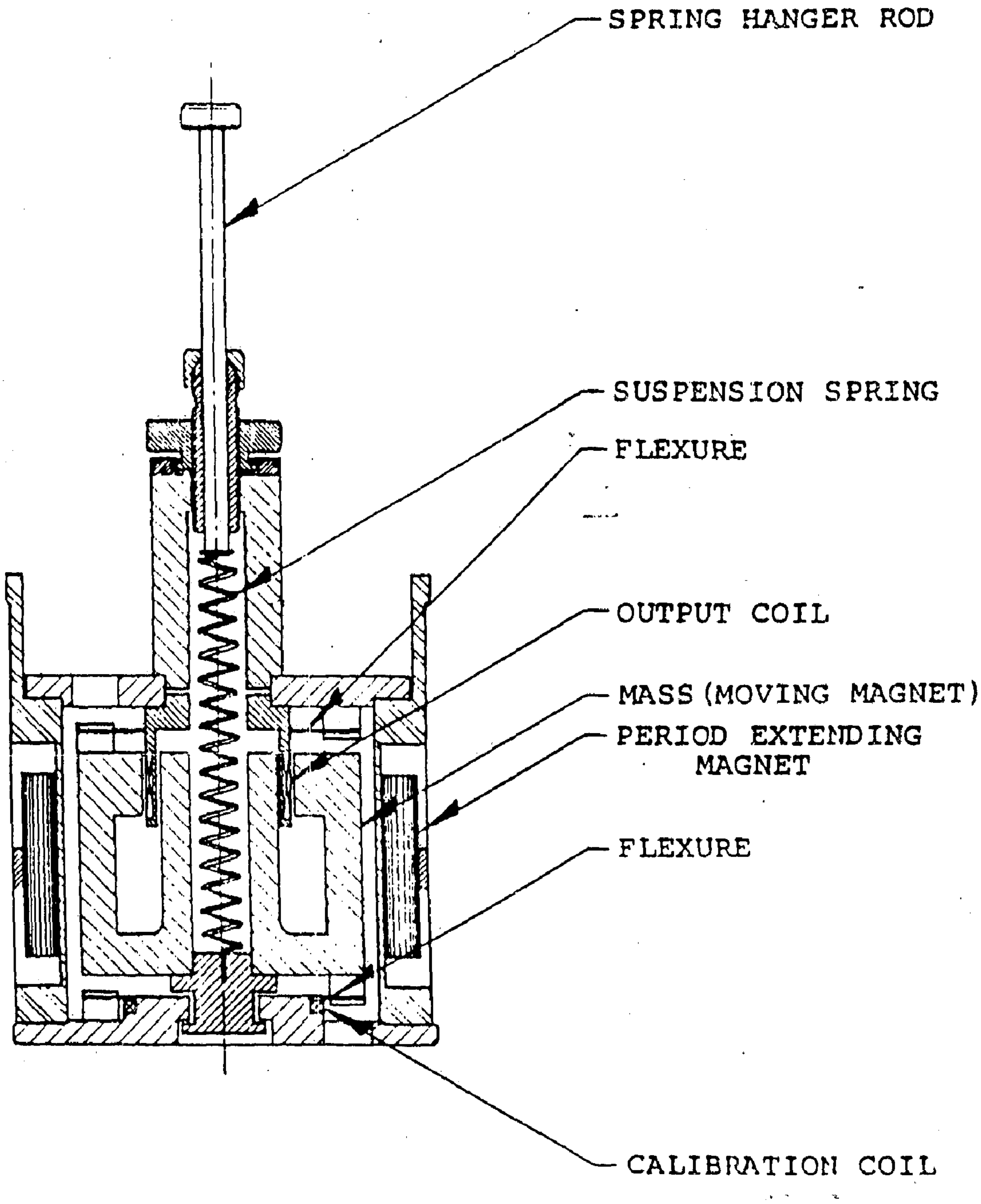


FIG :7 General construction

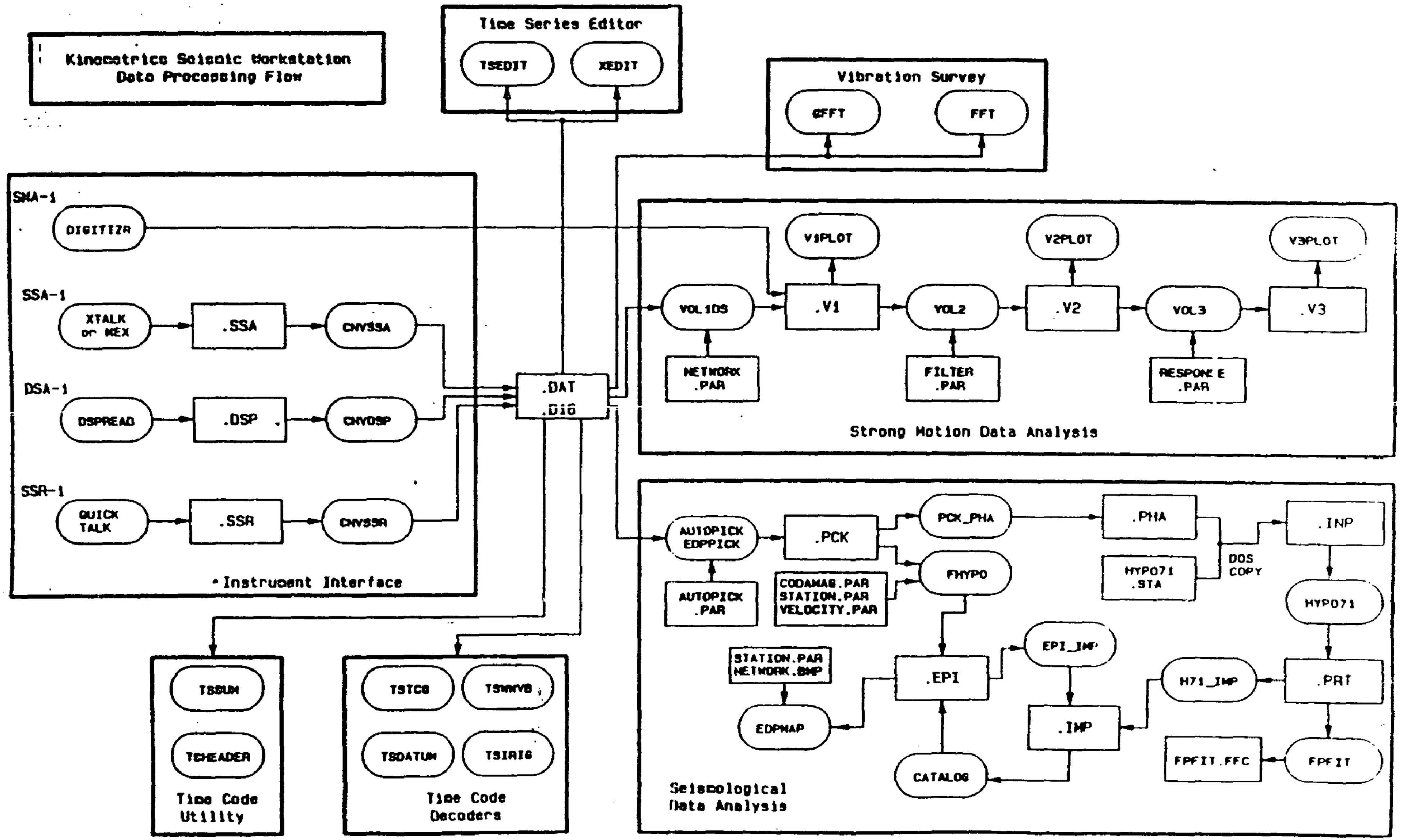


FIG :8 Block diagram

```
D:\WORKSTN\EXE>qfft AD500005
QFFT- Fast Fourier Transform Program (12/16 Bits)
SWS-1  Seismic Workstation Software Rev. F
       Seismic Workstation Libraries Rev. E (12/16 bits)
       Copyright (c) 1986,1987  Kinemetrics Systems
Number of analyzer channels [1..4]? 4
Transform order [5.. 9]? 9
Window [1=none,2=Hanning,3=Hamming]? 1
Editing file ---> AD500005.D16
Data width ---> 16 bits
                                        sample rate:  200.0

Channels:
 1 TIME     3          5          7
 2          4          6
Select channel (#1) [1.. 7] -2
Select channel (#2) [1.. 7] -3
Select channel (#3) [1.. 7] -4
Select channel (#4) [1.. 7] -5
Time offset (seconds)?
Reading data file...
Calculating ch 1 fft...
Calculating ch 2 fft...
Calculating ch 3 fft...
```


FIG :9   QFFT initial dialog example

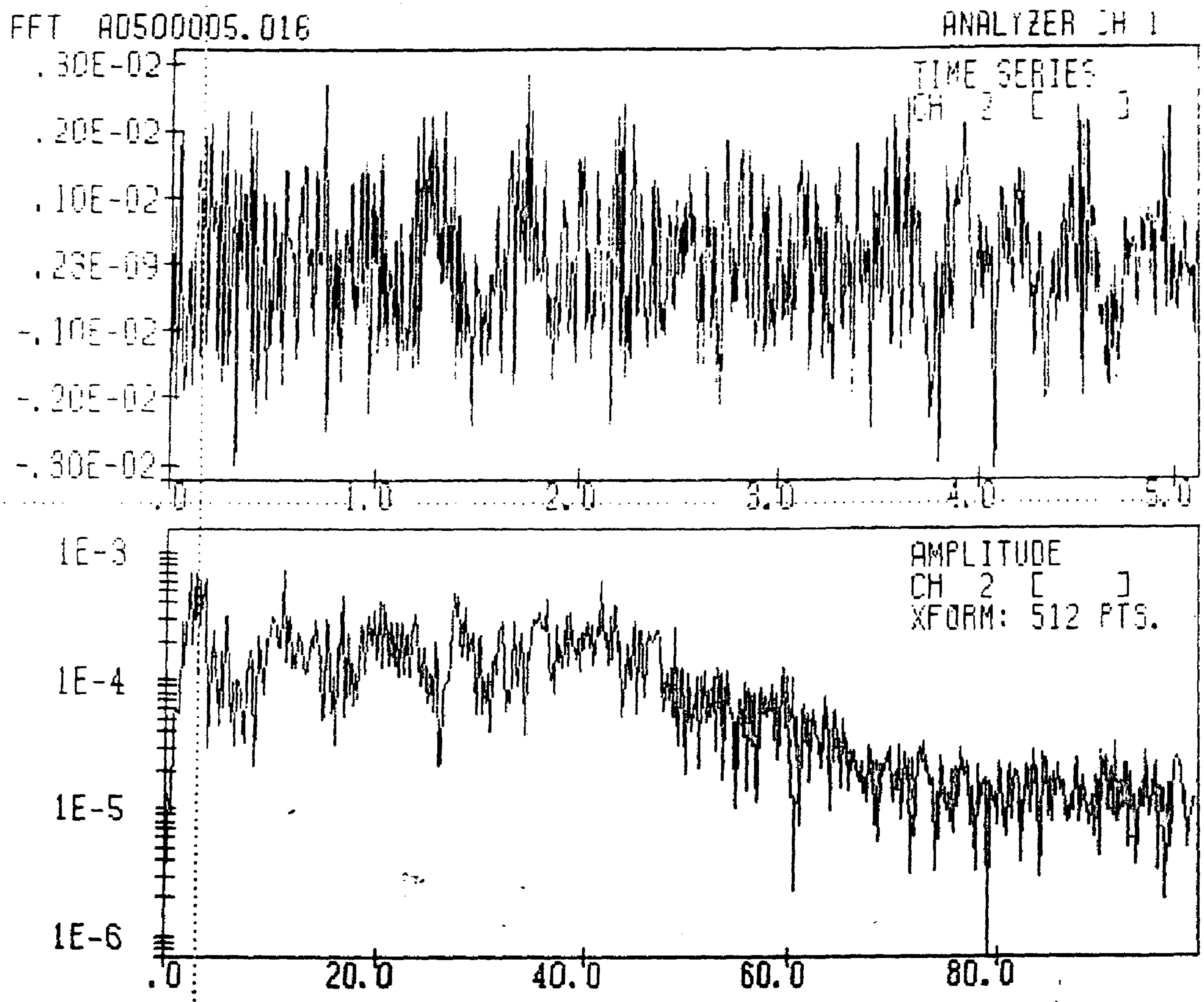


FIG :10 FFT (Fast Fourier Transform)

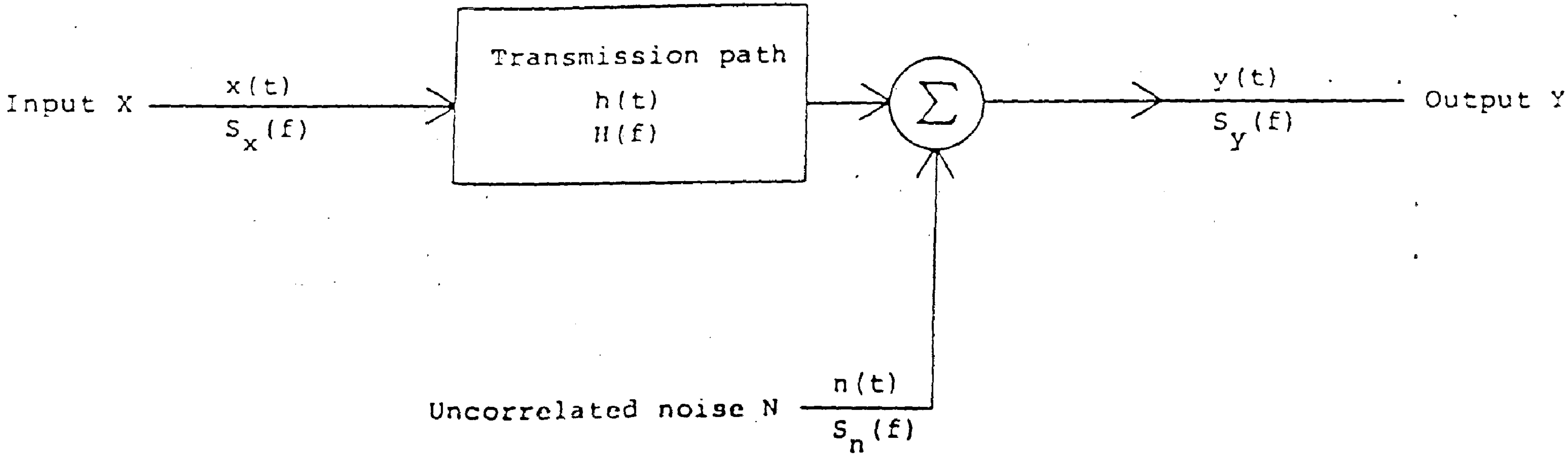
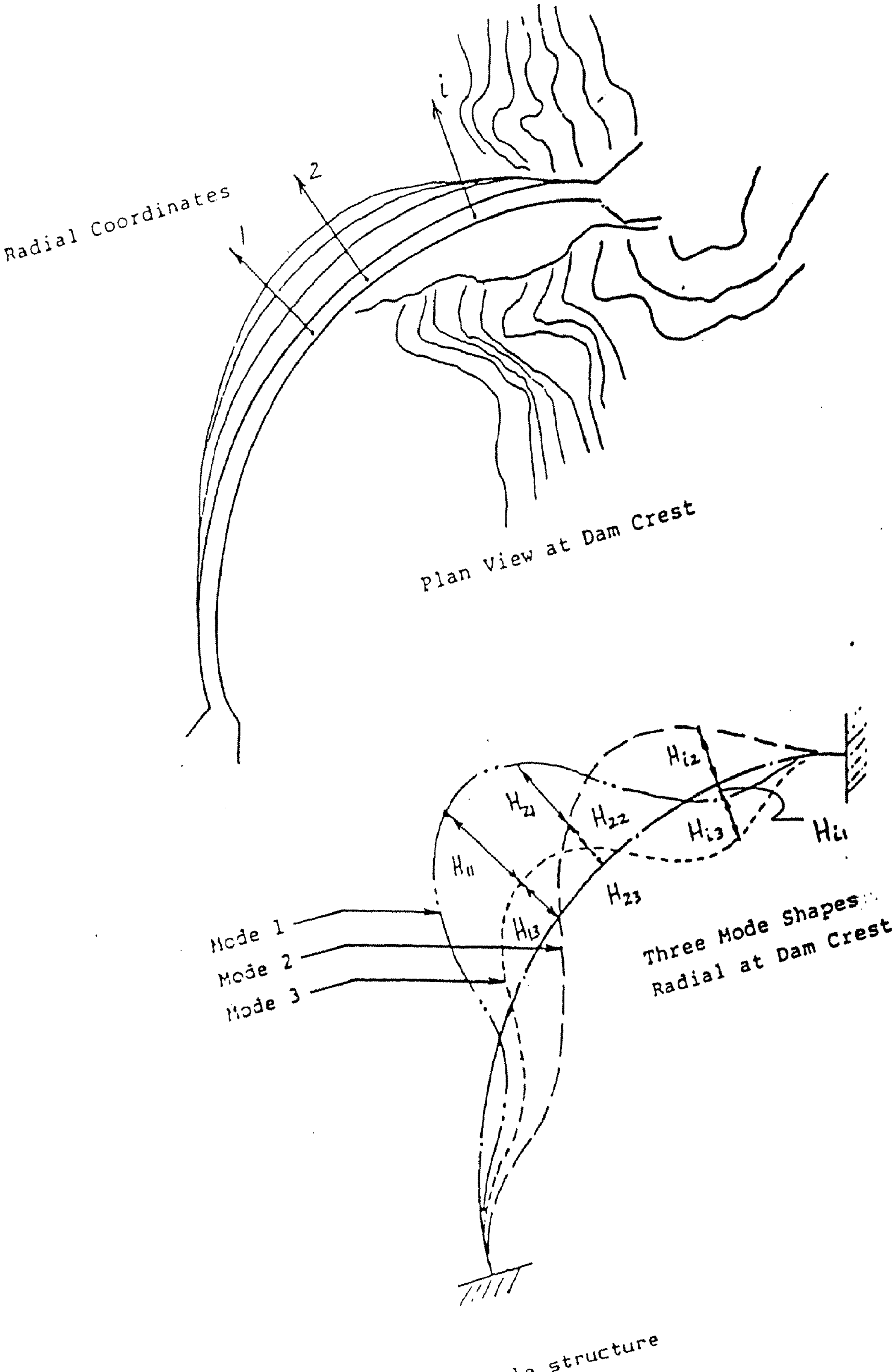


FIG :11 **General measurement system**



Example structure

FIG :12

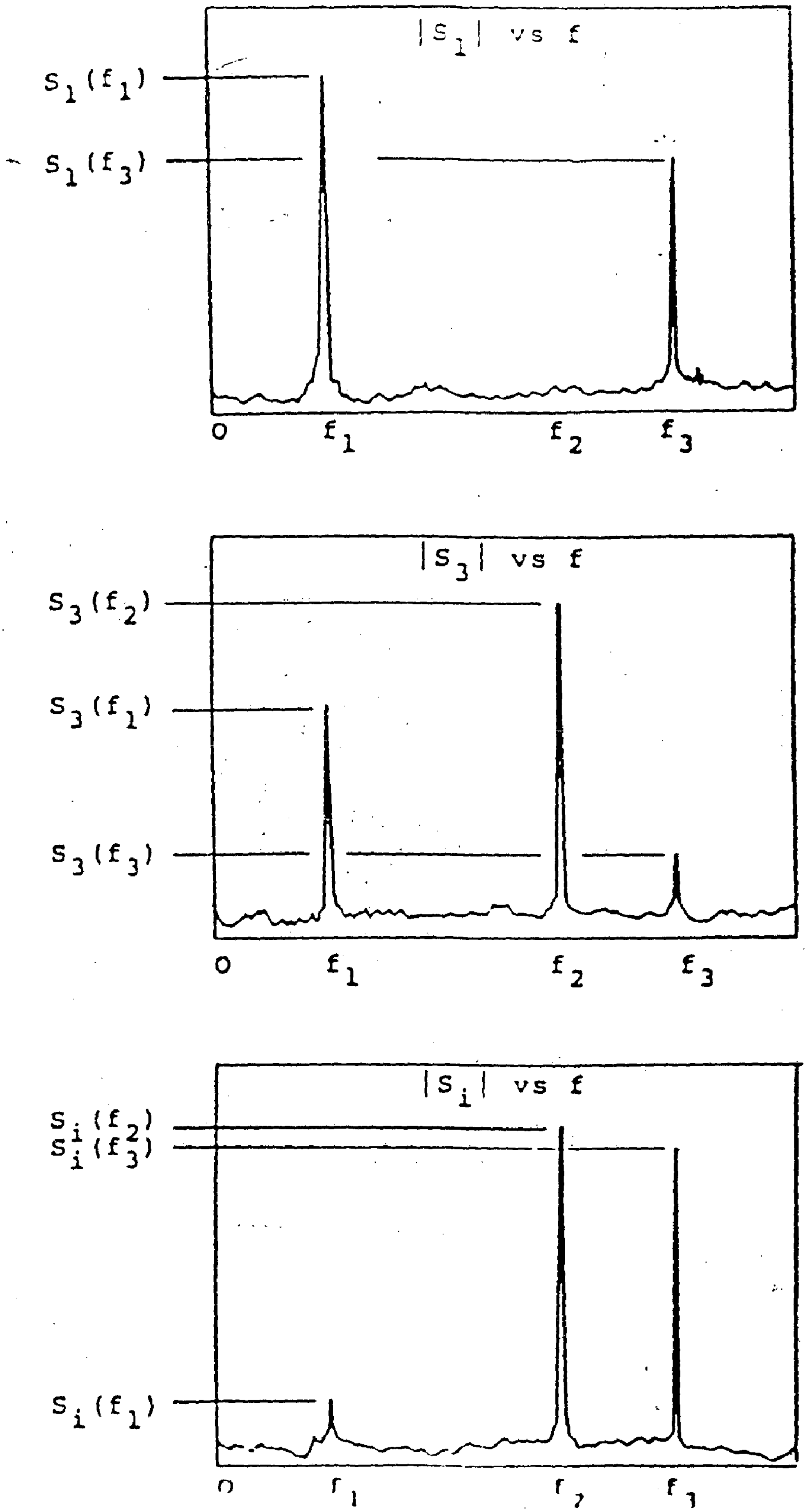


FIG :13 Amplitude spectra

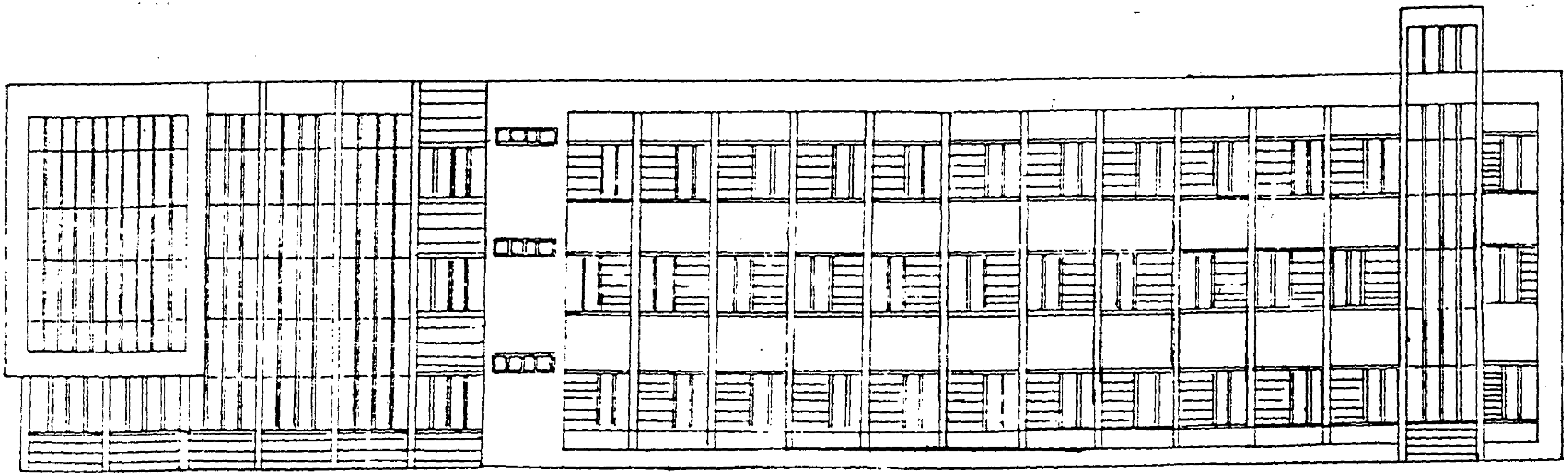


FIG :14 Front elevation of Department of Earthquake Engineering

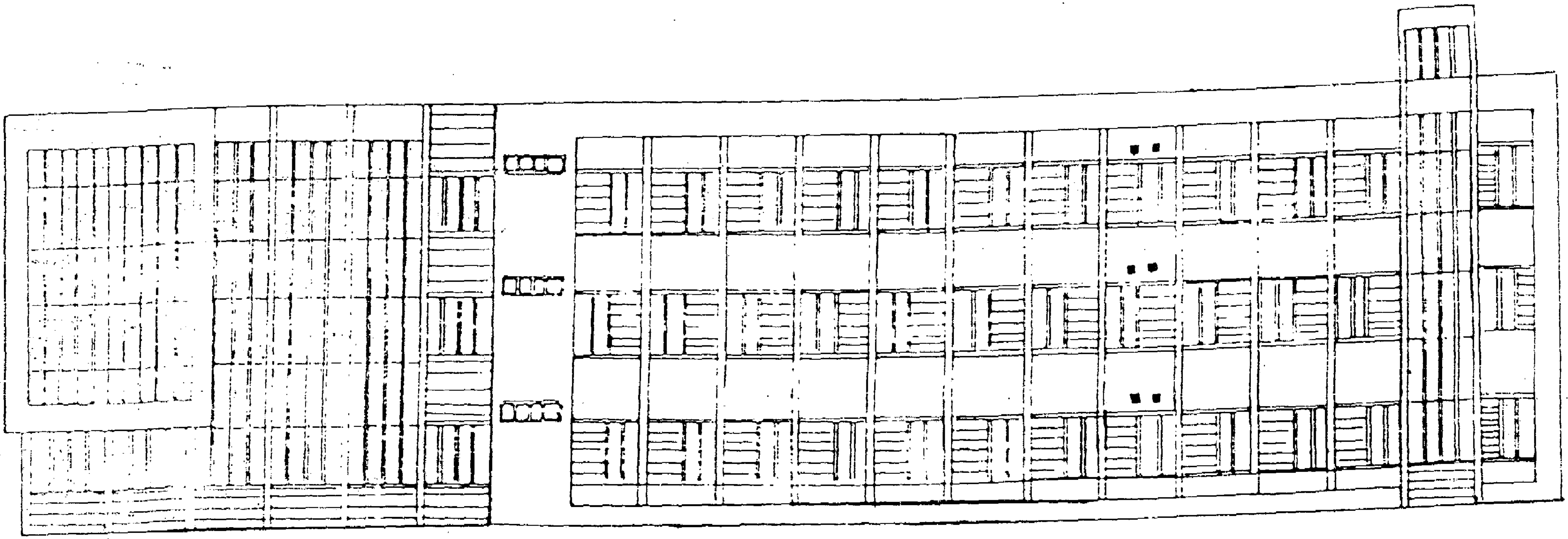
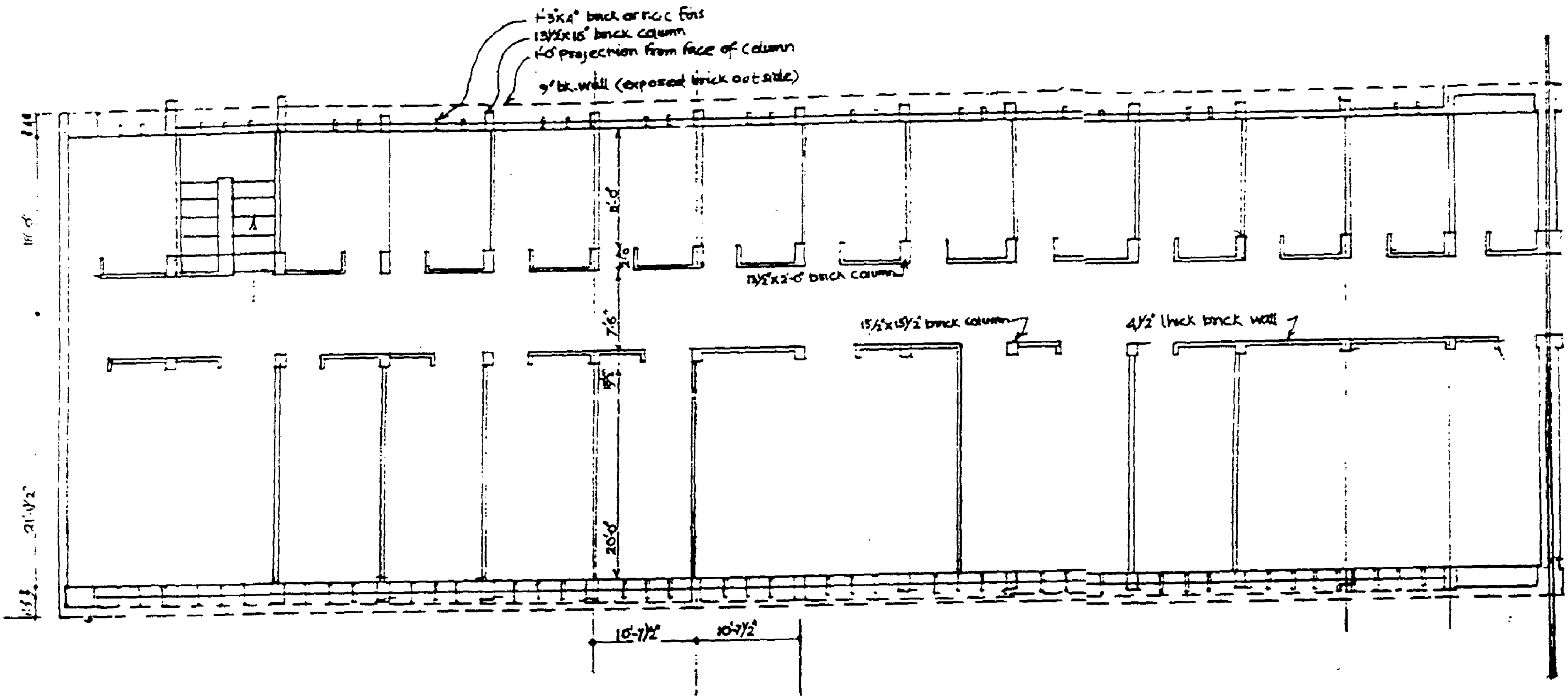
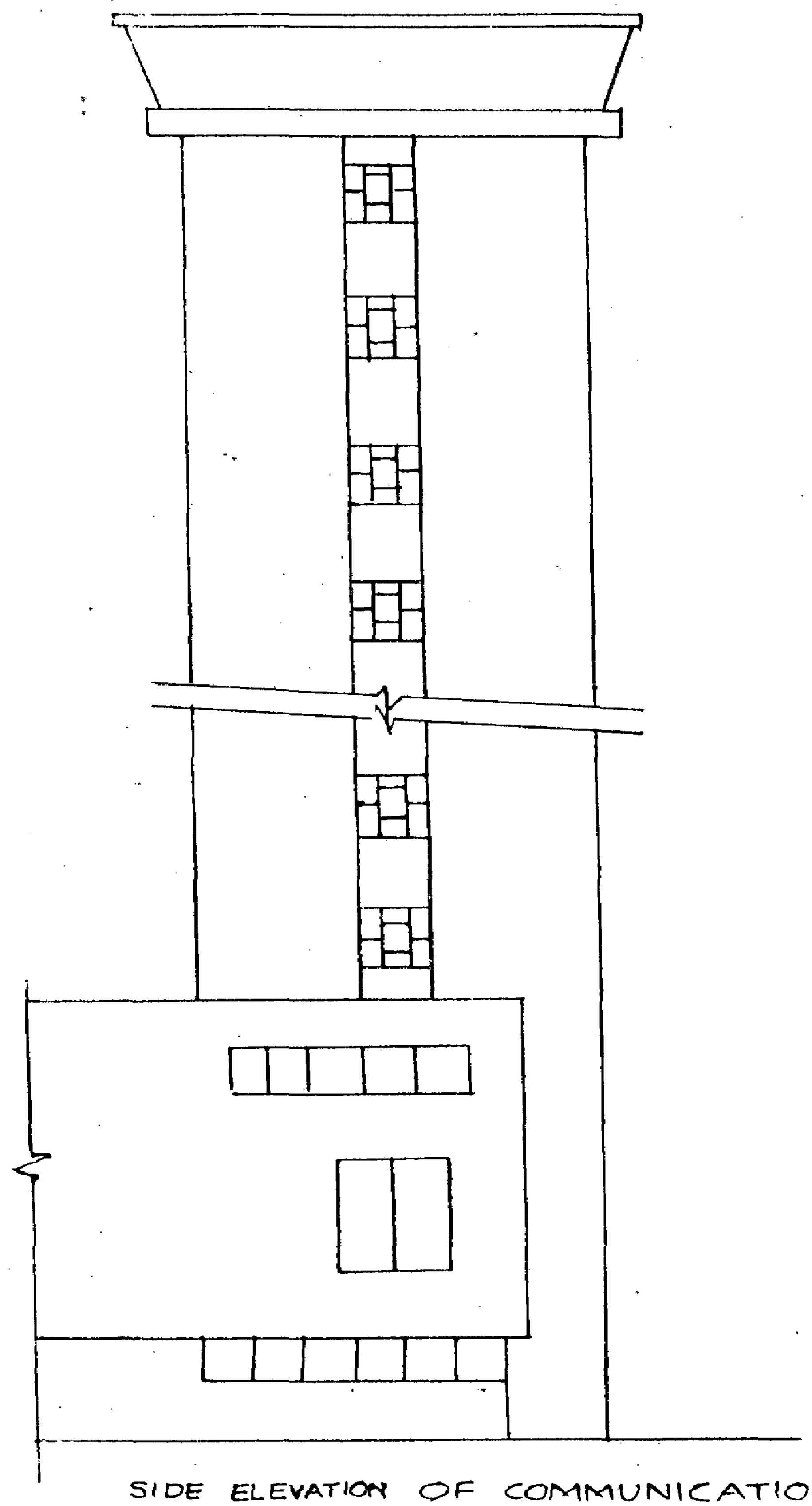


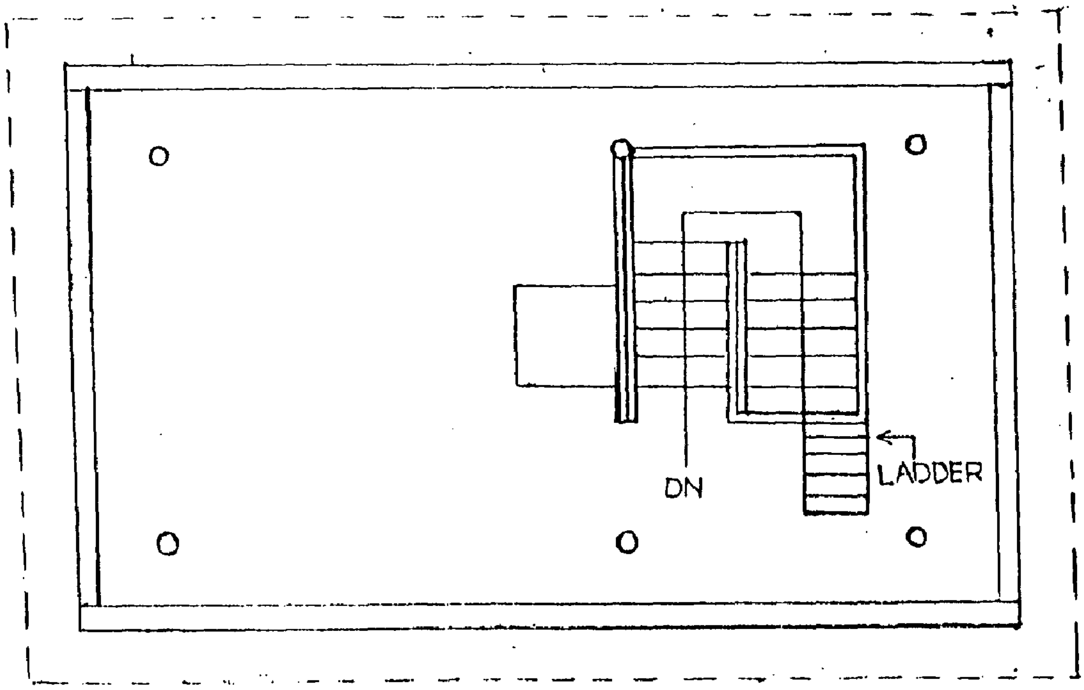
FIG :15 Location of Ranger Seismometer in Department of Earthquake Engineering



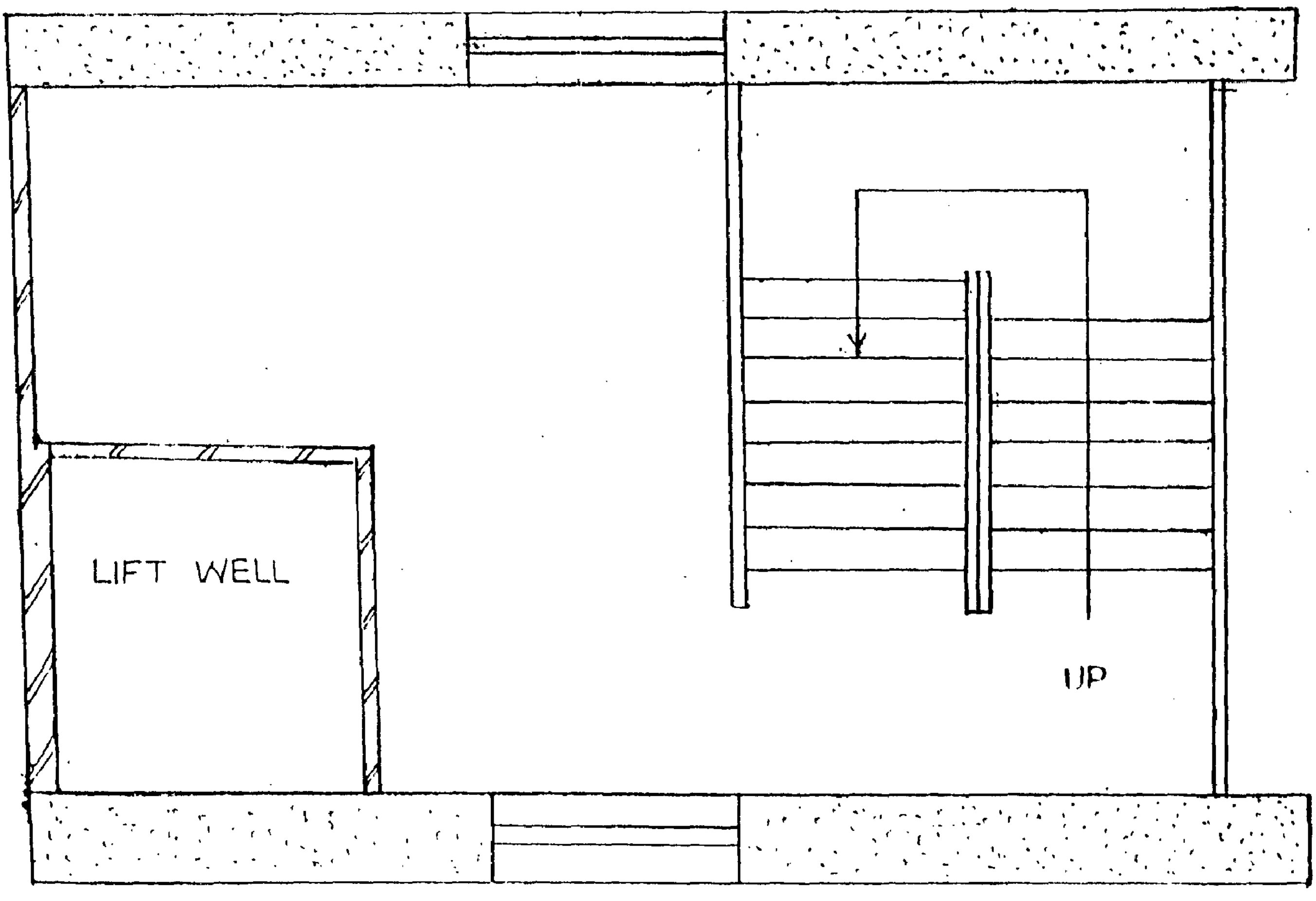
FIRST FLOOR PLAN
FOR
EARTHQUAKE ENGG.
DEPARTMENT



SIDE ELEVATION OF COMMUNICATION TOWER OF ELECTRONICS ENGG. DEPARTMENT



TOP FLOOR



INTRMIDIATE FLOOR

TYPICAL FLOOR PLAN OF TOWER

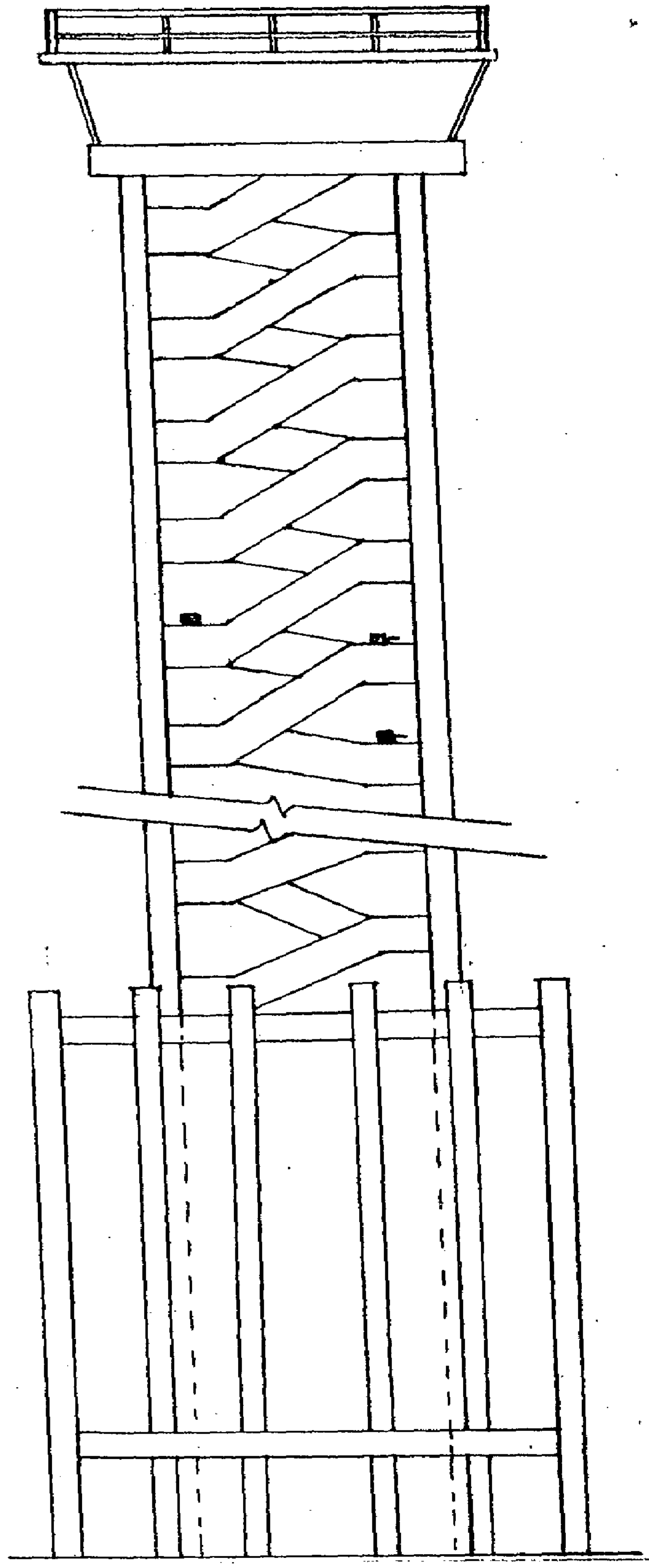


FIG :17 Location of Ranger Seismometer in Communication Tower

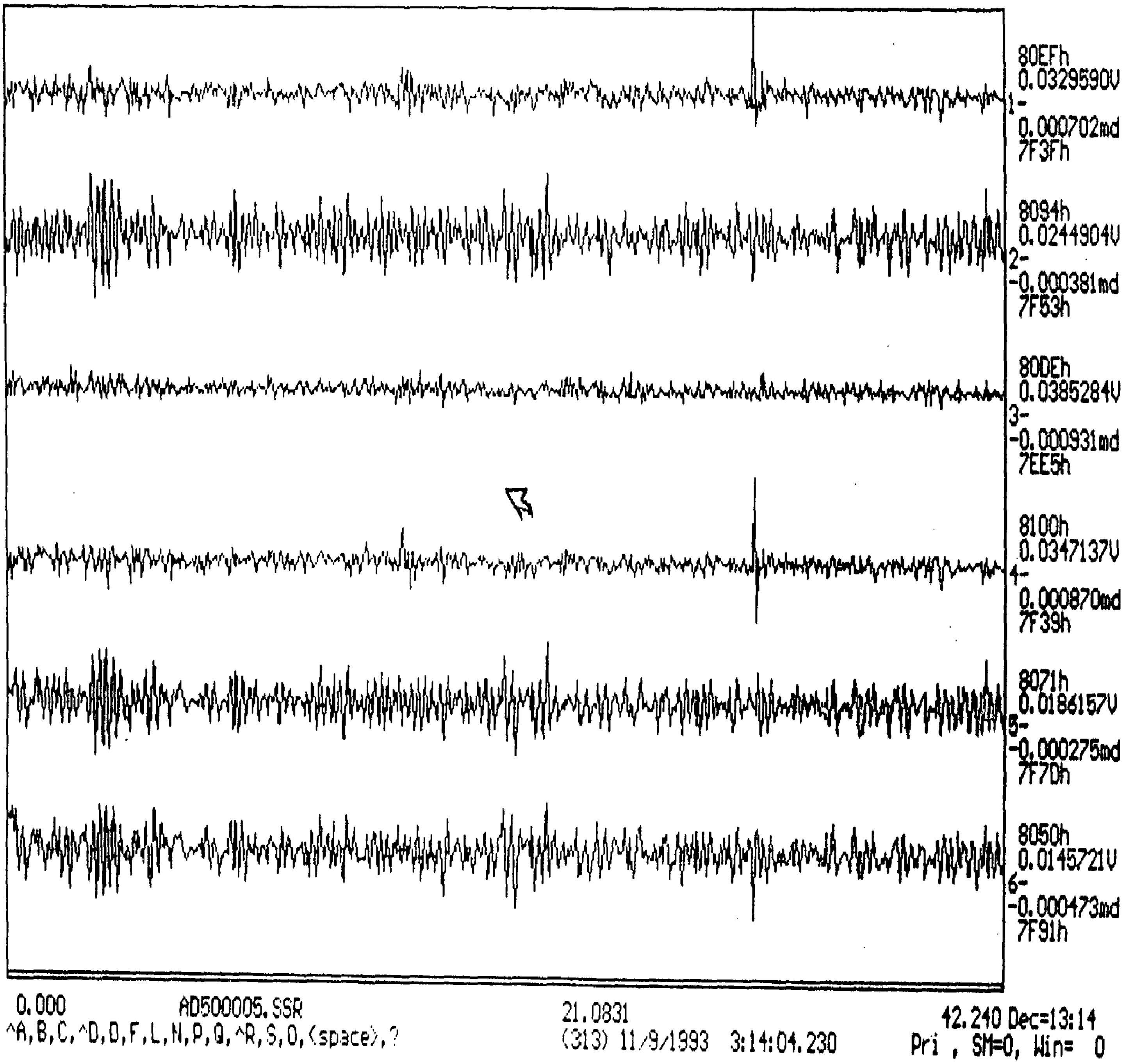
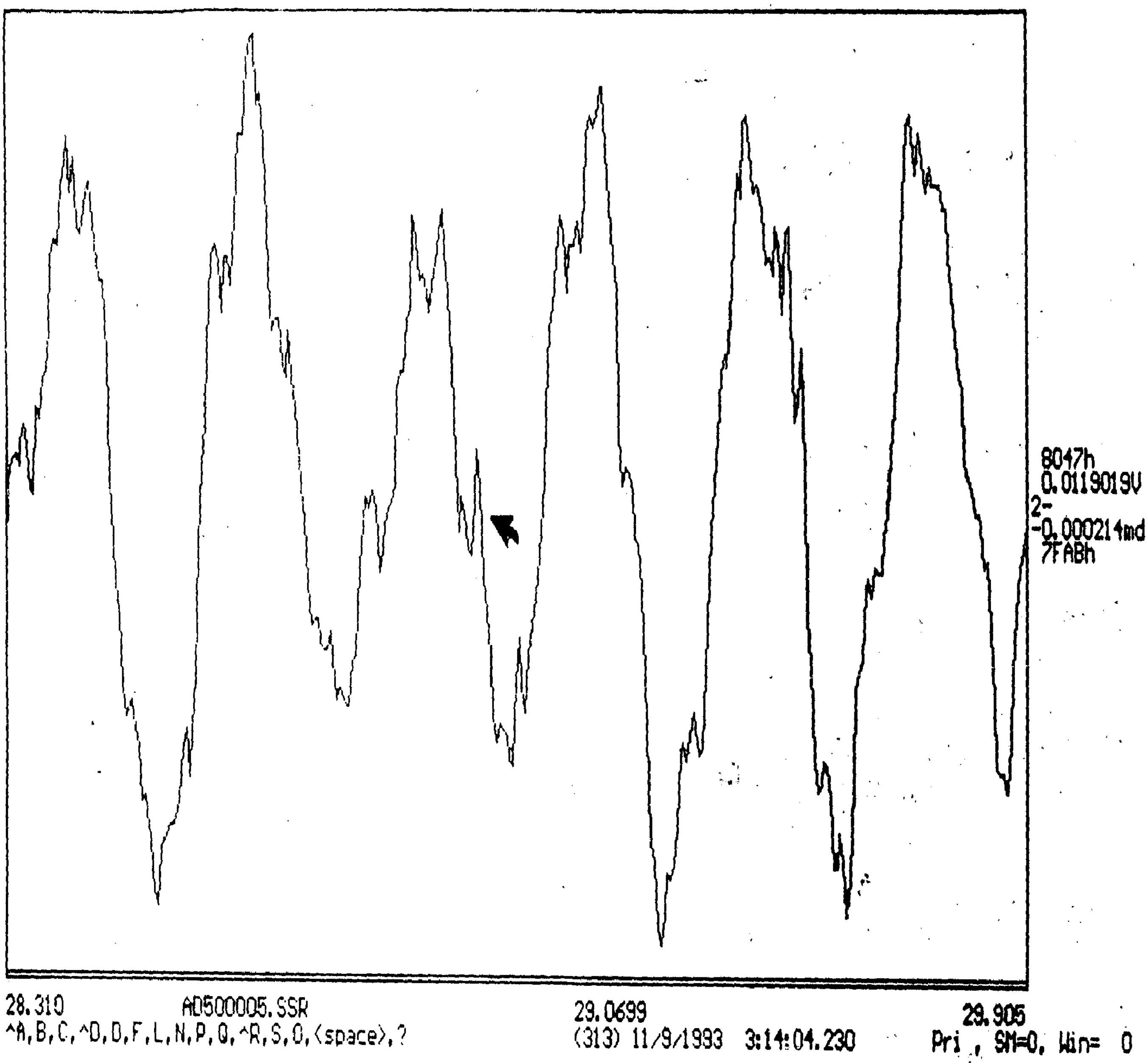


FIG :18 Showing QUICKLOOK


8047h
0.0119019V
2-
-0.000214md
7FABh
28.310
AD500005.SSR
29.0699
29.905
^A,B,C,^D,D,F,L,N,P,Q,^R,S,0,(space),?
(313) 11/9/1993 3:14:04.230
Pri , SM=0, Win= 0

Plot Parameters

Chan:	1	2	3	4	5	6
Gain:	1	1	1	1	1	1
V Max:	0.0182343	0.0112915	0.0169373	0.0195313	0.0086212	0.0061035
V Min:	-0.0147247	-0.0131989	-0.0215912	-0.0151825	-0.0099945	-0.0084686
V P-P:	0.0329590	0.0244904	0.0385284	0.0347137	0.0186157	0.0145721
V Median:	0.0017548	-0.0009537	-0.0023270	0.0021744	-0.0006866	-0.0011826
V Mean:	-0.0005571	-0.0003628	-0.0008011	-0.0002908	-0.0004128	-0.0003312
Peak:	80EF hex	8094 hex	80DE hex	8100 hex	8071 hex	8050 hex
Valley:	7F3F hex	7F53 hex	7EE5 hex	7F39 hex	7F7D hex	7F91 hex
P-P cnts:	432	321	505	455	244	191

Baseline Corrected Peaks

V Max:	0.0187914	0.0116543	0.0177383	0.0198221	0.0090340	0.0064347
V Min:	-0.0141676	-0.0128361	-0.0207901	-0.0148917	-0.0095817	-0.0081375

Autoscale = TRUE, DAC = FALSE, Relative = FALSE
Filename:AD500005.SSR Nblocks=33
200.000 Sps,
MaxX=639 MaxY=349
Driver path = Data path =
Heapsize in blocks: 119 [any key]

FIG :19 Plot parameters for QUICKLOOK

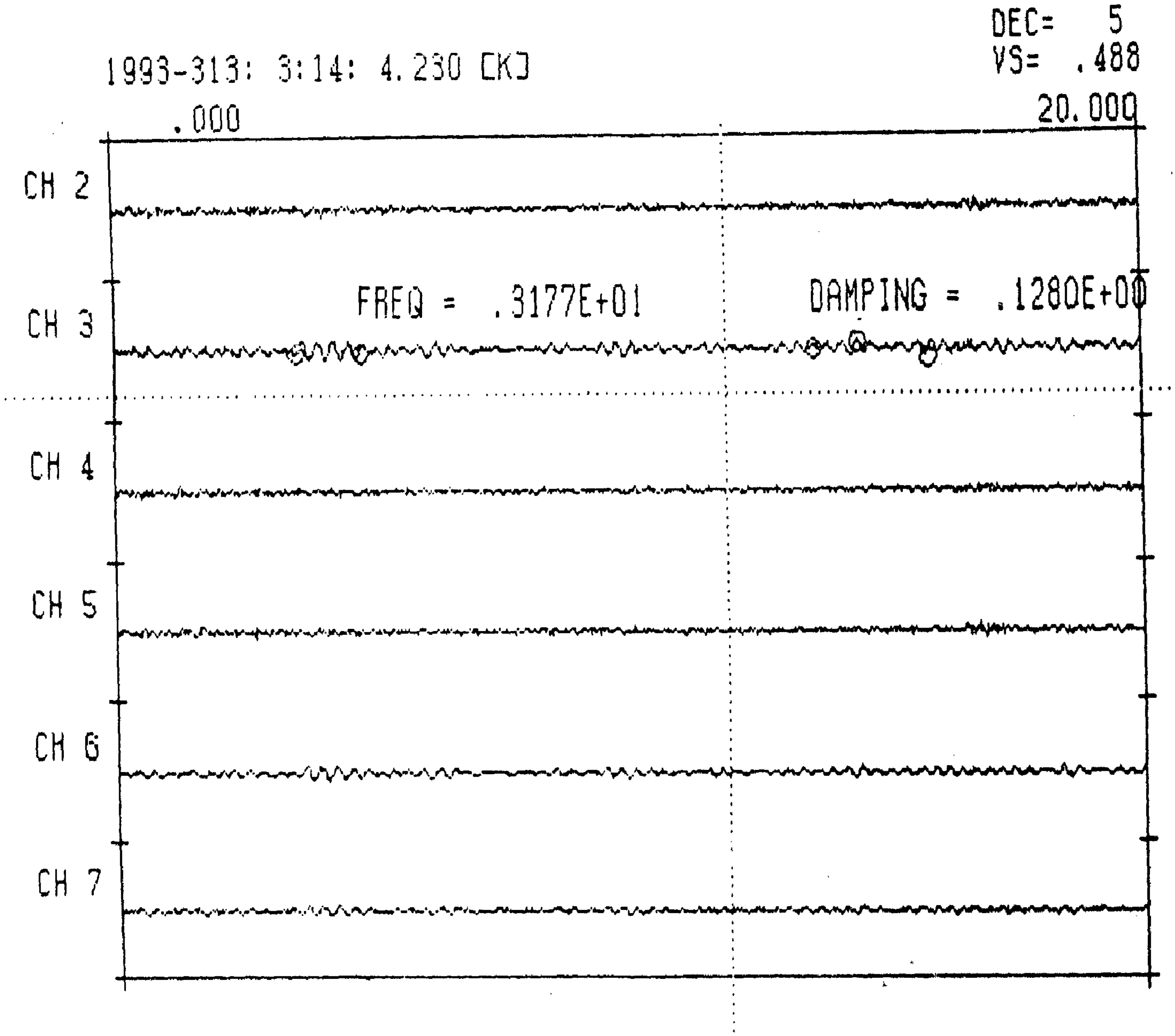


FIG :20 Showing frequency & damping

c Ch	x1	y1	x2	y2	cycle	freq	name
1	.0000E+00	.0000E+00	.0000E+00	.0000E+00	0	.0000E+00	TIME
2	.0000E+00	.0000E+00	.0000E+00	.0000E+00	0	.0000E+00	
3	.3529E+01	-.5024E+02	.4788E+01	-.5024E+02	4	.3177E+01	
4	.0000E+00	.0000E+00	.0000E+00	.0000E+00	0	.0000E+00	
5	.0000E+00	.0000E+00	.0000E+00	.0000E+00	0	.0000E+00	
6	.0000E+00	.0000E+00	.0000E+00	.0000E+00	0	.0000E+00	
7	.0000E+00	.0000E+00	.0000E+00	.0000E+00	0	.0000E+00	

c

c Damping Markers

c Ch	x1	y1	x2	y2	x3	y3	Damping
1	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	.1447E+02	.8200E+02	.1360E+02	-.6160E+01	.1583E+02	-.1384E+03	.1280E+00
4	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
6	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
7	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

Total no. of channels = 7
Sample rate = 200.000
Display width = 20.000
Display height = 2000.000
Press <return> when ready

FIG :21 Plot parameters for frequency & damping

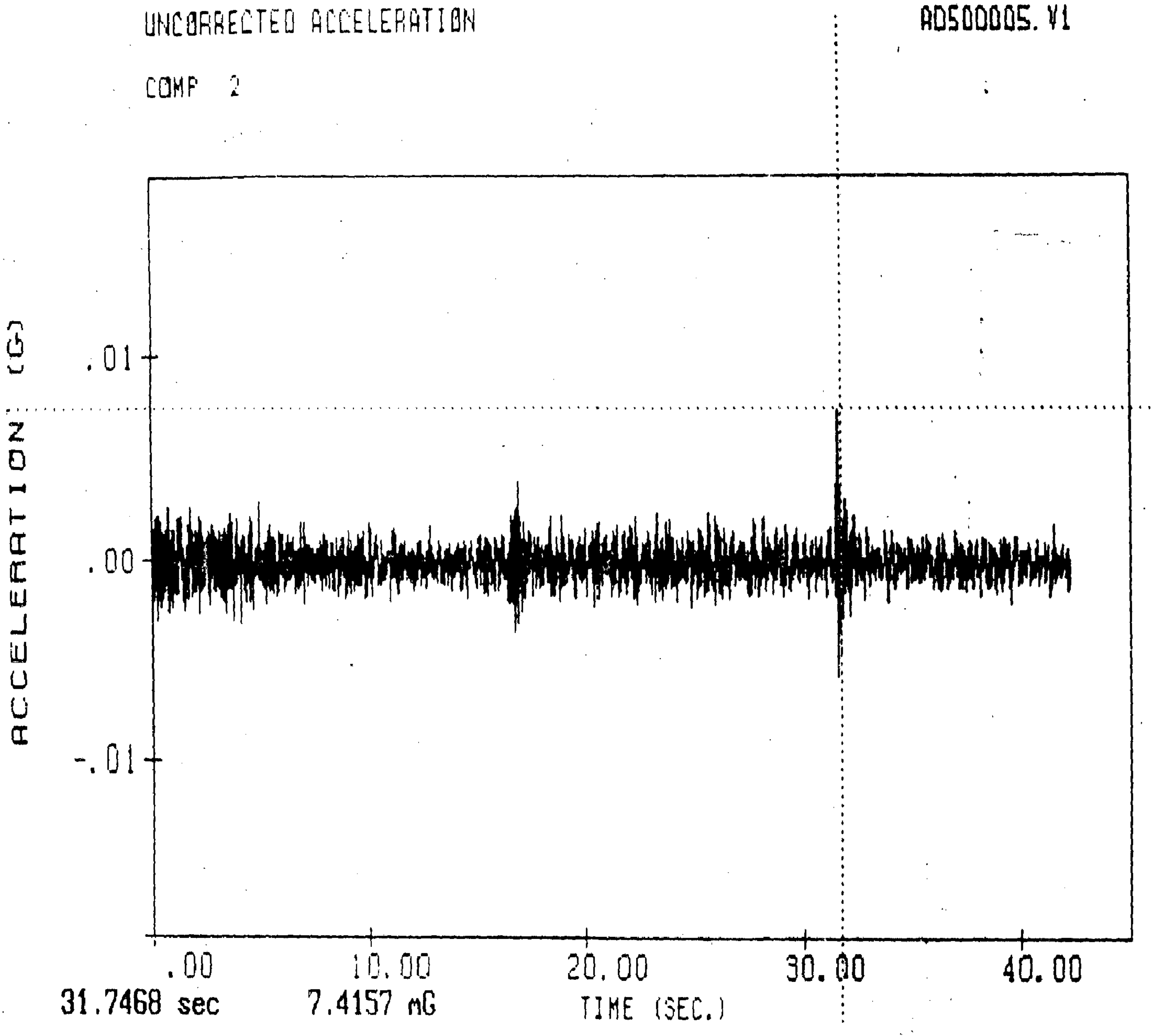
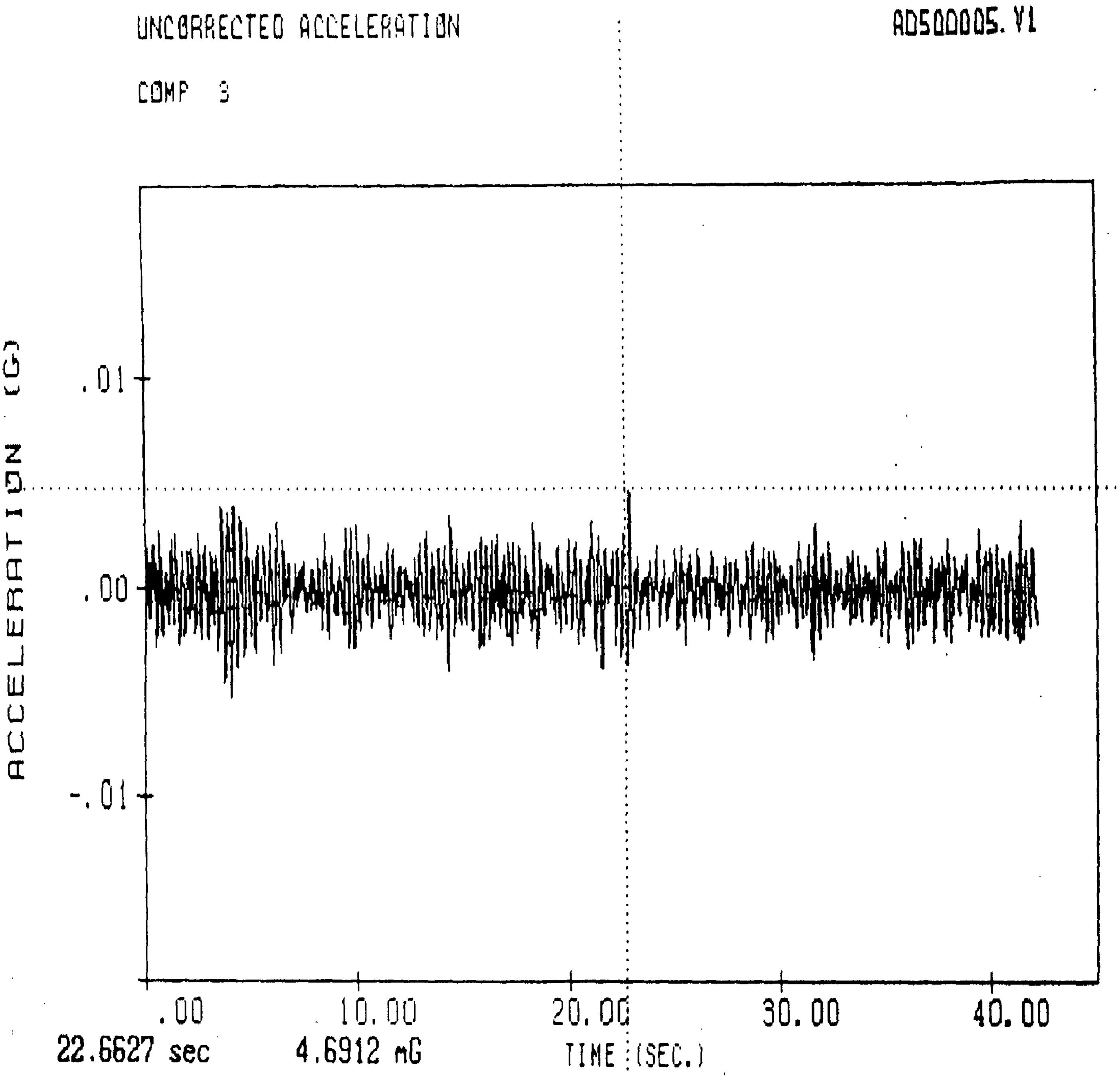


FIG :22 Uncorrected Accelerograph



UNCORRECTED ACCELERATION
AD500005.V1
COMP 3
ACCELERATION (G)
.01
.00
-.01
.00
10.00
20.00
30.00
40.00
22.6627 sec
4.6912 mG
TIME (SEC.)

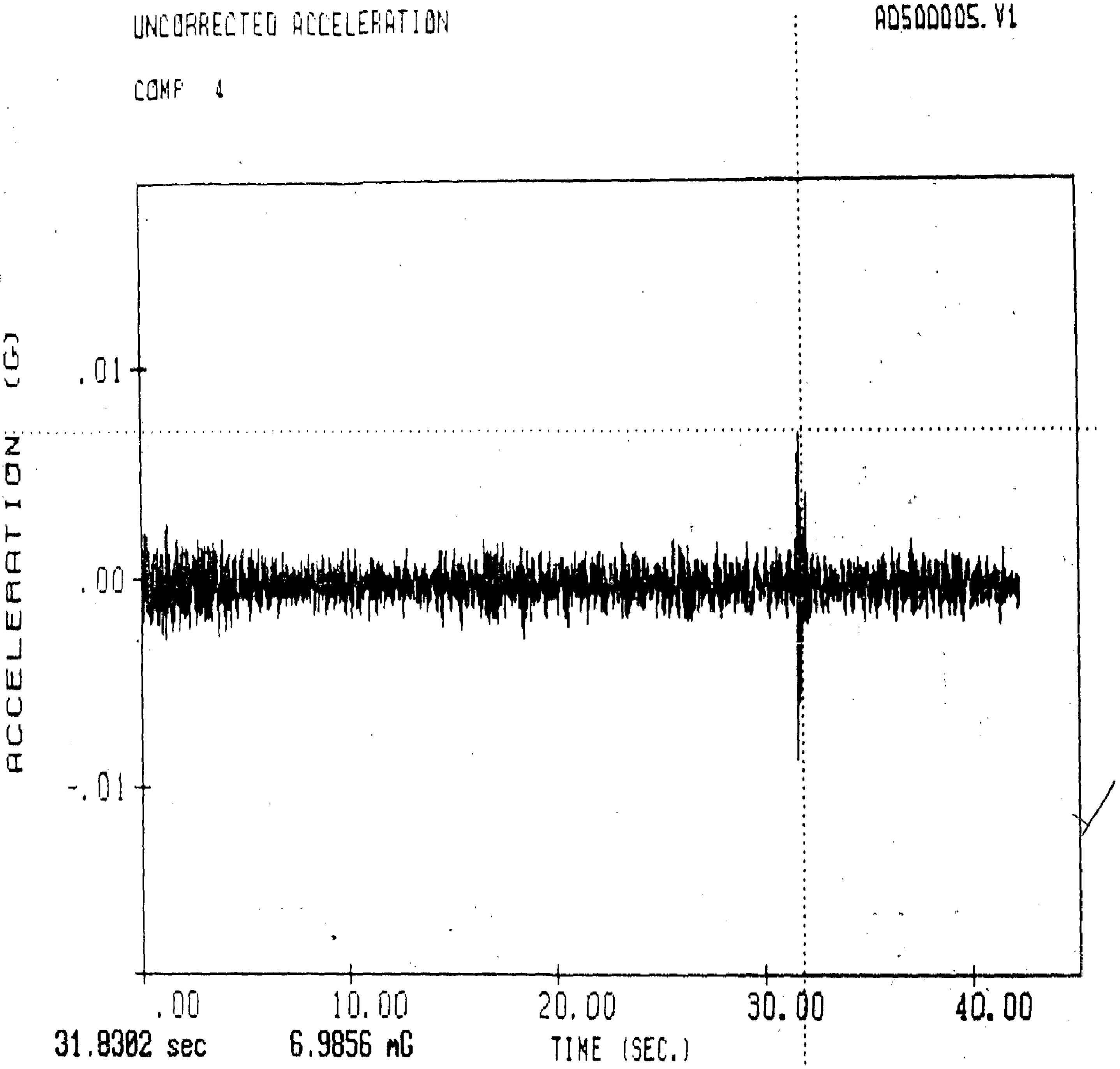


FIG :22 Uncorrected Accelerograph

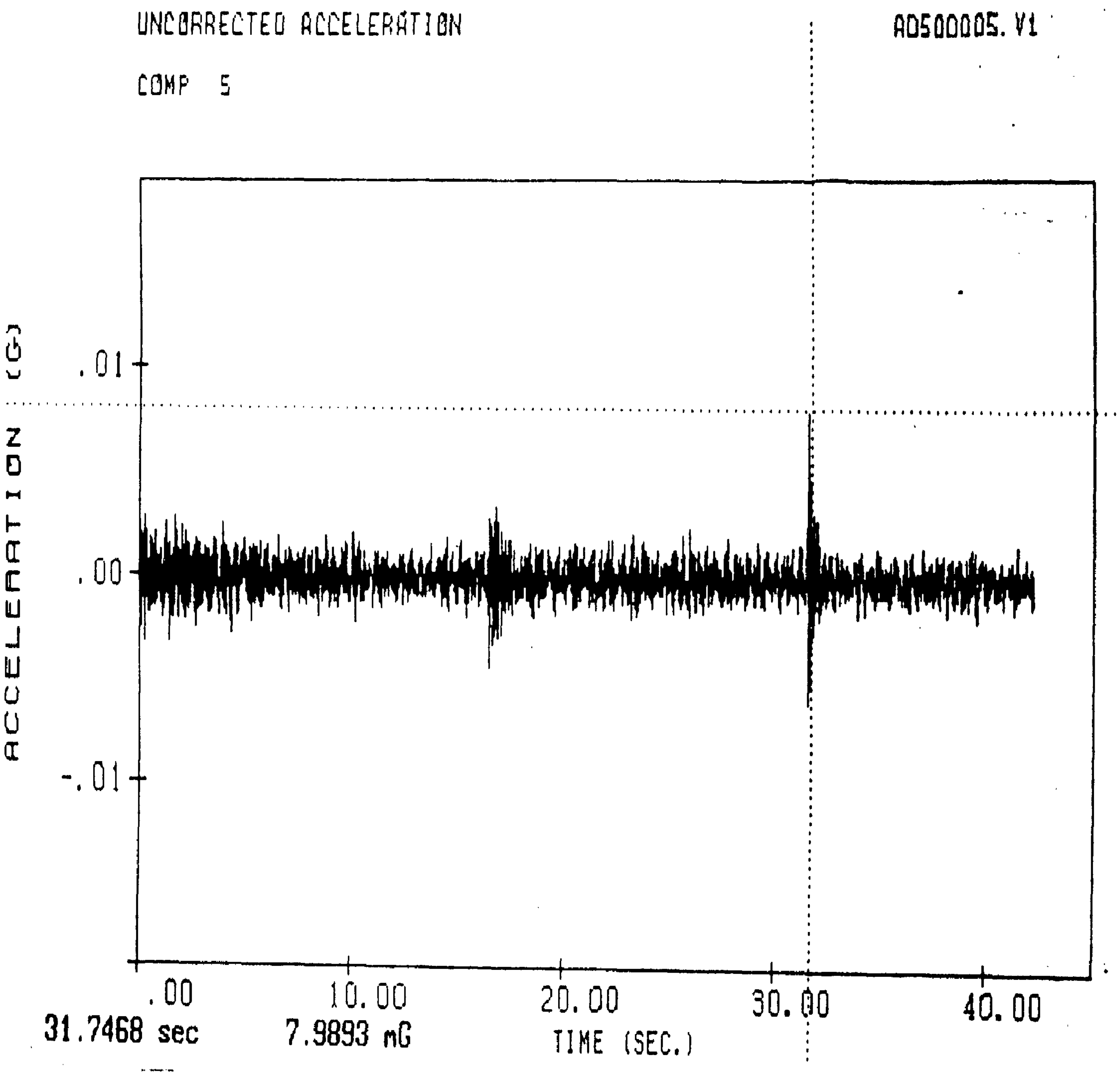


FIG :22 Uncorrected Accelerograph

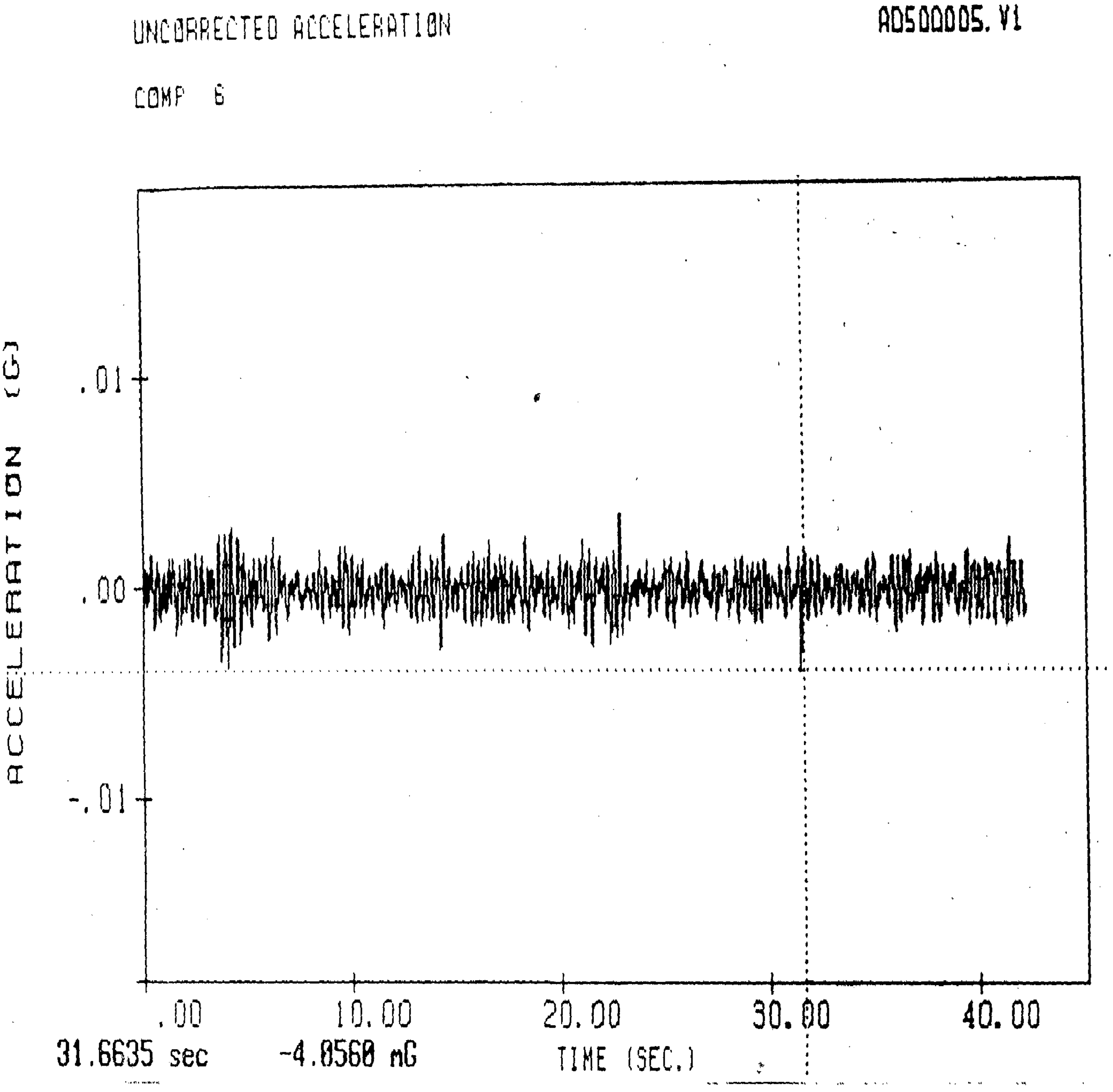


FIG :22 Uncorrected Accelerograph

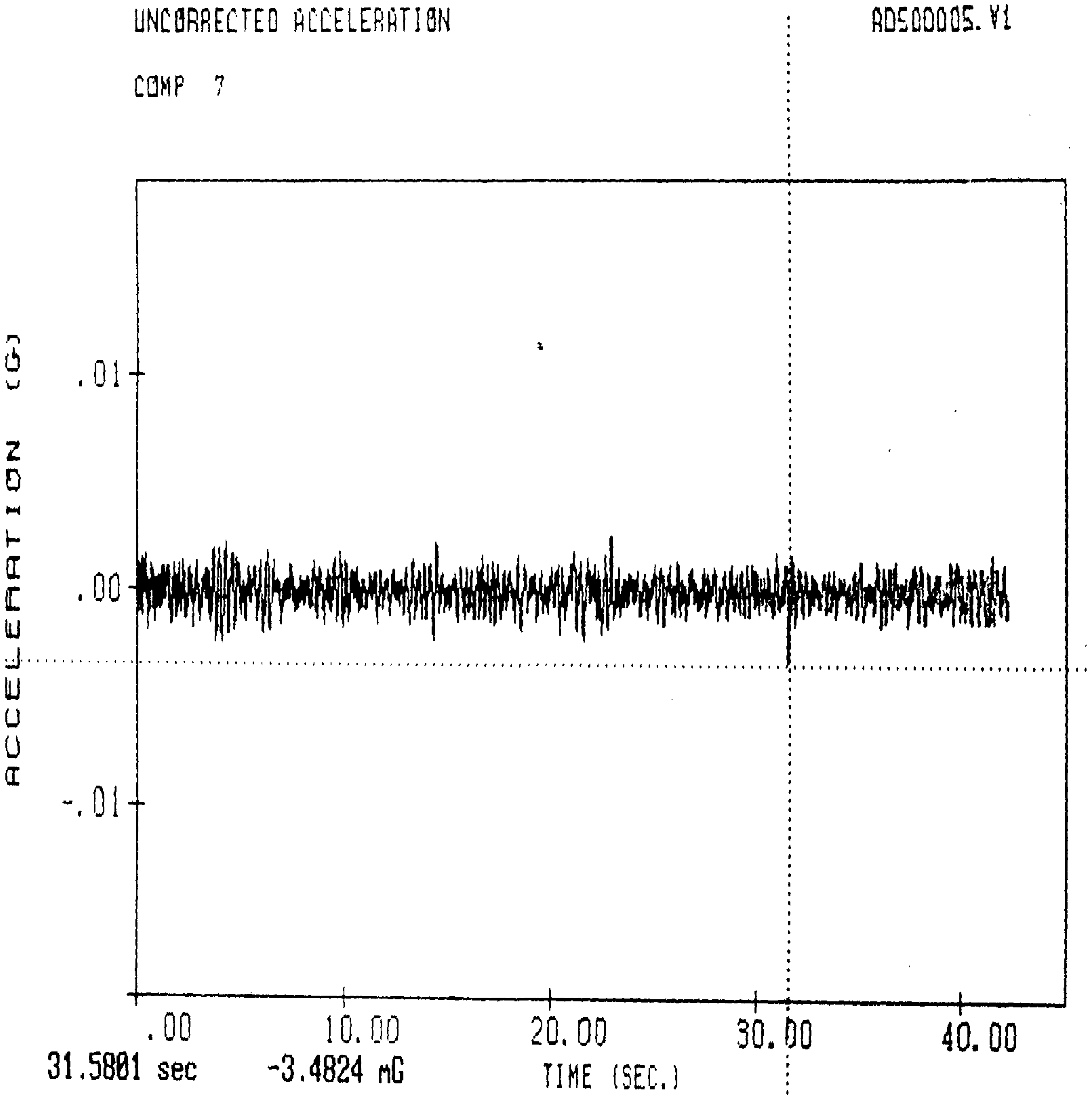


FIG :22 Uncorrected Accelerograph

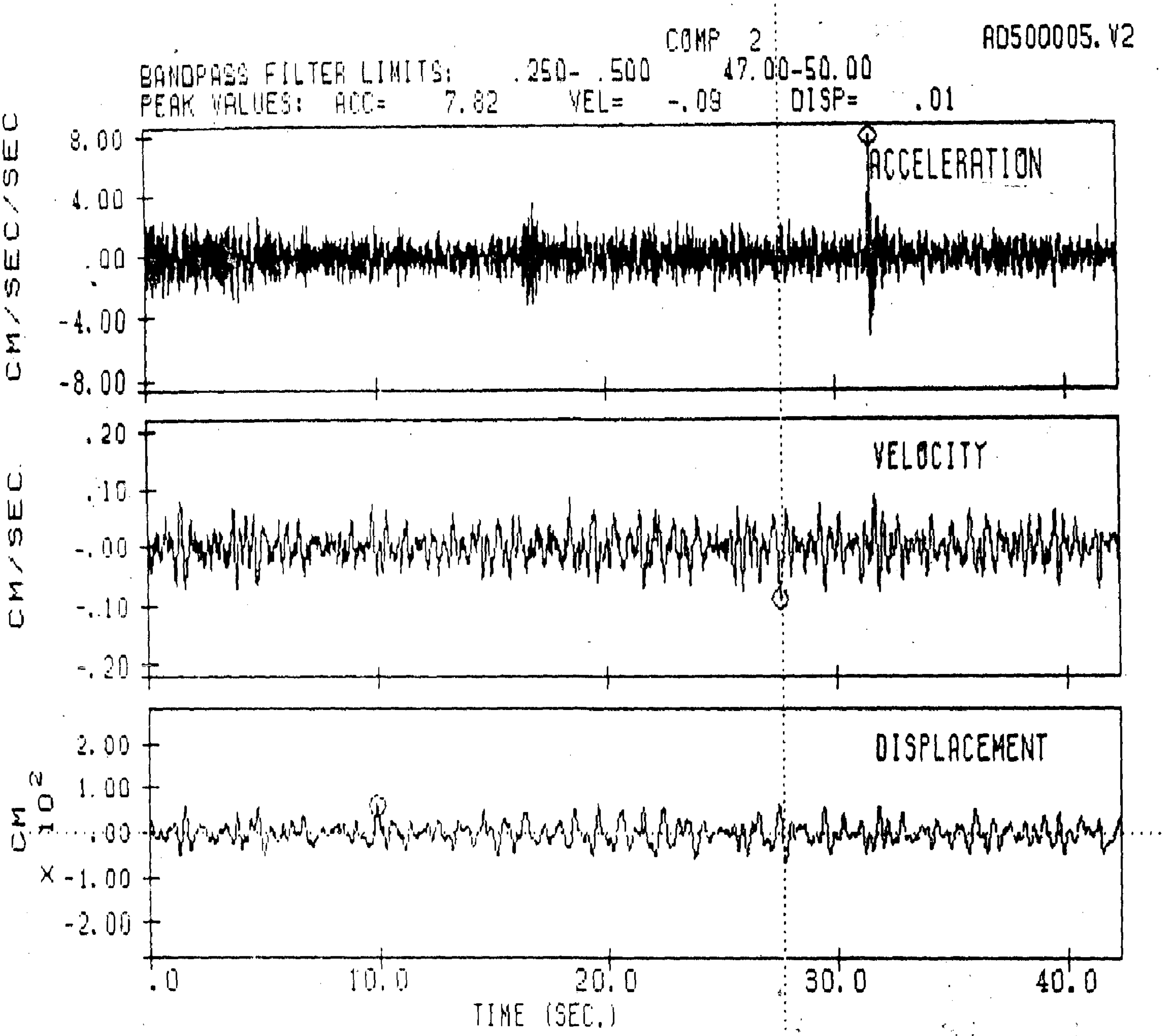
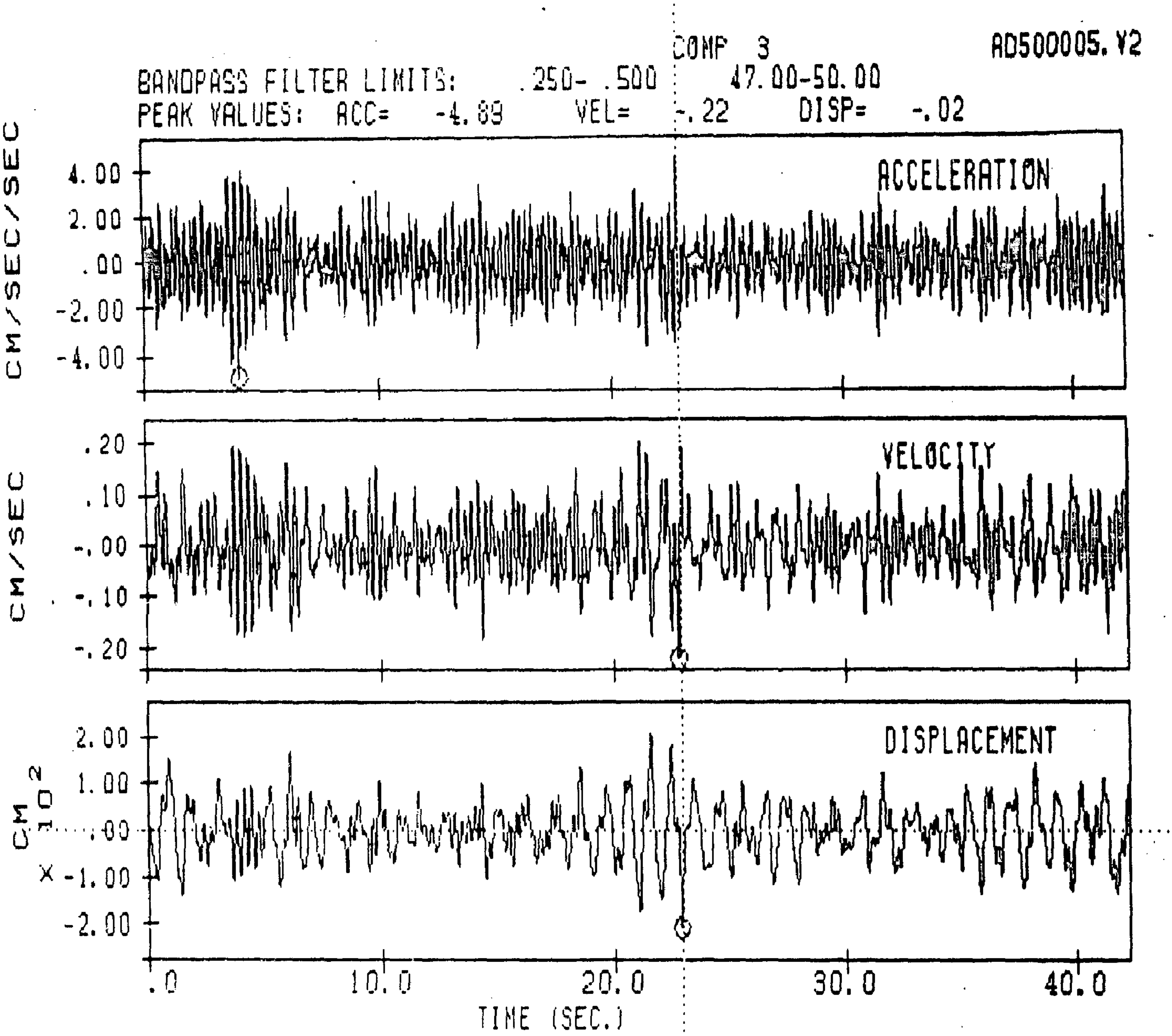


FIG :23 Showing acceleration, velocity and displacement Vs time


COMP 3
AD500005.V2
BANDPASS FILTER LIMITS: .250- .500 47.00-50.00
PEAK VALUES: ACC= -4.89 VEL= -.22 DISP= -.02
ACCELERATION
VELOCITY
DISPLACEMENT
CM/SEC/SEC
CM/SEC
CM $\times 10^2$
TIME (SEC.)

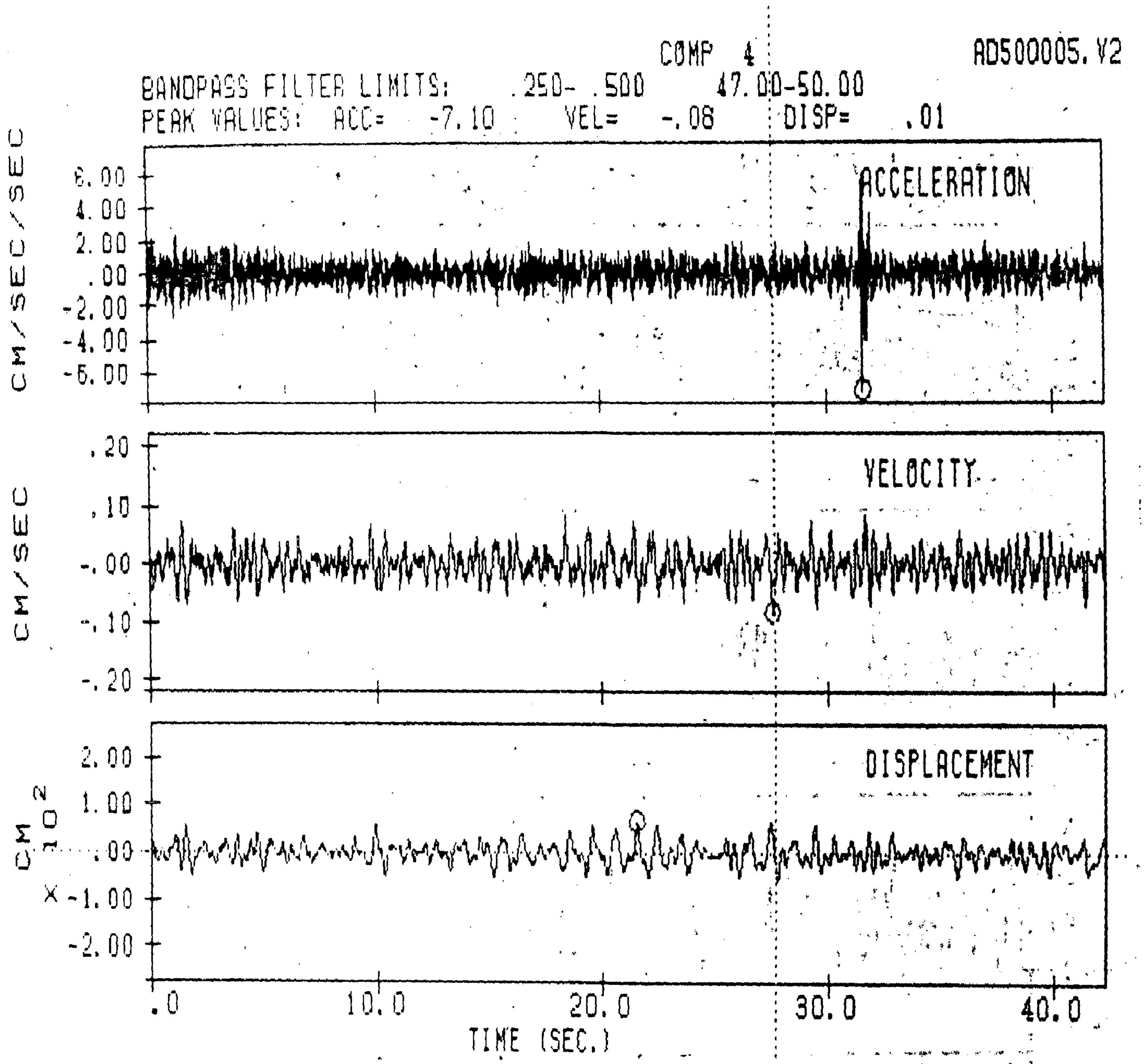


FIG :23 Showing acceleration, velocity and displacement Vs time

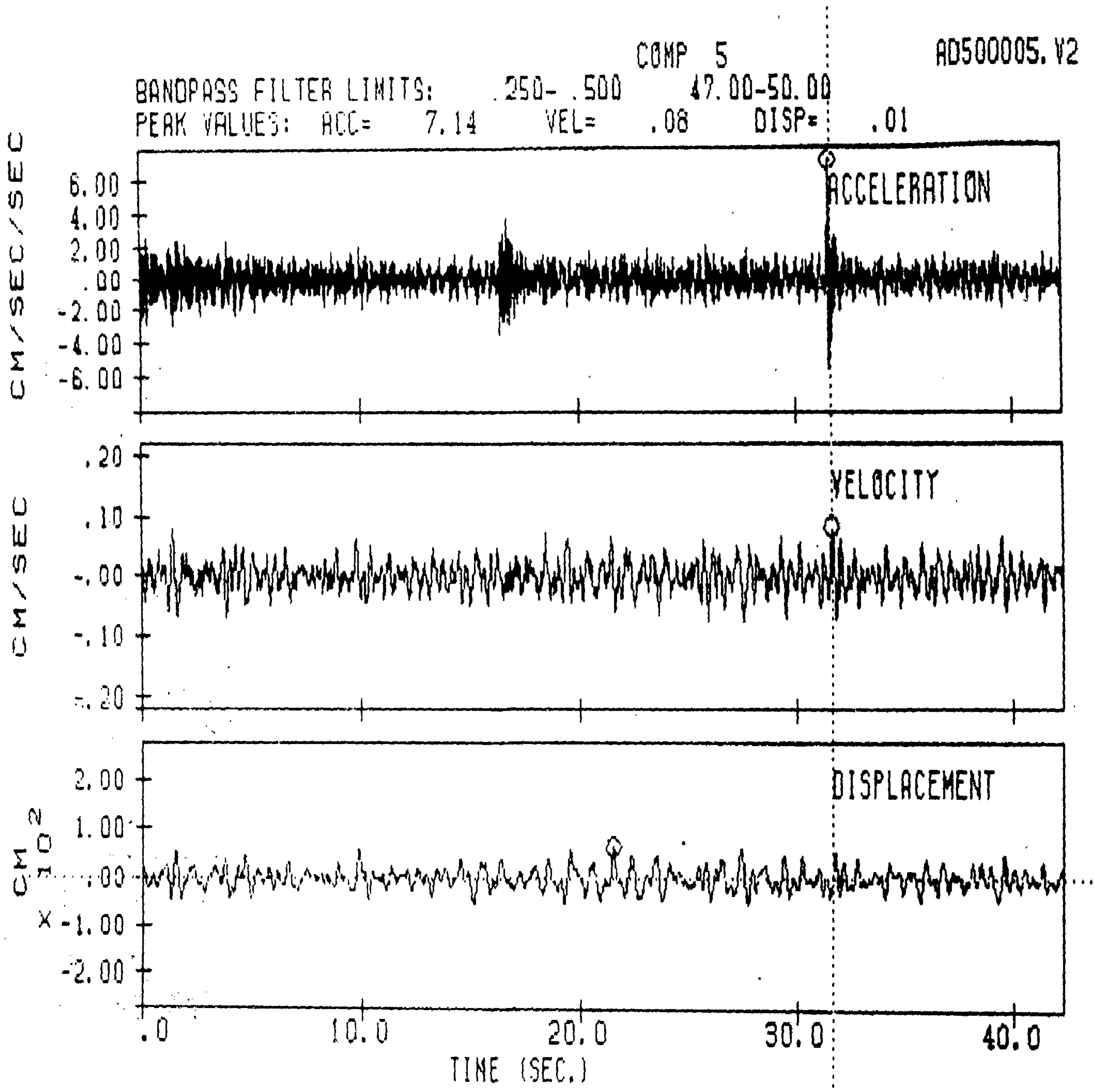


FIG :23 Showing acceleration, velocity and displacement Vs time

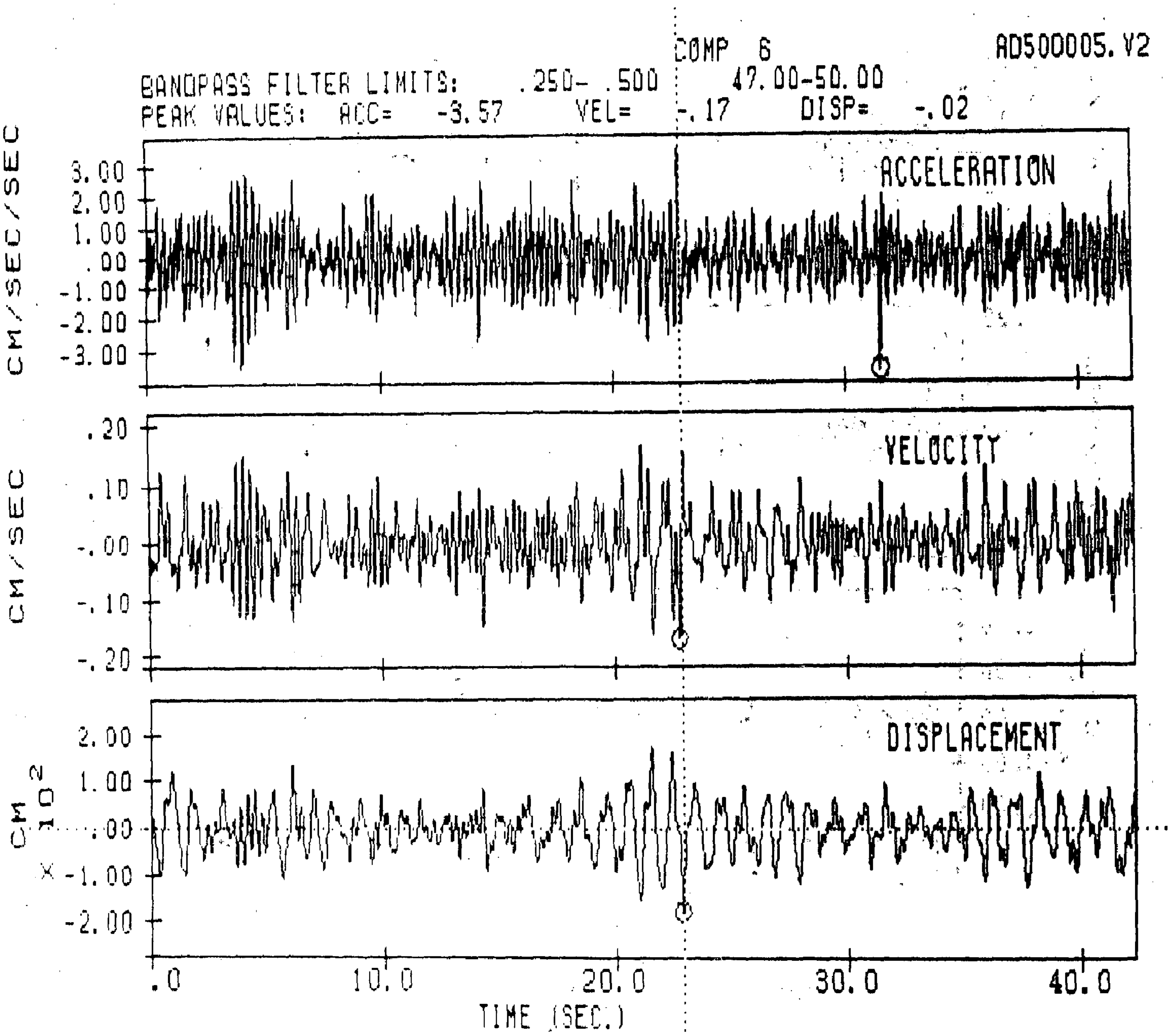


FIG :23 Showing acceleration, velocity and displacement Vs time

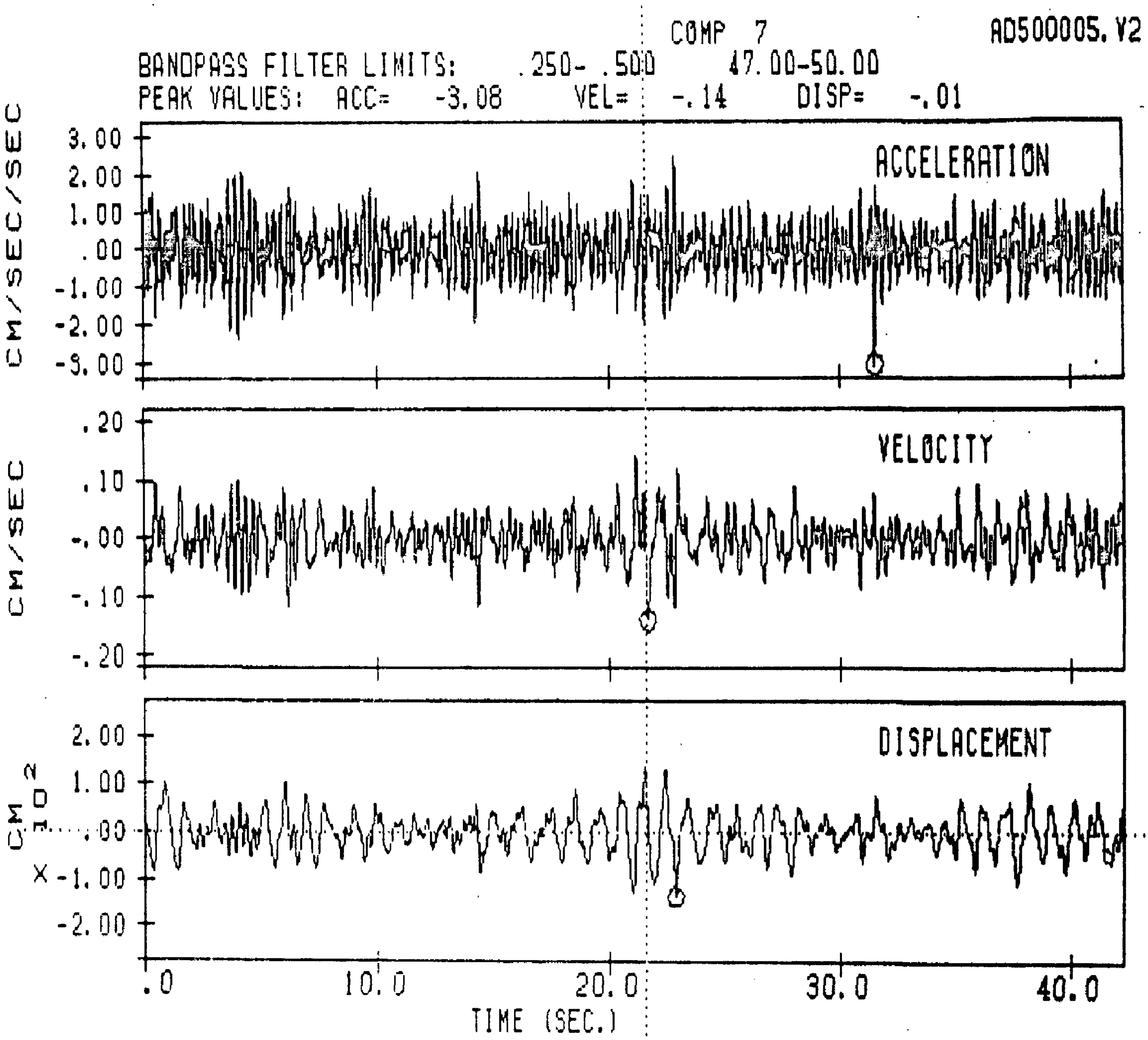


FIG :23 Showing acceleration, velocity and displacement Vs time

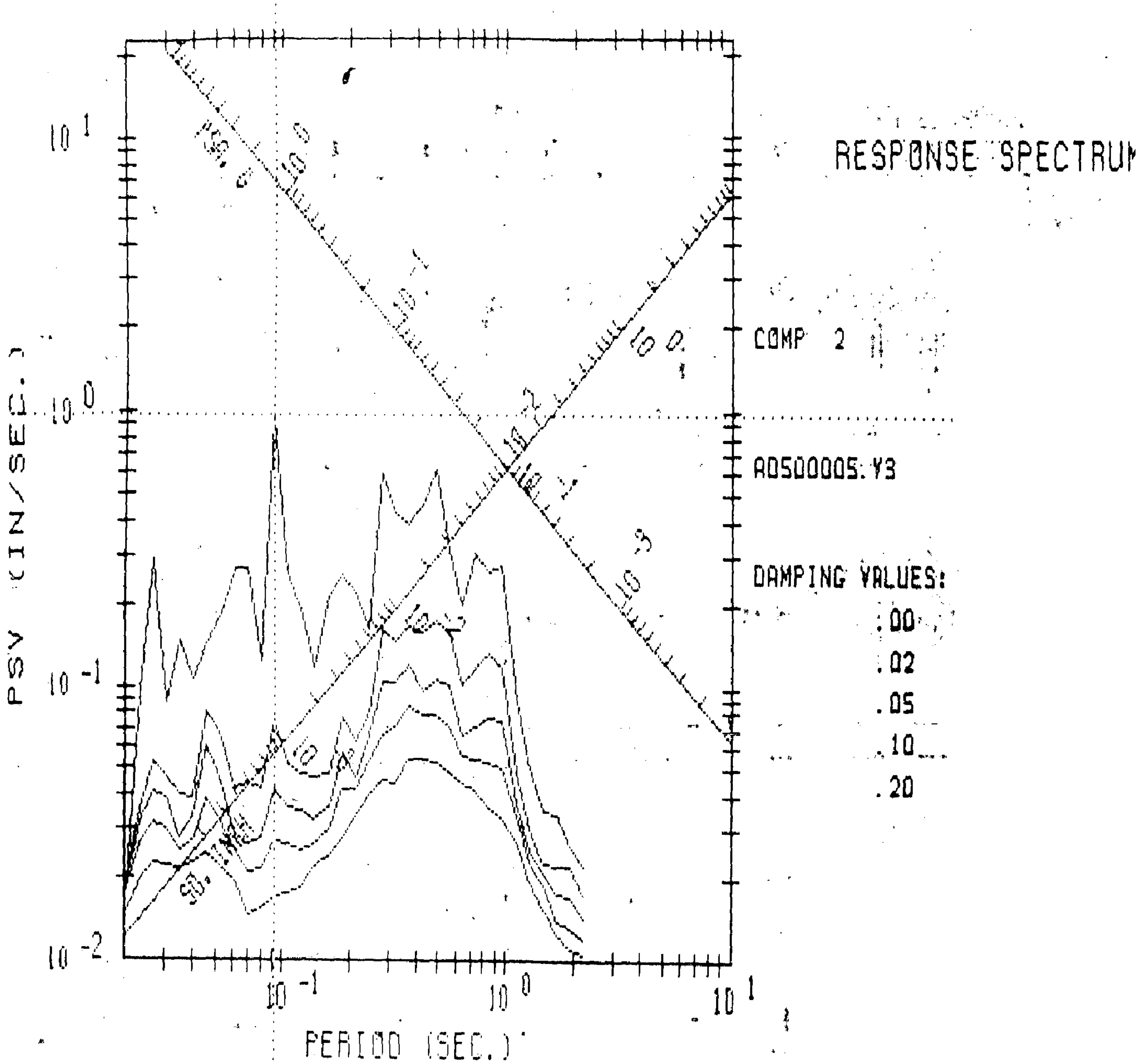
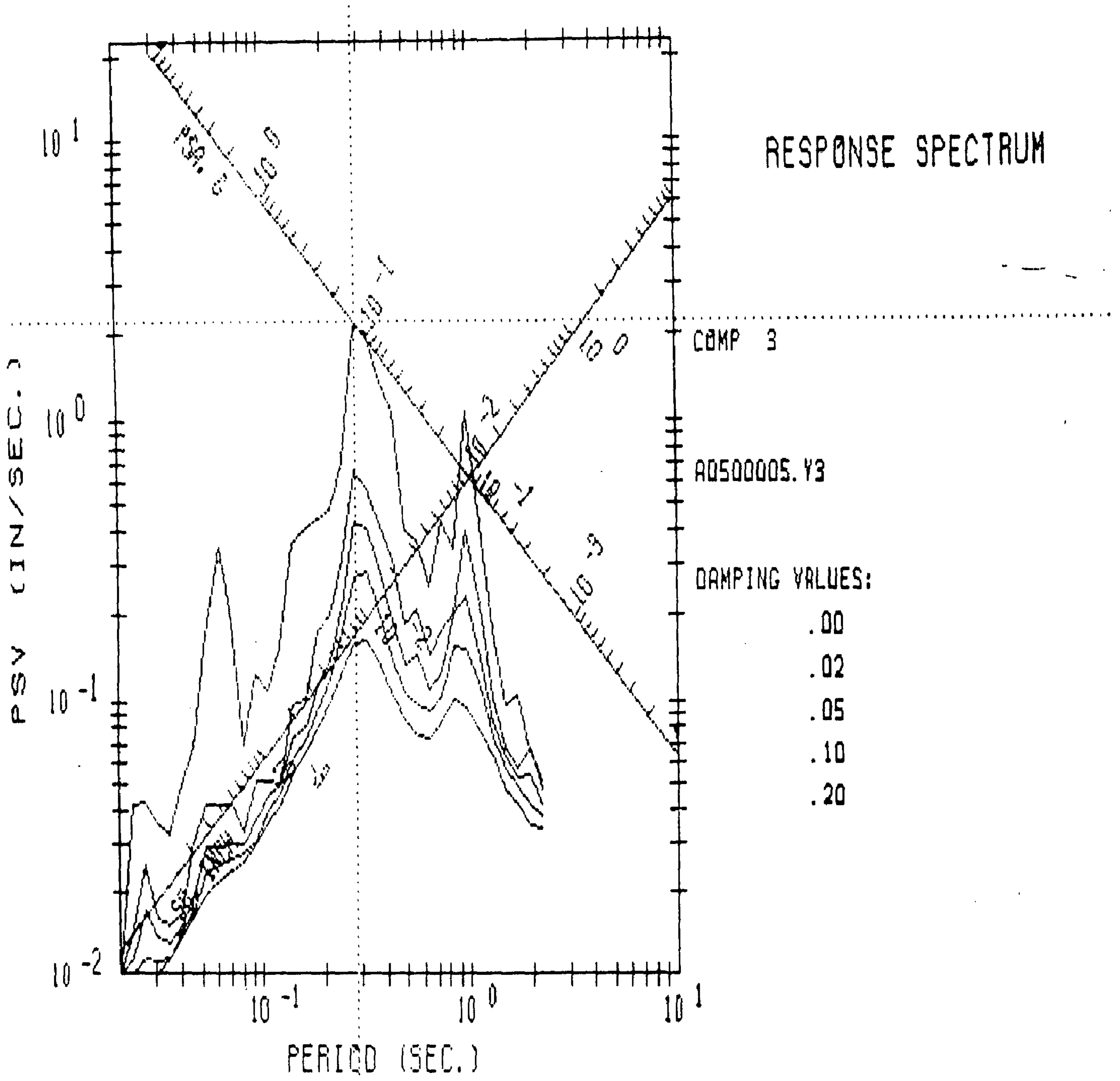


FIG :24 Response spectra


RESPONSE SPECTRUM
COMP 3
AQ500005.Y3
DAMPING VALUES:
.00
.02
.05
.10
.20
PSV (IN/SEC.)
PERIOD (SEC.)

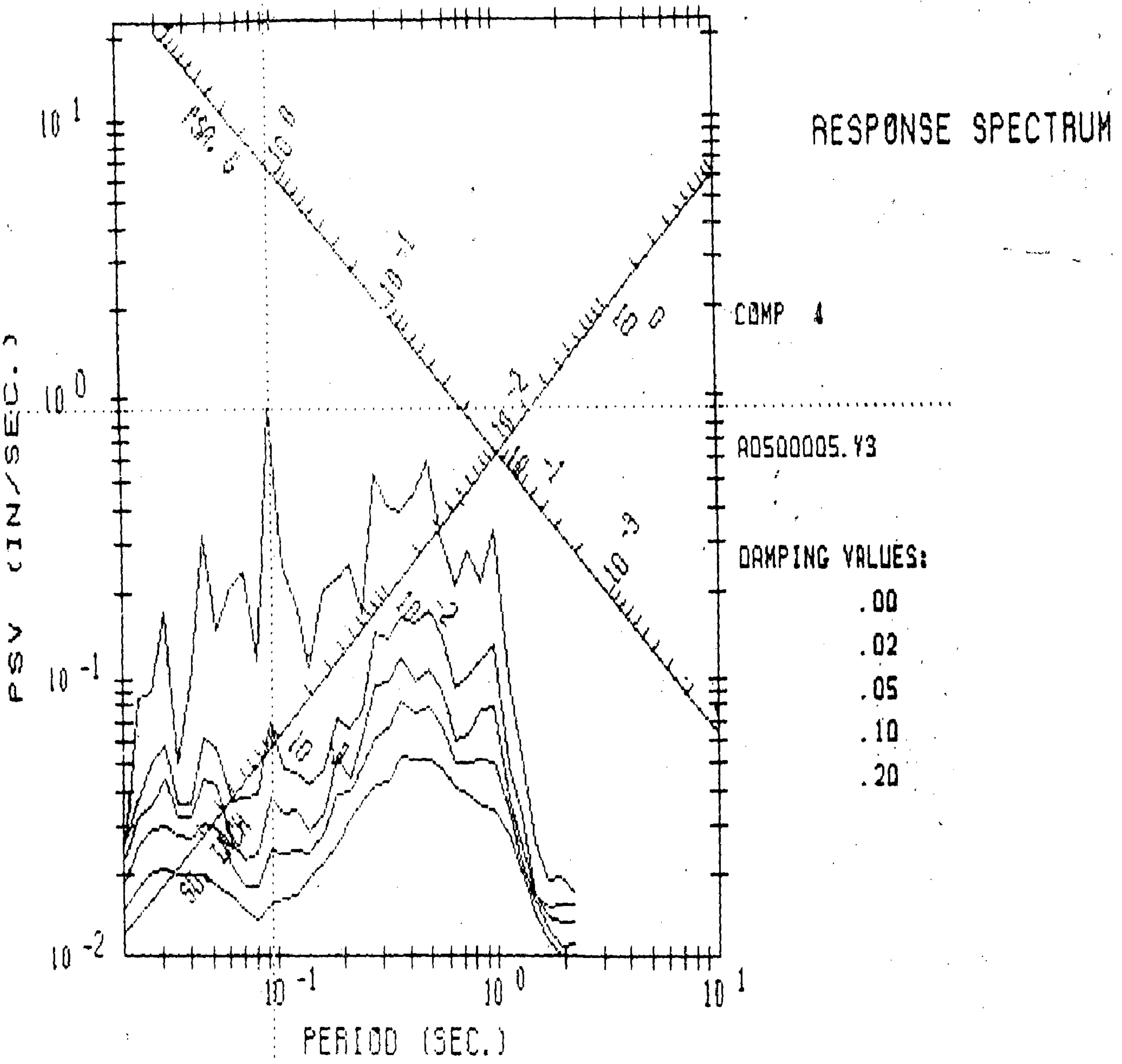


FIG :24 Response spectra

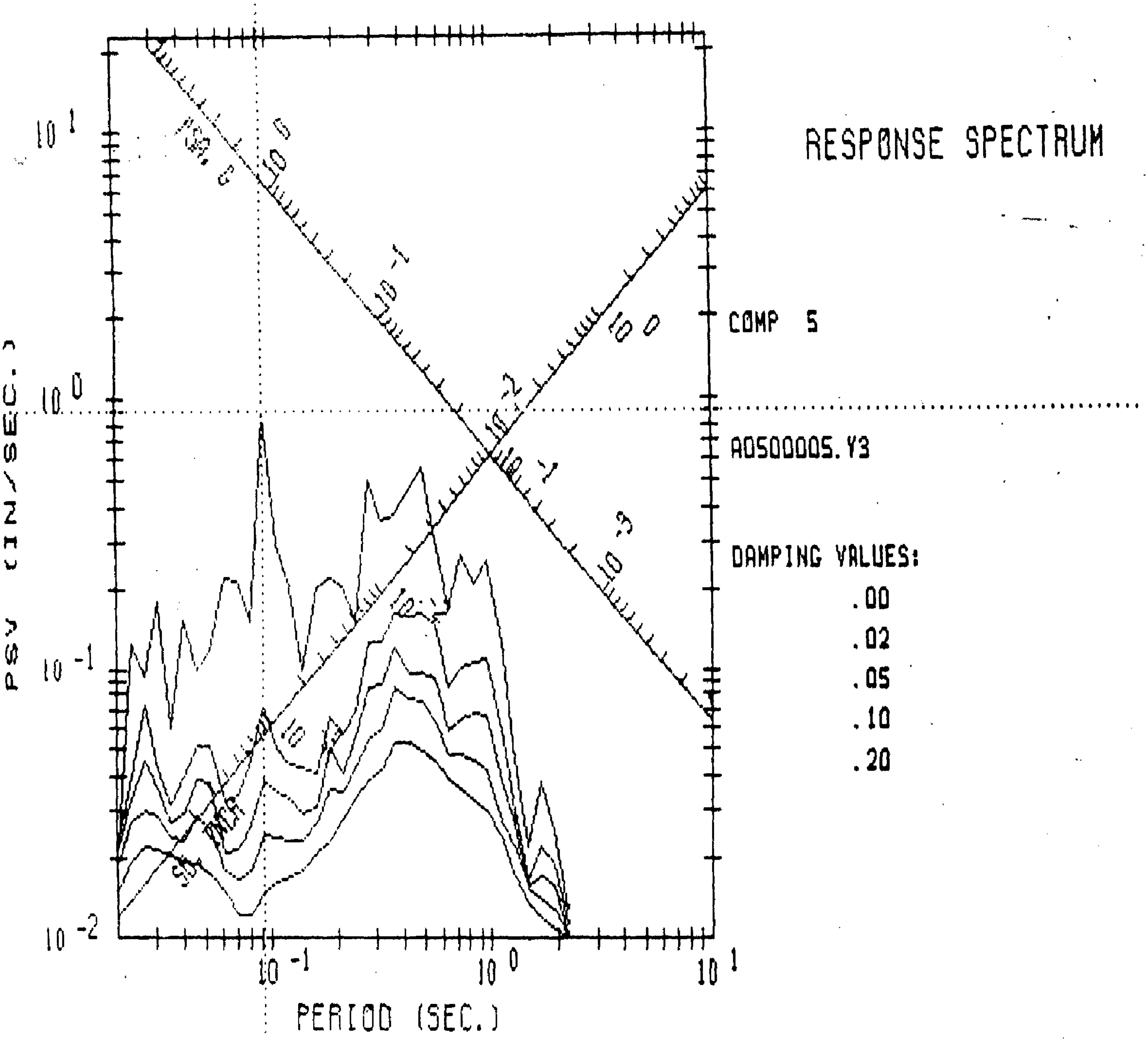


FIG :24 Response spectra

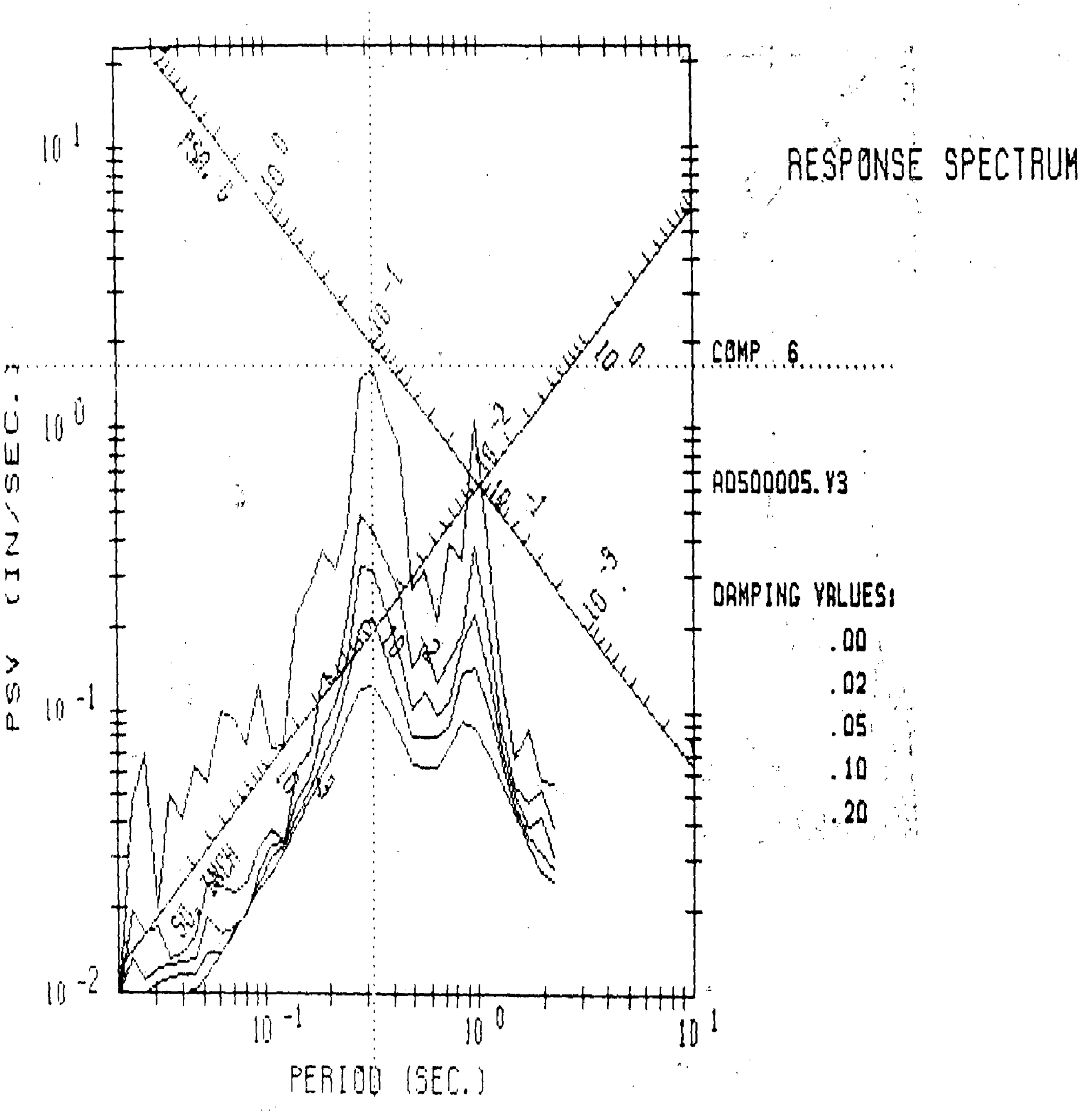


FIG :24 Response spectra

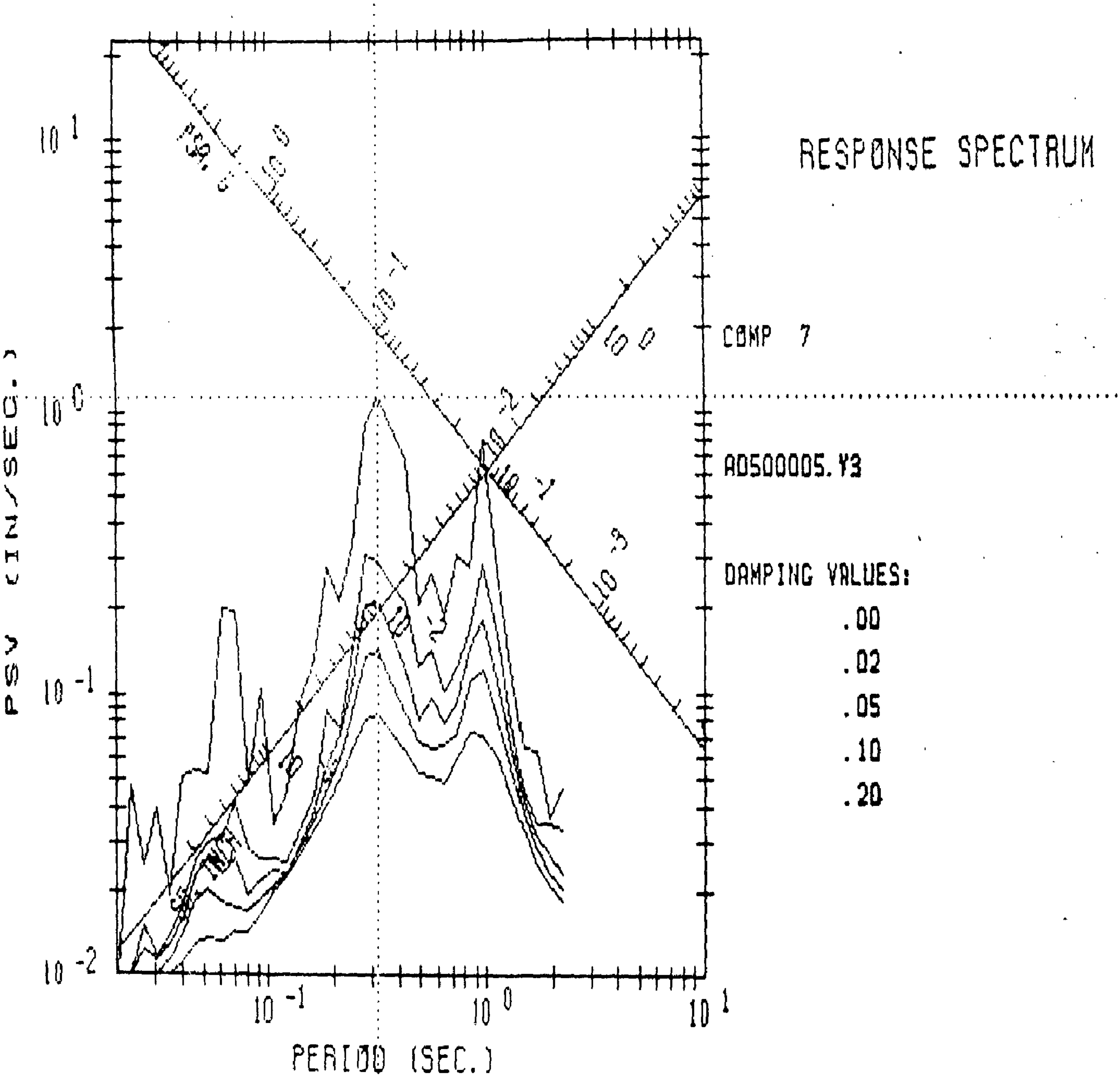


FIG :24 Response spectra

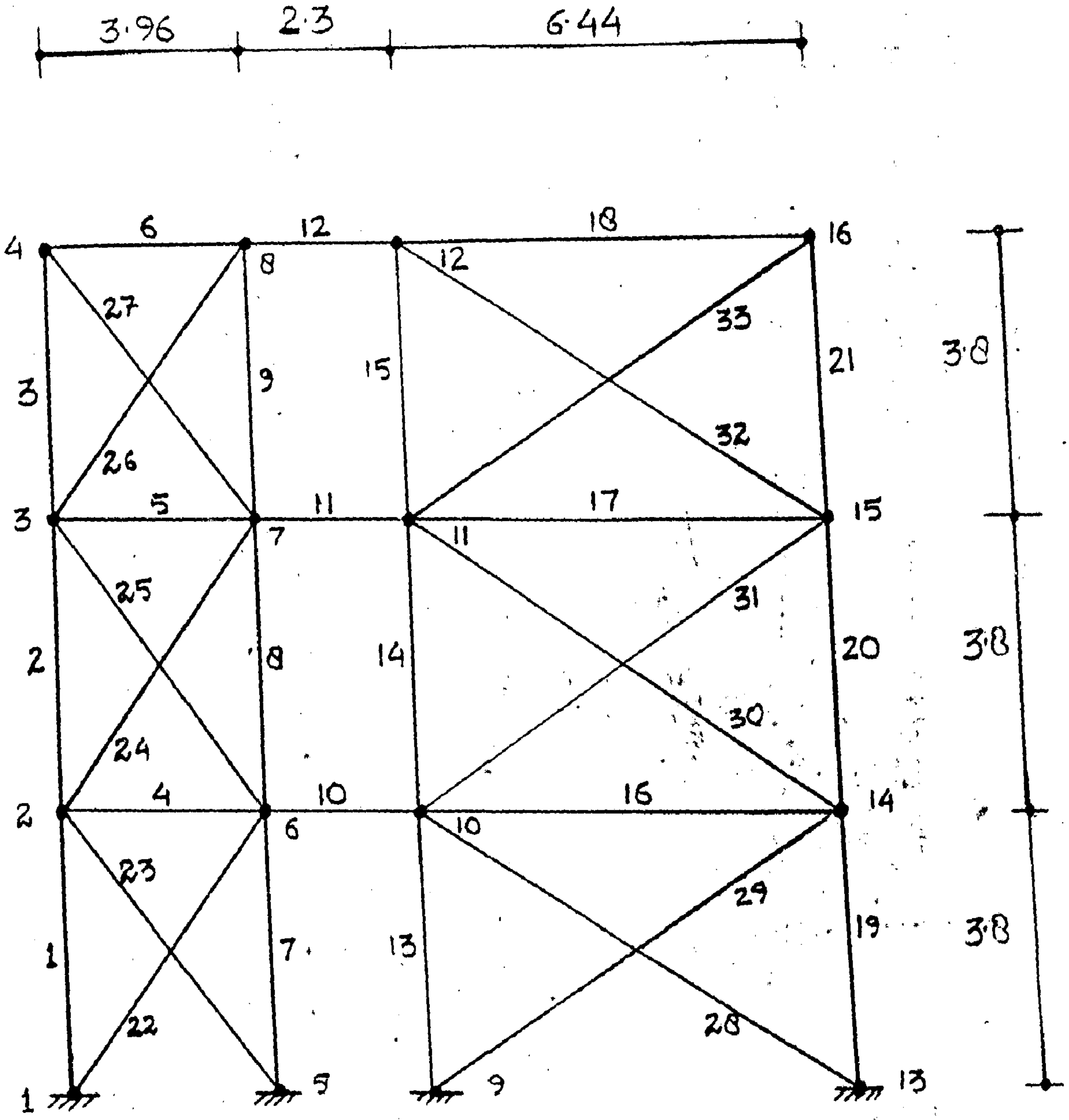


FIG :25 Showing Mathematical Model of Earthquake Engineering Department in Transverse direction

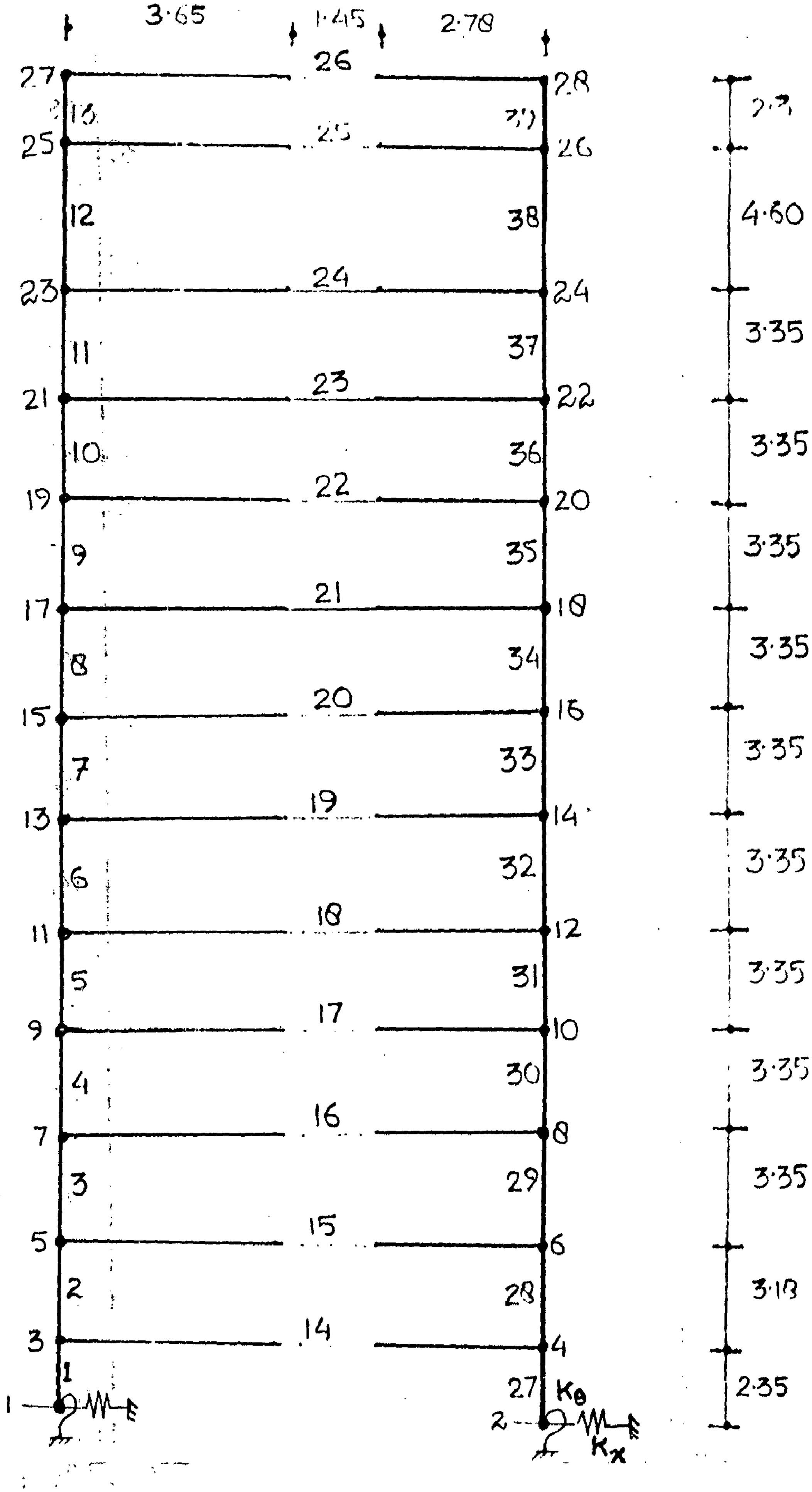


FIG :26 Showing Mathematical Model of Communication Tower in Longitudinal direction

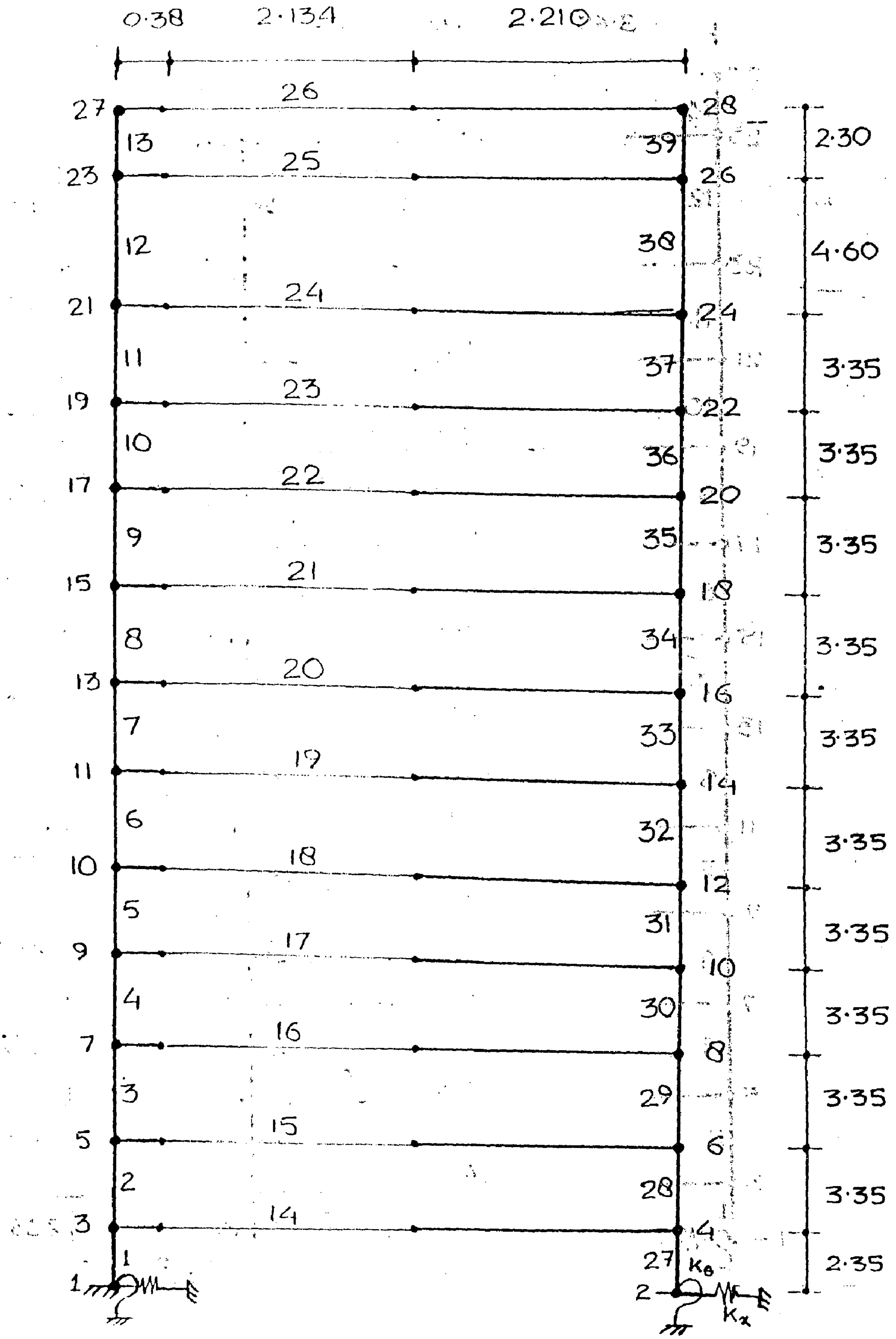


FIG :27 · Showing Mathematical Model of Communication Tower in Transverse direction