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GTOROTO: A SIMULATION SYSTEM FOR HTGR CORE SEISMIC BEHAVIOR

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A Simulation System for HTGR Core Seismic Behavior

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One of the most important design of HTGR core is its aseismic structure. Therefore, it is necessary to predict the forces and motion of the core blocks. To meet the requirement, many efforts to develop analytical methods and computer programs are made.

A graphic simulation system GTOROTO with a CRT graphic display and lightpen was developed to analyze the HTGR core behavior in seismic excitation. Feature of the GTOROTO are as follows:

(1) Behavior of the block-type HTGR core during earthquake can be shown on the CRT-display.

(2) Parameters of the computing scheme can be changed with the lightpen.

(3) Routines of the computing scheme can be changed with the lightpen and an alteration switch.

(4) Simulation pictures are shown automatically. Hardcopies are available by plotter in stopping the progress of simulation pictures. Graphic representation can be re-start with the predetermined program.

(5) Graphic representation informations can be stored in assembly language on a disk for rapid representation.

(6) A computer-generated cinema can be made by COM (Computer Output Microfilming) or filming directly the CRT pictures.

These features in the GTOROTO are provided in on-line conversational mode.

KEYWORDS: HTGR, HTGR Core, Core Seismic, Seismic Simulation, Computer Graphics, Graphic Display, Computer Program, VHTR, Prismatic-Core, Block Type Fuel HTGR, COM

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GTOROTO：高温ガス炉炉心地震シミュレーションシステム

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高温ガス炉の炉心耐震設計は重要であり，このためには，炉心ブロックの力と挙動を知る必要がある。この目的のために，解析手法と計算プログラムの開発がなされている。地震時の高温ガス炉炉心の挙動を解析するために，CRTグラフィック・ディスプレィとライトペンを使用するシミュレーション・システムGTOROTOが開発された。

GTOROTOには，(1)炉心ブロックの地震時の挙動をCRT面上に表示する，(2)図形表示のパラメータがライトペンによって変更でき，(3)計算手順がライトペンと変更スイッチによって変更でき，(4)図形が自動的に描かれ，プロッタによってハードコピが取れ，また必要な時刻から再び開始でき，(5)す早い図形表示のためアセンブラ言語を使用することができ，(6)COMまたは直接撮影で映画を作ることもできる。これらはオンラインの対話型で実施できる機能を有する。

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CONTENTS

目　　次

1. Introduction

One of the important aspects in developing a high temperature gas-cooled reactor (HTGR) is to insure integrity of the core and safety shutdown of the reactor in seismic excitation. It is necessary to know behavior of the core under earthquake. However, knowing the behavior is difficult, because the HTGR core uses a large number of graphite blocks. Each block has kinematic capability of motion during seismic excitation.

The properties of graphite vary in fast neutron exposure and in heating environment. Especially, graphite undergoes large geometrical change with fast neutron irradiation. The HTGR requires fuel contained in blocks, and an easily replacement of the fuel is essential. Therefore, gaps exist between the blocks in a horizontal direction in the fresh core, and these gaps increase with reactor operation. During an earthquake, there is repeated impact between blocks.

It is not known presently whether such a HTGR core can withstand possible major earthquakes. Since gas-cooled reactors with block-type graphite cores are built mostly in earthquake-free areas or in areas of low seismicity, so little consideration is given to the core deisgn against earthquakes. When such reactor plants are to be installed in areas of high seismicity, analysis and experiments in earthquakes-resistance design are necessary.

Vibration tests of the HTGR core are performed and some analytical models and computer programs are developed in the GA (General Atomic Co.)[(1),(2)] and the BNL (Brookhaven National Laboratory)[(3),(4)] in USA and the EPDC-MISM (Electric Power Developing Corp. - Muto Institute of Structural Mechanics),[(5),(6)] the Fuji Electric Co.[(7)] and the JAERI (Japan Atomic Energy Research Institute)[(8),(9),(10)] in Japan.

The GA has developed analytical models and computer programs for HTGR core behavior with simple consideration, e.g., one-dimensional core model. The EPDC-MISM has also developed some computer programs with two-dimensional model. The Fuji Electric has developed one and two-dimensional computer programs.

In the JAERI, design study of the experimental multi-purpose very high temperature gas cooled-reactor (experimental VHTR) was started in 1970, with emphasis on the aseismic aspect. Effects are also being made in computer programs for core seismic behavior and vibration tests of core models.

The HTGR core is made up with several thousand blocks. It is impossible to understand motion of the whole blocks pattern from the printed computer output. If a computer generated cinema which shows clearly the total pattern of block motion is used, we can easily imagine the core seismic behavior. Cinema is useful means of showing the overall moving pattern. If the process of the computer can be changed interactively with light-pen and/or keyboard in a conversational mode, the display of figures is made available efficiently in real time.

To meet the requirement, computer program TOROTO-1, -2[10] and GTOROTO-3, -4[11] have been already developed and used for seismic analysis of HTGR core. Simulation programs have been used for analysis of seismic behavior of one-dimensional block array. GTOROTO-3, -4 are used for seismic simulation of two-dimensional vertical and horizontal slice core. Moreover, GTOROTO-5 is developed for seismic simulation of two-dimensional vertical slice core of large HTGRs. Recently, GTOROTO-6 is also developed for analysis of column vibration test.

GTOROTO simulation system are combined the above all computer programs.

The system GTOROTO has thus attracted the BNL and the LASL (Los Alamos Scientific Laboratory)[(12),(13),(14)] as an excellent tool of analyzing the HTGR core seismic behavior.

2. HTGR Core

The block-type fuel core of a HTGR is such as in Fig.1, which shows the VHTR being developed in JAERI. The reactor core is enclosed in a core barrel, horizontally restrained at the top with an orifice block of a heat-resisting alloy, while the bottom is restrained similarly with a core support plate through keys. Then in the periphery, the core is restrained by the core barrel. Fuel blocks in the core are generally connected together in vertical direction with three dowel pins, but in the horizontal direction they are loose with gap between them.

The large HTGR core shown in Fig.2 is located and supported within a prestressed concrete reactor vessel (PCRV) by three structures: which are the core support structure, the side reflector and the core lateral restraint structure. Each refueling region consisted by seven fuel column, is supported by a graphite core support block which supported by three graphite posts. The core restraint structure has placed spring assemblies which span the side reflector and a PCRV liner. The spring assemblies keep graphite blocks in the core, the core support structure and the side reflector. They also diminish the effects of seismic impact loads.

In the periphery of a block-type fuel core, the fixed reflector in block form adjoins the core barrel certain restraint. In the unit I of the JAPC's Tokai Power station and the Fort St. Vrain reactor, restraint bars penetrate through the fixed reflector, thereby transmitting seismic force from the reactor core to the external barrel. Integrity of this scheme in an earthquake is going to be confirmed, and it is incorporated in the large HTGR and preliminary design of the experimental VHTR.

3. Calculation Models and Formulae

3.1 Models

In the block-type fuel core, this group of blocks extends in so-called three dimensions as shown in Fig.3. In the present study, the following simplified models as shown in Fig.4 through 7 for calculation will be considered.

(1) The blocks at the top are restrained the orifice block with some stiffness and damping.

(2) The blocks at the bottom are restrained the core support plate with some stiffness and damping.

(3) The blocks are restrained three dowels and dowel pins with some stiffness and damping.

(4) The blocks in the core periphery are restrained with the restrained structure with some stiffness and damping.

(5) Three models for blocks motion can be conceivable as shown in Fig.5:

(i) Sway motion,

(ii) Rocking motion,

(iii) Sway and rocking motion.

(6) Three models for the impact phenomena can be conceivable as shown in Fig.6:

(i) Spring-dashpot model,

(ii) Impact model,

(iii) Dry-friction model.

(7) Coulomb friction exists in interface of block as shown in Fig.7.

(8) Nine calculation models can be conceivable according to above (5) and (6) combination.

3.2 Formulae

3.2.1 Sway Motion

(1) General formulae

In Fig.3 through 8, the equation of motion for block i; at the core center, with its position in absolute coordinate as Y, is then given as,

$$C_{il}(\dot{Y}_i - \dot{Y}_l) + K_{il}(Y_i - Y_l) - C_{ki}(\dot{Y}_k - \dot{Y}_i) - K_{ki}(Y_k - Y_i)$$
$$\pm F_{fil} \mp F_{fki} = - m_i\ddot{Y}_i + F_p \qquad (1)$$

Where, F_p is the force from surrounding mass points. With y as the local coordinate from the core barrel instead of Y, and hence $y_i = Y_i - Y_o$, eq.(1) takes the following form:

$$m_i\ddot{y}_i + C_{il}(\dot{y}_i - \dot{y}_l) + K_{il}(y_i - y_l) - C_{ki}(\dot{y}_k - \dot{y}_i) - K_{ki}(y_k - y_i)$$
$$\pm F_{fil} \mp F_{fki} = - m_i\ddot{y}_o + F_p \qquad (2)$$

In eqs.(1) and (2) suffix zero means the core barrel, and hence, evidently $y_o = Y_o$. The equation of motion for a block i adjoining the core barrel, with stiffness coefficient and damping coefficient of the restraint structure as K_{Bi} and C_{Bi} respectively, is similarly given as,

$$m_i\ddot{y}_i + C_{Bi}\dot{y}_i + K_{Bi}y_i + C_{il}(\dot{y}_i - \dot{y}_l) + K_{il}(y_i - y_l) - C_{ki}(\dot{y}_k - \dot{y}_i)$$
$$- K_{ki}(y_k - y_i) \pm F_{fij} \mp F_{fki} = - m_i\ddot{y}_o + F_p \qquad (3)$$

(2) Spring dashpot model

In eqs.(2) and (3), if the mass i is in coupled state with its surrounding masses, F_p are given as,

$$F_p = -\left\{\sum_j C_{ij}(\dot{y}_i - \dot{y}_j) + \sum_j K_{ij}(y_i - y_j + \delta_{ij})\right\} \tag{4}$$

and

$$F_p = -\left\{\sum_j C_{ij}(\dot{y}_i - \dot{y}_j) + \sum_j K_{ij}(y_i - y_i + \delta_{ij})\right\} \tag{5}$$

Concerning the effect of gap between blocks, as shown in Fig.8 the three different models are conceivable.

(i) Model-A: no restraint in the gap

In Fig.8(a), when the two adjoining masses i and j, adhere together, there exist stiffness coefficient K_{ij} and damping cieffi-cient C_{ij} in eqs.(4) and (5). And if they do not, both the values are zero.

$$\left.\begin{array}{ll} K_{ij} = C_{ij} = 0 & : \; y_i - y_j \geqq -\delta_{ij} \\ \left.\begin{array}{l} K_{ij} = K_{ij} \\ C_{ij} = C_{ij} \\ \delta_{ij} = \delta_{ij} \end{array}\right\} & : \; y_i - y_j < -\delta_{ij} \end{array}\right\} \tag{6}$$

(ii) Model-B: some restraint in the gap

In Fig.8(b), when the masses i and j adhere or do not, the K_{ij} and C_{ij} in eqs.(4) and (5) take the corresponding different values.

$$\left.\begin{array}{ll} \left.\begin{array}{l} K_{ij} = K_{ij}^{(1)}, \; C_{ij} = C_{ij}^{(1)} \\ \delta_{ij} = 0 \end{array}\right\} & : \; y_i - y_j \geqq -\delta_{ij} \\ \left.\begin{array}{l} K_{ij} = K_{ij}^{(2)}, \; C_{ij} = C_{ij}^{(2)} \\ \delta_{ij} = \delta_{ij}^{(2)} \end{array}\right\} & : \; y_i - y_j < -\delta_{ij} \end{array}\right\} \tag{7}$$

(iii) Model-C: some restraint in the gap with limitation

In Fig.8(c), if the two masses adhere or do not, the K_{ij} and C_{ij} in eqs.(4) and (5) are different, correspondingly. When the masses i and j are separated beyond a certain distance, however, both the values become zero.

$$\left.\begin{array}{lll} K_{ij} = C_{ij} = 0 & : & y_i - y_j \geqq 0 \\ \left.\begin{array}{l} K_{ij} = K_{ij}^{(1)},\ C_{ij} = C_{ij}^{(1)} \\ \delta_{ij} = 0 \end{array}\right\} & : & 0 > y_i - y_j \geqq -\delta_{ij}^{(2)} \\ \left.\begin{array}{l} K_{ij} = K_{ij}^{(2)},\ C_{ij} = C_{ij}^{(2)} \\ \delta_{ij} = \delta_{ij}^{(1)} \end{array}\right\} & : & y_i - y_j < \delta_{ij}^{(2)} \end{array}\right\} \tag{8}$$

As seen, above equations are non-linear, and of these three models, Model-A can be applied to the motion of blocks when there exists some gap between them in horizontal direction. And Model-B and C are applicable to the case when the adjoining blocks are joined together with key and keyway.

(3) Impact model

In the impact model, the impulse and momentum technique for the collision is used. Velocity and the collision force after collision are calculated from the impulse-momentum equation.

$$\left.\begin{array}{l} v_{i1} = \dfrac{(m_i v_{io} + m_j v_{jo}) - e m_j (v_{io} - v_{jo})}{m_i + m_j} \\[2ex] v_{j1} = \dfrac{(m_i v_{io} + m_j v_{jo}) + e m_i (v_{io} - v_{jo})}{m_i + m_j} \\[2ex] F = \dfrac{(v_{jo} - v_{io})\cdot(1 + e)}{t_c} \cdot \dfrac{m_i m_j}{m_i + m_j} \end{array}\right\} . \tag{9}$$

(4) Dry friction model (mixed model)

This model is a combination of impact and spring dashpot model. In eqs.(2) and (3), F_p are given as,

$$F_p = \begin{cases} K_{ij}(y_i - y_j) + \dfrac{K_{ij}(1-e)}{1+e}(y_i - y_j) : \dot{y} \geqq 0 \\ K_{ij}(y_i - y_j) - \dfrac{K_{ij}(1-e)}{1+e}(y_i - y_j) : \dot{y} \leqq 0 \end{cases} \tag{10}$$

3.2.2 Rocking Motion

The equations of motion for the i-th block may be written as compared with equation (3),

$$\left.\begin{aligned} m_i\ddot{y}_i &= F^R_{Bi} + R^{L_f}_{Bi} - m_i\ddot{y}_o \\ m_i\ddot{z}_i &= F^U_{Vi} + F^L_{Vi} - m_i g \\ I_i\ddot{\theta}_i &= M^R_{Bi} + M^{L_f}_{Bi} + M^U_{Vi} + M^L_{Vi} \end{aligned}\right\} \tag{11}$$

3.2.3 Sway and Rocking Motion

The equation of motion for the i-th block may be written as compared with equation (3),

$$\left.\begin{aligned} m_i\ddot{y}_i &= F^U_{Di} + F^L_{Di} + F^U_{Fi} + F^L_{Fi} + F^R_{Bi} + F^{L_f}_{Bi} - m_i\ddot{y}_o \\ m_i\ddot{z}_i &= F^U_{Vi} + F^L_{Vi} - m_i g \\ I_i\ddot{\theta}_i &= M^U_{Di} + M^L_{Di} + M^U_{Fi} + M^L_{Fi} + M^R_{Bi} + M^{L_f}_{Bi} + M^U_{Vi} + M^L_{Vi} \end{aligned}\right\} \tag{12}$$

3.3 GTOROTO Program

In the present version of the computer system GTOROTO, the calculation model can be chosen one of above models.

4. Methods of Seismic Response Simulation

Figure 9 shows the time-history response of midplane blocks of the experimental VHTR two-dimensional vertical sliced core model. It is difficult to grasp the blocks motion pattern from the figure. If the picture is animated as shown in Photo 1, the viewer gets an immediate scene of the core block's motion pattern.

Computer generated cinema can be used to communicate the technical information to not only researcher but also many collegues.

Computer generated cinema are made with a COM (Computer Output Microfilming) or directly graphic display as shown in Fig.10. In the GTOROTO system direct method is used.

Procedure of making animation film using the CRT graphic display is shown in Fig.10. First of all, response of core blocks is calculated using a seismic analysis computer program such as PRELUDE-2.[8] Displacement data of blocks are stored on a magnetic tape. Secondary, block motion pattern under seismic excitation is represented on the CRT graphic display using the GTOROTO computer program.

A picture is drawn on the screen of CRT (Cathode Ray Tube) and photographed by 16 mm cine camera by hands. The computer then causes the camera to advance the film to the next frame to draw the next picture in the animated sequence and so on.

When a simulation analysis is needed, the time required to complete the analysis can be greatly reduced by the use of interactive graphics. This time consuming area is the interpretation of the output from the analysis results.

With interactive graphics, the analyst can interact with the simulation program to edit data, plot when it is desirable to examine the core motion pattern during execution, and re-execute after editing. Since the GTOROTO can be operated in a conversational mode through the CRT graphic display and lightpen, the analyst can activate the job interactively and obtain the desired plotter data before leaving the interactive console.

5. Graphic System and Graphic Program

5.1 Graphic System

5.1.1 Characteristics of Graphic System

The graphic simulation system GTOROTO developed for seismic response analysis of the HTGR core using the graphic display has the following features:

(1) An object to be analyzed and the results of calculation can be represented as graphic simulation figures on the CRT screen.

(2) The graphic representation can be performed in plan or vertical view.

(3) In comparison with the case of a plotter or COM, it is enough of short time to view the graphic representation on the CRT.

(4) Parameters for the graphic representation and processing routines for the computing scheme can be changed by light pen, keyboard and ASW (Alteration Switch).

(5) Setting off the ASW during graphic representation, progress of the graphic representation stops. Then, one can view the graphic representation closely and produce hardcopy images of the CRT screen on the plotter. Moreover, the graphic representation can restart at a specified time.

(6) Information of the graphic figures can be stored on a disk for obtaining a rapid animation.

The difference in generating simulation films between COM and graphic display will be briefly described. Generally, the COM generates films from the output data of computer. Therefore, in this sense, the film generation process through the graphic display already described in Chapter 4 can be called the COM. However, the COM in its usual sense, displays graphic figures on the CRT of the COM through the tape for the COM or the plotter, and automatically photographs the figures on the films. Thus, the graphic simulation system developed by us, is distinguished from the COM.

5.1.2 Flow of Graphic System

Flow of the graphic simulation system will be explained with the flowchart of Fig.11. When execution of the system is started, Photo 2 is first displayed on the CRT screen, and the system becomes a waiting state at the place of light button A in Fig.11. At this place, the parameters for the graphic representation can be changed and the processing routines for the computing scheme can be specified.

If one of the items of 1 through 3 in Photo 2 is selected by lightpen, Photo 3 is displayed on the CRT, which indicates the parameters to be changed and their input formats. Then, if a parameter in Photo 3 is selected, the message KEY-IN DATA is displayed on the CRT, as shown in Photo 4, and one can input a new value for the parameter. When a change of the parameter is finished and a button CONTINUE is selected by lightpen, the system goes back to the place of light button A in Fig.11.

At this place, a processing routine can be specified by selecting one of the items of 4 through 11 in Photo 2. The items of 4, 5 and 6 indicate the methods of data setting, and the item 7 indicates the termination of the system. The items 8 and 9 indicate whether graphic information is stord on a disk as graphic display words for obtaining a rapid animation. The items 10 and 11 indicate whether block numbers are displayed on all blocks of reactor core.

If one of the processing routines is selected by lightpen, the system reads accelaration wave from an input data tape, and displays the seismic input wave on the CRT, as shown in Photo 5. Then the system reads input data of core vibration, and displays the vibration of reactor core continuously until end of the input data. When the input data become empty, control of the system is transferred back to the initial state.

During the display of the core vibration, if the ASW 8 is set off, then the system becomes a waiting state at the place of light button B in Fig.11, where RESET, CONTINUE and HARDCOPY buttons shown in Photo 7, may be selected by lightpen. By the RESET button, progress of the graphic representation stops and the system goes back to the initial state. By the HARDCOPY button, hardcopy images of the graphic figures on the CRT are produced on the plotter. By the CONTINUE button, the system restarts and redisplays the graphic representation. When the control of the system is transferred back to the initial state, the input data tape can be changed to another tape, and the system can re-execute to simulate the calculation results under other conditions. By this feature, comparison between the calculation results under different conditions can be carried out. Moreover, comparing the calculation results with the experimental results, experiment may be well analyzed.

5.2 Graphic Program

5.2.1 Structure of Graphic Program

The graphic simulation system consists of calculation program PRELUDE-2[8] and graphic program GTOROTO. The PRELUDE-2 performs numerical calculation for seismic response analysis of reactor core, and writes data of the calculation results on a tape. Reading the data on the tape, the GTOROTO performs graphic representation of the calculation results. The GTOROTO has 14 graphic subprograms and these are programmed in FORTRAN using PGSLIB[15] and GSP.[16] Interrelation between the subprograms is shown in Fig.12 and 13.

5.2.2 Functions of Graphic Subprograms

(1) GTOROTO

This is a main program for GTOROTO system. It controls the flow of the system.

(2) INPUT

This reads input data for problem identification, scaling factor of figures, number of masses, etc. from a card reader.

(3) VIBRAS

This reads input data of core vibration from the tape generated by the PRELUDE-2, and represents the core vibration results as graphic simulation figures.

(4) VIEWVE

This displays seismic input wave in graph with x, y axes.

(5) VIEWGD

This displays the frame of reactor core and the core vibration results in vertical view.

(6) HEXA

This displays the core vibration results in plan view.

(7) HEXDJ

This displays the frame of reactor core in plan view.

(8) SCALEX

This scales data for displaying seismic input wave.

(9) VIEWST

This opens graphic display and makes it ready to be used.

(10) FINE

This closes graphic display and makes it not ready to be used.

(11) GDATAS

This is a subroutine to change parameters for graphic representation and processing routines for computing scheme by lightpen, keyboard and ASW.

(12) GNEWGD

This is a subroutine to process the light buttons RESET and CONTINUE.

(13) GX0Y0

This is a subroutine to save and restore original point on the CRT.

(14) GX0Y01

This is a subroutine to create and erase an element name of graphic figures.

6. Input and Output

The GTOROTO is designed as an interactive graphics system, as already described in Chapter 5. Therefore, input data of the system are mainly given by lightpen and keyboard, and output data of the system are also mainly displayed on the CRT. Thus, input data from a card reader and output data to a printer are few.

6.1 Input

The input data from the card reader and their formats are shown in Tables 1, 2, 3. Moreover, these data can be changed by lightpen and keyboard during execution. The main input data are as follows:

(1) Problem identification

(2) Scaling factor of figure

(3) Scale of problem

Seismic response analysis is made by the PRELUDE-2 program and the results are stored on a tape. The system uses the tape as input data of core vibration. Set-up of job control cards and input data cards for the system is shown in Fig.14.

6.2 Output

The output data to the printer are very few, as shown in Table 4. The following are displayed on the CRT:

(1) Problem identification

(2) List of various parameters for graphic representation

(3) List of various processing routines for computing scheme

(4) Identification of seismic input wave

(5) Graphic representation of seismic input wave

(6) Graphic representation of core vibration

These displays are already shown in Chapter 5.

7. Examples of Simulation

In order to describe capability of the GTOROTO system, it is appropriate to describe some examples of the simulation.

7.1 Vertical Sliced Core Model of VHTR

Photo 8 shows the block motion extracted from the CRT graphic display in which seismic behaviors are illustrated in case of the two-dimensional vertical sliced core model of the experimental VHTR under seismic excitation. In the case, the core subject to sinusoidal wave of 5 Hz-frequency and 1000 gal-acceleration.

Displacement of blocks displays exaggeratively with thirty or forty times compared with block diameter for the purpose of clearly showing of blocks motion.

Photo 9 is another simulation results in which case the core subject to El Centro wave of 1000 gal acceleration.

7.2 Horizontal Sliced Core Model of VHTR

Photo 10 shows the behaviors of the block motion for the two-dimensional horizontal sliced core model of the experimental VHTR under seismic excitation. In the case, the core subject to sinusoidal wave of 5 Hz-frequency and 1000 gal acceleration.

It can be seen from Photo 10 that star-symbols appear between blocks on the blocks collision. This motion pictures may be considered the mid-plane blocks of the experimental VHTR core.

7.3 HTGR Core Model

Photo 11 indicates the block motion for two-dimensional vertical sliced core model of the large HTGR as previously shown in Fig.2.

In the case, the core subject to sinusoidal wave of 5 Hz-frequency and 1000 gal-acceleration. It can be seen from the motion picture that most column vibrate in lumping.

7.4 Analysis of one stacked column

Photo 12 indicates an example of column behavior produced from analytical results in case of sinusoidal wave of 3.5 Hz-frequency and 500 gal-acceleration. The same deftection mode is observed in the test of one stacked column.

8. Concluding Remarks

A simulation system GTOROTO has been developed for analysis of HTGR core seismic behavior. It is obviously seen from these examples that the GTOROTO system is very useful for simulation of VHTR and HTGR core seismic.

The following features are emphasized from the operational experiences obtained during the simulation analysis performed by the GTOROTO system.

(1) Behavior of the block-type HTGR core during earthquake can be shown on the CRT-display.

(2) Parameters for the graphic representation can be changed with the lightpen.

(3) Routines of the computing scheme can be changed with the lightpen or an alteration switch.

(4) Simulation pictures are shown automatically. Hardcopies are available by plotter in stopping the progress of simulation pictures. Graphic representation can be re-started with the predetermined program.

(5) Graphic representation informations can be stored in assembly language on a disk for rapid representation.

(6) A computer-generated cinema can be made by COM (Computer Output Microfilming) or filming directly the CRT pictures.

These features in the GTOROTO are provided in on-line conversational mode.

NOMENCLATURE

C : Damping coefficient

e : Coefficient of restitution

F : Force

g : Gravity constant

h : Damping factor, $2h\omega = C/m$

I : Rotation of inertia

K : Stiffness coefficient

M : Moment

m : Mass

t_c : Contact time

v_{io}: Velocity before collision

v_{i1}: Velocity after collision

Y : Displacement in absolute coordinate

y : Displacement from core barrel

z : Vertical displacement

δ : Gap between blocks

θ : Rotational degree

ω : Natural frequency, $\omega = \sqrt{K/m}$

Upper subscripts

L : Lower

L_f: Left

R : Right

U : Upper

Lower subscripts

B : Boundary

D : Dowel

F : Friction

M : Impact plate

V : Vertical

i : i-th element

Others

• : Velocity

¨ : Acceleration

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Acknowledgements

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(15) Nakamura, Y. and Onuma, Y.: JAERI-M 6023 (1975).

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Table 1 Input data list

Card number	FORMAT	Variables	Descriptions
1	I1	TITLE 2	Calculation control. =0 : Calculation continue. =1 : Calculation stop.
	9A8	TITLE 1(I) (I=1,9)	Problem identification.
2	4F10.0	TPRINT	Graphic represent interval time (sec).
		BETA	Scale factor of gap.
		XFCT	Scale factor of figure.
3	I3	NPOINT	Number of masses.
	I6	IPLT 2	Length of time axis, IPLT 2 (mm/sec).
	I3	LAMD(9)	Option for keyed block. =0 : No-key block. =1 : Keyed block.
	12X		
	I3	LAMD(14)	Option for reactor frame. =0 : No-reactor frame. =1 : Represent of reactor frame.

Table 2 Sample of input data

INPUT DATA SHEET

氏名	日付 / /	プログラム名	JOB NO.	カード色指定	PAGE OF
所属	電話	研究テーマ番号	IBJOB DECKNAME	備考	PUNCH 73−80 YES □ NO □

```
$NO       A001,
                                                                       /
                                                                    T.3/TIME  2M
                                                                    C.2/CORE256
                                                                    W.0/PAGE  40
                                                                   ,P.0/PGH    0
                                                                   ,PLT/
$GJOB   2112322,IKUSHIMA,194.02,GTOROTO
                                                                       /00331
$FORT

              PROGRAM

$LIEDRUN       PGSLIB=CALL,GDSP=ON,GDBG=ON
$TAPE    F01,J2322.GTORO,OLD,008043
$DISK    F08
$DISK    F10
$PLOT
$DATA

TITLE0  TITLE1(I), I=1,18                                      (I1, 18A4)        #1
```

共通E 173

* 73−75 : DATAID / 76−80 : SEQUENTIAL NUMBER

INPUT DATA SHEET

PAGE OF

氏名	日付 / /	プログラム名	JOB NO.	カード色指定	PUNCH 73--80
所属	電話	研究テーマ番号	IBJOB DECKNAME	備考	YES [] NO []

```
         1         2         3         4         5         6         7 * 
1234567890123456789012345678901234567890123456789012345678901234567890123456780
     DA       TPRINT     BETA      XFCT                       ( 4F10.0)    #2
NPOINT IPLT2  LAMD(9)       LAMD(14)                          ( I4, I6, I4, 12X, I4 )
                                                                           #3
$JEND
```

共通E 1 7 3

* 73-75：DATAID / 76-80：SEQUENTIAL NUMBER

Table 3 Input data of sample problem

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

          GTOROTO-3 SAMPLE
 0.4       0.1       1.0        0.77
156    50                   1
1     LAST  CARD
```

Table 4 Output list of sample problem

```
                            GTOROTO-3 SAMPLE
     * VIBRAS * IS CALLED.
NCASE....   1  IPLT2....    50  TPRINT...   0.10000  DA ....    0.40000
BETA......    1.00000  XFCT.....  0.770 L(UNIT-NO.)..  1
                                         * * I N P U T   D A T A * *
1. EARTHQUAKE WAVE          EARTHQUAKE WAVE NAME
                                 1      EL  CENTRO  40NS
                            GALMAX (GAL)        1000.0
                             CASE 1-NORMAL END.
```

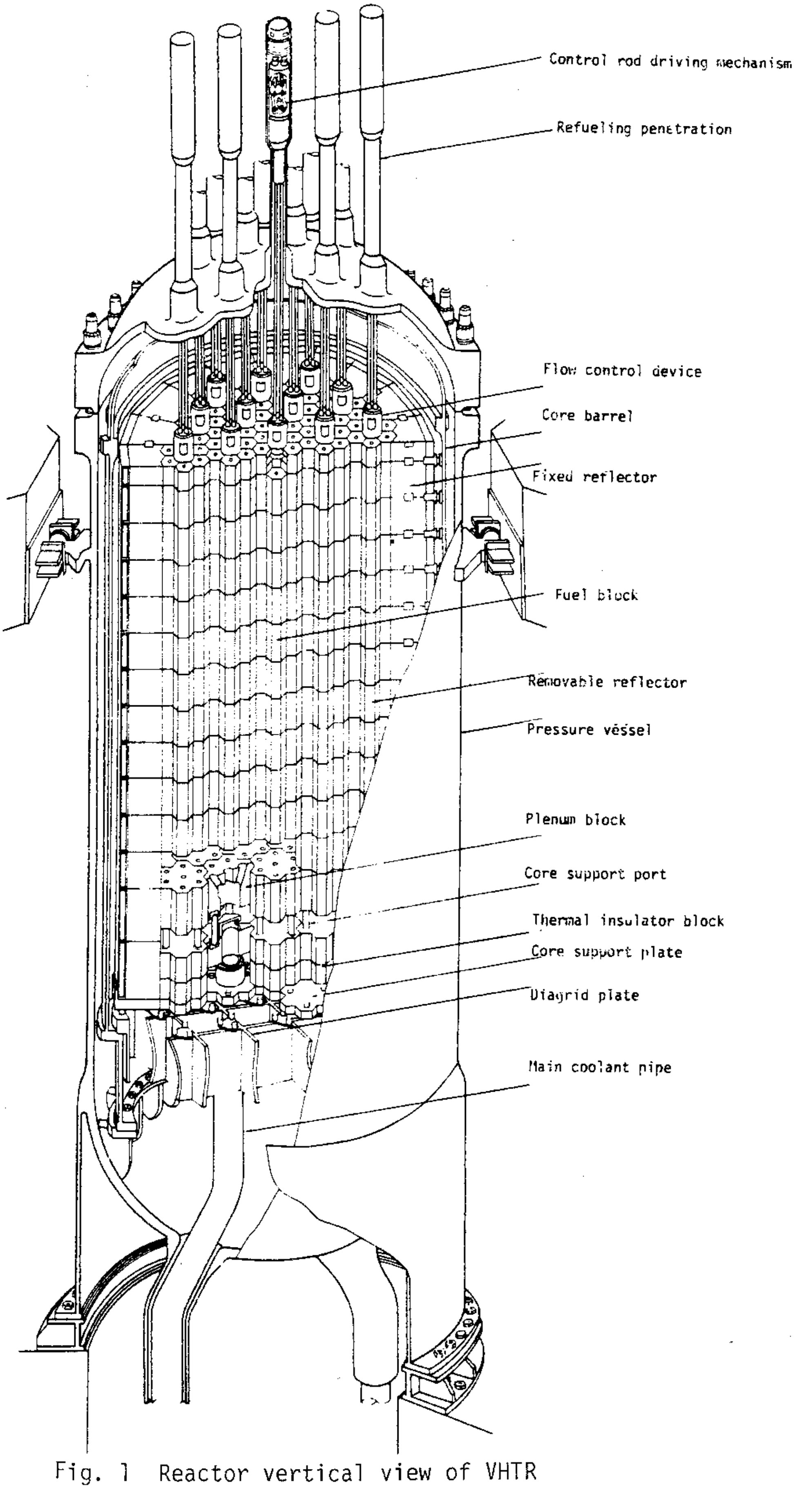
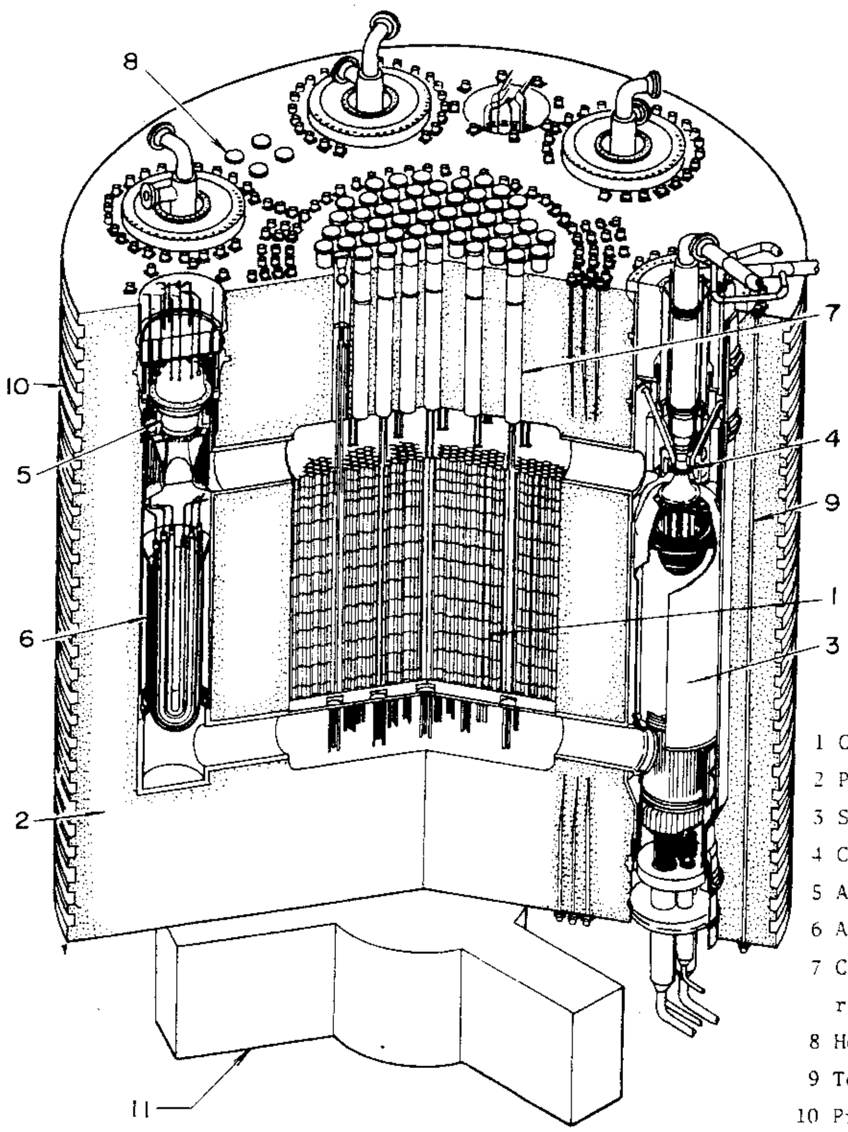


Fig. 1 Reactor vertical view of VHTR



1 Core
2 PCRV
3 Steam generator
4 Circulator
5 Auxiliary circulator
6 Auxiliary heat exchanger
7 Control rod and refueling penetration
8 Helium purification wells
9 Tendon
10 Prestress channel
11 PCRV support structure

Fig. 2 Reactor vertical view of large HTGR

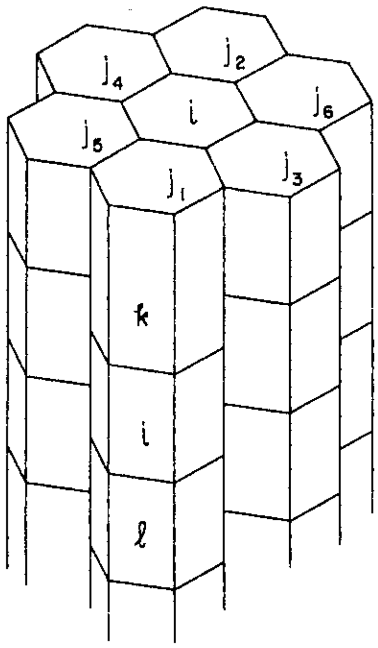


Fig. 3 Block array

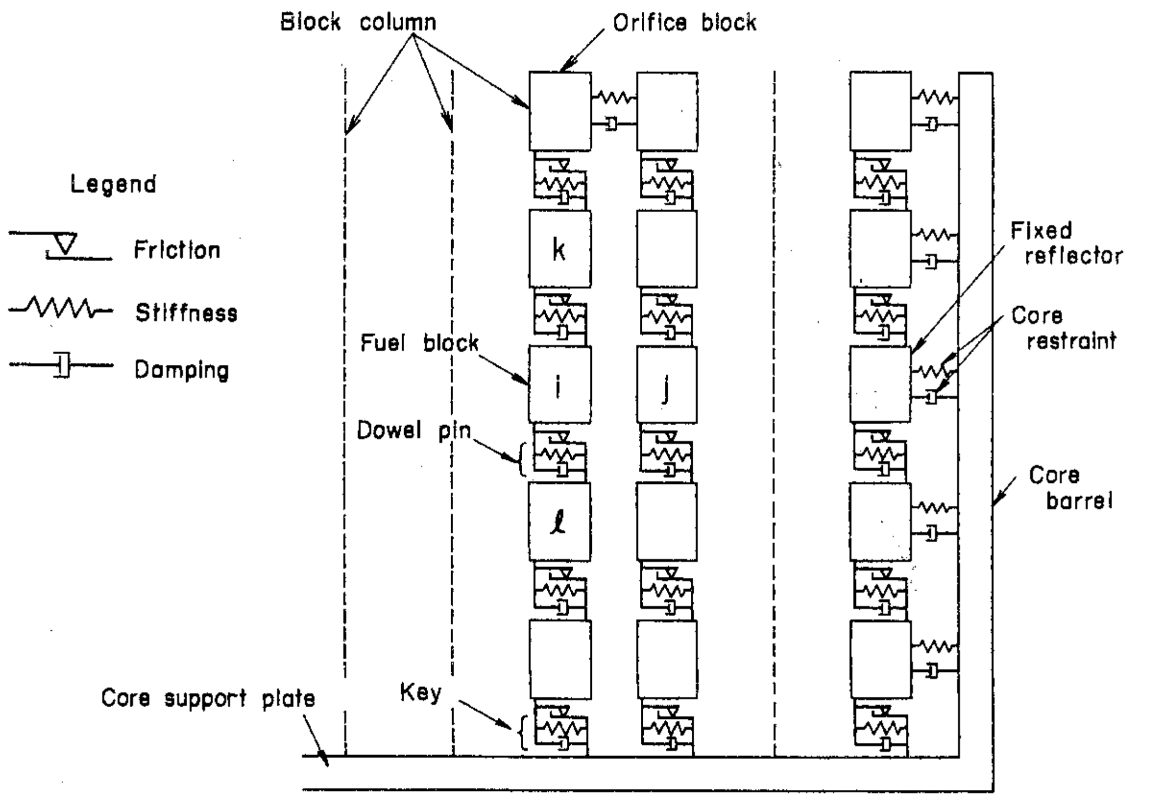


Fig.4 2-D calculation model for seismic response analysis of HTGR vertical sliced core

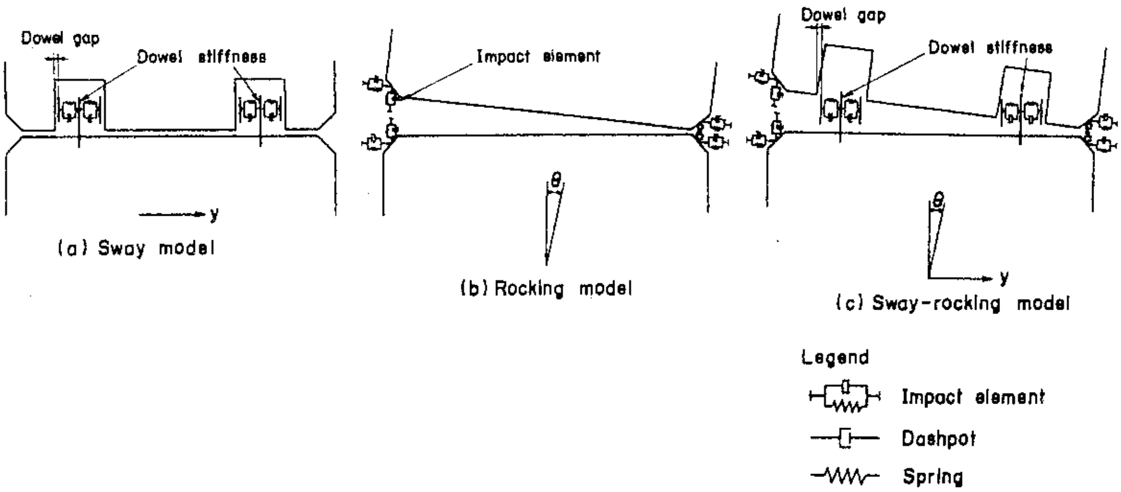


Fig. 5 Block motion model

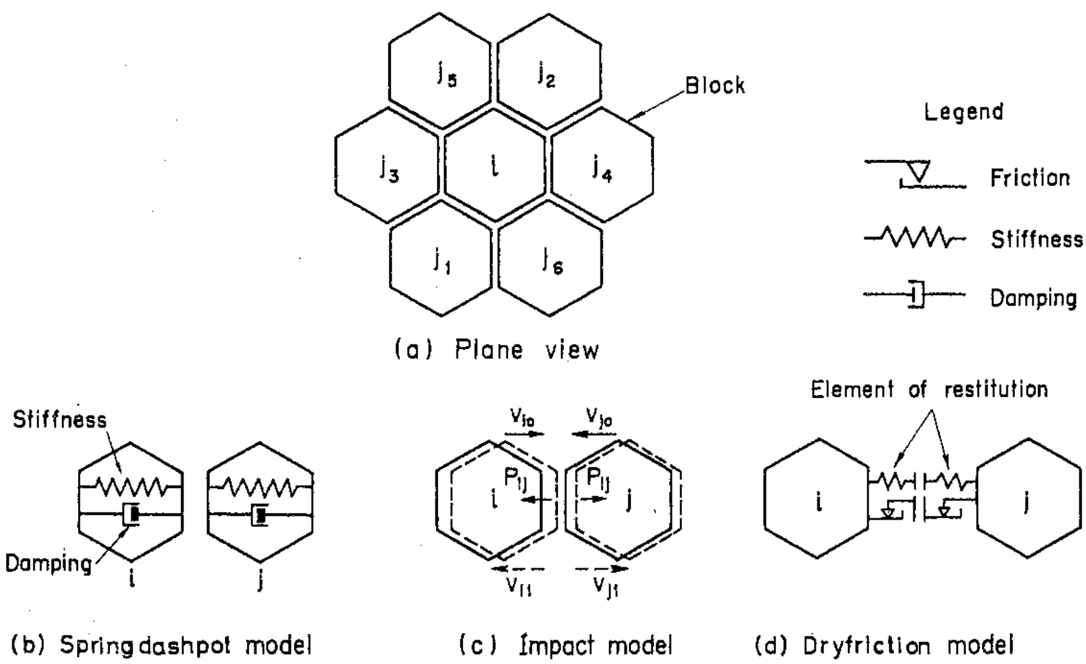
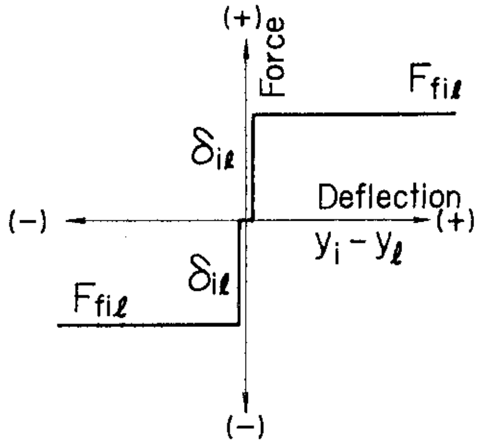


Fig. 6 Block plane arrangement and calculation models



$$\begin{cases} F_{fi\ell} = 0 \ ; & |y_i - y_\ell| < \delta_{i\ell} \\ F_{fi\ell} = \pm F_{fi\ell} & \begin{cases} \pm(y_i - y_\ell) \geqq \delta_{i\ell} \\ \dot{y}_i - \dot{y}_\ell > 0 \end{cases} \end{cases}$$

Fig. 7 Calculation model for friction

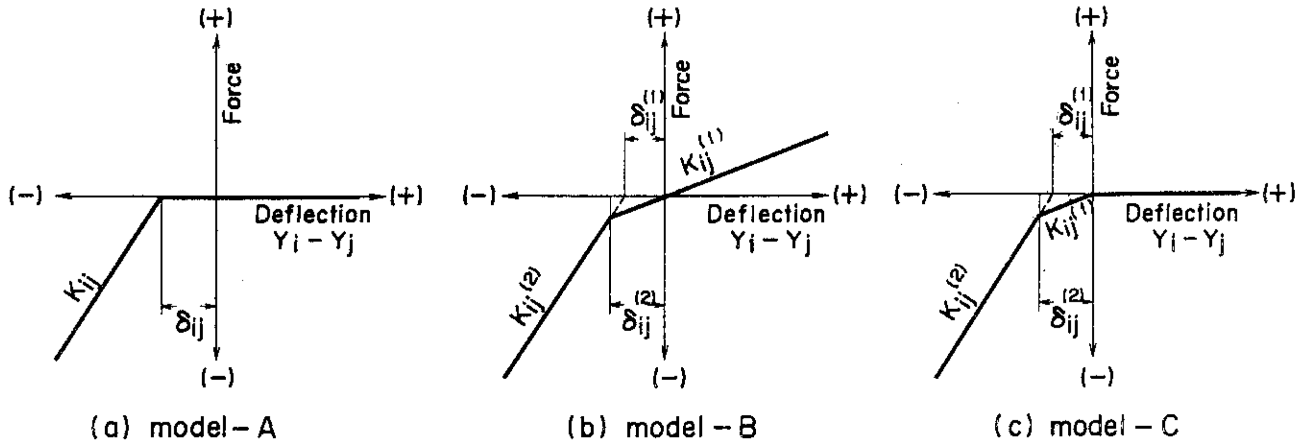
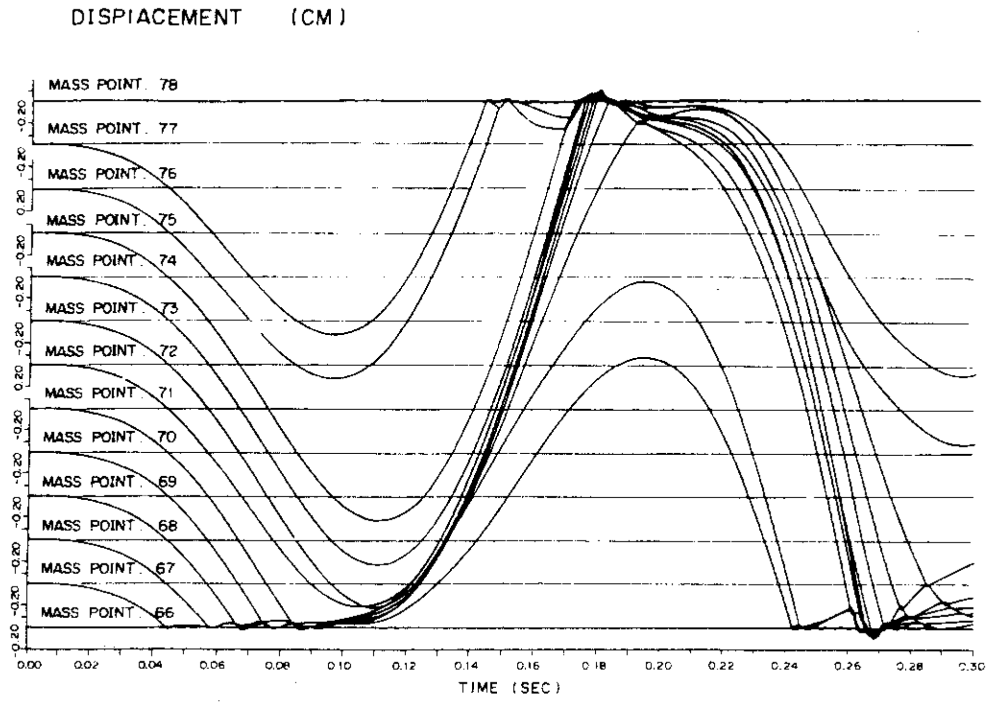
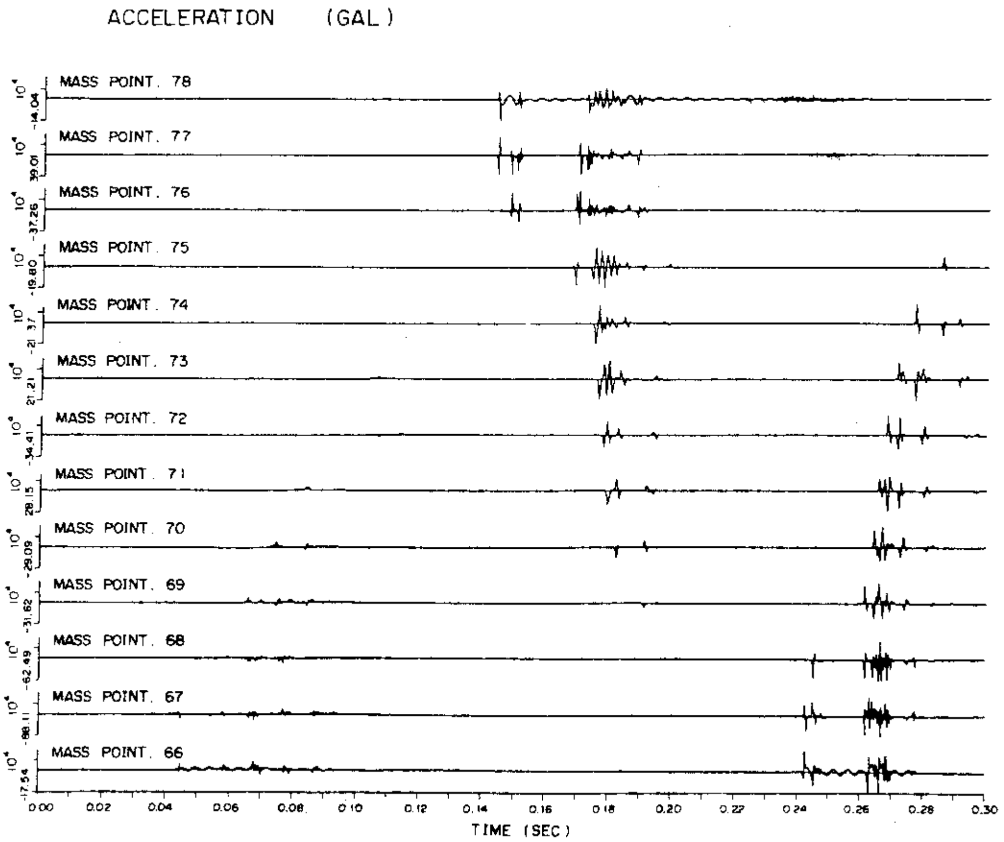


Fig. 8 Calculation model for discontinuous mass system





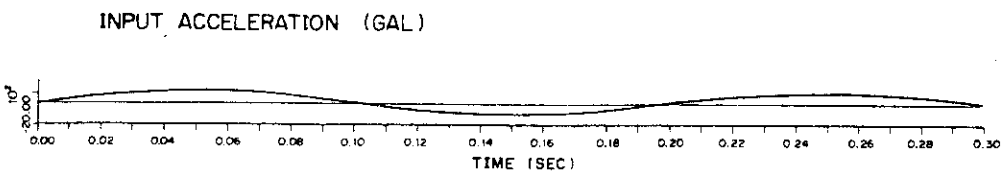


Fig. 9 Seismic response histories

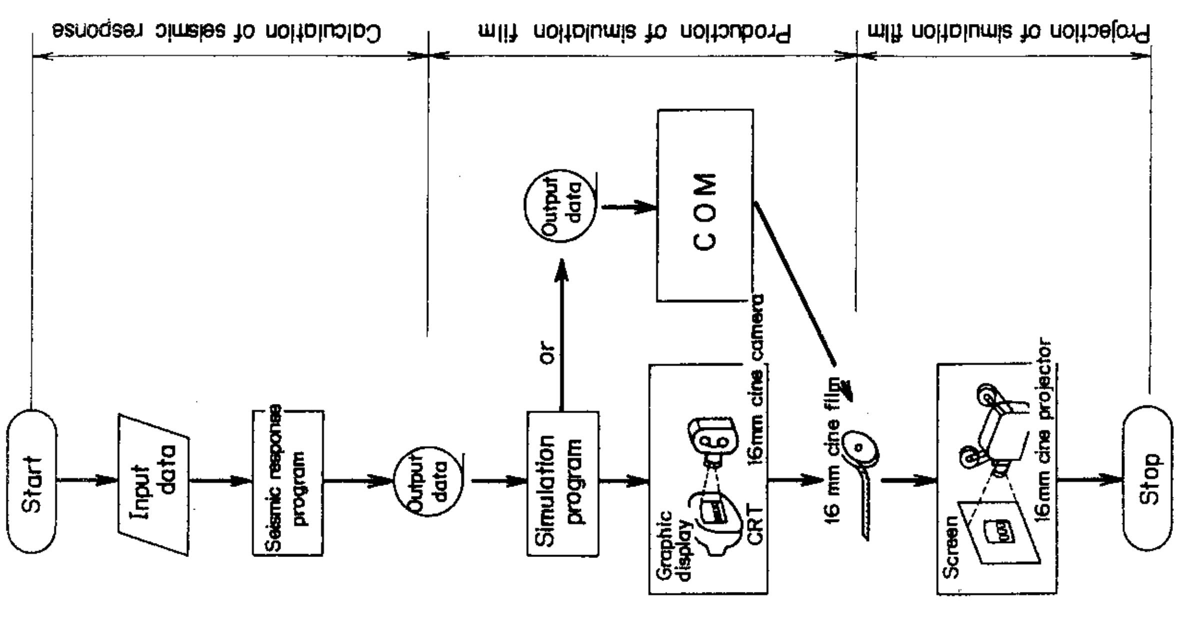


Fig.10 Flow sheet of simulation

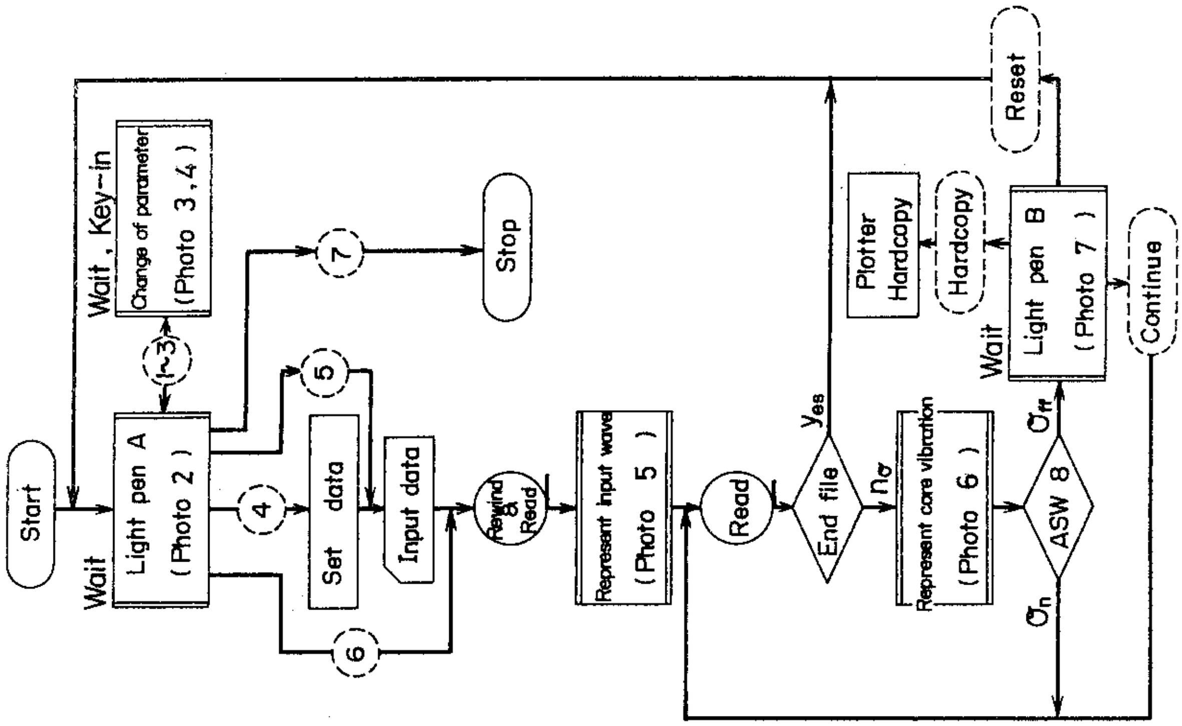


Fig.11 Flow sheet of calculation program

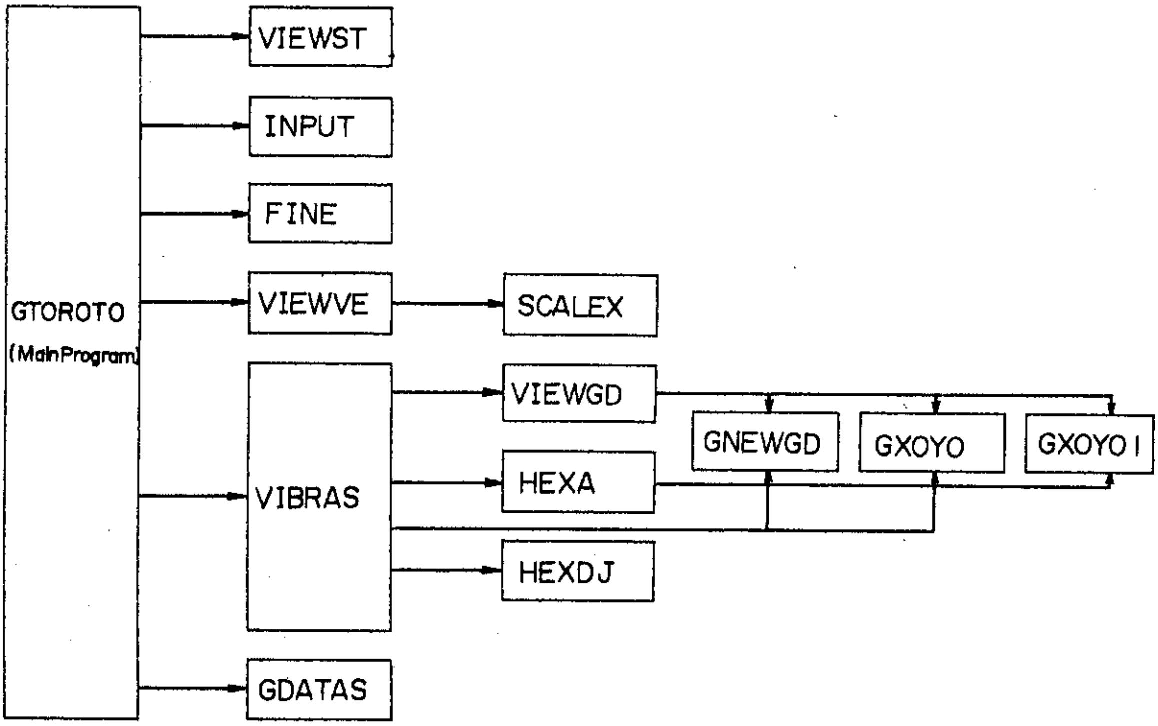


Fig. 12 Interrelation of the subprogram in graphic program GTOROTO.

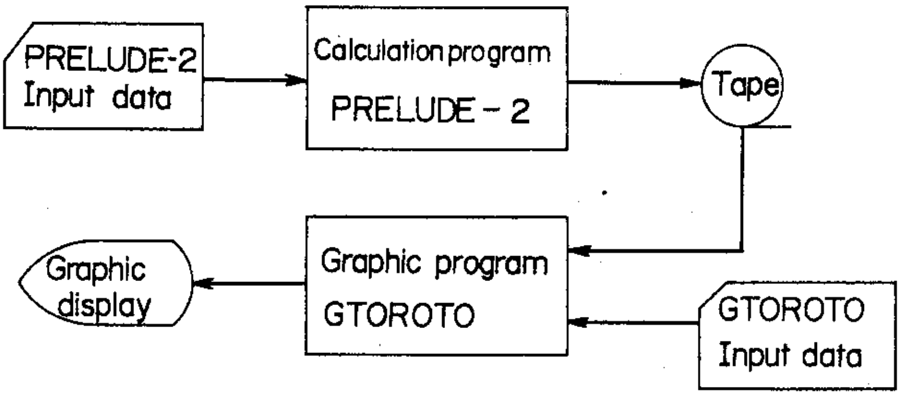


Fig. 13 Graphic Simulation System GTOROTO.

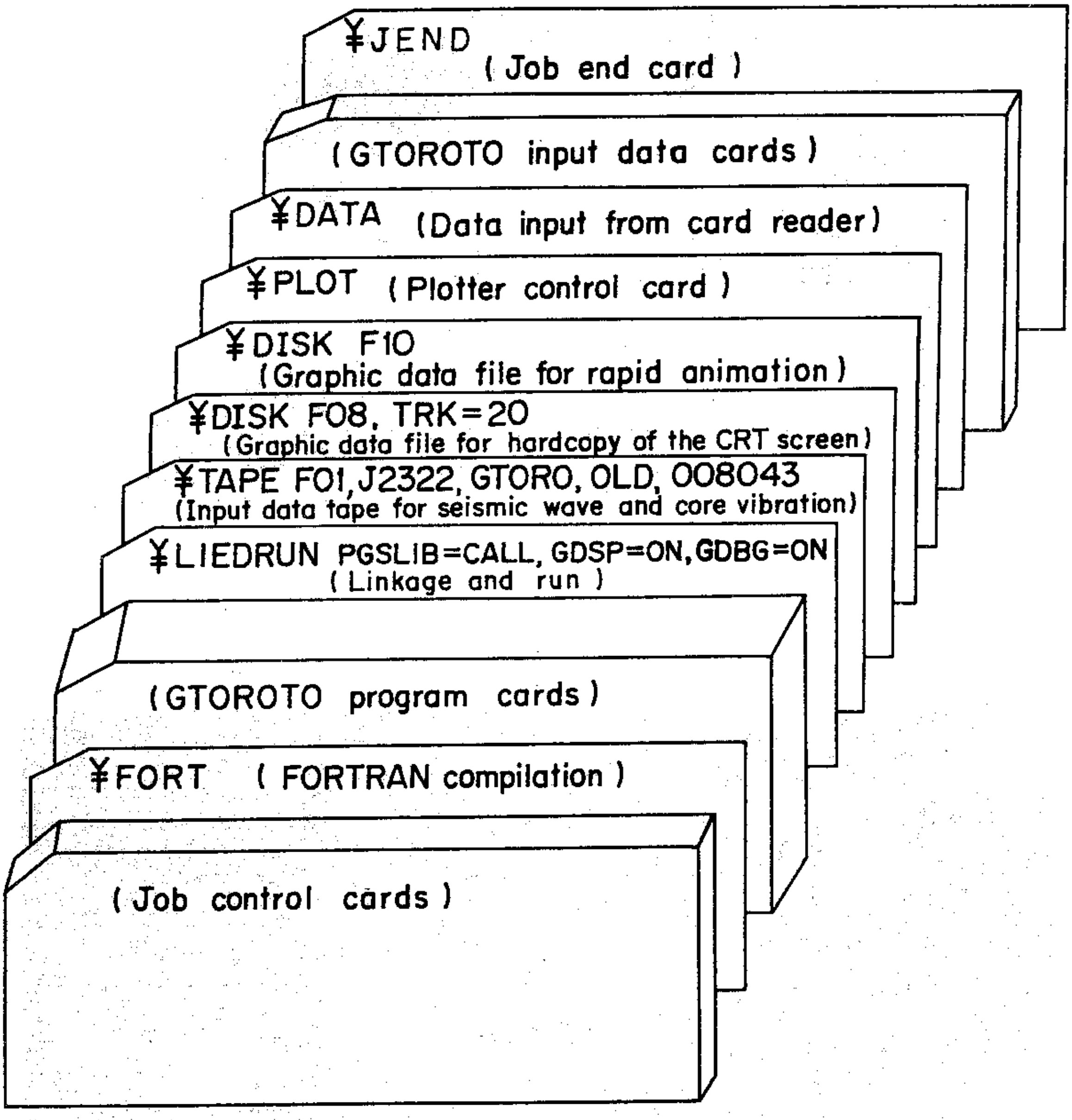


Fig.14 GTOROTO job cards set-up

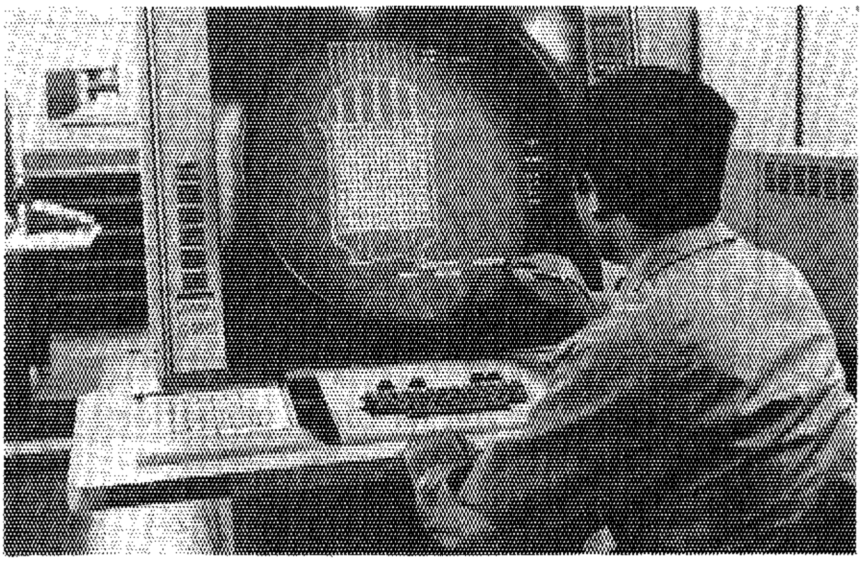


Photo.1 Core seismic analysis using interactive display

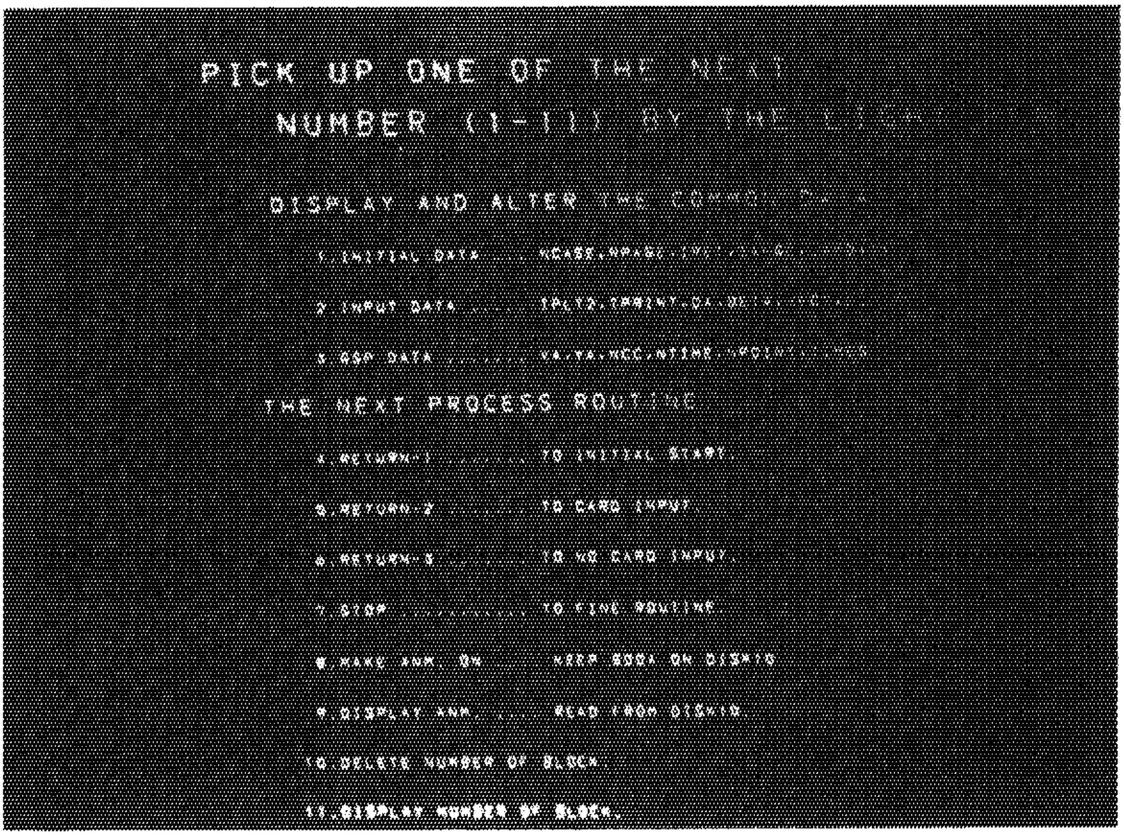


Photo.2 CRT-display for selection of processes and parameters

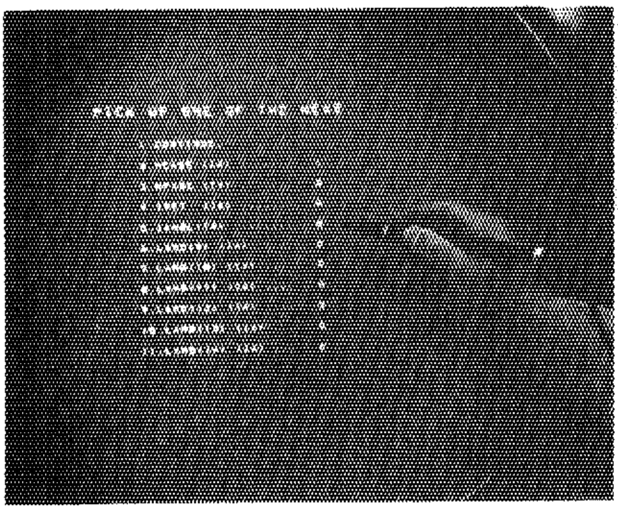


Photo. 3 (a)

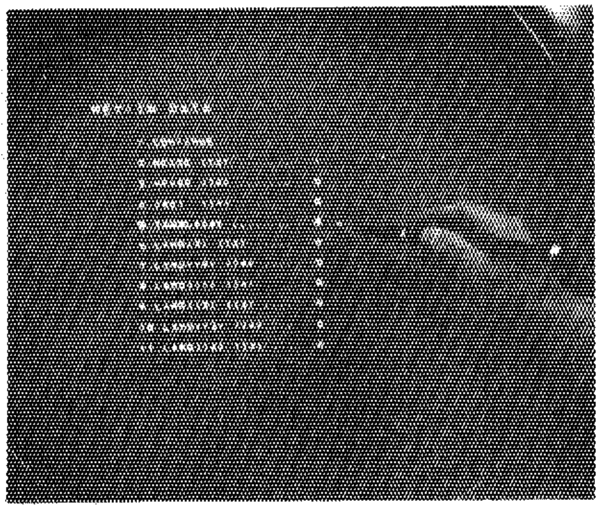


Photo. 4 (a)

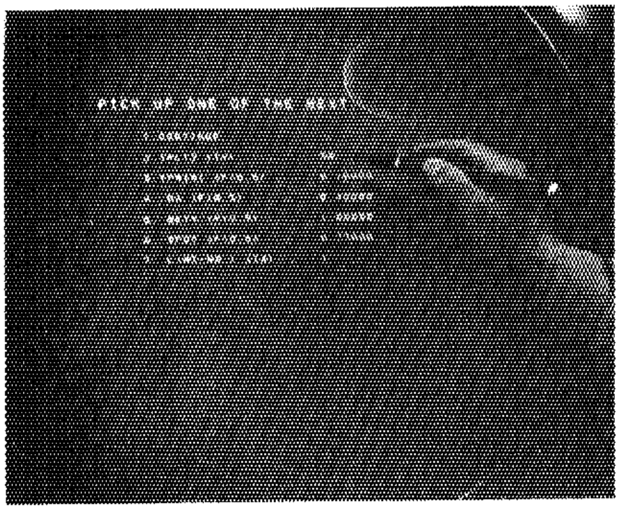


Photo. 3 (b)

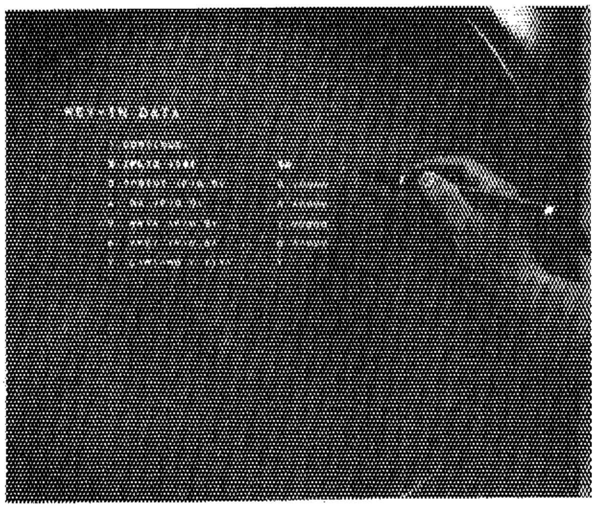


Photo. 4 (b)

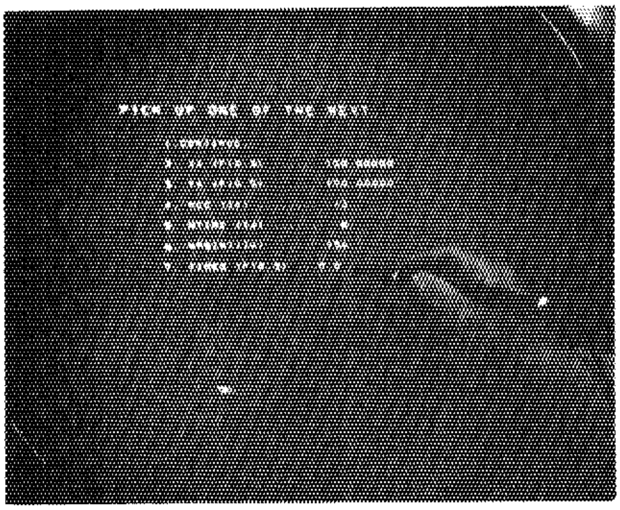


Photo. 3 (c)

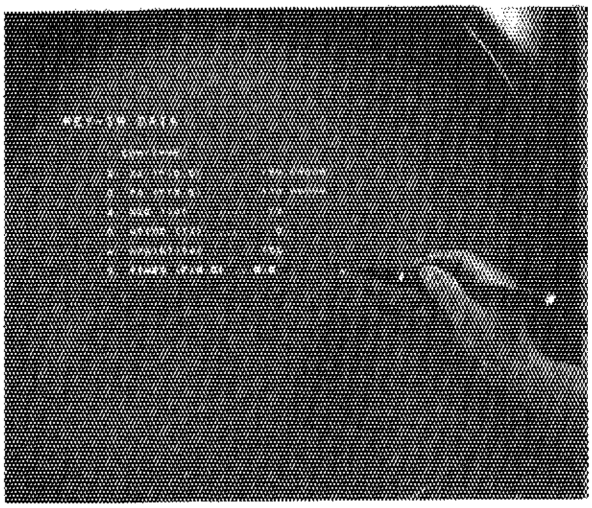


Photo. 4 (c)

Photo. 3 Change of parameter

Photo. 4 Input of changed parameter

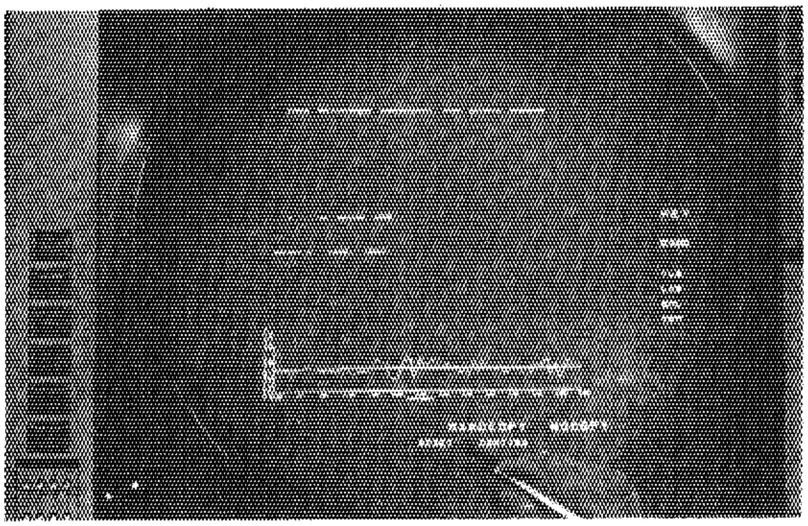


Photo.5 Display of input acceleration wave

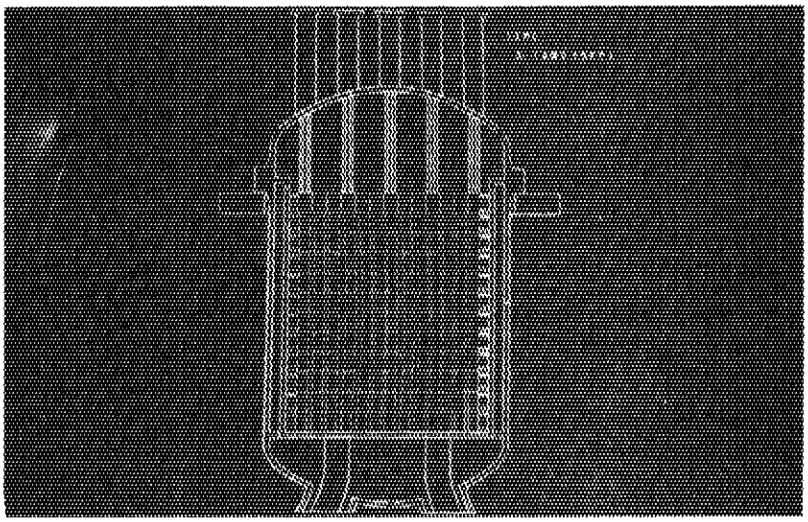


Photo.6 Disply of core seismic behavior

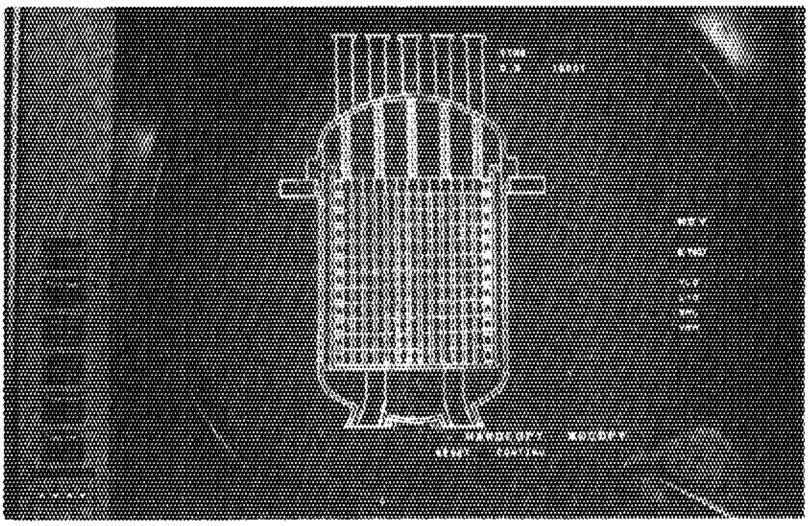


Photo.7 Interactive process using lightpen

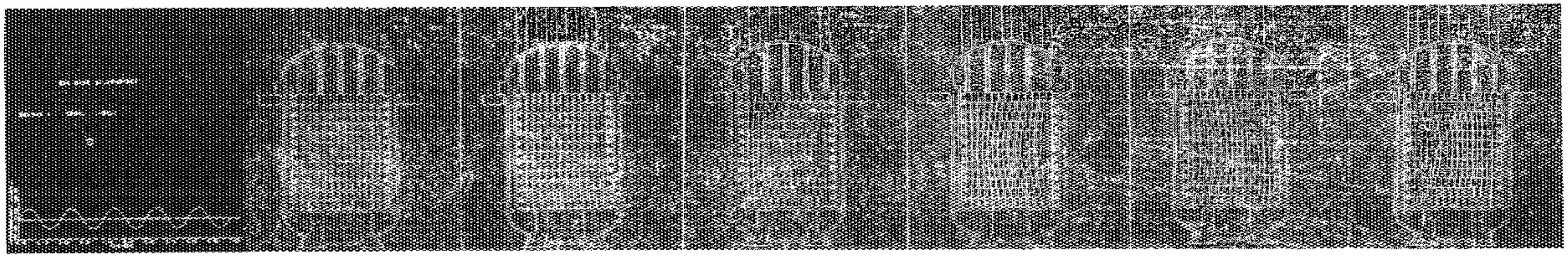


Photo.8 Example of seismic behavior of 2-D vertical sliced core model

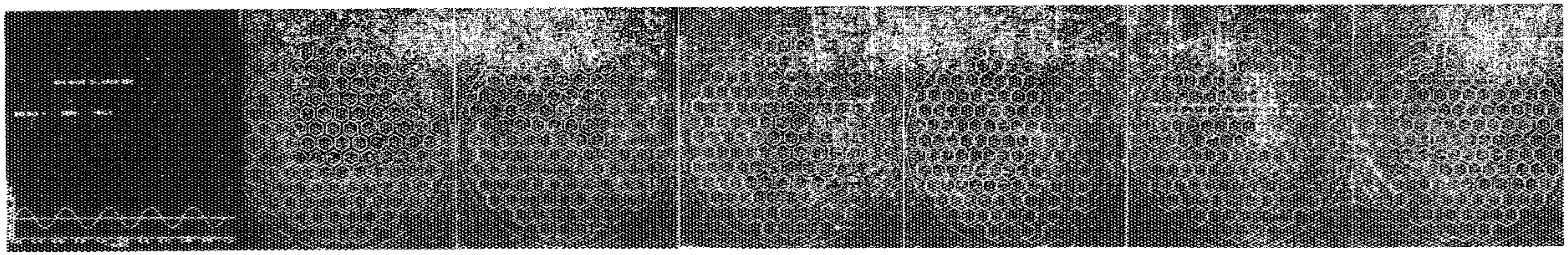


Photo.10 Example of seismic behavior of 2-D horizontal sliced core model

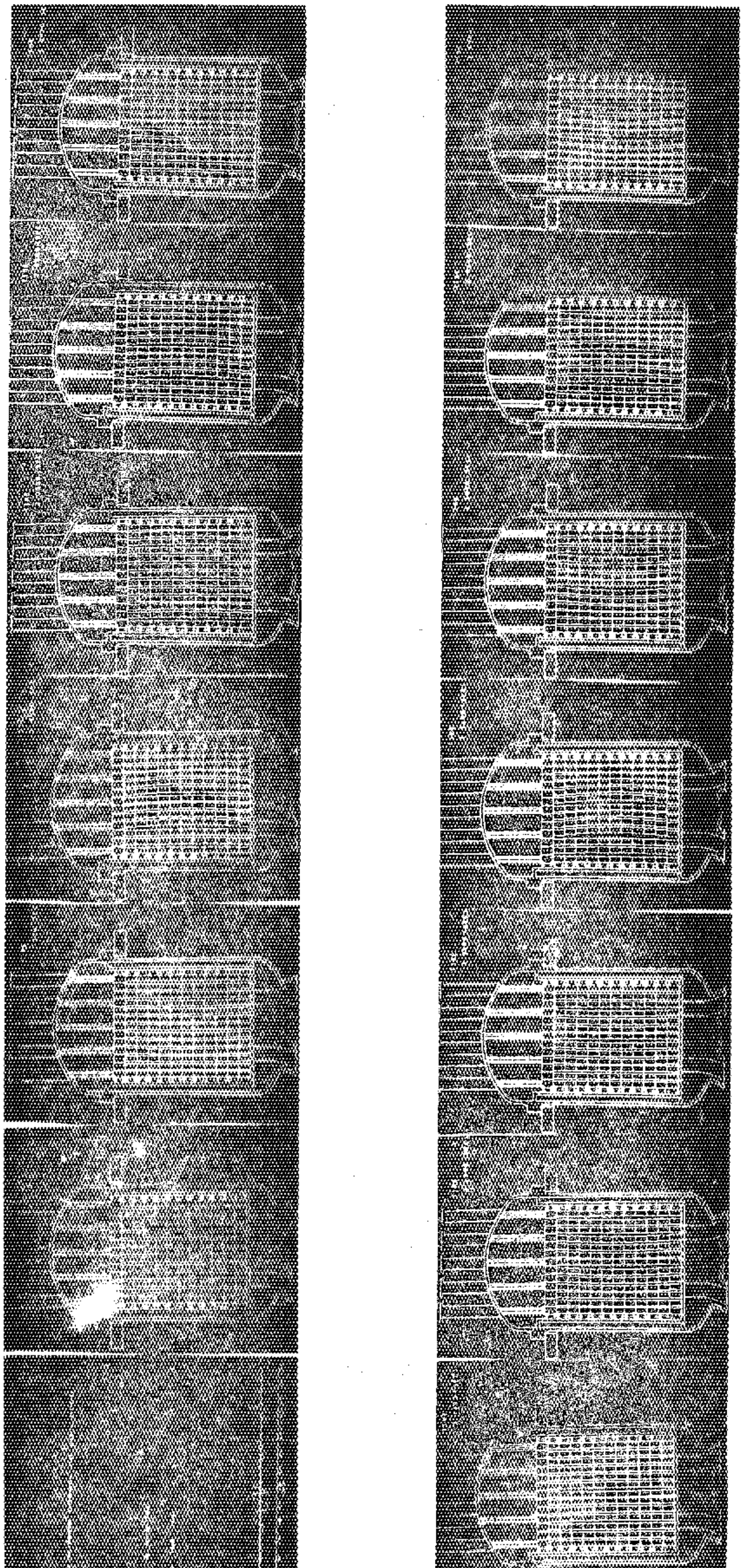


Photo.9 Example of seismic behavior of experimental VHTR core

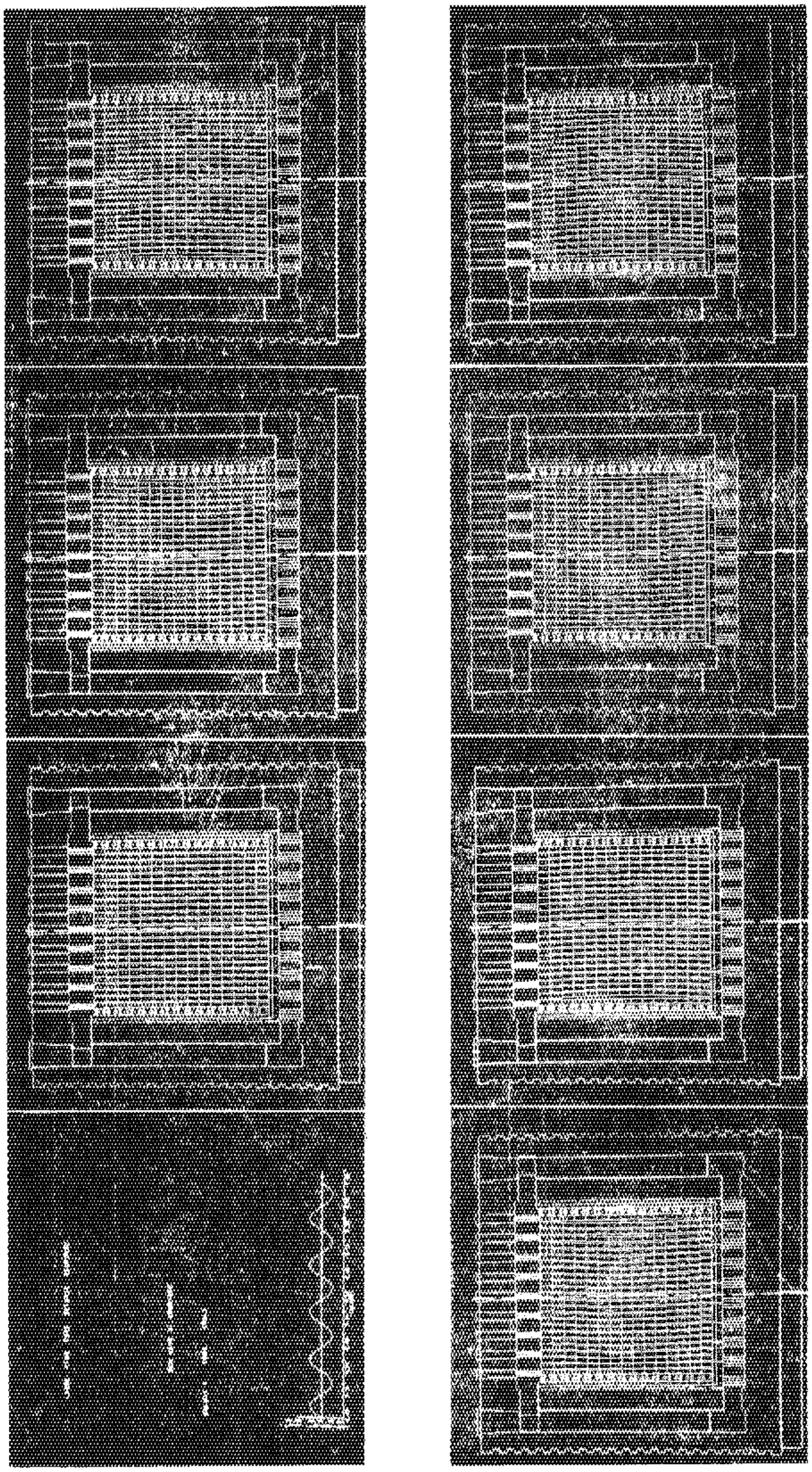


Photo.11 Example of seismic behavior of large HTGR core

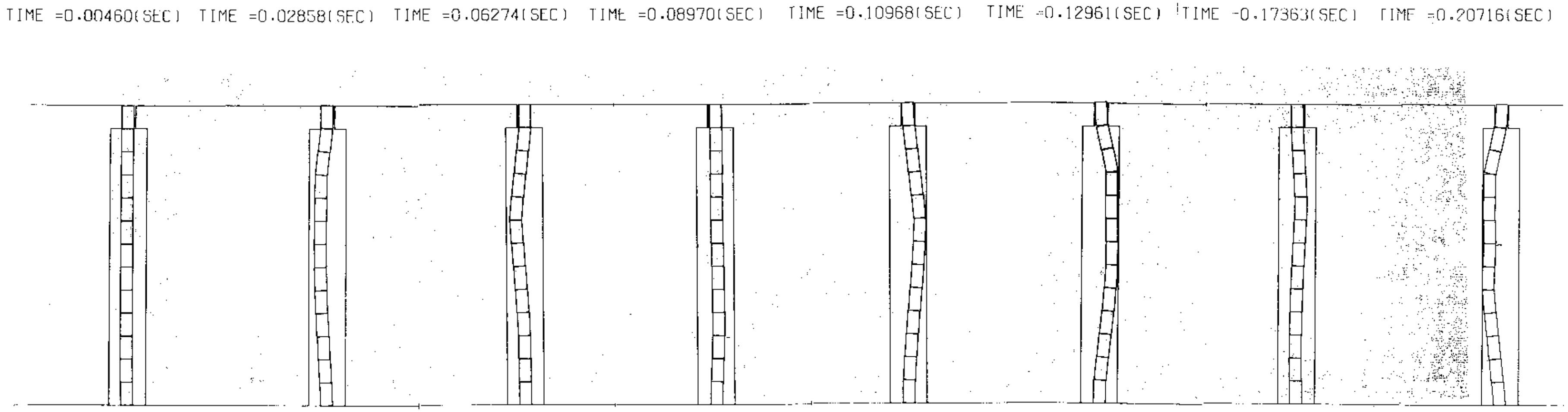


Photo.12 Example of seimic behavior of one stacked column
(Hard copy)