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# Study on the Vibration Characteristics of Filldam with a Rigid Core
## – I. Analytical Study –

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## Abstract

In this report, as to the filldam with a rather rigid core, the vibration characteristics are discribed from the results obtained by using F. E. M. program, ISAP, in which modal analysis and time historical analysis are employed.

Recently, a rigid core as likely as concrete is not used so many in Japan because the dynamical behavior of dams with such a core is not cleared.

But authors try to treat such problem in order to find out the possibility to construct them and show various characteristics of them.

## I. Introduction

Dynamic problems for Civil Engineering Structure are the most important in our country which has been subjected with earthquake impaction several times.

We study about the vibrational characteristics of filldams with a rigid core as same as concrete material.

Generally, it is not used to construct them because of some structural problems. Those are concerned with the interaction of some materials.

However, if such structural problems are able to be solved step by step, we can construct such a filldam with a rigid core. And so, we try to investigate the characteristics of dynamical responses of the dam firstly in anlalytical methods which are the mode analysis and response analysis with time history.

We analyze the some cases of core type filldams by using the finite element method developed by Wilson and et al. which is called as ISAP. But this method is just within the elastic zone and so, we cannot check the properties over elastic zone of materials.

## II. General presentation of F. E. M. program, ISAP

This program can be used to analyze a few cases which mean the modal analysis, vibration analysis, time historical analysis of response and also frequency analysis. We are just using the modal analysis and time historical analysis of response.

Basical problems are analyzed by following equation,

$$[M]\,\{\ddot{u}\} + [K]\,\{u\} = 0 \qquad (1)$$

where,
- $[M]$ : Total mass matrix
- $[K]$ : Total stiffness matrix
- $\{u\}$ : Vector of displacement

Equation (1) has the one solution as same as $\{u\} = q\ \{\phi\}\ e^{-iwt}$ and so we can take

$$[K]\ \{\phi\} = w^2\ [M]\ \{\phi\} \qquad (2)$$

This belongs to the eigen value problem.

where, $w$ : eigen value

$\{\phi\}$: eigen vector

In other case, which means vibration analysis, following equation is analyzed by some numerical methods, which are, for example, the direct integration method, modesuperpose method and so on.

$$[M]\ \{\ddot{u}\} + [C]\ \{\dot{u}\} + [K]\ \{u\} = [\ F(t)\ ] \qquad (3)$$

where, $[M]$ : mass matrix

$[C]$ : damping matrix

$[K]$ : stiffness matrix

$[F(t)]$ : external force with time

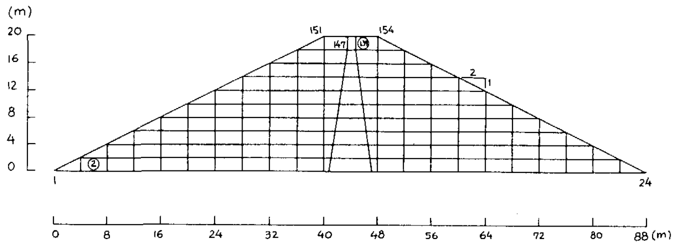
and so, from $[C] = \alpha\ [M] + \beta\ [K]$, we can obtaine constants, $\alpha$ and $\beta$ using the results of modal analysis and determine the damping matrix $[C]$.

It is just meaning of taking assumption of Rayleigh's damping.

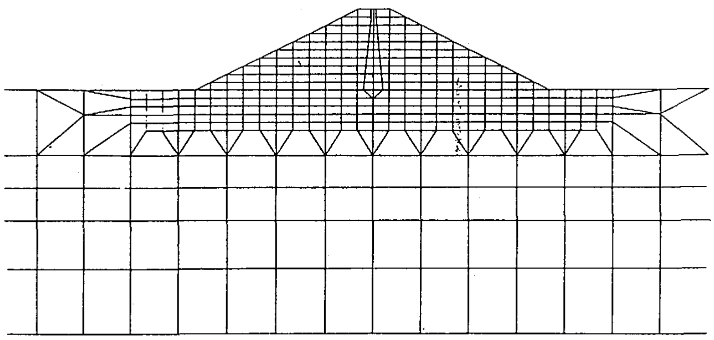
## III. Analytical results and consideration

### 1. *Analytical models*

We took the models of core type filldam as follows. As shown in Fig. 1, we took two models for analysis, the first case is the model which has no-foundation and the other is the model which has relatively rigid core composed of concrete as rock as likely as shown in Table 1 for basical physical properties.




no foundation



with foundation

Fig. 1 Analytical Models

Table 1　Cases analyzed and material property

| Properties / Material | Weight density $\rho_w(t/m^3)$ | Mass density $\rho_m(t/m^3)$ | Possion ratio $\nu$ | Shear Modulus $G(t/m^2)$ | Elastic Modulus $E(t/m^2)$ | Core bottom width (m) | Case identification |
|---|---|---|---|---|---|---|---|
| Earth | 2.0 | 0.2041 | 0.4 | 1.786 E3 | 5.0 E3 | | Homogeneous |
| Concrete | 2.3 | 0.2347 | 0.3 | 1.15 E6 | 3.0 E6 | 2.8 | I−1 |
| 〃 | 〃 | 〃 | 〃 | 1.15 E6 | 3.0 E6 | 4.8 | II−1 |
| 〃 | 〃 | 〃 | 〃 | 1.15 E6 | 3.0 E6 | 6.8 | III−1 |
| 〃 | 〃 | 〃 | 〃 | 5.769 E5 | 1.5 E6 | 2.8 | I−2 |
| 〃 | 〃 | 〃 | 〃 | 5.769 E5 | 1.5 E6 | 4.8 | II−2 |
| 〃 | 〃 | 〃 | 〃 | 5.769 E5 | 1.5 E6 | 6.8 | III−2 |
| 〃 | 〃 | 〃 | 〃 | 3.846 E5 | 1.0 E6 | 2.8 | I−3 |
| 〃 | 〃 | 〃 | 〃 | 3.846 E5 | 1.0 E6 | 4.8 | II−3 |
| 〃 | 〃 | 〃 | 〃 | 3.846 E5 | 1.0 E6 | 6.8 | III−3 |

2. *Results of the modal analysis*

Fig. 2 shows the mode shapes for both homogeneous and core type models. From this figure, it can be said that 1 st mode is vibrating excellently in horizontal direction, 2 nd mode is vibrating excellently in vertical direction and 3 rd mode seems to vibrate in both horizontal and vertical directions.

And so actually, 3 rd mode mainly may appear in real field because an earthquake has three dimensional components which mean two horizontal and one vertical directional component of propagation under the ground.

Fig. 3 shows the mode shapes for the cases with foundations, which are the case C′, D and E. Cases of C′ and D are almost same for each mode, but case of E is different so much from others. This means to depend on the difference of property for the foundation. And so, it is suggesting some porblems which are concerned with the design of filldams.

Generally, the actual foundation is almost composed of rocks in which there may be some faults and also they have been relatively more stiffened than in earth foundation. In such a case, foundation may have higher natural frequency than the earth dam. As it can be seen from the results of case E, the mode shape is getting more complicated and also the displacement becomes more bigger, which means that some failure in earth dam may be coming.

Table 2 shows the results of natural frequencies for each case by 3 rd mode and also the results for the case of no-foundation. From these results, we can say as follows.

In analysis of natural frequencies for an actual dam, we must consider the scale of foundations according to the field states of foundation. If it is not so, we may have some errors for the design of dams. Because the scale of foundations affects so much to the natural frequency of the dam system.

From the other viewing point of the core, the core affects to the dam system as to the natural frequency because of it's stiffness, which means that the bigger the scale of the core becomes and the heigher the stiffness becomes, the heigher the natural frequency of the dam system. And so we can control the natural frequency of the dam system by selecting the scale and the stiffness of the core.

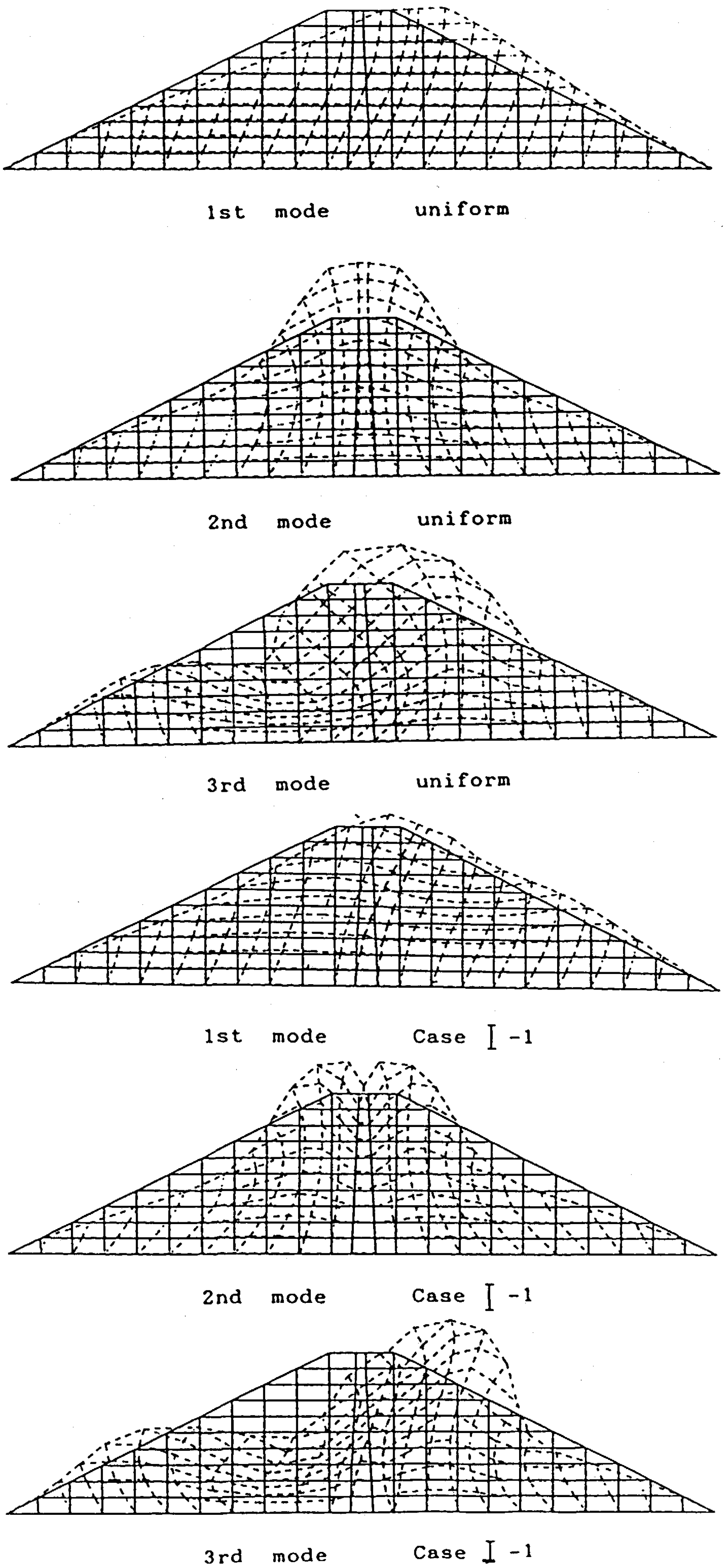



Fig. 2 Modes analyzed for uniform and I−1

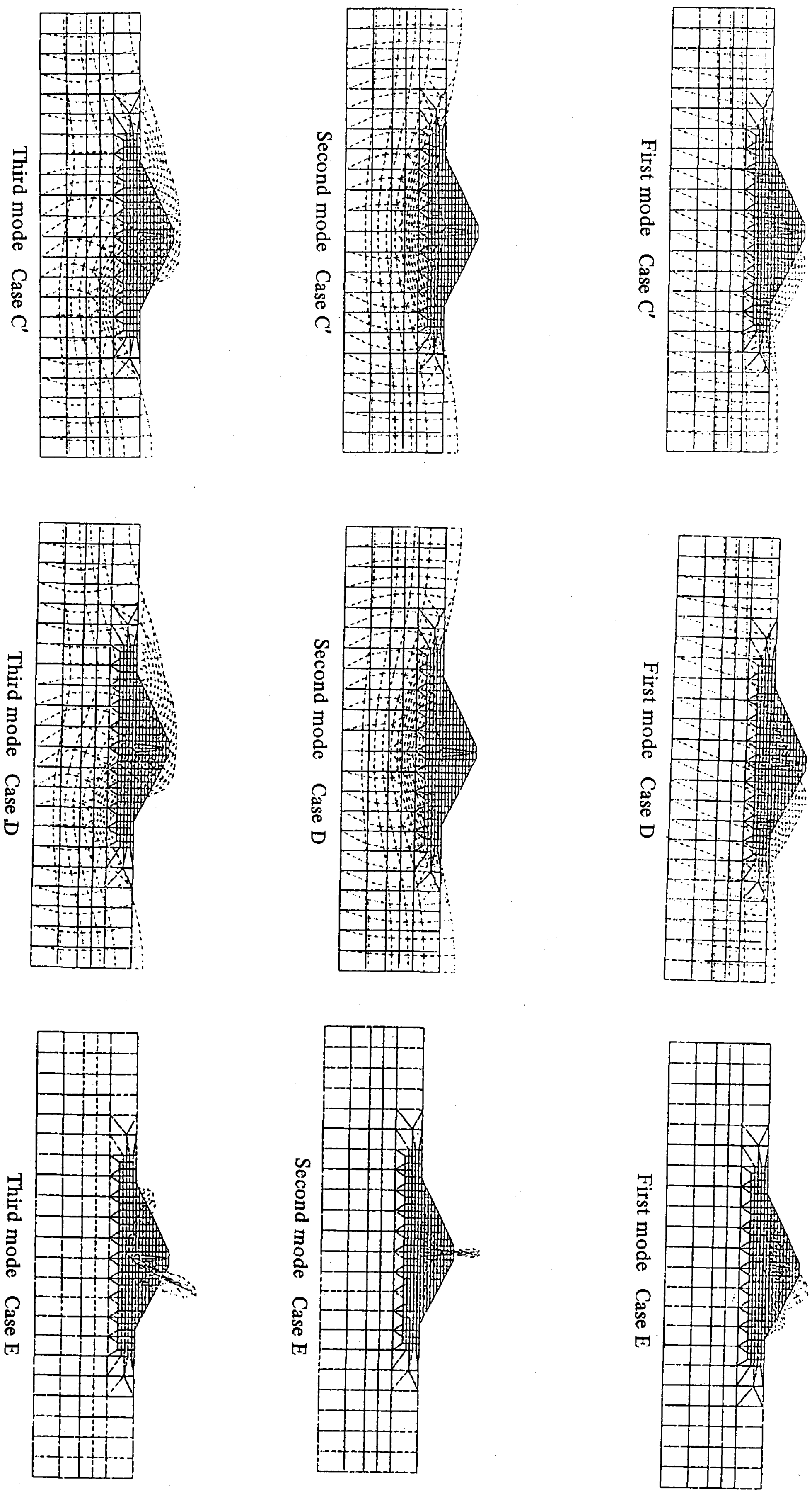



Fig. 3 Modes analyzed for C', D and E

Table 2 Frequency to mode and material property

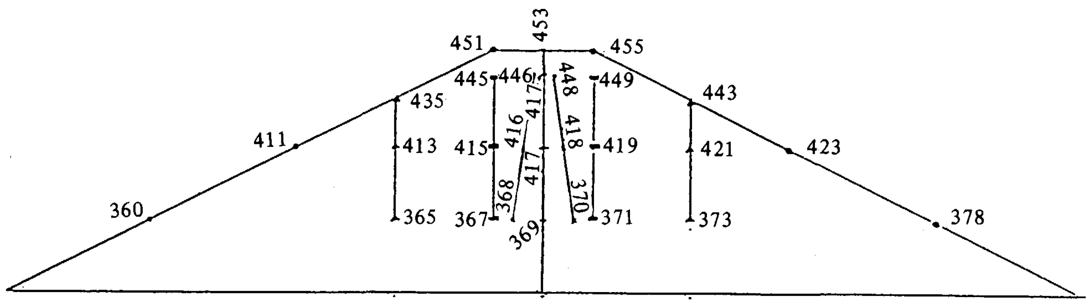
| Mode / Case | 1 | 2 | 3 | Elasticity for foundation | Elasticity for Emban. | Elasticity for Core | Remark |
|---|---|---|---|---|---|---|---|
| A | 2.328 | 2.887 | 3.550 | —— | ($t/m^2$) $5.0 \times 10^3$ | ($t/m^2$) $1.5 \times 10^6$ | No foundation |
| B | 1.537 | 2.383 | 2.796 | —— | $5.0 \times 10^3$ | $5.0 \times 10^3$ | No foundation Homogeneous |
| C | 0.346 | 0.470 | 0.639 | $5.0 \times 10^3$ | $5.0 \times 10^3$ | $5.0 \times 10^3$ | With foundation· Homogeneous Only bottom of foundation is fixed |
| C′ | 0.454 | 0.637 | 0.727 | $5.0 \times 10^3$ | $5.0 \times 10^3$ | $5.0 \times 10^3$ | With foundation Homogeneous all boundary of foundation is fixed |
| D | 0.453 | 0.637 | 0.727 | $5.0 \times 10^3$ | $5.0 \times 10^3$ | $1.5 \times 10^6$ | |
| E | 2.189 | 2.878 | 3.464 | $1.5 \times 10^6$ | $5.0 \times 10^3$ | $1.5 \times 10^6$ | |

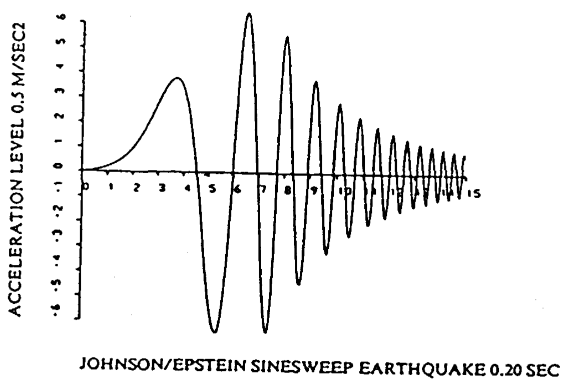
## 3. *The results of the historical analysis with time*

Fig. 4 shows the model for the historical analysis with time and also the input earthquake wave of acceleration corrected from the Elcentro earthquake.

We applied these waves to the bottom of the dam and foundation models. And also, we took the cases as shown in Fig. 5 being changed properties of materials for earth and foundation.

The properties of each material for the cases to be analyzed are shown in previous Table 2.




| Section | Node No. |
|---|---|
| L-L | 369, 417 447, 453 |
| M-M | 368, 416 446 |
| N-N | 367, 415 445 |
| P-P | 365, 413 435 |
| Q-Q | 360, 411 451 |

Fig. 4 Model analyzed and input acceleration wave.

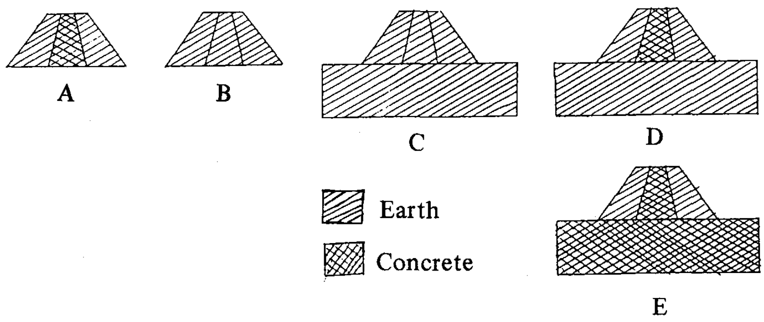



Fig. 5 Cases for analysis

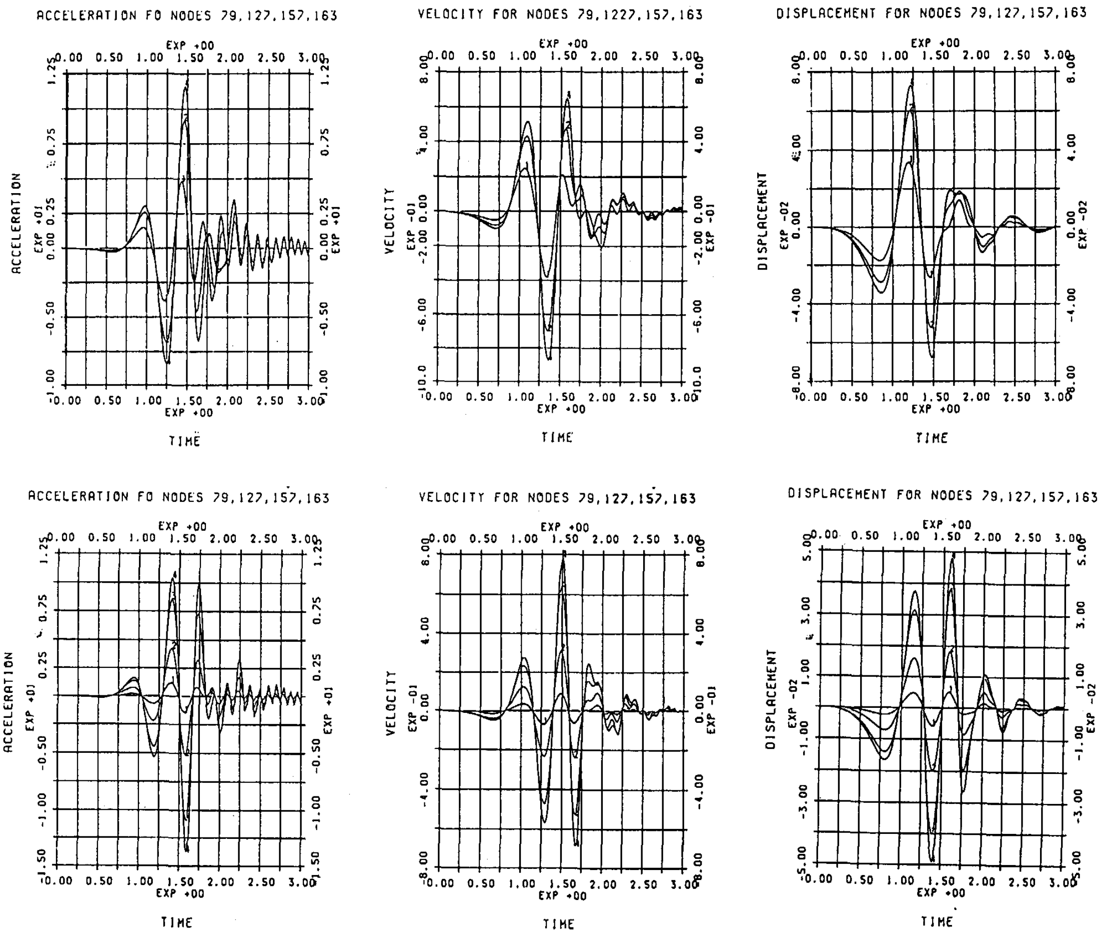



Fig. 6 Response analyzed for some points

Fig. 6 shows the results of respons for time history at the center section of models which have no foundation. Upper side of the figure shows the results for no core and the lower side shows the results for core types.

Comparing core type with homogeneous type as to acceleration time history, the core type has larger amplitude than the homogeneous type.

That means the wave (acceleration) propagates easier than in earth and the amplitude in upper point becomes larger than in the lower point.

Fig. 7 shows the results for C, D and E cases for the response of acceleration.

From these results, C and D cases show no difference with each other, however, E case which has more rigid core and foundation show the results as same as previous case which has no foundation. This can be said that when the foundation is less rigid than concrete, dam and foundation vibrate as samely as these are the one body, and so in the case as like as this, the core may not affect to the dam and the foundation system.

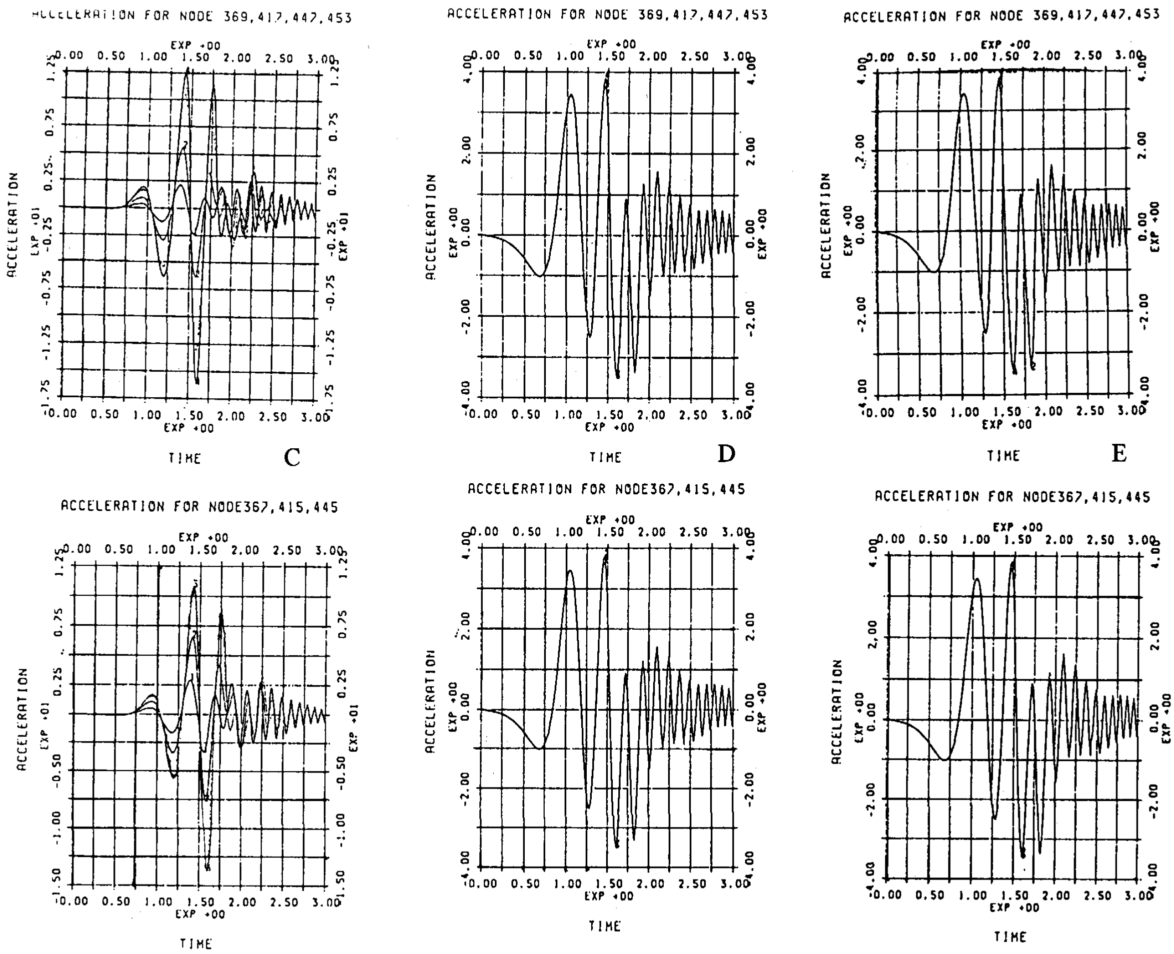



Fig. 7 Response analyzed for C, D and E

Fig. 8 shows all the results for each case as to the distribution of absolute maximum amplitude of acceleration, velocity and displacement at representative sections as shown in Fig. 5.

From this figure, it can be said that, in cases of A, B and E almost same distribution of acceleration, velocity and displacement can be seen, but in cases of D and C these are different from other cases and the almost same distribution for each parameter.

This result gives some important suggestion for the design of filldams which means that the scale of foundation to be selected in design problems is the most important for the earthquake response of filldams and we must think of it carefully.

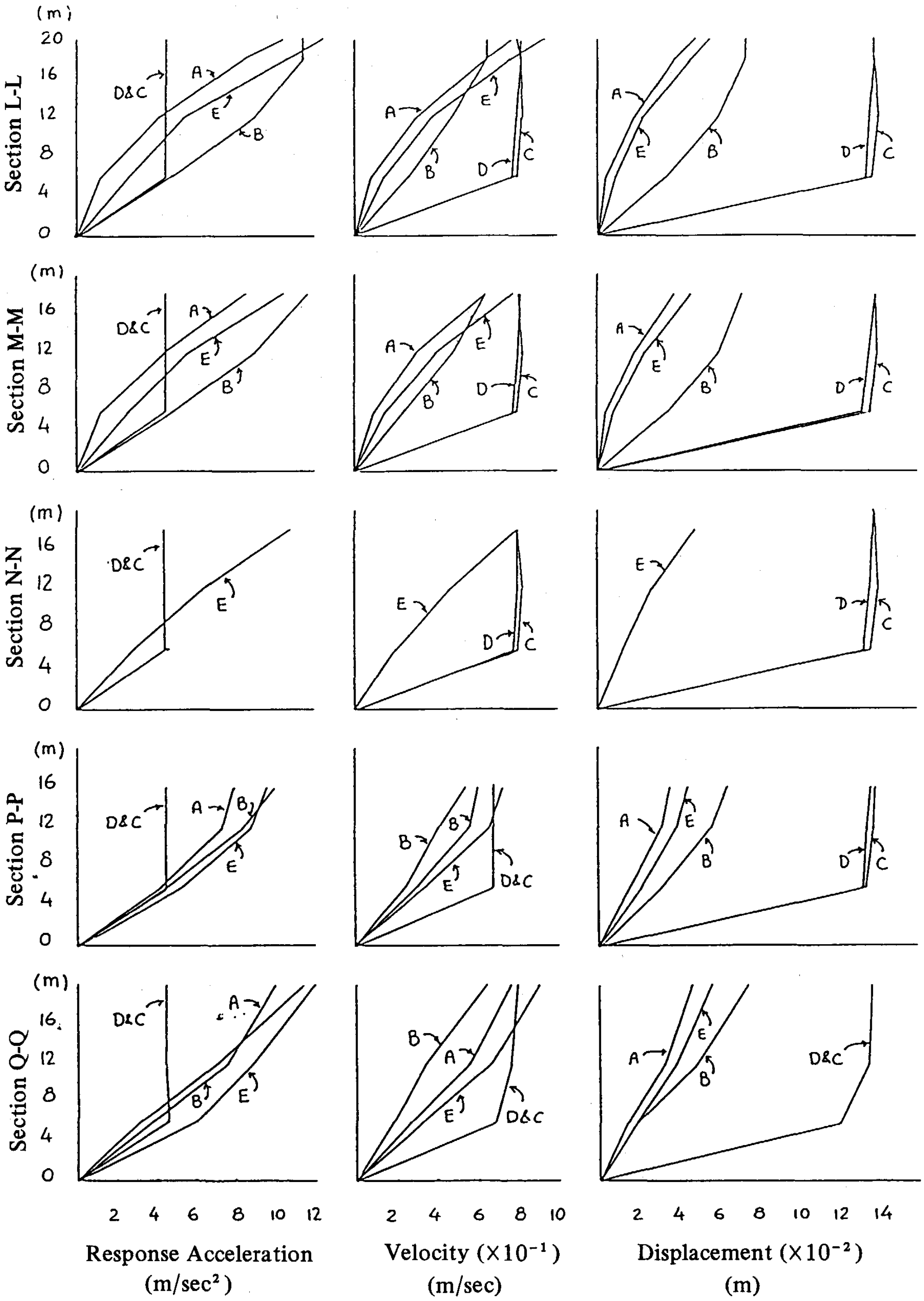



Fig. 8 Distribution of parameters

## IV Conclusion

From the results obtained by analytical study, it can be concluded as follows;

(1) It can be thought that 1 st to 3 rd modes may be appeared in actual vibration of dams.

(2) As the stiffness of the core increases, the effects of the core to a natural mode come to appear.
(3) The natural frequency of dams can be controlled by selecting the scale and the stiffness of the core.
(4) The natural frequency of the dam system can be changed largely by the method of taking the foundation area.
(5) As the foundation comes to be rigid, the natural frequency of dams comes to be complicated.
(6) By the combination of materials for the dams and the cores, the response of vibration may be changed variously.

## V Reference

1. NEC (1984): Manuals of Analytical system for composite structure (ISAP) *(in Japanese)*
2. SAKAI Y. (1984): Design for earthquake of earth structures. Civil Engineer report, 26-1. (*in Japanese*)