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A Study on the Dynamic Response Characteristics of the Embedded Reactor Building for Pool Type LMFBR

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SUMMARY

The objective of this study is to investigate the general characteristics of the response of the Liquid Metal Fast Breeder Reactor (LMFBR) Pool Type Structure especially focusing on the effect of the embedment and the effect of the step mat configurations.

Mathematical models are used to simulate the dynamic response characteristics of the structure and the surrounding soil in the one horizontal direction. In order to take into account of the soil-structure interaction effect, the Lattice Model techneque is used. In the Lattice Model techneque, a single stick lumped mass model is used to model the reactor building and lattice pattern multi stick lumped mass model is used to model the surrounding soil. Dynamic elastic analysis is performed. Damping factor of 5 % is applied to both structure and soil. The shear wave velocity of 2000 m/sec for hard soil and 250 m/sec for surface soil are chosen for this study. An earthquake input motion applied to the base of the model is calculated by a deconvolution method based on a wave propagation theory.

Analytical results from three cases are compared and examined to study the effect of the embedment of the structure and step mat configurations on the response. Floor response spectra at the roof slab on the reactor cavity are produced and examined. The response of the structure is reduced as the embedment effects. The reasons and factors for the response reduced are investigated.

1. Introduction

The structure of reactor for a pool type FBR building is comprised of various equipment for primary system in addition to the nuclear reactor, and each item is supported by the roof slab. In examination of the earthquake resistances of these pieces of equipment, the availability of the floor response spectra at roof slab locations is necessary and it is easier to maintain earthquake resistance when the lower spectral value is held.

In this paper special attention is given to the form of the building and the floor response spectra at roof slab locations. Dynamic elastic analyses are performed for 3 buildings of respective different forms placed at a site of hard rock (shear wave velocity V_s = 2,000 m/sec), and comparative studies of vibration characteristics and earthquake response characteristics are made.

2. Reactor buildings for analysis

For the building forms for this study, three types, the Prototype, the Stepped Mat Layout No.1 and the Stepped Mat Layout No.2 have been selected. The cross sections of these buildings and the plan of the prototype are given in Fig.1 and 2, respectively.

The plan of Prototype is square-shaped dimensions of 96m x 96m, which has a cavity wall of outside diameter of 15.5 m at the center. Outside diameter of a cylindrical wall is 26.0 m surrounding the cavity wall, resulting in an integral body of reinforced concrete structure. The height of the structure is 84 m from the bottom face of its mat.

The Stepped Mat Layout No.1 and No.2 are arranged based on the Prototype structural layout. Therefore, plan configurations are basically the same as that of the Prototype. The Stepped Mat Layout No.1 is a stepped mat structure with the cavity wall portion lowered by 4 m compared with the Prototype, while in the Stepped Mat Layout No.2 the cylindrical wall portion is lowered by 8 m.

3. Basic concept of dynamic analysis

Soil conditions, specifications of earthquake motion and vibration models assumed are as follows,

(1) Soil conditions assumed are shown in Fig.3. The site is considered to be a homogeneous and uniform hard rack of V_s = 2,000 m/sec continuing infinitely downward with the top surface at FL - 26.0 m for all of the building forms. On top of this hard rock, there is comparatively soft, homogeneous and uniform surface layer soil of V_s = 250 m/sec up to FL ± 0 m. The soil constants are shown in Table 1.

(2) The "Lattice Model"$^{1)}$ as shown in Fig.5 is used for dynamic analysis as a soil-structure interaction model in order to take into account the effect of embedment of structures. This model is a lumped mass system.
With regard to the vibration model of the structure and the surface layer soil including the underlying hard rock, it is necessary for the soil to be considered as a finite domain, but the fact of the rigidity of the hard rock being extremely high (V_s = 2,000 m/sec), the level of the bottom surface of the model, where is the earthquake input location, is set at FL - 38.0 m. It is considered as a plane strain problem where the model has the building width (96 m), while the horizontal length is 396 m, approximately four times the building width.

(3) As the basic design earthquake ground motion at the free surface of the base stratum (assumed as FL − 26.0 m), a high seismic activity zone (S_1), $M = 7.0$, $\Delta = 20$ km, phase angle El Centro 1940 NS of the simulated earthquakes, prepared by the Light Water Reactor Improvement Standardization Earthquake-Resistant Design Subcommittee (1979) is used, with earthquake motion $2 \cdot E_s$ (E_s: ascending wave) with stipulation that no surface exists. For obtaining the input earthquake motion for the lattice model from the basic design ground motion, the earthquake ($E_R + F_2$) at elevation FL − 38.0 m, which is assumed to have existing surface layer soil, is created by the one-dimension wave propagation theory$^{2)}$ (the SHAKE program). The conditions assumed are that below FL − 38.0 m, hard rock ($V_s = 2{,}000$ m/sec) continues downward. infinitely, or in other words is "Input Foundation". Also assumed is that the ascending wave E_R at the rock surface is the same regardless of whether or not the surface soil layer exists.

(4) For the damping factor in dynamic analysis, a damping theory of a strain energy proportionate type not depending on frequency is adopted, and the damping factor is taken as 5 % for the concrete structure, hard rock and surface layer soil.

4. Analysis results

4.1 Eigenvalue analysis results

The primary and secondary modes of the building are shown in Fig.6 and 7. The following results are obtained through the comparative studies.

(1) The foundamental periods exist in the range of 0.194 ∿ 0.197 sec and the differences in periods are extremely slight. The participation functions βu in the primary modes are compared at the roof slab location. These are 0.425 for the Prototype, 0.339 for Stepped Mat Layout No.1 and 0.259 for Stepped Mat Layout No.2. The values decrease as the base mat is increasingly stepped.

(2) The second natural periods exist in the range of 0.089 ∿ 0.098 sec and the differences in periods are also slight. The participation functions βu in the secondary modes are compared at the roof slab location. These are 0.490 for the Prototype, 0.458 for Stepped Mat Layout No.1 and 0.336 for Stepped Mat Layout No.2. There is decrease as the base mat becomes stepped.

(3) It is thought that the participation functions βu at the roof slab location in the primary and secondary modes of the building become smaller compared with the Prototype as the base mat is increasingly stepped.

4.2 Results of frequency response analysis of ground

The ratio between the input earthquake (identified as I) of a lattice model to the basic earthquake ground motion (identified as S) of the free surface of the base stratum is studied.

Figure 8 shows the absolute acceleration ratio of I to S where the basic earthquake ground motion, S, is a sine wave having a unit acceleration and its period is varied between 0.05 and 5.0 sec.

This ratio of I/S is an identical value for all three cases since the bottom locations of the models are the same. Computation of I/S is derived according to the one-dimensional wave propagation theory at free ground in a condition of no building existing.

The following can be said on the relationship between I/S and period.

(1) In a range where the period of the surface layer ground is long at 0.8 sec or more, the value of I/S is 1.0 and there is no change in this period component.

(2) At periods corresponding to the first, second, third and forth natural periods of the surface layer ground, the values of I/S slightly decrease.

(3) In a range of periods shorter than 0.8 sec, the values of I/S are roughly lower than 1.0. The value of I/S is roughly 1.0 at the first natural period of the building, approximately 0.9 at the second natural period of the building, 0.75 at the third natural period of the building. It will be said that the secondary and tertiary modes of the building there are decrease phenomena in the input earthquake.

4.3 Results of earthquake response analysis

Figure 9 shows comparisons of maximum response accelerations. The maximum accelerations at the roof slab location are 450 gal for the Prototype, 393 gal for Stepped Mat Layout No.1 and 384 gal for Stepped Mat Layout No.2.

4.4 Floor response spectra

Figure 10 shows comparisons of the floor response spectra (damping factor h = 1%) at the roof slab location.

The peak values of the spectrum in fundamental period of the building are 4,140 gal for the Prototype, 3,460 gal for Stepped Mat Layout No.1, and 2,830 gal for Stepped Mat Layout No.2. The ratios of these values to the basic earthquake ground motion spectral value are 3.5 for the Prototype, 2.9 for Layout No.1 and 2.4 for Layout No.2.

The peak values of the spectrum in the second natural period of the building are 4,110 gal for the Prototype, 3,310 gal for Stepped Mat Layout No.1 and 2,280 gal for Stepped Mat Layout No.2. The ratios of these values to the basic earthquake ground motion spectral value are 3.4 for the Prototype, 2.8 for Layout No.1 and 1.9 for Layout No.2.

5. Conclusions

The vibration characteristics and earthquake response characteristics at the roof slab location including soil-structure interaction effect are studied and compared with regard to three different layouts for a pool type FBR building at a site of hard rock (V_S = 2,000 m/sec).

The results of these studies indicate there is a trend for response spectral values at the roof slab to become smaller as base mats are increasingly stepped.

The factors contributing to this reduction are considered to be three items below.

(1) Decrease in participation function βu due to existence of surface layer soil,

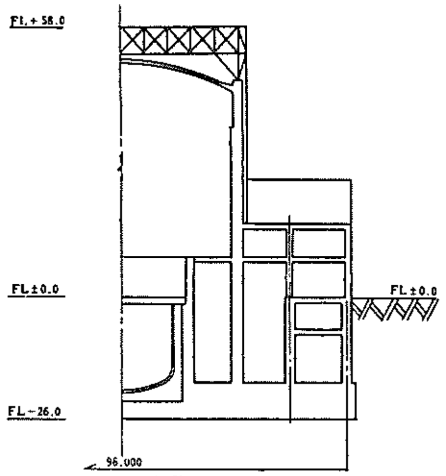
(2) Decreasing effect in generating input earthquake from the basic earthquake ground motion due to surface layer soil,

(3) Decrease in participation function βu due to stepping of base mat.

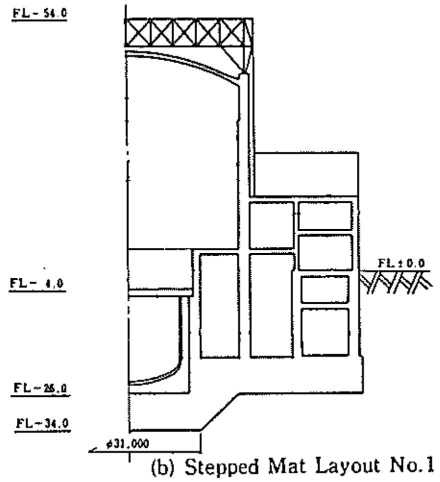
References

1) K. Muto and H. Kanayama, "Response Analyses by New Earthquake-Resistant Analytical Method (Multi-mass 'Lattice Model') for a Recent Nuclear Power Station", 26th Structural Engineering Symposium, Feb. 1980 (in Japanese).

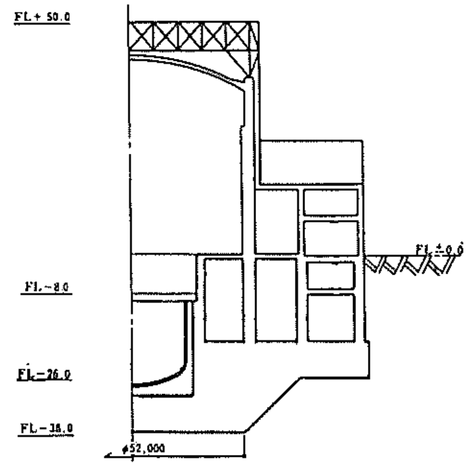
2) P. B. Schnabel, J. Lysmer and H. B. Seed, "SHAKE, A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites", EERC 72-12, Dec. 1972.



(a) Prototype



(b) Stepped Mat Layout No.1



(c) Stepped Mat Layout No.2

Fig. 1. Sections

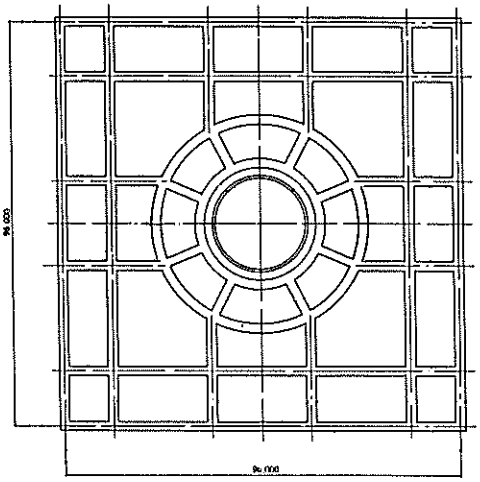
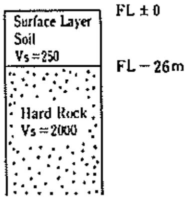


Fig. 2. Plan (FL−18.0)

Table 1. Soil Constants



	Surface Layer Soil	Hard Rock
Shear Wave Velocity Vs (m/sec)	250	2000
Density ρ (ton/m³)	1.8	2.6
Poisson's Ratio ν	0.44	0.36

Fig. 3. Soil Profile

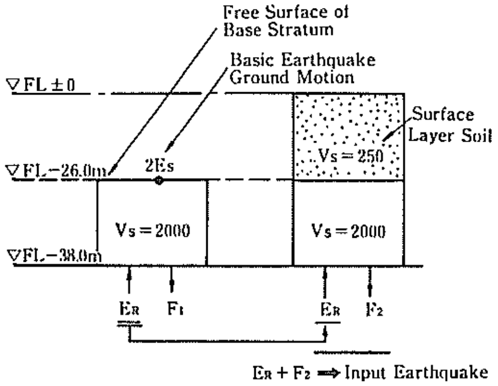
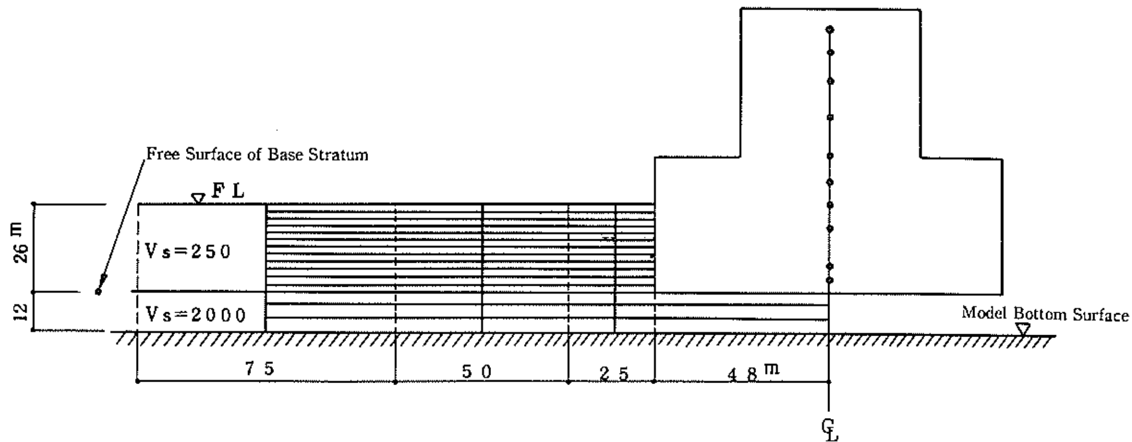
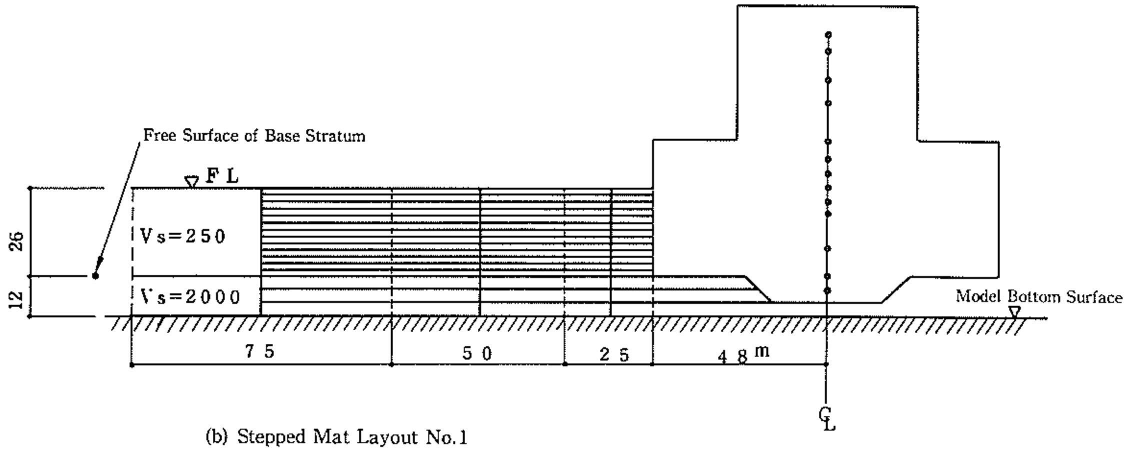


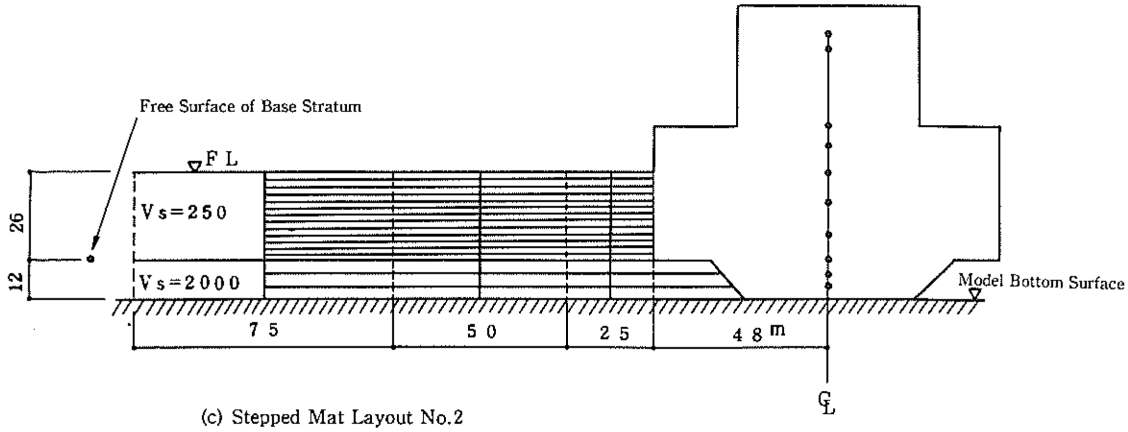
Fig. 4. Generation of Input Earthquake



(a) Prototype Model



(b) Stepped Mat Layout No.1



(c) Stepped Mat Layout No.2

Fig. 5. Lattice Vibration Model

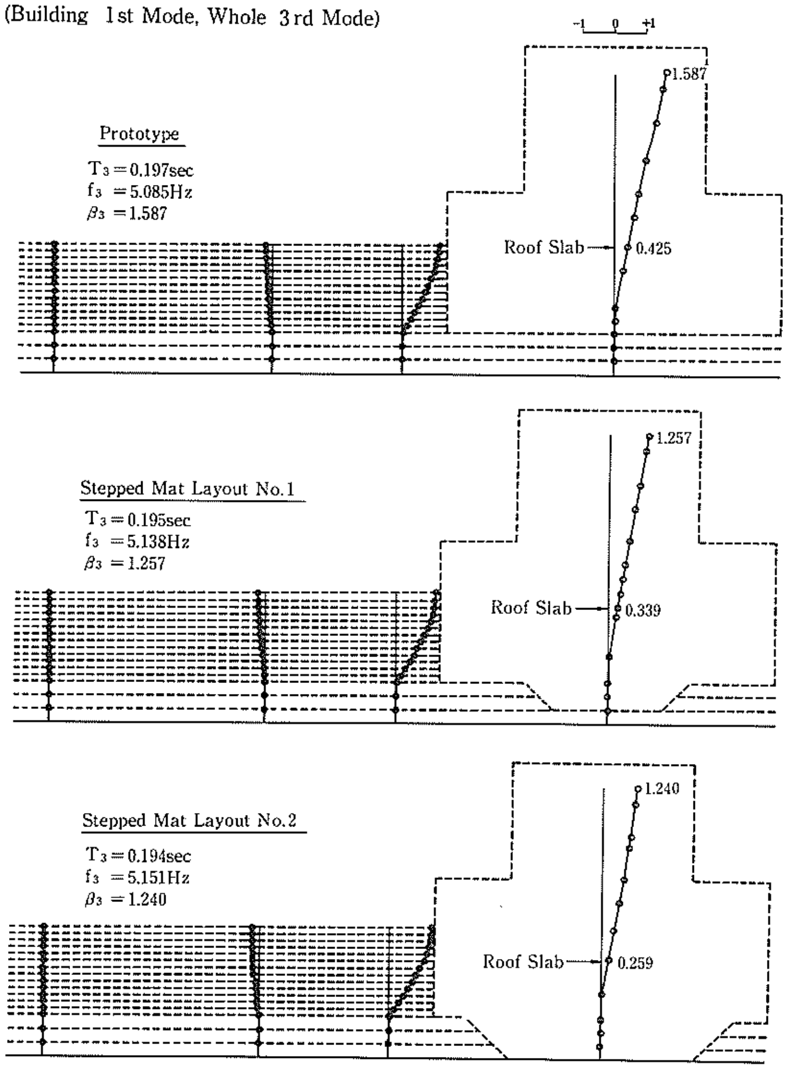


Fig. 6. Comparisons of Primary Modes of Building

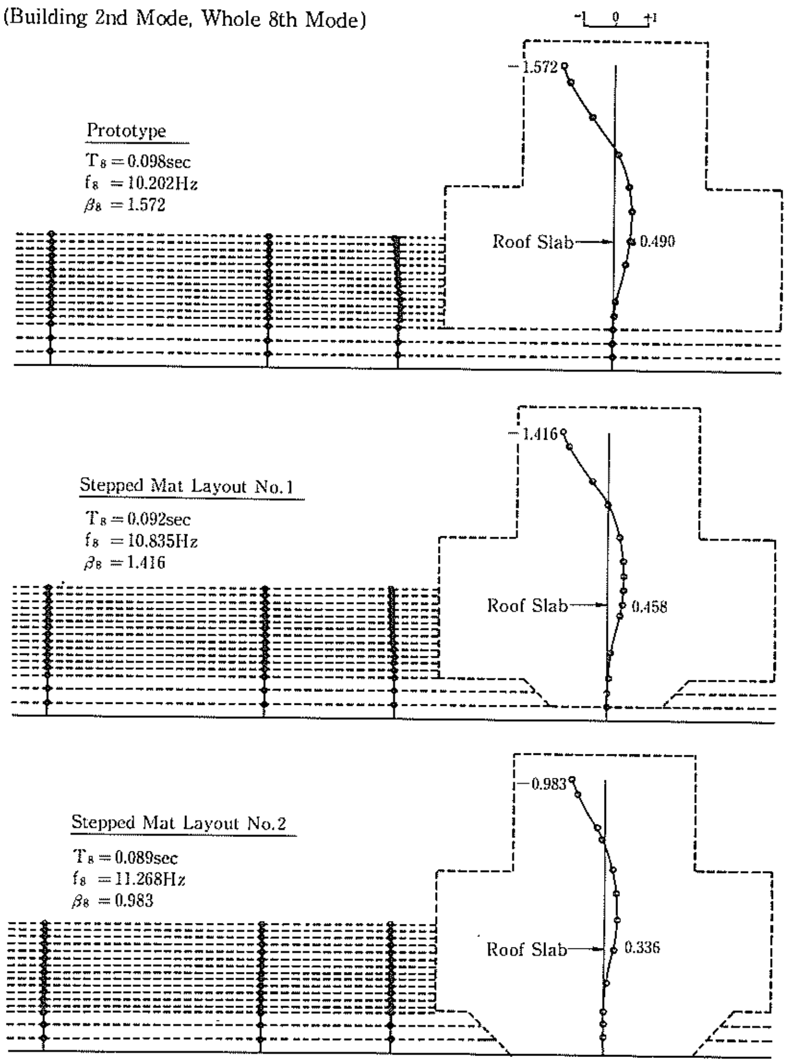


Fig. 7. Comparisons of Secondary Modes of Building

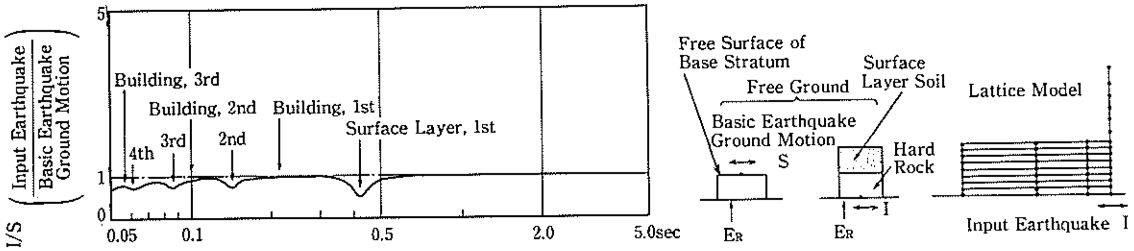
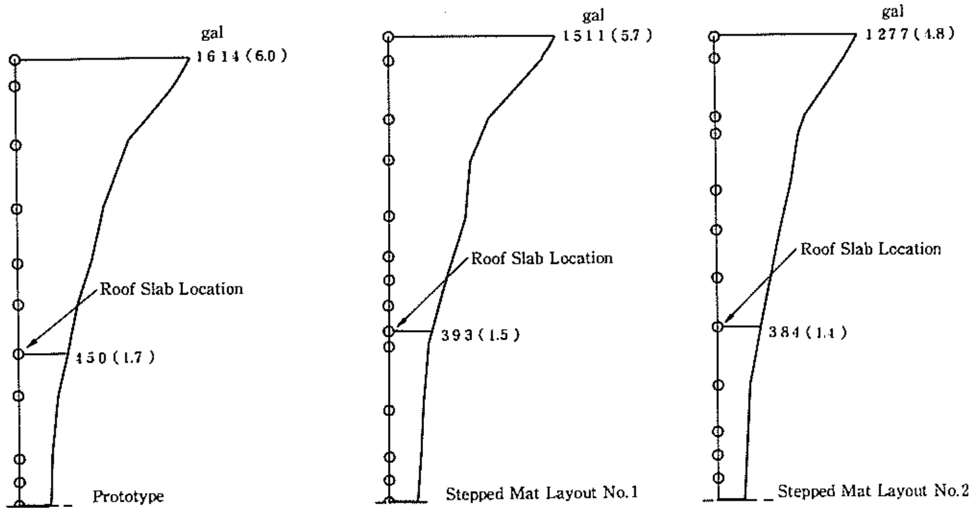


Fig. 8. Comparison of Input Earthquake of Lattice Model and Basic Earthquake Ground Motion by Resonance Curve



Maximum Acceleration of Basic Earthquake Groundmotion; 267gal
Figures in ( ) indicate Ratios to Basic Earthquake Ground Motion

Fig. 9. Comparisons of Maximum Response Accelerations

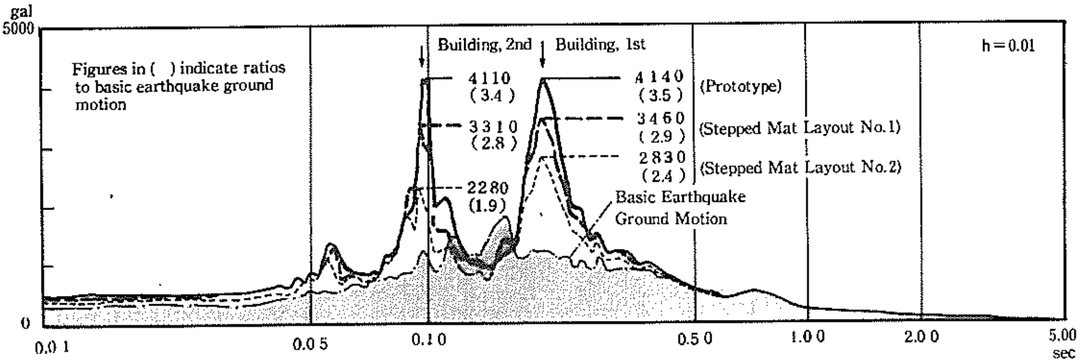


Fig. 10. Comparisons of Floor Response Spectra (Roof Slab Location)