Seismic qualification of nuclear control board by using base isolation technique

T.Koizumi & N.Tsujiuchi
Central Research Laboratory, Mitsubishi Electric Corp., Amagasaki, Japan
T.Fujita
Institute of Industrial Science, University of Tokyo, Japan

1 INTRODUCTION

Seismic qualification is essential for any kind of electric equipment or control board especially for nuclear use. Therefore, for the safety of nuclear power, plant, structural analysis and experimental verification have been needed to qualify the earthquake loading according to the demand of nuclear safety regulation. Eventually, structural rigidity has been regarded as the most prior characteristics for structural designing and this causes excessive weight and complexity of shape.

The purpose of the author's investigation here is to adopt base isolation technique(Fujita et al 1984) as a new approach for seismic qualification of nuclear control board. First part of this paper, basic concept of base isolation technique is expressed. In here, two dimensional linear motion mechanism with pre-tensioned coil springs and some dampers are included in the isolation device. Control board is regarded as a lamped mass system with inertia moment. Fundamental movement of this device and control board is calculated as a non-linear response problems.

After this fundamental analysis and numerical estimation, experimental investigation has been undertaken using an actual size control board. Sufficient agreement was recognized between experimental results and numerical estimation.

2 STRUCTURAL CONFIGURATION OF BASE ISOLATION DEVICE

The fundamental configuration of this base isolation device is composed of a orthogonally coupled linear motion mechanism(Figure 1 and Figure 2 (a),(b)). By using this mechanism, the upper table is movable in any direction of two dimensional plane. These two rails of X and Y direction shown in Figure 1 are composed of a couple of plate and 2 set of roller bearings for vertical loading. Therefore this structure has sufficient endurance for toppling moment. A set of coil springs and oil filled viscous dampers are installed between base frame and movable table. The coil spring works as a linear spring, however the damper behaves non-linearly depending on its' magnitude. This reason is that the damper is located at right angle to displacement direction. Another friction damper is installed as shown in Figure 1 and 2. This works to fix the table to the base frame as far as the seismic movement runs up to a certain extent.

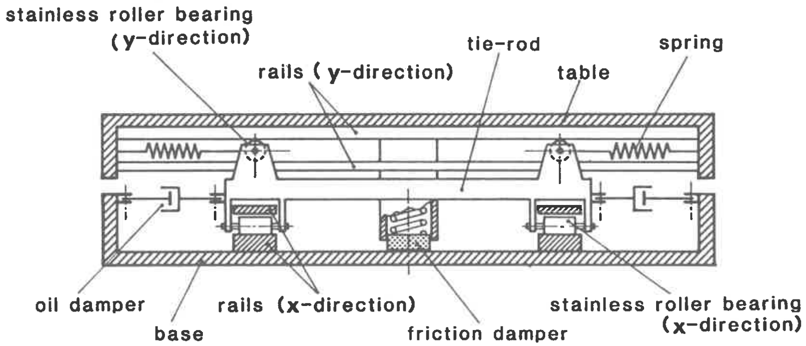
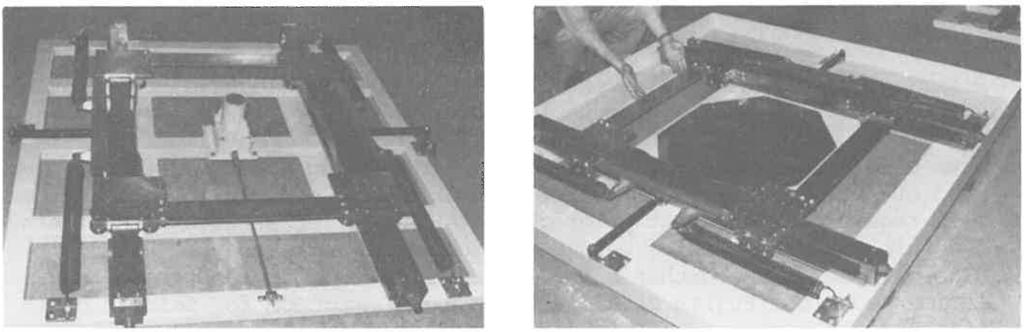


Figure 1. Fundamental configuration of base isolation device



(a) (b)

Figure 2. Inside view of isolation mechanism

3 RESPONSE ANALYSIS

To investigate the effect of base isolation technique, a typical control board for nuclear power plant use was selected. Some specification of this board is that the external dimension is $1350^W \times 1000^D \times 2300^H$ (in mm) and total weight is approximately 1200 kg with dummy weights to represent the electric instrumentations. These two structures of base isolation device and control board were connected rigidly, so the analytical model was considered as shown below(Figure 3).

The equation of motion derived from this analytical model is as follows ;

(i) In the case of no friction damper slippage is involved - Phase I

(1) $x_1 = \text{const.}, \quad \dot{x}_1 = 0$

(2) $m_2\ddot{x}_2 + c_2(\dot{x}_2 - H\dot{\psi}) + k_2(x_2 - H\psi - x_1) = -m_2\ddot{z}$

(3) $I\ddot{\psi} + c_3\dot{\psi} + c_2H(H\dot{\psi} - \dot{x}_2) + k_3\psi + k_2H(H\psi + x_1 - x_2) = 0$

(ii) In the case of friction damper slippage is occured - Phase II

(4) $m_1\ddot{x}_1 + c_1\{x_1^2/(x_1^2 + h^2)\}\dot{x}_1 + \{(m_1 + m_2)g\mu_1 + F\mu_2\}\text{sgn}(\dot{x}_1)$
$+ c_2(\dot{x}_1 - \dot{x}_2 + H\dot{\psi}) + k_1x_1 + k_2(x_1 - x_2 + H\psi) = -m_1\ddot{z}$

(5) $m_2\ddot{x}_2 + c_2(\dot{x}_2 - H\dot{\psi} - \dot{x}_1) + k_2(x_2 - H\psi - x_1) = -m_2\ddot{z}$

(6) $I\ddot{\psi} + c_3\dot{\psi} + c_2H(H\dot{\psi} + \dot{x}_1 - \dot{x}_2) + k_3\psi + k_2H(H\psi + x_1 - x_2) = 0$

(iii) Switching condition from Phase I to Phase II is anticipated when,

(7) $|m_1\ddot{z} - c_2(\dot{x}_2 - H\dot{\psi}) + k_1x_1 + k_2(x_1 - x_2 + H\psi)| > (m_1 + m_2)g\mu_1 + F\mu_2$ is satisfied.

On the other hand, when

(8) $x_1 = 0$ and

$|m_1(\ddot{x}_1 + \ddot{z}) - c_2(\dot{x}_2 - H\dot{\psi}) + k_1x_1 + k_2(x_1 - x_2 + H\psi)| \leq (m_1 + m_2)g\mu_1 + F\mu_2$,then Phase II to Phase I shift is anticipated.

Where x_1 and x_2 are relative displacements of movable table and gravity center of board respectively in reference to the installation floor, ψ is the rotational angle of the panel, I and m_2 are the moment of inertia around the gravity center and mass of board. H is the height of gravity center, k_2 and c_2 are the spring constant of the board for shearing and damping coefficient, k_3 and c_3 are the spring constant of the board for rotation and damping coefficient. And m_1 is the mass of isolation table, k_1 and c_1 are the spring constant and damping coefficient of isolation device, h is the length of viscous damper installed, and μ_1 and μ_2 are the friction coefficient of roller part and friction damper. F is depressing force of the friction damper, g is gravity constant, and $\ddot{z}$ is the horizontal acceleration of the floor on which the device is located. According to this configuration the resultant friction coefficient $\bar{\mu}$ is given as,

(9) $\bar{\mu} = \mu_1 + \mu_2 F / \{(m_1 + m_2)g\}$

And also resonant period T of total system and the critical damping ratio ζ_1' are defined as,

(10) $T = 2\pi\sqrt{(m_1 + m_2) / k_1}$

(11) $\zeta_1' = c_1 / \{2\sqrt{(m_1 + m_2)k_1}\}$

A simulation software program was coded for this nonlinear equations. The Newmark's β method was used for direct integration in the condition of β = 1/6. Results from this simulation is compared with experimental data and that is discussed in the following chapter.

4 EXPERIMENTAL VERIFICATION AND FURTHER DISCUSSION

As the verification of this technique, experimental analysis was undertaken using large scale two dimensional (horizontal / vertical) shaker table (Takahashi et al 1981). The horizontal vibration was imposed to X direction of the specimen and the control board was installed on the shaker table in such a manner as the direction of the vibration being

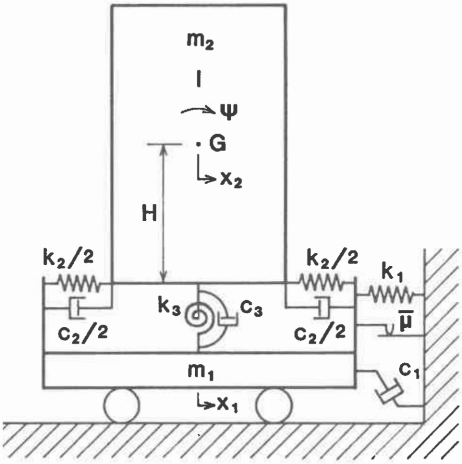


Figure 3. Analytical model of base isolation system

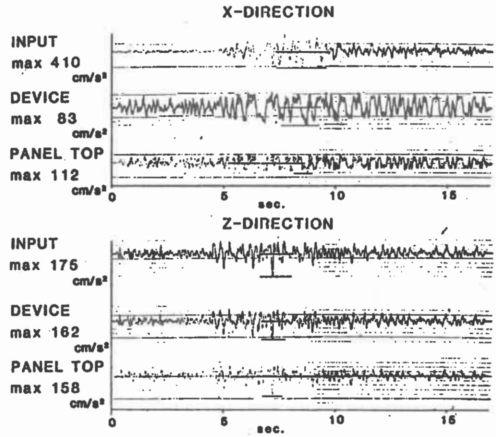


Figure 5. A typical result of experimental verification

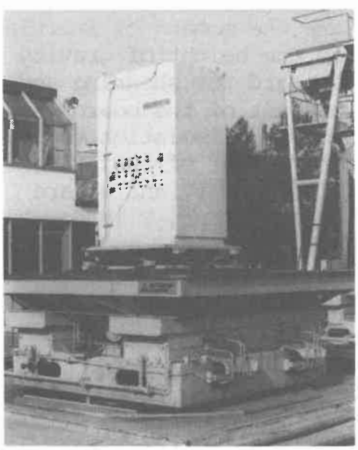


Figure 4. Experimantal setup of vibration test using two dimensional shaker table

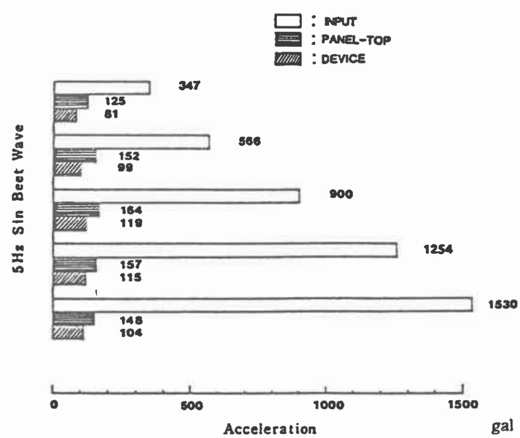


Figure 6. Experimantal verification of base isolation effect for sine beet waveform input

conformity with the transversal direction of the board (Figure 4). One of the typical exsample of the experimental records is shown (Figure 5) in the condition of simultaneous vibrations of horizontal and vertical directions. An actual seismic waveform records of E41° S and UD at Oofunato site on Off-Miyagi Earthquake (1978,Japan) was used for exciting input. Referring from the results shown on Figure 5, it could be said that an adequate vibration isolation effect was realized in horizontal direction, while no amplification was noticed in vertical direction at all. The slite amplification of vibration from the device to the panel top of control board was recognized in Figure 5. However it was proven experimentally that this amplification stayed under a certain level even the input vibration level exceeded more than 1.5 G (Figure 6).

Comparison between computer simulation and experimantal results has been performed using same seismic waveform as shown in Figure 5. Sufficient agreement can be obtained (Figure 7) and this result allows us to conclude that the simulation model and argorithm could be usable for further estimation of the base isolation effect. And as far as this structural conbination is applied, the magnitude of horizontal vibration is suppressed under one-third of input level without any amplification of vertical vibration.

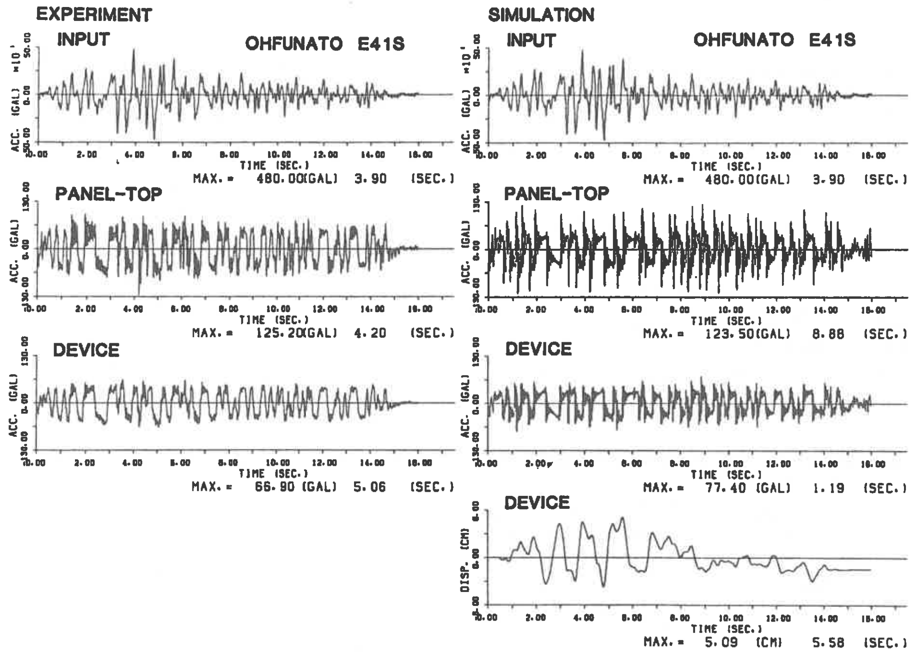


Figure 7. comparison between experimantal result and analytical simulation for actual earthquake waveform excitation

In order to obtain the design parameters which would be needed when a control board is installed with this isolation device in some nuclear power plant, response behaivior has been simulated under the condition of a certain floor response spectrum (Figure 8). Some results of the response analysis related to T (Figure 9) express the characteristics of this device, and as $T = 3.5$ s, $\bar{\mu} = 0.02$ and $\zeta_i' = 0.0$. In here,the oil filled damper is omitted because of the reason that the stroke displacement of this damper is negligibly small and also it might be a limitation to use this kind of oil filled part for nuclear power plant. Accordingly the floor response waveform is estimated using these design parameters and an artificial earthquake waveform (Figure 10). As it can be recognized from the figure that more remarkable effect of base isolation is achieved and the response level of panel top decreases at least one-forth of input level.

5 CONCLUSIVE REMARKS

Consequently following conclusive remarks could be proposed.

(i) As far as this type of base isolation device would be used, the

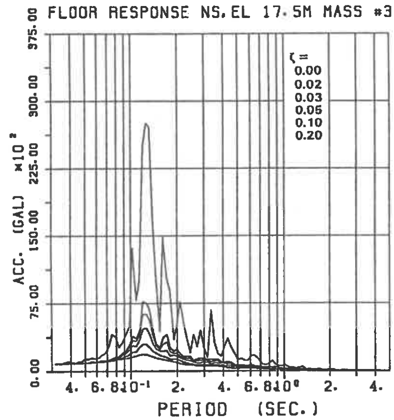


Figure 8. Floor response spectrum of a certain nuclear power plant

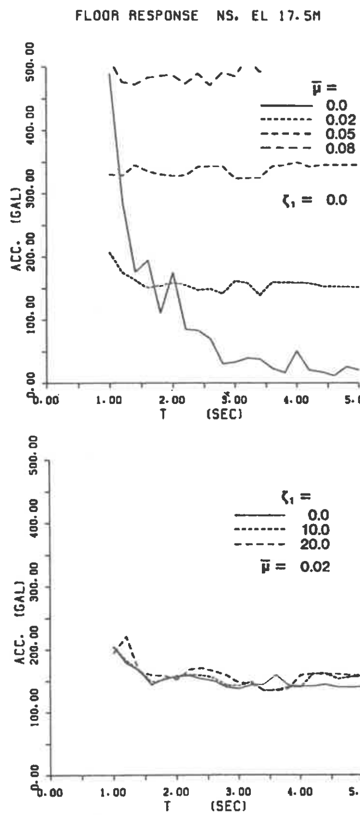


Figure 9. Design parameters estimation using floor response spectrum

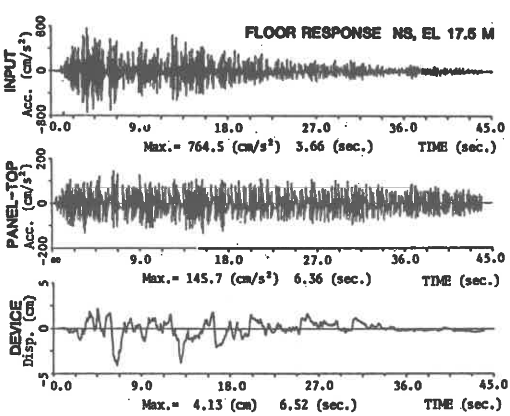


Figure 10. Simulated floor response

mechanism of isolation has been appropriately formulated and simulated with the verification of experimental observations.

(ii) The effect of reduction by using this isolation technique would be estimated at least one-third in vibrational level for arbitraty earthquake waveforms in averaged level.

(iii) Seismic qualification of control board would have been controllable by using this new technique for any nuclear power plant use.

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