SECTION 3

SHAKING TABLE EXPERIMENT

In order to examine the performance of the proposed hybrid isolation system and to study the feasibility of its applications in structural engineering, experimental studies have been performed. For this purpose, a prototype hybrid isolation system with the friction controllable sliding bearings has been developed. A rigid structural model supported on the hybrid system was experimented on a shaking table at Taisei Technology Research Center in Yokohama, Japan. This three dimensional shaking table has a maximum stroke of 40 cm in each horizontal direction and maximum loading capacity of 20 tonf weight.

3.1 Structure Model and Isolation Device

The structure model used for experiments is shown in Fig. 3.1. The model, representing a rigid structure, consists of a steel frame and steel weights. The total weight of the model is 12 tonf.

Figures 3.2 and is a photograph of the structure model in the experiments. The model is supported equally by four friction controllable sliding bearings on the shaking table, as shown in Figs. 3.1 and 3.2. The bearing developed for the experiments is shown in Fig. 3.3 and Fig. 3.4. Figure 3.5 is a photograph of the bearing being used in the experiments. The bearing, with a brass sheet of 1 mm thickness attached to be used as sliding surface, slides on a stainless steel plate fixed on steel I-bars bolted down on the shaking table, as shown in Figs. 3.1 and 3.2. Furthermore, a rubber O-ring of 5.7 mm in diameter acts as seal for the fluid in the fluid chamber. The area of the sliding surface is 86.0 cm^2, and the vertically projected area of the fluid chamber is 57.7 cm^2. No restoring force device is used in order to study the effect of friction force only. A servo valve is located at the center of the experimental structure from which the pressurized fluid is distributed to each sliding bearing as described in Fig. 3.1.

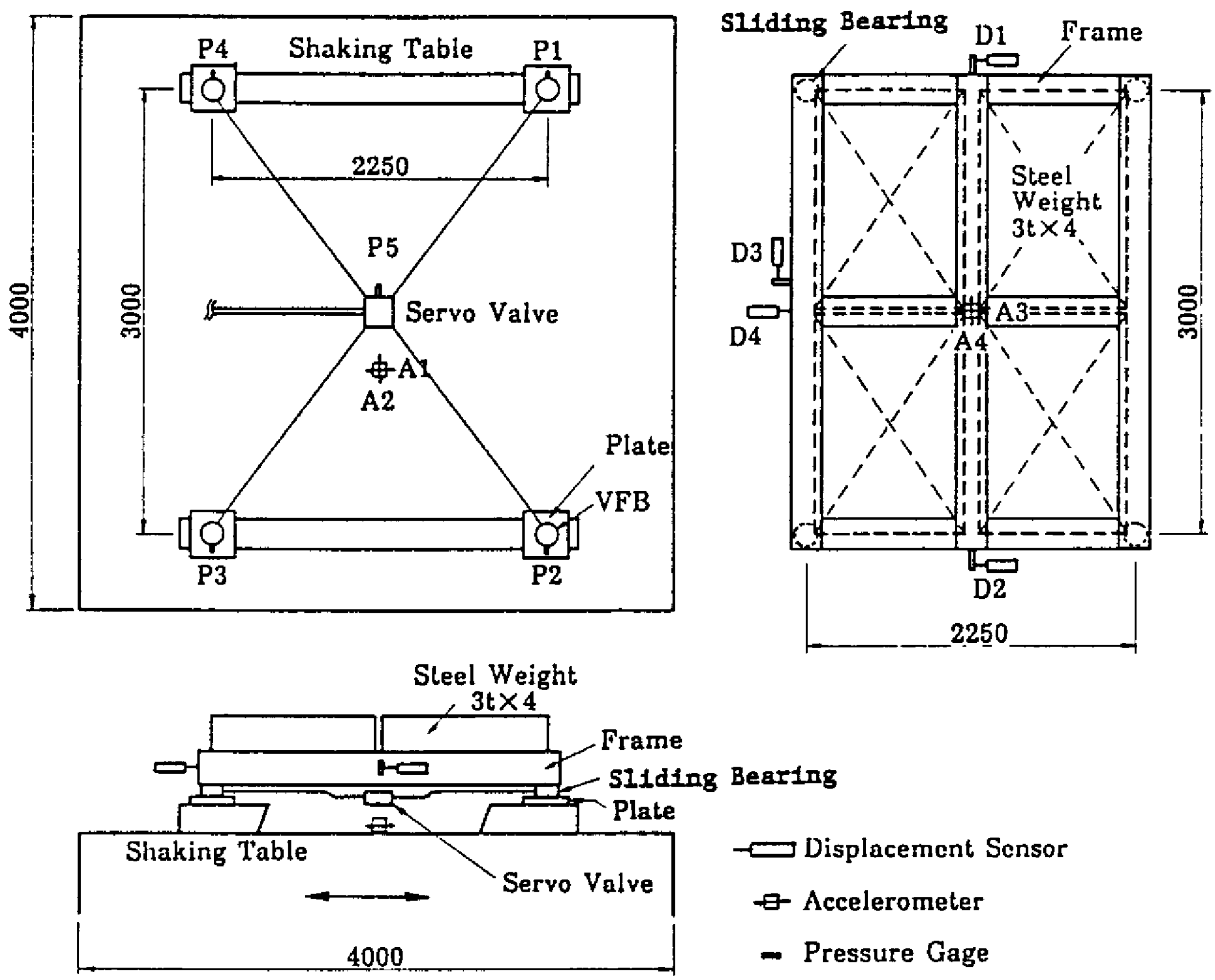

Figure 3.1: Structure Model with Hybrid Sliding Isolation Device

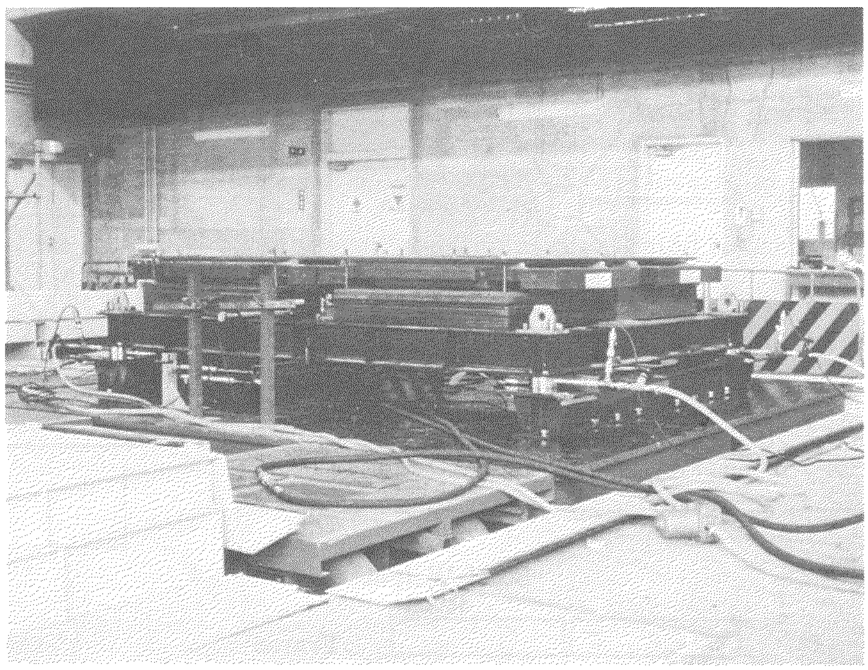

Figure 3.2: Structure Model with Hybrid Sliding Isolation Device in Experiment

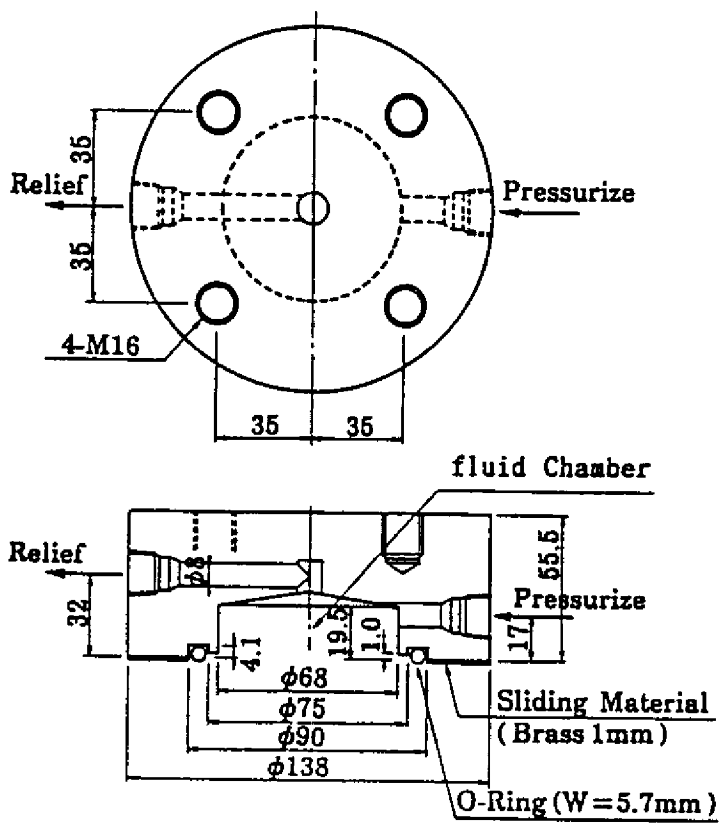

Figure 3.3: Friction Controllable Sliding Bearing

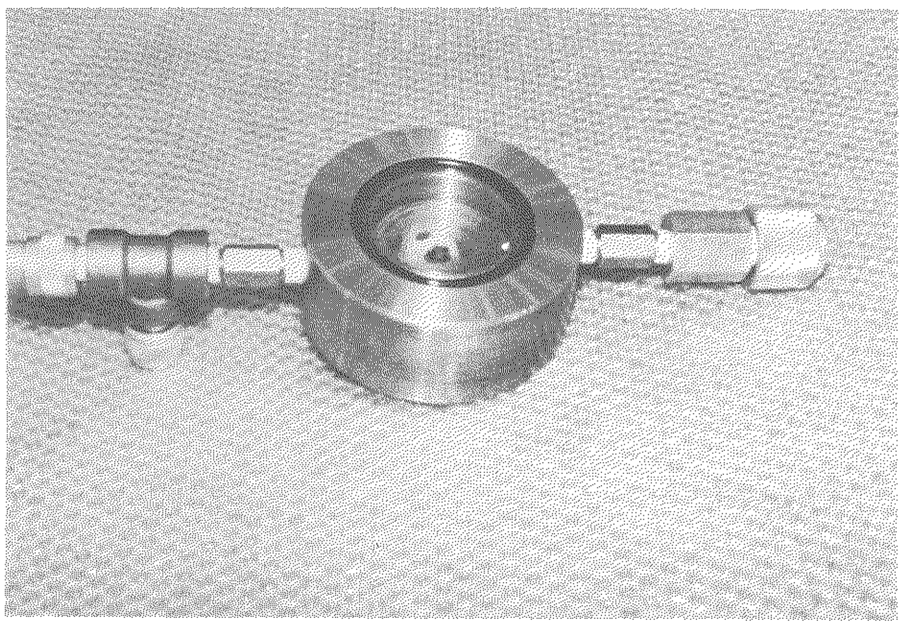

Figure 3.4: Friction Controllable Sliding Bearing for Experiment

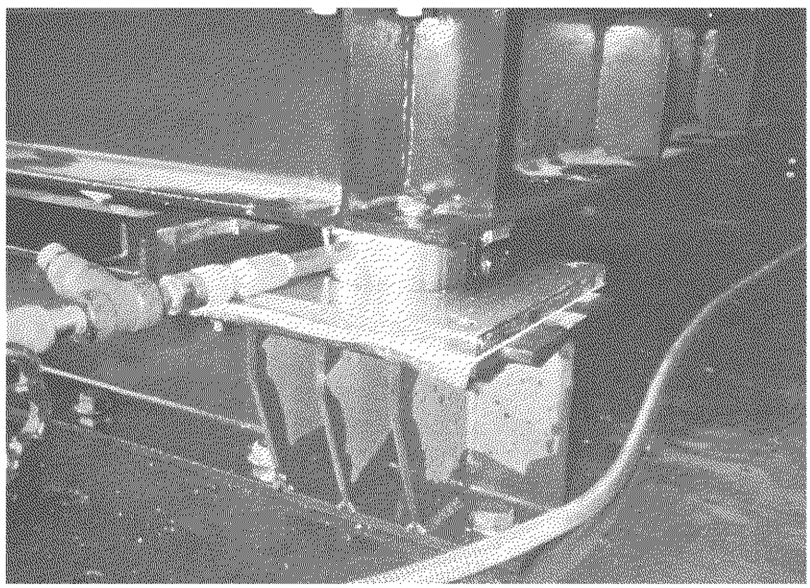

Figure 3.5: Friction Controllable Sliding Bearing in Experiment

3.2 Control System and Instrumentation

A block diagram of the control system is shown in Fig. 3.6 [17, 18]. The controller is a 16 bit micro-computer (80286) with a numerical co-processor (80287) to facilitate faster computation. The response signals for feedback purpose are measured by sensors and sent to the micro-computer through 12 bit A/D converter. Then, the control signal is calculated according to one of the feedback control algorithms described in the previous section, and sent to the servo valve and servo amplifier through a 12 bit D/A converter to control the fluid pressure in the bearing chamber.

A computer code for control implementation in experiments is developed using the C language.

Sensors are placed to monitor (1) accelerations on the shaking table and on the structural model, (2) relative displacement between the shaking table and the model, and (3) fluid pressure at each fluid chamber and at the servo valve. The locations of the sensors are also shown in Fig. 3.1.

The measurement performed by the displacement sensor D4 and the accelerometer on the structural model A4 are used for the feedback control purpose, while the pressure at the servo valve P5 is used for the analog regulation of the pressure in the servo valve.

Figure 3.7 is a photograph showing the computer, some of the measuring and recording equipment used in the experiments.

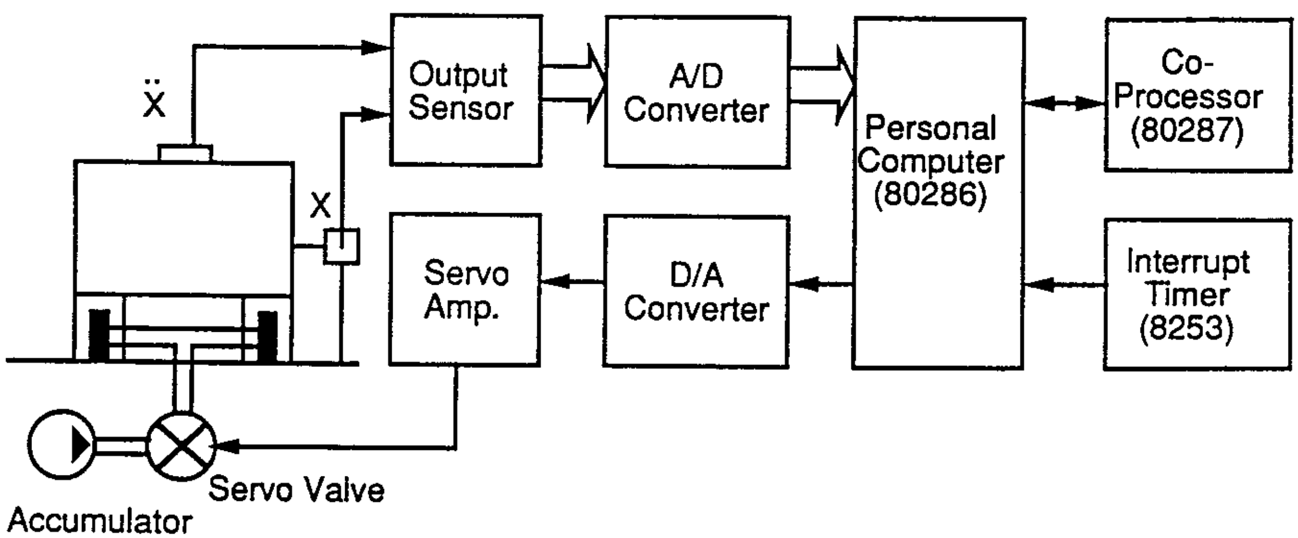

Figure 3.6: Block Diagram of Control System

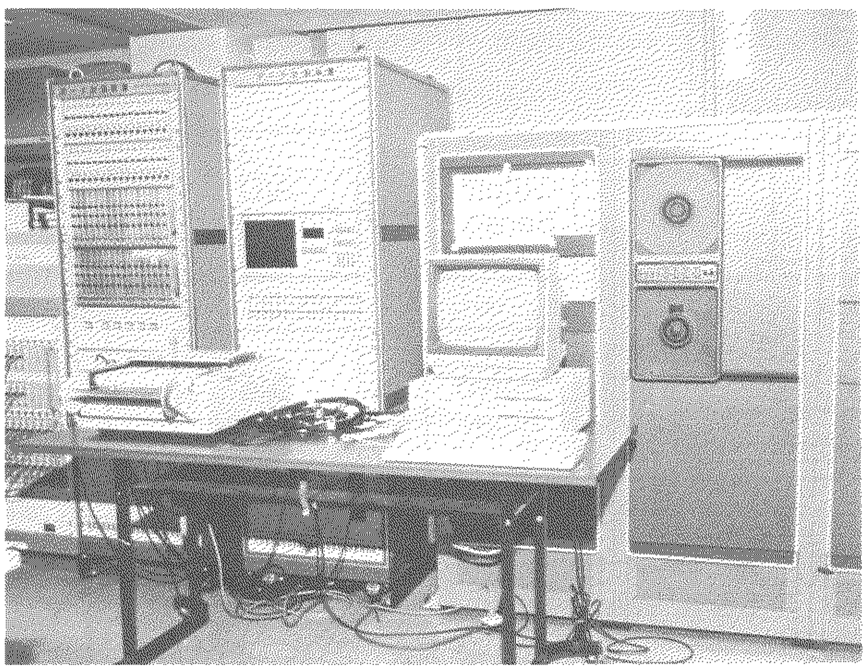

Figure 3.7: Computer and part of control system in experiment

3.3 Experimental Program

The experimental program, as described in Table 3.1, involves the following three isolation types;

1. Passive isolation

   The pressure control signal is kept constant at a certain value for each shaking table experiment (at 10, 20, 30, 40 and 45 kgf/cm^2).

2. Hybrid isolation using bang-bang control

   The pressure control signal is switched between the following two values: u_{max} = 45 kgf/cm^2 and u_{min} = 10 kgf/cm^2.

3. Hybrid isolation using instantaneous optimal control

   3a. algorithm with time delay

   3b. algorithm without time delay

   The pressure control signal is bounded by u_{max} = 45 kgf/cm^2 and u_{min} = 10 kgf/cm^2 for both cases. In case 3a, both response acceleration and sliding displacement are used for the feedback purpose with the feedback gains F_f = 1.0 kgfs^2/cm^3 and F_d = -45.0 kgf/cm^3 in Eq. 2.25. In case 3b only sliding displacement is used, as indicated in Eq. 2.30, with the feedback gains F = 16.5 kgf/cm^2 and F_d = -16.4 kgf/cm^3. In this case, the pressure control signal is nominally equal to the minimum value at the sliding displacement of 2.5 cm. The value of u_{max} = 45.0 kgf/cm^2 is determined by the maximum pressure which can be applied to the bearing chamber, depending on the

Table 3.1: Experimental Series

SERIES	PURPOSE	INPUT MOTION
1. Passive Isolation	1. Isolation performance 2. Identification of friction -pressure relationship	El Centro (NS) 100,200,300,400,450 gal Hachinohe (NS), 300 gal Taft (EW), 300 gal
2. Bang-Bang Control	1. Isolation performance 2. Identification of time delay of control device	El Centro (NS), 300gal Sinusoidal waves, 1 Hz 150 gal and 250 gal
3. Optimal Control without time delay	1. Isolation Performance 2. Study of time intervals 3. Effect of feedback gains 4. Effect of window comparator	El Centro (NS) 100,200,300 gal Hachinohe (NS), 300 gal Taft (EW), 300 gal
4. Optimal Control with time delay	1. Isolation performance 2. Study of window comparator	El Centro (NS) 100,200,300 gal Hachinohe (NS), 300 gal Taft (EW), 300 gal

vertical load identical to the structural weight equally shared by the four bearings:

$$u_{max} = \frac{W}{4S} * \lambda = 45.0 \ kgf/cm^2 \tag{3.1}$$

where, S is the vertically projected area of the fluid chamber of each bearing with the value of 57.7 cm^2 , and λ is a safety coefficient with the value $\lambda = 0.87$ providing some margin of safety. On the other hand, the value of $u_{min} = 10$ kgf/cm^2 is set because the experiment indicates that the pressure response p to the control signal u is too slow for the control to be effective if it is below 10 kgf/cm^2.

The relationship between the pressure and the coefficient of friction is identified from the passive isolation experiments which are refered to as Experimental Series 1. The dynamic response characteristics of pressure and friction to the control signal is identified from the bang-bang control experiment in Experimental Series 2. The time intervals for measurement and control are examined using the optimal control experiments without time delay (Experimental Series 3), and the appropriate values of the window comparator are studied using the optimal control experiments with and without time delay (Experimental Series 4). More importantly, the results of these experiments are used to examine and compare the isolation performance of each isolation type under different input motions at differing levels of intensity. These experimental series and their purpose are summarized in Table 3.1.

The shaking table experiments were conducted under one-dimensional horizontal motion (as shown in Fig. 3.1). The El Centro (NS, 1940) record was used as ground input motion for most of the experiment cases, by linearly adjusting the maximum acceleration to 100, 200, 300 400 and 450 gal as shown in Table 3.1, where it is also shown that Hachinohe NS, Taft EW , and sinusoidal waves were also used in some experiment cases.