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Structural Control with Variable Friction Damper For Seismic Response

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ABSTRACT

This paper investigates the application of the variable friction damper system (VFDS) for the 1/10 scaled multiple-stories building model so that reduce the response to the earthquake. The VFDS uses the Piezoelectric actuators that change the load to the brake-pad according to the electric signal from the main-controller with the LQ-algorithm. Five devices were distributed between each floor of the model, and excitation test was carried out with 3 kinds of seismic wave on the shaking table. Through this examination, the effect of VFDS was confirmed and will be reported in this paper.

KEYWORDS

Structural Control; Building application; Variable Friction; Piezoelectric actuator; LQ-algorithm; Servo Controller

INTRODUCTION

Recently in Japan, many interest have been taken in the safe-guarding system of the structures for the earthquake after Hyogoken-nanbu-earthquake, January 1995. Before this earthquake occured, some kind of safe-guarding methods have been investigated such as the base-isolation system, passive controlling system using various kind of dampers (Hirai et al., 1994), (Tsiatas, Daly, 1994), active controlling system using actuators and so on. And these methods seem to be not enough as the best solution for the safe-guarding issue in terms of cost or performance. Consideration for the case of power-failure is also important.

This paper investigates the application of the variable friction damper system (VFDS), which has been newly developed, for the building. The VFDS is the structural controlling device that supplies the *variable* friction force between the floors of building according to the seismic response using the Optimum Controlling Algorithm, though the usual friction damper works in the constant friction force. In this paper, Experimental and numerical investigation were carried out to evaluate the effect of VFDS for the huge earthquake comparing to the usual constant friction damping devices.

VARIABLE FRICTION DAMPER SYSTEM (VFDS)

Elements of VFDS unit

Fig 1 shows the detailed cross section of VFDS unit. The primary elements of VFDS are outer casing, sliding rod, a pair of braking pads, piezoelectric actuators, back-up plate, and clearance adjusting bolt. Sliding rod is sandwiched between the braking pads. Lower pad is sticked to the outer casing, and upper pad is put on the sliding rod. Piezoelectric actuators are adhesive bonded on behind the upper braking pad and on the other side of the actuators the back-up plate is also bonded to the actuators. The movement of the upper pad and back-up plate is guided by outer casing and these are movable only in the virtical direction. Clearance adjusting bolt is screwed to the outer casing. Driving the screw, some virtical load is applied to the braking pad and decide the initial friction force between the pads and sliding rod. Piezoelectric actuator changes its own length related to the voltage supplied by the main controller, and changes the pressure between the braking pad and sliding rod so that the friction force between them will be same to the refference signal from the controller.

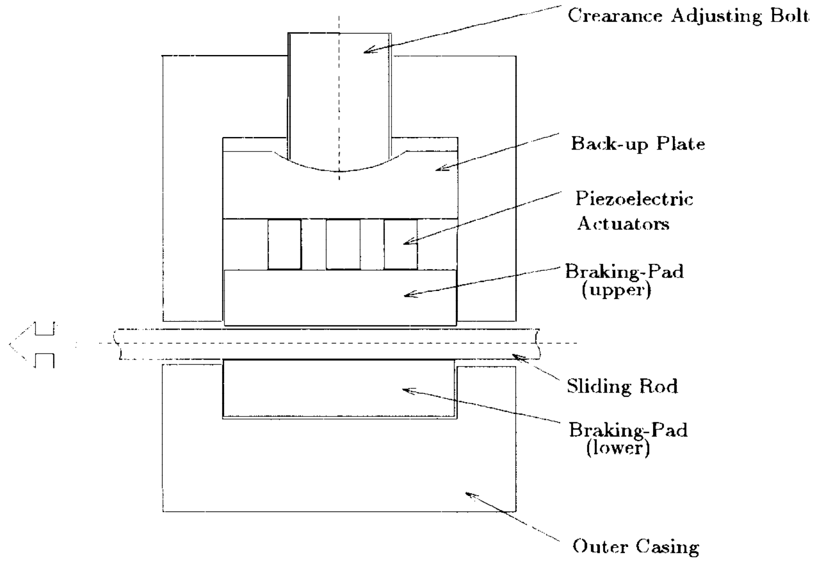

Figure 1: Detailed cross section of VFDS unit

Controlling property

In the application of VFDS, the actual friction force is measured between the device unit and the object of application by the load cell, and errors between the output force and the refference signal from the main controller will be corrected by the servo controller. Fig 2 shows the controlling property of VFDS with the servo controller system which was experimentally acquired. This figure shows the $P - \delta$ hysteresis of friction force and displacement of the sliding rod in sinusoidal motion. It indicates that the friction force output is changing according to the step refference force signal.

Algorithm

LQ controlling algorithm is used for the main controller of VFDS. Generally, the character of LQ controller is decided by the figure of weighting function of state equation. In this investigation, the weighting function was specially designed so that the output force will *never* give the work for the object of application. In other words, the refference signal of the controller is decided to be always in the direction to which the controlling device unit will consume the energy of the building. Thus the friction force is available for use and the actuator is needless for the control. Fig 3 shows the numerical acquied example of the variation of controll force and power about the temporary simulation model. This figure indicates that response of the model in the case of without control b) is reduced by LQ controlling c), while the controlling device is consuming the vibration energy of the building model. The e) is the time historical products of relative velocity between the joints in which the device model exists c) and the reaction of control force d). This value means the power of the device in each time. Note that it is always positive.

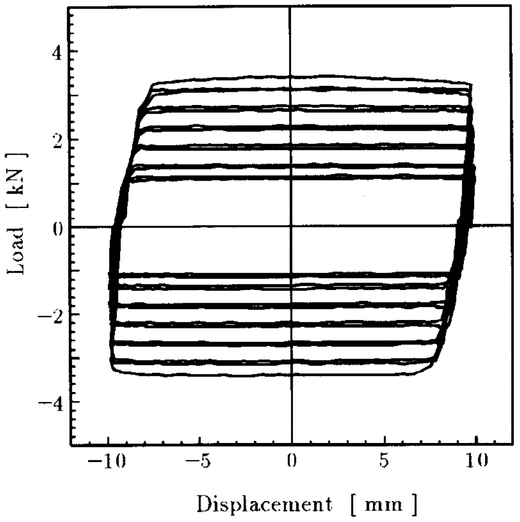

Figure 2: Controlling property of VDFS

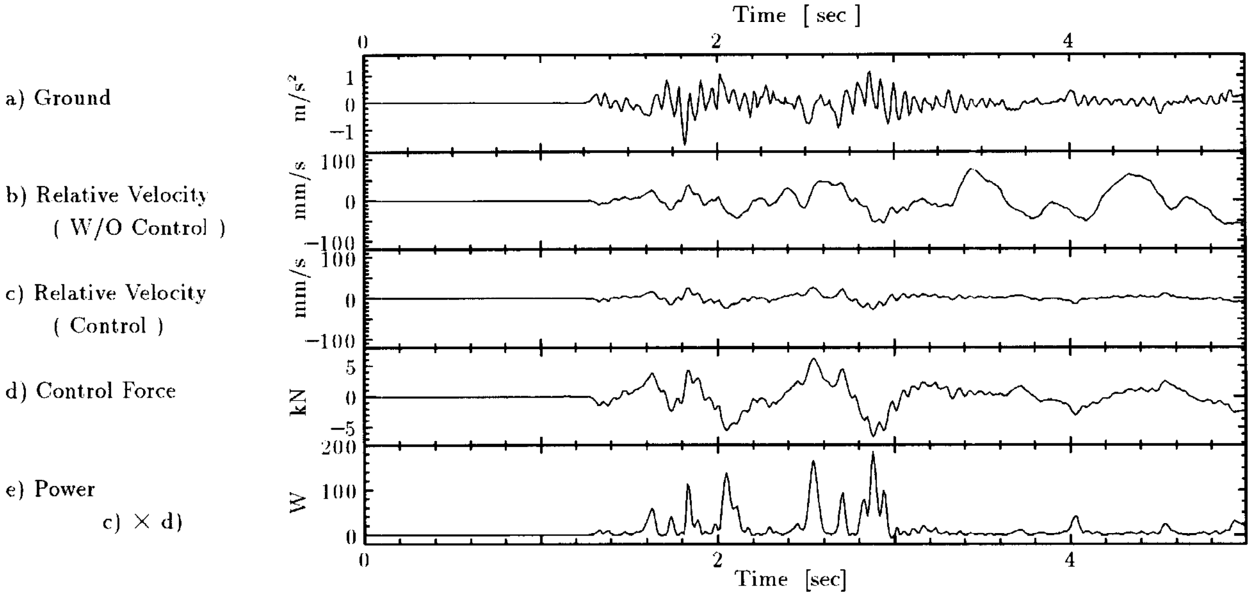

Figure 3: Consumed energy by VDFS

EXPERIMENT

The effect of VFDS was evaluated in the scaled-down model experiment.

Experimental set up

Fig 4 shows the experimental set up. Building model is 5 stories and is constructed so that 5 steel mass is connected by high-tensile steel bars. It is set upside-down on the main frame so that the natural period of the model is lengthened. The weight of steel mass is 4400kg each so total weight of the model is 22000kg. The diameter of the steel bar is $\phi 28$ between the 5th floor ,4th floor and 3rd floor. The others between 3rd floor, 2nd floor,1st floor and main frame are $\phi 32$. The natural period of the 1st mode is about 1 sec. Main frame is set on the shaking table so that excitation test is available.

The VFDS is constructed with 5 set of units, load cells for each unit, displacement pick-ups and accelerometers on each floor of the building model, the computer for the main LQ controller, and desital signal procceser (DSP) for servo controlling system. Feed-back gain for LQ controller has been obtained with the 5DOF equivalent model considering every five natural mode.

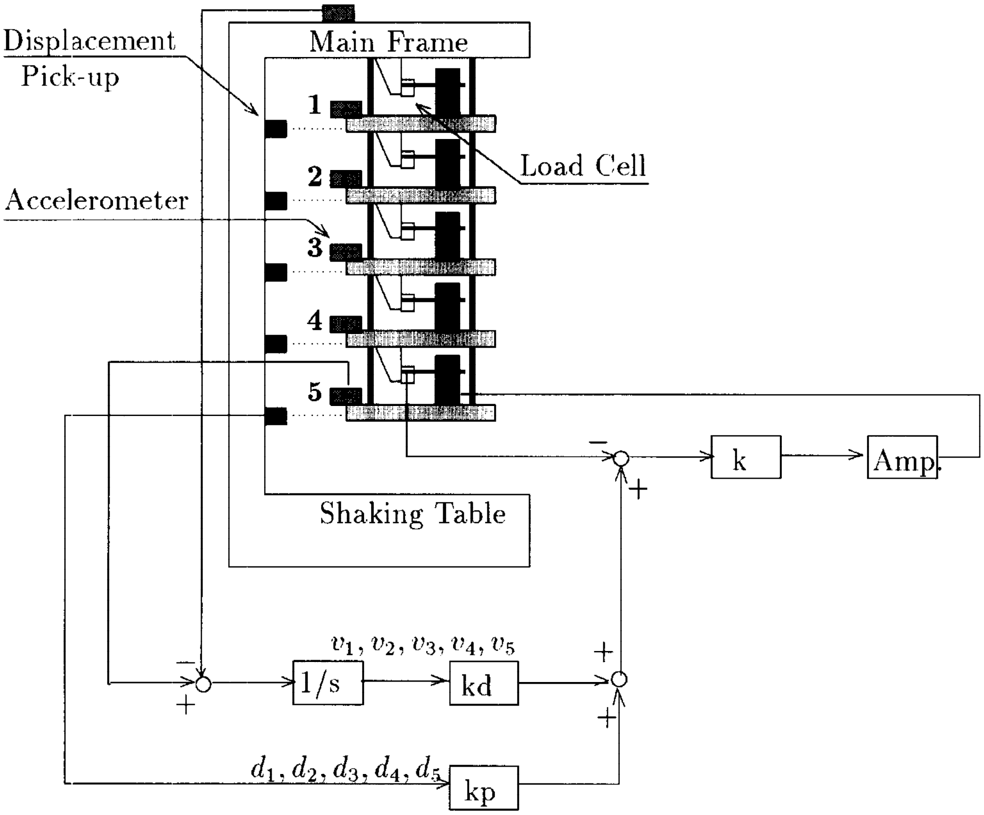

Figure 4: Experimental set up

Experimental result

All excitation tests were carried out on the shaking table. Fig 5 shows the experimentally acquired friquency transfer function. Each peak response except for the 5th mode which was not defined is reduced to about 1/100 by controlling with VFDS. It indicates that the equivalent inherent damping of the building model is highly increasing with VFDS.

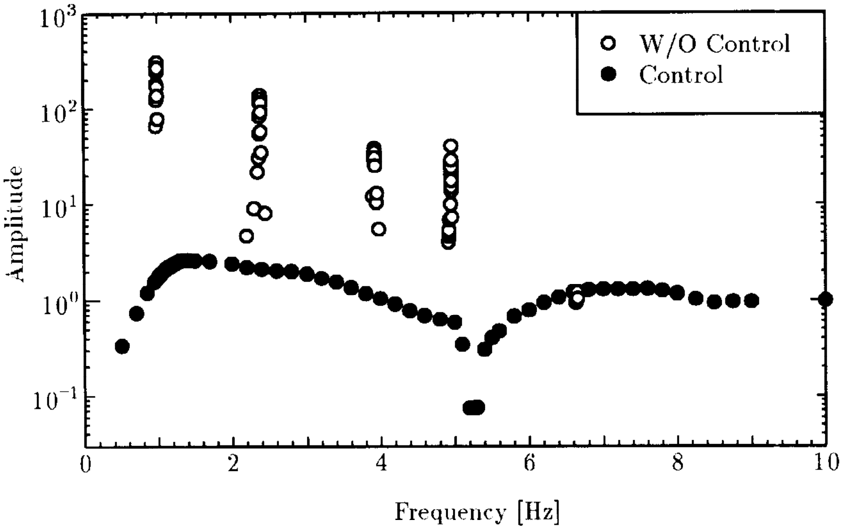

Figure 5: Experimental Result -Frequency transfer function in the case of with and without control

Using the same instrument, the seismic excitation test was also carried out. The seismic disturbances for excitation were Elcentro NS (standard wave), Hachinohe NS (long periodical wave) and Hyogoken-nanbu NS (short periodical wave). Fig 6 show the experimental result about the maximum value of relative displacement between each floor of the building model. The response is reduced to less than the half of the case of without control by VFDS controlling in all cases. Note that this reduction is markable especially in the critical member between 3rd floor and 4th floor.

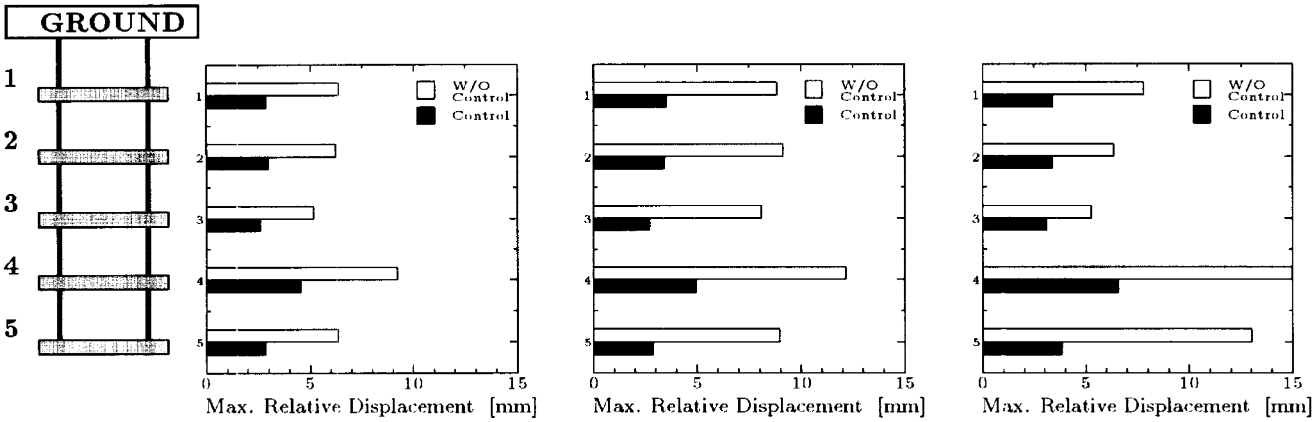

Figure 6 (a): Elcentoro NS

Figure 6 (b): Hachinohe NS

Figure 6 (c): Kobe.NS

Figure 6: Experimental Result -Relative displacement

The effect of VFDS is evaluated also in the acceleration response. Fig 7 shows the friquency response function acquired from the result of FFT analysis of measured acceleration.

NUMERICAL SIMULATION RESULT

Numerical simulation with the experimental model was carried out to compare the effect of VFDS to the performanse of usual constant friction damper system. The building model for the simulation is same to the former one which was used for the calculation of the feed-back gain in the experiment.

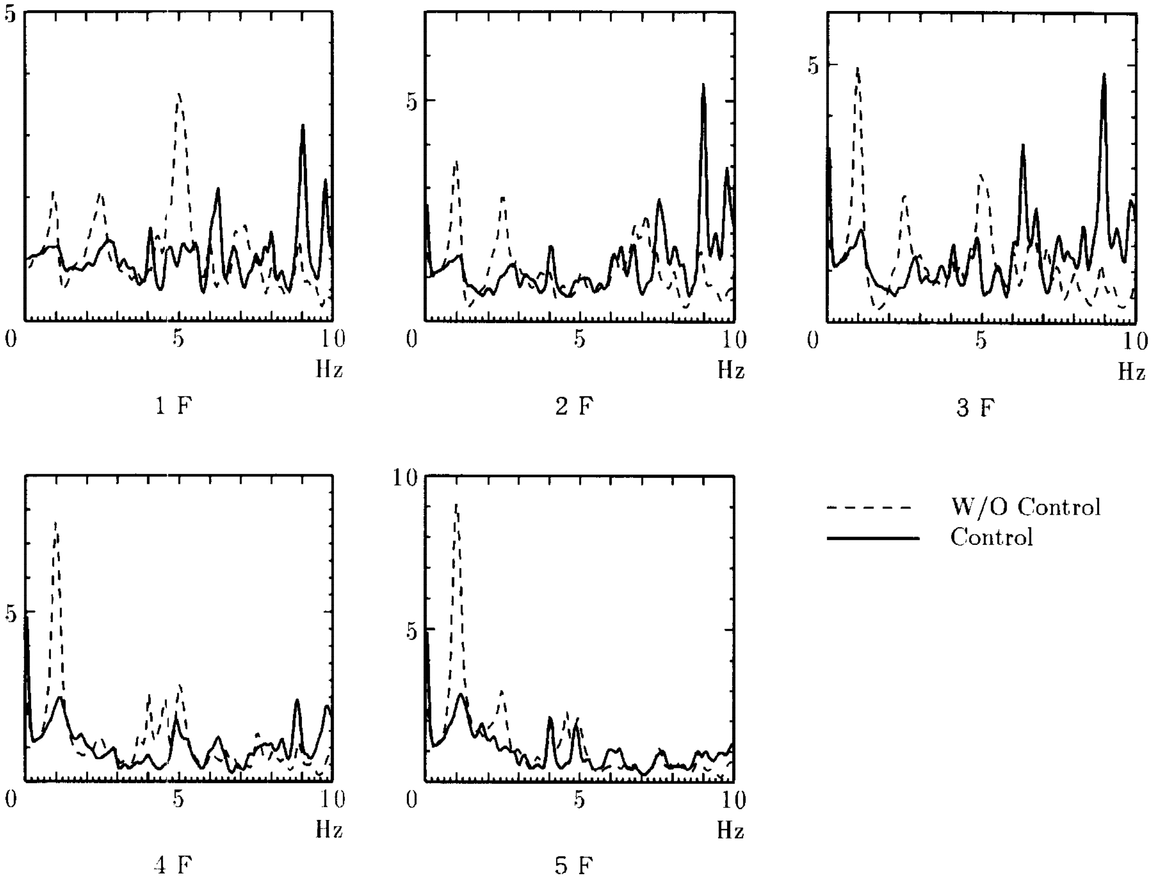

Figure 7: Experimental Result -Frequency response function in the case of with and without control

The experimental cases were simulated firstly in order to confirm the accuracy of the simulation model. Fig 8 shows the example of the results about the Hyogoken-nanbu earthquake. Both results are matching well so that indicate the accuracy of the simulation model.

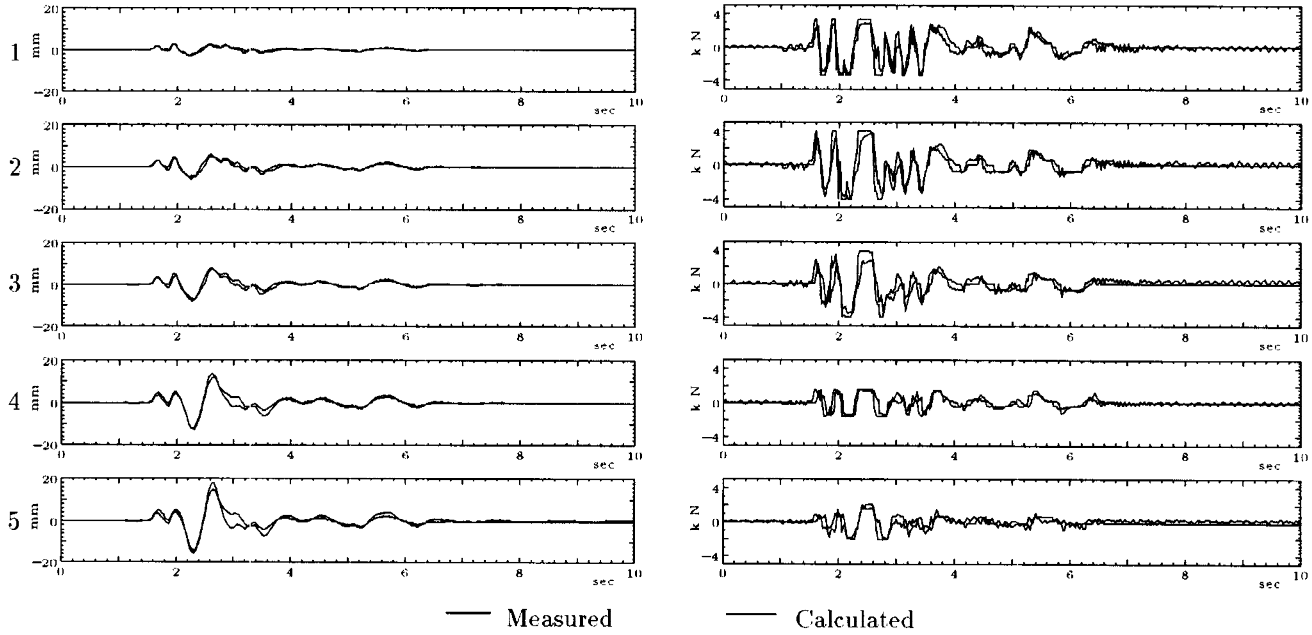

Figure 8 (a): Displacement of each floor

Figure 8 (b): Friction force between each floor

Figure 8: Result of Simulation -Experimental case of VFDS controlling

Furthermore the performance of the constant friction damping was calculated. Friction forces were modeled as tri-linear model between each floor mass and the force strengths were equal to each other in any case. The friction force strength and the level of the input seismic wave were set as the parameter. Fig 9 shows the example of the results about the case of EL CENTRO earthquake. The figure shows the maximum value of relative displacement in which the response is the largest in all the structure. The results are shown as the ratio to the simulated maximum response to the same level input wave in the case of LQ control.

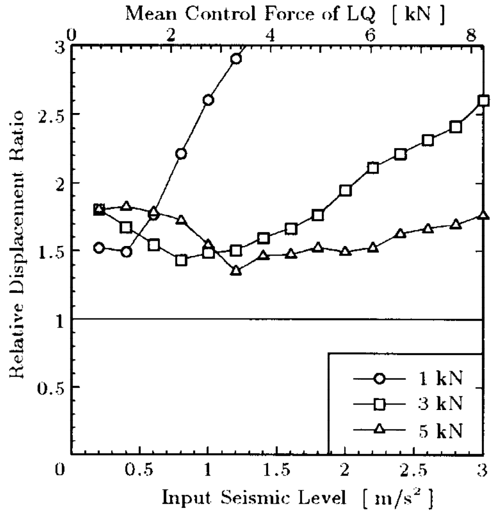

Figure 9: Result of Simulation -performance of the constant friction damping

The mean values of each maximum LQ controlling force in each seismic level are also indicated in the horizontal axis. This figure indicates that the effect of constant friction damping does not exceed that of LQ control in all cases. Furthermore, the performance of constant friction damping is depending on the seismic level comparing to the LQ control. This tendency can be seen in both cases that the constant friction force is larger than mean control force of LQ control and is smaller.

PRACTICAL BUILDING APPLICATION

All experimental and numerical approaches mentioned before were carried out in the elastic region and this condition was the ideal one for the LQ controlling algorithm. In this section, the property of VFDS in the inelastic condition is discussed. The response of the assumed RC building model to the huge earthquake was numerically simulated considering the plastic deformation. The character of the building model is shown in Table 1.

Table 1: Building model character

structure	RC
Floors	9
Total weight	27000ton
Natural period	0.58sec(1st mode)
Inherent damping	0.03(each mode)
Hysteresis model	D Tri-linear(Takeda model) (Takeda et al., 1970)
Yielding displacement	15mm(each floor)

Fig 10 shows the example of the result about the Hyogoken-nanbu earthquake. The largest deformation appears between 4th and 5th floor in the case of without control, and it is much bigger than the yielding displacement. This deformation is reduced to less than 15mm between each floor by controlling with VFDS and maximum frictional force is about 50,000kN.

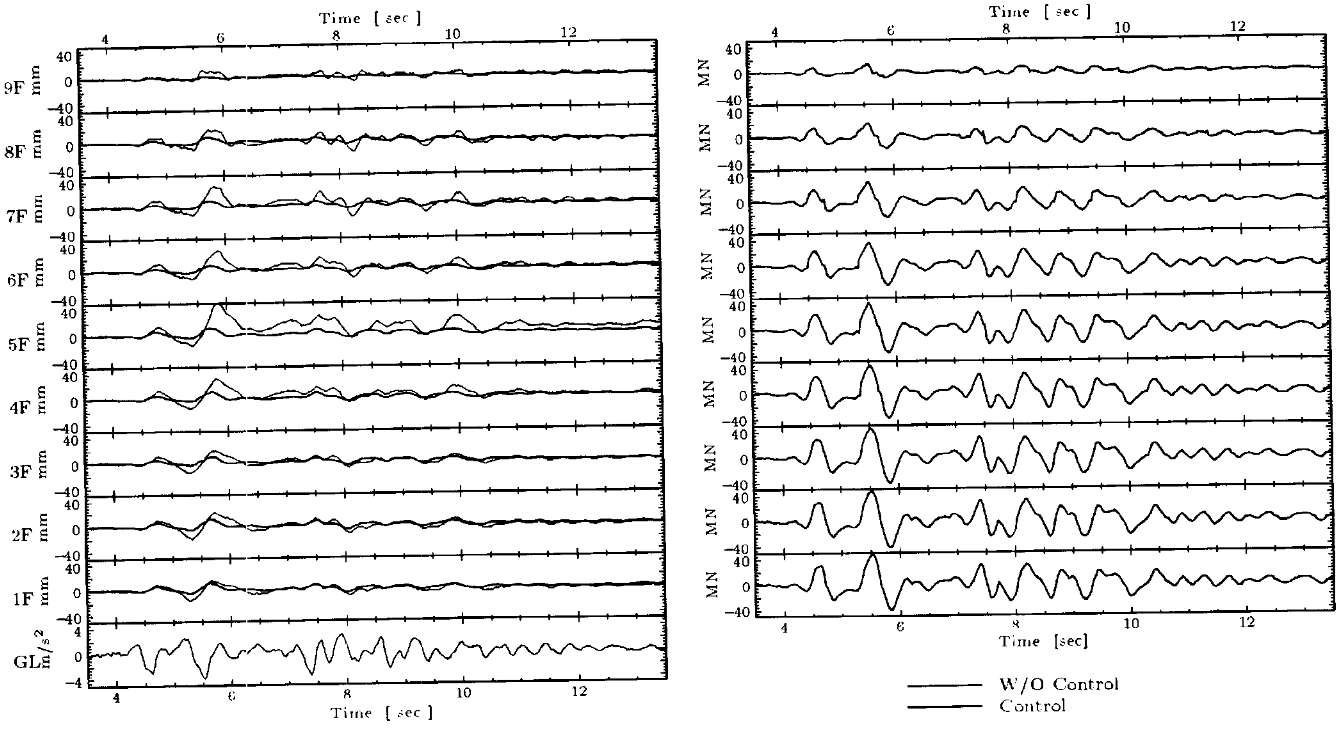

Figure 10 (a): Relative Displacement between each floor Figure 10 (b): Friction force between each floor

Figure 10: Numerical acquiered effect of VFDS for practical building

CONCLUSION

It was confirmed that the VFDS is effective for reduction of the structural response to the huge earthquake through the experimental and numerical approaches. Its performance is higher than that of the usual constant friction dampers and is shown also in the inelastic condition. The requied force for the controlling of the practical building model is about 50,000kN. Practical device is now under development. Further study by the authors will concentrate on this new device system.

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