(128) ACTIVE CONTROL OF SLIDING STRUCTURES

by

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ABSTRACT

The objective of this study is to find the dynamic characteristics of a hybrid system so that stable performance results near its natural frequency, especially for low mass-ratio structures. Experiments were also conducted on a single degree of freedom rigid frame model and tested for sliding response, as well as its control with the active mass. These results were also compared with the fixed base response of the same model. Significant reduction in response results for the sliding model because of the friction damping characteristics of teflon. A small feedback controlled proof mass further reduced the response. The sliding frame response to harmonic excitation as well as to random excitation, and feedback has been successfully attenuated.

INTRODUCTION: Conventional designed structures could be significantly damaged if the induced energy exceeds the hysteretically dissipated energy capacity. Extensive research on base isolation systems has also shown such systems to be unstable at resonance and ineffective for slender structures. The use of active control exclusively for earthquake resistance is also economically impracticable. This warrants innovation in the use of simple control procedures, such as direct acceleration feedback in combination with stable isolation mechanisms. This report is the second part of the study concerning passive isolation characteristics of Teflon under rigid mass vibrating system[1)] and its main purpose is to examine the effects on the inertia and the response acceleration of the flexibly mounted sliding mass. The control forces minimize only the decoupled accelerations resulting above the isolation elements. This would certainly require very weak control forces in comparison to all other schemes proposed till now. Experiments on the fixed base structure were for comparison and an evaluation of the structural parameters only.

HYBRID ACTIVE CONTROL: A practical structural control approach utilizing dry friction isolation and active control force to minimize the first mode accelerations by a direct acceleration feedback has been experimentally implemented. Here we would like to call it a 'hybrid active control approach'. It is to be emphasized that the time delay involved in this control system is only the time constants of the acceleration feedback sensors and those of the proof mass actuator (PMA). The maximum control force equals the magnitude of the disturbing force transmitted to the base and the top floor after isolation times an acceleration gain.

EXPERIMENTAL TESTS, RESULTS AND DISCUSSION: Figure 1 shows the experimental set up with the direct acceleration feedback arrangement and the proof mass actuator. The main feature of the set up is the feedback of the acceleration through the strain amplifier to the proof mass actuator. Here, an optimum positioning of the strain amplifier produced the desired results without the involvement of a microprocessor often used for gain multiplication in case of the velocity and displacement feedback. The model shown in Fig. 2 is a steel frame 424 *mm* wide and 167 *mm* high. The proof mass actuator is fixed to the top of

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the frame. The top mass is 16.2 kgf (including 3.0 kgf proof mass) and the foundation mass is 26.7 kgf. Four Teflon bearings were attached to the bottom of the frame model as shown in Fig. 1. A total Teflon bearing area of 4 cm^2 was used producing a pressure of 10.7 kgf/cm^2. Before an attempt could be made to test the single story frame, it was necessary to evaluate the characteristics of the PMA.

The experimental sequence was divided into five cases, (1) proof-mass actuator characteristics, (2) system damping and stiffness parameter evaluation, (3) response of sliding frame to base excitation, (4) response of sliding frame to base excitation and PMA control force, (5) response of sliding frame to random excitation with and without acceleration feedback. Accelerations were recorded at the shaking table level, the top of the frame (TOF) and at the top of the proof mass actuator. An extra channel was added for the Teflon mounted frame to measure the accelerations above the Teflon mountings and feedback acceleration from the top of the frame. Tests were carried out at a base excitation amplitude of 30, 100 and 150 gal and at frequencies between 3 $\sim$ 12 Hz so as to generate the frequency response data. Recordings were made to ascertain the experimental phase changes at each frequency. The PMA was adjusted to produce an opposite inertial force relative to the first story except near sudden phase changes. The proof mass actuator's frequency response characteristics are shown in Fig. 3. A peak response results at a frequency between 4 $\sim$ 5 Hz. This is also verified by the phase plot in Fig. 4.

The damping ratio of the fixed base frame by the half-power method was evaluated to be 1.8%. Free vibration tests were also conducted to find the value of the actual structural damping ratio for sliding and feedback conditions. This was observed to be 5.1 and 5.9% for the sliding frame, and 6.4 and 8.4% for the feedback position at input amplitudes of 100 and 200 gal respectively. These results are shown in Fig. 5. The case 2 results shown in Fig. 6 indicate a resonant frequency of 7.1 Hz and a maximum response acceleration of 1300 gal for 30 gal input excitation. The large amplification of the response is due to low structural damping already reported. A further insight is the fact that a large control force would be needed to suppress the vibrations of the fixed base frame, which becomes impracticable for large structures. This necessitated the implementation of Teflon sliding bearings and the active mass control for two main reasons, (1) to attenuate the response accelerations, and (2) to practically control the response by application of weak control forces in the neighborhood of the resonance condition.

Fig. 7 shows the Teflon mounted structure's frequency response characteristics. The 100 gal input does not shift the natural frequency, but attenuates the peak acceleration. This could be explained by the sliding initiated close to the resonant frequency, isolating the model, but not altering its structural parameters. Whereas the 150 gal input produces a continuous slip state between 5.0 and 8.0 Hz by taking advantage of the Teflon's isolation characteristics[1]. The peak response is substantially reduced in comparison to the fixed base structure, and a second peak in the natural frequency of 7.8 Hz is also observed, perhaps due to the mass-ratio effect. The response of the foundation shows an interesting feature of reducing below the peak input amplitude and exposing the sliding region.

Fig. 8 shows the frequency response curves for case 4 with the application of the proof mass feedback control force. The response is quite similar to the sliding frame response except a reduction in the natural frequency in the vacinity of 6.0 Hz due to the PMA characteristics already explained. Significant effect of the control force on the peak response acceleration is observed for large input accelerations and near the resonance frequency. The plot of the foundation response does not seem to vary in form when compared with that of the sliding response though the reduction trough has moved towards 5.0 Hz.

The arrangement for carrying out the random excitation and feedback is the same as for the sinusoidal excitation except with the addition of the white noise generator. A peak random shaking acceleration of above 500 gal input for the sliding and the feedback frame was used. A comparison of top of the frame response for the sliding and the hybrid frame shows a reduction in the peak response of the order of 30% in Fig. 9.

CONCLUSIONS:

1. A hybrid system with closed-loop feedback proof mass control is necessary to reduce the response at the natural frequency of the sliding structure, especially for simple systems.
2. A comparison of the fixed base structure and the sliding structure show significant reduction in response due to the friction damping characteristics of Teflon.
3. When the structure is isolated, the relative displacement of the top mass decreases and as such a small proof mass could further reduce the response acceleration near the resonance condition. A reduction of up to 40% in response is obtained for the feedback controlled proof mass. The residual sliding displacement is also reduced near the natural frequency.
4. The randomly excited and proof mass fed system shows attenuation in the response of about 30%, indicating the robustness of the proof mass controlled, direct acceleration feedback sliding structure. Such systems could find application in certain special situations, such as nuclear power plant components, and robotics.

REFERENCES:

[1] Qureshi, S.M., Miyahara, S., Tsutsumi, H. and Uno, K., ' Rigid Mass on Teflon Interfaces Under Dynamic Excitation ', Eighth Japan Earthquake Engineering Symposium, 1851-1856, (1990).

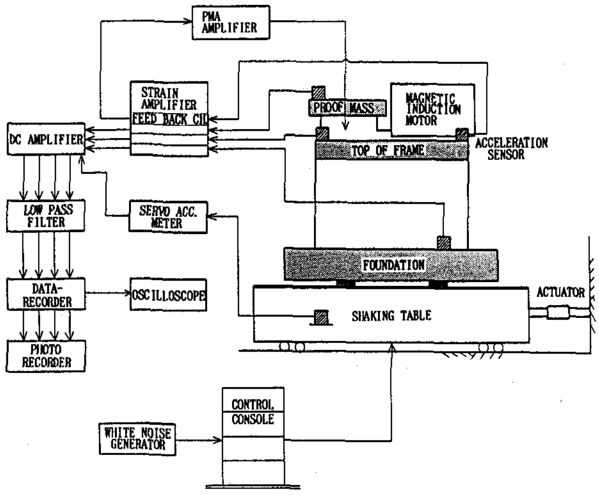

Fig. 1: Experimental Setup with Direct Acceleration Feedback

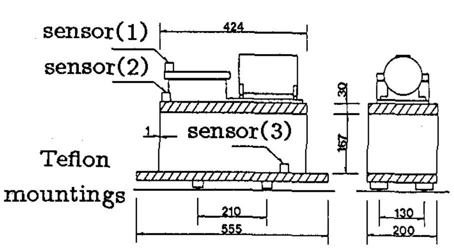

Fig. 2: Experimental Model (all dimensions in mm)

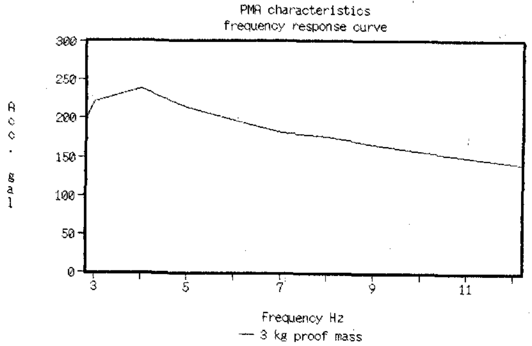

Fig. 3: Proof Mass Characteristics

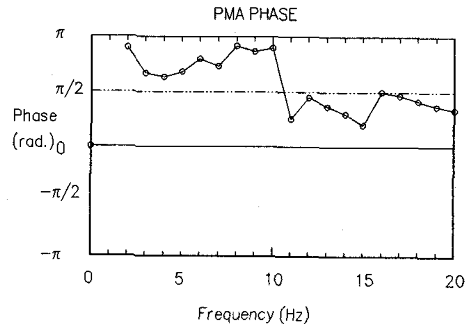

Fig. 4: Proof Mass Phase

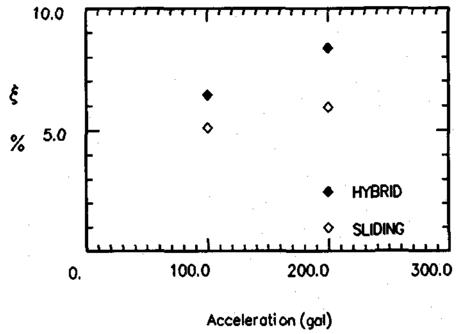

Fig. 5: System Damping

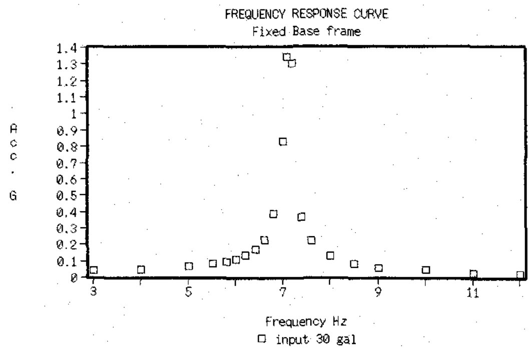

Fig. 6: Fixed Base Response

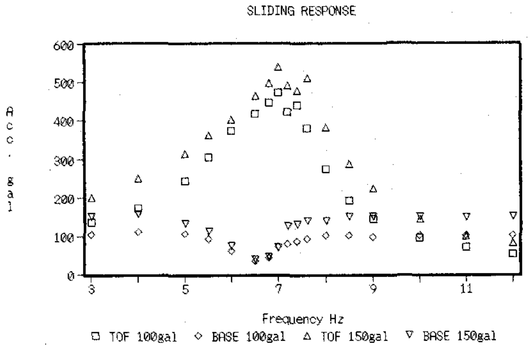

Fig. 7: Sliding Frame Response

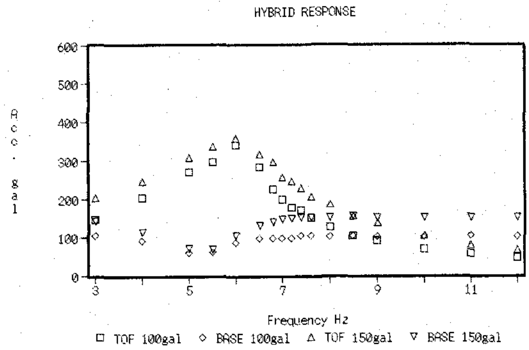

Fig. 8: Hybrid Frame Response

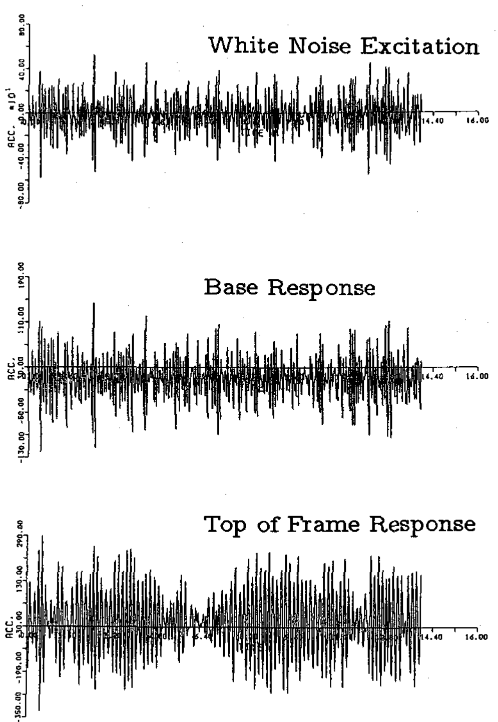

Fig. 9: (a) Sliding Frame Random Response

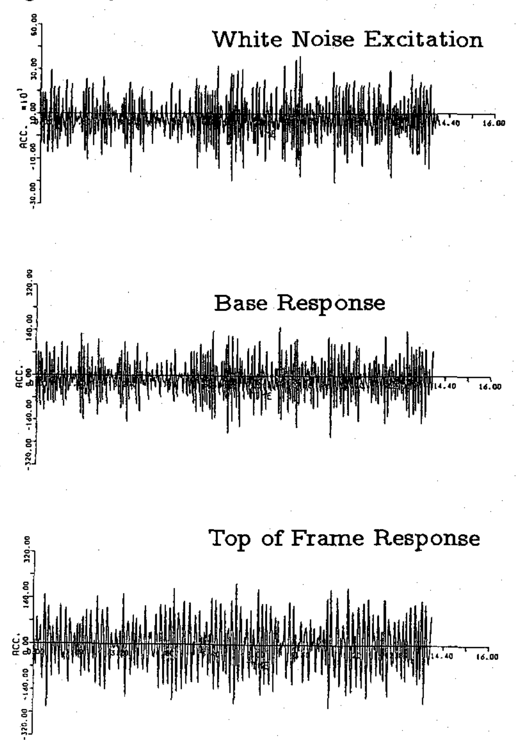

Fig. 9: (b) Hybrid Frame Random Response