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**Title**
SEISMIC ISOLATION OF AN ELECTRON MICROSCOPE

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SEISMIC ISOLATION OF AN ELECTRON MICROSCOPE

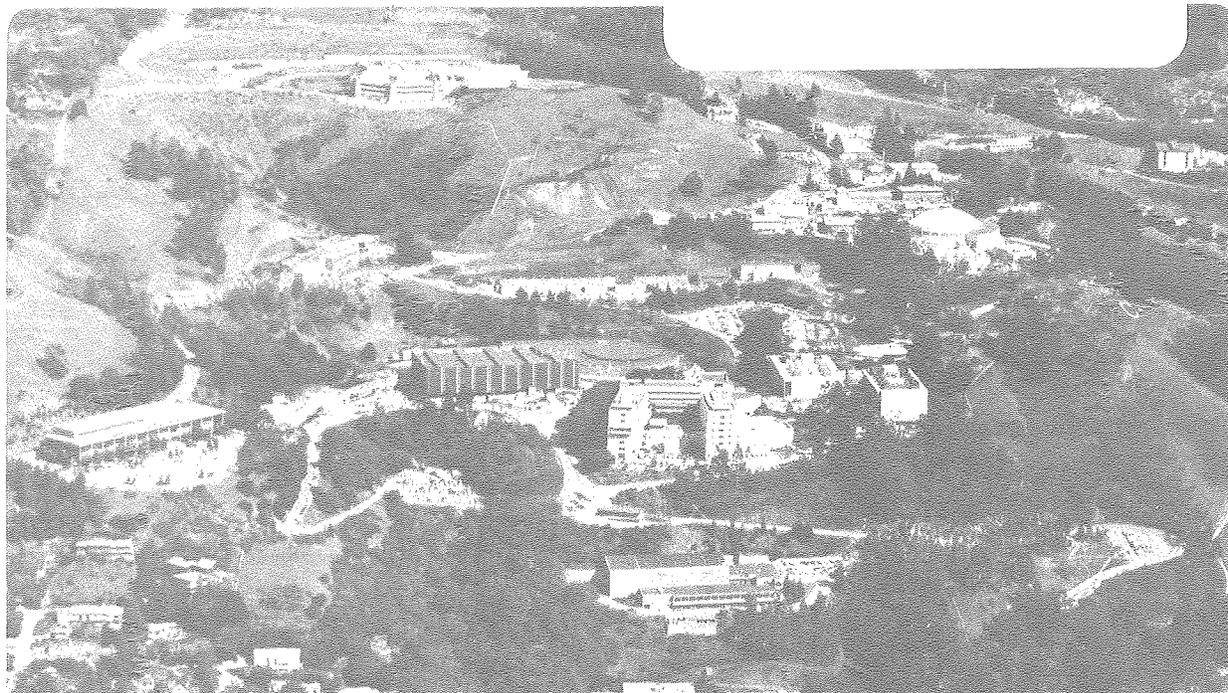W. G. Godden, M. Aslam, and D. Theodore Scalise

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## DISCLAIMER

# SEISMIC ISOLATION OF AN ELECTRON MICROSCOPE

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## SUMMARY

A unique two-stage dynamic-isolation problem is presented by the conflicting design requirements for the foundations of an electron microscope in a seismic region. Under normal operational conditions the microscope must be isolated from ambient ground noise; this creates a system extremely vulnerable to seismic ground motions. Under earthquake loading the internal equipment forces must be limited to prevent damage or collapse. An analysis of the proposed design solution is presented. This study was motivated by the 1.5 MeV High Voltage Electron Microscope (HVEM) to be installed at the Lawrence Berkeley Laboratory (LBL) located near the Hayward Fault in California.

## INTRODUCTION

The design basis and principles for the Foundation Isolation System of a high-voltage electron microscope are described in this paper. The required resolving power of the microscope is such that a high degree of isolation from ambient noise is necessary, and a typical means of achieving this is to mount the microscope on a foundation consisting of a long-period resonator with minimum damping. Such a foundation typically consists of a massive concrete block mounted on linear springs, sometimes airbags, with resulting natural periods in the horizontal and vertical directions on the order of one second.

This system behaves as a low pass filter, and due to the absence of damping, would tend to have large amplitude sinusoidal-type displacements in the X, Y, or Z axes under seismic ground motions. These displacements would be large enough to create problems in the design of the equipment, the foundation, and particularly, in the design of the airbags that can be subjected to a limited amount of shear deformation without damage. Hence, some type of additional seismic restraint is called for — a restraint that must be inoperative under normal conditions, that must restrict the maximum displacement of the microscope support block relative to the ground, and at the same time, reduce the internal forces in the microscope when compared with forces that would be caused by the original earthquake.

One possible solution is to install a coulomb friction device that engages only above a small prescribed level of block displacement. Such a device can be effective in limiting the maximum relative block motion, but at the same time it alters the frequency content of the ground motion transmitted to the equipment. Both of these factors are studied in this paper.

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The results of computer analysis are presented in the form of time-history and spectral response graphs, and these show the conflicting requirements in the dual-isolation problem. Introducing friction damping to the ambient-vibration isolation system reduces maximum block displacements as would be expected. But depending on the friction coefficient selected and on the significant natural frequencies of the microscope, the resulting internal forces may either be reduced or in certain circumstances increased, compared with subjecting the equipment to the original earthquake. This suggests the domain of effective coulomb damping in such an application.

### PHYSICAL DESCRIPTION OF FOUNDATION ISOLATION SYSTEM

The HVEM Foundation Isolation System includes four major components: (a) HVEM Support Block, (b) Vibration Isolation System, (c) Seismic Restraint System, and (d) Ground Foundation.

The HVEM Support Block (abbreviated herein as "Block") is designed to receive the HVEM microscope support legs and to satisfy the dynamic require-ments of the ambient Vibration Isolation System. The Ground Foundation is designed to withstand all loads imposed by the Block and microscope and its own mass, due to gravitational or earthquake forces; its motion is herein referred to as motion of the Ground. The two isolation systems act between the Block and the Ground to modify the Ground motion.

The Vibration Isolation System is designed to isolate the Block and microscope from all ambient Ground vibrations, and requires the Block and microscope system to have natural frequencies in the one Hertz range. Such natural frequencies would pose extremely severe amplification problems (see Fig. 10) during an earthquake and call for the addition of damping. The Seismic Restraint System is designed to limit the peak accelerations of the Block during an earthquake using horizontal friction surfaces between the Block and the Ground.

Figures 1, 2, and 3 show components of the Foundation System including the air-bags which act as linear springs The friction devices, which are not shown, are located between the air-bags and consist of friction washers under a constant normal compression. A small horizontal clearance ensures that these devices operate only during an earthquake.

### BACKGROUND OF PRESENT ANALYSIS

#### Prior Developments

The earthquake sliding response [1] and the earthquake rocking response [2,3,4] of rigid bodies, unattached to the ground, have been previously investigated. These investigations derived mathematical models that were validated by experiments using the shaking table at the U.C. Earthquake Engineering Research Center [5].

In these studies, a computer program named BLOKSLD was written to solve the seismic sliding problem [1]. In the present study, BLOKSLD has been further developed to determine the response of the HVEM Seismic Restraint System.

The BLOKSLD program gives the instantaneous, maximum, and residual displacements (relative to the ground) and the accelerations of a rigid body responding in the sliding-mode to simultaneous vertical and horizontal earthquake accelerations as a function of the coefficient of friction between the rigid body and the ground. The forces on the Block are friction and the elastic spring force which is assumed to be proportional to the relative displacement between the rigid body and the ground.

## Equation of Motion

Figure 4 shows the horizontal forces acting on a sliding Block at (a) the threshold of sliding and (b) during sliding. The notation is as follows: $g$ = acceleration of gravity; $K$ = spring stiffness; $M$ = mass of Block; $s = u-x$ = relative horizontal displacement of Block; $\dot{s} = ds/dt$; $t$ = time; $u$ = absolute horizontal ground displacement; $\dot{u} = du/dt$; $\ddot{u} = d^2u/dt^2$; $W$ = weight of Block; $x$ = absolute horizontal displacement of Block; $\dot{x} = dx/dt$; $\ddot{x} = d^2x/dt^2$; $\mu$ = coefficient of friction. Subscript "0" on u and x denote their initial values.

At the threshold of sliding, the inertial force equals the frictional force:

$$M|\ddot{u}| = \mu W \tag{1}$$

Sliding commences when $|\ddot{u}| > \mu g$. During sliding the equation of motion derived from the relationship among the inertial, frictional, and linear spring forces is

$$\ddot{x} = \mu g \text{ (sign of } \dot{s}) + \frac{Ks}{M} \tag{2}$$

where $\dot{s} \equiv \dot{u} - \dot{x}$ = velocity of block relative to ground $\tag{3}$

The block reattaches to the ground when $\dot{s} = 0$. The BLKSLD program is used to integrate the equation of motion subject to the above sliding and reattachment conditions for the given ground motion.

## ANALYSIS FOR HVEM ISOLATION FOUNDATION

The design-basis earthquake for this study was defined by Professor Bolt [6]. It has a peak acceleration in horizontal shaking of 0.7 g, a peak displacement if 1.77 ft and the bracketed duration of the sharp shaking is 25 seconds.

The motion of the HVEM foundation Block subjected to this earthquake depends on the natural period of the Block in horizontal motion, and the coefficient of friction which restrains this motion. The motion of the Block is the base motion as seen by the HVEM.

## HVEM Foundation Block Motion

In this study it is assumed that the total mass of the Block in horizontal motion includes the mass of the HVEM as a rigid body, and that the horizontal friction operates immediately following the horizontal

movement of the block (i.e., the very small clearance in the design to isolate the Block from ambient ground motions is neglected).

The following values related to the Block design have been used in this study:

| | |
|---|---|
| Weight of Block + HVEM | $W = 260$ kips |
| Horizontal stiffness of 12 airbags | $K = 15.1$ k/in $= 0.058$ W/in |
| Undamped natural period of horizontal motion of the Block | $T = 2\pi\sqrt{M/K} = 1.33$ seconds |
| Horizontal friction coefficient | $\mu = 0.20$ to $0.25$ |

As the peak acceleration of the earthquake is 0.7 g, if $\mu = 0.7$ the motion of Block and Ground are identical. For smaller values of $\mu$ the Block motion is different from the base ground motion; in effect the response of the Block provides a modified earthquake to the HVEM.

## Time-Histories of HVEM Support Block Motions

The results of the analysis are shown in Figures 5-8 which give the time-histories of the horizontal accelerations, velocities, and displacements for both the ground and the Block for different values of $\mu$ and K. The air-bag spring constant K is expressed as a ratio of the Block weight per inch displacement.

Figure 5 shows that in the limiting case of very small friction ($\mu = 0.01$), the harmonic Block accelerations and displacements are too large. Figure 6 shows that in the design friction range ($\mu = 0.20$), the Block acceleration is reduced and relative displacements are small. Figure 7 is an enlargement of the first 12 seconds of Fig. 6. Figure 8 is for the limiting case of Block motion with friction but without linear spring ($K = 0$).

These time-histories show clearly the significant reduction in Block accelerations achieved by the addition of friction restrainers.

## Maximum Block Movement

The relative displacement between Block and ground is important in that a maximum clearance of 4 in. has been specified in the design. When $\mu$ is reduced from 0.70 the relative displacement increases from zero and becomes very large at the resonant frequency of the block as $\mu$ approaches zero. Computed values of Block displacement relative to ground for the design earthquake, for $T = 1.33$ seconds, and for a wide range of $\mu$ values are given in Fig. 9.

It will be noted that the minimum value of $\mu$ which maintains the maximum relative block displacement within 4 in. is $\mu = 0.175$. It was recommended that a value slightly above this be used in the design.

## Response Spectra of Block Motion

The horizontal motion of the Block can be considered as a new earthquake, and its effect on the HVEM studied using response spectra is shown in Fig. 10. Comparing the response spectra for the Block motion with the original earthquake, the following can be noted:

1. Neglecting the case of very small values of friction coefficient ($\mu$ = 0.01), and except in the vicinity of T = 1.3 (the undamped natural period of the block), the response spectrum due to Block motion is less than that for the original Ground motion.

2. In the vicinity of T = 0.13 seconds (the undamped natural period of the HVEM in horizontal motion considering the HVEM as a lumped mass on its supporting frame), a reduction in $\mu$ results in a reduction in seismic response of the HVEM. This is important in selecting an appropriate value of $\mu$ as indicated above.

3. Using smoothed spectral values, Fig. 11 shows the spectral acceleration of the HVEM structure for discrete values at T and for a wide range of $\mu$. This indicates that at the suggested design value of $\mu = 0.20$, the peak acceleration of the HVEM as a SDOF system is in the order of 1.6g. All values shown are for 2% damping.

4. The isolation system using friction devices does provide a considerable reduction in spectral response, though possibly not as much as by more-costly continuously-yielding ductile devices.

### ACKNOWLEDGEMENTS

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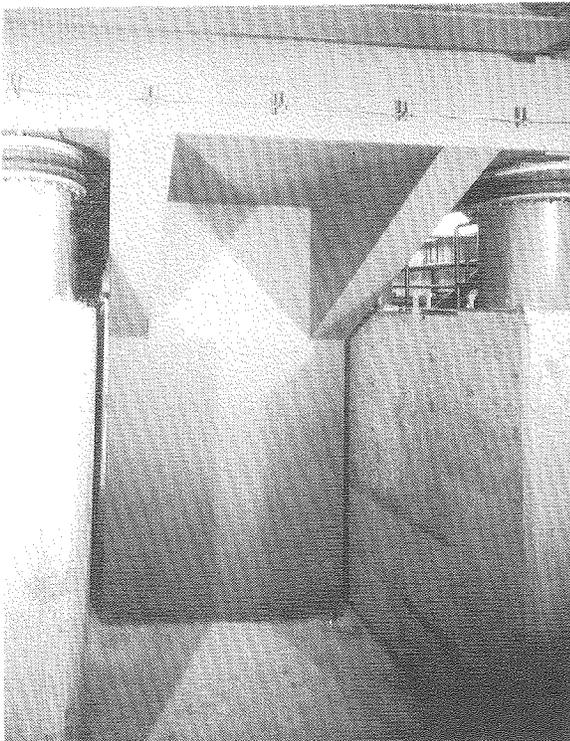6. Bolt, Bruce; Private Communication, February 15, 1979.
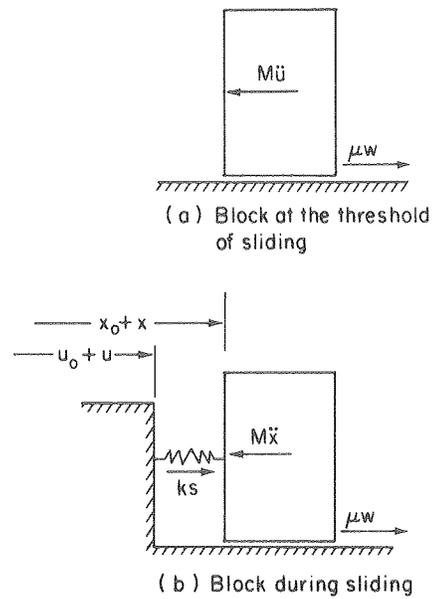
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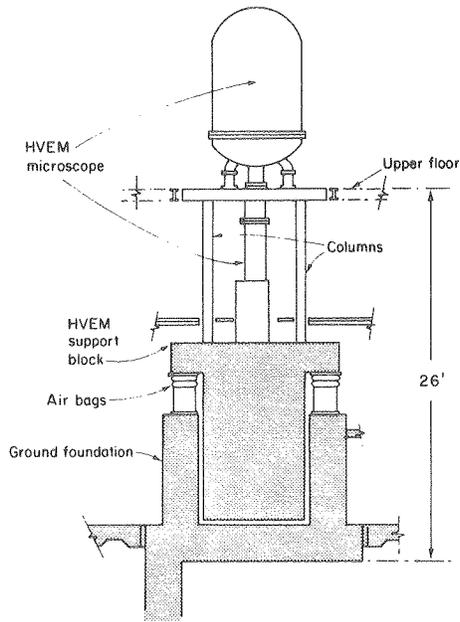


Fig. 1. HVEM physical layout diagram.
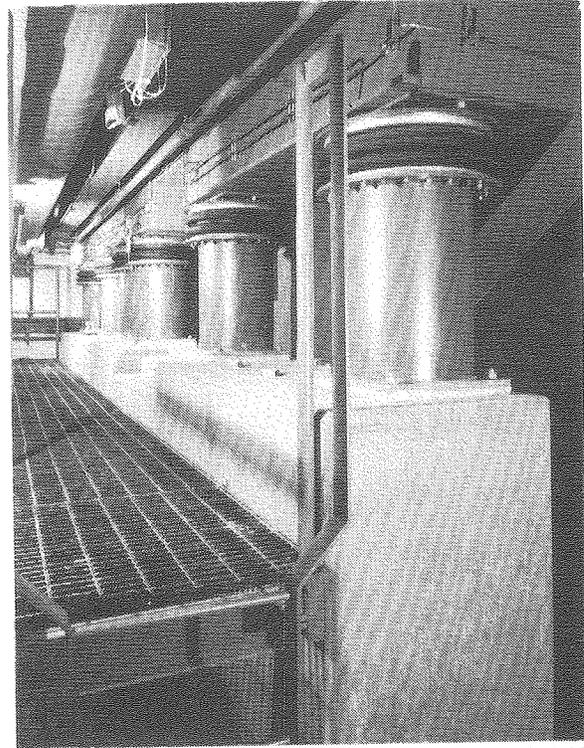


Fig. 2. Side-view photograph showing air bags.



Fig. 3. End-view photograph showing HVEM support block.



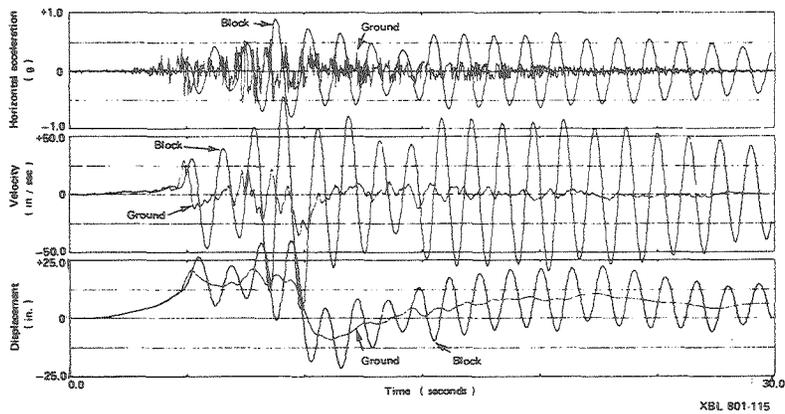Fig. 4. Horizontal forces on unattached rigid block during an earthquake.

Fig. 5. Motion of microscope foundation block
subjected to design earthquake [Bolt 2/15/79],
μ = 0.01, K = 0.058 W/in., W = 260 Kips



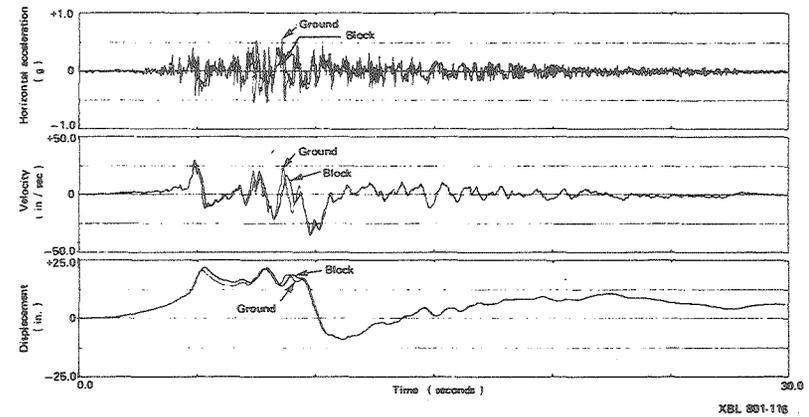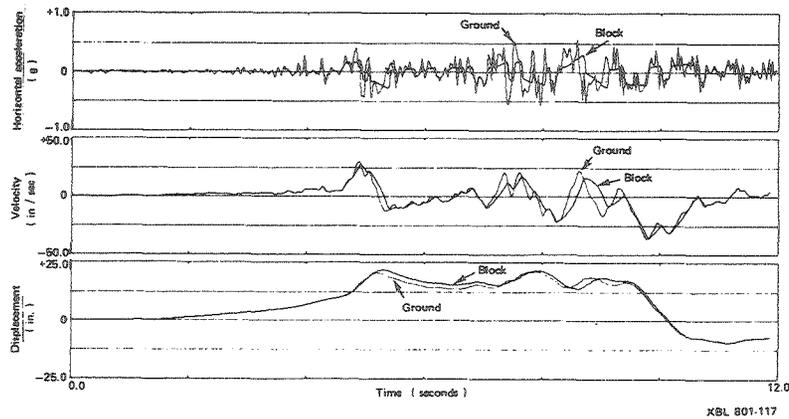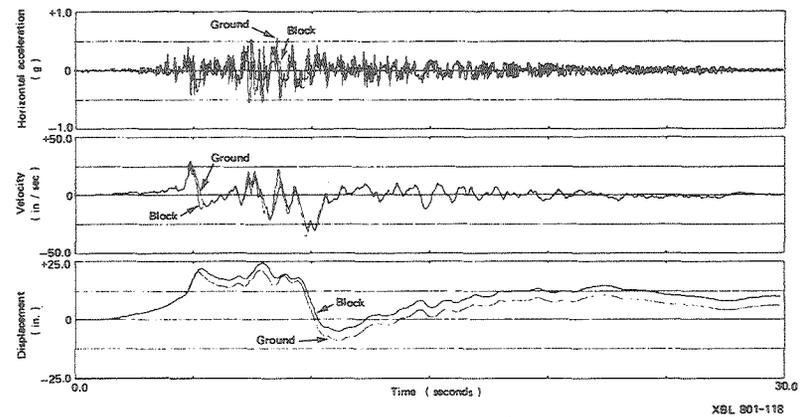Fig. 6. Motion of microscope foundation block
subjected to design earthquake [Bolt 2/15/79],
μ = 0.20, K = 0.058 W/in., W = 260 Kips.



Fig. 7. Enlargement of first 12 seconds of Fig. 6,
μ = 0.20, K = 0.058 W/in., W = 260 Kips.



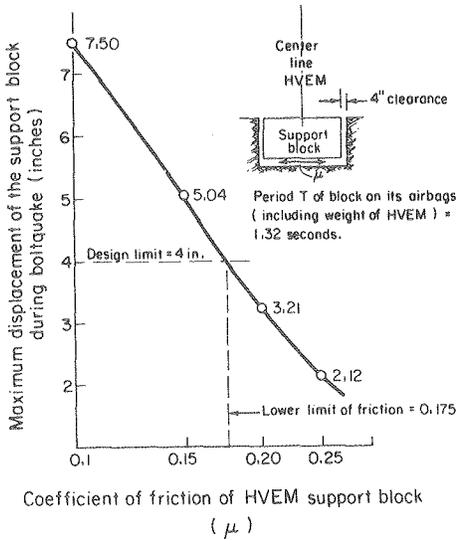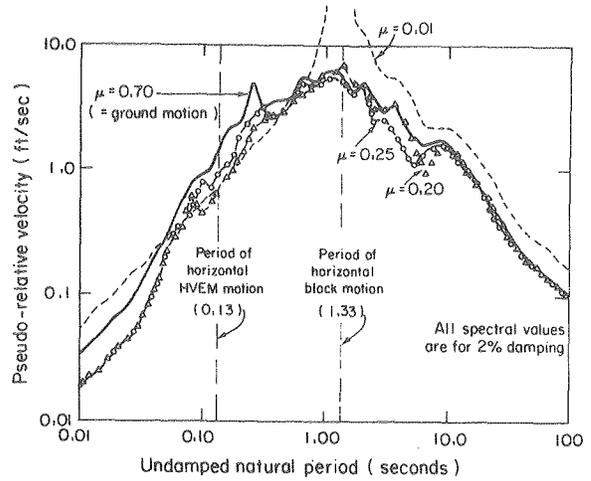Fig. 8. Motion of microscope foundation block
subjected to design earthquake [Bolt 2/15/79],
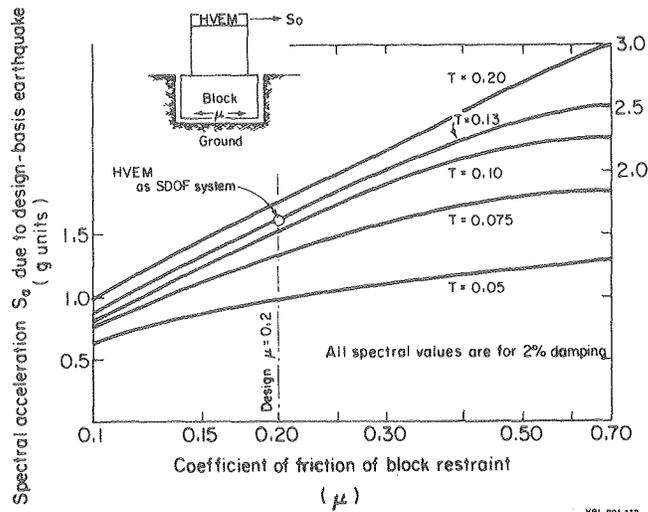μ = 0.20, K = 0.000 W/in., W = 260 Kips.

Fig. 9. Effect of friction on the maximum relative displacement of HVEM support block during design-basis earthquake.



Fig. 10. Effect of block friction on spectral response of block motion.



Fig. 11. Influence of block friction on spectral acceleration ($S_a$) response due to design-basis earthquake.