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Shock Evader™

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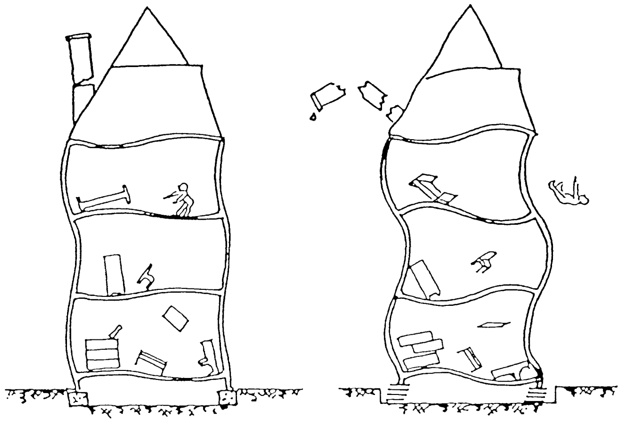
INTRODUCTION

The purpose of the work is a further development of the engineering concept of *seismic isolation*. The suggested isolation technique, called ***Shock Evader***, can be classified as an automatic passive control based on non-destructive softening ability of low friction sliding isolators of a special design. A working sample of the ***Shock Evader*** is continually demonstrated in action on the earthquake simulation platform at the California Museum of Science and Industry. The analytical investigation which has been performed for the NSF proves: *it is possible to break with damping dependancy* in the seismic isolation control technology.

MISTAKEN IDENTITY

Despite a wide variety of practical implementations, the common concept of seismic isolation is resting mostly on two pillars: flexible mounting and damping [1]. Unfortunately, the last one has nothing to do with the isolation proper. Still in 1975 Ray W. Clough and Joseph Pensien [2] had demonstrated that the damper's contribution into the process of isolation is negative. James M. Kelly [3] also admits that "damping can be viewed as a contaminant of the isolation process". Regardless of a widespread belief in a magic power of seismic isolation, the true capacity of the existing damping-dependent isolation systems to mitigate the earthquake induced forces of inertia, according to the Uniform Building Code™ (1991) and its Regulations (Appendix Chapter 23, Division III), is revealed in Figure 1 [4] which provides a comparative visualization from the perspective of the International Conference of Building Officials.

However, a mere lessening the damping ability of a bearing is none of a remedy: when frequency separation gets unsufficient, the damping's shielding contribution can become indispensable.



Conventional Structure per UBC　　*Seismically Isolated Structure per Regulations*

Figure 1: Comparison of design forces of inertia.

NEW APPROACH

An alternative can be found in the utmost lessening the damping and substituting its positive, mitigating quality with any sort of tuning-out mechanism that meets the following requirements:

1. Let the earth move its way.
2. Prevent resonant amplifications.
3. Restore the superstructure in its correct position on the foundation.

An example of seismic isolation meeting those requirements was described in [4, 5, 6, 7 and 8]. A new concept, first embodied in ***Shock Evader*** or, which is the same, in the Antifriction and Multi-Step Base Isolation (AF&MS BI) unit, incorporates the merits of traditional flexible mounting but without compulsory heavy damping mechanism. ***Shock Evader*** consists (Figure 2) of a ball transfer unit (1) supporting a superstructure (2) and resting on a depression (3) of a pedestal plate (4). The depression is shaped in comliance with the configuration of the contacting surface of the ball and is centered at the lowest point of the pedestal plate that has a concave upper surface (5) and rests on a foundation (6). The depth of the depression at given radius of the ball is governed by the weight of the superstructure and by the design wind load. The force of gravity will keep the

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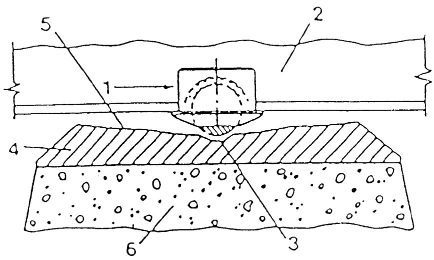

Figure 2: **Shock Evader**^{tm}.

position on the pedestal plate both at any wind or minor earthquake. When the magnitude of the earth movement exceeds a certain treshold, the ball rolls away from the depression and the transfer of horizontal loads on the superstructure considerably decreases.

To confine the base shear by an acceptable level, the upper surface of the pedestal plate is shaped as a combination of some spherical surfaces with successively increasing radii of curvature which are continuously transforming into each other. The maximum vertical grade of every component surface is pre-determined in compliance with the sliding friction of the ball transfer unit and with allowable base shear. Such design provides a multi-step non-destructive softening the system that protects it against resonant amplifications.

The system works like a sort of a *sliding pendulum*. Its pushing mechanism consists of two major components: a velocity-related force (friction force) and a force of rigidity which depends on the vertical curvature of the sliding surface. While designing a seismic isolator, its friction characteristic is of primary importance. It controls the corresponding radius of curvature R to satisfy the following controversial criteria:

a) To be as big as possible to provide a better frequency separation.

b) To be as small as to create the necessary steepness of the sliding slope in order to secure returning the superstructure to its initial position.

Lateral load-deflection curves for different embodiments of ***Shock Evader*** can be easily obtained without any tests: this technology makes it possible to create isolators with preset properties by merely changing their working surface configuration. Another advantage of ***Shock Evader*** in comparison with any type of shear bearings (elastomeric, for example) is the absence of alternating, eccentrically applied vertical reactions that can excite damaging flextural stress waves.

A working sample of ***Shock Evader*** has been continually exposed in action since May, 1992 on the earthquake simulating

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posed in action since May, 1992 on the earthquake simulating platform at the California Museum of Science and Industry (Los Angeles).

COMPUTER ANALYSIS

On basis of a global mathematical model including the superstructure, isolation system and mechanism of the ground input, the Step-by-Step method [2] as the only completely general approach to non-linear analysis is employed. It avoids any modal superposition and is described in [4] where the superstructure is treated as a multi-degree-of-freedom linear shearing system, and the isolators as single-degree-of-freedom non-linear ones. Earthquake input can be executed in two ways:

a) Real time-history.

b) Imitational regime **Cone**tm per [9].

Application of **Cone**tm does not leave any chances for missing a single hazardous frequency: all natural periods of vibration between T_o and T_* (in this research it was assumed that T_o = 0.03 sec and T_* = 2.0 sec) are rung up in the state of transient resonance. Besides, you have no need to filter "wrong" frequencies [2, 10], and any moment of time here is associated with a definite instantaneous period of excitation which is a real advantage while interpreting various responses vs time. In all computational experiments of the current research the duration of ground shaking was taken the same: t_* = 15 sec but the maximum velocity was of three different levels: $(\dot{u}_g)_{max}$ = 20, 40 and 80 cm/sec.

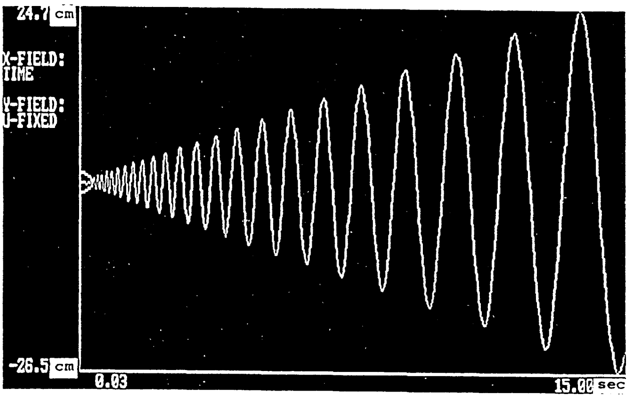

Figure3: Imitational regime **Cone**tm.

The following format of experiments was accepted in the research:

1) Six different systems are compared simultaneously in each experiment, namely: **Fixed** ("zero" isolation), **AF&MS** (Shock Evader^{tm} or AF&MS BI *without* a central depression) **AF&MS/CD** (Shock Evader^{tm} or AF&MS BI *with* a central depression), **Sliding** (visualized here as a gravitational pendulum system but actually representing any sliding model with a permanet rigidity), **Shear-vis** (Shearing type isolation incorporating a linear viscous damping mechanism) and **Shear-hys** (Shearing type isolation with a hysteretic damping mechanism).

2) Three versions of story numbers can be viewed simultaneously in any experiment: **one**-storied, **four**-storied and **eight**-storied structures with the same interstory heights and rigidities.

3) The Standard Case is chosen which includes the Standard Isolation Systems and the Standard Input.

4) Two sorts of deviations from the Standard Case are investigated: deviation of input intensity and deviation of parameters associated with velocity-related resistance ("damping" parameters).

5) Time-histories and response spectra for secondary systems (building contents) are also available for any story and any type of isolation devices.

Parameters, defining rigidities and damping coefficients of compared isolators, have the following values:

Shock Evader^{tm} (AF&MS and AF&MS/CD):

$$K_o = W/R \quad \text{and} \quad C_o = fW\,|\dot{v}_o|^{-1},$$

where W = weight of the superstructure per one isolation unit;

R = radii of vertical curvature. For the Standard Case R_1 = 100 cm, R_2 = 200 cm, R_3 = 400 cm and R_4 = 800 cm;

f = friction coefficient. For the Standard Case f = 0.025;

v_o = relative displacement of the isolator.

Sliding:

$$K_o = W/R \quad and \quad C_o = fW\,|\dot{v}_o|^{-1},$$

where $R = 50$ cm and $f = 0.05$.

Shearing:

$$K_o = 69.7 \exp(-0.3\sqrt{v_o})M \quad \text{and}$$

$$C_o = 2\xi_o \omega m_o \qquad \text{for viscous damping,}$$

$$C_o = 2\xi_o K_o \left|v_o/\dot{v}_o\right| \qquad \text{for hysteretic damping,}$$

where M = mass of the superstructure,

ξ_o = damping ratio,

ω = instantaneous frequency of excitation,

m_o = mass of ground floor,

$\dot{v}_o$ = relative velocity of the isolator.

Superstructures are assumed to be linear for all systems of isolation, with interstory rigidities

$$k = 1500m$$

and damping coefficient

$$c = 1.233m$$

where m = mass of a floor.

Data presented in Figure 4 demonstrate that antifriction approach incorporated in the seismic isolation systems **Shock Evader**tm (AF&MS and AF&MS/CD) yields essentially better mitigating effect than that of conventional sliding or shearing isolation systems. All three investigated structures survive Standard Earthquake, performing *mostly elastically* if mounted on **Shock Evader**tm.

There is an evidence in Report [4] that the investigated buildings on isolators **Shock Evader**tm can easily live through each of the three levels of earthquake intensity while the 8-story structures on other types of isolators, as well as the fixed ones, will eventually collapse at a Superstandard Earthquake. Computational experiments with damping deviation prove: the less friction coefficient, the better performance of the structures mounted on isolators **Shock Evader**tm. The records from [4] also reveal that only museum artifacts resting on **Shock Evader**tm are on the safe side (0.21g and 0.24g), all others promise nothing but desperately large values: 9.13g, 5.56g and 8.66g (that of the **Fixed** system equels only 3.52g).

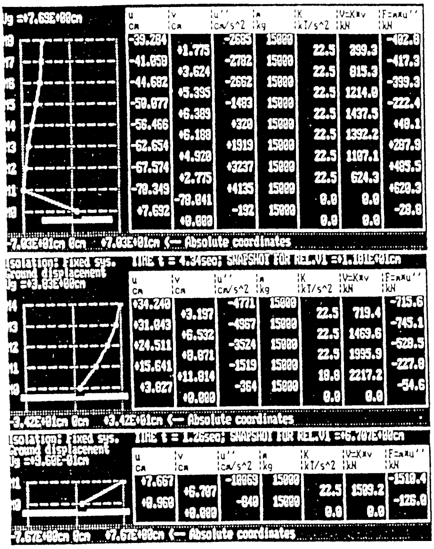

Figure 4-1: **Fixed** systems.

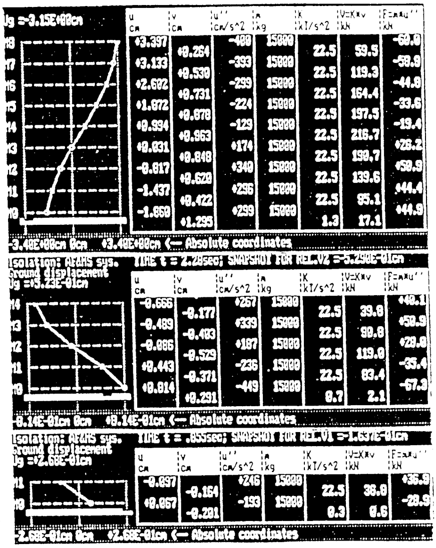

Figure 4-2: **AF&MS** systems.

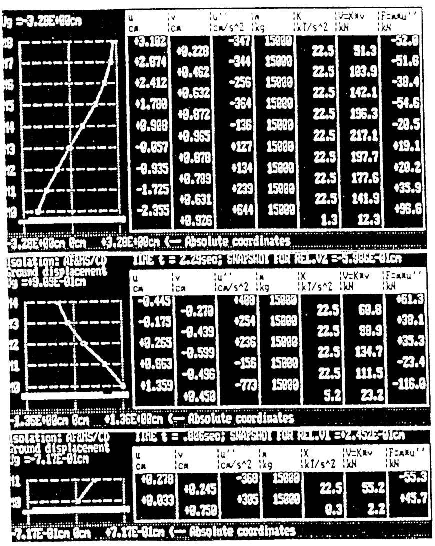

Figure 4-3: **AF&MS/CD** systems.

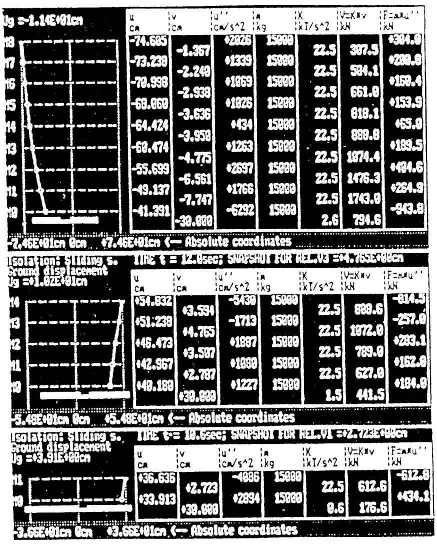

Figure 4-4: **Sliding** systems

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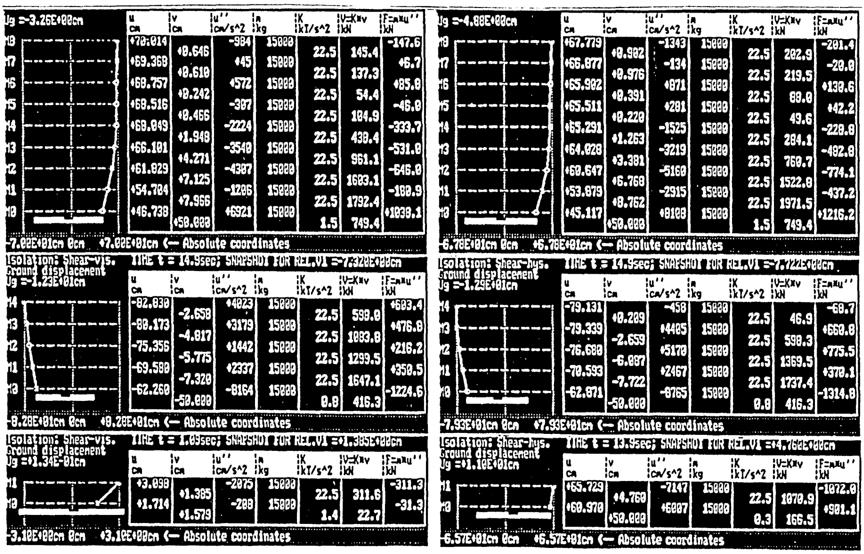

CONCLUSIONS

Analytical investigation proves: *damping-free approach works*. None of the damping-dependent isolation systems can render protection effectiveness even close to that of the antifriction and multi-step softening technology incorporated in **Shock Evader**™. This is true both for structural elements and contents, and at any magnitude of the earth shaking.

ACKNOWLEDGEMENTS

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