A NOTE ON THE NON-INCLUSION OF HDNR BY USNRC.

by

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Statement of NRC

A draft report has been issued by the US Nuclear Regulatory Commission entitled "Technical Considerations for Seismic Isolation of Nuclear Facilities" for consideration by interested parties. The report has been prepared by NRC and MCEER. It sets out to describe different types of isolators and to make recommendations.

4.2.3 Properties of High Damping Rubber Bearings.

High damping rubber (HDR) bearings use natural rubber with additives (or fillers) as the elastomer. These additives modify the mechanical characteristics of the rubber, including its hardness, stiffness, damping, elongation-at-break, creep and relaxation properties. The most important consequence of adding these fillers is the increase in damping of the elastomer. HDR bearings have damping ratios greater than 7% of critical, with some bearings having as much as 13% damping. [..] <u>As noted earlier, due to scragging and unpredictable changes in properties over time, HDR bearings are not considered appropriate for use in NPPs, but are discussed here for completeness.</u>

It is the purpose of this short note to take issue with the exclusion of High Damping Natural Rubber (HDNR) bearings for consideration as isolators for NPPs.

The reason given for not including HDNR is that the scragging of bearings before installation leads to an uncertainty in the behavior of the bearing. This is based on observations of very high damping compounds developed by Bridgestone in Japan which use various oils and resins to achieve the high damping response. Other compounds with lower levels of damping have much less variation of response due to scragging.

Due to the very conservative seismic isolation code which must be used for all seismic isolated buildings in the United States seismic isolation is flourishing in other countries but it is underused in the USA. It is probable that this conservatism has influenced the engineers who advised the USNRC. The compounding of the conservatism of the US structural engineers with the conservatism inherent in nuclear applications could lead to this valuable technology being avoided for nuclear.

For static analysis and for the selection of time histories for dynamic analysis, the US code spectrum is constant-velocity for periods of one second and longer, leading to large displacements for long period systems and forcing the designer to use added damping to reduce these displacements. The damping systems used are hysteretic with the characteristic that damping decreases with increasing displacement. To achieve the damping needed to reduce these large displacements, from very rare events, means that at smaller displacements, caused by realistic levels of input, the damping will be very much higher with stiffening of the isolation system, meaning that the building may not act as isolated and there will be an impact on sensitive internal equipment. It is the intention of this note to show that highly damped isolation systems are counterproductive to isolation.

Theoretical Basis of Seismic Isolation

We know that if $\varepsilon = \omega_b^2 / \omega_s^2$ is in the range 0.10 to 0.01 then:

- Response is only in the first mode.
- Participation factor of higher modes is zero.
- Effective modal mass of first mode is the total mass.
- These results are independent of damping, isolation works not by absorbing energy but by excluding it through the dynamics of the isolation process.

We also know that if damping is > 15% then energy is transmitted to higher modes causing floor accelerations and inter-story drift.

Comparisons of HDNR and LRB and FPS

- The uncertainties in the behavior of HDNR bearings are much less than those in Lead Rubber Bearings (LRB) and Friction Pendulum (FPS) bearings.
- The essential issue is self-generated heat.
- The larger the isolator the more critical the heat problem becomes.
- Both LRB and FPS bearings dissipate large quantities of energy within a small volume of the bearing.
- In the LRB the dissipation is in the lead plug itself. The dissipated energy manifests itself in heat which accumulates in the plug thus softening the lead. The lead is not a good conductor of heat. The lead is in contact with the potential heat sink of the steel plates only across the very thin edges of the shims which are generally about 3 mm. in thickness.
- Conduction into the plates is negligible and radiation is impossible. The change in the yield stress of the lead due to this heat is largely unpredictable.

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Comparisons of HDNR and LRB and FPS, Contd.

- In the FPS bearings the energy dissipation is on the sliding surface and can generate very high surface temperatures. The stainless steel and Teflon are not good conductors of heat and a large part of the surface is covered by the articulated slider which prevents radiation. The consequences of these high surface temperatures on the friction, wear and surface stability are very uncertain.
- In contrast, in the HDNR bearings the energy dissipation is produced throughout the whole volume meaning that there is less temperature rise for the same amount of energy dissipation and the rubber is in contact with the potential heat sink of the steel plates over the entire surface of the steel.
- The result is that the behavior of the moderately damped HDNR is much less uncertain than for the other types of isolation systems.

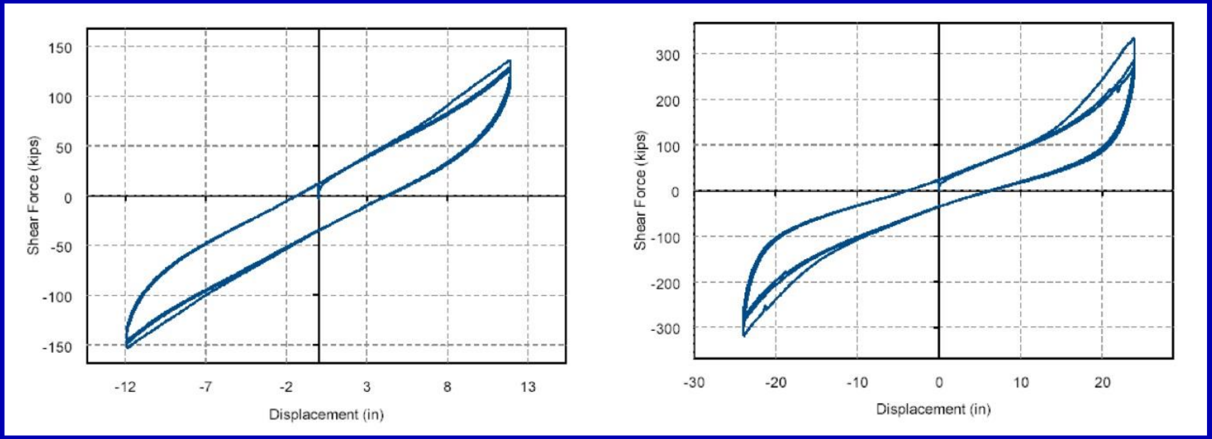
PROPOSAL FOR A SYSTEM USING CRYSTALLIZING HDNR RUBBER

The proposed system is a natural rubber bearing **system** that up to a certain level of displacement is linear with low damping. The intent is to design a system that will permit full isolation for sensitive internal equipment at moderate levels of seismic input. The control of displacements at high levels of input is to be achieved by exploiting a property of natural rubber known as strain-induced crystallization. This phenomenon has been known for a long time and has been extensively studied for the behavior of thin sheets of rubber in tension. It is the reason for the inherent toughness of rubber in tension. It has been less well studied for rubber in shear, but many natural rubber compounds will crystallize at some level of shear strain depending on the compounding and the amount of filler; it can range from 100% or higher but most natural rubber compounds will show the beginning of crystallization for shear strains around 200%. The next slide shows typical hysteretic loops of an Andre (Silvertown UK Ltd.) natural (crystallizing) rubber bearing tested to 110% shear strain (left) and 222% shear strain (right). The bearing exhibits a linear elastic behavior up to approximately 100% shear (12 in. displacement), after which it stiffens up. It should be noted that the compound used in the LPS bearings is selected by manufacturers so as not to stiffen at displacements smaller than those corresponding to the MCE level.

PROPOSAL FOR A SYSTEM USING CRYSTALLIZING HDNR RUBBER, CONTD.

- While it is possible to develop natural rubber compounds that have essentially no damping in the linear range, it is actually easier to use compounds that have moderate levels of damping, e.g., equivalent linear viscous damping around 5% to 8%. For example, the equivalent linear viscous damping ratio of the CRS in the hysteresis loops in the figure is 8.6% at 110% shear strain (left) and 8.4% at 222% shear strain (right). Lower or higher amounts of damping can be obtained by modifying the rubber compound. Another aspect of this crystallization process is that, in addition to stiffening, it leads to a large increase in energy dissipation in the rubber. This can be seen on the right figure where the hysteretic loops become fatter once the rubber starts to stiffen. A system using these characteristics can combine low transmission of energy to equipment items at low and moderate seismic input and displacement control for large and beyond design basis input.

. Hysteretic loops of typical CRS tested at 110% shear strain (left) and 222% shear strain (right).



NUMERICAL SIMULATION OF THE EFFECTS OF DAMPING IN ISOLATION

- While the focus in this is on the effects of non-linear hysteretic isolation systems it is useful to first consider the effect of linear damping on a linear isolation system. The emphasis in all the numerical studies will be on the floor acceleration response expressed through the floor response spectrum as a way of showing its effects on equipment items. We do not emphasize the bearing displacement since it probable that for nuclear power plant application the isolators will be large and the controlling factor for displacement is the relationship between the isolator size and the isolator displacement. Also the base shear of the superstructure is not likely to be a problem for the NPP,s which are bound to be robust. The main problem is internal equipment and piping.

- To study the effects of isolator damping both linear and hysteretic we use the simple 2-DOF model and develop a suite of earthquake records for the numerical simulation.

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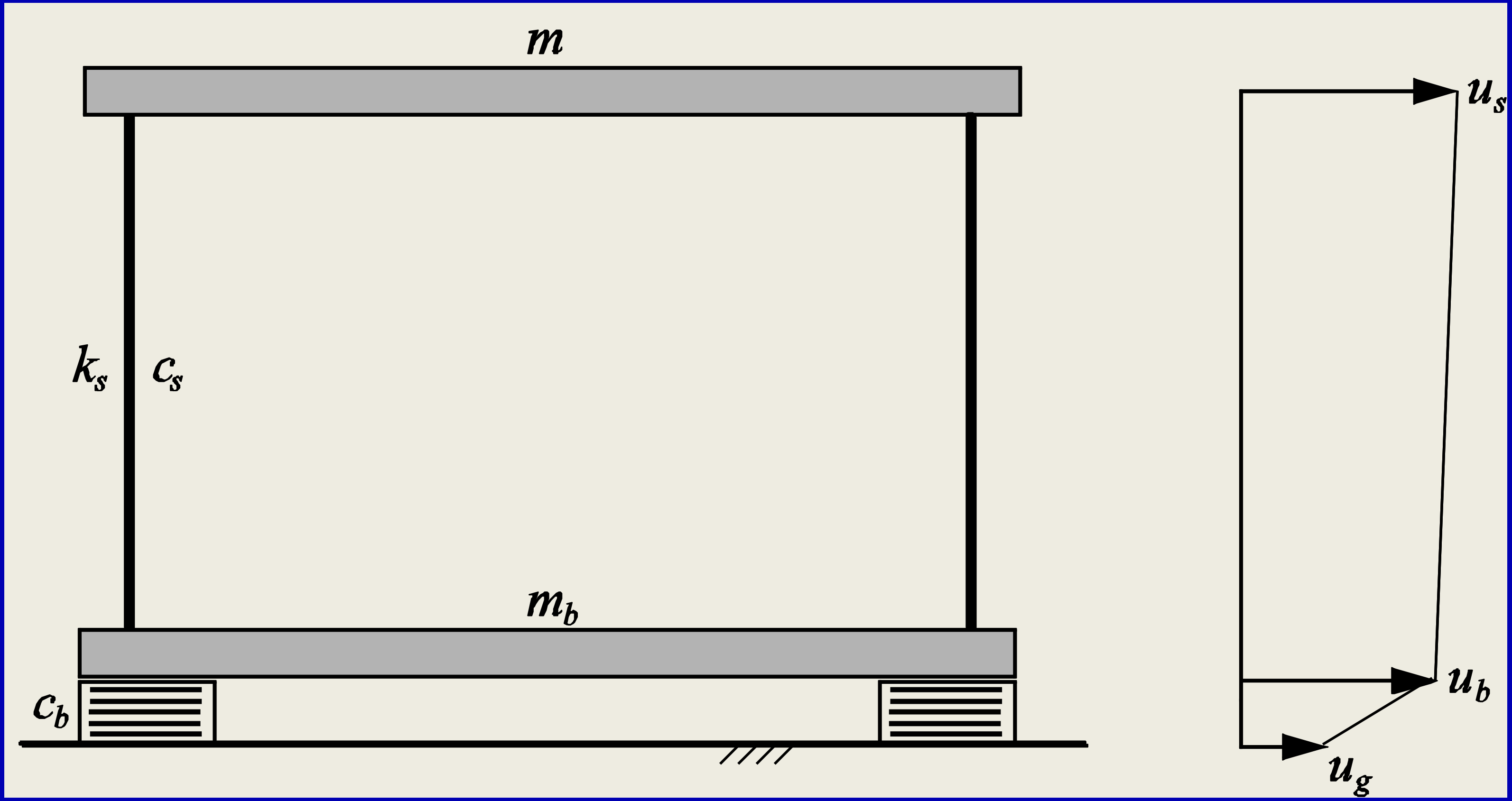
Two-degree-of-freedom isolated system on which analysis for floor acceleration was based



SELECTION AND SCALING OF THE GROUND MOTIONS

This study examines the floor acceleration response of a seismic-isolated building subjected to earthquake motions from three seismic hazard levels:

(1) Maximum Considered Earthquake (MCE): Very rare earthquakes;

(2) Design Based Earthquake (DBE): Rare earthquakes;

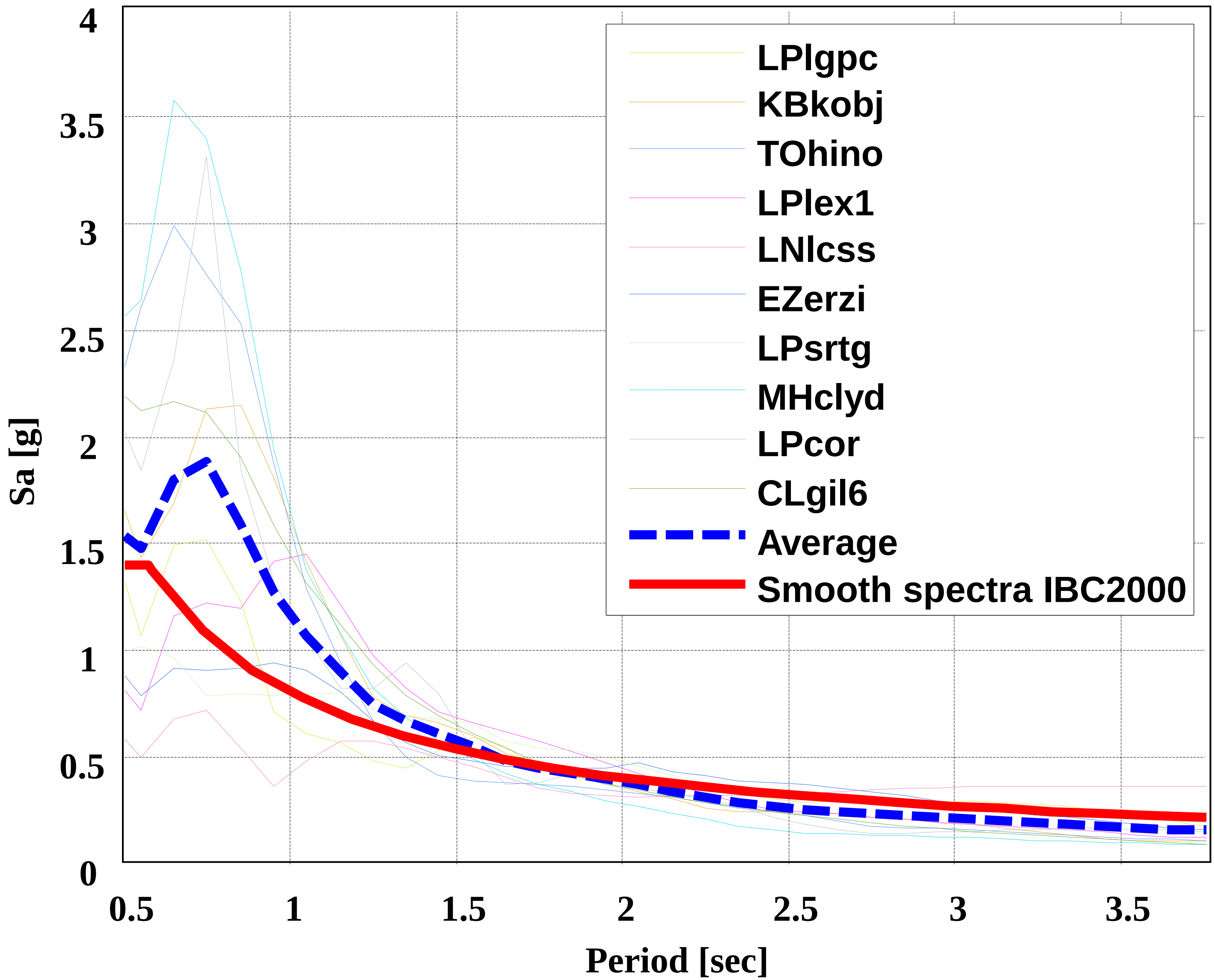
(3) Service Level Earthquake (SLE): Moderate earthquake events that are more likely to occur over the lifetime of the building. The spectral acceleration of SLE is chosen by the authors to be 1/2 of DBE. This is not intended to represent any particular return period or probability of occurrence but merely to be the basis for an assessment of the impact of damping on the floor accelerations and interstory drifts at earthquake levels below those of the code.

Suites of ground motions

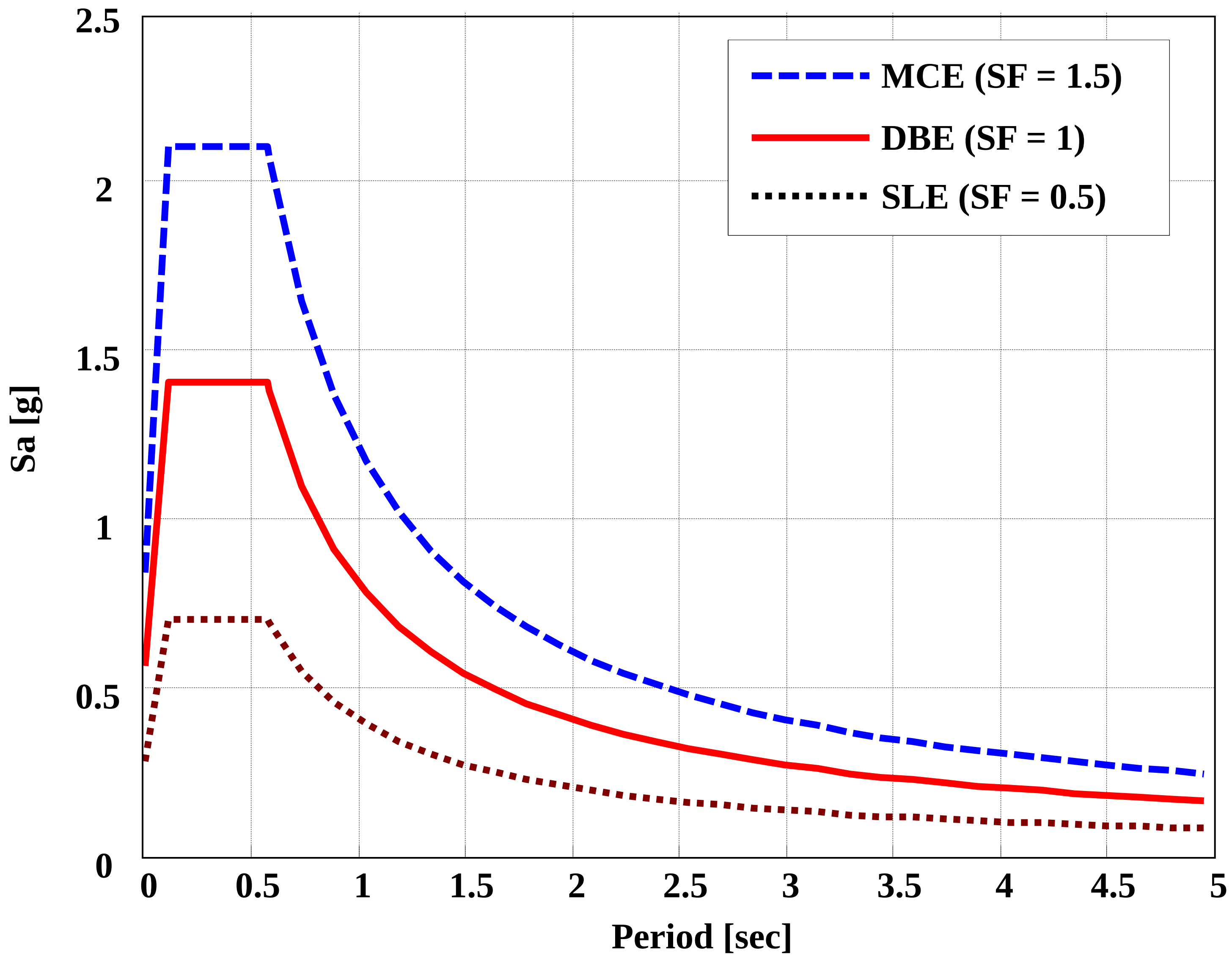
Seismic hazard level: 10% in 50 years

Earthquake	Mw	Station	Distance	Site	Record
Loma Prieta, 1989/10/17	7.0	Los Gatos Present Center	3.5	C	LP_lgpc
		Saratoga Aloha Ave	8.3	C	LP_srtg
		Corralitos	3.4	C	LP_cor
		Gavilan College	9.5	C	LP_gav
		Gilroy Historic Building		C	LP_gilb
		Lexington Dam Abutment	6.3	C	LP_lex1
Kobe, Japan 1995/1/17	6.9	Kobe JM A	4.4	C	KB_kobj
Tottori, Japan 2000/10/6	6.6	Hino	1	C	TO_hino
Erzincan, Turkey 1992/3/13	6.7	Erzincan	1.8	C*	EZ_erzi

Ground motions used in this analysis



Scaling of the ground motions: three levels of input

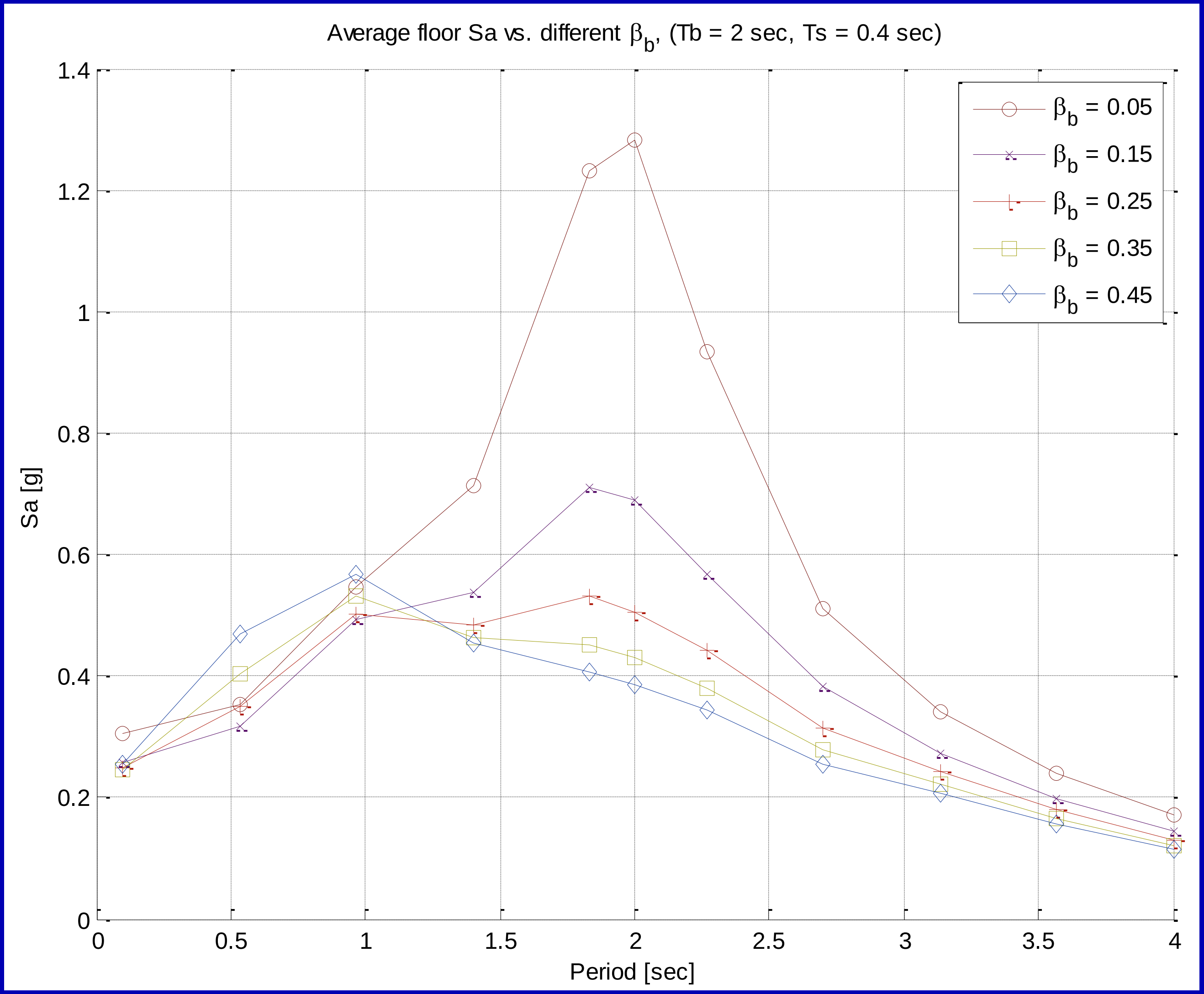


NUMERICAL ANALYSIS OF THE EFFECTS OF LINEAR DAMPING IN A LINEAR ISOLATION SYSTEM

- Before looking at the response of the isolated structure with hysteretic damping let us look first at effect of linear damping on a linear isolation system.
- To do this we apply all ten records at DBE levels to the 2-DOF model and calculate the response spectrum of the upper level accelerations (the floor response spectrum) and average them over the full suite of records.
- We set the isolation period at 2,3,4,5 seconds and the superstructure period at 0.4 seconds.

- What is interesting is:
- 1. The floor spectra shows a peak at the isolation period. This is expected. Because the floor acceleration is filtered through the first mode of the structure.
- 2. By adding damping at the isolation level , the floor spectra decreases around the isolation period, but increases at the short period range relevant to equipment.
- 3. The transition seems to be at around half the isolation period.

Influence of isolation damping on floor spectra



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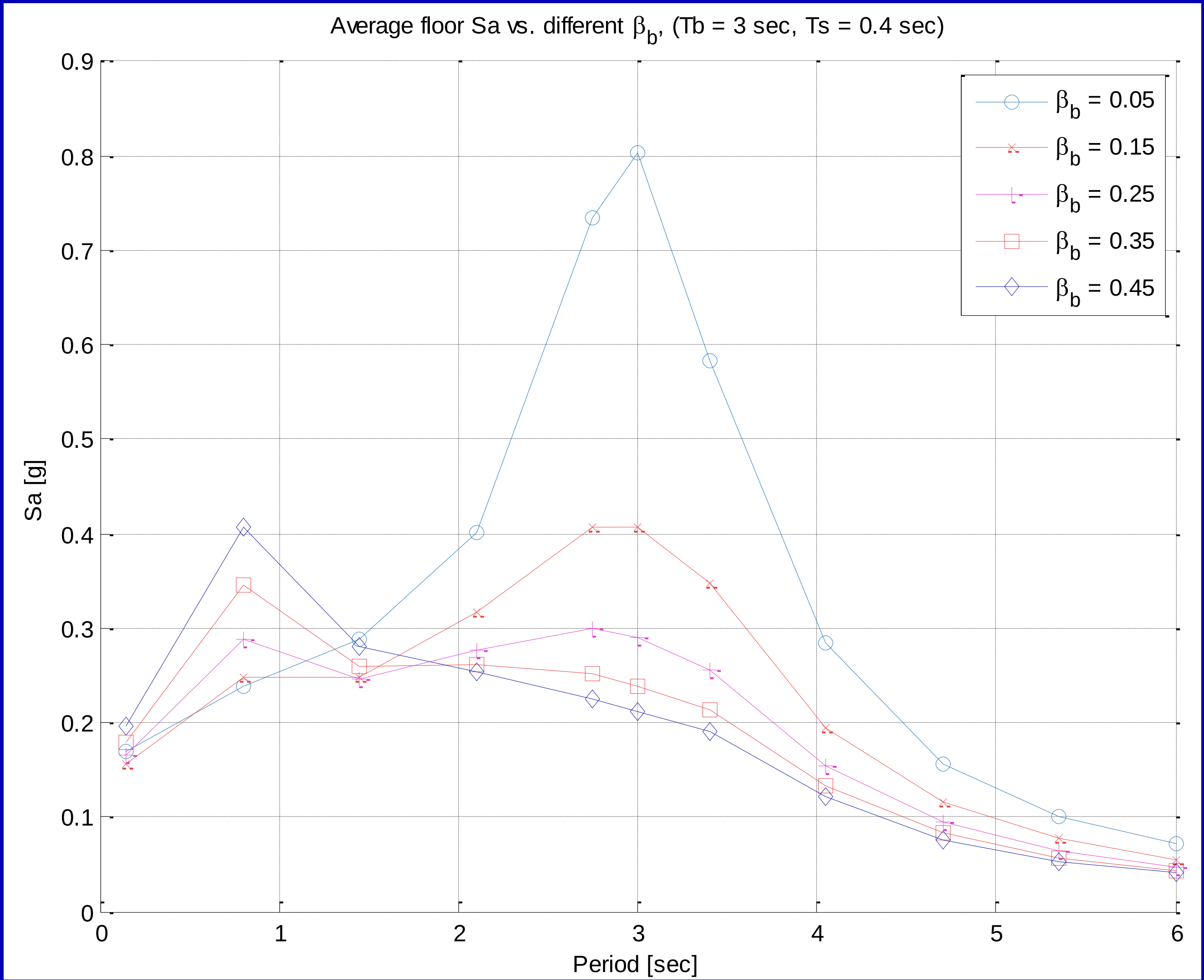

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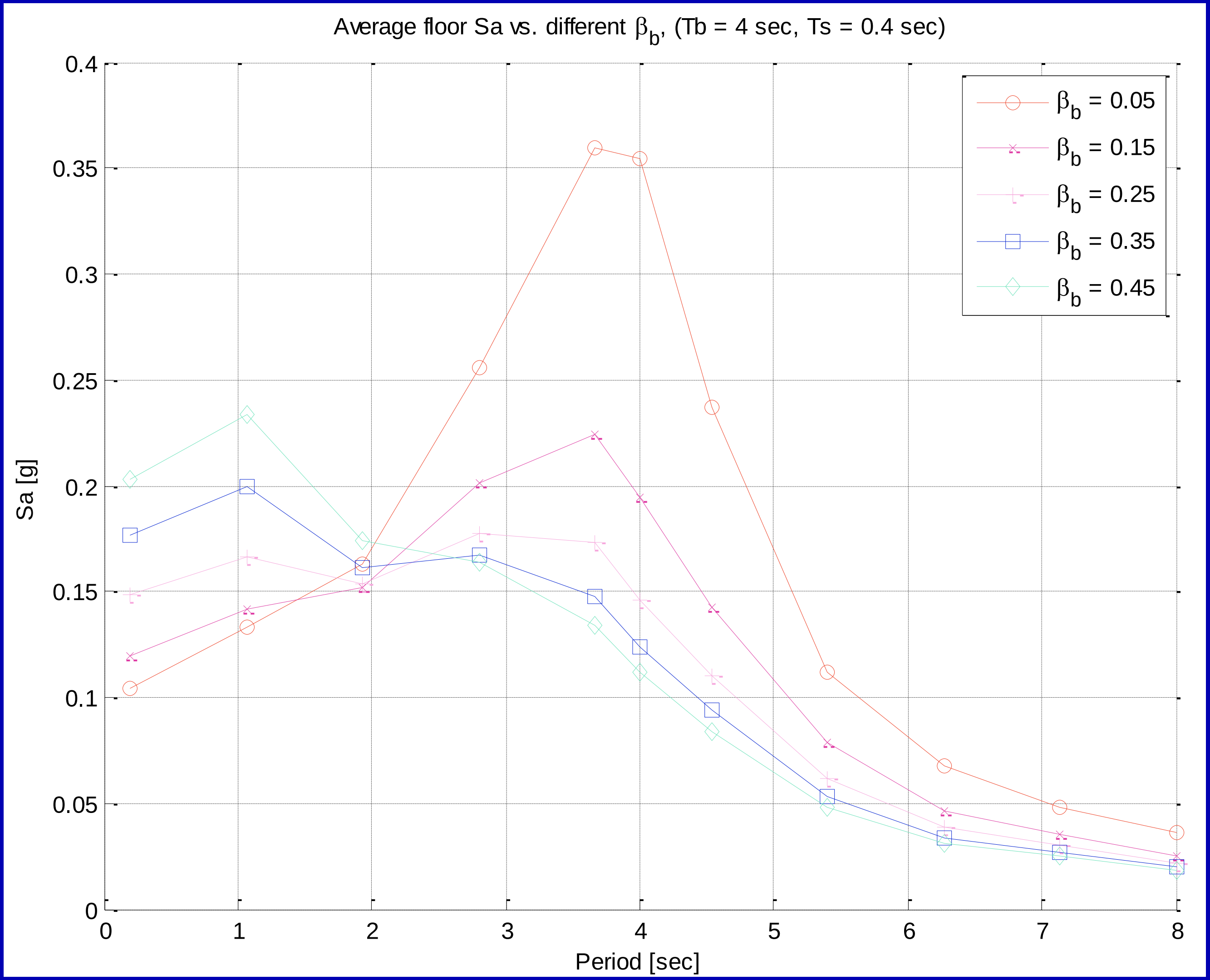

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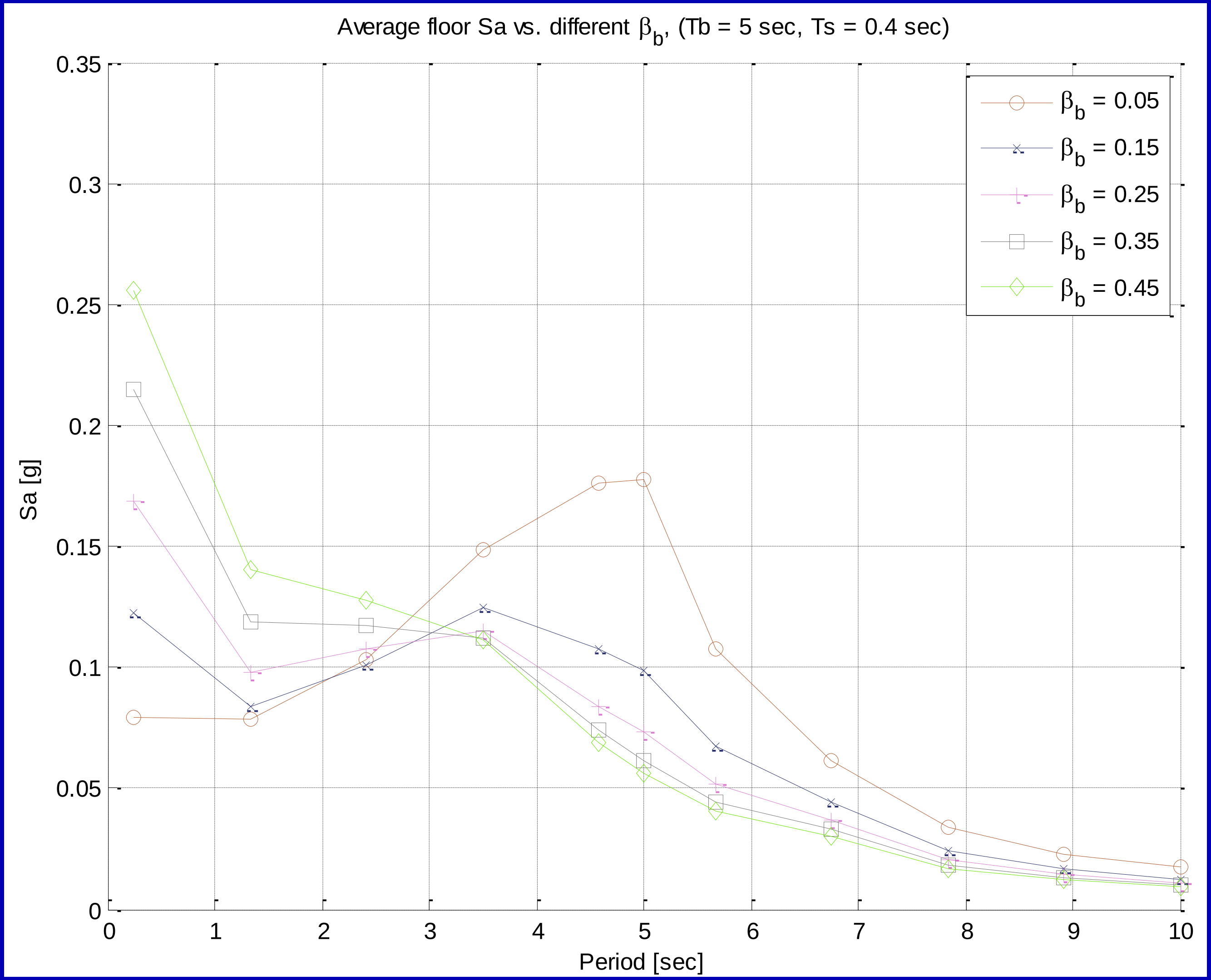
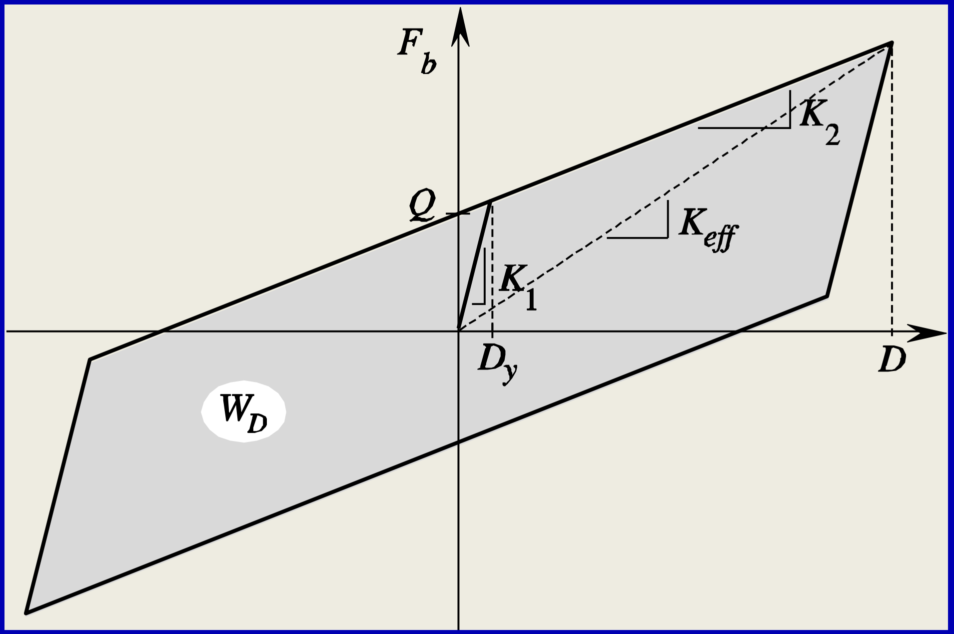
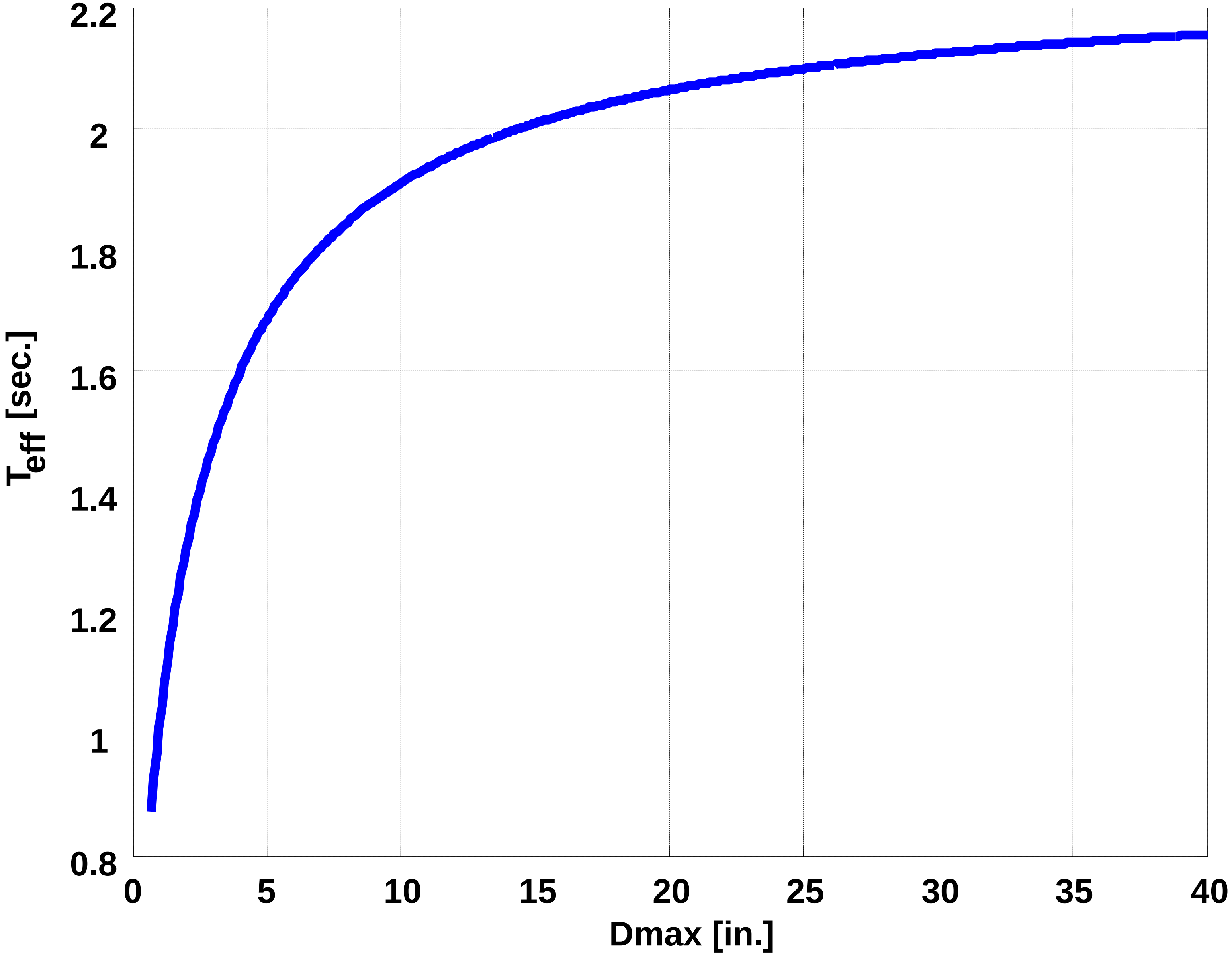


Bilinear hysteretic behavior of isolator.



Isolation Period as a Function of Displacement for an Isolation System based on the Bilinear Model.



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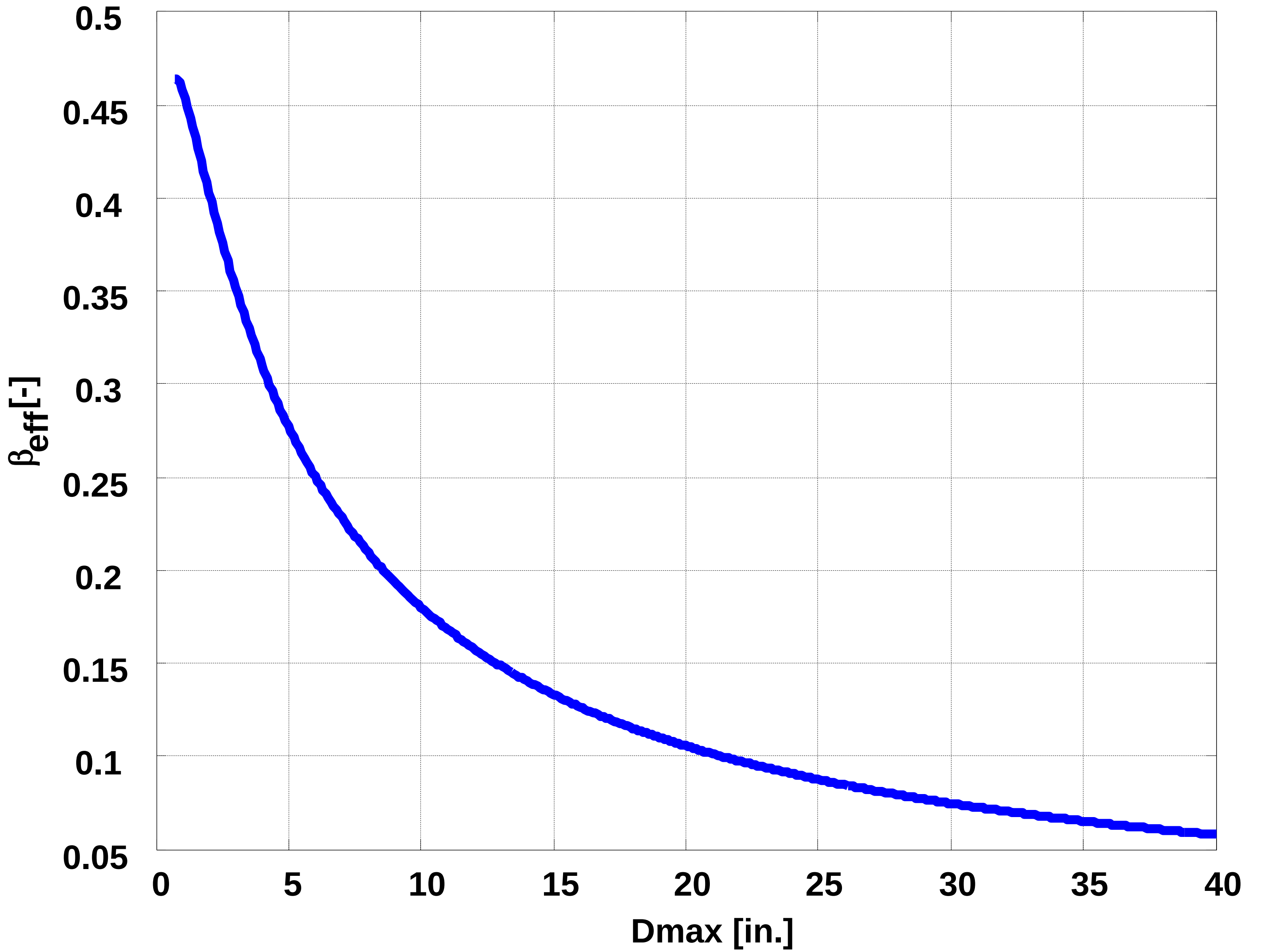
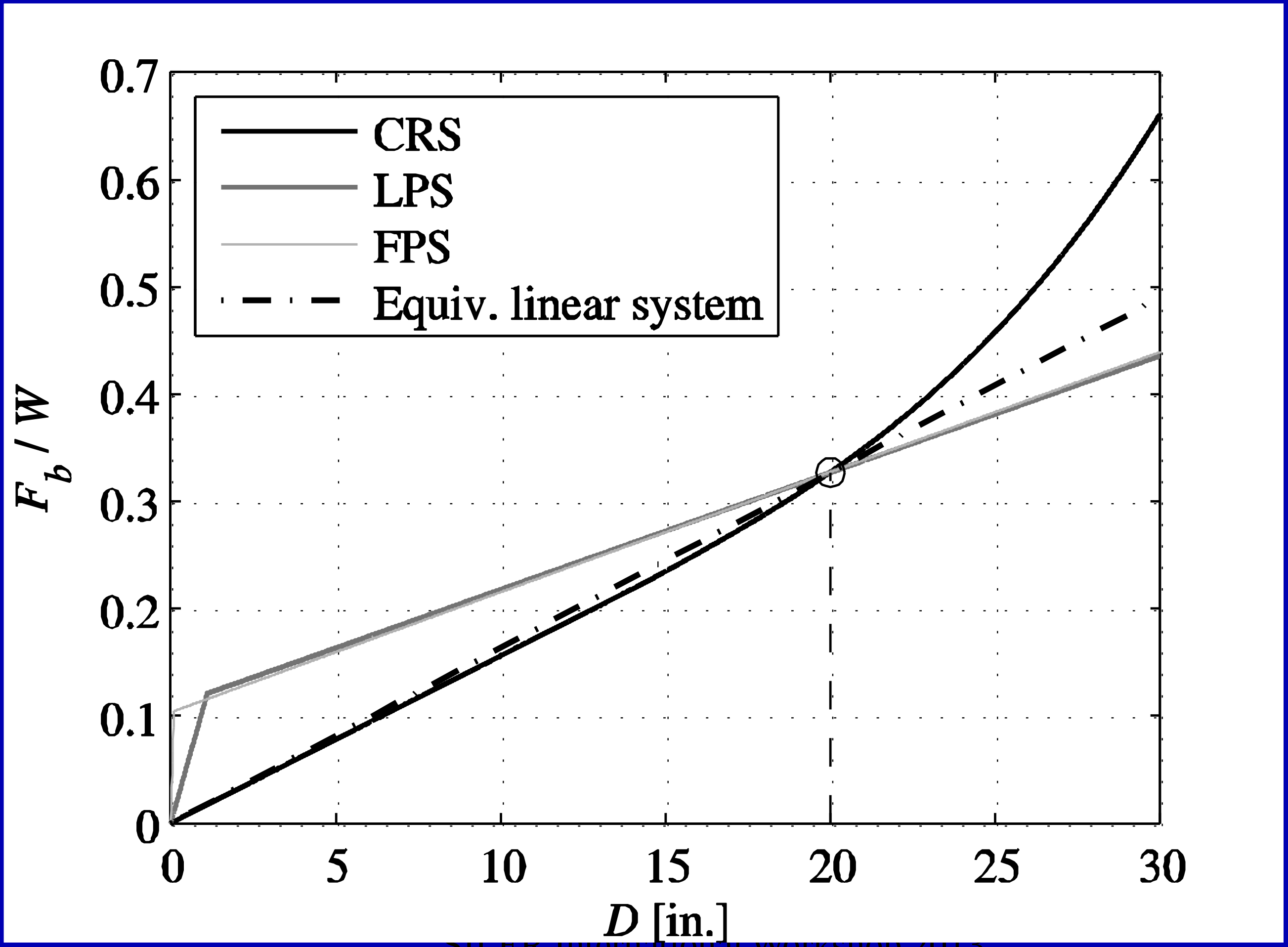
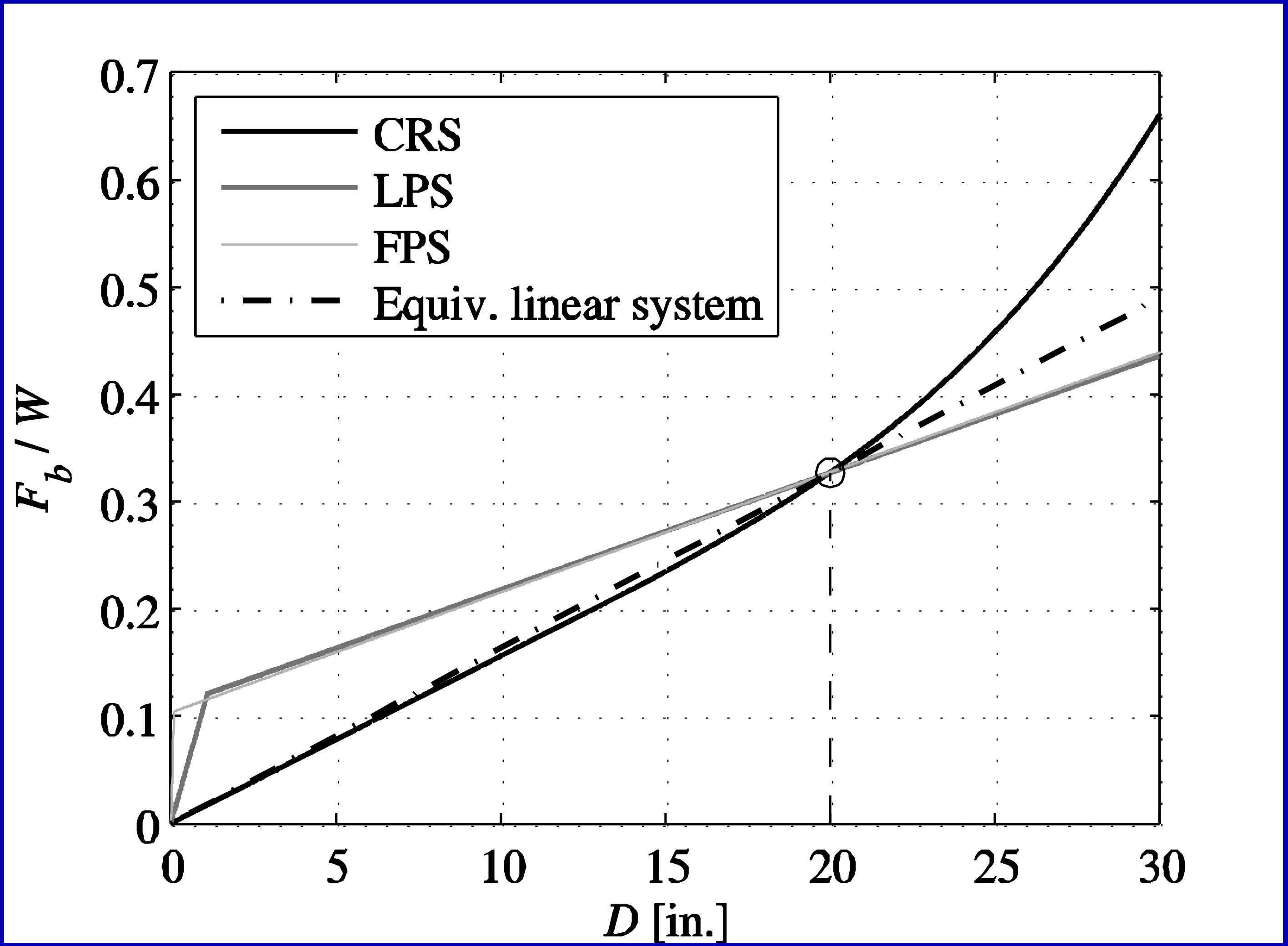


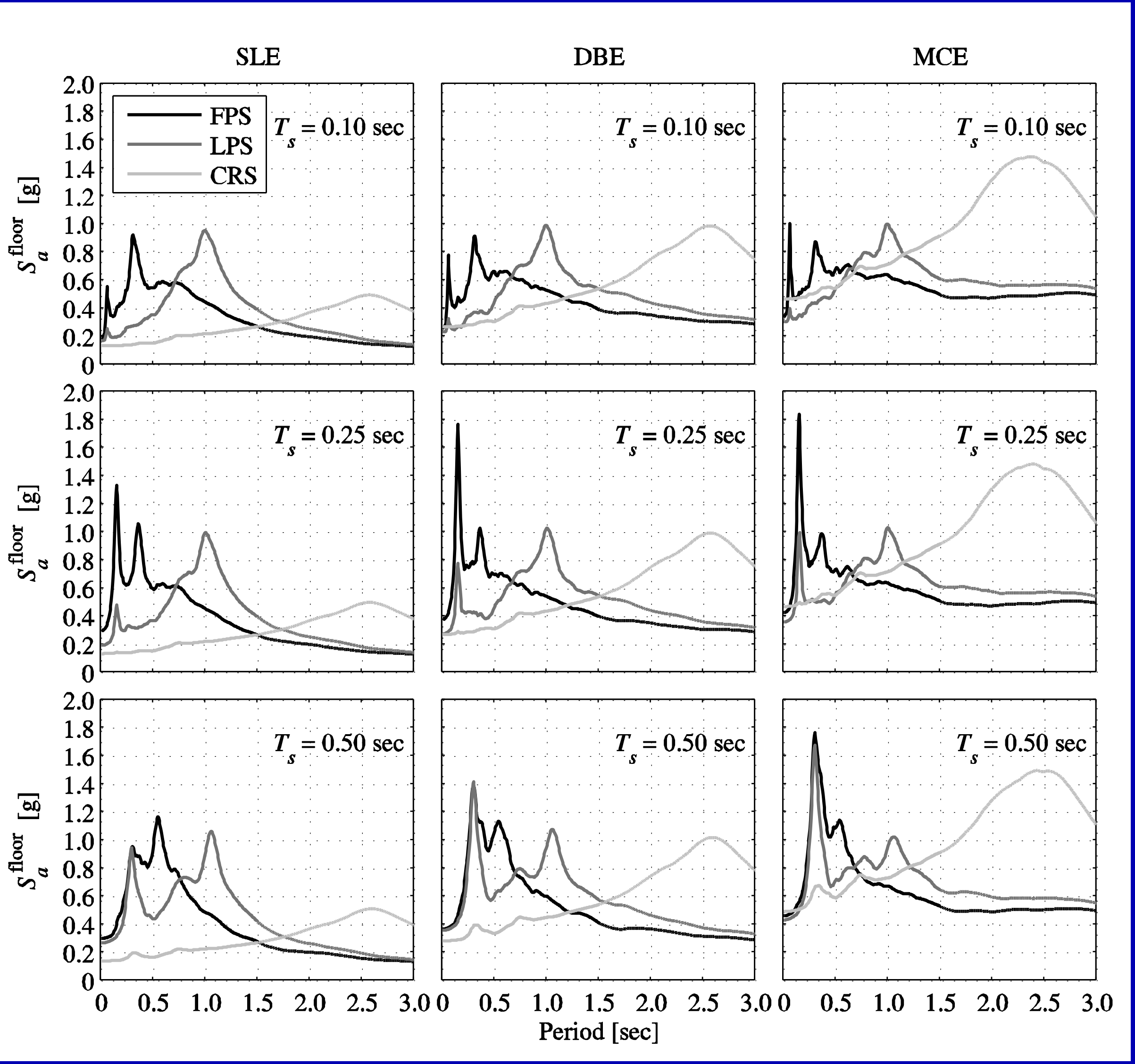
Load-displacement behavior of the different isolation systems and the equivalent linear system.



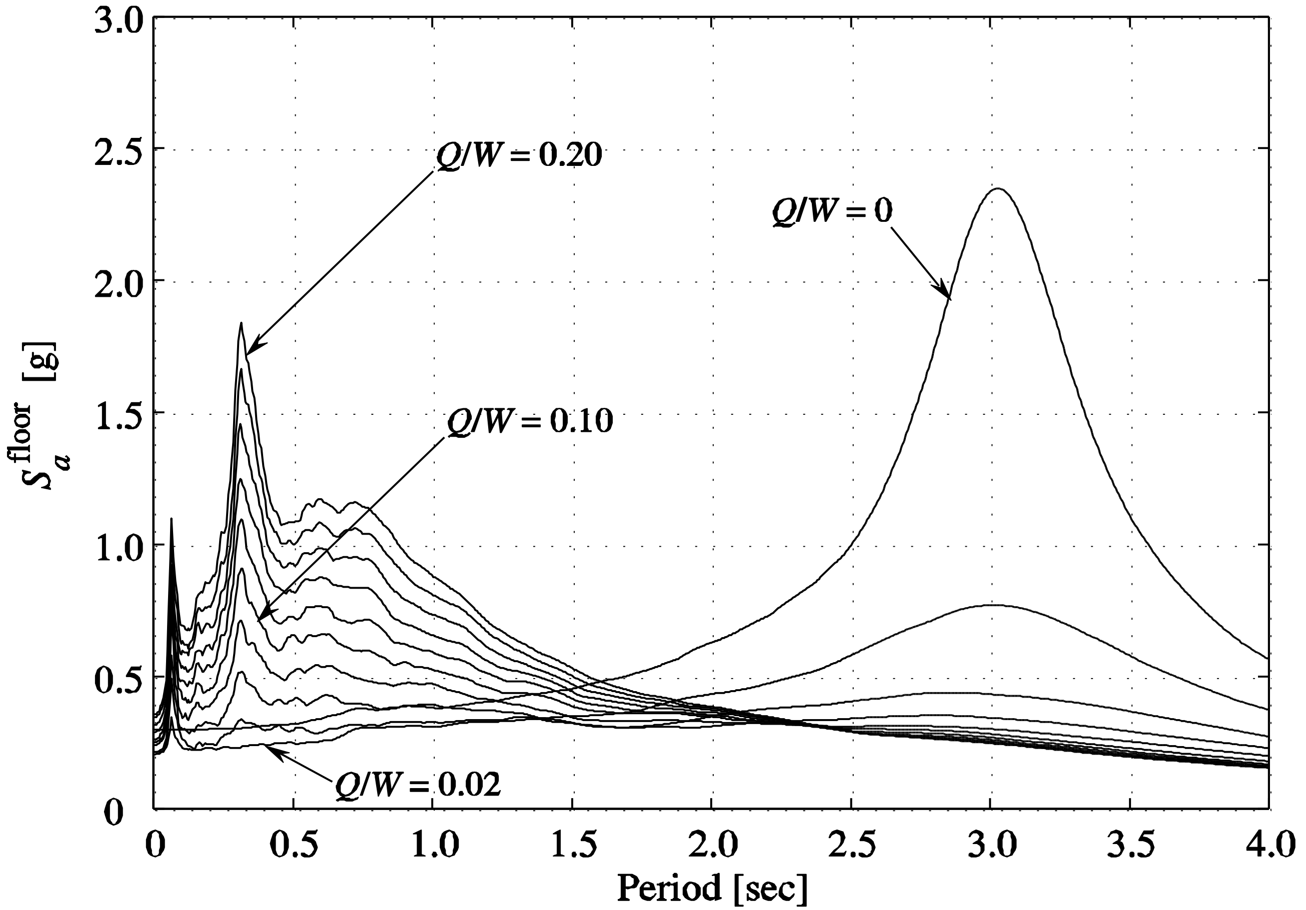
Load-displacement behavior of the different isolation systems and the equivalent linear system. All systems scaled to 20 inches displacement



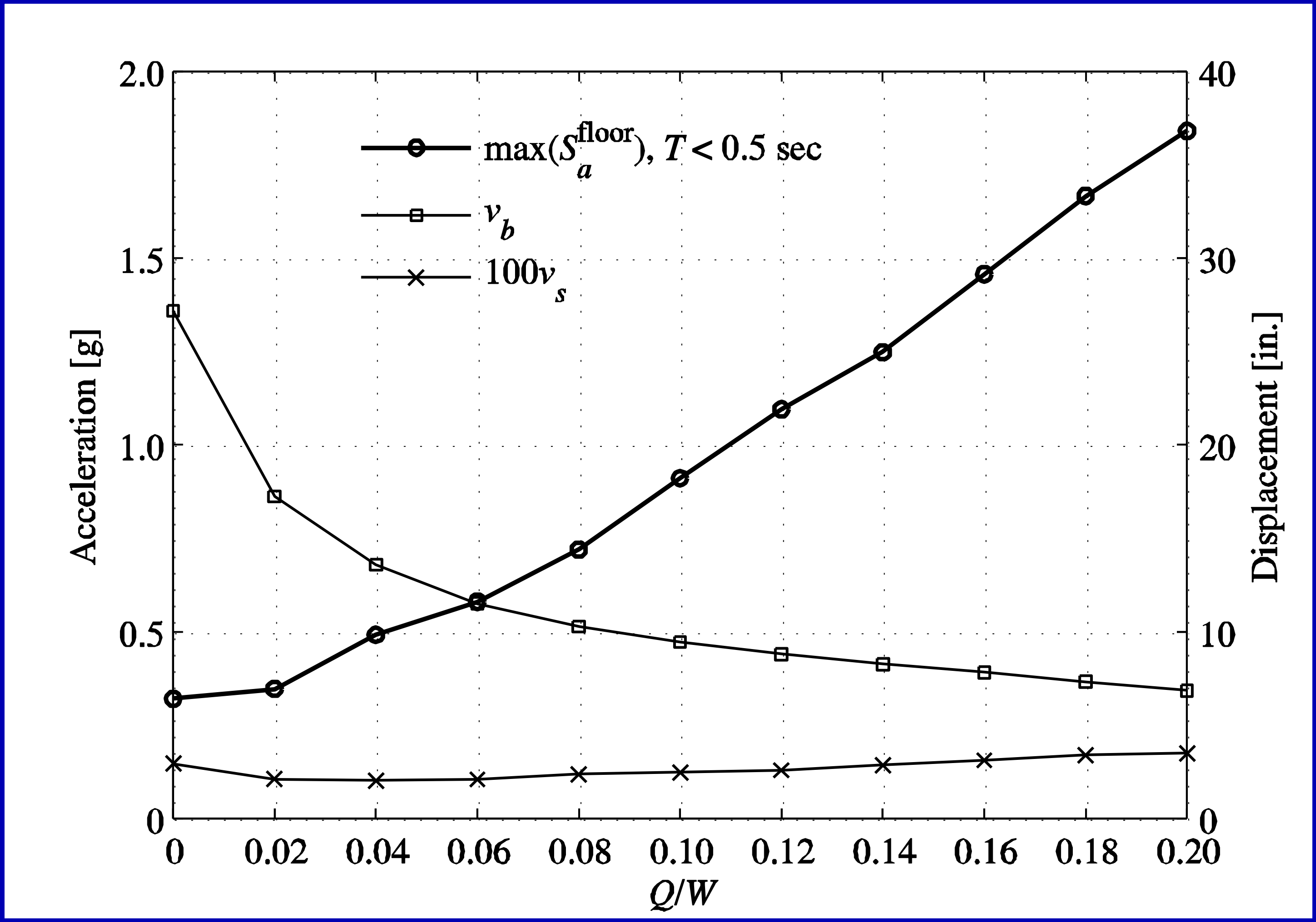
Mean floor acceleration spectra for the three isolation designs at the three hazard levels.



Mean Floor acceleration spectra of the FPS with superstructure period and various characteristic strengths subjected to DBE hazard level motions



Peak mean floor spectral acceleration, mean maximum isolator displacement and superstructure displacement as a function of characteristic strengths



Conclusions for SILER

- To demonstrate the advantage of the HDNR isolation system three isolation systems were designed to comply with U.S. building code requirements (ICC 2000), and a series of 270 nonlinear dynamic analyses were conducted to compare the dynamic response of the systems. The nonlinear dynamic analyses were carried out for three isolation types (FPS, LPS and HDNR) with three superstructure periods and three hazard levels (SLE, DBE and MCE). Ten nonlinear dynamic analyses were conducted for each of the seismic hazard levels.
- This numerical analysis has emphasized the effect influence of the three systems on the performance of equipment in an isolated structure. Two these types of isolators, (FPS and LPS), have bilinear hysteresis due to which as the isolator displacement decreases for less extreme and more realistic earthquake shaking, both the effective damping and stiffness of the isolation system increase. As a consequence, the building will not be effectively isolated, leading to higher story drifts and floor accelerations.
- To overcome these disadvantages, it is suggested that using HDNR and exploiting the property of strain induced crystallization to create an isolation system that behaves essentially linearly elastic with low viscous damping at lower and moderate shaking intensities (SLE and DBE). As the shaking intensity increases, the isolators will stiffen, thus controlling the isolation displacement. With the combination of these advantages, the HDNR will form an efficient isolation system to protect both the equipment and structural components of the building at all hazard levels.

What needs to be done?

The benefits of using seismic isolation design are many: isolation leads to a simpler structure with much less complicated seismic analysis as compared with conventional structures, isolated designs are less sensitive to uncertainties in ground motion; and, finally, the components are much more reliable than conventional.

Therefore:

Reconsider HDNR Systems

Fund basic research on Strain-induced Crystallization in Natural Rubber

Reference

"The Influence of Isolator Hysteresis on Equipment Performance in Seismic Isolated Buildings" by T.Y. Yang, Dimitrios Konstantinidis, and James M. Kelly, Earthquake Spectra, Vol. 26, No. 1, pp 275-293 Feb. 2010