Application of Base Isolation to Nuclear Equipment

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The paper presents a base isolation concept and discusses its potential application to nuclear equipment subjected to high frequency (20-80Hz) loads which can result from Loss-Of-Coolant Accident (LOCA) and/or Safety/Relief Valve (S/RV) discharge events. The high frequency content of these loads has little effect on the structural integrity of most types of equipment. However, serious problems can be encountered in the operability of some electro-mechanical devices such as relays. Typical of this situation is control panels. Response spectra computed at component locations can exhibit high acceleration peaks in the high frequency range - often considerably above the levels for which the components can be qualified.

When equipment is subjected to high accelerations in the low frequency range, the equipment is usually designed in such a way that its fundamental frequency is well above the frequencies of the applied loads so that little or no amplification occurs in the equipment. This approach is typically used for equipment excited by seismic loads whose dominant frequencies occur in the 1 to 15 Hz range. When the fundamental frequency of the equipment is raised to 33 Hz or higher, it is considered rigid for seismic loads and no amplification is assumed to occur.

This approach may be used to reduce high accelerations occurring in equipment resulting from high frequency loads. However problems arise with local modes of vibration in the 20-100 Hz range. It may be neither practical nor economical to qualify such equipment by stiffening because of the difficulty in raising the frequencies of the local modes out of the frequency range of the applied loads.

In contrast, base isolation takes the opposite approach. It reduces the fundamental frequency of the equipment and eliminates the amplification effects due to high frequency loads. Qualification of the equipment is greatly simplified and is focused on the design of base isolation devices which optimally balance acceleration and displacement in the equipment under the required loading conditions.

Herein a typical control panel has been selected and is subjected to a LOCA load typical of an actual nuclear power plant. The panel was analyzed with and without base isolation devices for these loads. The results of the analysis demonstrate that a properly designed base isolation system effectively eliminates high accelerations due to the high frequency component of the load.

1 INTRODUCTION

This paper presents a base isolation concept and discusses its potential application to nuclear equipment subjected to loads in the high frequency range. High frequency loads can result from Loss-Of-Coolant Accident (LOCA) and/or Safety/Relief Valve (S/RV) discharge events.

It has been shown that the high frequency content of these loads has little effect on the structural integrity of most typical types of equipment. However, serious problems can be encountered in the operability of some attached devices such as relays and other electro-mechanical components. Typical of this situation is control panels. High frequency loads have little influence on the stress levels within the panels or the adequacy of the base anchorage. However, response spectra computed at component locations exhibit high acceleration peaks in the high frequency range - often considerably above the levels for which the components can be qualified.

When equipment is subjected to high accelerations in the low frequency range, the equipment is usually designed in such a way that its fundamental frequency is well above the frequencies of the loads and little or no amplification occurs in the equipment. This approach is typically used for equipment excited by seismic loads whose dominant frequencies exist between 1 and 15 Hz. When the fundamental frequency of the equipment is raised to 33 Hz or higher, it is considered rigid for seismic loads and no amplification is assumed to occur.

This approach has also been used to reduce high accelerations occurring in equipment resulting from high frequency related loads. However a problem may arise with some types of equipment with local modes of vibration in the 20-100 Hz range. It may be neither practical nor economical to qualify such equipment by stiffening because the fundamental frequency has to be raised to above 100 Hz and all significant local modes have to be eliminated.

This is particularly true in retrofit situations where equipment originally designed for seismic only has to be requalified for high frequency loads. Raising the local mode frequencies to above 100 Hz can require an increase in stiffness of a factor of 10 or more. For equipment already built (and installed) this can be a formidable task - both practically and economically.

In contrast, base isolation takes the opposite approach and reduces the fundamental frequency of the equipment. The amplification effects of local modes on the equipment response due to high frequency loads is eliminated. Qualification of the equipment is greatly simplified and is focused on the design of base isolation devices which optimally balance acceleration and displacement in the equipment under the required loading conditions.

2 BASE ISOLATION

A base isolation system isolates equipment or a structure from harmful vibration. The most common use of base isolation is seen in heavy machinery or equipment whose vibration and noise are isolated from the floor at the mounting base. Another use exists in buildings which are isolated from earthquake ground motion. This paper studies the latter application and extends it to nuclear equipment. A significant amount of research has been performed on base isolation systems for buildings in both the U.S. and New Zealand [1][2]. Base isolation devices have been incorporated in the design of several structures in earthquake regions throughout the world and is now a viable concept to be considered by designers.

An effective earthquake isolation system for buildings must satisfy the following requirements:

(1) Reduction of the fundamental natural frequency of the building well below the frequencies where peak seismic accelerations occur.

(2) Maintenance of an acceptable level of displacement in the building when it is softened by the use of base isolation.

The first requirement determines how much amplification (or reduction) will be achieved in the building response against earthquake ground motion. When this requirement is met, the frequency of the base isolation system governs the building response and the original frequencies of the building itself produce negligible response. The second requirement, determines how soft the base isolation system can be before the displacement becomes unacceptable. It is apparent that these two requirements conflict with each other. Therefore the earthquake isolation system for a building must be designed such that the requirements for acceleration and displacement are satisfied in an optimum manner.

Nuclear equipment generally has the following characteristics, compared with those of a building:

(1) Its fundamental frequency is much higher.

(2) It weighs much less.

(3) It may experience high frequency related loads in addition to seismic loads.

It is not difficult to design a base isolation system which significantly reduces the equipment response to high frequency related loads such as LOCA and S/RV discharge loads. However more thought is required to design a system for effective isolation of seismic loads as well.

It is worth discussing at this stage the mechanism by which base isolation is effective. Contrary to a common belief, the high frequency modes of vibration of a system are not eliminated by the addition of base isolation devices - in fact, the natural frequencies remain essentially unchanged (except for the addition of "rigid body" modes). However, the corresponding mode shapes have superimposed on them a rigid body component (corresponding to base movement) which serves to substantially reduce the corresponding modal participation factor. As a result, these modes contribute little to the total response at points within the system - the high frequency motion is effectively "filtered" out.

Figure 1 shows a typical base isolation device applicable to nuclear control panels. Multilayer rubber bearings and steel sheets are designed such that the device provides the required stiffness in the horizontal direction and yet maintains a high stiffness in the vertical direction. The latter is required to prevent the introduction of any undesirable rocking or vertical modes of vibration.

3 APPLICATION

3.1 Control Panel

Control panels in nuclear plants appear to have the best potential for the use of base isolation. Therefore these panels are studied in more detail to demonstrate the effectiveness of base isolation for high frequency loads.

A typical control panel is a cabinet type of structure which is constructed using structural members such as angles and channels for its framing and plate steel for its paneling. A number of safety related devices will be mounted on the panel. Because of the structural characteristics of the panel there will be a number of local plate modes below 80 Hz. In addition, there may be some global modes of vibration in this range depending on the stiffness of the base/anchorage system. LOCA, S/RV discharge and seismic loads are likely to be the major loads. High frequency loads which could result from LOCA and S/RV discharge events may have peak accelerations in the 20-100 Hz range. These loads will excite both local and global modes of the panel and the devices mounted on the panel may experience high and possibly unacceptable accelerations.

3.2 Stiffening Approach

When a control panel experiences high acceleration in the 20-100 Hz frequency range, the conventional solution is to stiffen the panel and raise its fundamental frequency well above the exciting frequencies. If this approach is used then all the significant local modes of the panel have to be suppressed by stiffeners and the fundamental frequency has to be raised above 100 Hz. The following difficulties arise with this stiffening approach:

(1) All significant local modes of the panel which are sensitive to local structural characteristics will have to be identified.

(2) Extensive stiffening of the panel will be required to suppress the local modes.

Additionally, each panel may require a unique stiffening scheme because local modes of the panels are sensitive to local structural characteristics. When there are a number of panels which require stiffening, this approach will become very costly.

3.3 Base Isolation Approach

General

The difficulties associated with stiffening a control panel appear to be resolved by using base isolation. When a base isolation system is used, the panel response to high frequency related loads will be governed by the stiffness of the base isolation system rather than local structural characteristics of the panel. As a result, it is not difficult to identify panels which have similar dynamic response to the above loads. The parameters which determine the panel response will be the global stiffness and mass distribution in a panel and the base isolation stiffness.

This ease of the identification will result in the development of a few standardized base isolation devices and installation details which can be used for the qualification of all control panels of interest.

Example

Figure 2 gives a typical control panel chosen to study the effectiveness of base isolation for the above loads.

The panel is 96" wide, 48" deep and 84" high. It weighs approximately 3,000 pounds. Two finite element models were developed for this study:

(1) As-built model without base isolation.

(2) Model with the base isolation system which reduces the fundamental frequency of the panel to approximately 5 Hz.

The loading used is an acceleration time history, at the panel base, resulting from a LOCA event. The input time history was obtained at the floor where the panel is located. This example considered only the horizontal acceleration because in most cases the vertical acceleration induces much smaller response in the control panel.

Figure 3 shows the floor response spectra generated from the LOCA acceleration time history. This spectrum is presented to show the distinctive characteristics of the LOCA load. The LOCA floor response spectrum shows two dominant peak accelerations at about 25 and 75 Hz which could excite local as well as global modes of the panel.

The analysis was performed to obtain the response spectra (at two locations in the panel) which a device mounted on the panel could experience. When the panel response was computed, three sets of damping (2%, 5% and 10%) were used for the base isolation related modes and one set (2%) was maintained for the remaining modes.

The analysis consisted of:

(1) Mode/frequency analysis of the panel.

(2) Time history analysis of the panel using the modal superposition method.

(3) Response spectrum generation for devices on the panel.

Table 1 provides the first twenty natural frequencies and associated modal participation factors calculated for each model. Only the factors normal to the front of the panel, are presented because the greatest amplification occurred in that direction when subjected to the LOCA load. A number of local plate modes exist which could be significantly excited by the LOCA load. In the model where the base isolation system is incorporated, the results in Table 1 indicate that the local plate modes become insignificant and consequently the global base isolation related modes will govern the panel response. Note that in the base isolated panel the modal participation factors of all the higher modes are substantially less than the model with no base isolation

The acceleration response spectra resulting from the LOCA load is given in Figures 4 and 5. These response spectra are envelopes of those obtained at two locations on the panel.

As anticipated from the results in Table 1, the base isolation system drastically reduced the effects of the local plate modes on the panel response. All the peak accelerations above 30 Hz observed in Figure 4 were effectively eliminated by the use of the base isolation system as seen in Figure 5.

The maximum acceleration of the panel response spectrum with and without the base isolation is 0.9g and 84g respectively. The displacement obtained for both models is negligible under the LOCA loading considered.

A survey of the literature indicates that the use of 5% damping and even higher is easily justified for the base isolation devices being considered. The panel displacement decreases as the damping value for the devices increases and will not be more than one-half inch for all the loads considered - LOCA, S/RV, and seismic.

4 CONCLUSIONS

This paper has presented the application of base isolation to nuclear equipment subjected to vibratory loads with acceleration peaks in the 20-80 Hz frequency range.

The results of the study demonstrate that the base isolation system effectively eliminates high accelerations in the equipment, resulting from the high frequency component of these loads.

In contrast to the conventional stiffening approach used for equipment qualification, base isolation reduces the fundamental frequency of the equipment and substantially reduces the effect of the local modes on the equipment response to high frequency loads. The equipment response is governed by the global characteristics of the equipment and the base isolation stiffness rather than the local characteristics. Therefore the use of base isolation will reduce the effort required for the qualification of the equipment.

The use of base isolation appears to be particularly suitable for existing equipment that requires requalification because of newly identified, high frequency related loads. The use of base isolation will require substantially less structural modifications to the equipment than the conventional stiffening approach. Base isolation is even more cost effective when it is considered at the design stage of equipment.

Computech has designed several base isolation devices. The devices are relatively inexpensive and easy to install in both new and existing equipment. It is our opinion that the use of a base isolation system offers a cost-effective solution to the problems of nuclear equipment subjected to high frequency loads (LOCA and S/RV) as well as to seismic loads. Base isolation should therefore be seriously considered as a potential solution to the requalification of any existing nuclear equipment as well as its possible use for new equipment.

5 REFERENCES

1. Blakeley, R.W.G., et al., "Recommendations for the Design and Construction of Base Isolated Structures," Bulletin New Zealand. National Society for Earthquake Engineering, Vol.12, No.2, 1979.
2. Kelly, J.M., "Control of Seismic Response of Piping Systems and Other Structures by Base Isolation," Report No. UCB/EERC-81/10, Earthquake Engineering Research Center, University of California, Berkeley, 1981.

TABLE 1

NATURAL FREQUENCIES AND MODAL PARTICIPATION FACTORS
OF CONTROL PANEL

MODE NO.	CONTROL PANEL MODEL			
	NO BASE ISOLATION		BASE ISOLATED PANEL	
	FREQUENCY (H_z)	MPF	FREQUENCY (H_z)	MPF
1	37.4	0.708	4.9	0.068
2	47.7	-1.863	5.0	2.867
3	48.6	0.314	5.2	-0.057
4	55.5	0.157	19.5	-0.003
5	56.7	-0.805	25.1	0.011
6	61.1	-0.330	39.1	0.006
7	62.7	-0.039	41.7	0.009
8	65.8	0.067	49.4	-0.002
9	68.6	-0.415	53.1	-0.003
10	69.5	0.084	53.9	0.010
11	71.7	-0.059	57.1	0.002
12	75.2	-0.345	62.1	-0.004
13	78.6	0.186	64.2	0.010
14	80.2	0.046	64.8	0.004
15	88.8	0.035	68.8	0.006
16	92.2	0.165	69.3	0.003
17	94.3	0.015	71.4	0.003
18	96.3	0.117	75.6	0.001
19	100.6	0.117	78.1	-0.005
20	101.3	-0.030	80.0	-0.002

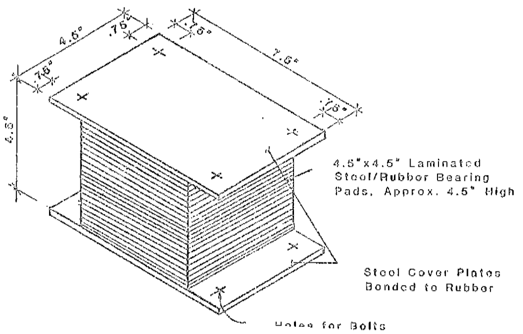

FIGURE 1

BASE ISOLATION DEVICE

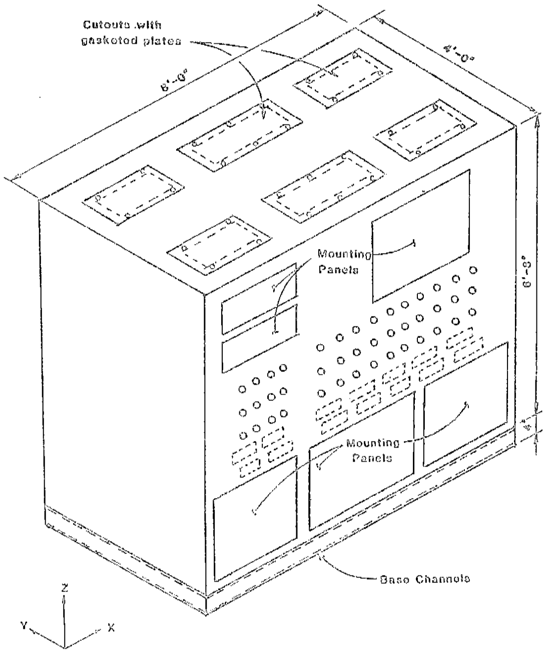

FIGURE 2

TYPICAL CONTROL PANEL

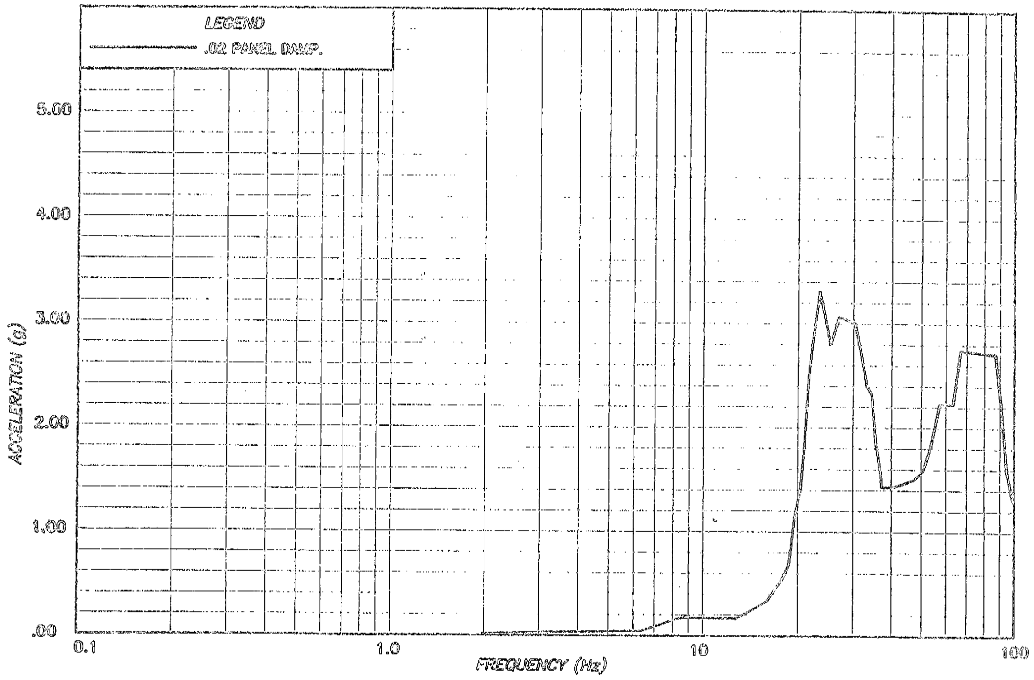

FIGURE 3

FLOOR RESPONSE SPECTRUM DUE TO LOCA HORIZONTAL

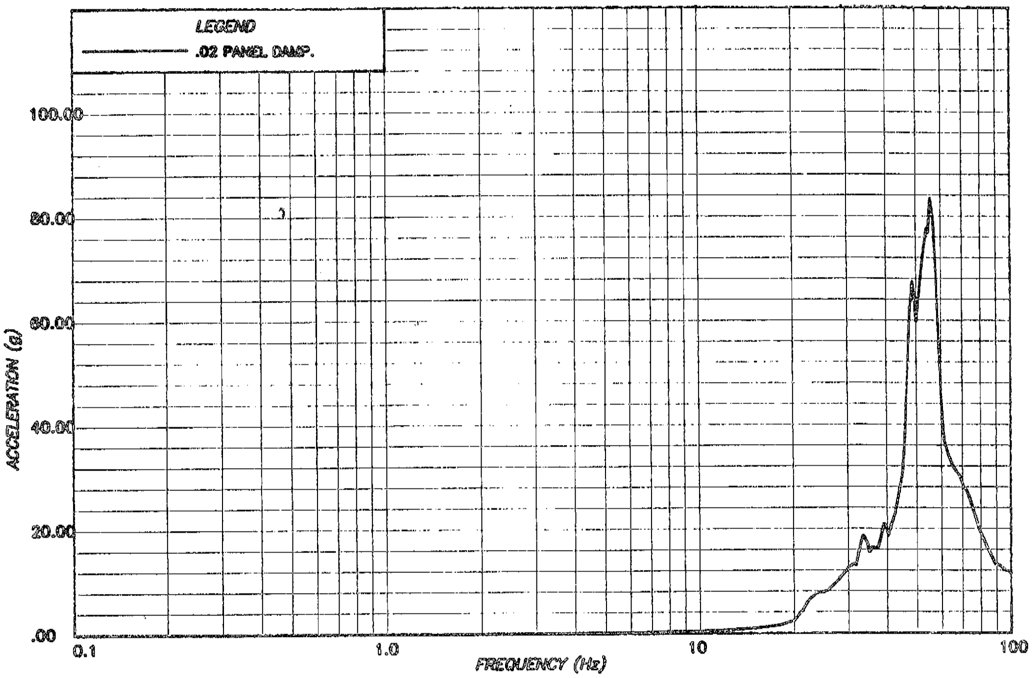

FIGURE 4

IN-PANEL RESPONSE SPECTRUM DUE TO LOCA

(WITHOUT BASE ISOLATION)

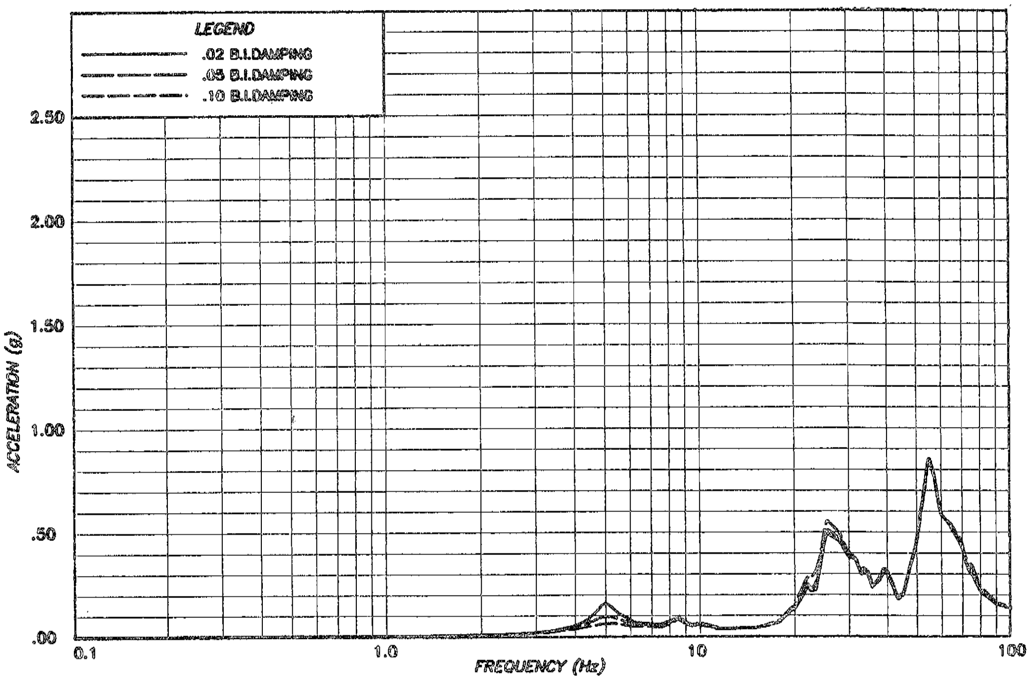

FIGURE 5

IN-PANEL RESPONSE SPECTRA DUE TO LOCA

(WITH $5H_Z$ BASE ISOLATION)