Subduing the Structural Shakes

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INTRODUCTION

The evolution of seismic design practices is related to the occurrence of major earthquakes such as the 1906 San Francisco, 1923 Kanto, Japan, the 1925 Santa Barbara, the 1933 Long Beach, the 1940 El Centro, and the 1971 San Fernando earthquake. The amount of damage sustained by power equipment and structures during these earthquakes pointed out a necessity for the Power Industry to consider the dynamic behavior of equipment and structures and to reassess seismic design practices.

Conventional designs typically use codes whose main intent is life safety, and whose failure criteria is structural collapse. These methods allow the entire ground motion to be transmitted to the superstructure; absorbing the seismic energy through inelastic behavior which invariably gives rise to damage, both structural and non-structural. From the standpoint of the structure's essential function, conventional designs may reduce injury to people, but the corresponding damage to the building's equipment and other non-structural components may be catastrophic. The ideal solution for this seismic design problem is to provide a system which absorbs or mitigates the seismic forces before they enter into the structural system. Base isolation offers such an alternative.

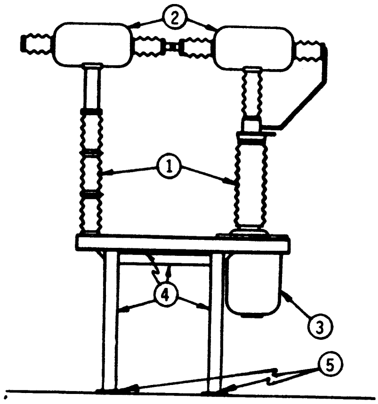
BASE ISOLATION CONCEPT

The base isolation concept used for mitigating seismic response in structures and equipment is both old and new. For years, aerospace and mechanical engineers have recognized the effectiveness of such systems which can isolate a structure from damaging vibrations.

Base isolation systems are an attractive and practical alternative. By using an isolation system, the structure's overall frequency is considerably reduced; in effect, deamplifying the floor spectra and virtually eliminating the damaging accelerations which act upon the equipment and its components. Of course, the equipment will see larger displacements relative to the ground, but these displacements can be controlled through the use of damping available in both the isolator and the equipment.

BASE ISOLATION SYSTEMS

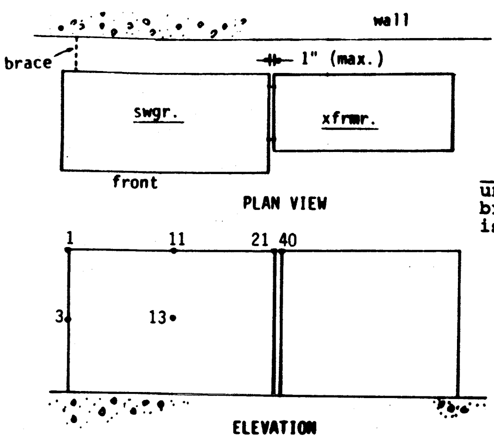
During the past decade, several isolation devices have become available of which the elastomeric bearing offers the simplest method (Kelley 1986). The bearings, composed of steel plates bonded to vulcanized rubber posses the following characteristics (Derham 1986): 1) very stiff in the axial direction, supporting dead and live loads, 2) very flexible in the lateral direction, providing energy dissipation through the distortion of the bearing, 3) high



KEY (Kircher 1977):
1) Porcelain insulator
2) Breaker head
3) Liquid gas resevoir
4) Platform skid (steel structure)
5) Elastomeric bearings (proposed)

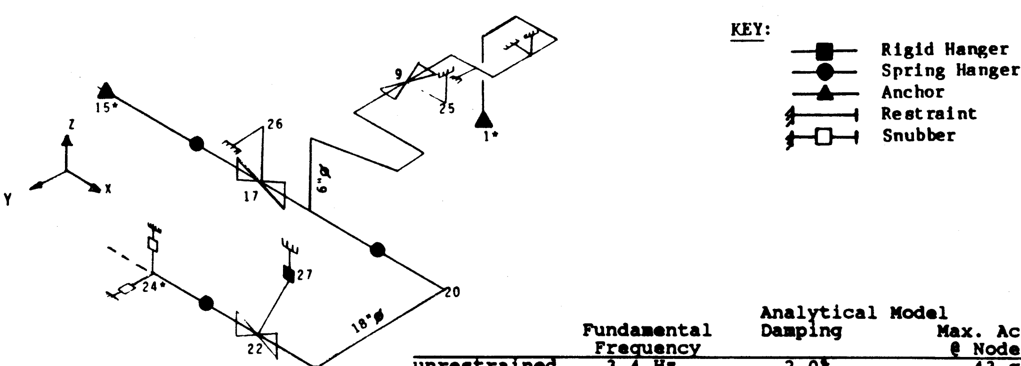
	Fundamental Frequency	Analytical Model Damping	Max. Accel. @ Breaker
fixed	2.74 Hz	0.9%	9.7 g
isolated	0.3	10.0%	0.7

FIGURE 1: CIRCUIT BREAKER (Sharma et al., 1988)



	Fundamental Frequency	Analytical Model Damping	Max. Accel. @ Node 1
unbraced	4.5 Hz	2.0%	38 g
braced	9.2	2.0%	4.2
isolated	0.5	10.0%	1.7

FIGURE 2: SWITCHGEAR-TRANSFORMER ASSEMBLY (Sharma et al., 1988)



	Fundamental Frequency	Analytical Model Damping	Max. Accel. @ Node 20
unrestrained	3.4 Hz	2.0%	43 g
restrained	8.1	2.0%	28
isolated	0.3	10.0%	0.3

*Location of proposed elastomeric bearings

FIGURE 3: PIPE-VALVE ASSEMBLY (Sharma et al., 1988)

damping, 4) effective in main shock as well as aftershocks, 5) self centering, 6) minimum maintenance and inspection, and 7) available in different sizes, accommodating a variety of structures. In addition, elastomeric bearings have a long history of in-service performance with an existing large body of knowledge relating to their mechanical properties, quality control, and long-term reliability.

NEED FOR EQUIPMENT ISOLATION

In power plants, all structural systems and components important to safety are required to be designed to withstand the effects of earthquakes without loss of safety performance capability. These requirements point to the need for seismic qualification of equipment and systems to ensure structural integrity and functional capability during and after a seismic event. The current practice is to qualify such equipment by either testing them on a shake table or by performing detailed dynamic analysis. Equipment which has its fundamental frequency of vibration in the range of frequencies where the earthquake's energy is the strongest acts as an amplifier of the floor vibration, imposing excessive acceleration on the equipment and its devices and subcomponents. In several instances, the equipment requires stiffening or additional bracing to shift its fundamental frequency above the damaging frequency range of the earthquake. Such modifications are costly and, in many instances, difficult to implement because of the physical limitations of the equipment and its location in the plant.

COMPARATIVE STUDIES PERFORMED

The following equipment was analyzed to demonstrate the effectiveness of isolation systems: A) Circuit breaker (figure 1), B) Switchgear-transformer assembly (figure 2), and C) Pipe-valve system (figure 3). Each case was analyzed for conventional design, modified design using conventional stiffening methods, and finally base isolated design.

<u>Circuit Breakers</u>

Circuit breakers are vital components in switchyards which provide electrical power to large facilities. These facilities are completely dependent upon the performance of the circuit breakers. Therefore maintaining electrical power supply, especially during and after seismic events, is critical.

In California, many circuit breakers are located in seismically active areas and, in some cases, earthquake damage to circuit breakers has been extensive. Generally, circuit breaker failure has occurred due to failure of its main component, the porcelain insulator. This failure is so severe that restoring power to a switchyard is both a costly and time consuming process.

The dynamic characteristics of a 230 KV air blast circuit breaker determined from the experimental work of Kircher (1977) were used as typical values in this study. Utilizing these dynamic characteristics, a few simple analytical models were developed which had fixed base conditions representing current circuit breaker design and installation practice. The purpose of these analytical models was to simulate circuit breaker design and dynamic response characteristics. These models were subjected to the 1940 El Centro NS component. The dynamic analyses results for both the fixed base and base isolated analytical models are listed in Figure 4.

The dynamic analyses results of fixed base and base isolated circuit breaker models demonstrate the effectiveness of base isolation in the seismic design of circuit breakers.

<u>Switchgear-Transformer Assembly</u>

To further illustrate the case for base isolation, a problematic switchgear-transformer assembly was examined. The switchgear and transformer were originally tested and dynamically qualified separately, but when they were installed, the clearance between the two units was insufficient to accommodate

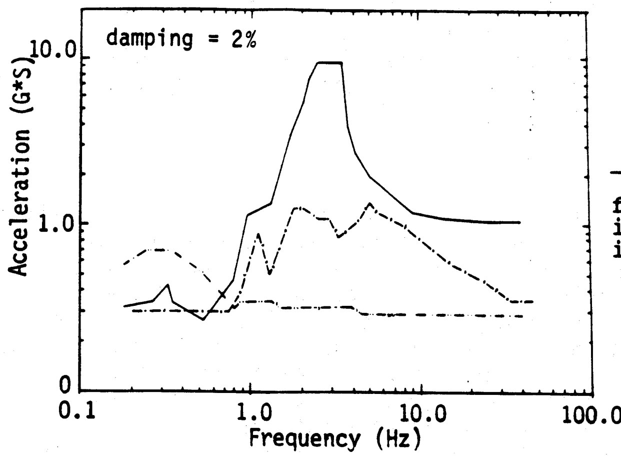


FIGURE 4
(Sharma et al., 1988)
CIRCUIT BREAKER

fixed
isolated
input spectra

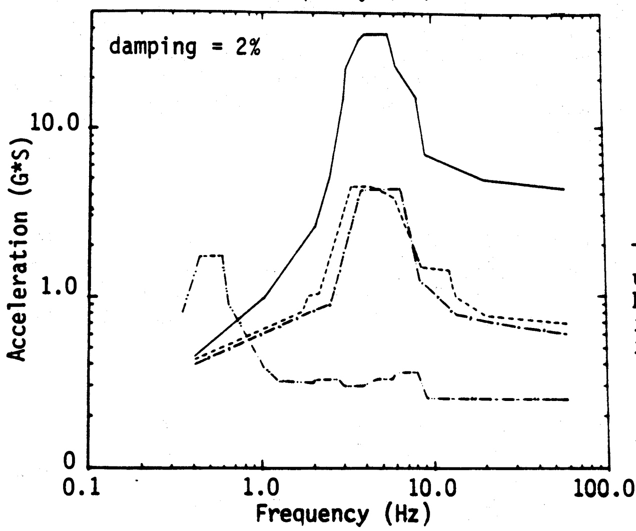


FIGURE 5
(Sharma et al., 1988)
SWITCHGEAR-TRANSFORMER ASSEMBLY

unbraced
braced
isolated
input spectra

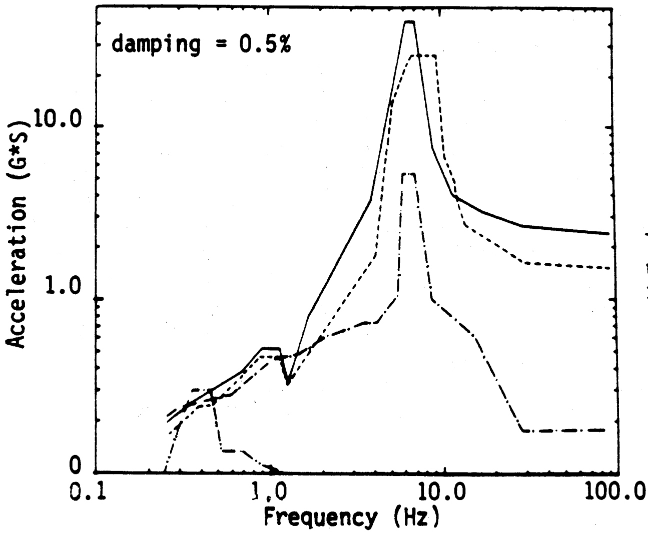


FIGURE 6
(Sharma et al., 1988)
PIPE-VALVE ASSEMBLY

unrestrained
restrained
isolated
input spectra

the seismic displacements of the equipment. To dispel this problem, the two units were tied together by coupling mechanisms. A mathematical model of the coupled system was developed and analyzed. The analysis of this mathematical model revealed a dominant torsional mode which produced high acceleration values in the combined assembly (see figure 5). This meant that the panel mounted devices were not qualified for their actual installed condition. A solution was needed to resolve this problem.

The conventional stiffening approach was applied to the assembly by introducing a brace which connected the rear top corner of the switchgear to the wall located directly behind the two units (see figure 2). The assembly's retrofit reduced the device's required acceleration levels to within their qualified test levels (see figure 5). Although this stiffening approach produced the desired results for the above problem, it was a specific solution for this specific case. Future devices added to the panel would require minimum test levels of 9 g's (depending upon their panel location) which would be costly if not prohibitive. When there are a number of panels which require stiffening, this approach becomes very expensive since each panel must be examined on a case-by-case basis.

The same switchgear-transformer assembly (without bracing) was analyzed with base isolation. The analysis results of the base isolated system showed a significant reduction in the acceleration response (see figure 5). Base isolation effectively eliminated high accelerations in the switchgear-transformer assembly. If these units had been retrofitted with elastomeric bearings, not only would the problem of high acceleration response have been solved, but the future qualification of panel-mounted devices would have been made easier and less costly since the peak required acceleration would only be 1.7 g's.

Pipe Valve Model

Of equal relevance in the qualification of power plant equipment are valves and their associated piping system; their importance cannot be overstressed.

Valves, in certain zones of BWR nuclear power plants, are designed for dynamic loads from the combination of seismic and hydrodynamic loads. The combination of all these loads and the low damping associated with pipe systems create a potential for high acceleration response in the valves and pipe system. Many plants have undergone retrofit programs to upgrade equipment which were originally designed for seismic loads only, but require requalification for the above high frequency loads. For already installed equipment, requalifying and retrofitting is a difficult task based on both practical and cost reasons. A case in point was a torus attached pipe system revaluated for hydrodynamic loads. In this case, the pipe system was stiffened in order to reduce the loads. Stiffening was achieved through the application of restraints at some valves, and springs, snubbers and restraints on the pipe (see figure 3). Adding restraints to a valve reduced the pipe's response, but created large reactions at the valve, overstressing it and inducing high accelerations at the valve operator. In order to resolve these problems, additional stiffness was added to the valves to increase their local frequency and reduce their component stresses. The numerous constraints of an operating plant created many design and installation difficulties.

An alternate to the extensive amount of work required to stiffen a pipe system is base isolation. The unrestrained pipe-valve system was analyzed with base isolation placed at some selected locations (see figure 3). The results of this analysis are shown in Figure 6. Not only does this approach alleviate the high responses in the pipe system, but it also eliminates the need for additional restraints.

SUMMARY AND CONCLUSIONS

From the results of these studies, the following conclusions are derived:

1) *Base isolation provides a very effective means of mitigating seismic and vibrational responses in the equipment and systems in nuclear power plants.* Properly installed, isolation devices substantially lower

seismic demand on equipment and piping systems, thereby eliminating the need for costly fixes and retrofitting. In addition, the system's energy absorption capacity is improved by virtue of its resilience. The reduction in response means that not just the structure but also its contents are given a similar degree of protection which is not possible without isolation.

2) *Isolation systems permit the analyst to preassign dynamic characteristics to the equipment, thereby making performance under seismic loads both predictable and controllable.* With base isolation systems, all significant deformations take place in the bearings whose properties are well documented and easily measured. This allows the engineer to optimize seismic design to improve equipment performance and reliability.
3) *Isolation systems do not require extensive detailed reanalysis for changing seismic demands on the systems, thereby saving time and cost.* Design studies are greatly simplified since the complexities of the structure, uncertainties of the structure's physical and material properties, and uncertainty in workmanship quality are greatly reduced. The analysis of an isolated structure is more reliable since the isolators can be tested for compliance with the design criteria after manufacture (Derham et al., 1986). The design analysis reduces to predicting the behavior of the bearings which is well understood, the behavior of the structure remains in the elastic range. In addition, experimental results have shown that design studies are extremely accurate in their predictions (Derham 1986).
4) *Seismic isolation is also effective for high frequency hydrodynamic loads and other in-plant vibrations, since most of these loads will be 'filtered' out.*

It is hoped that the preceding discussion will draw the attention of design professionals, utility owners, and researchers to the use of base isolation applications Future studies into base isolation applications will include further examination of their interface requirements. The studies presented above demonstrate the effectiveness of isolation systems in power plant applications. Base isolation subdues the structural shakes.

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