NEW DESIGN TECHNOLOGIES

The 1995 Kobe (Hyogo-ken Nanbu) Earthquake as a Trigger for Implementing New Seismic Design Technologies in Japan

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Executive Summary

The 1995 Kobe earthquake shook two seismic isolated buildings, both of which were located approximately 30 km from the epicenter. These two buildings, the Matsumura-Gumi Research Laboratory and the West Japan Postal Savings Computer Center (West-1), performed very well, though they were outside the region of strongest shaking. The West-1 building was, at the time, the largest seismic isolated building in the world. Both buildings were instrumented, and experienced ground accelerations of approximately 0.3g. Accelerations were reduced to 0.1g in the West-1 superstructure. Prior to the Kobe earthquake, no building with passive structural control in Japan had experienced a significant earthquake.

The number of isolated and passively damped* buildings built, or being built, has increased markedly since the January 17, 1995 Kobe earthquake. From 15 isolated buildings approved in the three years before the earthquake, construction approvals increased to more than 450 in the three years since. The authors suggest that this increase is due to the fact that seismic isolation technology had become relatively mature at about the time of the earthquake. The devastating human and economic losses in that event spurred society to look for alternatives to traditional seismic design approaches.

To synthesize a diverse cross-section of viewpoints, the authors conducted a written survey of about 150 designers, owners, and researchers. They also visited a number of building sites, design offices, and research facilities in Japan. The 30-question survey covered:

- General issues
- Project-specific information
- Design process
- Owner requirements and economics
- Regulatory and approval issues
- Future trends

This case study illustrates the marked increase in buildings that employ seismic isolation and passive energy dissipation in Japan. It identifies the technical, economic, political, and cultural factors that contributed to this trend. It provides an example of how being “in the right place at the right time” can lead to broad changes in practice in a short period of time. A window of opportunity to educate the public opened. The public was receptive to learning the basics about seismic design and the newest approaches for earthquake protection, and the media and the construction and development industries provided information. The survey results provide a broad perspective on the implementation of isolation technologies in the wake of the Kobe earthquake. Comparisons are made with practices and trends in the United States.

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* References to “passive damping” are restricted to distributed energy dissipation devices and do not include tuned passive control technologies such as tuned mass dampers and sloshing liquid dampers.

Introduction

The Kobe (Hyogo-ken Nanbu) earthquake of January 17, 1995 led to a sudden and significant change in application of passive control technologies for seismic design in Japan. In the three-year period prior to the 1995 earthquake, 15 seismic isolated buildings were licensed for construction. In the three years following the earthquake, 450 isolated buildings were approved. Even today, although the construction industry has slowed substantially due to national and regional economic difficulties, licenses for approximately 10 to 15 new seismic isolated buildings are granted every month, with additional approvals for the retrofit of existing structures. Statistics reflect similar increases in the rate of adoption of supplemental damping technologies. As is the case with most advances in earthquake engineering practice, a diverse array of technical, economic, and social influences have combined to bring about this evolution in earthquake-resistant construction.

The basic goal of this study was to understand how and why this change in engineering and construction practice has taken place. It is clear that the Kobe earthquake helped to trigger the acceptance of new technologies in the Japanese seismic design community, but the occurrence of severe earthquake shaking is not by itself enough to change the direction of engineering and construction practice.

Instead, it appears that a major factor was that passive control technologies had reached a level of maturity at about the time of the earthquake. The large human and property losses made engineers, building owners, and the general public aware of both the necessity for and the feasibility of constructing higher-performance structures and the potential benefits of improved performance.

Looking back at the events over the three years subsequent to the earthquake provides the opportunity to examine what went right in the process of improving both perceptions and practices in seismic design. Unfortunately, it also indicates that it may be difficult to institute significant change such as this without the catalyst of a damaging earthquake.

This research focused on the opinions and experiences of the primary decision makers in the seismic design process—building owners, design engineers and construction companies, and regulators. A detailed questionnaire was developed and distributed to over 150 individuals and firms. The most important question in the survey, which came to be known as Question Number 1, asked respondents' opinions as to the primary reason new technologies were being adopted at an accelerated rate since the Kobe earthquake. Knowing that the answers to this question would probably reflect a complex combination of influences within the construction industry, additional questions addressed a variety of technical and nontechnical issues: design criteria and expected seismic performance, analysis approaches, client expectations, construction cost and schedule, liability considerations, education programs, the licensing and approvals process, public awareness, and future trends in seismic design.

The written surveys were augmented with visits to a number of design offices, completed buildings, and construction sites in Japan. This series of on-site interviews was directed toward developing quantifiable measures of how new seismic design practices are adopted, with the hope that the factors identified would be useful in future efforts to improve seismic performance. The focus of this research was building structures, though significant changes in the use of new technologies in bridge design have also occurred as a result of the Kobe earthquake.

The surveys and site visits made clear the fact that there is no simple answer to Question Number 1. Clearly the large human and property losses have had a great influence as citizens in Japan have become more educated about the earthquake risk and ways to mitigate it, but there has also been a push from promoters of new technologies including construction companies, engineering organizations, and building development companies. Some of the respondents feel that portions of the general public have lost faith in traditional forms of construction after seeing the damage in Kobe, while others believe that deception and group anxiety are the real sources behind the demand for innovative structural systems.

The preponderance of research activities prior to and after the earthquake, coupled with the favorable performance of two isolated buildings in the region, lend technical support to the promises of improved seismic performance. The results of the survey illuminate the multidisciplinary nature of earthquake engineering and the need to understand the perspectives of all stakeholders in the building construction industry before positive, lasting change can be enacted.

Background

Early Developments

The modern era of passive structural control had its beginnings in New Zealand in the early 1970s. Numerous research and development efforts were under way around the world by the end of that decade, and the first applications of seismic isolation in Japan and the United States began in the early 1980s. In Japan, the first isolated structure was a small house built as a “demonstration project” in 1982 by a real estate development company. The first isolated building constructed in the United States was a county administration building in southern California, completed in 1985.

As the Japanese economy boomed throughout the second half of the 1980s, many more demonstration projects were built by a large number of construction companies to showcase their advances in technology. Funding for these buildings typically came from the construction companies' government-mandated research investments, and the buildings used many different types of proprietary isolation systems. Of the 85 isolated buildings approved for construction before the Kobe earthquake, approximately 35 were either dormitories, research centers, or other facilities owned by construction companies or bearing manufacturers and built for demonstration purposes.

The most common uses for these early buildings included offices (32), dormitories and apartment complexes (25, including company facilities), research centers (17), and computer centers (7). Details of many of the earliest applications are provided in Kelly (1988). Figure 1 charts the early growth of isolation applications in Japan prior to January 1995, indicating a period of relatively rapid development in the late 1980s, which then leveled off in the early 1990s as the Japanese economy slowed.

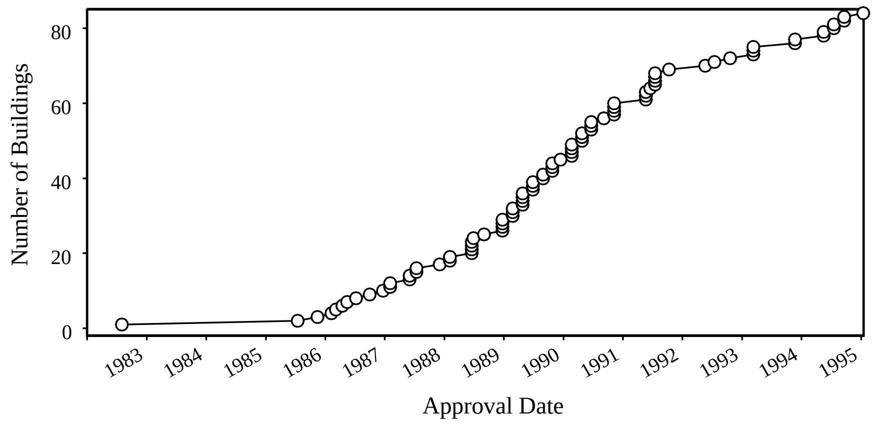

Figure 1 *Growth of seismic isolation applications in Japan prior to the 1995 Kobe Earthquake (Building Center of Japan, 1990—1998).*

The development of structures incorporating passive damping moved more slowly than did buildings that incorporated seismic isolation. Although relatively few were contractor-owned demonstration projects, many of the early applications were intended as much to mitigate motions due to wind and typhoons as to prevent damage in strong earthquakes. These buildings also used an array of different proprietary devices. Comprehensive data for these buildings are more difficult to obtain than for isolated buildings, but designers and construction companies responding to the present survey indicated that their firms were responsible for 28 buildings with passive damping systems prior to the Kobe earthquake.

No building with passive structural control in Japan had experienced a significant earth-quake until shaking from the Kobe earthquake was recorded at two isolated buildings located approximately 30 km from the epicenter. Both the Matsumura-Gumi Research Laboratory and the West Japan Postal Savings Computer Center (West-1) experienced ground accelerations of approximately 0.3g. The West-1 building performed very well, reducing accelerations in the superstructure to approximately 0.1g, and it became the focus of significant attention after the earthquake because at the time it was the largest seismic isolated building in the world (Naeim and Kelly, 1999). Even though these two isolated buildings were well outside of the region of strongest shaking, engineers, construction companies, the media, and other groups in Japan used these buildings to promote the potential benefits of seismic isolation.

Use of Isolation and Damping Technology Accelerates

Beginning in mid-1995, the rate of construction approvals in seismic isolated buildings and buildings with passive damping systems increased substantially. The clear differences between the pre-earthquake and post-earthquake construction trends are illustrated in Figure 2, which plots the available data for all isolated buildings licensed prior to June 1998

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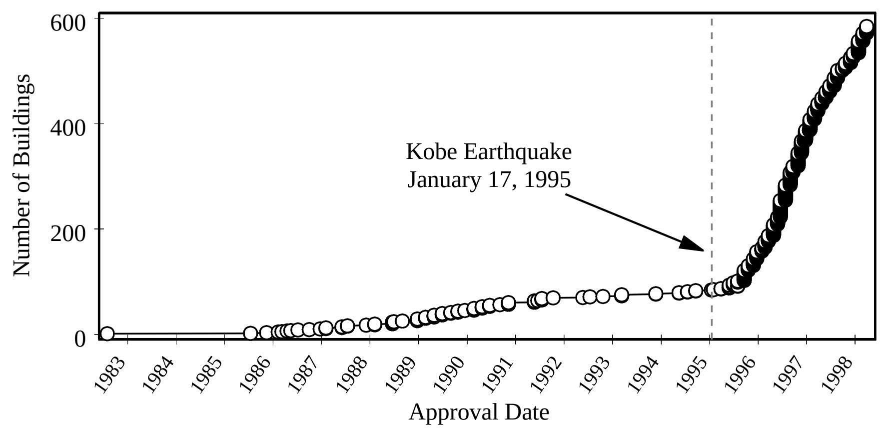

Figure 2 *Growth of seismic isolation applications in Japan before and after the 1995 Kobe earthquake*

Though the data are less complete, similar trends in construction approvals have been found for buildings incorporating passive damping systems. Before the earthquake, about 28 buildings with passive damping systems had received construction approval. More than 125 have been approved since. It is estimated that more than 50 percent of all high-rise buildings designed in Japan today employ some form of passive damping system—24 of 36 buildings reviewed by the Building Center of Japan (BCJ) high-rise committee in 1997 incorporated energy dissipation devices (Building Center of Japan, 1997; Comartin, 1998).

Because of the formal approvals process required for isolated buildings (described in the following subsection), detailed statistics are available for this population of structures. An illustration of differences in the scale of construction before and after the Kobe earthquake is provided in Figure 3. Not only have the numbers of isolated buildings grown, but the buildings being constructed today are taller and have much larger floor areas.

Before 1995, the average isolated building was between 4 and 5 stories in height. Since 1995, the average is more than 8 stories. It is interesting to note how the trend in the number of buildings as a function of building height drops off at approximately 11 stories, followed by a separate peak at about 14 stories and then almost no buildings above 16 stories. These seemingly artificial cut-off points are actually driven by provisions in the BCJ approval process that are activated for buildings over 31, 45, and 60 meters tall. On the basis of floor area, isolated buildings constructed after the Kobe earthquake are on average about 60 percent larger than those constructed before the earthquake. The total floor area of all isolated buildings constructed since the Kobe earthquake is approximately ten times that of all buildings constructed previously.

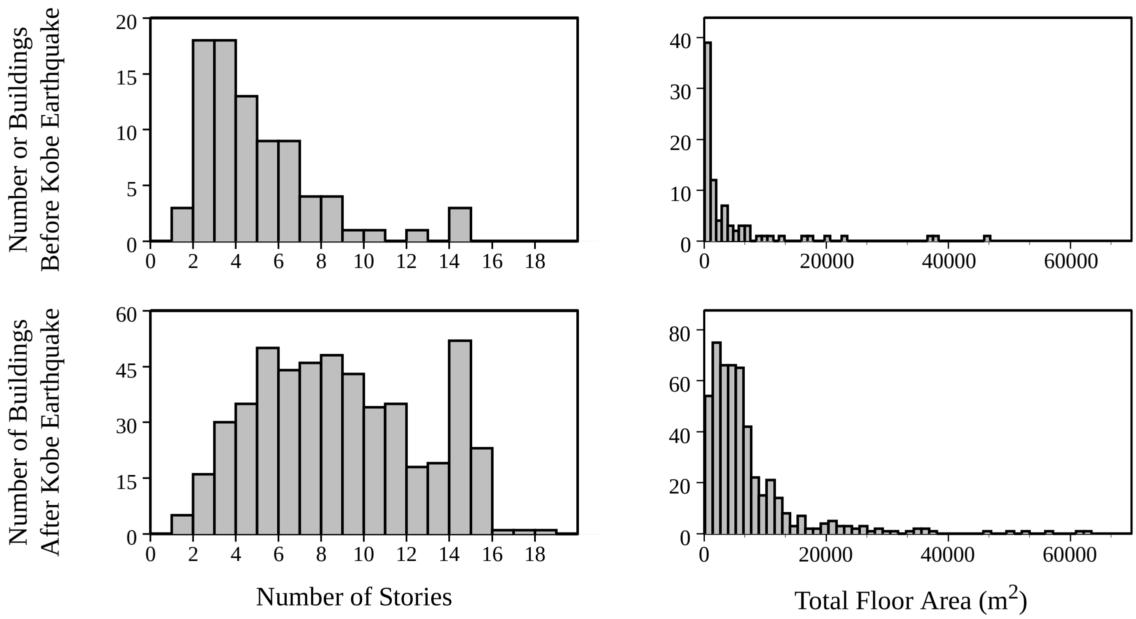

Figure 3 *Histograms of isolated building height and floor area before and after the Kobe earthquake*

Current Regulatory Environment in Japan

All seismic isolated buildings in Japan, and most buildings with passive damping, require a special license from the Ministry of Construction. BCJ acts as an agent for the Ministry, organizing review committees in various technical disciplines and administering building approvals. This process is known as “hyotei,” and four committees are of particular interest here: the committee for seismic isolated buildings, the committee for steel structures, the committee for concrete structures, and the committee for tall buildings (defined as buildings more than 60 meters in height). Each committee is composed of about 20 university professors who meet periodically to review submittals from designers and construction companies.

The isolation committee must review every isolated building, and if it is more than 60 meters in height, the high-rise committee must also review it. The high-rise committee will review buildings that incorporate dampers if the buildings are taller than 60 meters. If the designers are seeking to reduce the design forces below the code minimum through the use of dampers, regardless of the building height, either the steel or concrete committees will review the buildings. Buildings incorporating special materials (e.g., viscoelastic materials for damping devices) as part of the lateral force resisting system may also be subject to review by the appropriate committee.

In addition to administering the approvals process, the BCJ publishes a journal entitled *The Building Letter*, which documents all of the licenses granted by the various committees and periodically includes design recommendations that, taken together, define a sort of informal code. Designers tend to follow these recommendations to speed the review process. For an experienced company, the review may only take one month because their design processes have previously been reviewed and approved. An inexperienced company may take more than two months to get through the review process, depending on how responsive they are to the review committee's questions. A review typically costs about 1.8 million yen ($18,000), depending on building size.

Prior to the Kobe earthquake, the BCJ committee for isolated buildings met every two months to review submittals for, on average, two buildings; after the earthquake, this commit-tee has been meeting monthly, reviewing up to 20 buildings at a time. Many of the statistics on numbers of applications, building function, and isolation device type presented in this paper have been summarized from the BCJ *The Building Letter.* While this is a straightforward task for isolated buildings because there is a specific committee for isolated structures, it is not as simple to extract data on buildings with passive dampers from the BCJ publications. Unless due to height or design force reduction requirements, as described above, many of the buildings with passive dampers do not require any form of BCJ review. For these reasons, the statistics on buildings with passive damping systems are much less complete.

Use of Isolation and Damping Technologies in the United States

There was a great deal of interaction among researchers in New Zealand, Japan, and the United States throughout the 1980s, ensuring that advances in the technologies of seismic isolation and passive energy dissipation were disseminated widely. The rate of applications in New Zealand and the U.S., however, could not keep pace with Japan and its booming economy. By 1990 there were only four isolated buildings and no buildings with passive dampers completed in the U.S. By the end of 1993, three weeks before the 1994 Northridge earthquake, eleven isolated buildings had been completed, and two buildings had been retrofit using passive dampers.

When the Northridge earthquake struck southern California on January 17, 1994, at least five isolated buildings experienced measurable ground motions. The USC University Hospital in east Los Angeles, approximately 35 km from the epicenter, sustained stronger shaking than any other isolated building ever had previously. Peak ground accelerations of 0.38g below the building were attenuated to less than 0.13g over most of the superstructure, making this building a focal point for international study, and many researchers and engineers from around the world came to Los Angeles in the weeks following the earthquake (Asher et al., 1997).

The favorable performance of the USC University Hospital demonstrated that seismic isolation was a viable earthquake-resistant design approach. However, another important lesson from the Northridge earthquake—confirmation of the potential for severe, impulsive ground motions in the near-source region—came from numerous strong motion recordings in the northern San Fernando Valley and subsequent seismological studies. These records have led to a new generation of designs for isolated buildings, and as the technology has matured, the number of applications has increased steadily. At the end of 1998, there were approximately 40 isolated buildings completed or beginning construction in the United States, with more than 20 buildings incorporating passive damping systems for seismic protection either completed or in the design phase.

Research Survey

Survey Approach and Process

The goal in performing a formal written survey was to achieve a more quantitative and consistent form of measuring and evaluating the changes in the Japanese construction industry than could have been derived from a series of isolated interviews. The written survey also allowed a wider range of individuals and companies to be reached than could be accomplished in one-on-one meetings. The ultimate goal was to identify the catalysts in the post-earthquake environment that led to changes in practice. This required going beyond *Question Number 1* to collecting data on a wide variety of issues related to technical decision making, economic implications, and the expectations of building owners and the general public.

Two separate questionnaires were developed, with alternate pages in English and Japanese to allow the widest possible audience to be reached. The first questionnaire was targeted specifically at building designers and construction companies, with a total of 30 questions grouped into six categories:

- General issues
- Project-specific information
- Design process
- Owner requirements and economics
- Regulatory and approval issues
- Future trends

The second questionnaire was developed for a more general audience, including building owners, researchers, and regulators. This questionnaire contained a subset of 13 questions and did not include project-specific questions or questions regarding the design process. A two-page sample of one of the questionnaires is provided in Figure 4. With almost every question, ample room was provided for respondents to add their own opinions or comments.

It was recognized early in planning the survey that an exhaustive distribution (e.g., to all members of the Architectural Institute of Japan) was not possible, and it was not easy to identify a statistically representative subset of engineers or building owners. Instead, a list of approximately 120 individuals and firms was developed from the authors' personal contacts, recommendations from colleagues, members of industry associations, and academics involved in government design review committees. Questionnaires were mailed to this group first, and additional questionnaires were distributed during a visit to Japan. Several more questionnaires were distributed through third parties as well as at the annual meeting of the Japan Society for Seismic Isolation (JSSI). In general, those surveyed were given one month to respond, although questionnaires continued to be returned for some months after the initial distribution.

Of the approximately 150 questionnaires distributed, 63 people responded for a return rate of better than 40 percent; 32 of the *designer* questionnaires were returned, and 31 *owner/ researcher* questionnaires were returned.

It was initially feared that the approach outlined above might lead to a biased sample because the first list of potential recipients was made up from a selection of the largest construction companies and most of the major structural design firms in Japan. Very few of the engineers on this list represented small companies. It turned out, however, that the final group of respondents was quite diverse, since individuals from small companies tended to respond at a higher rate than those from large companies, and a number of the third-party referrals and JSSI meeting attendees were from small companies. It should be noted that respondents in the *designers* group generally had similar backgrounds and held similar positions in their respective companies; the *owners/researchers* group was made up of people with a range of different backgrounds, making it difficult to generalize the answers from this group to a broader sample.

The second part of the data collection effort involved visits to a number of building sites, design offices, and research facilities in Japan. These one-on-one meetings allowed more in-depth discussion of the issues raised in the questionnaires and provided the opportunity to follow up on interesting tangents to the main conversation. The authors worked from a set of introductory questions, and then let the conversation proceed unscripted. Each meeting typically closed with *Question Number 1*, after all of the other issues had been discussed. More meaningful information was often gleaned from gatherings held after business hours than from those that took place in the formal confines of company meeting rooms.

Detailed Survey Results

This section presents selected results from the questionnaires, grouped within the various themes as outlined above. Where it is believed to be important, the full text of the question is listed before the summary of responses; other questions are paraphrased for brevity. The following notes apply: *[sliding scale]* means the respondents were asked to mark an "x" on a scale between extremes such as "not at all" to "very often," and the answers were assigned numerical values to assist in reducing the data; *[Y/N]* means a yes-or-no question; *[list]* means a list of choices was provided. Question numbers listed correspond to those used in the questionnaire distributed to the *designers*; the numbers in the *owners/researchers* questionnaire were slightly different, since this questionnaire was a subset of only 13 of the 30 questions. Numerical answers are not always consistent throughout the survey due to phrasing of the questions or incomplete responses.

Distinctions are made in the responses among the various subgroups (*designers* vs. *owners/ researchers*) where there were significantly different trends in the answers. Comments were encouraged on almost all of the questions, and respondents were candid and frank in answering the survey questions and providing lengthy comments. The majority of respondents seemed to approach the survey as a unique opportunity to express their personal opinions on the issues and not as a platform for promoting any corporate or nationalistic beliefs.

22. Were life-cycle and/or cost-benefit studies performed to assist in the decision to use these new technologies on projects done by your company?

No ❑ Yes ❑

If yes, please describe:

____

____

____

23. What types of clients are implementing new technologies?
(Please select all that apply; if you can, please provide an example of the associated building function, e.g. hospital, condominium)

	isolation	***damping***
a. individual owners	❑	❑
typical building function: ____________________		
b. small companies (less than 500 employees).....	❑	❑
typical building function: ____________________		
c. large companies (more than 500 employees)....	❑	❑
typical building function: ____________________		
d. local government...	❑	❑
typical building function: ____________________		
e. national government	❑	❑
typical building function: ____________________		
f. other..	❑	❑
typical building function: ____________________		

Please add any additional comments:

____

____

____

24. a. What is the average additional project cost associated with implementing these new technologies in buildings completed by your company?

(i) for seismic isolation:

Additional Cost as Percentage of Total Construction Cost

-2% 1% 2% 5% 10% 20%

Figure 4 *Two matched pages from a questionnaire, showing questions in both English and Japanese (Japanese version, next page)*

２２．あなたの会社のプロジェクトで、これらの新技術を用いるかどうかの決定を下すために、ライフサイクルや費用・便益に関する調査を行ないましたか?

いいえ ☐　　　　はい ☐

「はい」とお答えの場合、簡単にご説明ください。

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２３．どのようなクライアントがこれらの新技術を導入していますか？

（該当する項目全てをご選択ください。それぞれの項目について、建物用途の例（病院、マンションなど）もご記入ください。）

	免震	制震
a．個人の建物所有者……	☐	☐
典型的な建物用途：________		
b．小規模な会社（従業員５００人以下）……	☐	☐
典型的な建物用途：________		
c．大規模な会社（従業員５００人以上）……	☐	☐
典型的な建物用途：________		
d．地方自治体……	☐	☐
典型的な建物用途：________		
e．国……	☐	☐
典型的な建物用途：________		
f．その他……	☐	☐
典型的な建物用途：________		

その他、ご意見などございましたら、お書きください。

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２４．ａ．あなたの会社によって建設された建物で、これらの新技術を使用するための平均的な付加コストはどのくらいですか？

（i）免震装置：

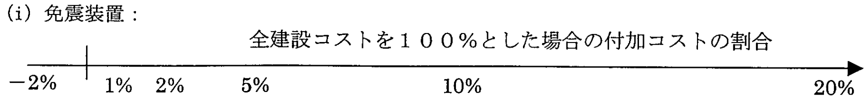

Figure 4 (continued) *Two matched pages from a questionnaire, showing questions in both English and Japanese (English version, previous page)*

Where appropriate, the survey results are augmented with additional information or illustrative examples from the site visits. Comparisons with practice in the United States are also discussed. The information obtained in the site visits was at a far greater level of detail than could be derived from written questionnaires, and in many cases these discussions clarified the implications of the survey results. On a few occasions, the survey results seemed to conflict with information obtained in the site visits. It is not clear if this is due to truly conflicting information or to difficulties in multiple translations of the concepts being discussed.

The first three questions of the written survey are discussed last in this summary, because they tie together all the other survey results in addressing the question of why seismic isolation and energy dissipation are increasing in use in Japan.

Project-Specific Information

The following questions were only included in the questionnaires distributed to the *designers*. Their purpose was to augment the general information provided on the BCJ lists of licensed buildings with more specific data, including unusual applications, types of soils, proximity to faults, and seismic monitoring instrumentation.

Question 4. How many buildings has your company built (before/after) the Kobe earthquake using (seismic isolation/passive damping)?

The results from this question provide one measure of the breadth of the survey, at least with respect to the total number of isolated building projects. The 32 respondents indicated that their firms were responsible for 71 of the 85 isolated buildings built before the Kobe earthquake, and 321 of the approximately 500 approved for construction since (as of June 1, 1998). They also claim responsibility for 28 buildings with passive damping before the earthquake and 125 after. These numbers may be biased upward, since in some cases one construction company and a different structural designer may both have claimed credit for the same building.

When the data are analyzed on the basis of experience, five of the companies represented were involved in 30 or more isolated building projects since the Kobe earthquake, and eight other companies were involved in at least 10 projects. Only two companies were responsible for more than 10 buildings before the earthquake. Four companies had worked on 10 or more buildings with passive damping after the Kobe earthquake; one of these claimed involvement in 28 projects. Of the 29 companies answering this portion of the questionnaire, only one had not been involved in an isolated building. Eleven of the companies had not yet built a building with passive damping.

Question 5. What is the function of the buildings described in #4? [list]

The answers to this question are provided in Table 1. Building functions that contribute to the “other” category for isolated structures included museums, nursing homes, schools, storage facilities, shrines, and chapels. In the “other” category for passively damped structures are hotels, arenas, towers, and a transportation facility.

Table 1 also lists statistics on building function for isolated buildings as derived from the BCJ lists, providing another means of evaluating the breadth of this survey. Discrepancies in the numbers are likely due to several factors: the definitions of building function are not consistent between the survey and the BCJ lists; BCJ often lists multiple functions for a single building; and one or more survey respondents may have been involved in the same building.

Table 1 *Statistics on building function*

Building Function	Number of Buildings Using...		
	Seismic Isolation		Passive Damping
	This Survey	BCJ Lists	
Multi-unit residence / condominium	131	304	5
Commercial Office	63	134	76
Research facility	37	46	3
Computer center	36	14	1
Hospital	34	35	11
Government building	18	NA	16
Communication center	15	6	14
Manufacturing facility	10	8	4
Emergency response facility	6	6	0
Chemical facility	1	NA	1
Other	40	141	9

The Japanese typically use the word “mansion” to describe a single unit in a multi-unit residential building. Typical residential buildings are reinforced concrete frame or wall construction larger than 5 stories in height, and may contain hundreds of individual units. Mansions can either be owned (like a condominium) or rented (like an apartment). Most of the multi-unit isolated buildings built since the Kobe earthquake have been developed for sale to the general public. For this reason, the word “condominium” is used in this paper to describe all multi-unit residential construction.

The 30 publicly owned isolated buildings designed to date in the United States have included offices or courthouses (9), emergency response centers (9), hospitals (4), and university buildings (4). Privately owned buildings include computer centers (8), offices (4), residential buildings (4), and hospitals (3). Note that some of these buildings have multiple functions and are therefore counted twice. Of the 20 passively damped buildings in the United States, 12 of these are publicly owned and serve a variety of functions. The privately owned damped buildings are primarily commercial office space (5 of 8 buildings).

Question 6. Has your company implemented new technologies in other categories of construction? [list]

This question was intended to explore other, unique applications of new technologies, including single-family homes, pieces of equipment, and computer floor isolation. There were a total of 9 isolated single-family homes and 15 pieces of equipment or museum artifacts and works of art, but by far the largest unique application was raised computer floors. A total of 110 isolated computer rooms were identified. In most cases these were for banking computer centers, but a few isolated floors have been implemented in government office buildings and fire stations.

Additional comments provided in response to this question indicated that some of these isolated computer floors were designed to provide protection against vertical ground motion as well as horizontal shaking. The largest application included more than 37,000 square meters of isolated raised floor in a seven-story steel-reinforced-concrete building.

The authors are not aware of any seismic isolated computer floors in the United States, but at least two single-family homes and several pieces of equipment and artwork have been isolated. At least two water tanks have been retrofit with passive dampers in the United States, and at least one tank also incorporates seismic isolation.

Question 7. What isolation systems have been used in the buildings designed and/or built by your company? [list]

A wide variety of isolation systems have been implemented in Japan, and it was quite typical of the early applications to distinguish between the isolator (usually natural rubber with no inherent damping) and the damping mechanism (typically an external, self-contained device such as a yielding steel coil, lead device, or a viscous damper). This question was intended to identify which types of systems are most popular with designers. Table 2 lists the results for the various types of systems.

Table 2 *Numbers of applications incorporating various types of isolation systems*

HDRB	LRB	SLB	LRB + NRB	LRB + SLB	NRB + SHD	NRB + LD	NRB + SLB	NRB + LD + SHD	NRB + VD	Other
82	130	7	35	25	20	18	17	87	11	14

HDRB: high-damping rubber bearing
LRB: lead-rubber bearing
SLB: sliding/friction bearing (includes Friction Pendulum™ bearings)
NRB: natural rubber bearing (no damping)
SHD: steel hysteretic damper
LD: lead damper
VD: viscous damper

Some of the “other” systems included friction dampers, crossed linear rail bearings, and combinations of the various components not specifically listed in the questionnaire. It is typical in large public construction projects in Japan for the isolation systems to incorporate a variety of different devices, often from several manufacturers. This parallels a more general trend in Japanese construction where the general contractor on public projects is often a joint venture, grouping at least one nationally prominent construction company with a number of smaller, local companies.

In the United States, the majority of applications have used one of three isolation systems: lead-rubber, high-damping rubber, or Friction Pendulum™ bearings. At the end of 1998, the number of buildings either completed or with bearings installed that used these systems totaled (Seismic Isolation Engineering, 1999):

- Lead-rubber 17
- High-damping rubber 11
- Friction Pendulum™ bearings 5
- Other 2

Five buildings have used viscous dampers in parallel with bearings in the isolation system.

Question 8: What passive damping systems have been used in the buildings designed and/or built by your company? [list]

The results of this question are summarized in Table 3. The total number of applications of hysteretic devices (all varieties of yielding steel dampers) is 67, compared with approximately 60 applications using viscous or viscoelastic devices. The low-yield-point steels referred to in Table 3 are being manufactured and marketed by several of the major steel companies in Japan with the goal of giving designers more flexibility in specifying hysteretic dampers.

Table 3 *Numbers of applications incorporating various types of passive damping systems*

Low-yield-point (LYP) steel shear walls	6
LYP steel stub columns	22
LYP steel unbonded braces	16
LYP steel triangular yielding elements	4
Normal grade steel yielding devices	15
Viscoelastic dampers	16
Viscous (oil) fluid dampers	43
Friction dampers	4
Other	12

Although a number of hysteretic and friction dampers are available, one of the more popular is the unbonded brace. Installed like traditional bracing, unbonded braces have a steel element that can yield in axial compression without buckling because it is encased in, but not bonded to, a stiff external element. Several types of these devices are manufactured and marketed in Japan.

The viscous damper applications consist primarily of the piston-in-cylinder type of device that is common in the United States, or they consist of large plates moving in hollow wall panels filled with viscous fluid, called viscous damping walls. Damping systems listed as “other” include combinations of viscous and hysteretic devices, beam-end struts (knee braces) using low-yield-point steel, lead dampers, high-damping rubber dampers, and tuned mass dampers for tower structures.

In the United States, the majority of applications of passive dampers for earthquake response have used viscous devices (12 out of approximately 20). Viscoelastic devices are the second most common form of device, and a handful of projects have also used some sort of friction or sliding device.

Question 9: How many buildings has your company designed and/or constructed using new technologies in the following situations? [list]

The goal of this question was to identify special environments in which new technologies have been applied, such as soft soil sites, sites near active faults, or post-earthquake repair or retrofit/ upgrade applications. Table 4 summarizes survey responses. Soil Types 1-3 are standard definitions within the Japanese seismic code, and much of the Tokyo area, where a large percentage of construction is obviously concentrated, is underlain with Type 2 soil.

The relatively large number of applications of seismic isolation on soft soil sites and at locations less than 5 km away from active faults is an indication of the overall constraints on development in Japan. Flat land is scarce, and development is invariably limited to coastal or river plain locations where soft soil conditions are prevalent. Further, there are few areas of Japan that are not close to active fault systems.

One respondent indicated that it was difficult to provide accurate statistics on soil condition and proximity to active faults for buildings constructed by his company, and a number of respondents left these fields blank, so these data are by no means comprehensive. Only a small number of post-earthquake repair applications were noted. Respondents believed that the number of projects on soft soil and the number of retrofit projects would increase with time.

Table 4 *Statistics on construction in special environments*

Site Condition or Type of Construction	Number of Buildings Using:	
	Seismic Isolation	Passive Damping
Soil type 1 — firm	70	19
Soil type 2 — medium	178	62
Soil type 3 — soft	23	8
Very close to an active fault (< 5 km)	19	4
Close to an active fault (5-15 km)	13	1
Near an active fault (15-30 km)	28	6
Post-earthquake repair	1	3
Retrofit or upgrade	6	4

This was borne out in discussions with representatives of several construction companies who indicated that the local and national governments are mobilizing significant retrofit programs, particularly in and around the Tokyo region. The construction companies are responding by developing marketing programs targeted toward retrofit and upgrade.

Statistics on soil type and fault proximity for the United States are also difficult to obtain, but the authors are aware of only one isolated building constructed on soft soil. It is estimated that well over than half of the applications of seismic isolation, however, are in near-fault regions (defined in U.S. building codes as being less than 15 km from an active fault). Retrofit applications are much more common in the United States, with 19 applications of seismic isolation and 11 of passive damping.

Question 10: What architectural challenges have been faced in incorporating new technologies into buildings? [list]

This question was intended to apply more to isolated buildings than to damped buildings. Following is the list of potential answers and the percentage of "yes" replies:

- Gap detailing (79 percent)
- Configuration of lateral force resisting system (28 percent)
- Utilities systems—mechanical/electrical/plumbing (31 percent)
- Other (7 percent)

Comments in response to this question were numerous, with many focusing on accommodating deformations across expansion joints, bridges, and hallways between adjacent structures, some of which were not isolated. Other interesting comments discussed problems with uplift along reinforced concrete walls in which architectural finishes had to be modified to accept both horizontal and vertical movements, allowances for the isolation gap on small pieces of land, details for flexible utilities when the isolation gap is at the mid-height of a floor, and elevator details. One respondent described a condominium building in which small vibrations frequently activated gas shutoff valves.

There were relatively few written comments related to the influence of new technologies on selection and configuration of lateral force resisting systems, but this issue was highlighted several times during the site visits. One example is a tall concrete building, shown in Figure 5, that has a two-story space frame extending from its main tower at the lower levels. This outrigger frame was required to prevent uplift in the isolators by distributing the overturning loads from the tower to the perimeter of the foundation system.

Another interesting aspect of this building was the selection of the isolation plane. The isolators are placed at the top of the first story walls, just below the space frame, a configuration referred to by the designers as capital isolation (Figure 5a). Architecturally, this emphasizes the presence of the isolation plane rather than hides it.

The issue of lost floor area over the height of the building as a consequence of the perimeter setback required for the isolation seismic gap was addressed by one owner, who indicated that he added an additional floor to his building during the design phase to make up for the otherwise lost area.

Another example of the isolation system driving the basic superstructure design derives from a desire to concentrate loading in a small number of isolators, thereby reducing the number of bearings required and permitting a longer-period system with a larger displacement capacity to be used. The schematic shown in Figure 6 illustrates how a system of transfer trusses in the

(a) Overall view of building *(b) Detail of isolators at top of first floor wall*

Figure 5 *Reinforced concrete building with outrigger space frames and capital isolation*

lower portion of a frame is used to bring load from 24 columns into only eight bearings. This concept has been used on a number of large buildings to date.

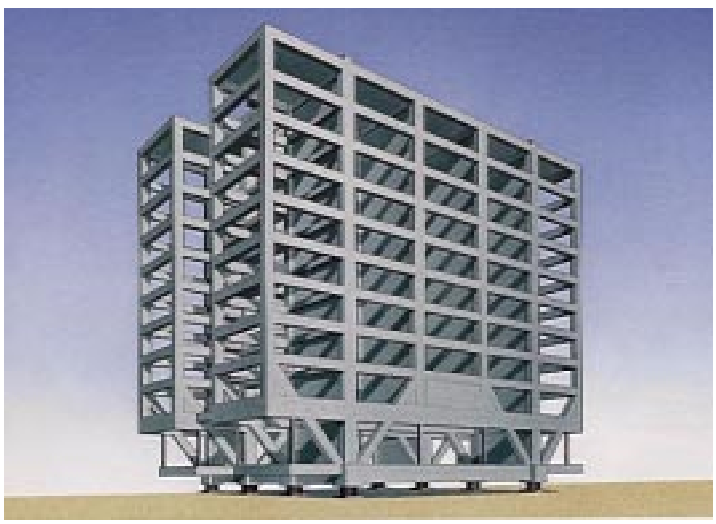

Figure 6 *Transfer trusses in lower stories of an isolated building to concentrate vertical load in a reduced number of bearings*

An installation of passive energy dissipation devices with implications for architecture and space planning is illustrated in Figure 7. The panels installed in the checkerboard pattern over the height of the structure (Figure 7a) are viscous-damping walls. It can be seen that the archi-tects clad only the central portion of the tower with glass, presumably because the windows would have been blocked by the viscous-damping walls in the exterior bays.

It is interesting to note that while the structural system often drives the architecture in Japan, in the United States the choice of seismic isolation or passive energy dissipation has in some

(a) During Construction (b) Completed Building

Figure 7 *Vertical distribution of viscous-damping walls in a tall building*

cases been made with the goal of preserving existing architecture. Such is the case for the retrofits of the Salt Lake City and County Building; the Oakland, San Francisco and Los Angeles city halls; and several other historic structures. In each of these buildings, a major factor in the selection of seismic isolation was the opportunity to minimize the degree to which the existing structure required intrusive lateral strengthening.

Question 11: a.) Are buildings incorporating new technologies being equipped with instrumentation to observe seismic response? [Y/N]; b.) What types of instrumentation are used? [list]; c.) Who pays for the instrumentation system? [list]

With the large numbers of buildings being built using seismic isolation and passive damping systems comes the opportunity to observe the behavior of these technologies in future strong earthquakes. The BCJ review process required that instrumentation be installed in many of the early projects, but more recently only government buildings with isolation have required instrumentation.

Eighty-one percent of the respondents indicated that at least one of the buildings they were responsible for had instrumentation. Although some respondents indicated that accelerometers were used in all of their buildings, in general only about one-third of all buildings are equipped with accelerometers. Apparently very few buildings have displacement transducers, although one construction company installs displacement transducers on 50 percent of their buildings.

Many of the respondents indicated that they often recommend that instrumentation be installed, but the final decision is typically made by the owner. According to one respondent, they will install instrumentation when they believe it may assist them in future technical development for particular building types or structural systems. When some form of instrumentation is used, the owners cover the costs in more than half of the projects.

Construction companies may pay for instrumentation about 25 percent of the time, typically when they are seeking specific data. There are no public subsidies available for seismic instrumentation. This is in contrast to practice in the United States, where virtually all seismic instrumentation is installed and maintained using public funds (for example the California Strong Motion Instrumentation Program and USGS instrumentation networks). The majority of the early applications of seismic isolation and passive damping have been instrumented, but it is becoming less common to instrument these buildings today.

Design Process

These questions were intended to identify trends in seismic design criteria (e.g., target isolation period, allowable interstory drift) as well as information about how specific devices are designed and selected. There were also several questions focusing on testing requirements, long-term maintenance issues, and education. These were only included in the questionnaire for *designers*.

Question 12: What are typical values of structural parameters used by your company in the design process? [list]

A multilevel design process incorporating nonlinear time-history analysis is typically required as part of BCJ reviews. Several ground motions are chosen and scaled to peak ground velocities corresponding to Level 1, Level 2, and in some cases Level 3 seismic intensities. In general the building is intended to remain elastic at Level 1 and 2 intensities, and the margin of safety is checked under the Level 3 ground motions. The first part of this question therefore focused on specification of seismic inputs.

Almost all of the *designers* reported scaling to 25 cm/s for Level 1, and 50 cm/s for Level 2, although one designer specified 50 and 100 cm/s for these intensities. There were more diverse answers for the scaling of the Level 3 inputs, ranging from 67.5 cm/s to 75, 80, or even 100 cm/s. One respondent indicated that his firm increments the ground velocities by 5 cm/s in a series of Level 3 analyses as a means of establishing the safety margin.

The ground motions used for time-history analysis have typically included two or three historical records and at least one site-specific ground motion. This reflects informal requirements for the BCJ review. Of 23 respondents listing specific input motions, 19 indicated that they use the El Centro (1940) record, 18 listed the Hachinohe (1968) record, and 16 listed the Taft (1952) record. These were by far the most popular ground motions used prior to the Kobe earthquake. Five respondents named specific records from the Kobe earthquake now in use, and one respondent listed the Sylmar record (Northridge, California, 1994). Twelve respondents indicated that they supplement historical records with simulated motions for the site-specific evaluation.

Respondents were next asked to list typical isolation system design quantities. Sixteen of 24 respondents specified target periods in the range of 3 to 4 seconds, several indicated some applications with periods as short as 2 seconds, and one preferred longer periods between 4 to 6 seconds. Target levels of equivalent viscous damping were selected as 15 percent or less by four respondents, seven respondents indicated target damping levels between 15 and 20 percent, and five respondents specified damping values greater than 20 percent. Twelve respondents indicated design displacements in the range of 40 to 65 cm, six listed displacements below 40 cm and as low as 19 cm, and two listed displacements greater than 65 cm and ranging as high as 90 cm. Two respondents commented that in soft soil applications they preferred to use displacements 1.5 to 2.0 times greater than those listed.

Several different superstructure criteria were summarized by the respondents, beginning with allowable interstory drift. This quantity had a significant scatter, ranging from drifts as low as 1/1000 to as high as 1/100, with the typical value between 1/200 and 1/300. These drift limits may be reflective of the use of more reinforced-concrete shear wall systems for isolated buildings in Japan, compared with the tendency toward steel frame structures in the U.S. There was relatively good agreement among the responses for allowable structure acceleration, with 15 out of 16 respondents indicating values between 0.2 and 0.3g. The median tar-get base shear coefficient was approximately 0.15, with most responses falling between 0.12 and 0.18.

Seismic isolated buildings designed according to United States building codes likely have narrower ranges of performance than those identified for Japanese buildings. A multilevel design procedure is required in the U.S., but it is typically based on probabilistic site-specific spectra. A minimum of three historical ground motions are required for time-history analysis, and in most cases designers will choose seven records to take advantage of averaging procedures for design. The records are usually amplitude- and frequency-scaled such that their averaged spectrum matches the target spectrum for the site at a specified return period. Synthesized ground motions are not typically used.

Target isolation system periods in the United States are generally slightly lower than those used in Japan, most likely because the softer soils in Japan lead designers to select longer periods. Many of the isolated building projects in the U.S. explicitly consider near-source ground motions in their design, and this leads to design displacements near the upper bound of the reported Japanese displacements (e.g. 75 cm maximum).

Target elastic drift levels in the United States are typically larger than those in Japan. Approximately 90 percent of all Japanese isolated buildings are reinforced concrete frames and walls, while the majority of new isolated buildings in the U.S. are of steel construction. Target base shear coefficients for design of isolated buildings in the U.S. are typically well below 0.20, though in near-source environments, the design base shear coefficients can be larger than 0.30.

Question 13: How does your company specify isolation or damping devices? [list]

Of 24 responses to this question, 12 indicated that a single device design was specified in more than 95 percent of their projects. Four of the designers used a general performance specification in at least some of their projects, and seven of the designers frequently develop multiple designs for different types of systems. Many of the respondents commented that their selections depend to a large extent on the type of building under consideration, and the owner often is asked to approve their final recommendation.

The tendency toward a single design was probably the typical approach early in the development of isolated buildings in the United States, but today the trend is toward multiple designs for different types of systems and general performance specifications.

Question 14: a.) Do you select standard device sizes from manufacturers' technical catalogs? [Y/ N]; b./c.) Do isolation/energy dissipation device manufacturers provide design assistance? [Y/N]

Eighteen out of 26 respondents indicated that they typically select standard device sizes based on catalogs. Among those who indicated that they use custom sizes for their particular projects, there was acknowledgement that this resulted in higher costs.

Twenty-one out of 27 respondents indicated that the manufacturers of isolation devices provide design assistance, and 18 out of 22 indicated that the manufacturers of energy dissipation devices provide design assistance. It appears from the comments that this question may have been misunderstood, because some of the respondents answered "no," with the comment that they have their own design procedures and therefore do not request assistance. Also, the representatives of the construction companies indicated that they often use their own proprietary systems, so obviously no design assistance is necessary.

None of the manufacturers who supply the U.S. seismic isolation and damping market has standard catalogs, with the exception of Japanese manufacturers. In most cases, designs for isolators and dampers in the U.S. are done on a project-by-project basis, although many of the manufacturers now have a range of sizes for which they have existing manufacturing equipment and test data available.

Question 15: a.) Has your company used devices manufactured by companies outside of Japan? [Y/N]; b.) Might your company use devices manufactured outside of Japan in the future? [Y/N]

Of the 28 responses to this question, only four respondents indicated that they had used foreign devices in their projects, but 82 percent indicated that they might in the future, should the price, delivery timing, and technical performance be acceptable.

In the United States, several international companies are often on the bidders list for seismic isolation projects. The majority of the passive energy dissipation devices used in the U.S. are made domestically.

Question 16: Does your company consider the performance of contents or other non-structural elements in designing buildings incorporating seismic isolation or passive damping? [Y/N]

More than 50 percent of the respondents indicated that they explicitly consider the performance of building contents in the design process. The most typical way this is achieved is by specifying an allowable floor acceleration that is derived from operational requirements of critical equipment in computer centers, telecommunications facilities, or biotechnology facilities. One respondent indicated that his office communicates anticipated acceleration levels to the mechanical and electrical design teams so they can provide appropriate detailing for equipment.

In the United States, simplified lateral force procedures are used for the design of mechanical and piping systems, and these are sometimes also used as the basis for the design of other nonstructural components and equipment. The authors are aware of only a few U.S. projects that have specified target floor acceleration requirements to protect particular internal components and equipment.

Question 17: a.) Is testing of devices required on your company's projects? [Y/N]; b.) If so, who requires the testing? [list]; c.) What testing protocol is used? [list]

Twenty of 23 repondents indicated that project-specific testing is performed, but there were conflicting answers regarding the testing requirements. Several respondents indicated that testing was required as part of the BCJ approvals process, but others reported that in the majority of cases the designer required the testing.

It appears from the various comments that the testing requirements depend on the building function as well. Some designers enforce a policy of testing 100 percent of all bearings for each project, while others perform testing when insufficient test data are available for a particular device design. The majority of respondents indicated that testing protocols are typically specified by designers on a project-by-project basis, although several reported that they had followed protocols specified by the device manufacturers. Some designers and construction companies have their own standard protocols, which they apply to every project.

It remains U.S. practice to test all isolators for every project before they are installed in the building. This typically involves a sequence of quality control tests following a protocol very similar to that recommended in the Uniform Building Code (ICBO, 1997).

Question 18: Is there any long-term maintenance, inspection, monitoring, or periodic testing program for the isolation/damping devices used by your company? [Y/N]

For isolated buildings, the BCJ review process currently requires that a long-term maintenance document be submitted for each building, and a maintenance subcommittee is responsible for review of this plan. For buildings with passive damping, it is solely the option of the designer as to whether or not long-term monitoring is implemented, and it is the owner who typically pays the cost of any long-term maintenance or monitoring program.

In almost all of the buildings visited, either full-scale or reduced-scale isolators were stored in the basement of the structure near the installed bearings. These were typically pre-compressed to their design load and kept on small carts to allow them to be removed easily. A typical retesting program might include tests at 1, 2, 5, and 10 years after construction, and every 10 years thereafter. The maintenance program for a particular building might also include a provision for the seismic gap to be inspected for obstructions every six months.

The majority of applications in the United States also include the provision for a number of extra isolators or dampers to be manufactured and installed in the building for future testing.

Question 19: How have designers in your company been educated in the use of new technologies? [list]

The purpose of this question was to understand how the engineering community was able to understand and implement a new suite of technologies for seismic design within a relatively short period of time after the Kobe earthquake. Of 29 responses to this question, the following types of education were reported: in-house seminars or training (15 responses); seminars by manufacturers (14); seminars by professional organizations (19); national or international conferences (9); company design manuals or guidelines (13); publications by professional organizations (18); university courses (0); and other (3, primarily on-the-job training). Based on these responses, it appears that professional organizations have played the most significant role in preparing designers for the implementation of new technologies. The Japan Society for Seismic Isolation (JSSI) and the Architectural Institute of Japan (AIJ) are the lead organizations in these efforts.

There is no direct parallel to JSSI in the United States, and to date there has not been any industry-wide educational effort to transfer to engineers and architects the skills needed to design isolated buildings and buildings with passive damping systems. The structural engineers' associations, particularly in California, have organized seminars on many of these topics, but there is no one source of educational materials and design support. Instead, the various manufacturers provide their own materials to assist designers.

Owner Requirements and Economics

The questions in this section were intended to determine how the market for buildings that incorporate new technologies is being driven by owner demand, and the reasons owners are considering these solutions to the earthquake problem. These questions were included in the questionnaires distributed to both *designers* and *owners/researchers*.

Question 20: Why are building owners investigating the use of new technologies? [list]

The list of possible answers to this question and a summary of the responses are presented in Table 5. The numbers in Table 5 represent the number of respondents (from a total of 60 who answered this question) that believe seismic isolation or passive damping is being used by owners to meet particular goals. The respondents clearly indicate that owners expect more benefits as a result of using seismic isolation compared with using passive damping.

It is interesting that the various benefits associated with seismic isolation are weighted fairly equally. One respondent suggested that while owners may select isolation for one primary reason, after the decision is made, they have expectations for a broad range of benefits. Expectations associated with passive damping are clearly focused on improved structural performance, particularly for tall buildings. It was not entirely surprising that 41 out of 60 respondents indicated that seismic isolation could be used to make a property more attractive to potential buyers or tenants, since some developers use isolation to differentiate their proper-

Table 5 *Owners' reasons for implementing new technologies*

Goal	Seismic Isolation*	Typical building function(s)	Passive Damping*	Typical building function(s)
Damage control for structure	39	Public usage (police/fire), offices, condominiums, historic structures	28	High-rise buildings, office buildings, telecommunications
Damage control for contents	46	Hospitals, computer centers, condominiums, research and manufacturing facilities	15	High-rise buildings
Seismic protection as a leasing/selling point	41	Condominiums, office buildings	13	Office buildings, government buildings
Improved life safety	38	Hospitals, schools, nursing facilities, condominiums	15	Long-span structures
Protection against business interruption	44	Computer centers, hospitals, emergency centers, offices, telecommunications	13	Office buildings, telecommunications, government buildings
Other	7	City centers, retrofit houses (peace of mind)	7	Improved comfort, retrofit, wind

* 60 responses were received between the *designers* and *owners/researchers*

ties in marketing materials. However, it was the impression of many that the general public was becoming less willing to pay a premium as the memory of the earthquake fades and the economy remains somewhat slow.

Detailed statistics related to owner attitudes are not available in the United States, but it is known that a large number of the seismic isolation retrofit projects have been undertaken to preserve historic structures and to allow continued occupancy during retrofit. Many of the new isolated buildings are emergency centers and hospitals constructed with the intent of remaining fully operation after a major earthquake. Applications of passive dampers have typically been undertaken with the goal of minimizing damage to the primary structural frame and minimizing business interruption. There are no significant applications of either technology in the United States in which the goal has been to enhance life safety in residential structures.

Question 21: Have you recommended to your clients that they use these new technologies? [Y/N]

(This question was only asked of the *designers*.) More than 90 percent (27/29) of those surveyed answered yes to this question, and three of the respondents volunteered that they recommend these technologies wherever possible, particularly for hospitals, telecommunications centers, and emergency management centers. This provides clear evidence that not only are building owners requesting new technologies, but also that designers are consistently promoting their use.

Question 22: Has your company performed life-cycle and/or cost-benefit studies to assist in the decision to use new technologies? [Y/N]

Approximately 60 percent of the *designers* who responded to this question reported that their firm had undertaken some form of cost analysis, but the majority of these studies evaluated only initial construction costs. Four of the *designers* commented that they try to perform life-cycle cost studies that include probability of damage and long-term maintenance expenses. Fewer than 50 percent of the respondents in the *owners/researchers* group reported participating in cost studies, but of the four actual building owners surveyed, all of them answered affirmatively.

Long-term maintenance costs were one of the most frequently cited concerns. Another owner suggested that they evaluated initial costs with respect to the selling price of individual condominium units to help with their advertising. This theme was also mentioned by representatives of one of the construction companies, who described a study in which their company had determined the cost premium to purchase a condominium unit in an isolated building was approximately equal to the price of a new car.

There are some instances of life-cycle costs being performed in support of retrofit or new building designs using isolation or damping in the United States, but to the authors' knowledge these are relatively uncommon.

Question 23: What types of building owners are implementing new technologies? [list]

This question was the corollary to Question 20, and the results are provided in Table 6. The question was intended to identify the types of owners most likely to invest in or purchase a building incorporating seismic isolation or passive damping. For example, 30 of 59 respondents indicated that individual owners are likely to consider purchasing a condominium unit in an isolated building, and the statistics in Table 1 clearly show that condominium and multi-residence owners make up the largest single category of owners of isolated structures.

Table 6 *Types of building owners implementing new technologies*

Owner	Seismic Isolation*	Passive Damping*	Typical building function(s)
Individual owners	30	5	Condominiums, shops, small offices, houses
Small companies (less than 500 employees)	17	4	Office buildings, hospitals, nursing homes, factories
Large companies (more than 500 employees)	38	27	Main offices, computer centers, research facilities
Local government	33	10	City halls, fire stations, schools, offices, hospitals, emergency centers, towers
National government	28	14	Offices, computer centers, museums, hospitals, emergency centers
Other	9	4	Condominiums built by developers, hospitals, storage facilities

* 59 responses were received between the *designers* and *owners/researchers*

Large companies are also perceived to be interested in new technologies for their critical facilities, and the majority of applications have been for large corporations or large developers. One respondent indicated that developers were attempting to attract tenants in leased office buildings by specifying damping systems for improved seismic performance. Public agencies that were once very conservative in implementing new technologies have become more aggressive, in large part due to pressure from their constituents. Also, many older public structures in Japan are vulnerable to future earthquakes, and new technologies are being considered that would allow retrofit without vacating these buildings during construction and that would minimize the amount of invasive construction work required.

The split between public and private owners in the United States is approximately equal, with local and state governments undertaking the majority of projects in the public sector and large corporations undertaking the majority of projects in the private sector. Only three of the approximately 50 isolated buildings in the U.S. are owned by individuals; two of these are single-family homes and the third is a small apartment building. None of the buildings in the U.S. that incorporate passive damping is owned by individuals; about half of these structures are owned by public agencies.

Question 24: a.) What is the average additional project cost associated with the use of (i) seismic isolation (ii) energy dissipation? [sliding scale]; b.) What is the acceptable additional cost? [sliding scale]; c.) Is the cost of new implementing new technologies decreasing? [Y/N]

A numerical summary of the answers to this question is provided in Table 7. Several respondents indicated that it was difficult to generalize cost trends because of the variety of applications for isolation and energy dissipation, but there was good agreement between the *designers* and *owners/researchers* on current cost premiums. The potential for a negative premium was suggested by one respondent for situations in which a passive damping system allows significant reductions in the primary lateral force resisting frames.

Table 7 *Cost premiums (percent of total structural cost) associated with the use of new technologies*

Cost Premium	Seismic Isolation (current)		Passive Damping (current)		Acceptable for New Technologies	
	Designers	Owners/ Researchers	Designers	Owners/ Researchers	Designers	Owners/ Researchers
Average*	7.8	7.5	5.8	5.4	7.2	5.6
Minimum	1.5	3	-1	1	2	0
Maximum	15	20	15	20	15	20

*25 *designers* and 24 *owners/researchers* answered this question

Eighty-four percent of the respondents reported that the costs associated with implementing new technologies are decreasing, but there was concern that safety margins for these buildings were also decreasing. The primary reduction in cost was reported to be associated with decreases in isolator costs due to standardization and economies of scale. The costs of damping systems do not appear to be declining as rapidly. One respondent indicated that design costs remain high due to the approvals process.

Relatively few industry-wide studies of construction cost premiums associated with isolated and damped buildings have been conducted in the United States. Because the U.S. construction industry tends to be more price-driven than it is in Japan, uncertainties associated with construction cost for isolated and damped buildings may serve to slow the adoption of these approaches.

Question 25: Has the use of new technologies resulted in construction schedule problems? [sliding scale]

There was significant disagreement between the *designers* and the *owners/researchers* on this question. The average *designer* indicated that construction problems were about the same as for a typical building, with seven out of 29 respondents reporting “many” problems. Three *designers* reported only “minor” problems, the lowest possible answer on the scale. In contrast, 11 out of 20 *owner/researchers* suggested schedule problems greater than for typical buildings; only one reported “minor” problems.

The primary complaint associated with schedule was the length of time required for the BCJ review process. It was implied that some owners did not want to wait the additional one to two months for the review process, and in some cases this meant that seismic isolation was dropped from consideration. Some respondents indicated that construction took longer for certain types of buildings, and “people in construction sites are not familiar with dealing with gaps and isolation systems.”

There are clearly impacts on schedule for some buildings built in the United States with new technologies because of the tendencies for extensive testing and peer review. Design and analysis is often more complicated as well, which can lead to additional delays. Even so, there have been at least four fast-track projects in the U.S. that have incorporated seismic isolation technology. Fast-track projects require the preselection of the isolation system supplier so that they become part of the project design team at the earliest possible stage.

Question 26: Does your company consider potential legal liability when using new technologies? [Y/N/]

Forty-three percent of the *designers* and 53 percent of the *owners/researchers* indicated that they do consider liability issues. The range of comments on this issue was very interesting. Many of the respondents believed that the BCJ review process protected them from liability. Some felt that there was an implied higher performance with isolated buildings compared to conventional buildings and this better performance lessened their potential liability. Some were uncertain as to the extent of liability and felt that the responsibilities of manufacturers, designers, and contractors should be clarified. One suggested that their firm provided “warranty documents” to their clients. Several of the respondents indicated that as Japanese seismic codes become more oriented toward performance-based design, the “constructors will have to take responsibility in the event of unsatisfactory performance due to strong earthquakes.”

Expanding on this comment, one individual reported that “I believe that we don't have legal liability, but we are morally responsible.” Discussions with employees of several construction companies showed just how seriously they take their responsibility to their clients. After the Kobe earthquake, all of these companies had a tremendous amount of work in the Kansai area. However, they reported that they also lost a great deal of money because their work for clients with damaged structures was billed at or below cost, as a show of good faith and responsibility.

Liability has been a significant concern for designers of buildings incorporating new technologies in the United States. This has been one reason behind the push for provisions for these approaches to be incorporated into design codes. One of the reasons that peer review is accepted is that it provides designers with some liability protection under “standard of care” statutes.

Regulatory and Approval Issues

The purpose of these questions was to investigate the efficacy of the current system for designing and approving buildings with seismic isolation and passive damping. Although the mechanics of the process were relatively well understood prior to the survey, this section of the questionnaire gave respondents the opportunity to provide their own opinions on the strengths and drawbacks of the current system as well as suggestions for improvement.

Question 27: What design codes / guidelines / regulations are used for: a.) seismic isolation; b.) energy dissipation/passive damping?

The respondents indicated that for seismic isolated buildings the informal guidelines published in the BCJ *The Building Letter* are often used for design because they help to ensure a relatively smooth approval process. A number of respondents also indicated that they use guidelines developed by AIJ (Architectural Institute of Japan, 1993) and/or JSSI, and it is also possible for companies to submit their own design procedures to BCJ for approval, thus speeding the approval process for their subsequent submittals.

With respect to structures incorporating energy dissipation devices, there appear to be no specific codes or regulations and designers are free to use their own judgment. If the primary structural frame meets the requirements of the building code and energy dissipation devices are provided to enhance performance beyond the bare minimum, no BCJ reviews are required. If the structure falls outside of the building code because it is designed to reduced forces or has nonstandard materials, then a review by the appropriate BCJ committee(s) is required.

Concerns were expressed in some of the interviews that the review process in place after the Kobe earthquake may have resulted in structures that have varying margins of safety, because some designers were trying to reduce costs through the use of inexpensive isolators and designing on the boundary of acceptable performance. This has apparently been addressed in revisions to the review process implemented at the end of 1996, in which a performance-based form of evaluation was developed. In this procedure, the intensity of the design seismic input is classified within four levels (C1 to C4, C4 being the most severe). The resulting structural performance under the specified input is classified within three levels (A to C, A corresponding to minimal damage). As a minimum, all isolated buildings are required to meet the C2-C performance requirements.

In the United States, the Uniform Building Code (ICBO, 1997) contains provisions for the design of seismic isolated buildings, but no such provisions exist for buildings that incorporate passive damping systems. It is typically the local building official, often working in conjunction with a peer review panel, who is responsible for approving any deviations from applicable codes.

Question 28: a.) How easy or difficult was the approvals/permitting/licensing process for your company's most recent project? [sliding scale]; b.) Is the approval process becoming easier?

Both *designers* and *owner/researchers* had very similar answers to part A of this question: the approvals process is "somewhat difficult." There were a wide variety of comments, both positive and negative, suggesting drawbacks in the current system and how the review process could be improved. A number of respondents complained about the time required for approvals and the level of detail involved, and there were suggestions that the process could be simplified for designers able to show sufficient experience. Others reported that too much emphasis was placed on the selection of design ground motions. One person implied that the current system of forming subcommittees of two to three people (within the main committee of 20) to review individual projects leads to varying standards because of the reviewers' varying expertise. There was hope for change, however, as 60 percent of all respondents indicated that the approval process is becoming easier, and many felt that the use of new technologies may increase as this occurs. Some suggested that the responsibilities for approvals for isolated buildings might eventually be transferred to professional institutions like JSSI.

In the United States the approval process typically depends primarily on the involvement of the responsible building official and the peer review panel. The cost and overall time required for the peer review activity in the U.S. varies significantly, depending on the type and size of the project (for example, a large hospital complex would be subject to a much more extensive and lengthy review than would a small residential structure). The review usually occurs in parallel with the design phase, and while it does not necessarily lengthen the project duration, it typical covers a period of at least about two months. As more people become familiar with new technologies, this process is bound to become easier.

Future Trends

These questions were intended to identify possible changes in the Japanese design and construction community in the coming years and to give respondents a final opportunity to express their opinions about the current and future state of seismic isolation and passive damping technologies in Japan.

Question 29: In your opinion, how will the demand for buildings incorporating new technologies change in Japan in the next five years? [sliding scale]

On average, both the *designers* and *owners/researchers* believed that applications of new technologies would increase "a little" in the coming years. Four respondents out of 63 felt that there would be a significant decrease in interest because the general public's awareness of the earthquake hazard was waning, and any construction approach that results in increased costs will be avoided. Trends in the Japanese economy were also acknowledged as having a large influence on future developments. It was generally agreed that "the fever is gone," and only a large earthquake would cause a significant acceleration of applications. Several people were optimistic, however, that the number of publicly owned buildings and the number of retrofit projects would increase, and it was hoped that this might continue to spur applications in the private sector. The evolution of seismic design toward performance-based approaches was also cited as an incentive for growth in applications.

Question 30: In your opinion, what are the future trends in: a.) codes and regulations for new technologies; b.) new devices or approaches to earthquake-resistant design; c.) expectations for the performance of buildings (and their contents) in severe earthquakes?

The majority of individuals are in favor of relaxing and simplifying current codes and regulations toward a performance-based design approach in which the designer's judgment is given more weight. Many realized that this trend will require engineers to "make the effort to have wider knowledge," and "only capable engineers will survive in the future." One respondent made the point that this process must be undertaken in a selective manner, because if, in a future earthquake, an isolated building does not "... perform well, all the effort will be nullified." As in Question 28, many respondents hoped that the approval process would become easier as isolation devices are standardized.

Perhaps half of those surveyed felt that there would be fewer new ideas for isolation and damping devices in the future, with more emphasis on combining systems, reducing costs, and better understanding structural behavior. It was thought that there would be continued development related to vertical vibration isolation and small structures such as houses. Several people indicated the importance of improving damping in high-rise structures and the need to balance energy dissipation between dampers and the primary structural frame. One person suggested that energy dissipation in non-structural elements would become popular, while another felt structural systems would be developed having independent vertical and horizontal load-carrying elements. The desire to move toward performance-based design was reflected in many comments, including "Design[er] should have freedom to [make] a building... either very safe or can collapse in ten years," although this comment rather overstates the designer's prerogative—minimum levels of performance are regulatory stipulations and not simply a matter of choice for designers.

There was general agreement that "people are expecting higher safety without increasing... cost," and some respondents expressed the need to consider performance on a regional level to minimize long-term economic losses. A number of respondents suggested greater awareness of the need to secure contents to prevent injuries and loss of life and realized that isolation and damping technologies will have their real test in future severe earthquakes. Finally, a handful of individuals noted that they "... hope [for] future collaboration between engineers and society."

General Questions: Why Isolation and Damping Now?

Having gained a broad perspective on individual projects, the design process, owner requirements and economics, regulatory and approval issues, and future trends, it is time to return to the first two questions of the survey that address the basic objective of this study: “In your opinion, what is the primary reason that the use of seismic isolation [Question 1] (energy dissipation/passive damping [Question 2]) has increased substantially since the Kobe earthquake?” These two questions elicited much more comment and discussion than any of the other questions in the survey, and the answers were very diverse. Even within each of the various subgroups surveyed (e.g., designers, construction companies, owners, and researchers) there were often divergent viewpoints with no clear consensus. Before discussing the responses to Questions Number 1 and Number 2, answers are provided for the following question, which was included to investigate the awareness within the general public of the changes taking place.

Question 3: In your opinion, how well educated is the general public on earthquake engineering and new technological advances (such as isolation and energy dissipation)? [sliding scale]

There was general agreement among all respondents that the general public was more aware of seismic engineering after the Kobe earthquake because of the prevalence of reports on the damage and reconstruction efforts in the mass media. However, in qualitative terms, the general assessment of the public's knowledge was slightly better than “a little” on the sliding scale of possible responses, and many respondents suggested that public awareness had already waned in the three years since the Kobe earthquake. One respondent felt that the level of awareness likely correlated with experience of strong earthquakes. Several individuals indicated that the Kobe earthquake had focused attention on the lack of understanding of the implications of building codes, particularly the “misunderstanding that codes and regulations guarantee the safety of structures.” It was suggested that damage criteria are understood by structural designers but “... are neither known to nor approved by society,” and structural engineers should “tighten their relationship with society.”

With respect to new technologies, many respondents believed that the general public was vaguely aware of the various approaches but tended to “blindly believe the seismic performance.” One exception was in large cities, where some respondents felt that advertisements for condominiums and television commercials made people aware of seismic isolation, and rubber bearings in particular. One designer felt that company facilities managers, in particular, had changed their attitudes after the Kobe earthquake.

Questions 1 and 2: In your opinion, what is the primary reason that the use of seismic isolation [Question 1] (energy dissipation/passive damping [Question 2]) has increased substantially since the Kobe earthquake?

Among all of the written questionnaires and interviews, the responses to the basic question of why isolation and damping have increased in use can be distilled into the following categories:

- Increased public awareness of and demand for seismic safety that encompasses protection of life and property, particularly the structure and its contents (“Now, the general public knows the danger of earthquakes so they are requiring buildings with better safety”).

- Observed damage to buildings designed according to recent codes, and a critical view or sense of doubt regarding the reliability of traditional construction approaches ("... a gap between structural designers and [the] general public").

- Proof of the maturity and effectiveness of the technologies (particularly for seismic isolation), by the performance of buildings in the Kobe and Northridge earthquakes ("Isolation has moved from the research stage to the... production stage").

- Recommendations from engineering organizations and the Ministry of Construction ("For high-rise buildings, the evaluation committee of BCJ has a strong opinion to use new technologies").

- The large promotional efforts of developers, construction companies, and designers ("... it was good advertisement for general contractors to obtain more clients").

- A form of group behavior capitalizing on the anxiety felt by many after the earthquake ("... they are very much afraid of earthquake hazards").

- People's fascination with new technologies and their desire to be early adopters ("the increase is the response to the demand for aseismically superior technologies").

The survey results clearly indicate that timing plays an important role: passive control technologies were sufficiently mature for widespread implementation prior to the Kobe earthquake, and strong motion recordings from buildings in the area confirmed their effectiveness under moderate earthquake shaking. After the earthquake, the general public gained a greater appreciation for the earthquake hazard and implications of seismic performance, particularly with respect to the costs and time required for repair and reconstruction. Apparently, many people began to take a critical view of traditional forms of construction, and the media, construction companies, engineering organizations, and building development companies began to promote alternate methods of earthquake-resistant design.

The great loss of life in the Kobe earthquake came as a shock to many Japanese because it was thought that the Kansai region was not prone to earthquakes to the same extent as the Tokyo area. The general public seems to understand, however, that while the majority of deaths came in older, traditional-style housing, the difficulties of repair and reconstruction from damage to newer buildings posed an equal social and economic burden. A number of individuals recounted stories about multi-unit condominium buildings damaged beyond repair in the earthquake and the difficulty of balancing the demands of the individual owners in the reconstruction process. The government was apparently slow to intervene in such disputes, and the resulting negative press generated a desire among individuals purchasing new condominium units to prevent future difficulties by investing in seismic isolation. The results of these experiences may be responsible for the more than 300 isolated condominium complexes constructed to date.

Similar trends apply to large businesses afraid of business interruption or losing market share due to earthquake damage. For example, NTT DoCoMo ("Doing Communications Mobile"), the leading provider of cellular telephone service throughout Japan, experienced wide disruptions in service after the Kobe earthquake due to damage to their facilities. Since that time, they have used new technologies in virtually all of their new construction as a means of protecting both their investment in equipment and their business market share. Public agencies responsible for hospitals, emergency response facilities, and other important government buildings have also begun to recognize their vulnerabilities and have adopted new technologies to help ensure that their communities have access to critical services after a major earthquake.

Although the questionnaires and interviews have helped to clarify the technical environment surrounding the adoption of new technologies, there remain conflicting opinions as to whether the demand for new technologies was real or manufactured. Many respondents spoke of the public's desire for personal safety, prevention of property damage, business continuity, and other potential benefits of improved seismic performance. Others, however, stated that promoters created and capitalized on people's anxieties, taking advantage of the country's fascination with technology and the fact that the Japanese term for seismic isolation, *menshin*, translates literally as "free from earthquakes."

Advertisements for isolated condominiums can be found in newspapers and on subway billboards. The majority of the seismic isolated buildings built since 1995 have been large condominium buildings in which individual property owners have willingly paid a premium for enhanced seismic protection. This is in contrast to the experience with passively damped buildings. The majority of passively damped structures have been large office buildings and in communications facilities, in which the owners have specifically required post-earthquake functionality, and have used this to attract commercial tenants. Still, construction job boards that illustrate details of the damping systems, with diagrams of the anticipated reductions in response under earthquake ground motions can be seen in the streets of Kobe—presumably to interest the general public and draw attention to the technologies offered by the construction companies.

A final, disappointing observation that was echoed several times in the written surveys and interviews was the belief that the time had passed in which the public was interested in and informed about earthquake engineering and advances in design practices. Several people in the Kansai region felt that the people took a "soon hot, soon cold" attitude to earthquake risk, and there was the suggestion that because the return period for the Kobe earthquake was estimated to be at least 1000 years, people in the region did not expect another earthquake in their lifetime. Although the "fever" may be over, the construction industry in Japan has clearly acknowledged that seismic isolation and passive energy dissipation are viable methods of construction for an increasingly broad range of structures. However, as one respondent indicated in the final question of the survey, "Even though there is a strong sense of confidence in this technology, there are a lot of uncertainties that will be clarified only after a severe earthquake."

Conclusions

Evolutions in earthquake engineering practice by necessity take place in a diverse environment of conflicting social, economic, and technical influences. Any new methodologies or technologies will face resistance until they are perceived to be better than current approaches with equal or greater reliability and similar cost. The case study of the growth in seismic isolation and passive energy dissipation in Japan provides an example of how being "in the right place at the right time" can lead to broad changes in practice in a short period of time. These technologies were relatively mature prior to the 1995 Kobe earthquake, and the devastating human and economic losses in that event spurred society to look for alternatives to traditional seismic design approaches.

A window of opportunity opened in which the mass media and the development and construction industries educated the general public on the basics of seismic design, and then promoted the newest approaches for earthquake protection to a public that wanted something better. Although extensive research and performance data from moderate shaking were available that illustrated the potential benefits of seismic isolation and passive damping, advertising and promotion also took advantage of people's anxieties, a fascination with new technology, and the quirk of language in which seismic isolation translates as "free from earthquakes."

Several implications for promoting improvements in earthquake engineering practice are clear. The first is preparation — a convincing body of technical development needs to be available before a new approach will be accepted by the construction industry and the general public, and there needs to be an infrastructure of human and material resources (e.g., trade associations, manufacturers, equipment) that can be mobilized as demand for their products and services increases. Unfortunately, the second requirement for accelerating change appears to be a damaging earthquake. It is difficult to accept that human and economic losses are necessary to improve current practice, but the window of opportunity that opens in the wake of a severe earthquake allows more education and technology transfer to take place than would be possible in many years of grassroots effort. It is hoped that the results of this work and the insights drawn will further our understanding of the forces at work in order to achieve better seismic protection for our built environment.

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