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SEISMIC HAZARD MITIGATION DECISIONS USING PBEE: FINANCIAL METRICS AND A CASE STUDY[1]

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SUMMARY

We explore the analysis and communication of seismic investment decision variables to corporate decision makers and investors within the Performance Based Earthquake Engineering (PBEE) framework. One approach in facilitating the communication between the corporate clients and PBEE practitioners is based on making tradeoffs between several alternative levels of mitigation: status quo, moderate/extensive retrofit. Annual exceedance probability curves are obtained from the PBEE framework for three hazard dimensions most frequently demanded by decision makers: number of fatalities, downtime, and structural loss. The level of mitigation and the reduction in structural losses are modeled and simulated using several financial decision-making criteria.

INTRODUCTION

Performance-based approaches to regulation offer several potential advantages over prescriptive approaches. Ideally, they can reduce "rigidity and compliance burdens while promoting innovation and lower compliance costs" [May, 2003]. Assuming effective implementation and enforcement, performance-based earthquake engineering (PBEE) has potential to yield better building performance at lower total cost than code-based engineering by allowing engineers to design customized solutions for specific conditions. If this intent were achieved, PBEE could yield a number of private and public benefits, including better performance in terms of safety, disruption and damage at similar or lower cost (see Table 1).

Though PBEE holds promise for significant advantages, widespread adoption is most likely if it achieves a good fit with the social and economic forces that drive earthquake engineering investment decisions. At this time, engineering clients are accustomed to a code-based decision environment that shields them from the complexity of and responsibility for choices about preparing their structures for earthquakes. PBEE demands far more involvement by clients and, at least in these early days of its development, greater initial expense. The question of how to interest clients in authorizing PBEE assessments is nontrivial.

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Table 1. Potential private and public benefits from PBEE in case of major earthquakes

Fewer lives lost and injuries
Lower direct economic loss
Less disruption
More predictable levels of injury, loss and disruption

The Van Nuys testbed sheds some interesting light on how building owners currently tend to think about earthquake upgrades. Testbed interviews revealed that this building's owners never wanted to consider upgrades other than those mandated by building codes. We examine their reasoning with an eye toward lessons about what might increase building owners' interest in PBEE upgrades. Section 8.2 describes what we learned in Van Nuys about owners' decision processes and criteria. Section 8.3 explores the implications of these findings for potential widespread adoption of PBEE, drawing an analogy to medical practice.

It may be possible to overcome resistance to PBEE by educating clients to its potential advantages. Toward this end, the testbed served as an opportunity to develop an analysis tool tailored to the criteria and contexts of client decisions about retrofit investments. Section 8.4 describes this multiple-objective decision tool. It is building specific, includes the major decision criteria PBEE clients express concern with, and employs the financial metrics preferred by most corporate and financial investment analysts.

Finally, Section 8.5 summarizes the testbed's lessons for PBEE decision-making, including conclusions about how best to promote some early adoption and to assess its potential for widespread adoption. Continued development of site-specific tools and heuristics for potential economic and other benefits would seem to be the keys to potential future adoption.

PAST INVESTMENT DECISIONS

Since the Van Nuys building was damaged in the 1971 San Fernando and 1994 Northridge earthquakes, its owners have been well aware that earthquake risks in this location are real and can significantly affect the value of the property. Damage from the Northridge earthquake was such that the facility could not reopen as a full-service hotel because the economically viable repair and retrofit made it impossible to include an adequate kitchen. Without a full-service kitchen, the earning potential of the hotel was reduced by more than $1 million a year.

Van Nuys has had two types of owners with different economic goals and different levels of business sophistication in the years since Northridge: an investment consortium and an individual owner. As previously mentioned, neither owner type has been interested to make physical seismic improvements other than those required by code. In fact, the testbed building's recent owners were not even interested in exploring the possibility of improved earthquake performance when their engineers and architects raised the option. Both, however, have been concerned enough about earthquake risks to secure earthquake insurance. We explore both owners' thoughts on earthquake preparation in some detail below. Their financial sophistication, asset bases and business goals were quite different but there were striking similarities in their concern (or lack of concern) about the property's earthquake risks.

Investment consortium

An investment consortium specialized in hotel ownership owned the Van Nuys building at the time of the Northridge earthquake. They oversaw the repair and renovation of the building after it was damaged in that quake. We interviewed the architects who worked on the renovation. The architects shared their understanding of the owners' decision criteria based on their interactions with the owners.

The owners were initially interested to return the building to operability for minimum investment. They were not concerned with future earthquake risks beyond meeting the requirements of code. City codes were the most important influence on the design of the retrofit and repair. At one point, the building insurer became an important constraint on the owners' options because the insurer would not accept a shoring solution that was acceptable under older City building codes. In the end, though, damage was so extensive that it was determined the building would have to meet newer codes which, like the insurer, excluded the initially proposed shoring solution. A new structural system was adopted that was, unfortunately, not compatible with returning the hotel to function as a full-service hotel. The hotel was closed for three years for design, repair and re-sale. It finally re-opened as a limited service (i.e., no food or beverages) hotel. As mentioned previously, expected revenues were reduced by approximately $1 million per year because they could not operate a full-service kitchen.

Table 2 summarizes the consortium's repair and retrofit decision criteria. They sought to minimize investment subject to regulatory constraints.

Table 2. Consortium owners' repair and retrofit considerations

Minimum cost
Minimum time to re-open and sell
Meet code requirements
Meet insurer requirements
Resell at good price

We examined the consortium's approach to potential upgrades in terms of three investment-decision variables: the probability of a loss, the magnitude of a potential loss and the likelihood of recouping an investment in improvements. The first two of these relate to the expected losses, the third to expected returns.

Loss probability
Since the consortium was expected to hold this asset for only a short period of time they could have presumed that the chances of another earthquake during the short period of their ownership were quite low. Their expected loss from a quake would therefore not be large enough to justify investment in an earthquake engineering upgrade.

Loss severity
Since the consortium owned hotels in a number of locations, their financial vulnerability to a disaster in any single location was limited. A total loss of this asset would not have been financially devastating. Research in other domains suggests that risk of ruin may often precipitate investments to mitigate the effects of low-probability threats. In this case, geographic diversification ensures that this firm does not face a risk of ruin from an earthquake in a single location.

Direct Return on Investment
The resale value of the Van Nuys hotel had to be a crucial consideration for this set of financially sophisticated owners. If they anticipated that potential buyers would fully value an earthquake upgrade, they would have considered such an investment worthwhile. Their lack of interest in exploring improvements beyond code implies that these sophisticated hotel owners believed that other potential owners would not value earthquake improvements.

Individual Owner

The hotel's current owner purchased the building in 1998, after its retrofit and downgrading from full-service. He is an individual approaching retirement. The hotel is the major asset in his retirement portfolio. He apparently relies heavily on his general manager to ensure the business viability of the property, as he himself has no experience working in the hotel industry.

Unlike the previous owners, the current owner's investment portfolio is not well diversified. A disaster in this location would be a financial disaster for him, yet he lives quite comfortably with this risk. The owner has lived in Southern California his entire life. The hotel's General Manager indicated that the owner is not worried about earthquakes because he has lived with them for so long. This familiar risk does not worry him.

The General Manager has several decades of experience in hotel management, including a number of years in the Los Angeles area. He is familiar with common attitudes and practices in this industry in Southern California. According to the General Manager, while visitors ask hotel employees about earthquake risks nearly every day, quakes have never been a source of worry to him or his colleagues. He is not aware of hotels investing in earthquake mitigation except insofar as required by building codes. This suggests that even though customers ask about this risk, the industry is not convinced they could recoup an investment in greater safety by marketing this advantage to customers.

The manager assumes the Van Nuys building is earthquake safe because it has performed well in recent small quakes. "We've had a couple of shakers, no cracks," he noted. He said that the hotel does carry earthquake insurance, though he was not sure whether the insurance policy includes business interruption coverage.

Even though the hotel is instrumented for quake and we presented ourselves as a team of experts knowledgeable about both earthquake risks and structural performance for this particular location, the manager asked no questions about what earthquake risks they faced, whether the building might be made safer or whether we had any advice or concerns about the building. His complete lack of curiosity about the risks to his building actually seemed a bit odd to us at the time; it seemed as if he might have been actively avoiding specific information about these risks. The manager agreed to meet with us as a courtesy, to help us with our work, not in order to learn about the building or the risks.

Thus, the owner, who relies on the property for his future financial security, and his manager, who is safeguarding the value of the business, showed no concern for earthquake risks beyond adhering to codes and purchasing earthquake insurance (see Table 3). Yet, unlike the previous owners, this owner is not diversified and expects to own the property for a relatively long period of time.

Table 3. Current owner's EQ preparation considerations

Meet code Maintain earthquake insurance

Van Nuys allowed us to study the investment priorities and decisions of two quite different owners. Neither considered an investment in earthquake mitigation to be of interest. They sought to meet code and secure insurance. Beyond these measures, they showed no concern for the effects of earthquakes on the future operation or value of the business.

Both owner types offered clues to the beliefs and attitudes of a larger marketplace. The consortium implicitly bet that potential buyers would not fully value earthquake improvements other than meeting code. The current manager believes that hotel customers may ask about earthquakes but that they would not pay more to stay in an exceptionally earthquake-safe building. It seems that markets may not currently value earthquake performance and provide incentives for mitigation. This question deserves further attention.

ENABLING A PBEE MIND SET

Code-based strictures render design and retrofit decisions relatively simple, particularly from the client's perspective. They remove responsibility for deciding which risks to worry about. They eliminate the need to consider tradeoffs between costs and risk reduction. They conceal most of the uncertainties inherent in risk assessments. Most clients presume code compliance takes care of their legal and moral responsibility for worrying about earthquake risks. It seems that most also presume that code compliance means that no one will be killed in their building in an earthquake.

For building owners to become involved in PBEE decisions, they must be willing and able to think about earthquake risks in a different way. This means not just grappling with different analytic assessments but also different willingness to confront complexity, to face risks rather than deny them and to share responsibility for choices about risk reduction. Also significant is the fact that, in the current environment, clients have to commit to pay for PBEE analyses with little information in advance about whether such investments will be likely to yield designs with significant cost-benefit advantages.

Code-based vs. PBEE mind sets

To appreciate the change in mind set necessary for PBEE adoption, consider an analogy to medical practice. In the middle part of the 20th century, the practice of medicine was largely paternalistic. Patients asked few questions and ceded the dominant role for treatment to their physicians. It was presumed that "best" treatments existed, based on scientific studies, that doctors knew which were most current and valid, and that doctors (rather than patients) were in the best position to evaluate tradeoffs and make treatment choices [Charles et al., 1999]. As Parsons [1951] described this paternalistic model, patients were essentially passive and fully dependent on their physician experts. Physicians were seldom questioned; second opinions were rare; good patient relations had more to do with reassurance than with information sharing.

The code-based decision environment that currently characterizes most earthquake engineering resembles paternalistic medical practice. Clients leave it to their engineers to ensure code compliance. They presume there are "best" design solutions, that these are based on scientific study and are captured in building codes, and that their engineers are best positioned to make design tradeoffs and decisions. Clients need not be concerned with frightening or complicated information about earthquake risks and building performance. They are also shielded from cost-risk tradeoffs and from grappling with the reality that "built to code" does not mean absolute life safety. Engineers in turn face few client questions or challenges and are left to essentially practice and make decisions on their own.

A continuum of alternatives to paternalistic medical practices – from "informed consent" to "professional-as-agent" and "shared decision making" models – has evolved during the latter half of the 20th century [Charles et al., 1997]. All involve greater information sharing, more patient responsibility, less presumption of physician omnipotence and recognition that diagnoses and treatment options are based on values and judgment, not just on facts or formulas. Patients are now commonly apprised of likely (but not certain) prognoses and the risks and benefits associated with treatment options. Patients share responsibility for choices and introduce decision criteria related to their own lifestyles and life objectives. Doctors have to communicate better and to work *with* client decision makers rather than on behalf of them.

Fully implemented, PBEE would transform engineering practice from paternalism to shared decision making. Clients would have to accept responsibility for decisions about protections. Engineers would cede some autonomy and control and develop greater skills in collaborating with clients on decisions involving complex, probabilistic and sometimes frightening information.

At least two other issues associated with PBEE and engineer-client relations will matter to adoption. First, liability issues are potentially simpler for clients and engineers in a regulated situation than in a performance-based one. Though the argument that regulations (e.g., building codes) were followed is not a fail-safe liability shield [Huber, 1990], it can mitigate charges of negligence in at least some professional domains. PBEE removes this shield. To the extent that the advantages of PBEE methods derive because structures are less "over engineered" than code-based designs, liability issues could become quite serious.

Second, PBEE analyses almost always take more time and cost more than analyses associated with code-based design. Before clients can even consider potential superiority of a PBEE solution over a traditional one, they will have to have authorized (i.e., agree to pay for) a PBEE analysis. They will also have to be willing to allow the design phase to take more time. It is worth noting that clients may suspect that engineers will prefer more costly, time-consuming analyses not because they are in the client's interest but because they may yield higher fees and greater profits for engineers.

Table 4 contrasts some important differences in client mind set required under PBEE versus under code-based regulation. These sorts of "soft" factors will make it challenging to get clients to adopt PBEE. The experiences of the medical profession suggest these need not be insurmountable barriers but that they are major and will take time and significant changes in attitudes. This process took nearly half a century in medicine. Notably, medical practice evolved because patients clamored for change. As yet, the public is not clamoring for more involvement in or responsibility for their earthquake exposures.

Table 4. Contrasts in "mind sets" associated with code- vs. performance-based earthquake engineering practice

Mind Set	Code-based	Performance-based
Client aware of specific earthquake risks	Not necessary	Necessary
Client aware of residual risk after code compliance	Not necessary	Necessary
Client given options for risks borne	Not necessary	Necessary
Client faces cost-risk tradeoffs	Not necessary	Necessary
Engineering analysis costs	Less Costly	More Costly
Time for engineering analysis	Shorter	Longer
Liability risk	Lesser	Greater
Concern about engineers' profit motives	Lesser	Greater

The Role of Emotion in Earthquake Investment Decisions: Working with Worry

Our research team was struck by the description of Van Nuys' current owner as being "not worried" about earthquake risks. That description resonated with what is known about what predicts investments in preparing for and preventing rare but serious risks. It seems that the best predictor of voluntary preventive investments is an emotional-cognitive factor: worry. Individuals with identical rational estimates of the probability and severity of, for example, an earthquake will take radically different decisions about investing to prepare for quakes depending on whether quakes worry them or not [Baron et al., 2000]. This is true for business owners as well as homeowners [Palm, Carroll, 1998; Meszaros, Fiegener, 2003]. We do not yet understand well what worry is and what creates it, but is has become clear that prevention decisions include an emotional side that must be addressed.

Providing scenario-type information that vividly portrays the potential effects of a bad event may be the best means to ensure that a decision maker has engaged their emotions as well as their cognition before making a decision [Kunreuther, Schade 2001]. The PBEE methodology offers significant opportunities to develop scenarios that are meaningful to particular structures and, therefore, to help decision makers integrate the emotional and rational components of their decision preferences. The Investment-Decision Support System described below is designed to engage both emotion and rationality by being site specific and event specific and by enabling tradeoffs among noncommensurable, multidimensional objectives for outcomes from potential earthquakes.

A PBEE-ENABLED SEISMIC INVESTMENT DECISION SUPPORT SYSTEM

As with many investment decisions, seismic upgrade decisions will hinge on a single or a limited set of performance variables that are deemed to be of high priority by key decision makers. If only a single variable matters, optimization is relatively straightforward. When multiple decision variables (DVs) are to be considered, the decision maker's task is more complicated. The optimization process will involve subjective trade-offs and joint optimization.

In the Van Nuys testbed we pursued four essential steps for making PBEE analyses maximally appealing and useful to potential decision makers:

A. Determine the set of DVs that are important to stakeholders.
B. Devise a methodology to generate structure-specific exceedance probabilities for these DVs.
C. Communicate the decision framework involving multiple DVs in a way that imitates decision metrics that are familiar to and preferred by building owners of many types.
D. Validate the resulting decision tool via surveys and case applications.

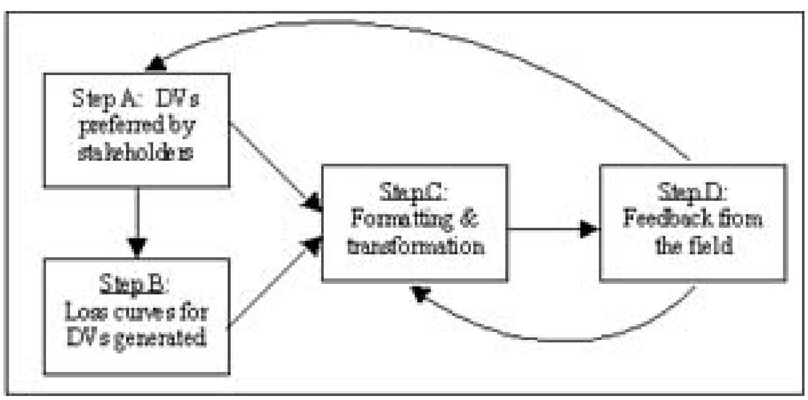

Fig. 1. The process of creating a PBEE decision support system

In this section, we describe the current status of the PBEE methodology with respect to each of these steps. Researchers are pursuing each of the four steps outlined in Figure 1 and there has been significant progress in completing a working prototype of the seismic investment decision support system. Step A requires the reconciliation of what the ultimate end users of the system see as relevant consequences. Step B requires determination of losses and costs the PBEE methodology can reliably measure. Step C involves creating a format for presentation and communication of analyses. The format is designed to be consistent with established industry practices. This should minimize resistance to adoption. Step D will ensure the generalizability and reliability of the decision support system are solidly established.

Table 5. Current status of the match between client needs and PEER[4]-PBEE capabilities

		PEER-funded projects	Prior test-bed meetings	ATC 58 Project workshop	Van Nuys Testbed
Methodology		"Investor-based" decision making explictly addressing costs and benefits at different levels of seismic safety		Rigorous cost-benefit analysis	The framework output is compatible with well known investment decision tools such as NPV, IRR and PP
		Tradeoffs between investing in seismic resistence or alternative forms of risk management			Securitized risk transfer is not included. At the retail client level not feasible. Insurance is a viable alternative. Not yet incorporated.
		Consequences and tradeoffs among different levels of safety		Range of potential outcomes may be desirable.	Financial and Non-financial consequences at different safety levels presented to facilitate trade-off
Relative vs. absolute		Consequences expressed in relative terms rather than absolute	Relative risk considerations		Consequences expressed in relative terms
Probability			Move from scenario analysis to more refined probabilistic statements	Probabilistic statements are not favorably received. Scenario analysis preferred. 90% confidence level.	The output is % probability of annual loss for three DVs under various mitigation levels. Possible to pare down to scenario based presentation
Decision Variables		Public safety: saving lives/avoiding injuries	Life-safety	Life losses (not the focus of discussion, though)	Life safety may be possible to incorporate in the future
		Cost of damage repair	Repair costs	Direct economic losses (especially down-time)	Loss curves available for the structure as is. Loss curves under different retrofit scenarios still needed
		Cost of down-time	Down-time		It is a significant variable for Van Nuys. Currently work ongoing. Likely to be available in the near future
Time Horizon			Relevant time horizon needs to be considered	*Annual* probability is not desirable	Reduction in *annual* expected losses at different levels of mitigation investments is obtained.
Externality		Consider externalities		Indirect economic losses	No. These are location/structure specific and hard to incorporate in a general framework. For Van Nuys externality data not available

Table based in part on material provided by Peter May

Step A: Decision variables that are important to stakeholders

Over the last several years, researchers have used several different venues and methods in order to understand which DVs are of critical importance for various stakeholders. A general pattern has emerged that we call the "3-D model", with the three "Ds" being "deaths" (i.e., preventing harm to occupants), "downtime" (i.e., preventing business disruption) and "dollars" (i.e., preventing direct losses and repair costs). According to a survey of practicing engineers, these three factors, in this order of importance, are what clients tell practicing engineers most concern them when they undertake PBEE projects (Meszaros et al. 2003). Table 5 outlines several engineering-based efforts that have drawn similar conclusions about what matters most to clients in terms of decision variables.

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[4] Pacific Earthquake Engineering Research Center, Berkeley, CA.

The order of importance of the 3Ds may vary for different stakeholder groups. For example, owners with an exclusively financial interest in a property may focus almost exclusively on dollar exposures. By contrast, businesses with significant operational exposures (e.g., manufacturing plants that might be shut down or retail businesses that might not be able to receive customers) may focus more heavily on downtime as a threat to their survival. In any case, the ability to provide information about the 3Ds should help meet the decision needs of a large swath of stakeholders.

Deaths
Historically, life safety has been the prime motivator for seismic mitigation [Mileti, 1999]. However, recent earthquakes in the U.S. have yielded huge economic losses and relatively few fatalities. Lack of significant human toll in recent decades may provide a false sense of security and thereby discourage seismic investments. PEER discussions and ATC-58 notes as reflected in Table 5 suggest that life safety is still a big decision criterion. To the extent that PBEE-based designs can make building occupants safer, they should interest a number of building owners.

Downtime
Downtime looms as a frightening prospect for many types of building owner. For small business owners, particularly those with tight cash flows, relatively brief closures can threaten business survival (Webb et al. 2000; Meszaros and Fiegener 2003). Large businesses may suffer losses in revenue when a manufacturing line stops or a reservation system is not available for even a short period. Both small and large businesses worry that closures and disruptions will lead customers to switch to other sources. Market share may never fully recover (Chang 2003). Finally, downtime losses are harder to insure than direct losses. Downtime may be a priority for physical mitigation to the extent that adequate financial mitigation for downtime is not readily available.

Dollars
Significant and rising economic losses may make PBEE interesting to many owners. The 1989 Loma Prieta quake yielded an unprecedented $8.6 billion in monetary losses. In Northridge, the insurance industry sustained losses beyond anyone's expectation ($20.8B). Even relatively moderate quakes now yield large losses because large asset bases are located in seismically active areas. The moderate 2001 Nisqually earthquake was the most costly natural disaster in Washington State's history ($2B). Private building owners may be willing to invest in preparation and mitigation beyond the requirement of the code if such investments are cost effective. Exposures for relatively common earthquakes may, in some cases, justify PBEE upgrades that coincidentally also provide better performance in less frequent, more serious quakes.

Step B: Methodology to generate structure-specific exceedance probabilities
Having ascertained that potential PBEE clients favor the 3D variables, we employed the PEER methodology to generate the desired DVs for the testbed structure. The effort is currently most successful in generating information relevant to the "dollar" variable, i.e., building repair cost estimates given a particular structure. Exceedance probability curves for repair costs are available. Depending on the specific needs and sophistication of the end-user, output can be pared down to a scenario-based, probable maximum loss (PML) or other suitable presentation format, including probabilistic distributions of PMLs. Figure 2 shows how this information can be applied to an investment decision problem for a hypothetical Van Nuys owner. Expected repair costs for the building in case of the most likely severe earthquake given two potential levels of retrofit are graphed in this figure. The repair cost loss curves were obtained from Miranda and Aslani (2003).

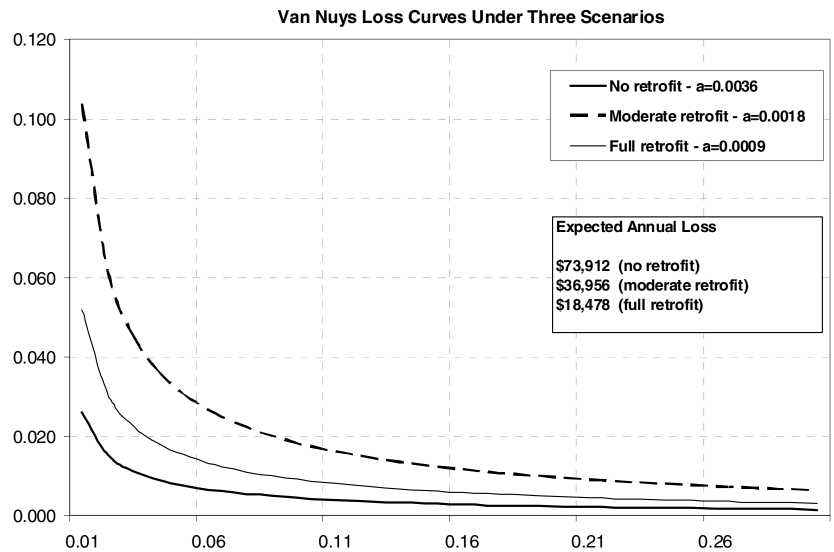


Fig. 2. Repair cost loss curve and its variations under two retrofit assumptions

There is further research underway to generate similar output for the downtime and life-safety DVs [Krawinkler, Miranda, 2002]. The ideal output for these two DVs would be exceedance probability curves expressed in number of days and number of fatalities, similar to the exceedance curves for losses in Figure 2. At this time, only probability distributions for deaths and downtime are available. Even this less complete information can be useful to an owner, however. A multiattribute presentation of expected outcomes can allow an owner to compare and impute priorities among these several objectives. Note also that downtime lends itself to being expressed in dollars. Miranda and Aslani [2003] have found that in the case of Van Nuys there is a close relationship between repair costs and downtime.

It would also be desirable to include content losses when developing a complete analysis of PBEE options. These can be significant. For example, we know that expected non-structural damage is quite large at about 70% of the expected structural losses [Miranda, Aslani, 2003].

Step C: Communication of decision alternatives

To gain widespread adoption rates, the presentation and communication of PBEE analyses should fit well with the decision tools that are widely used by potential end-users. The PEER methodology is capable of generating a relatively rich, building-specific output for the repair costs DV in the form of an annual exceedance probability curve. Although this is an extremely valuable output, it is certainly not the end of the story.

A user-friendly “shell” that will enable end-users to make informed assessments of the financial and non-financial consequences of varied levels of mitigation investments is desired. Using such information, end-users can make well-informed decisions about how much (if at all) to invest in structural mitigation.

In for-profit business settings, large-scale capital investment decisions are made using relatively straightforward, widely used capital-budgeting metrics, including net present value (NPV), internal rate of return (IRR), and payback period (PP). All these metrics are similar to the output of cost-benefit or cost-risk analysis, which are quite familiar to the engineering community. However, depending on the nature of investments and the industry, some companies will tend to prefer some methods to others. Additionally, while these metrics are most commonly expressed in terms of point estimates, they can also be expressed in more advanced and/or specialized forms such as value at risk (VAR) and Monte-Carlo (MC) simulation.

A recent survey of Chief Financial Officers of Fortune 500 companies found that 75% of the respondents report that they always or almost always use IRR or NPV when evaluating capital investment alternatives [Graham, Harvey, 2001]. PP is also relatively popular, used almost always by 56% of respondents. PP is essentially an inferior tool because it is biased against long-term investments, ignores cost of capital, and it lacks a clear criterion for acceptance and rejection. Nevertheless, its relatively wide use among a relatively sophisticated community indicates that a simpler method may have an advantage over a more complicated but sounder decision-making tool.

The PEER-PBEE methodology can be used to generate rich DV output that can be transformed into all the decision metrics that the business end-user community is familiar and comfortable with. Currently, the most sophisticated and sound corporate investment decisions in probabilistic settings are made using NPV methods.

Using building-specific loss-exceedance probability curves for Van Nuys, generated by the PEER testbed researchers, we are able to outline an NPV/MC simulation-based procedure that would meet the needs of the more sophisticated corporate end-users [Ince, Meszaros, 2003]. This procedure requires repair-cost exceedance curves for three different levels of structural mitigation investment levels: zero, moderate, and full retrofit. The analysis also demands: a time-horizon for the useful life of the proposed retrofit investments, a cost of capital (i.e., discount rate) based on the riskiness of the project and the funding costs of the investing company, and the initial cost of retrofit investments at the three levels. Once design options have been generated, engineers and clients can presumably generate all of these parameters relatively easily. At this point, expected NPVs, IRRs, and PPs for the three investment levels can be generated and used to inform decisions made on a strictly financial basis. These are presented in Figure 3. Those can then be presented together with other relevant DVs so that a decision maker can directly compare options across all relevant decision considerations (see Figure 4).

Fig. 3. Financial decision metrics for two different mitigation levels

	Moderate retrofit	Full retrofit
Payback period	➡ 6.8 years	9.0 years
Net Present Value	$ ➡ 69,093	$ (40,088)
Internal Rate of Return	➡ 14.8%	11.0%

Fig. 4. Decision/trade-off table presenting financial and non-financial DVs

	Expected NPV (Structural)	Downtime	Injuries	Fatalities
Do nothing	$0	4.2 days	1.64	0.40
Moderate retrofit	$69,093	2.1 days	0.80	0.19
Extensive retrofit	-$40,088	1.1 days	0.43	0.10
	Distributional or expected values	Expected values		

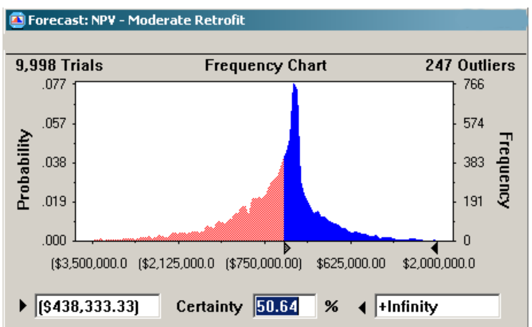
If Van Nuys owners had had access to the decision platform described above following the Northridge quake, they would have been able to assess various possible retrofit scenarios based on cost-effectiveness criteria. Additionally they would have been able to consider downtime and safety consequences of their potential choices. By explicitly trading off financial and non-financial DVs, they would have considered a more complete picture. We do not know if they would have chosen the financially unattractive full retrofit option because of the additional days of downtime and fatalities avoided. A planned survey of corporate managers will allow us to explore what people do when faced with such trade-offs.

Step D: Presenting Distributions of Potential Outcomes

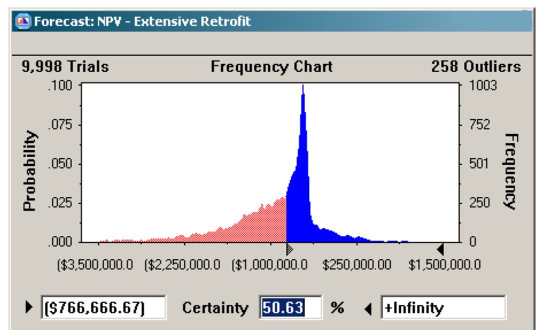
By taking advantage of the probabilistic output of PEER-PBEE methodology one can generate distributions of NPVs in addition to point estimates. This form of presentation allows end-users to appreciate the extremely skewed nature of the high-loss, low-probability-event driven cash flows.

Once full NPV distributions have been generated, engineers can format outputs in ways that best suit the sophistication levels and preferences of their clients. For example, one could present the 90% probability NPV, that is, the NPV levels that would almost surely be exceeded by a specific mitigation investment level (see Figure 5).

Fig. 5. Simulated Structural Loss Net Present Value Distributions



a. Moderate retrofit



b. Extensive retrofit

To the degree that loss curves or expected losses for downtime and life-safety DVs can be obtained from the PBEE methodology, the non-financial dimensions of mitigation decisions could also be presented to the decision maker in a manner similar to NPV information. The decision maker would then be able to consider the expected annual reductions in downtime and in number of fatalities that would be achieved at each level of investment and at what financial consequence.

Given that ATC 58 participants expressed distaste for annualized probabilities across multiple seismic events, it would be helpful to study the question of how to extract scenario-based presentation from the probabilistic model. Fortunately, the process for generating the loss exceedance curves enables an analyst to focus on individual scenario earthquakes, which is a good starting point for tackling this issue.

Communication of expected NPV values to a manager with basic finance training is relatively easy. When one moves into simulated probability distributions of NPV, the benefits of conveying a more complete picture of future outcomes that are highly skewed should be weighed against the difficulty encountered by many laymen to relate to and interpret NPV probability distributions. In fact, the feedback from a particular venue, the ATC 58 Project workshop in 2002, was mixed with regard to presentation of risk information in probabilistic terms. Some participants deemed annual exceedance probabilities not desirable, and expressed a preference for scenario-based presentation. However, some in the same group were receptive to expressions in terms of 90% confidence level of exceeding a particular value, which is a metric derived from a probability distribution.

With time and exposure, we should expect stakeholders to become more comfortable with probability-based expressions. Sophisticated statistical techniques are used with regularity in certain segments of the corporate world, particularly in financial sectors. Insurance companies simply cannot exist without a strong in-house expertise in probability. Many risk-consulting firms have been using PBEE-like methods for a while now. We should expect more acceptance and enthusiasm for the PEER-PBEE methodology among decision makers in financial, insurance and trading companies.

LESSONS FOR PBEE IMPLEMENTATION AND DIFFUSION

The Van Nuys testbed has highlighted both challenges to and opportunities for PBEE acceptance:

- *Clients not worried about earthquake risks will not invest in PBEE assessment*

PBEE-based decision models can create highly specific descriptions or "scenarios" of expected outcomes from expected earthquakes. Specific and vivid descriptions of risks are thought to be the best available means to ensure that decision makers have engaged their emotions (i.e., worry) as well as their rationality (i.e., expected value) in consideration of potential earthquake risks.

- *Clients prefer to leave earthquake tradeoffs and liabilities to building codes and engineers (i.e., paternalism is comfortable).*

PBEE-based design can enable clients and engineers to customize solutions to particular structures and particular shake risks. In return for accepting responsibility for earthquake exposure decisions, they may find opportunities to achieve better earthquake performance for similar or lesser investments.

- Clients do not make earthquake investment decisions on financial grounds alone. They are concerned with human risks and disruptions.

PBEE-based analyses can enable clients to directly examine tradeoffs among multiple performance objectives, particularly among the 3Ds of deaths, downtime and dollars.

- Sophisticated clients make investment decisions based on measures such as IRR and NPV.

PBEE enables multiple outcome measures to be converted to multiple investment-return measures.

- Clients may need help relating to probabilistic performance information. PBEE demands changes in engineering practice, including significant changes in client relations as well as greater sophistication in technical practice.

The client-relations problem is in some ways a chicken-and-egg problem. When clients recognize the value of participating in earthquake design tradeoffs, they will demand that their engineers engage them. Until engineers make the value of participation apparent, clients will not make this demand.

Complicating the chicken-and-egg problem is the fact that a client who agrees to PBEE will pay more in engineering fees as PBEE analysis will take more time than code compliance. This switching cost needs to be addressed.

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