Accounting for seismic risk in financial analysis of property investment

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ABSTRACT: A methodology is presented for making property investment decisions using loss analysis and the principles of decision analysis. It proposes that the investor choose among competing investment alternatives on the basis of the certainty equivalent of their net asset value which depends on the uncertain discounted future net income, uncertain discounted future earthquake losses, initial equity and the investor's risk tolerance. The earthquake losses are modelled using a seismic vulnerability function, the site seismic hazard function, and an assumption that strong shaking at a site follows a Poisson process. A building-specific vulnerability approach, called assembly-based vulnerability, or ABV, is used. ABV involves a simulation approach that includes dynamic structural analyses and damage analyses using fragility functions and probability distributions on unit repair costs and downtimes for all vulnerable structural and nonstructural components in a building. The methodology is demonstrated using some results from a seven-storey reinforced-concrete hotel in Los Angeles.

1 INTRODUCTION

The intrinsic value of commercial investment property comes from the net operating income stream that it generates. Since future income is uncertain because of changes in the real estate market, property value is subject to market risk. This risk is typically assessed during the financial analysis performed as part of the due-diligence phase of a property purchase. In such an analysis, the uncertain future operating expenses must also be considered. In earthquake-prone countries, earthquake losses are a potential operating expense so the property value is also subject to seismic risk, although this is often not explicitly treated in any financial analysis.

Current practice in many seismic areas is to commission a study of earthquake probable maximum loss (PML) during the due-diligence phase of a property purchase. PML is usually defined in terms of the level of loss associated with a large, rare event. If the PML exceeds a certain fraction of the building replacement cost, lenders may either decline to underwrite a mortgage, or require earthquake insurance. However, PML does not represent an operating expense that can be used in a detailed financial analysis of the investment opportunity. Consequently, a potentially significant expense is usually ignored, thus overestimating return. Because the earthquake expense varies between properties, the investor cannot reasonably consider it a constant error that can be neglected in a choice between competing opportunities.

This paper gives an overview of a methodology from a recently completed study that addresses how a commercial property investor could deal with seismic risk when making an investment decision (Beck et al., 2002). The investment decision might involve choosing between several properties for a purchase. For example, if two buildings for sale in the same area are expected to produce the same net income stream over a specified time period in the absence of earthquakes but Building A is more earthquake-resistant than Building B, how much more should an investor be willing to pay to purchase A? The investment decision might also be related to seismic mitigation of an already-owned property. For example, is a proposed seismic upgrade to a building cost beneficial?

To address such questions through a financial analysis requires that seismic risk be quantified in monetary terms. One approach is to quantify it in financial analyses as an uncertain operating expense expressed as the discounted present value of future earthquake losses due to repairs and loss of use, net of any insurance recovery. In the financial analysis of a property, seismic risk can then be integrated with market risk, which may be represented by the discounted uncertain future net income stream neglecting earthquake losses.

Since future earthquake losses for a building are very uncertain, a probabilistic loss analysis is required which integrates a probabilistic seismic hazard analysis with a building vulnerability analysis. Also, because property investment involves significant financial uncertainty and typically substantial sums relative to the investor's wealth, the risk attitude of the investor may be important. A decision-analysis approach to property investment may be used employing the concept of certainty equivalent of the property value as the central decision parameter.

In this paper, an overview is given of the methodology of Beck et al. (2002) for explicitly dealing with seismic risk when making property investment decisions. The methodology is illustrated using some results from a study of a 7-storey reinforced-concrete moment-frame hotel in Van Nuys, California that was built in 1966 and has been extensively studied (Beck et al., 2002). The building was lightly damaged by the M6.6 1971 San Fernando event, approximately 20 km to the northeast, and severely damaged by the M6.7 1994 Northridge earthquake, whose epicenter was approximately 4.5 km to the southwest.

2 OVERVIEW OF METHODOLOGY

2.1 *Probabilistic Loss Analysis*

A fundamental part of the loss analysis is a building-specific probabilistic description of possible future earthquake losses that is derived by combining a probabilistic seismic hazard analysis for the site with a building vulnerability analysis. The seismic hazard is described by a frequency form of the hazard function for the site, denoted by $g(S)$, where the parameter S describes the ground motion intensity at the site and is taken to be the spectral acceleration for 5% damping at the small-amplitude fundamental period of the building. The hazard function is defined so that $g(S)dS$ is the expected rate of occurrence of events at the site (mean annual frequency) with shaking intensity S in the range $(S, S+dS)$.

The assembly-based vulnerability method, or ABV, is used to derive a building-specific vulnerability function that gives a probabilistic description of earthquake losses conditional on the level of shaking intensity S (Porter et al 2001a,b; Beck et al 1999, 2002). The ABV methodology is illustrated in Figure 1. It involves a simulation approach to develop a probability distribution $p(C|S)$ on earthquake losses C (repair cost plus loss-of-use cost, net of insurance recovery) as a function of ground shaking intensity S. It treats the building as a unique collection of standard assemblies, each with their own probabilistic fragility, repair cost and repair duration. By defining building components at a more elementary level, ABV enables one to examine the effects of detailed changes to an individual building, or different buildings of the same category.

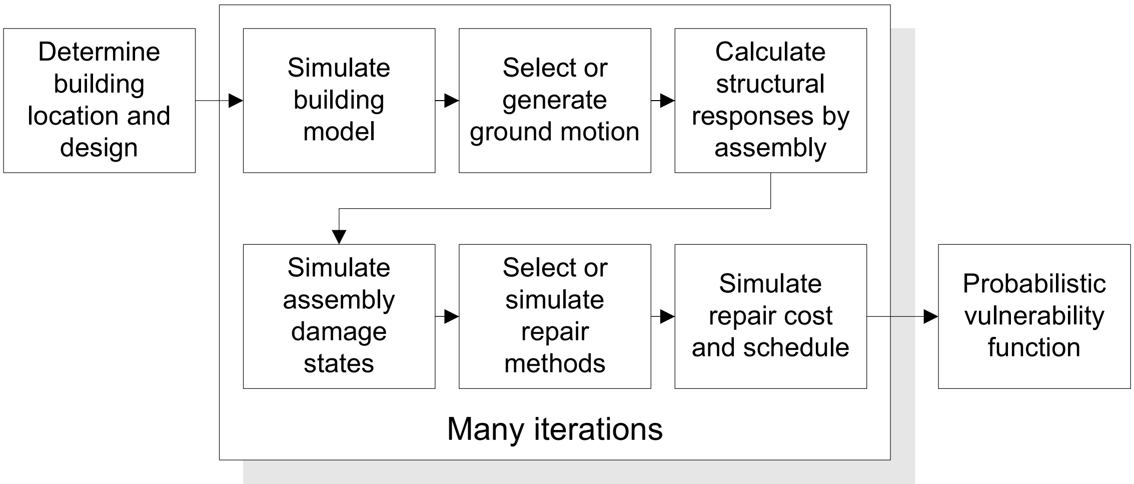

Figure 1. ABV methodology.

The ABV procedure accounts for uncertainties in ground motion, structural mass, damping, assembly capacity, assembly repair cost, and contractor overhead and profit. For each simulation in the procedure, a nonlinear time-history structural analysis is performed for a randomly selected ground motion record scaled to the specified shaking intensity *S* in order to estimate structural response on a floor-by-floor basis. Assembly damage is then simulated for the calculated structural response parameters in a probabilistic damage analysis that utilizes fragility functions for each of the building's assemblies. For this simulated building damage state, the cost of repairs and loss of use is then simulated using probability distributions on unit repair costs and repair durations for all assemblies. As an example, Tables 1 and 2 give the lognormal distribution parameters for the fragility functions and unit repair costs of the damageable assembly types in the Van Nuys hotel (Beck et al., 2002).

For each simulation of the ABV procedure, the total earthquake repair cost C_R is evaluated as the sum of the cost of repair tasks for individual components:

$$C_R = (1 + C_P)\left(\sum_{j=1}^{N_J}\sum_{d=1}^{N_D} C_{j,d} N_{j,d}\right) \quad (1)$$

where C_P is a factor to account for overhead and profit, N_J is the number of assembly types in the building, N_D is the number of damage states an assembly can be in, $C_{j,d}$ is the direct cost to repair one unit of assembly type j in damage state d, including materials, labor, and equipment related only to that particular task, and $N_{j,d}$ is the number of assemblies of type j in damage state d for that simulation. Overhead includes the additional direct costs of project management such as mobilization and demobilization, inspections, permitting, etc., which are more closely related to the size and duration of the project as a whole than to individual tasks.

2.2 *Decision Analysis*

There is widespread agreement that the present value of the discounted after-tax cash flow over some period should be used as the basic parameter in evaluating a property investment opportunity. The difference between this quantity and the investor's initial equity is referred to as the *net asset value V*. However, this valuation of property is uncertain because of market risk and seismic risk, and this uncertainty should be treated explicitly in the decision-making.

It is reasonable to use as the decision criterion maximizing the expected net asset value, $E[V]$. Suppose, however, that for two possible investments, an investor predicts for one property a higher expected net asset value but with more uncertainty than that predicted for the other property. How should this extra risk influence the ranking of the two investment alternatives?

There is a well-developed theory for decision making under risk that can be applied to property investment decision-making. The fundamental principles are presented in the seminal work of Von Neumann and Morgenstern (1944). A more modern reference is Howard and Matheson (1989). The objective in this approach is to maximize the expected *utility* E[u(V)] of the net asset value where utility is a measure of the investor's preference and is used to reflect his or her attitude toward risk.

A relationship between utility and financial outcome is referred to as a *utility function*. It is a monotonically increasing function of financial outcome, since a larger amount has greater utility (greater desirability). The utility function used in Beck et al. (2002) has the form:

$$u(x) = 1 - \exp(-x/\rho) \tag{2}$$

where u(x) represents the utility of a monetary amount x and ρ is a measure of risk attitude called the *risk tolerance parameter*. An interview procedure is presented in Beck et al. (2002) for estimating the parameter ρ to reflect an investor's attitude towards risk. Based on interviews with U.S. property investors, the authors relate the value of this parameter to the net wealth of a private investor or the company revenue for a corporate investor. It was also found that investors typically work with property deals whose values are 10% to 50% of their risk tolerance.

The utility scale is arbitrary to within a linear (affine) transformation (two constants have been chosen for convenience to give Equation 2). Also, the expected utility of value is not expressed in terms of a monetary value. These features motivate the introduction of the *certainty equivalent* of an uncertain property value V which is defined to be the single monetary amount that has the same utility value as the expected utility of V, that is, according to decision theory, it is the certain amount of money that the investor should consider equivalent to the uncertain investment. The investor should be indifferent between accepting the certainty equivalent immediately, or buying the property whose future net income (including future earthquake losses) is uncertain. Since utility is a monotonically increasing function of property value, a property has higher expected utility if, and only if, it has higher certainty equivalent. For decision-making purposes, property investments can therefore be ranked by the size of the certainty equivalent of their net asset value; the larger the certainty equivalent, the more preferable the investment.

Based on the utility function in Equation 2, the certainty equivalent of an uncertain net asset value V that is Normally distributed with mean value denoted by $E[V]$ and variance denoted by Var[V] is given by:

$$CE = E[V] - \mathrm{Var}[V]/2\rho \tag{3}$$

Beck et al. (2002) show that this expression gives a good approximation for CE if earthquake arrivals are modeled as a Poisson process and the net operating income stream is modelled as a Gaussian process (there are additional terms in Equation 3 that involve higher order moments but they are small and may be neglected). For a property whose uncertainty in value is small compared with the decision-maker's risk tolerance ρ, the certainty equivalent equals the expected net asset value. For deals with larger uncertainty relative to the decision-maker's risk tolerance, the certainty equivalent is less than the expected utility of the property value, with the decrease in CE being larger for higher uncertainty.

To evaluate the certainty equivalent of the property value using Equation 3, the mean and variance of the net asset value V based on a specified property lifetime t_L may be calculated using the following equations:

$$E[V] = E[I(t_L)] - C_o - E[L(t_L)] \tag{4}$$

$$\mathrm{Var}[V] = \mathrm{Var}[I(t_L)] + \mathrm{Var}[L(t_L)] \tag{5}$$

where

$$E[L(t)] = E[C]\frac{\nu}{r}\left(1 - e^{-rt}\right) = \frac{\overline{C}(1)}{r}\left(1 - e^{-rt}\right) \tag{6}$$

$$\mathrm{Var}[L(t)] = \frac{\nu}{2r}E[C^2](1 - e^{-2rt}) \tag{7}$$

$$\begin{aligned}\overline{C}(t) &= \nu t E[C] \\ &= t\int_{S_o}^{\infty} E[C \mid S]\nu p(S \mid EQ)\,dS \\ &= t\int_{S_o}^{\infty} E[C \mid S]g(S)\,dS\end{aligned} \tag{8}$$

$$\begin{aligned}\overline{C^2}(t) &= \nu \ \ tE[C^2] \\ &= t\int_{S_0}^{\infty} E[C^2 \mid S]g(S)\,dS\end{aligned} \tag{9}$$

and $I(t_L)$ = present value of after-tax net income stream over the property lifetime t_L, ignoring earthquakes; $L(t_L)$ = present value of the total earthquake losses over time period t_L; C_0 = initial equity in the building; $\overline{C}(t)$= mean loss over time period t; C = earthquake losses given occurrence of an earthquake with intensity $S>S_0$; r = inflation-adjusted risk-free discount rate; $g(S)$ = frequency form of the seismic hazard function for the site; and ν = Poisson rate of occurrence of shaking at the site with intensity $S>S_0$.

3 ILLUSTRATIVE RESULTS FOR VAN NUYS HOTEL

Four investment alternatives are compared for the Van Nuys hotel on the basis of their corresponding certainty equivalents calculated using Equation 3. An "as-is" alternative considers the purchase of the original hotel before any retrofitting and without any earthquake insurance coverage. An "insure" alternative considers the same purchase but with earthquake insurance coverage. A "retrofit" alternative refers to the purchase of the hotel followed by a seismic retrofit scheme involving the addition of new shear walls (details may be found in Beck et al. 2002)). The fourth alternative is to not buy. A time period t_L = 30 years is considered and an inflation-adjusted risk-free discount rate of r = 2% is used.

The mean and variance of the discounted total earthquake losses $L(t_L)$ in Equations 4 and 5 are calculated using Equations 6 to 9. An appropriate seismic hazard function $g(S)$ is chosen for the site (Beck et al. 2002). It gives a mean occurrence rate of ν = 0.059/yr for events with shaking intensity $S > S_0$ = 0.1g, which implies a period of 17 years on average between events with shaking greater than this threshold level. The conditional mean loss E[$C|S$] and conditional mean-square loss E[$C^2|S$] in Equations 8 and 9 are determined using the ABV procedure. The details of the loss analysis, including the structural model and the set of ground motion records used in the ABV simulations, are given in Beck et al. (2002). Only the south moment-resisting frame, which was heavily damaged in the 1994 Northridge earthquake, is modelled in the 2-D nonlinear time-history structural analyses.

The mean and variance of the discounted after-tax net income stream $I(t_L)$ in Equations 4 and 5 depend on the probability model for the market risk, that is, the variability in the net income stream over the specified time period t_L. For the Van Nuys hotel, E[$I(t_L)$] is estimated using a cash purchase price of \$US10M, an expected capitalization rate of 0.13 (based on published figures for similar hotels for sale in the Los Angeles area) and a tax rate of 0.40. The variance on $I(t_L)$ is calculated assuming a coefficient of variation of 1.0. Earthquake insurance is assumed to cost \$US0.25M per year with a deductible (excess) of \$US0.25M and a limit equal to the replacement cost of \$US7M for the building. The cost of the retrofit is \$US2.4M.

Using Equations 4 and 5, the mean and variance of the net asset value for three of the decision alternatives are calculated and shown in Table 3. The fourth alternative, do not buy, has $E[V]$ = Var[V] = 0 and so CE = 0. All figures are in units of millions of US dollars after tax except the variance figures are in units of $(\$M)^2$ and the coefficient of variation COV[V] is, of course, non-dimensional. Earthquake insurance premiums are deducted from $E[I]$, and retrofit costs are added to the initial equity C_0 = \$US10M. The CE based on Equation 3 is also shown in Table 3 for the three investment alternatives for an investor with a risk tolerance of ρ=\$US100M. The table shows that the CE of all three alternatives is positive, meaning that all three alternatives are preferable to the do-not-buy alternative. Also, the CE is substantially less than the expected net asset value $E[V]$, showing that risk aversion plays an important role in the decision-making process. Notice that the earthquake insurance alternative is significantly less desirable than either the as-is or retrofit alternatives. Note, however, that there is no mortgage on the property because it is assumed that the investor paid cash; a lender may require earthquake insurance. The as-is alternative has the highest CE, and is therefore the preferable choice for the conditions examined here. (This study neglects the value of human life, which if considered might make the retrofit alternative preferable.)

Table 3. Net asset value and certainty equivalent of Van Nuys hotel.

	Alternative		
	As-is	Insure	Retrofit
$E[I]$	39.0	31.5	39.0
C_0	10.0	10.0	12.4
$\overline{C}(1)$	0.016	0.007	0.004
$E[L]$	0.78	0.34	0.18
$E[V]$	28.2	21.2	26.4
Var[I]	1521	1521	1521
Var[L]	1.5	0.04	0.02
Var[V]	1521.4	1521.0	1521.0
COV[V]	1.4	1.8	1.5
CE	20.6	13.6	18.8

Observe from Table 3 that expected present value of earthquake loss $E[L]$ of the as-is case is a small fraction (2%) of the expected present value of income, $E[I]$. This is equivalent to a reduction in the capitalization rate from the expected level of 13%, to an earthquake-risk-adjusted value of 12.7%. Thus, earthquake risk represents a borderline-significant impact on the capitalization rate, and might therefore be considered in a prudent financial analysis. Also observe from Table 3 that variance on earthquake loss is small compared with the variance on income, which shows that the uncertainty on lifetime earthquake losses is unimportant in the decision-making here. Thus, the distribution on net asset value has very nearly the same form as that of net income. As the present value of net income is the sum of many random variables (albeit correlated ones), it is reasonable to approximate the distribution of income, and therefore net asset value, as Gaussian. With this assumption and the results shown in Table 3, one can readily determine the risk-return profile of the property as the probability of the net asset value V exceeding a specified value, given the seismic risk and market risk. This shows that the property is more than likely to be a profitable investment since the net asset value is positive with at least 75% probability for the as-is and retrofit alternatives.

The certainty equivalent is affected by several important uncertain parameters, so a sensitivity study to three important parameters was performed. This showed that the investment decision is not materially affected by the after-inflation risk-free discount rate r, since over a range $1\% \leq r \leq 7\%$, the preferable alternative remains to buy and leave the property as-is. In no case is the decision to insure or retrofit preferable. The sensitivity study also showed that risk tolerance matters, since for low values of risk tolerance, ρ< US27M, the preferable alternative is to not buy the property, primarily because the decision-maker would find that the pain associated with the possible losses outweighs the pleasure associated with the likely gains. For higher risk tolerance than this, such as the original value of $US100M, the as-is alternative is slightly preferable to the retrofit alternative. Market risk also makes a material difference in the preferred alternative. Market risk is parameterized by the coefficient of variation on the present value of future net income $I(t_L)$. For $COV[I(t_L)] < 2$, the as-is alternative is preferred slightly to retrofit. For greater market risk, the do-not-buy alternative is preferred because greater losses become more likely, thus increasing the perceived downside of the deal.

Table 1. Summary of assembly fragility parameters for Van Nuys hotel.

Assembly type	Description	d	Limit State	Resp	x_m	β
6.1.510.1202.02	Stucco finish, 7/8", on 3-5/8", on metal stud, 16"OC, typical quality	1	Cracking	PTD	0.012	0.5
6.1.500.0002.01	Drywall finish, 5/8", 1 side, on metal stud, screws	1	Visible Damage	PTD	0.0039	0.17
6.1.500.0002.01	Drywall finish, 5/8", 1 side, on metal stud, screws	2	Signif. Damage	PTD	0.0085	0.23
6.1.500.0001.01	Drywall partition, 5/8", 1 side, on metal stud, screws	1	Visible Damage	PTD	0.0039	0.17
6.1.500.0001.01	Drywall partition, 5/8", 1 side, on metal stud, screws	2	Signif. Damage	PTD	0.0085	0.23
3.5.180.1101.01	Nonductile CIP RC column A_g [250,500) in^2, L [100,200) in	1	Light	PADI	0.080	1.36
3.5.180.1101.01	Nonductile CIP RC column A_g [250,500) in^2, L [100,200) in	2	Moderate	PADI	0.31	0.89
3.5.180.1101.01	Nonductile CIP RC column A_g [250,500) in^2, L [100,200) in	3	Severe	PADI	0.71	0.8
3.5.180.1101.01	Nonductile CIP RC column A_g [250,500) in^2, L [100,200) in	4	Collapse	PADI	1.28	0.74
3.5.190.1102.01	Nonductile CIP RC beam A_g [100, 250) in^2, L [200,300) in	1	Light	PADI	0.080	1.36
3.5.190.1102.01	Nonductile CIP RC beam A_g [100, 250) in^2, L [200,300) in	2	Moderate	PADI	0.32	0.89
3.5.190.1102.01	Nonductile CIP RC beam A_g [100, 250) in^2, L [200,300) in	3	Severe	PADI	0.71	0.8
3.5.190.1102.01	Nonductile CIP RC beam A_g [100, 250) in^2, L [200,300) in	4	Collapse	PADI	1.28	0.74
4.7.110.6700.02	Window, Al frame, sliding, heavy sheet glass, 4'0" x 2'6" x 3/16"	1	Cracking	PTD	0.023	0.28

"Resp" = type of structural response to which the assembly is sensitive; PTD = peak transient drift ratio; PADI = Park-Ang damage index (displacement portion); x_m = median capacity; β = logarithmic standard deviation of capacity

Table 2. Summary of unit repair costs for Van Nuys hotel.

Assembly Type	Description finish	d	Repair	Unit	x_m	β
6.1.510.1202.02	Stucco, 7/8", on 3-5/8" metal stud, 16"OC, typical quality	1	Patch	64 sf	125	0.2
6.1.500.0002.01	Drywall finish, 5/8", 1 side, on metal stud, screws	1	Patch	64 sf	88	0.2
6.1.500.0002.01	Drywall finish, 5/8", 1 side, on metal stud, screws	2	Replace	64 sf	253	0.2
6.1.500.0001.01	Drywall partition, 5/8", 1 side, on metal stud, screws	1	Patch	64 sf	88	0.2
6.1.500.0001.01	Drywall partition, 5/8", 1 side, on metal stud, screws	2	Replace	64 sf	525	0.2
3.5.180.1101.01	N/D CIP R/C column A_g in [250,500) in^2, L in [100,200) in	1	Epoxy Injection	ea	8,000	0.42
3.5.180.1101.01	N/D CIP R/C column A_g in [250,500) in^2, L in [100,200) in	2	Jacketed Repair	ea	20500	0.4
3.5.180.1101.01	N/D CIP R/C column A_g in [250,500) in^2, L in [100,200) in	3,4	Replace	ea	34300	0.37
3.5.190.1102.01	N/D CIP R/C beam A_g in [100, 250) in^2, L in [200,300) in	1	Epoxy Injection	ea	8000	0.42
3.5.190.1102.01	N/D CIP R/C beam A_g in [100, 250) in^2, L in [200,300) in	2	Jacketed Repair	ea	20500	0.4
3.5.190.1102.01	N/D CIP R/C beam A_g in [100, 250) in^2, L in [200,300) in	3,4	Replace	ea	34300	0.37
4.7.110.6700.02	Window, Al frame, sliding, hvy sheet glass, 4'-0" x 2'-6"x 3/16"	1	Replace	ea	180	0.2
09910.700.1400	Paint on exterior stucco or concrete	1	Paint	sf	1.45	0.2
09910.920.0840	Paint on interior concrete, drywall, or plaster	1	Paint	sf	1.52	0.2

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