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UNIFICATION OF PROBABILISTIC SEISMIC PERFORMANCE ESTIMATION AND REAL ESTATE INVESTMENT ANALYSIS TO EVALUATE COST-EFFECTIVENESS OF POST-EARTHQUAKE BUILDING REPAIR

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ABSTRACT

This extended abstract provides an overview of a framework for modeling cases where repair of damaged commercial buildings is feasible but redevelopment or leaving the building unrepaired and vacant might offer greater economic value – a situation not currently modeled in engineering risk analysis. Previous studies have shown that while the level of damage and repair cost are significant factors in building owners' decision-making, factors such as repair time, future cash flow, capital availability and real estate market conditions often become drivers in the final decision. The proposed methodology attempts to explicitly incorporate these drivers into seismic loss assessment by combining net present value (NPV) analysis – a means of evaluating investment opportunities – with seismic loss estimation framework, FEMA P-58. P-58 and REDi methodologies are used to estimate the joint probability distribution of repair cost and time. Given a set of repair costs and times, NPV analysis is then used to determine whether repair, redevelopment or doing nothing with the building is the preferred financial option. Finally, the two analyses are integrated to quantify the probability of different decisions following a damaging earthquake. An illustrative case study is provided to demonstrate how the likelihood of post-earthquake decisions changes when financial and market parameters are considered.

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Unification of probabilistic seismic performance estimation and real estate investment analysis to evaluate cost-effectiveness of post-earthquake building repair

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This extended abstract provides an overview of a framework for modeling cases where repair of damaged commercial buildings is feasible but redevelopment or leaving the building unrepaired and vacant might offer greater economic value – a situation not currently modeled in engineering risk analysis. Previous studies have shown that while the level of damage and repair cost are significant factors in building owners' decision-making, factors such as repair time, future cash flow, capital availability and real estate market conditions often become drivers in the final decision. The proposed methodology attempts to explicitly incorporate these drivers into seismic loss assessment by combining net present value (NPV) analysis – a means of evaluating investment opportunities – with seismic loss estimation framework, FEMA P-58. P-58 and REDi methodologies are used to estimate the joint probability distribution of repair cost and time. Given a set of repair costs and times, NPV analysis is then used to determine whether repair, redevelopment or doing nothing with the building is the preferred financial option. Finally, the two analyses are integrated to quantify the probability of different decisions following a damaging earthquake. An illustrative case study is provided to demonstrate how the likelihood of post-earthquake decisions changes when financial and market parameters are considered.

Introduction

Following an earthquake, building owners are faced with a decision of whether to repair, redevelop (demolish and rebuild) or leave their building as is and vacant. Engineering seismic performance estimation models, such as FEMA P-58, implicitly consider demolition and redevelopment in cases where the building is collapsed, has excessive residual drift, or the loss ratio (repair cost as a fraction of the replacement cost) is above a user specified threshold. However, during the 2010-2011 Canterbury Earthquakes, many reparable multi-story commercial buildings with loss ratios as low as 1% were demolished [1]. Previous researchers have identified several economic factors

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that contributed to high demolition rates and influenced the owners' decisions, including access to capital, trajectory of future cashflow, uncertainty on regional recovery, and pre-disaster economic and real estate market trends [1,2]. However, current seismic loss estimation techniques do not consider such factors and therefore their effects are not reflected. This extended abstract describes a framework for modeling decision-making for commercial buildings when repair is feasible, but redevelopment or doing nothing might offer greater economic value. Probabilistic seismic risk analysis (FEMA P-58) and net present value (NPV) analysis are combined to evaluate possible decisions and to quantify the probability of repairing, redeveloping or doing nothing with a damaged building. An illustrative case of two buildings in California is also presented.

Post-earthquake Investment Evaluation Framework Overview

The proposed framework evaluates three potential decisions: (1) *repair*; (2) *redevelopment*, where the building is demolished and new one is built according to the "highest and best use", i.e. one that yields highest returns in current market conditions; and (3) *do nothing*, where the building is left damaged and unoccupied until the market improves, or financial circumstances change (ex. sale to a new owner). The first stage of the framework quantifies the joint probability distribution for building loss ratio (*LR*) and repair time (*RT*) following an earthquake. This is calculated using a combination of FEMA P-58 and REDi methodologies. FEMA P-58 quantifies the potential repair costs and times by analyzing building response and assessing damages to the structural and non-structural components, given an earthquake hazard level [3]. The Resilience-based Earthquake Design Initiative (REDi) provides a methodology for calculating building repair time considering the damage of different building components [4]. These two methodologies can be used to quantify the joint probability distribution of loss ratio and repair time for a potentially reparable building (no collapse or excessive residual drift) at a given level of spectral acceleration.

The second stage of the proposed framework uses net present value (NPV) analysis to determine the owner's preferred decision, given a loss ratio and a repair time. In commercial real estate, decisions on properties are driven by their ability to generate future income, where income is typically earned by leasing space to tenants. One commonly used technique to evaluate different investment options is NPV analysis, which calculates the present value of the investment by considering all future cash flows during a specified investment period (or holding period). The cash flows are discounted annually by a rate that considers the investor's required return and investment risk. The proposed NPV formulation uses the following cash flows: the initial investment, i.e. repair or redevelopment cost; the net operating income (NOI) after the building becomes occupiable; and the reversion value or sale price at the holding period. The NOI is determined by subtracting operating expenses from the rental income. The reversion value is calculated using direct capitalization approach, where the value is the expected NOI a year after the sale, divided by capitalization rate – rate of return that a property is expected to generate. The analysis is conducted on a before-tax basis, assuming no existing debt and 100% capital availability. The final decision is made in accordance with the highest NPV. If the NPV's for repair and redevelopment are less than zero, it is assumed that the owner would 'do nothing', since either option would result in a net loss. The final stage of the model integrates the joint probability of loss ratio and repair time with the highest NPV decision to quantify the probabilities of repair, redevelopment, and doing nothing with the damaged structure, given a level of shaking, $S_a(T_1)$.

Illustrative Case Study: Probability of Repair of Reinforced Concrete Buildings

To illustrate the effects of the proposed model on post-earthquake decisions, two 4-story commercial office buildings were analyzed, one constructed in 1967 (4-1967) and one in 2003 (4-2003) [5]. The reinforced concrete perimeter moment frame structures are located in Commerce, California with soil type D. They have 86,400 ft^2 gross area (75% rentable), T_1=0.62s, and a yield base shear coefficient of 0.067g and 0.133g for 4-1967 and 4-2003, respectively. The replacement cost of both buildings is \$14.2 million, redevelopment cost (including demolition) is \$16.1 million, and redevelopment time is 1.3 years (from FEMA P-58). Real estate parameters are assumed to be in line with 2016 Greater Los Angeles real estate market reports: annual rental rate (net of operating expenses) is \$20 and \$25 per square foot for 4-1967 and 4-2003, respectively, and the redeveloped rental rate is \$30, reflecting the highest and best use premium. 15% vacancy following re-occupancy, 7% capitalization rate and a 10-year holding period are also assumed.

Stage 1: joint probability distribution of loss ratio and repair time. The joint probability distributions for reparable buildings (no collapse or excessive residual drift) at various spectral accelerations, were calculated using 15,000 Monte Carlo realizations. An example of a joint distribution for 4-1967 is shown in Figure 1a. The figure shows a strong correlation between loss ratio and repair time, with a mode at *LR* = 0.9 and *RT* = 1 year.

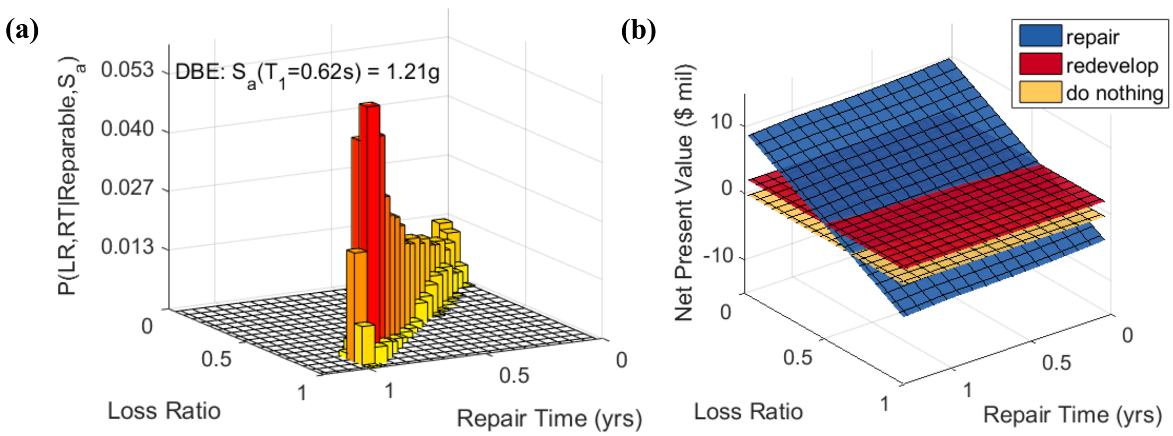

Figure 1. (a) estimated joint probability mass function for *LR* and *RT* at the spectral acceleration of the design basis earthquake and (b) NPV surfaces of the three post-earthquake decisions for different combinations of *LR*'s and *RT*'s for building 4-1967.

Stage 2: NPV analysis. The three NPV surfaces for different loss ratios and repair times are shown in Figure 1b. The preferred investment decision is based on the surface with the maximum NPV value for a given loss ratio and repair time. It can be observed that the NPV's for redevelopment and doing nothing are constant, since they do not depend on repair cost or time, while the NPV of repair decreases as loss ratio and repair time increase.

Stage 3: integration and resultant probabilities of repair and redevelopment. The results from the first two stages are integrated over all loss ratios and repair times to obtain the probability of different decisions. Figure 2a shows that the probability of repairing a damaged building using the proposed model is significantly lower than when FEMA P-58 criteria are used. Conversely, the probability of redevelopment (Figure 2b) increases with increasing levels of shaking. For a given level of shaking, the older building (4-1967) is more likely to be redeveloped, due to higher repair costs and higher rental benefit from redevelopment. The probability of doing nothing is zero for the assumed market parameters.

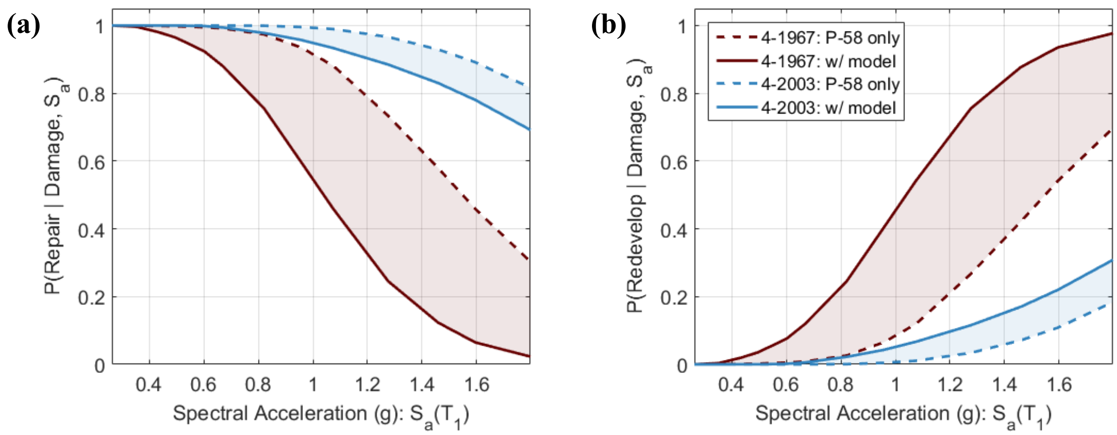

Figure 2. Resultant probabilities of (a) repairing and (b) redeveloping the two buildings using the proposed investment model (solid) and FEMA P-58 criteria (dashed).

Conclusions

The above framework incorporates investment analysis into probabilistic seismic performance assessment with the goal of determining the financial feasibility of post-earthquake repair. The framework includes of several financial and real estate market factors identified as important in post-earthquake decision-making, into performance estimation. The illustrative case study demonstrated the impact that market parameters and future cash flow can have on the probability of repair and redevelopment, thereby highlighting the significance of incorporating these factors into seismic risk analysis. Future work will focus on exploring how changes in market parameters, different economic conditions, and varying levels of available capital influence various decisions. The framework will further be used to see how these factors affect decisions at a community scale and influence the trajectory of post-disaster recovery.

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