To repair or not? Modeling post-earthquake building repair decisions using PBEE and real estate investment analysis

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Background

Many buildings with relatively low damage from the 2010-2011 Canterbury were deemed uneconomic to repair and were replaced [1,2]. Factors that affected commercial building owners' decisions to redevelop rather than repair, included capital availability, uncertainty with regards to regional recovery, real estate market conditions, ability to generate cash flow, and repair delays due to limited property access (cordon). This poster provides a framework for modeling decision-making in a case where **repair** is feasible but **redevelopment** or **leaving the building vacant** and unrepaired might offer greater economic value – a situation not currently modeled in engineering risk analysis.

Objective: model factors that drive post-earthquake decisions, and support development of engineering and recovery policies that lead to better post-earthquake outcomes.

Fig 1. Vacant buildings in Christchurch (September, 2017).

Model Formulation

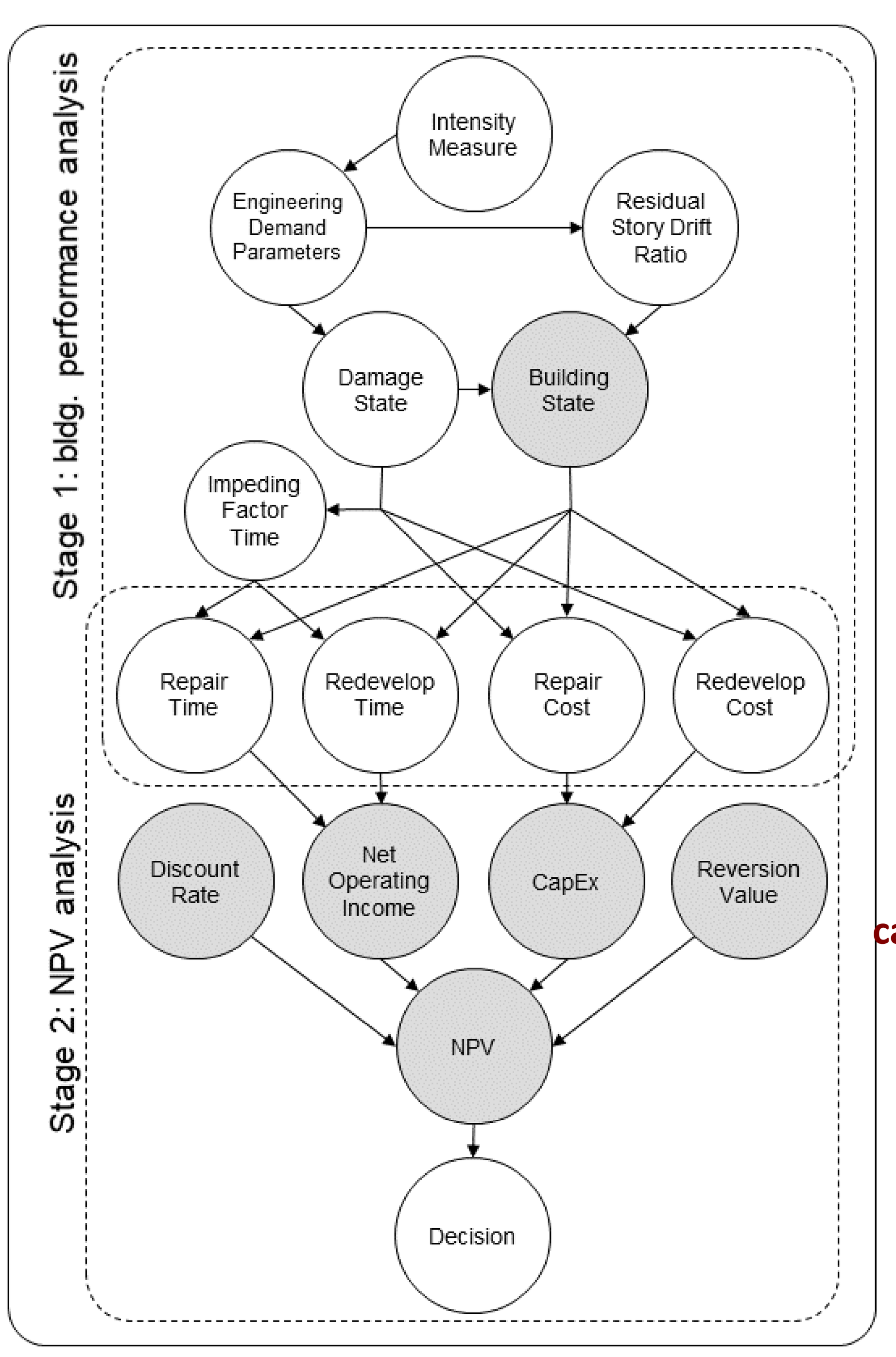


Fig 2. Visual representation of the framework

Stage 1: Seismic Performance Analysis

Using FEMA P-58 and REDi methodologies, first quantify probability of being in **building states** – undamaged, repairable or irreparable – given spectral acceleration: $P(BS|s_{a(T_1)})$

Then, estimate joint probability distribution of loss ratio, repair time and redevelopment time conditioned on a building state and spectral acceleration: $P(LR, T_R, T_{DEV}|s_{a(T_1)})$

Stage 2: NPV Analysis

Use the Net Present Value (NPV) decision rule to determine the best building decision (D) – repair, redevelop or leave vacant – given a loss ratio, repair time and redevelopment time:

$$NPV_D = \underbrace{-CapEx_D}_{\text{capital expenditure}} + \underbrace{\sum_{t=1}^{N} \frac{NOI_{t,D}}{(1+r)^t}}_{\text{net operating income}} + \underbrace{\frac{REV_D}{(1+r)^N}}_{\text{sale price at holding period}}$$

$$Decision = \underset{D}{\operatorname{argmax}}(NPV_D)$$

Stage 3: Integration

Integrate results from Stages 1 & 2 to quantify the probability of repair, redevelopment or leaving vacant given spectral acceleration:

$$P(Decision|s_a(T_1)) = \sum_i \sum_j \sum_k \sum_l P(Decision|LR_l, T_{R,k}, T_{DEV,j}) \times P(LR_l, T_{R,k}, T_{DEV,j}|BS_i, s_a(T_1)) \times P(BS_i|s_a(T_1))$$

Illustrative Example

Hazard: site in Commerce, California (Los Angeles County); soil class D

Buildings: 4-story, 1967 and 2003 commercial office buildings after [3,4]. Demolition cost is 13% of the replacement cost.

NPV assumptions: calculations are done on before-tax basis not considering financing.

Building	4-1967	4-2003
Gross area, A_{gr} (sf)	86,400	86,400
First-mode period, T_1 (s)	0.62	0.62
Yield base shear coefficient, V_y	0.067	0.133
Replacement cost[a], per square foot (\$ psf)	160	160
Replacement cost, total (\$ mil.)	13.9	13.9
Redevelopment cost[b] (\$ mil.)	15.7	15.7
Rentable area[c], A_r (sf)	64,800	64,800
Repaired rental rate, RR^R (\$ psf/yr)	20	25
Redevelop. rental rate, RR^{DEV} (\$ psf/yr)	30	30
Vacancy rate (%)	15	15
Repaired capitalization rate, R^R_{cap} (%)	9%	9%
Redevelop. capitalization rate, R^{DEV}_{cap} (%)	7.5%	7.5%
Holding period, N (yrs)	10	10

Stage 1: Seismic Performance Analysis

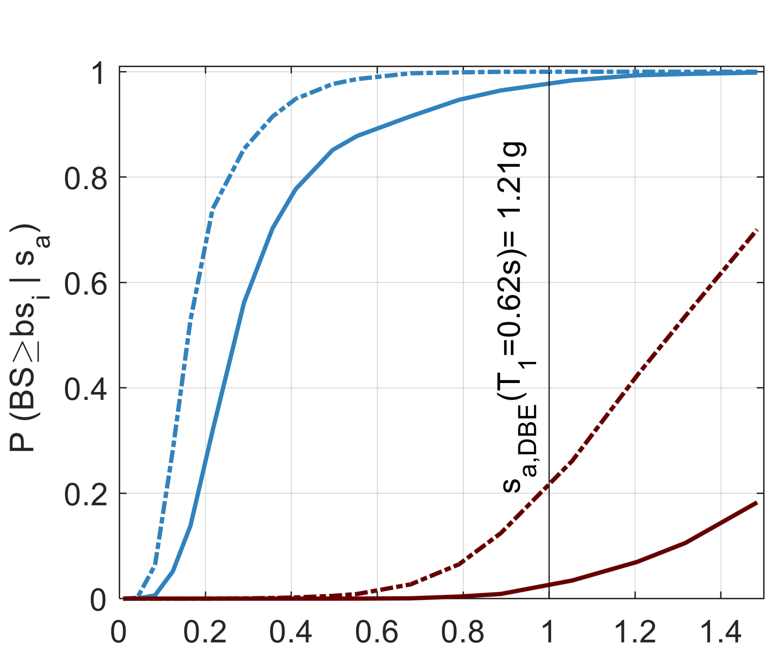
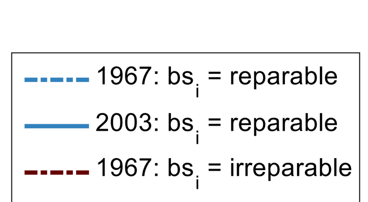


Fig 3. Probability of being in a building state *i* or worse for buildings 4-1967 and 4-2003, as a function of spectral acceleration normalized by spectral acceleration of design basis earthquake. The order of building states from best to worst is no damage, reparable and irreparable.



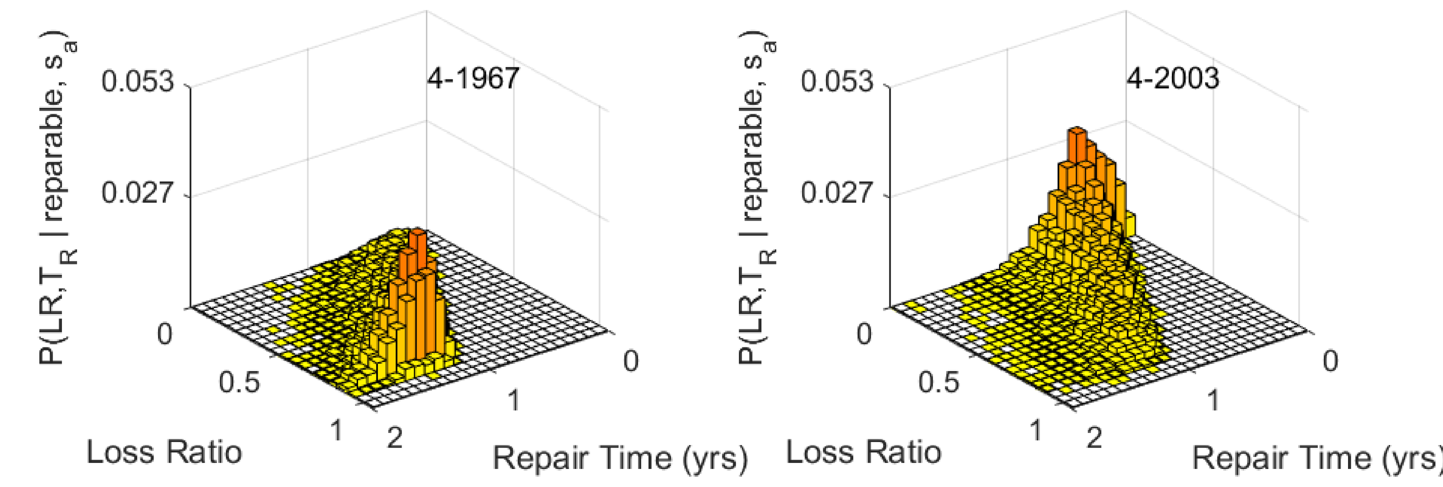


Fig 4. Estimated joint probability mass functions of loss ratio (LR) and repair time (TR) for the buildings conditioned of reparable building state (BS = reparable) and spectral acceleration for design basis earthquake. The older building (4-1967) has a higher probability of large loss ratios and repair times as a result of more vulnerable structural elements .

Stage 2: NPV Analysis

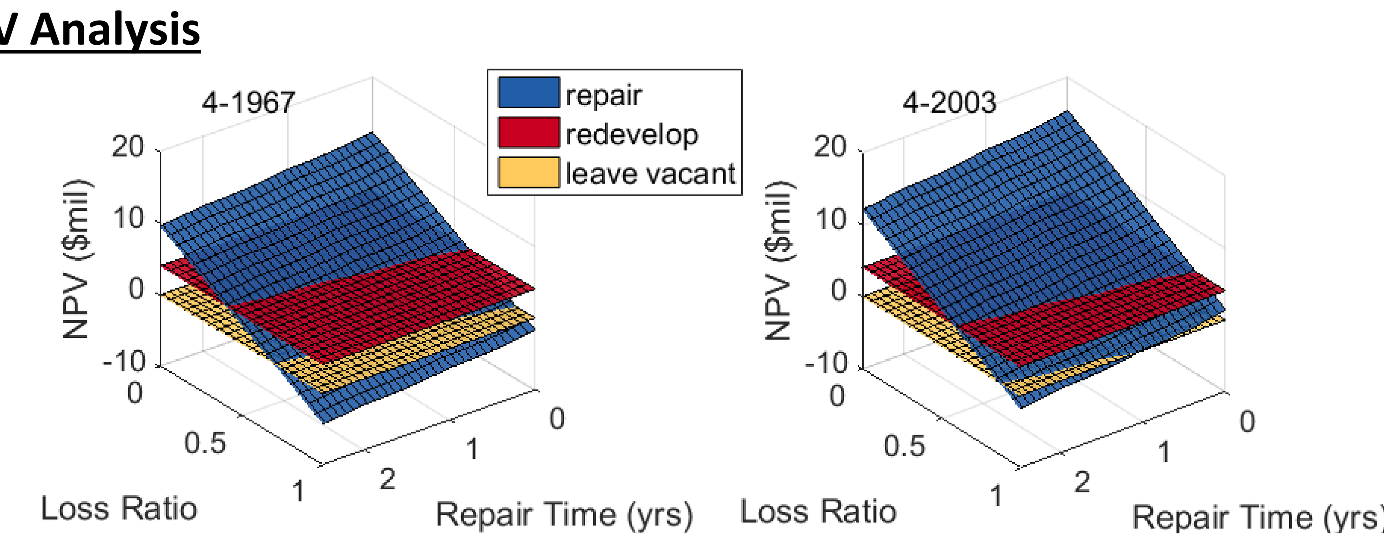


Fig 5. NPV's of repair, redevelop and leave vacant decisions for different loss ratios and repair times. The redevelopment time is held constant at 1.8 years. The surface with the highest NPV represents the financially preferred decision.

Stage 3: Integration and Quantification of Decision Probabilities

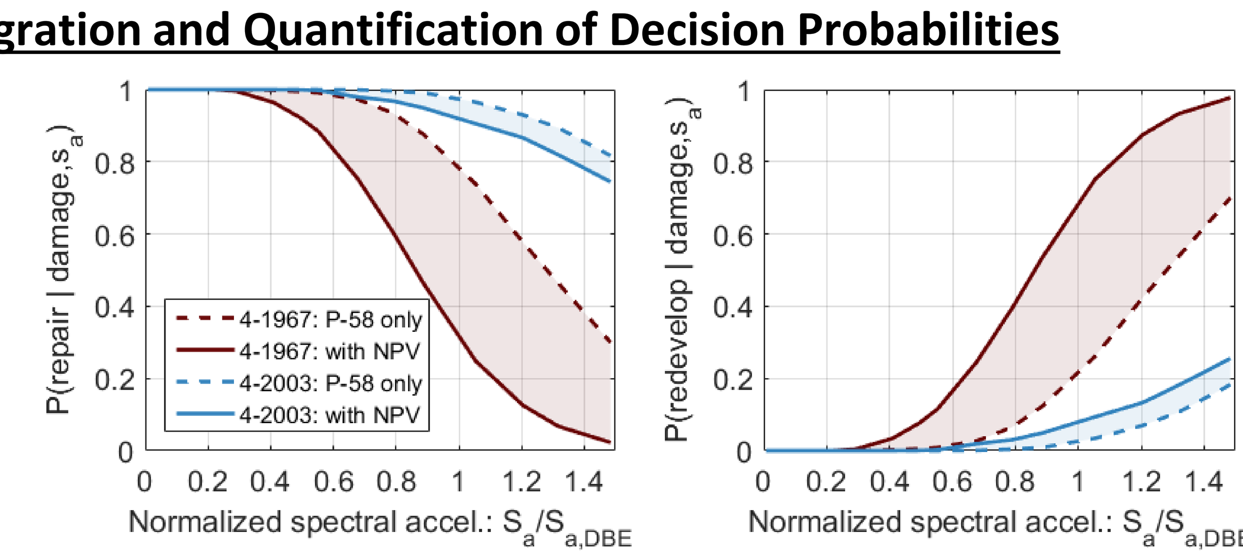


Fig 6. Probabilities of repair (left) and redevelopment (right) conditioned on damage (BS = reparable U irreparable) and hazard level, using P-58 criteria (P-58 only) and the proposed model (with NPV). Probability of leaving vacant in this case was 0. The lower likelihood of repair obtained using the NPV model is a reflection of captured cases when repair is feasible but is not financially preferred.

Sensitivity to Inputs Parameters

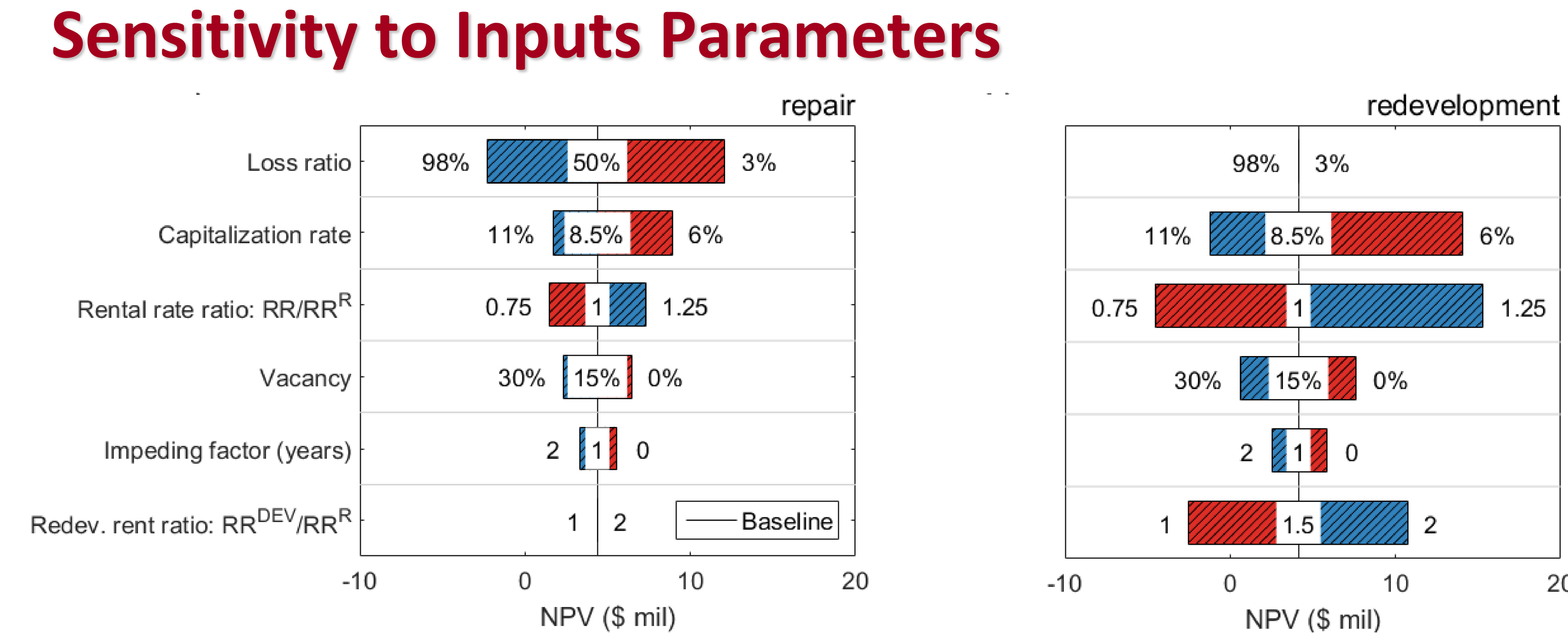


Fig 7. Graphical representation (pseudo tornado diagram) of sensitivity of repair (left) and redevelopment (right) NPV's to changes in several input parameters. Red bars indicate a decrease in input parameter and blue bars, an increase. Parameter ranges used in these calculations are shown to the left and right of each bar, and baseline parameter values are shown in the middle.

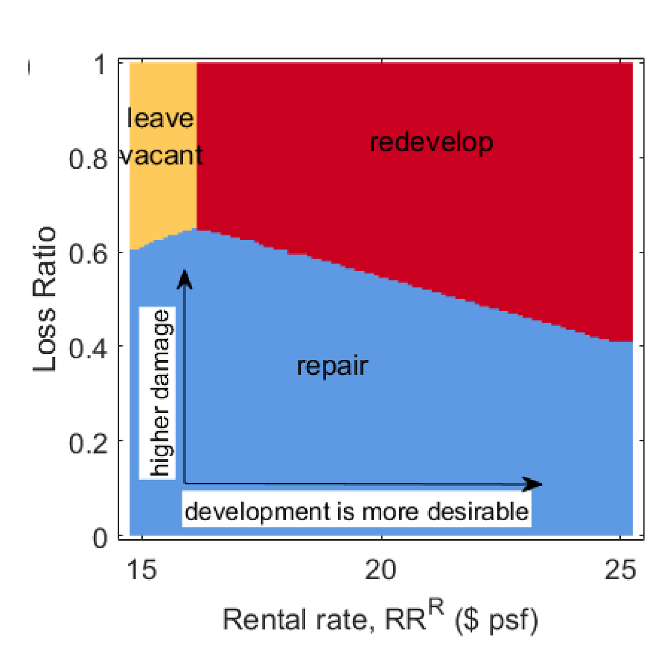


Fig 8. Boundaries for repair, redevelop and leave vacant decisions for building 4-2003 as a function of loss ratio and rental rate. If the loss ratio is low (<40%) the decision will always be to repair since the relatively low capital expenditure will be recovered by the generated income and sale. For higher loss ratios, the decision will be to redevelop for high rental rates (increased demand, more desirable development environment, and relatively low additional investment as compared to the benefits), and leaving vacant for lower rental rates (oversupply of rental space and high vacancy rates resulting in investments not paying off).

Future Work

- Incorporation of debt and after-tax investment analysis in order to understand how access to capital and different policies can affect building owners' decisions.
- Extension to a regional level to understand the potential loss in built environment and subsequent recovery on a community level.

[1] Kim, J. J., Elwood, K. J., Marquis, F., & Chang, S. E. (2017). Factors Influencing Post-Earthquake Decisions on Buildings in Christchurch, New Zealand. *Earthquake Spectra*.

[2] Marquis, F., Kim, J. J., Elwood, K. J., & Chang, S. E. (2017). Understanding post-earthquake decisions on multi-storey concrete buildings in Christchurch, New Zealand. *Bulletin of Earthquake Engineering*, *15*(2), 731-758.

[3] Haselton, C. B., Liel, A. B., Deierlein, G. G., Dean, B. S., and Chou, J. H. (2011). Seismic Collapse Safety of Reinforced Concrete Buildings. I: Assessment of Ductile Moment Frames. *Journal of Structural Engineering*, 137(4):481–491.

[4] Liel, A. B., Haselton, C. B., and Deierlein, G. G. (2011). Seismic Collapse Safety of Reinforced Concrete Buildings. II: Comparative Assessment of Nonductile and Ductile Moment Frames. *Journal of Structural Engineering*, 137(4):492–502.

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