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QUANTIFYING THE POST-EARTHQUAKE DOWNTIME INDUCED BY CORDONS AROUND DAMAGED TALL BUILDINGS

A. M. Hulsey[1], G. G. Deierlein[2], and J. W. Baker[3]

ABSTRACT

The proposed framework establishes a method for quantifying post-earthquake downtime in buildings across a community, based both on damage to individual buildings and on restricted access due to safety cordons around tall buildings that are identified as collapse hazards. Building profiles contain thousands of FEMA P-58 simulations to offer comprehensive damage and repair time results for each building type in the community. Sampling from these profiles for every individual building generates Monte Carlo realizations of building-level impacts for the community, informed by statistically generated response spectra for many earthquake rupture scenarios. For each damage realization, the residual drift and repair sequence of the tall buildings are used to define safety cordons in space and time. A spatial analysis of these cordons is then used to identify construction delays due to access restrictions, in addition to other impeding factors (such as engineering design and permitting) that extend recovery time. Recovery curves track the community's total functional square footage over time and, when combined with the probabilities of the underlying rupture scenarios, offer probabilistic assessments for community downtime. This type of assessment can inform a range of policy and planning decisions, such as requiring certain buildings to employ mitigation measures to reduce their cordon impacts or evaluating cordon placement strategies.

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Introduction

Resilience has been a growing area of interest across academia, organizations, and government. San Francisco has been a front-runner in addressing seismic resilience, outlining time targets for the post-earthquake recovery of key functions versus the current expectations [1]. However, the current conditions are difficult to quantify. The long-term closure of the Central Business District (CBD) after the February 2011 earthquake in Christchurch, New Zealand (Fig. 1) highlights the fact that buildings may be unoccupiable due to access restrictions, rather than the individual building damage that is typically the focus of building downtime estimates across a community.

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Therefore, the proposed framework incorporates the additional downtime induced by safety cordons' access restrictions around damaged tall buildings that may collapse in an aftershock.

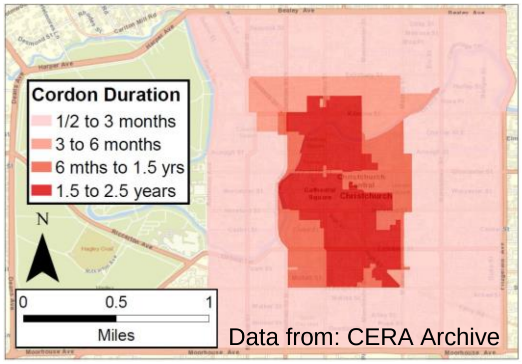

Figure 1: Safety cordons established access restrictions around Christchurch, New Zealand's Central Business District for up to 2.5 years after the February 2011 earthquake.

Community Recovery Analysis Framework

FEMA P-58, *Seismic Performance Assessment of Buildings*, represents the current best practice for estimating individual building downtime, using Monte Carlo simulations to explicitly consider uncertainty in hazard, building response, damage, and decision variables [2]. Due to the computational effort and extensive data required for individual building analysis, community analysis methods such as HAZUS have instead relied on community aggregates using average building results [3]. This section outlines an efficient method for incorporating FEMA P-58 and spatial analysis of cordons into a community downtime analysis framework, based on the flowchart in Fig. 2.

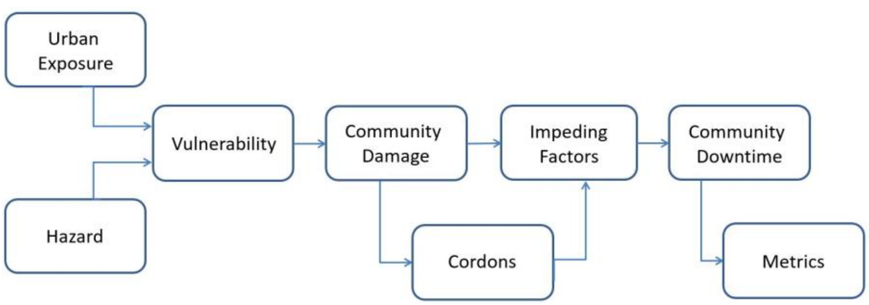

Figure 2: Flowchart of the proposed community recovery analysis framework.

A spatially distributed building inventory characterizes the community's urban exposure. The analyst then categorizes the inventory into archetypes based on structural system, occupancy, height, and date of construction, similar to HAZUS's building types. Each archetype is associated with a building profile containing the FEMA P-58 damage and repair time results for thousands of Monte Carlo simulations, for a range of intensity measures. These profiles represent the vulnerability, linking the urban exposure to the hazard, which is described next.

Following the FEMA P-58 methodology, the hazard is defined by the spectral acceleration at a building's first-mode period, $Sa(T_{building})$. Given the heterogeneity of the building inventory, this requires a response spectrum to represent all the relevant building periods. However, as in

HAZUS, rupture scenarios reflect possible earthquake events better than the uniform hazard spectrum. Therefore, the analyses employ spatial and spectral correlation models, together with ground motion prediction equations, to simulate response spectra for each rupture scenario [4].

The rupture scenarios serve as the basis for community-wide realizations of damage in individual buildings. The simulated response spectra provide the $Sa(T_{building})$ input for the various building vulnerability profiles. The analyst randomly samples from the many simulations in the profiles to assign damage, residual drift, and repair times to each building in the community.

The likelihood that a damaged building will collapse during an aftershock is best characterized by the residual drift [5]. Residual drift is also one of the most readily apparent damage indices after an earthquake and is included in the simulations for the building profiles. Therefore, this framework uses residual drift as the trigger for a cordon around a tall building. The tall buildings are of particular interest due to the large number of neighboring buildings that could be affected by a collapse. Using this framework to evaluate the downtime ramifications of various residual drift thresholds could inform community policy in determining appropriate cordoning strategies. Nonlinear dynamic response histories for aftershock analysis are also employed to establish a residual drift threshold based on an appropriate level of risk.

Building downtime includes "impeding factors," or delays prior to the initiation of repairs, such as engineering design and permitting or construction mobilization. The Resilience-based Earthquake Design Initiative (REDi) provides a systematic way to incorporate the uncertainty of each impeding factor for an individual building [6]. To account for observations of community-wide trends based on the total level of damage [7], the proposed framework includes modifications to REDi's median and dispersion parameters. The downtime also considers the duration of each cordon (taken as the time required to stabilize the damaged tall building) as another type of impeding factor for any buildings located within the cordon extents.

Once the downtime is available for each building, based on the FEMA P-58 repair times and the impeding factors (including presence within a cordon), the total functional square footage is aggregated across time to develop community recovery curves. Combining the recovery curves for each realization with the probability of the underlying rupture scenario provides downtime estimates and annual exceedance probabilities.

Preliminary Results and Implications

A hypothetical example illustrates the marginal effect of including cordon-induced downtime. The building inventory includes 5-, 10-, and 40-story buildings of either steel or reinforced concrete moment frames as, shown in Fig. 3a. Five corresponding building profiles provide the damage and repair times for each building. The baseline FEMA P-58 recovery status after one year is reflected in Fig. 3b's red to green color scheme, ranging from not occupiable to full recovery. The three circles represent cordons around the unstable tall buildings, with a radius equal to the building height. The fully recovered (green) buildings within these circles demonstrate the discrepancy between community assessments that only consider individual building damage and this framework, which also includes access restrictions.

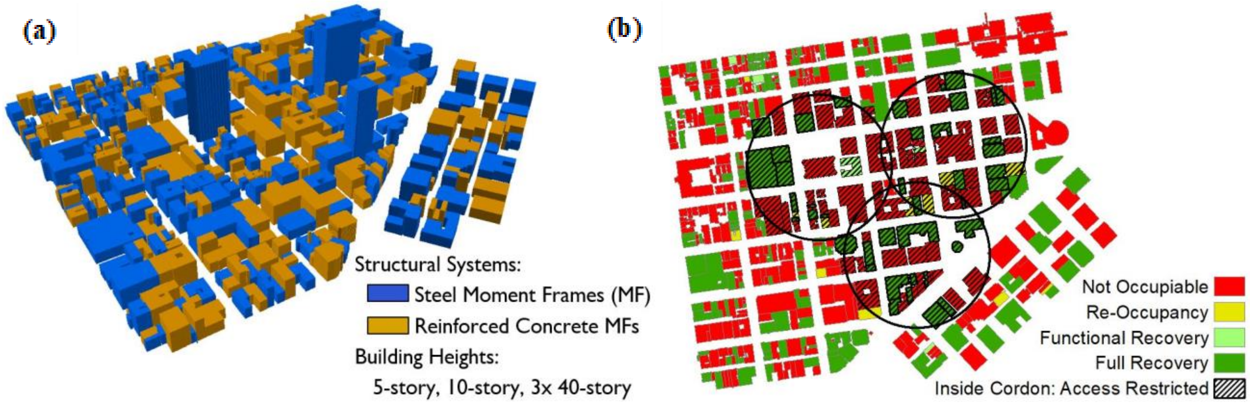

Figure 3: (a) A hypothetical community and (b) the baseline FEMA P-58 recovery status one year after an earthquake, versus the cordon-induced access restrictions.

Comparisons between the community recovery curves for existing conditions and those that incorporate building retrofits or measures to reduce recovery delays can assist policy makers in developing effective interventions. Including the additional effect of safety cordons brings these evaluations one step closer to reality.

Conclusions

The proposed framework incorporates the building downtime effects that damaged, collapse-hazardous buildings may have on surrounding buildings through safety cordons' access restrictions. Evaluating the ramifications of potential cordoning strategies can inform emergency response protocol. In addition to the spatial analysis of cordons, this framework also incorporates FEMA P-58's individual building damage and repair simulations into community-level analysis and addresses community-wide trends in impeding factors. Future work will apply this framework for downtown San Francisco.

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