A METHODOLOGY FOR BENCHMARKING LOSS PREDICTIONS OF THE FEMA P-58 SEISMIC PERFORMANCE ASSESSMENT PROCEDURE

Stanford | ENGINEERING
Civil & Environmental Engineering

Student Investigator: Gemma Cremen
Advisor: Jack W. Baker
The John A. Blume Earthquake Engineering Center, Stanford University

Introduction

As performance-based earthquake engineering (FEMA P-58) becomes more widely adopted in design and risk analysis practice, it is important to determine the degree to which the calculations reflect reality.

We develop a methodology for benchmarking loss predictions of FEMA P-58, using component damage data collected during reconaissance efforts. These survey data are categorical in nature, so we evaluate whether P-58 analyses can order buildings according to component damage severity.

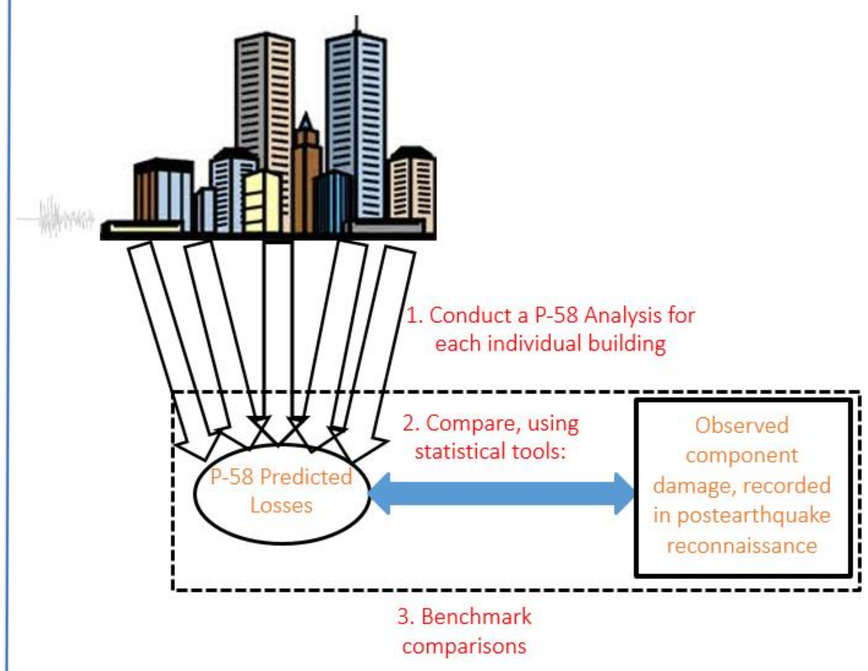
Our proposed methodology has several useful features:

1. It uses rank-order test statistics to enable comparison of numerical and categorical data.

2. It utilizes a benchmark (i.e. ground shaking intensity) to determine if P-58 analyses, using knowledge of building properties, provide more insight into damage than variations in ground shaking between buildings.

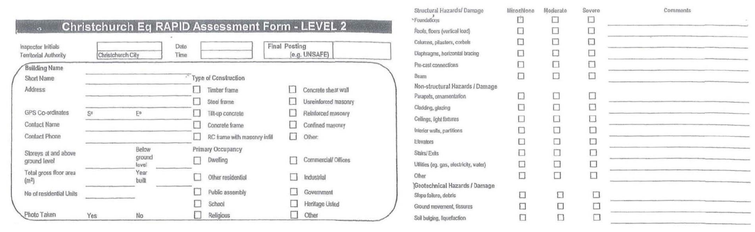
Overview of the Methodology

The methodology is intended to evaluate P-58 component-level loss predictions across a group of buildings subjected to a given seismic event, using postearthquake survey damage data collected.



Observed Component Damage Data

New Zealand Level 2 Rapid Assessment Form



P-58 Predicted Loss Data

Predicted losses for P-58 components are grouped together, in accordance with the damage categories of the postearthquake survey.

The predicted loss for a component group is obtained for each sample of the P-58 analysis as follows:

1. Sum the component repair costs included in the group ($\sum$ repair cost).
2. Sum the component replacement costs included in the group ($\sum$ replacement cost).
3. Predicted Loss Ratio = $\frac{\sum \text{repair cost}}{\sum \text{replacement cost}}$

Comparing Observed Damage and Predicted Loss

We use two rank-order test statistics that can relate the categorical observed damage data and the numerical P-58 predicted losses:

1. **Wilcoxon Rank-Sum Test (W R-S)**
Indicates the ability of P-58 loss predictions to distinguish between two different levels of observed component damage (i.e. minor/none and more heavy) in the correct order.

$$\text{p-value} = \frac{\#(w;n,m)}{\binom{N}{n}}$$

where: N = total no. of buildings
m = no. of buildings with minor/none damage
n = no. of buildings with more heavy damage
w = sum of ranks of all n predicted loss ratios
#(w;n,m) = no. of all possible n from N ranks with sum ≥ w

2. **Jonckheere-Terpstra Test (J-T)**
Indicates the ability of P-58 loss predictions to distinguish between all different levels of observed component damage (i.e. minor/none, moderate, and severe) in the correct order.

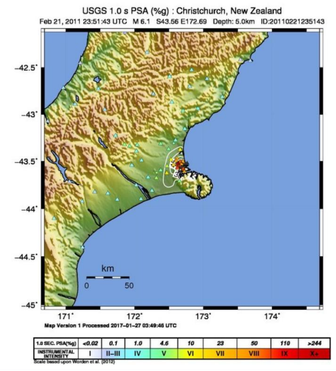
$$\text{p-value} = 1\text{-}\Phi(T^*)$$

where: $T^* = \frac{T - E(T)}{\sqrt{\text{var}(T)}}$
T = total no. of all predicted loss ratios in any higher observed damage level > predicted loss ratios in any lower observed damage level (equal predicted loss ratios counted as 0.5)

The lower the p-value for each statistical test, the better the comparison between observations and predictions.

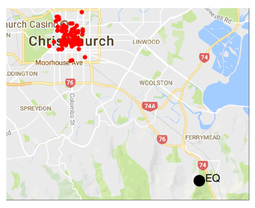
Benchmarking Comparisons

Ground shaking at each building (i.e. 1-second spectral acceleration at the nearest grid point on the USGS ShakeMap) is used as a benchmark to evaluate the predictive performance of the P-58 predicted losses relative to that of the variation in ground shaking for a given seismic event.



Example Application of the Methodology

- 95 buildings subjected to the 2011 M_W 6.1 Christchurch earthquake in New Zealand
- All reinforced concrete structures
- Ages range from > 46 to < 8 years
- Benchmarking predictions of elevator damage



P-58 Predicted Loss

P-58 Traction Elevator Components

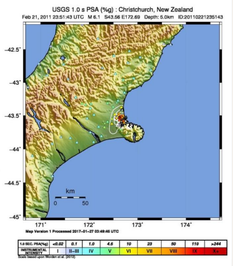
$$\text{Predicted Loss Ratio} = \frac{\sum \text{repair cost}_{\text{Elevator}}}{\sum \text{replacement cost}_{\text{Elevator}}}$$

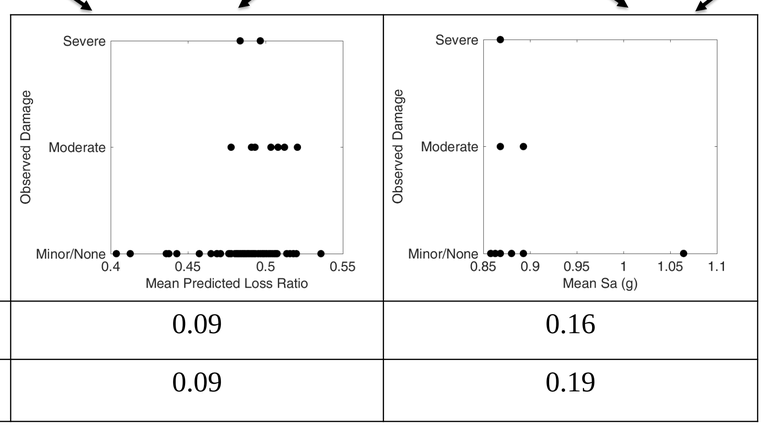
Observed Component Damage

New Zealand Level 2 Rapid Assessment Form

Non-structural Hazards / Damage	Minor/None	Moderate	Severe
Elevators	☐	☐	☐

Benchmark





W R-S p-value	0.09	0.16
J-T p-value	0.09	0.19

p-values are lower for P-58 predicted losses in both rank-order tests => P-58 predicted losses are better predictors of elevator damage than variation in ground shaking.

Conclusions

We developed a methodology for benchmarking component-level loss predictions of the FEMA P-58 seismic performance assessment procedure across a group of buildings subjected to a given seismic event, using categorical damage data collected in postearthquake damage surveys.

The methodology uses statistical tools that specifically enable comparison of categorical and numerical data. Ground shaking intensity acts as a benchmark to investigate whether P-58 loss predictions are more powerful predictors of damage than variations in shaking between buildings.

We apply the methodology to a group of buildings in the 2011 M_W 6.1 Christchurch earthquake. We find that P-58 loss predictions of elevator component damage perform better than the ground shaking benchmark, suggesting that FEMA P-58 provides benefit over simply using ground shaking intensity as a predictor of damage.

The methodology offers a promising initial understanding of the degree to which performance-based earthquake engineering calculations reflect real-life seismic events.

Acknowledgements

We thank Dr. Ken Elwood for sharing the New Zealand Rapid Assessment data used in our example.