

**WHITE PAPER ON EXPECTED SEISMIC PERFORMANCE OF
NEW BUILDING-CODE-COMPLIANT BUILDINGS IN CALIFORNIA**

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INTRODUCTION AND INTENDED AUDIENCE

This short white paper is written for audiences interested in better understanding the expected seismic performance of new code-compliant buildings in California, with language provided for both non-engineering and engineering audiences. The current research data is briefly presented and this paper will be expanded in the future as there is need.

GENERAL PERFORMANCE EXPECTATIONS

The Building Code aims at ensuring safety (non-collapse) in the event of a large earthquake; both research and the sentiment in the structural engineering profession is that the Code is expected to meet this safety goal well. However, the Building Code does not have a primary aim of preventing damage, limiting building closure times, or limiting financial losses (for typical occupancy buildings, excluding occupancies like hospitals). This white paper looks at what level of performance the Building Code provides for the measures of building closure time and repair cost.

ANALYSIS RESULTS FOR PERFORMANCE OF NEW CODE BUILDINGS IN CALIFORNIA

Performance of an Example Building in Northridge California

Figure 1 provides the repair costs and building closure times for an example new 8-story steel frame building in Northridge California, at two different levels of earthquake shaking. For a design earthquake¹, the computed building closure time is ~8 months and the repair cost is ~15% of the building value. For a rare earthquake², the computed building closure time is over a year and the computed repair cost is ~50% of the building value (so the building will probably be demolished in reality). To generalize this beyond this example 8-story building, similar analyses have also been done of taller buildings and repair times are much longer (since there is more to fix), with a recent study of an 40-story building showing up to two years downtime for the design earthquake; similarly with this trend, repair times tend to be shorter for smaller buildings. Note that the building closure time includes both the time that it takes to repair the building and the time it takes to mobilize before starting the repairs.

¹ Design earthquake – refers to an earthquake shaking level that occurs once in 500 years (this is essentially what buildings are designed for).

² Rare earthquake – refers to an earthquake shaking level that occurs once in 2,500 years.

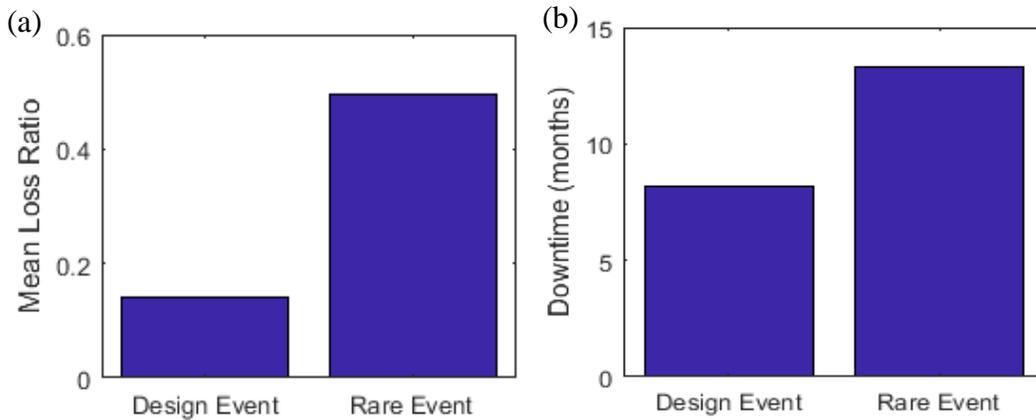


Figure 1. Expected performance for an 8-story steel frame building in Northridge CA

Performance for Selected Cities in California

The example in the last section was for a single building at a single location; this section generalizes the results to look at how seismic performance may vary between different cities in California.

Figure 2 shows the repair costs for the same new 8-story steel special moment frame, but redesigned and located in 12 different California cities; Figure 2a is for the design earthquake level (with resulting repair costs from 5-25%) and Figure 2b is for the rare earthquake level (with repair costs from 10-80%). The differences between performance at various locations (higher seismic sites generally have higher losses) comes from the effects of seismicity level and also from the fact that the Building Code intentionally allows buildings to accept higher risk when they are close to active faults.

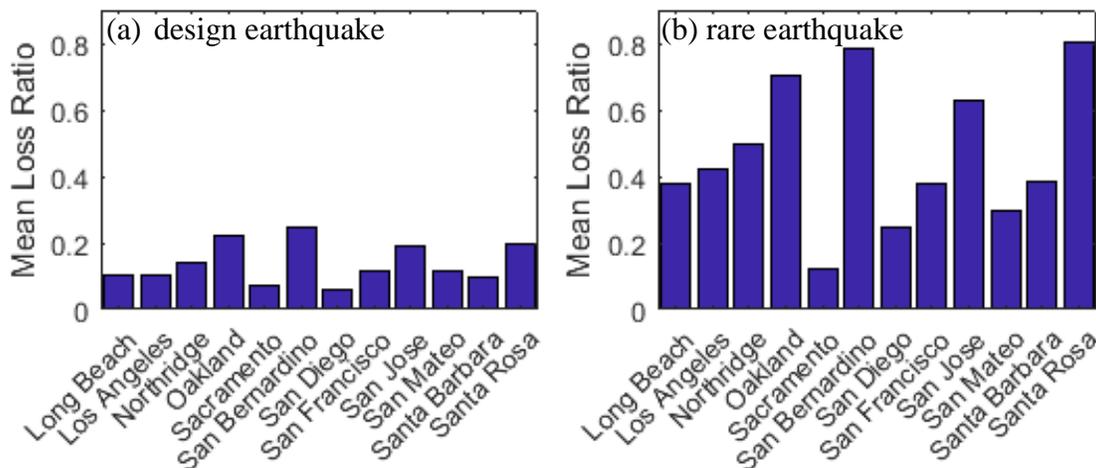


Figure 2. Expected repair costs for an 8-story steel frame office building in various California cities

Figure 3 shows the building closure times for this same set of 8-story steel moment frame buildings designed and located in various cities; Figure 3a is for the design earthquake level (with closure times ranging from 7 to 10 months) and Figure 3b is the rare earthquake level (with closure times ranging from 7 to 18 months). These figures show that (similar to repair cost) the Code does not limit repair time and that building performance varies based on building location.

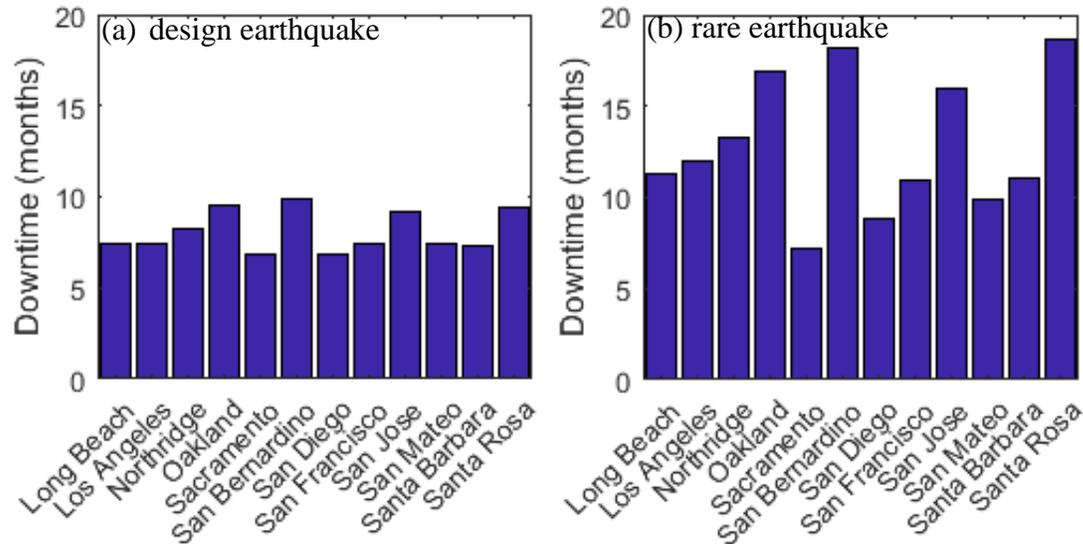


Figure 3. Expected closure times for an 8-story steel frame office building in various California cities

DOCUMENTATION OF ANALYSIS METHODS UTILIZED

The seismic performance predictions in this paper are based on the comprehensive FEMA P-58 Analysis Method (FEMA 2012) and the complimentary Resilient Design Initiative (REDi) Guidelines (REDi 2013). The analyses were run using the SP3 software (SP3 2018) using methods that do not require an engineer to create a model of the building, so each analysis took less than an hour to complete.

SUMMARY OF FINDINGS

This short and simple white paper shows the seismic performance expectation for an 8-story steel frame building designed and built in various cities throughout California. This same analysis has also been completed for a wide range of building types, but these additional data are not provided here to keep this summary succinct. Though the expected performance differs between building types, the big-picture results are similar – new code-compliant buildings are expected to be closed for 6-12 months (or more for taller buildings) after a design earthquake and up to 1.5+ years for a rare earthquake (with a substantial chance of demolition). Repair costs are expected to be 5-25% for the design earthquake and 10-80% for the rare earthquake.

This shows that the current approach to designing new buildings in California results in *safe but disposal buildings*.

There is desire to build buildings better in California, such that buildings can be immediately occupied and used after an earthquake. As a possible next-step toward this goal, Appendix A shows the seismic performance expectations for the same 8-story building designed to be a critical facility³. This appendix shows that the repair costs are substantially reduced by this better design, and that the building closure times, though reduced some, are still substantial; though this alternative design method creates a better building, it does not achieve Immediate Occupancy performance. Long closure times, even for these better designs, come from the fact that *there will still be damage that requires repair before the building can be occupied and used* (even though the damage is reduced); this maintains the need for mobilization time before the building repairs can begin (which can be ~6 months, especially after a large urban

earthquake). Even though this approach to designing a building as a critical facility clearly does not achieve Immediate Occupancy performance, this is probably *the best quick fix* to get better performance in the interim period, while more complete design rules are created for achieving Immediate Occupancy performance. It should be made clear that such an approach is an interim fix and has been shown to not achieve the fundamental goal of Immediate Occupancy.

Appendix A also shows performance results for multiple recent resilient-design projects in California (where the owner electively decided they wanted a resilient building); these recent projects have shown that resilient design substantially reduces building closure time and repair costs and can be used to achieve Immediate Occupancy performance. These projects have also shown that direct resilient design is feasible in practice, and that the additional cost for resilient design (for near-Immediate-Occupancy performance) is estimated to be approximately 1-3% of the building cost. Additional information about these recent resilient design projects is available in Haselton et al. (2018). This direct resilient design process could also be used to determine what the prescriptive Building Code design requirements would need to be to ensure that Immediate Occupancy is achieved.

POSSIBLE NEXT STEPS AND FUTURE WORK

The analysis shown in this white paper could be extended to create quantitative prescriptive Building Code design requirements would need to be in order to achieve Immediate Occupancy seismic performance.

Additionally, the FEMA P-58 analysis process that was used in this paper can be used directly in the structural design process, in order to design a building to achieve Immediate Occupancy seismic performance, which has already been done for several recent new buildings in California (Haselton et al. 2018).

APPENDIX A: SEISMIC PERFORMANCE EXPECTATIONS FOR IMPROVED DESIGN

This appendix looks at how the seismic performance can be improved by changing how California buildings are designed, looking at two possible approaches (a) making a simple modification to the Building Code such that all buildings being designed as critical facilities³ and (b) using a direct resilient-design approach that has been recently used for some buildings in California (being done electively by the owner, since they desired better performance).

Figures 4 and 5 show the results for buildings being designed as critical facilities, with Figure 4 showing expected repair costs and Figure 5 showing the expected building closure times. This shows that the range of repair costs are substantially reduced by this better design, but that the building closure times (though reduced some) are still substantial and do not achieve an Immediate Occupancy performance goal.

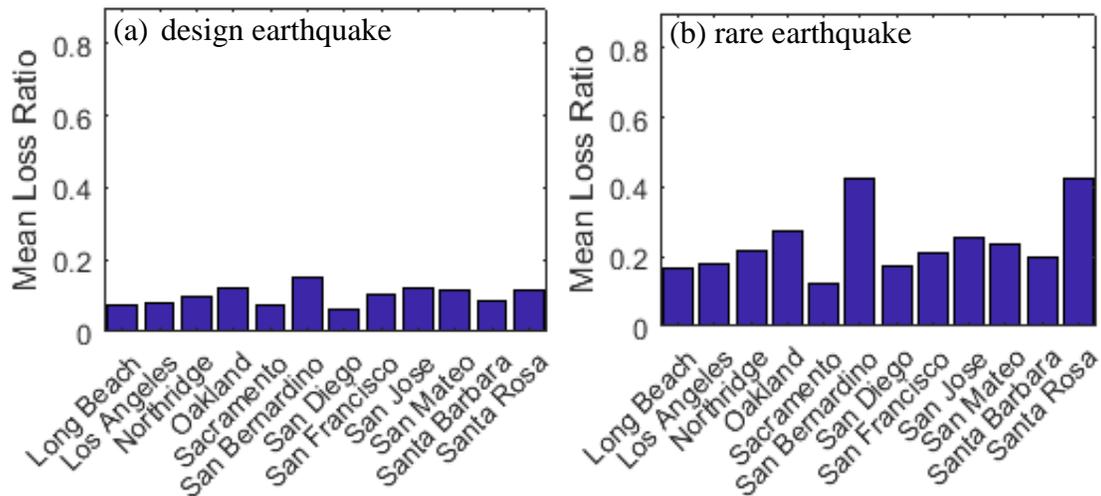


Figure 4. Expected repair costs for an 8-story steel frame enhanced design³ building in various California cities

³ These examples show results for the same 8-story building, but now designed as critical facilities, which are called Risk Category IV in the Building Code.

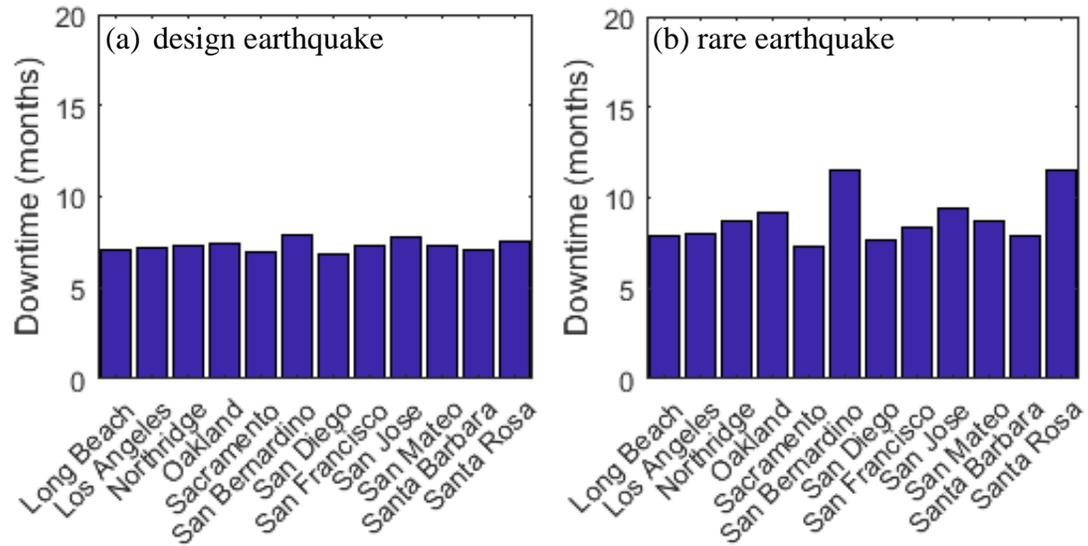


Figure 5. Expected building closure times for an 8-story steel frame enhanced design³ building in various California cities

Table 1 summarizes the results from Figures 4-5 (for critical facility design), and then also shows the performance expected from recent California projects that were intentionally designed to be resilient (as described in Haselton 2018). This shows that this process of direct resilient design can deliver much better performance as compared with simply using a prescriptive requirements of designing a building as a critical facility.

Table 1. Comparison of seismic performance between a standard code design, an enhanced code design method, and recent resilient-design projects

Seismic Performance Metric	Design Approach	Design Earthquake	Rare Earthquake
Closure time	Code	7-10 months	7-24 months
	Enhanced	7-8 months	7-12 months
	Resilient	1-4 weeks	--
Repair Costs	Code	5-25%	10-80%
	Enhanced	5-15%	10-40%
	Resilient	~2%	--

REFERENCES

FEMA 2012, *FEMA P-58-1: Seismic Performance Assessment of Buildings*, Applied Technology Council, Redwood City, CA.

Haselton, C.B., R.O. Hamburger, and J.W. Baker (2018). *Resilient Design and Risk Assessment using FEMA P-58 Analysis*, Structure Magazine, March 2018.

REDi 2013. *Resilience-based Earthquake Design Initiative for the Next Generation of Buildings*, Ibrahim Almufti and Michael Willford, Arup.

Seismic Performance Prediction Program (SP3) (2018). © Haselton Baker Risk Group, www.hbrisk.com.