Recovery Model for Commercial Buildings Considering the Earthquake Hazard

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Recovery Time/Downtime

Cimellaro et al. (2010)
Resiliency Index is the area under functionality curve.
Direct vs. Indirect Losses
Kobe Earthquake, 1995

3 Trillion Yen = 26.7 Billion US Dollars

(Toyoda, 2008)
PBEE/FEMA P-58 + Recovery Model

PBEE

Hazard Analysis → Numerical Modeling & Simulations → Damage Analysis

FEMA P-58 (FEMA 2012)

Loss Analysis

Downtime/Recovery Model

Expected Annual Loss or Intensity-based Loss

Resiliency Index

Fault-tree Analysis → Functionality Limit State → Repair Time Model → Mobilization Time Model
Recovery model integrated with FEMA P-58
Functionality Limit State
Functionality Limit State (FLS): Fault-Tree Analysis for Office Occupancy

Legend
- Event related to a system or subsystem
- Or gate: the event connected above occurs if any event connected below occurs
- Switch: the event can be turned ON or OFF.

- HVAC system fails
- Electrical system fails
- Elevators and stairs dysfunctional
- Plumbing and piping break
- Major damage to partition walls
- Major damage to exterior walls
- Major damage to ceiling system
- Server fails
- Major Structural Damage

Operation fails
Repair Time Model

- Downtime/Recovery Model
  - Fault-tree Analysis
  - Functionality Limit State
  - Repair Time Model
  - Mobilization Time Model
Repair Time Model utilizing the **Critical Path Method**

- **Repair Time Model**
- **Resource Scheduling**
- **Gantt Chart and Labor Allocations**
- **Realistic Labor Allocation**
- **Average damage states and number of damaged units**
- **Define the predecessor and successor relationships for all repair activities**

**Validated by contractors, engineers, and building inspectors!**
Mobilization Time Model

- Fault-tree Analysis
- Functionality Limit State
- Repair Time Model
- Mobilization Time Model

Downtime/Recovery Model
Mobilization Time - challenges

Mobilization time depends on:

- Socio-political factors
- Economy of the affected area (supply and demand)
- Size and importance of the affected region
Mobilization Time Model

Legend

Mobilization Time Contributors

Earthquake → Rapid inspection of buildings → Is building reparable?

Downtime = Replacement time

NO

Is detailed inspection needed?

YES

Major non-structural damage?

NO

YES

Downtime = 0

Financing

Contractor/material mobilization

Site preparation

Clean up

Detailed inspection

Arch. and eng. drawings

Permits

Repair

Downtime
Case Study:
3 Story Code-Compliant SMRF building Located in Los Angeles

The seismic hazard levels:
- 50% in 50 years.
- 10% in 50 years.
- 2% in 50 years.
Repair Time Model

Critical Path Method
Repair Schedule

Realistic Contractors

For each repair activity, number of workers is based on the amount and severity of damage.
Repair Time

- 50% in 50 yrs.
- 10% in 50 yrs.
- 2% in 50 yrs.
Repair and Resource Scheduling
2% in 50 years: Median Realization
Neither strategy is likely to represent the actual schedule used to repair a particular building, but the two extremes are expected to represent a reasonable bound to the probable repair time.” (FEMA P-58)
FEMA P-58 Repair Time Model vs. Our Model

50% in 50 yrs.

10% in 50 yrs.

2% in 50 yrs.
## NIST CRPG table

<table>
<thead>
<tr>
<th>Functional Category: Cluster</th>
<th>(4) Support Needed</th>
<th>(5) Target Goal</th>
<th>Expected Hazard Level</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Phase 1 – Short-Term Days</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>0</td>
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<tr>
<td><strong>Critical Facilities</strong></td>
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<tr>
<td>Emergency Operation Centers</td>
<td>...</td>
<td>A</td>
<td>90%</td>
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<tr>
<td>First Responder Facilities</td>
<td>90%</td>
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<tr>
<td>Acute Care Hospitals</td>
<td>90%</td>
<td></td>
<td></td>
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<tr>
<td>Non-ambulatory Occupants (prisons, nursing homes, etc.)</td>
<td>90%</td>
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<tr>
<td><strong>Emergency Housing</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Temporary Emergency Shelters</td>
<td>30%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>Single and Multi-family Housing (Shelter in place)</td>
<td>60%</td>
<td></td>
<td>90%</td>
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<tr>
<td><strong>Housing/Neighborhoods</strong></td>
<td></td>
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<tr>
<td>Critical Retail</td>
<td>30%</td>
<td>60%</td>
<td>90%</td>
</tr>
<tr>
<td>Religious and Spiritual Centers</td>
<td>30%</td>
<td>60%</td>
<td>90%</td>
</tr>
<tr>
<td>Single and Multi-family Housing (Full Function)</td>
<td>30%</td>
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<td>60%</td>
</tr>
<tr>
<td>Schools</td>
<td>30%</td>
<td>60%</td>
<td>90%</td>
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<tr>
<td>Hotels &amp; Motels</td>
<td>30%</td>
<td></td>
<td>60%</td>
</tr>
<tr>
<td><strong>Community Recovery</strong></td>
<td></td>
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</tr>
<tr>
<td>Businesses - Manufacturing</td>
<td>30%</td>
<td>60%</td>
<td>90%</td>
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<tr>
<td>Businesses - Commodity Services</td>
<td>30%</td>
<td>60%</td>
<td>90%</td>
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<tr>
<td>Businesses - Service Professions</td>
<td>30%</td>
<td>60%</td>
<td>90%</td>
</tr>
<tr>
<td>Conference &amp; Event Venues</td>
<td>30%</td>
<td></td>
<td>60%</td>
</tr>
</tbody>
</table>
Summary

The presented recovery model is realistic, flexible, and applicable to any building size.

To advance our estimates of building downtime and recovery it is crucial to talk with general contractors, inspectors, and engineers.