Resilience-based Earthquake Design Initiative (REDi) Rating System for the Next Generation of Buildings

SECED/EEFIT Meeting

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Our challenge

“the true costs of a disaster are **felt most acutely at community level**”

Jo da Silva, Director of International Development, Arup
Brunel Lecture Series for Institute of Civil Engineers, UK
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Modern Building Codes – "Life Safety" Objective

Code protects lives – does *not* limit damage or maintain functionality

 “Life-Safety” Performance – Building Contents

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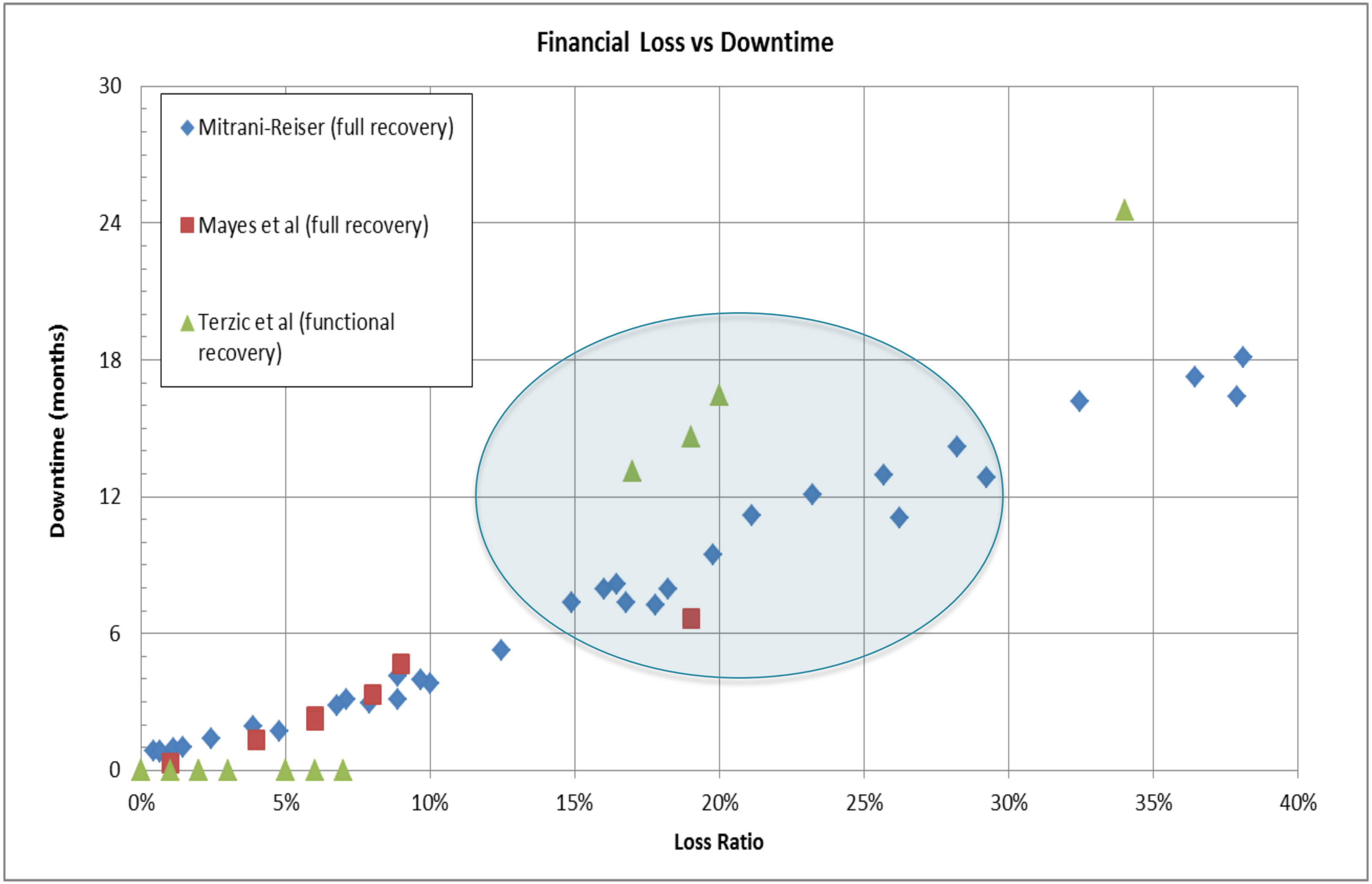
Consequences of code design



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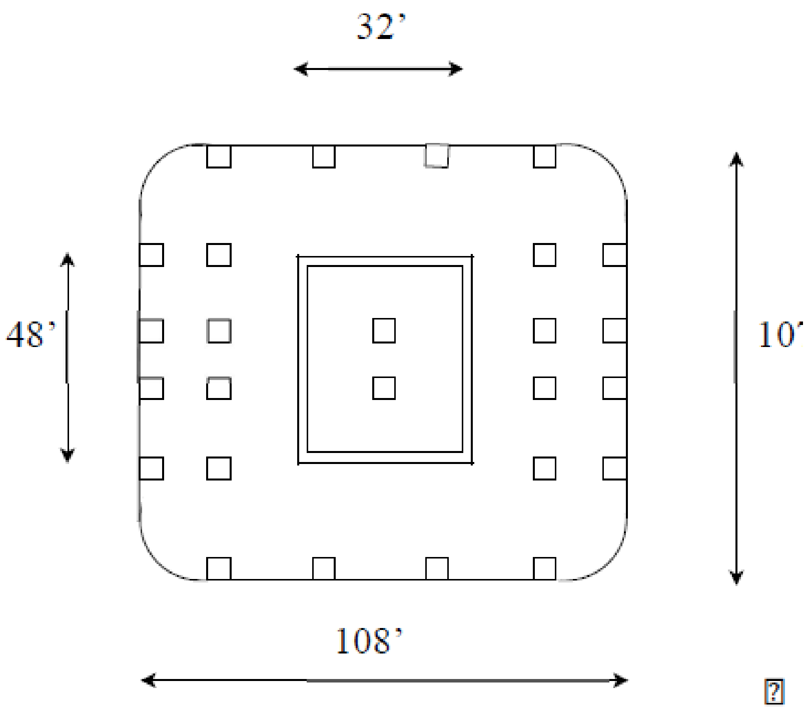
Performance Expectation for RC Tall Buildings in San Francisco



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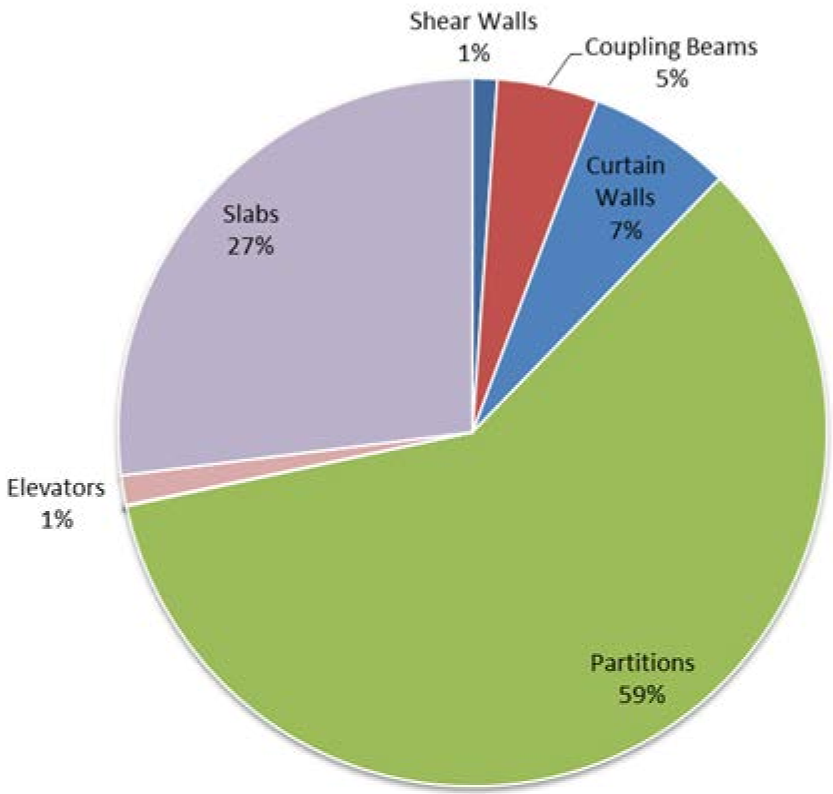

Loss drivers

2.5 years to achieve functional recovery after a big earthquake

$47M to repair the building (~26% of building value)

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Central Business District was closed for more than 2 years.

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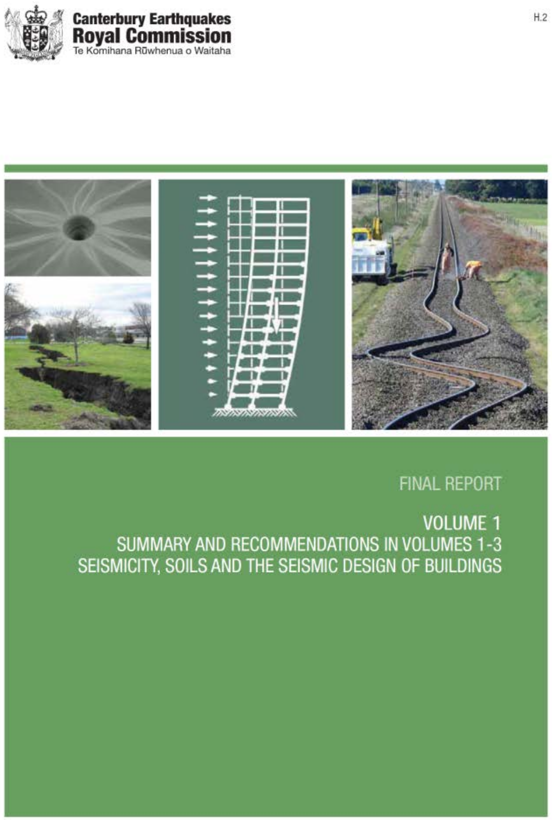
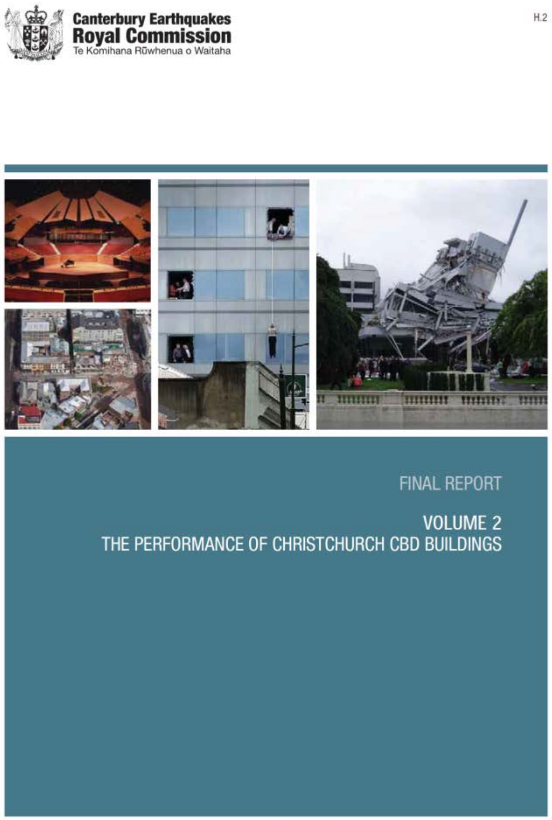
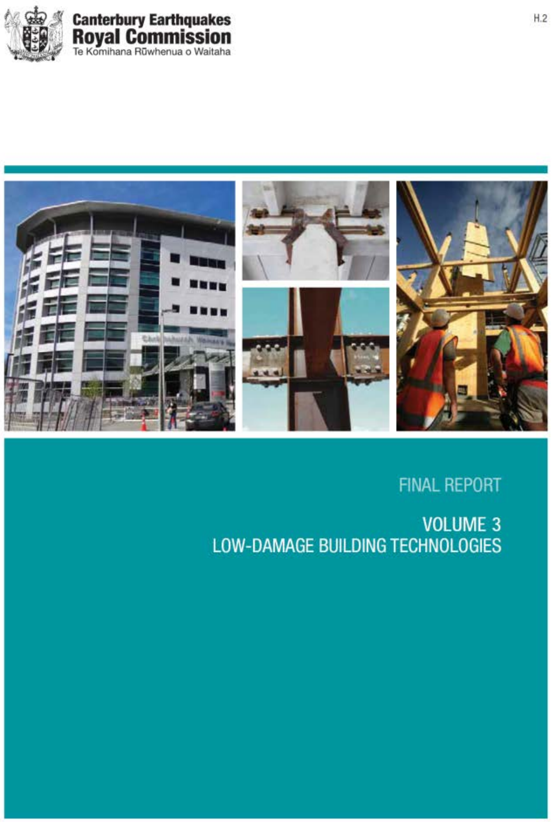
Royal Commission Reports







Royal Commission Conclusions

- *"...it would not be sensible, in our opinion, to conclude that the performance of buildings in the February earthquake demonstrates a need for wholesale change."*
- *"…the objective should be incremental improvement, rather than a change of direction, and the necessary improvements can be incorporated within the framework of the present rules."*
- *"However, once the objective of life-safety is achieved, the question of the extent to which buildings should be designed to avoid damage is a social and economic one, and the answer depends on choices that society as a whole must make."*
- *"In the circumstances, our concept of "best practice" is one that reflects the existing objective of life-safety, and looks to ensure that building damage is minimized within the limits established by the existing knowledge about earthquake risk and our understanding of the cost implications of more onerous requirements."*
- *"Any other approach would be a radical change that we do not consider would be justified by the experience of the Canterbury earthquakes."*

Other consequences – loss of culture, sense of community, and quality of life

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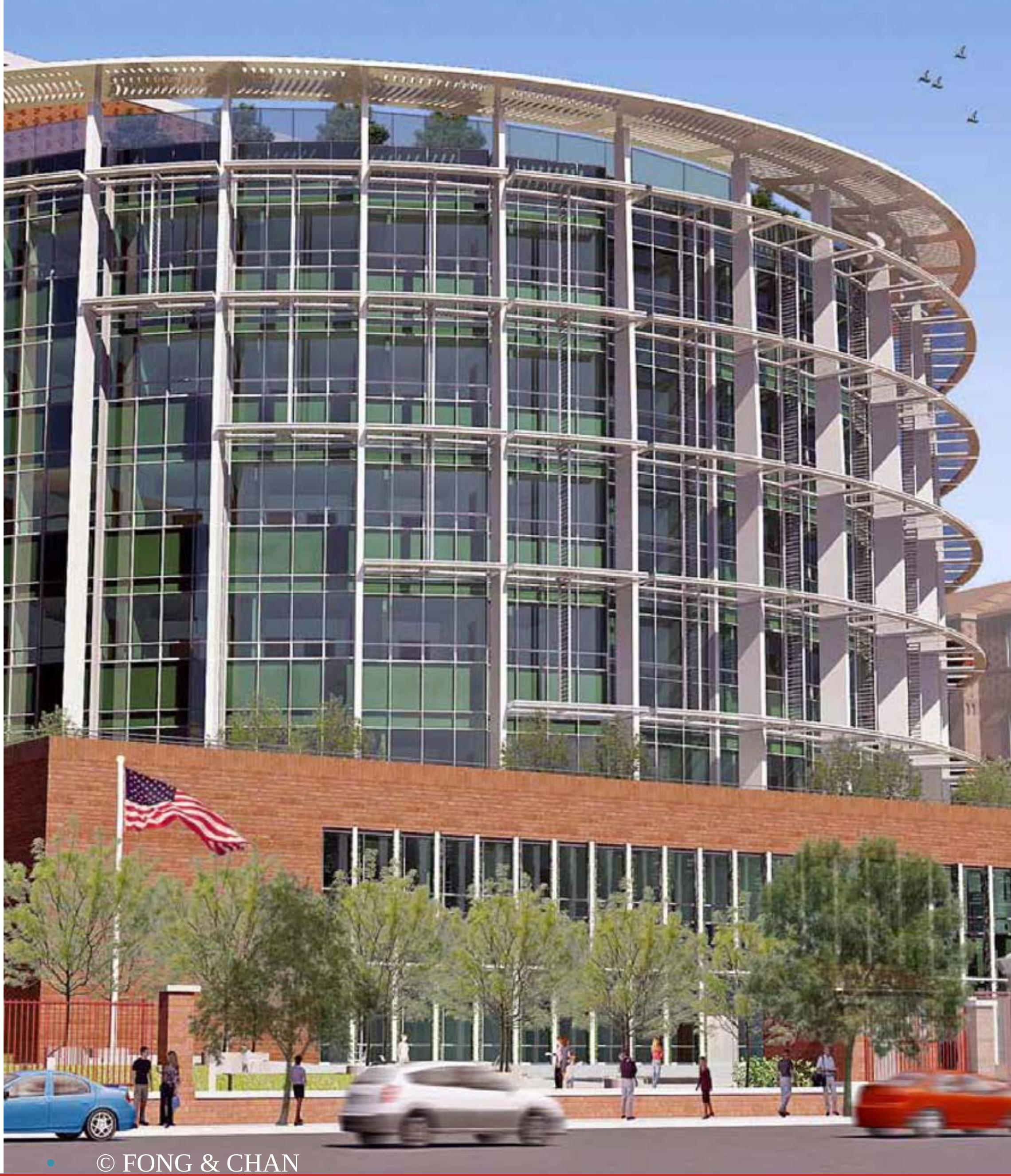
Design to resume business operations and provide livable conditions quickly after an earthquake



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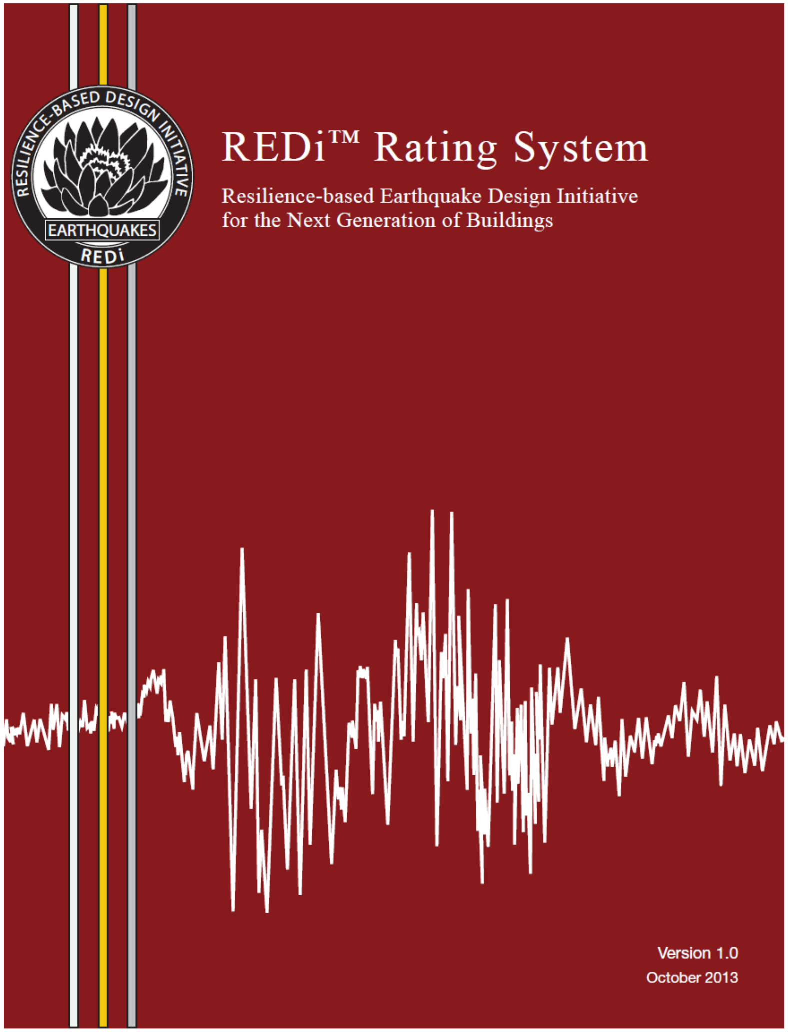
REDi™ Rating System



A framework to implement "resilience-based earthquake design" for achieving '*beyond-code*' resilience objectives.

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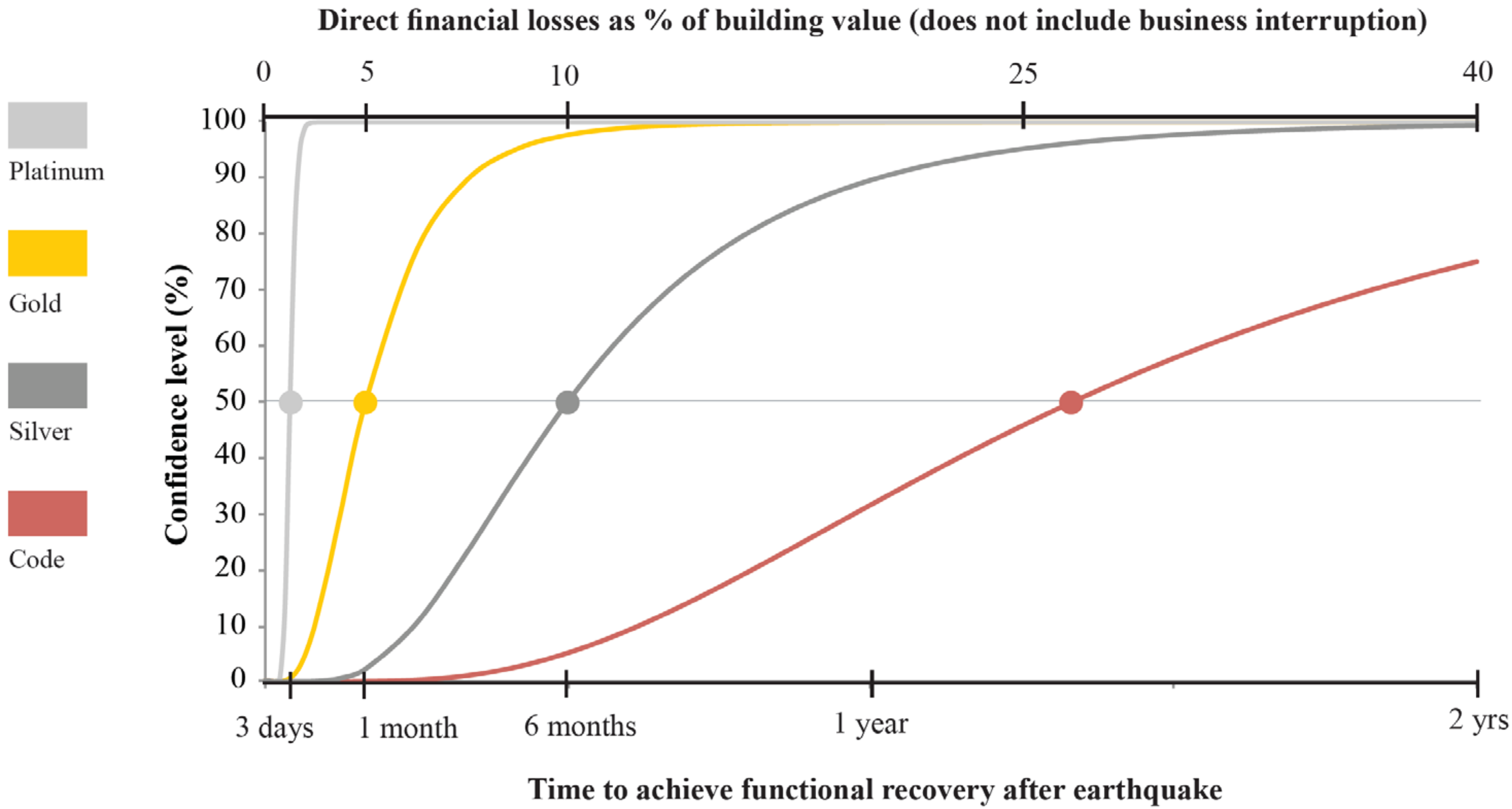
REDi Resilience Objectives



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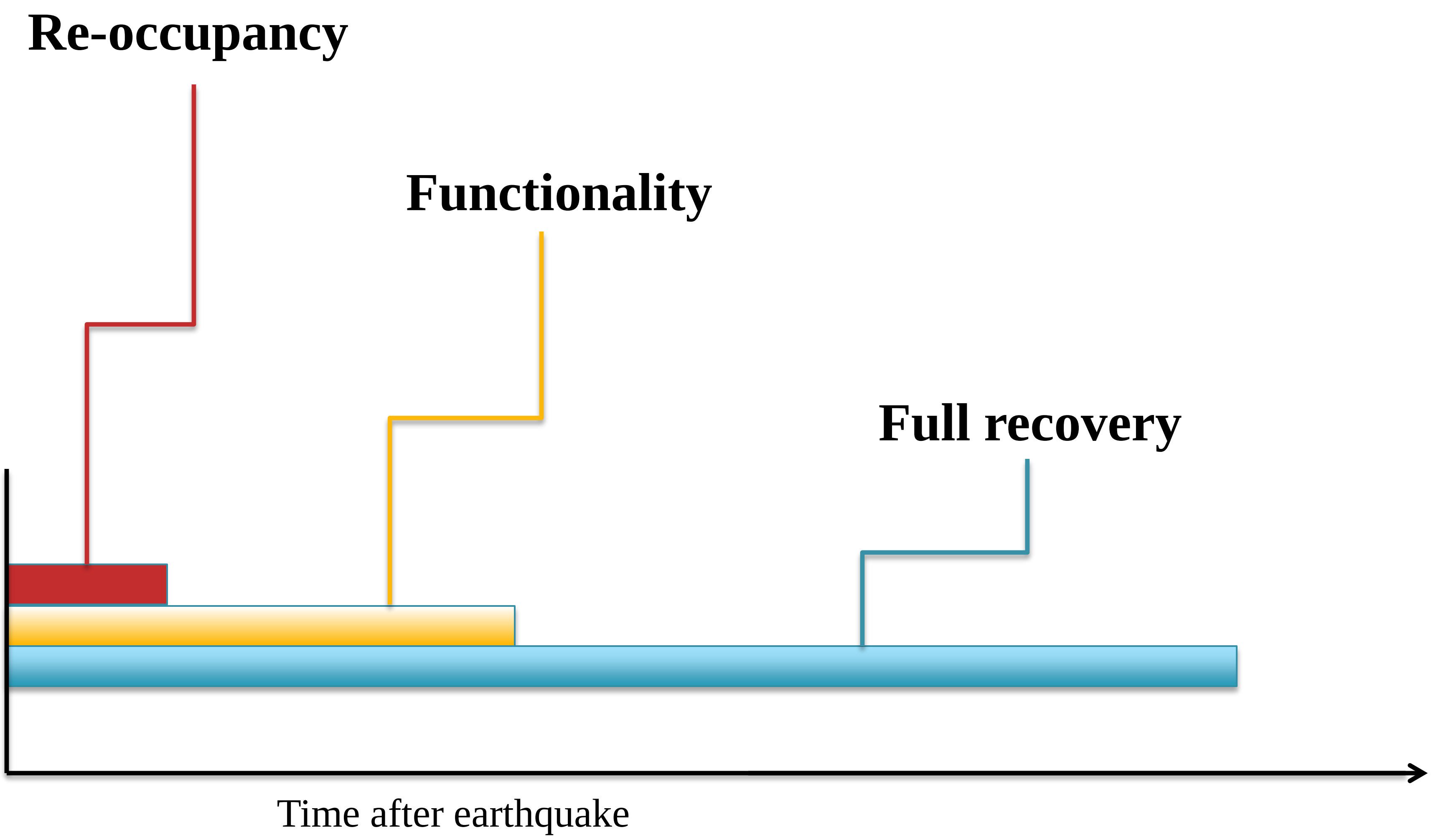
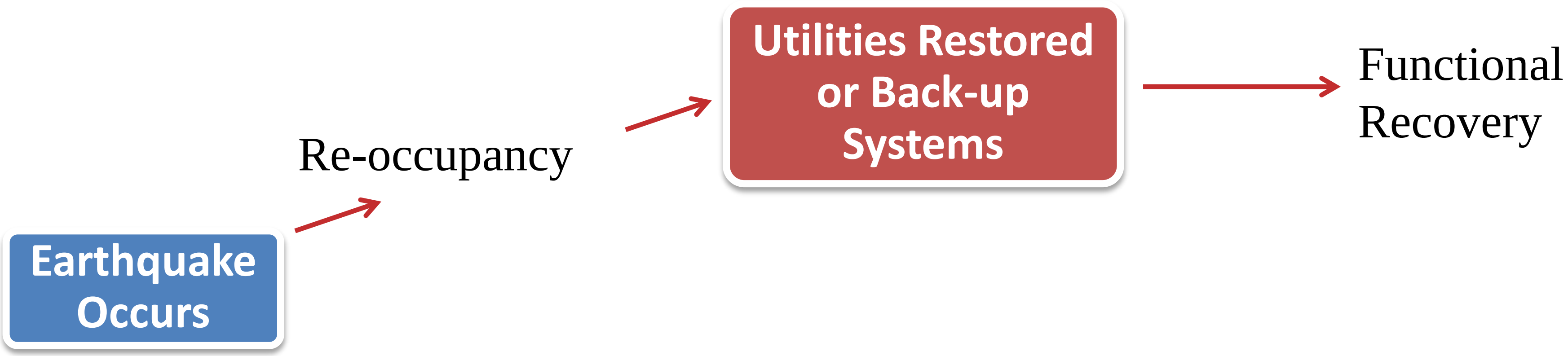
Defining Post-Earthquake Recovery States



Paths to Re-occupancy and Functional Recovery if Building Undamaged



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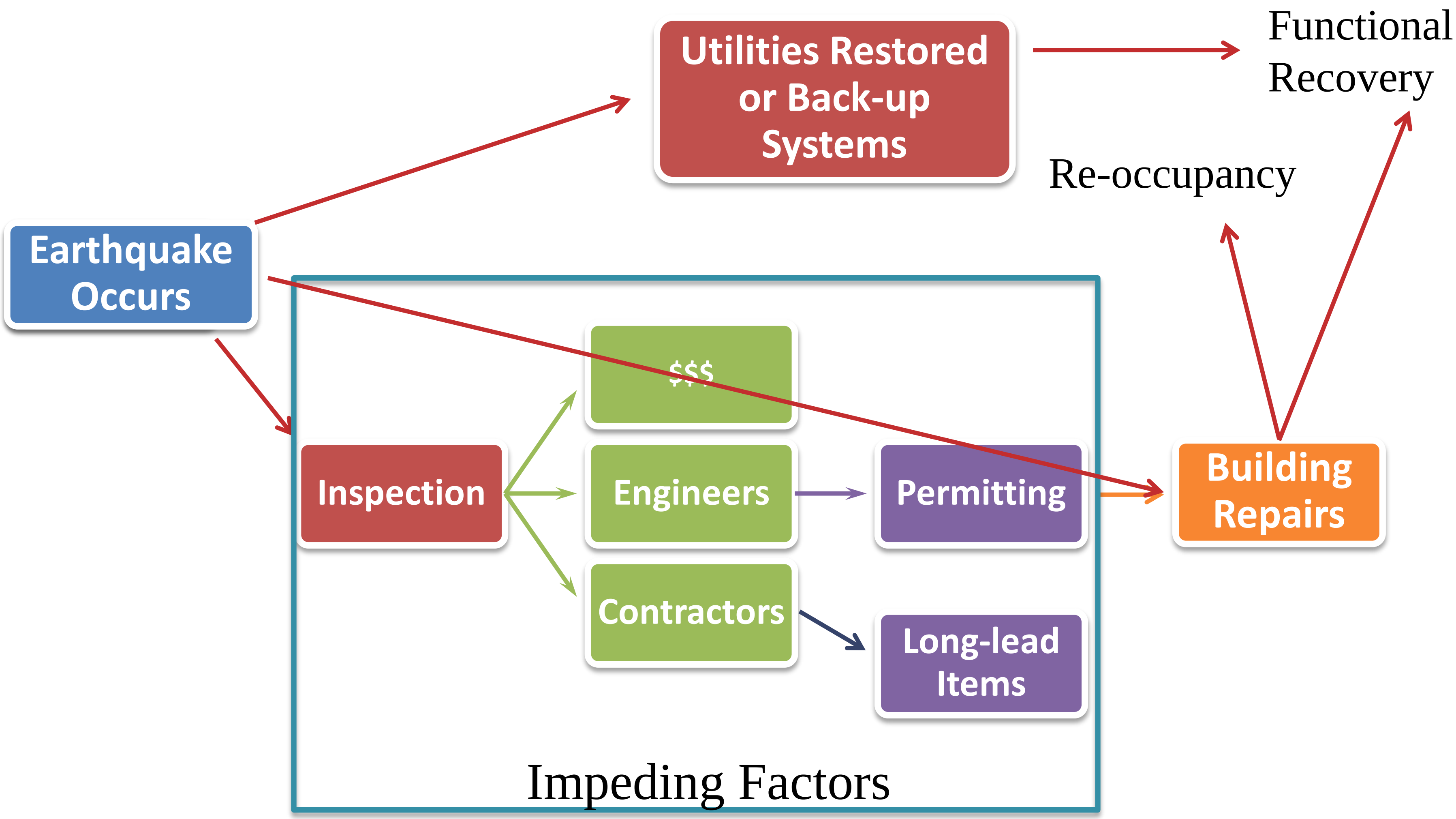
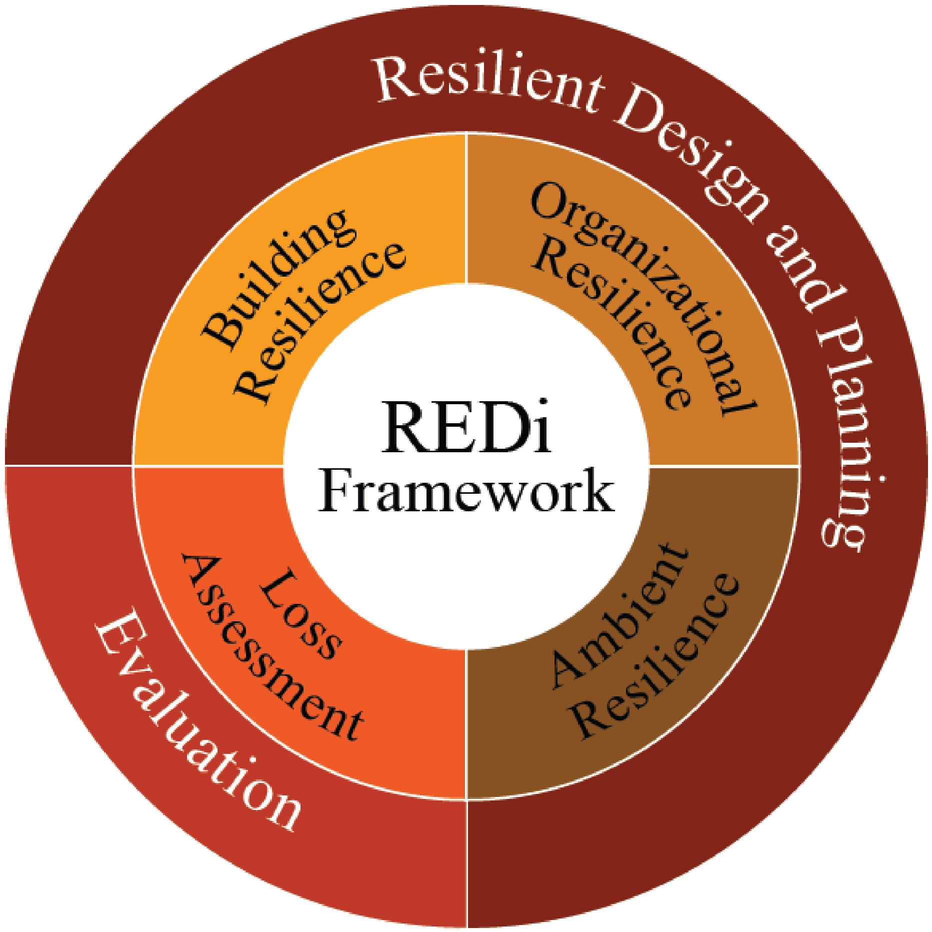
Paths to Re-occupancy and Functional Recovery if Building Damaged



REDi Roadmap to Resilience



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Guiding Principles

Platinum

* Enhance design of structure and architectural components such that the building and contents suffer only minimal (aesthetic) damage.

*Provide "beyond-code" provisions for egress systems and other improvements to occupant safety

* Protect MEP components and other critical systems. Provide back-up systems. This enables continued operations of primary functions in the absence of utilities.

* Pre-identify contingency plans to provide water and fuel and waste removal or employ alternative off-grid technologies in the event of extended utility disruption.

* Minimize risk of generally uncontrollable externalities which may affect functionality, including site access restrictions and potential damage from external hazards such as surrounding buildings.

Gold

* Enhance design of structure and architectural components such that the building and contents suffer only minimal (aesthetic) damage .

*Provide "beyond-code" provisions for egress systems and other improvements to occupant safety

* Protect MEP components and other critical systems or guarantee that they are replaced/repaired within 1 month. This enables normal operations to resume once utilities are restored

Silver

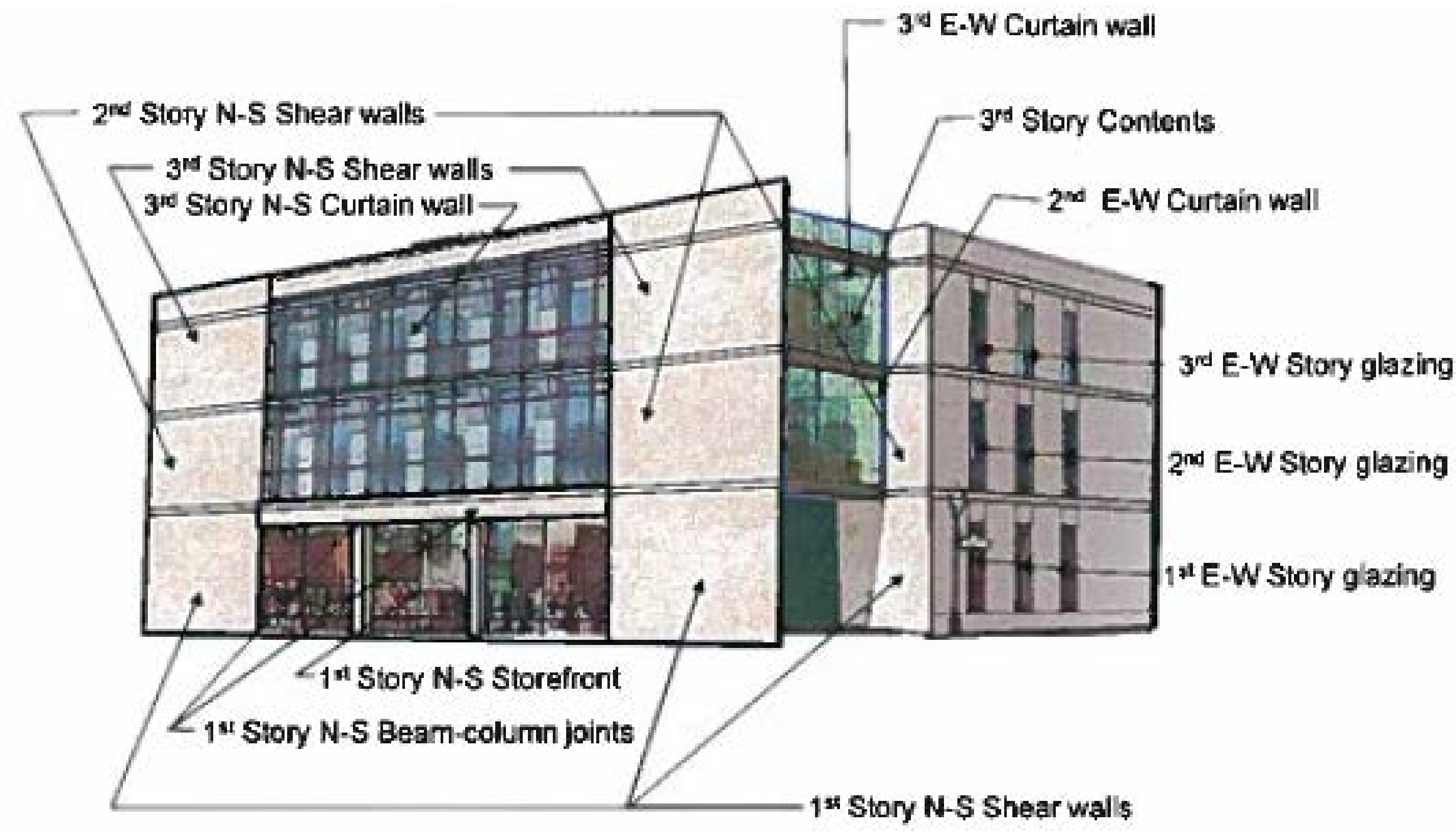
* Damage to the building may potentially result in a "Yellow Tag" which would prevent re-occupancy until the building is repaired.

*Provide "beyond-code" provisions for egress systems and other improvements to occupant safety

* A skilled contractor is required to make repairs to restore the building to a state which can support functional recovery within 6 months. It may be necessary to mitigate "impeding factors" (see Glossary of Terms) to meet this downtime objective.

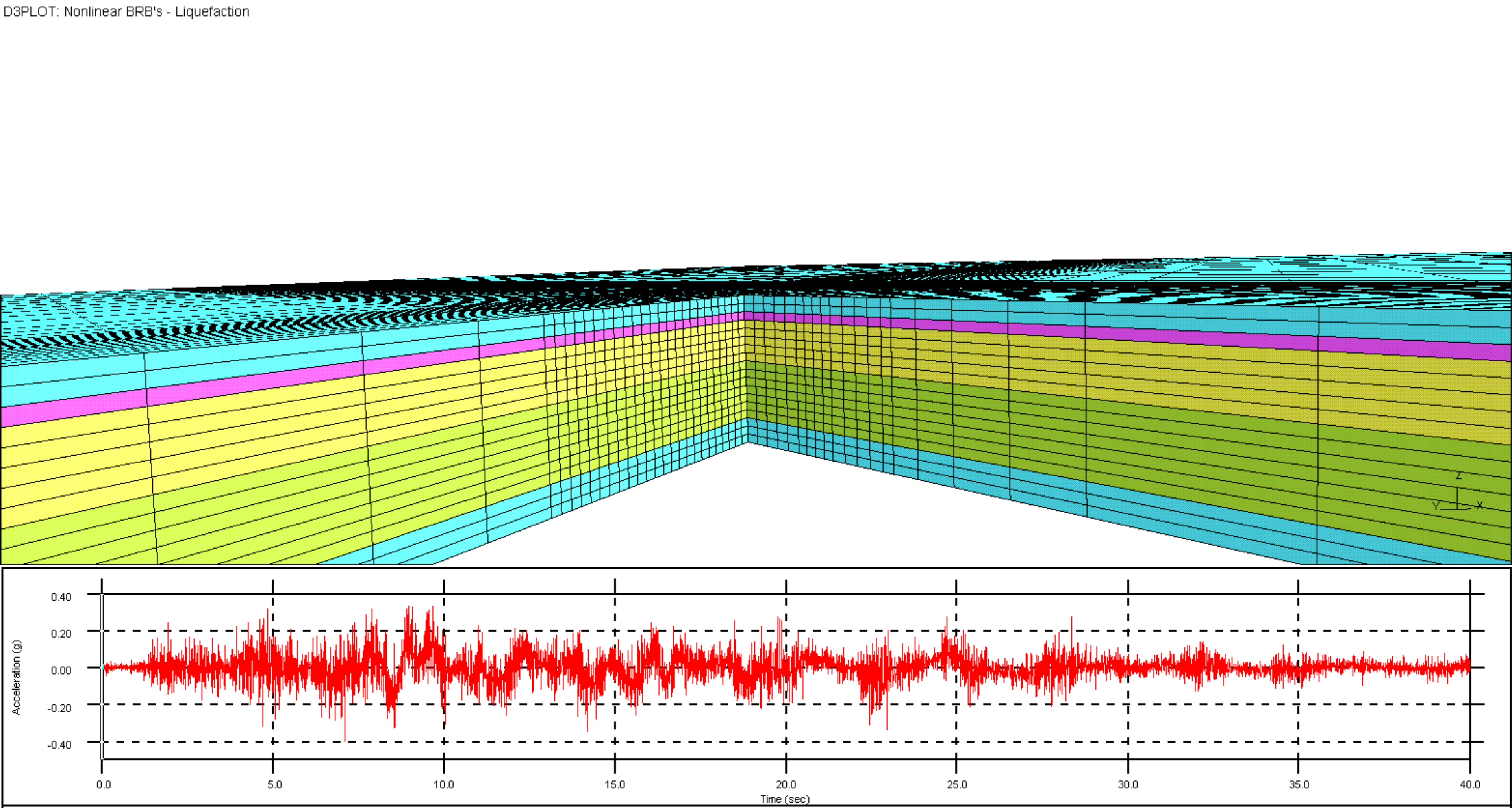
* The building can resume normal operations only once the building is repaired and utilities are restored.

FEMA-based Earthquake Loss Assessment



 Credit: FEMA P-58

Performance-based Seismic Analysis



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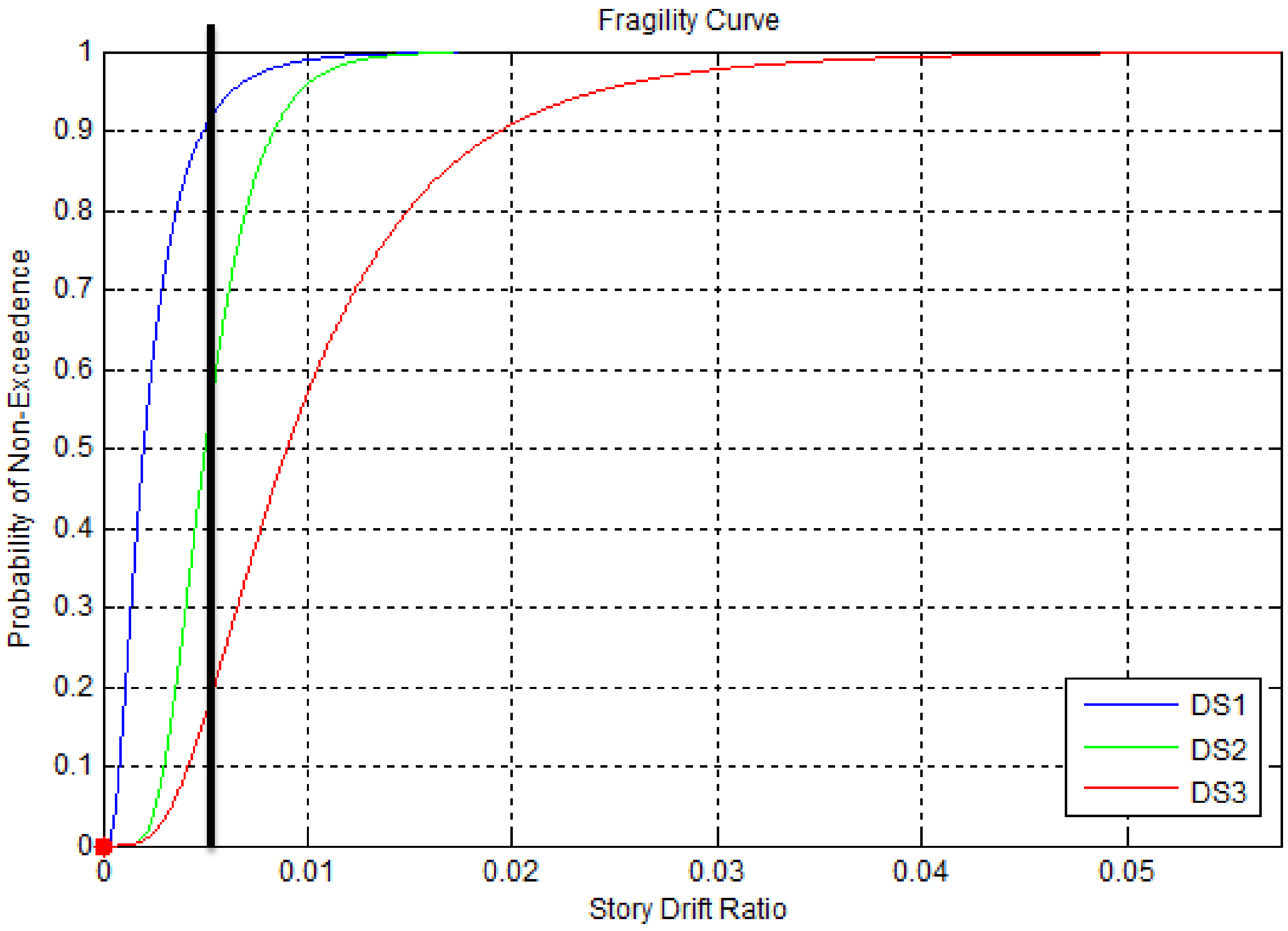
Fragility Curves



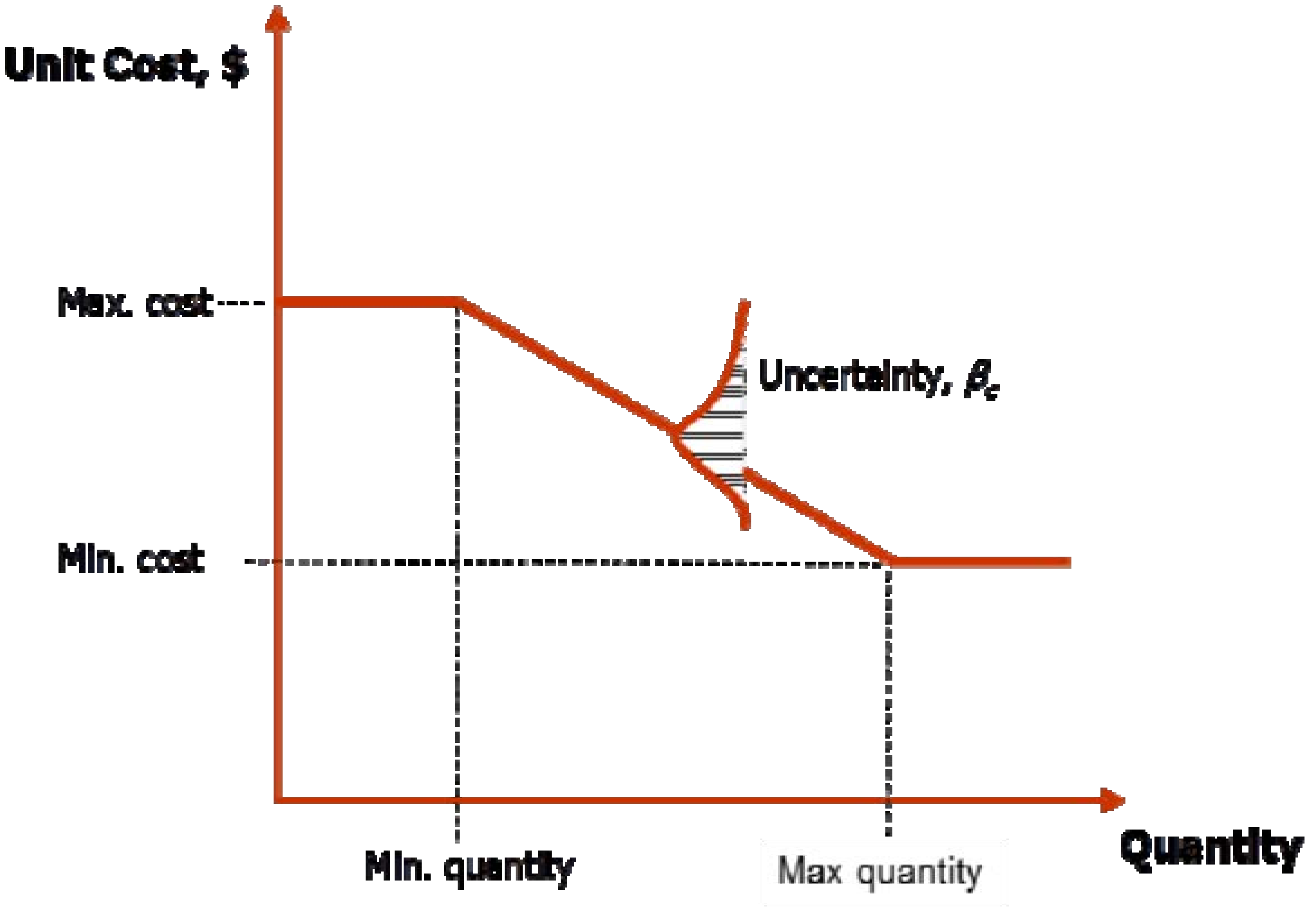
<u>Partitions</u>

DS1:
Cracking

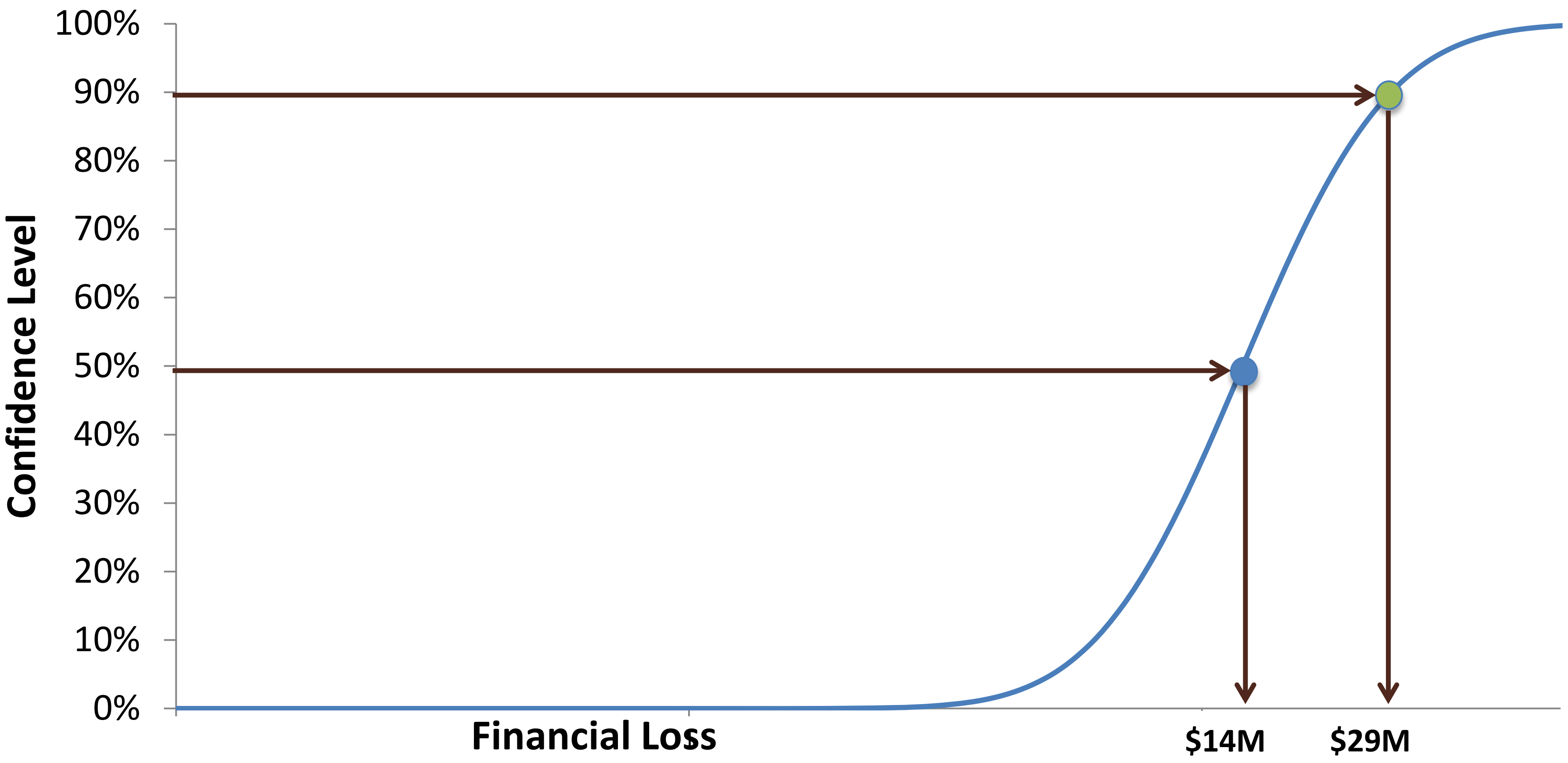
DS2:
Crushing

DS3:
Warping of studs

Consequence Functions



Confidence Levels for Earthquake Losses



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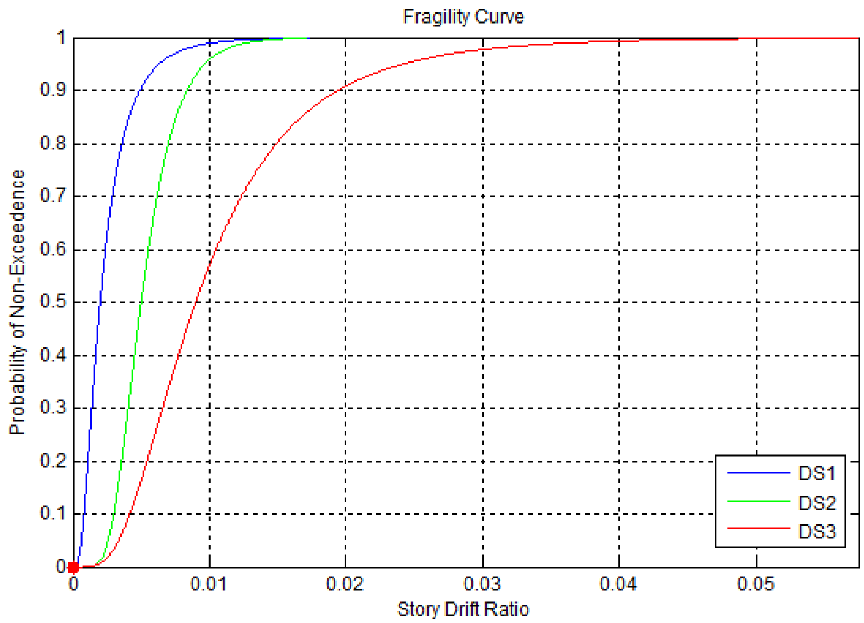
Improvement of FEMA Method for Downtime

1. Definition of “Repair Classes”
2. Estimates of delays due to “Impeding Factors”
3. Estimates of utility restoration times
4. Sequential logic for calculating the time to achieve re-occupancy, functional recovery, and/or full recovery.

“Repair Classes”

- Purpose to determine whether damage to specific components will hinder a specific recovery state
- Maps FEMA Damage States for each component into “Repair Classes”
- Depends on criticality of component and extent of damage



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Impeding Factors to Recovery

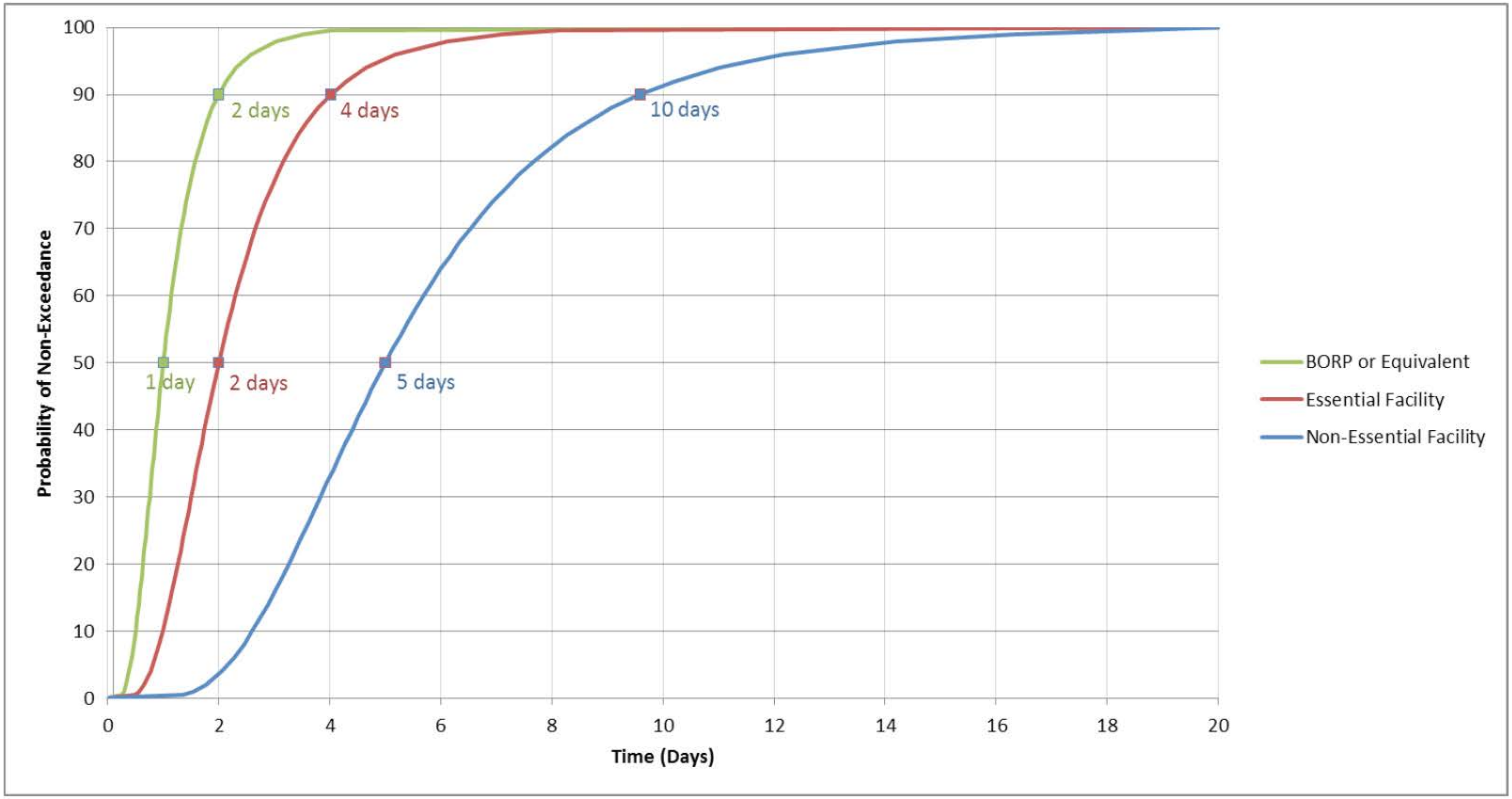

Figure 12. Impeding curve for post-earthquake inspection

Impeding Factors to Recovery

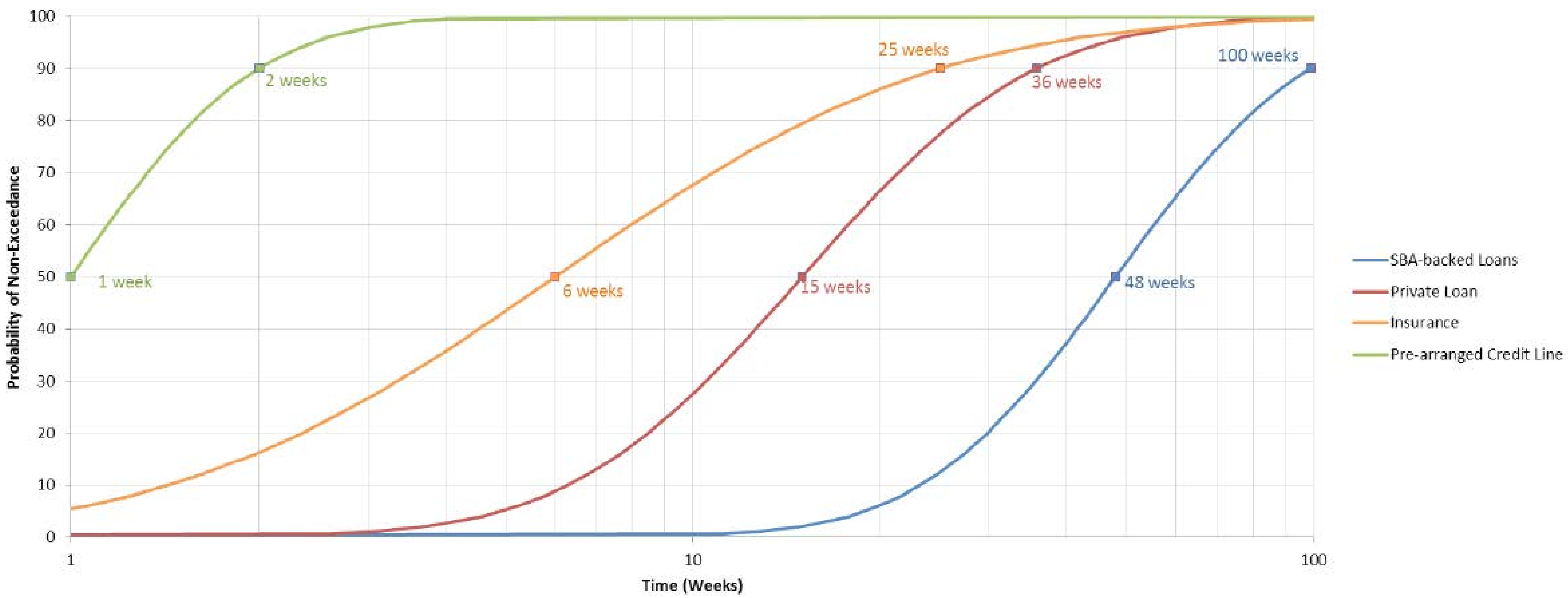

Figure 14. Impeding curves for financing repairs

Utility Restoration Curves

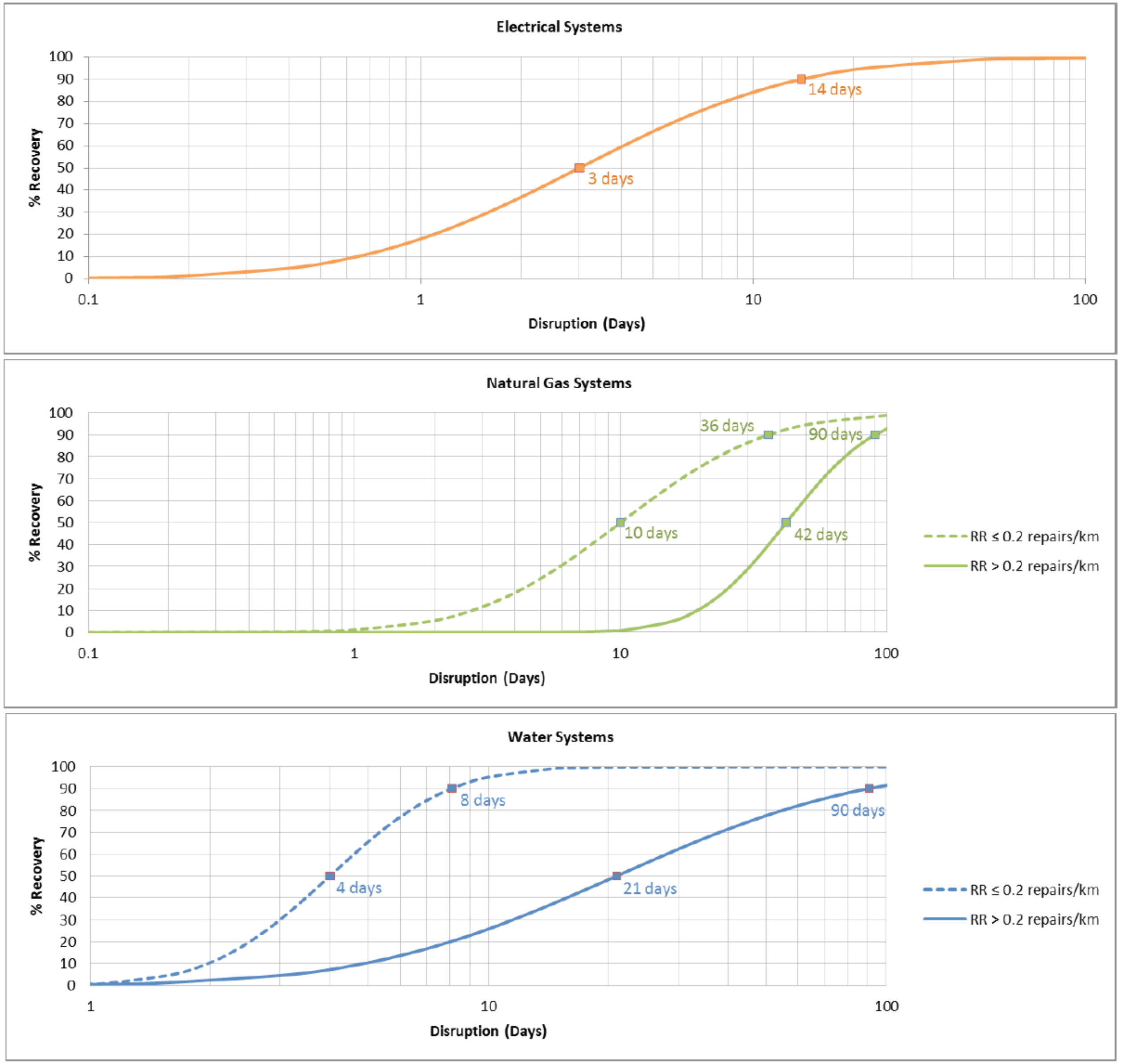

Figure 19. Utility disruption functions - electrical (top), water (middle), gas (bottom)

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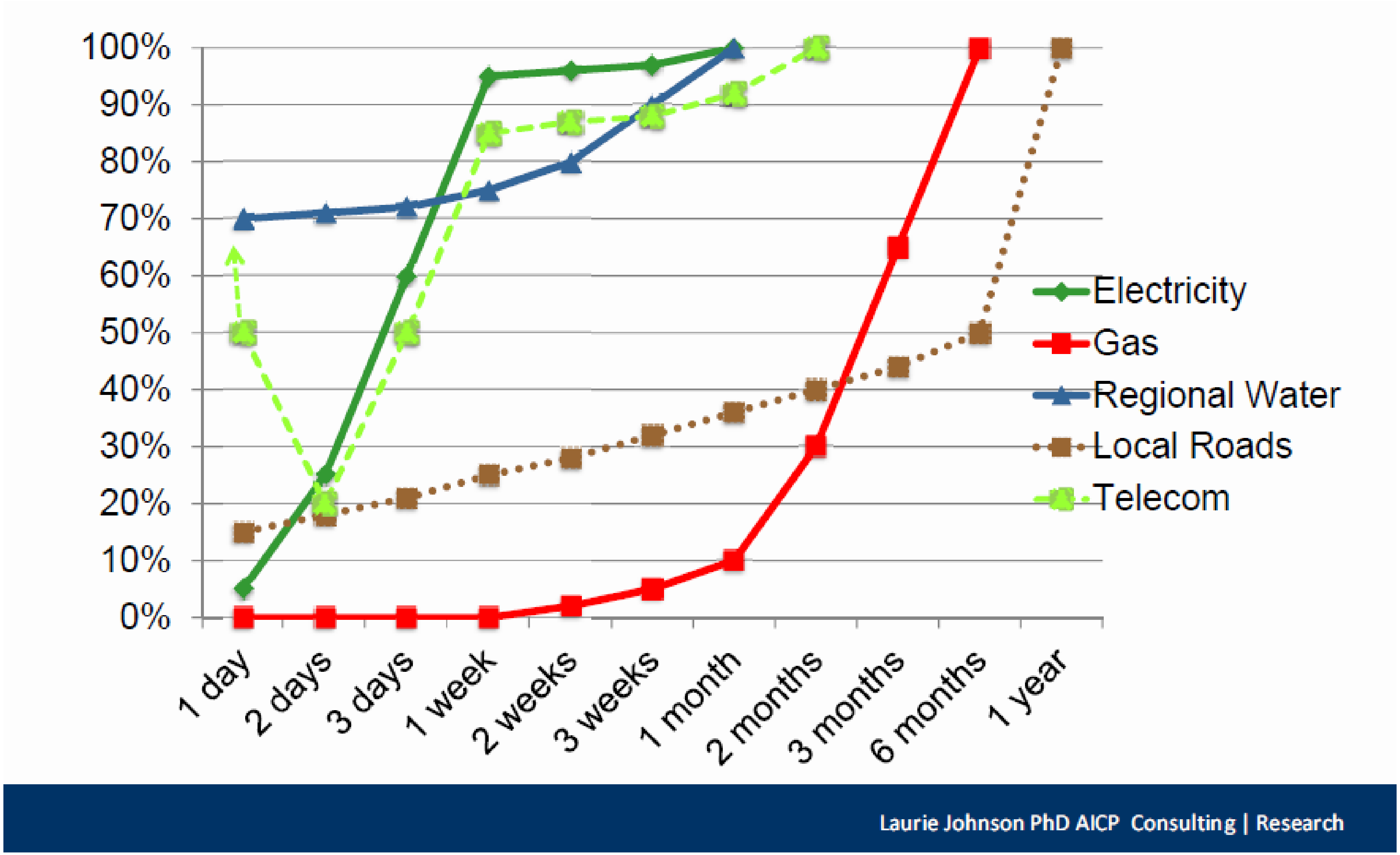
Site-specific Utility Restoration Curves for SF



Performance Expectation for REDi-designed Tall Buildings in SF

- $5.8M to repair *cosmetic* damage (~3.5% of building value)
- Immediate re-occupancy
- Functionality is achieved within *1 month*

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Performance Expectation for REDi-designed Tall Buildings in SF

- $5.8M to repair *cosmetic* damage (~3.5% of building value)
- Immediate re-occupancy
- Functionality is achieved within *1 month*

How?

- Innovative structural system
- Enhanced partition connections
- More displacement-tolerant façade system
- Stronger elevator guiderails
- MEP equipment functioning
- Contingency plans

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But that must cost a fortune!?

REDi building costs *only 2%* more than the conventionally designed building

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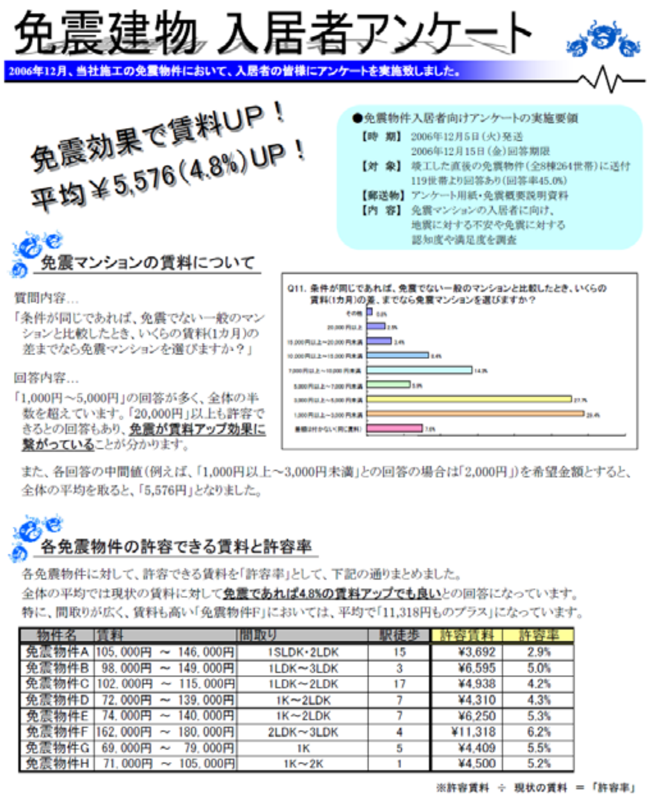
Potential Incentives

Increased rental premiums for resilient buildings – approximately 5% to 10%



免震建物 入居者アンケート

2006年12月、当社施工の免震物件において、入居者の皆様にアンケートを実施致しました。

免震効果で賃料UP！
平均￥5,576(4.8%)UP！

●免震物件入居者向けアンケートの実施要領
【時　期】 2006年12月5日(火)発送
2006年12月15日(金)回答期限
【対　象】 竣工した直後の免震物件(全8棟264世帯)に送付
119世帯より回答あり(回答率45.0%)
【郵送物】 アンケート用紙・免震概要説明資料
【内　容】 免震マンションの入居者に向け、
地震に対する不安や免震に対する
認知度や満足度を調査

免震マンションの賃料について

質問内容…
「条件が同じであれば、免震でない一般のマンションと比較したとき、いくらの賃料(1カ月)の差までなら免震マンションを選びますか？」

回答内容…
「1,000円～5,000円」の回答が多く、全体の半数を超えています。「20,000円」以上も許容できるとの回答もあり、**免震が賃料アップ効果に繋がっている**ことが分かります。

Q11. 条件が同じであれば、免震でない一般のマンションと比較したとき、いくらの賃料(1カ月)の差、までなら免震マンションを選びますか？

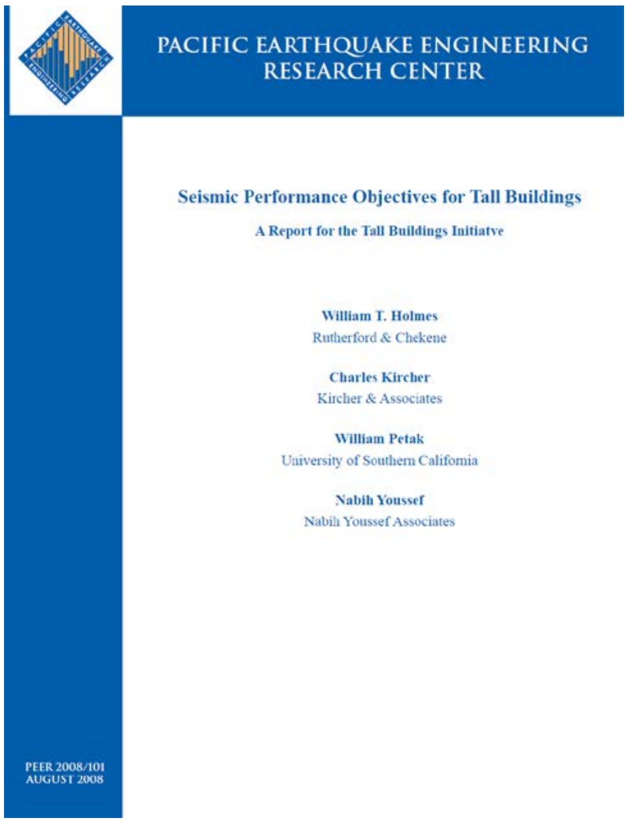
また、各回答の中間値(例えば、「1,000円以上～3,000円未満」との回答の場合は「2,000円」)を希望金額とすると、全体の平均を取ると、「5,576円」となりました。

各免震物件の許容できる賃料と許容率

各免震物件に対して、許容できる賃料を「許容率」として、下記の通りまとめました。
全体の平均では現状の賃料に対して**免震であれば4.8%の賃料アップでも良い**との回答になっています。
特に、間取りが広く、賃料も高い「免震物件F」においては、平均で「11,318円ものプラス」になっています。

物件名	賃料	間取り	駅徒歩	許容賃料	許容率
免震物件A	105,000円 ～ 146,000円	1SLDK・2LDK	15	¥3,692	2.9%
免震物件B	98,000円 ～ 149,000円	1LDK～3LDK	3	¥6,595	5.0%
免震物件C	102,000円 ～ 115,000円	1LDK～2LDK	17	¥4,938	4.2%
免震物件D	72,000円 ～ 139,000円	1K～2LDK	7	¥4,310	4.3%
免震物件E	74,000円 ～ 140,000円	1K～2LDK	7	¥6,250	5.3%
免震物件F	162,000円 ～ 180,000円	2LDK～3LDK	4	¥11,318	6.2%
免震物件G	69,000円 ～ 79,000円	1K	5	¥4,409	5.5%
免震物件H	71,000円 ～ 105,000円	1K～2K	1	¥4,500	5.2%

※許容賃料 ÷ 現状の賃料 ＝「許容率」



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Seismic Performance Objectives for Tall Buildings

A Report for the Tall Buildings Initiatve

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Rutherford & Chekene

Charles Kircher
Kircher & Associates

William Petak
University of Southern California

Nabih Youssef
Nabih Youssef Associates

PEER 2008/101
AUGUST 2008

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Potential Incentives

- **Governments**: zoning flexibility, expedited permits, etc

- **Insurers**: reduced premiums and capacity

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Project Example

- Downtown SF
- 55 stories, 800' tall
- Mixed-use

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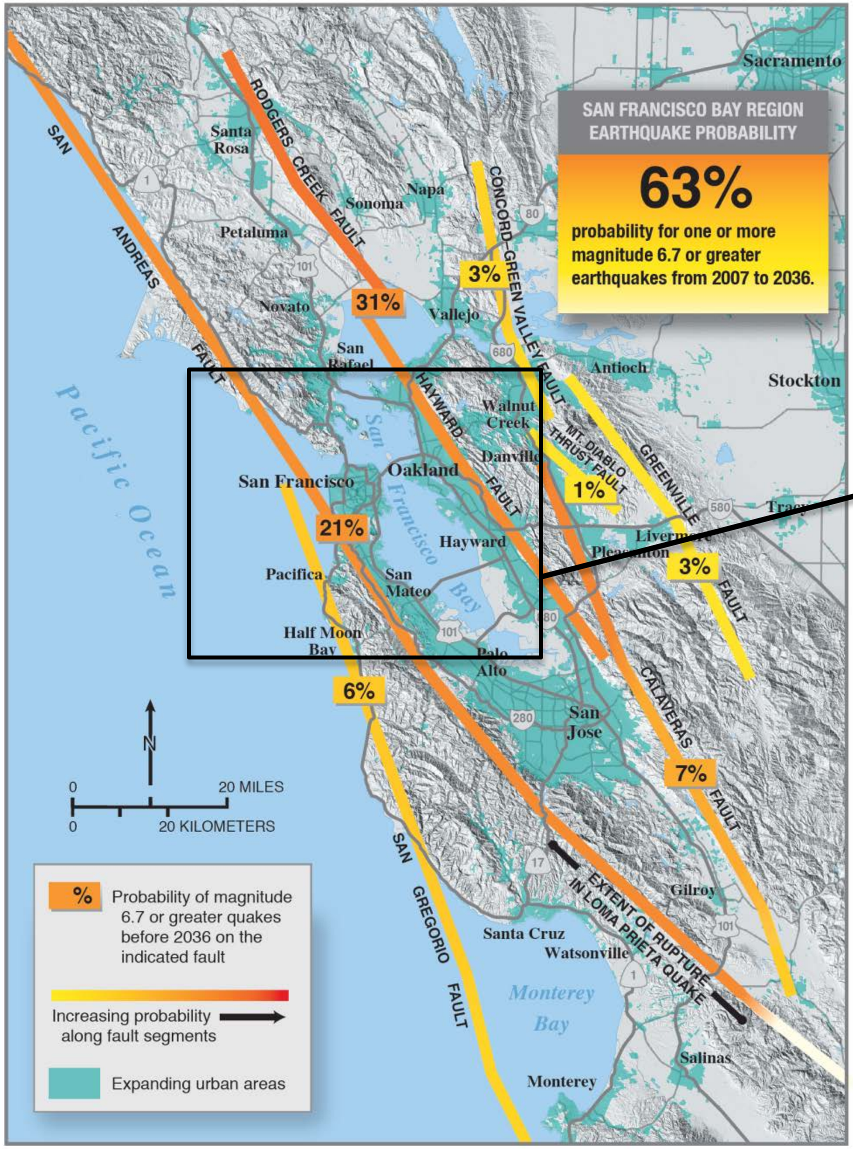
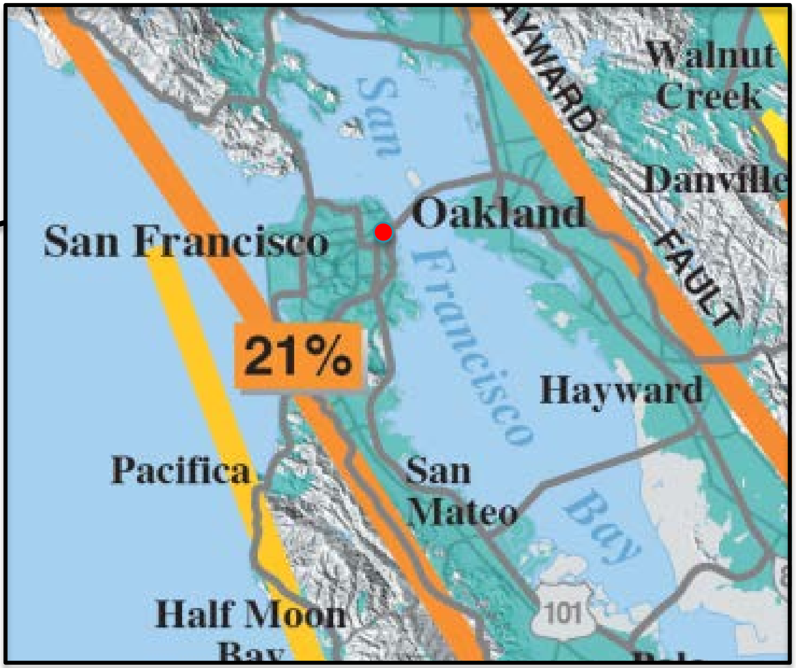
Earthquake Hazard in SF Bay Area





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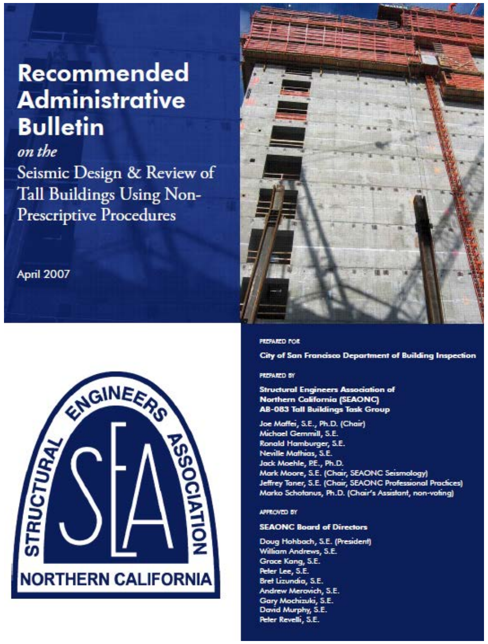
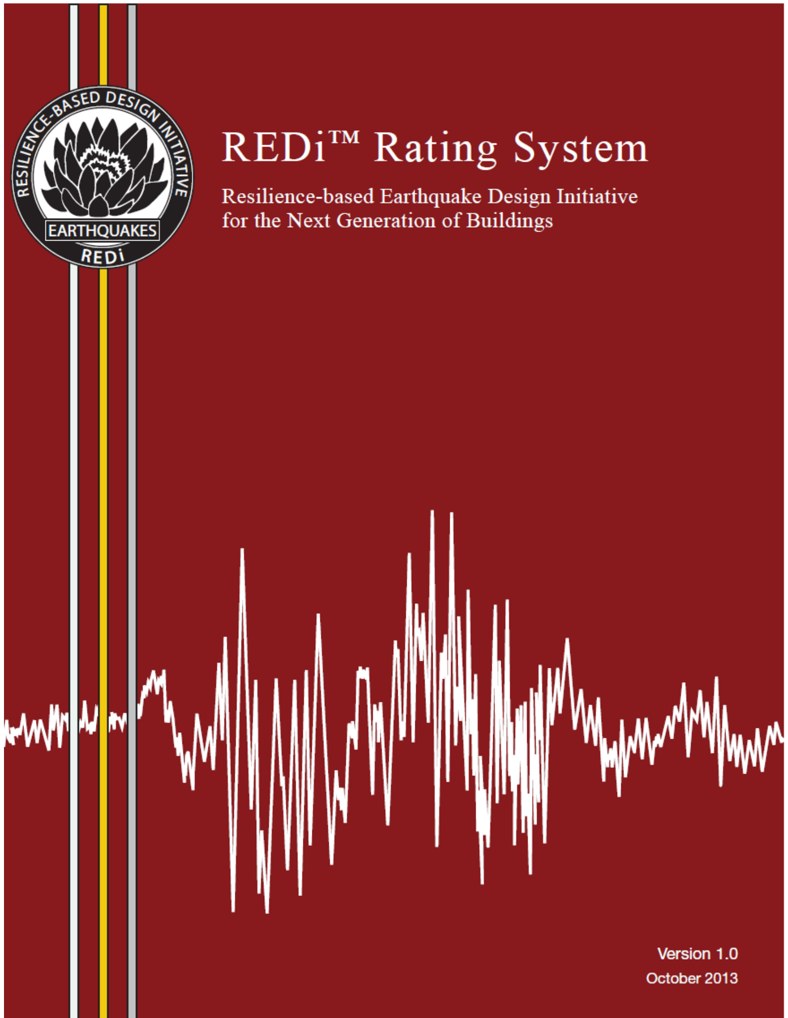
Tall Building Performance-based Design Guidelines (PEER TBI)

- SF required for most tall buildings
- Requires code-equivalent performance (i.e. “life-safety” and “collapse prevention”)



First REDi "Gold" Building



- Owner (developer) wants to pursue REDi "Gold" objectives
- Incorporated into Basis of Design

1.1.1 - Resilience Workshop
Conduct a comprehensive workshop with the Owner…to agree on resilience objectives and to identify risk drivers and a resilience plan for the facility…

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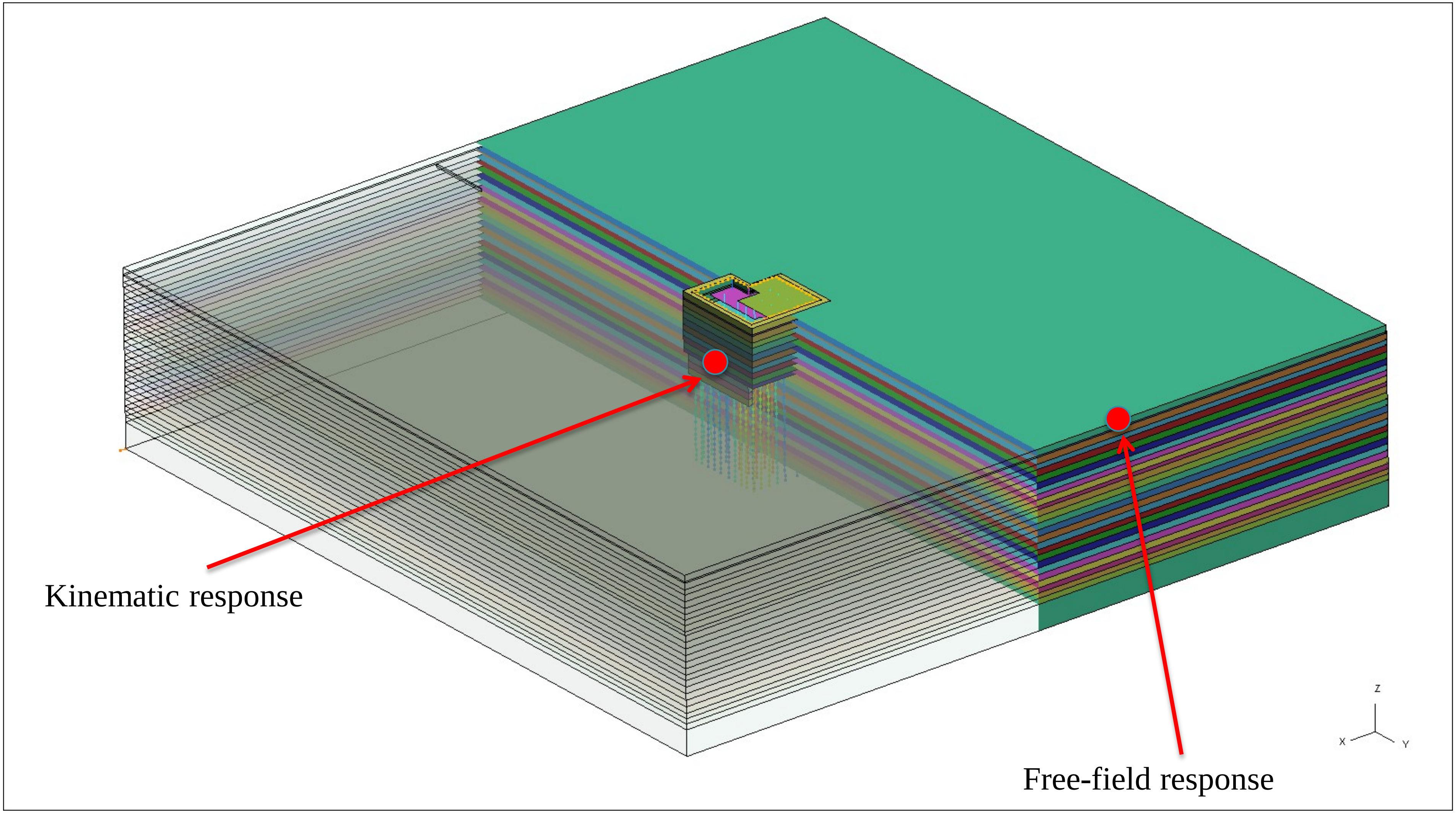
Structural Design

2.2.4 - Minimize Structural Damage

The superstructure (and foundations) are designed to remain essentially elastic (e.g. cracking allowed) for the demands in 2.2.2

Reduced Earthquake Demands



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Non-structural Enhancements

2.3.1 - Minimize Non-structural Damage
For non-structural components…design the anchorage to remain essentially elastic and design the components to accommodate relative displacements with minimal (aesthetic only) damage.

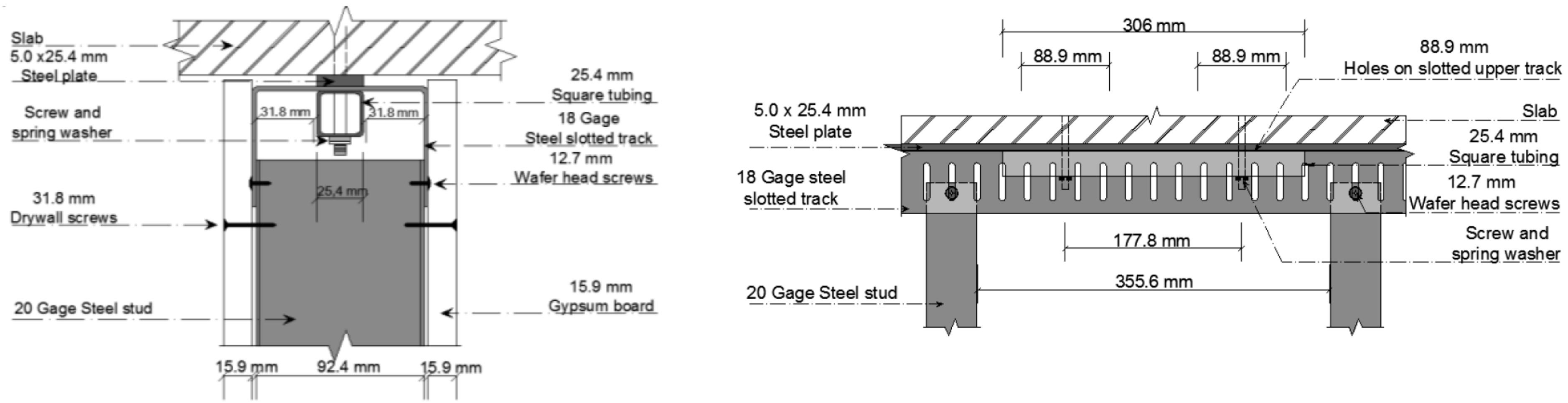

Figure 2.1. Cross section (on the left) and side-view elevation (on the right) of the proposed new sliding/frictional connection.

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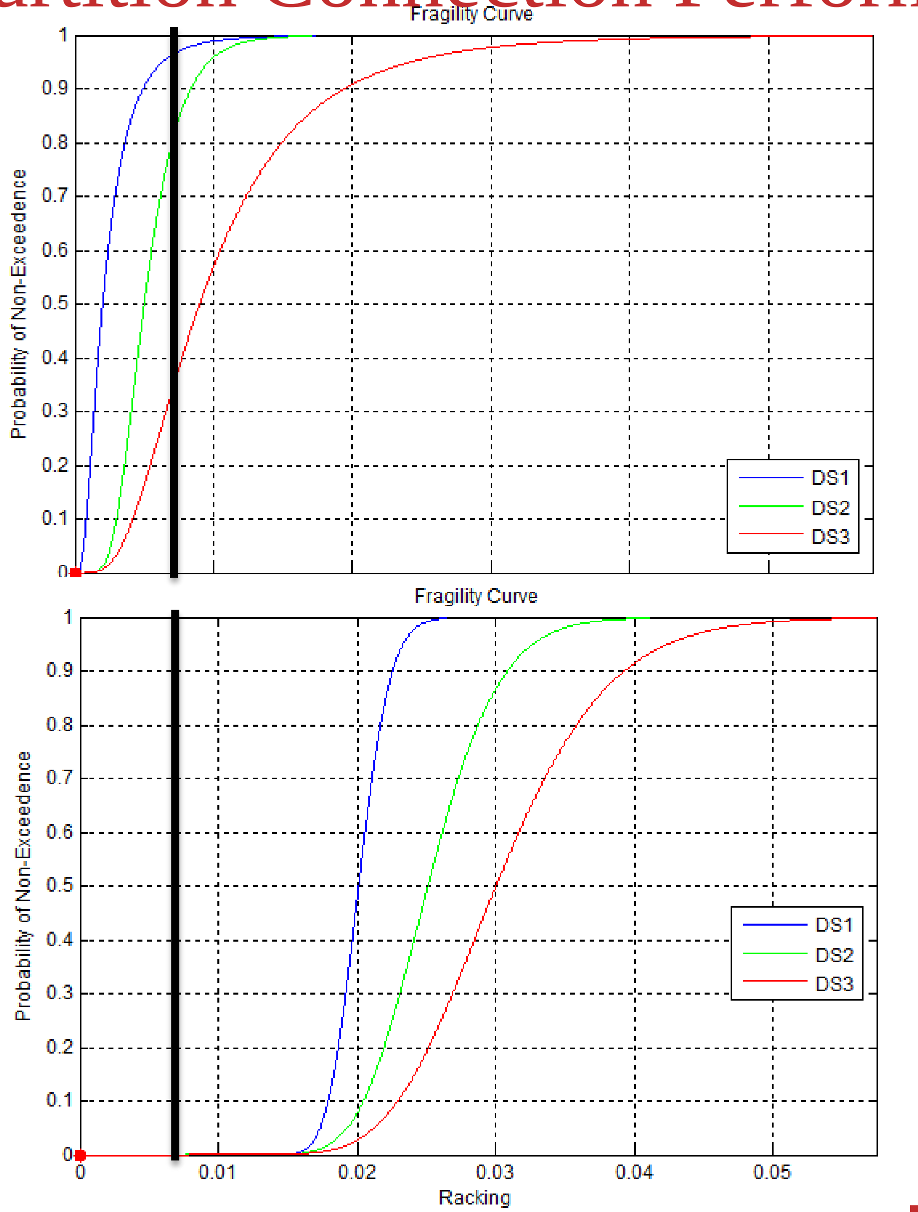
Improved Partition Connection Performance

Standard Partition

Improved Partition



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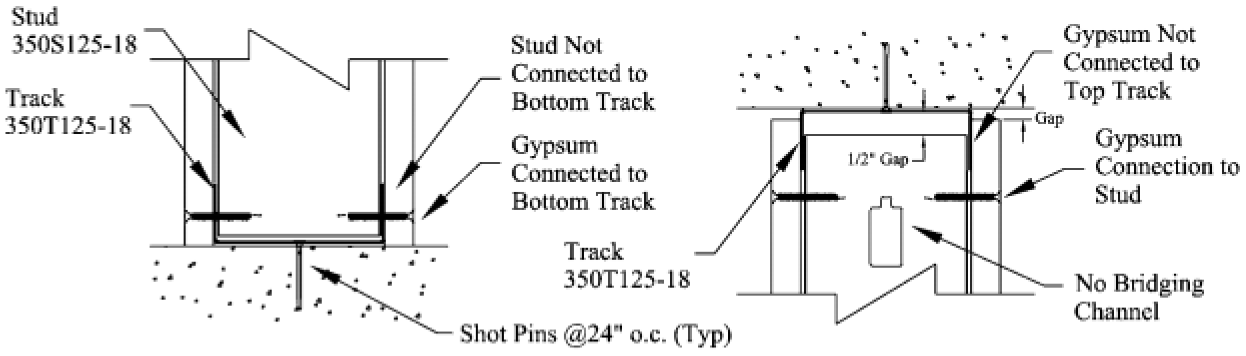
Viable Alternative?



(a) Friction Connection (Slip Track)

(b) Friction Connection: corner

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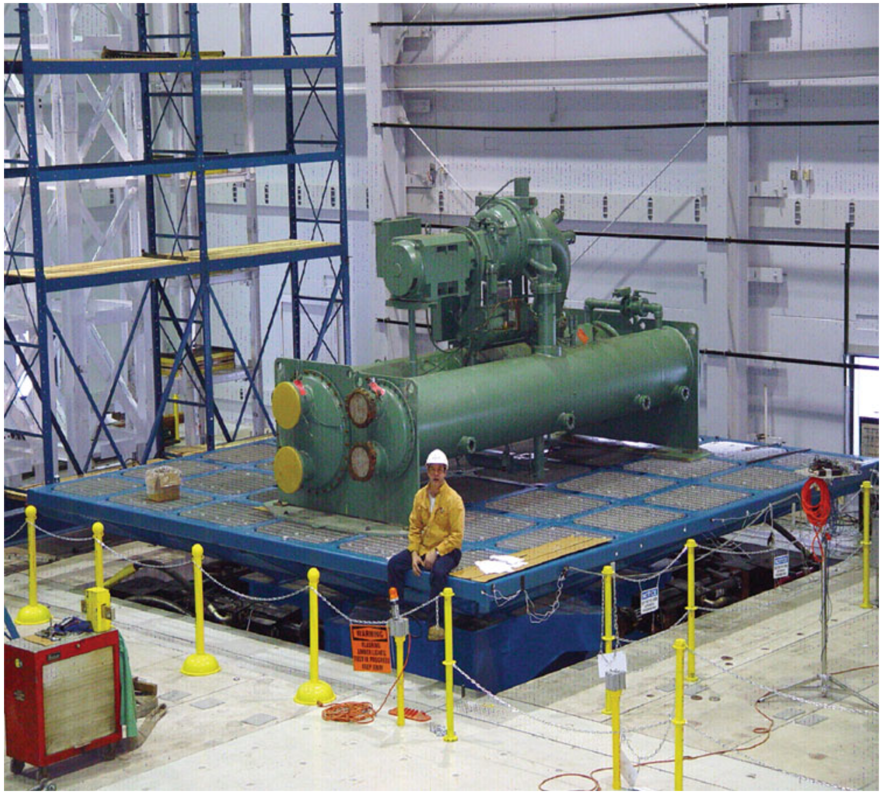
Functional MEP Systems

2.3.2 - Equipment Functionality

Mechanical and electrical equipment, back-up systems, or any other mission-critical components…to remain operable in the design level earthquake.



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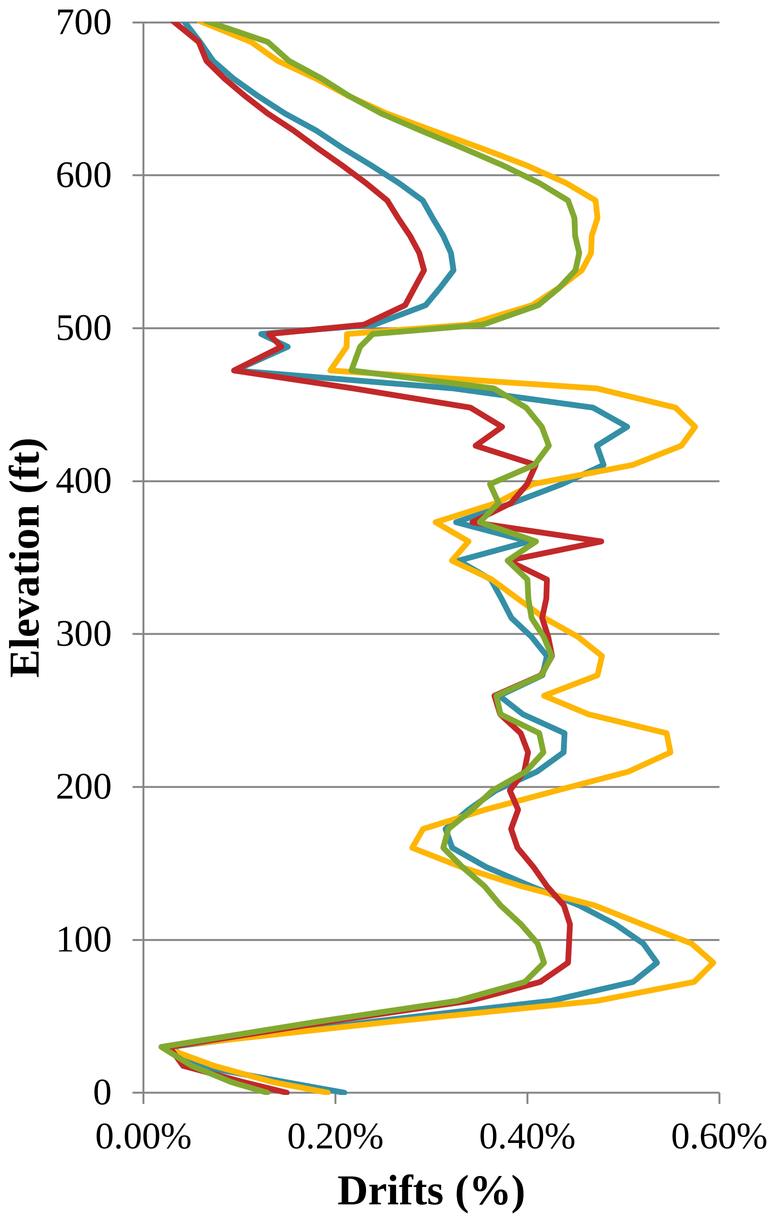
Façades

2.3.4 Protect Facades

Façades and curtain walls are designed and tested to accommodate relative displacements such that connections remain elastic and the building envelope remains effective in preventing air and water intrusion.



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Elevators

2.5.3 - Elevators

Elevator design meets the California Office of Statewide Health Planning and Development (OSHPD)…

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Expected Cost Implications to Achieve REDi Gold

Enhancement	Cost above Baseline
Essentially elastic structure using innovative seismic features	**None**
Enhanced partition connections	**~5% premium**
Displacement-tolerant façade system	**None**
Stronger elevator guiderails to meet CA hospital requirements	**$63k to upgrade S1**
Seismically-certified MEP equipment	**?**
Essentially elastic component anchorage	**Nominal**
Contingency planning: - Retain professional for post-EQ inspection - Train facility manager to certify elevator	**$15k/yr**
Recommendations for tenant fit-out contracts: - Anchor heavy and mission-critical contents - Improved partitions - Food and water	**None**
Observation of non-structural component installation	**$50k**
Seismic Peer Review	**None**

Lessons (being) learned

- People comfortable with the status quo
- Some cost premium OK
- All design team members are key – especially the architect
- Supportive and willing owner
- The prospect of reduced earthquake insurance premium is a driver

REDi Guidelines available for download

www.arup.com/publications