Chapter 2 (Section 2.7) Resilience-Based Design

2020 NEHRP Provisions Training Materials

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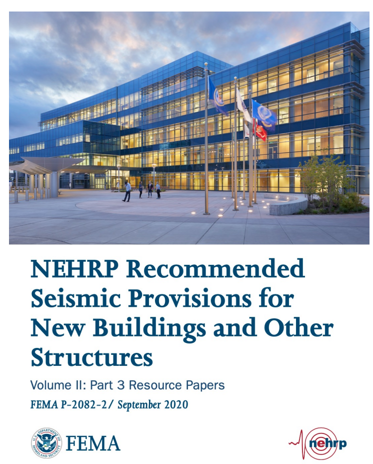
Content

- Development of resilience-based earthquake design
  - 2020 NEHRP Provisions, Resource Paper 1
- Functional Recovery (FR)
  - Its relation to resilience
  - Its relation to current building code provisions
- Hypothetical application to the CLT Design Example
  - CLT Shear Wall Design Example is in Chapter 6
  - Discussion in terms of resilience-based design is in Section 2.7



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Consensus

NIST, 2016 | ICC, 2019 | EERI, 2019 | FEMA, 2020 | FEMA-NIST, 2021

Oregon, 2013 | White House, 2016 | San Francisco, 2016 | Los Angeles, 2018 | Public Law, 2018 | California, 2021

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Consensus understanding of *resilience*

- An attribute of organizations or social units, not buildings
  - Congress' 2018 NEHRP Reauthorization focuses on resilience at the *community* scale
- Emphasis on recovery, not just safety
- Measured in terms of time, not immediate damage
- Relative to a natural hazard event

Q: If resilience is not about individual buildings, what does it mean to design individual buildings for resilience?

A: Design to achieve a "functional recovery objective."

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The “Resilience Field”

Technical

About the physical building
- Structure
- Nonstructural systems

Facility — Community

About one building. Typical context for:
- Engineering
- Building code implementation

About the group. Typical context for:
- Planning
- Public policy

About more than a building
- Contents → Use, Occupancy
- Purpose

Holistic

Meister Consultants Group, 2017

The “Resilience Field”

Technical

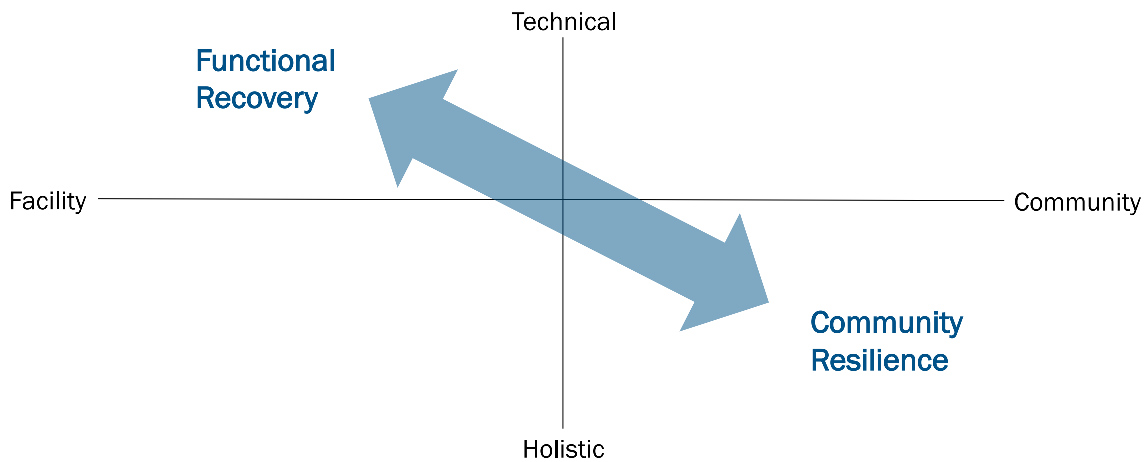
Design
- *NEHRP Provisions*
- ASCE 7
- IBC

Facility — Community

Thinking
- NEHRP Reauthorization
- City resilience plans

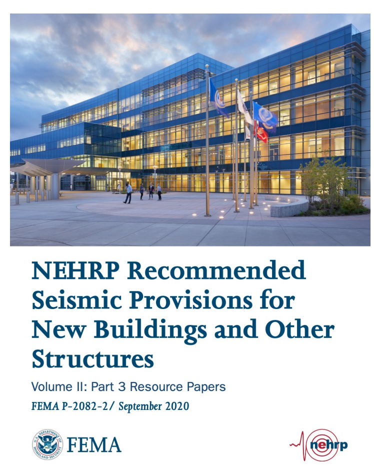
Holistic

FR : Building :: CR : Community



"Resilience-Based Design and the *NEHRP Provisions*"

- Federal policy now prioritizes earthquake resilience
- Improve resilience by designing for functional recovery
- Current "code and standard" model is promising for development of functional recovery design provisions
- NEHRP Provisions can support a functional recovery design standard



New definitions: Functional Recovery

NIST, 2016 | ICC, 2019 | EERI, 2019 | FEMA, 2020 | FEMA-NIST, 2021

Oregon, 2013 | White House, 2016 | San Francisco, 2016 | Los Angeles, 2018 | Public Law, 2018 | California, 2021

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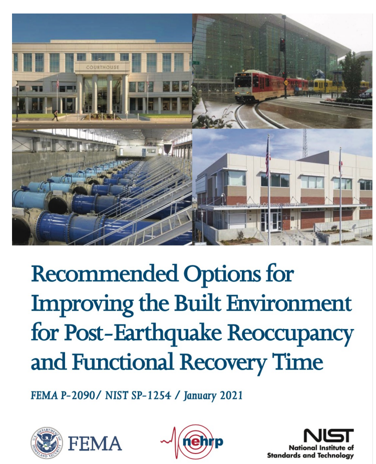
FEMA-NIST definitions*

- Functional Recovery (FR) is …
  - A post-earthquake performance state in which a building is maintained, or restored, to support the basic intended functions associated with the pre-earthquake use or occupancy.
- A Functional Recovery objective is …
  - FR achieved within an acceptable time following a specified earthquake, where the acceptable time might differ for various building uses and occupancies.



* The FEMA-NIST definitions consider infrastructure systems as well as buildings. These versions are edited to address only buildings.

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Functional recovery and performance-based engineering

- A structural safety objective may be written as: P(collapse) < X%, given $2/3*MCE_R$
- Analogously, a functional recovery objective may be written as:

  $P(T_{FR,\ expected} > T_{FR,\ acceptable}) < Y\%$, given $2/3*MCE_R$ (or other specified hazard)
- Open policy questions for developers of FR codes:
  - What is the acceptable or desirable FR time, $T_{FR,\ acceptable}$, for a given occupancy?
  - What is the appropriate confidence level, Y?
  - What hazard level should be used for FR?
    - For this example, use $2/3*MCE_R$ (See Resource Paper 1 and Design Example 2.7 for discussion.)

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The technical question

$P(T_{FR,\ expected} > T_{FR,\ acceptable}) < Y\%$, given $2/3*MCE_R$ (or other specified hazard)

- For a given building, what is the expected functional recovery time, $T_{FR,\ expected}$?
  - The subject of ongoing research, using analysis and testing
  - Also answerable by judgment, experience (reconnaissance research), and, in the interim, with our established consensus procedures for developing codes and standards.

Q: Can't we ask a similar question about safety? How do we know a given design is "safe"?

A: Yes. Current design provisions in the NEHRP Provisions, ASCE standards, and building codes reflect engineering consensus applied to collected research, judgment, and experience. The same approach can be used to develop provisions for functional recovery design.

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Functional recovery and the current building code

- Risk Category IV (IBC Table 1604.5)
  - Used for "essential facilities" to preserve functionality after a design earthquake (NEHRP Provisions Section 1.1.5)
  - Could be used as interim FR criteria
- Two differences between FR and RC IV
  - RC IV presumes immediate performance; some FR objectives would allow time for repairs
  - FR provisions might cover externalities the current building code ignores

TABLE 1604.5
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES

RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV.
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IV	Buildings and other structures designated as essential facilities, including but not limited to: • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released.[b] • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

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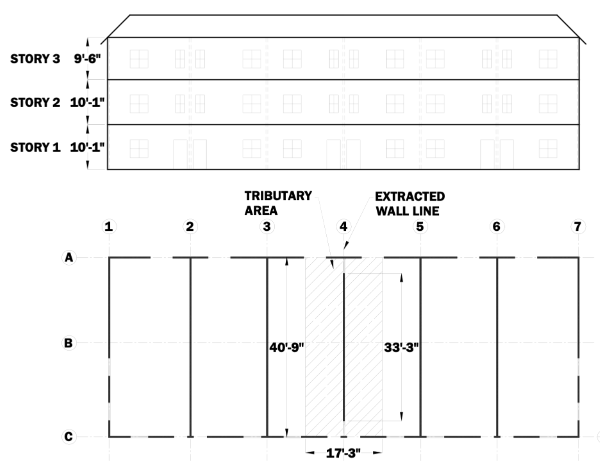
CLT Shear Wall Design Example (Chapter 6)

- 6-unit townhouse
  - Multi-family residential (R-2) occupancy
    - Occupant load less than 50
  - Risk Category II
  - Seismic Design Category D
- Similar structure could be used for:
  - Assisted living, or housing for other vulnerable tenants
  - Office suites
  - Mixed use or live/work units



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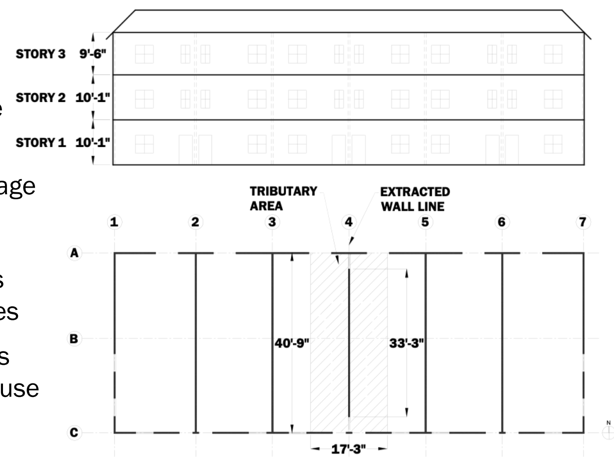
CLT Shear Wall Design Example (Chapter 6)

- Expected structural damage
  - Low *R*-factor
  - Inelasticity limited to replaceable ductile steel connectors
  - CLT tests showed no hard-to-repair damage
- Expected nonstructural damage
  - Residential systems typically lighter, less fragile than in office or other occupancies
  - For RC II buildings, current code exempts most components from anchorage because they pose no safety hazards



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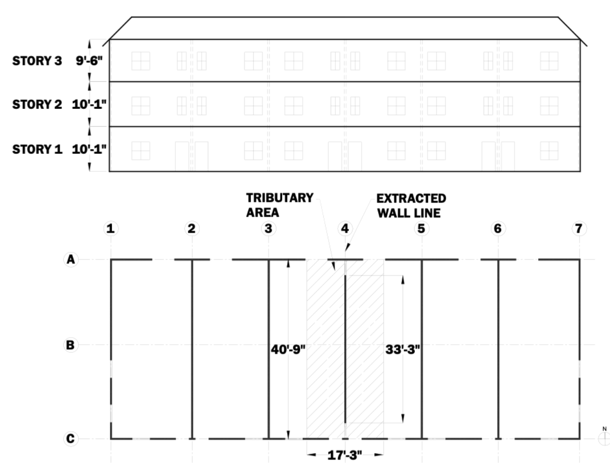
Functional recovery objective

- Presumed hazard: 2/3*MCE_R
- What is an acceptable FR time ($T_{FR,\ acceptable}$)?
  - Or *desired* FR time, absent code requirements
- What is the actual expected FR time ($T_{FR,\ expected}$)?



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Policy precedents for acceptable FR time?

NIST, 2016 ICC, 2019 EERI, 2019 FEMA, 2020 FEMA-NIST, 2021

Oregon, 2013 White House, 2016 San Francisco, 2016 Los Angeles, 2018 Public Law, 2018 California, 2021

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Policy precedents for acceptable FR time?

- NIST CRPG: 1 to 12 weeks for most housing, 3 days for vulnerable tenants
- SPUR, cited by San Francisco: Usable within a day of M7.2 event
- FEMA-NIST: "Days to weeks"
- ASCE 7: RC IV (immediate FR) should be considered where damage would cause "substantial economic impact" or "mass disruption" of normal community functions.
  - Does this apply to housing?
  - Consider pandemic lessons: is housing essential?

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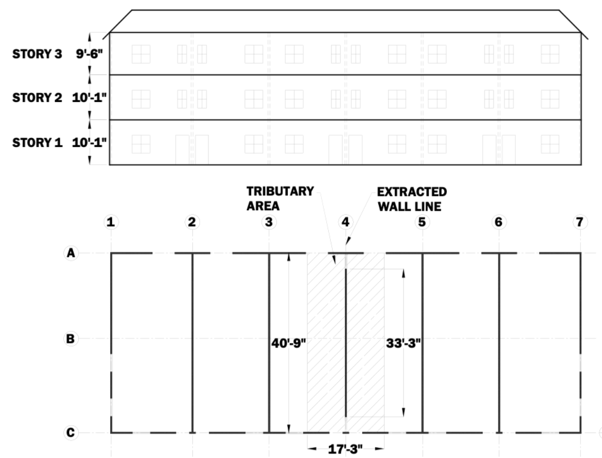
Functional recovery objective

- Presumed hazard: $2/3*MCE_R$
- What is an acceptable FR time ($T_{FR, acceptable}$)?
  - A few weeks, at most a month?
- What is the actual expected FR time ($T_{FR, expected}$)?



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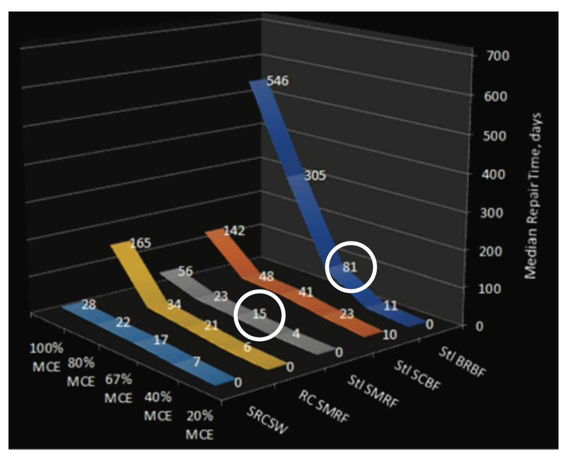
Expected FR time: What does current research say?

- FEMA P-58 (2018)
  - 5 concrete and steel systems; nonstructural for office occupancy
  - 5- to 13-story model buildings
  - High seismicity sites
- Repair time after $2/3*MCE_R$ event
  - 15 – 81 days
  - Does *not* include time for permitting, financing, mobilization, etc.
  - 12 – 33 days even if designed as RC IV
- FR time can be less than repair time



Risk Category II, Office

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Expected FR time: What does current research say?

- Haselton et al. (2021)
  - 5 woodframe residential model buildings (not CLT); nonstructural typical for woodframe residential occupancy
  - High seismicity site
- FR time after 2/3*MCE_R event
  - 3-story building: 1 – 6 months
  - Includes time for permitting, financing, mobilization, etc.

Building Type	Los Angeles Site (High-Seismicity)		
	Reoccup.	Functional Recovery	Full Repair
1-story (single-family)	0-1 wks.	0-1 wks.	1-6 mo.
2-story (single-family)	1-4 wks.	1-4 wks.	4-12 mo.
3-story (12-plex)	1-4 wks.	1-6 mo.	4-12 mo.
4-story (apartments)	1-4 wks.	1-6 mo.	1+ years
5-story (apartments)	1-4 wks.	4-12 mo.	1+ years
5-story on podium (apt.)	1-4 wks.	4-12 mo.	1+ years

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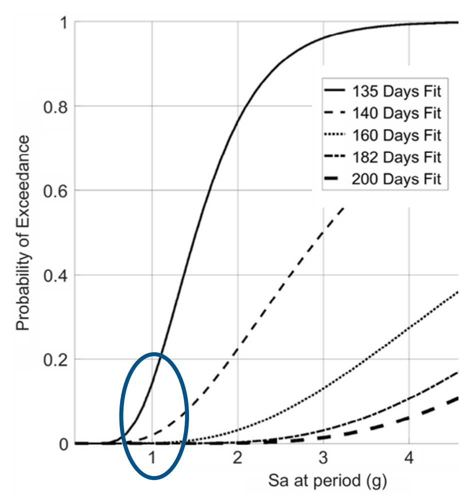
Expected FR time: What does current research say?

- Furley et al. (2021)
  - 2-story office building
  - Post-tensioned CLT rocking walls w/ UFP hysteretic dissipators; nonstructural systems for office occupancy
- FR time after 2/3*MCE_R event (S_{DS} = 1.0g)
  - ~135 days, w/ 10% probability of exceedance
    - But also ~95 days for just reoccupancy
  - Includes time for permitting, financing, mobilization, etc.
  - FR time driven by nonstructural damage.



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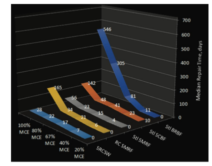
Expected FR time: What does current research say?

- Summary: Expected FR time after 2/3*MCE_R event
  - At least a few weeks, perhaps a few months
  - FR time for different seismic force-resisting systems varies widely
  - Effect of nonstructural damage on FR time can be substantial
  - Using RC IV criteria helps, but to an unknown degree
- Work to establish reliable predictive tool continues
  - Academia (PEER, CRCRP, etc.)
  - Government agencies (FEMA, NIST, etc., w/ ATC, etc.)
  - Professional associations (SEAOC, etc.)
  - Private sector



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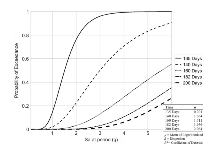

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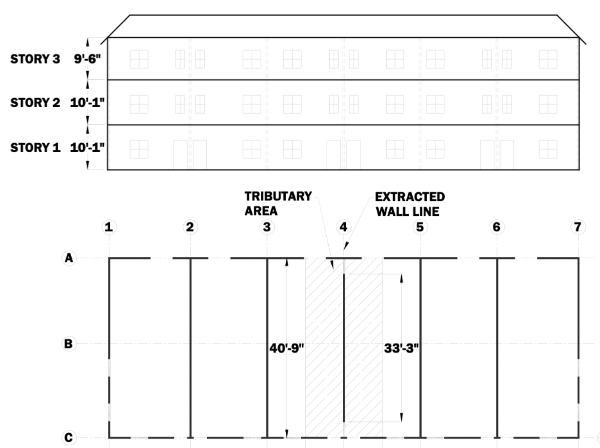
Functional recovery objective

- Presumed hazard: 2/3*MCE_R
- What is an acceptable FR time ($T_{FR,\ acceptable}$)?
  - A few weeks, at most a month?
- What is the actual expected FR time ($T_{FR,\ expected}$)?
  - Several months?

Q: How to address this discrepancy?

A: Review CLT design criteria.



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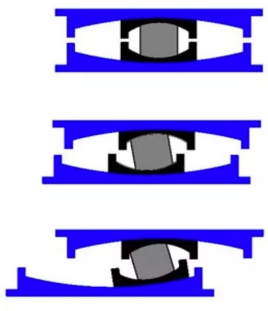
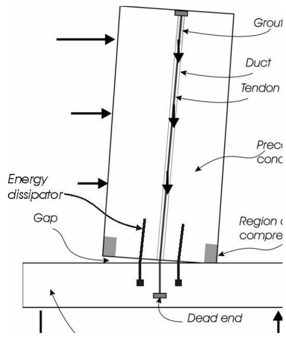
CLT Shear Wall structural design criteria

- Generally low damage already expected, so limited opportunities for improvement
- System selection is important; "Low damage design" beneficial for fast FR



Earthquake Protection Systems



Restrepo, in Filiatrault, 2004

Hogg, 2013

CLT Shear Wall structural design criteria

- Seismic importance factor, I_e ←
  - A tool provided by the code, usually taken as 1.0 for residential occupancy
  - Higher value can be used, but full RC IV performance requires more than $I_e > 1.0$.
- Height limit for CLT shear wall systems
  - Design example H = 30', already well under 65-ft code limit
- Response modification coefficient, *R*
  - Already limited to *R* = 3, a relatively low value that already limits expected inelasticity
- CLT material grade
  - Not likely to affect performance, since design is controlled by strength of connectors

CLT Shear Wall structural design criteria

- CLT partition classification
  - Unintended partition strength and stiffness beneficial, but difficult to codify
  - More effective to focus on intended shear walls
- Steel connector capacity ←
  - Lower presumed (or prescribed) capacity would reduce damage
  - But artificially low presumed capacity could interfere with test-validated design procedure
- Drift limit
  - Unlikely to affect performance, since predicted drift is already well under current limit

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CLT Shear Wall structural design criteria

- Hold-down deformation limit
  - Unlikely to affect performance, since predicted elongation is already well under current limit
- Hold-down design force
  - Unlikely to affect performance, since design force is set only to ensure yielding in steel connectors
- CLT panel aspect ratio
  - Unlikely to affect performance, since current design already uses low *R* value
  - For other designs, prohibiting higher *R* value for high aspect ratio panels could reduce inelasticity demands and damage

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Townhouse nonstructural design criteria

- Not addressed in CLT Design Example
  - But expected to have significant effect on building FR time
  - Even more significant for a low-damage structural system like CLT shear walls
- Current code for RC II buildings
  - Functionality considered for life safety systems (alarms, exit lighting, sprinklers)
  - Other components exempt from protection because they pose no safety hazards

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Townhouse nonstructural design criteria

- Current code for RC IV buildings
  - Broader scope of bracing, anchorage
  - Importance factor I_p = 1.5
  - Backup utility service
- 2020 *NEHRP Provisions* Section 1.1.5
  - Eight characteristics of expected RC IV performance
  - Focus on "essential functions"
  - Useful reference for voluntary FR improvement

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Characteristics of RC IV functionality (*NEHRP Provisions* Section 1.1.5)

- Immediate reoccupancy
  - Largely a function of structural performance; see above.
  - Also a function of fire safety and hazmat protection, already provided by code for RC II
- Functional equipment for "essential functions" ←
  - For residential building, housing code habitability standards are useful reference
    - Light, ventilation, power, potable water, heat in winter, sanitation, cooking and food storage
    - For some tenants, elevators and communications systems
  - Difference between FR and RC IV: FR might not require these to be available immediately
    - Some of these are even waived after large events to facilitate basic reoccupancy

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Characteristics of RC IV functionality (*NEHRP Provisions* Section 1.1.5)

- Limited damage to contents for "essential functions" ←
  - Contents are not usually considered by building code, but can be important for FR
  - For residential building, could include kitchen appliances, etc.
- For non-essential equipment and contents, no damage affecting "essential functions"
  - Might include extensive damage to architectural components (glass, ceilings)
  - Often repairable (or removable) within desired FR time
- Building envelope "maintains integrity ... To preserve essential functions."
  - Mostly already covered by code for RC II (glazing, cladding, roofing)
  - Repair can often be done from exterior with limited effect on functional recovery

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Characteristics of RC IV functionality (*NEHRP Provisions* Section 1.1.5)

- Only “minor leakage” in “piping carrying nontoxic substances”
  - Intent seems clear, but subject to broad interpretation
- “Controlled” release of toxic substances
  - Intent seems clear, but subject to broad interpretation
  - Unlikely to be an issue in new residential buildings
- Egress “maintained”
  - Needed for basic reoccupancy as well
  - Mostly covered by code for RC II (drift limits, protection from falling hazards, lighting)
  - Could apply to special accessibility features or equipment

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Voluntary FR and emerging best practices

- Basic strategies for improving FR time
  - SFRS selection: Low-damage design
  - Drift limits
  - Nonstructural & contents scope
  - Quality assurance
  - Planning strategies
- Needed tools
  - Consensus design criteria
  - Design and analysis software

Casa Adelante, San Francisco

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Voluntary FR and emerging best practices

Project	Building Use	Functional Recovery Objective or Expectation	Recovery-focused Design Features or Criteria
181 Fremont (Almufti et al., 2016)	Office high-rise	Within weeks after design EQ	Reinforced concrete core, designed w/ ARUP's REDi criteria
Beaverton, OR schools (SEFT, 2015)	Public schools	RC IV performance, to suit services as post-EQ shelter	RC IV criteria, backup generator
UCSF Mission Hall (Bade, 2014)	University offices	Operational performance after 84th percentile Hayward event	Enhanced RC II criteria, concrete shear walls
Casa Adelante (Mar, 2021)	Senior housing	Within 1 day after 475-year event, no tenant relocation	Rocking walls, dampers
85 Bluxome (Moore, 2021)	Office mid-rise	Within "days to weeks" after "major EQ"	Tight drift limits (zero lot lines), SidePlate moment-resisting frame

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Voluntary FR and emerging best practices

Project	Building Use	Functional Recovery Objective or Expectation	Recovery-focused Design Features or Criteria
UCSF Center for Vision Neuroscience (Berkowitz, 2021)	University research	Within 60 days after M7 San Andreas event	1.25 importance factor, 1.5% allowable drift
Oregon Treasury (Zimmerman, 2021)	Gov't offices	Within 0 days after MCE_R	Base isolation, minimized nonstructural components
Stanford Biomedical Innovations (Lizundia, 2021)	University research	Within 26 days after 475-year event	Modified RC III criteria, element-specific *R* values, 1.5 importance factor
Allenby Building (Westermeyer, 2021)	Gov't offices	Within 0 days after 475-year event	Reduced drift limits, amplified demand, post-EQ recovery plan

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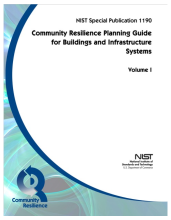
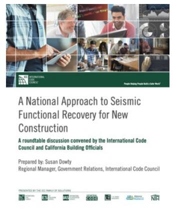
Q&A



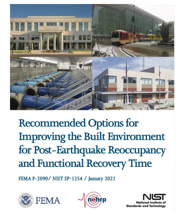
NIST, 2016



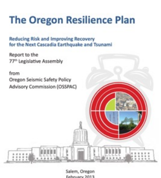
ICC, 2019

EERI, 2019

FEMA, 2020

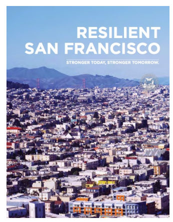


FEMA-NIST, 2021

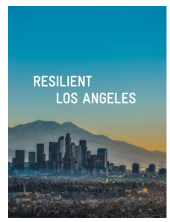


Oregon, 2013

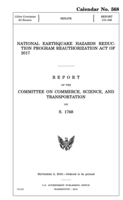
White House, 2016

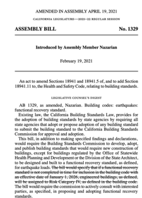


San Francisco, 2016



Los Angeles, 2018


Public Law, 2018


California, 2021

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