Measuring the resilience of the built environment across multiple scales

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Outline

• Current practice
• New modeling tools
• Next generation codes
Current practice

Focuses on assessing safety using performance metrics like displacements and accelerations
Performance-based engineering

Casualties
Repair costs
Downtime
PBE assessment tools

Quantify performance in terms of:
- Casualties
- Repair costs
- Downtime

Shortcomings:
- Not required by code
- Not adequate for assessing continuity of services

FEMA P-58 / PACT
Scale

Individual building  Neighborhood  Community
Scale

Individual building  Neighborhood  Community
Summary of current practice

Current metrics and models: Focus on safety at scale of individual buildings

New metrics and models: Focus on continuity of services across multiple scales

New modeling tools

Next generation codes
Fault trees

- Loss of building functionality
  - OR
    - Fire safety compromised
      - OR
        - Fire suppression systems fail
          - Means of egress compromised
    - Structural integrity compromised
      - Structure out-of-plumb
    - Weather tightness compromised
      - Falling hazards exist
    - Building services compromised
      - Roof damaged
        - Water unavailable
      - Gas unavailable
    - Usable space compromised
      - Interior partitions damaged
    - Neighborhood compromised
      - Threatened by nearby structure
      - Located within red zone
      - Contents damaged
Continuity of services
Continuity of services

1. Emergency department space is unavailable
   - 10. Emergency department staff are unavailable
   - 2. Physicians are unavailable
   - 3. Nurses are unavailable
   - 4. Non-Clinical Staff are unavailable

2. Emergency department space cannot be accessed
   - 4. Emergency department space may be damaged
   - 5. Critical infrastructure fails
     - 6. Clinical capital equipment is unavailable
     - 7. Clinical re-usable equipment is unavailable
     - 8. Clinical supplies are unavailable

3. Structural damage occurs
   - 2. Exits are unavailable
   - 3. Structural damage occurs
   - 4. Critical infrastructure
     - 5. Capital equipment (Clinical)
     - 6. Re-usable equipment (Clinical)
     - 7. Supplies (Clinical)
Continuity of services
Duration of service disruption

Resilience Based Earthquake Engineering (RBEE)
Duration of service disruption

Services by Floor

Mechanical Floor

Level 7: Medical/Surgical, Acute Care for Elderly, Palliative Care, Roof Garden
Level 6: Medical/Surgical
Level 5: Medical/Surgical Unit, Forensic Unit
Level 4: Step Down Medical/Surgical, Step Down ICU, Dialysis
Level 3: Intensive Care Units (ICU)
Level 2: Labor and Delivery, Postpartum, Pediatrics, Neonatal Intensive Care
Level 1: Emergency Department and Trauma Center
Basement 1: Operating Rooms, Pre-op, Post Op, Endoscopy, Blood Bank
Basement 2: Dietary, Pharmacy, Cardiology, Pulmonary, Diagnostic Imaging (X-ray), Sterile Processing
Duration of service disruption

- Service completely unavailable for \( \approx 25 \) days
- Service fully restored after 300 days
- Service fully restored after \( \approx 27 \) days
Regional service disruptions
Next generation codes

Need to connect performance objectives across multiple scales

Life safety

Individual building

Neighborhood

Community
Christchurch earthquake

Demolished

Soon-to-be demolished

Partially demolished

http://maps.cera.govt.nz
Recent developments

Need to think more holistically about the performance of the entire community
Community-centric approach

What are the services within a community that are vital to its normal functioning?
Vital services

Public safety

Nourishment

Sanitation

Government

Communication

Education

Energy

Shelter

Economy

Healthcare

Transportation
Supporting infrastructure

Shelter
- Single family homes
- Apartments
- Condominiums
- Emergency shelters
- Hotels and motels
Hierarchy of performance objectives

Community

Vital services
- Economy
- Shelter
- Education
- Healthcare

Systems
- Commercial buildings
- Housing stock
- School district
- Hospital network

Buildings
- Office
- Apartment
- Elementary school
- Clinic
Conclusions

To better measure resilience we need to:

– Quantify performance in terms of continuity of services
– Evaluate performance across multiple scales
– Develop consistent performance objectives