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ACI Web Sessions

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Post-Earthquake Repairs, Part 2

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

The Performance of Concrete Structures in the Canterbury Earthquakes:

Lessons to be Learned and the Future of Concrete Buildings

Des Bull
New Zealand

The Performance of Concrete Structures in the Canterbury Earthquakes:

Some Issues relating to Repairs

Des Bull
New Zealand
New Brighton Pier
Christchurch NZ

Magnitudes and Intensities

- In Christchurch CBD
  - September 4: Mw 7.1, MMI 7-8, 15 sec
  - December 26: Mw 5.1, MMI 7-8, 5 sec
  - February 22: Mw 6.3, MMI 9-10, 7 sec
  - June 6: Mw 5.5, MMI 6-7, 5 sec
  - June 13: Mw 6.3, MMI 7-8, 9 sec
- 6 km deep and 20 km from CBD
- Effect at the site is dependent on magnitude, depth, proximity, soil type, and duration

Chch September 4

Some Issues relating to Repairs

1. Concrete Strength
   - Far higher than expected?
2. Residual Plastic Capacity of Rebars & Structural steel
   - All been used up?
3. Floor Plates/Diaphragms
   - Repairs
   - Load paths
     - Elongation of Plastic Hinge Zones.
1. Concrete Strength

- Higher than in lab testing
  - Target strength for supply: 1.2 times 28 day $f'_{c}$
  - Aging strength gain: 1.5 times
  - Rapid rate of loading – seismic deformations
    - 1.2 – 1.4 times, possibly higher
  - Total increase over 28d $f'_{c}$: 2.0 – 2.5 times

**Implications:**
- Minimum longitudinal reinforcement requirements, based on $f'_{c}$:
  - INADEQUATE ? - PROBABLY

Case studies:
- Failure of bars in walls
- Inelastic capacity of bars exhausted

2. Residual Plastic Capacity of Reinforcing Bars & Structural Steel

- Cracking in Plastic Hinge Zones:
  - Limited a few cracks, rather than “100s” seen in lab tests.
  - At the cracks, localised strains the longitudinal bars are relatively higher than seen in tests.
  - Inelastic capacity of bars exhausted
**Inelastic capacity of bars exhausted?**

- For an engineering assessing a building:
  - Can the building withstand the aftershocks to come?
  - Safe to reoccupy?
  - Is it repairable?
  - In Chch, no...
  - Most damaged buildings have little inelastic capacity left.

**Inelastic capacity of bars - verification**

- **Leeb Hardness test** (a dynamic hardness)
  - Portable test equipment, testing at the location being investigated.
  - Leeb Hardness (HL) is related to the location on the stress strain curve of the element.
  - Stressing of selected (parent material) under strain, calibrates the insitu HL readings.

**Leeb Hardness**

- Open up side of RC beam

**Eccentrically Braced Frames**

EBFs: Leeb H and coupons
Eccentrically Braced Frames (EBFs): Leeb H and coupons

- Weld in wrong place
- Bending of lower flange

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Eccentrically Braced Frames (EBFs): Leeb H and coupons

- Blue and Red very high strains
- Cut EBF out and weld or bolt in new piece

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Critical Structural Issues

- Conventional Beams:
  - Yield or go plastic
  - Elongate under cyclic loading from earthquake
    - Concrete worst
    - Then steel
    - Then timber (in connection hardware)
  - Loss of floor support
  - Loss of load path across

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Plastic Hinge in a RC Beam

- Conventional Beams:
  - Yield or go plastic
  - Elongate under cyclic loading from earthquake, up to 4% of beam depth

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Elongation of the beams – push the columns

- Loss of connection: floor - supports

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Total Collapse of the floor

- Interstorey drift (%):
  - 1.0
  - 2.5
  - 3.5
  - -3.5
  - -2.0
  - 0
  - 0.5
  - 2.5
  - -0.5
  - -2.5

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Matthews et al. 2008
**Clarendon, Chch 2011**
- 18 storeys

Red arrows:
Beam elongate pushing the corner column away from the floor.

**Flange hung detail**
Flange hung detail

Elongation of the beams – push the columns
- Loss of connection: floor - supports

Available Force paths across Floor Diaphragms
- Loss of connection: floor - supports

Clarendon, 1987
Concluding comments:

1. Minimum flexural steel based on a realistic concrete strength
   - Damaged structures will need to have residual plastic capacities investigated.
2. Residual Plastic Capacity of Rebars & Structural steel have been found to be small
   - Damaged structures will need to have residual plastic capacities investigated.
   - By be not be repairable or may be too costly

Concluding comments: cont.

3. Floor Plates/Diaphragms
   - Elongation of Plastic Hinge Zones in beams cause severe, localised damage and gravity capacity and in-plane diaphragm actions are compromised. Exterior columns can become unstable.
   - Repair will be difficult: gravity and diaphragm action
   - Replace reinforcement in the floor (in critical areas?)

Transpot Beam: as-built! %$**

Thank you... Any questions, if there is time?