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American Concrete Institute®
Advancing concrete knowledge

Post-Earthquake Repairs, Part 2

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

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Desmond Bull ME (Civil), FIPENZ, CPEng Technical Director of Holmes Consulting Group Ltd. Marketing and development of structural engineering services for HCG, emphasizing concrete structures (commercial and bridges). Practicing structural engineer for 30 years. Holcim Adjunct Professor in Concrete Design, at the Department of Civil and Natural Resources Engineering, University of Canterbury, lectures on design of concrete structures. Initiating and supervising a number of research programs over the last 18 years. Past President of the NZ Concrete Society and served on the Revision Code Committees for NZS 3101: Concrete Structures and NZS 1170.5: Earthquake Loads. Serves on the Engineering Advisory Group: Seismic Performance of Commercial Building, for the Department of Building and Housing, Government of New Zealand. Des is the Senior Structural Specialist, Field Operations, NZ Urban Search & Rescue of the NZ Fire Service. During the Christchurch earthquakes, was firstly involved with search and rescue and then with the deconstruction of dangerous buildings in the CBD. Des has written or co-written some 130 papers and 8 design guidelines/manuals.

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The Performance of Concrete Structures in the Canterbury Earthquakes:

Lessons to be Learned and the Future of Concrete Buildings

Des Bull

New Zealand

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The Performance of Concrete Structures in the Canterbury Earthquakes:

Some Issues relating to Repairs

Des Bull

New Zealand

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New Brighton Pier Christchurch NZ

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Magnitudes and Intensities

- In Christchurch CBD

Date	Mag.	MMI	Duration
– 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 5.6,	MMI 6-7	5 sec ?
– June 13	Mw 6.3,	MMI 7-8 (9)	10 sec ?
• 6 km deep and 20 km from CBD			
– December 23	Mw 5.9 & 6.2	MMI 7-8	10 sec ?

- Effect at the site is dependent on magnitude, depth, proximity, soil type, & **duration**

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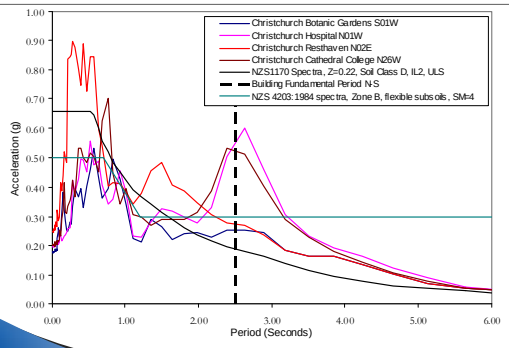
Chch September 4



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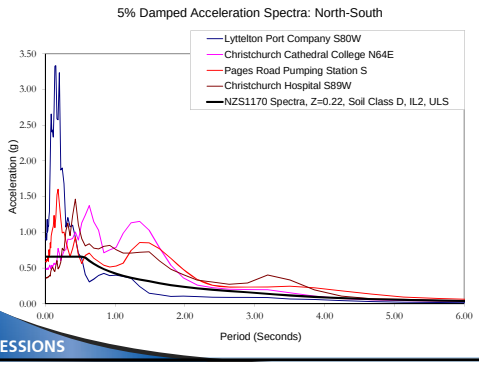
Chch February 22



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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.

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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*

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1. Concrete Strength

Implications:

- Minimum longitudinal reinforcement requirements, based on f'_c:
  - INADEQUATE ? ***- PROBABLY***

Case studies:

- *Failure of bars in walls*
- *Inelastic capacity of bars exhausted*

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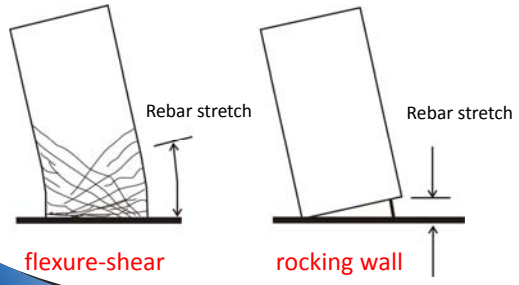
Flexure-shear crack pattern and a rocking wall/one crack wall.



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12 Story Condominium ('05)

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12 Story Condominium ('05)

CAUTION:

Hair line crack

- first impressions – little damage
- peak drift at roof = single crack at base 1½ " wide.
- Bars fracture at ⅝ "

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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*

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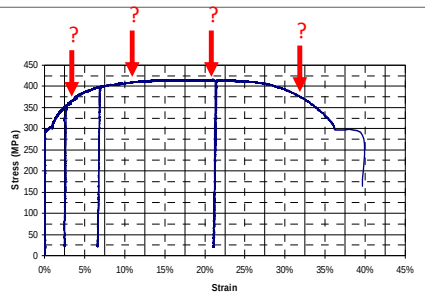
Steel stress-strain curve



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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.

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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.
    - ASTM International, "Standard Test Method for Leeb Hardness Testing of Steel Products", ASTM Designation A956-06, 2006

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Leeb Hardness

- Open up side of RC beam

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Leeb Hardness

- Open up side of RC beam

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Eccentrically Braced Frames EBFs: Leeb H and coupons

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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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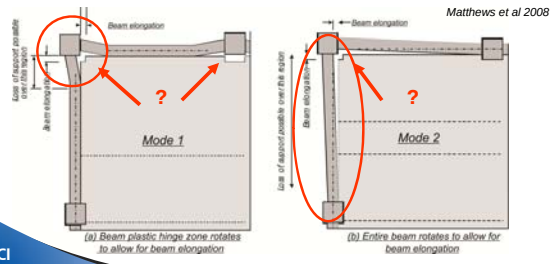
Elongation of the beams – push the columns

- Loss of connection: floor - supports

Matthews et al 2008



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Total Collapse of the floor

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Clarendon, Chch 2011

- **18 storeys**

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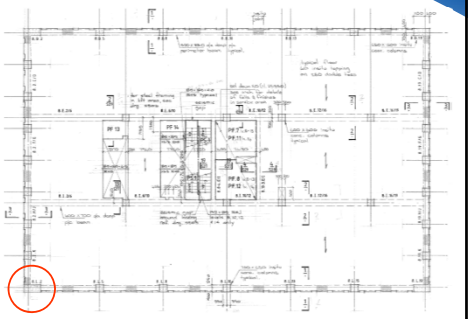
Perimeter RC MRF



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Red arrows:

Beam elongate pushing the corner column away from the floor.

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Cold-drawn wire mesh fractures from 1/16" to 1/4"

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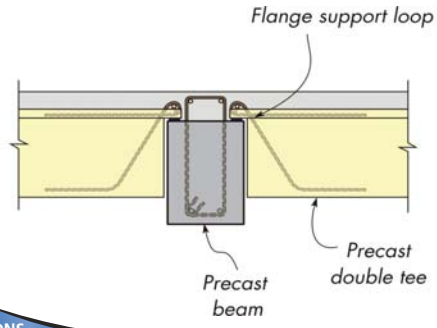
Flange hung detail



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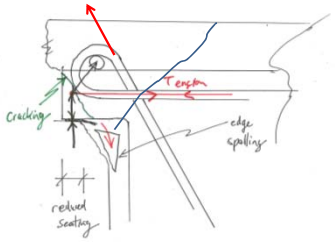
Flange hung detail



1. Edge spalling will reduce the available bearing
2. If the end of the rest cracks and spalls the bearing width may be lost all together.

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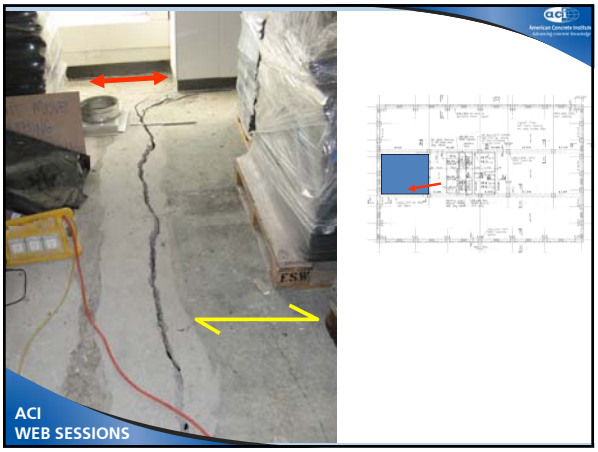

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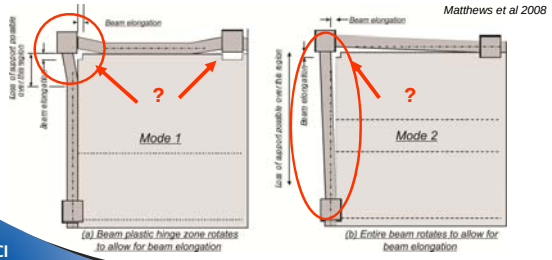
Elongation of the beams – push the columns

- Loss of connection: floor - supports

Matthews et al 2008



(a) Beam plastic hinge zone rotates to allow for beam elongation

(b) Entire beam rotates to allow for beam elongation

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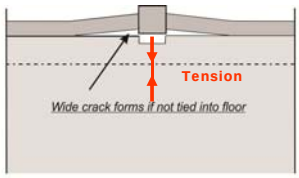
Available Force paths across Floor Diaphragms

- Loss of connection: floor - supports



Column not adequately tied into floor slab pushed out from column due to elongation of beams

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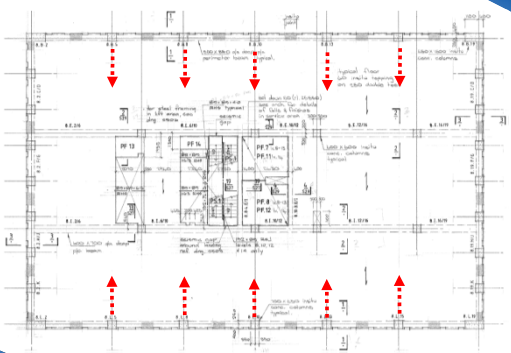
Clarendon, 1987



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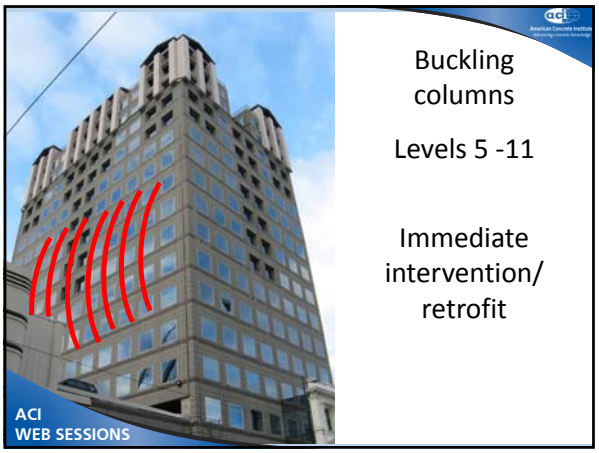

Concluding comments:

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

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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?)

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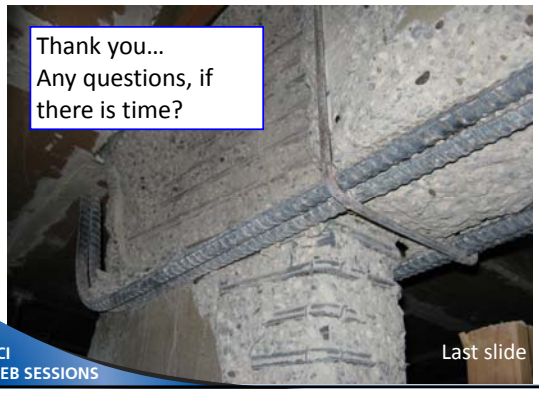
Transfer Beam : as-built ! %$*#



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