Understanding Structural Selection Decisions in Christchurch's Reconstruction

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http://resources.quakecentre.co.nz/reconstructing-christchurch/
Mw 6.3, Lyttleton, 21 February 2011

Source: GeoNet
Why this study?

- **Before 2011**
  - RC construction *dominated* Christchurch before EQ
  - Plenty of cement, water, and aggregate readily available (from the river gravels) in NZ (e.g., Waimakariri near Christchurch)
  - Influences of Park, Paulay, Priestley at University of Canterbury helped “cement” concrete as the major construction material in Christchurch

- **Rebuilding of Christchurch**
  - Steel construction seemed to dominate
  - Is it true? Why?
Methodology (in a few words)

- **4 steps:**
  - A street survey (2013-2016);
  - A scoping exercise (2016);
  - Data collection (2017) – databases from SCNZ, CCC, + Engineers; and
  - Data analysis and writing of the report (2017)

- **Scoping Study – Preliminary interviews clear message:**
  - Gather data by visiting engineers in their own offices to talk through their experiences with individual buildings

- **Data Collection Focus:**
  - Building having 2+ stories in CBD and Addington
  - Engineering firms with greatest number of new buildings in Christchurch

- Full details on methodology in report itself

- **Disclaimer:** The authors are not social scientists and have not conducted a rigorous social science study; results should be interpreted accordingly
Quantitative results

- Information presented as a function of year of consent (=year of building permit in a North American context)
  - Note: Results for 2017 are only for the first three months of the year (data collected up to March 2017).
- Data on 74 buildings, adding to 482,317 m² floor space.
- For buildings with different types of structural systems in orthogonal directions, each direction was counted as one half of a building when tallying the numbers.
  - One building had masonry walls in one direction (counted as 0.5 building), but this small number was lumped together with the concrete walls.
Cumulative number of new buildings having lateral-load resisting systems of each material type
Gravity System in RC Buildings

- Gravity-resisting frame systems (i.e., steel beams+columns) used in:
  - Approximately ¾ of buildings having lateral-force-resisting system consisting of RC walls (still counted as a RC building in presented quantitative results)
  - For this reason, the number of buildings containing structural steel is significantly greater than that indicated by the quantitative results presented here
Floor Area of New Buildings (m²)

- Floor area of new buildings having lateral-load resisting systems of each material type: Cumulative numbers
  - Steel: 78.4%,
  - RC: 20.4%,
  - Timber: 1.2%
Type of Structural System

- BRB = Buckling Restrained Braces (11 total),
- CBF = Concentrically Braced Frames (3 total),
- EBF = Eccentrically Braced Frames (2 total),
- EBR = Eccentrically Braced Frames with replaceable links (4 total),
- MRF = Steel Moment Resisting Frames (9.5 total);
- MFF = Steel Moment Resisting Frames with friction connections (1 total),
- MRD = Steel Moment Resisting Frames with Reduced Beam Sections (4.5 total),
- RCW = Reinforced Concrete Walls (32.5 total),
- RCF = Reinforced Concrete Moment Resisting Frames (0.5 total),
- RFS = Rocking Frame Steel (1.5 total);
- RFC = Rocking Frame Concrete Precast Walls (0.5 total),
- LVL = Laminated Veneer Lumber (2.5 total),
- B = Base Isolation (11 total),
- D = Dampers (2 total),
- H = Hybrid (7 total).
Type of Structural System

- Data obtained on same 74 buildings, but, for clarity:
  - Not considered:
    - A building with masonry walls in one direction (0.5 masonry building)
    - A building with braced plywood walls (1.0 building)
  - New $\Sigma = 72.5$ buildings

- Some systems counted twice:
  - For example: A system on top of base isolators is counted twice (once as the structural system type, and once as a base isolated structure)
  - Same for buildings with dampers and hybrid buildings.

- Total of 92.5 buildings = 72.5 systems + 11 base isolated buildings + 2 dampers + 7 hybrids
Type of Structural System

- RC walls = largest number because this category (contrary to others) is not broken down into sub-categories
- Data shows only a few moment frame with friction connections, rocking systems, LVL systems, CBFs, and dampers
Type of Structural System

- **Focusing on steel structures:**
  - Rapid implementation of base isolation and rocking systems in the early years after the earthquake, with fewer numbers in the past few years
  - Base isolated buildings were first consented in 2012, rapidly growing and plateauing at a total of 11 by 2015 (i.e., 15% of the 74 buildings)
  - Results also show that BRBs were first consented in 2014, and have since grown in numbers at a steady pace, reaching a total of 11 by 2017
Type of Structural System

- The 11 base isolated buildings (15% of number of buildings) alone provide 190,000 m² = 40% of total floor area of buildings considered.
- The base isolated buildings have generally been large buildings:
  - The two largest base isolated buildings alone, built specifically for public sector tenants = 102,000 m² (21% of the total floor area).
  - The three largest = 129,000 m² (27% of the total floor area).
- Strong correlation between m² of base isolated buildings and steel MRFs.
Type of Structural System (Non Base isolated buildings)

- Worthwhile to consider (for steel structures – no change for RC), because:
  - More base isolation in years following earthquake, so data on non-isolated buildings could be indicative of future trends
  - Firms comfortable designing systems outside of standards (such as base isolation) might be over-represented in interviews
  - For its own sake, interesting to identify which systems more dominantly used when buildings not base isolated
Type of Structural System  
(Non Base isolated buildings)

- Total non-base-isolated reconstruction floor area is:
  - BRB: 111,000 square meters (38%)
  - CBF: 0 square meters (0%)
  - EBF+EBR: 27,500 square meters (9.5%)
  - MRF+MFF+MDF: 57,000 square meters (20%)
  - RCW: 78,000 square meters (27%)
Who determines the Structural System?

http://scrubsmag.com/shared-governance/
Hierarchy of Priorities (Pre-Earthquake)

Tenants
- Purpose
- Functionality
- Lease Cost
- Image

Developer
- Tenant expectations
- Return on Investment*
  *Cost
  *Speed of Construction
  *Lease Rates

Architect
- Client expectations
- Design Space
- Architectural Expression
- Engineering Constraints

Engineer
- Client expectations
- Code Compliance
- Design Constraints

*Cost
*Speed of Construction
*Lease Rates
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**Project Manager**

Hired by developer/clients to represent them in dealing with the architect, engineer, quantity surveyor, contractor, and other professionals.

**Quantity Surveyor and Contractor**
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"MOMENTUM"
"Natural tendency do things as they were done before"
Industry is set-up to deliver a familiar “product”, with well-understood practices, costs, risks, relationships, procurements, etc. leading to predictable return on investment
Hierarchy of Priorities (Post-Earthquake)

Tenants
- Purpose
- Functionality
- Lease Cost
- Image
- Business Continuity
- Reparability

Developer
- Return on Investment*
  - *Cost
  - *Speed of Construction
  - *Lease Rates

Tenant expectations
- Reputation

Architect
- Client expectations
  - Design Space
  - Architectural Expression
  - Engineering Constraints

Engineer
- Client expectations
  - Code Compliance
  - Design Constraints
  - Reparability
  - Business Continuity

*Cost, *Speed of Construction, *Lease Rates
Many felt RC buildings did not perform well
- Heavy media coverage of buildings collapses, severe damage, leaning buildings, trapped occupants (e.g. stair collapse), etc.
- Many buildings with low damage (beam plastic hinging and rebar elongation) were deemed “irreparable” and demolished
- Life safety seismic performance objective: buildings (generally) behaved / were damaged as engineers (but not as public) expected
- Two tallest steel structures in Christchurch reopening relatively fast after earthquake, led many tenants and owners to conclude that steel structures are preferable
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Purpose
Functionality
Lease Cost
Image
Business Continuity
Reparability
Hierarchy of Priorities (Pre-Earthquake)

- Professional culture and client relations
  - Engineering firm’s philosophy aligned with clients they seek (or that seek them)
- Philosophy of practice influenced by:
  - Type of work conducted for clients
  - Experience and professional opinion on the respective benefits of various structural systems
  - Opportunities provided by past project and business relationships
  - Professional development activities
  - Informal individual education by interpretation/synthesis of skills and information from various scientific and non-scientific field
  - Professional ethical and moral obligations
Hierarchy of Priorities (Post-Earthquake)

- Professional culture revisited
- Breadth of valid engineering solutions can be regarded as the expression of differences in this culture.
- Structural engineering decisions affected by this, together with different professional opinions regarding:
  - Expected seismic performance of various structural systems
  - Hierarchy of priorities in rebuilding Christchurch
  - How various priorities can be best met for specific buildings
  - No “one-size-fits-all” solution in structural engineering
Nearly all engineering firms interviewed designed the building containing their office, including:
- 3 in base-isolated buildings
- 2 in buildings having BRBs
- 1 in a building with viscous dampers.
Hierarchy of Priorities (Post-Earthquake)

Tenants
- Purpose
- Functionality
- Lease Cost
- Image
- Business Continuity
- Reparability

Developer
- Return on Investment*
  - *Cost
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- Tenant Expectations
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Architect
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Engineer
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- Reparability
- Business Continuity

Professional Culture
Hierarchy of Priorities (Post-Earthquake)

Tenants
- Purpose
- Functionality
- Reparability

Developer
- Return on Investment*
  *Cost

Architect
- Client expectations
- Design Space
- Code Compliance

Engineer
- Client expectations
- Professional Culture

“MOMENTUM IS LOST”
Industry adjusting to deliver various “product”, with new practices, costs, risks, relationships, procurements, leading to less predictable return on investment
Qualitative Factors Affecting Momentum

- 50 pages of the report present opinions expressed by engineers, in their own words (or paraphrasing) on:
  - The various issues and types of structural systems used
    - Base Isolation, Low Damage, IL4, IL3, Reparability, Buckling Restrained Braces, Viscous Dampers, Eccentrically Braced Frames, Steel Structures (General Issues), Reinforced Concrete Walls, etc.
  - These are not necessarily the authors’ opinions
  - Providing a sample of these opinions not possible in the limited time available, but a summary of general trends is possible
Post-Earthquake Choice of Structural System

Client required (37):
- No concrete: 2
- Base isolation: 6
- IL3: 10
- IL4: 4
- No Damage: 3
- Low damage: 12

Constraints (10):
- Site Layout: 4
- Soil Conditions*: 6

Cost-related (50):
- Construction Time: 5
- Construction Cost: 8
- Requested Construction Time: 9
- Requested Lowest Cost: 28

* Soil constraints in Christchurch are implicit in most designs so not necessarily “flagged” as driving decisions out-of-ordinary
Post-Earthquake Choice of Structural System

Client required: 37

Constraints: 10

Cost-related: 50

Showcasing Structure: 9

Engineer’s Choice: 52

Trends (Consolidated Categories)

- Tenant or Developer Requests
- Site Constraint (layout or soil)
- Engineer’s Decision
- Cost or construction time
- Showcasing structural system

Year:
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
Post-Earthquake Choice of Structural System

- Client required: 37
- Constraints: 10
- Cost-related: 50
- Showcasing Structure: 9
- SE's Choice: 52

Trends (Consolidated Categories)

- Tenant or Developer Requests
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Year:
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
Impact on Wellington and Auckland

- **Revised Seismic Zones Map ➔**
  

- **Auckland:**
  - Largest city in NZ (pop.: 1,500,000)
  - Low seismic zone

- **Wellington:**
  - 2^{nd} Largest city in NZ (pop.: 400,000)
  - National Capital
  - Largest seismic zone
Conclusion - 6 Key Points:

“Key points” drawn on the basis of above findings and discussions with those interviewed

1. It is becoming a more widely held belief that preventing loss of life as a seismic performance objective is simply not sufficient for a good modern structure
2. Structural engineers’ opinions impact the adoption of low-damage systems
3. Tenant expectations strongly impact choice of structural systems
4. Additional increase in seismic performance, if desired for all buildings, would need to come from government regulation
5. Context affects final decision outcome
6. Reconstruction experience has paralleled increase in stakeholder knowledge
**Christchurch Hospital—Acute Services Building**

Address/Building Name: Christchurch Hospital—Acute Services Building (ASB), 2 Riccarton Ave, Christchurch
Central, Christchurch 8011

Client: Ministry of Health

Year of Consent (Construction Permit): 2015/2016

The Acute Services Building is one of the two important Level 4 facility containing an emergency department, operating and level 20 operating suite. Above this is a roof with a roof-top helipad. The client aimed to meet and exceed its building standards, the site-specific design for the new building on the complex sites with a significant change in the existing building and the environment.

The use of flax to reinforce concrete in combination with steel reinforced forms provides a robust and effective balance of building performance and aesthetics. Several structures in New Zealand use OPUS One flax composite lintels in systems similar to this project.

**Case Study Example—Hereford Street Car Park**

Address/Building Name: 126-136 Hereford Street, Christchurch

Client: Cclerker Stewart Construction

Year of Consent (Construction Permit): 2015/2016

The structural system consists of concrete slabs and cast-in-place columns. The columns are 20 stories tall and have a 500 m² capacity designed to support the building. Gravity loads are designed to, with the use of flax composite lintels in combination with steel reinforced forms provides a robust and effective balance of building performance and aesthetics. Several structures in New Zealand use OPUS One flax composite lintels in systems similar to this project.

**EARTHQUAKE ENGINEERING TO EXTREME EVENTS**

MCEER\n
At the University at Buffalo, The State University of New York

REACHING OTHERS

"Bonus Content" – Case Studies

Case Study Example—141 Cambridge Terrace

Address/Building Name: 141 Cambridge Terrace

Client: Clarion Construction Limited

Year of Consent (Construction Permit): 2014

The case study of 141 Cambridge Terrace includes a detailed analysis of the building's construction and design features. The building undergoes a significant change in the existing building and the environment, with a focus on meeting and exceeding its building standards.

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Earthquake Engineering to Extreme Events
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For more information:

170 pages = more “nuggets” than could be covered today

Free Download

- http://resources.quakecentre.co.nz/reconstructing-christchurch/