ReCast Floors: Retrofit and Assessment of Precast Floor Systems

Ken Elwood
Des Bull
Nic Brooke

Wellington Structural Group
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ReCast Floors

Governance
- Advisory committee
- Project leadership

Industry bodies
- SESOC
- NZSEE
- CNZ Learned Society

Component-level investigations
- Unit tests UOA
  - Seating vs NMF
  - Poor bond
  - Hairpin
  - Torsion
  - Double tee
- In-situ floor tests
  - Ready to react to opportunities
- FEM analysis
  - Behaviour
  - Fragilities

System-level investigations
- ‘Big frame’ tests UOC
  - alpha+beta units
  - Retrofit-system interaction
  - Column restraint
- Detailed building case studies
  - In-situ damage documentation
  - Building inventory and retrofit examples
  - Downtime studies

Research

Outputs
- SESOC journal aim to be in all issues
- Precast floors retrofit guidance document
- Conferences NZSEE, CNZ

Advisory committee
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Component-level investigations
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- Detailed building case studies
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  - Building inventory and retrofit examples
  - Downtime studies
Funding

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  • funded by the Building Research Levy

• Support for seconded industry engineer from EQC through UC Quake Centre

• Student scholarship support from EQC and QuakeCoRE

• Further contribution from Concrete New Zealand Learned Society
Research team

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- Rick Henry (UoA)
- Angela Liu (BRANZ)
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- Lucas Hogan (UoA)
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- Alistair Cattanach (Dunning Thornton)
- James Jensen (Jensen and McArley)
- Jamie Macgregor (Jensen and McArley)
- Jamie Macgregor (C Lund & Son)
- Ray Patton (ex-Clendon Burns & Park)
- Chris Poland (Clendon Burns & Park)
- Peter Smith (ex Spencer Holmes)
- Derek Baxter (Wellington City Council)
- Greg Preston (UC Quake Centre)
- Rod Fulford (Concrete NZ - Precast)

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Student team:

- Mike Parr (UoC)
- Frank Bueker (UoA)
- Ana Sarkis Fernández (UoC)
- Mo Mostafa (UoA)
- ?
Wellington Building Database
- 112 buildings with hollowcore

Note:
Some(?) buildings have been retrofitted!
Approximate Assessment

- Use Yellow Chapter to estimate drift capacity for:
  - LoS
  - PMF
  - NMF

- Assumptions:
  - beam depth = 800 mm,
  - beam plastic hinge length = 400 mm
  - column depth = 1000 mm,
  - HC depth = 200 mm,
  - elastic drift = 0.6%,
  - strand diameter = 12.5 mm,
  - topping = 65 mm with 665 mesh,
  - no intermediate column (i.e. single span),
  - units are in elongation zone.
Assessment - LoS and PMF

Story drift demand at which LOS or PMF may occur

Seating Length (mm)

Story drift capacity for LoS or PMF
Assessment - LoS and PMF

![Graph showing story drift capacity for LoS or PMF vs. seating length](image-url)

- **LOS (with inspection)**
- **PMF**

- **Unit fully seated**
Assessment - LoS and PMF

-20 mm tolerance
Unit fully seated

- Story drift demand at which LOS or PMF may occur
- Seating Length (mm)
- LOS (without inspection)
- LOS (with inspection)
- PMF

- Assessment - LoS and PMF

- Unit fully seated
- -20 mm tolerance
Assessment - LoS and PMF

-20 mm tolerance
Unit fully seated

Seating Length (mm)

Story drift capacity for LoS or PMF

LOS (without inspection)
LOS (with inspection)

- 0% to 4.5%
- 0% to 50%

% of buildings in dataset

Assessment - LoS and PMF
Assessment - Drift Demand

Classification of frame stiffness

Drift Demand

% of buildings in dataset

Low

High

Seating<=40mm
41-60mm
>60mm

Highest priority for retrofit!
Assessment - Controlling Failure Mode

- LOS: 70% Without Inspection, 30% With Inspection
- PMF: 10% Without Inspection, 90% With Inspection
- NMF: 10% Without Inspection, 90% With Inspection
Assessment – Drift capacity

Retrofits of Precast Floors are Urgently Needed!
Seating retrofits: When can these cause NMF?

Michael Parr  UoC
Negative Moment Failure due to retrofit support?

- Effectively same as shorter starters!

→ Keep retrofit supports below the unit to ensure no contact!
Test setup

Starter bar configuration: 600 mm long HD12s at 400 mm c/c
## Test Matrix: M Parr

<table>
<thead>
<tr>
<th>#</th>
<th>Retrofit</th>
<th>End of starters precrack</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unretrofitted</td>
<td>No</td>
<td>Rotation only</td>
</tr>
<tr>
<td>2</td>
<td>Flexible angle</td>
<td>No</td>
<td>Rotation only</td>
</tr>
<tr>
<td>3</td>
<td>Stiffened angle</td>
<td>Yes</td>
<td>Rotation only</td>
</tr>
<tr>
<td>4</td>
<td>Flexible angle</td>
<td>Yes</td>
<td>Rotation only</td>
</tr>
<tr>
<td>5</td>
<td>Stiffened angle + NMF bars</td>
<td>Yes</td>
<td>Rotation only</td>
</tr>
<tr>
<td>6</td>
<td>Lowered stiffened angle</td>
<td>Yes</td>
<td>Rotation and Elongation</td>
</tr>
</tbody>
</table>
Flexible angle

- 12x150x150 angle installed “hard up” against unit soffit
- 25 mm notch cut into topping 50 mm beyond the end of the starter bars – critical case is a cracked section
- No critical failure
- NM cracking propagated a very short way into the unit

Parr 2019
Flexible angle
Flexible angle
Flexible angle

3.5%
Flexible angle

• Flexibility of common angle retrofit leads to deformations at unit-beam interface
  o Good result! This means many of the existing retrofit cases are acceptable

• But when does it become a problem?
Stiffened angle

• 5 stiffeners welded to the angle for worst case scenario
• 25 mm notch cut into topping 50 mm beyond the end of the starter bars – critical case is a cracked section
Stiffened angle

- Negative moment failure!
  - -0.75% drift – NM cracks develop
  - -1.75% drift – NM failure
    (vertical displacement across crack of 3 mm)
  - -2.25% drift – complete loss of stiffness
    - all mesh snapped, unit only held up by dowel action of the strands
Stiffened angle

- Hierarchy of failure mechanisms:
  - Back face crack first (starter bars engaging)
  - Negative moment cracking – once starters are engaged
  - Therefore – holes drilled at the back face of the unit is not a valid retrofit strategy for NM failure

Parr 2019
Stiffened angle

• At end of test
Stiffened angle + NMF retrofit

• Same configuration with stiffened angle case

• NMF Retrofit: 2 x post installed 1.4 m long HD12 bars epoxied into notches in the topping –
  • Bars stop at the beam-to-unit interface
  • Bars extend in to span – to cover the moment demand

• Saw cut 30 mm x 25 mm deep channels for retrofit bars
Post-Installed Bar NMF Retrofit

• NMF Retrofit example – increase the capacity at the end of the starter bars

Comparison of capacity-demand curve unretrofitted (top) vs retrofitted with post-installed epoxied bars (bottom)

Parr 2019
Stiffened angle + NMF retrofit

- Successful retrofit!
- NM cracking developed but was held closed by retrofit bars – non brittle
- Retrofit bars developed secondary cracks similar to beam plastic hinge zone

Parr 2019
Stiffened angle + NMF retrofit

• Epoxy developed single crack at the end of starters at -4.5% drift
• Slight loss of stiffness, but the retrofit held the crack from brittle and instant propagation
• Test concluded at -6.0% drift with no NM failure
Key (preliminary) observations

• Good news:
  • Typical angle or HSS installed hard up to unit will generally not cause NMF, but stiffness of support should be checked.
  • Post-installed reinforcement can protect against NMF.

• Bad news:
  • Stiff supports (e.g. stiffened angles, extended concrete seating) are likely to cause NMF if length or strength of starters not adjusted.
  • Precracking at back of unit not enough to protect against NMF.
Poor bond: Detection and PMF retrofit?

Frank Bueker UoA
PMF and Poor Bond of Prestressing Strands

- Soffit cracks away from support
- Not able to replicate crack pattern in lab

<table>
<thead>
<tr>
<th>Crack in soffit</th>
<th>Bond conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good bond + No crack</td>
<td>Poor bond + No Crack</td>
</tr>
<tr>
<td>Good bond + Crack</td>
<td>Poor bond + Crack</td>
</tr>
</tbody>
</table>

(a) Bending moments along hollow-core floor
Detection and Performance of Units with Poor bond

Methodology

1. Produce units with poor bond (early release)
2. Calibration of NDT testing
3. Bare unit bending test
4. Sub-assembly test (Beam rotation + elong)
   a) Influence on PMF
   b) Retrofit testing *(ideas?)*
5. Field NDT testing

Schedule: ~July-Sept 2019
Hairpin: Performance and Retrofit?

Frank Bueker UoA
Hairpin detail

- If seating too short on site
  → Remedial solution
  (documented in 1991 CAE Grey Book)

Unit test plan:

1. Test – unretrofitted
2. Test – Retrofit 1 (FRP or Rebars?)
3. Test – Retrofit 2 (Cut top bars?)

Schedule: ~Oct-Dec 2019
FEM of hollowcore floors

Ana Sarkis Fernandez UoC
Finite Element Modelling Campaign

Phase 1

Units
Identify factors affecting the web cracking due to flexural and torsional shear

Phase 2

Sub-systems
Identify drift expected to cause loss of seating, flexural positive and negative moment failures.

Phase 3

Systems
Assess floor diaphragm behaviour of PPHC slabs

Overall framework for each phase

Experimental database → Finite Element Modelling → Parametric Analysis → Revision of design and assessment approaches

Sarkis Fernández 2019
**Unit FEM – Initial results**

(a) Detailed solid FE model developed for 400mm unit

(b) Conceptual experimental test set-up

(Nguyen et al., 2019)

(c) Total strain cracking constitutive model

Sarkis Fernández 2019
Unit FEM - Initial results

(a) Principal shear stresses at ultimate conditions

(b) Failure of specimen during experimental test (Nguyen et al., 2019)

(c) Comparison load-displacement relationship between experimental results and FEM predictions

Specimen HC2.400   FE prediction
System Performance
System performance

• Case Study buildings
  • Capturing and documenting building performance in past earthquakes → *highlighting the importance of system response on floors performance.*
System Performance - Big Frame test

Lindsay 2007
Big Frame test

Schedule:
~Sep-Dec 2019
Big Frame test

Schedule:
~Sep-Dec 2019

Parr 2019
Big Frame test

Schedule:
~Sep-Dec 2019
Industry Liaison
& Future Plans
Industry liaison

• ReCast was conceived as a means for addressing the industry’s issues:
  • Performance of existing floors
  • Behaviour of (past and current) retrofit approaches

• A two way street

• We need:
  • Input on preferred retrofit approaches
  • Feedback regarding problem areas

• We can provide:
  • A (high level) ‘FAQ’ service for Appendix C5E
  • (Progressive) improvement of understanding of behaviours
Clarification 1 - summation of elongations

Unit does not move relative to beam

Support beam moves to left by $\frac{\Delta}{2}$

Support beam moves to left by $2\Delta$

Deformed frame

Undeformed frame
Clarification 2 – torsion of hollowcore floors

- Guidelines state that:
  - Web splitting causes failure in conjunction with transverse PM crack
  - PM crack suppressed by presence of bearing strips
  - Correct interpretation is that bearing strip suppresses torsion failure*

* Subject to ongoing work

* Seating need not be checked if supplemental support can be provided by two anchored R16 bars

** Supports with low-friction bearing strips, positive moment crack can be assumed to be suppressed.
Future plans 1 - torsion of hollowcore floors

- Hollowcore planks known to be vulnerable to torsion:
  - Relatively high stiffness
  - Low strength
  - Brittle behaviour

- No validation that methods provided are realistic

- Aim is to undertake single unit tests to inform understanding of response to torsional demands
Torsion of hollowcore

Vertical Displacement
(Seating Beam Rotation)

Seating Beam
75mm Topping
300 Series Hollowcore

6000mm

Adapted from Jensen 2006
Future plans 2 - Double tee floors

• Understood for 10+ years that critical load paths of the ‘loop bar’ detail rely on the tensile strength of concrete

• No basis on which to estimate capacity

• Aim is to undertake testing and finite element analysis to inform understanding of criticality
Communications and deliverables

- We have a key aim of staying in touch with the industry - progressive delivery

- ‘Live updates’ – seminars like this evening

- Periodic formal outputs
  - SESOC journal – problem/solution articles in most issues
  - Key conferences

- The end game – “C5E for retrofit”
Questions?