Session 5: Precast Concrete Floors

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Courtesy of University of Auckland, Faculty of Engineering
Background

• Precast concrete floors widespread in NZ
• Many advantages with precast units
• Connections must be adequate to ensure:
  – Diaphragm action (inertia + transfer)
  – Gravity loads
Overview

• Review of diaphragm behaviour
  – Covered at 2014 Strut and Tie seminars
• Deformation mechanisms at precast unit supports
• Design of support connections
  – EQ performance and testing
  – Best practice details
Diaphragm Behaviour

[Des Bull 2014 slides]
Function and performance of floor diaphragms

- *Transfer lateral inertial forces to vertical elements of the seismic force-resisting system.*

Inertia effects, distributed across the floor.

Note: the tie $T$ is connected at the interior columns.
Plastic Elongation of the beams – push the columns

- Loss of floor supports and load paths.

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

(b) Entire beam rotates to allow for beam elongation
Case study Canterbury Earthquakes: Perimeter RC MRF

Detailing of Precast Cladding, Flooring Systems & Stairs for Multi-Storey Buildings – September 2015
Red arrows:

Beam elongate pushing the corner column away from the floor.
Cold-drawn wire mesh fractures from 2 mm to 5 mm.
Loss of Strut load paths.

- Elongation causes the loss of the load path for the struts.
Diaphragms: Connections or *Nodes* of the Struts and Ties

**Column-Beam Node: Traditional view**
- Higher compressive stress - smaller contact surface

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![Diagram of Column-Beam Node](image)

**SCHEMATIC**

- **Reaction, R**
- **Strut (Compression field, C)**
- **Tie (Tension, T)**

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**BEAMS PROVIDE TIE FORCE**

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Diaphragms: Connections or *Nodes* of the Struts and Ties

**Easiest visualisation:**

- Intermediate column act as *NODES of truss*
- *But middle of beams – OK – except for corner bays?*
Diaphragms: Connections or *Nodes* of the Struts and Ties

- Ties provided already as column restraint
  - = 5% Axial load
- Or a % of shear in columns
- NZS 3101:2006
  - e.g. 4 - D16

*Detailing of Precast Cladding, Flooring Systems & Stairs for Multi-Storey Buildings – September 2015*
Deformation Mechanisms in Floors
Earthquake Induced Actions in Multi-storey Buildings

- Structure conforms to beam sway profile
- Dominant actions at support connection:
  1. Relative rotation induced between flooring units and support
  2. Beam elongation in plastic hinges
Relative Rotation

• Between precast unit and supporting beam
  – Can develop flexural failure modes in floor unit
    (both positive and negative moments)

After Jenson et al.

Worst case = loss of support
Beam Elongation

- Often 2-4% of the beam depth
- Increases the distance between the unit supports
- Displacement incompatibilities
NZS 3101

• Support connections cl. 18.7.4
  – Seating details to accommodate rotation and elongation at peak interstorey drifts + 50% larger than ULS earthquake
  – Seating length / detailing
  – Precast unit design
  – Support beam design

Fenwick et al.
Precast Floor Unit Connection Details
Link Slabs

- Incompatibility with both single and double bay spans
- Either floor is designed to deform (+fixed connections), or, isolate floor and frame incompatibility

Des Bull

Displacement incompatibility between the frame and h/c unit

Hollow-core unit sags, (applies to any precast floor)

Frame deforms in double curvature
Link slabs:
Matthews, Lindsay & MacPherson

Existing grade 430 starters at 300 crs & ductile mesh in 75mm topping

Timber in-fill
≥ 600 mm

Hollow-core Units

Perimeter beam

Column face

NZS 3101:2006 Cl. 18.6.7.2

Des Bull
Link slabs:
Maintain struts

Struts

Ties

Des Bull
Hollow-core

• Extruded prestressed section
Hollow-core – CHCH

- Positive moment cracking – Old detailing

Credit: John Marshall

(b) Positive moment crack opens up due to elongation and shear transferred to in situ concrete above hollow-core unit

Fenwick et al.
Hollow-core – CHCH

- Displacement incompatibilities
  - Resolved with modern detailing
Hollow-core – CHCH

- Minor spalling of support ledge – Newer details
Hollowcore Support Detail

- NZS 3101:2006 recommended detail:
  - Prevent rotation damaging brittle hollowcore unit
  - Sufficient seating length
Link to UC Research Report 2010-02

“Assessment of hollow-core floors for seismic performance”

http://hdl.handle.net/10092/4211
Double Tees

- Flange hung or web supported / dapped end
- High bearing stresses

Supported on web

“Flange hung”
Double Tees – CHCH

Credit: Rod Fulford and John Marshall
Double Tees

- Support detailing

Web supported:
Armoured (SESOC)

Flange hung:
Robust hanger
Rib and Timber Infill
Rib and Timber Infill

- Rib sometimes cast into support
- Concerns with positive moment cracking
Rib and Timber Infill

• Positive moment cracking
Rib and Timber test
Rib and Timber Infill

- Support detailing
Rib and Timber test
NZS 3101

• New provisions in A3 for floor seating, when:
  – Interstorey drift > 0.6% or elongation > 10mm

• Seating width calculated, including:
  – Bearing
  – Elongation @ MCE
  – Rotation @ MCE
  – Loss of cover (unit + support)
  – Shrinkage
  – Tolerances
NZS 3101

- Support beam ledge:
  - Bearing design (corbel)
  - Armouring when necessary

- Recommended support details shown in commentary
Design Example

[Additional notes]
Seating Length Example

Design interstorey drift of 2%

1000

600

100 mm

300HC
Seating Length Example

Elongation of parallel hinge (one hinge per end)

= calc. @ peak ULS drift x 1.5 (max = 0.036h_b)
= 0.036 x 1000
= 36 mm
Elongation is measured at the beam centreline.

Additional elongation can occur at the support ledge due to the support beam rotation.

Rotation of support beam reducing support:
\[= (\text{peak ULS rotation} \times 1.5) \times \text{height to ledge}\]
\[= (0.02/0.7\times1.5) \times 100\ mm\]
\[= 5\ mm\]
Seating Length Example

Spalling at back of unit = **20 mm** (unarmoured)

Spalling of support ledge = face to centerline of longitudinal bars (when in plastic hinge region)
- = cover (30) + stirrup (10) + ½ bar (10)
- = **50 mm**
NZS 3101 – A3

- Seating width calculated, including:
  - Bearing = 10 mm (check bearing stress)
  - Elongation @ MCE = 36 mm (0.036*1000 mm parallel beam)
  - Rotation @ MCE = 5 mm (0.02/0.7*1.5 × 100 mm)
  - Loss of cover (unit + support) = 20 mm + 50 mm
  - Shrinkage = 2 mm (assume 0.5mm/m)
  - Tolerances = 17 mm

- Total = 10+36+4.5+20+50+2+17 = 140 mm

- Extreme case: Would be less for lower drifts, or could be reduced by armouring ledge
Summary

• Floors need to accommodate deformations including rotations and elongations in ductile multi-storey buildings

• Extensive research on recommended connection detailing
  – Preventing damage to floor unit
  – Seating width for larger than ULS earthquake
  – Robust support detailing
Questions?