Modelling of RC Moment Resisting Frames with Precast-prestressed Flooring System

Brian H. H. Peng, R. Dhakal, R. Fenwick, A. Carr and D. Bull
Dept. of Civil and Natural Resources Engineering
University of Canterbury
Seismic design of structures

- Plastic hinges allocated in beams rather than in columns

Ductile beam sway mechanism

Brittle column sway mechanism
Background

- This is achieved using capacity design philosophy

  Column flexural strength > Maximum likely beam strength (over-strength NZS3101)

- Consideration of beam over-strength
  - Reinforcement strain-hardening
  - Increase in lower characteristic design yield stress
  - Slab reinforcement participation

\[ \phi_{o, fy} = 1.25 \]
Background

- Experimental studies 
  \((Peng, Lau, Lindsay, MacPherson, Matthews)\) containing precast-prestressed floor units
  
  - Strength of beam plastic hinges is much higher than that specified in NZS 3101:1995

Matthews, Lindsay, Macpherson  
Lau
Guidelines for assessing strength of beams were proposed and incorporated in NZS 3101:2006
The Need

- May not apply to other structural arrangements

- An analytical model is required
  - Elongation of plastic hinges
  - Interaction between prestressed floor and beam
Experimental Set-up

Peng et al 2008 NZSEE Conference

End slab

Prestressed floor spanning parallel to frame supported on transverse beams

Plan view

One way linear bearing on steel pedestal

Two way linear bearings coupled with load cell

Side elevation
3D Computational Model

Floor slab (Elastic shell element)

Transverse beam (Non-linear Giberson beam element)

Linking slab

End slab (Elastic element)

Prestressed rib (Elastic element)

Transverse beam and floor slab interface (Non-linear axial truss element)

Plastic hinge

Longitudinal beam (Elastic element)
3D Computational Model

Rigid link

Isometric view
Linking Slab

- Prestressed rib
- Compression struts
- Tension tie
- Effective strut width
- Edge of the longitudinal beam
- Exterior column
- Centre column
Plastic Hinge Element

Peng et al 2007 NZSEE Conference

- Rigid plane
- Side elevation
- 72 longitudinal springs
- Unconfined cover concrete
- Confined core concrete
- Reinforcing bar
- Cross section
Length of Plastic Hinge Element

- $L_P \sim$ controls the horizontal component of diagonal force contributing to section equilibrium

$$L_P = \frac{V_{yc} s}{A_v f_{vy}}$$
Length of Steel Spring

- $L_{steel} \sim$ controls stiffness of steel springs and plastic hinge element

$$L_{steel} = \frac{M}{V} \left( \frac{M_{max} - M_{yc}}{M_{max}} \right) + L_t + L_e$$

Bending moment profile

Tension Force in flexural reinforcement
Force-Displacement Comparison

- Over-strength (NZS 3101:2006)
- Theoretical flexural strength (NZS 3101:2006)
- Flexural strength of beam only (without flange effect)
Strength Enhancement Mechanisms

1) Torsional resistance of transverse beams
   • Increase both positive and negative column shear force demand (~18%)

2) Slab reinforcement participation
   • Increase negative strength of plastic hinges only (~31%)
Slab Participation

Interior plastic hinge

Exterior plastic hinge

Applied Displacement (mm)

Axial Force (kN)

Analytical prediction
Elongation Comparison

- **Interior plastic hinge**
- **Exterior plastic hinge**

Graphs showing elongation (mm) versus applied drift (%) for analysis and experiment.
Floor Deformation Comparison

- Bending of floor slab (deep beam)
- Crack width between floor and transverse beam interface
- Diagonal cracks (shear deformation)
Conclusions

- Experimental results show significant beam strength enhancement in frames with prestressed floor units
- 3D Analytical model with elongating plastic hinge element was developed
- Analysis predicts hysteretic, floor deformation and elongation response of plastic hinges satisfactorily
- This model can be used to assess the seismic performance of RC frame buildings
Thank you

Questions?

Brian H. H. Peng, R. Dhakal, R. Fenwick, A. Carr and D. Bull
Dept. of Civil and Natural Resources Engineering
University of Canterbury
+3% drift

Column A

-20.8  -144.5  -94.2  -94.0  -104.2  +0.0
-0.0   +27.5  +73.3  +67.0  +77.6  +61.4

Column B

Compression

Tension

Column C

-214.1  -29.8  -18.0  -17.0  -0.0  +0.0
-50.2  +17.6  +3.0  +7.4  -3.6  +0.0
### +3% drift

<table>
<thead>
<tr>
<th>Distance from the column face (mm)</th>
<th>Deformation along east transverse beam (mm)</th>
<th>Deformation along west side of internal transverse beam (mm)</th>
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<tr>
<td></td>
<td>Experiment</td>
<td>Analysis</td>
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<tr>
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</table>
+3% drift
9.4.1.6.2 Contribution of slab reinforcement to overstrength of plastic region in a beam

In T- and L-beams built integrally with slabs, slab reinforcement in the over-hanging portion of flanges, which are identified in (a), (b) or (c) below, shall be assumed to contribute to the overstrength moment of resistance at the critical section of plastic regions in the beam being considered. Where precast units are contained in a portion of slab within the effective overhanging flange width their contribution to strength shall be included as specified in (d). In no case need the flexural tension force contribution of an overhanging flange exceed the value given in (f).

(a) Where a beam containing the potential plastic region is at right angles to the edge of the floor and it frames into an exterior column, but no transverse edge beam is present, the effective width of overhanging flange, $b_k$, shall be taken as the smaller of the distance at the critical section of the potential plastic region in the beam between the web and a line drawn at 45° from the intersection of a line drawn parallel to the web and touching the side of the column and the edge of the slab, or the value given by (c). Any reinforcement passing through this section shall be assumed to be stressed to $f_{y}$, where the value of $f_{y}$ is given in 2.6.5.5.

(b) Where a beam containing the potential plastic region is at right angles to the edge of a slab frames into an external column and the slab is supported by a transverse beam, the effective overhanging flange width, $b_k$, shall be taken as the smaller of:

(i) the widths defined in (a) above plus twice the width of the web of the transverse beam, or

(ii) the value given in (c) below.

The tension force sustained by the overhanging flange shall be calculated as in (a).

(c) Where a beam containing a potential plastic region or regions passes through a column the effective overhanging flange width on each side of the beam shall be taken as the smaller of:

(i) Three times the overall depth of the beam;

(ii) The clear distance between adjacent beams times the factor $\frac{h_{b1}}{h_{b1} + h_{b2}}$

Where $h_{b1}$ is the depth of the beam being considered and $h_{b2}$ is the depth of the adjacent beam.
8.5.3.3
In T- and L-beams built integrally with slabs, the slab width within which effectively anchored longitudinal slab reinforcement shall be considered to contribute to the negative moment flexural strength of the beam, in addition to those longitudinal bars placed within the web width of the beam, shall be defined as the lesser of the following criteria:

(a) One-quarter of the span of the beam, extending each side as appropriate from the centre of the beam section;

(b) One-half of the span of the slab, transverse to the beam under consideration, extending each side as appropriate from the centre of the beam section;

(c) Where the beam is in the direction at right angles to the edge of the floor and frames into an exterior column, 1/4 of the span of the transverse edge beam, extending each side from the centre of the beam section;

(d) Where the beam is in the direction at rights angles to the edge of the floor and frames into an exterior column but no transverse edge beam is present, 1/2 of the column width, extending each side from the centre of the beam section.

For the purpose of 8.5.3.3(a), (b), (c) and (d), top and bottom slab reinforcement shall be considered to be effectively anchored only if those bars can develop their tensile strength at a line drawn in the plane of the bars from the centre of the support column an angle of 45° to the axis of the beam extending away from the beam span under consideration.