Recent Research on Seismic Resistant Design and Retrofit of Structures

Research at the University of Ottawa, Canada

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General

Research has been underway at the University of Ottawa on development and use of innovative materials and techniques for earthquake-resistant structures. The research program focuses on both new construction and older existing infrastructure which requires seismic upgrades and retrofits. It includes experimental and analytical research components.
Research in Seismic Resistance and Retrofit of Structures

- Improvements at the element level.
  - R/C columns and beams
  - R/C shear walls
  - Concrete block masonry walls

- Improvements at the global performance level (frame bracing).
  - New Buckling Restrained Brace (BRB) for R/C Frames
  - Progressively Engaging Steel Strand Braces

Transverse Prestressing as Transverse Column Reinforcement

- Lack of shear reinforcement
- Lack of concrete confinement
Transverse Prestressing as Transverse Column Reinforcement

Transverse Prestressing of Columns
Transverse Prestressing of Columns

![Image of prestressed columns](image1)

![Image of prestressed columns](image2)

![Graph showing lateral force vs. lateral displacement](image3)

**Graph Details**:
- **Drift (%)**
- **Lateral Force (KN)**
- **Lateral Displacement (mm)**
- **BR-C1**

**Legend**:
- F: Force
- Δ: Drift
- L: Lateral
- M: Lateral Displacement

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Transverse Prestressing of Columns

![Image of prestressed columns](image4)

![Image of prestressed columns](image5)
Transverse Prestressing of Columns

Field Application
Transverse Prestressing of Columns

Column retrofit with high-strength steel straps

Precast concrete raiser units were manufactured to complete square and rectangular sections to circular and elliptical shapes,
Transverse Prestressing of Columns

Column retrofit with high-strength steel straps @ 7% Drift

Welded Wire Grids as Transverse Column Reinforcement
Welded Wire Grids as Transverse Column Reinforcement

Column tests

Welded Wire Grids as Transverse Column Reinforcement

Drift (%)
Half Beam Tests

**Welded Wire Grids as Coupling Beam Transverse Reinforcement**

- **BGB-3**
  - $f'_c = 40$ MPa
  - 4-legged grids
  - $S_{pm} = 264$ mm

- **BGB-4**
  - $f'_c = 40$ MPa
  - 4-legged grids
  - $S_{pm} = 132$ mm
Welded Wire Grids as Coupling Beam Transverse Reinforcement

• Aspect ratio: 3:1 (4.35m H: 1.45m L)

• Aspect ratio of 2.0 is considered high-rise shear wall by ACI 318

• 1600 kN axial load

• 82 MPa concrete

• Failed by buckling of longitudinal bars in compression in boundary elements

WWG as Shear Wall Boundary Element Reinforcement
Welded Wire Grids as Shear Wall Boundary Element Reinforcement

FRP Reinforcement as Internal Reinforcement

Lead Line Bars
Pultrall Bars
NEFMAC Grids
CFRP Reinforced Concrete Columns

- FRP bar failure in compression
- FRP rupturing in tension
- Bar buckling
- Core crushing

H = 1900 mm
L = 2180 mm
P = 27% P_o

Moment, M (kN.m)

Drift(%)
CFRP Reinforced Concrete Beams

Moment (kN.m)

Drift (%)

CFB4

H = 1900 mm

L = 1780 mm

s = d/2

s = 180mm

Flexural failure (Bars ruptured and concrete crushed)

FRP Stay-in-Place Formwork
FRP Stay-in-Place Formwork

Ties inserted

Ends fastened

Final layer

FRP Stay-in-Place Formwork

@ Failure
FRP Jacketing of Columns

Examples of field applications
FRP Jacketing of Columns

BR-SS-R
Short Square Column
L = 1500 mm
Continuous bars
3 CFRP plies (wrapping)
P = 1160 kN (15% Po)

M = FL + P

Drift Ratio
Moment, M (kN-m)

Steel Belted Tires as Column Transverse Reinforcement

Eight Grade 8, 19 mm bolts
12 No. 20 Bars
Tire
Sidewall
Treads
Rim
Cover
51 mm
75 mm Diameter
322 mm
423 mm
550 mm
530 mm
1730 mm
1725 mm
175 mm
520 mm
75 mm Diameter holes

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Steel Belted Tires as Column Transverse Reinforcement

Tires are inserted through the longitudinal bars.
Steel Belted Tires as Column Transverse Reinforcement

At 5% Drift

At Failure

Steel Belted Tires as Column Transverse Reinforcement

Moment, M (kN.m)

Lateral Displacement, D (mm)

Lateral Drift (%)
Development of a New Buckling Restrained Brace (BRB)

Innovative end units
Frame Bracing with Prestressing Strands

Strands are initially left loose until they are needed to brace the frame, at which time they engage in the bracing action.
Frame Bracing with Prestressing Strands

Masonry Infill Walls

Crushing of Blocks at 2% Drift

End of Test
Fiber anchor, inserted into hole in column with epoxy
Strip width: 2 feet

Surface-Bonded FRP

BL-2

Retrofitted
Unretrofitted

Force, kN

Displacement, mm (Drift)

(1%) (2%) (3%)
PRM Wall – FRP Retrofit with FRP Anchors

FRP Anchors

Rounding of FRP

PRM Wall – FRP Retrofit with FRP Anchors

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PRM Wall – FRP Retrofit with FRP Anchors

![Graph showing lateral load vs. drift% for Unretrofitted Wall Envelope.]

URM Walls – FRP Retrofit with Ductile Steel Sheet Anchors

![Diagram of URM Walls with FRP Retrofit and Ductile Steel Sheet Anchors.]
Stainless steel developed 60% elongation prior to tensile rupture

Foundation concrete is cut

FRP anchors are placed and epoxy is glued. They are bolted to delay buckling.
URM Wall – FRP Retrofit with Ductile Steel Sheet Anchors

Unretrofitted capacity: 55 kN
Thank You for Your Attention

Questions or Comments?