ReCast Floors

Hollow-core Floors in Earthquakes: *Assessment and Retrofit*

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Frank Büker, Mo Mostafa, Mike Parr, Giovanni De Francesco

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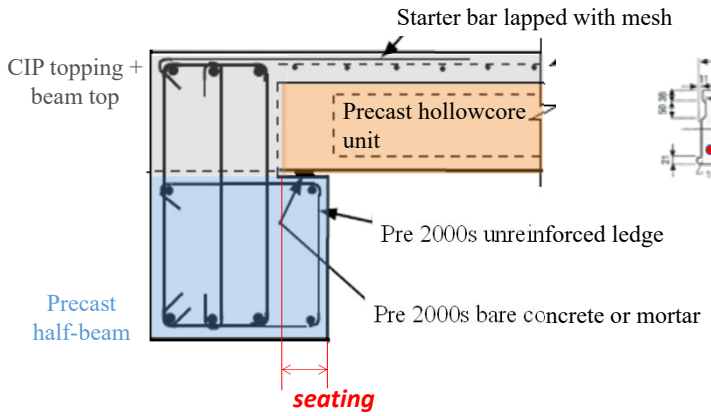
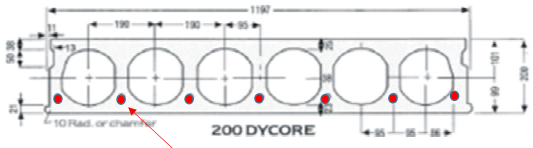
Typical Hollow-core Seating Details (NZ)





Prestressed strand

Pre-2000s : typ 50mm seating specified
0-50mm achieved?

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1994 Northridge Earthquake

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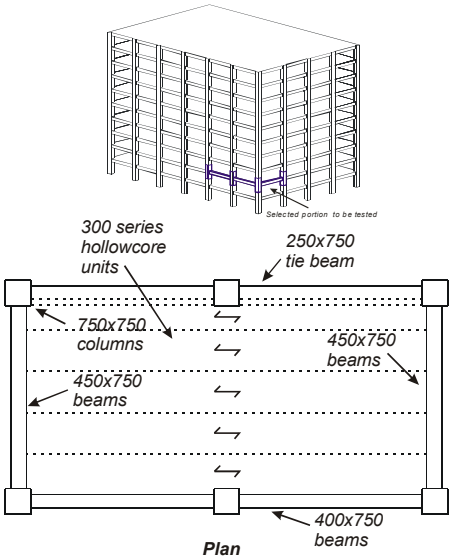
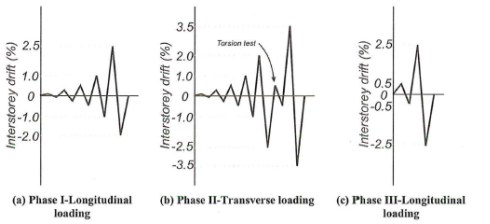
Matthews and Bull (2004)
2-bay x 1-bay specimen





Matthews(2004)

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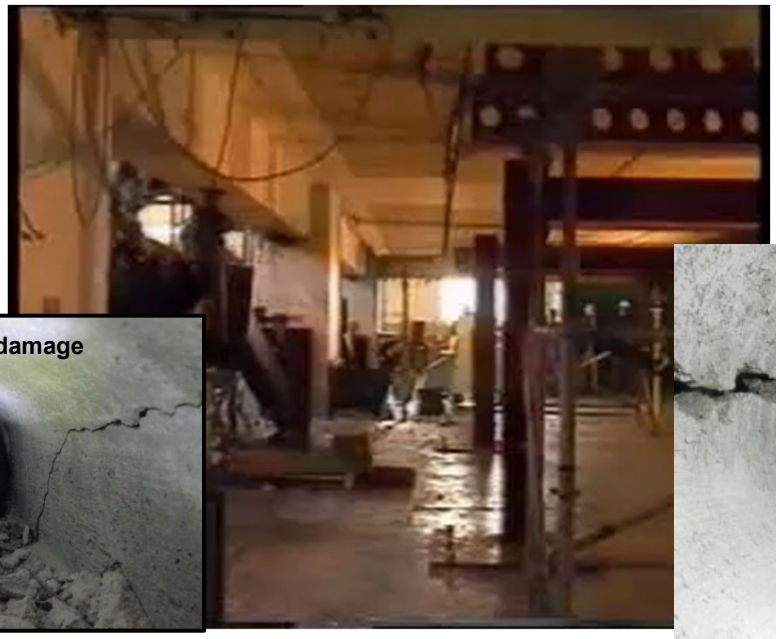
Matthews and Bull (2004)



UoC test – *Matthews (2004)*

2.5% drift

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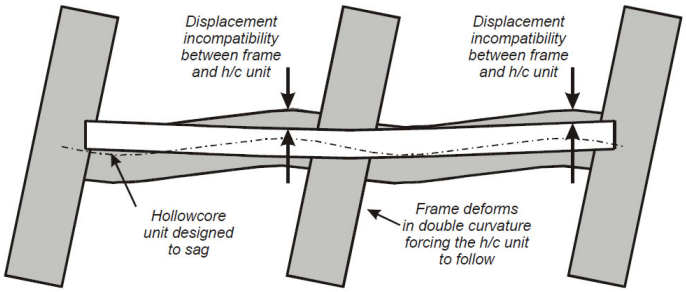
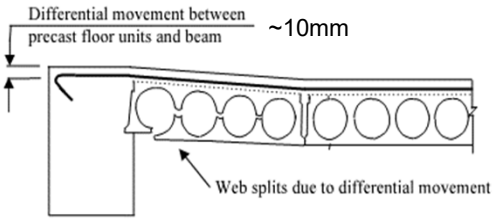
Incompatible displacements



Matthews et al (2004)



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Matthews and Bull (2004)

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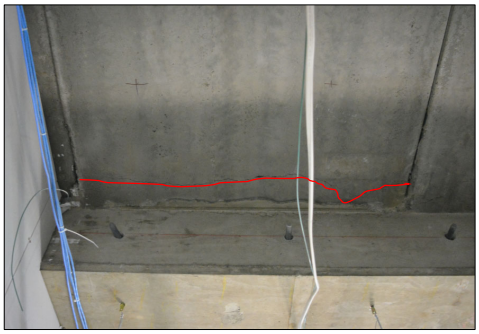
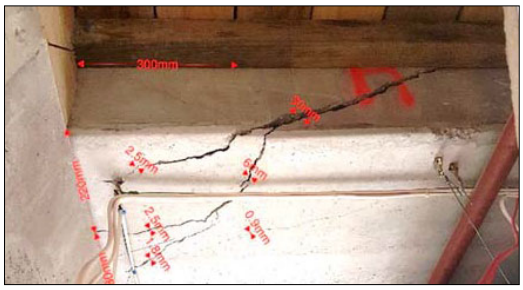
2016 Kaikoura EQ – Hollow-core floor damage





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2016 Kaikoura Earthquake
-Case Study Building

2006 Ductile Moment Frame with 400HC

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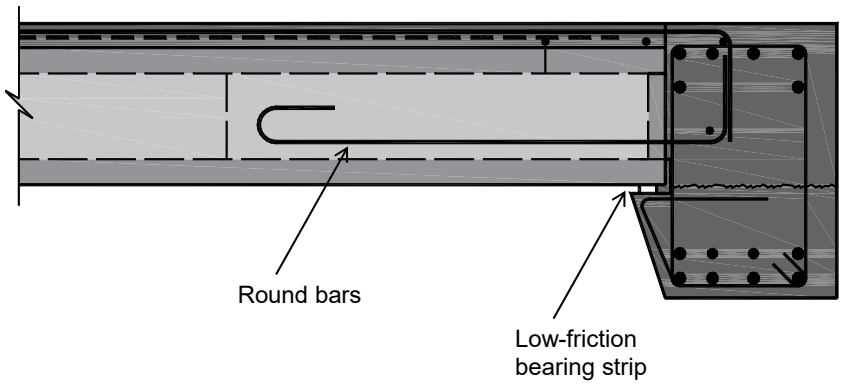
Seating details

- Connection details per NZS 3101:2006



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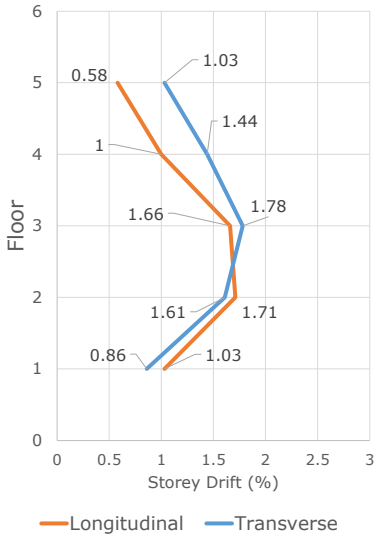
2016 Kaikoura EQ

-*Drifts based on instrumentation*



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Damage Data Collection

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Damage Data Collection

Thanks to UW RAPID Facility!

821 Laser Scans

105K+ HD Photos

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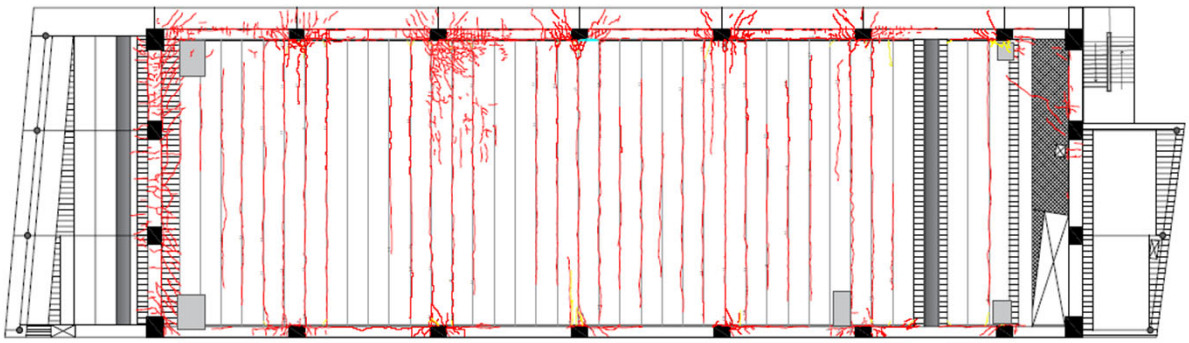
Crack maps



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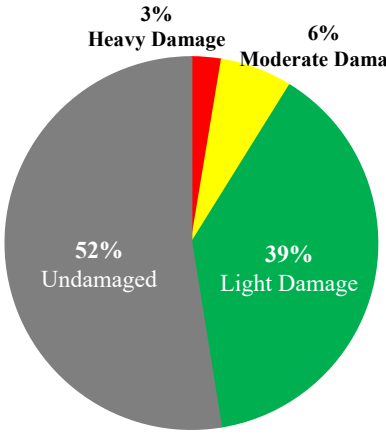
Quantification of Damage



Observed Damage State	Supported on a column	Supported in plastic hinge zone	Supported outside of plastic hinge zone
Undamaged	26	87	249
Lightly Damaged	88	84	94
Moderately Damaged	33	5	5
Heavily Damaged	16	2	0

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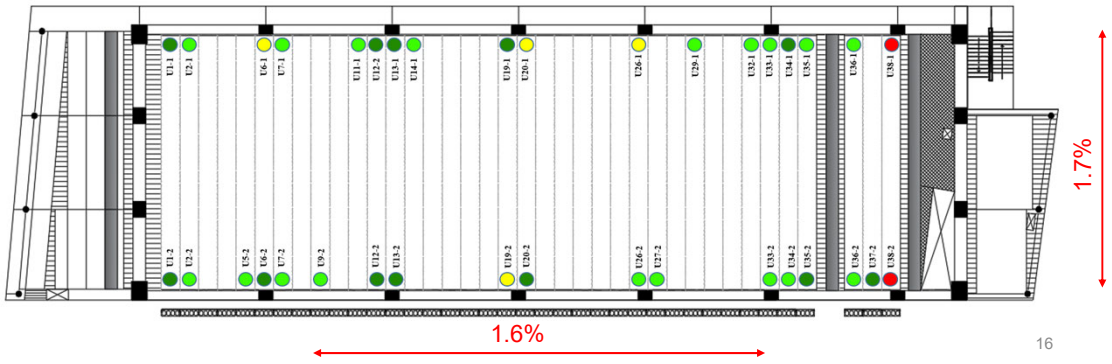
P3-Level 2



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ReCast Floors
P3-Level 2
1.7%
1.6%
17

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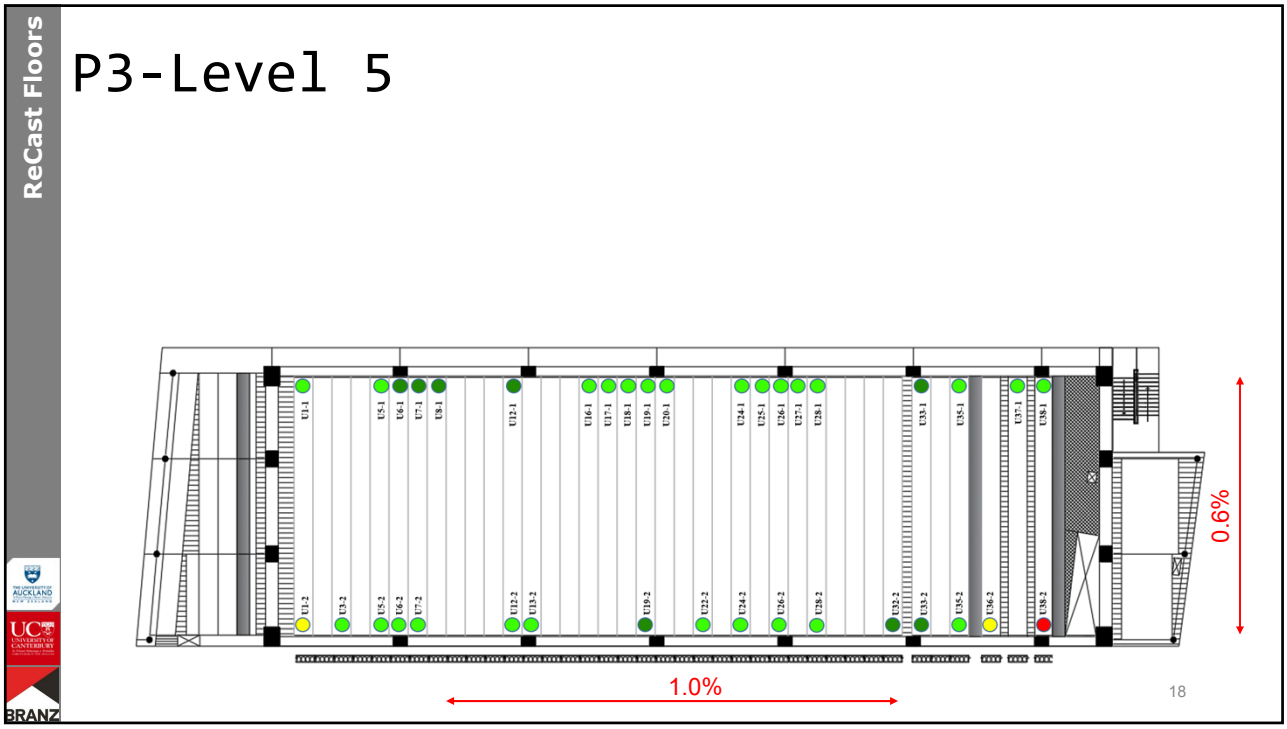
ReCast Floors
P3-Level 5
0.6%
1.0%
18

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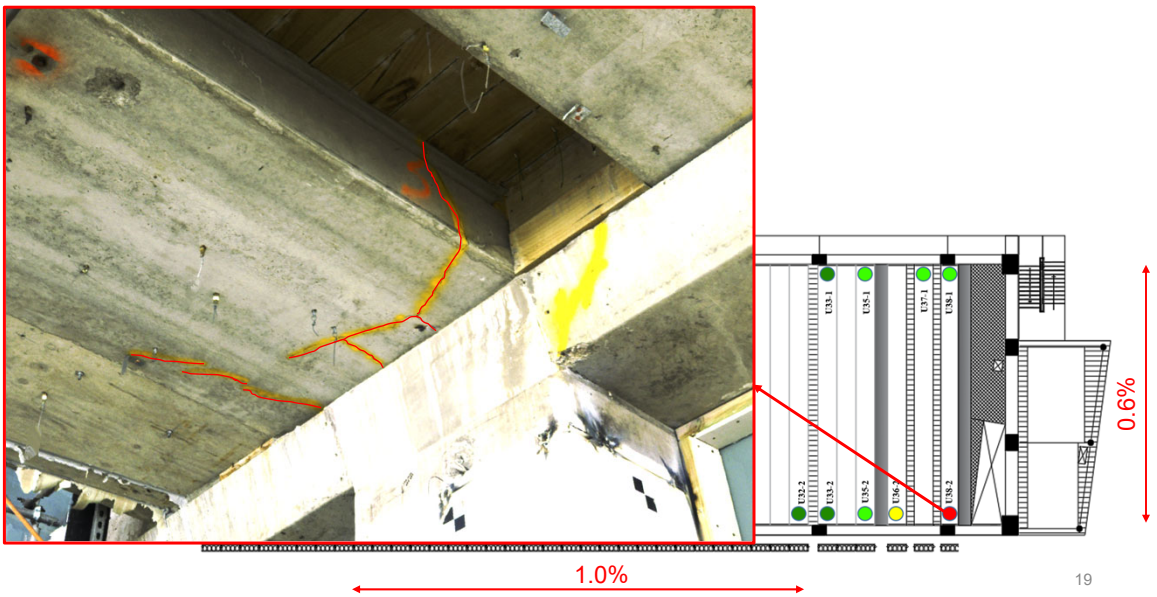
Pier 3-Level 5



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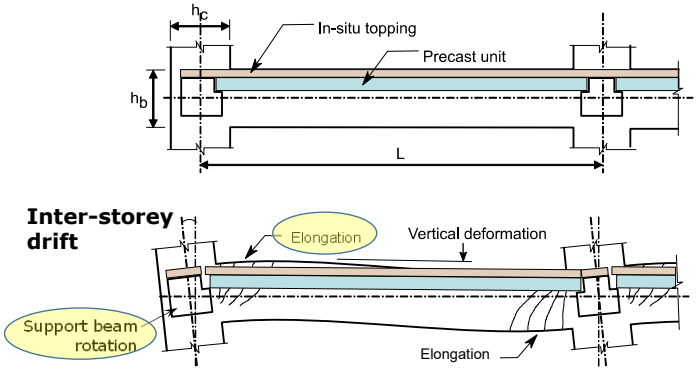
Assessment of Precast Floors – *Demands*



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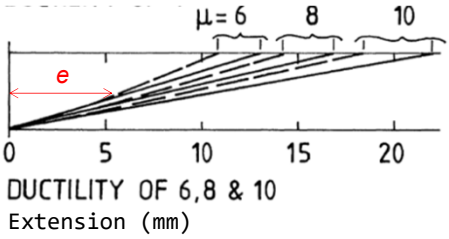
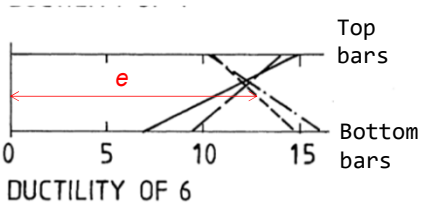
Elongation - *Fenwick and Megget (1993)*

Unidirectional Plastic hinge



Reversing Plastic hinge



Unidirectional plastic hinge:

$$e = \theta \frac{(d - d')}{2}$$

Reversing plastic hinge:

$$e = C\theta \frac{(d - d')}{2}$$

(NZS 3101: C=2.6)

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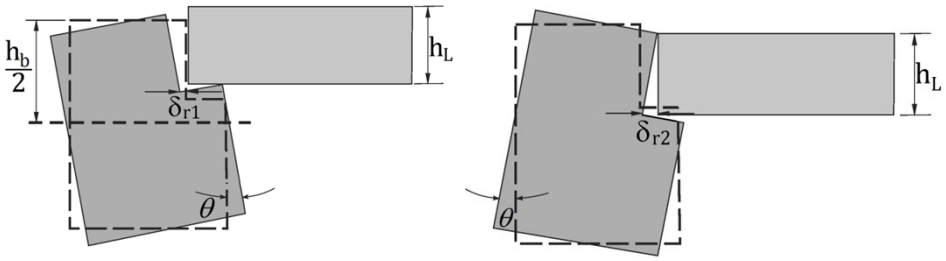
Rotation

- Movement at support ledge due to rotation added to elongation



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Drift Capacity of Hollow-core Floors
– *Failure modes*

Loss of Seating (LOS)

Positive Moment Failure (PMF)

Negative Moment Failure (NMF)

Objective:

- Determine inter-storey drift at which floor units no longer have ***reliable*** gravity load path.

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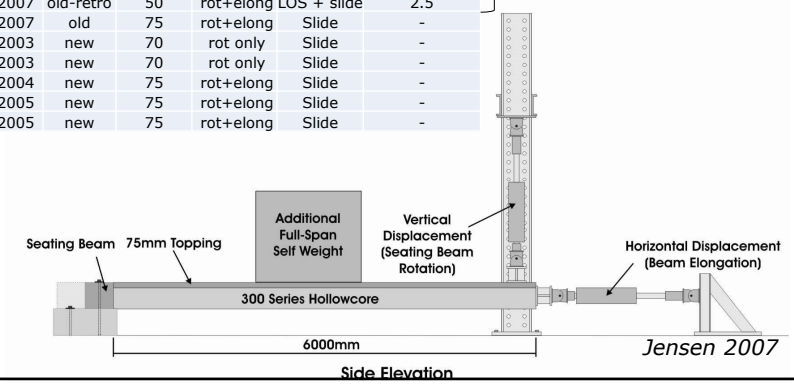
Hollow-core Floor Subassemblies
– *test data (Des Bull + students)*

Name	Researcher	Date	Type	Seating (mm)	Loading	Failure mode	Drift capacity (%)
HC1-B-03	Bull and Matthews	2003	old	50	rot only	PMF	3.0
HC4-B-03	Bull and Matthews	2003	old	50	rot only	PMF	1.8
S1-L-04	Liew	2004	old	0	rot only	NMF	1.1
S2-L-04	Liew	2004	old	70	rot only	NMF	1.9
S3-L-04	Liew	2004	old-retro	20	rot only	NMF	1.8
HC1-J-07	Jensen	2007	old	35	rot+elong	LOS	1.7
HC3-J-07	Jensen	2007	old	50	rot+elong	LOS	1.7
HC4-J-07	Jensen	2007	old-retro	50	rot+elong	LOS + slide	2.5
HC2-J-07	Jensen	2007	old	75	rot+elong	Slide	-
HC2-B-03	Bull and Matthews	2003	new	70	rot only	Slide	-
HC3-B-03	Bull and Matthews	2003	new	70	rot only	Slide	-
S1-T-04	Trowsdale	2004	new	75	rot+elong	Slide	-
S1-M-05	Macpherson	2005	new	75	rot+elong	Slide	-
S2-M-05	Macpherson	2005	new	75	rot+elong	Slide	-

Loss of reliable load path

Pre-2006 details



Jensen 2007

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Loss of Seating (LOS) - Spalling

- Kaikoura Earthquake evidence

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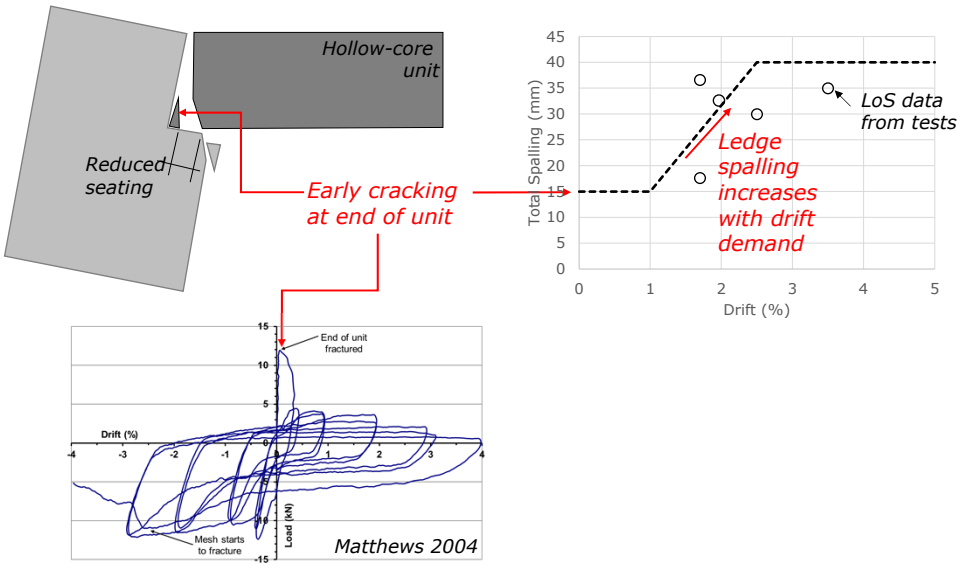
Loss of Seating (LOS)



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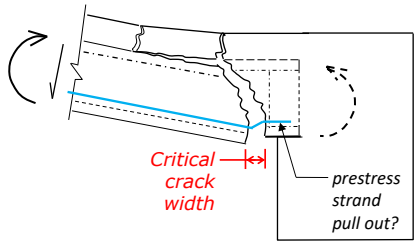
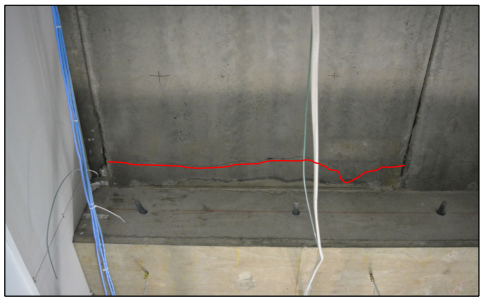
Positive Moment Failure (PMF)



Matthews (2004)



Kaikoura EQ damage

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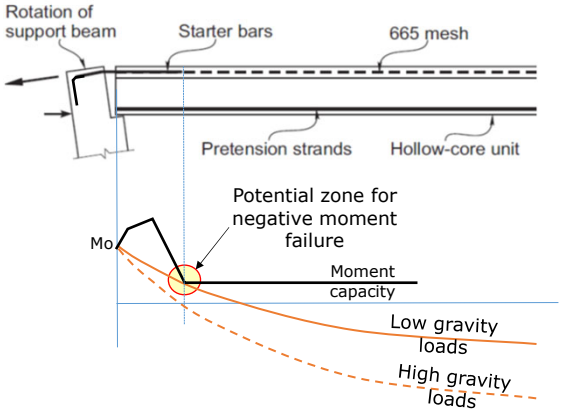
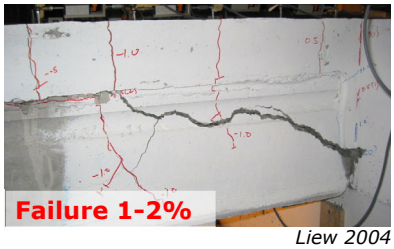
Negative Moment Failure (NMF)



If NMF triggered
→ **Limiting drift = 1%**



Liew 2004

NMF concern for:
- *Low gravity loads*
- *Strong or short starters*

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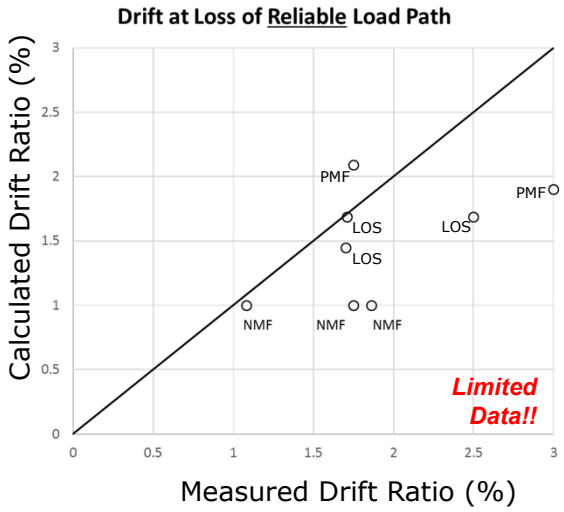
Hollow-core Floors – test data

- Validation of assessment

Precast floor assessment provisions available at:
www.eq-assess.org.nz



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Retrofits for hollow-core floors?

Kaikoura EQ damage

Angle-only retrofits sufficient?

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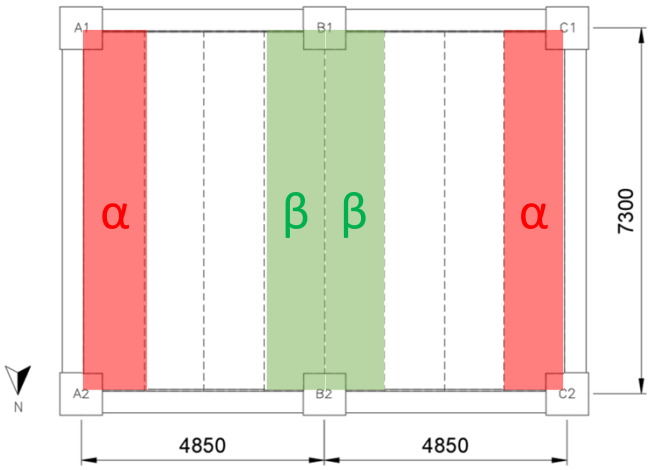
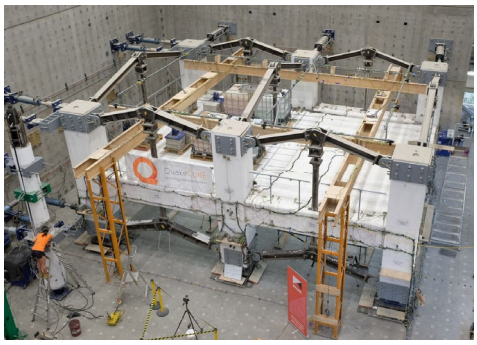
"Big Frame" Tests





Test 1 (Aug-Sep 2020):
- Kaikoura EQ
- Circular bidirectional loading

Test 2 (Feb-Mar 2021):
- Pulse-type EQ
- Elliptical bidirectional loading

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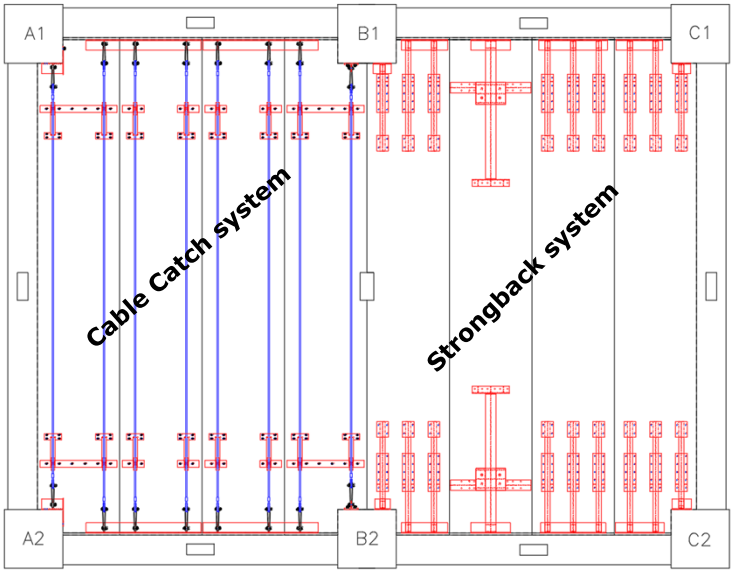
Retrofits in Big Frame Test II



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Strongback retrofit

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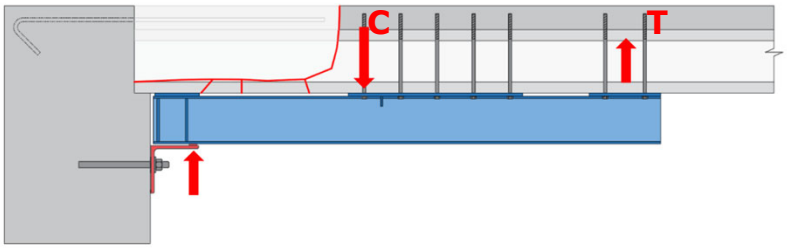
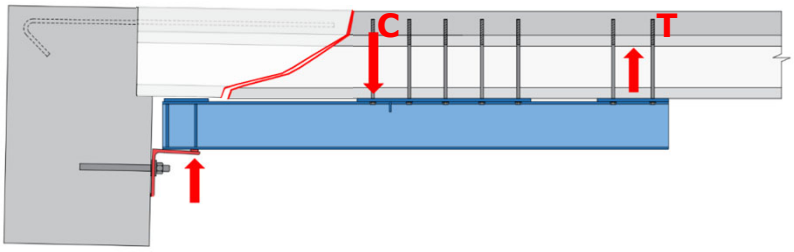
Strongback retrofit

NMF



(a)

PMF



(b)

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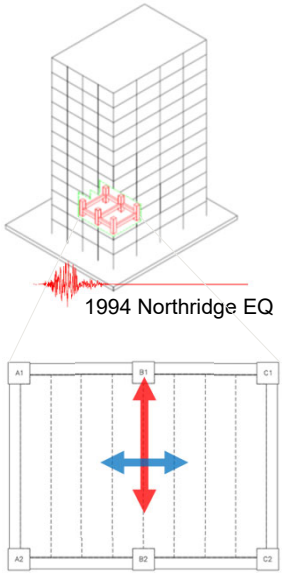
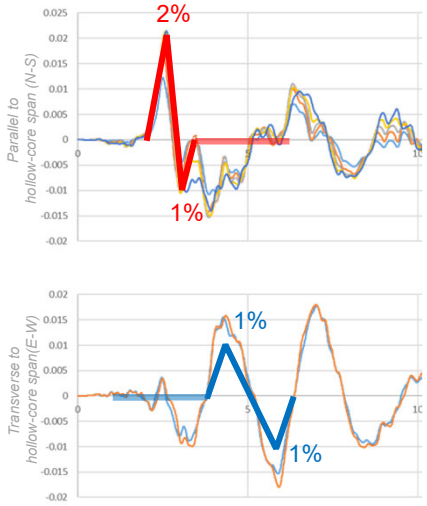
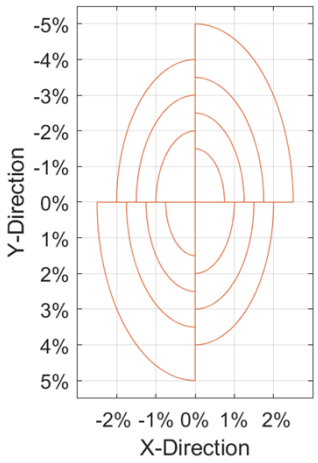
Test 2 – Loading Protocol

G. De Francesco & T. J. Sullivan (UC)







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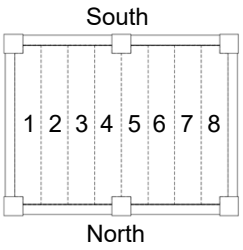
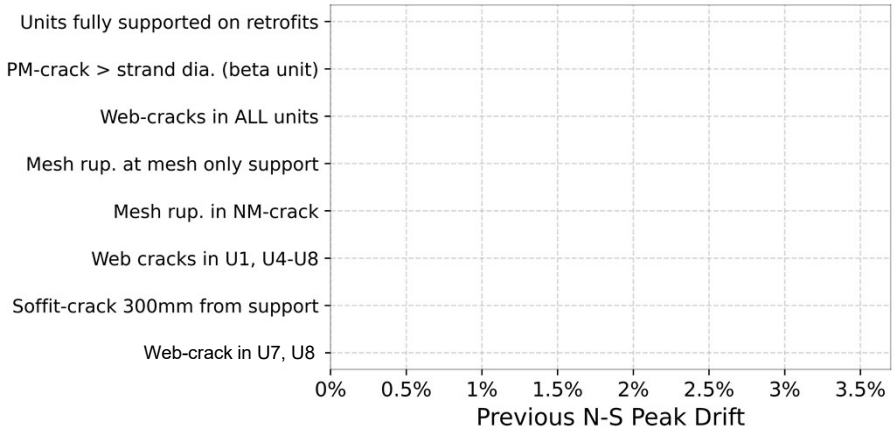
Test 2 - Damage Progression





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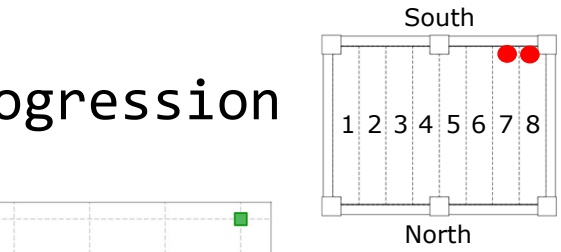
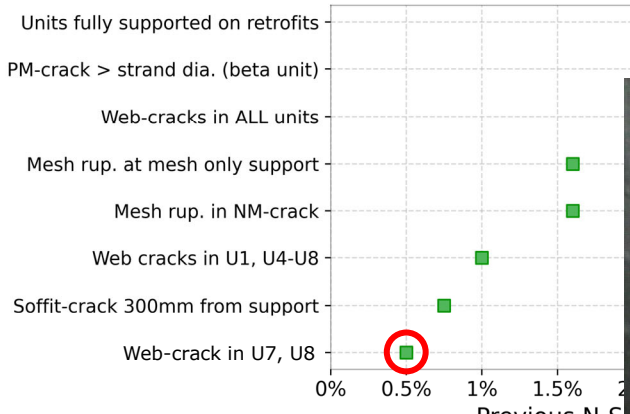
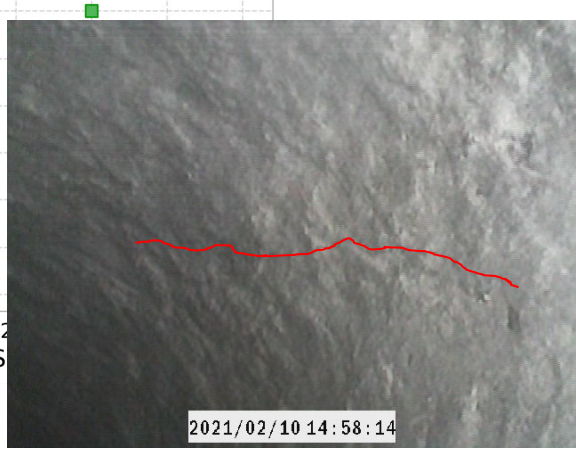
Test 2 - Damage Progression







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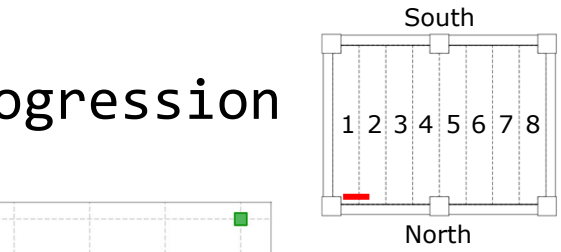
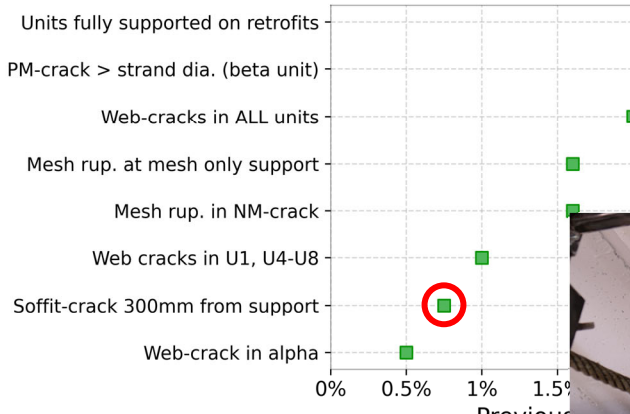
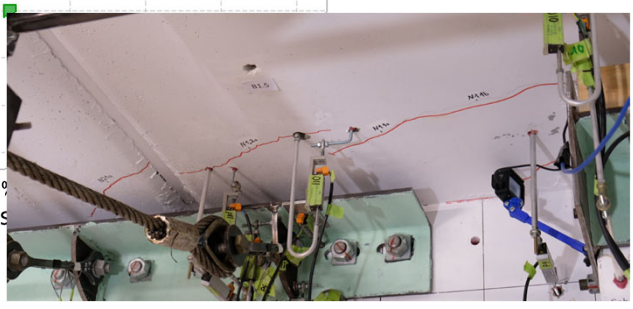
Test 2 - Damage Progression







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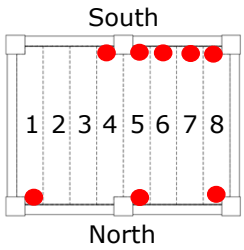
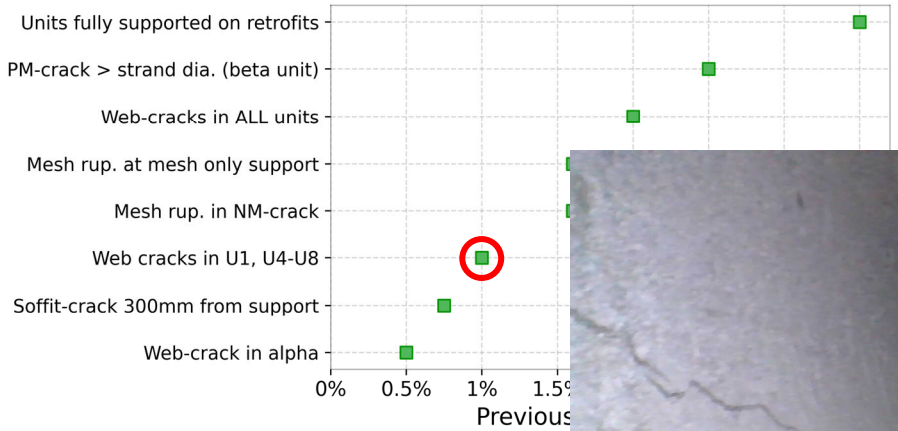
Test 2 - Damage Progression





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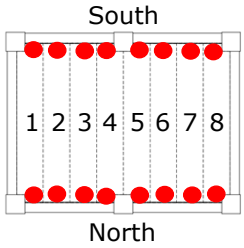
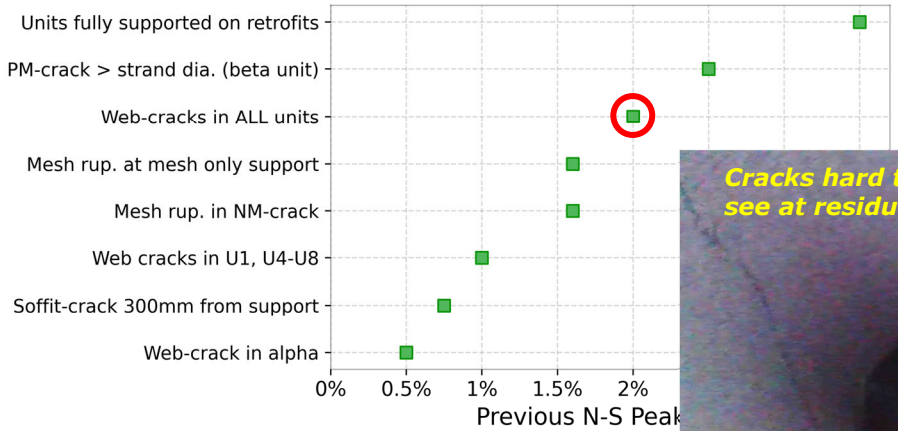
Test 2 - Damage Progression





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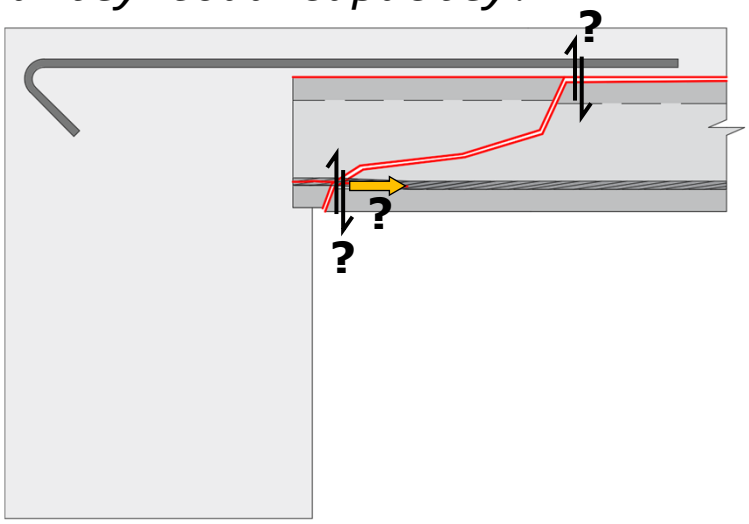
Why do these cracks matter??

- Gravity load capacity?



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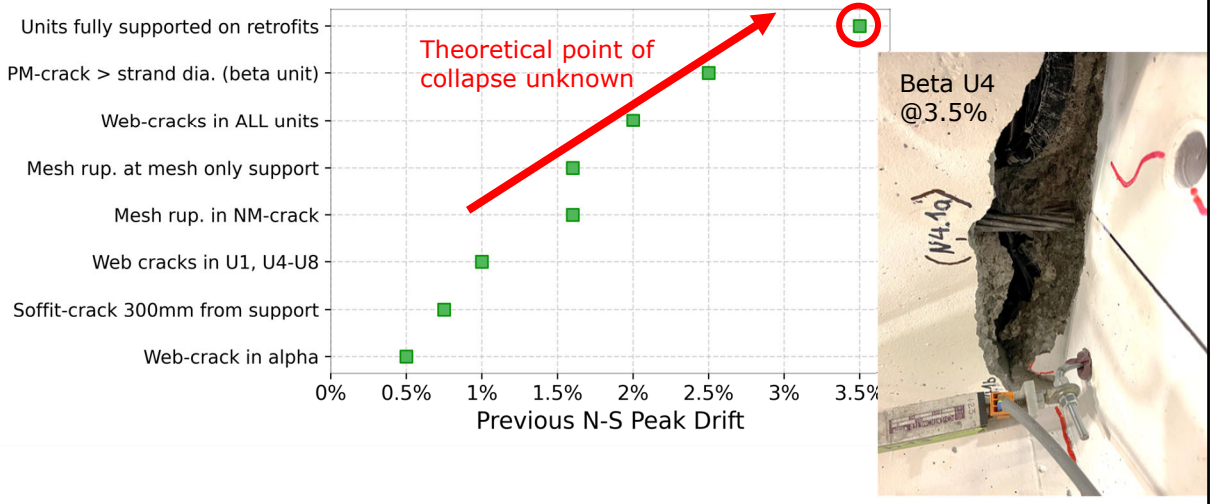
Test 2 - Damage Progression



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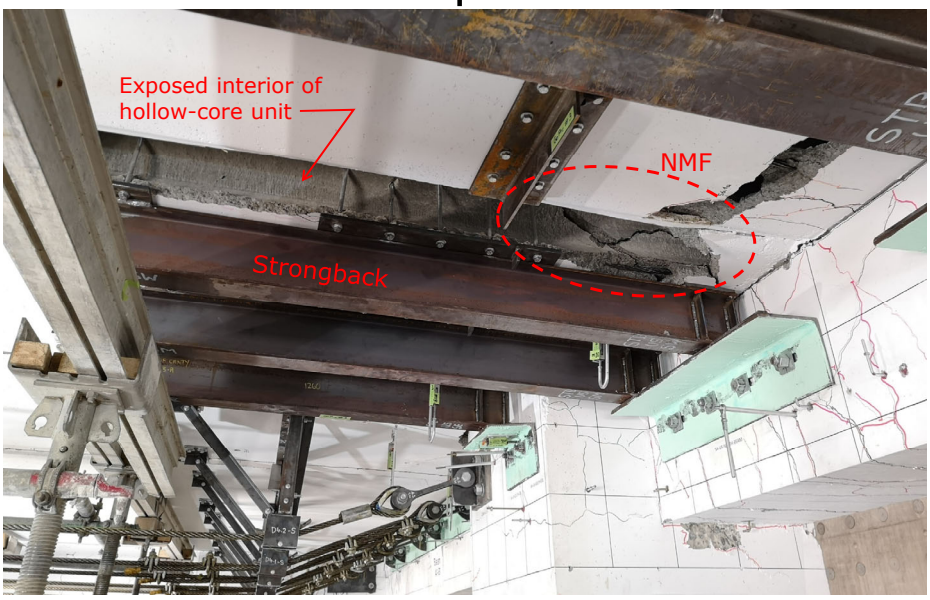
Excellent retrofit performance!



Beta Unit 5 – After Test

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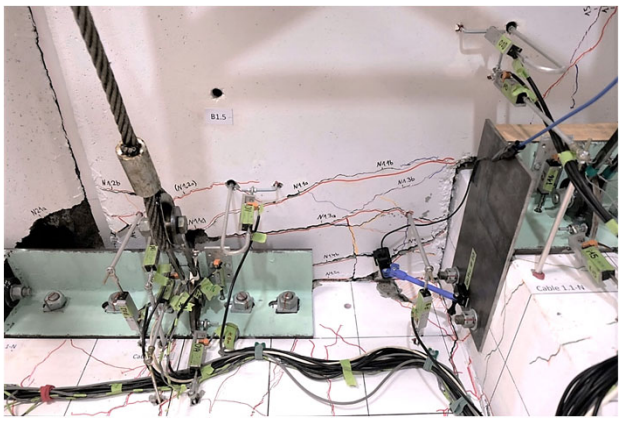
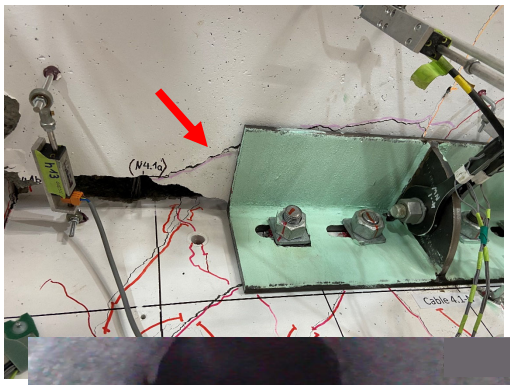
Effectiveness of angle-only retrofits???





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Summary

- Hollow-core floors are **vulnerable to damage and collapse** in earthquakes.
- **Web cracking** is initiated at **very low drift** demands (~0.5%) and hard to detect in the field.
- **Assessment procedures** have been developed to estimate the drift at loss of reliable load path for hollow-core floors considering LoS, PMF, and NMF.
- **Strongback retrofits** provides confidence in continued gravity load support after earthquakes.

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Thank you!

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LEARNED SOCIETY

Precast floor assessment provisions available at:
www.eq-assess.org.nz

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