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Accelerated Bridge Construction (ABC) Low Damage in High Seismicity: Concept, Experimental Validation and Real-Life Application

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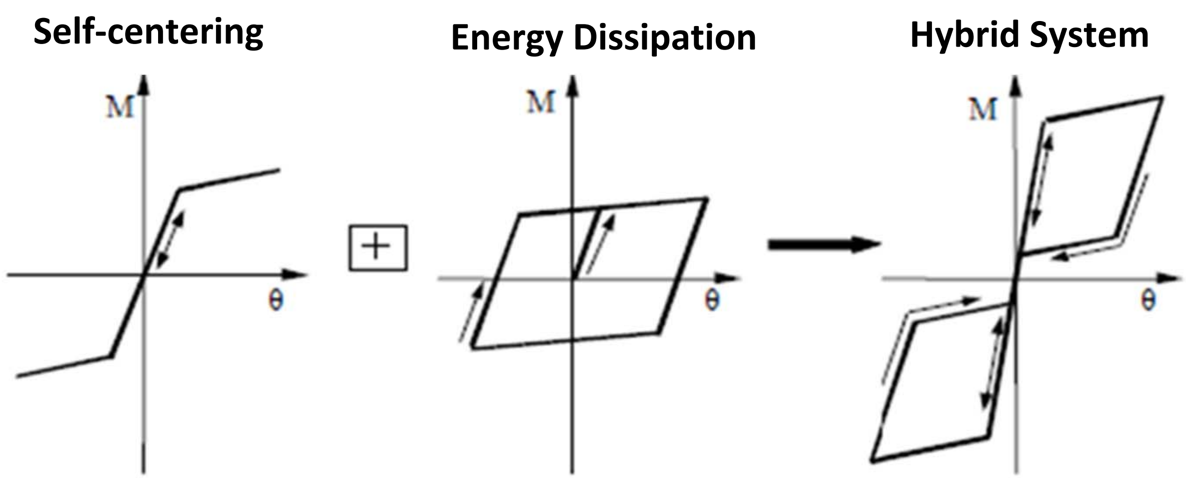
Outline

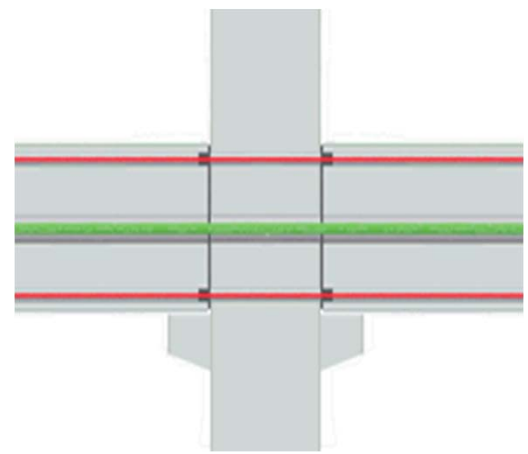
1. Concept for ABC Low Damage
2. University of Canterbury Research
3. Experimental Validation
4. Real-life Application
5. November 14th 2016 Kaikoura Earthquake
6. Conclusions
7. Facilities at ISU for Structural Testing
8. Potential Partnership/Opportunities

Concept for ABC Low Damage

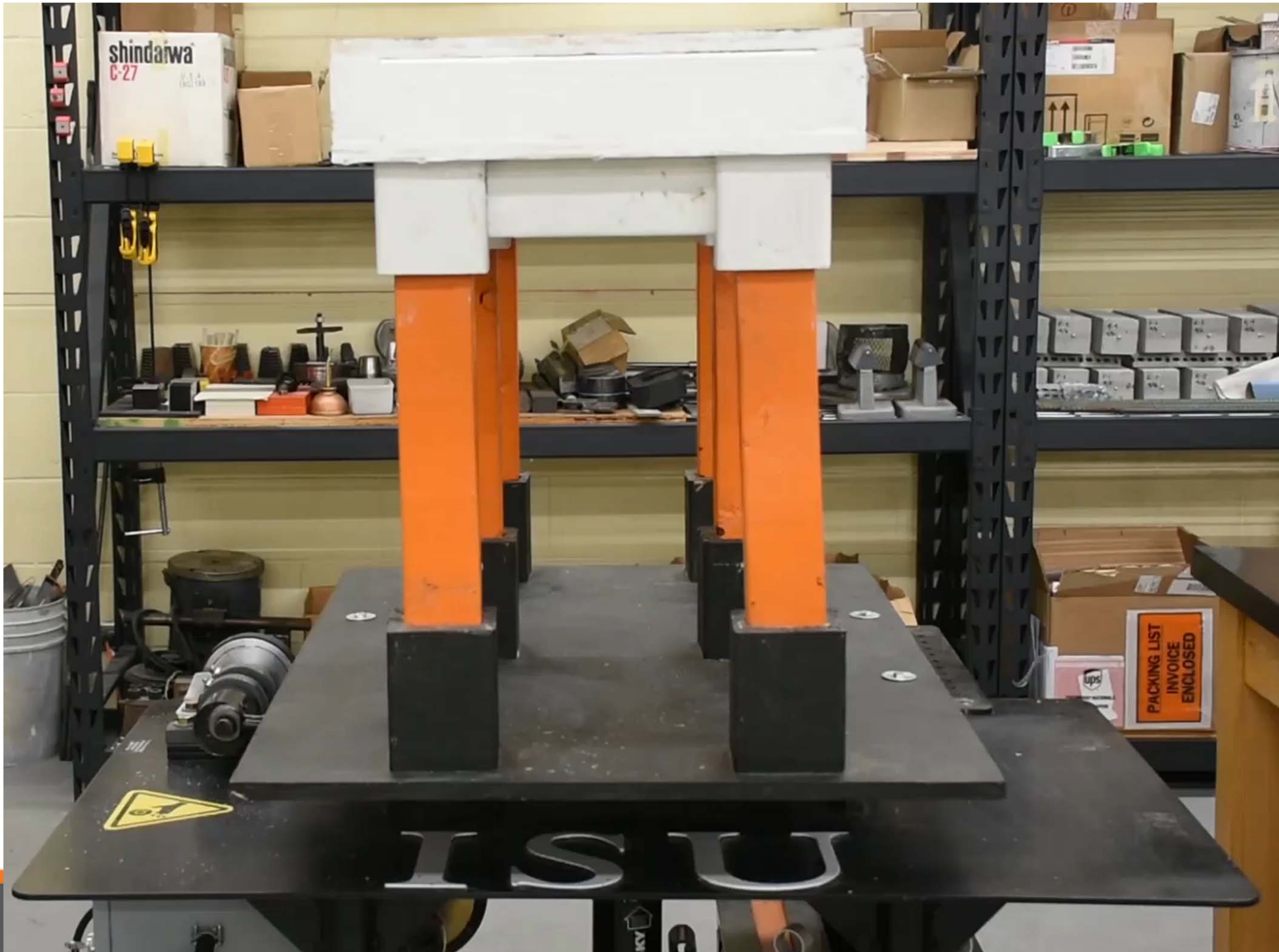
- ABC Low Damage combines unbonded post-tensioning with external energy dissipaters for seismic resistance
- Post-tensioning provides self-centering and dissipaters absorb seismic energy



Flag-shaped hysteretic behavior of hybrid connection (Stanton 1997, Priestley et al. 1999, Stanton 2003)



Beam-Column Joint
Rocking Mechanism (CCANZ)

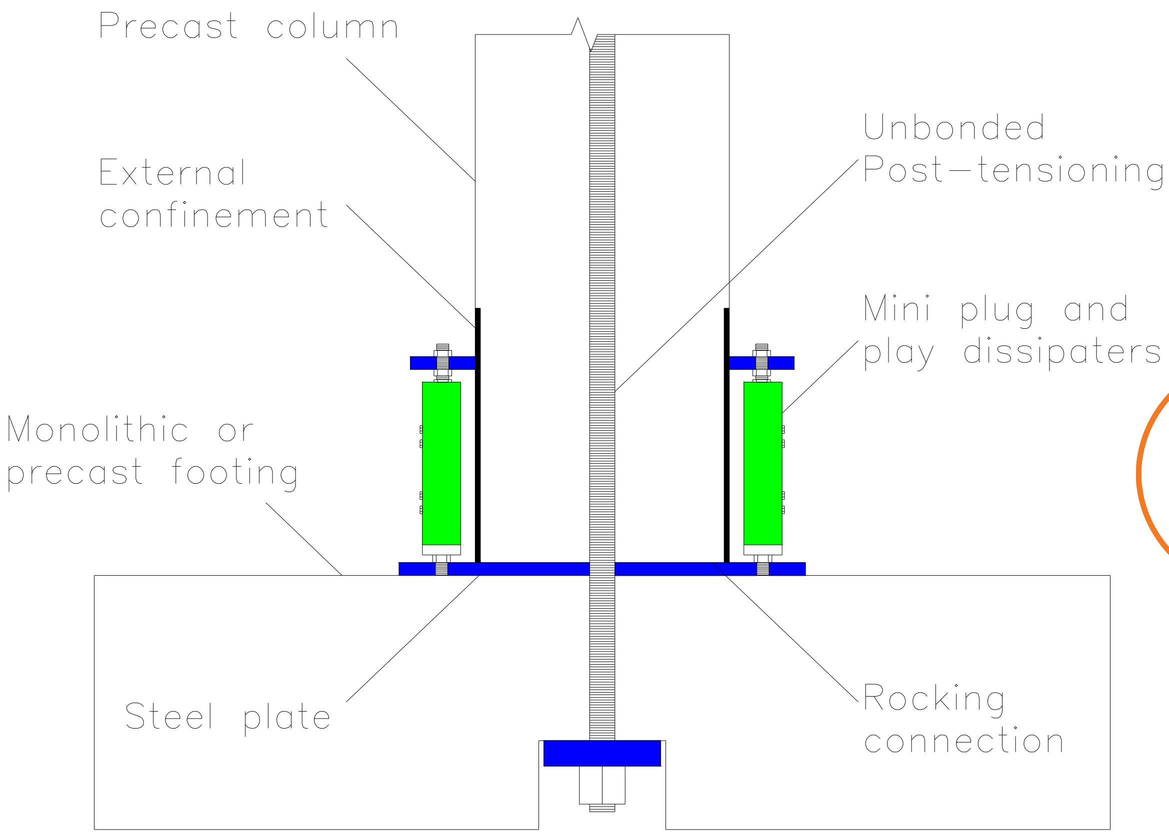


shindaiwa
C-27
PACKING LIST
INVOICE
ENCLOSED
ISU

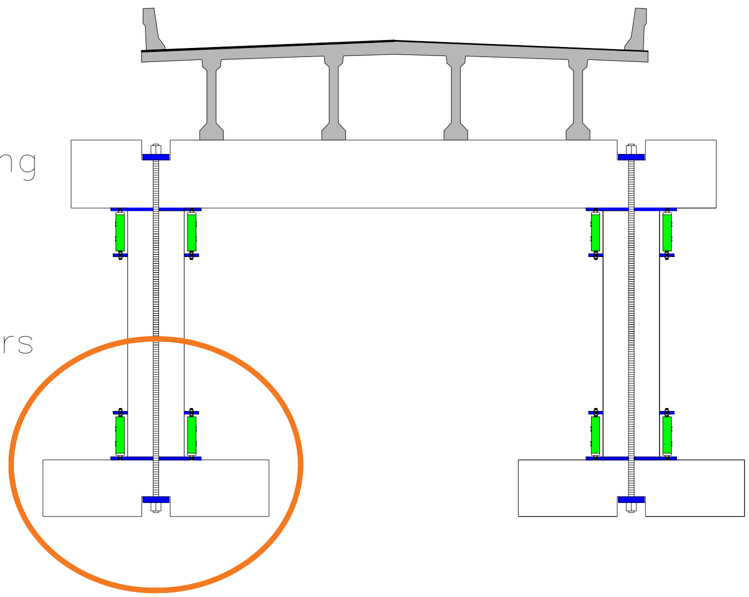
University of Canterbury Research

- Hybrid connections are called "Dissipative Controlled Rocking" (DCR) connections
- Research at the University of Canterbury by Mustafa Mashal and Alessandro Palermo (2011-2015) extensively studied the performance of DCR connections in half-scale fully precast bent
- Research included development of concepts /detailing, invention of dissipaters, experimental validation, and analytical modeling
- Research contributed in construction of the world's first DCR bridge in Christchurch (2016)

University of Canterbury Research

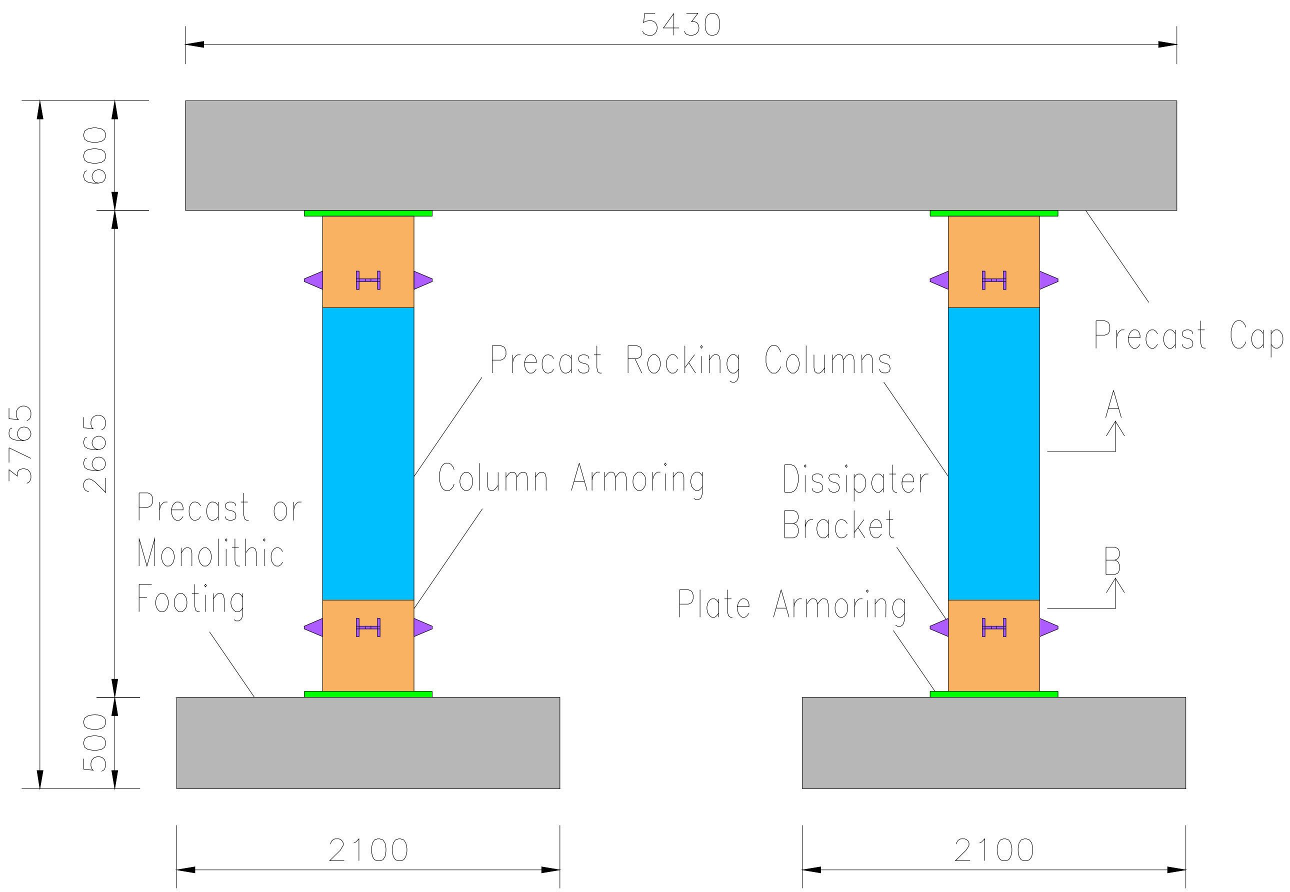


Typical DCR Connection in a bent



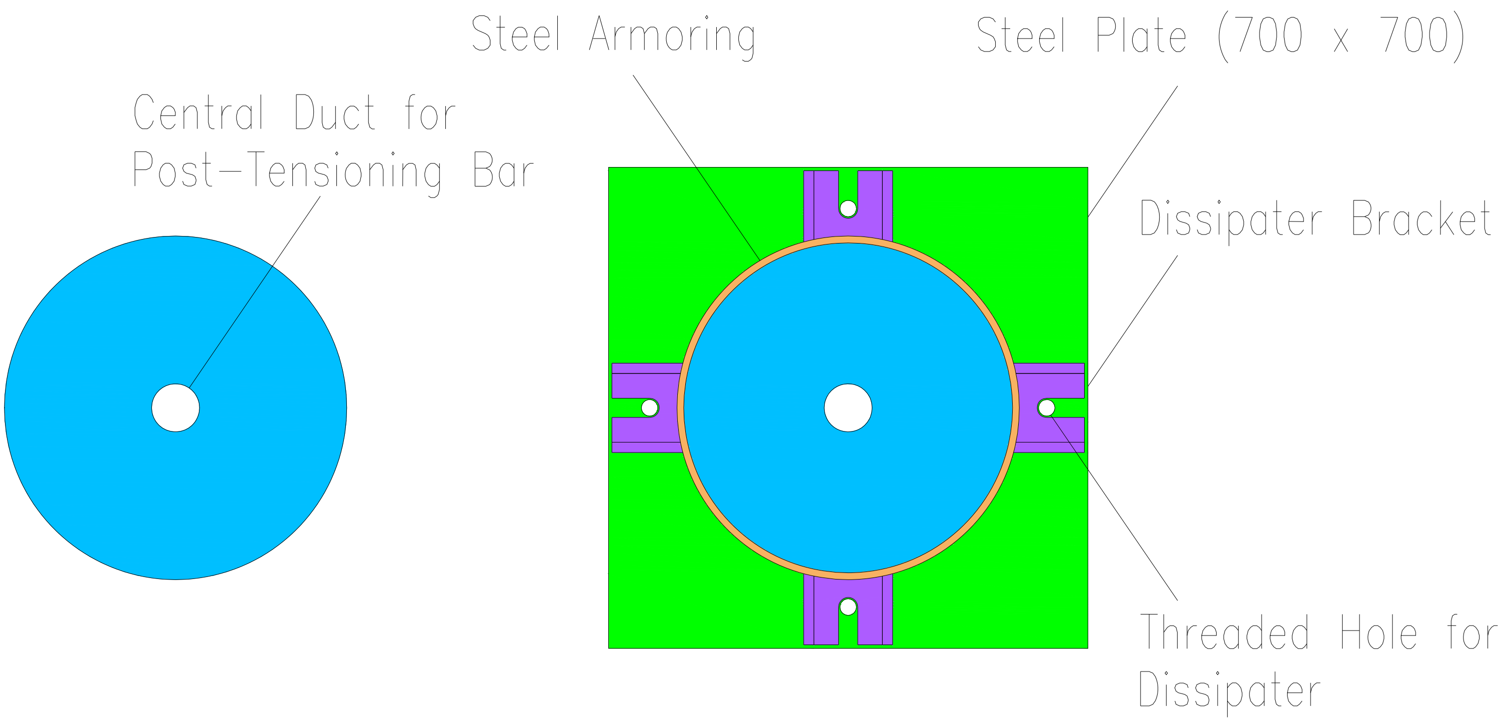
Prototype Bent

University of Canterbury Research



Half-scale precast bent by Mashal and Palermo, dimensions in "mm"

University of Canterbury Research



Column and DCR connection details

Experimental Validation

Half-scale bent with DCR connections

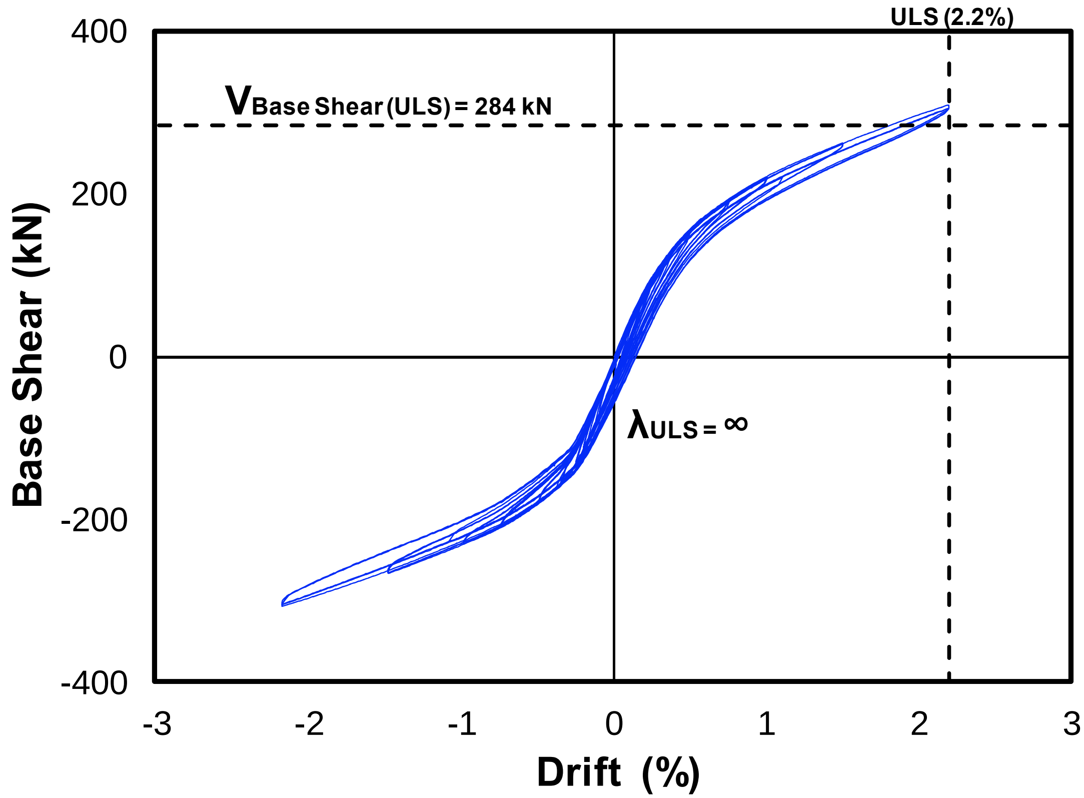
Experimental Validation

Typical DCR Connection

Shear key to restraint twist

Shear key to restraint slide, but to allow rocking

Experimental Validation



Quasi-static cyclic testing using unbonded post-tensioning without energy dissipaters

Typical rocking joint in the bent

Experimental Validation

- To absorb noticeable seismic energy, a rocking connection should be supplemented by dissipaters
- Several types of dissipaters were invented and validated through full-scale testing by Mashal, Keats, and Palermo

Mustafa Mashal

Gavin Keats

Alessandro Palermo

Experimental Validation

- M. Mashal, G. Keats, and A. Palermo (2015). "Energy Dissipating Device", US Patent 61/149,199.
- M. Mashal, G. Keats, and A. Palermo (2016). "Energy Dissipation Device", PCT/NZ2016/050061.
- Dissipaters made of metallic parts and can achieve ductility (μ) of 16 or more without any degradation
- No low-cycle fatigue under many cycles of large drift
- Obtained investments for a start-up company (2.2g Ltd.) to commercialize the dissipaters in New Zealand and around the world

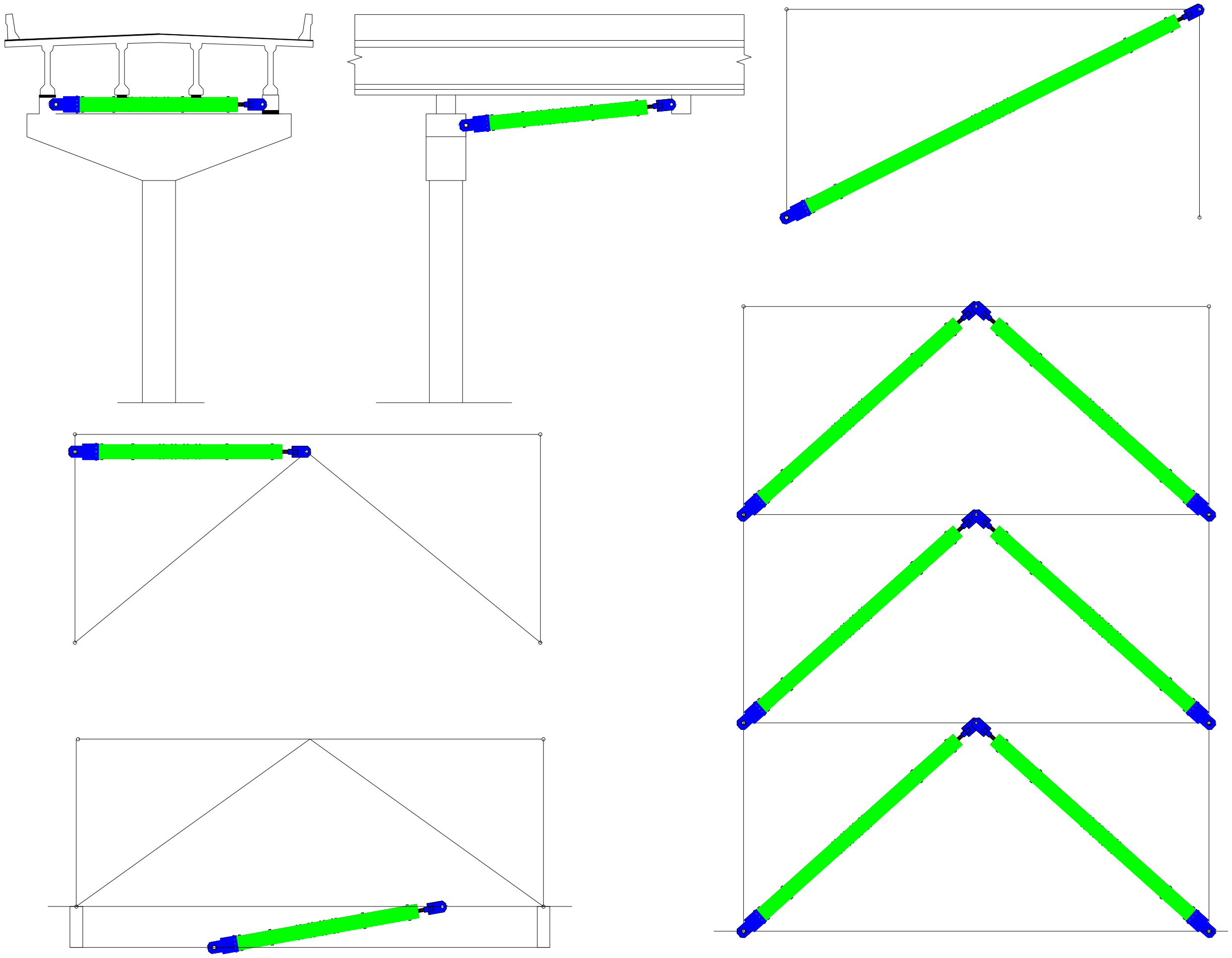
Experimental Validation

Bracing type dissipater

Mini plug and play type dissipater

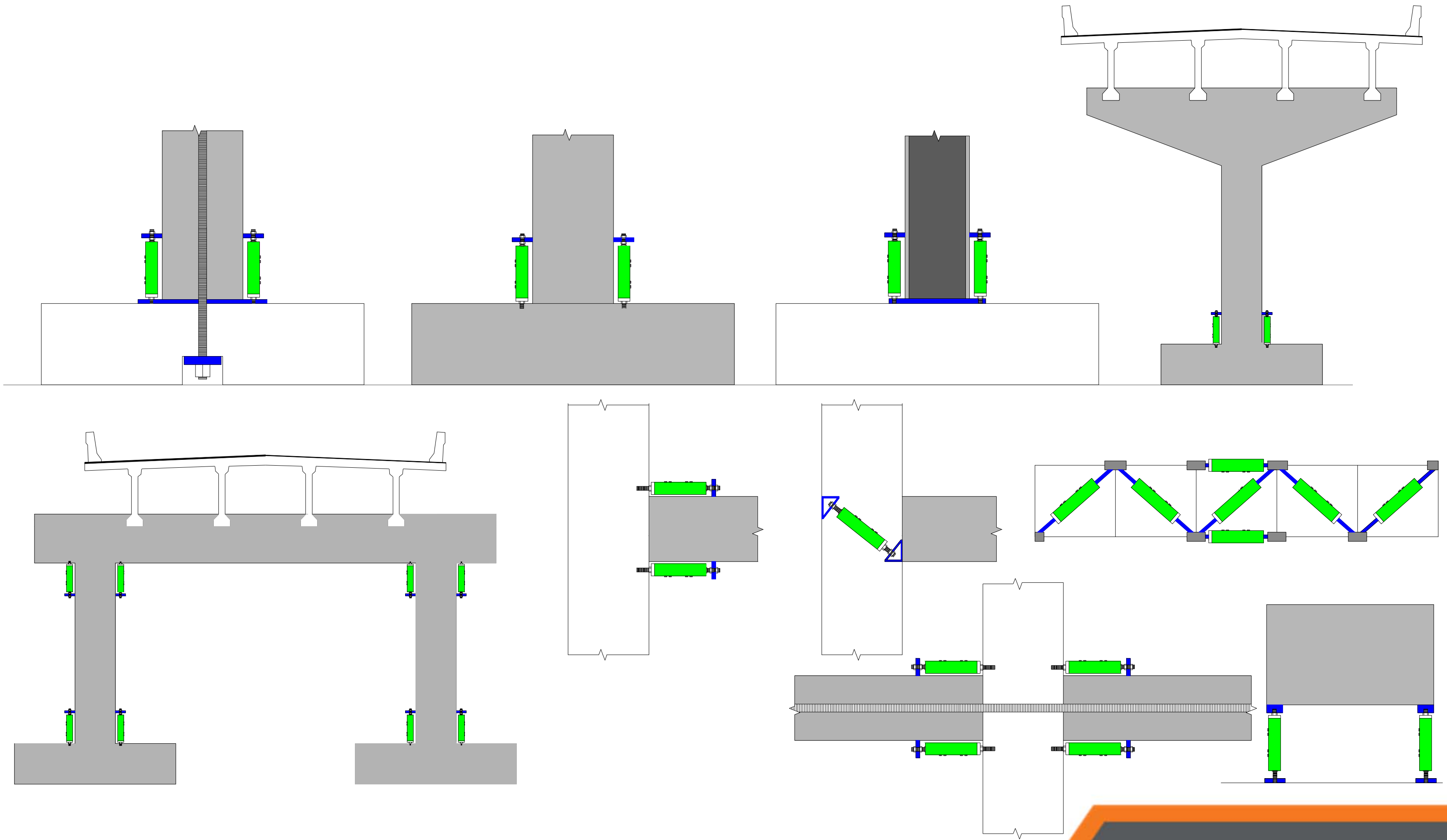
Bracing type dissipater

Experimental Validation



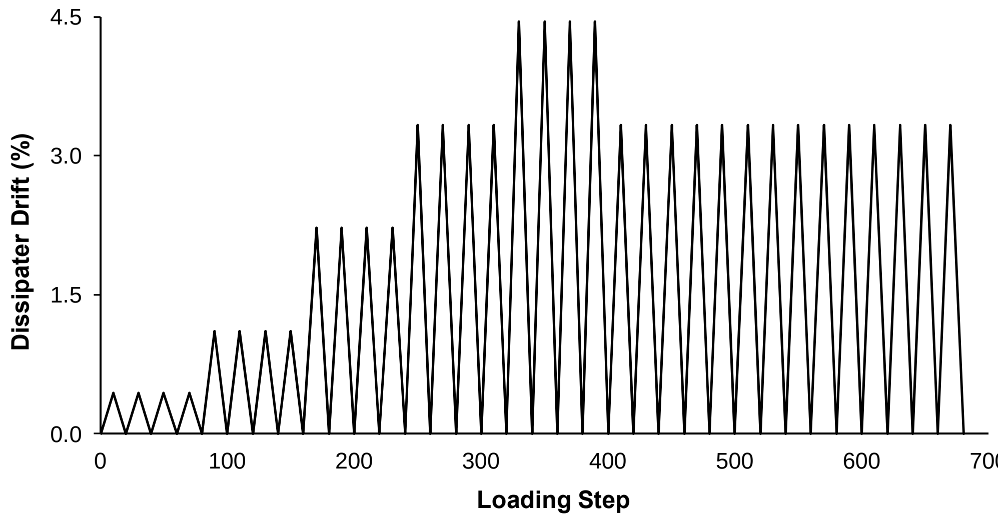
Bracing type dissipaters can be used in both buildings and bridges

Experimental Validation



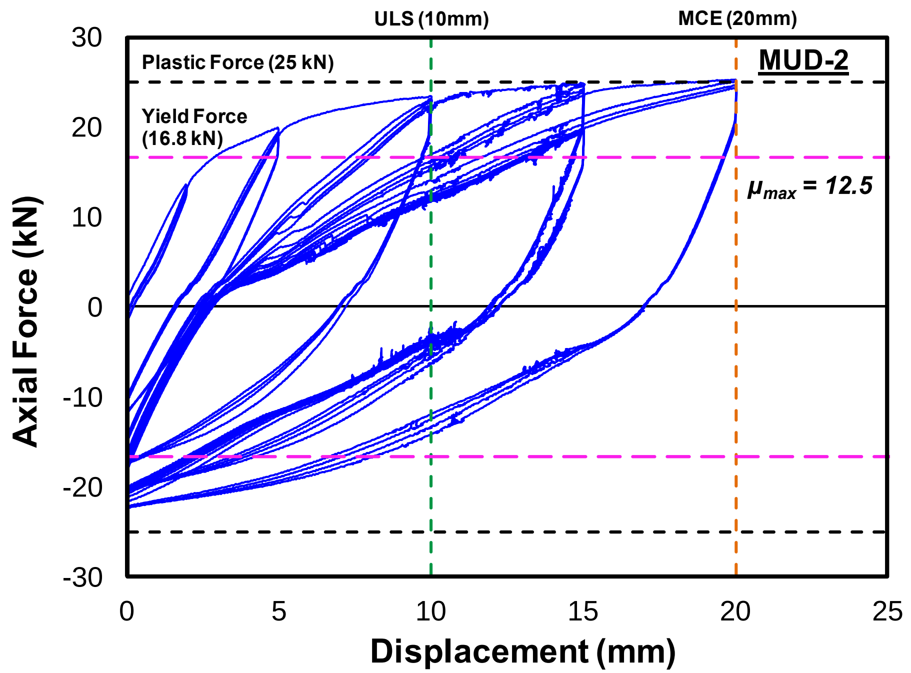
Mini plug and play type dissipaters can have a wide range of applications

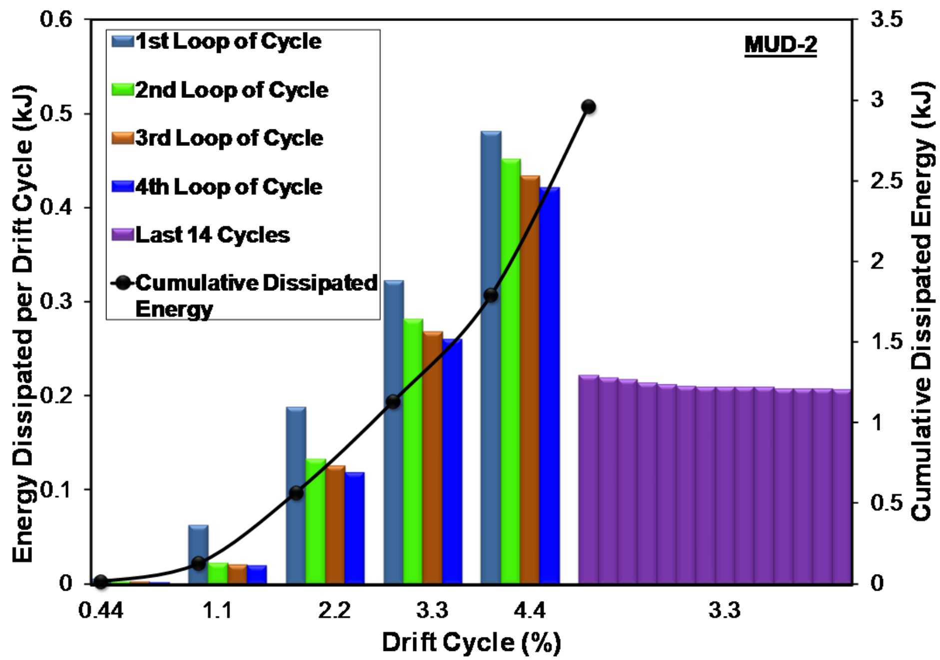
Experimental Validation



Dissipater under cyclic quasi-static testing

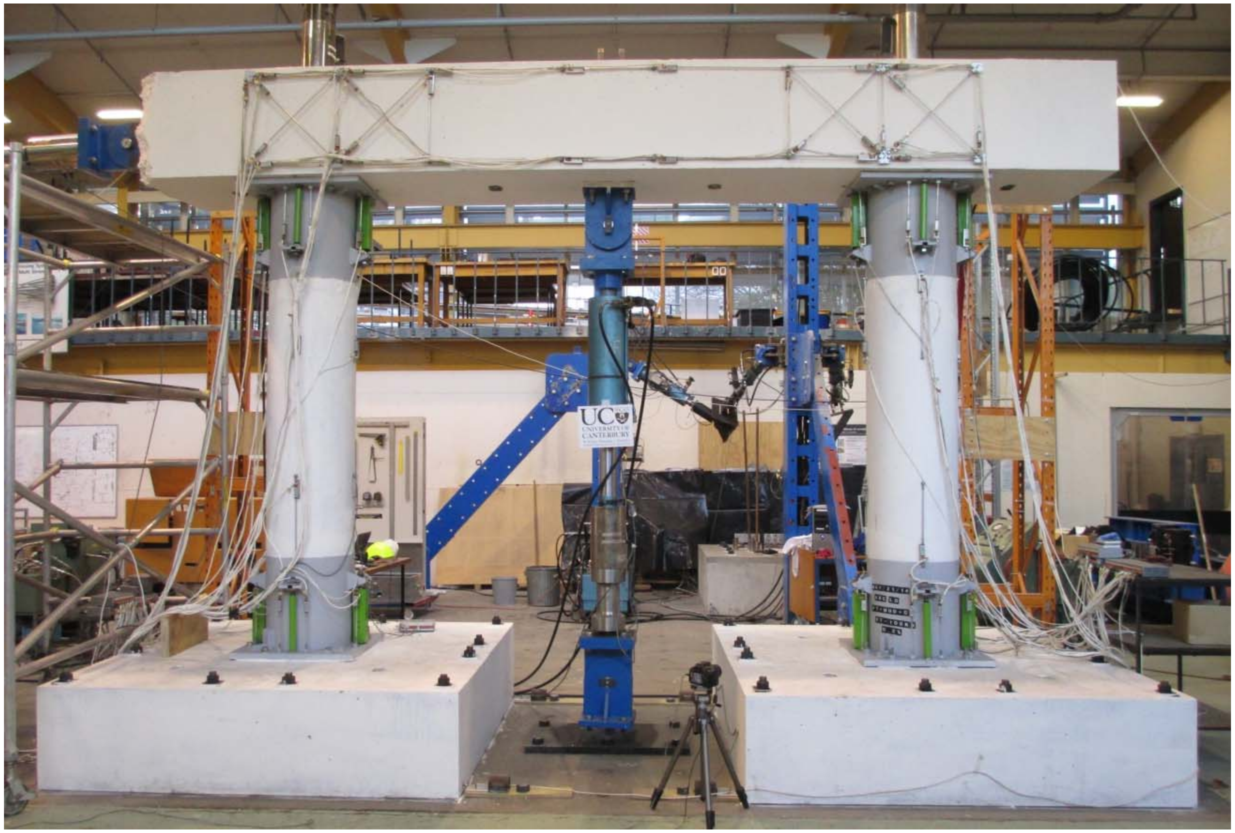
Experimental Validation





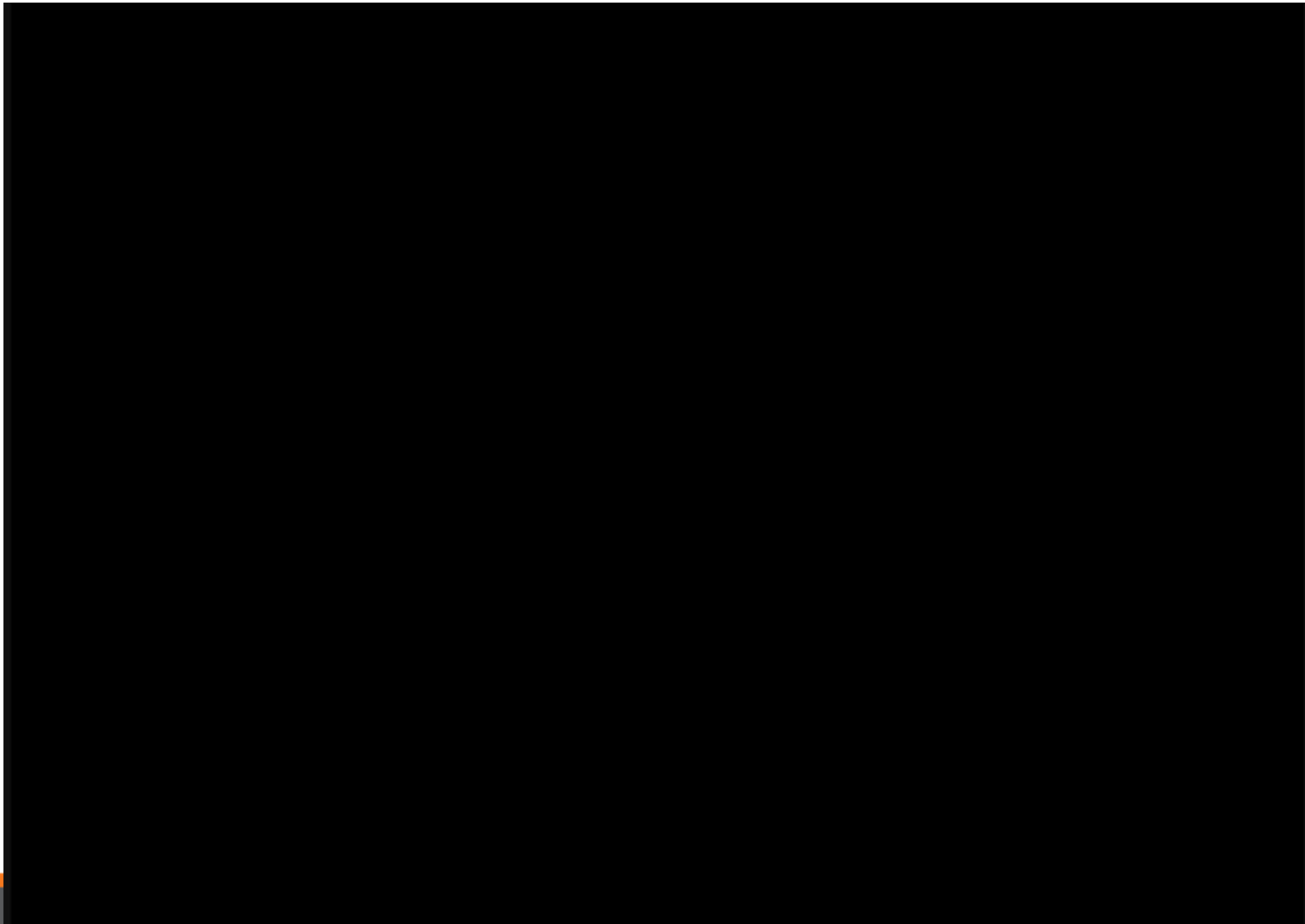
Experimental results from testing of mini plug and play type dissipater

Experimental Validation

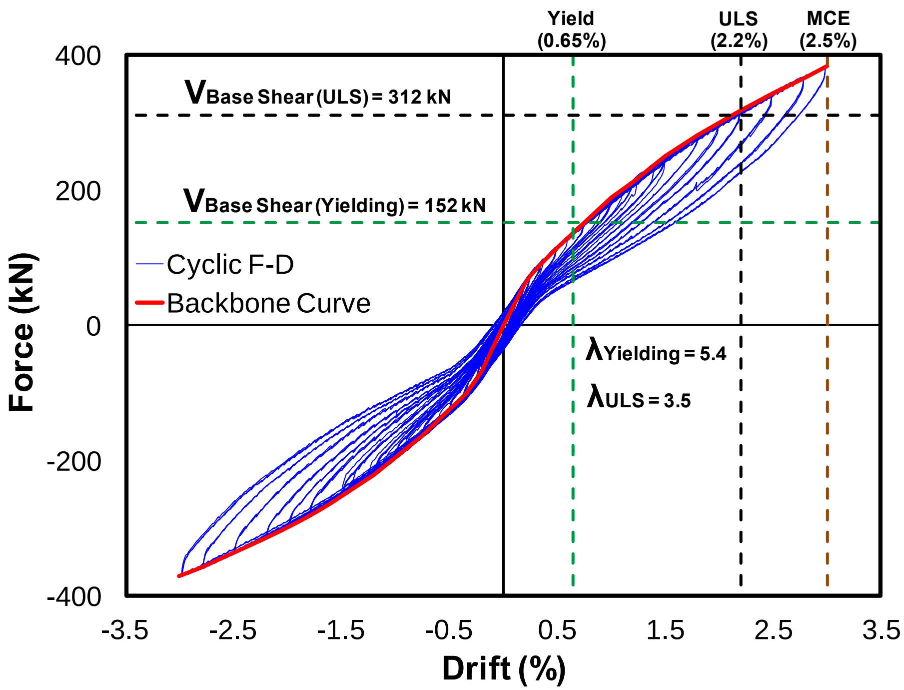


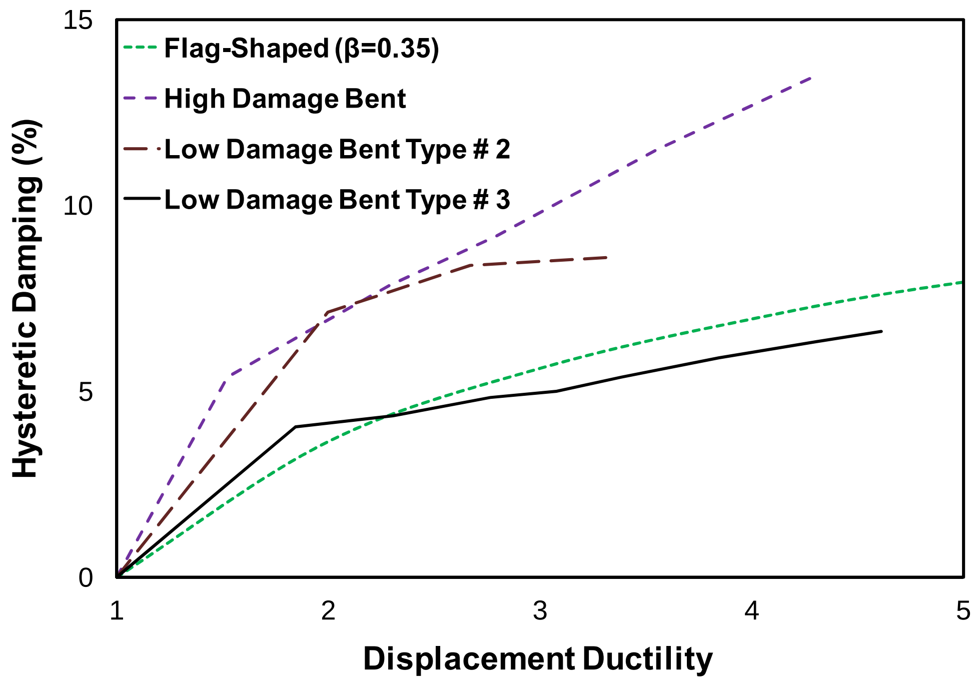
Half-scale fully precast bent using both unbonded post-tensioning and external innovative dissipaters (DCR connections)

Typical DCR Connection



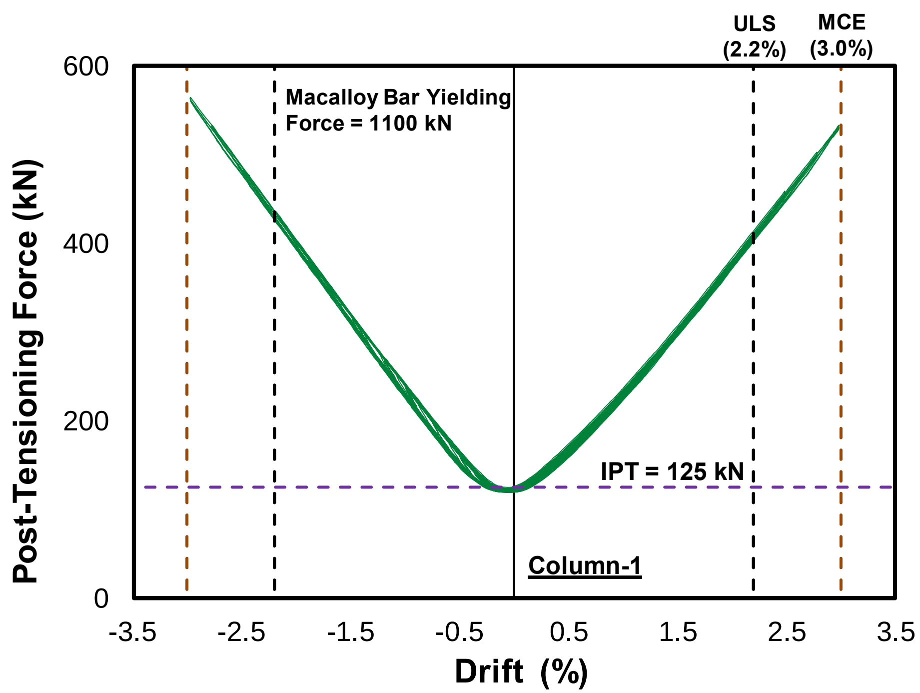
Experimental Validation

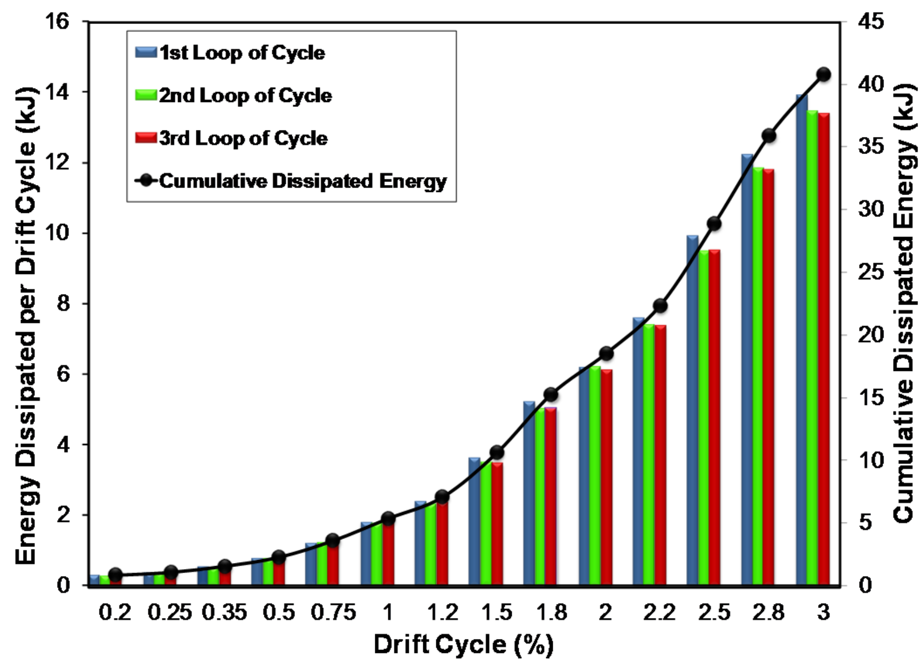




Experimental result from the bent with DCR connections

Experimental Validation



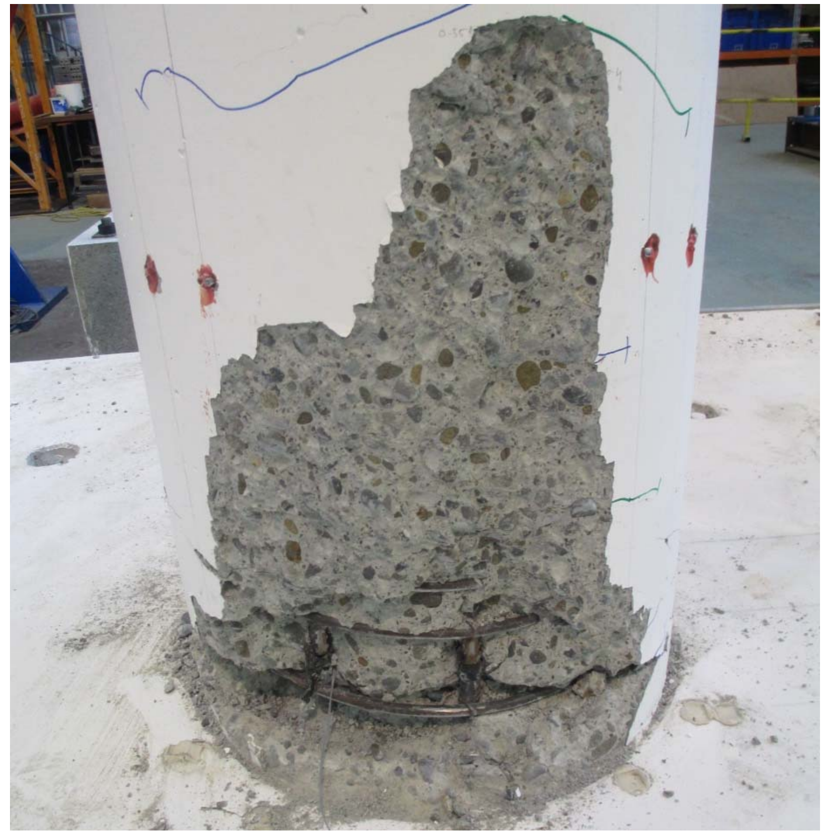


Experimental result from the bent with DCR connections

Experimental Validation

ABC Low Damage comparison to an equivalent cast-in-place emulative (ABC High Damage) fully precast bent, tested under the same loading protocol

Experimental Validation

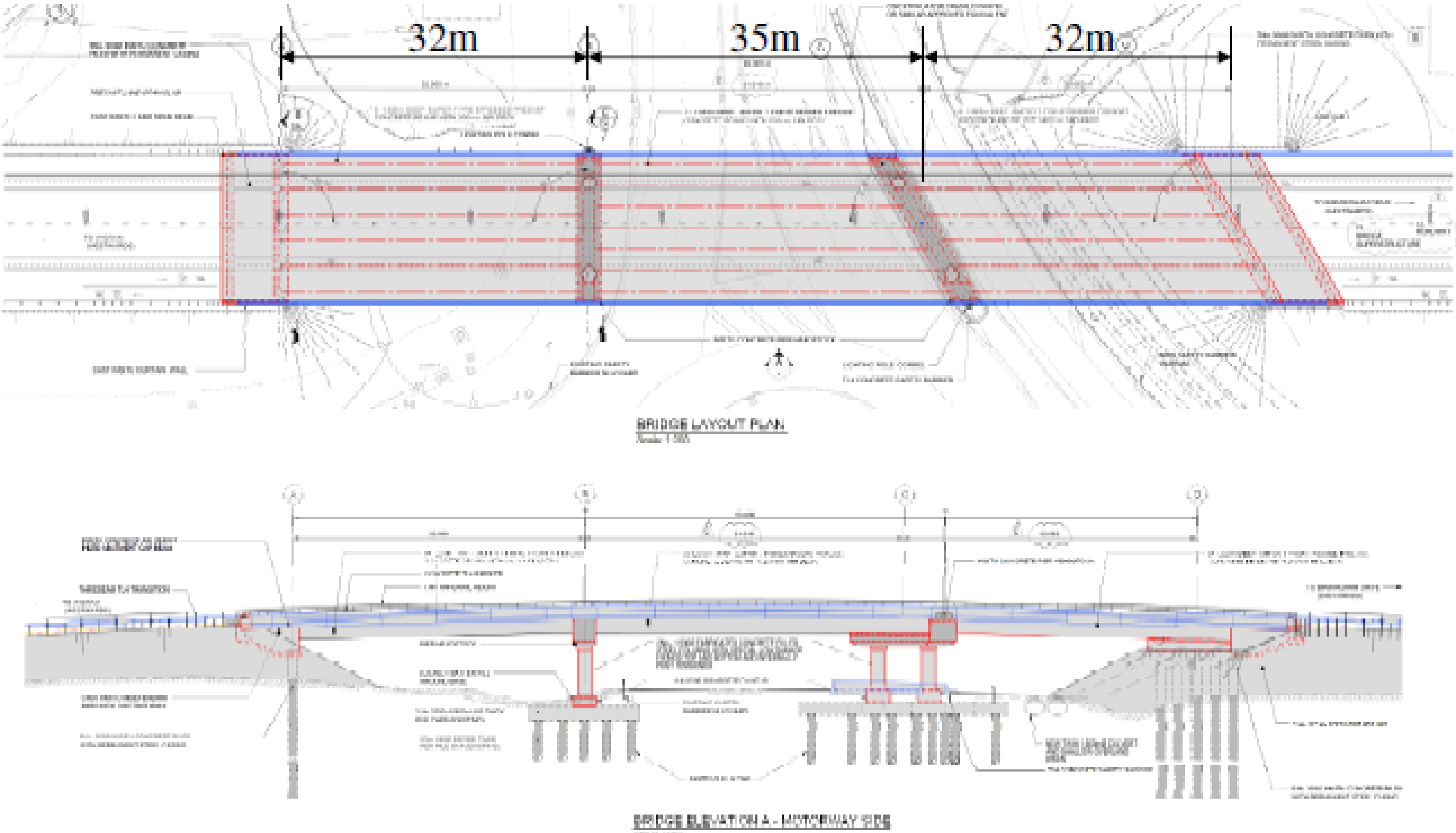


ABC Low Damage comparison to an equivalent cast-in-place emulative (ABC High Damage) fully precast bent, tested under the same loading protocol

Real-Life Application

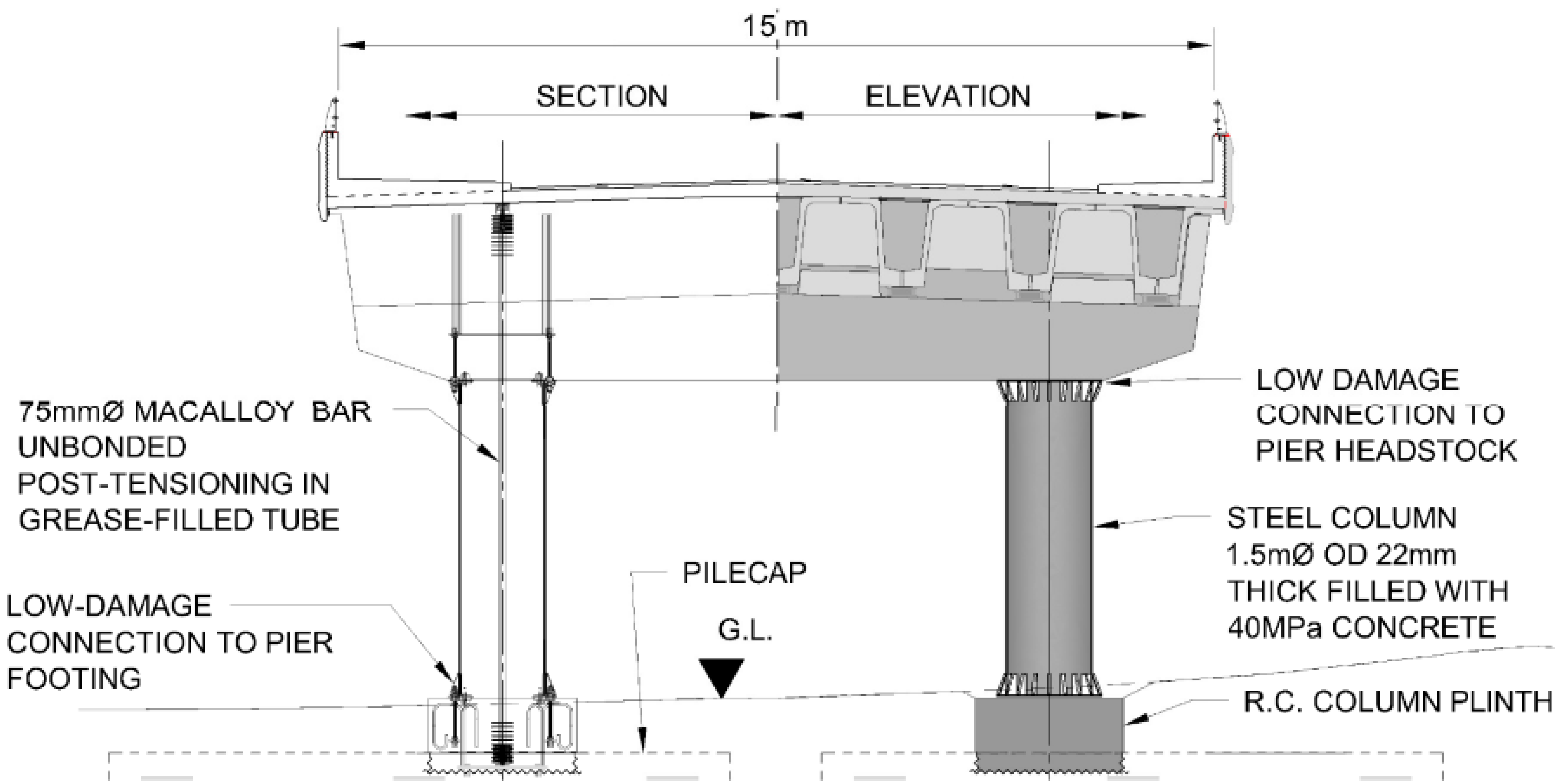
- Wigram-Magdala Link Bridge in Christchurch, NZ
- Designer: Opus International Consultants
- Client: Christchurch City Council
- Contractor: Hawkins Construction
- 100 m (328 ft) long with 3 spans
- World's first DCR Bridge
- Used the DCR technology tested at the University of Canterbury by Mashal and Palermo
- Opened in July 2016

Real-Life Application



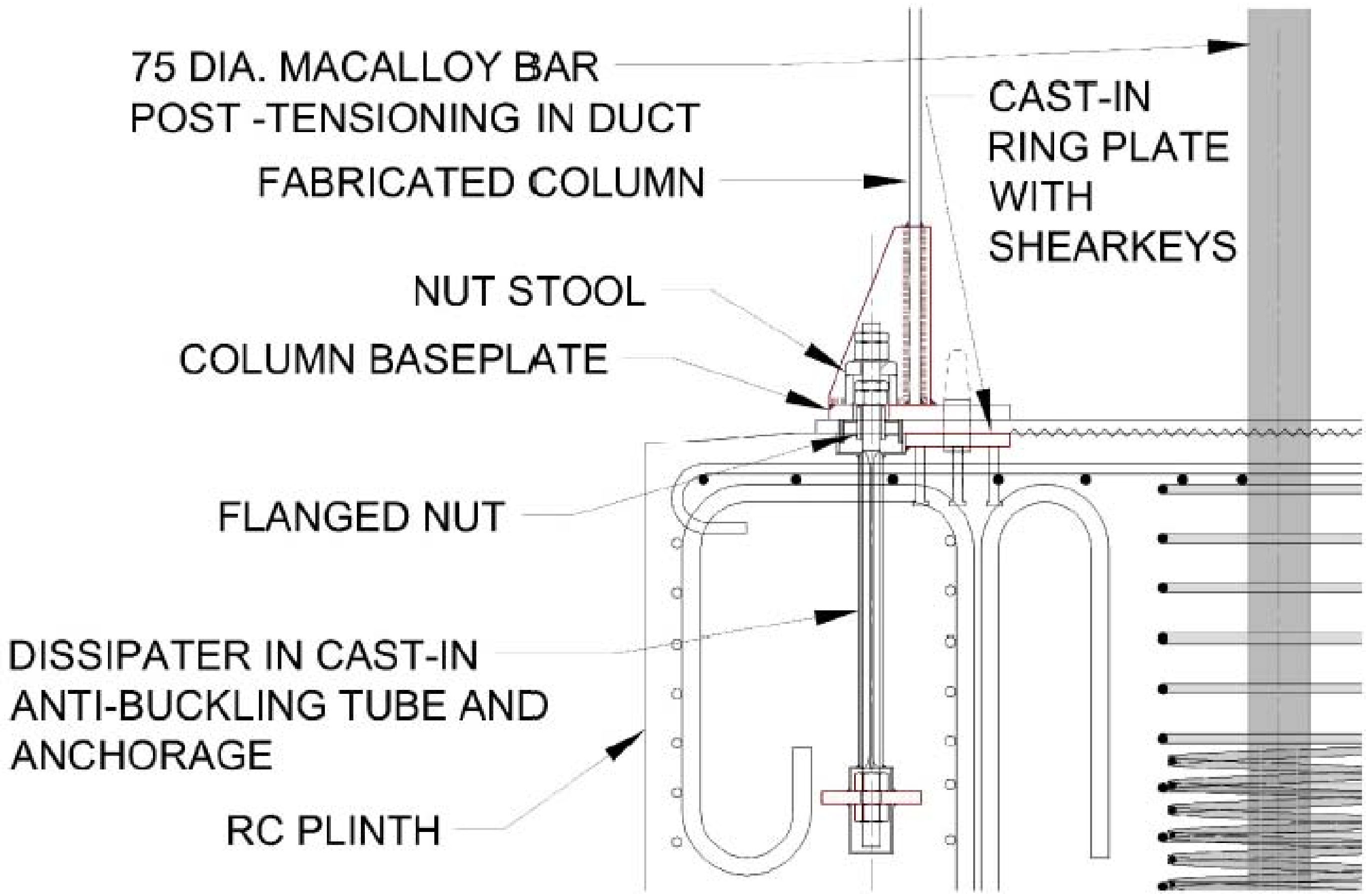
Courtesy of Routledge and Cowan (2016)

Real-Life Application



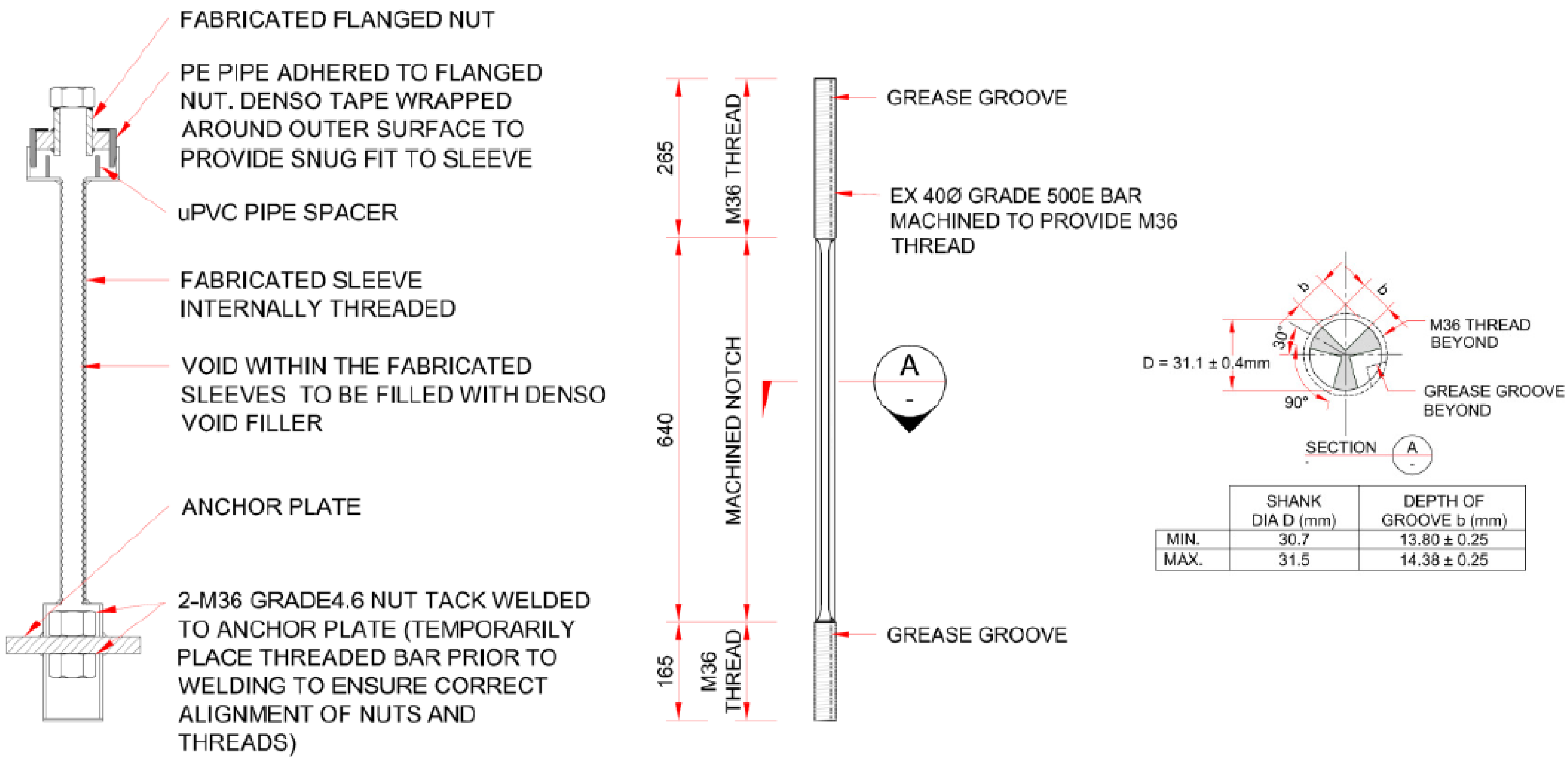
Elevation view of the rocking bent, courtesy of Routledge (2016)

Real-Life Application



Column-to-footing DCR connection, courtesy of Routledge (2016)

Real-Life Application



	SHANK DIA D (mm)	DEPTH OF GROOVE b (mm)
MIN.	30.7	13.80 ± 0.25
MAX.	31.5	14.38 ± 0.25

Dissipater detail inside the footing, courtesy of Routledge and Cowan (2016)

Real-Life Application

Construction photos, courtesy of Routledge and Cowan (2016)

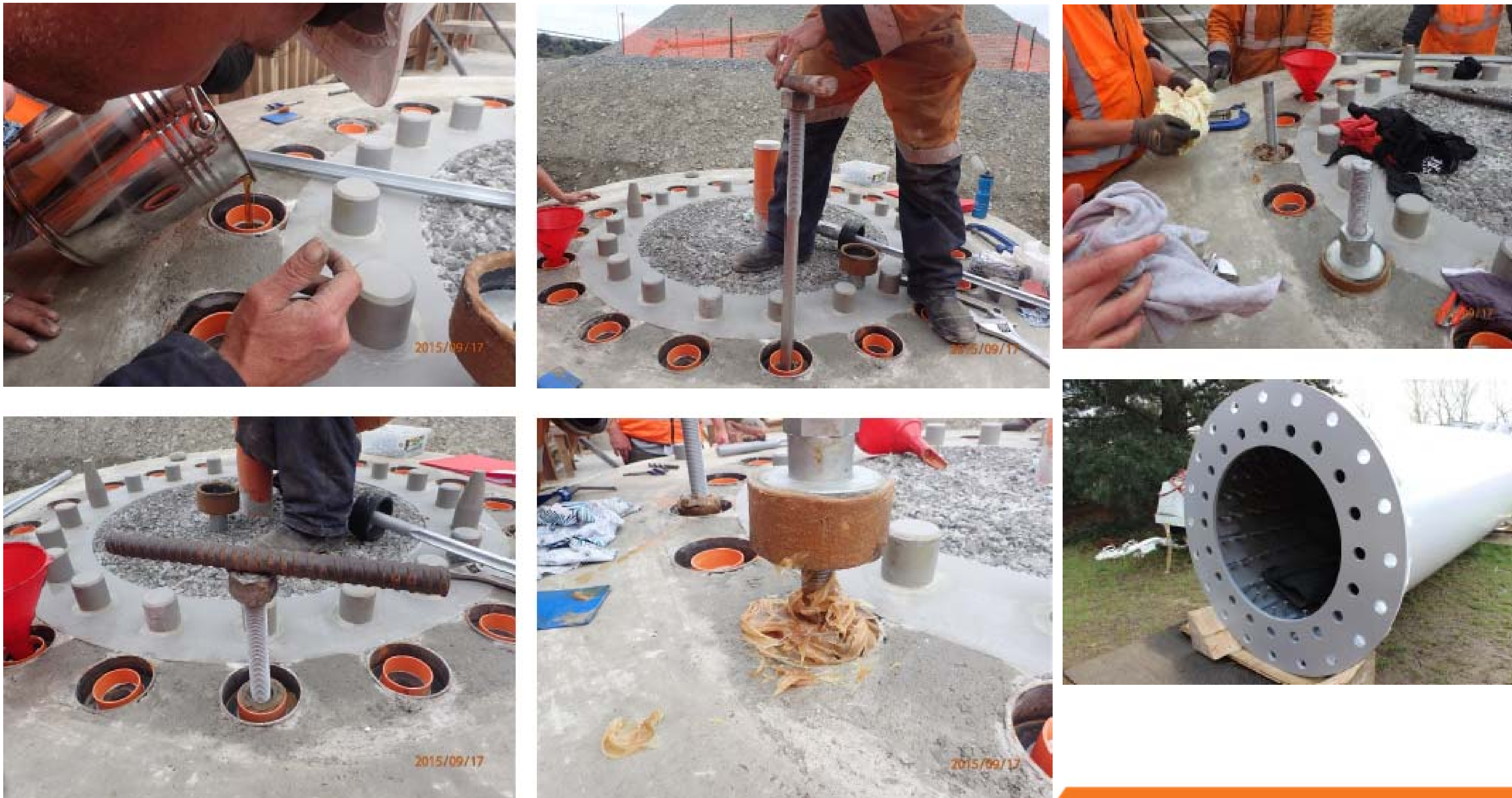
Real-Life Application

Construction photos, courtesy of Routledge and Cowan (2016)

Real-Life Application

Construction photos, courtesy of Routledge and Cowan (2016)

Real-Life Application



Construction photos, courtesy of Routledge and Cowan (2016)

Real-Life Application

Construction photos, courtesy of Routledge and Cowan (2016)

Real-Life Application

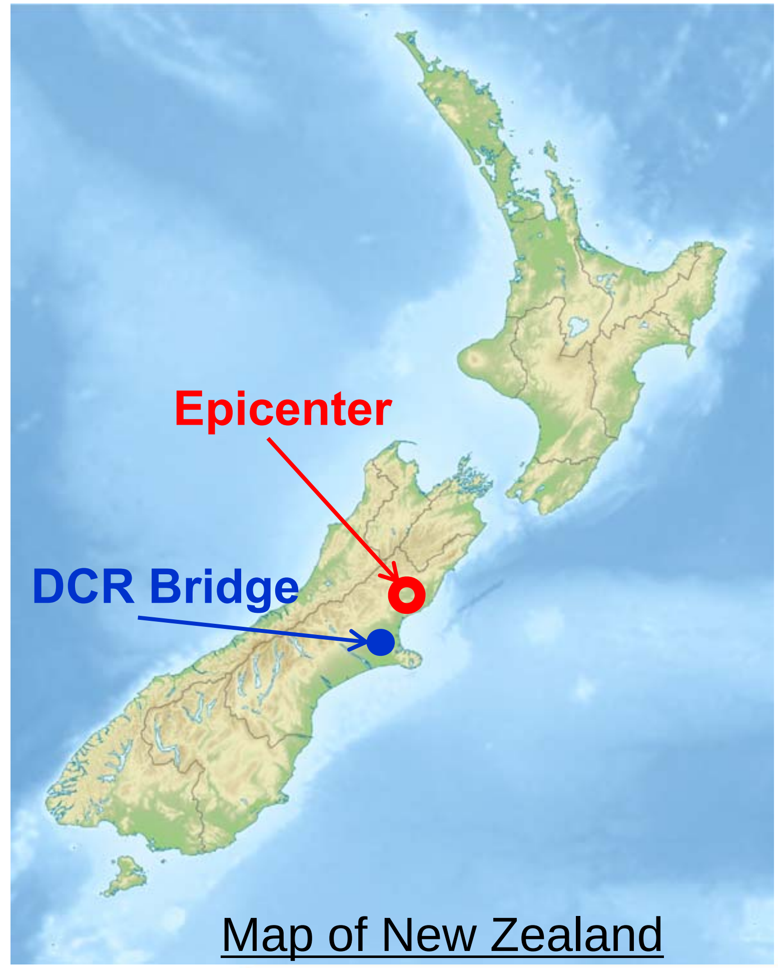
Construction photos, courtesy of Hawkins (2016)

Real-Life Application

Completed Bridge, courtesy of Hawkins (2016)

Nov 14th 2016 Kaikoura Earthquake

- Magnitude 7.8 (Mw), total of 21 faults ruptured
- 904 bridges across Hurunui, Marlborough, and Kaikoura districts were affected
- Two bridges reached life safety limit state with severe damage
- Other bridges experienced minor to moderate damage
- Severe damage to ground, landslides
- In some locations, ocean bed lifted up more than 10 ft high



Kaikoura Earthquake Nov 14 2016

Kaikoura Earthquake Nov 14 2016

No damage to DCR Bridge, courtesy of Jeremy Kelleher (2016)

Kaikoura Earthquake Nov 14 2016

No damage to DCR Bridge, courtesy of Jeremy Kelleher (2016)

Conclusions

- Prefabrication of bridge elements offers significant construction time savings
- ABC Low Damage offers great ductility and seismic performance (e.g. minimal to no damage, energy dissipation, and self-centering) during an earthquake
- An ABC Low Damage Bridge would remain serviceable without delayed functionality
- The life cycle cost of ABC Low Damage can be comparable to that of cast-in-place (CIP) or emulative CIP bridge

Conclusions

- Wigram-Magdala Link Bridge presents a good example of ABC Low Damage in high seismic zone
- Dissipaters can be replaced following a big earthquake - if necessary
- DCR details were constructed successfully in case of Wigram-Magdala Link Bridge in Christchurch, NZ
- The bridge did not suffer any visible damage during the Nov 14th 2016 Kaikoura Earthquake
- Further refinements can be carried out to improve the detailing and aesthetics of DCR connections

Conclusions

- Wigram-Magdala Link Bridge total cost was over 8 million NZD (5.6 mil USD).
- ABC Low Damage Solution cost was about 200,000 NZD (140,000 USD) more than a conventional design (e.g. cast-in-situ).
- The contractor completed the bridge 6 weeks in advance.

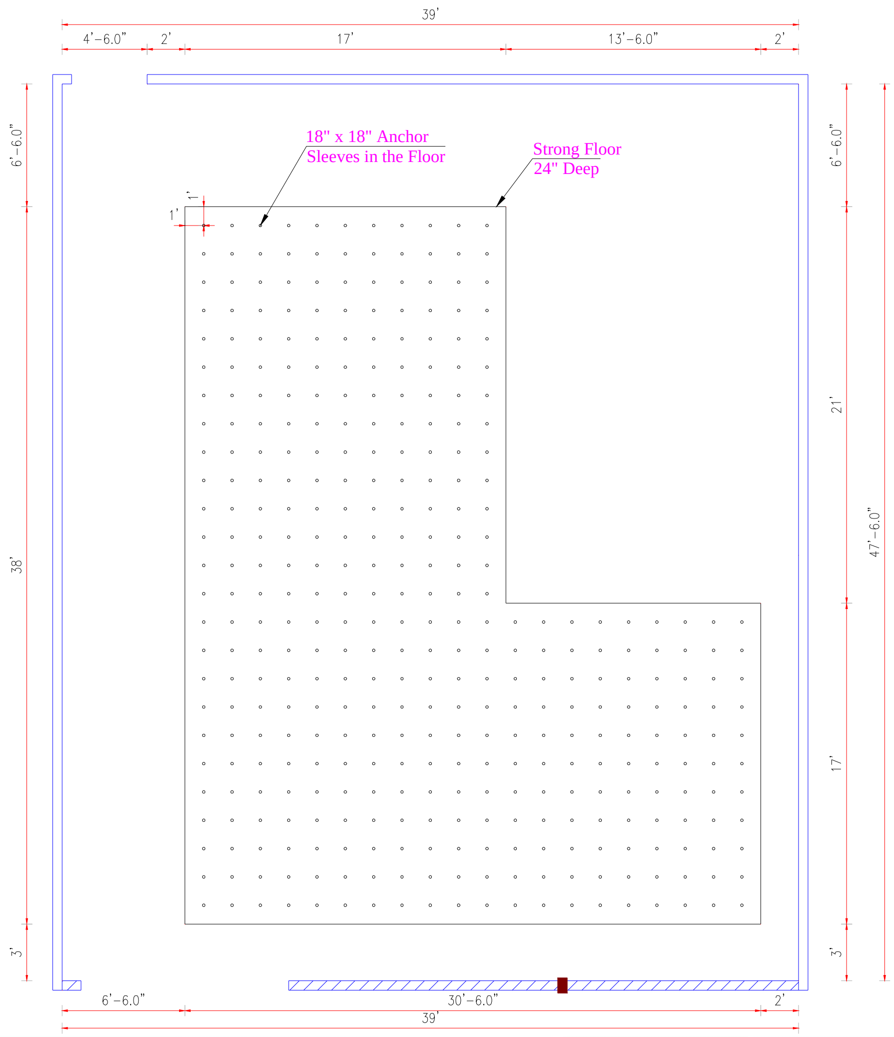
New Structural Lab at ISU

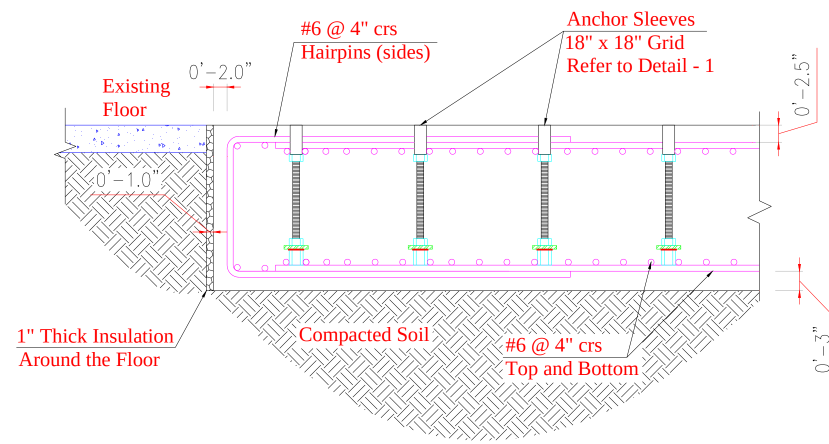
- **Unique facility** in Idaho
- Capable of testing **large-scale** specimens in excess of **36 ft in length** and **14 ft height**
- **Total Lab** Area = **1520 sqft**
- Strong floor is **2 ft deep** and **875 sqft** of structural **floor**
- 374 **anchor sleeves** (each rated **100 kips**) in **grids of 18in**
- The hydraulic **actuators** can **collectively** produce **force** in excess of **1.3 million lbs**
- The new lab will **compliment** the **existing** Structural Dynamics (**Shake Table**) Lab

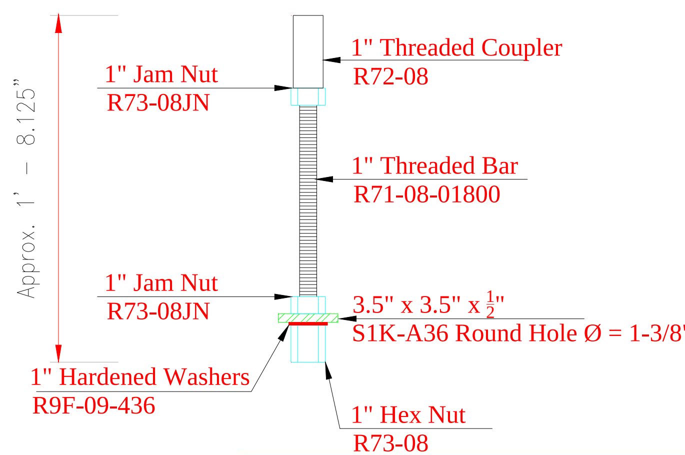
New Structural Lab at ISU

- **Dual** set of hydraulic servo-valve **actuators**, each 160 kips, **±12” stroke** for static and dynamic cyclic testing
- **Heavy** duty **reaction frames** rated for **400 kips**
- **Assortment** of hydraulic **jacks and actuators**
- New Data Acquisition System (**DAQ**)
- **Students** with the supervision of **ISU faculty constructed** the new **Structural Lab**
- **80% of work** (design, construction, equipment, and instruments) was **done in 4 weeks**
- **Lab** to **open** in early **October of 2017**

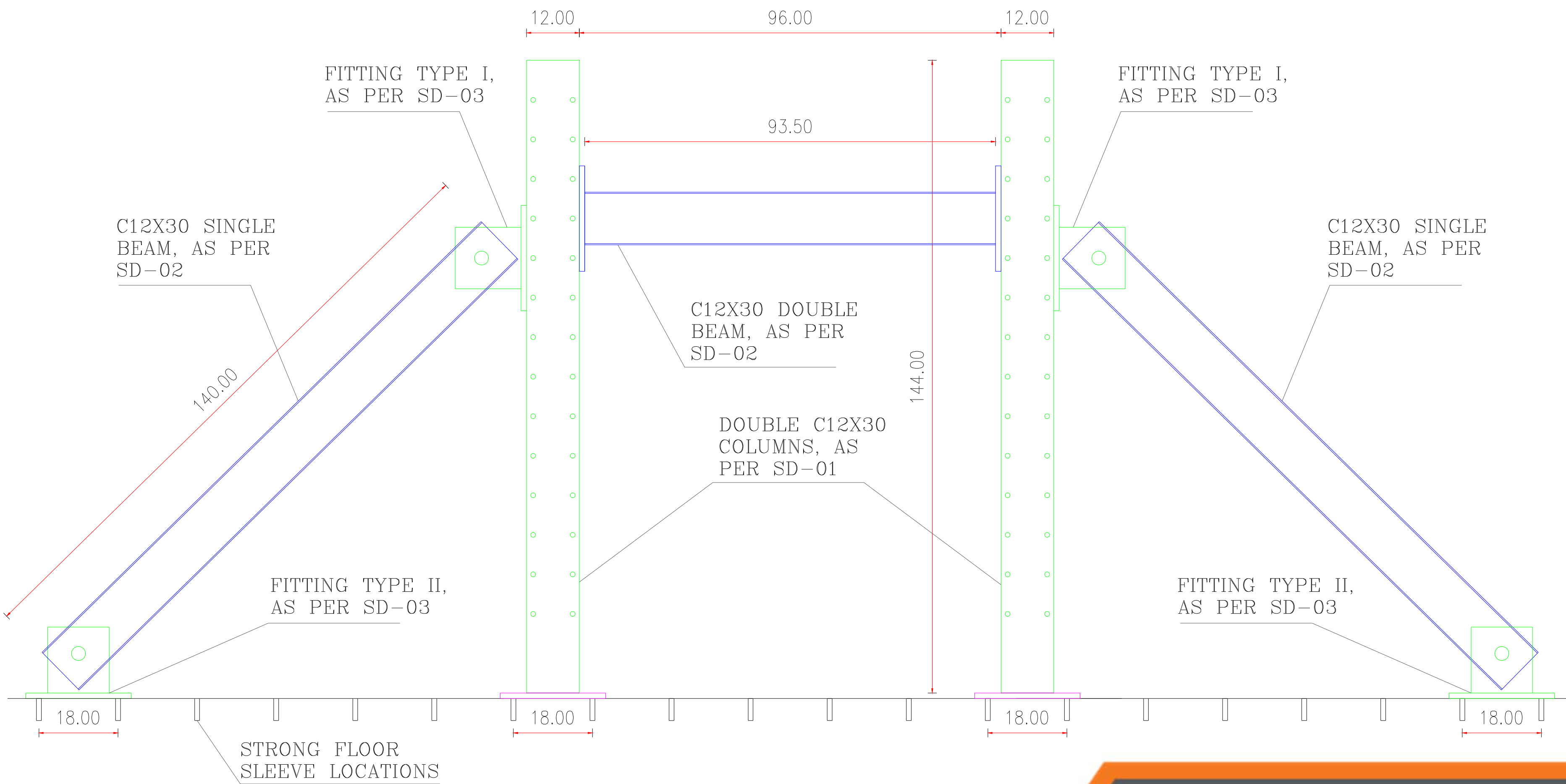
Floor Plan and Details







Demountable Reaction Frames



Strong Floor Reinforcing

Strong Floor Reinforcing

Servo-valve Static/Dynamic Actuators

- Capable of **cyclic static, fatigue**, and **dynamic** testing

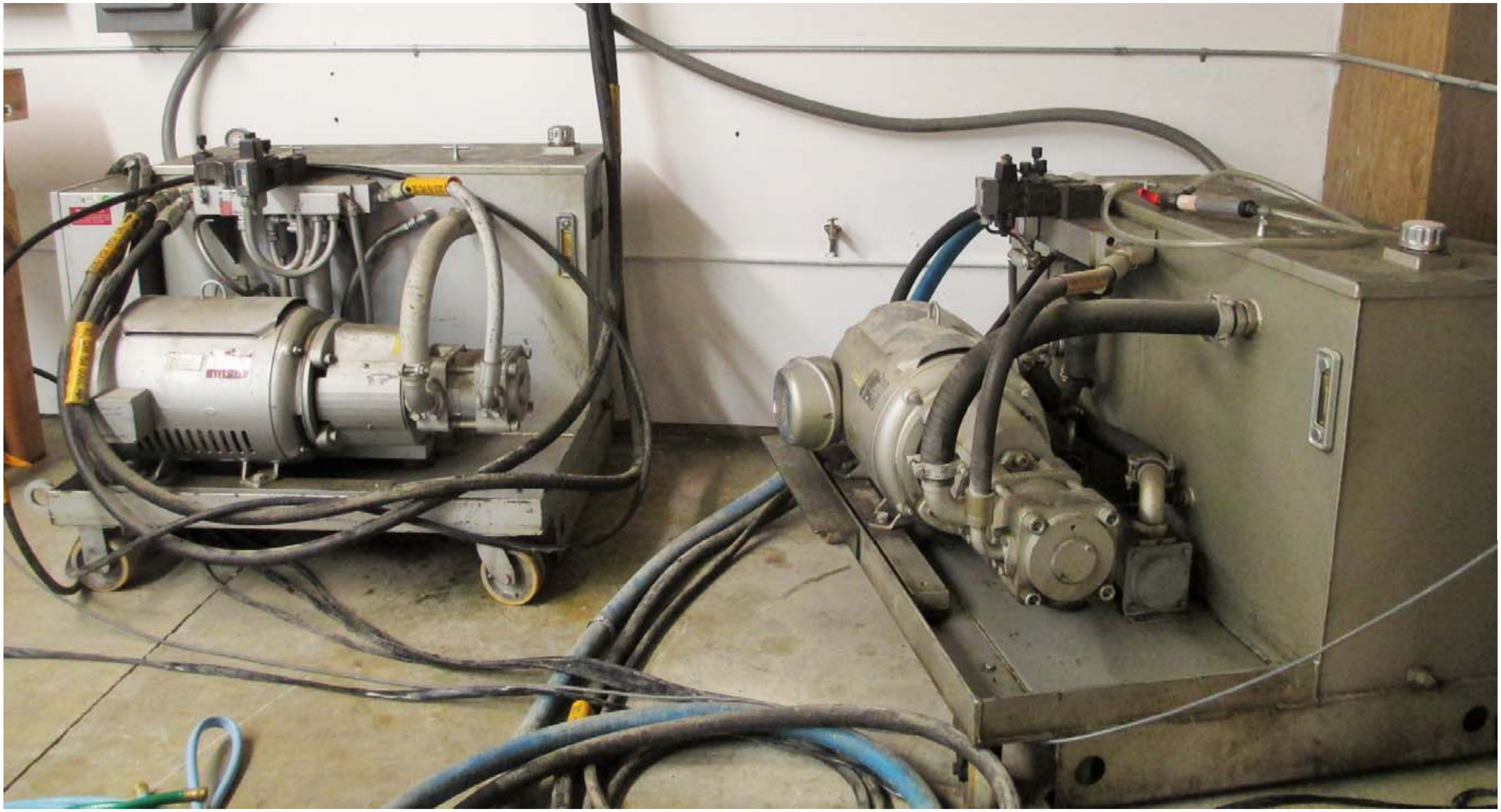
Structural Dynamics Lab

4.5 ft x 4.5 ft hydraulically powered horizontal shake table, 10 kips capacity and ± 3 in stroke

Structural Dynamics Lab

2 ft x 2 ft hydraulically powered vertical shake table, 3 kips capacity

Structural Dynamics Lab



Powerful hydraulic pumps for the shake tables and other actuators

Potential Opportunities/Partnership

- Would like to use the **new lab and existing rehabilitated** facilities for **collaborative research** in structural and earthquake engineering
- Can conduct a variety of **large-scale structural** in our facilities, for example:
  - **Fatigue, cyclic, and slow** testing of structural elements and connections
  - **Static and dynamic testing** of large-scale specimens that represent bridges, buildings, connections, elements etc.
  - **Material characterization** (concrete, steel, timber, composites etc.)

Acknowledgments

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

Idaho State UNIVERSITY

IDAHO TRANSPORTATION DEPARTMENT

NHRP
Natural Hazards Research Platform

Idaho State Board of Education

Servo Hydraulic Solutions

Steel West

WILLIAMS FORM ENGINEERING CORP.

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

POCATELLO READY MIX CONCRETE

AMERICAN CONSTRUCTION COMPANY

SPECTRAL DYNAMICS

Thank You!

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