Resilient Slip Friction Joint (RSFJ)

A Novel Connection System for Seismic Damage Avoidance Design of Structures

QuakeCoRE Flagship 4 meeting 13.06.17

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AUT UNIVERSITY

THE UNIVERSITY OF AUCKLAND
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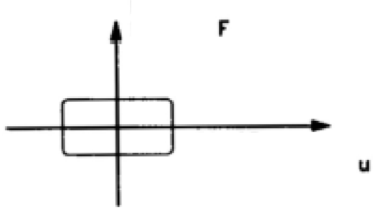
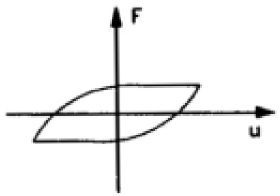
NEW ZEALAND

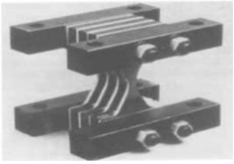
Earthquake Energy Dissipating Devices

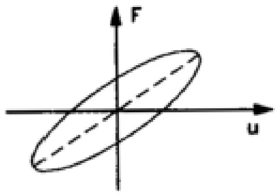


Friction

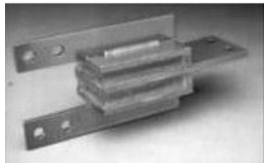


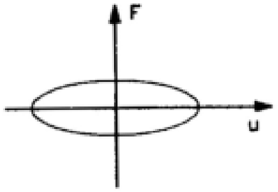
Metallic





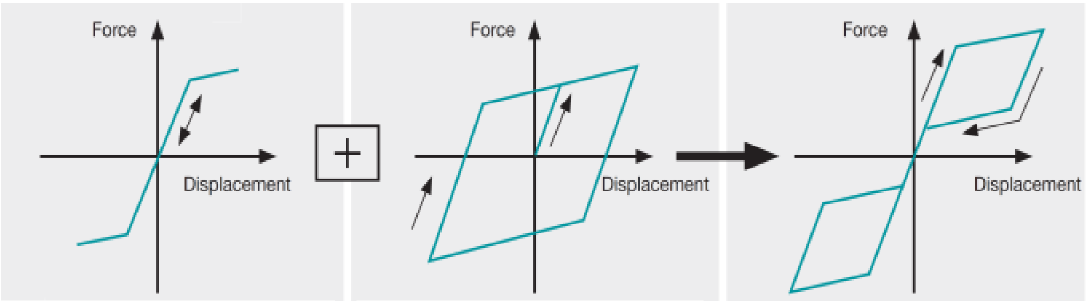
Viscoelastic





Viscous

(Constantinou and Symans, 1993)

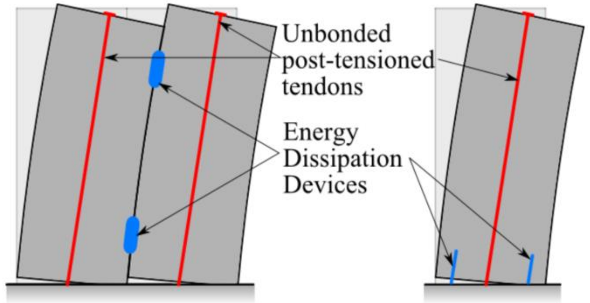


Self-centring **Energy dissipation** **Equivalent system**

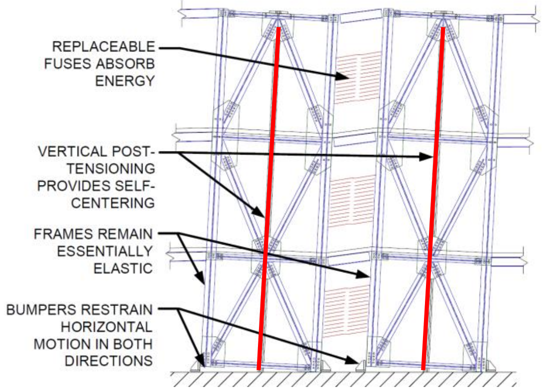
(CERC, 2012)

Recent Earthquake-Resistant Technologies

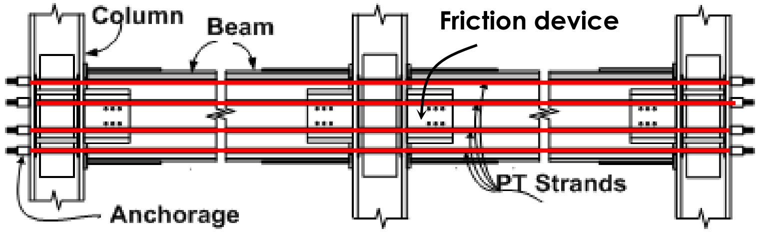
(use of post-tensioning cables for self-centring in addition to dampers)



(Sarti et al., 2012)



(Eatherton et al., 2008)



(Lin et al., 2008)

(Rodger et al., 2007)

(Midstate Precast, L.P., 2012)

(TimberLab Solutions, 2013)

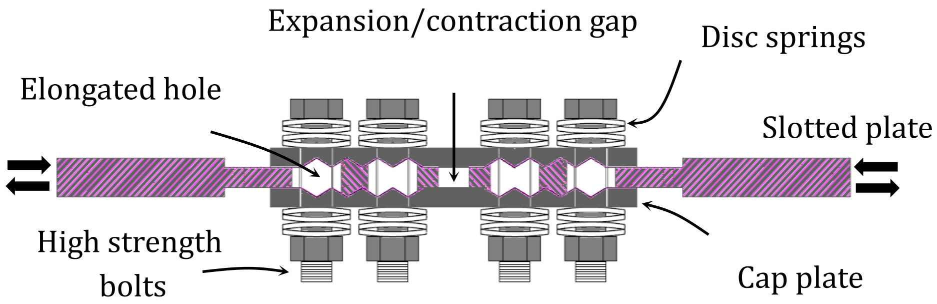
(Buchanan et al., 2012)

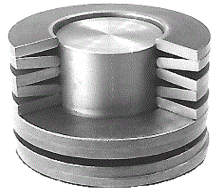
(Lin et al., 2008)

(Build Magazine, 2014)

Innovative Resilient Slip Friction Joint (RSFJ)

(Energy dissipation and self-centring, all in one joint system – Patent filed)



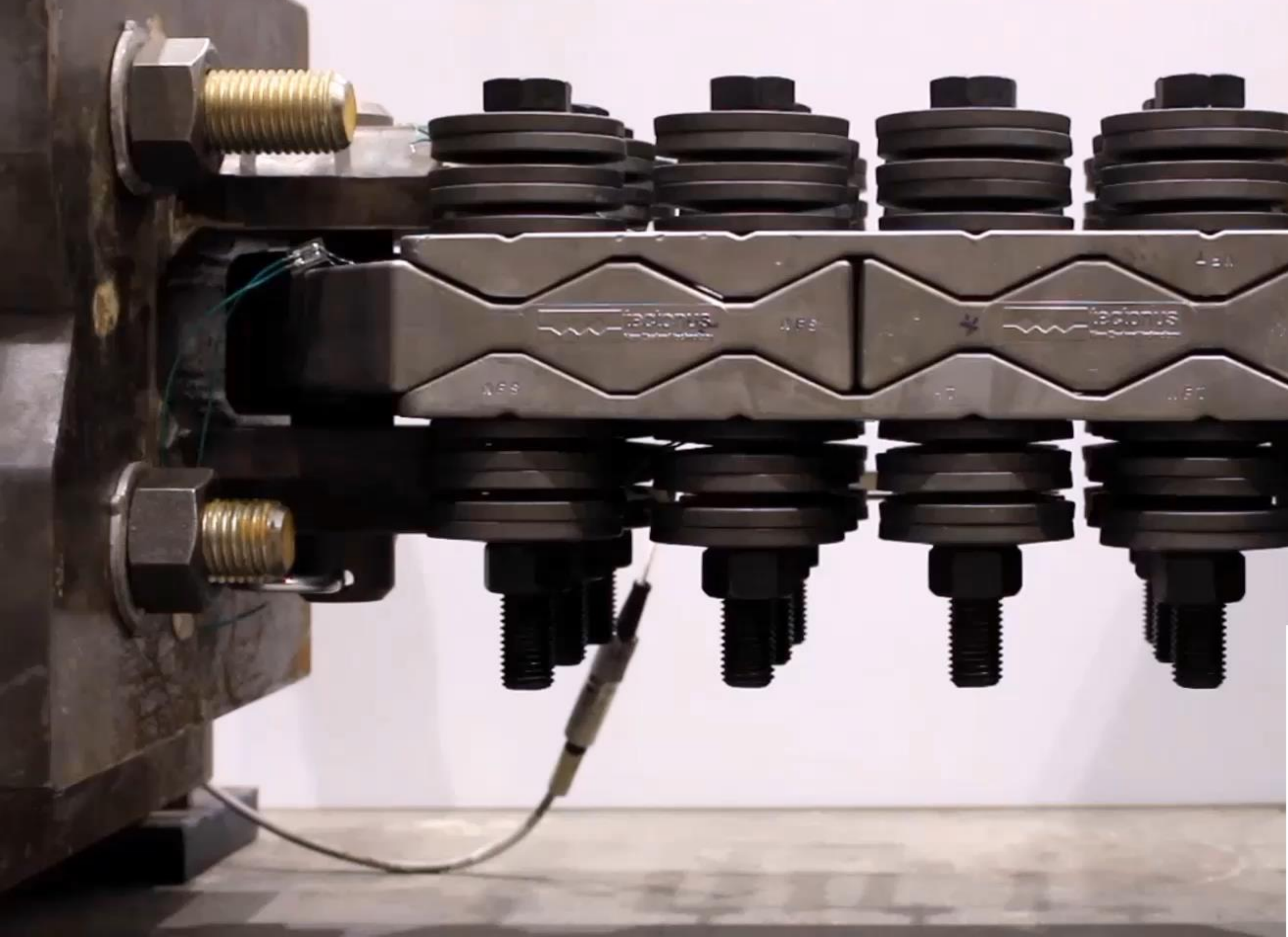


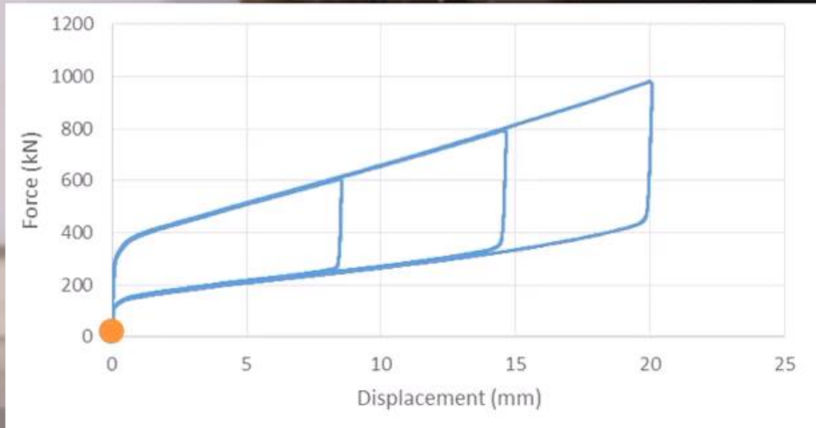
Disc springs

High strength bolts

Cap and slotted plates

NELSON AIRPORT TERMINAL RSFJ TESTING





Design Procedure

- **Slip capacity**

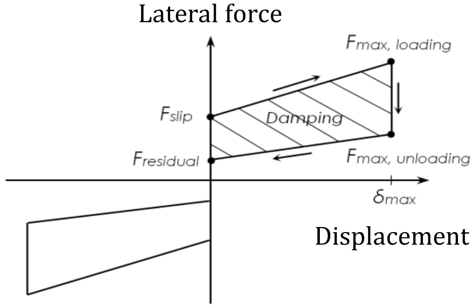
$$F_{slip} = 2n_b F_{b,pr} \left(\frac{\sin\theta + \mu_s \cos\theta}{\cos\theta - \mu_s \sin\theta}\right)$$

- **Residual capacity**

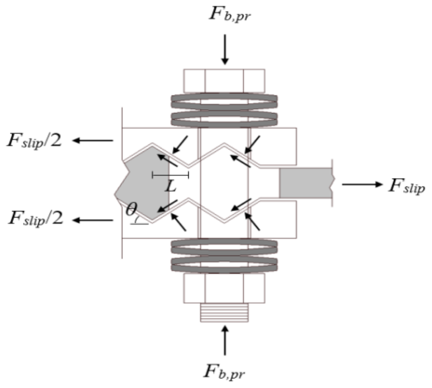
$$F_{residual} = 2n_b F_{b,pr} \left(\frac{sin\theta - \mu_k cos\theta}{\cos\theta + \mu_k sin\theta}\right)$$

- **Ultimate loading and unloading capacities**

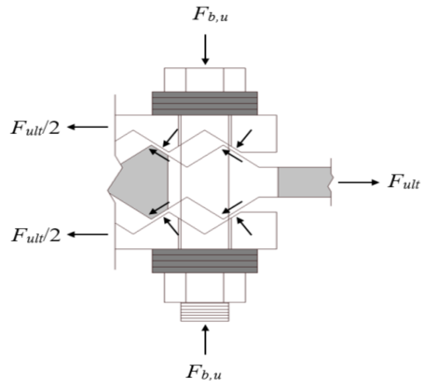
Replacing the μ_s , μ_k and $F_{b,pr}$ with μ_k , μ_s and $F_{b,u}$ in F_{slip} and $F_{residual}$ equations, where $F_{b,u} = F_{b,pr} + k_s \Delta_s$



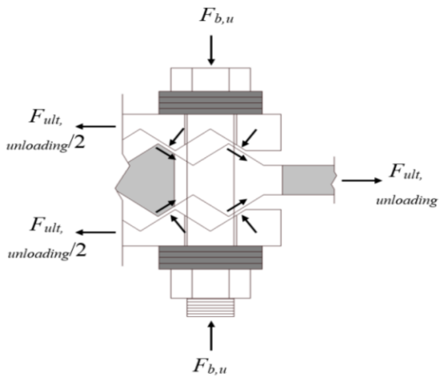
Hysteresis curve



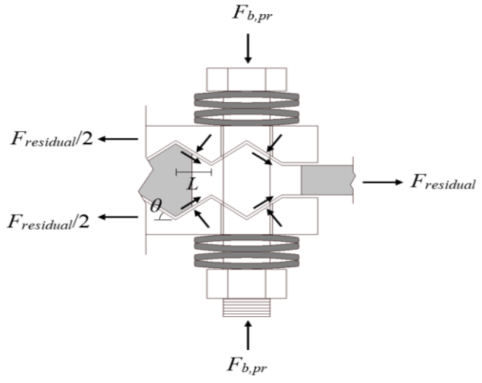
At rest before slip



At ultimate loading

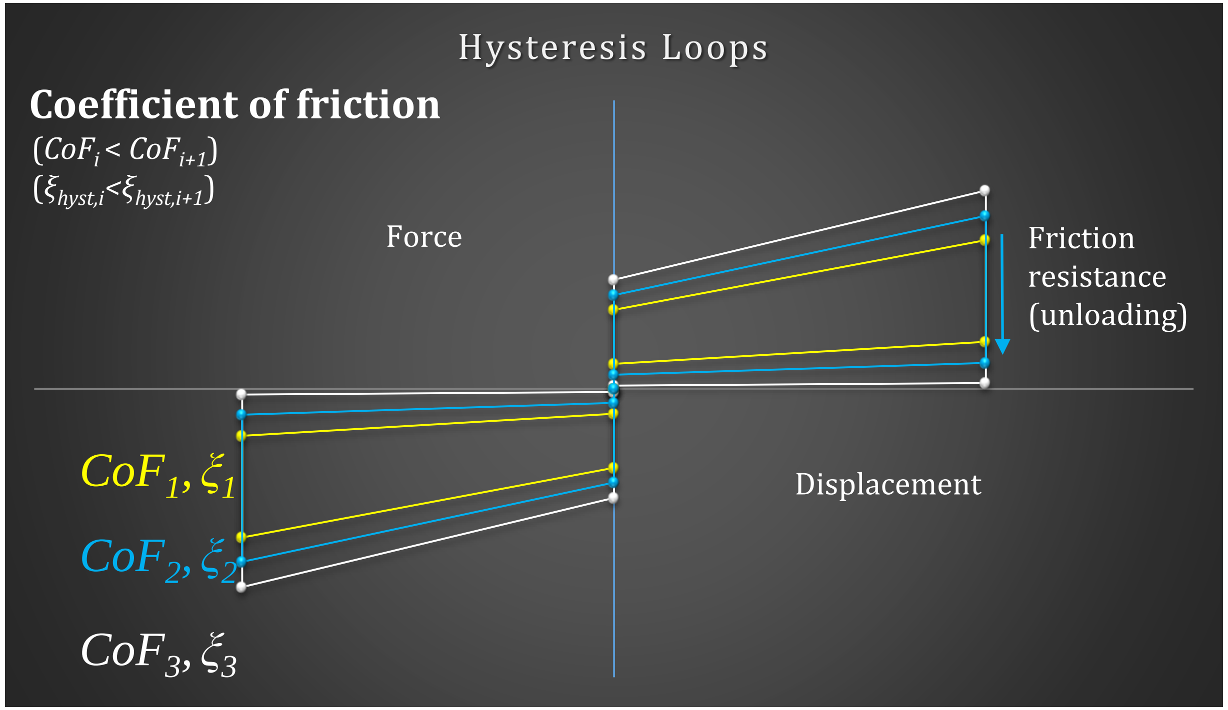


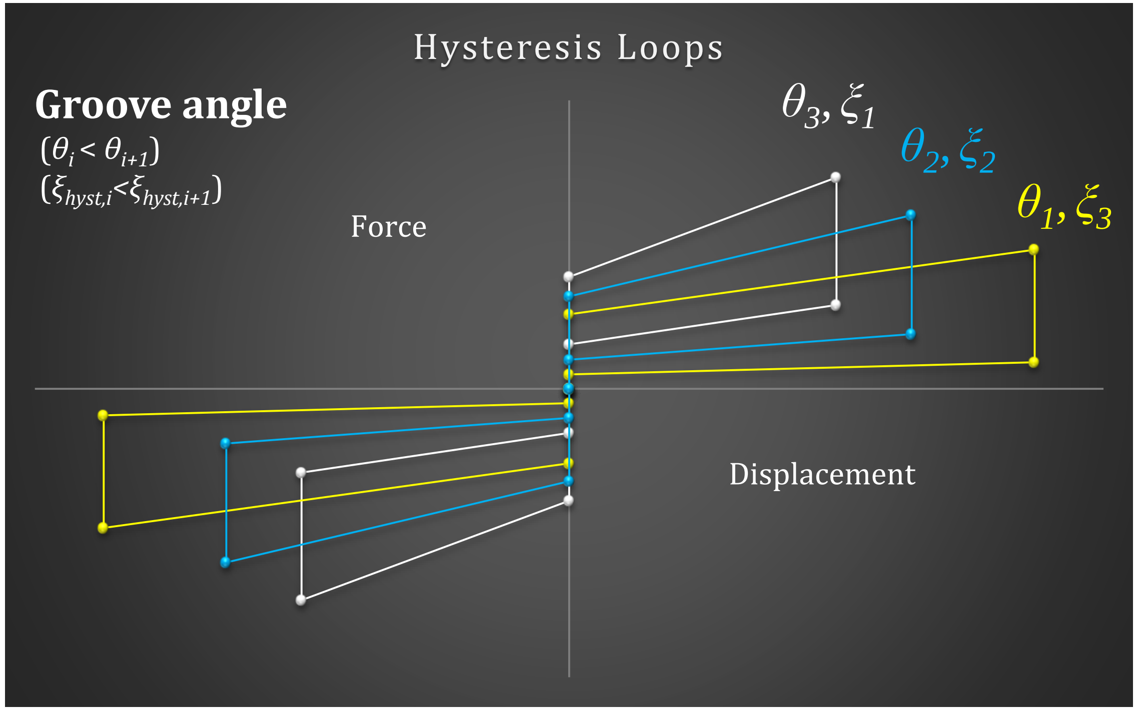
At ultimate unloading



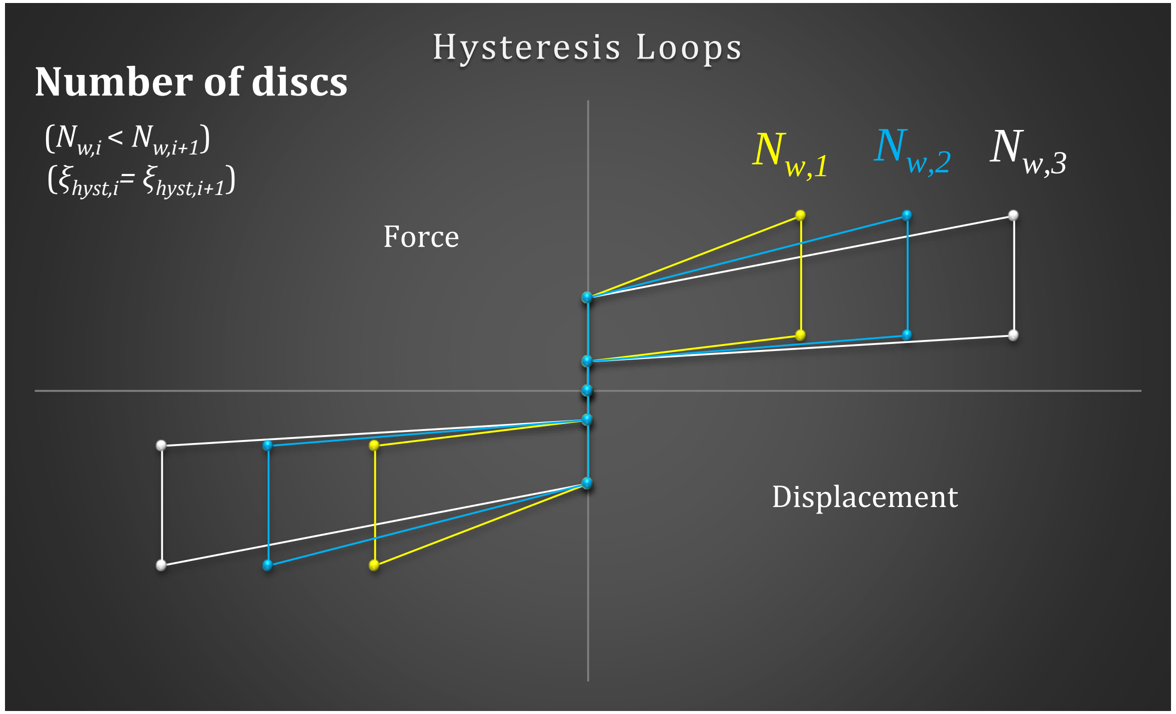
At restored position

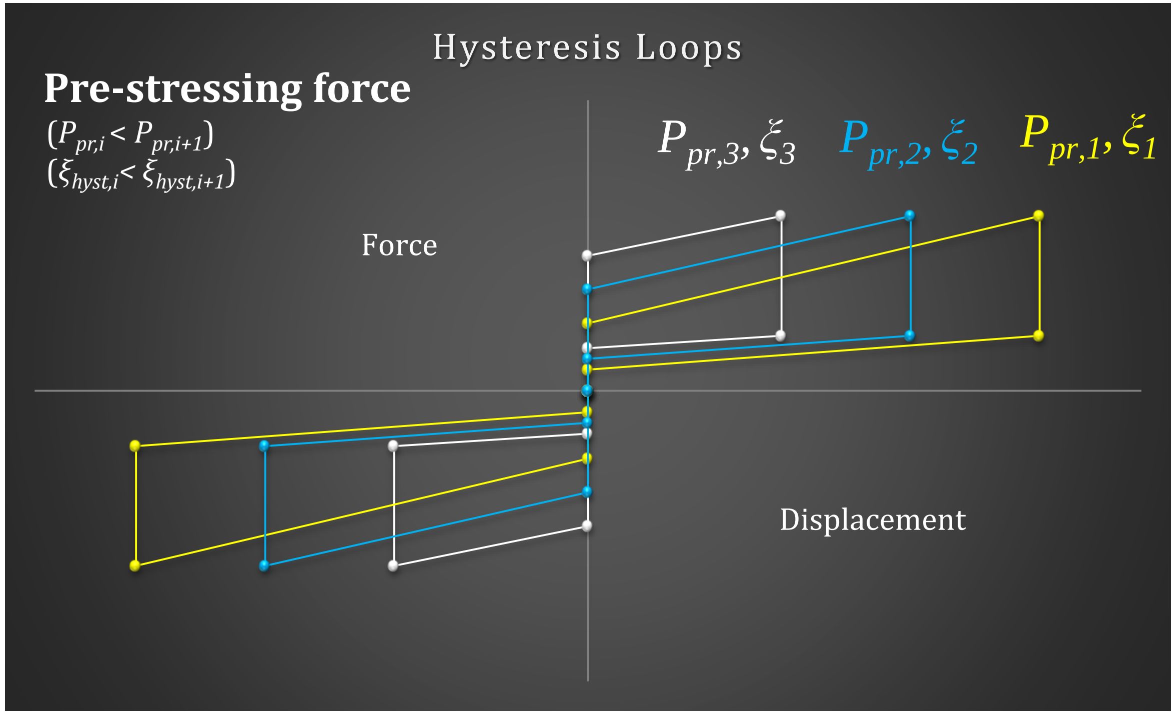
Connection Parameters Effect





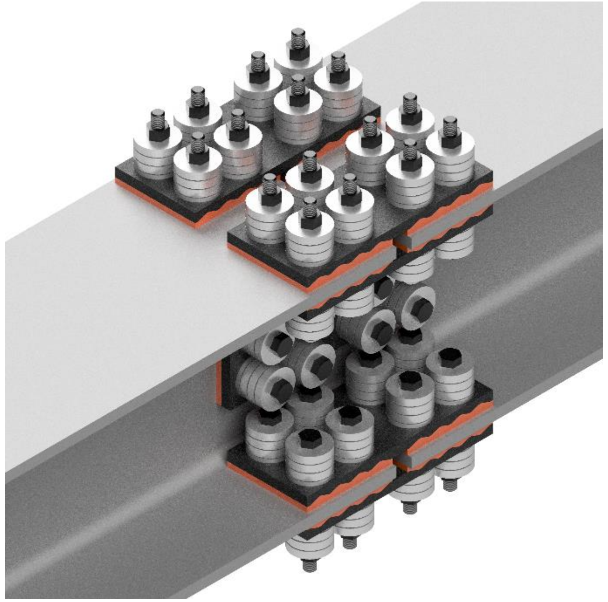
Connection Parameters Effect (Cont’d)

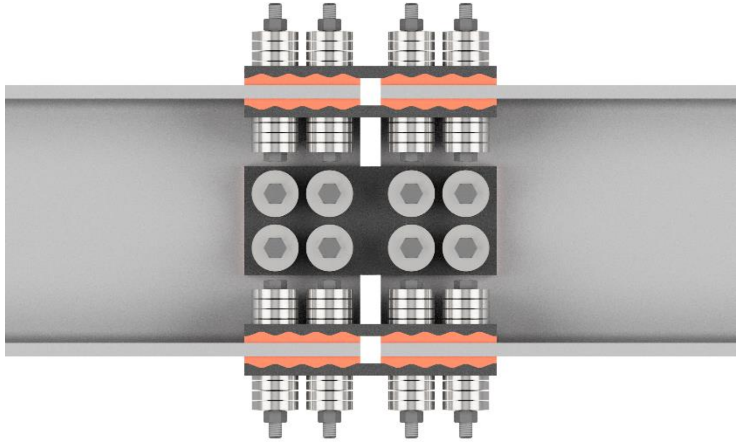




Potential Applications of RSF joint

(for new structures and existing earthquake-prone buildings)

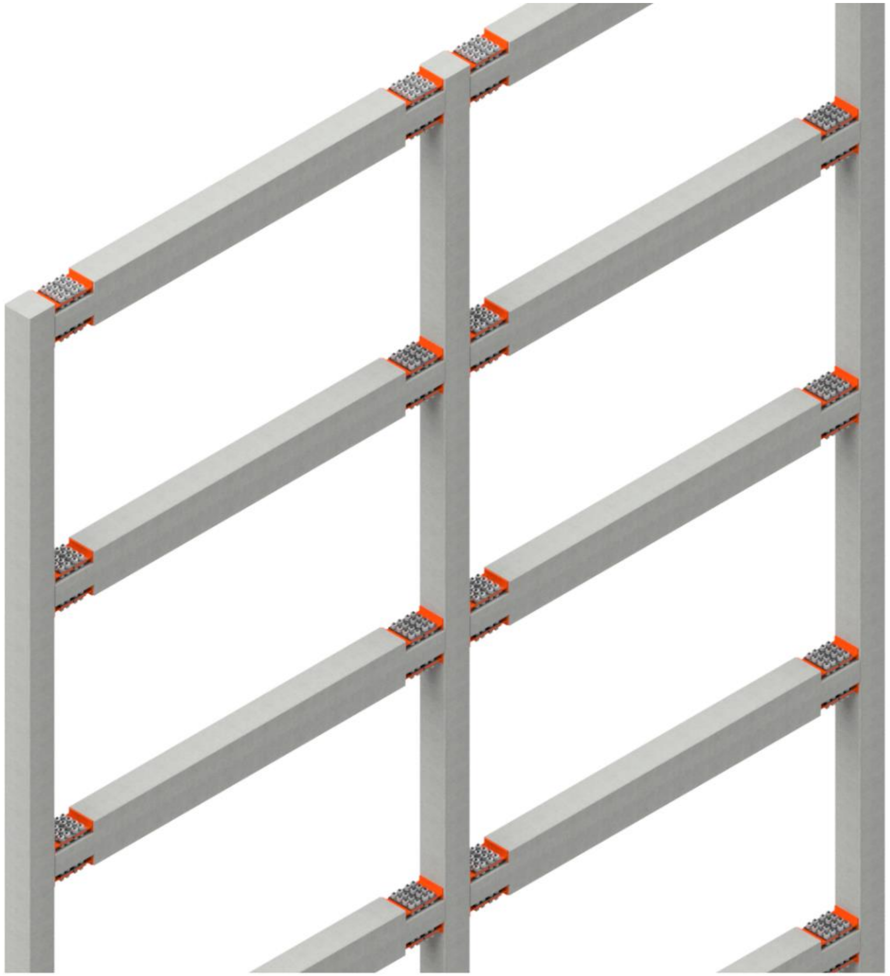


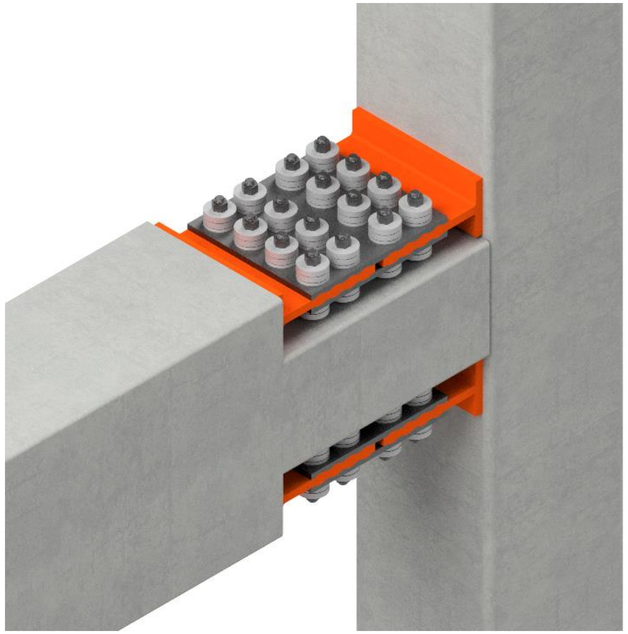


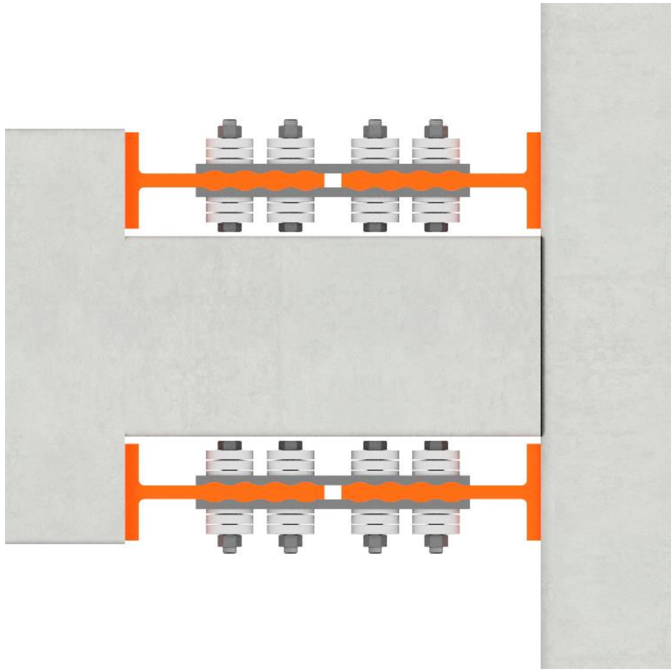
Sample of Braced Fame Connections
(over 3,000 kN)

Potential Applications of RSF joint

(for new structures and existing earthquake-prone buildings)

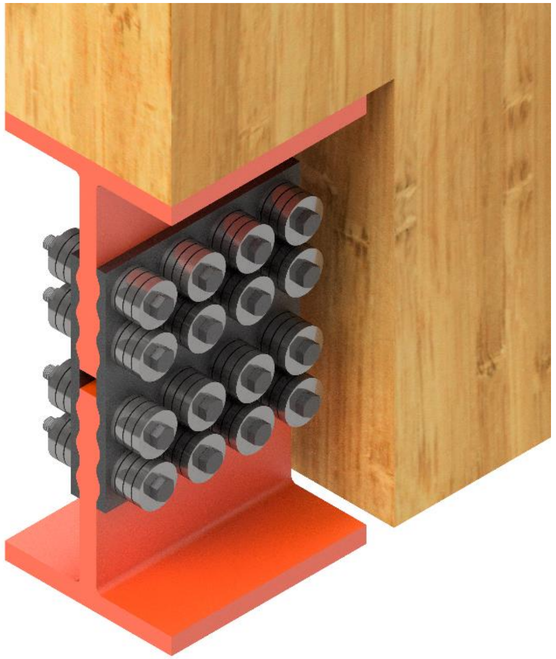


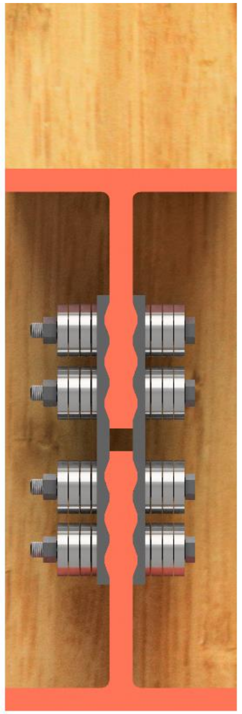




Sample of Moment Resisting Frame Connections
(over 1,500 kN)

Potential Applications of RSF joint
(for new structures and existing earthquake-prone buildings)

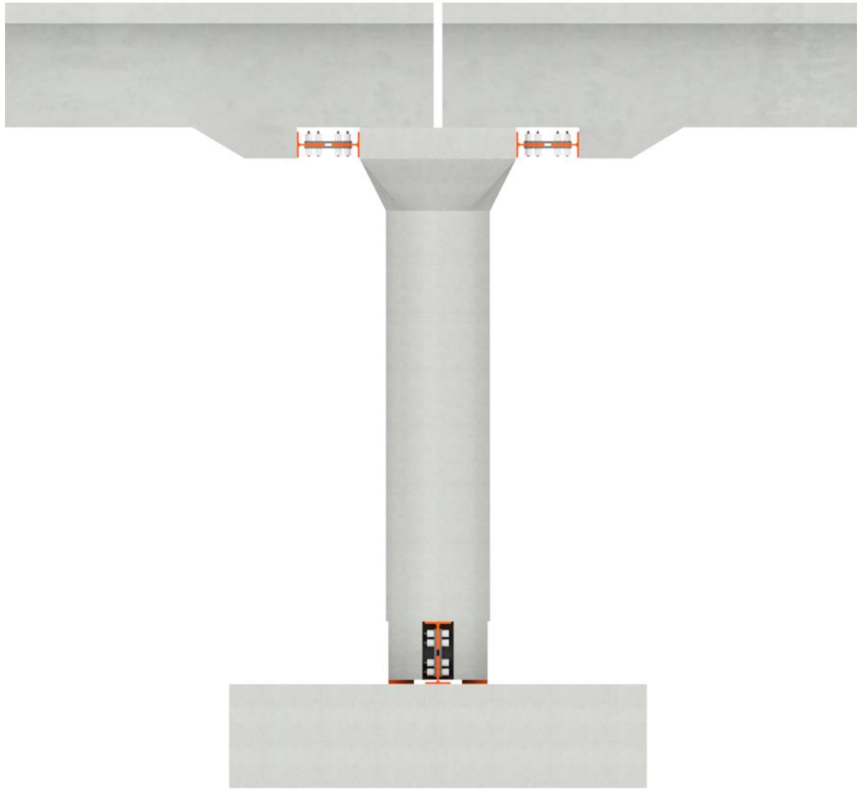




Sample of Shear Wall Connections
(over 1,000 kN)

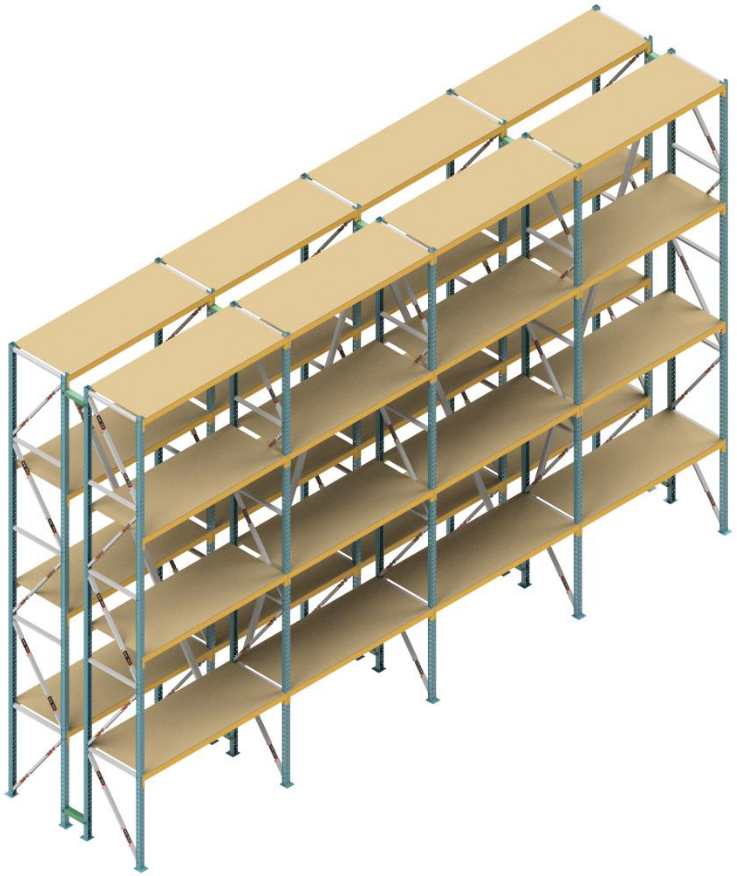
Potential Applications of RSF joint
(for new structures and existing earthquake-prone buildings)

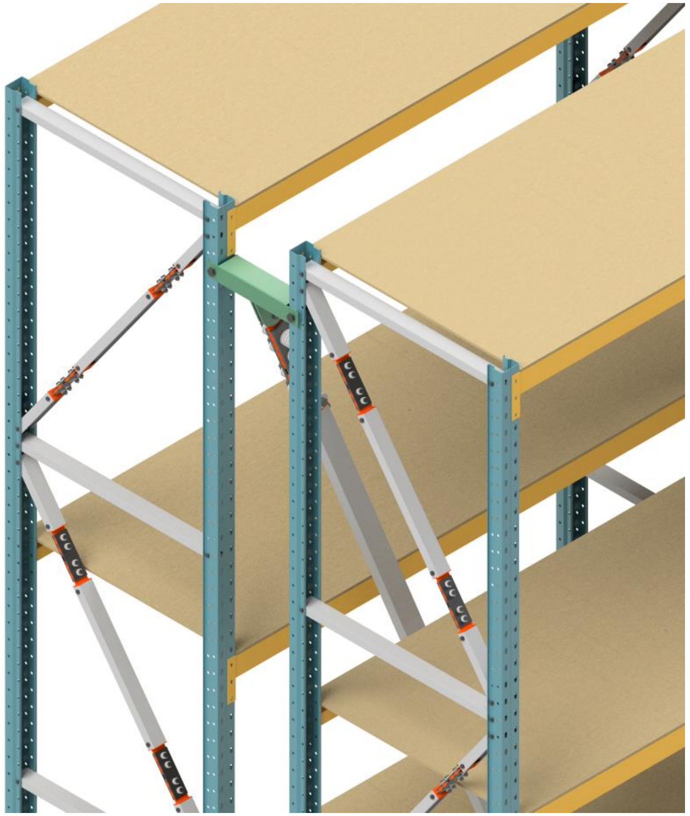
Sample of Bridge applications: Deck-to-Pier Connection (Controlling the Unseating and Pounding); Pier-to-Foundation Connection



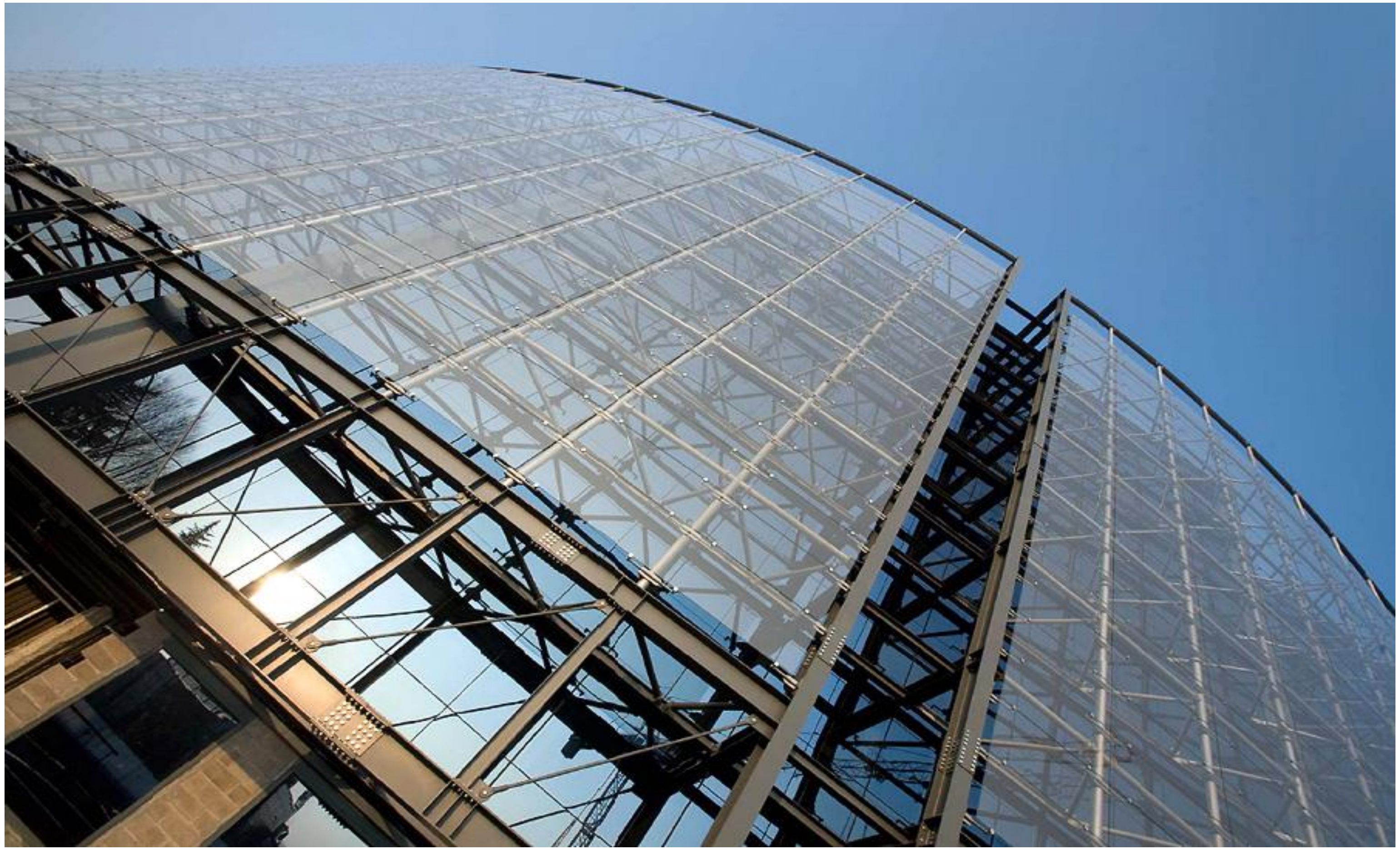
Potential Applications in Secondary Structural Elements

Sample of Storage Unit/Pallet Racking Applications (high scalability)





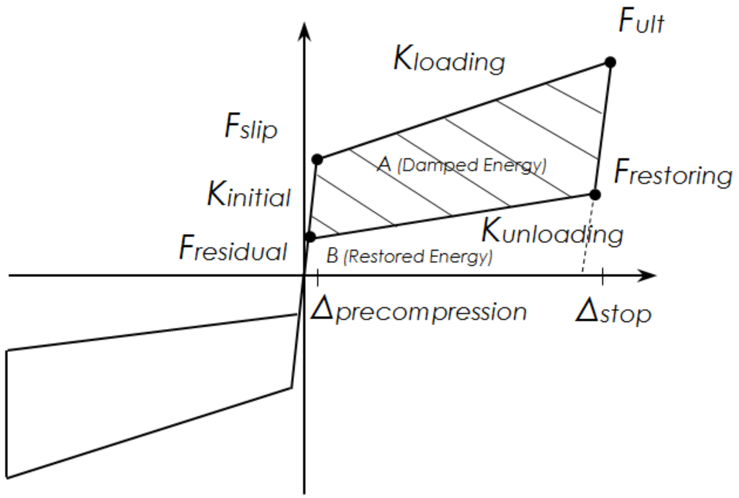
Potential Applications in Secondary Structural Elements



Facades

Easy Implementation for Structural Analysis and Design

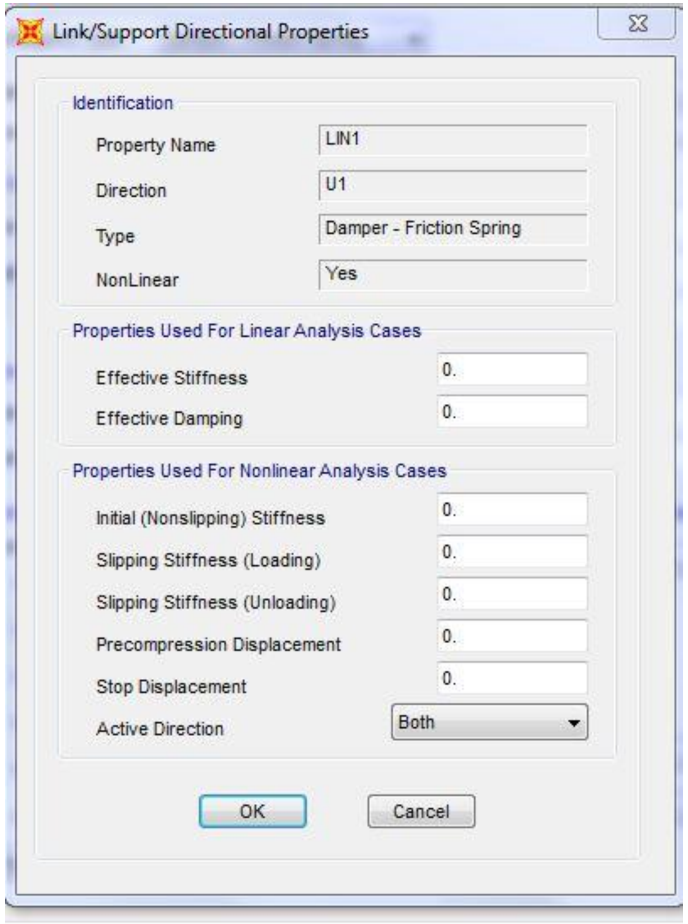
Nonlinear Analysis



Linear Analysis

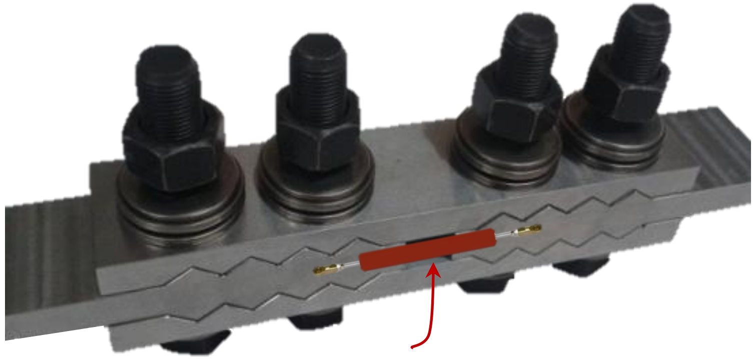
$$\text{Effective Stiffness} = \text{Initial Stiffness}$$

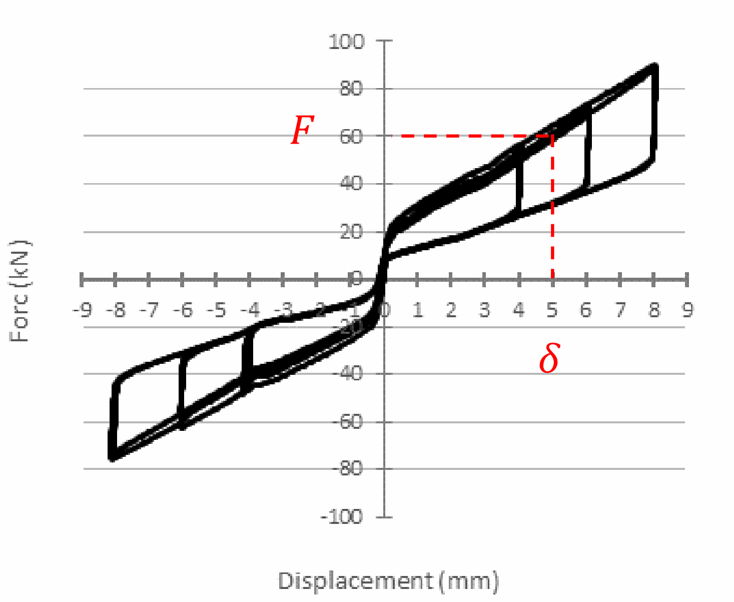
$$\text{Effective Damping} = \frac{\text{Damped Energy}}{\text{Introduced Energy}} = \frac{A}{A+B}$$

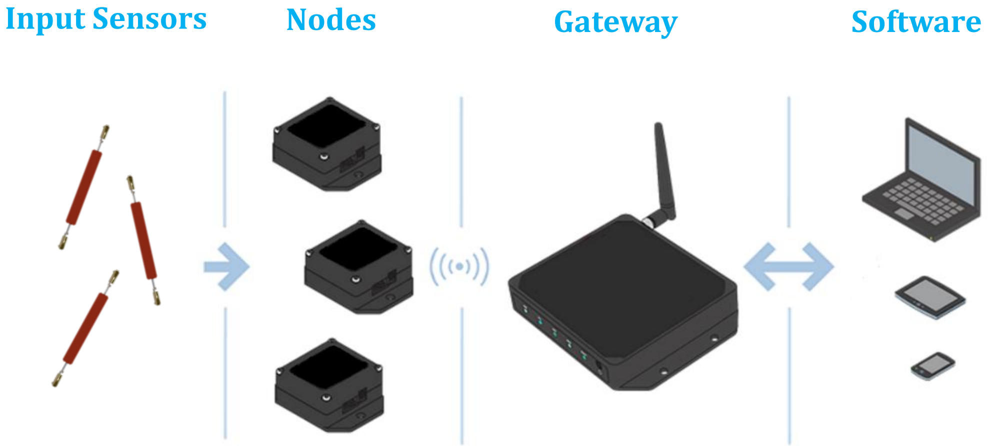


Smart RSFJ
(For structural health monitoring)

- Instrumented RSFJ
- Joint displacement can be related to the force applied to it with sufficient precision, as one of RSFJ features.

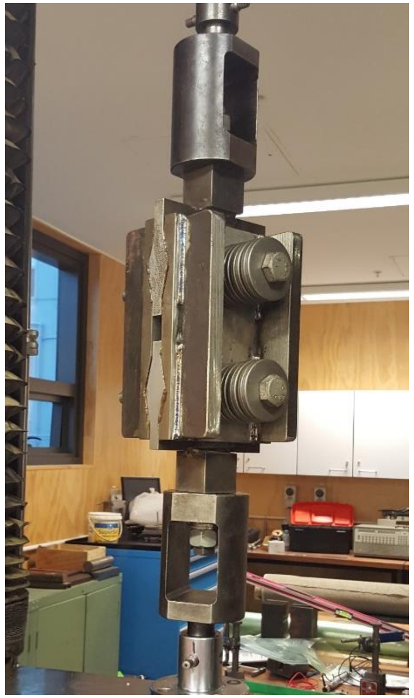






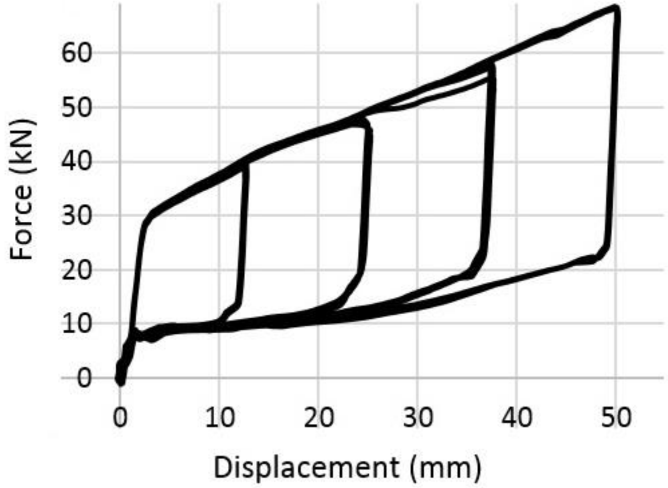
Completed Projects

(PhD project by Ashkan Hashemi – funded by EQC)



Before slip

After slip

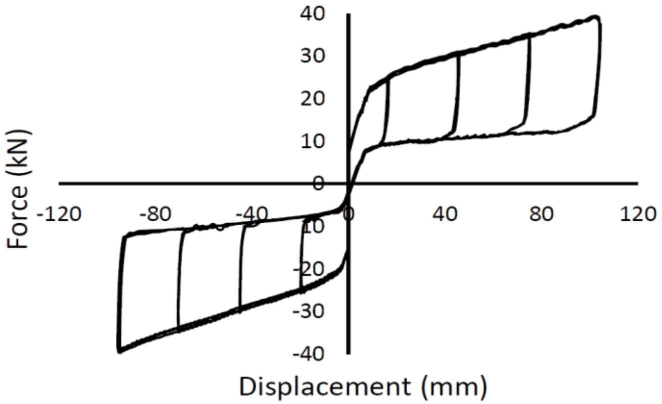


Joint Component Testing

Completed Projects

(PhD project by Ashkan Hashemi – funded by EQC)

Large-scale shear wall Testing



Completed Projects

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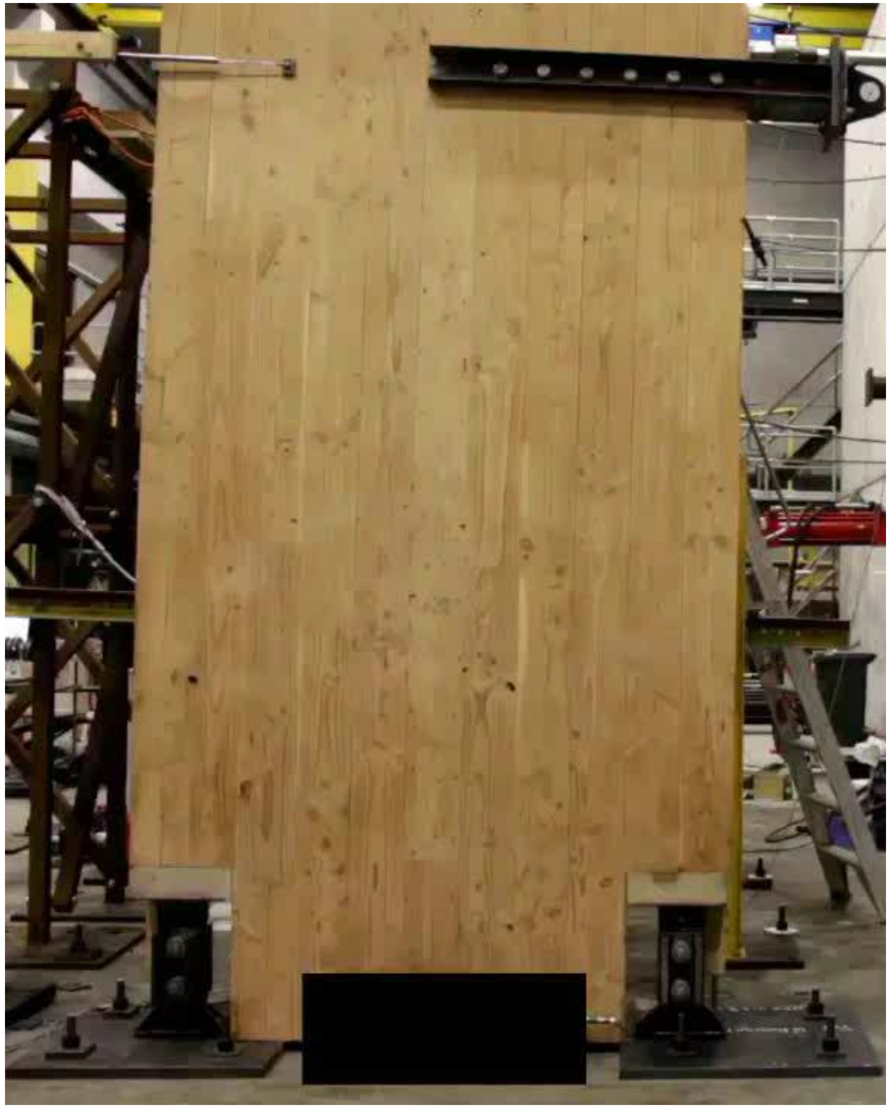


MBIE Research Team
($3.4M funding)

Science Leaders:
Dr Pouyan Zarnani (AUT)
Prof Pierre Quenneville (UoA)

Key Researchers:
Dr Sherif Beskhyroun (AUT)
A/Prof Charles Clifton (UoA)
Dr Rick Henry (UoA)
Dr Maziar Ramezani (AUT)

Researchers:
1 Postdoc, 5 PhD's, 1 Master

International Collaborators:
Dr Marjan Popovski, Principal Scientist (FP Innovations, Canada)
Prof Ario Cecotti (IVALSA, Italy)

Advisory Partner:
BECA Group Ltd (New Zealand)

Project Description	Duration	Start	End	Oct 2016 to Sep 2020			
				Yr 1	Yr 2	Yr 3	Yr 4
MBIE Research Programme Completion	**4 yrs**	**Oct-16**	**Sept-20**				
Project #1: Studying and testing of a concrete moment-resisting frame using RSFJ	3 yrs	Oct-16	Sept-19				
Project #2: Studying and testing of timber shear wall to floor connection using RSFJ	3 yrs	Oct-16	Sept-19				
Project #3: Studying and testing of a steel braced frame using RSFJ	3 yrs	Oct-16	Sept-19				
Project #4: Studying and testing of a full-scale 3-storey hybrid structure using RSFJ	2 yrs	Oct-16	Sept-18				
Project #5: Studying and testing of retrofitting techniques using RSFJ	3 yrs	Oct-17	Sept-20				
Project #6: Studying and testing of potential variations of RSFJ (e.g. Rotational, 2D to 4D)	3 yrs	Oct-17	Sept-20				

Real-life projects
(from theory to practice)

By Dunning Thornton Consultant Ltd:

- Nelson airport new terminal – RSFJ adopted as hold-downs
  (More efficient while compared to PRESSS technology)

By BECA Consulting Engineers:

- Retrofitting of a 6 storey concrete building – RSFJ to be adopted potentially in braces
  (More efficient while compared to viscous dampers)

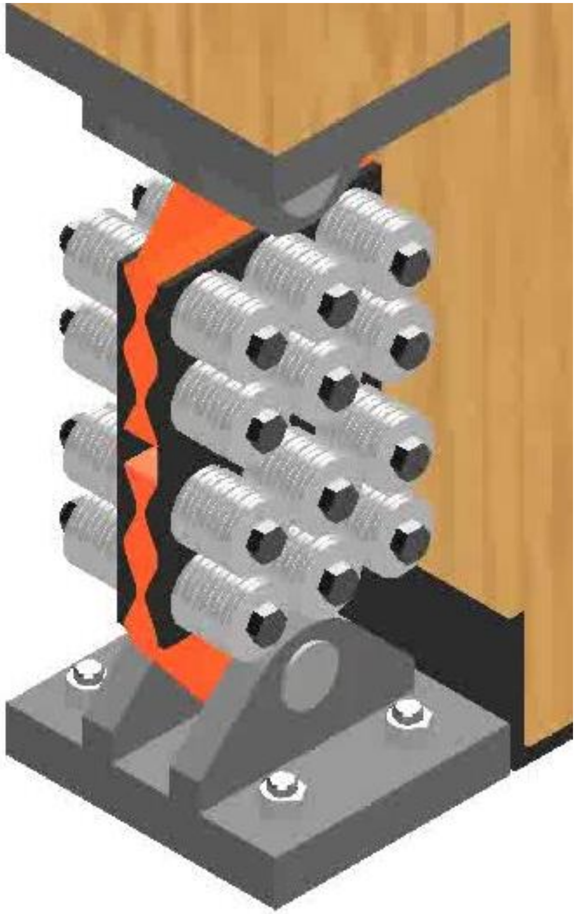
By New Zealand Consulting Engineers Ltd (NZCEL):

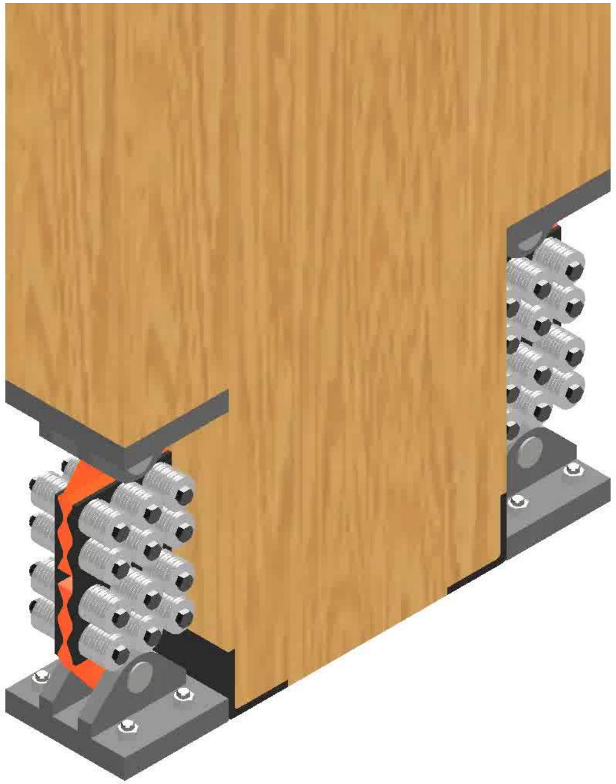
- Hybrid steel-timber 7 storey building – RSFJ to be adopted potentially in beam-to-column connections

Resilient Slip Friction Joint (RSFJ)
(designed for Nelson Airport Terminal)

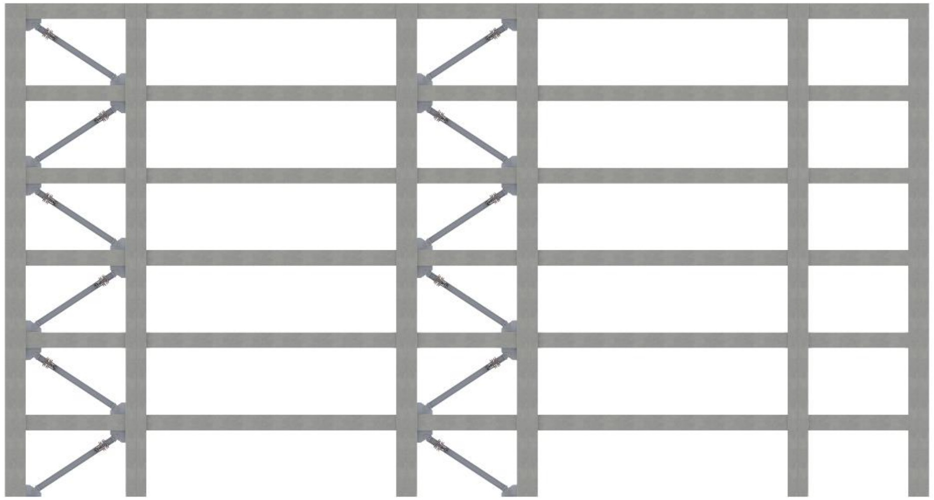
Connection detailing and performance (designed for Nelson Airport Terminal)

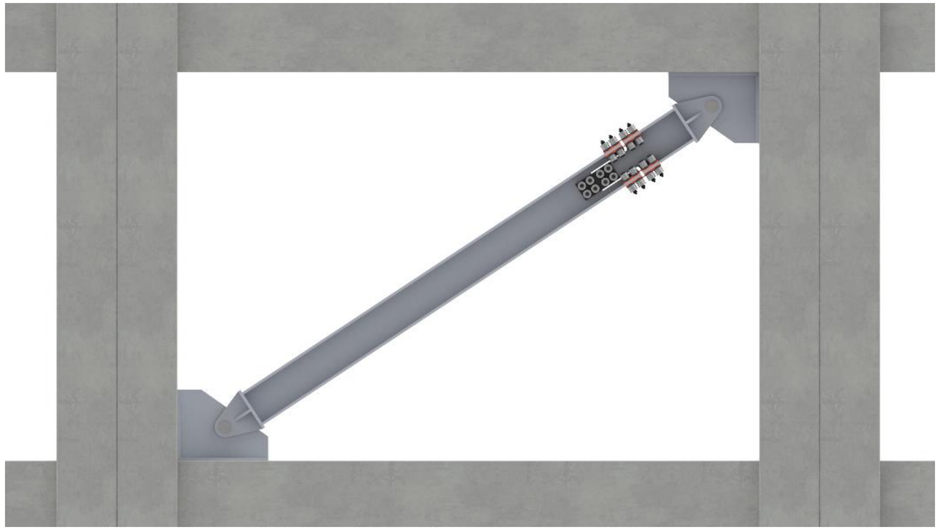
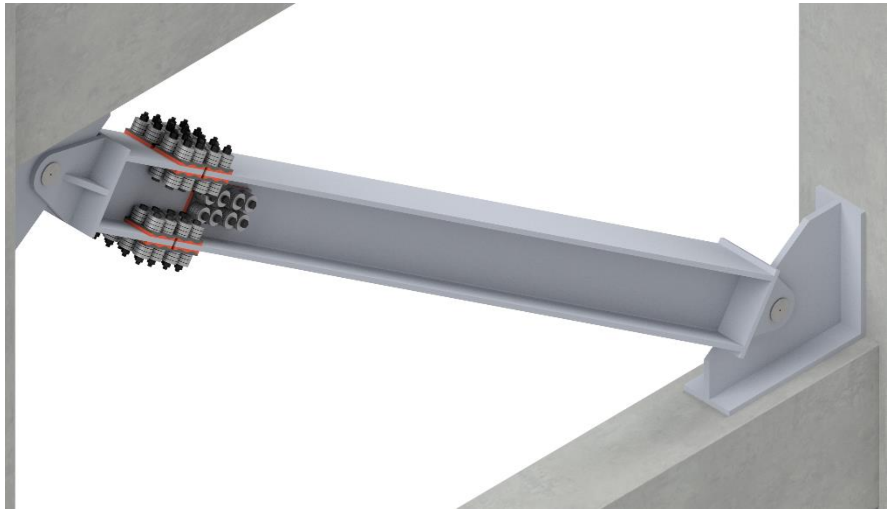
- In-plane rocking (joint, connection and column performance)



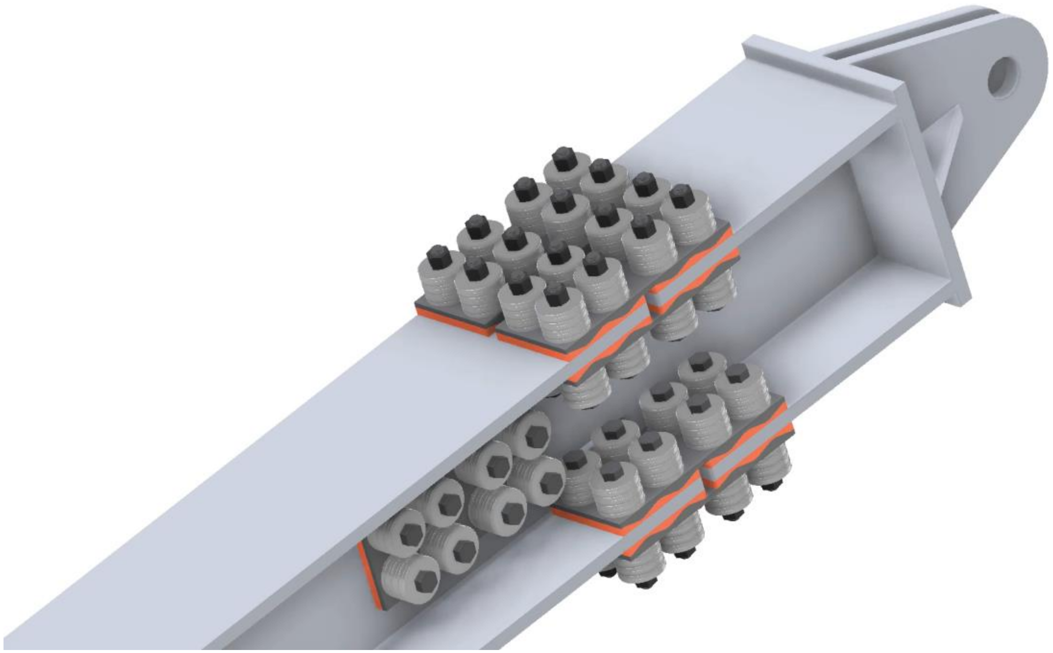


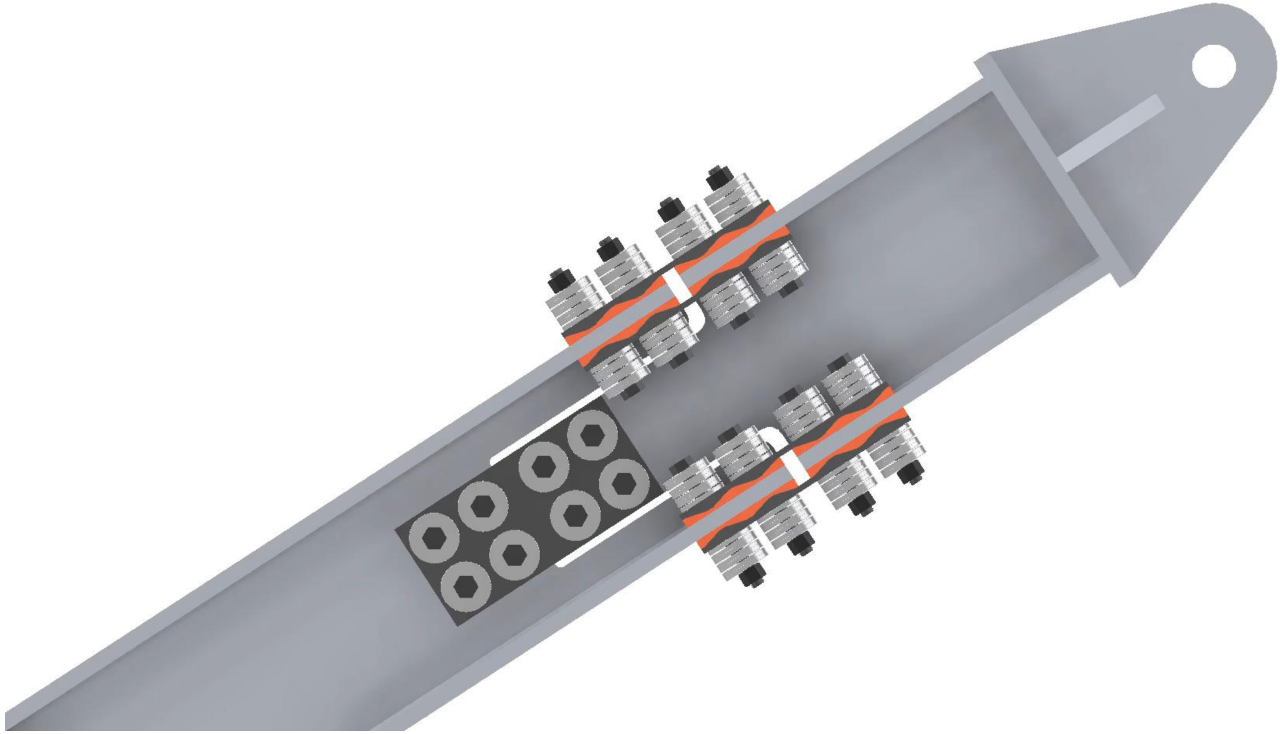
Preliminary design for BECA brace project
(Retrofitting of a concrete building)



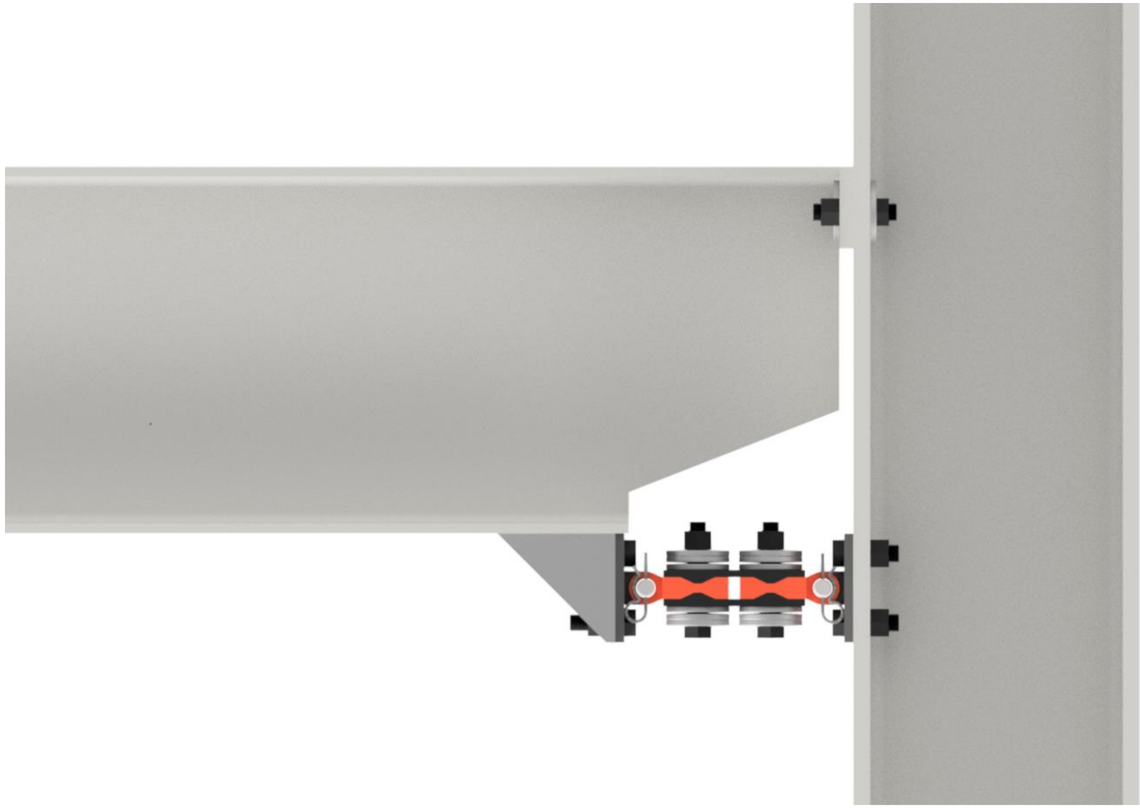
Preliminary design for BECA brace project





Resilient Slip Friction Brace (RSFB)
Over 3000kN capacity

Preliminary design for NZCEL project



Steel moment resisting frame

Preliminary design for NZCEL project

Summary

"High Damage" Concepts (1st generation)

(Traditional Seismic Solutions)

- ☑ **Dissipating energy**

"Low Damage" Concepts (2nd generation)

(State-of-the-practice)

- ☑ **Dissipating energy**
- ☑ **Self-centring**

RSFJ as "Damage Avoidance" Concept (new 3rd generation)

(Checking all the boxes)

- ☑ **Effectively dissipating energy**
- ☑ **Self-centering capacity**
- ☑ **No post-event maintenance for RSFJ**

(All in one compact joint)

Protecting occupants and building in following aftershocks

(over 40 strong aftershocks within 24 hrs as high as M6.3 after Kaikoura earthquake M7.8)

Acknowledgments

Special thanks for the support received

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

EQC
EARTHQUAKE COMMISSION
Kōmihana Rūwhenua

uniservices
Auckland UniServices Limited

Beca

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

AUT
UNIVERSITY
AUCKLAND, NEW ZEALAND

tectonus
resilient seismic solutions

Thank you for your kind attention

"Ensuring safety and restoring order in seismic prone locations"