NHERI@UC SAN DIEGO
LARGE-SCALE GEOTECHNICAL SHAKE TABLE TEST
PLANNING WORKSHOP

MAY 31, 2017; SAN DIEGO, CA

# Experiences in New Zealand: Geo-structural observations

Waiheke Island, New Zealand, 2015

**Alessandro Palermo**

Professor in Structural Engineering

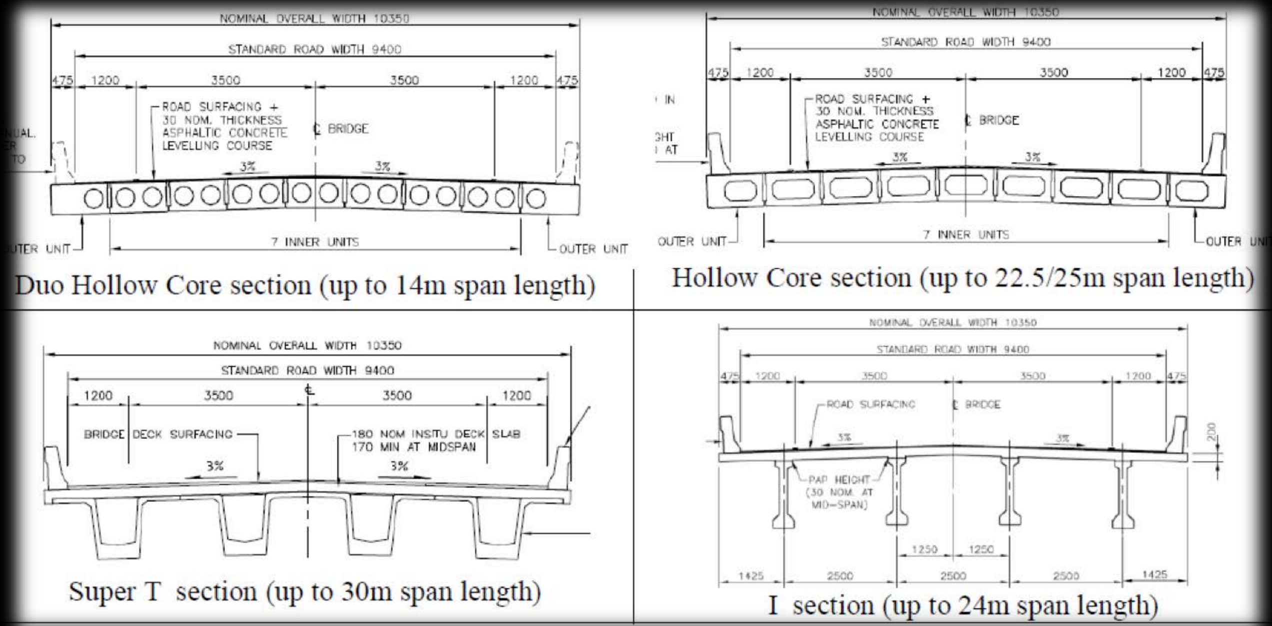
# *Presentation Outline*

- NZ bridge portfolio
- Lesson learnt from recent NZ earthquakes
- Initiatives taken after the NZ earthquakes
- Shift towards repairable connections
- Research questions and opportunities for collaboration

## *New Zealand Bridge portofolio*

# *New Zealand Bridge portofolio*

## Low-medium span bridges (mainly precast concrete decks

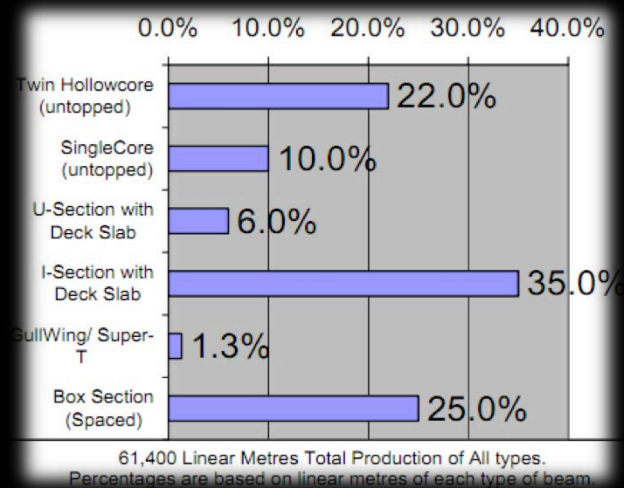



Duo Hollow Core section (up to 14m span length)

Hollow Core section (up to 22.5/25m span length)

Super T section (up to 30m span length)

I section (up to 24m span length)




## NZTA Research report 364, 2008

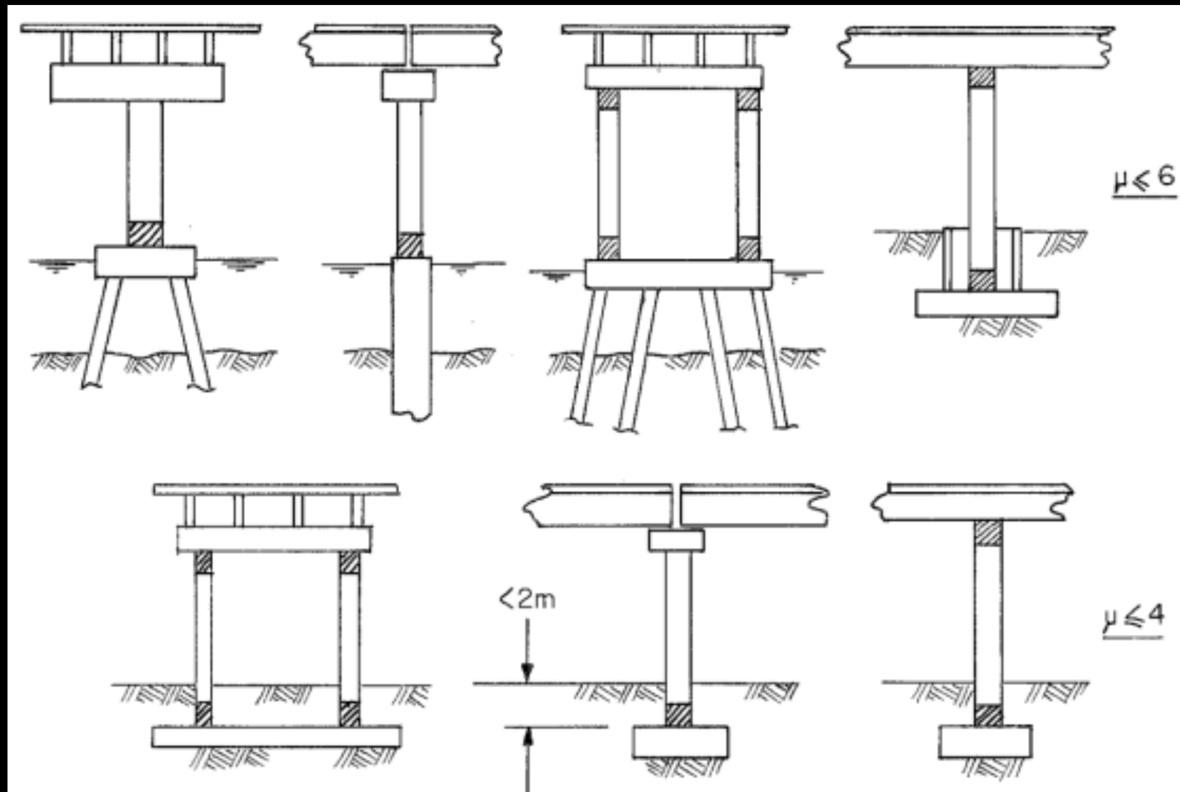
Currently the state highway network in NZ includes about 11-12,000 kilometers of roads, more than 4000 bridges and large number of culverts. The combined length of bridges on the state highway network is over 160 kilometers

# *New Zealand Bridge portofolio*

## Current Design Ductility

In the NZTA Bridge Manual the allowable ductility is defined by:

1. Robustness of the structural form
2. Redundancy of the system
3. Predictability of behavior




NZTA Bridge Manual 3rd edition (Figure 5.3)

Preliminary Draft BM limits ductility to 4 rather than 6 (for reasons associated with monolithic connections)

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# *Lessons Learnt from recent NZ earthquakes*

# Lessons Learnt from recent NZ earthquakes

*Canterbury Earthquakes (2011)*

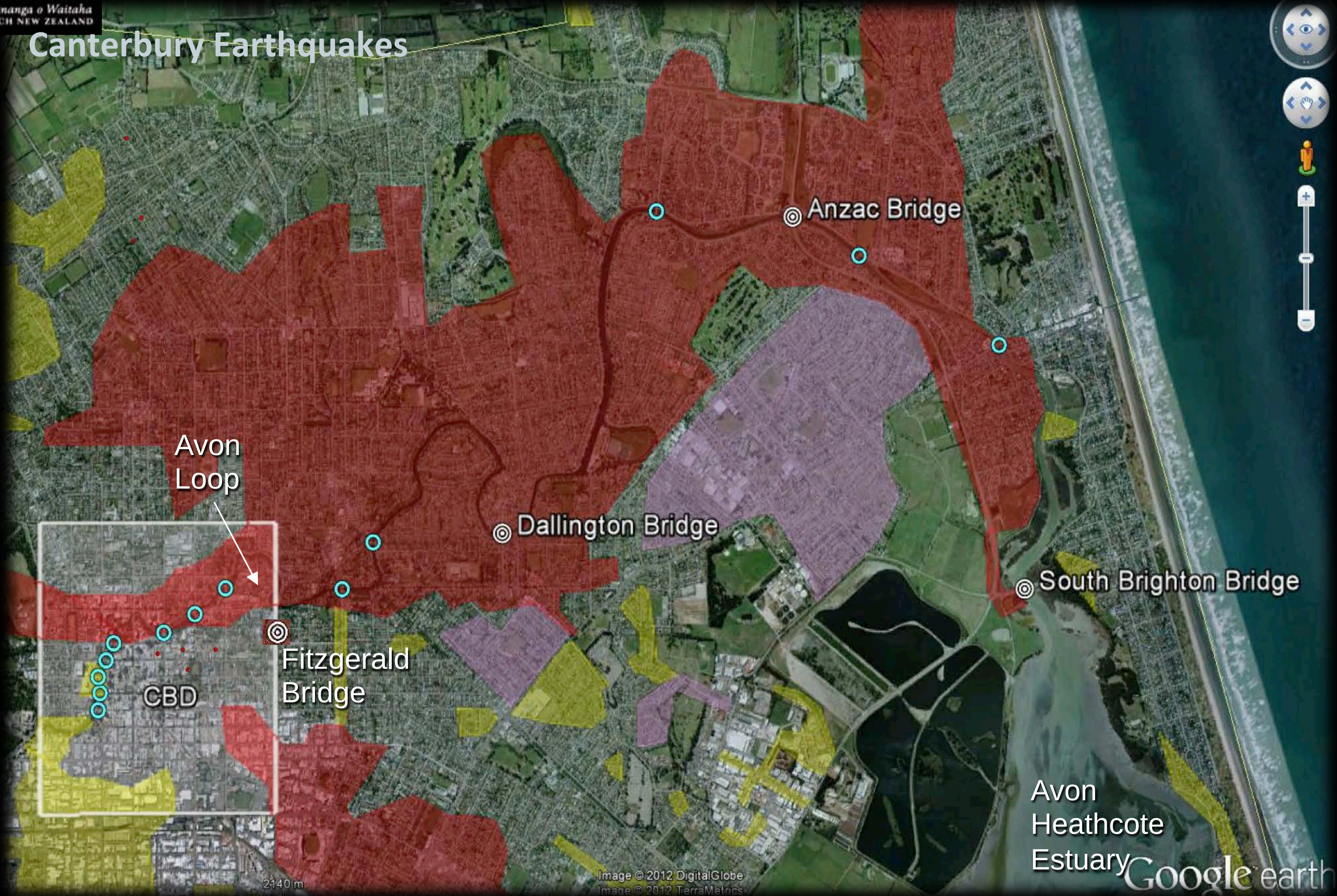
*Cubrinovski et al. (2011)*

*Kaikoura Earthquake (2016)*

*Dizhur & Giaretton (2016)*

# Lessons Learnt from recent NZ earthquakes

Canterbury Earthquakes

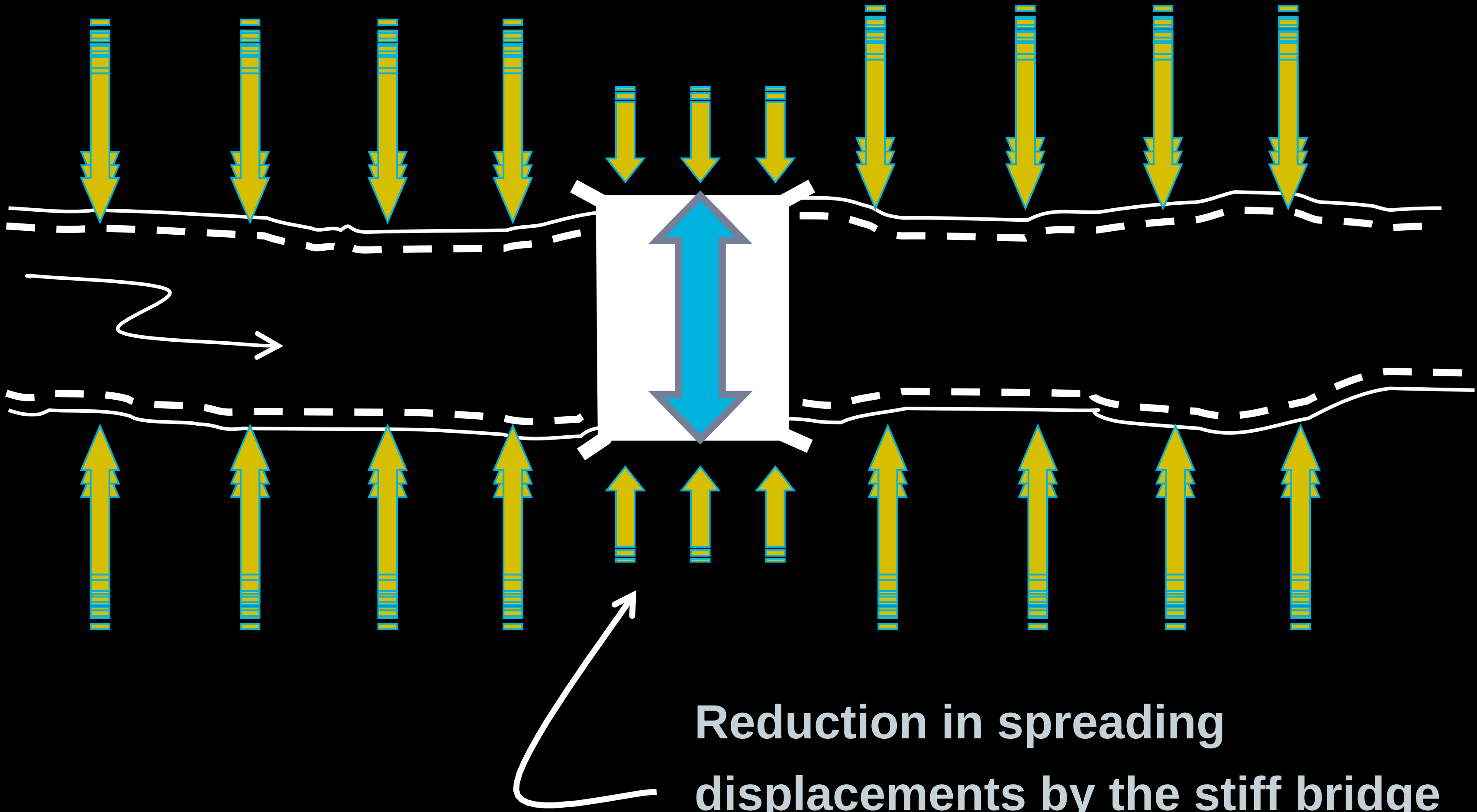



*Cubrinovski et al. (2014) ASCE J. of Constructed Facilities*

*Cubrinovski et al. (2014) EQ Spectra*

# Lessons Learnt from recent NZ earthquakes

## Spreading-induced Damage Mechanism



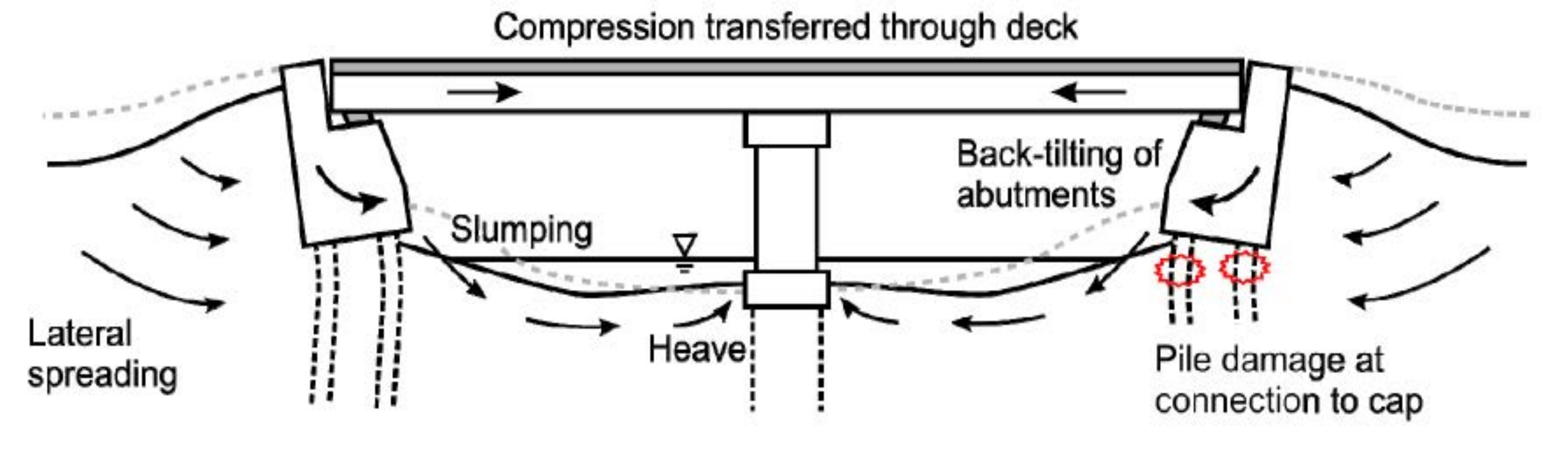
**Reduction in spreading displacements by the stiff bridge structure**

*- short, two or three span bridges, L = 25 – 50 m (65m)*

Courtesy of M. Cubrinovski

# *Lessons Learnt from recent NZ earthquakes*

- Short span/length bridges; two or three spans, L = 25 m – 50 m (65m)
- Stiff/robust superstructure with high capacity to resist lateral loads




**Deck-strutting → Abutment inward-rotation → Pile displacement → deformation → damage**

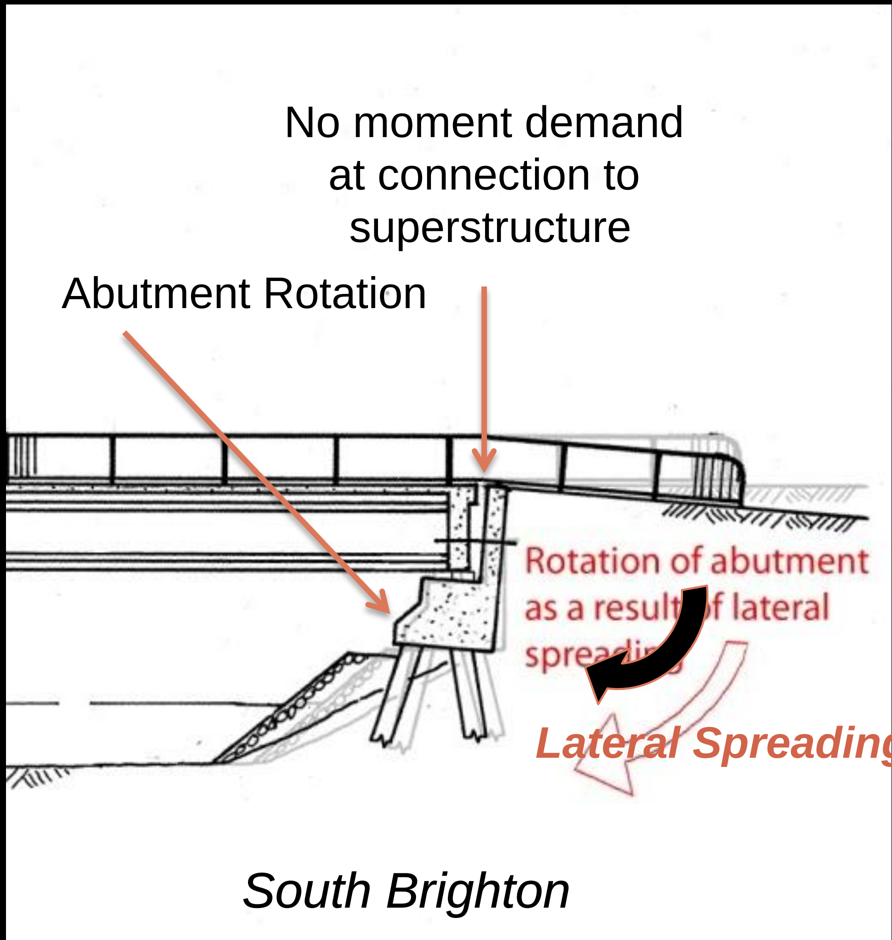
Courtesy of M. Cubrinovski

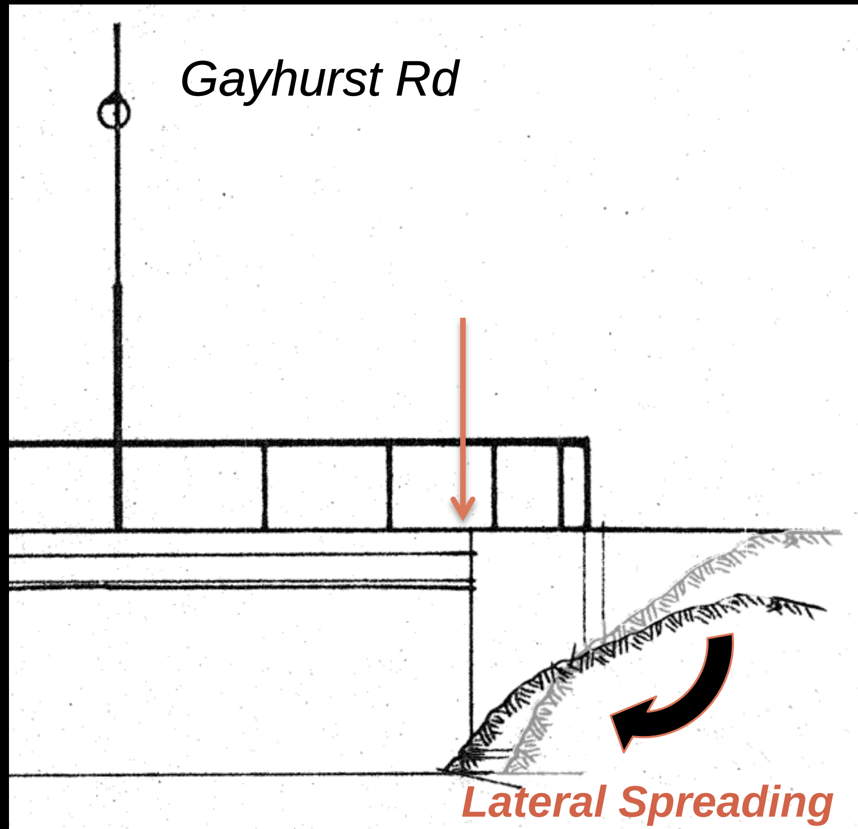
# *Lessons Learnt from recent NZ earthquakes*


Displacements of foundation soils substantially smaller than free field displacements (~50%)

*Cubrinovski et al. (2014) EQ Spectra Special Issue*

# Lessons Learnt from recent NZ earthquakes




<u>***Typical integral bridge***</u>

<u>***Typical simply supported bridge***</u>

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# *Lessons Learnt from recent NZ earthquakes*

## BEST PERFORMANCE:

## *Integral or Precast Bridges?*

***Pages Road Bridge (Integral)***

***Anzac Drive Bridge (Precast)***

# Lessons Learnt from recent NZ earthquakes

## South Brighton Road Bridge

*02/22/2011 Christchurch earthquake*

# *Lessons Learnt from recent NZ earthquakes*

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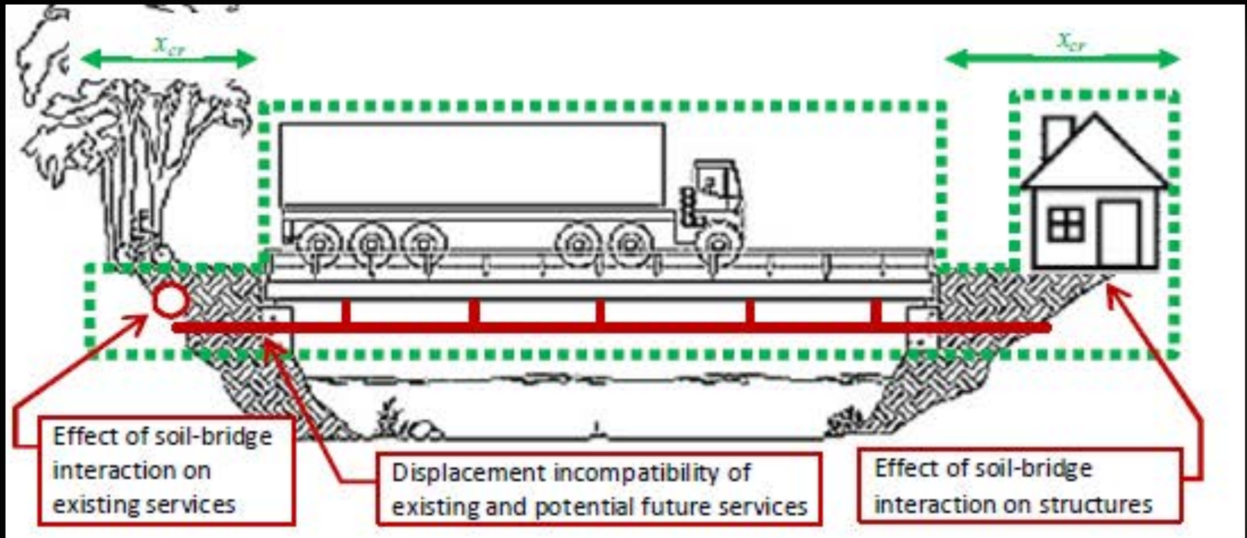
## BUS (Bridge Utilities System)



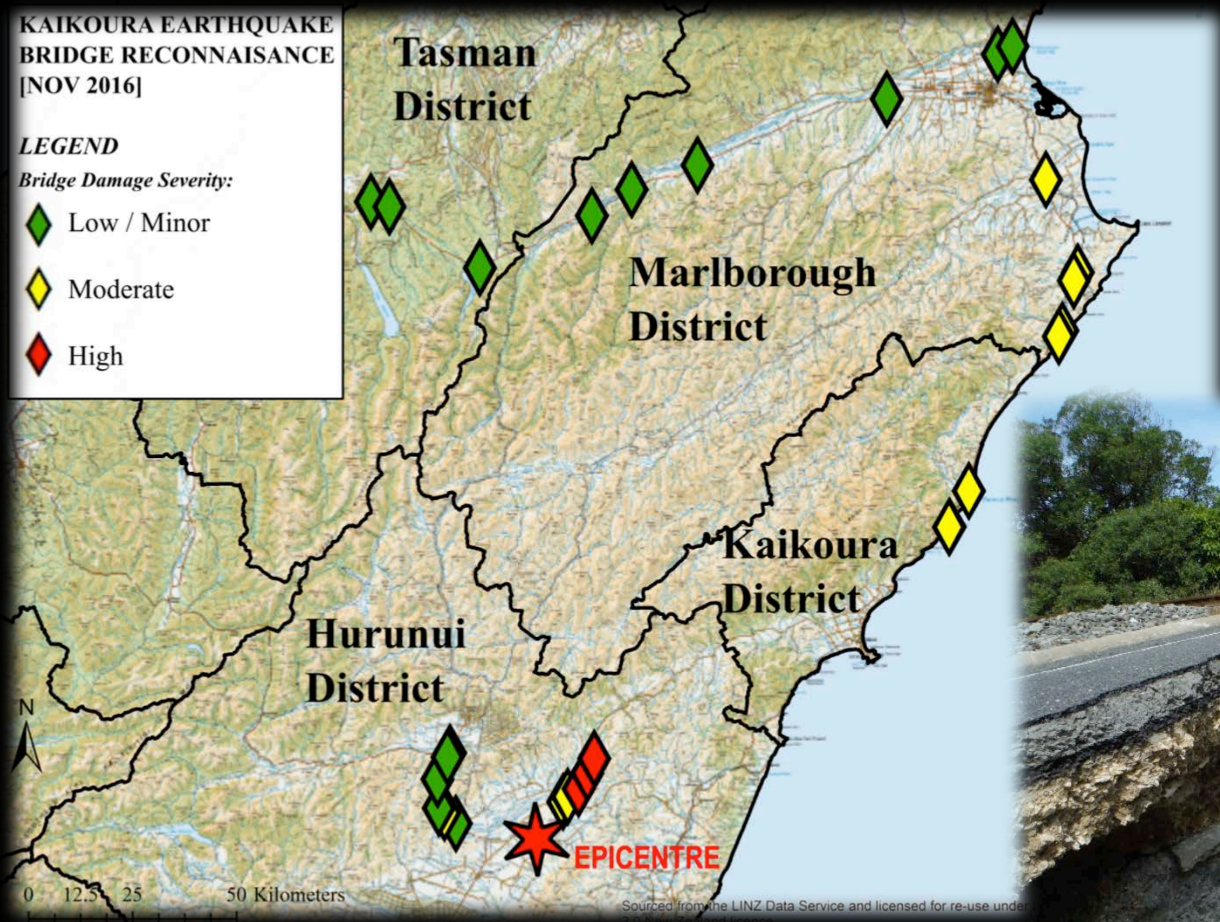

Kainga Road Bridge

Gayhurst Road Bridge

Bridge Street Bridge

# *Lessons Learnt from recent NZ earthquakes*

2016 Kaikoura Earthquake (New Zealand)

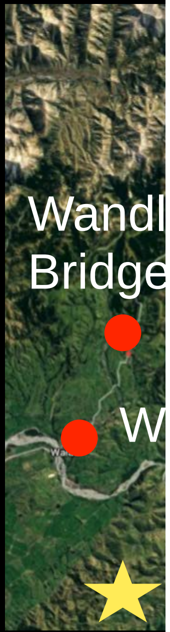


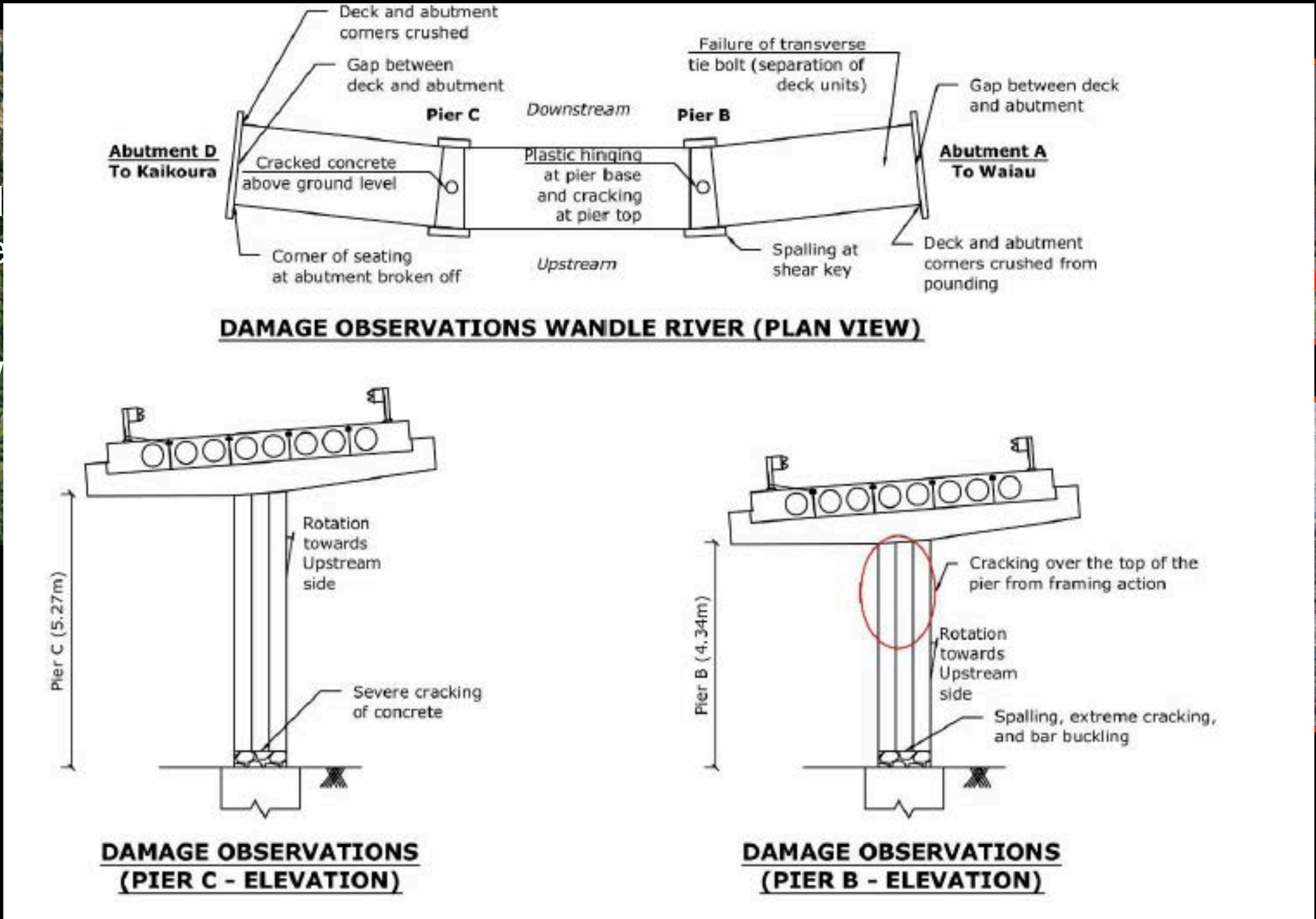

*Reconnaisance Survey*

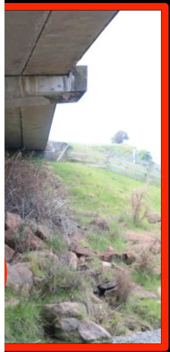
*Palermo et al. 2017, Bulletin of NZSEE – Special Kaikoura Eq.*

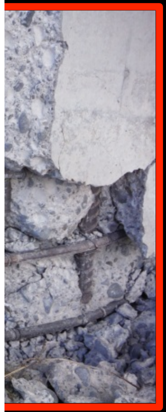
# Lessons Learnt from recent NZ earthquakes

## Wandle River Bridge





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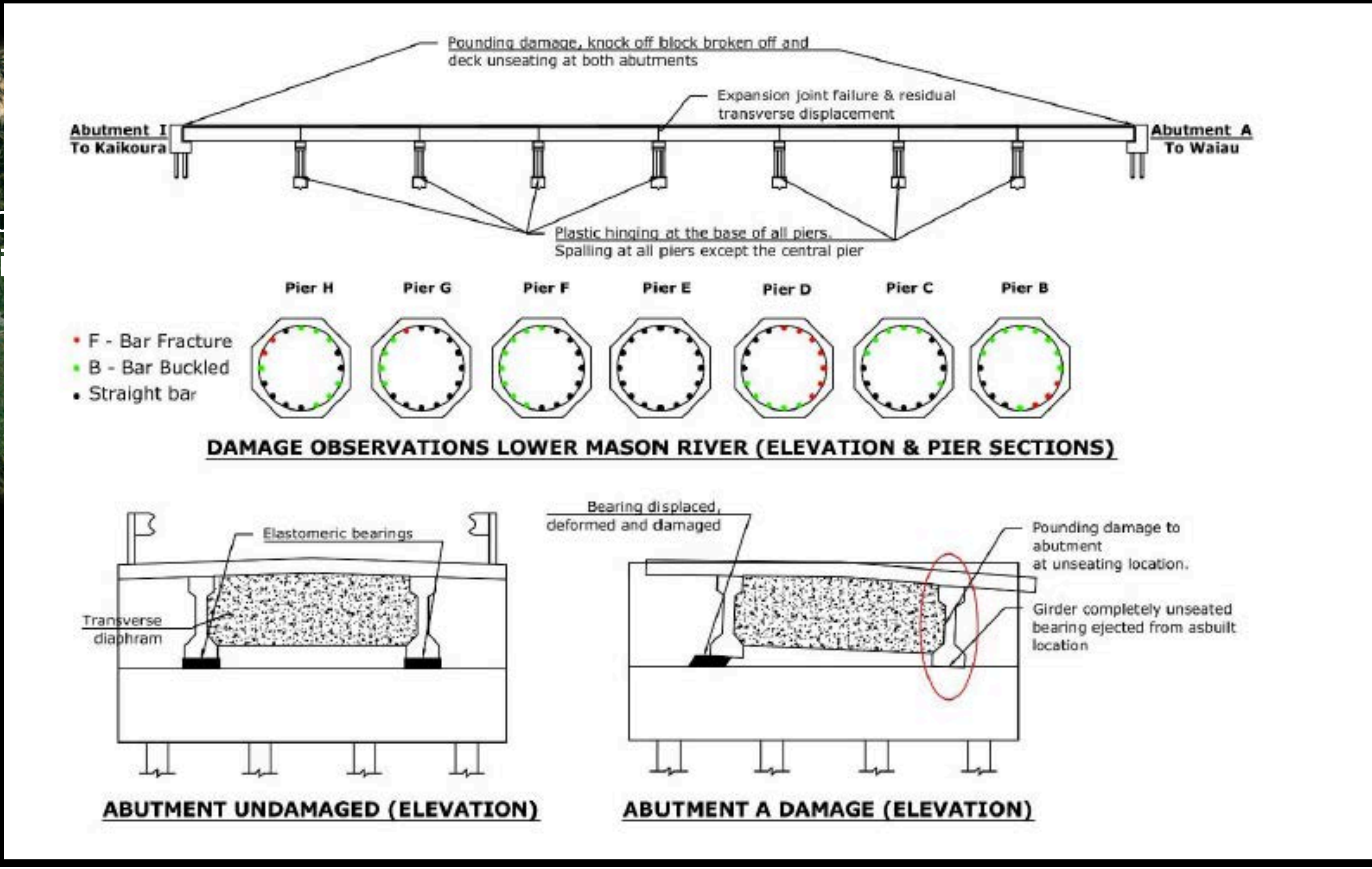
# *Lessons Learnt from recent NZ earthquakes*

## *Lower Mason River Bridge (1986)*

Lo
Ri



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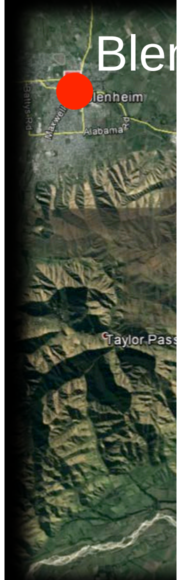
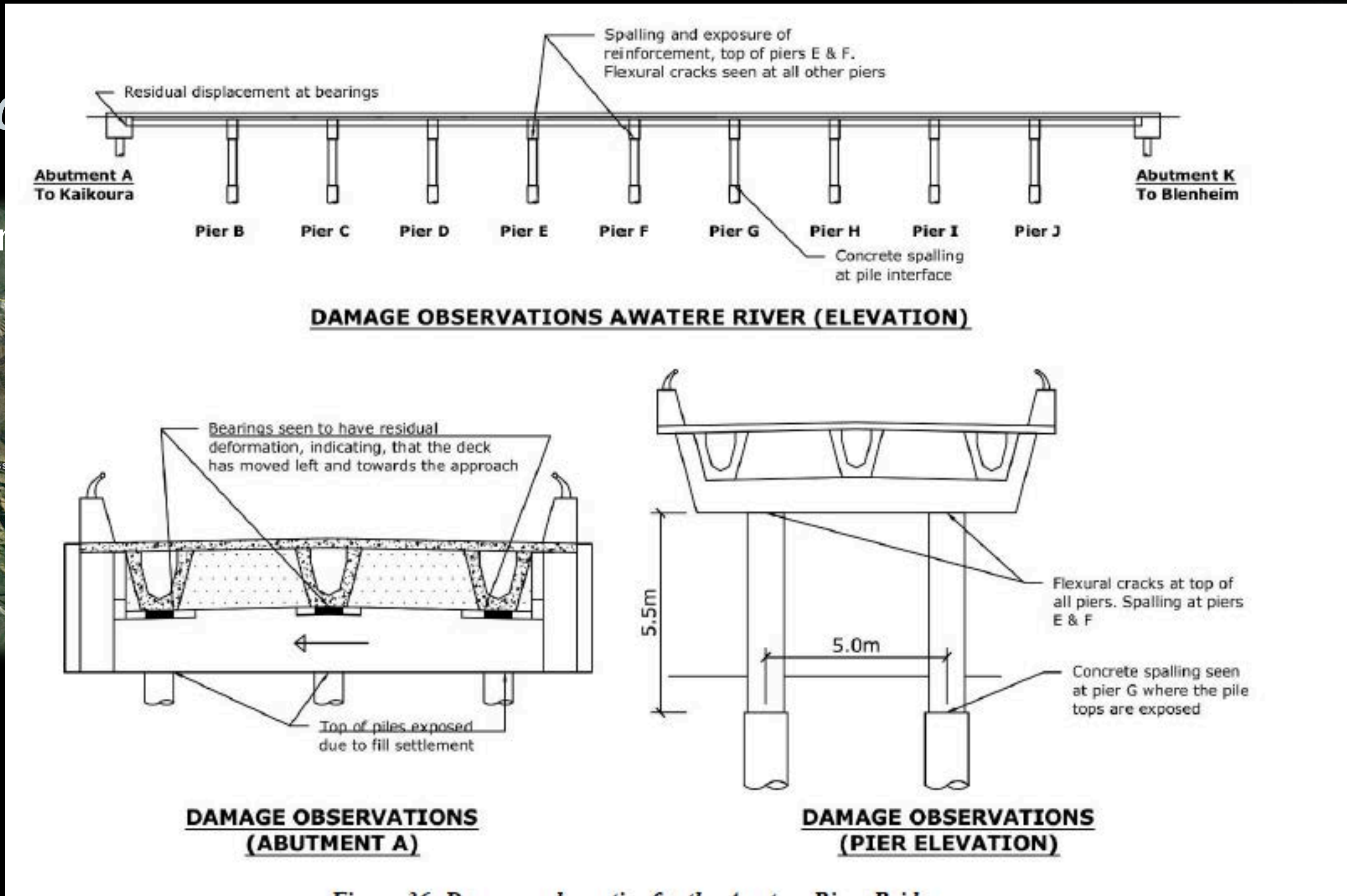
# Lessons Learnt from recent NZ earthquakes

## Aw



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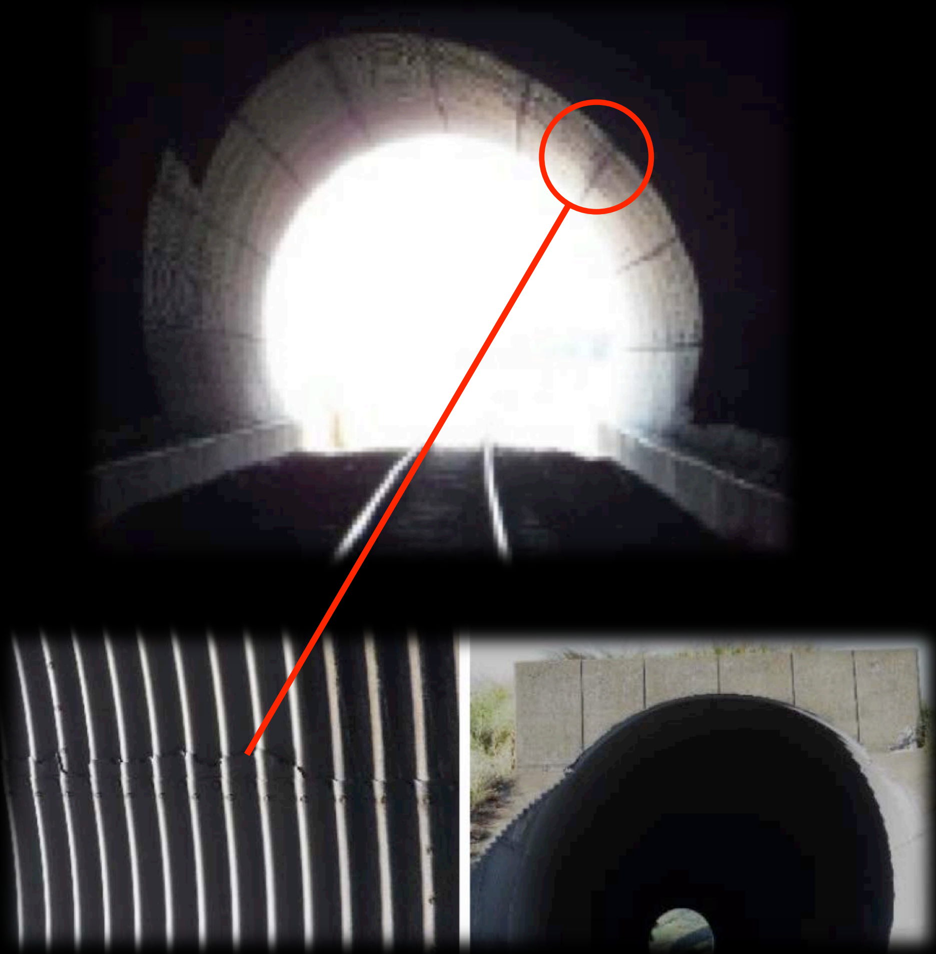
# Lessons Learnt from recent NZ earthquakes



Railway Corrugated steel tunnel

Slight tilt of South pier

Shear cracking in the piled footing

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# *Initiatives taken after the New Zealand Earthquakes*

# *Initiatives taken after the NZ Earthquakes*

- NZTA report 553, (2014). The development of design guidance for bridges in New Zealand for liquefaction and lateral spreading effects.

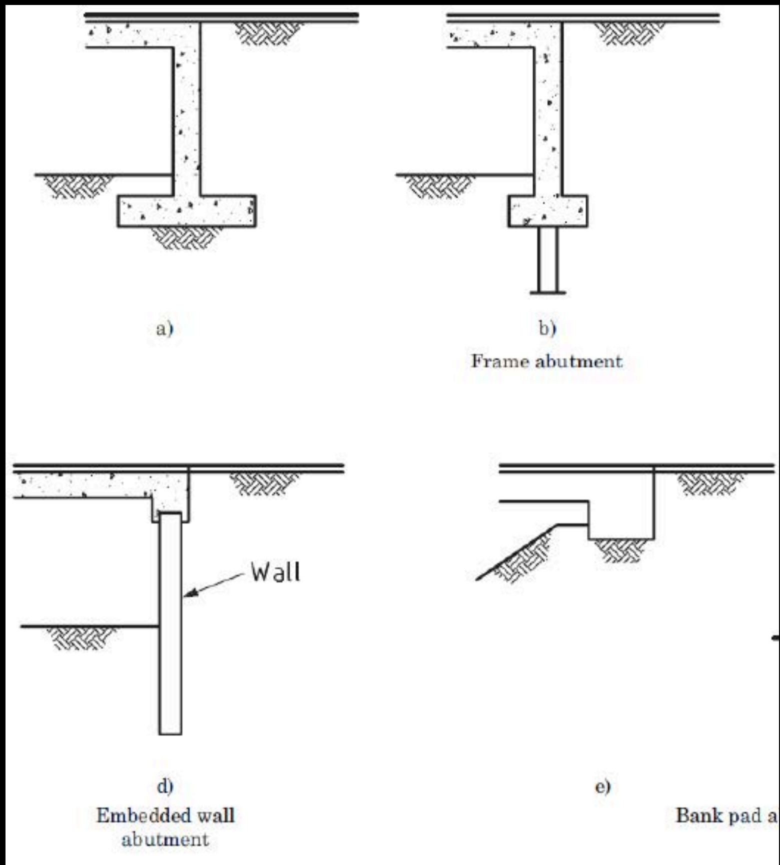
- NZTA (NZ Transportation Agency) Bridge Manual section 5 – Earthquake Resistant Design of Structures: inclusion of Displacement Based Design.

- NZTA (NZ Transportation Agency) Bridge Manual part 6 – Site Stability, foundations, earthworks and retaining walls: variation on the liquefaction part.

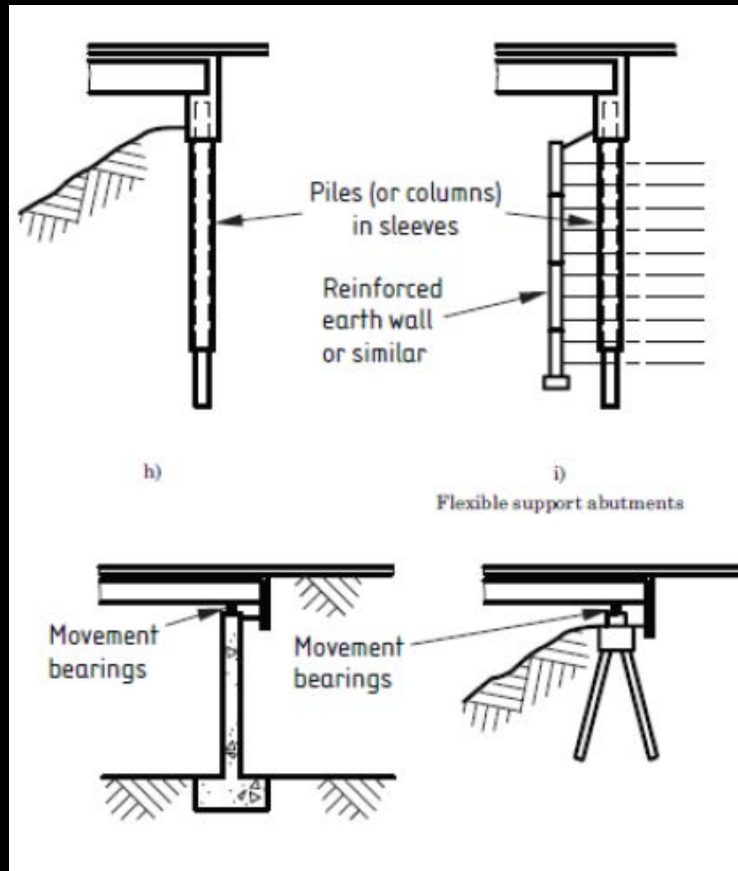
Pdfs all free-dowloadable from NZTA website!

# *Initiatives taken after the NZ Earthquakes*

- **NZTA report 577, (2015). Criteria and guidance for the design of integral bridges in New Zealand .**




**Fully integral bridge**




**Semi-integral bridge**

Pdfs all free-dowloadable from NZTA website!

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# *Shift towards post-earthquake repairabile connections*

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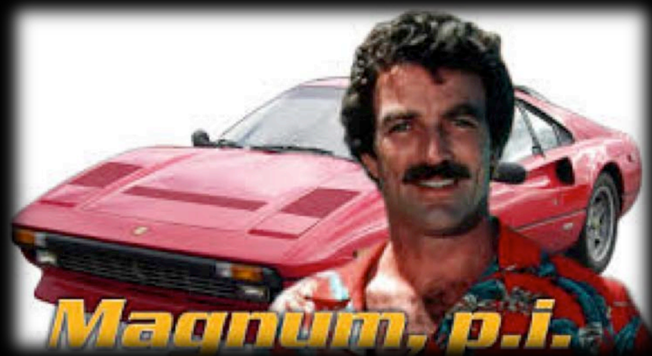
# *Shift towards post-earthquake repairabile connections*

*...In the 80s...*

*Civil Engineering*

*Lower Mason (1986)*

*Mechanical Engineering*




*Ferrari GTB 308*

*2017?*

*Ferrari 458*

Can we have higher seismic performance "specs" than Awatere Bridge?

***New Zealand Natural Hazard Research Platform***

University of Canterbury research programme for 4+4 year duration (October 2011-19, $ 900k)

## *Advanced Bridge Construction and Design for New Zealand (ABCD – New Zealand Bridges)*

**Scope of the project:** develop cost-competitive seismic resistant bridge systems which features aspects such as high-speed of construction and low life-time maintenance.

**Obj. 1:** Develop earthquake resistant bridge systems which features high speed of construction and/or low post-earthquake repair costs

**Obj. 2:** Guarantee long term seismic resilience by improving the durability of the materials and the seismic resistant connections

**Obj. 3:** Build robust modeling techniques and loss-estimation tools for an easier implementation in the Industry

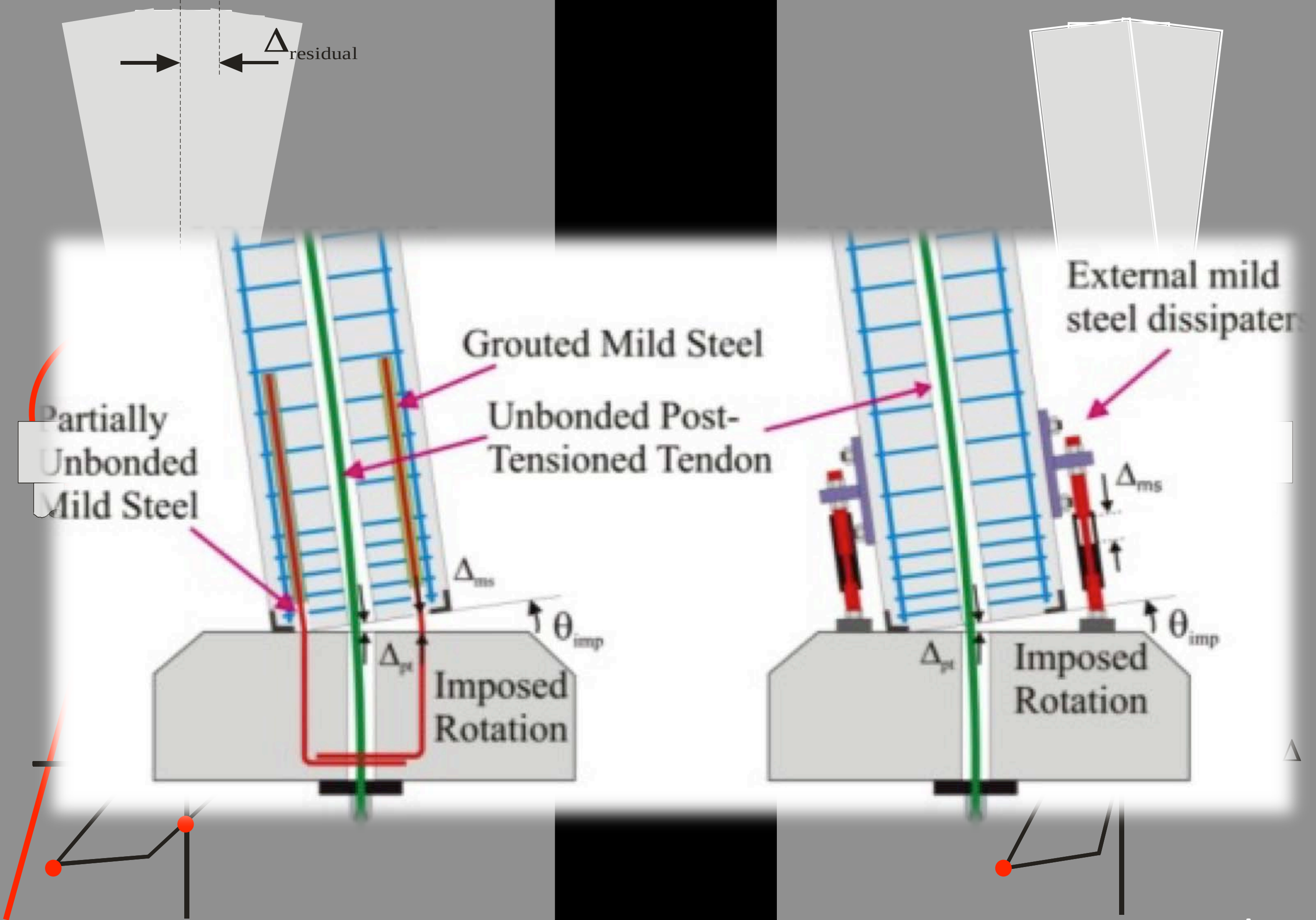
**End users:** NZ Transport Agency,  City Councils, Construction companies, Practitioners

# *Shift towards post-earthquake repairabile connections*

## Dissipative Controlled Rocking Design

Traditional (monolithic)

New generation (DCR)

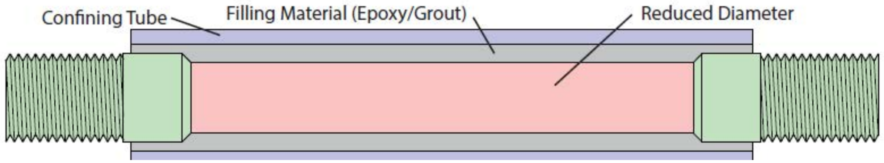



*Typically Accepted Damage*

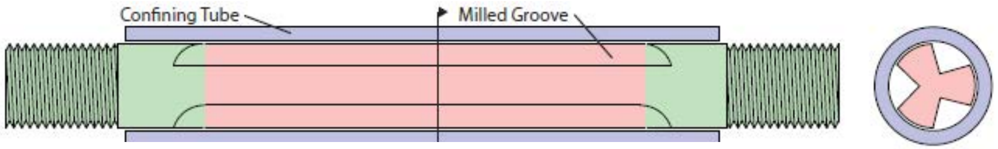
Marriott 2009, PhD Thesis)

# *DCR rocking design for bridges*

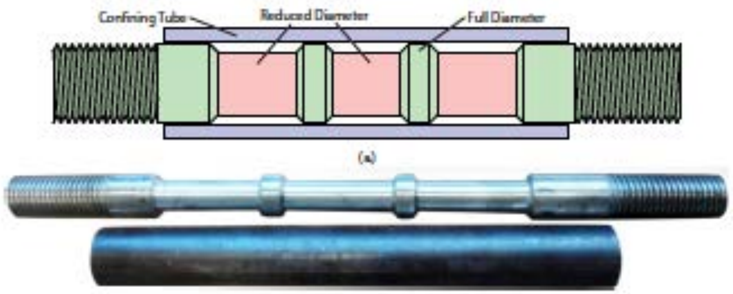
*Bar Dissipaters*




Conventional Buckling-Restrained Fused-type (BRF)

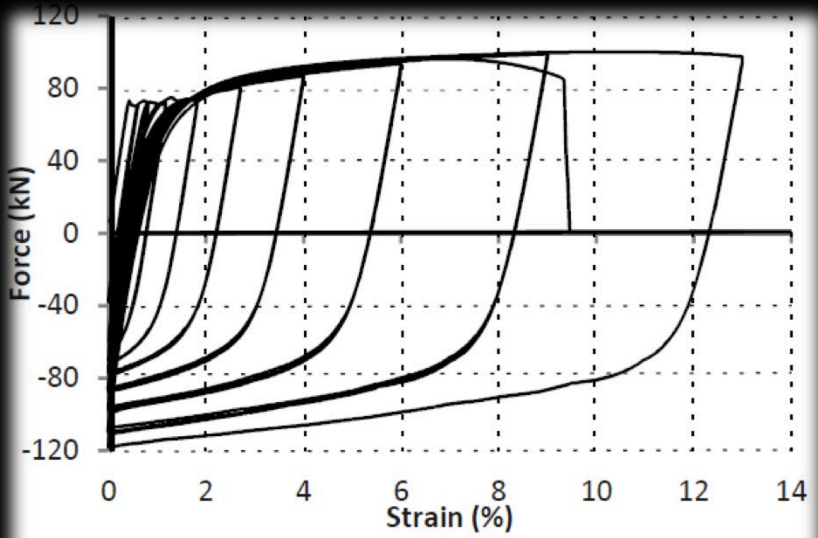



Grooved Bar Dissipater




“Multi-fuse” dissipater

*More than 100 tests including bi-axial loading*




(a) Force-strain behavior of grooved dissipaters

*Sarti et al. 2013, Marriott et al. 2009 Earth. Eng. Structural Dynamics, Kaveh et al. 2017, ASCE journal of bridge engineering (under review).*

# *Shift towards post-earthquake repairabile connections*

100 tons
Damper, built from
recycled steel

(Keats/Palermo/ Mashal)
patented device

***Dissipative Controlled Rocking (DCR)***

# *Shift towards post-earthquake repairabile connections*

Designer: Opus International Consultants supported by UoC
Owner: Christchurch City Council
Opened: July 2016


Site Location

**Courtesy of Jeremy Kelleher (Dec, 2016)**

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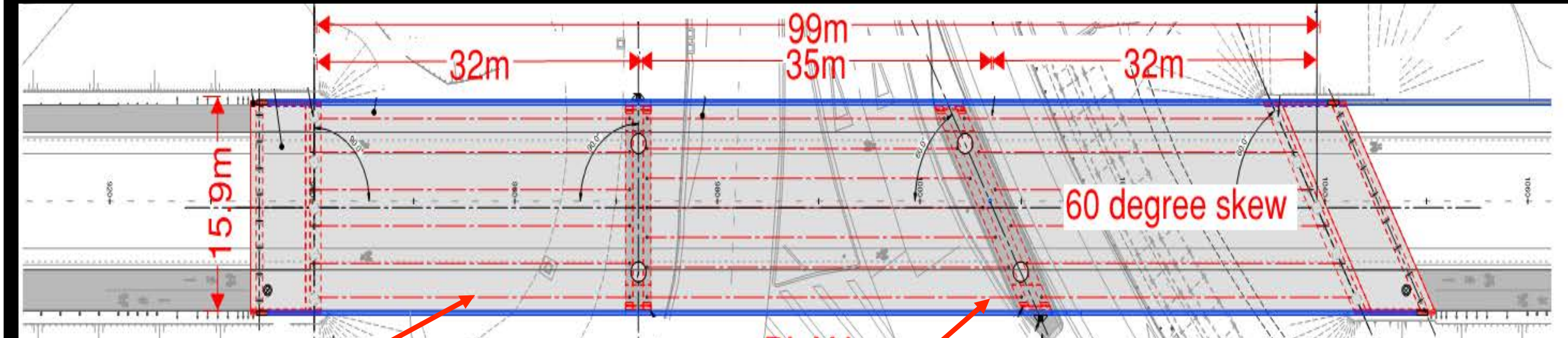
# *Shift towards post-earthquake repairabile connections*

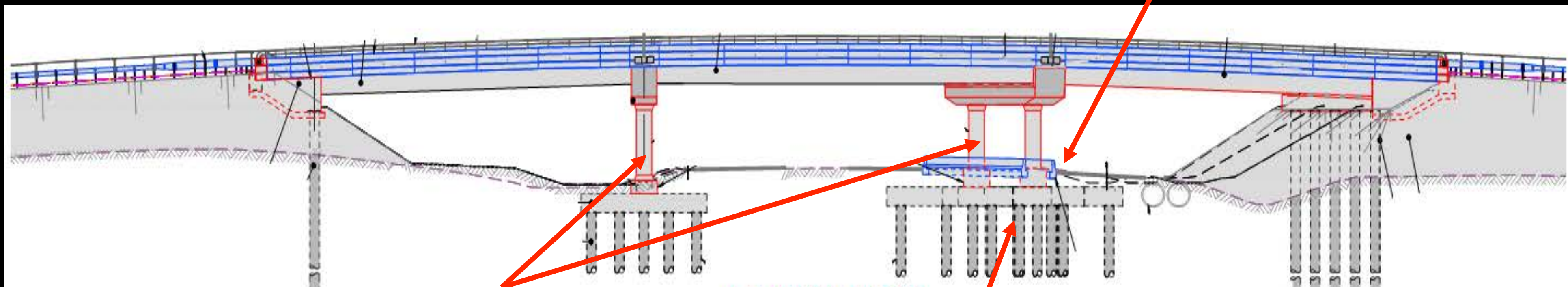
## The Wigram-Magdala Bridge Link, Christchurch, NZ




1525mm deep Super-tee beams with 200mm thick slab

In-situ pier headstocks

Concrete plinths

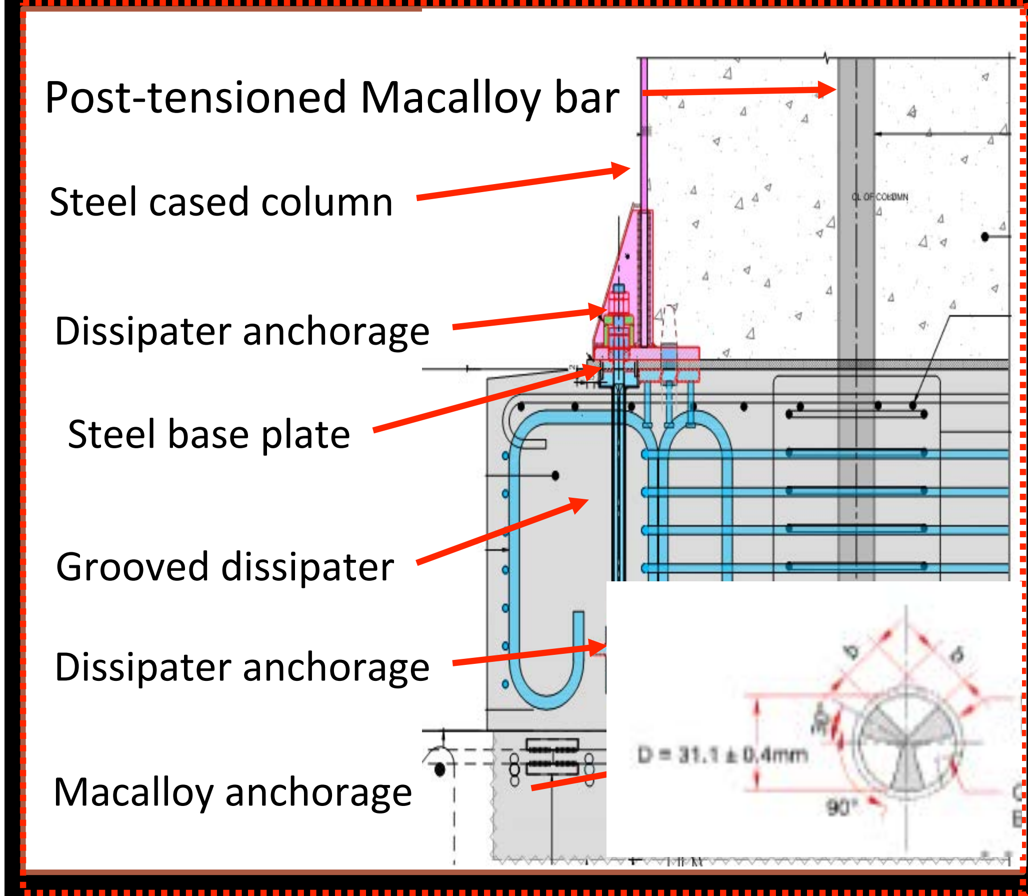


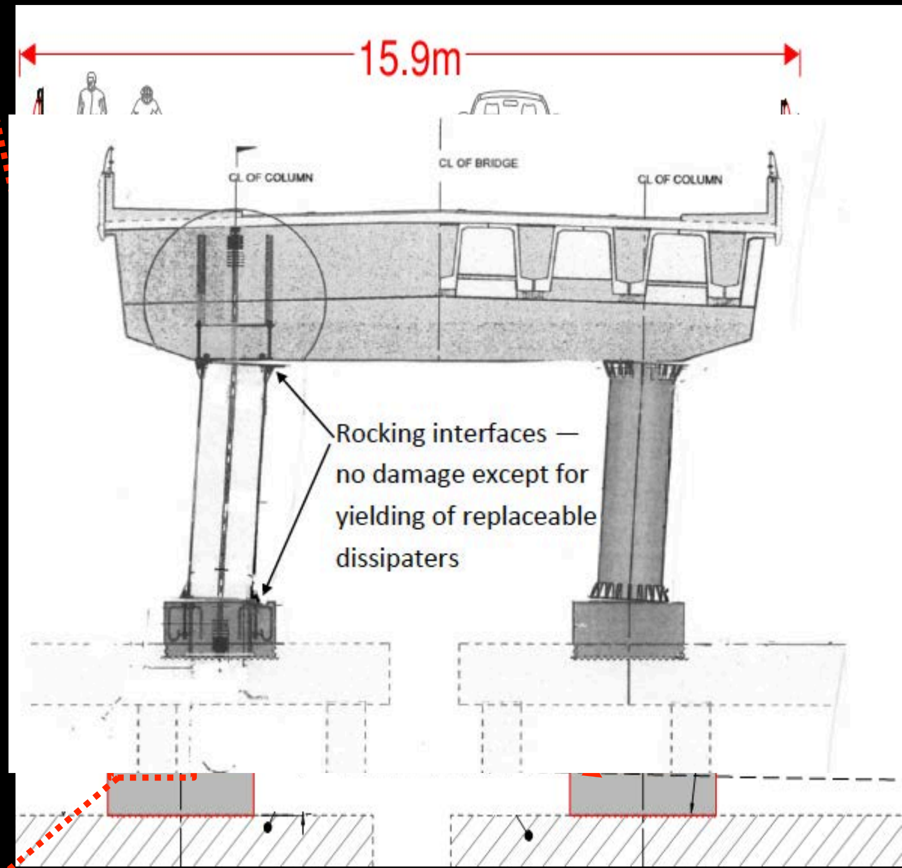
1500mm dia. steel cased columns with low damage connections

900mm diameter piles

# *Shift towards post-earthquake repairabile connections*

## *Dissipator detailing*



# *Shift towards post-earthquake repairabile connections*

Design detail of bridge piers: steel armoring and dissipators

# *Shift towards post-earthquake repairabile connections*

# *Shift towards post-earthquake repairabile connections*

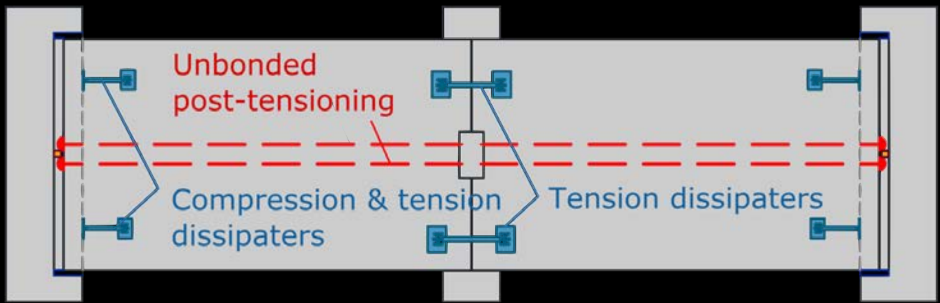


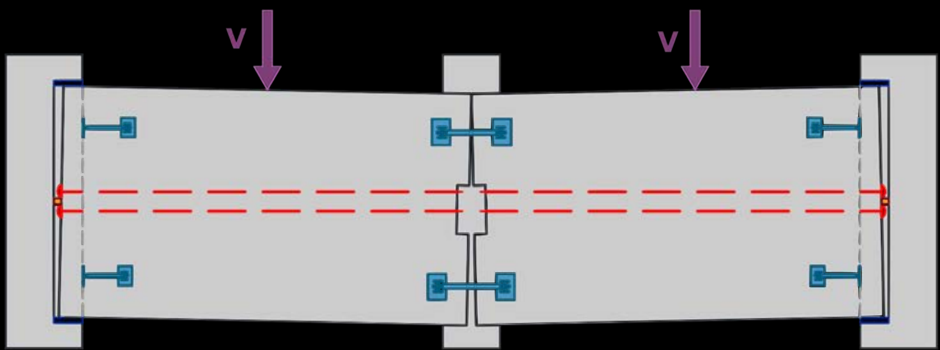


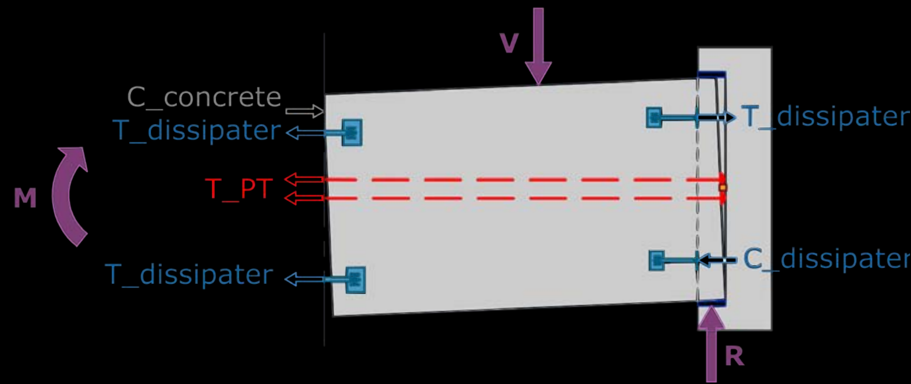
# *Shift towards post-earthquake repairabile connections*

NZTA Seismic Strengthening Program

DCR rocking design in the superstructure



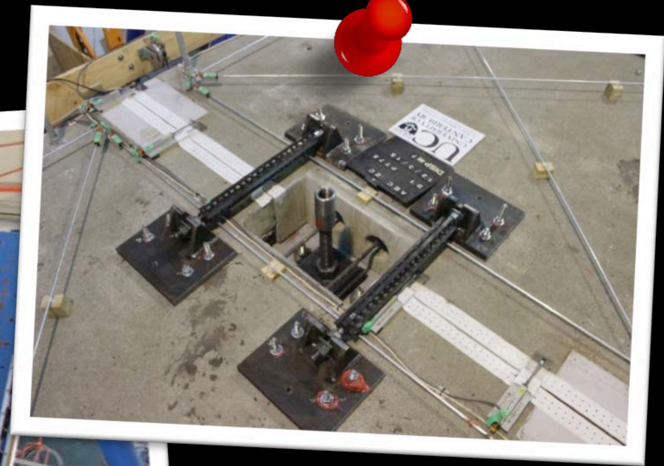



# *Shift towards post-earthquake repairabile connections*

**Concept → Realization**

Testing (will this actually work?)

*Quasi static cyclic testing (1:3 scaled prototype)*

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# *Research questions and opportunities for collaboration*

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# ?

Skew or curved bridges and their interaction with back-fill

Longitudinal seismic response of linked passive soil restraint abutments/flexible pier systems including effect of cyclic soil ratcheting.

Mono column/pile & twin column bent with column/piles: damping and stiffness (transversal response DBD).

Damping and stiffness from interaction at abutments (long response DBD).

DCR bridge piers and interaction with mono-pile and abutment-back-fill

DCR bridge deck and interaction with abutment-back-fill

# *Collaborations*

- ***Erskine Fellowships offered by University of Canterbury (1-3 months).***

- ***Co-funding with in-kind NSF research programmes:***

  a) EQC research proposal (under scrutiny) Cost-effective low damage piled foundations: A design “shift” for residential low-rise medium density buildings. **Start early 2018.**

  b) NZ Natural Hazard Research Platform: applications open in mid-June 2017. Proposal due by the of July 2017. **Start November 2017.**

## *Collaborations*

*If you want to go **fast** ... go **alone**!*

*If you want to go **far** ... go **together**!*

*(African Proverb)*