

4 September 2010 and 22 February 2011 Christchurch Earthquakes from a Transmission Grid Infrastructure Perspective



Asset Structural Performance and Lessons Learned

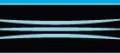
By Craig McGhie and Christophe Tudo-Bornarel

TRANSPOWER

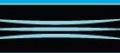
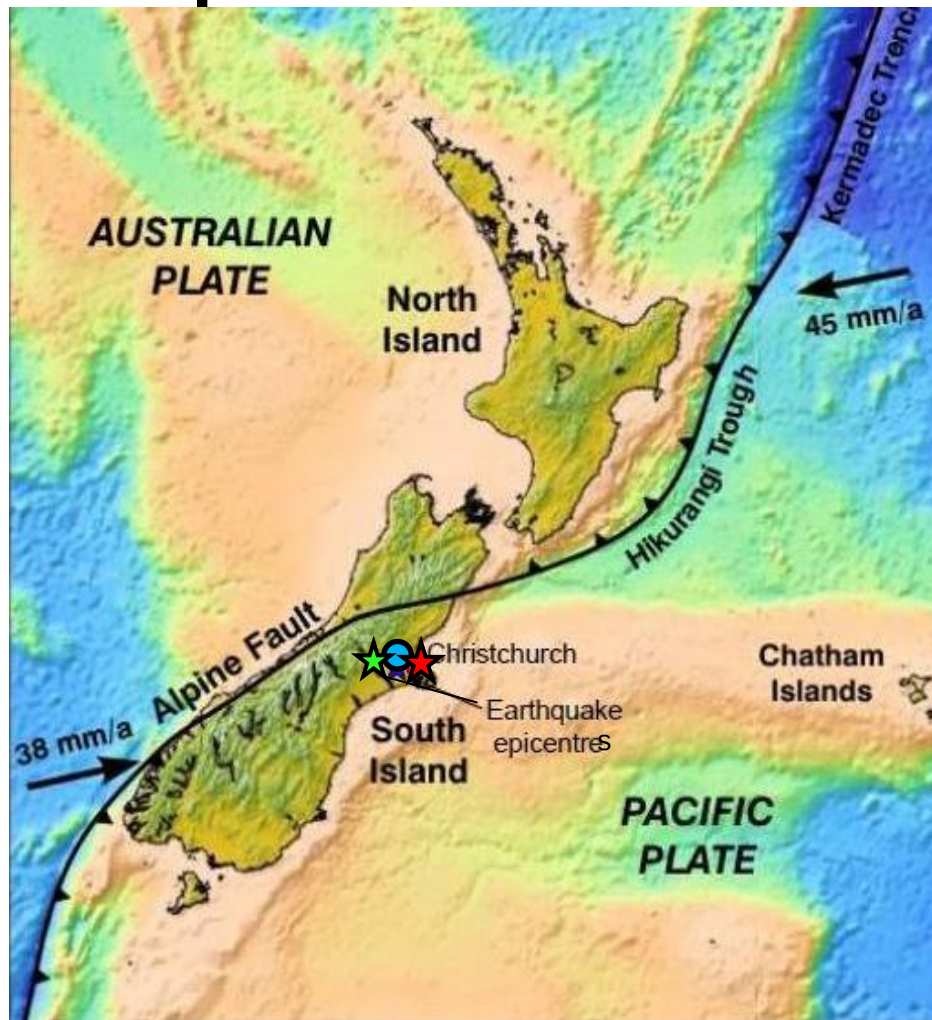


Key Points

- Overall the transmission grid performed well.
- The transmission grid in the Canterbury region experienced considerable variation in the nature and level of seismic loading.
- Transpower experienced a small number of equipment breakages and transformer trips in both events.
- Earthquake risk identification and strengthening programmes following 1987 Edgecumbe earthquake paid dividends.
- Further/continuing work required to identify risks and built resilience into transmission grid.



Earthquake - In Summary



Earthquakes & Aftershocks

- ★ 4 Sep 2010 4:36am, M7.1, 10km deep, 40km West of CHC
- ★ 22 Feb 2011 12:51pm, M6.3, 5km deep, 10km SE of CHC

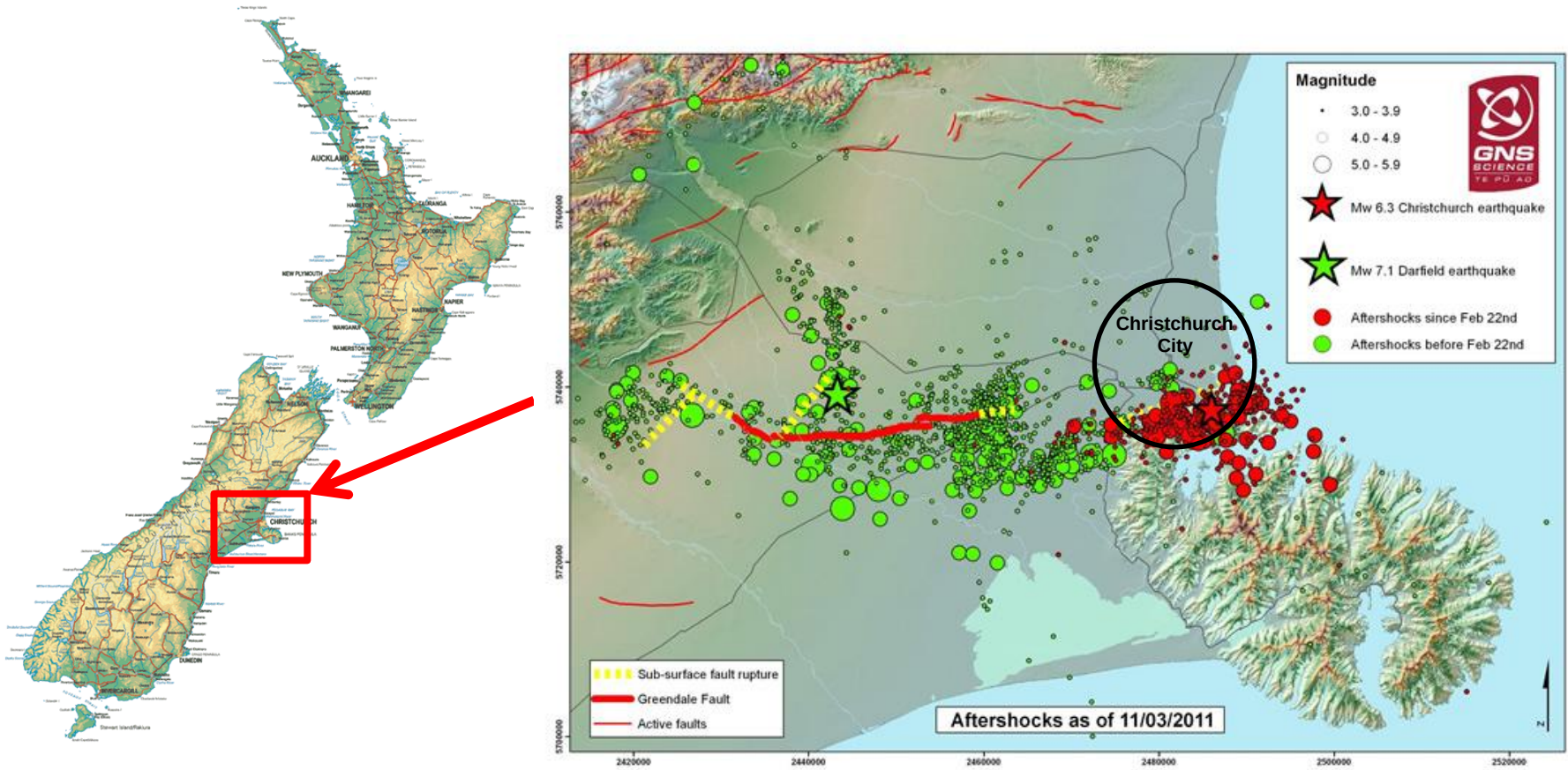


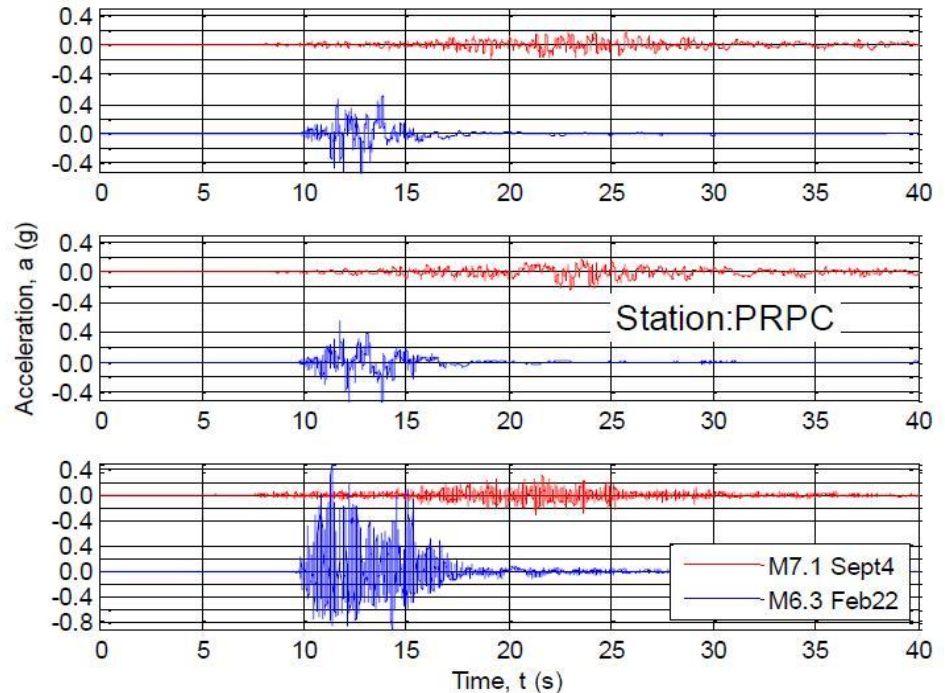
Image Courtesy of GNS

Earthquake Accelerations

Peak Ground Accelerations

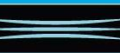
Direction	Darfield 4 Sept 2010	Christchurch 22 Feb 2010
Horizontal PGA	0.8g	1.7g
Vertical PGA	1.25g	2.2g

Ground accelerations recorded at Pages Road Pumping Station approximately 1.5km NW of Bromley Substation



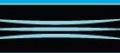
Courtesy Brendon Bradley, from NZSEE database website
http://db.nzsee.org.nz:8080/en/web/chch_2011/home

Data source GNS

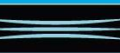
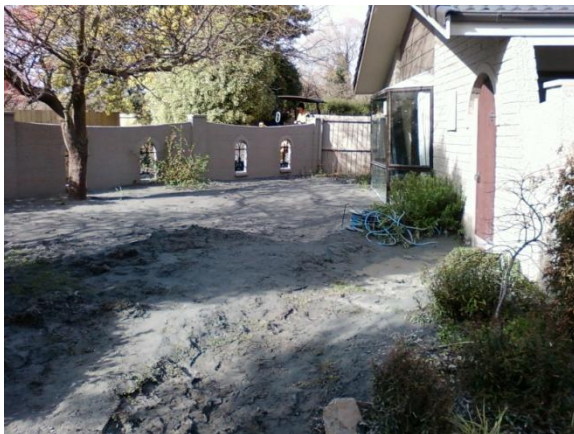


Darfield Earthquake

- Saturday, 4 September 2010 at c. 4:36 a.m. local time
- Magnitude 7.1, 40 km West of Christchurch at a depth of 10km
- 0 fatalities, only 2 serious injuries
- Surface rupture of c. 29 km, with strike-slip displacements of up to 4m.
- Shaking damage
 - predominantly confined to pre-1930's brick and un-reinforced masonry structures.
- Liquefaction, lateral spreading and surface rupture damage
 - Significant damage to residential buildings, lifeline infrastructure (power, water, wastewater), and roads.
- Cost: Estimate of \$4 billion

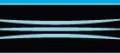


Darfield Earthquake



Christchurch Earthquake

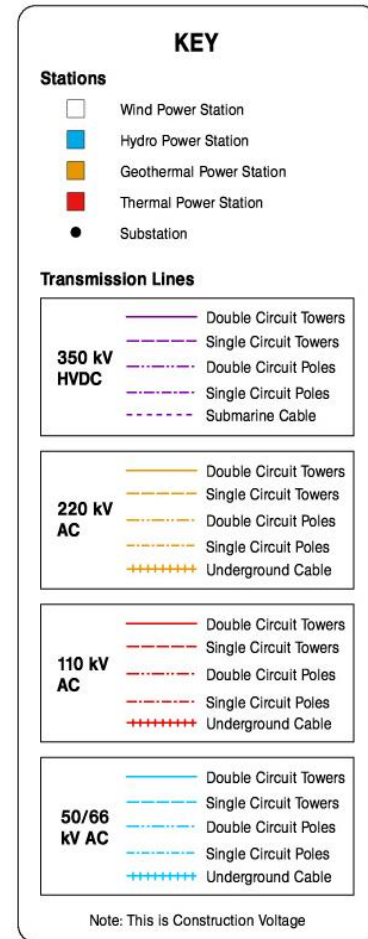
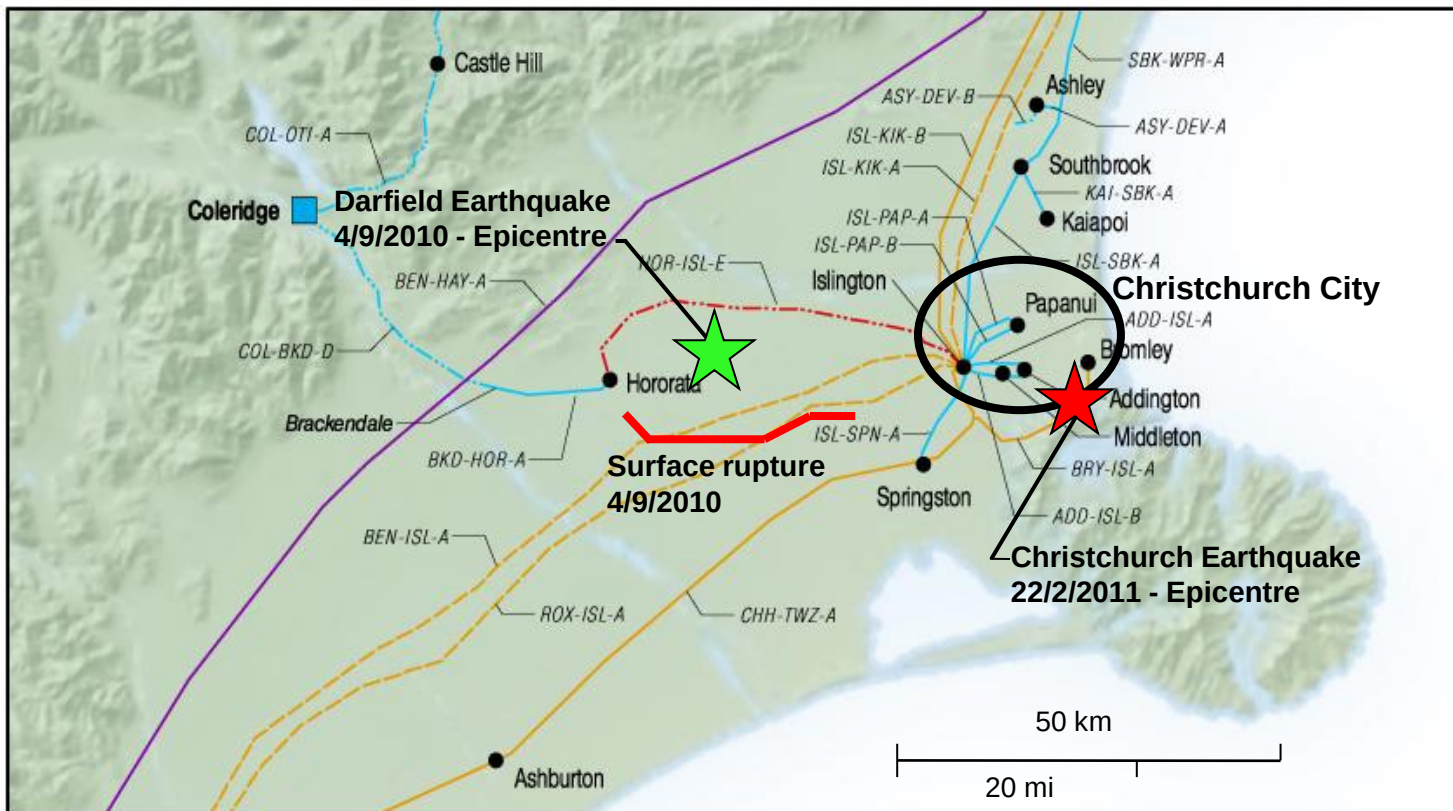
- Tuesday, 22 February 2011 at 12:51 p.m. local time
- Magnitude 6.3, 9 km SW of Christchurch CBD at a shallow depth of 5km
- 181 fatalities and 161 seriously injured
- Shaking damage
 - Widespread damage with collapse of many buildings.
 - Over 1000 buildings requiring demolition in the CBD
- Liquefaction, lateral spreading and surface rupture damage
 - Extensive damage to residential buildings, lifelines (power, water, wastewater), and roads.
- Slope stability and rock fall damage
 - Extensive damage residential buildings and roads.
- Cost: estimate of \$16 billion



Christchurch Earthquake



Transmission Network and Assets



Earthquakes Impact

DARFIELD EARTHQUAKE – 4 SEPTEMBER 2010

- Minor damage to Transmission infrastructure
- Loss of Service, restored 8:30 a.m. (4 hours after event) with 100% capacity and n-1 security

CHRISTCHURCH EARTHQUAKE – 22 FEBRUARY 2011

- Minor damage to transmission infrastructure at Bromley substation
- Further minor damage at Papanui substation
- Loss of Service, restored 17:29 p.m. (4 hours:40min after event) with 100% capacity and n security at Bromley substation



Physical Damage

Darfield Earthquake

- Minor cracking of control buildings
- Dislodgement of base isolated control cabinet at ROC
- Spare 66kV CT (two damaged)
- Fractured 220kV Surge arrestor
- Cracked yard slabs and transformer bunds
- ISI-PAP B 66kV line failed terminal span
- BEN-ISL A 220kV line bent earth peak
- BEN-ISL A and ROX-ISL A insulator displacement
- Collapsed storage racks at warehouse.
- Tripping of mercury and aseismic switches on transformers

Christchurch Earthquake

- Minor cracking of control buildings
- Fractured 66/11kV transformer bushing (two damaged)
- Fractured 220kV CVT
- Damaged 11kV Switchgear
- Cracked yard slabs and transformer bunds
- Collapsed storage racks at warehouse.
- Tripping of mercury and aseismic switches on transformers

Physical Damage - Substations

Darfield Earthquake



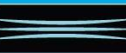
Hororata substation

- 1940's reinforced concrete crane building sustained large shear cracks but repairable.
- Damaged spare 66kV CT



Islington substation

- 220kV surge arrester mounted on top of radiators failed
- Control cabinet dislodged from base isolation unit at Islington ROC



Physical Damage - Substations

Darfield Earthquake

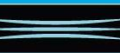
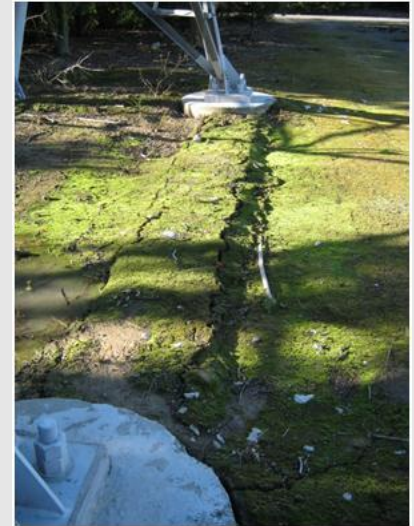
Papanui Substation



- Liquefaction and minor differential settlement.
- Transformer bund walls and shallow pads with minor cracks



- ISL- PAP B Failed termination span at gantry connection.
- Liquefaction settlement around tower bases



Physical Damage – Substations

Christchurch Earthquake

Bromley Substation



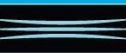
Failure of one 220 kV CVT
BRY-ISL1 RFS



Failure of two HV bushings on
T2 (66kV/11kV)



Damage to 11 kV switchboard;
remained operational during the
event – is being replaced



Physical Damage – Substations

Christchurch Earthquake

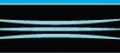
Bromley Substation (cont)



- Intense liquefaction with silt and water covering part of the switchyard
- Foundations remained largely unaffected



- Only minor non-structural damage to control/relay building



Physical Damage – Substations

Christchurch Earthquake

Papanui substation



- Damaged during September 2010 earthquake; further liquefaction and soil settlement around the transformer bunds
- New cracks in slab and bund walls



- Yielded holding down bolt supporting cable termination support structure.



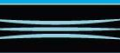
Physical Damage - Warehouse

Christchurch Earthquake

Addington Warehouse



- Collapsed shelving units.
- Similar damage occurred during Darfield earthquake.
- All shelf units to be replaced.

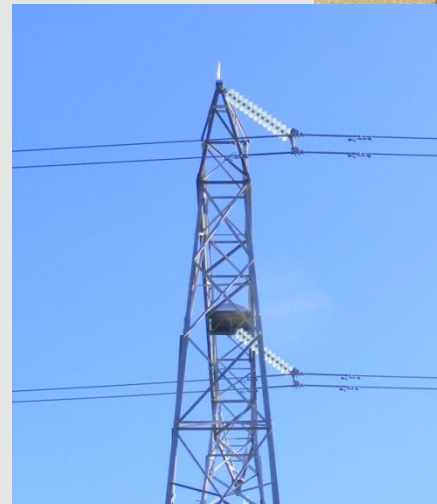
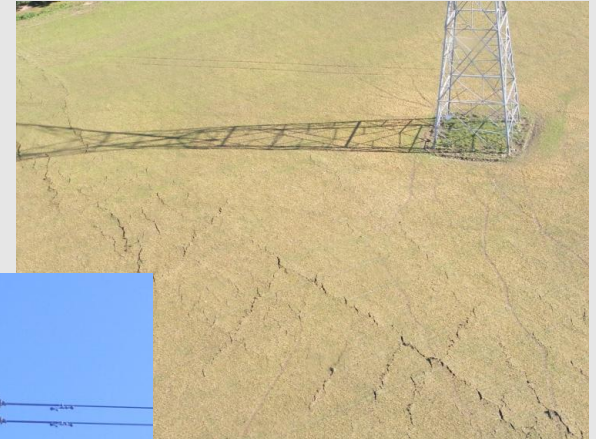


Physical Damage - Transmission Lines

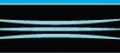
Darfield Earthquake



- Liquefaction caused 3 towers on BRY-ISL A 220kV line to lean.
- Remediation to be carried following cessation of aftershocks.



- Fault line cutting the 220kV lines alignment at 45deg angle, strike-slip displacements of 2-4m.
- Insulators displaced (shown) and bent earthwire peaks resulted.

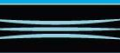


Physical Damage - Transmission Lines

Christchurch Earthquake

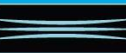


- Liquefaction around piles on BRY-ISL A 220 kV line and ISL-PAP A & B Lines.
- Towers remained stable and no loss of service occurred due to liquefaction.

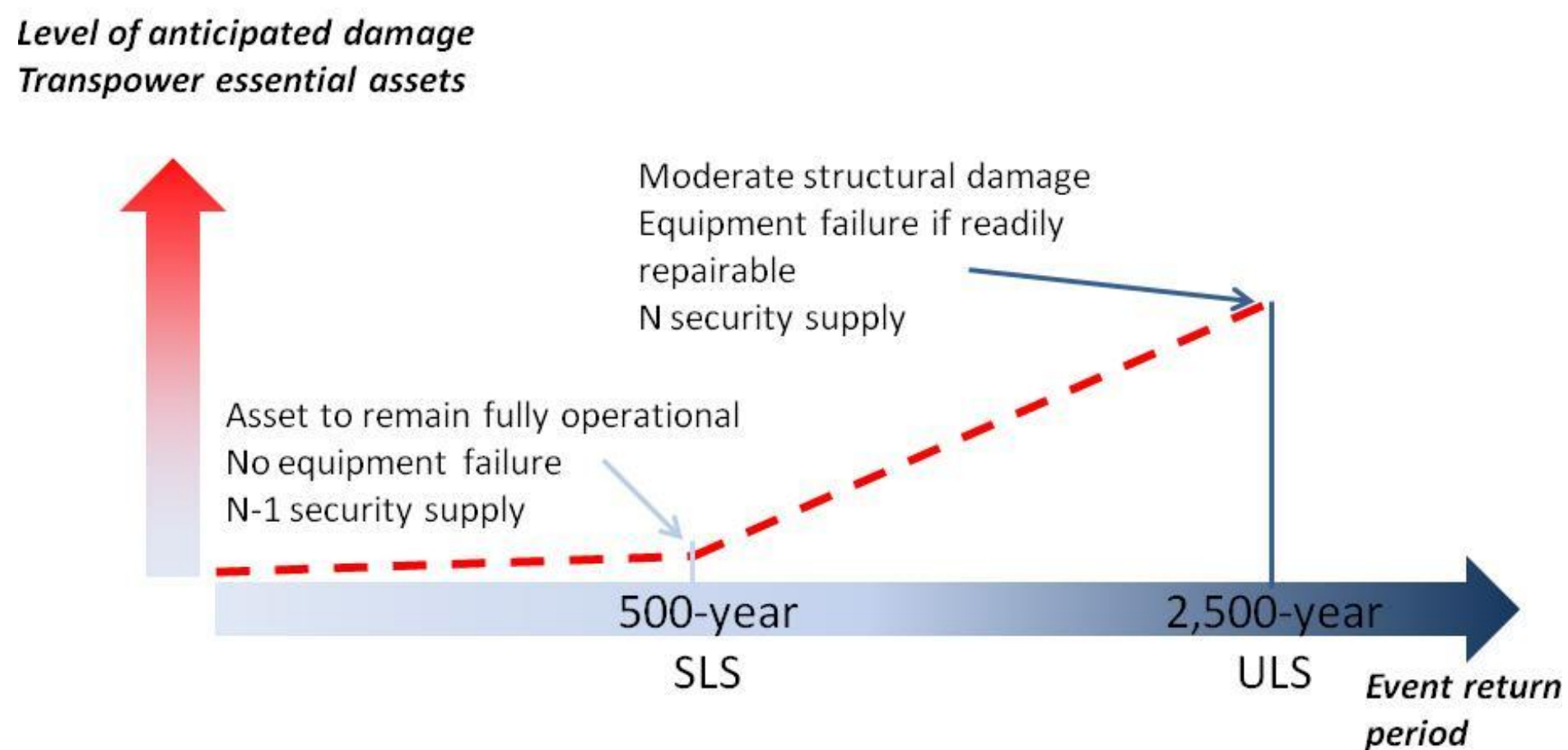


Transpower Seismic Policy

- Civil Defence and Emergency Management Act 2002 require Transpower to “ensure it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency”.
- Essential buildings and facilities are deemed Category 4 structures in terms of AS/NZS 1170.
- ULS – 2500 year return period event. Reduction permitted where spares available.
- SLS – 500 year return period event.
- Equipment purchase to comply with IEEE693:2005



Transpower Seismic Policy



Transpower Seismic Policy – Existing Assets

- Essential buildings (e.g. substation) shall be strengthened to, at least, 75% of new building standards
- Program to assess all essential buildings 2011, 2012
- Building strengthening work proposed 2012 to 2015
- Retrofit seismic restraints for transformers has been completed.
- Equipment shall be assessed with respect to remaining service life. Risk mitigation and availability of spares.

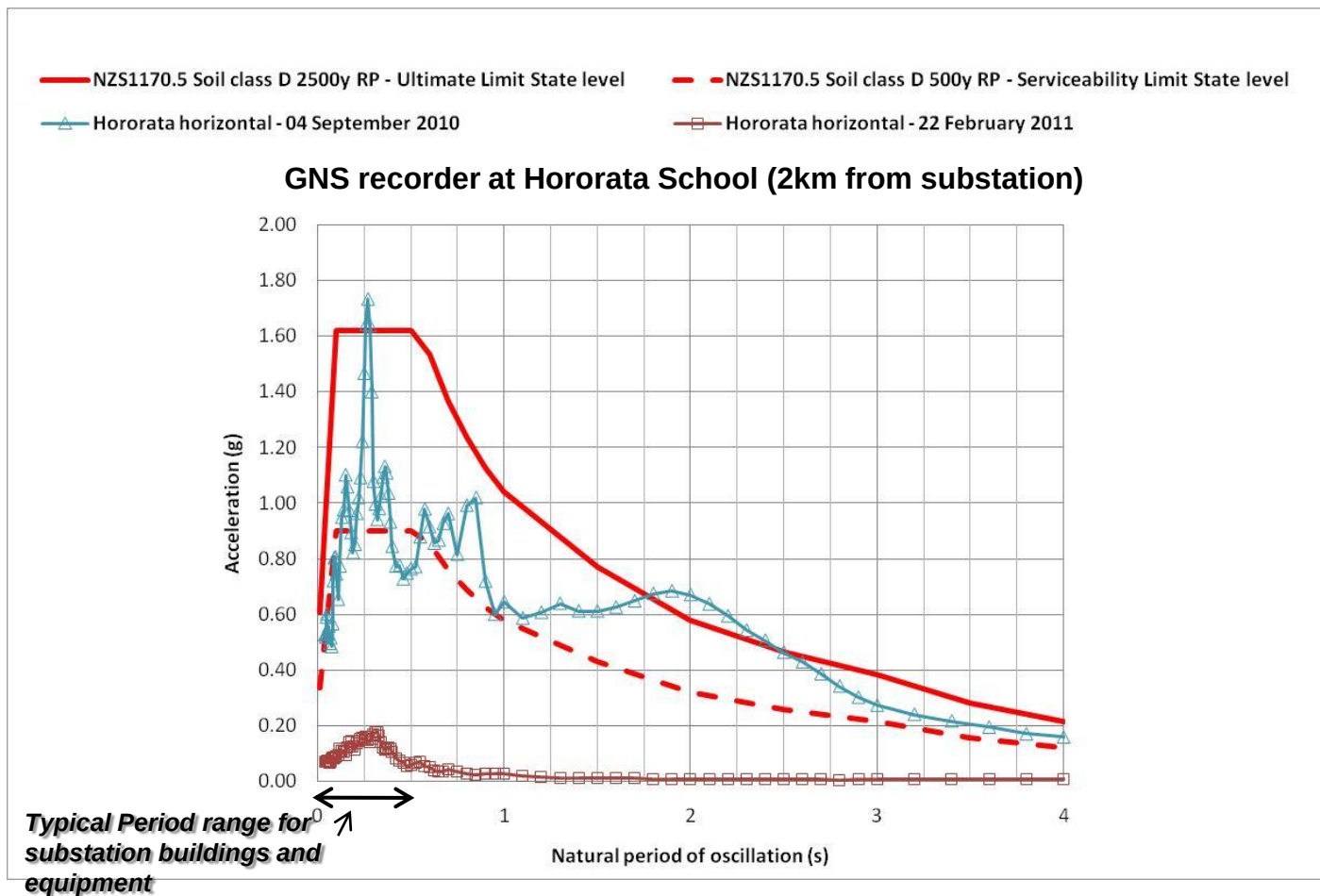


Structural Performance

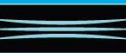
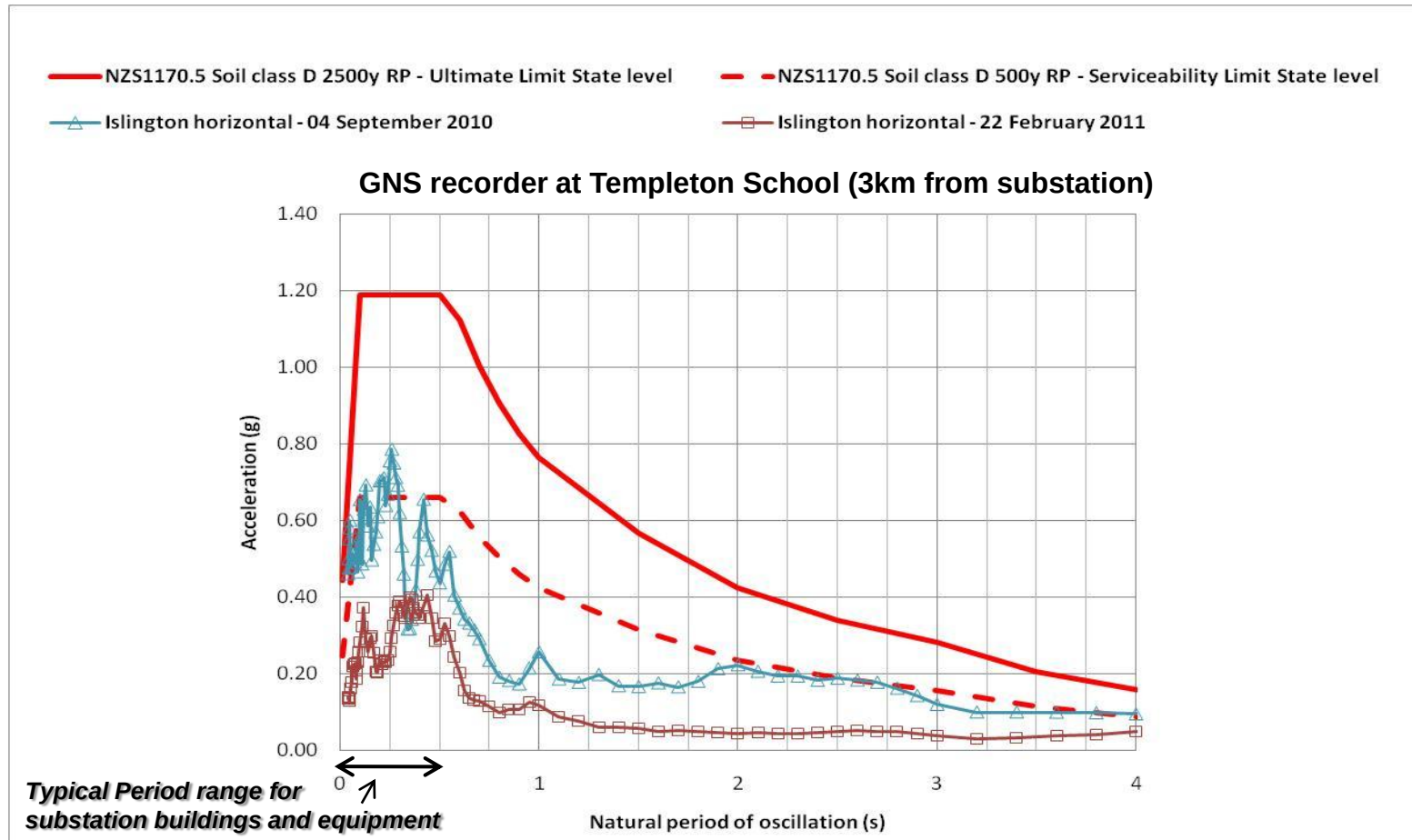
- Earthquake response spectra was generally in the range from SLS (500 year RP) to ULS (2500 year RP).
- Some damage and disruption was to be expected, but there were notable exceptions (e.g. ISL 220kV Surge Arrestor).
- The performance of aged infrastructure (pre seismic standards) was above expectations.
- The length of time to put the grid back in service was as much a function of the time it took to undertake safety inspections, given the transport issues post earthquakes, than poor structural performance.



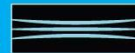
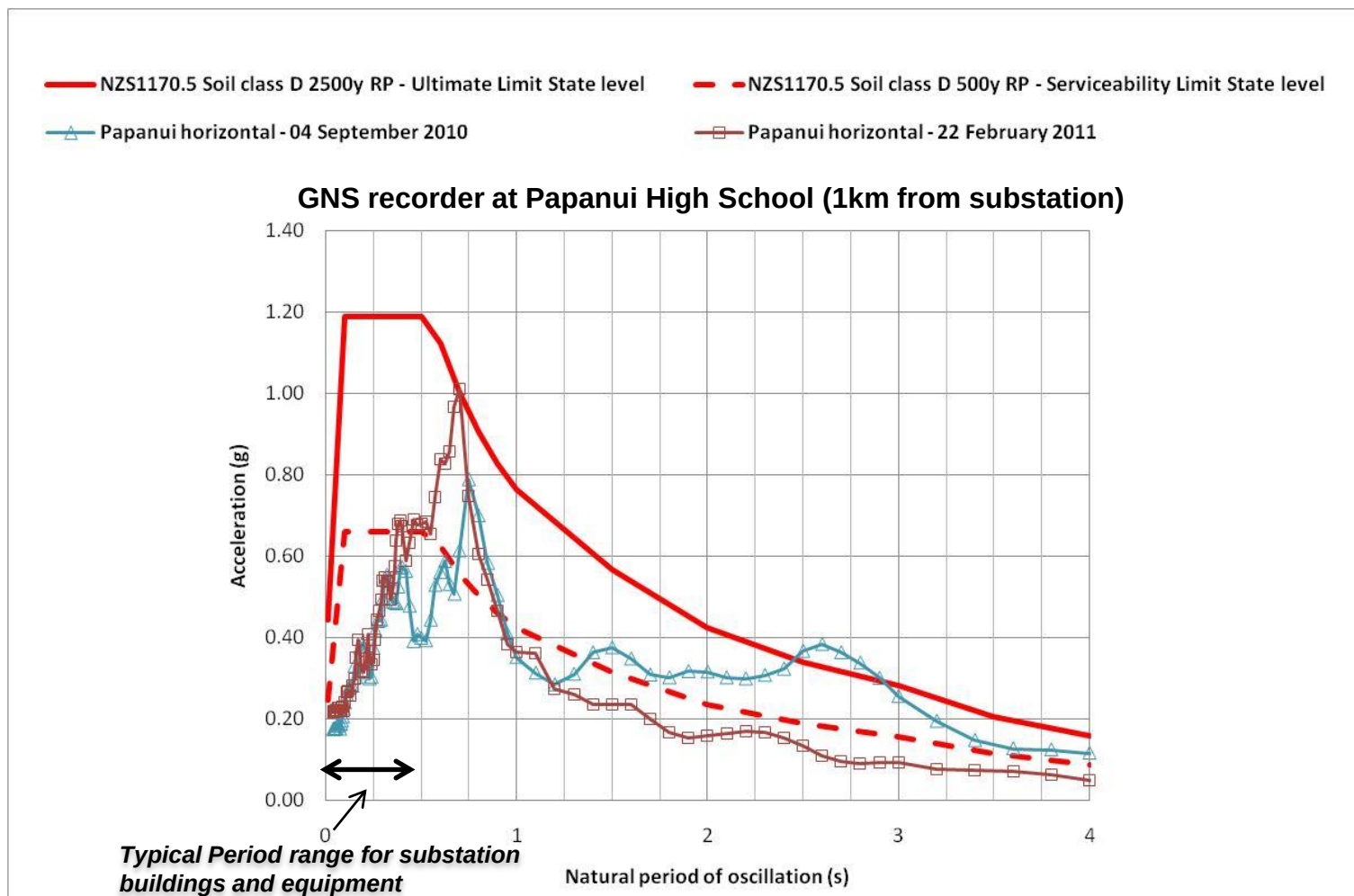
Darfield vs Christchurch Earthquake Spectra Hororata Substation



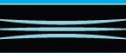
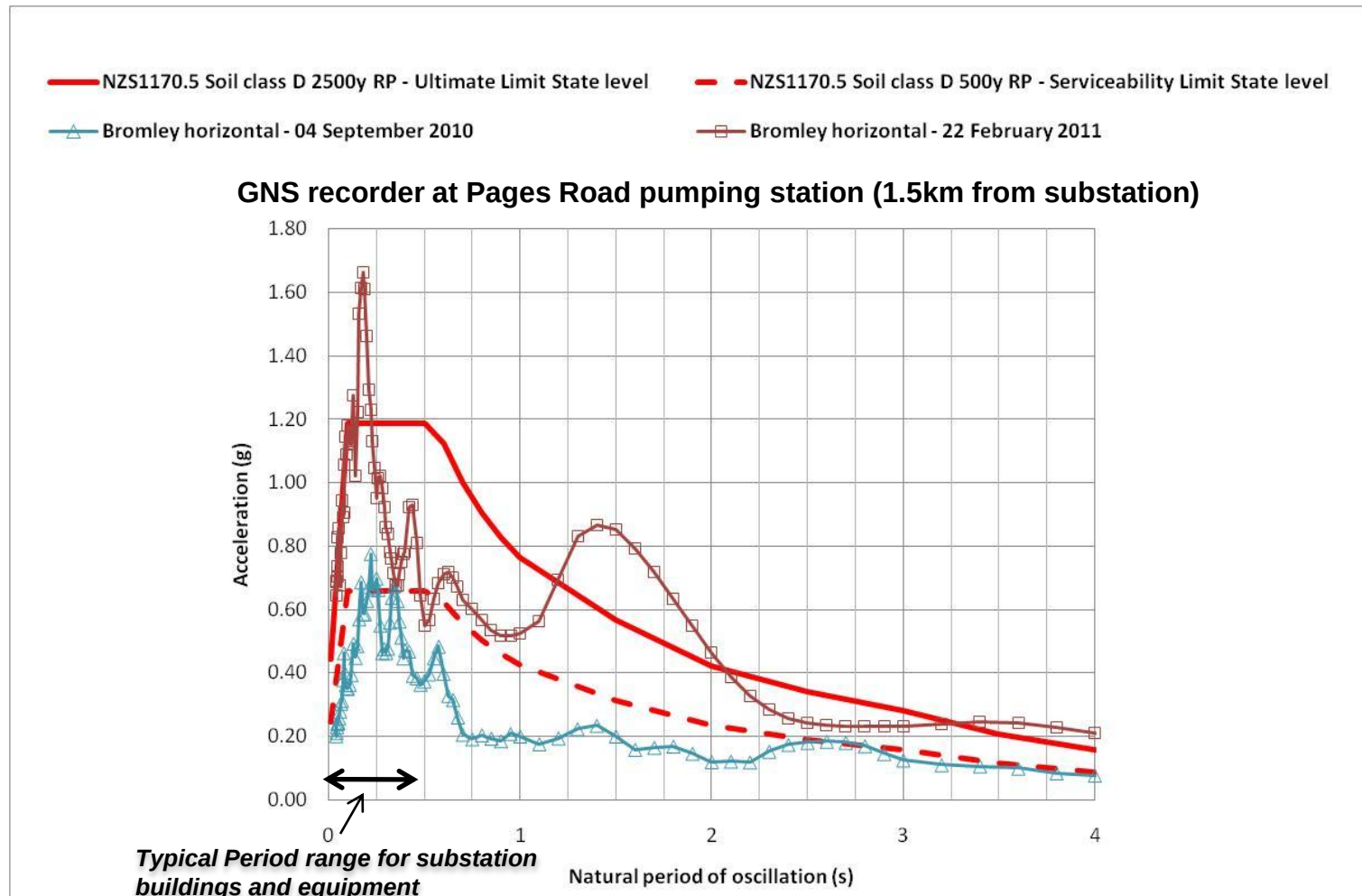
Darfield vs Christchurch Earthquake Spectra Islington Substation



Darfield vs Christchurch Earthquake Spectra Papanui Substation



Darfield vs Christchurch Earthquake Spectra Bromley Substation



Lessons learnt

- Priority - replace old mercury switches on transformers.
- The benefits of the seismic restraint programme undertaken in the 1990's following the Edgecumbe earthquake were realised in these events.
- Transpower is to continue to support the development of international seismic design standards for HV equipment.
- Further identification and mitigation of earthquake risk to the transmission network is required to provide resilience.



Transformer damage Edgecumbe 1987

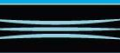


Transformer seismic restraints Hororata



Conclusions

- These earthquake events were a good test of the transmission network in the Canterbury region.
- Structure performance was satisfactory, but improvements can be made.
- The benefits of previous seismic strengthening programmes were realised in these events.
- Our work is not done:
 - participate in the development of international seismic design standards
 - identify and mitigate earthquake risk to the network
 - Continue to build a resilient system.



Other slides



Earthquake damage



Monitoring technology to prevent instability

