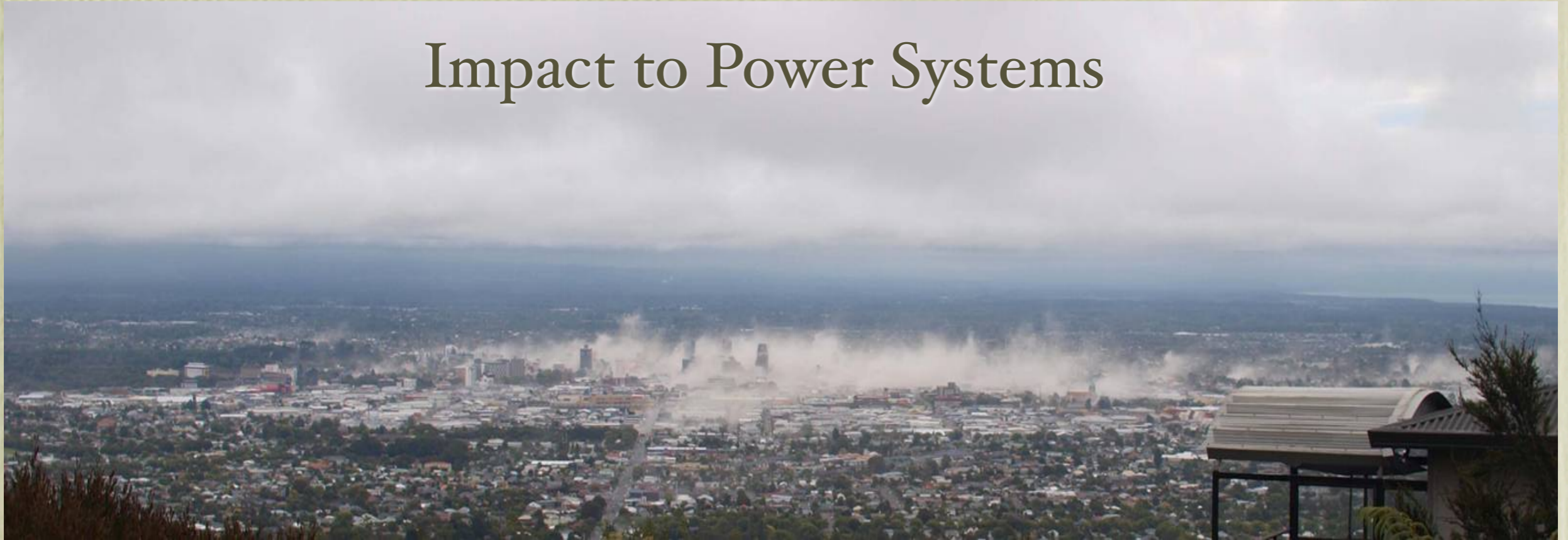


Christchurch, Feb 22 2011 and Sept 4 2010

## Impact to Power Systems



Looking North, from the Port Hills

John Eiding  
G&E Engineering Systems Inc.  
[eidinger@geEngineeringSystems.com](mailto:eidinger@geEngineeringSystems.com)

M 7.1 Canterbury Earthquake Sept 4 2010  
M 6.3 Christchurch Earthquake Feb 22 2011

## Impact to Electric Power Systems

ASCE - Structural Congress

April 14, 2011

John Eiding

G&E Engineering Systems Inc.

[eidinger@geEngineeringSystems.com](mailto:eidinger@geEngineeringSystems.com)

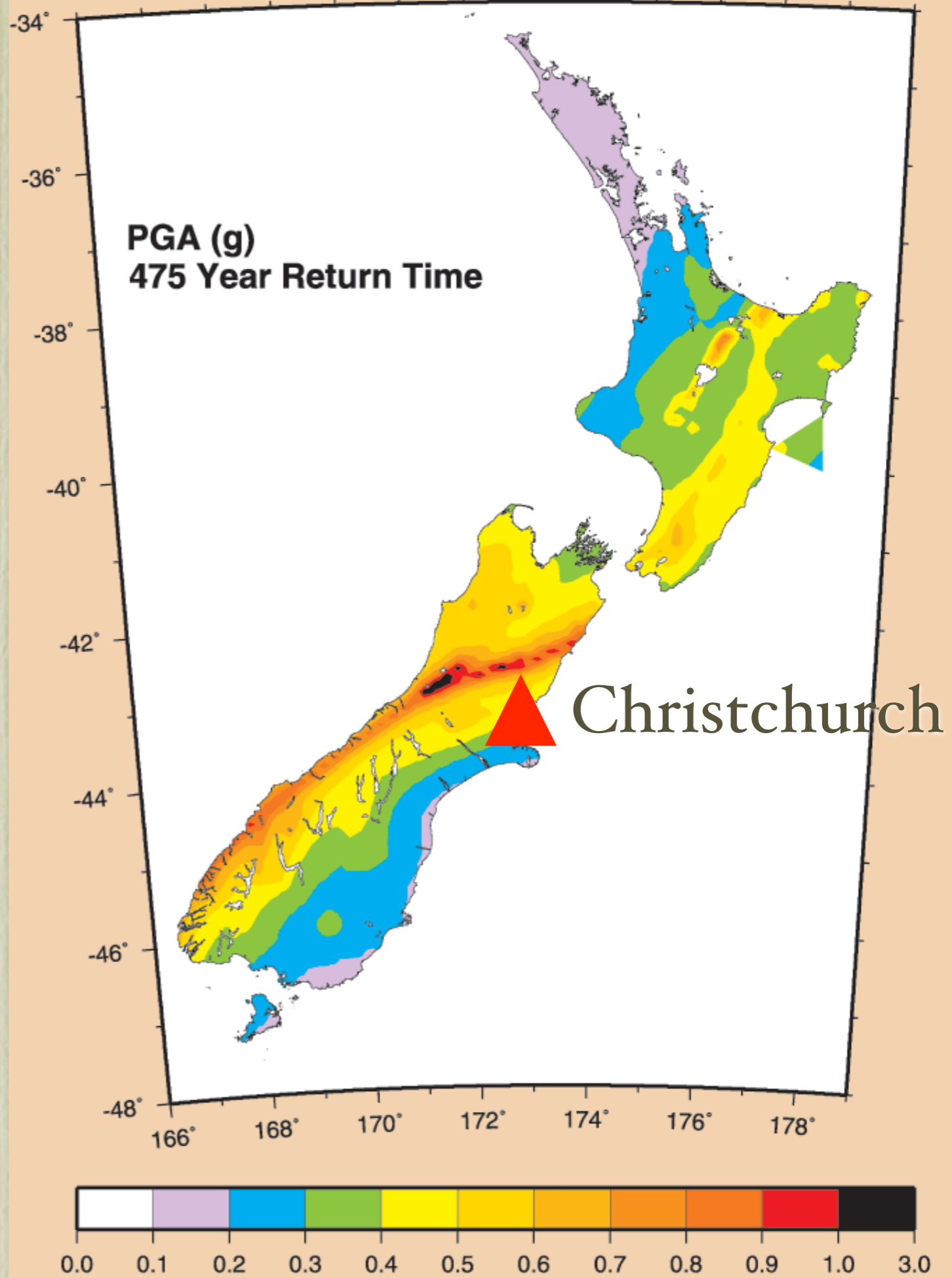
# Key Observations

- 220 kV Substations: IEEE 693, some damage, restoration times rapid
- 66 kV Substations: URMs retrofitted, 265/268 performed well; 3 failed completely
- 11 kV, 66 kV buried cables: widespread damage, long outages
- Power outage times:
  - M7.1 ~ 90,000,000 customer-minutes.
  - M6.3: ~ 500,000,000 customer-minutes

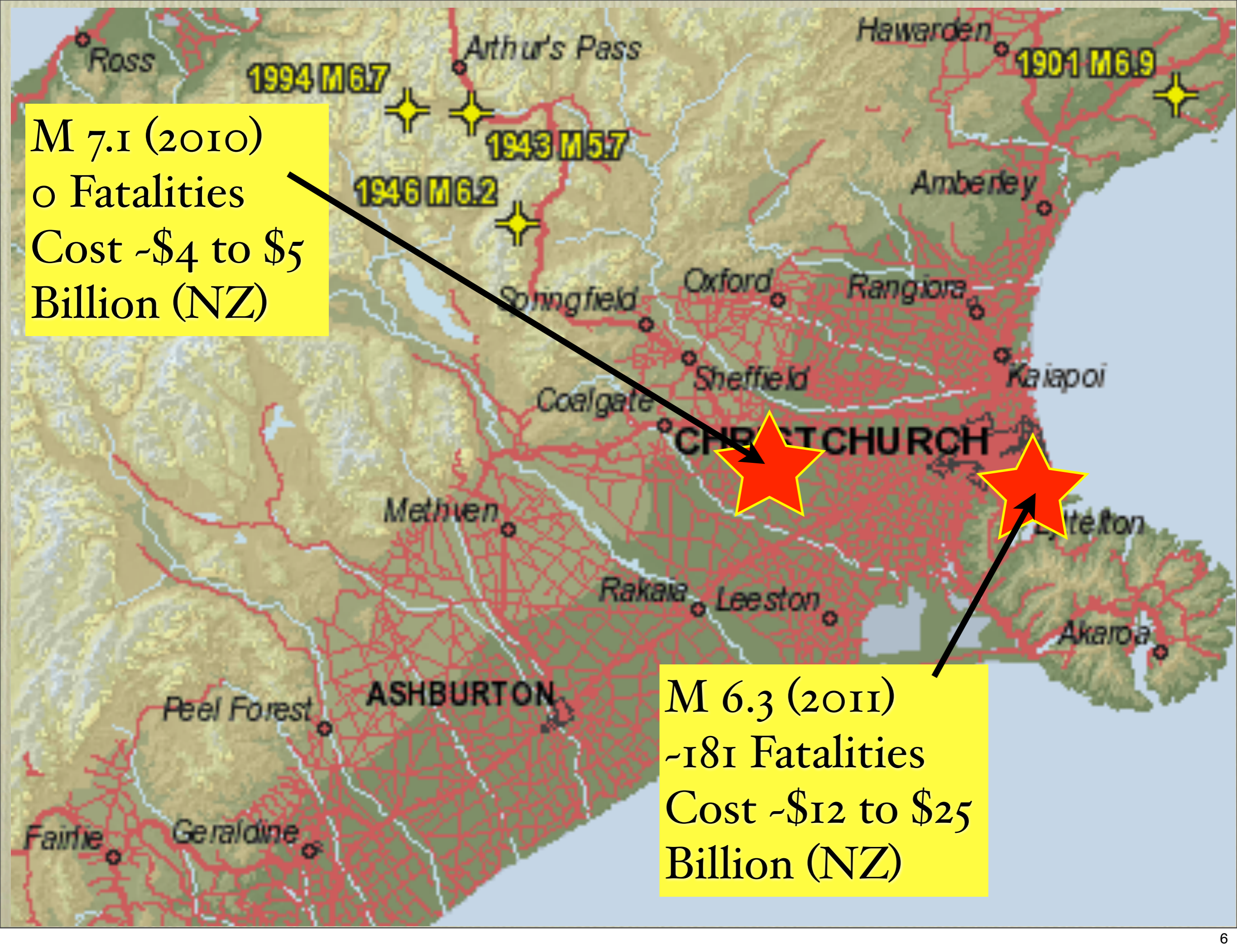
# New Zealand



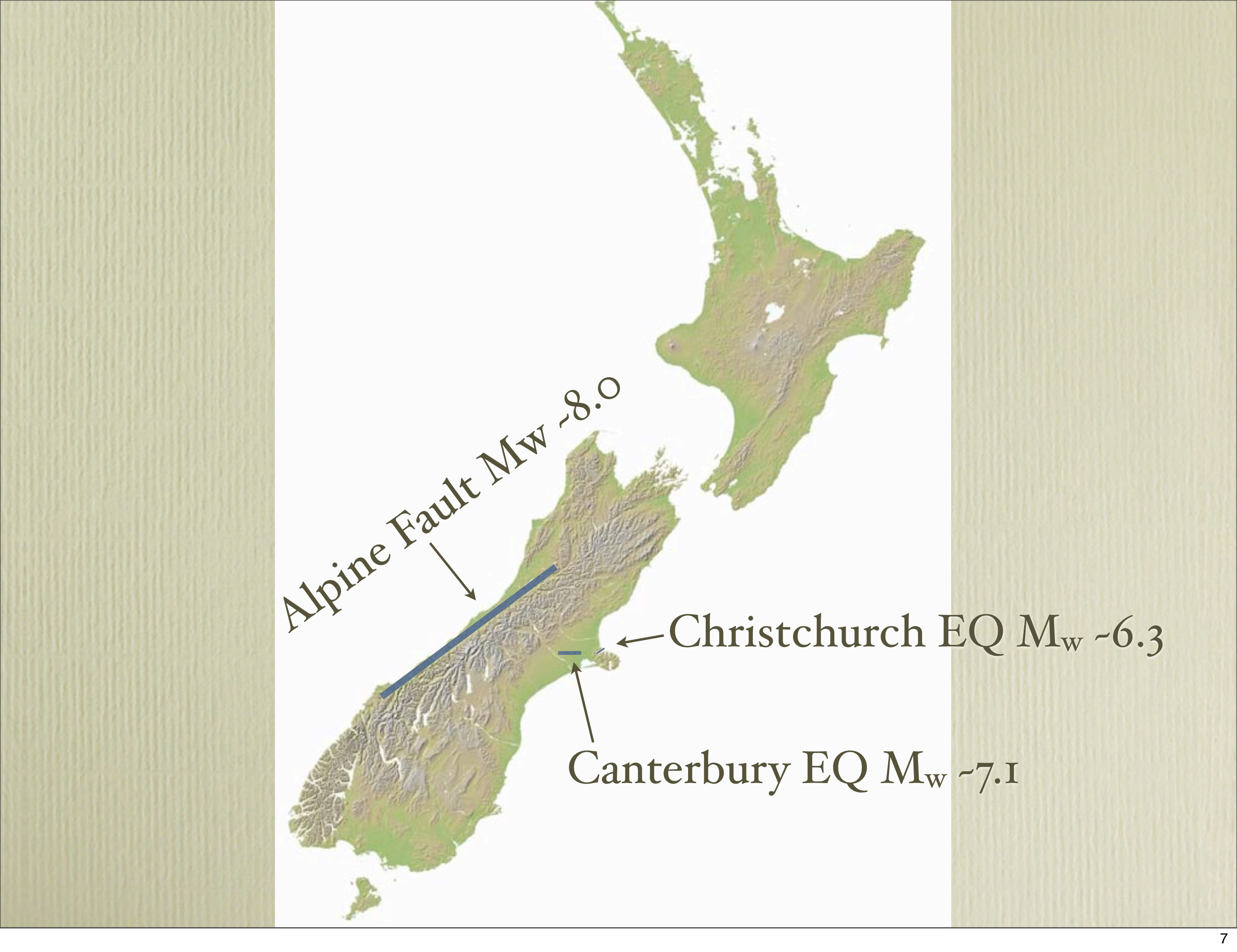
475 Years



M 7.1 (2010)  
o Fatalities  
Cost ~\$4 to \$5  
Billion (NZ)



M 6.3 (2011)  
~181 Fatalities  
Cost ~\$12 to \$25  
Billion (NZ)

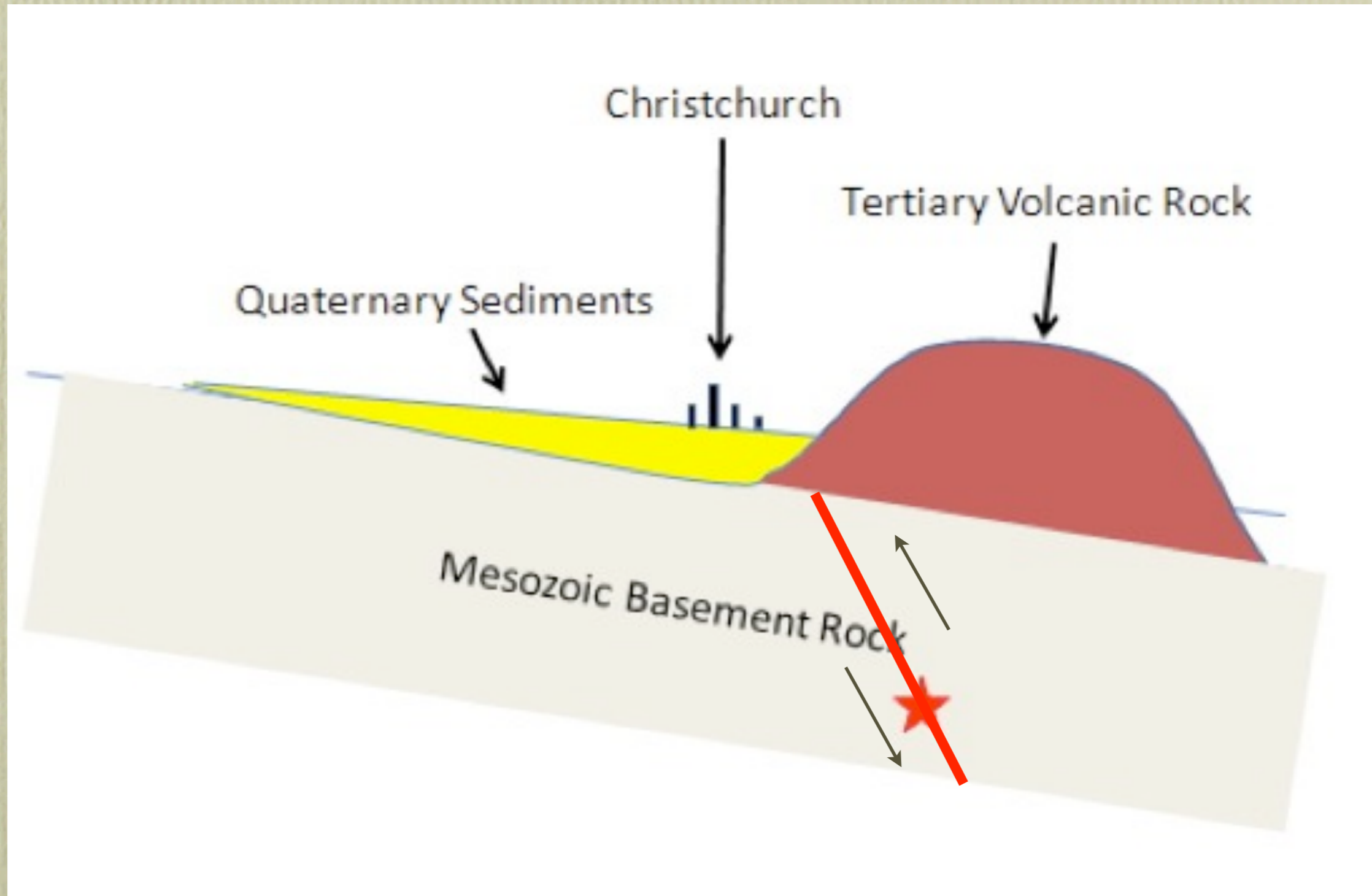
A topographic map of New Zealand showing the North and South Islands. A thick blue line runs along the length of the South Island, representing the Alpine Fault. Three specific seismic events are marked with arrows and text labels: the Alpine Fault (Mw ~8.0), the Christchurch EQ (Mw ~6.3), and the Canterbury EQ (Mw ~7.1).

Alpine Fault  $M_w \sim 8.0$

Christchurch EQ  $M_w \sim 6.3$

Canterbury EQ  $M_w \sim 7.1$

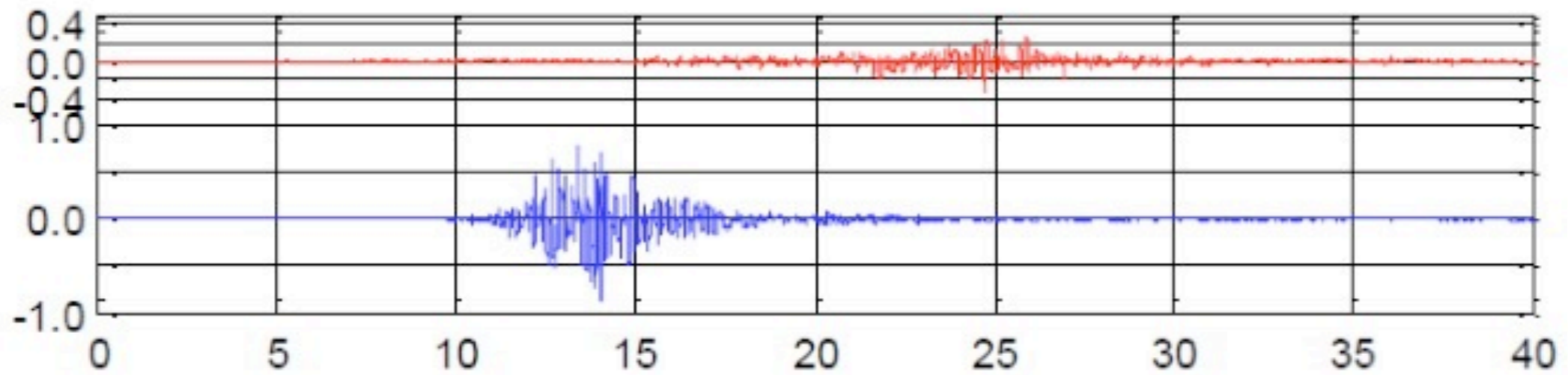
# Cross section, Feb 22 2011 (Looking Northeast)



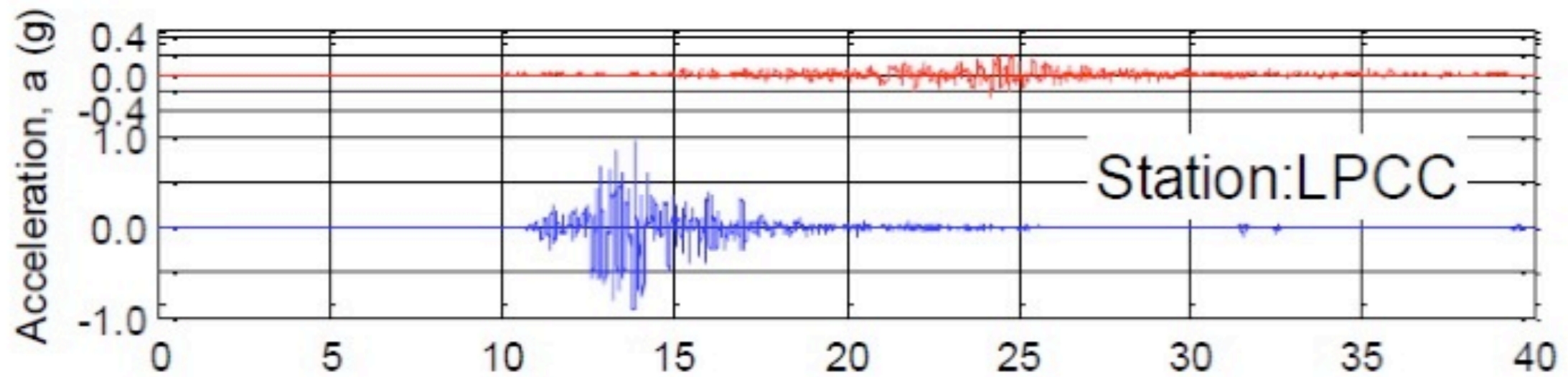


# Comparison: Time Histories at Lyttleton Port (Rock Site)

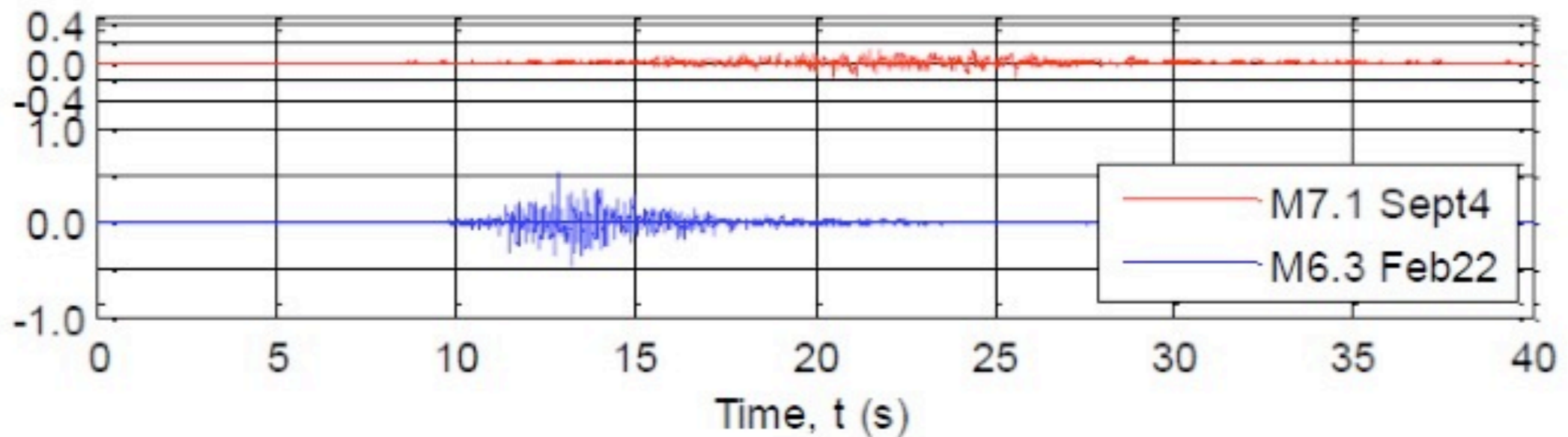
H<sub>1</sub>



H<sub>2</sub>



V



# Collapsed CTV Building



Christchurch EQ  $M_w$  -6.3

# Pyne Gould Guinness Building



Christchurch EQ  $M_w$  ~6.3

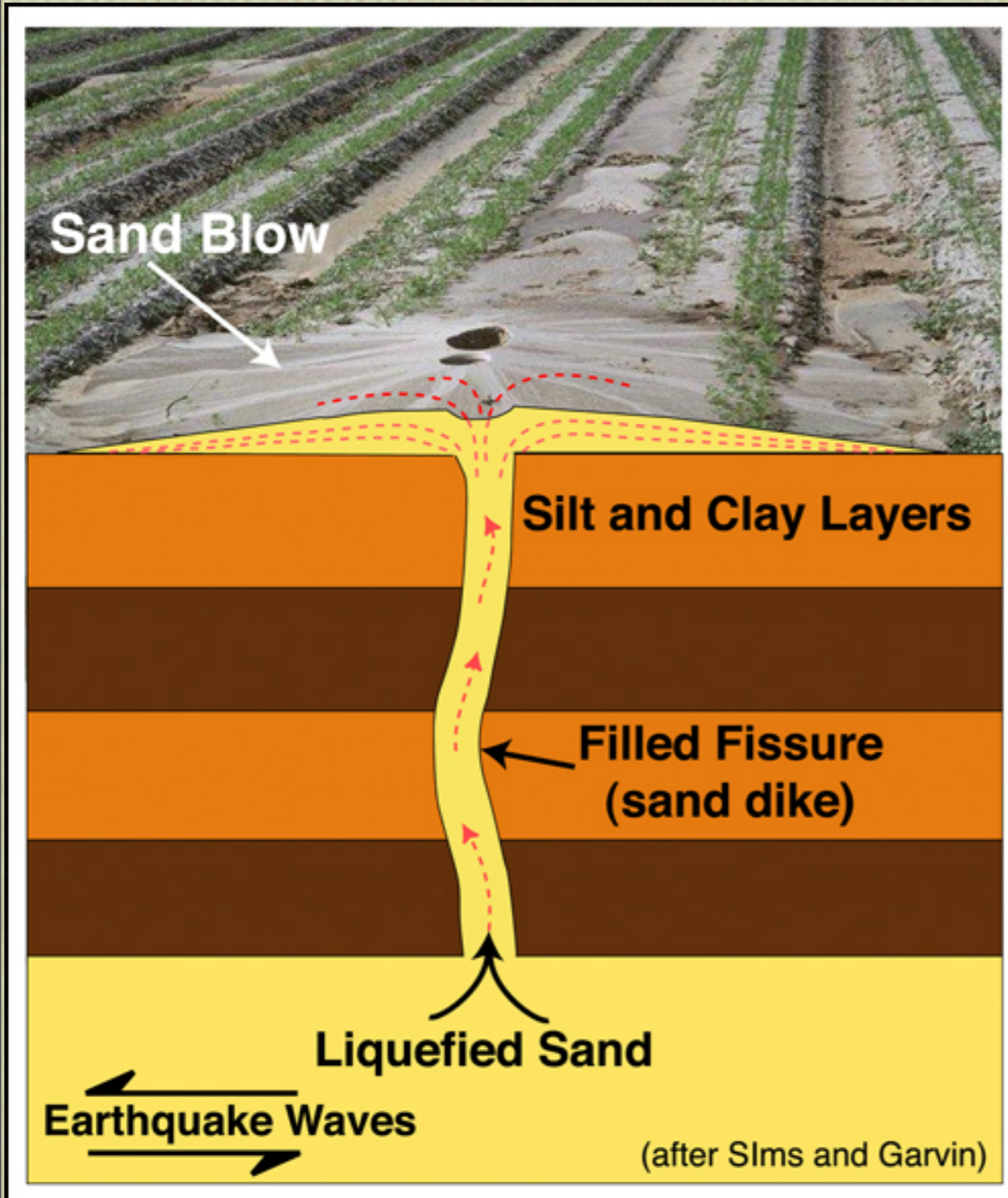
# Christchurch Cathedral



Christchurch EQ  $M_w \sim 6.3$

# Liquefaction

# Liquefaction and flooding



Canterbury EQ  $M_w \sim 7.1$



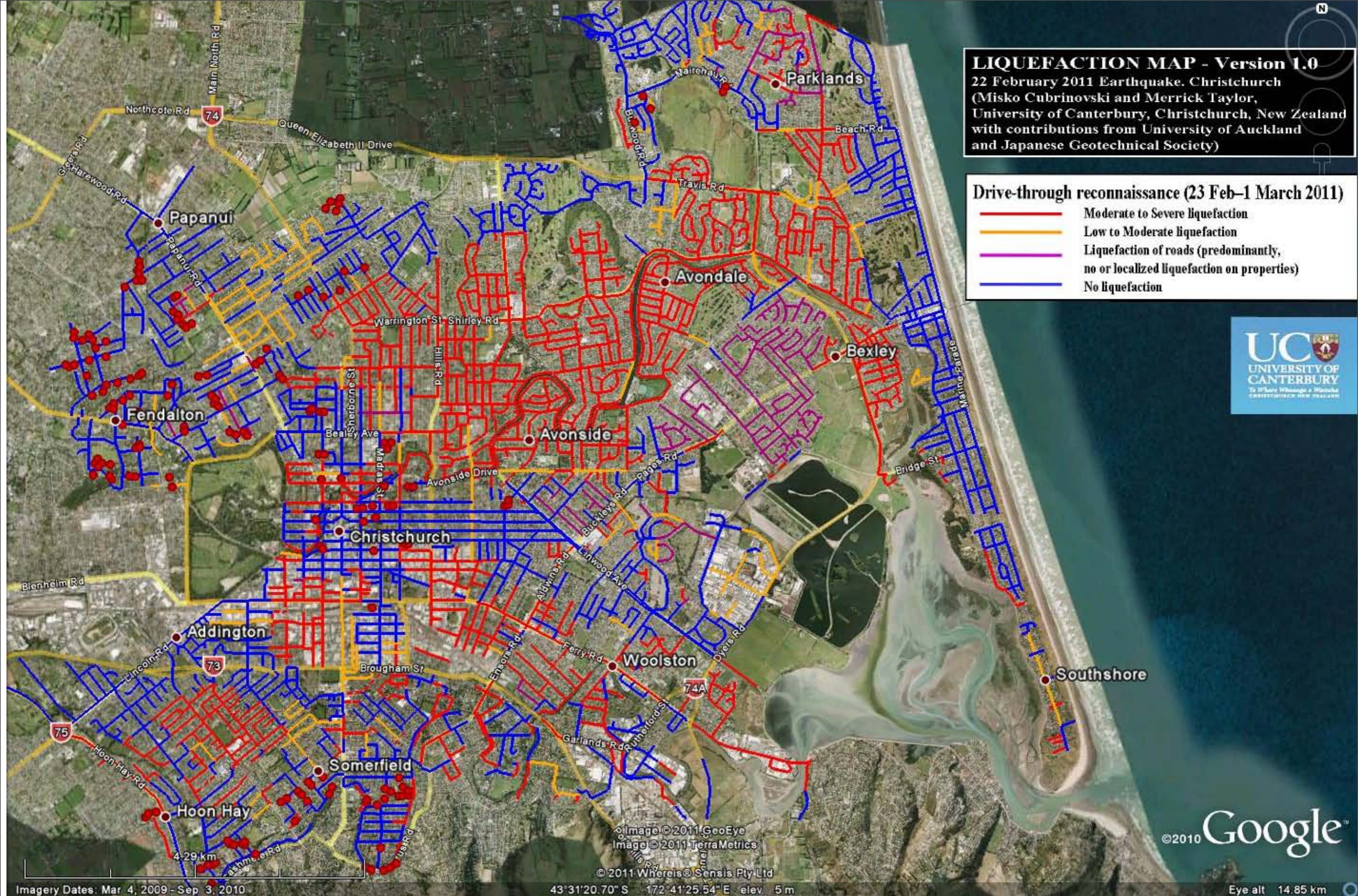
Christchurch EQ  $M_w$  -6.3

# Liquefaction, Kilmore Street



Christchurch EQ  $M_w$  ~6.3





**LIQUEFACTION MAP - Version 1.0**  
 22 February 2011 Earthquake, Christchurch  
 (Misko Cubrinovski and Merrick Taylor,  
 University of Canterbury, Christchurch, New Zealand  
 with contributions from University of Auckland  
 and Japanese Geotechnical Society)

**Drive-through reconnaissance (23 Feb–1 March 2011)**

- Moderate to Severe liquefaction
- Low to Moderate liquefaction
- Liquefaction of roads (predominantly, no or localized liquefaction on properties)
- No liquefaction

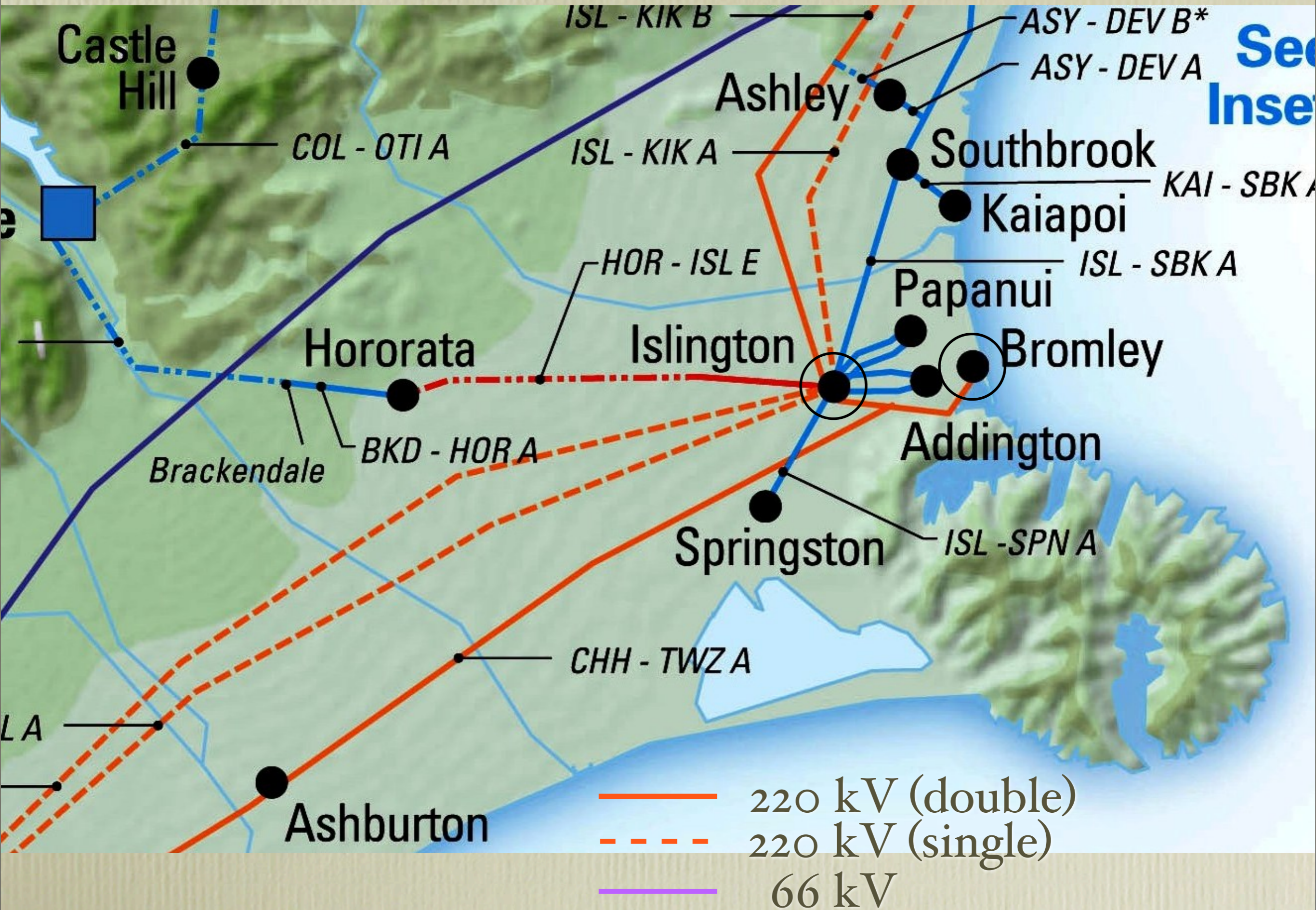


Liquefaction: RED Lines: Moderate to Severe, Roads + Properties  
 MAGENTA Lines: Roads. ORANGE: Low to Moderate. BLUE: None

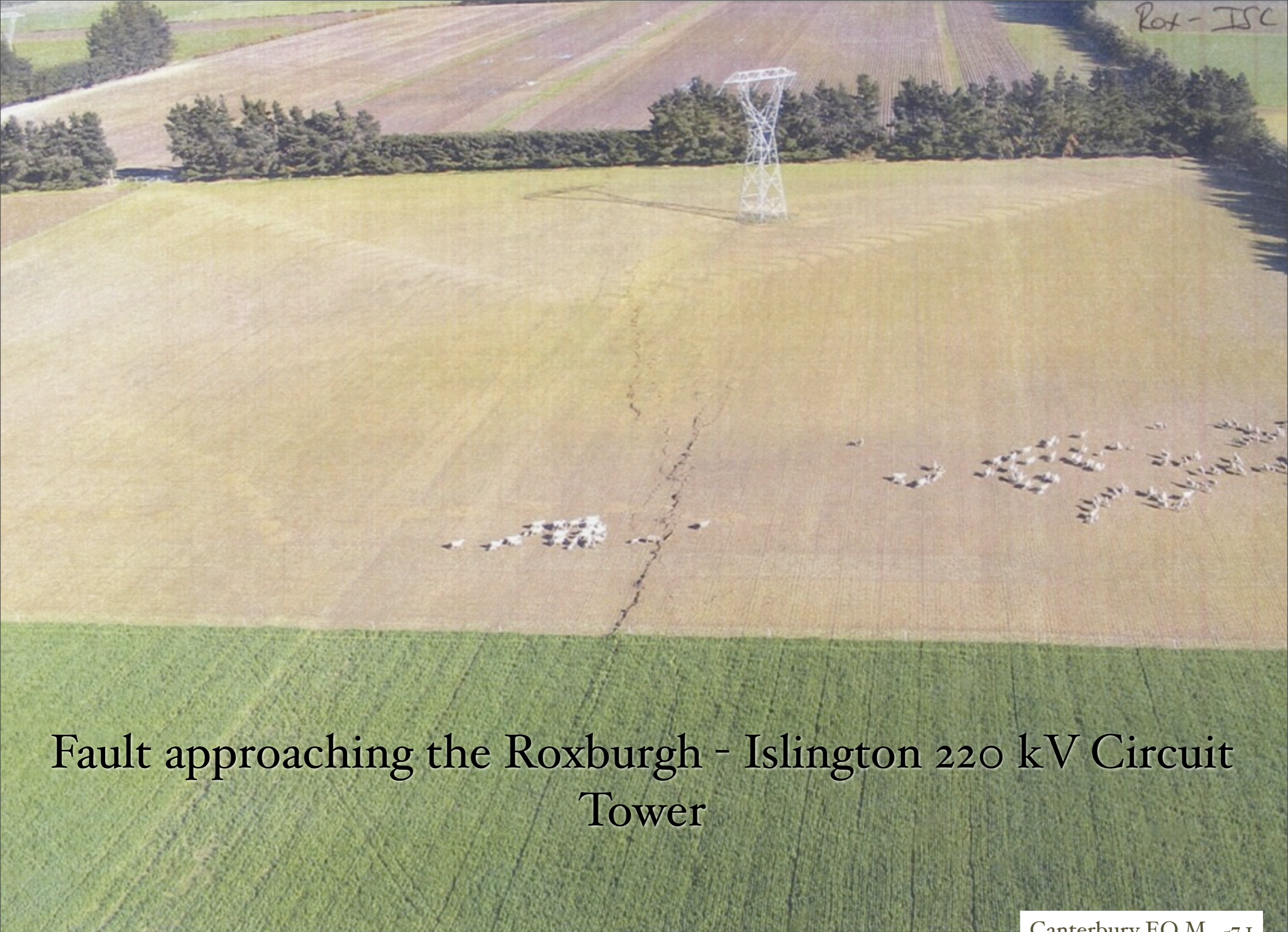
Christchurch EQ  $M_w$  -6.3

Transpower  
(High Voltage Transmission)  
66 kV - 220 kV

# Transpower System



Rox - ISC



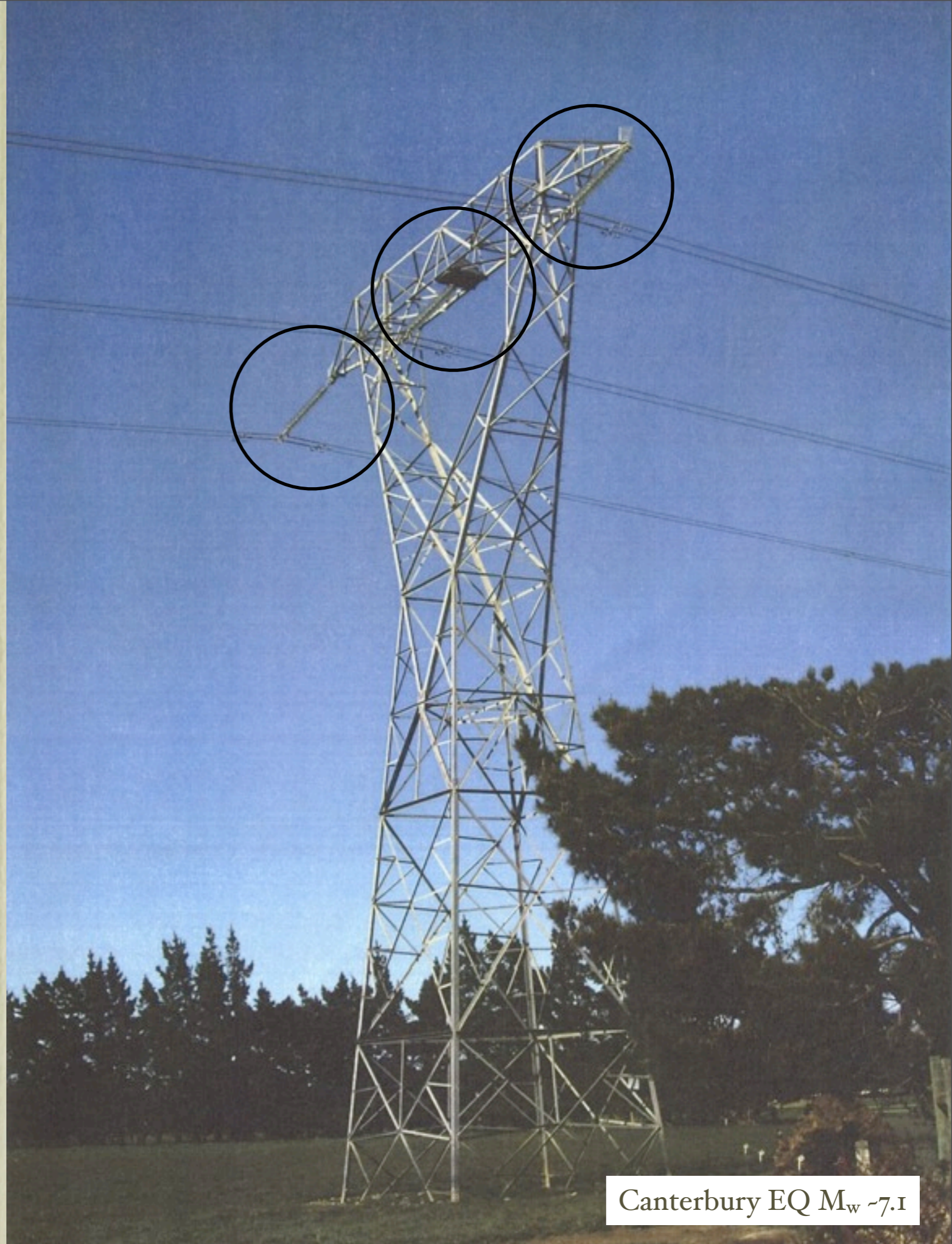
# Fault approaching the Roxburgh - Islington 220 kV Circuit Tower

Canterbury EQ  $M_w$  ~7.1



Canterbury EQ  $M_w \sim 7.1$

Roxburgh-Islington  
220 kV Fault Offset  
Two-bundle. No  
ground wire.  
Insulators remain  
stretched as of  
October 14, 2010,  
awaiting a suitable  
outage. Line Tensions  
are unbalanced but  
tolerable



Canterbury EQ  $M_w$  ~7.1

# 2010 Power Supply Restoration Times

(Earthquake time: 4:35 am)

- Papanui. 08:28 am
- Springston. 07:48 am
- Hororata. 08:23 am
- Coleridge. 12:16 pm

# 2011 Power Supply Restoration Times

(Earthquake time: 1:51 pm)

- 17:29 pm (100% capacity and N security)
- Bromley: 1 CVT, 1 66kV / 11 kV Bushing; 11 kV switchboard



2010: Islington  
(PGA ~0.20g - 0.25g)

220 kV SA Broken  
220 Bushing OK  
SA failure found 2 days  
later. SA replacement is  
identical.

Cracks in wall and floor of battery room

Holding bolts sheared off for roof  
support frame at Condenser Building





# Addington Warehouse

Canterbury EQ  $M_w$  ~7.1

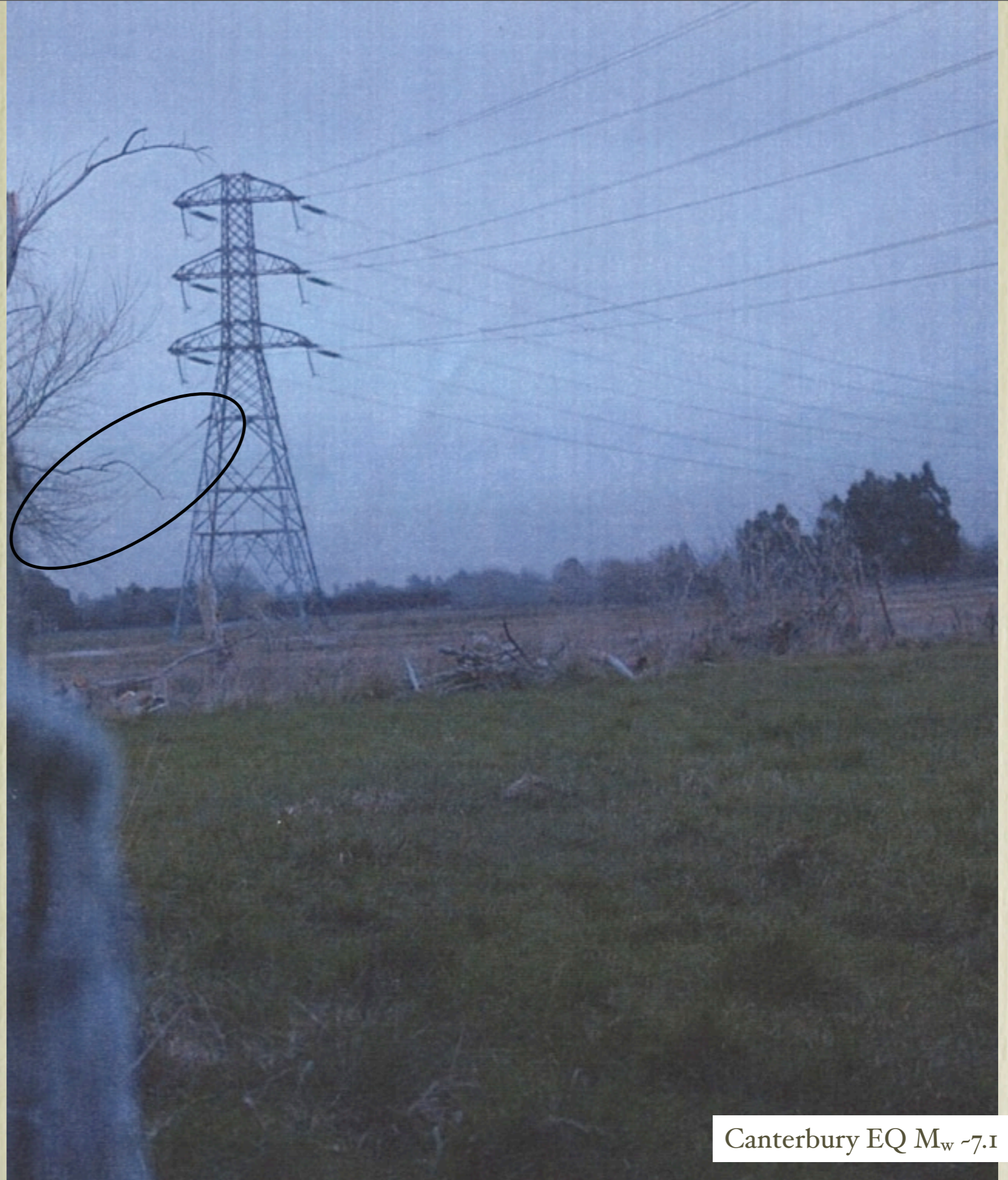
# Addington Warehouse



Canterbury EQ M<sub>w</sub> ~7.1

ISL-BRY  
Angle Tower  
Liquefaction  
PGD Tilted(?)

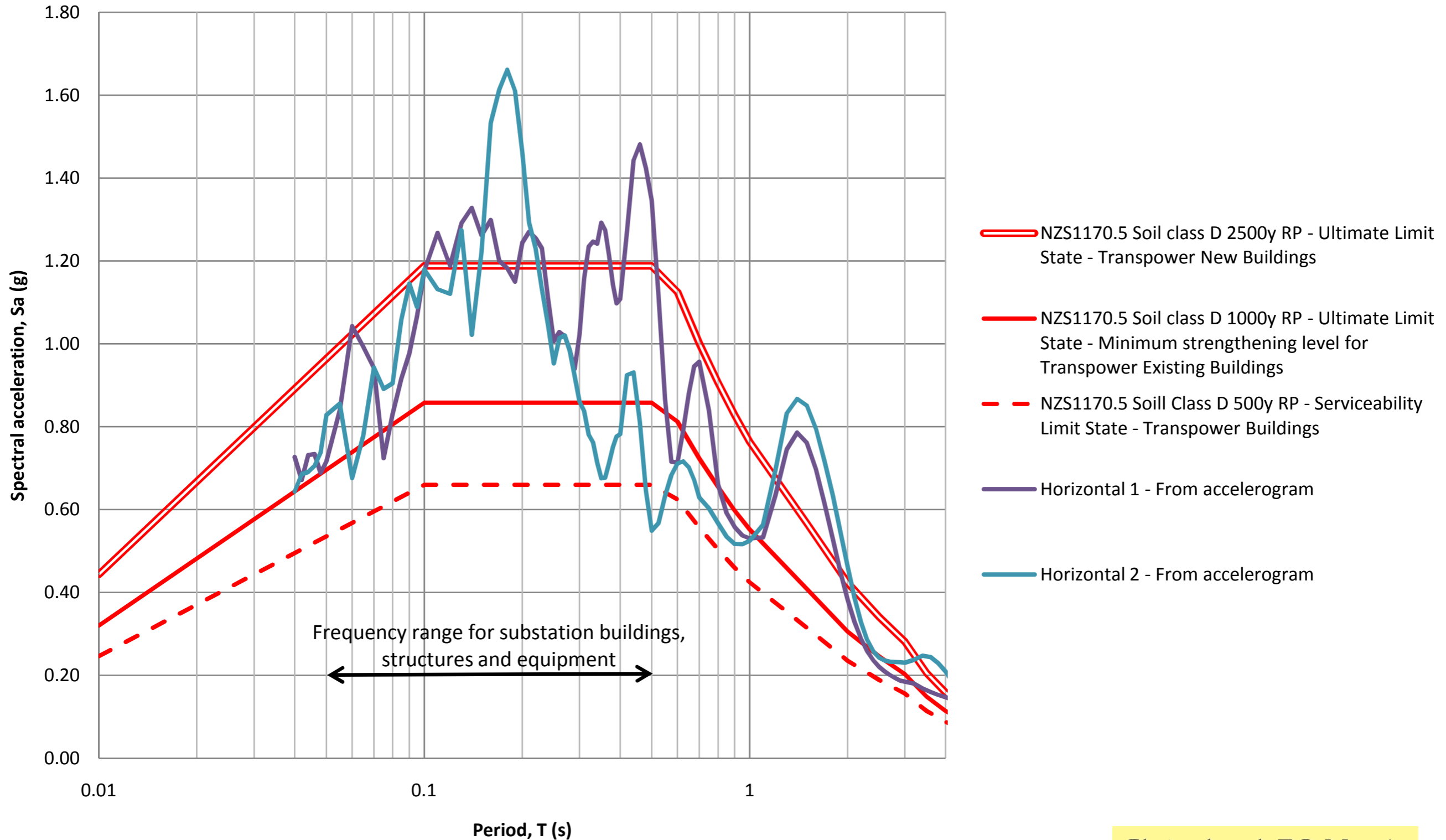
2 Guys Added  
post EQ



# 2011 Impact at Bromley 220 kV Substation (PGA ~0.5g)

## Bromley Substation - Response spectra - 5% of critical damping

From GNS accelerogram at Pages Road Pumping Station (distance from substation 1.5km)



Christchurch EQ  $M_w$  ~6.3



Desktop Monitors had seismic hold-downs. OK!



Non-essential cabinets had restraints. OK!



Control Room Ceiling.,  
Some tiles fell. No injuries,  
no impacts



2 braced battery racks. But, batteries were not snug within the rack, and they slid and impacted (?)





About 5 inches of sliding



OCBs had high forces, cracked castings. One OCB in disengaged position fell to the ground. In-service OCBs remained functional, although lots of evidence of anchorage overloads

John MacKenzie







Bromley Substation 2011

66 kV Yard, Looking South

Large sand boils surrounding substation, and about 10% of area within substation



# 66 kV Yard, Looking North





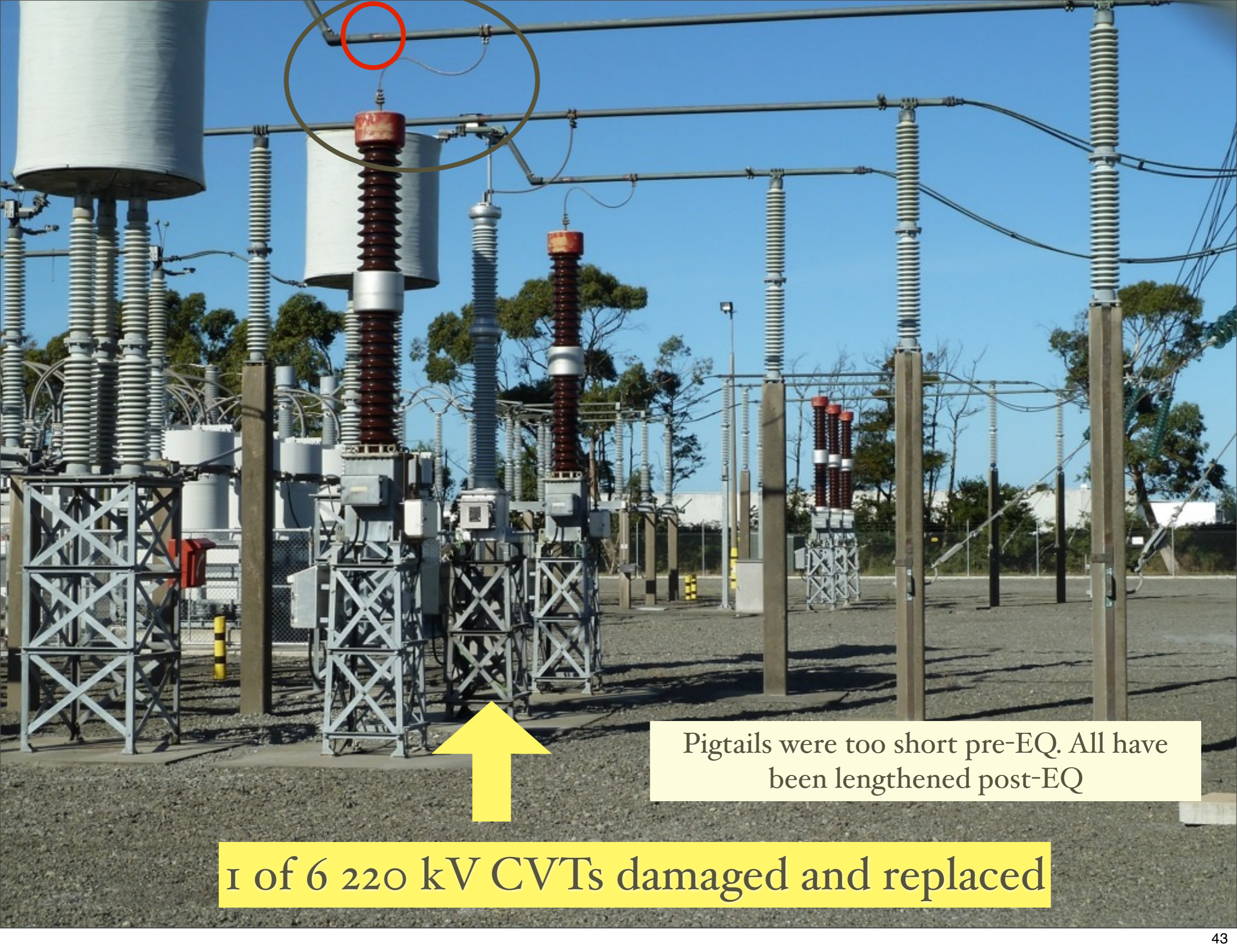


Large sand boil in 220 kV Yard

Bromley Tower - 220  
kV Double Circuit,  
Drop into 220 kV Yard

All springs "tight"

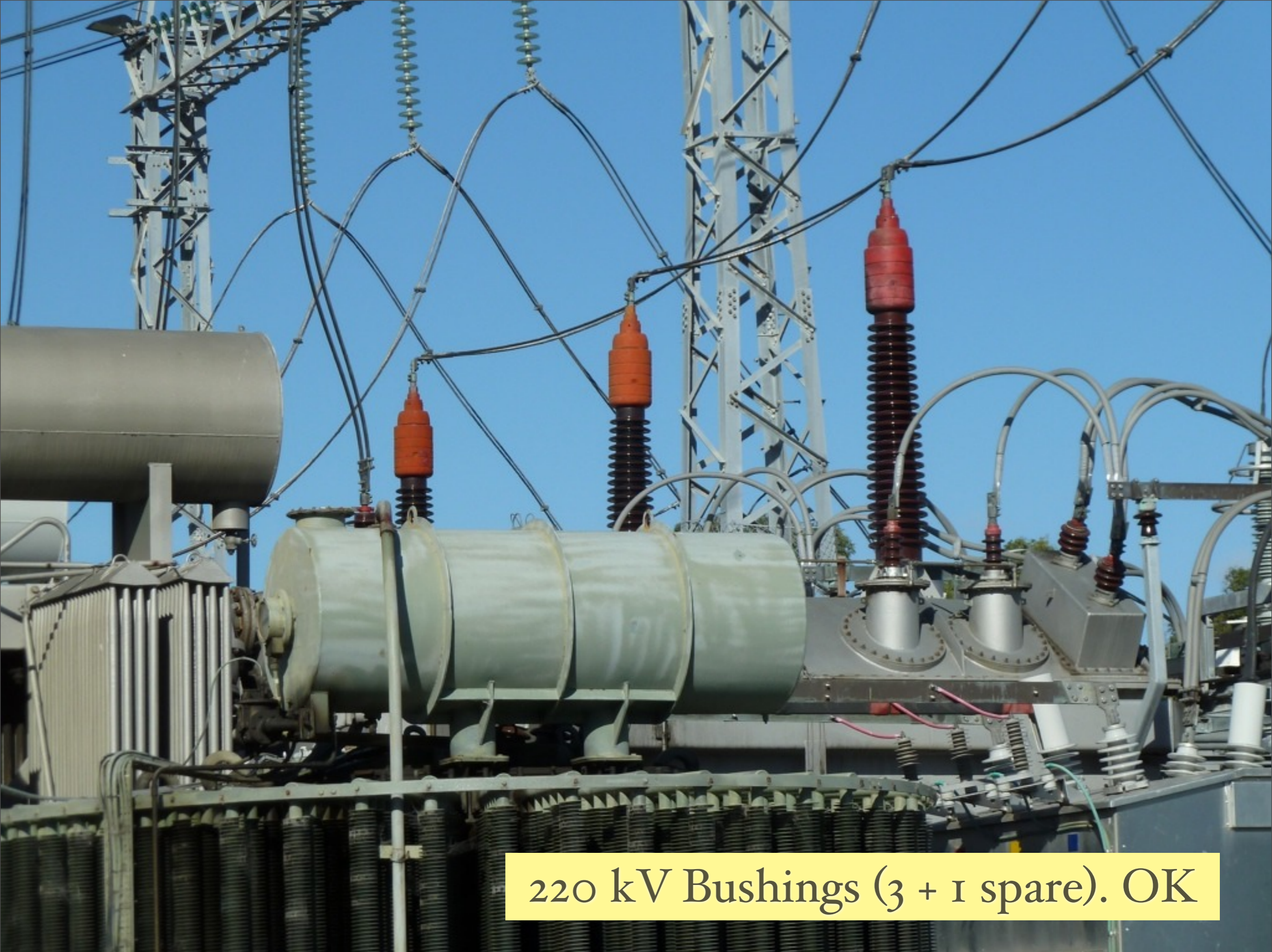




Pigtails were too short pre-EQ. All have been lengthened post-EQ

1 of 6 220 kV CVTs damaged and replaced



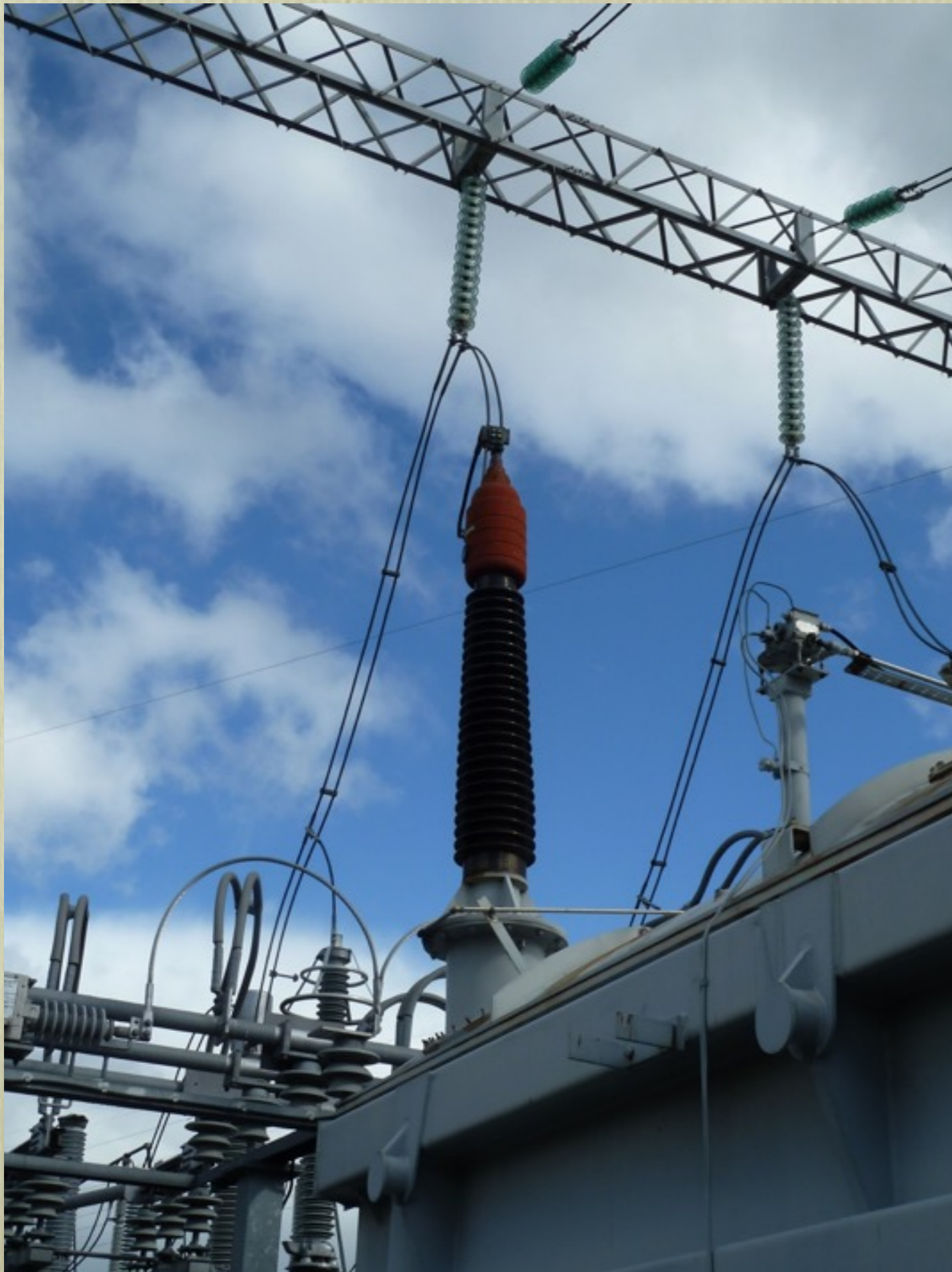


220 kV Bushings (3 + 1 spare). OK

Savigliano  
1965 1Ø  
W = 165 Kips  
38.9 MVA

220 kV Spare 1Ø TR. All 4 TRs and radiators were originally on wheels, but had been heavily anchored. OK

# Cemented bushing



Cracked paint  
suggests yielding?

Very minor oil  
leakage





Some slippage

284

# Bolted Connections: slight slip in 220 kV yard



~20 mm slip to right



# Spill Prevention Containment Walls, Drain Damage (liquefaction ?)



220 kV center break DS. Some contact problems, misalignments. No contact burns. Needed to be manually reset.



220 ABB Candlestick  
Breakers. (18 total).  
OK

LTB245E1  
Years: 2002, 2005

No IEEE 693 posting





Newer installations do not use grout pads. Up to 1 inch clear height for bolts

# 66 kV TR. 1 bushing failure





Bus Structure (1951-  
vintage) showed no  
signs of yielding,  
slight spalling in  
concrete  
foundations









Oil Tanks for  
Buried 66 kV  
Cables. 2 of 3 were  
tilted on their  
foundations, one  
spalled concrete  
foundation



0 psi pressure to buried oil-filled cables  
(3 cables from this substation)

DALLINGTON No.2



# Regional Operations Center

- Cabinet dislodged in computer room. Removed.
- Seismic isolators under cabinet failed (ball bearings came out). No longer seismically free to move
- Suspended ceiling tiles fell down in lunch room, near entrance.
- Lighting diffusers in ceiling fell down in the control room





Canterbury EQ  $M_w \sim 7.1$



# Orion

- 3rd largest NZ distribution company
- \$5 million NZ spent, 1995-2009 on seismic strengthening at URM substations, lines and cables
- Seismic payoff: \$30 to \$50 million NZ in reduced direct damage.
- \$3 million repairs (2010) ~\$30 NZ million repairs (2011)

# 2011 Earthquake

66kV UG: 50% Failure Rate

11 kV UG: 5.5% Failure Rate

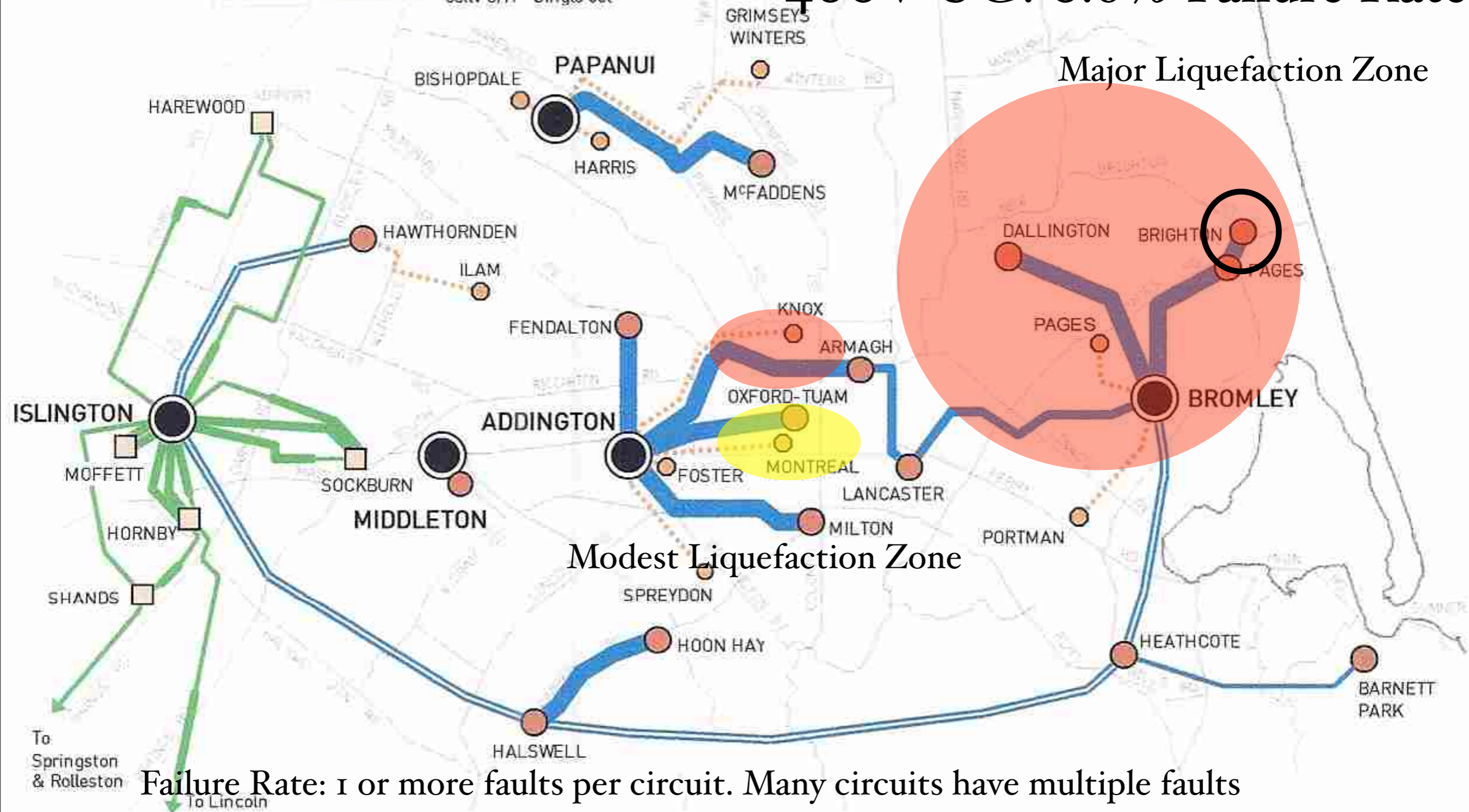
400V UG: 0.6% Failure Rate

## Substation key

- Transpower GXP
- Orion 66kV Substation
- Orion 33kV Substation
- Orion 11kV Substation

## Circuit key

- 66kV U/G - Double cct
- 66kV U/G - Single cct
- 33kV U/G
- 11kV U/G
- 66kV O/H - Double cct
- 66kV O/H - Single cct
- 33kV O/H - Single cct



Failure Rate: 1 or more faults per circuit. Many circuits have multiple faults

# 2010 Earthquake

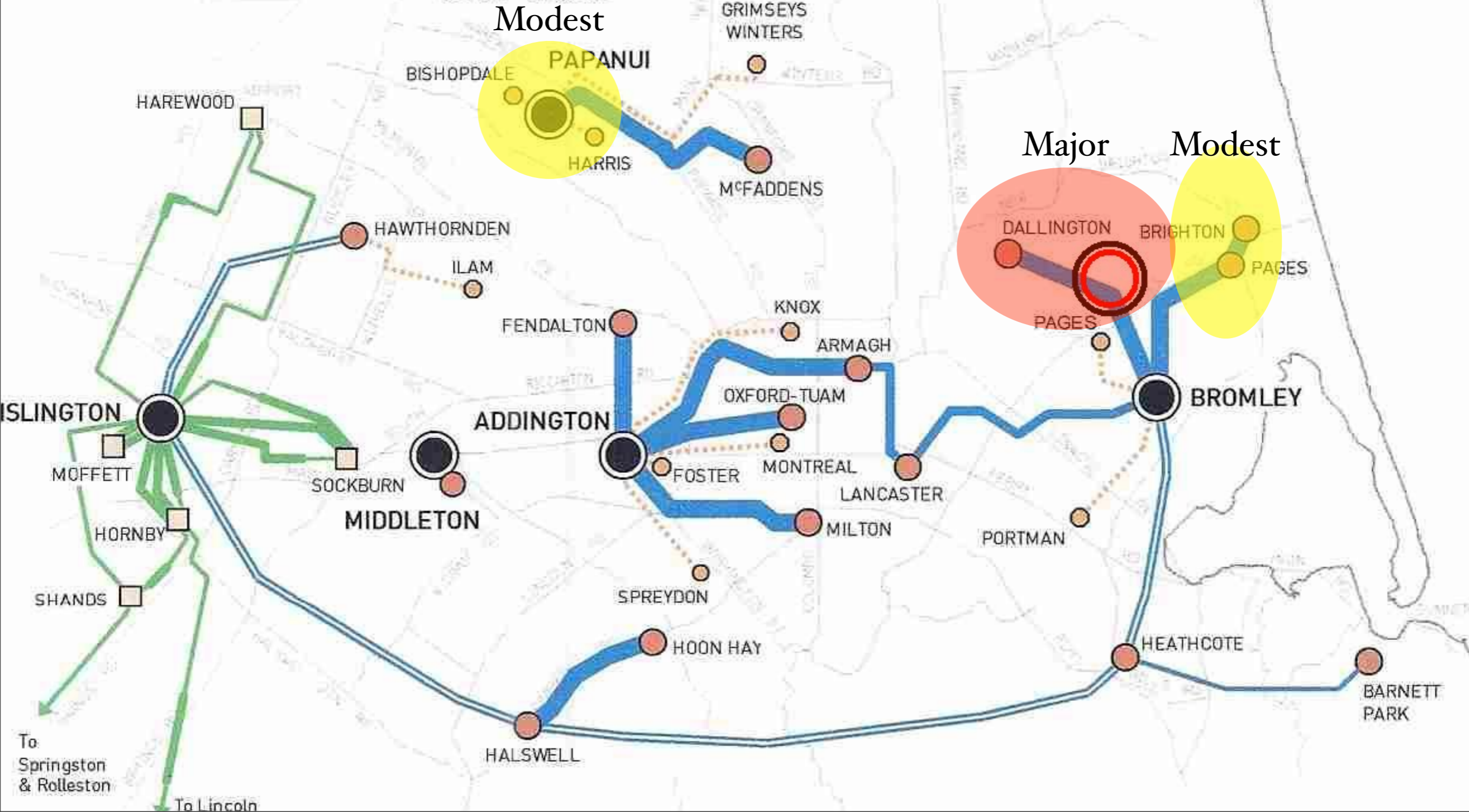
## 66kV UG: 2 damaged and functional 11 kV UG: several faulted

### Substation key

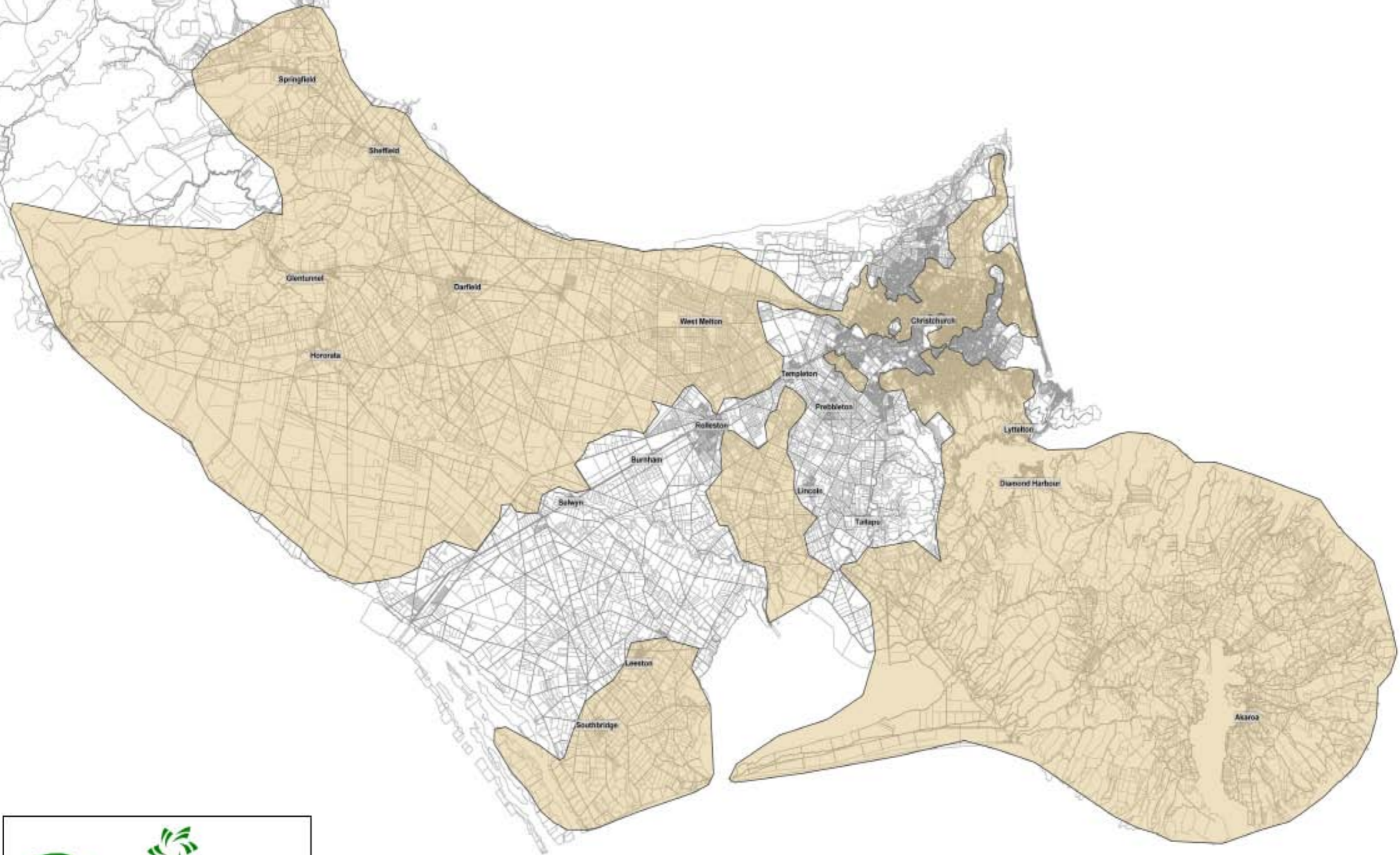
- Transpower GXP
- Orion 66kV Substation
- Orion 33kV Substation
- Orion 11kV Substation

### Circuit key

- 66kV U/G - Double cct
- 66kV U/G - Single cct
- 33kV U/G
- 11kV U/G
- 66kV O/H - Double cct
- 66kV O/H - Single cct
- 33kV O/H - Single cct



# Initial area with power loss, Sept 4 2010



# Orion: Number of Customers Off

140,000

120,000

100,000

80,000

60,000

40,000

20,000

-

Total Customers: 198,000

**5.1  
Aftershock**

Date/Time	Number of Customers Off
4 Sept 4:36am	~131,000
4 Sept 9:00pm	~10,000
5 Sept 9:00pm	~3,000
6 Sept 9:00pm	~1,000
7 Sept 9:00pm	~1,000
8 Sept 7:49am	~31,000
8 Sept 9:00pm	~1,000
9 Sept 9:00pm	~1,000
10 Sept 9:00pm	~1,000

Canterbury EQ  $M_w \sim 7.1$

est. 629,000,000 (still counting)



# Orion Outages - Storms and Earthquake

## 198,000 Customers

Customer Minutes, Millions

90.0  
67.5  
45.0  
22.5  
0

1992

2000

2002

2005

2005

2006

2010

2011

Snow Storm

Wind Storm

Snow Storm

Wind Storm

Snow Storm

Snow Storm

M 7.1 Earthquake

M 6.3 Earthquake

Year

# Orion 2011

- 10 days to restore power to 90% of customers (10x worse than 2010)
- Main Administration buildings damaged (structural, liquefaction, non-structural)
  - Had to relocate control center

# Substation Seismic Risk

- 51 District Substations (6,000 customers, Outdoor yards) (2 failed, 2011)
  - Anchor transformers
- 268 Building Substations (300 customers, generic upgrade for small URMs) (3 failed 2011, 1 by inertia, 2 by avalanche)
- 5000 Distribution substations (30 customers, pole or ground mounted)





Canterbury EQ  $M_w \sim 7.1$



Canterbury EQ  $M_w \sim 7.1$

Former Orion  
substation.

Abandoned by  
Orion, given  
to the city

Now a Boy  
Scout meeting  
room





2011 Earthquake

New Brighton Rd III

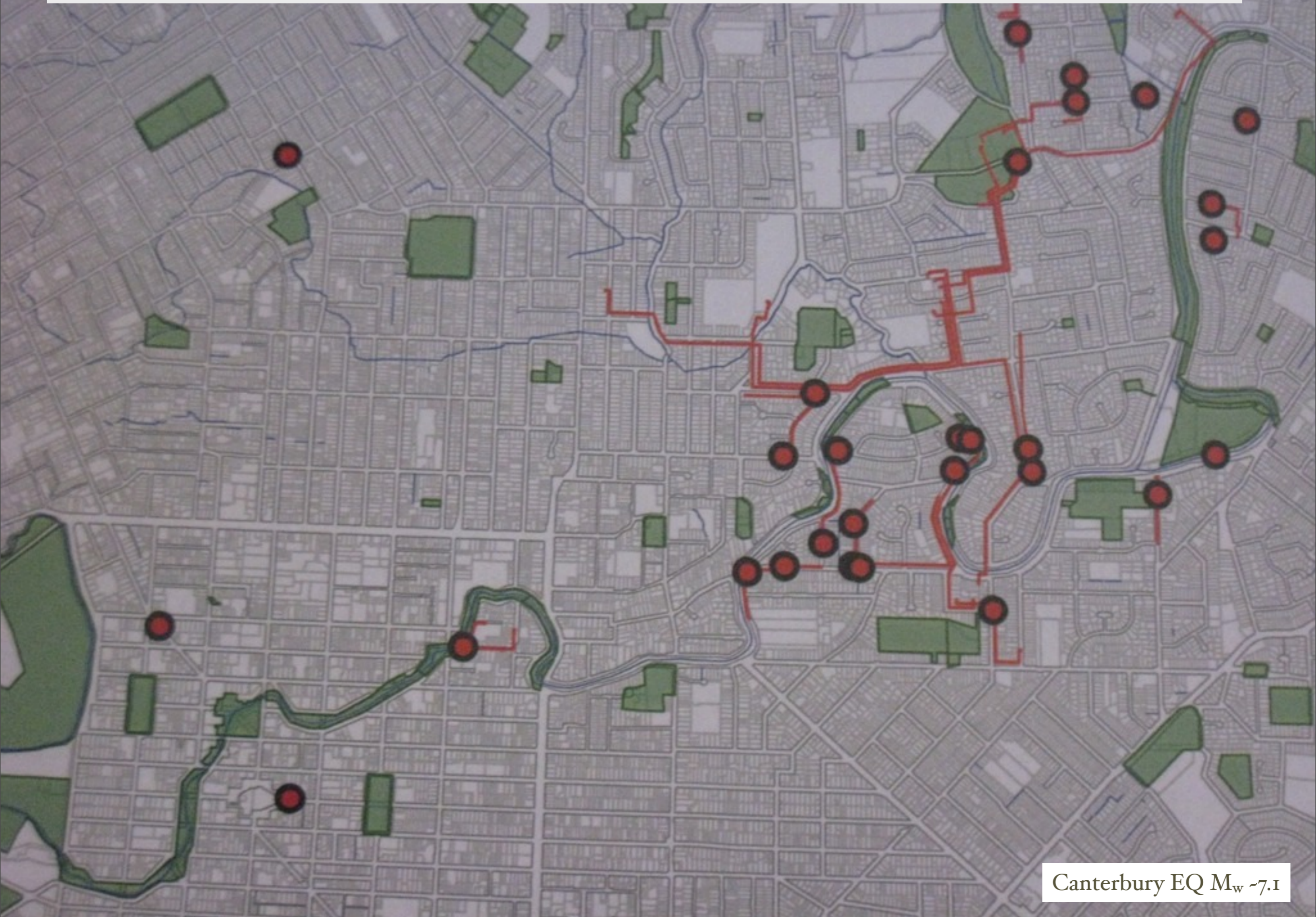


2011 Earthquake



2011 Earthquake

# HV Cable faults recorded between Sept 4 and Oct 7 2010



Canterbury EQ  $M_w$  ~7.1

66 kV oil-filled cable



Canterbury EQ  $M_w$  ~7.1





Canterbury EQ  $M_w \sim 7.1$



2011: More lateral Spreading, now forming a 3-pin arch

(2010) Two 66 kV cables, Buckled, pinched, not faulted (2010)



(2011) Same cables faulted, not yet dug up or repaired (as of April 5 2011)



## Faulted 11 kV Cables

Canterbury EQ  $M_w \sim 7.1$

# Typical 11 kV cable damage



Canterbury EQ  $M_w$  ~7.1

# Typical 11 kV Cable Damage





Armagh Street - failed 66 kV cables (multiple)  
Similar damage for Brighton, Dallington

66 kV Cable - Buckled, but remains operational (for now)





# Response (2011)

- Build overhead “temporary” 66 kV cables:
  - 3 km to Brighton
  - 4.5 km to Dallington
  - 1.5 km to Keys. New substation at Keys

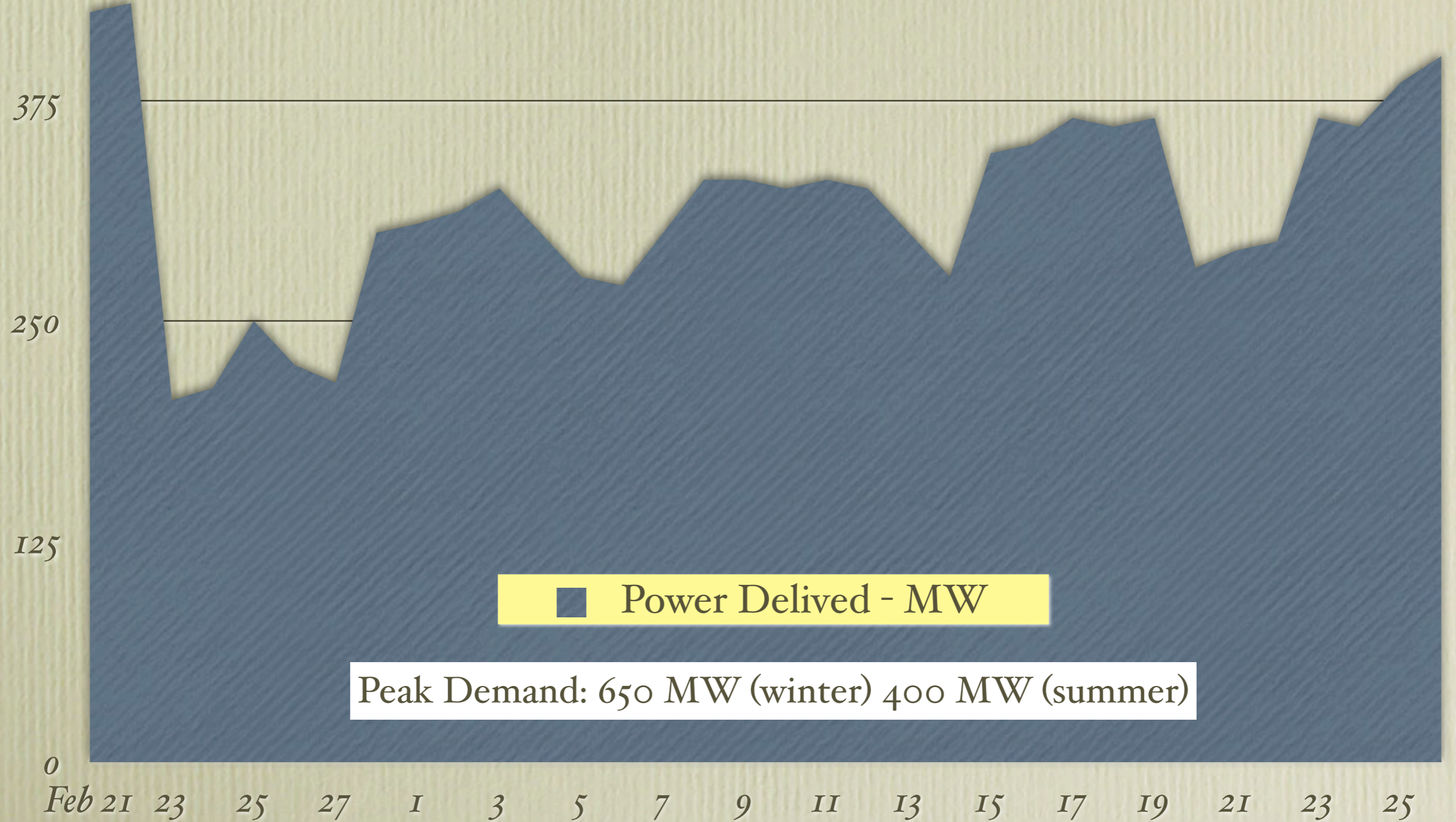
# 2011 Earthquake

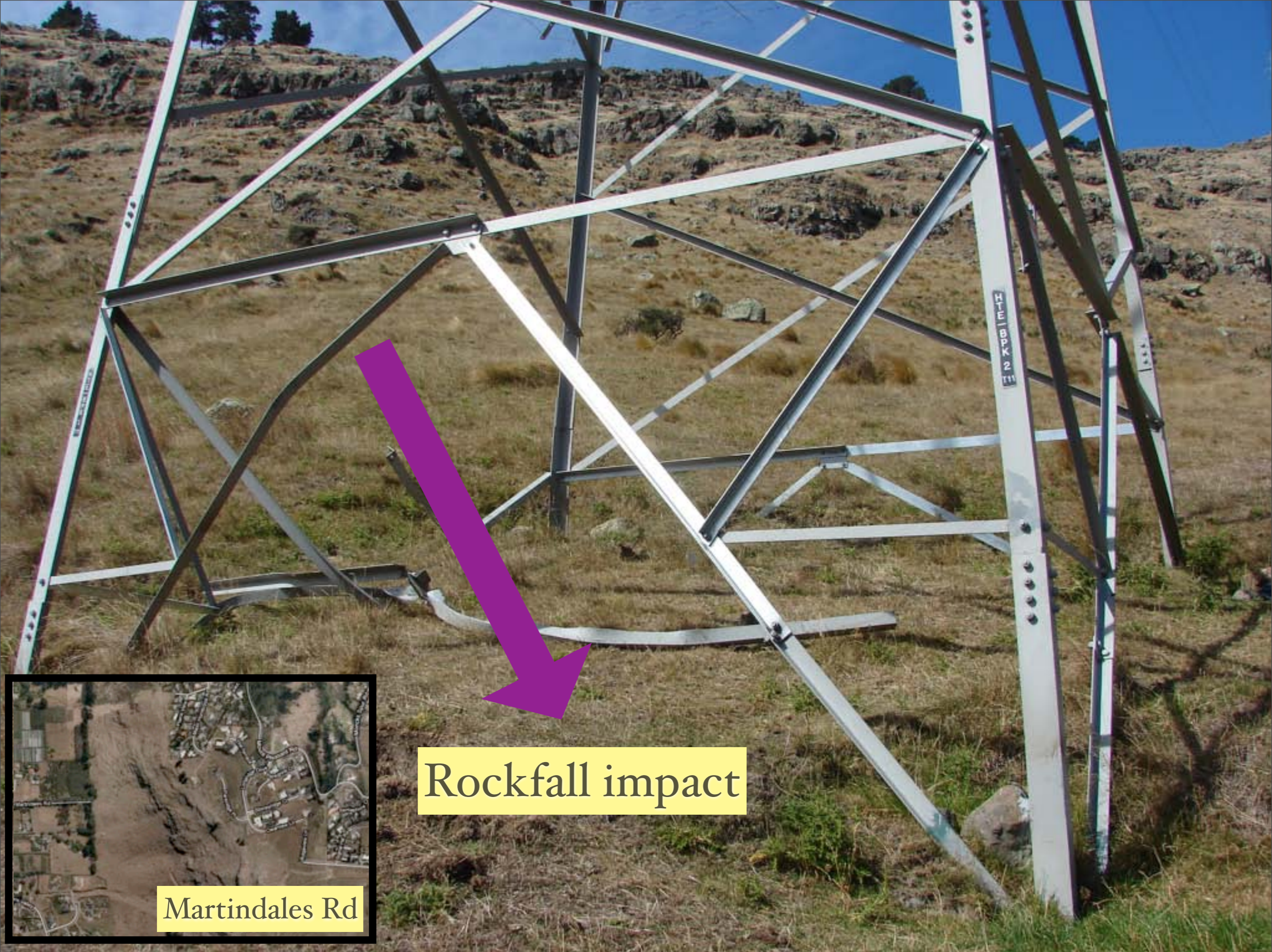
-85% of demand restored by day 42

Winter demand restrictions likely

500

Loss of demand: damage (now) supply restrictions (winter)





Rockfall impact

Martindales Rd

66 kV Db1

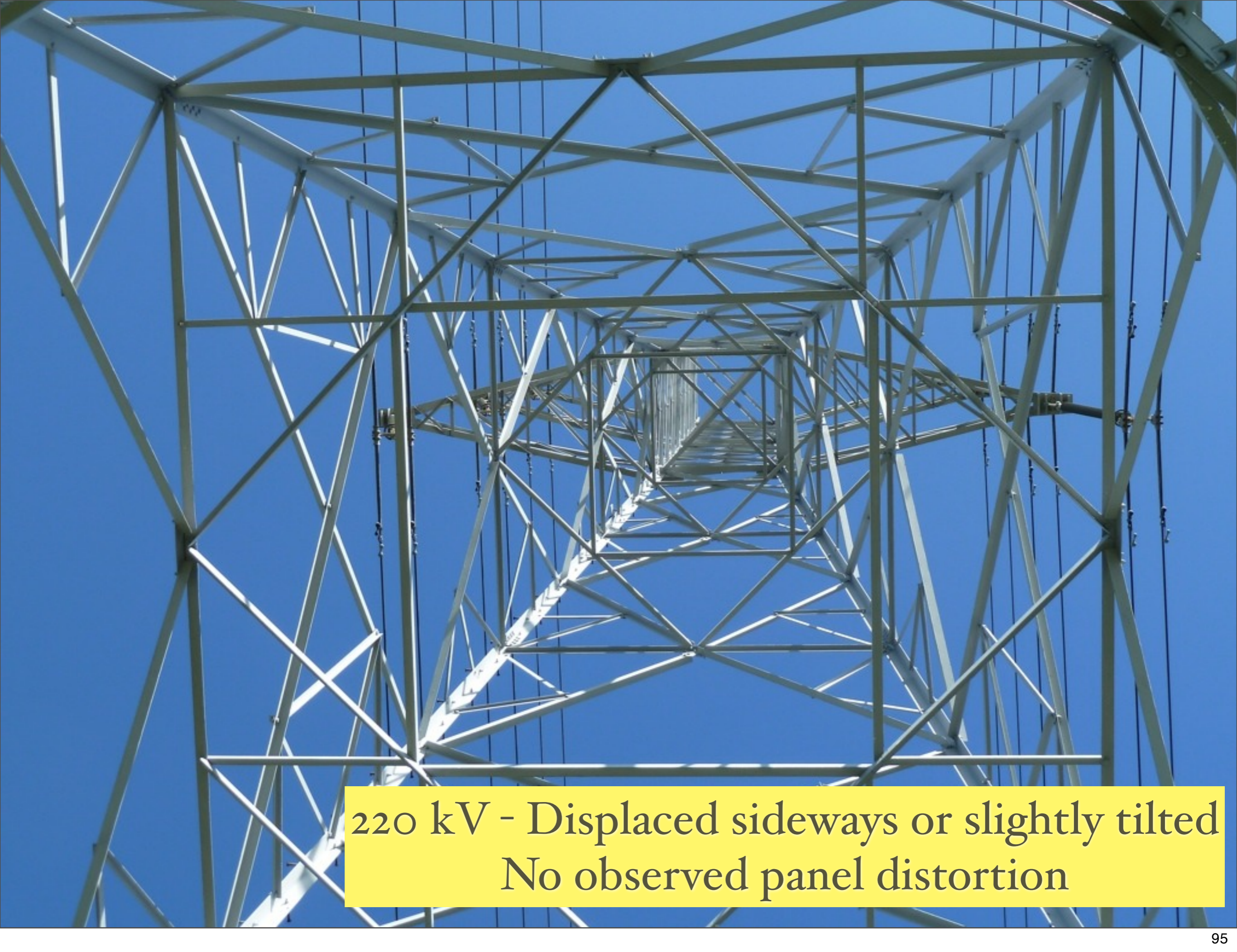
220 kV Db1





220 kV - Displaced sideways or slightly tilted  
No observed panel distortion





220 kV - Displaced sideways or slightly tilted  
No observed panel distortion



66 kV Double

Bromley -  
Heathcote  
4-TII





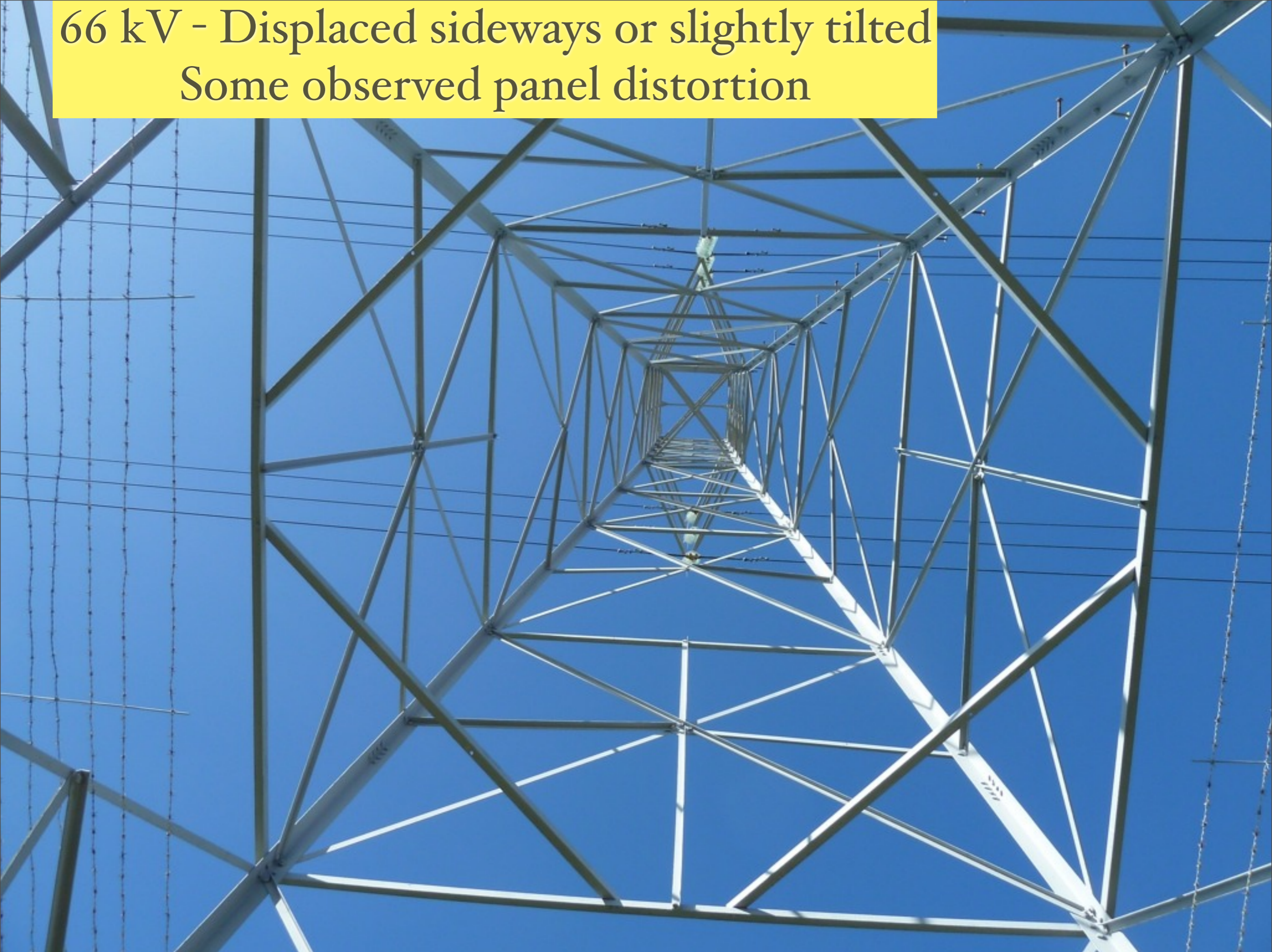
Buckled inwards



Buckled outwards



66 kV - Displaced sideways or slightly tilted  
Some observed panel distortion



Inward and outward  
buckles

Outward

Inward



# Bromley-Heathcote 4T1



None-slight observed permanent distortions



# Bromley-Heathcote 4T2



Sand Boils 1 foot deep.  
No observed  
permanent distortions



# Brighton Substation (2010)



Canterbury EQ  $M_w \sim 7.1$



# Brighton Substation



Sand Boils (2010)

# Brighton Substation (2011)



Transformer Building

# Brighton Substation (2011)



Radiators

# Brighton Substation (2011)



Solution: Brand New Transformer and Circuit Breaker

T1

  
KEEP OUT  
Oraah 07 0800 343 8888

OWEN  
GLOBAL LOGIST

# Brighton Substation (2011)



# Brighton Substation (2011)

Water Depth, Feb 23 2011



Water Depth, 0.5 meters  
Brighton Substation (2011)







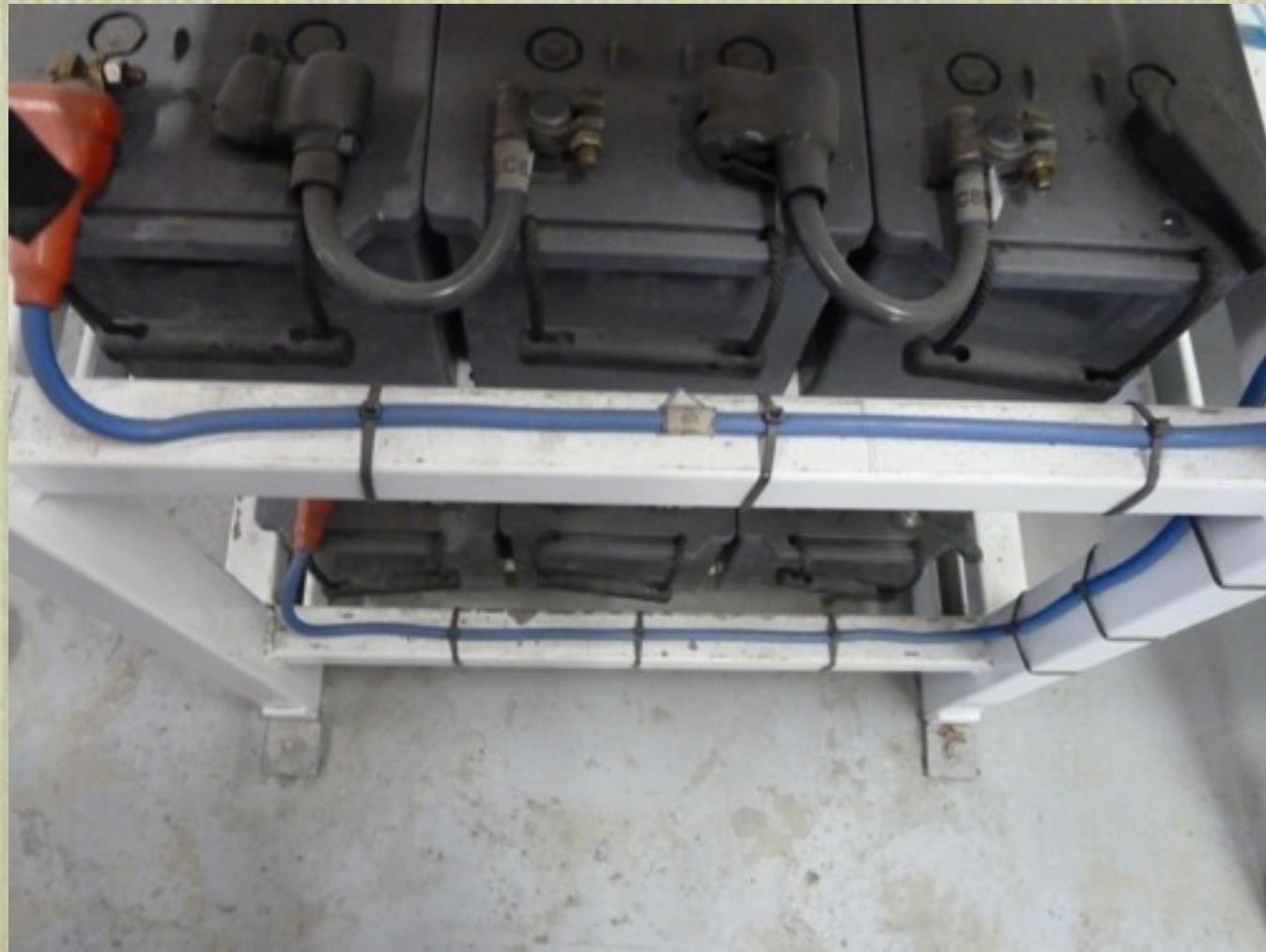
# Brighton Substation (2011)



Mud Damage



After removal of mud and replacement of damaged equipment



Design-Build in 5 Days!



Thank You!