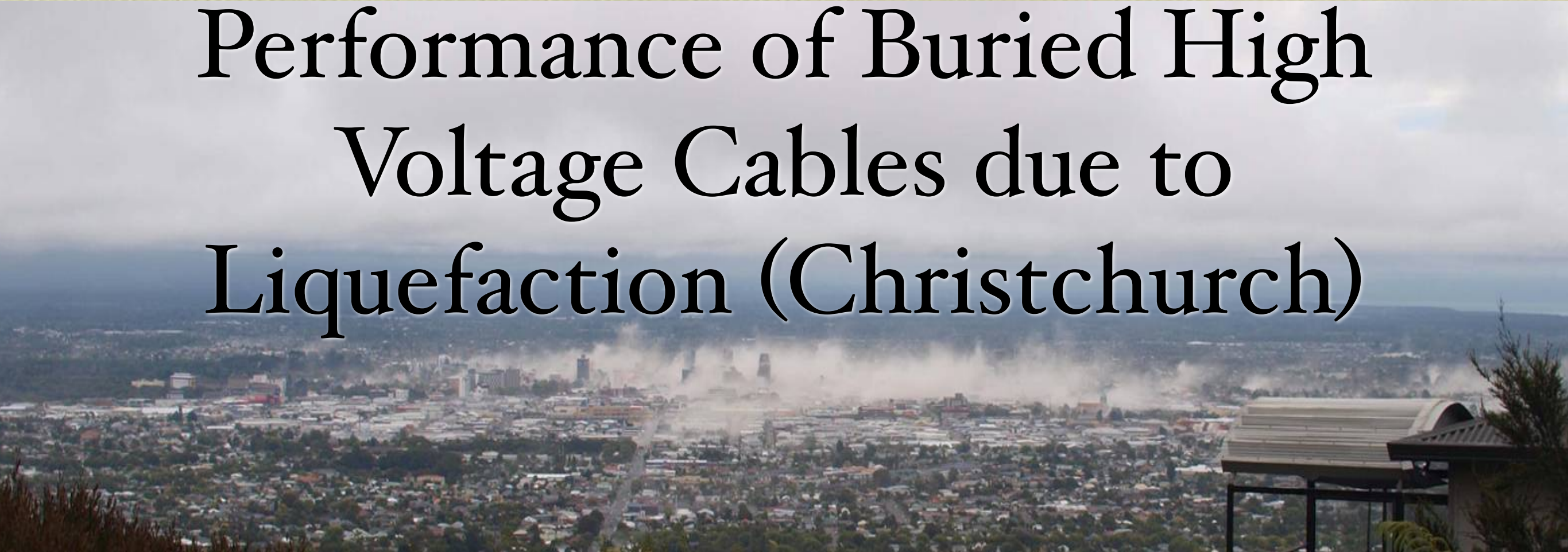


Performance of Buried High Voltage Cables due to Liquefaction (Christchurch)



John Eidinger

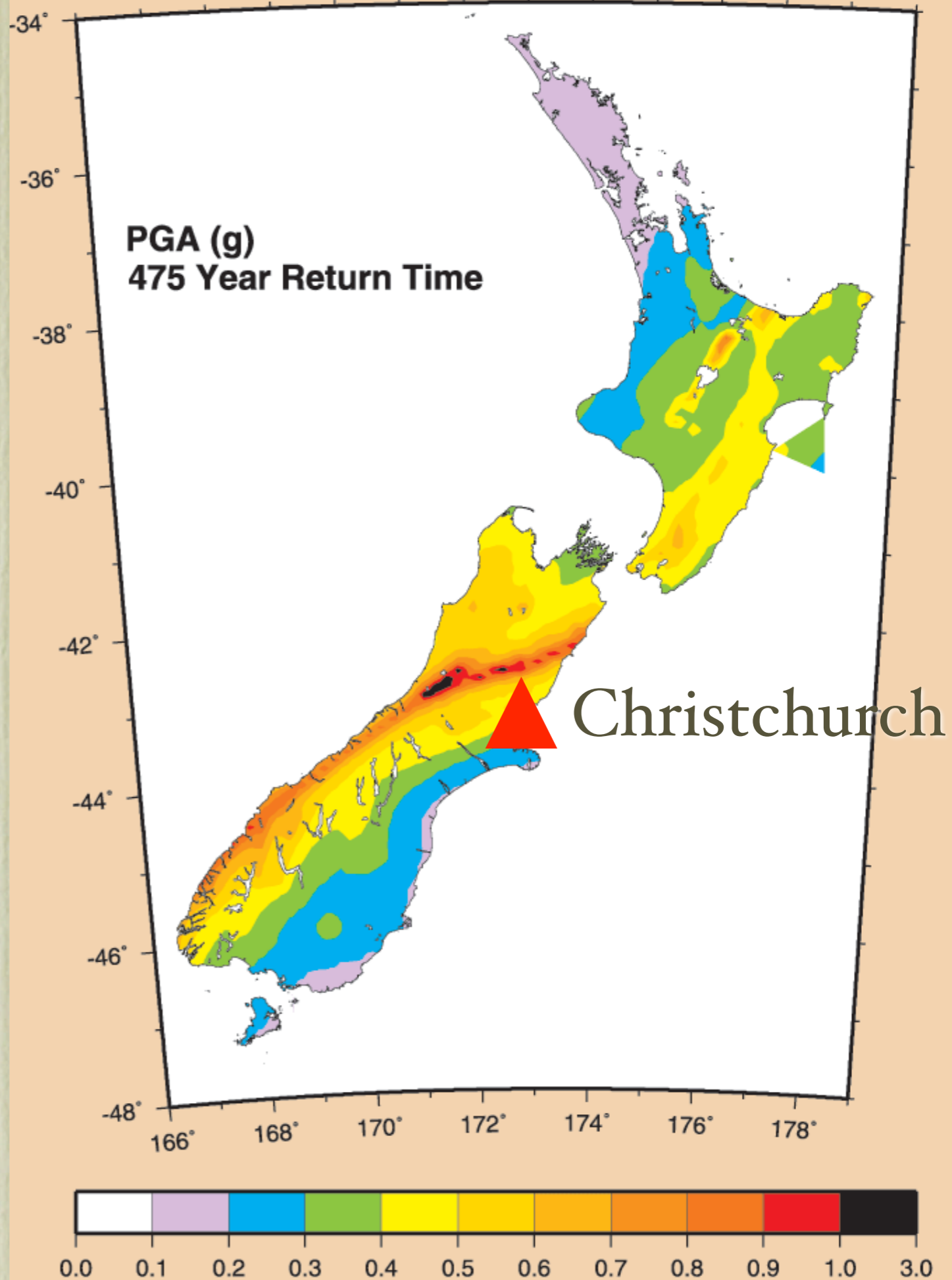
eidinger@geEngineeringSystems.com

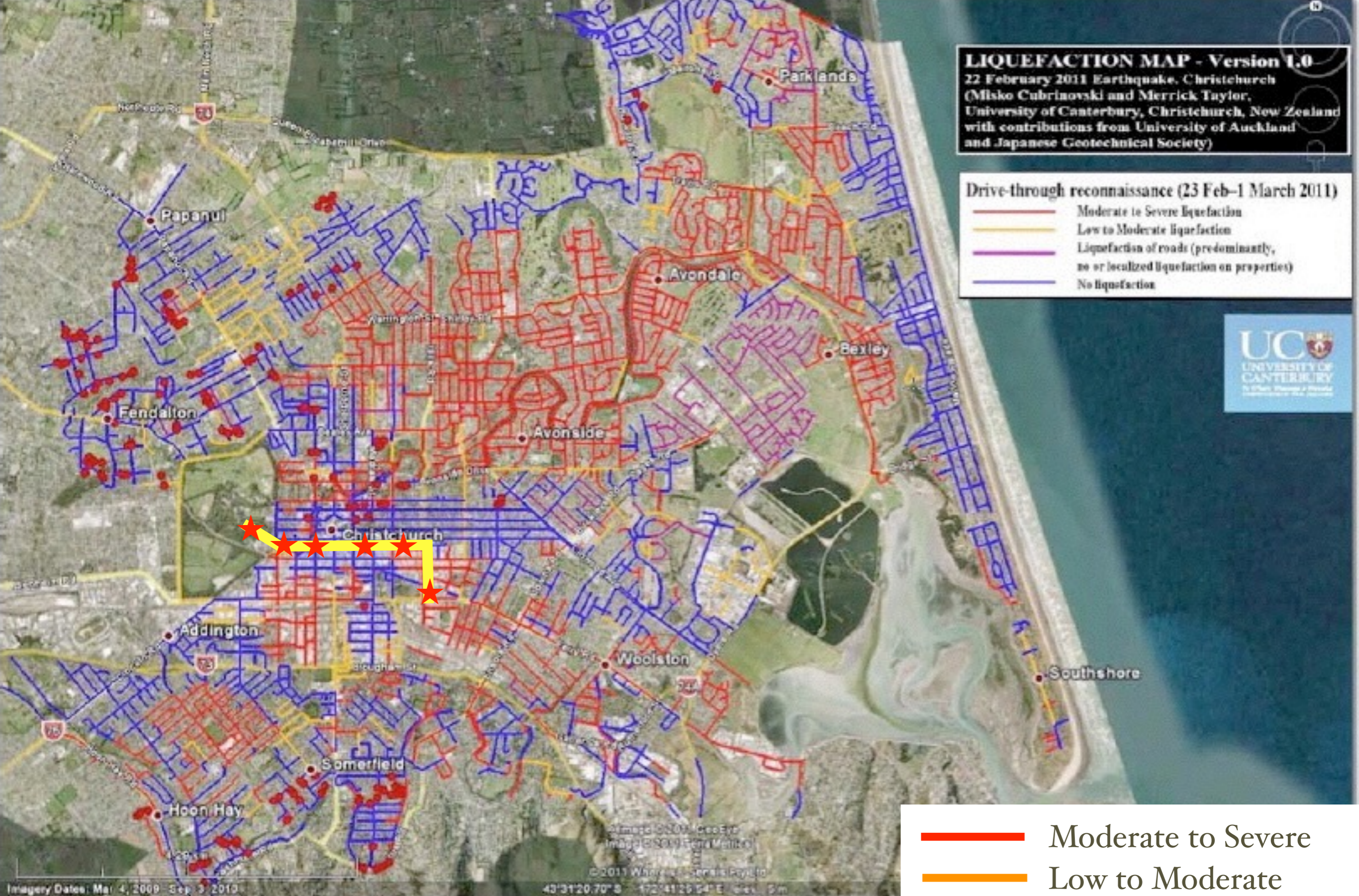
May 29, 2013

Sixth China-Japan-USA
Trilateral Symposium on
Lifeline Earthquake Engineering

475 Years

Design basis for
regular buildings =
220 gal (early
1990s until 2011).





- Moderate to Severe
- Low to Moderate
- Local
- Nil

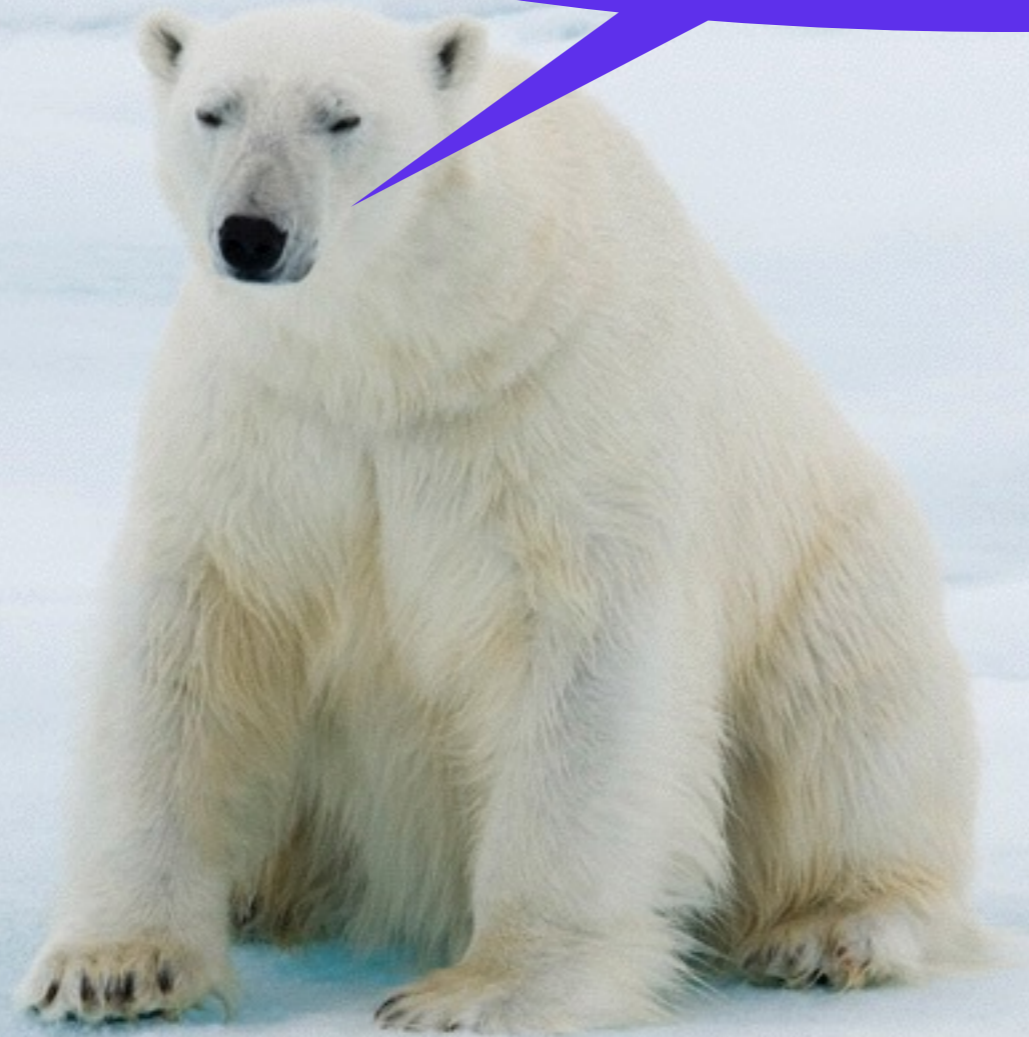
Liquefaction from the Feb 22 2011 Event

WHAT IS THIS?



Answer: Earthquake - destroyed 66 kV Power Cable (XLPE)..... 400 similar cable failures.... Why did they fail?

How many cm of liquefaction is needed to break a direct burial 66 kV cable ?????



Vote for: 2 cm?
Vote for: 20 cm?

Bromley-Heathcote 4T1



None-slight observed permanent distortions





Large sand boil in 220 kV Yard

Brighton Substation 2010



Brighton Substation (2011)



Solution: Brand New Transformer and Circuit Breaker

Brighton Substation (2011)



Transformer Building

February 22, 2011 Earthquake

66kV UG: 50% Failure Rate

11 kV UG: 10% Failure Rate

400V UG: 1% Failure Rate

Major Liquefaction Zone

Modest Liquefaction Zones

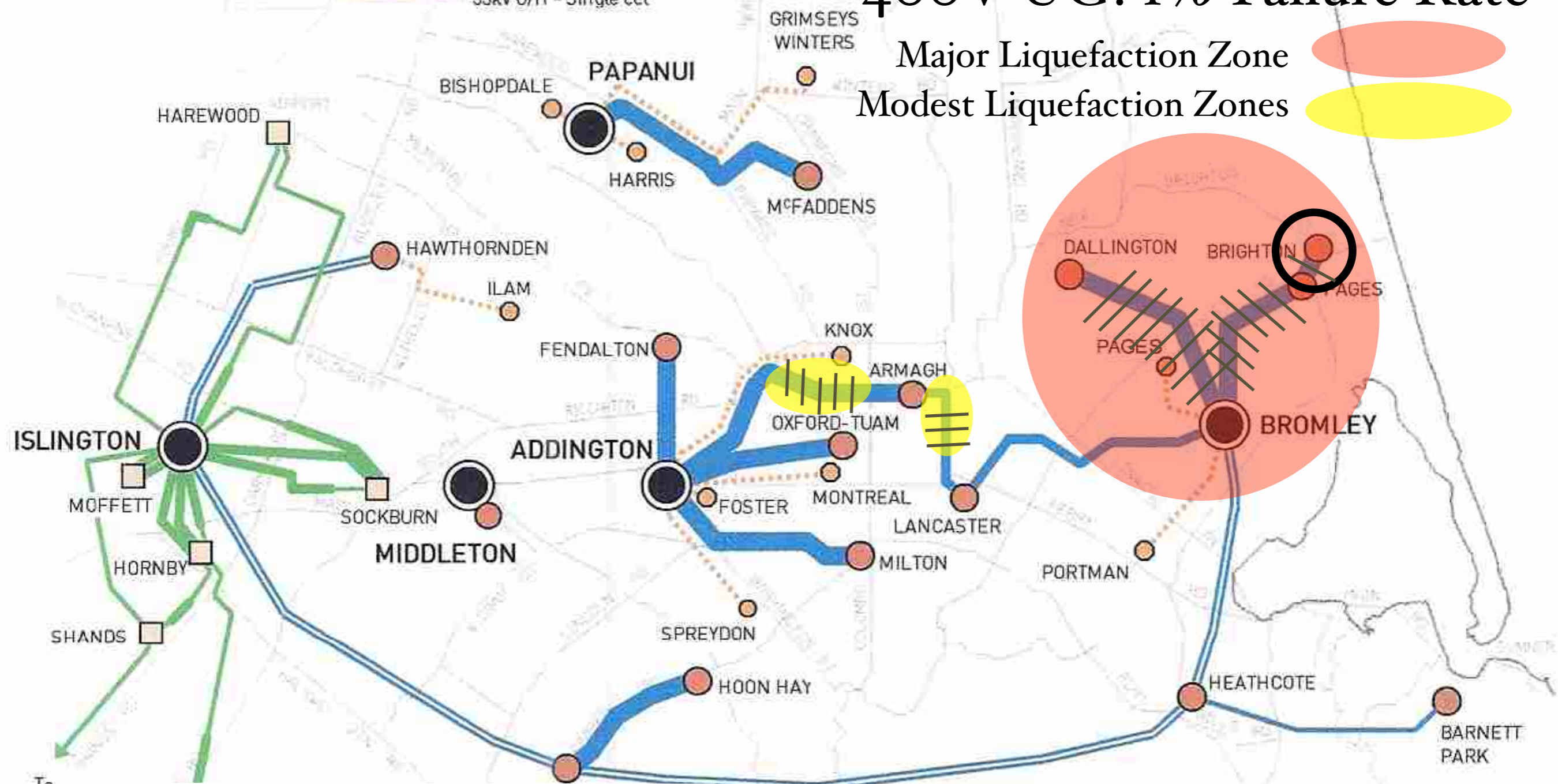


Substation key

- 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



To Spr & F
 Failure Rate: 1 or more faults per circuit.
 Many circuits have multiple faults

Substation destroyed due to liquefaction
 Faulted buried 66 kV Circuit

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



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

DALLINGTON No.2



Orion's Buried Cable Failures

- Damaged underground cables in 3 earthquakes:
- September 2010: 30 11 kV cable failures (4%) typically 40-50 years old
- February 2011: 250 cable failures (many with multiple failures)
- June 2011: 120 cable failures
- Question: how many cm does it take to break a buried power cable?

2010 Earthquake

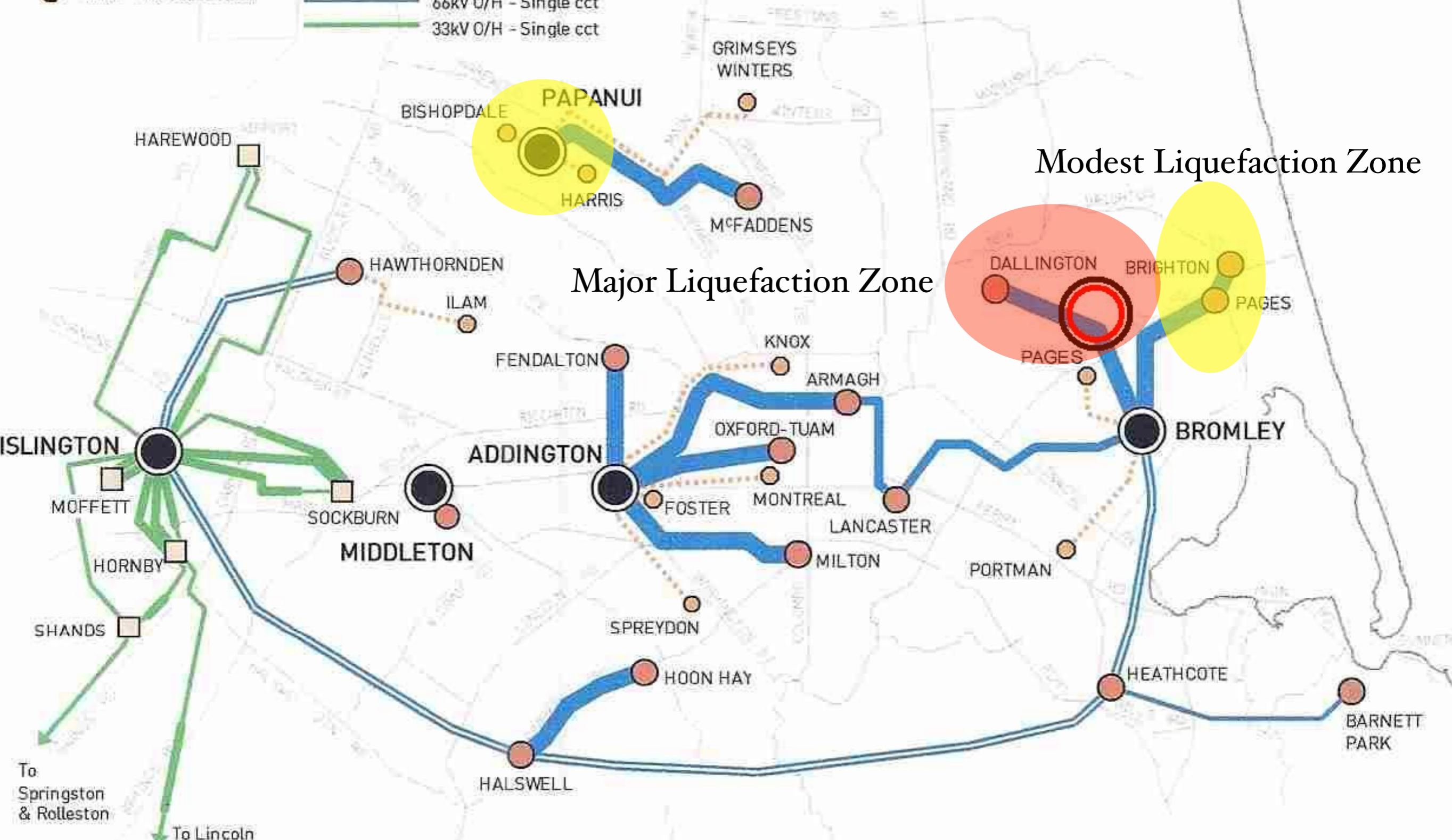
66kV UG: 2 damaged and functional
11 kV UG: several faulted

Substation key

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

Circuit key

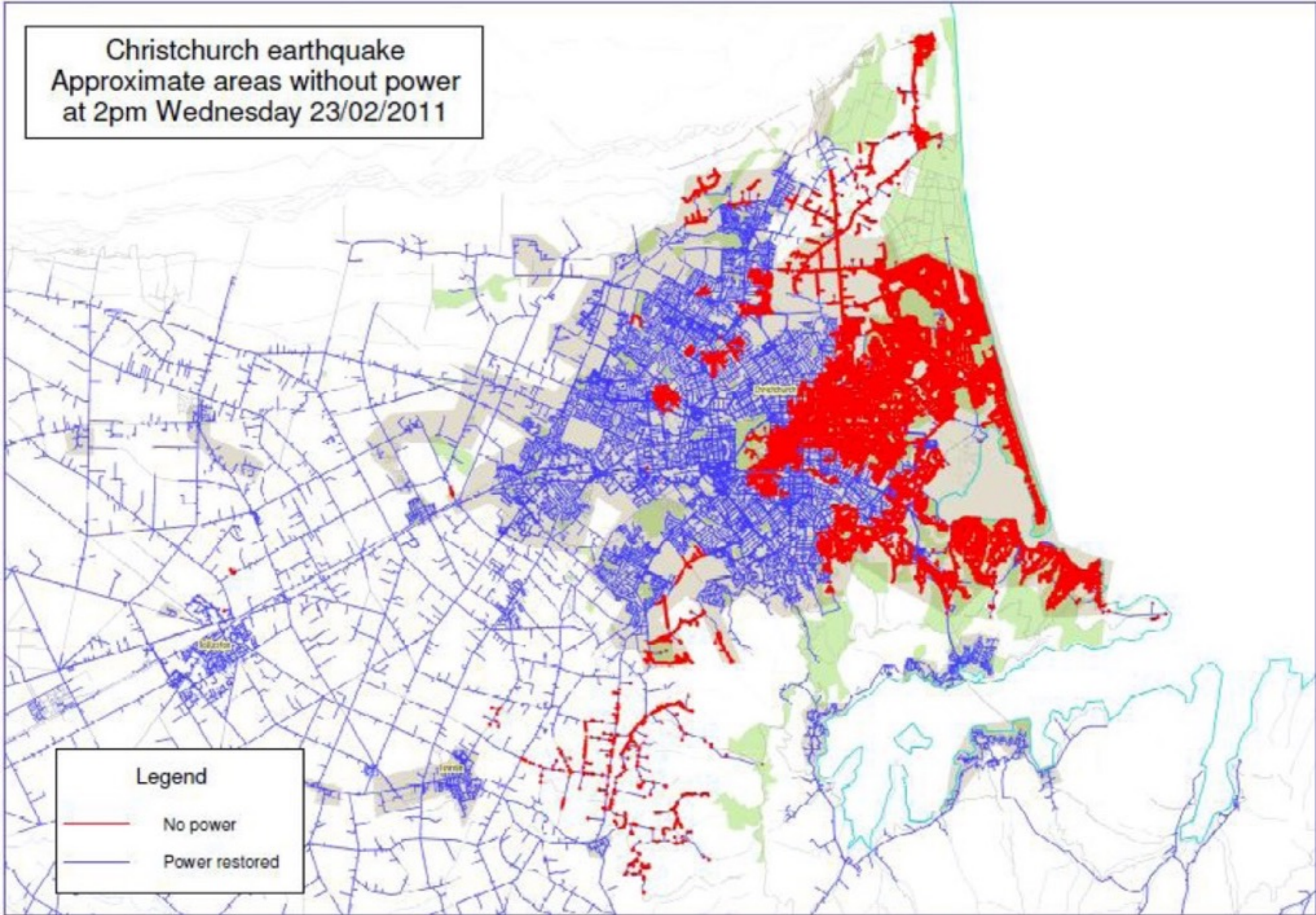
- 66kV U/G - Double cct
- 66kV U/G - Single cct
- 33kV U/G
- 11kV U/G
- 66kV O/H - Double cct
- 66kV O/H - Single cct
- 33kV O/H - Single cct



Modest Liquefaction Zone

Major Liquefaction Zone

Christchurch earthquake
Approximate areas without power
at 2pm Wednesday 23/02/2011



Legend

- No power
- Power restored

11 kV cable





Faulted 11 kV Cables

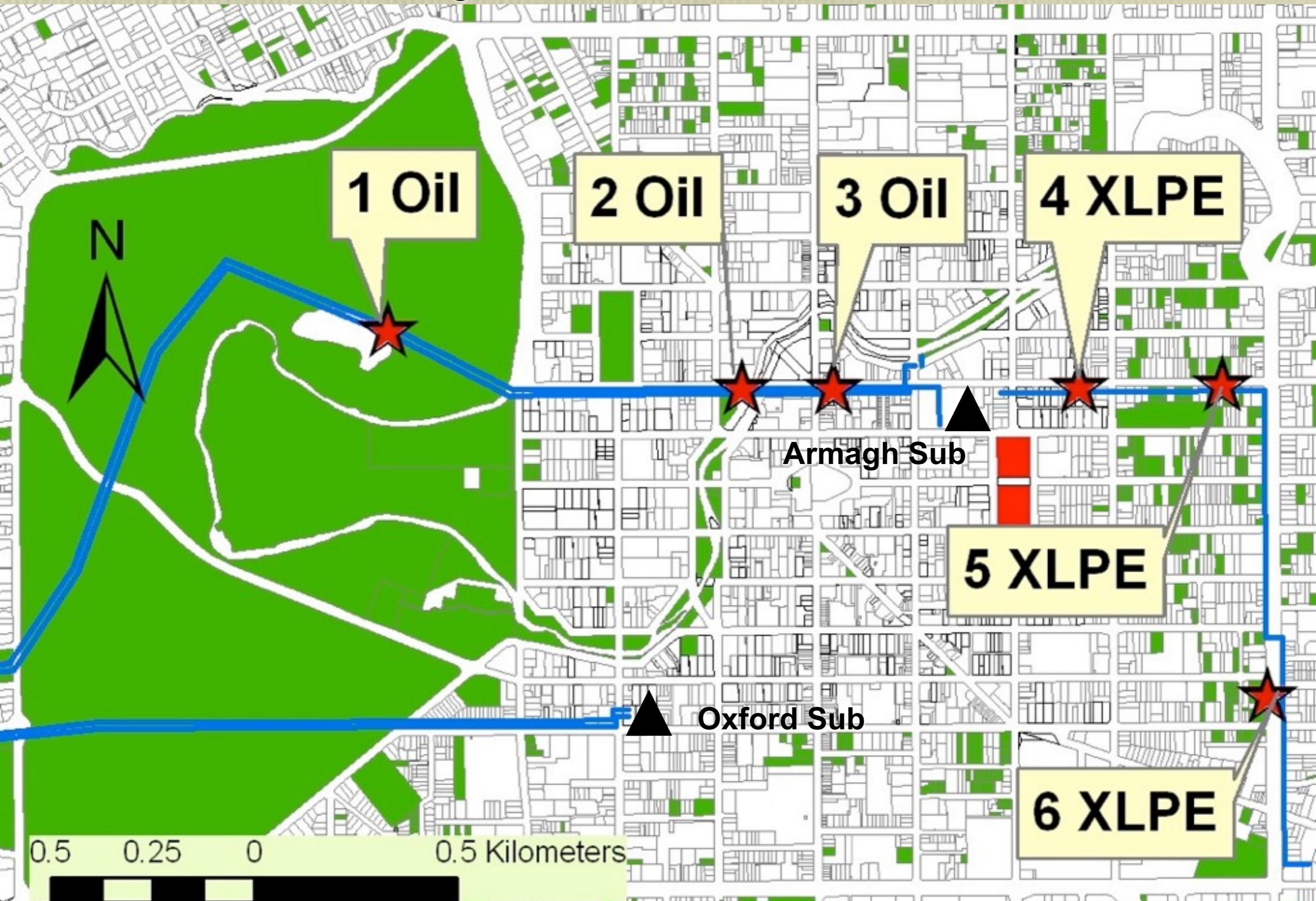
Typical 11 kV cable damage



Typical 11 kV Cable Damage



Locations of 66 kV Underground Cable Failures in Central Business District



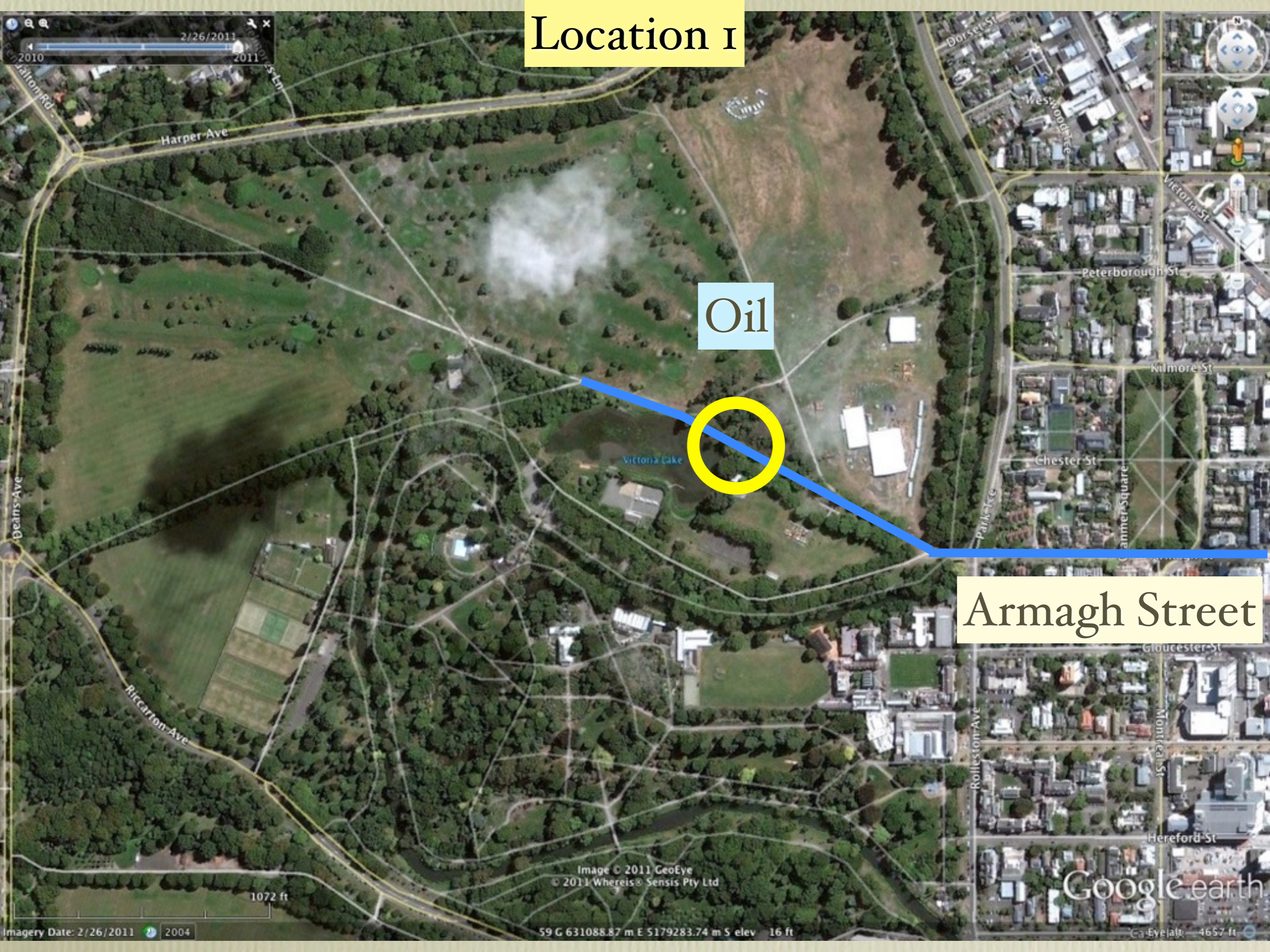
Pipe-type
Oil-filled
66 kV
cable



Location 1

Oil

Armagh Street



1072 ft

Image © 2011 GeoEye
© 2011 Whereis® Sensis Pty Ltd

Google earth

Imagery Date: 2/26/2011 2004

59 G 631088.87 m E 5179283.74 m S elev 16 ft

Eyealt: 4657 ft

Location 1



Location 1



Location 1



Location 1



Location 1



Location 1



Location 2

Location 3



120 Armagh St, Christchurch Central, Christchurch, New Zealand

Feb 15 2011

Google earth

2004

59 G 63 1984 12 m, E 51 793 16 90 m S elev 13 ft

Eye alt 1307 ft



Handwritten blue chalk markings on the asphalt, possibly a date or time, such as "11/11" and "11:11".





Location 3



Location 3



Location 3



Location 3



Location 3





AUTONS photography

ANZ

GREEN PINE



Kodak
EXPRESS

KENS
CAMERAS

KENS CAMERAS
PROFESSIONAL EQUIPMENT

ANZ

KENS CAMERAS
PROFESSIONAL EQUIPMENT

KENS DIGITAL
FUTURE PAPER SOLUTIONS

Metallic Screen



XLPE Insulation



HDPE Sheath



Copper Core



Lead Sheath



XLPE 66 kV Cable

2/23/2011

Gloucester St

Location 4

Feb 23 2011



Madras St

Gressons Ln

Gloucester St

263 ft

© 2011 Whereis Sensis Pty Ltd
Image © 2011 GeoEye

Google earth

Every Date: 2/23/2011 2004

59 G 632912.65 m E 5179138.48 m S elev 13 ft

Eye alt 1150 ft

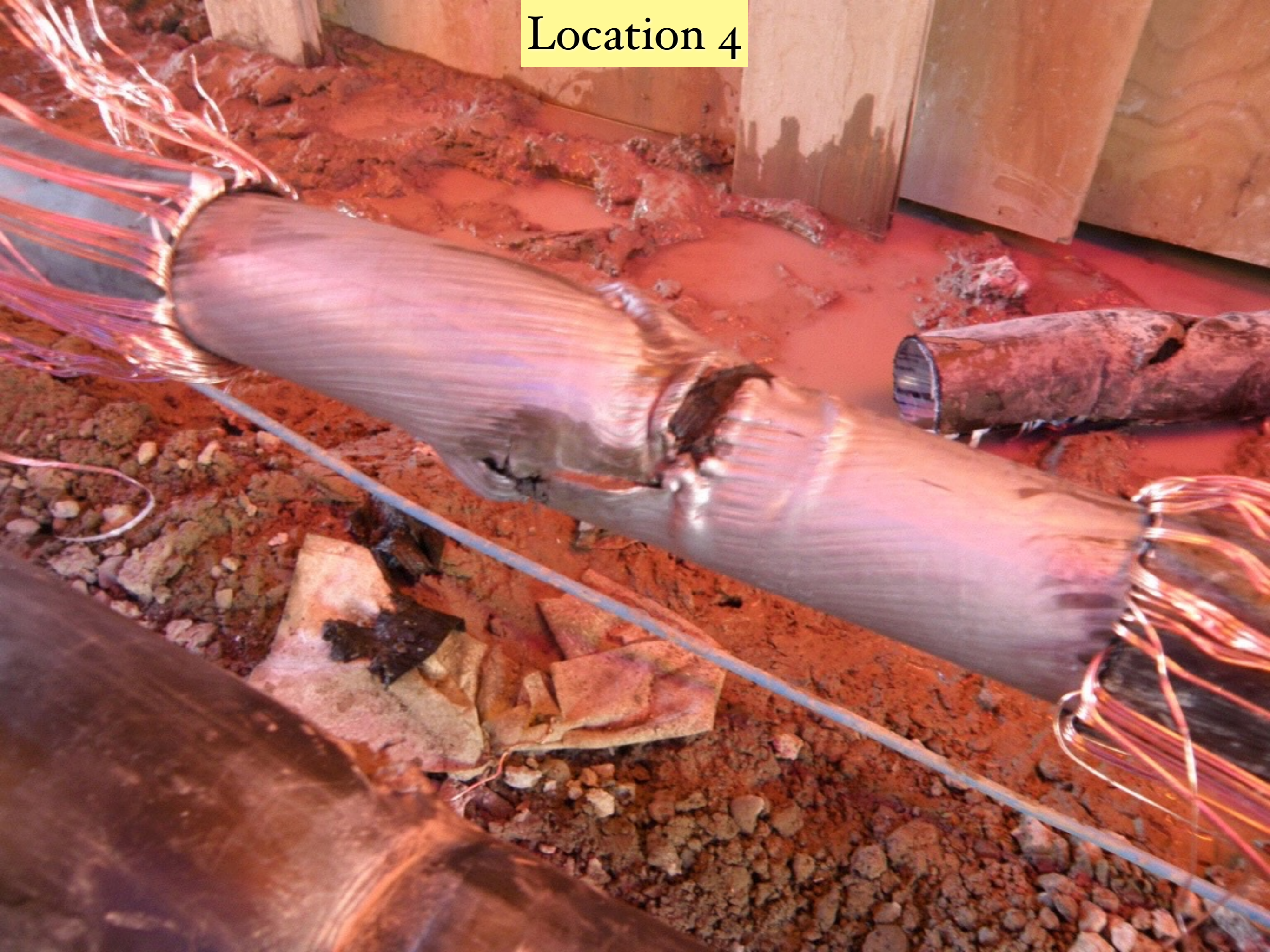
Location 4



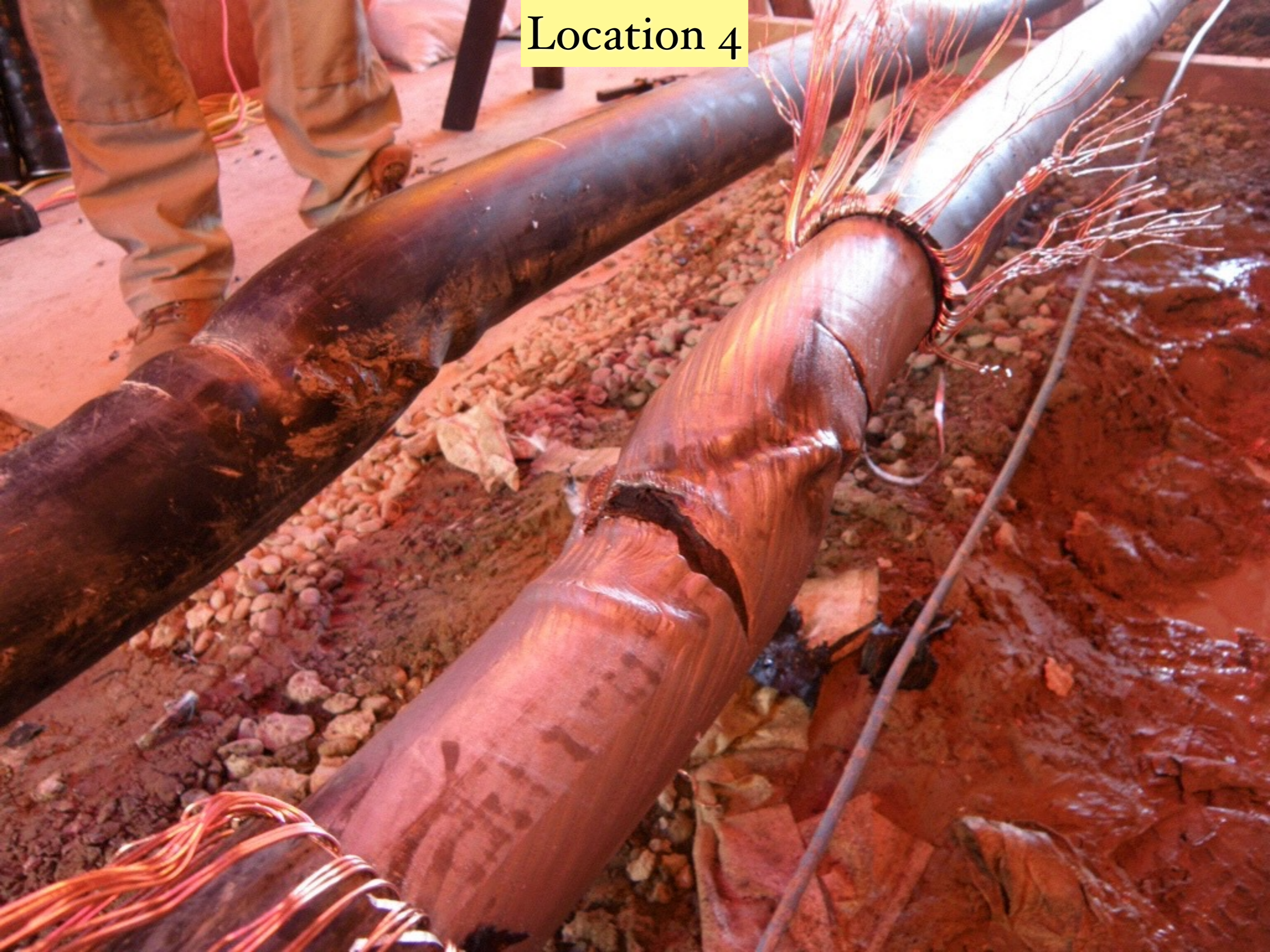
Location 4



Location 4



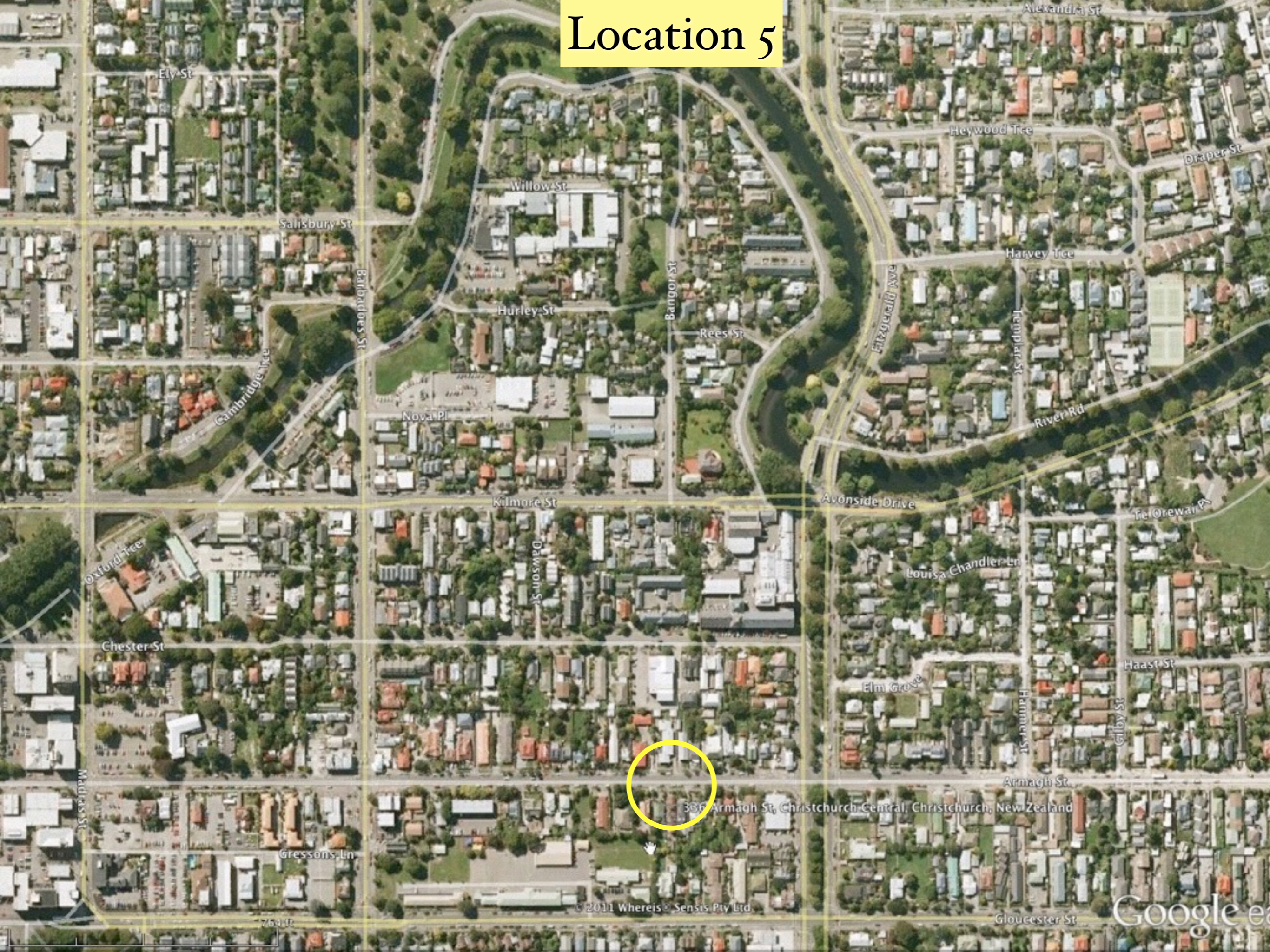
Location 4



Location 4



Location 5



385 Armagh St, Christchurch Central, Christchurch, New Zealand

Location 5



Location 5





Location 6

Tuam Street

Fitzgerald Ave

1081 feet

Image: Feb 26, 2011



Location 6

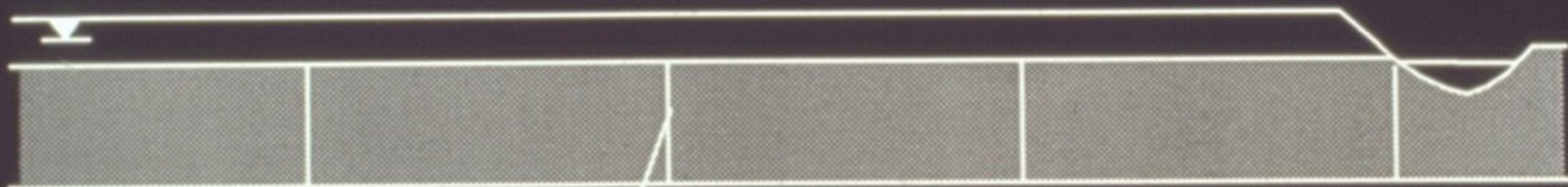


Location 6

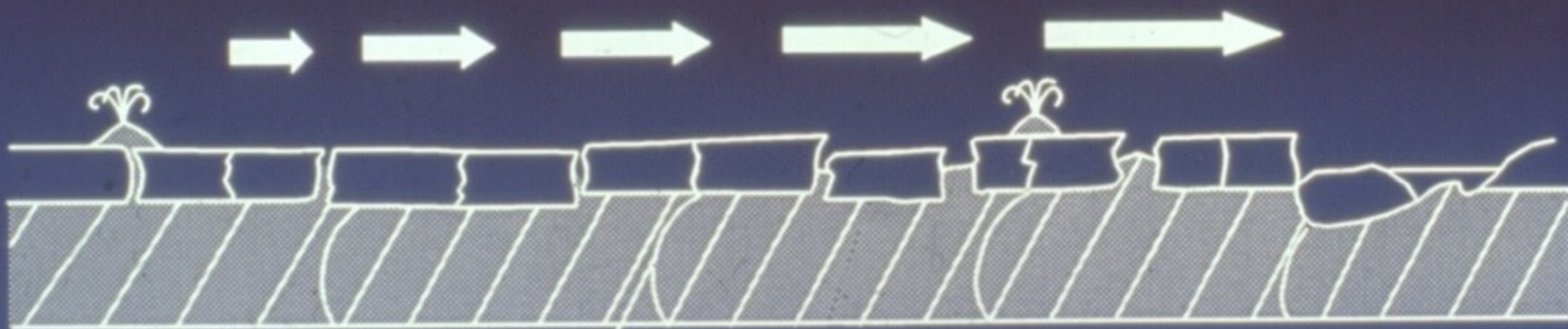


Why do the cables fail?

- Choice 1 .Ground settlements to 2 to 5 cm (LESS LIKELY)
- Choice 2. Lateral cracking of top soil cap, followed by block vibration (MOST LIKELY)

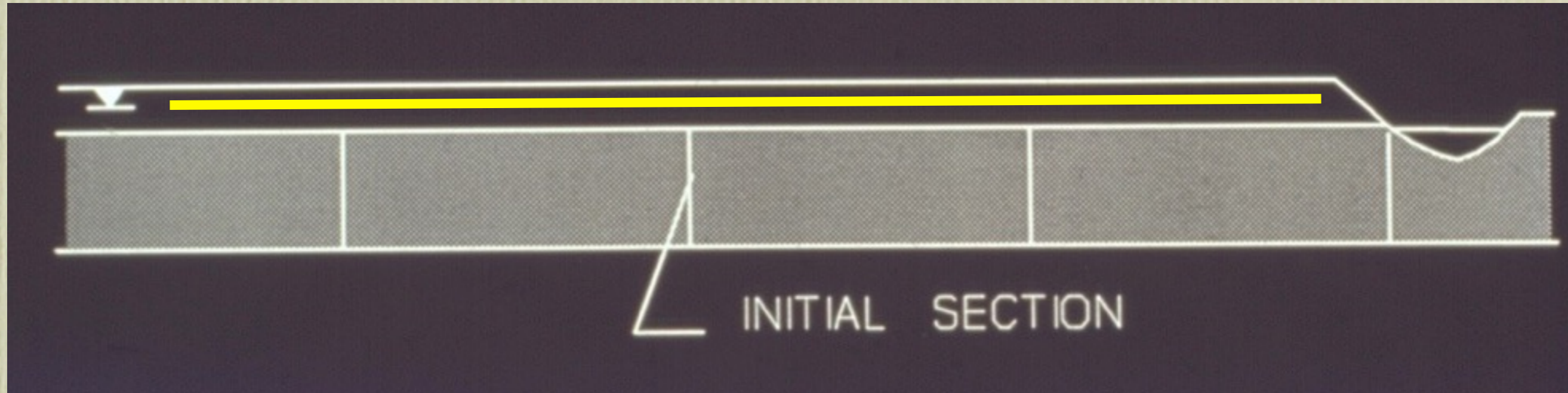


INITIAL SECTION



DEFORMED SECTION

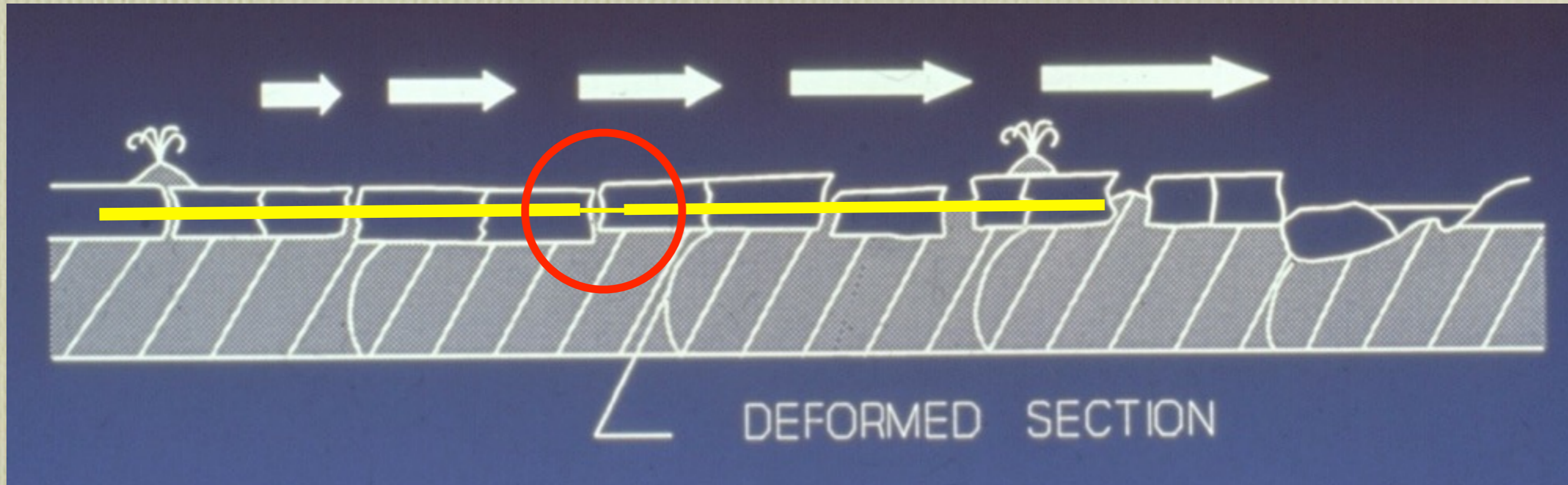
Before the Earthquake



High Voltage Buried Cable

During the Liquefaction Phase of the Earthquake

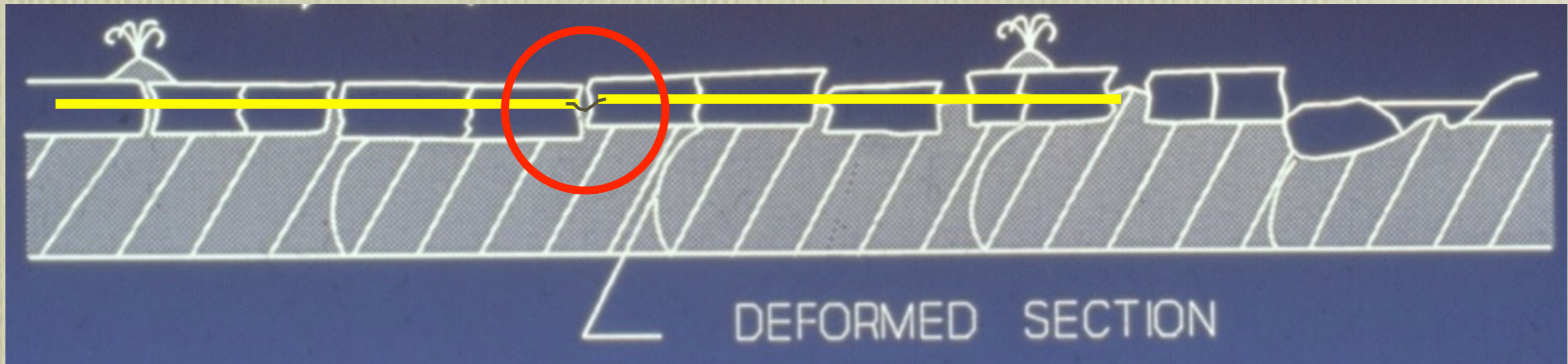
Soil cap breaks into independent blocks and begin to slosh around, tending towards free face



Cable Stretches

After the Earthquake (hours)


Soil cap blocks close into their final position



1. Concrete cracks in tension ($t_u * L > f'_t * A$)
 2. Pipe-Type Cable Stretches
 3. Pipe-Type Cable Buckles in Compression
 4. Oil Pressure Lost (as observed at substation gage, 2-3 hours post-earthquake)

Mitigation Strategies

- NEVER use direct burial cables in thermal concrete in liquefaction zones.
- In liquefaction zones:
 - Use overhead (if possible)
 - Use buried cables in PVC or HDPE conduits within reinforced thermal concrete duct banks



How many cm of liquefaction is needed to break a direct burial 66 kV cable ?????

Vote for: 2 cm?
Vote for: 20 cm?

- Report on the Christchurch Earthquake Sequence (September 2010, February 2011, June 2011, December 2011):

- <http://www.geEngineeringSystems.com>