Seismic Performance of Buried Cables and Pot Heads

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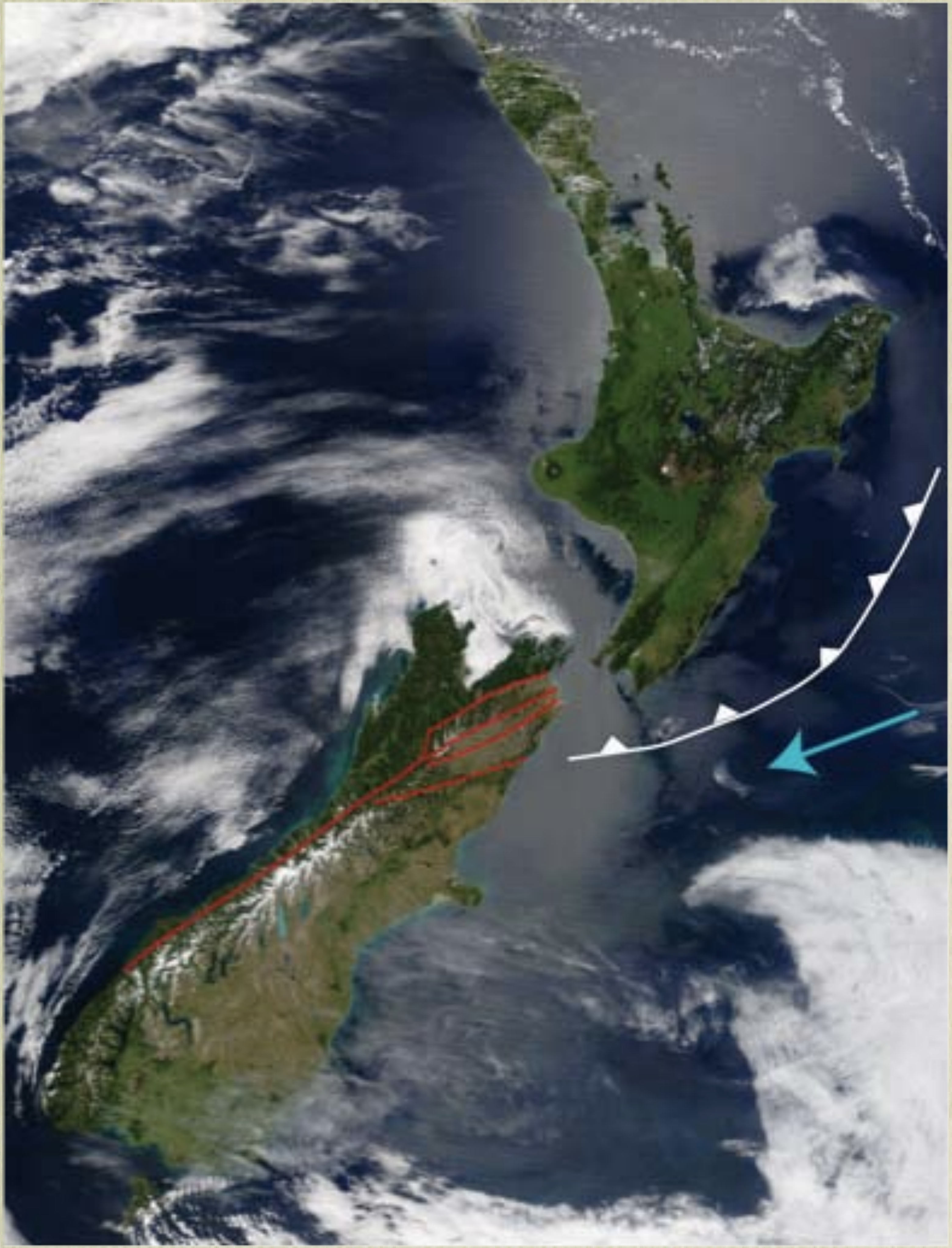
Agenda

- Performance of Buried Cables in Past Earthquakes (Christchurch 2010, 2011, Napa 2014)
- Shake Table and In Situ Testing of Pot Heads (115 kV, 230 kV, 300 kV, Composite, Porcelain)
- Tests of Duct Banks
- Who has these problems on the West Coast (PG&E, BC Hydro recognizes and mitigatates. Some others have less exposure, or are "don't see don't worry (yet)"
- There are NO standards. What should we do? What about submarine cables?

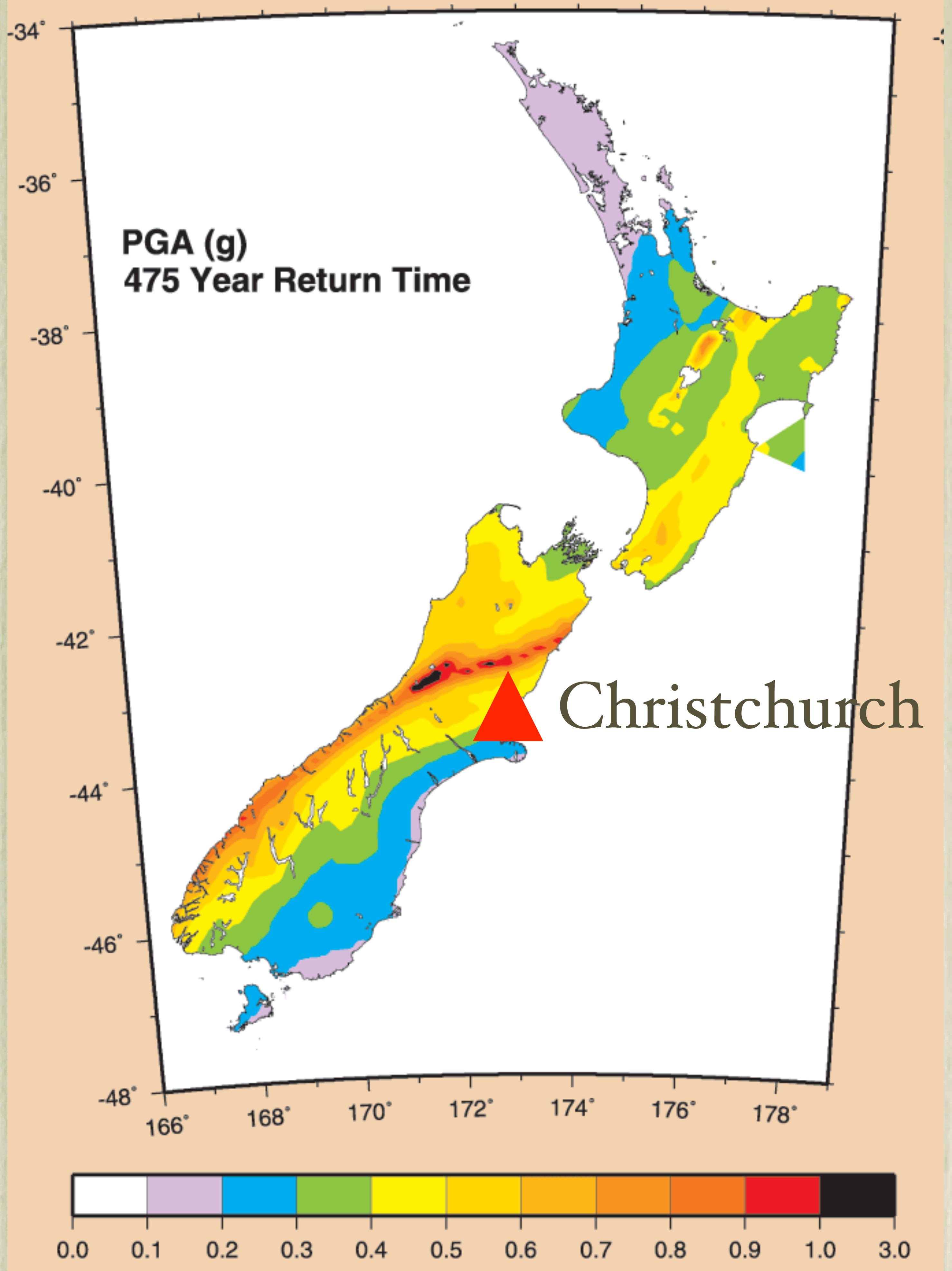
Anshel Schiff: “Father” of Earthquake Performance of High Voltage Equipment

2014 Tests of 230 kV
Bushing and Surge Arrestor with
“pseudo” top plate of transformer,
various types of conductors.
PSU, BPA

New Zealand



Earthquake
Level of Shaking
475 Years



Christchurch, Feb 22 2011, 1:51 pm

Looking North, from the Port Hills

Collapse of the Central Business District

Christchurch Cathedral

February 2011

Orion

- 3rd largest NZ power distribution company
- $5 million NZ spent, 1995-2009 on seismic strengthening at unreinforced masonry substations, lines and cables

Orion Inventory 11 kV

Construction Type	Length (km)
PILCA	1523.8
PILCA HDPE	67.1
XLPE	601.0
Unknown	24.3
Total	2,216.2

Table 7-10. Orion 11 kV Cables – Length, by Cable Type (2010)

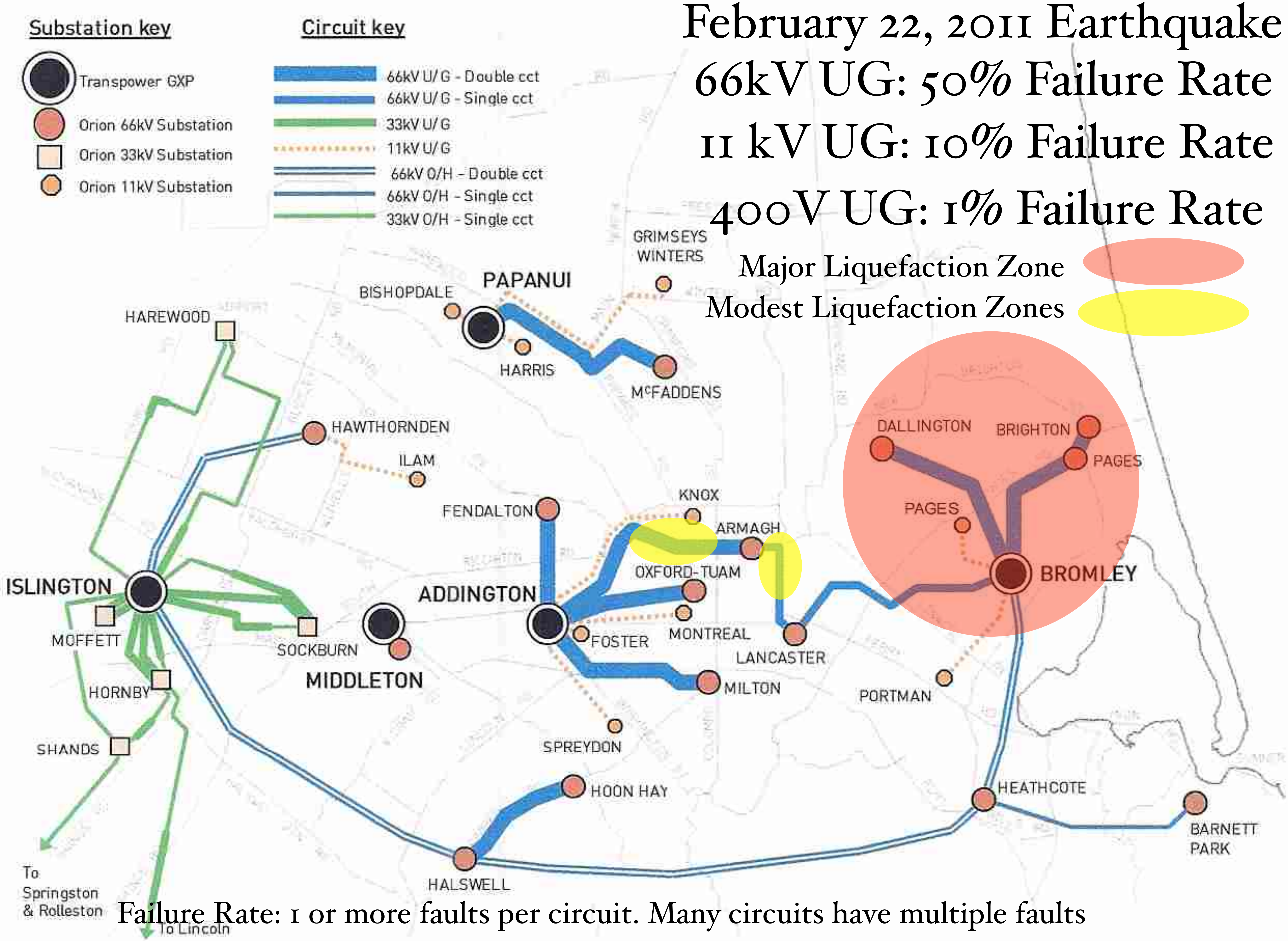
Conductor Size	Units	Conductor Area mm^2	Length (km)
630	sq. mm.	630	3.2
400	sq. mm.	400	26.5
300	sq. mm.	300	277.0
240	sq. mm.	240	14.8
185	sq. mm.	185	215.4
180	sq. mm.	180	1.0
150	sq. mm.	150	68.0
95	sq. mm.	95	410.9
70	sq. mm.	70	41.3
35	sq. mm.	35	126.2
25	sq. mm.	25	123.8
16	sq. mm.	16	0.4
.6	British SWG	182	0.8
.5	British SWG	127	123.9
.4	British SWG	81	1.1
.3	British SWG	46	14.0
.25	British SWG	32	223.4
.2	British SWG	19	60.6
.15	British SWG	10.5	120.2
.1	British SWG	5.5	9.1
.06	British SWG	2.1	39.6
.05	British SWG	1.2	2.4
.04	British SWG	0.81	301.5
.0225	British SWG	0.25	1.8
Unknown	Unknown	Unknown	8.7
Total	Total	Total	2,216.2

February 22, 2011 Earthquake

66kV UG: 50% Failure Rate

11 kV UG: 10% Failure Rate

400V UG: 1% Failure Rate



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

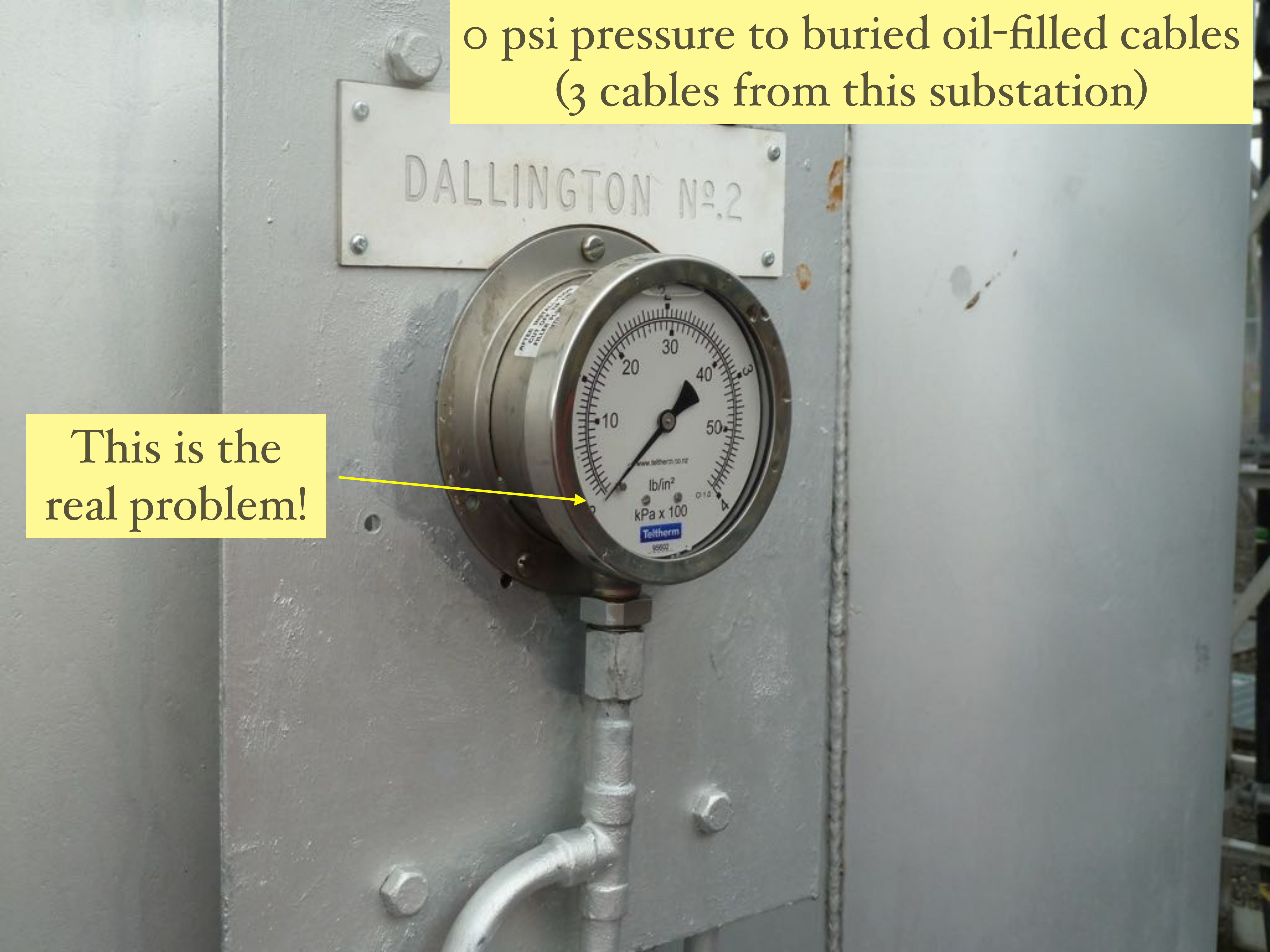
Oil Tanks for Buried 66 kV Cables.

2 of 3 were tilted on their foundations, one spalled concrete foundation....

but that is not the real problem....

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

This is the
real problem!

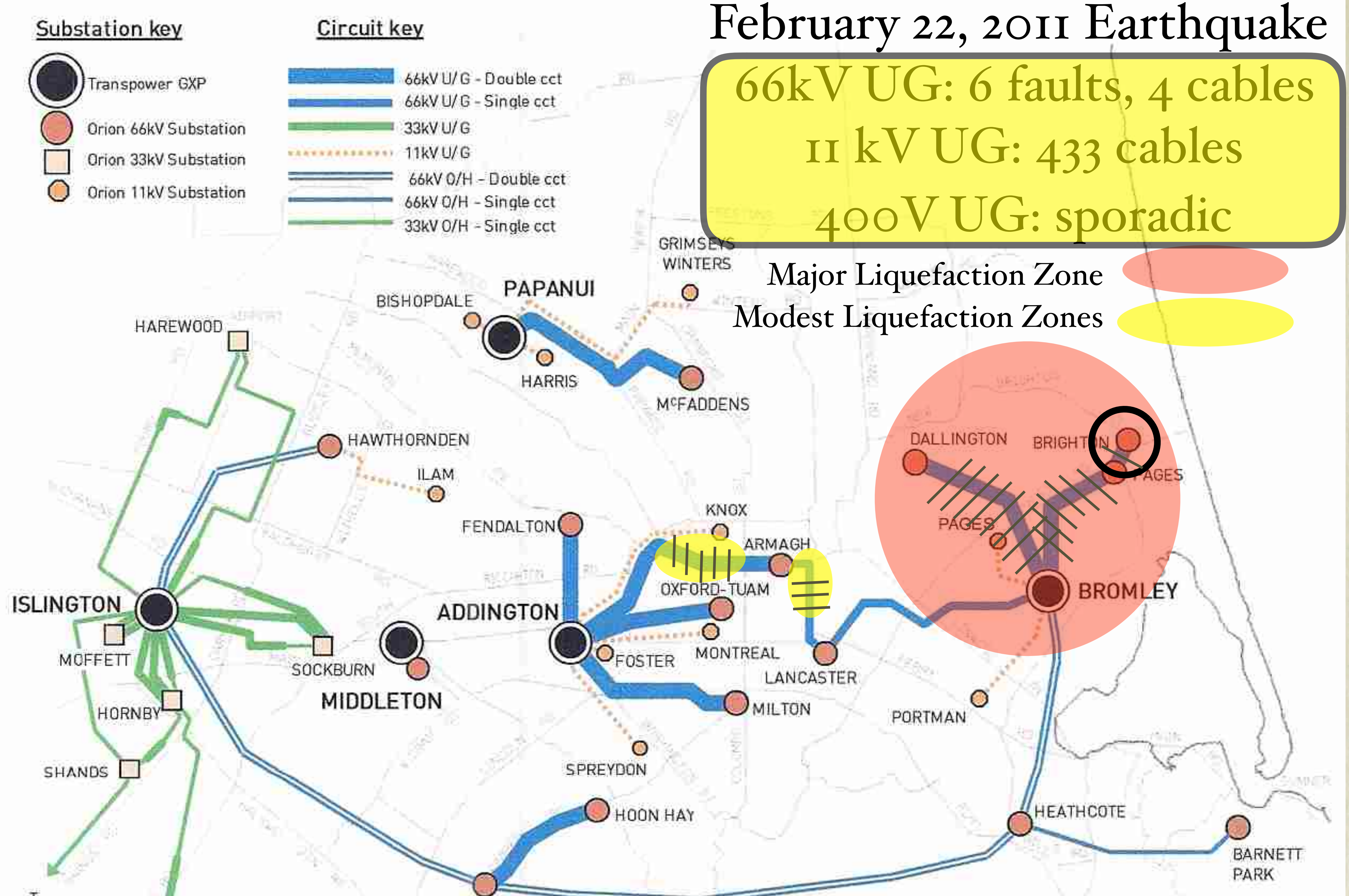


February 22, 2011 Earthquake

66kV UG: 6 faults, 4 cables
11 kV UG: 433 cables
400V UG: sporadic

Major Liquefaction Zone

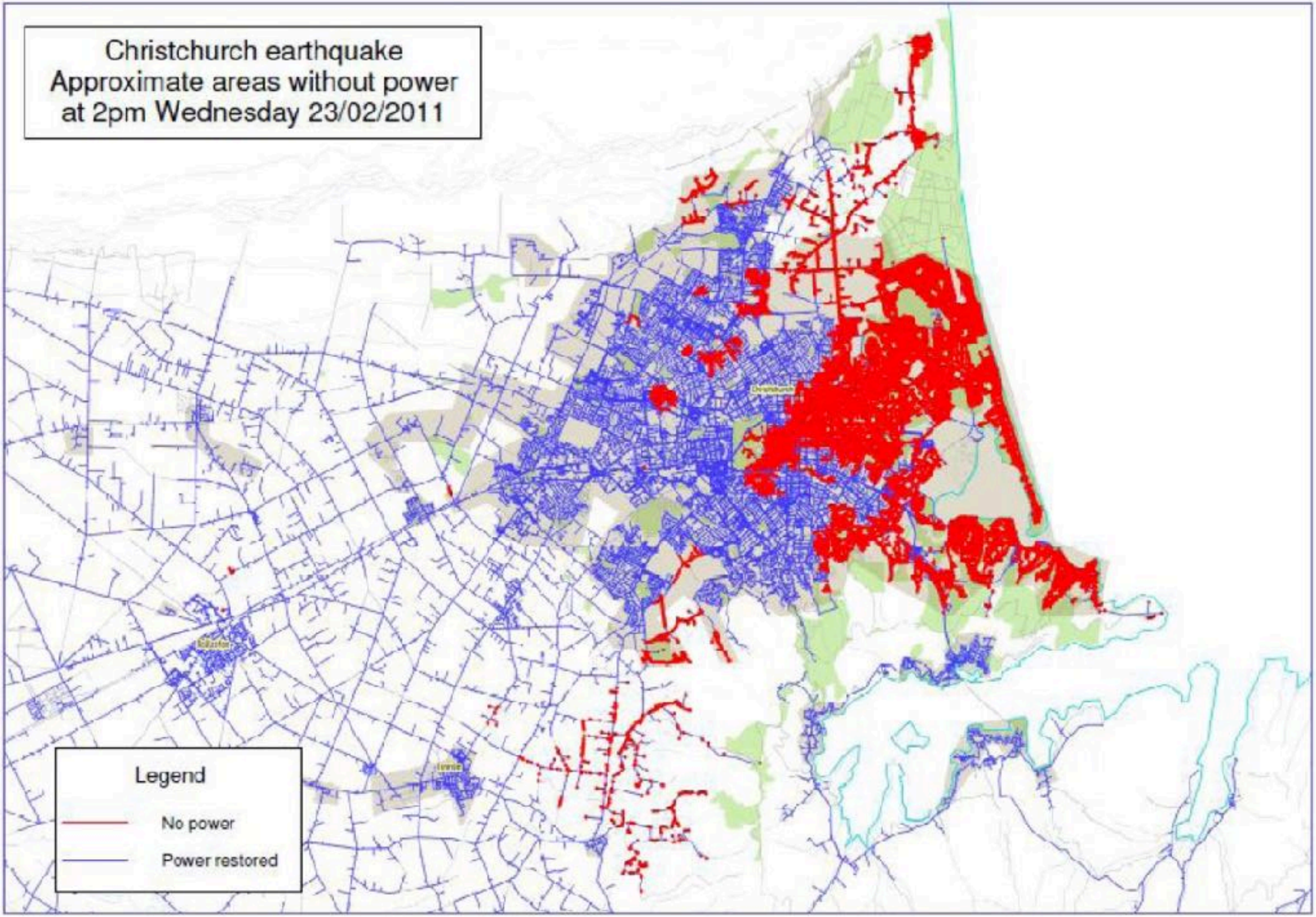
Modest Liquefaction Zones

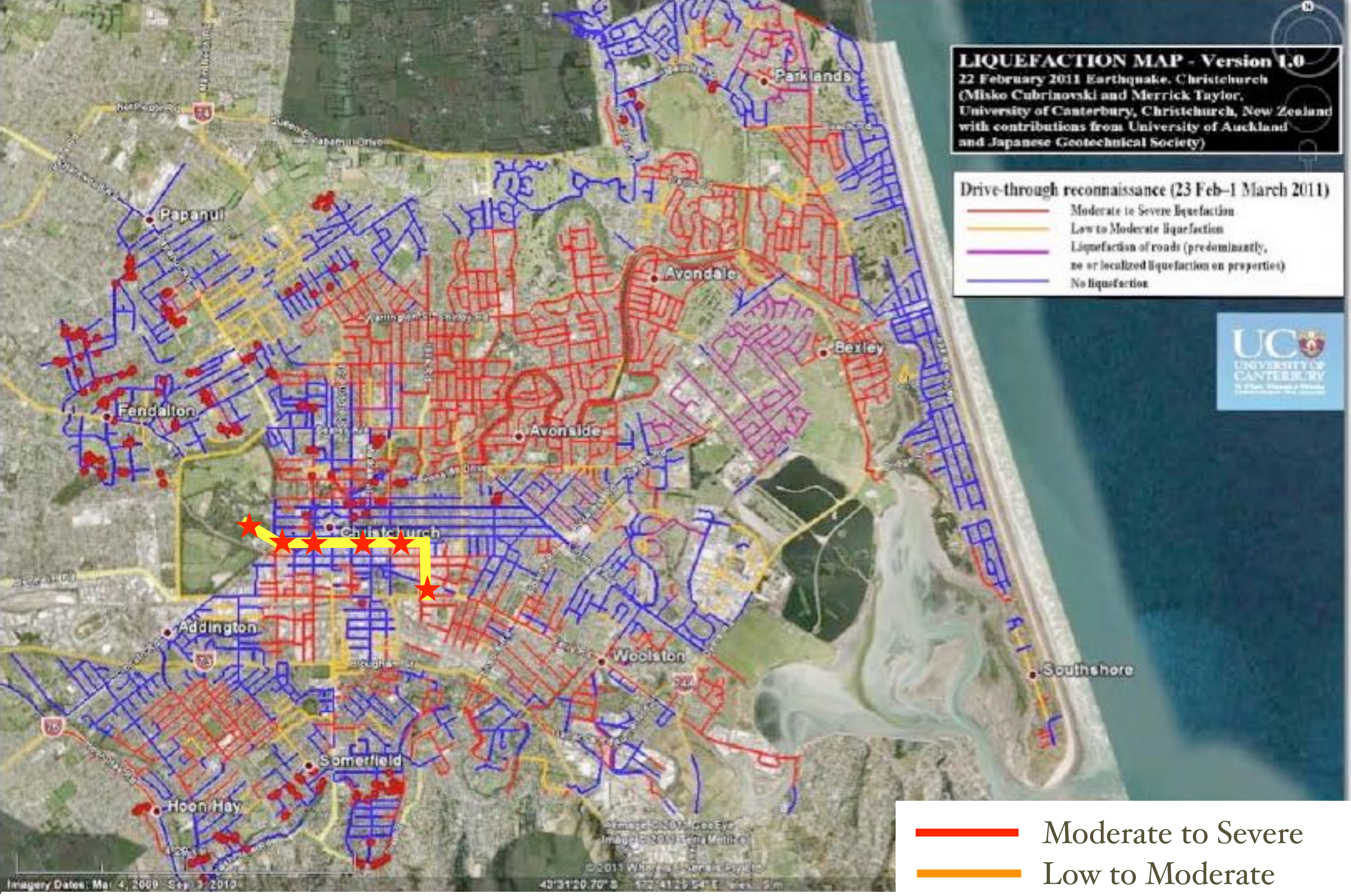


Failure Rate: 1 or more faults per circuit.
Many circuits have multiple faults

Substation destroyed due to liquefaction

Faulted buried 66 kV Circuit

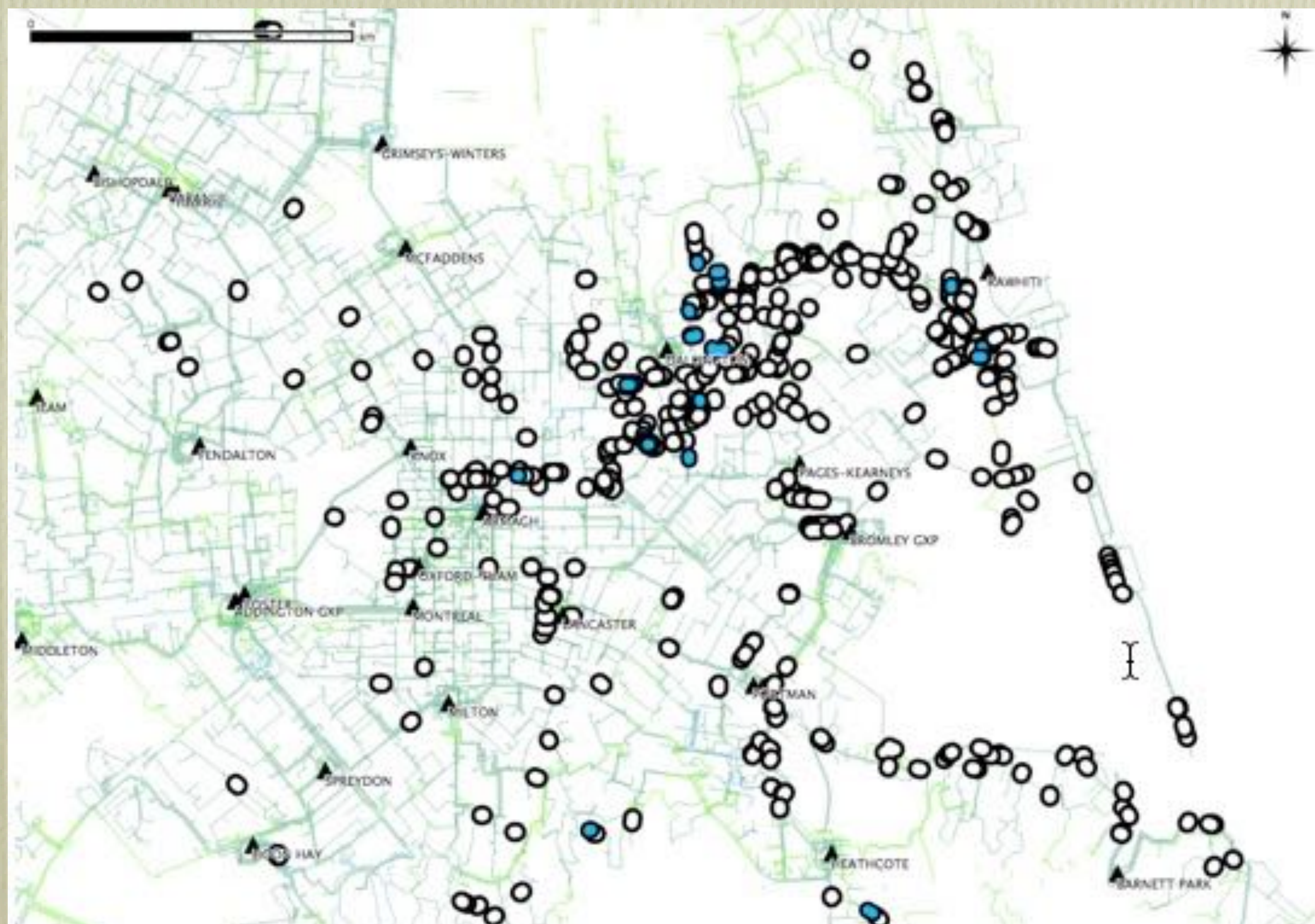

Christchurch earthquake
Approximate areas without power
at 2pm Wednesday 23/02/2011
Legend
No power
Power restored



Liquefaction from the Feb 22 2011 Event

Buried Cable Failures in Christchurch

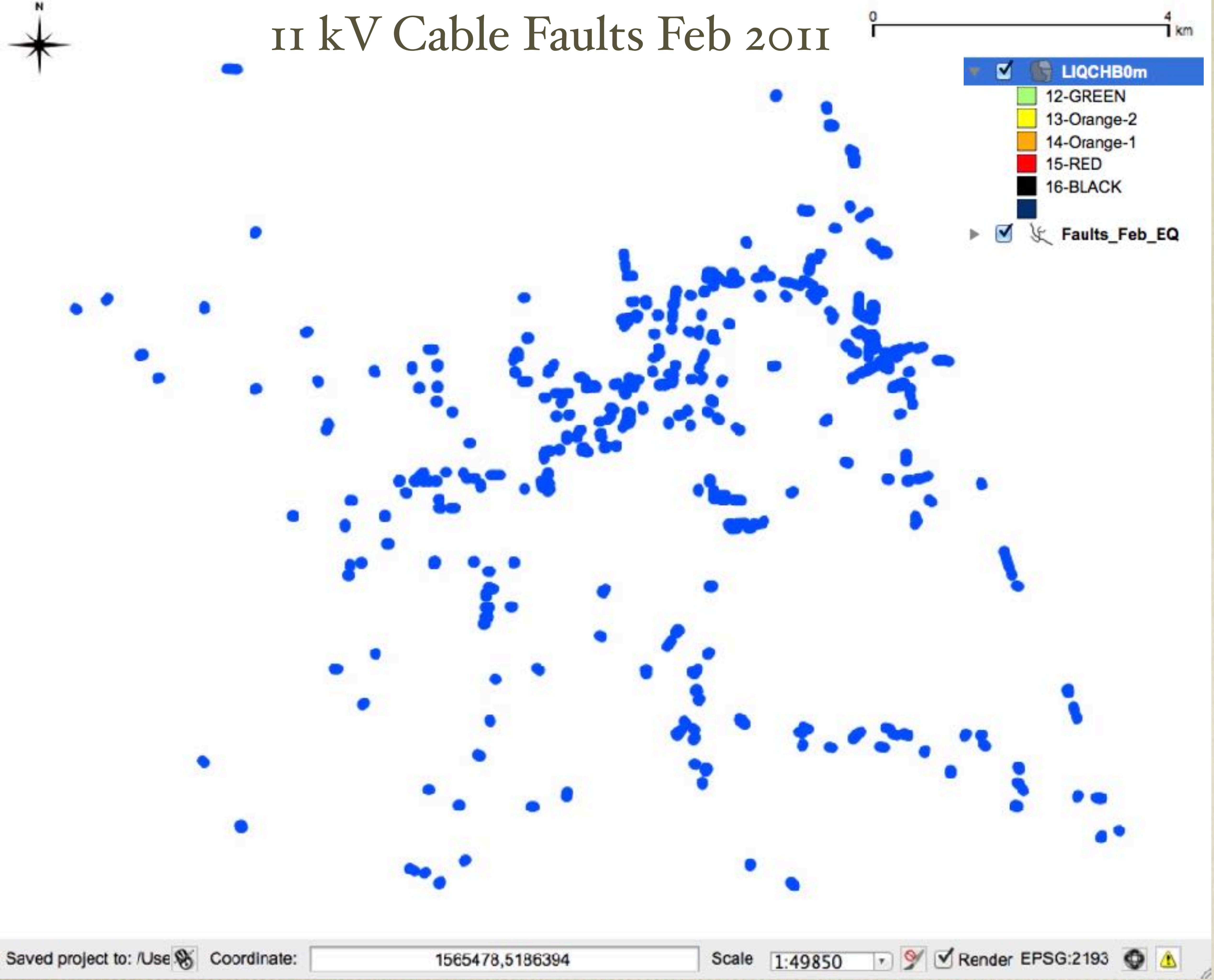
Sept 2010: 24
Feb 2011: 433
June 2011: 63



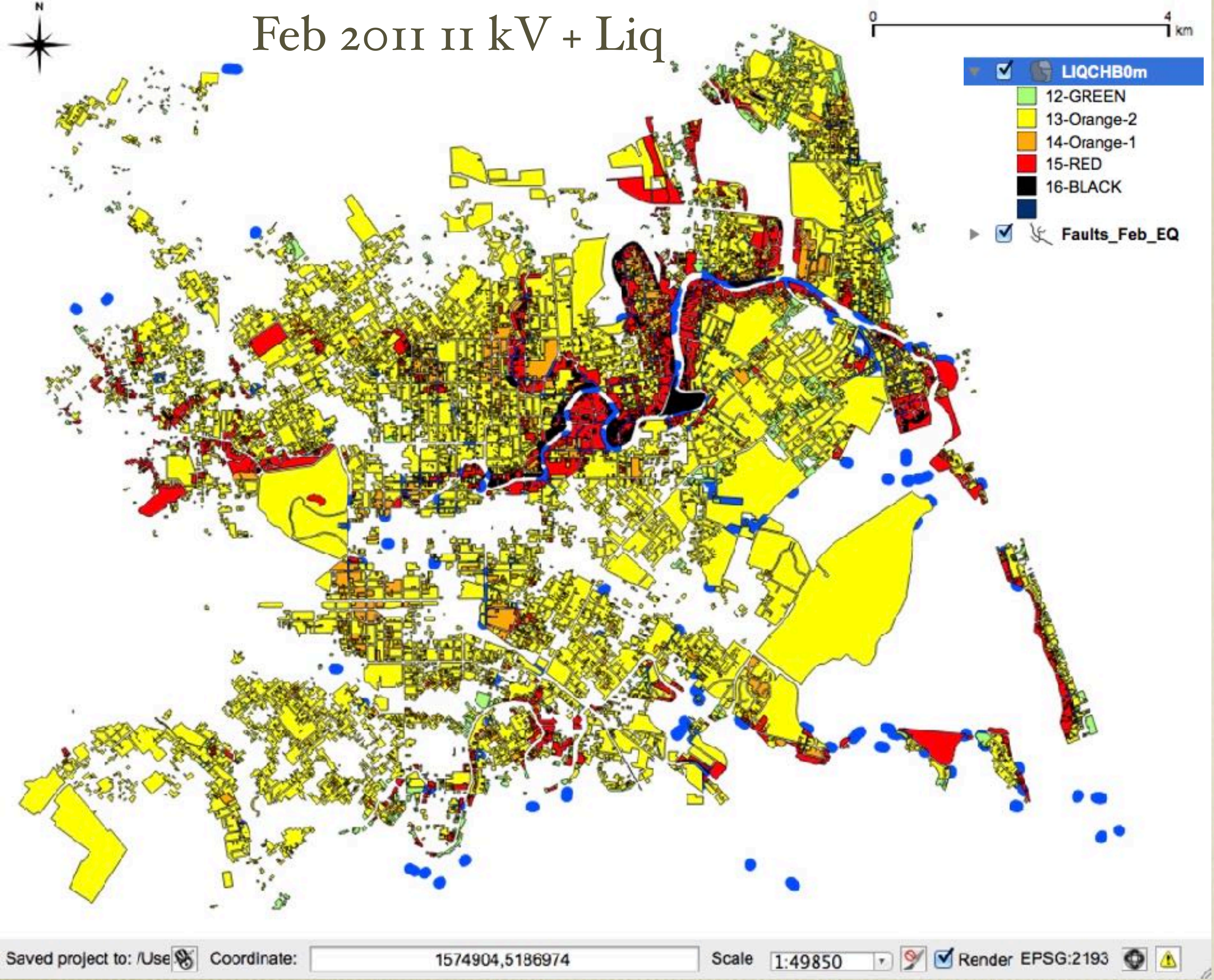
- PILCA: 418 repairs
- PILCA with HDPE Sheathing: 10 repairs
- XLPE: 5 repairs (installed 1999 - 2006)

- 1910-1919. 1 repair
- 1920-1929. 0 repairs
- 1930-1939. 8 repairs
- 1940-1949. 7 repairs
- 1950-1959. 49 repairs
- 1960-1969. 122 repairs
- 1970-1979. 170 repairs
- 1980-1989. 60 repairs
- 1990-1999. 29 repairs
- 2000-2009. 8 repairs
- 2010. 1 repair

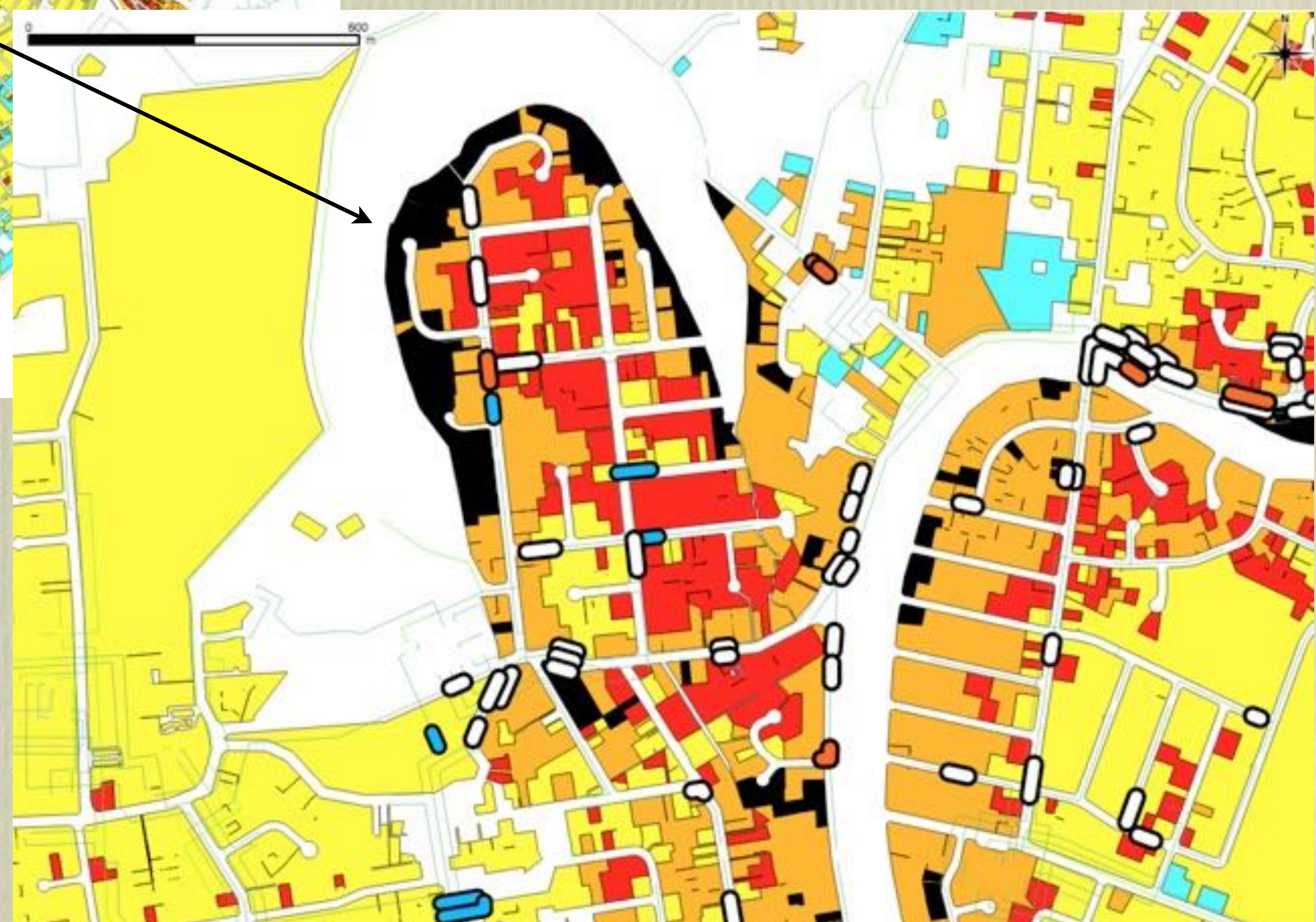
11 kV Cable Faults Feb 2011



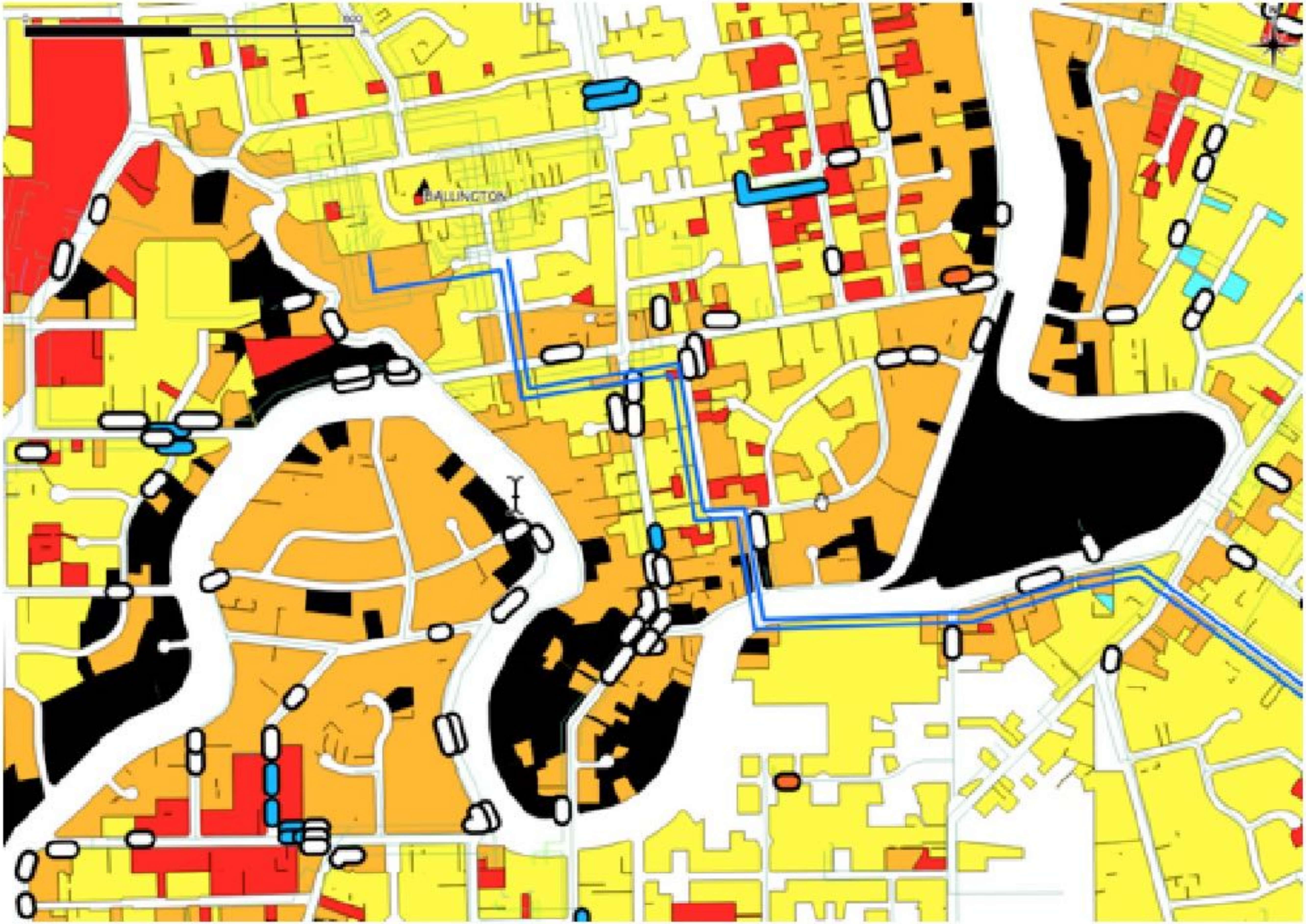
Feb 2011 11 kV + Liq



Liquefaction Map for Christchurch



Blue: Sept 2010
White: Feb 2011
Red: June 2011

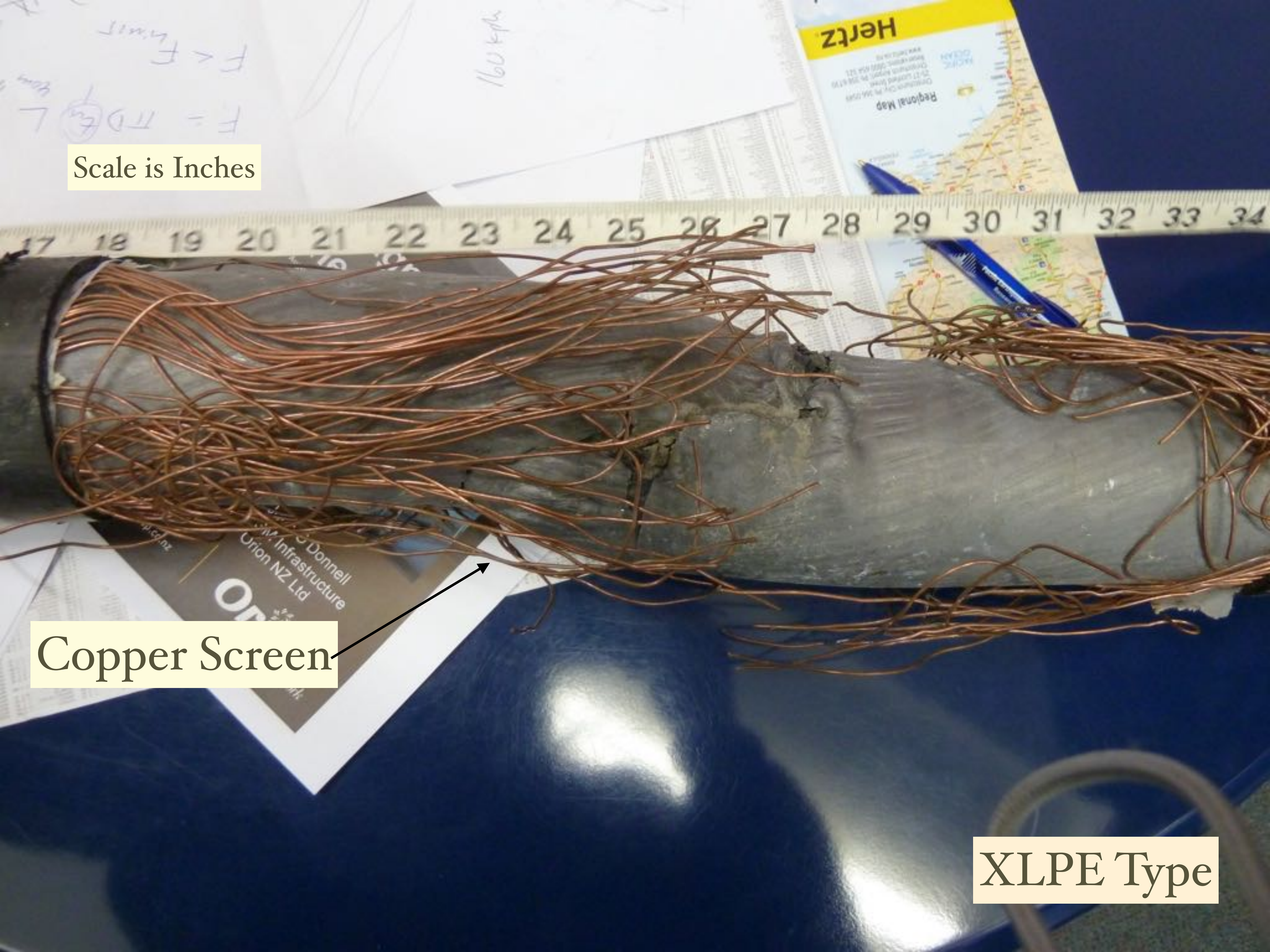


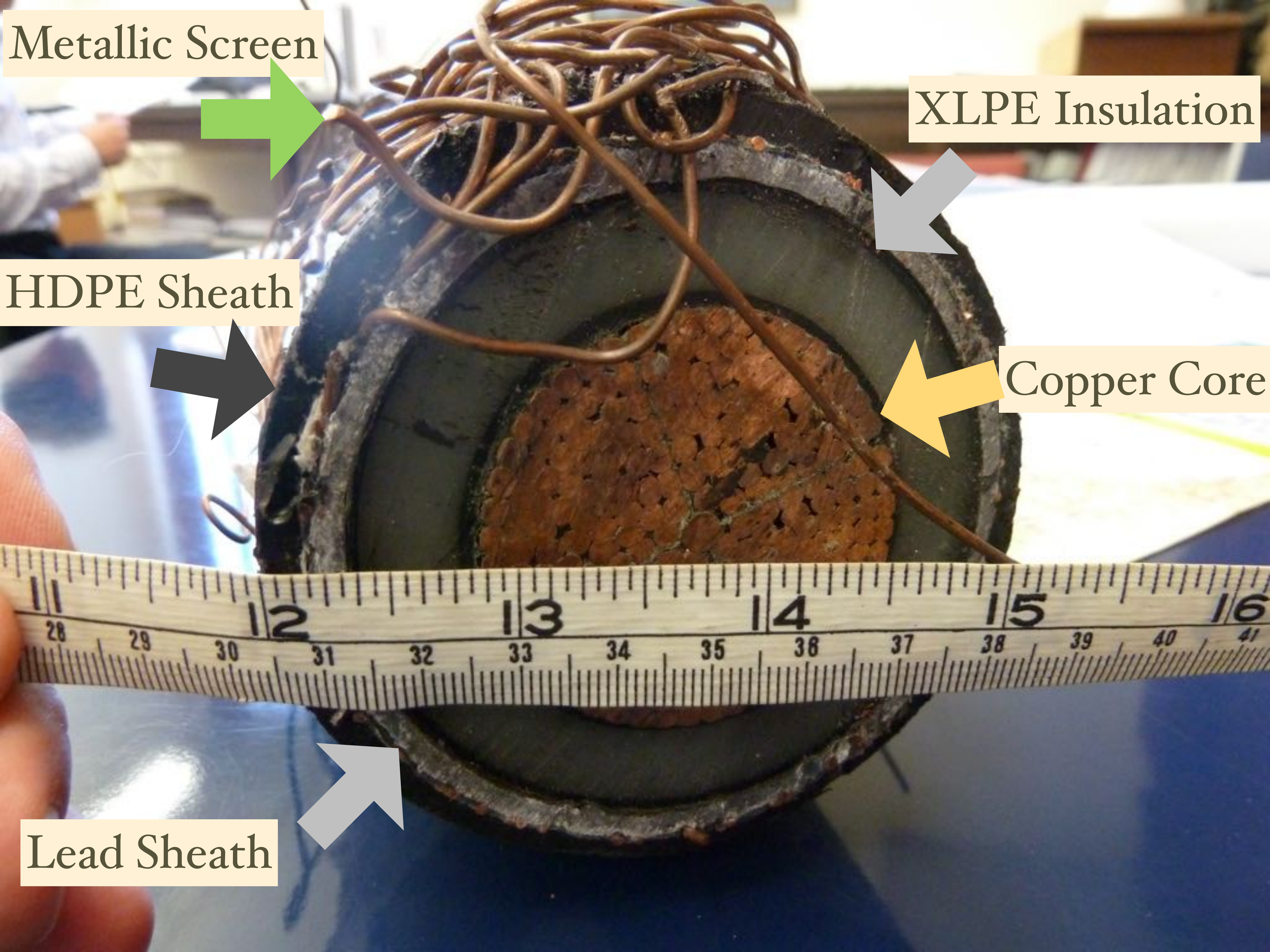
BALLINGTON

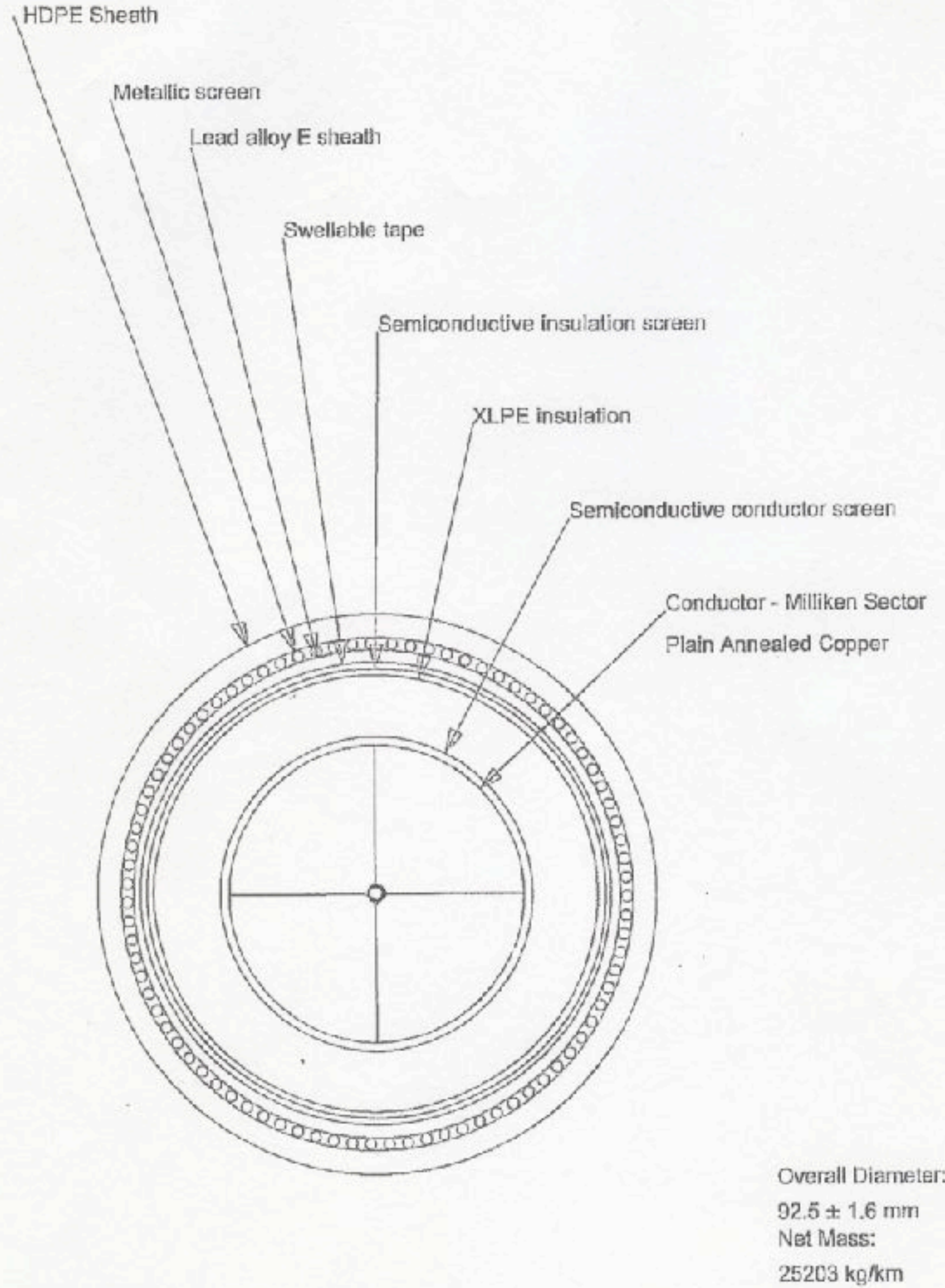

John O'Donnell - Chief Operating Officer
XLPE Type

Shane Watson - Network Asset Manager

XLPE Type


Scale is Inches
Copper Screen
XLPE Type

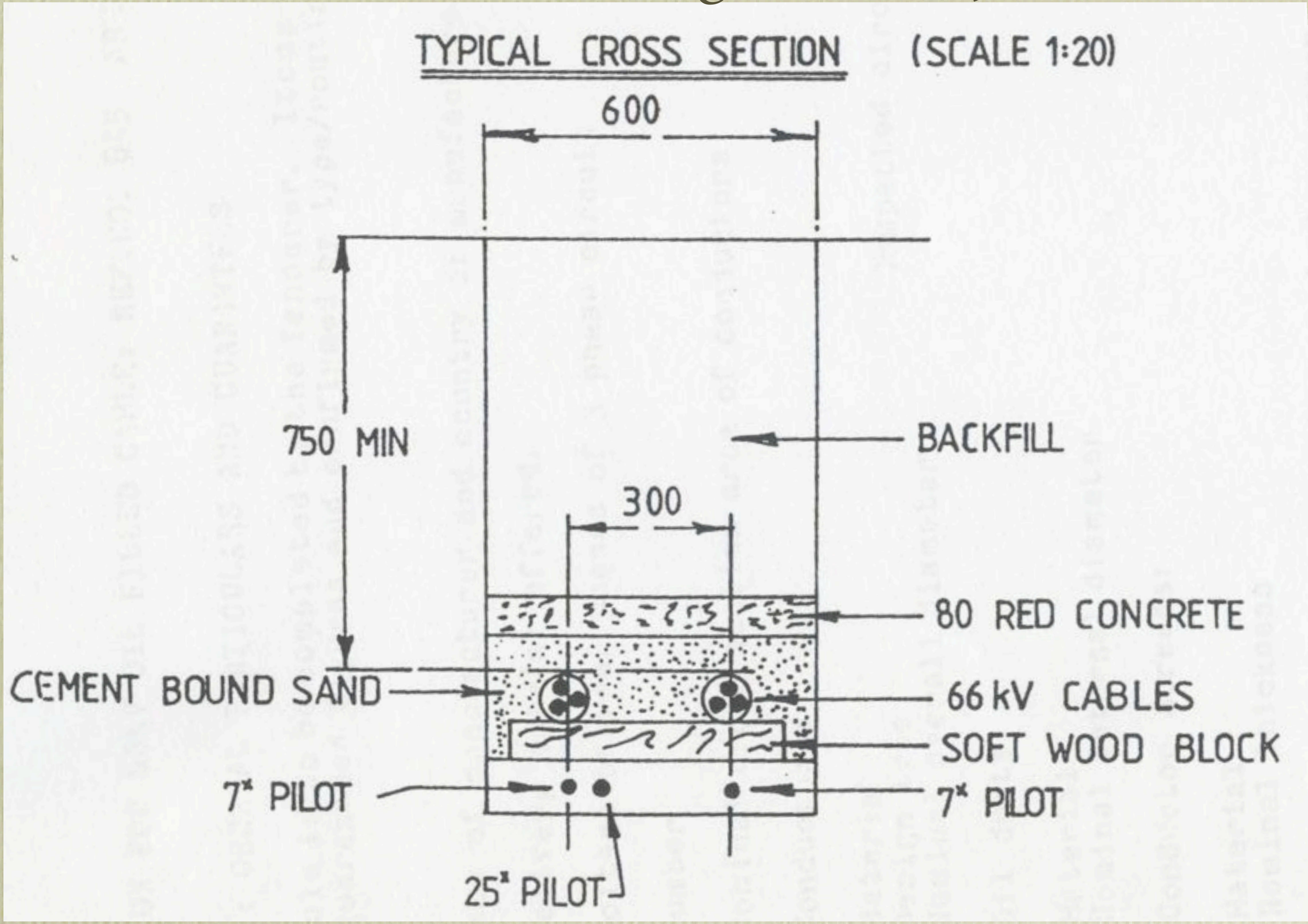

Metallic Screen
XLPE Insulation
HDPE Sheath
Copper Core
Lead Sheath



DESCRIPTION: 1 Conductor 1600 mm2 Milliken Sector Plain Annealed Copper, Semiconductive XLPE Conductor Screen (1.6 mm nominal wall), 38/66 kV XLPE Insulated (10 mm min av wall), Semiconductive XLPE Insulation Screen (1.0 mm min av wall), Waterblocking Screen Taped, Lead Sheathed (2.0 mm min av wall), Copper Wire screened (area 119 mm2), HDPE Sheathed (3.6 mm min av wall), Graphite coated, EHV cable to AS 1429.2.

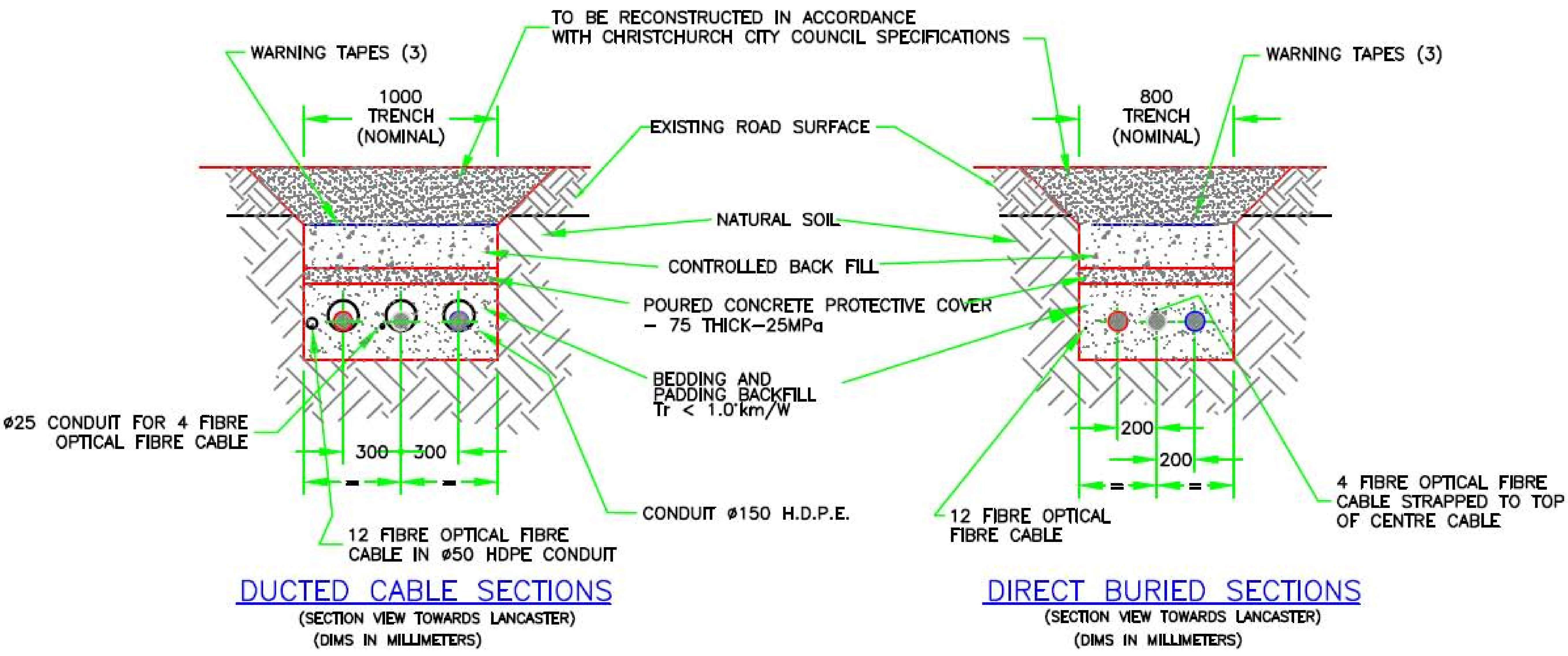
May 6 1999 Installations

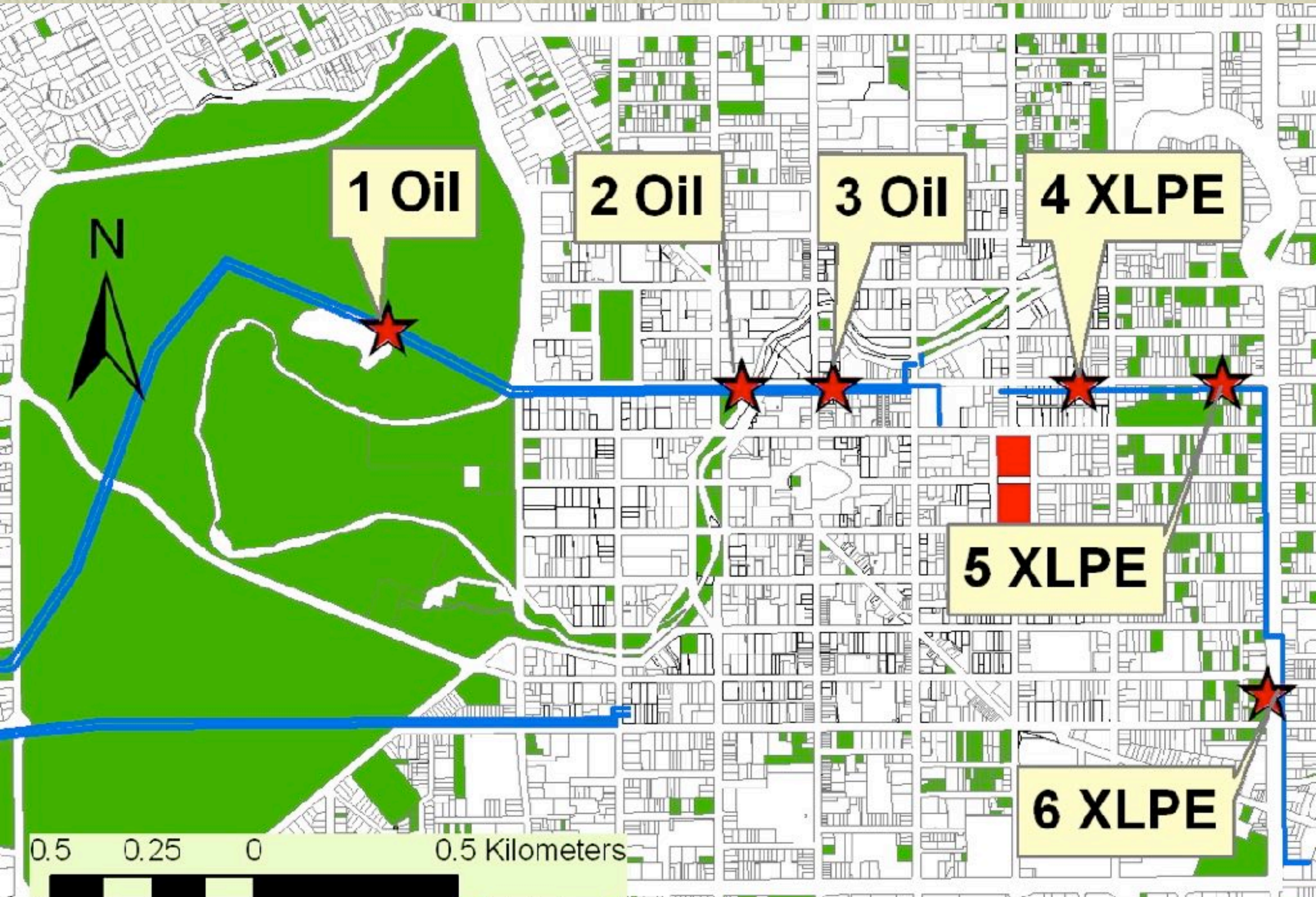
66 kV Cable, Armaugh. OD = 89.1 mm

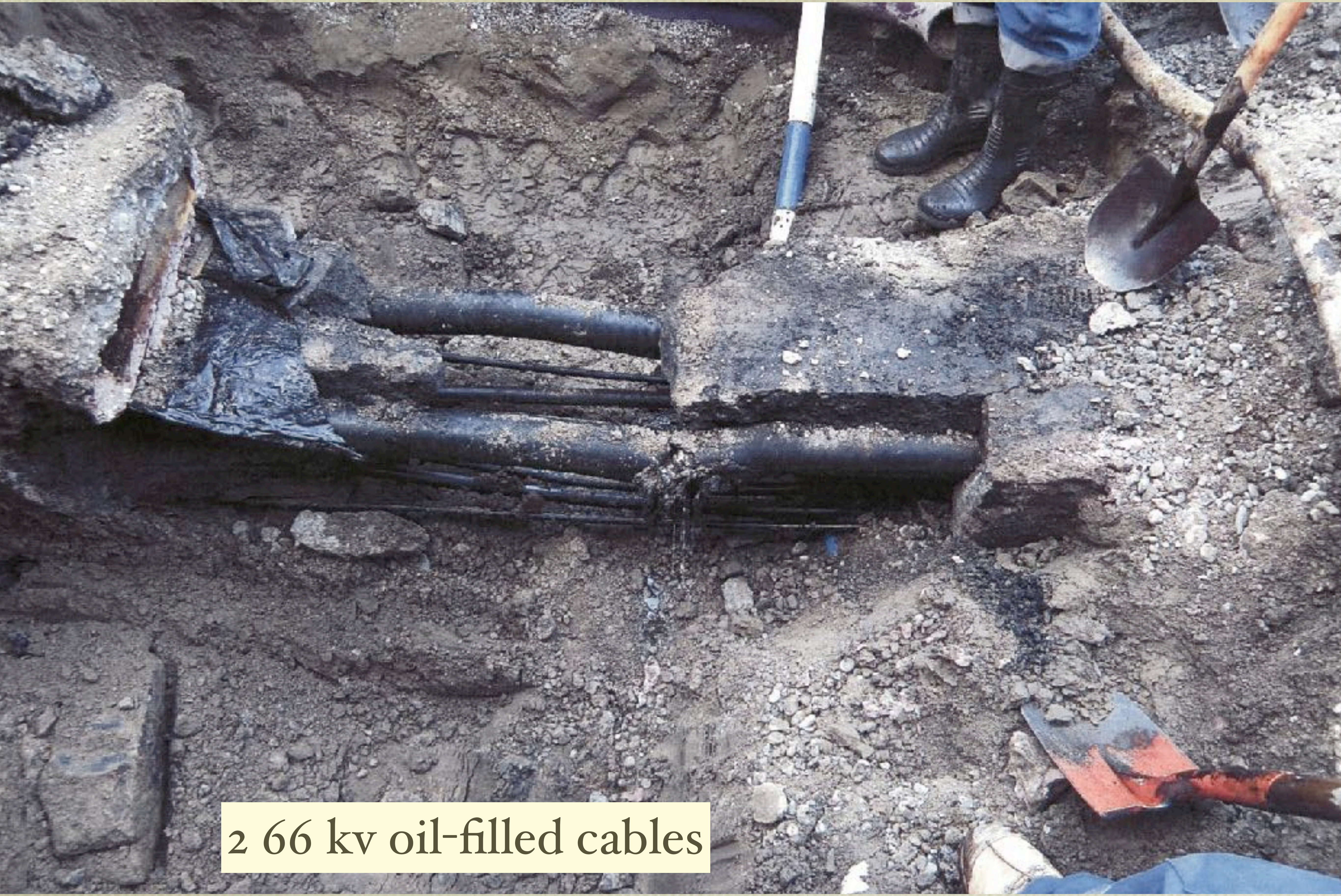


Conductor: 20.35 mm diameter, aluminum 300 mm^2
Oil ducts: 12.5 mm diameter, aluminum
Corrugated aluminum sheath: t = 1.5 mm 3.7mm depth 29.3 mm pitch 0.5 mm OD; Fy (0.01%) = 34.5 MN/m^2. Fa = 12.2 MN/m^2. W = 9.6 kg/m

1600Cu XLPE TRENCHING DETAILS



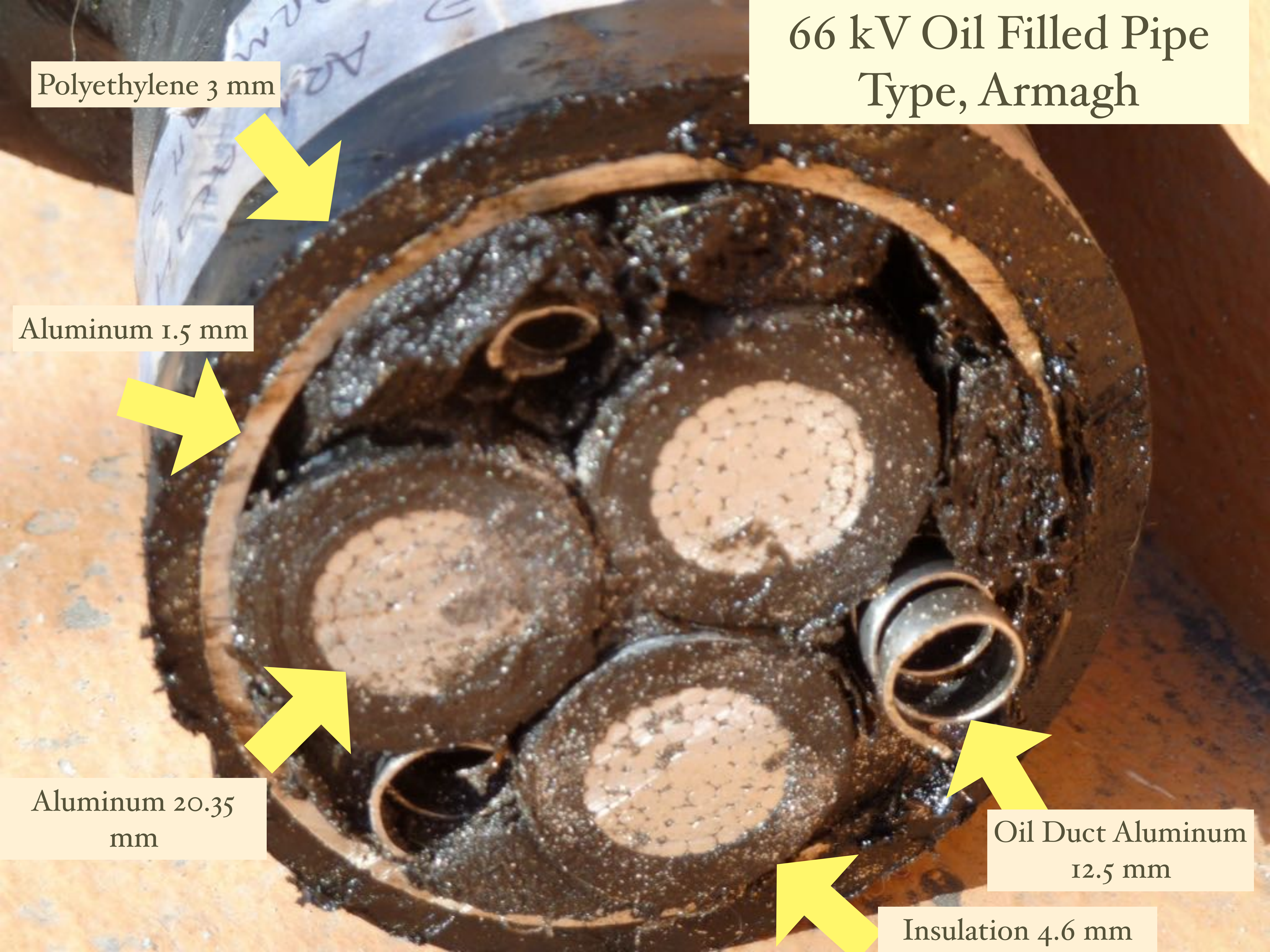

1 Oil
2 Oil
3 Oil
4 XLPE
5 XLPE
6 XLPE
N
0.5 0.25 0 0.5 Kilometers

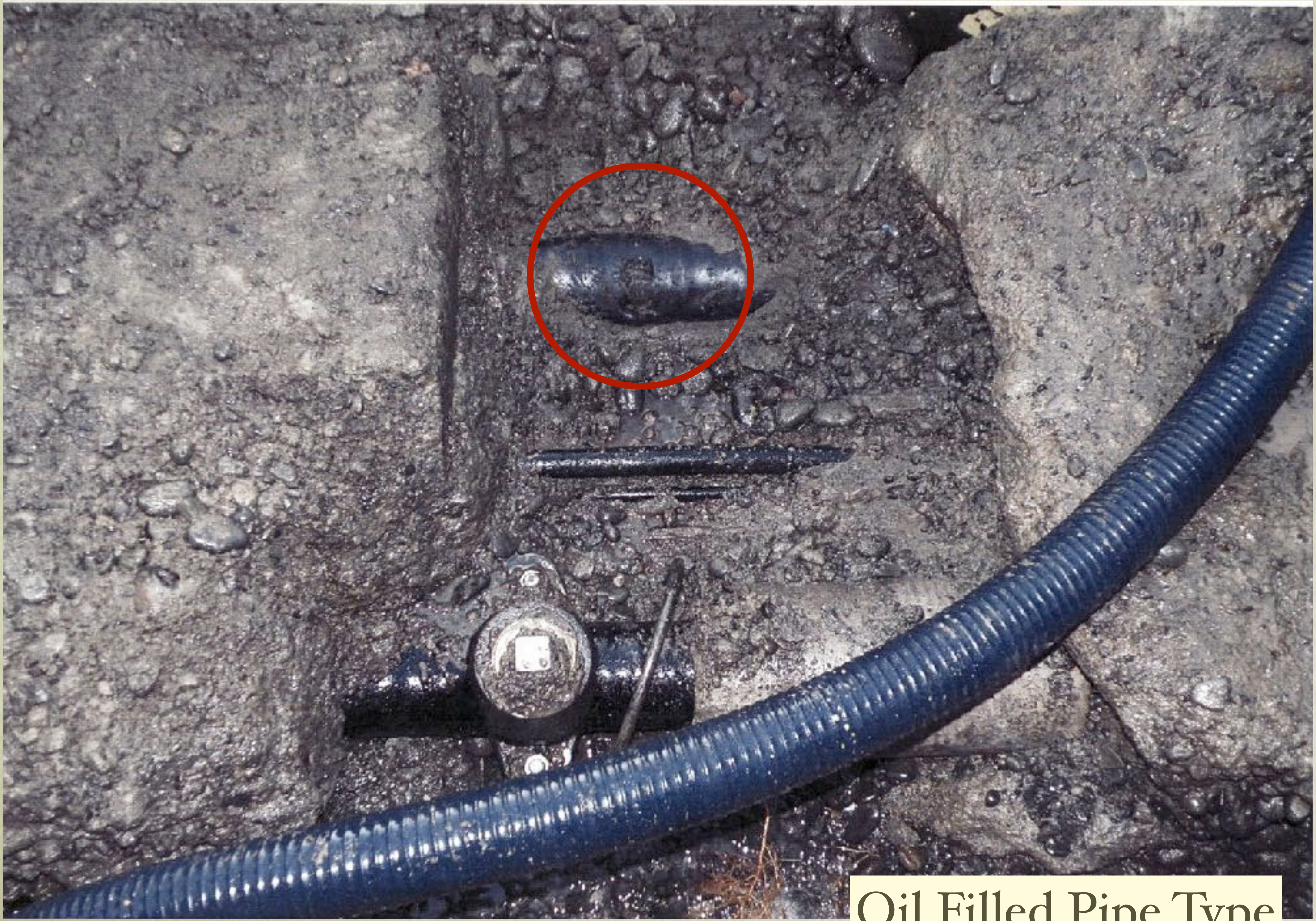


2 66 kv oil-filled cables

Oil-Filled Pipe Type 66 kV Cable - Armagh

66 kV Oil Filled Pipe Type


66 kV Oil Filled Pipe Type, Armagh
Polyethylene 3 mm
Aluminum 1.5 mm
Aluminum 20.35 mm
Oil Duct Aluminum 12.5 mm
Insulation 4.6 mm



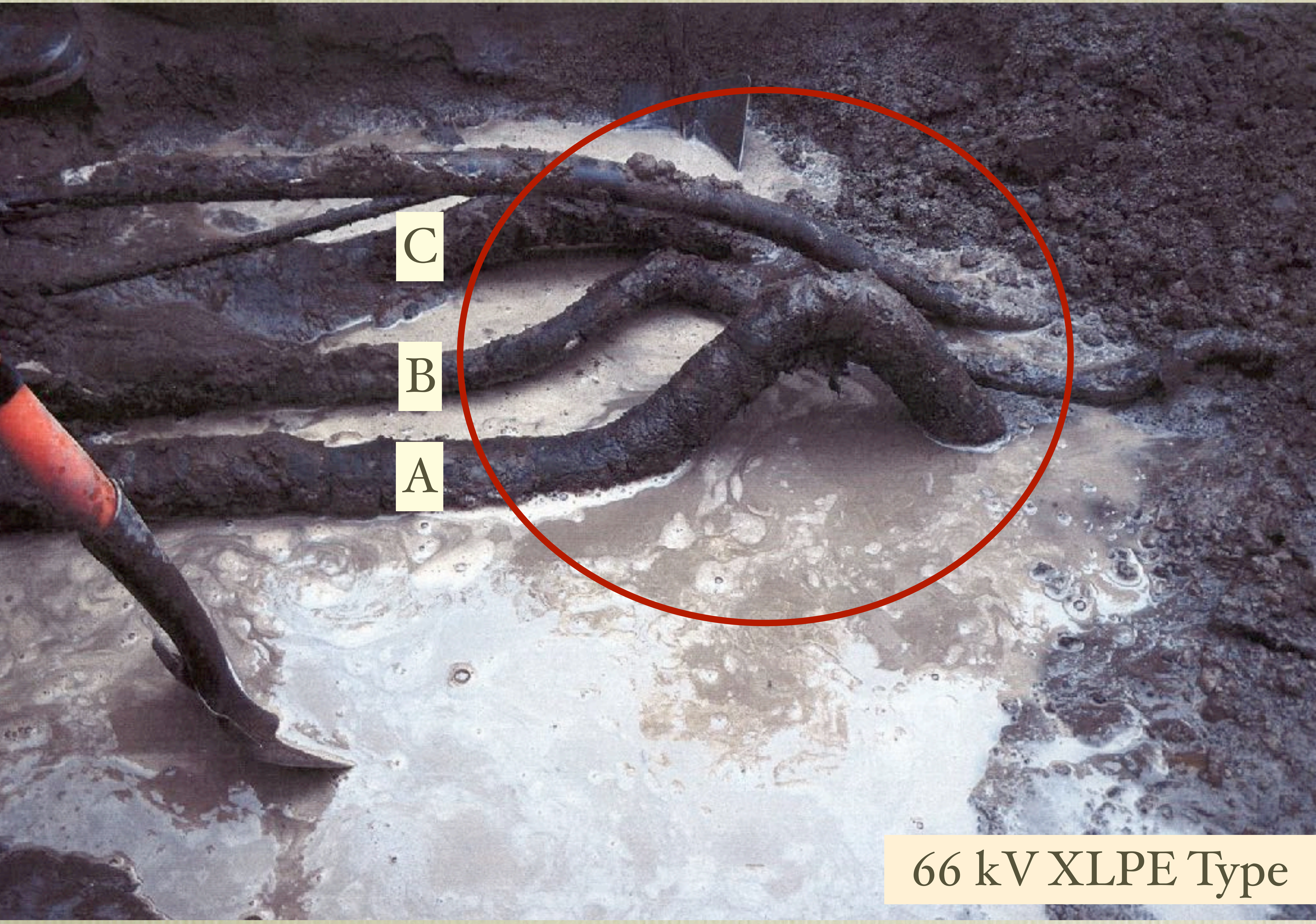
Oil Filled Pipe Type

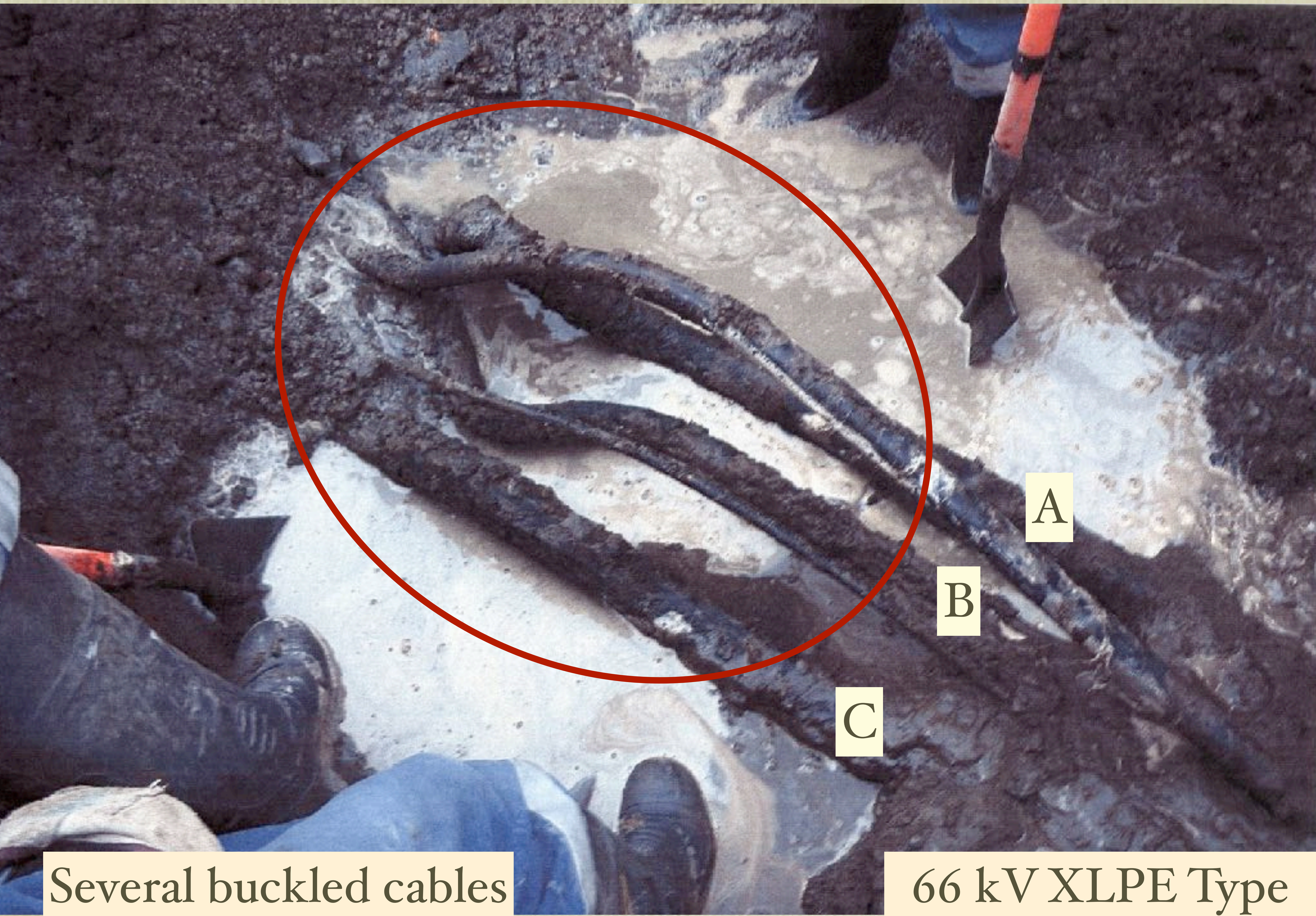
Oil Filled Pipe Type

Oil Filled Pipe Type

Oil Filled Pipe Type

66 kV XLPE Type


C
B
A
66 kV XLPE Type



Several buckled cables

66 kV XLPE Type


66 kV XLPE Type

66 kV XLPE Type

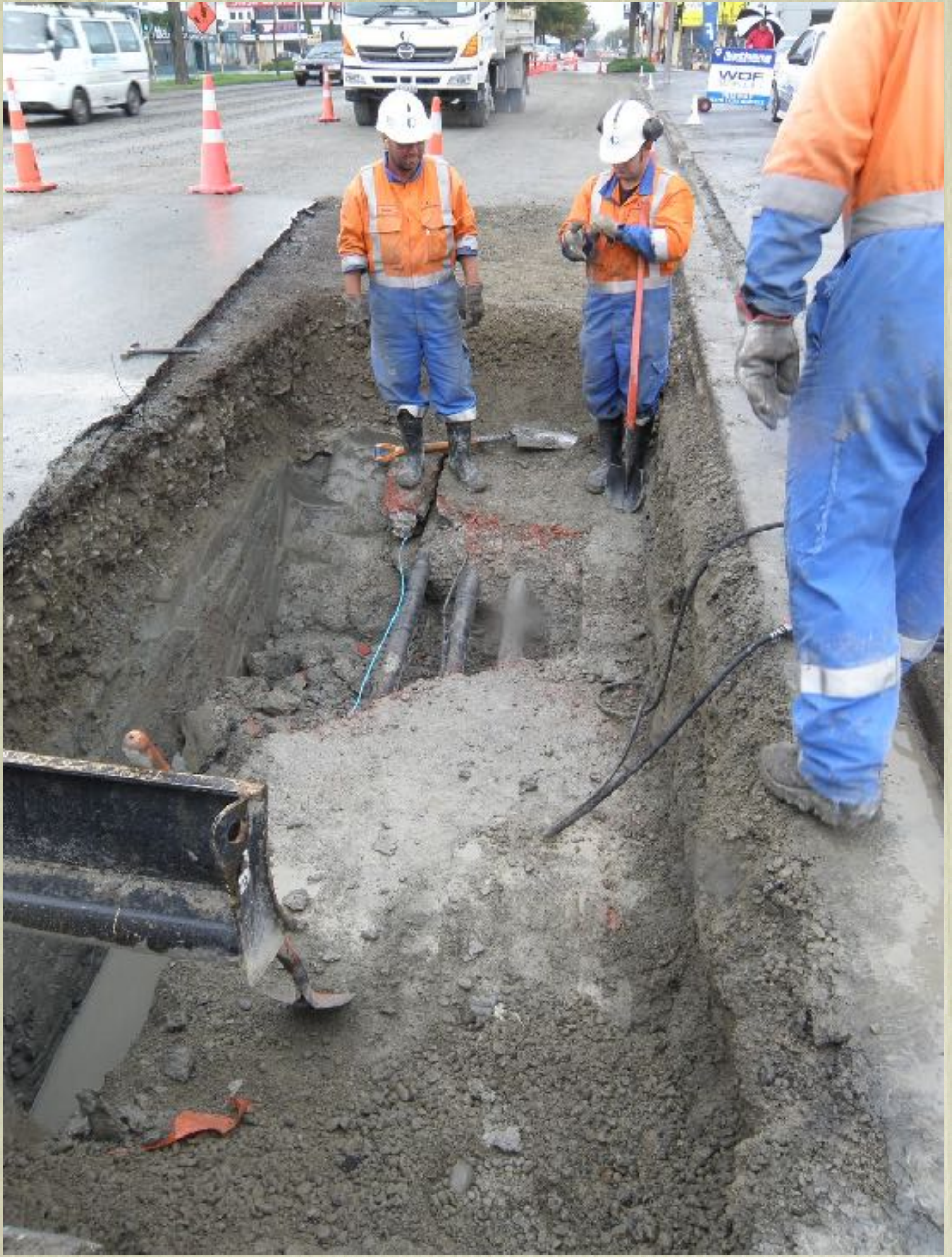
Two 66 kV Oil Filled Pipe-Type Cables

11 kV Cable

11 kV Cable

11 kV

11 kV - Transition from direct burial to conduit


WOF

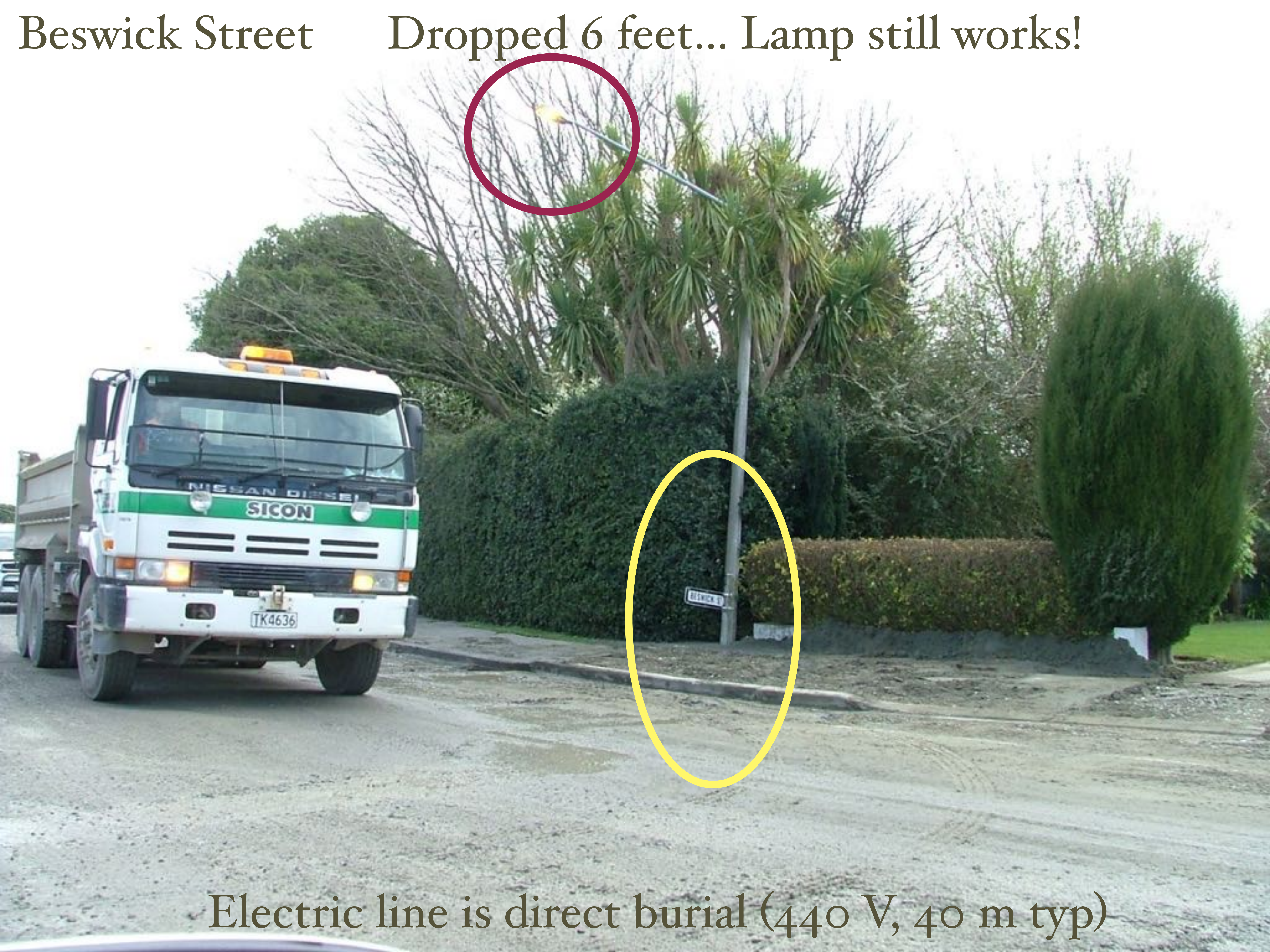
MainPower Buried Cable Damage

M7. 2 Canterbury Earthquake of September 4 2010

Sept 4 2010. 714 am
t + 3 hours


Cnr Beswick And Sewell Sts, Kaiapoi
© 2010 Brian Greenwood
http://www.brians-place.com

Beswick Street Dropped 6 feet… Lamp still works!



Electric line is direct burial (440 V, 40 m typ)

Kaiapoi, Opposite Police Station, Williams Street


FAHEY FENCE HIRE
021 334 766
Tyco Electronics


TAGGART

Failed Meter Service to House (Liquefaction)


Rolleston, Looking Southeast

Rolleston, Looking Northwest

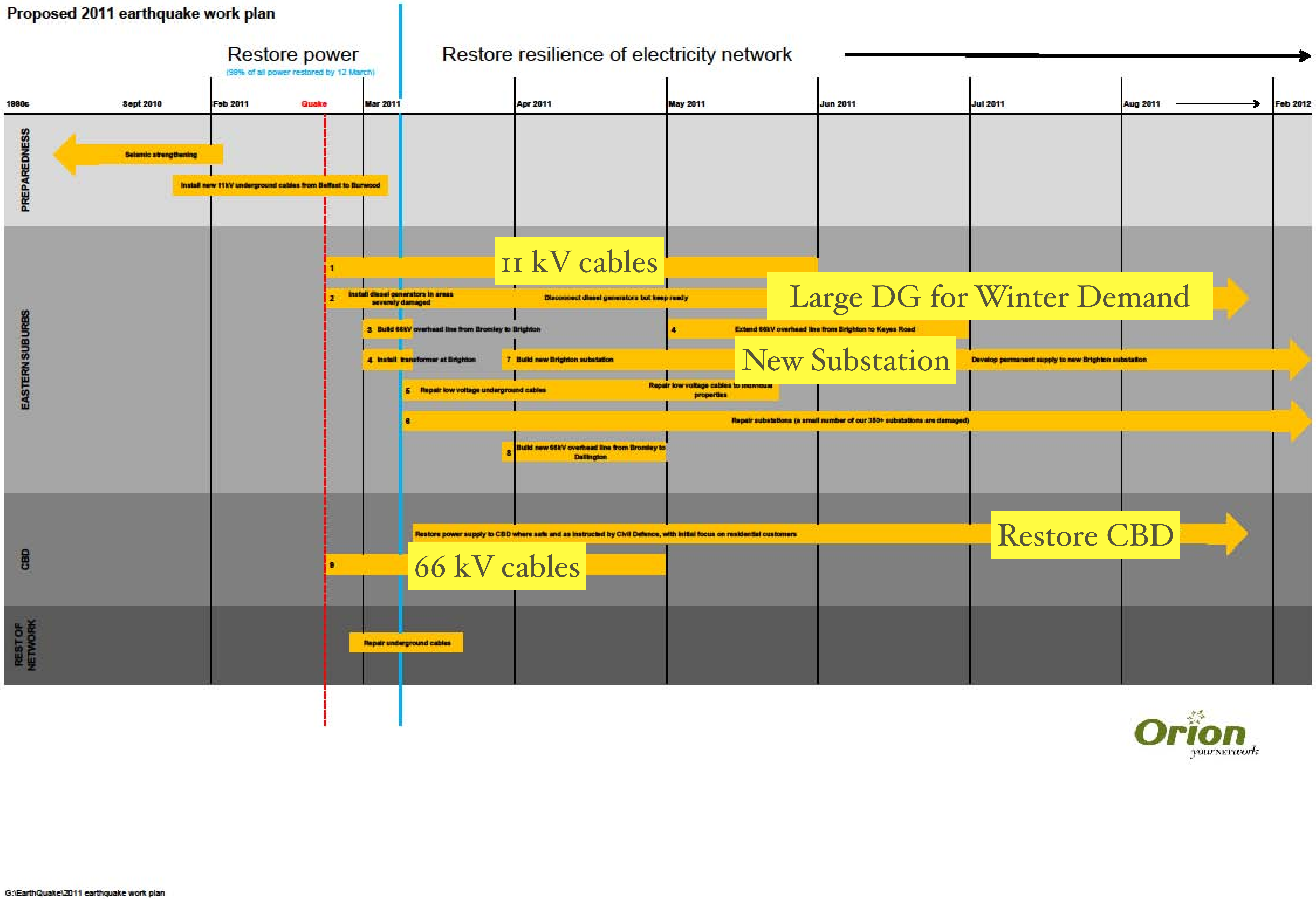
Fault Crossing - Post Earthquake


Liquefaction along the Main North Line
Sept 4 2010 3:14 pm

Liquefaction along the Main North Line
Several days later

Christchurch EQ M_w ~7.1

98% Restored

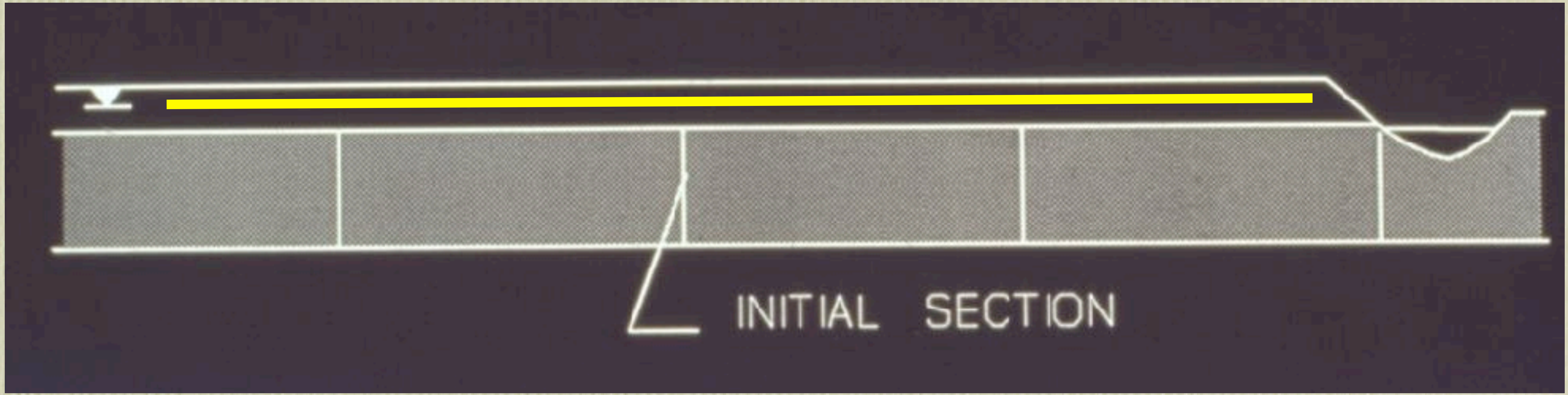


Proposed 2011 earthquake work plan
Restore power
(98% of all power restored by 12 March)
Restore resilience of electricity network
1990s
Sept 2010
Feb 2011
Quake
Mar 2011
Apr 2011
May 2011
Jun 2011
Jul 2011
Aug 2011
Feb 2012
PREPAREDNESS
Seismic strengthening
Install new 11kV underground cables from Belfast to Burwood
EASTERN SUBURBS
1
11 kV cables
2 Install diesel generators in areas severely damaged
Disconnect diesel generators but keep ready
Large DG for Winter Demand
3 Build 66kV overhead line from Bromley to Brighton
4 Extend 66kV overhead line from Brighton to Keyes Road
4 Install transformer at Brighton
7 Build new Brighton substation
New Substation
Develop permanent supply to new Brighton substation
5 Repair low voltage underground cables
Repair low voltage cables to individual properties
6 Repair substations (a small number of our 350+ substations are damaged)
8 Build new 66kV overhead line from Bromley to Dallington
CBD
Restore power supply to CBD where safe and as instructed by Civil Defence, with initial focus on residential customers
Restore CBD
9
66 kV cables
REST OF NETWORK
Repair underground cables
G:\EarthQuake\2011 earthquake work plan

Why do the cables fail?

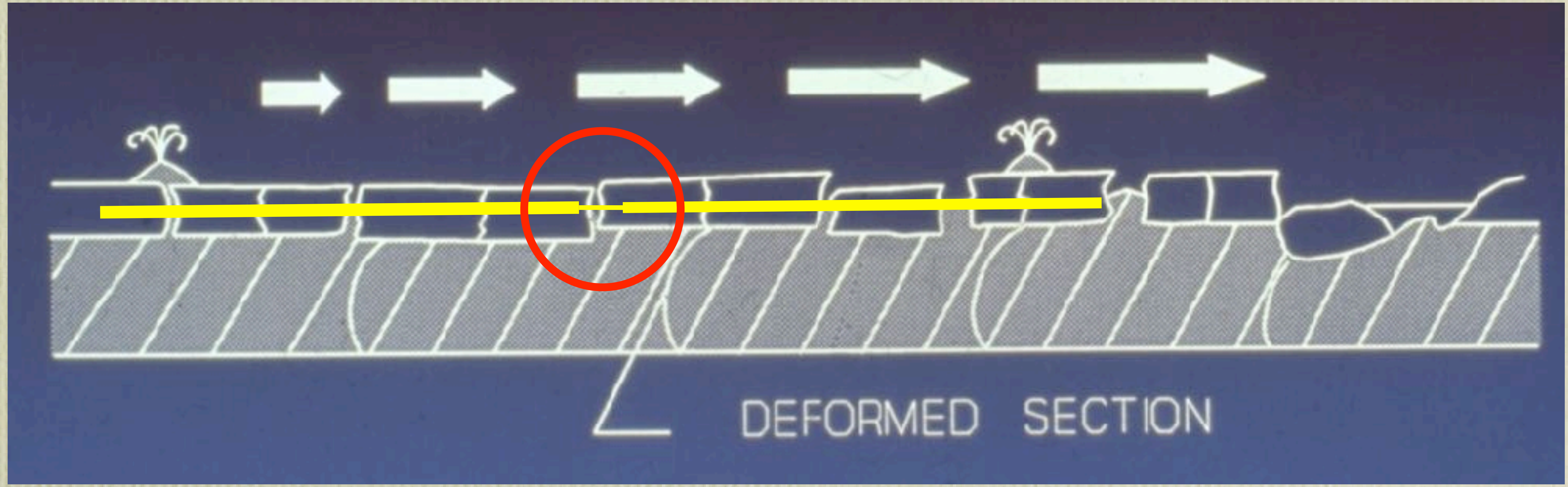
- Choice 1 .Ground settlements to 2 to 5 cm (LESS LIKELY)
- Choice 2. Lateral cracking of top soil cap, followed by block vibration (MOST LIKELY)

Before the Earthquake



During the Earthquake

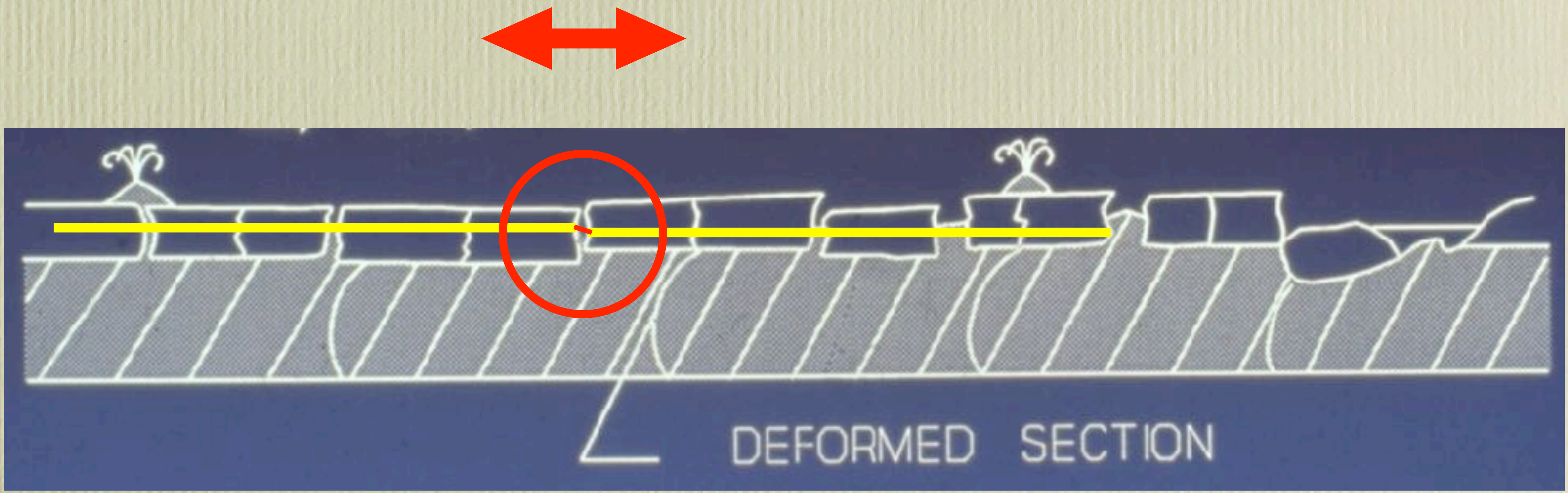
Soil cap break into independent blocks and begin to slosh around, tending towards free face



Cable Stretches

After the Earthquake (minutes)

Soil cap blocks continue to vibrate back and forth



Cable Compresses, High Curvature, Buckles and Fails


66 kV Cable


INCH
MADE IN CHINA

Mitigation Strategies

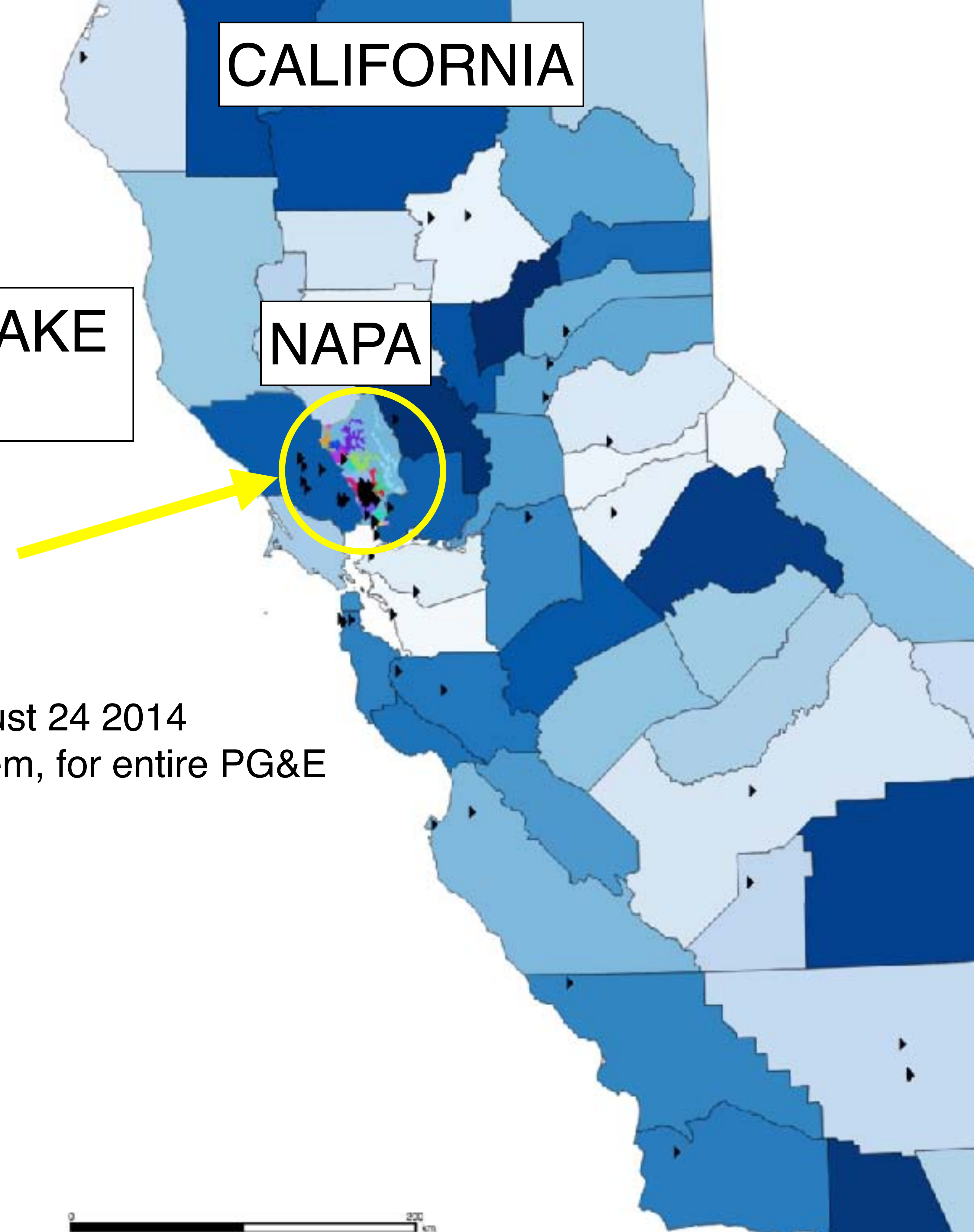
- Never use direct burial cables in thermal concrete in liquefaction zones.
- Use overhead (if possible)
- User buried cables in PVC or HDPE conduits within reinforced thermal concrete duct banks

Napa California
August 23 2014

Distribution System

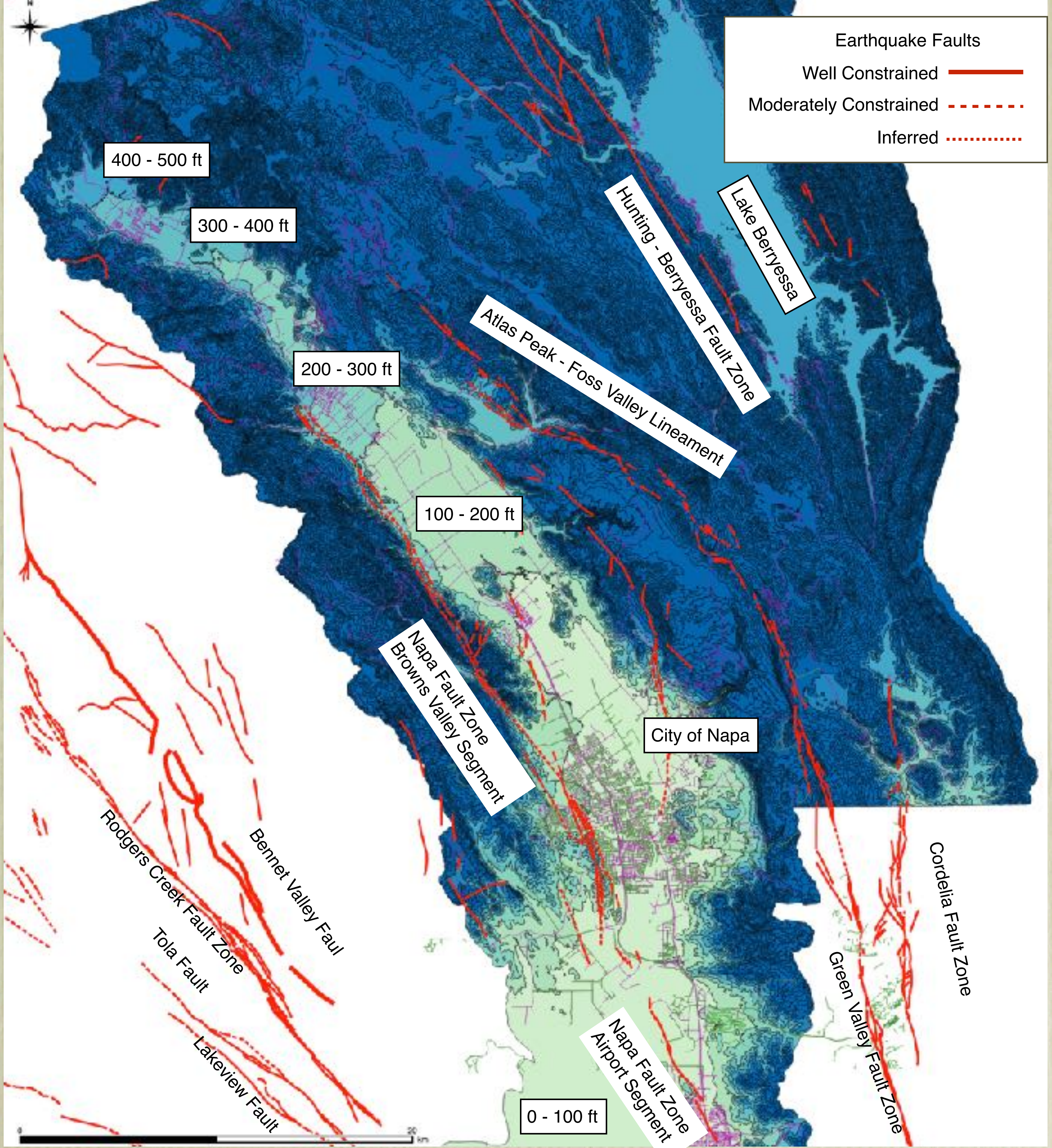
- Key findings. Napa 2014 Earthquake.
- 127 damage locations.
- 23 “types” of damage.
- Most common (53%) is overhead conductors; then overhead cross arms and overhead jumpers.
- No broken poles.
- No broken underground cables.

NAPA M 6 EARTHQUAKE OF AUGUST 23 2014

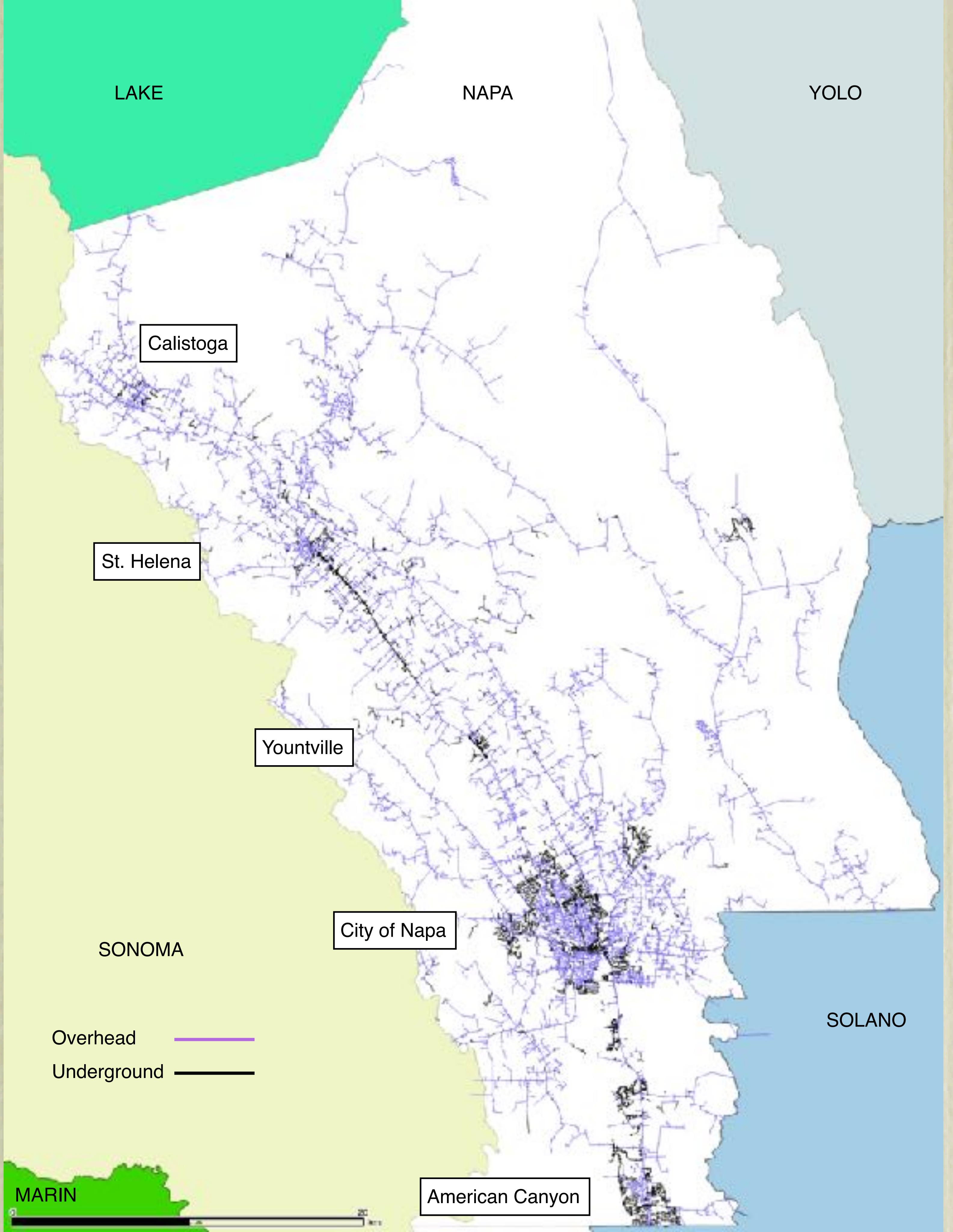


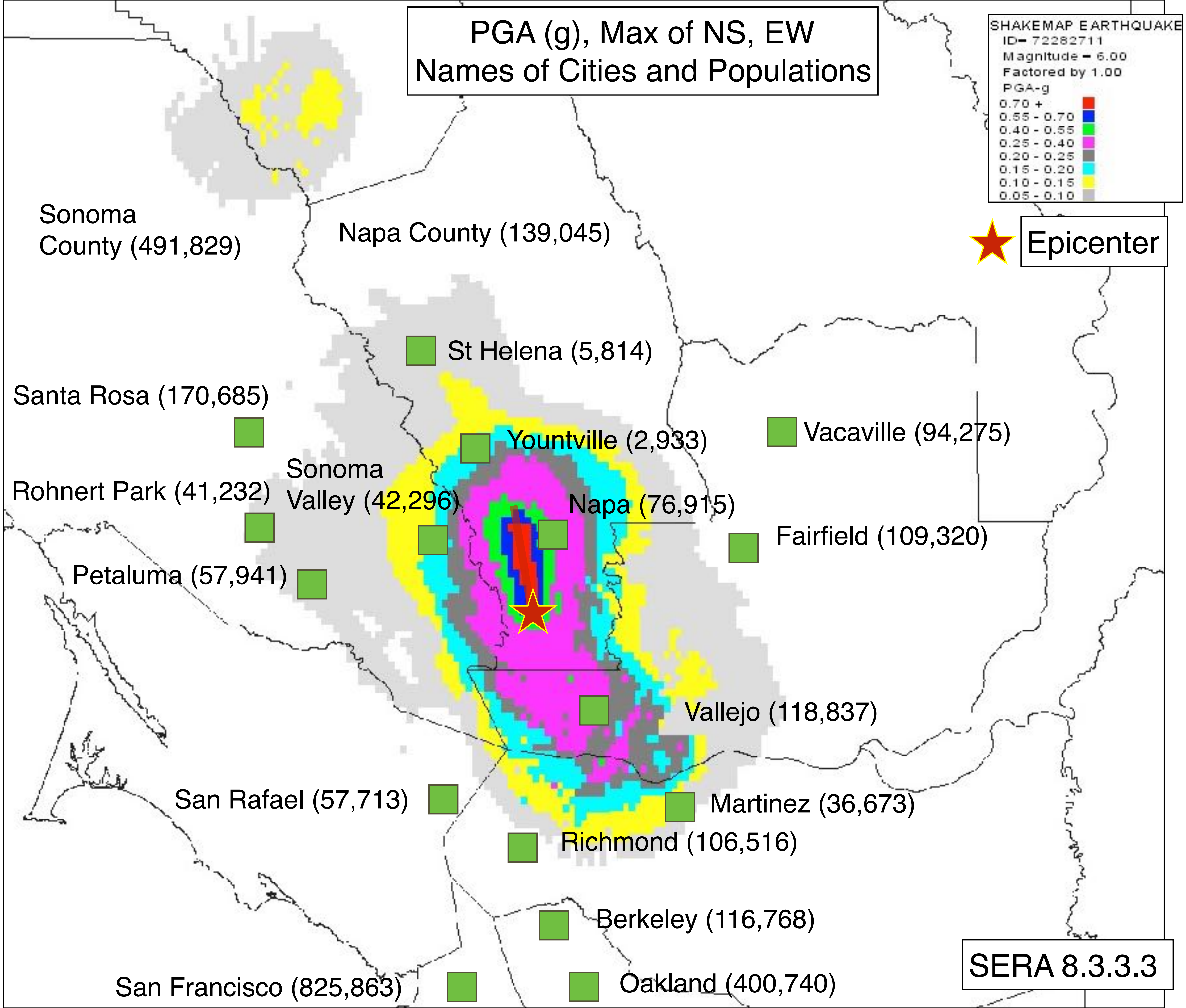
Area with PGA > 0.02g

▶ Location of Repairs, August 24 2014 Electric Distribution System, for entire PG&E System

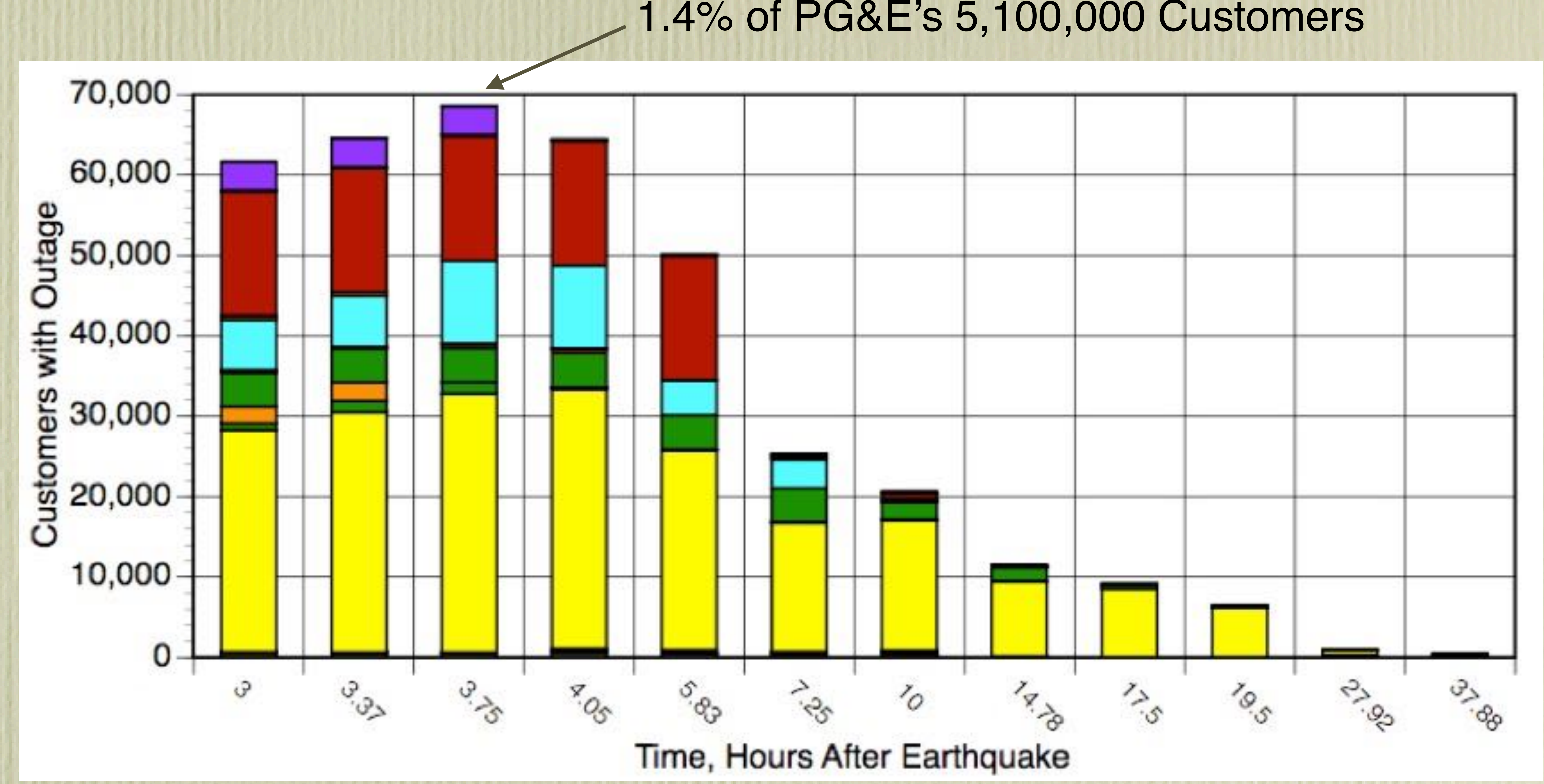


Earthquake Faults
Well Constrained
Moderately Constrained
Inferred
400 - 500 ft
300 - 400 ft
200 - 300 ft
100 - 200 ft
0 - 100 ft
Lake Berryessa
Hunting - Berryessa Fault Zone
Atlas Peak - Foss Valley Lineament
Napa Fault Zone
Browns Valley Segment
City of Napa
Rodgers Creek Fault Zone
Bennet Valley Faul
Tola Fault
Lakeview Fault
Napa Fault Zone
Airport Segment
Green Valley Fault Zone
Cordelia Fault Zone


LAKE
NAPA
YOLO
Calistoga
St. Helena
Yountville
City of Napa
SONOMA
SOLANO
Overhead
Underground
MARIN
American Canyon

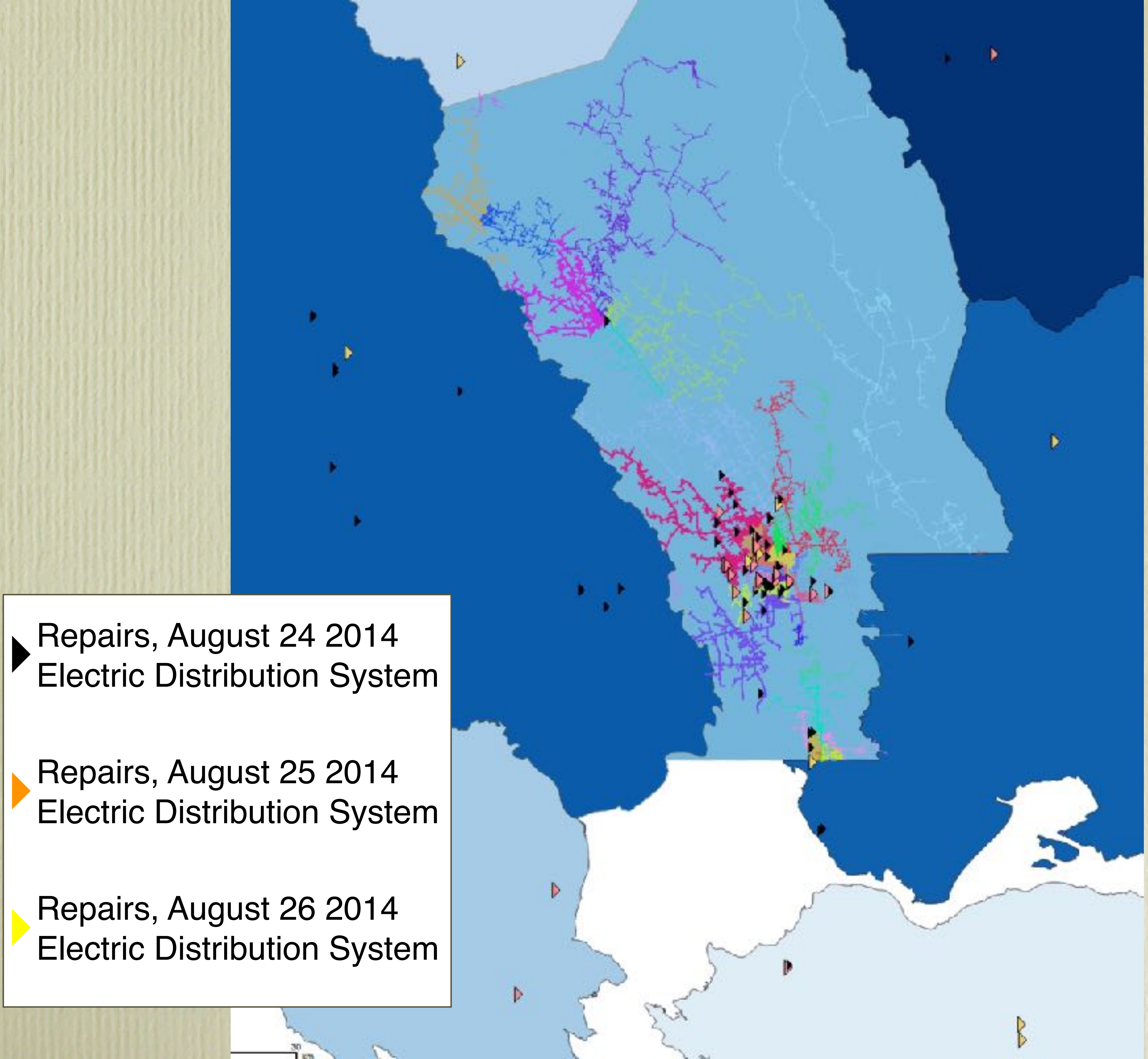

PGA (g), Max of NS, EW
Names of Cities and Populations
SHAKEMAP EARTHQUAKE
ID= 72282711
Magnitude = 6.00
Factored by 1.00
PGA-g
0.70 +
0.55 - 0.70
0.40 - 0.55
0.25 - 0.40
0.20 - 0.25
0.15 - 0.20
0.10 - 0.15
0.05 - 0.10
Epicenter
Sonoma County (491,829)
Napa County (139,045)
St Helena (5,814)
Santa Rosa (170,685)
Yountville (2,933)
Vacaville (94,275)
Sonoma Valley (42,296)
Rohnert Park (41,232)
Napa (76,915)
Fairfield (109,320)
Petaluma (57,941)
Vallejo (118,837)
San Rafael (57,713)
Martinez (36,673)
Richmond (106,516)
Berkeley (116,768)
San Francisco (825,863)
Oakland (400,740)
SERA 8.3.3.3

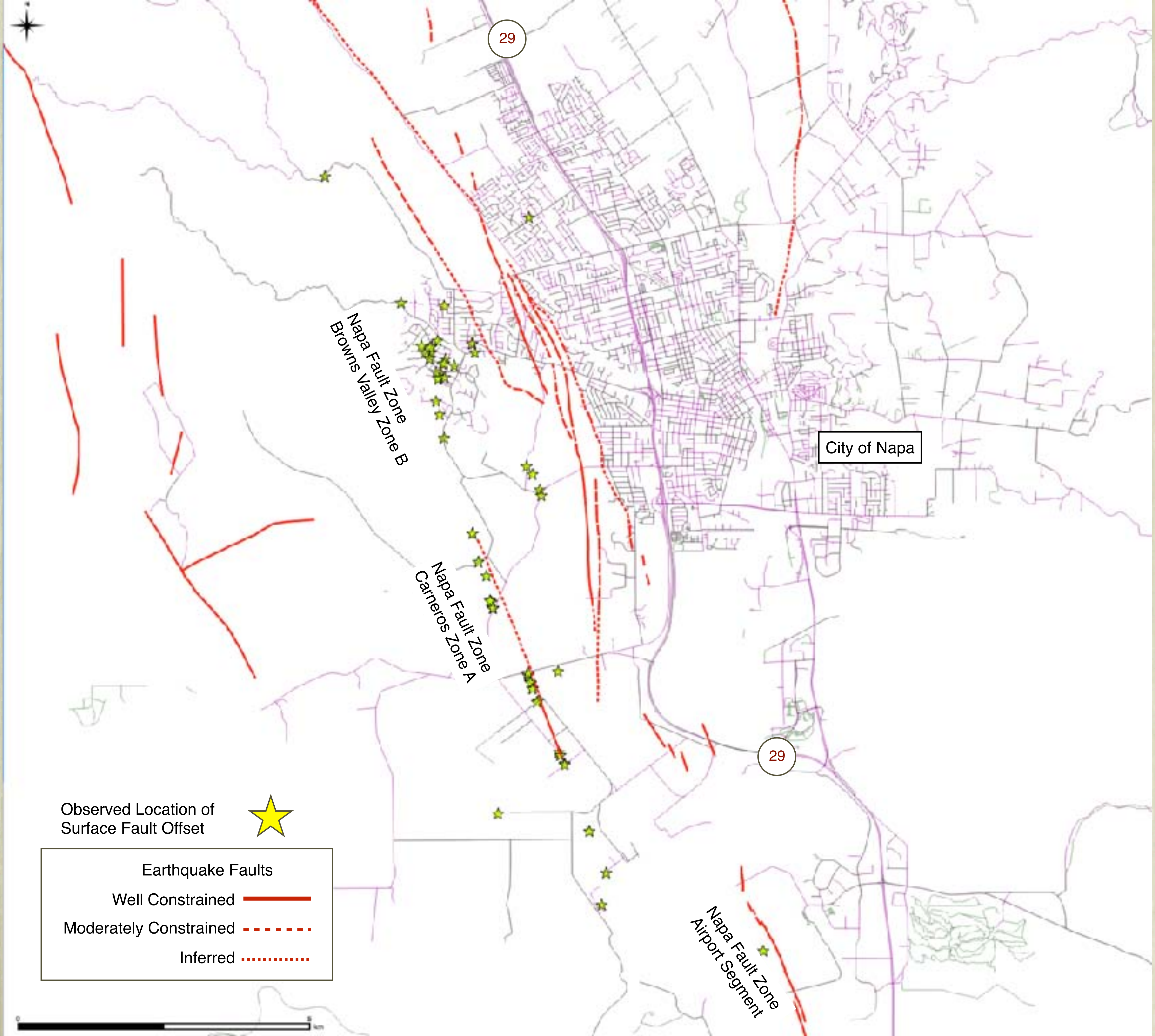
PG&E Customers without Power



Yellow: Napa
Orange: Rohnert Park
Green: Saint Helena
Cyan: Santa Rosa

Red: Sonoma Valley
Grey: American Canyon
Blue: Vallejo

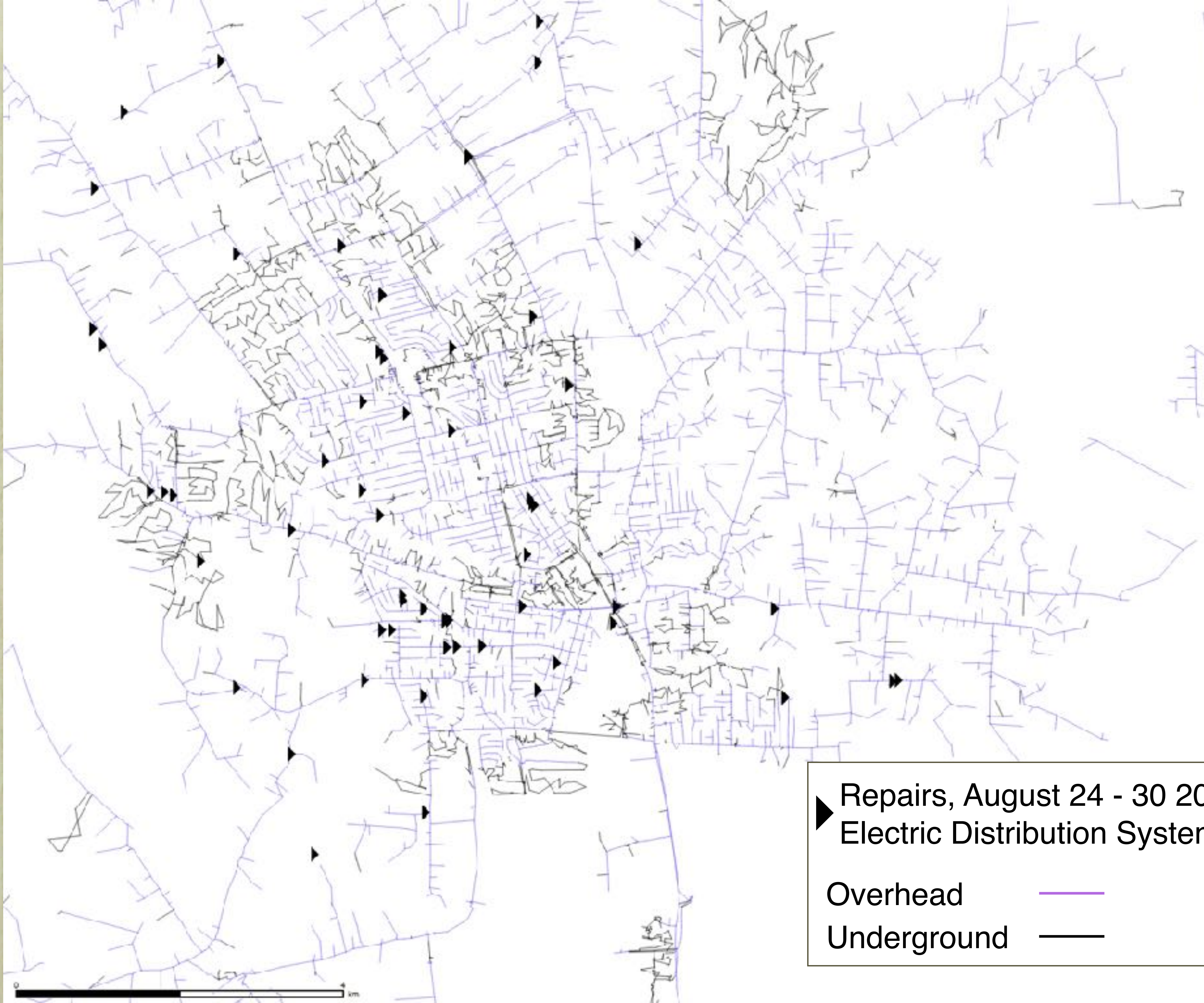

Repairs, August 24 2014
Electric Distribution System
Repairs, August 25 2014
Electric Distribution System
Repairs, August 26 2014
Electric Distribution System


29
Napa Fault Zone
Browns Valley Zone B
City of Napa
Napa Fault Zone
Carneros Zone A
29
Observed Location of
Surface Fault Offset
Earthquake Faults
Well Constrained
Moderately Constrained
Inferred
Napa Fault Zone
Airport Segment

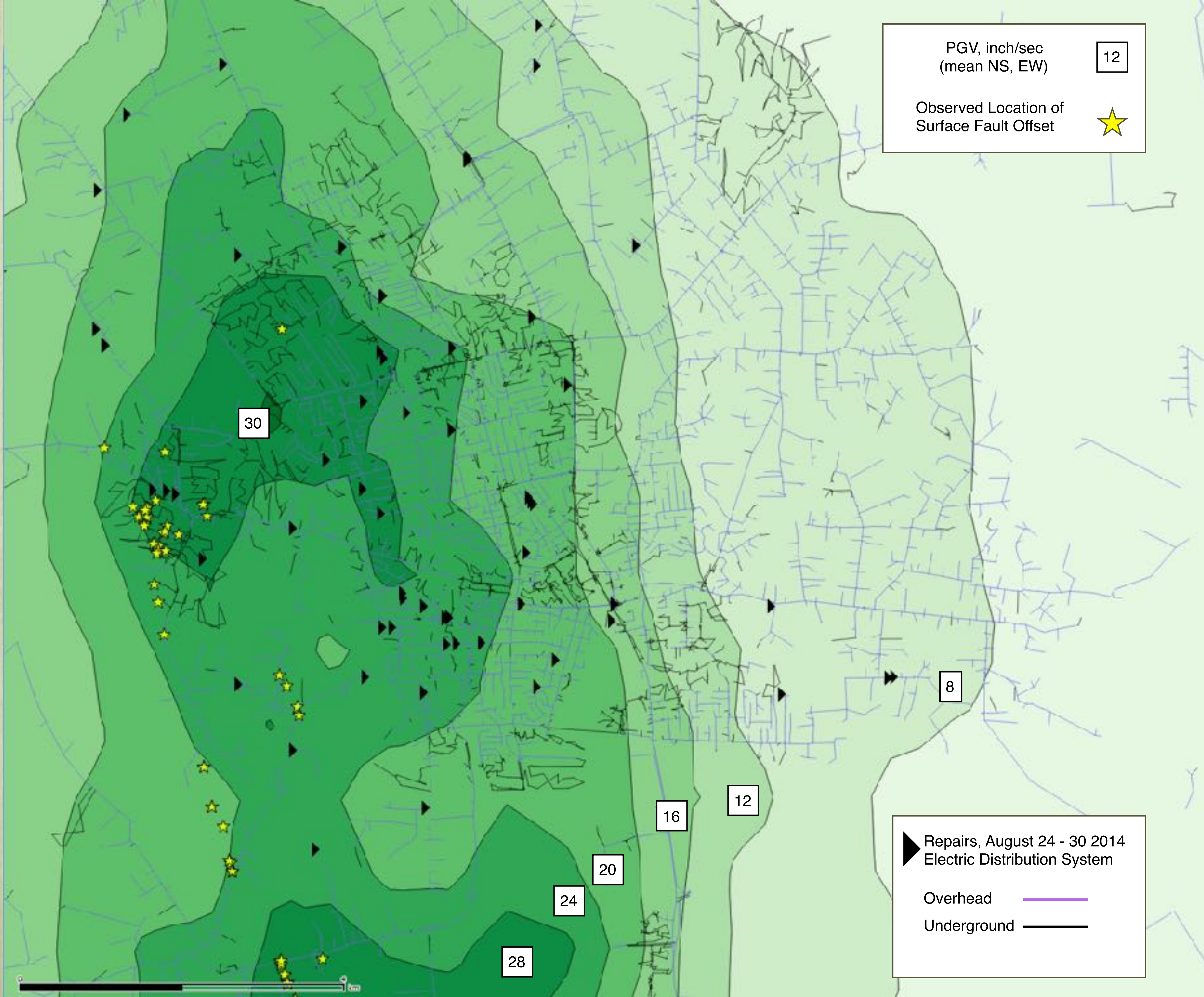

NO

Distribution Damage

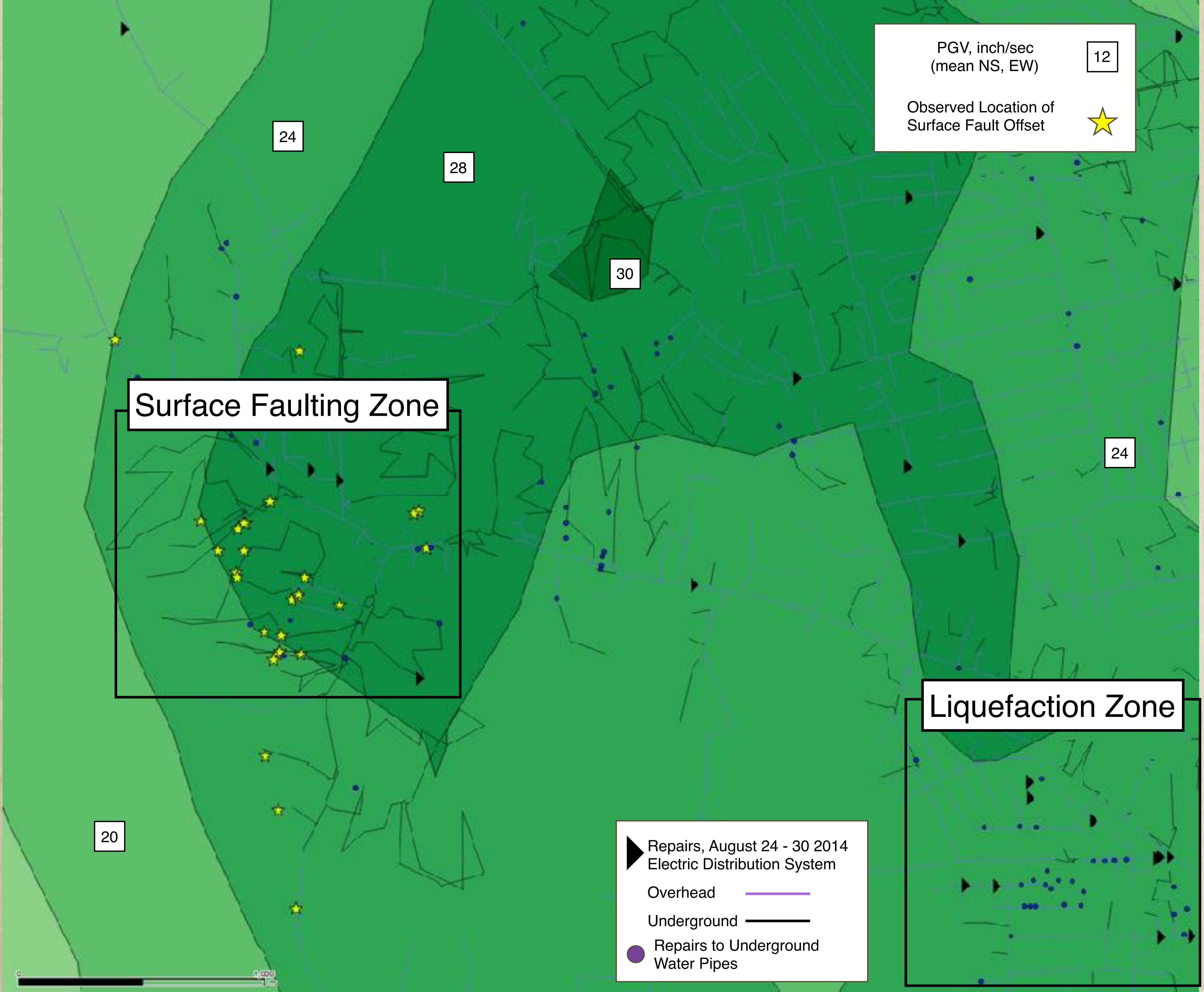
- 166 overhead, 3 underground
- 52 fuse related
- 41 wire related
- 10 equipment related
- 6 pole / cross arm / insulator related


Repairs, August 24 - 30 2014
Electric Distribution System
Overhead
Underground

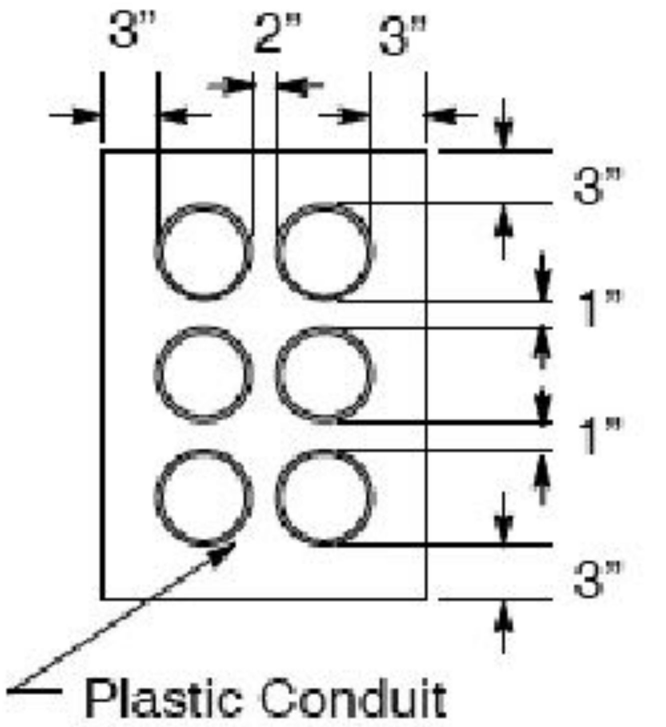
Correlating the Hazard and the Damage

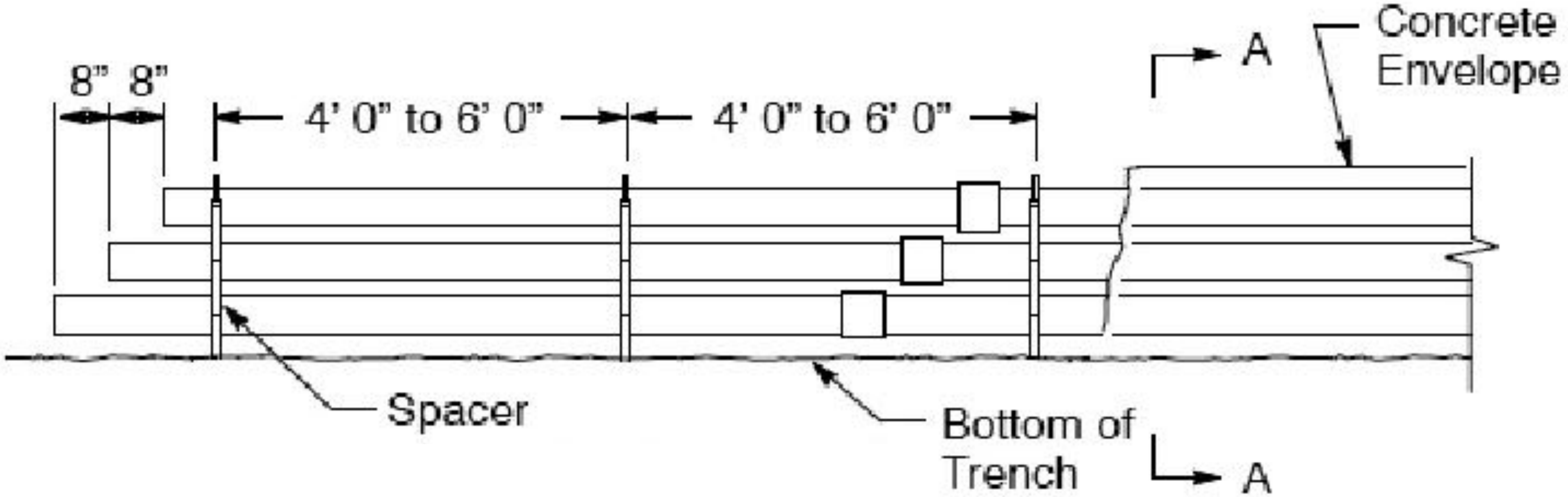


PGV, inch/sec
(mean NS, EW)
12
Observed Location of
Surface Fault Offset
30
8
12
16
20
24
28
Repairs, August 24 - 30 2014
Electric Distribution System
Overhead
Underground



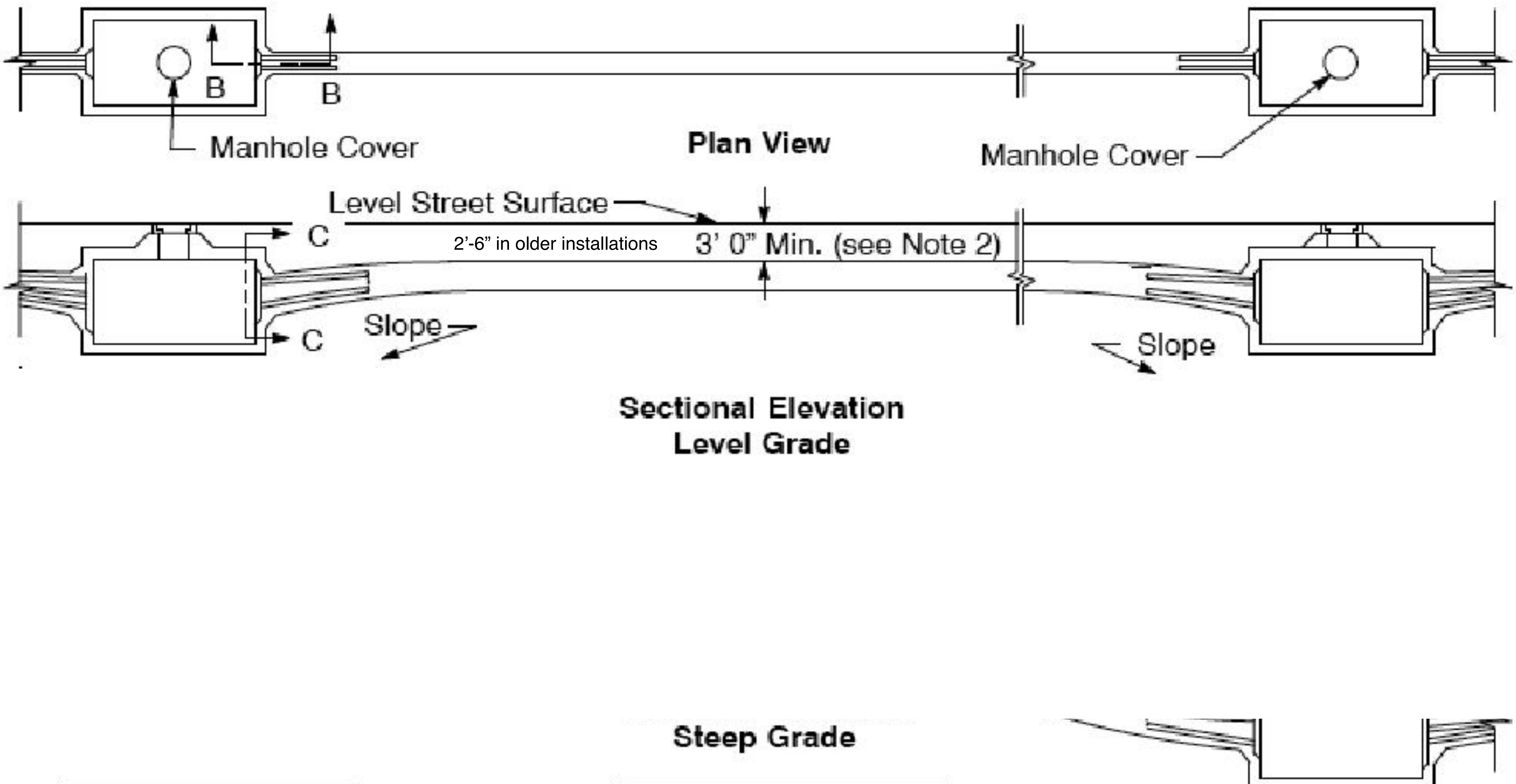
PGV, inch/sec
(mean NS, EW)
12
Observed Location of
Surface Fault Offset
24
28
30
24
20
Surface Faulting Zone
Liquefaction Zone
Repairs, August 24 - 30 2014
Electric Distribution System
Overhead
Underground
Repairs to Underground
Water Pipes

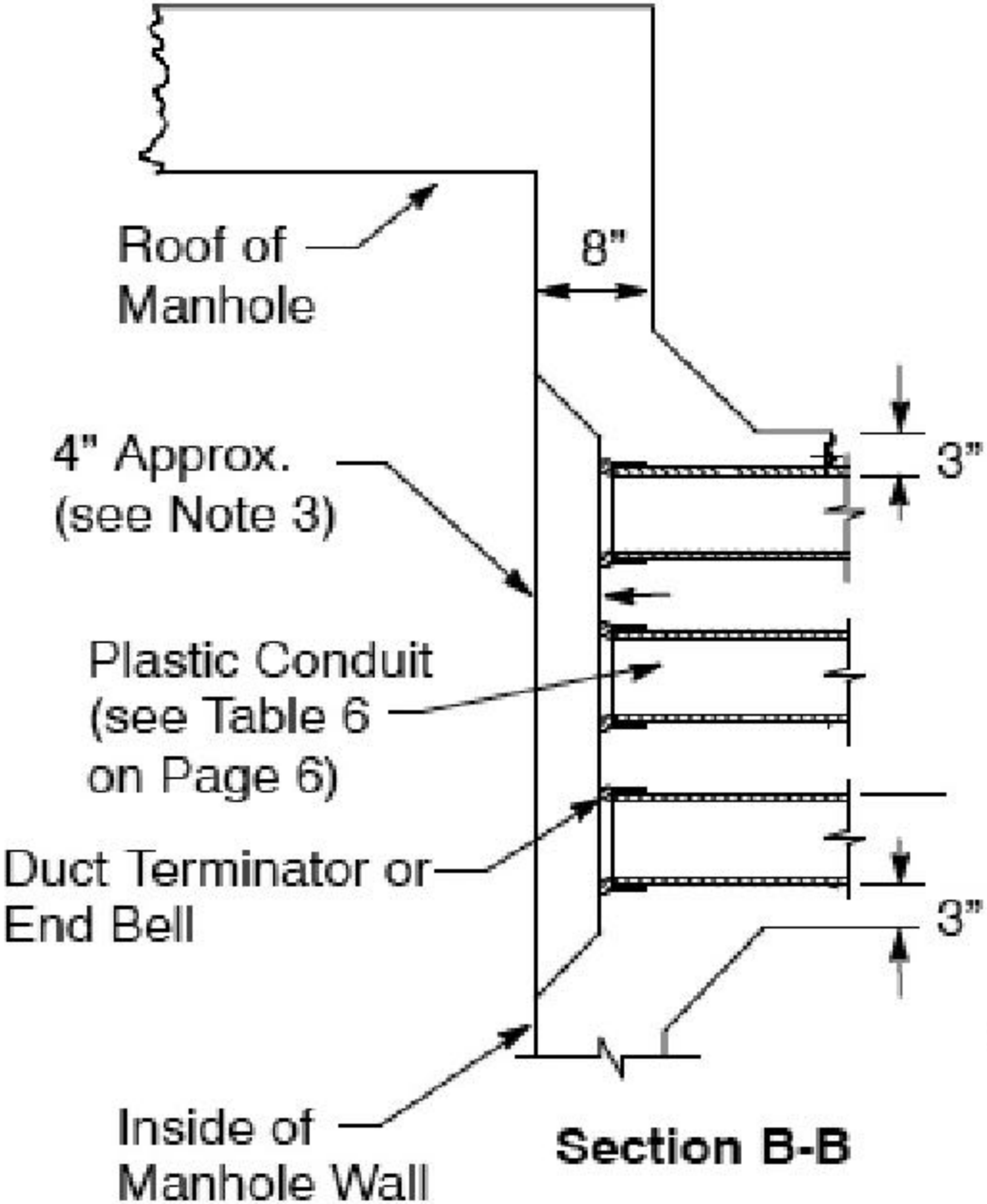




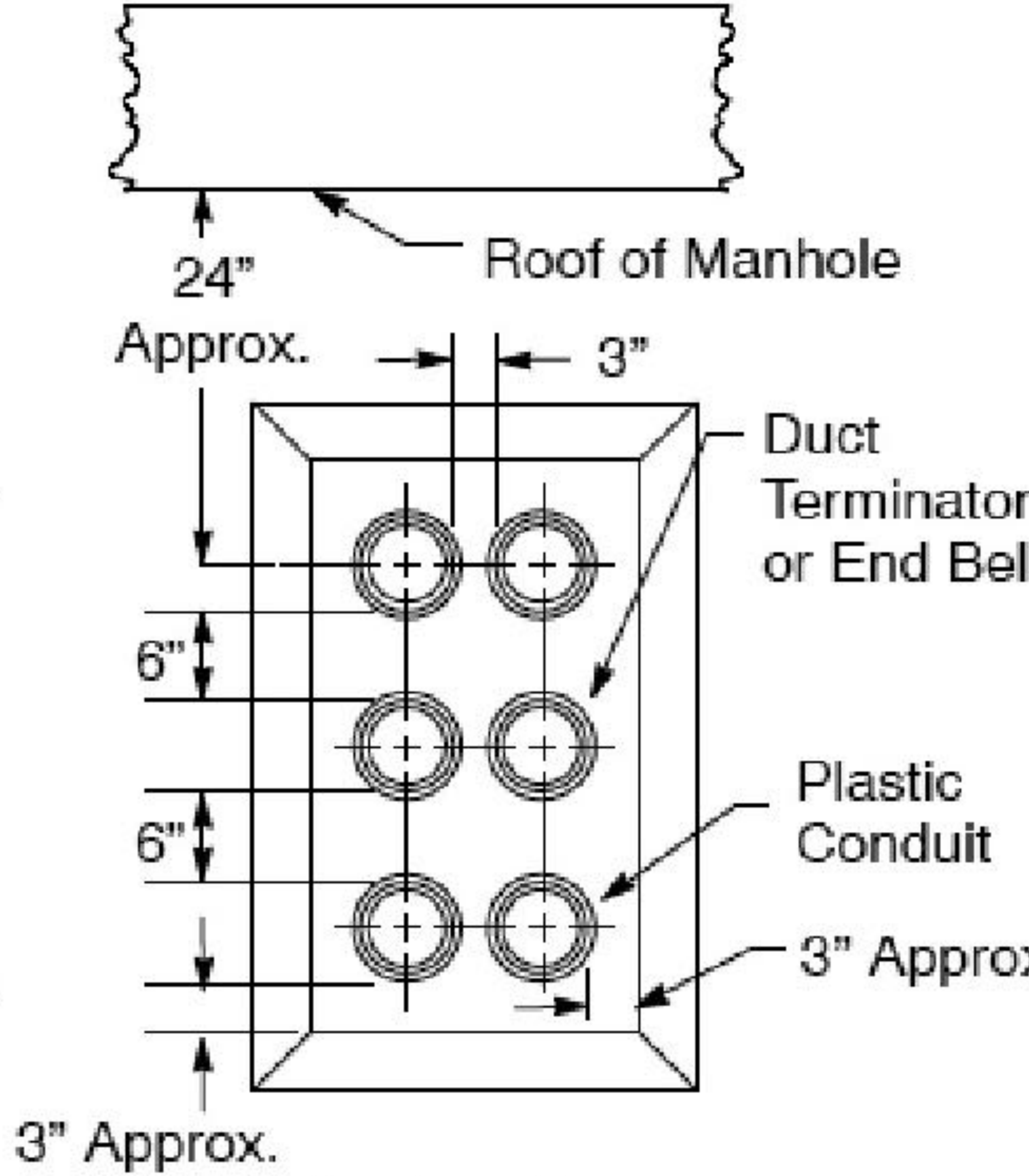
Section A-A

Typical Straight Run Installation
(5" conduit, 6-way shown)


B
B
Manhole Cover
Plan View
Manhole Cover
Level Street Surface
C
2'-6" in older installations
3' 0" Min. (see Note 2)
C
Slope
Slope
Sectional Elevation
Level Grade
Steep Grade



Section B-B



Section C-C
Conduit Window
(6-way conduit formation shown)

$$Damage = \sum overhead\ \ damage + underground\ \ damage$$

$$Overhead\ \ damage = SUM[inertial,\ PGD]$$

$$Underground\ \ damage = SUM[inertial,\ PGD]$$

Ground Shaking Fragility Model

Underground

$$RR_{shake} = k1 * k2 * k3 * k4 * 0.00187 * PGV, \; inch/sec$$

RR is repairs per 1,000 feet

Case	k1	k2	k3 (age)	k4 (not used)
1. Pre 1960 overhead primaries with overhead secondaries	1.0	1.0	0.8 to 1.25	1.0
2. Post 1960 overhead primaries with underground secondaries	1.0	0.75	0.8 to 1.25	1.0
3. Underground in non-filled duct	0.3	1.0	1.0	1.0
4. Underground in filled duct	1.0	1.0	1.0	1.0

Table 4-19, Repair Rate, due to Shaking

k1 = 1.0 for overhead construction with overhead secondaries. PG&E did not provide us with information about secondaries. Based on visual observations, we estimated that if the overhead circuit was installed 1960 or earlier, it was likely to have overhead secondaries; post-1960, the secondaries are assumed to be buried.

k2 = 1.0 for overhead secondaries.

k3 = 1.25 if year of construction is 1945 or earlier; 1.0 if 1946 to 1990; 0.80 for 1991 or later. For overheads, the k3 factor is thought to be a reasonable proxy for the age-related effects on wood pole and cross arm strength owing the cumulative effects of termites and wood rot. For undergrounds, the incremental strains due to shaking are assumed to not have an age related effect.

PGD Fragilty Model

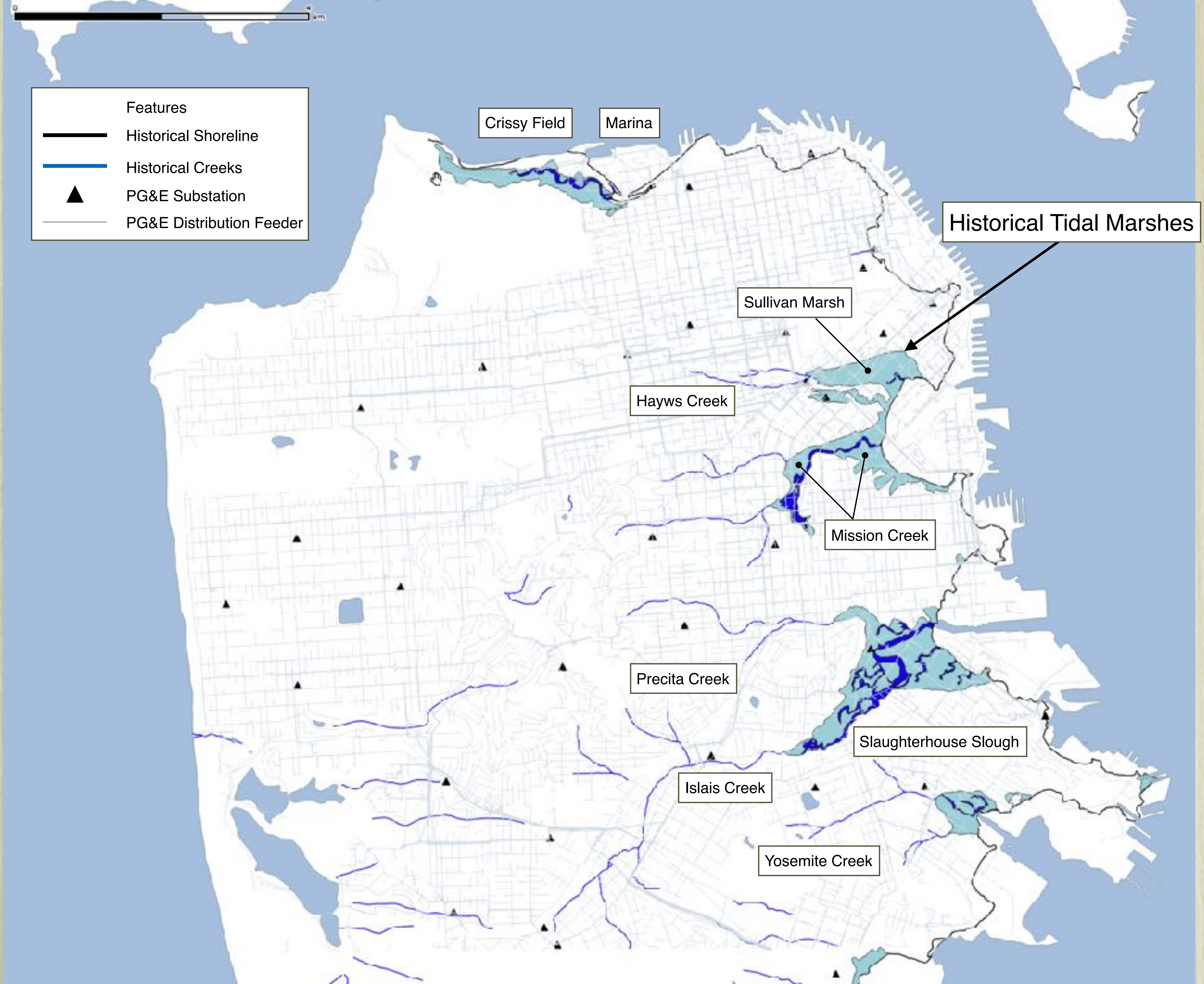
$$RR_{liq} = k1 * k2 * k3 * k4 * PGD^{1.1245}, \; PGD > 0.5 \; inches$$

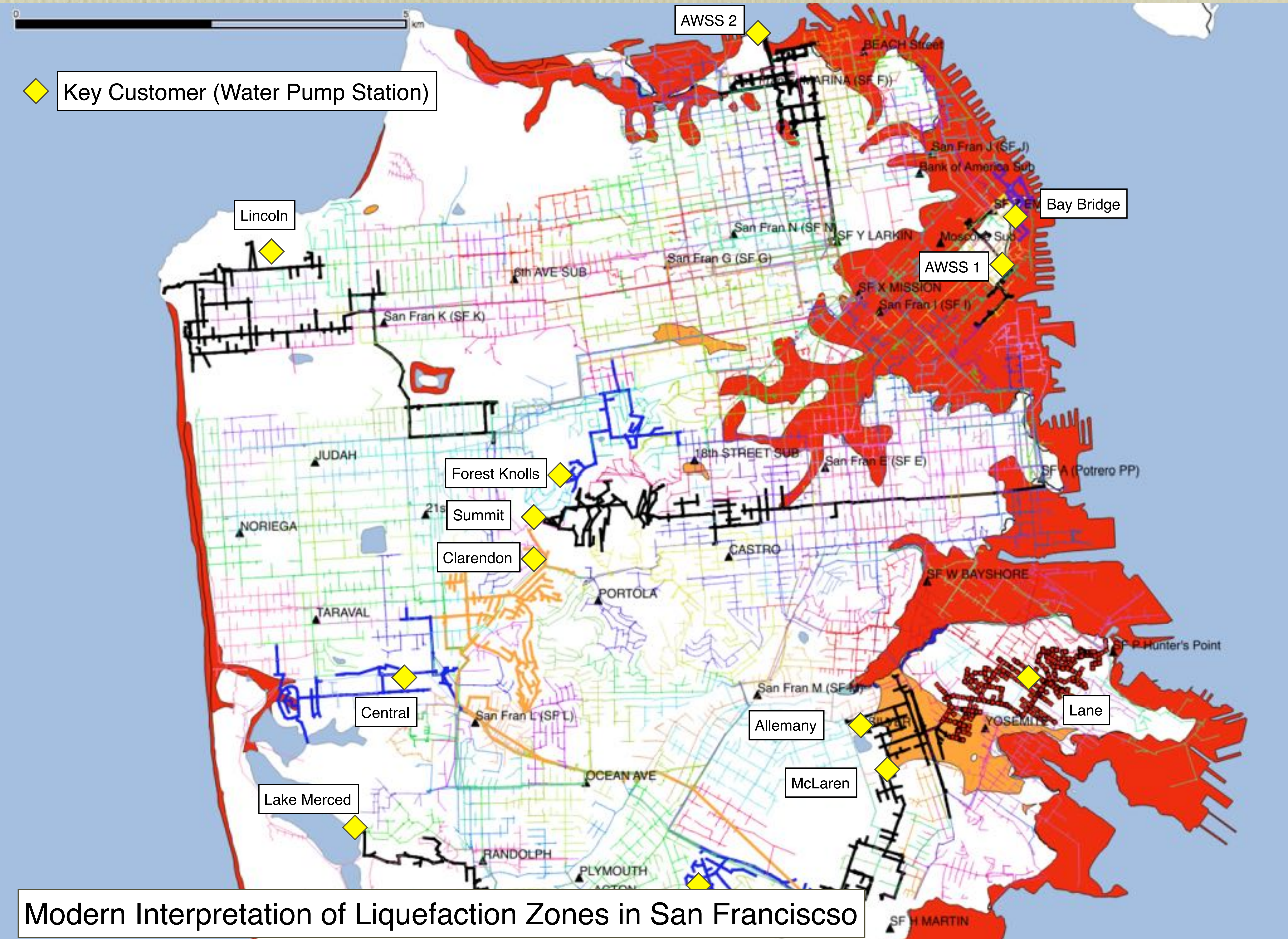
$$RR_{liq} = 0, \; PGD < 0.5 \; inches$$

where RR(liq) is repairs per 1,000 feet, and PGD is in inches.

Case	k1	k2	k3 (age)	k4 (not used)
3. Underground in non-filled duct	0.01	1.0 unreinforced 0.125 reinforced	0.8 to 1.25	1.0
4. Underground in filled duct	0.026	1.0 PILC 0.80 XLPE 0.80 EPR	0.8 to 1.25	1.0

Now, Lets Apply These Fragility Models for San Francisco in a future San Andreas Earthquake


Features
Historical Shoreline
Historical Creeks
PG&E Substation
PG&E Distribution Feeder
Crissy Field
Marina
Historical Tidal Marshes
Sullivan Marsh
Hayws Creek
Mission Creek
Precita Creek
Slaughterhouse Slough
Islais Creek
Yosemite Creek



Modern Interpretation of Liquefaction Zones in San Franciscso

SF Damage Forecast

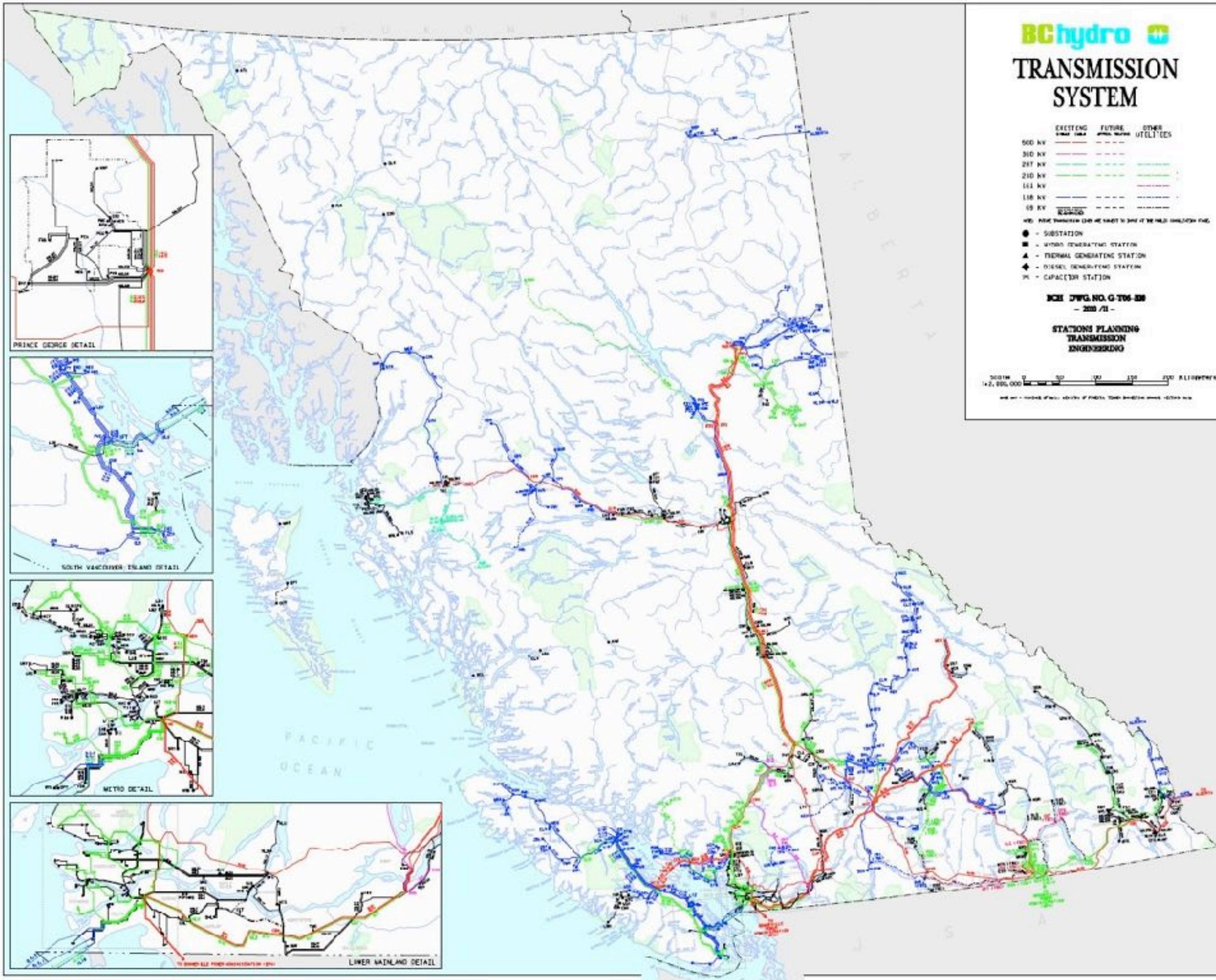
Fault / Segment	M	Shaking	Liquefaction	Landslide	Total
San Andreas SAP	6.0	1.9	0.0	0.0	1.9
San Andreas SAP	6.2	5.3	0.0	0.0	5.3
San Andreas SAP	6.4	13.3	0.0	0.0	13.3
San Andreas SAP	6.6	25.8	0.3	0.0	26.1
San Andreas SAP	6.8	45.4	2.3	0.0	47.7
San Andreas SAP	7.0	77.3	6.4	0.1	83.8
San Andreas SAP	7.2	116.2	13.7	0.2	130.1
San Andreas SAP	7.4	132.6	22.2	0.3	155.1
SA SAN+P+S	7.5	139.3	28.4	0.4	168.1
SA SAN+P+S	7.7	153.1	47.3	1.4	201.8
SA SAN+P+S	7.8	160.2	60.6	2.1	222.9
SA SAN+P+S	8.0	175.0	97.0	4.3	276.3
SA Repeat 1989	7.0	1.6	0.0	0.0	1.6
Hayward N+S	7.5	36.6	4.5	0.0	41.1

Number of repairs to electric distribution system

In the High Seismic Zone along the West Coast of USA and CANADA,
Who Has Buried High Voltage Cables Exposed to Liquefaction?

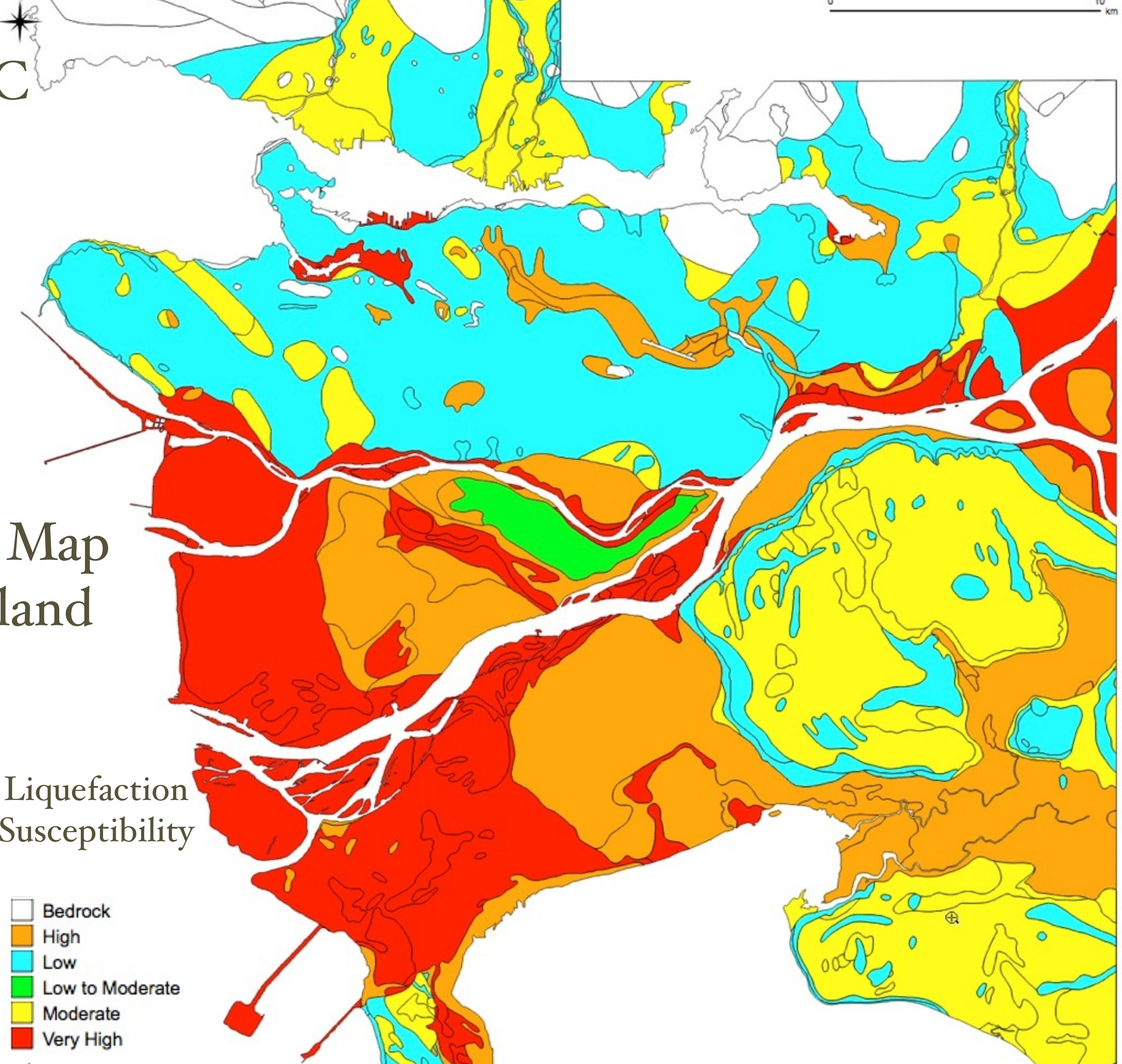
Transmission
Pacific Gas and Electric (Lots)
BC Hydro (Lots)
San Diego Gas and Electric (Some)
SCE (Some)
BPA (Little)

Distribution
Alameda, Palo Alto, Silicon Valley, PacifiCorp,
Portland General Electric, Seattle City Light

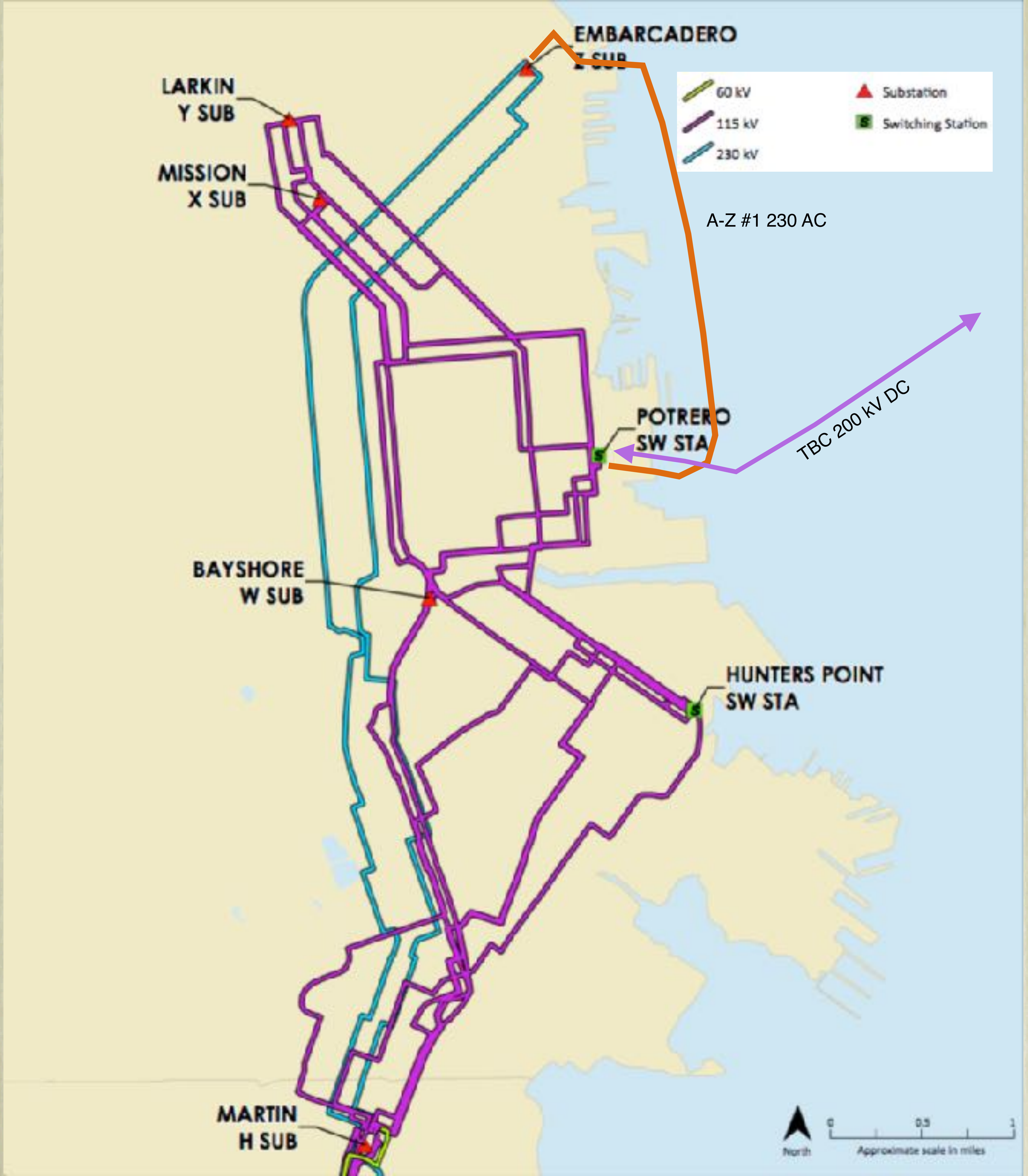

BChydro
TRANSMISSION
SYSTEM
EXISTING
FUTURE
OTHER UTILITIES
500 kV
360 kV
287 kV
230 kV
161 kV
138 kV
69 kV
SUBSTATION
THERMAL GENERATING STATION
CAPACITOR STATION
STATIONS PLANNING
TRANSMISSION
ENGINEERING
PRINCE GEORGE DETAIL
SOUTH VANCOUVER ISLAND DETAIL
METRO DETAIL
LOWER MAINLAND DETAIL
PACIFIC
OCEAN

Vancouver, BC (BC Hydro)

Liquefaction Map Lower Mainland

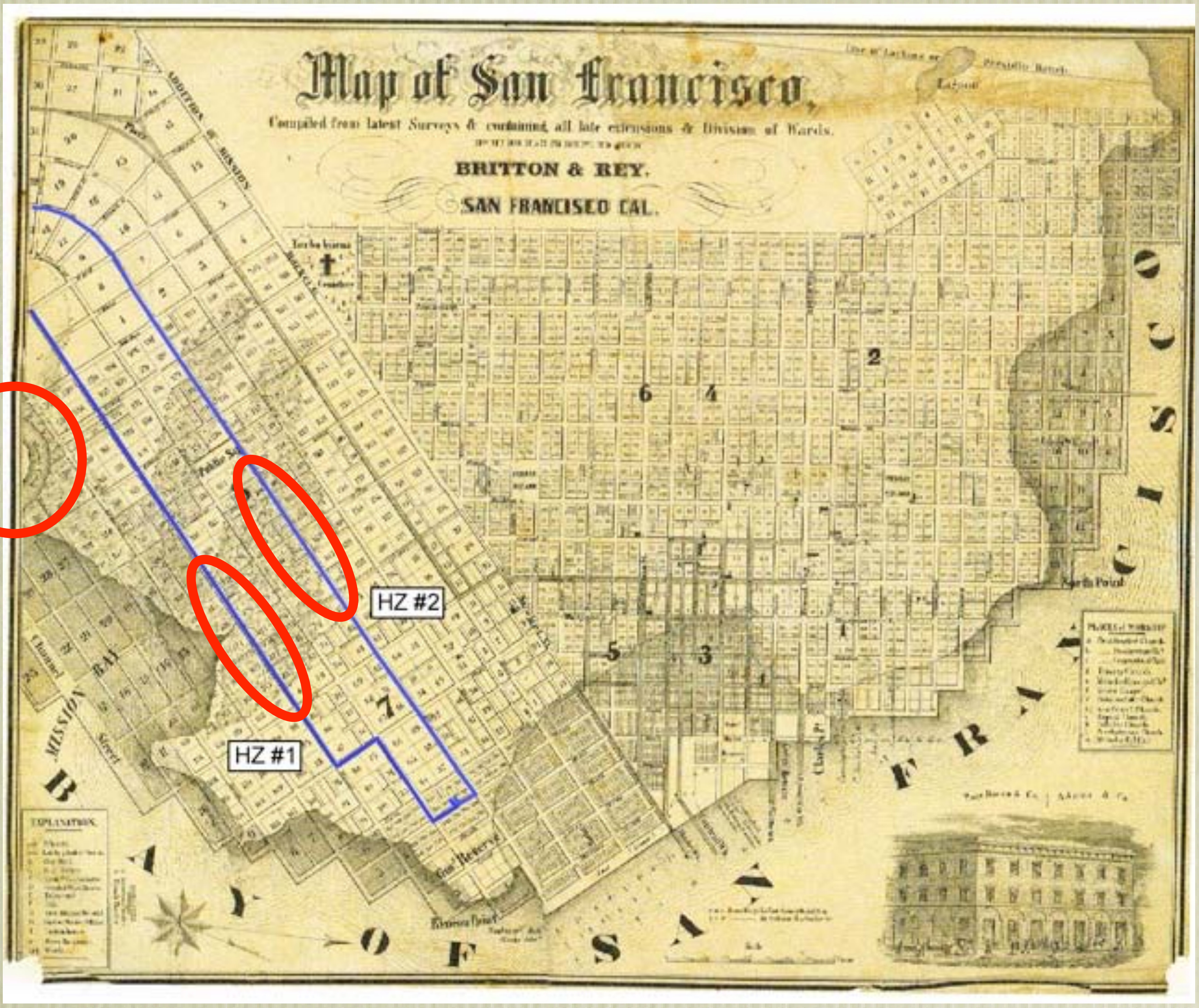


UTM NAD 83 Zone 10 (meters)



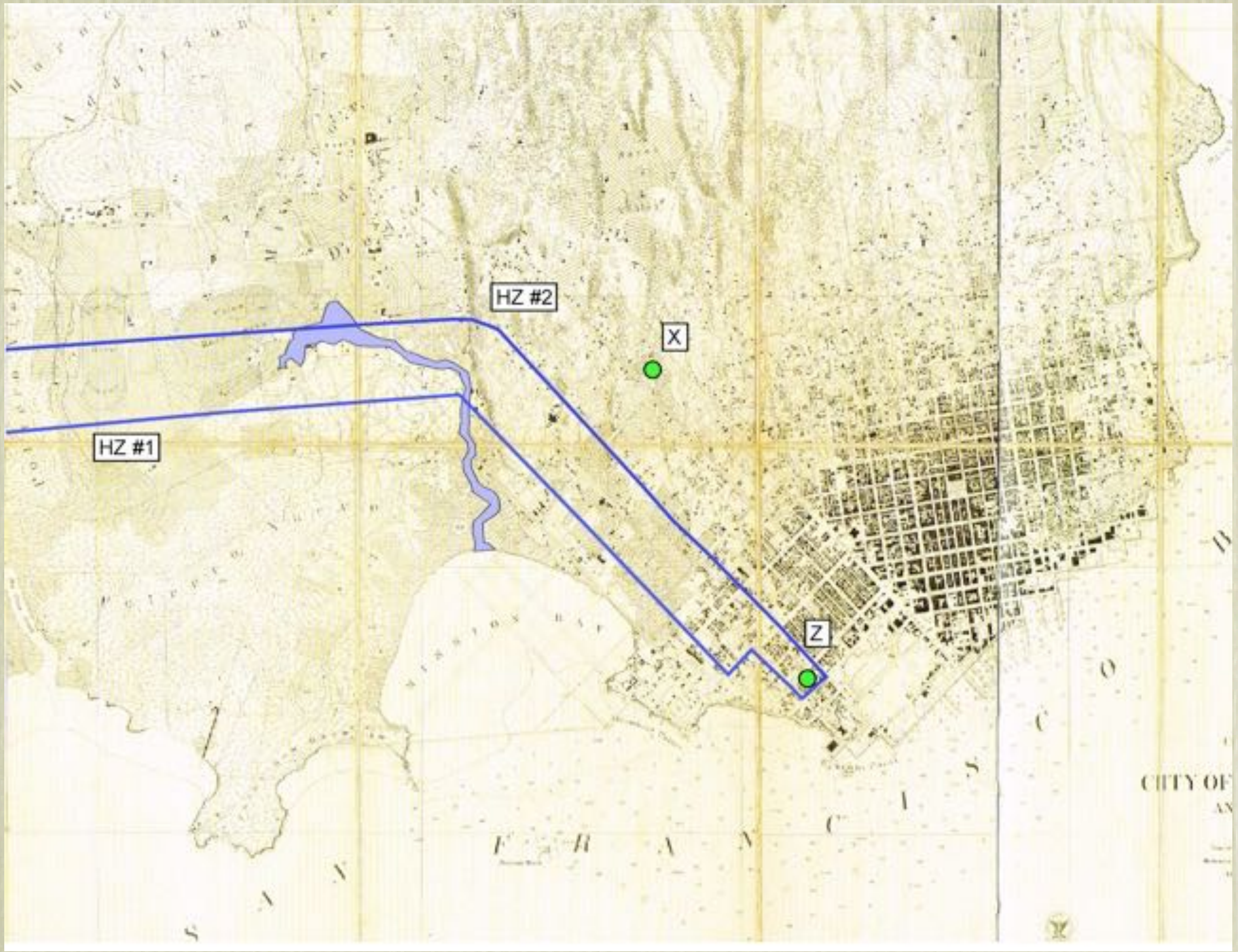
EMBARCADERO
Z SUB
LARKIN
Y SUB
MISSION
X SUB
60 kV
115 kV
230 kV
Substation
Switching Station
A-Z #1 230 AC
TBC 200 kV DC
POTRERO
SW STA
BAYSHORE
W SUB
HUNTERS POINT
SW STA
MARTIN
H SUB
North
0
0.5
1
Approximate scale in miles

1852 Map



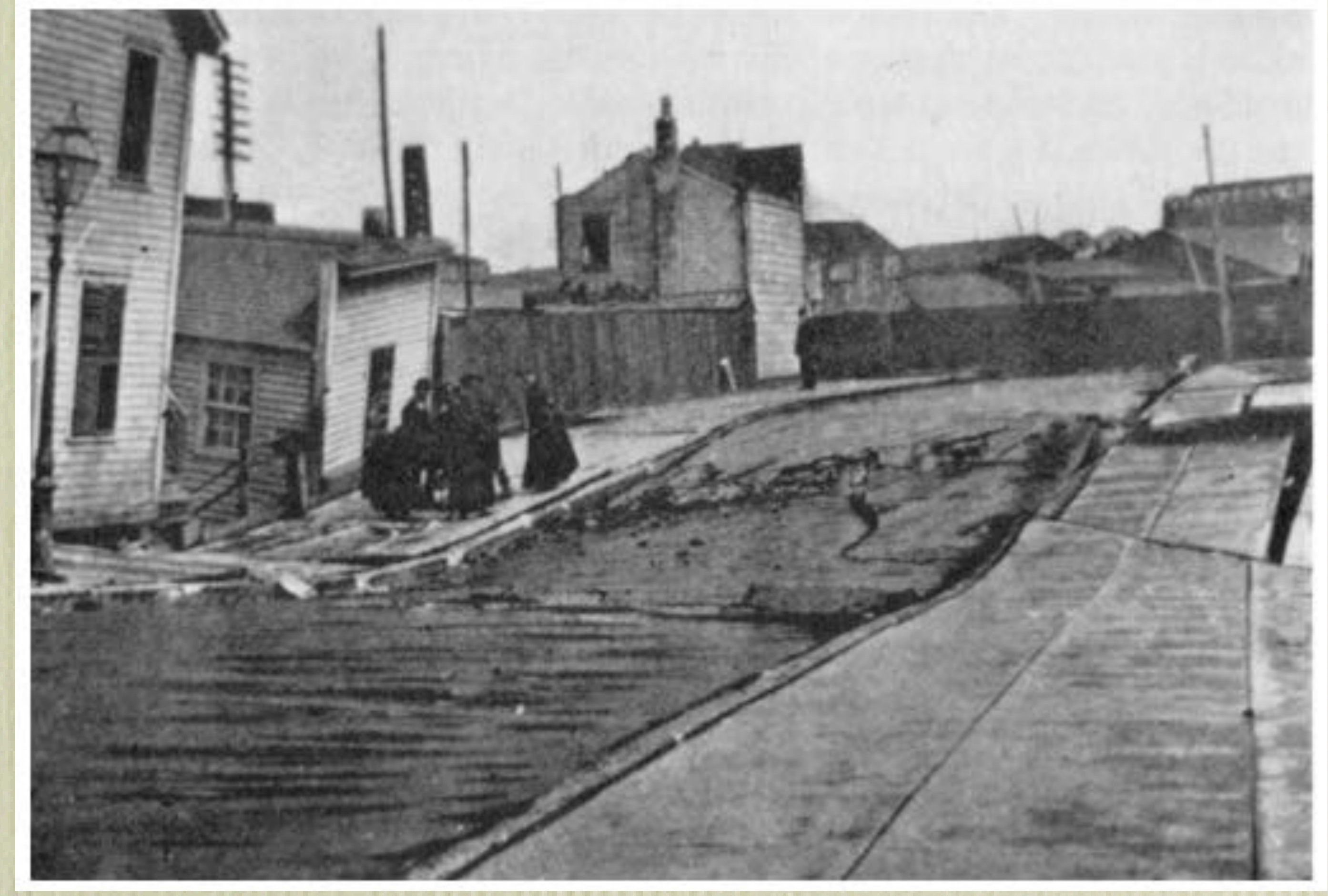
Zones of Primary Concern

1859 Map



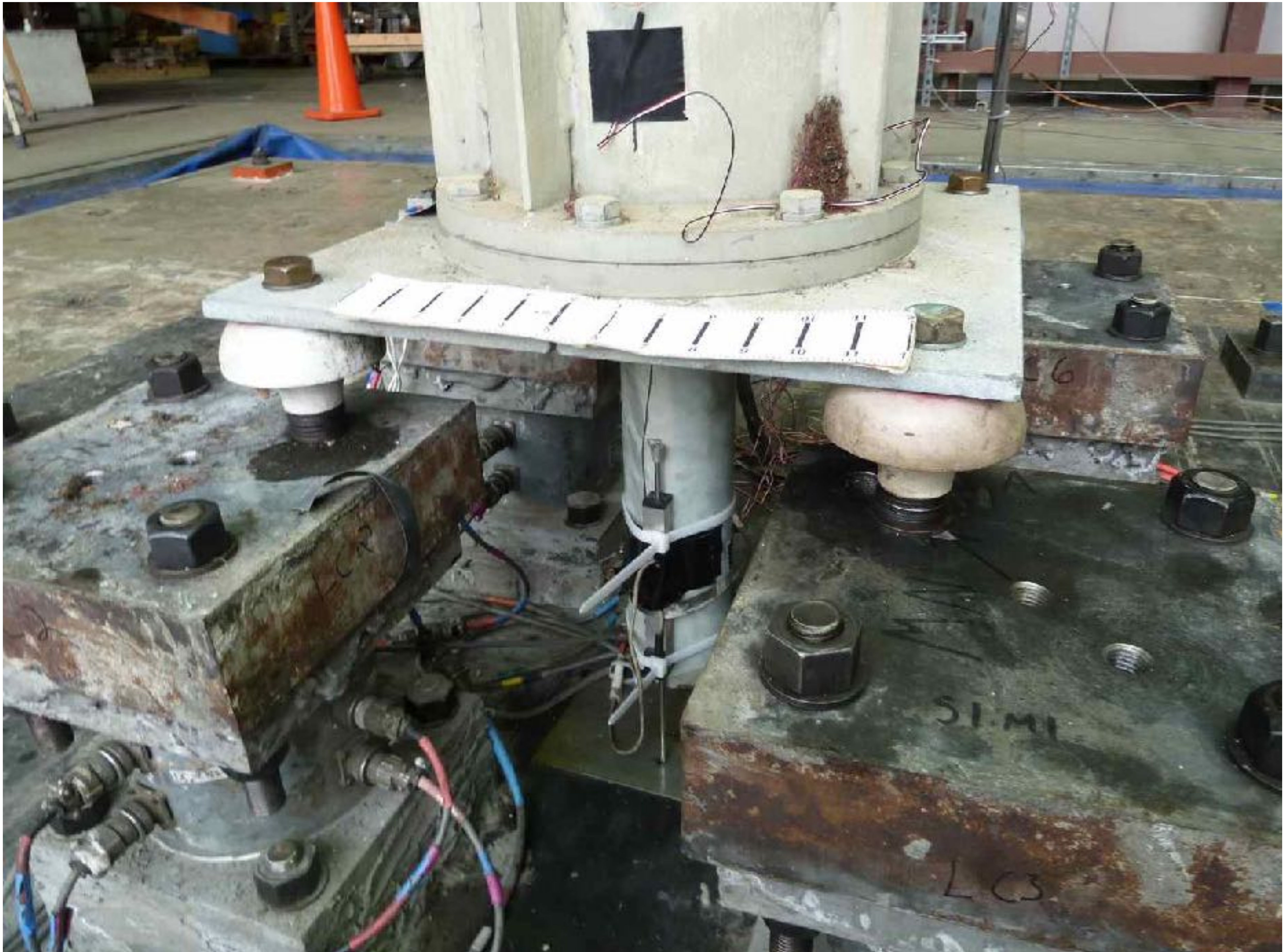
Mission and 7th Street at Post Office

Dore and Bryant



Cable Terminations (Potheads):

Their Importance, Seismic Qualification, and Dynamic Characteristics


S1 M1
LC3


24-36

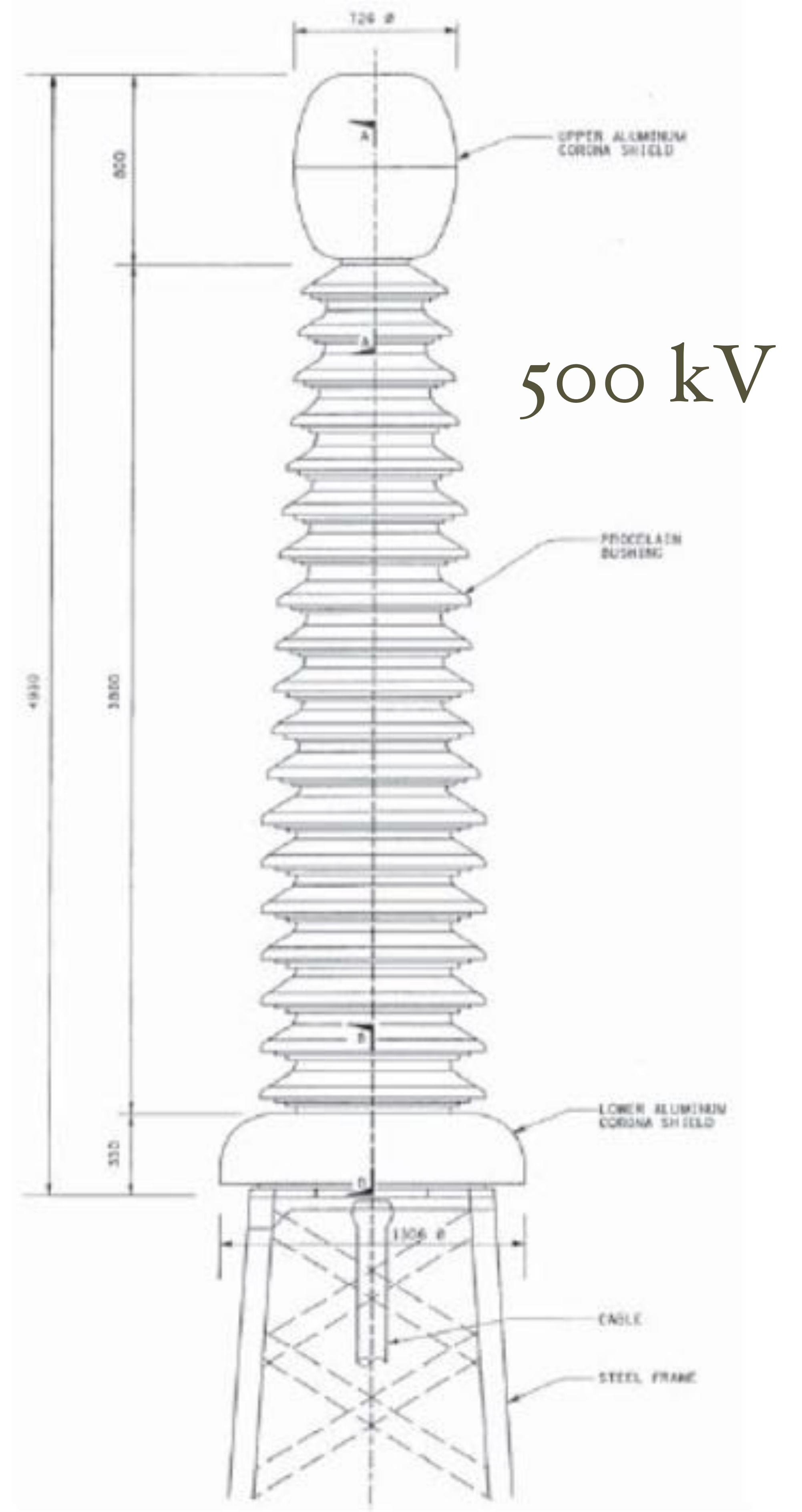
Pot Heads with Weak Standoffs (fail at PGA 0.25-0.5g)


NW
NE
SW
SE

PG&E 115 kV Pot Head
Shake Table Test September 10 2013

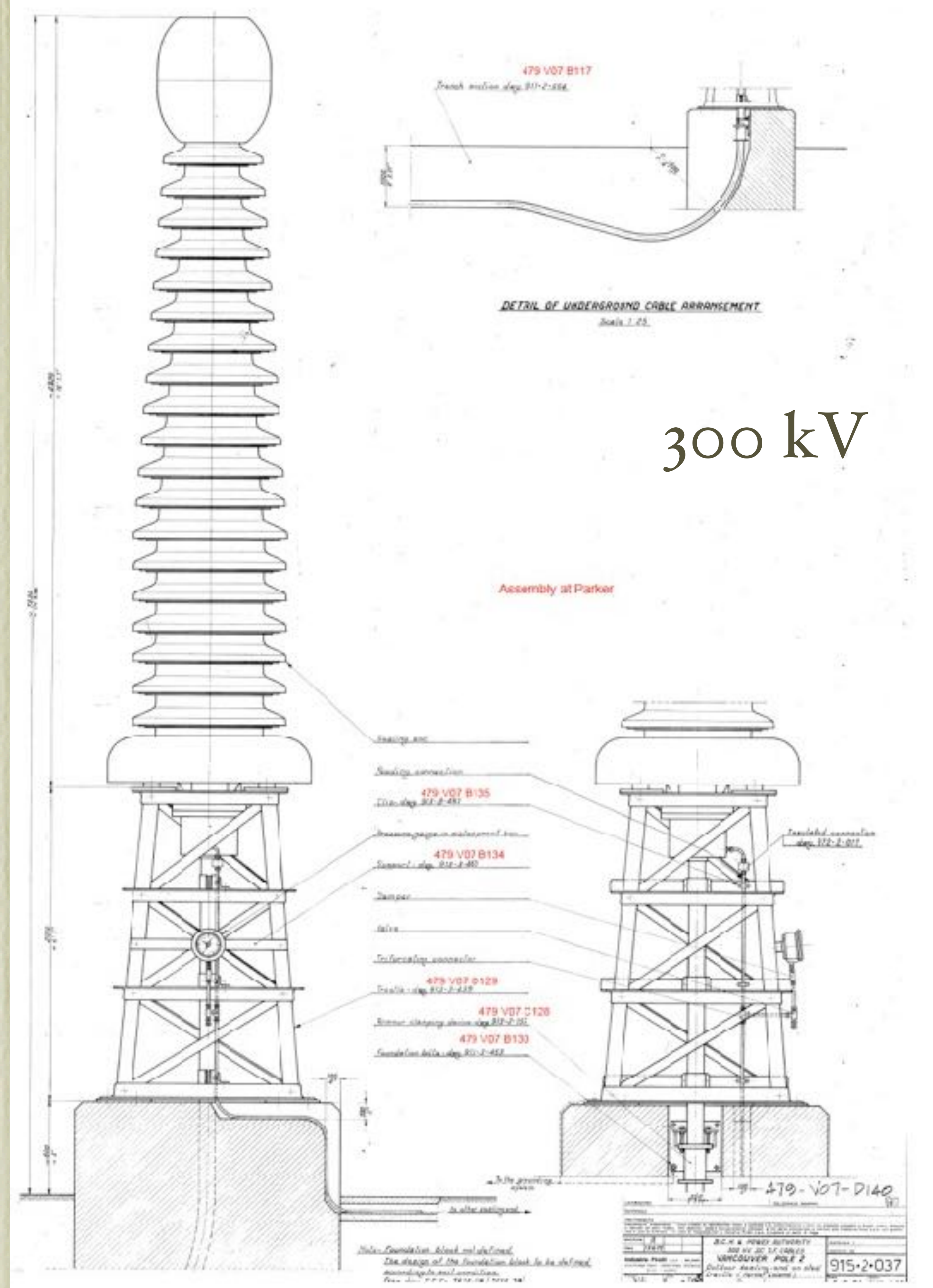
Movie

500 kV Potheads



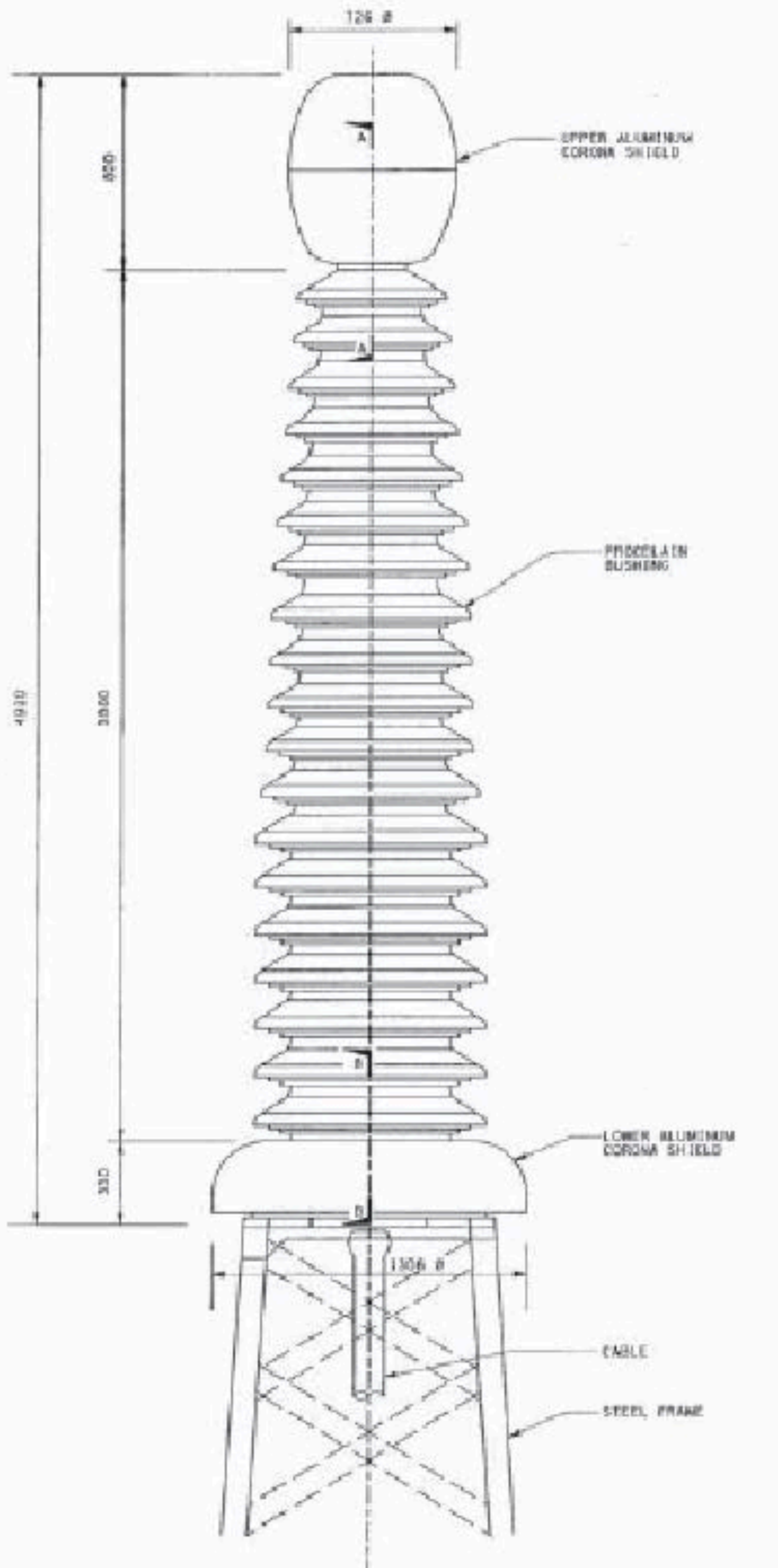
726 ⌀
UPPER ALUMINUM
CORONA SHIELD
800
PORCELAIN
BUSHING
4930
3800
LOWER ALUMINUM
CORONA SHIELD
330
1306 ⌀
CABLE
STEEL FRAME

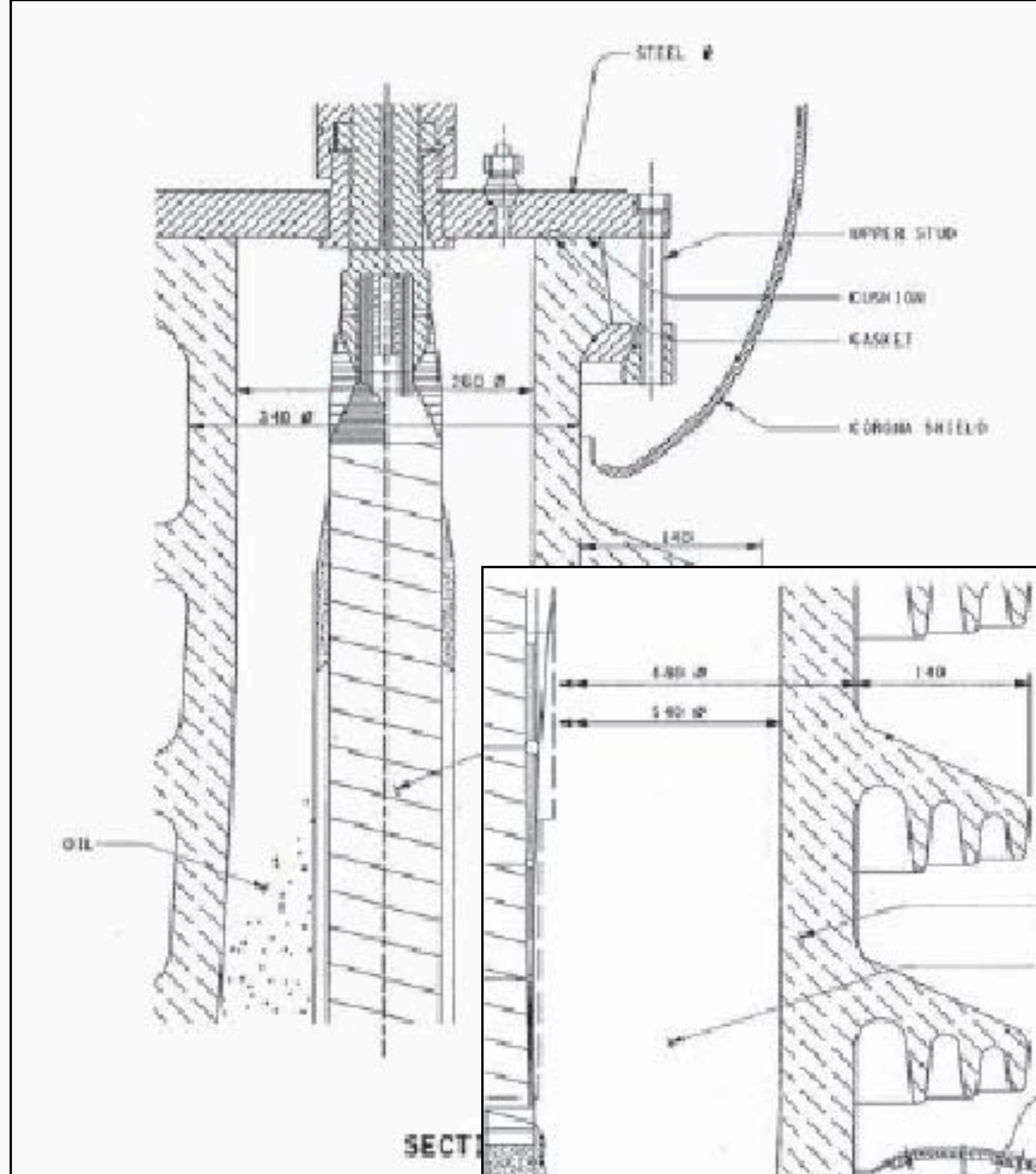
500 kV

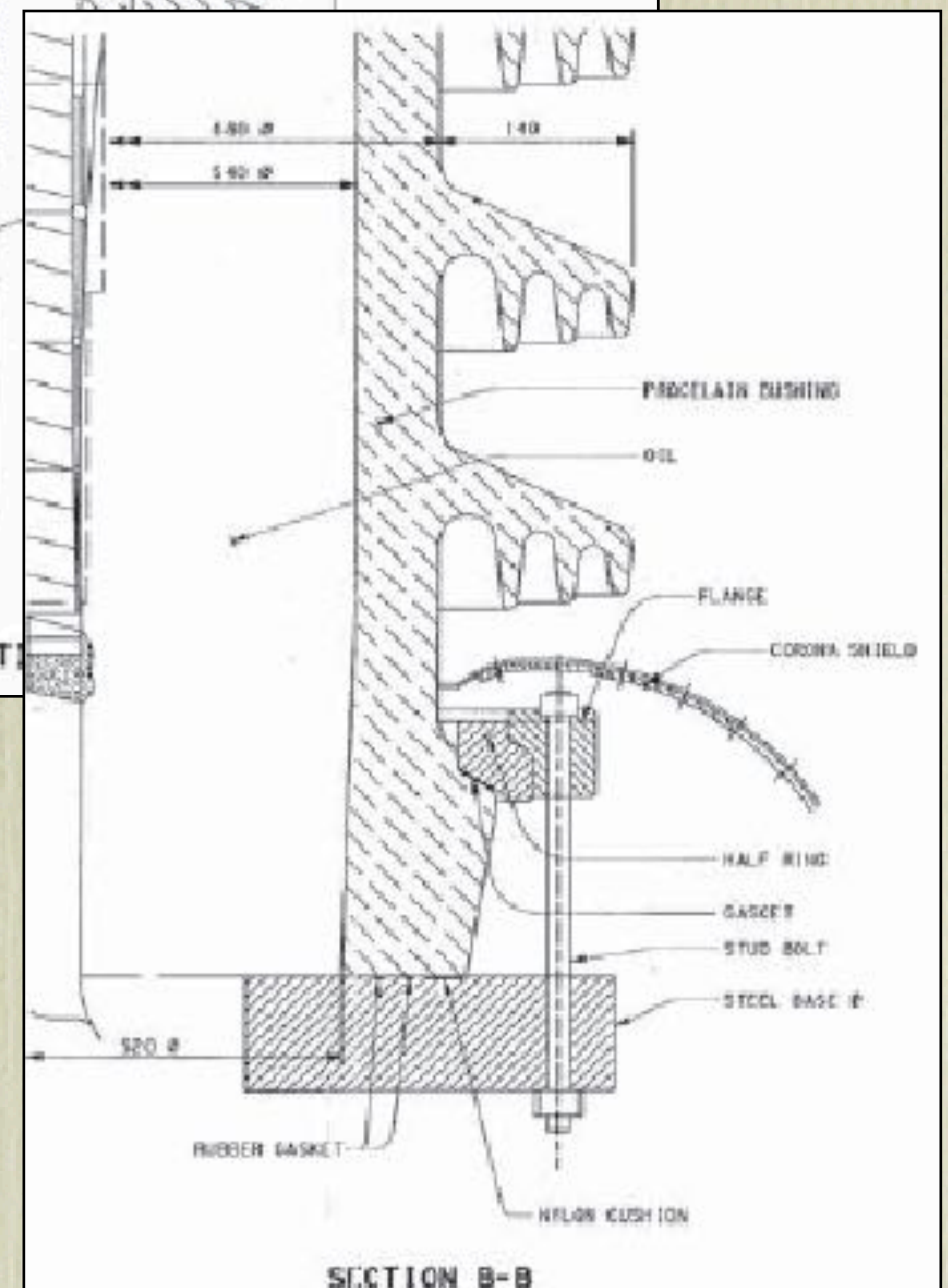


479 V07 B117
DETAIL OF UNDERGROUND CABLE ARRANGEMENT
Scale 1:25
Assembly at Parker
479 V07 B135
479 V07 B134
479 V07 D129
479 V07 D128
479 V07 B130
479-V07-D140
915-2-037

300 kV

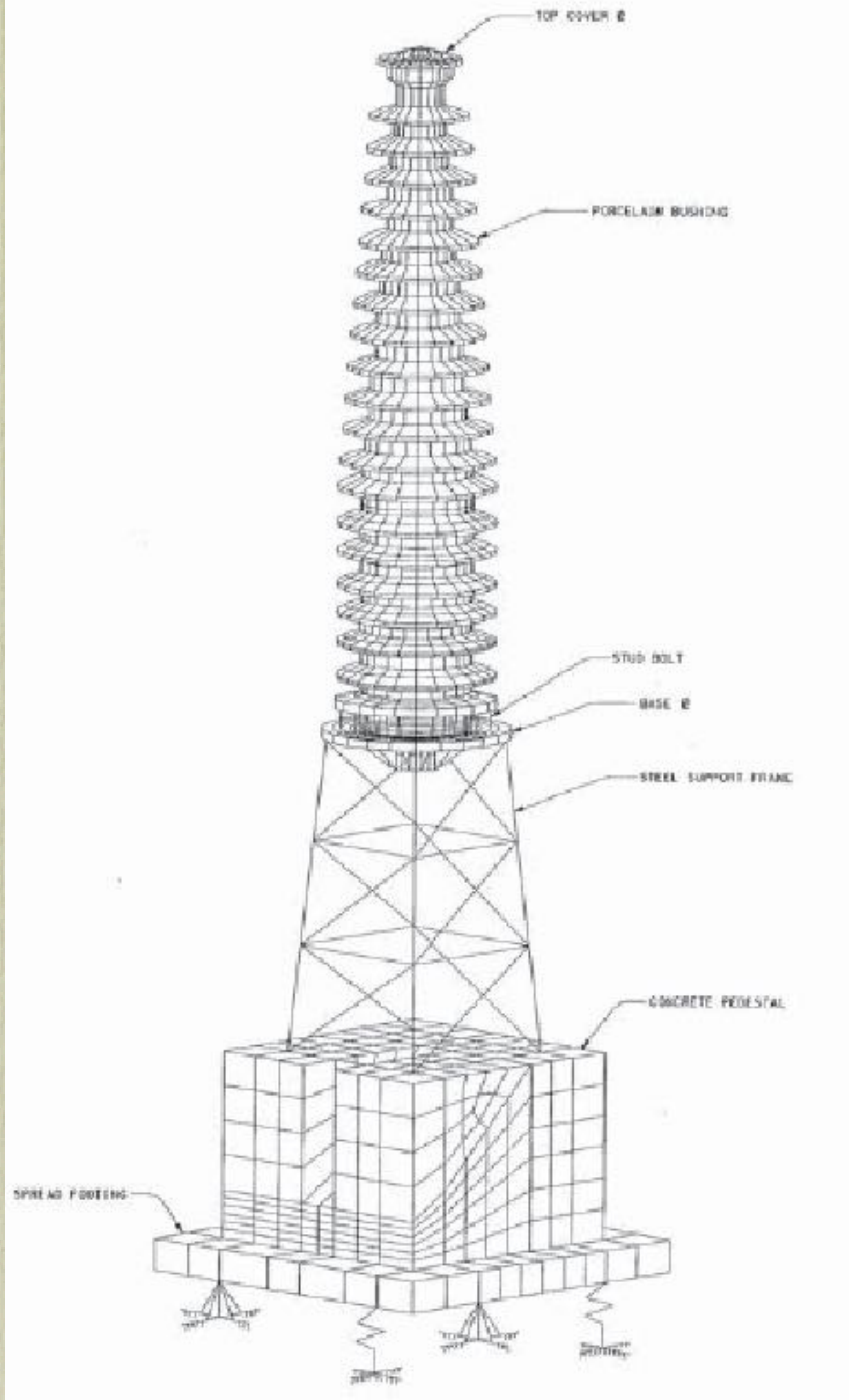

UPPER ALUMINUM CORONA SHIELD
PORCELAIN BUSHING
LOWER ALUMINUM CORONA SHIELD
CABLE
STEEL FRAME

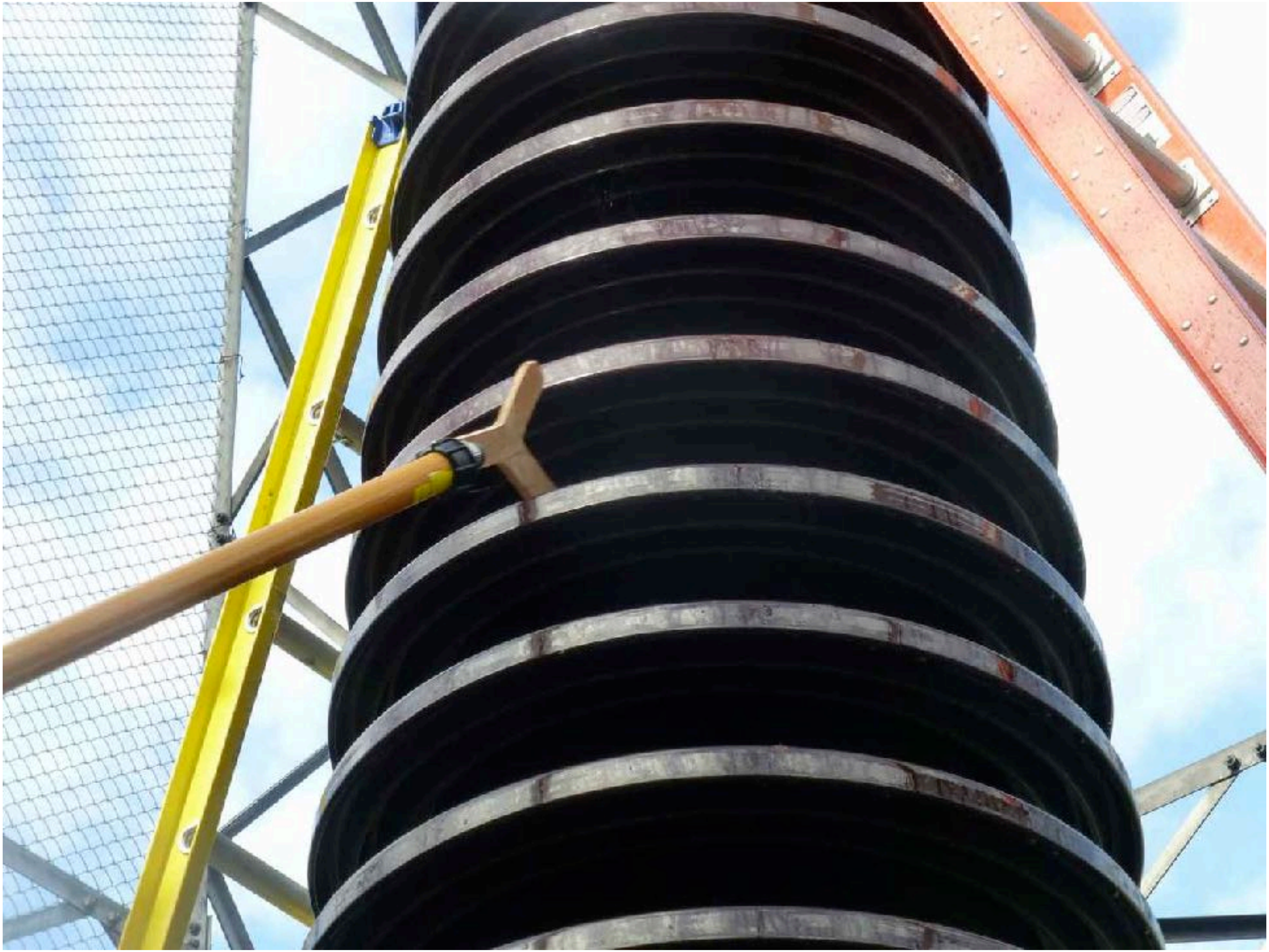

STEEL Ø
UPPER STUD
CUSHION
GASKET
CORONA SHIELD
260 Ø
340 Ø
140
OIL

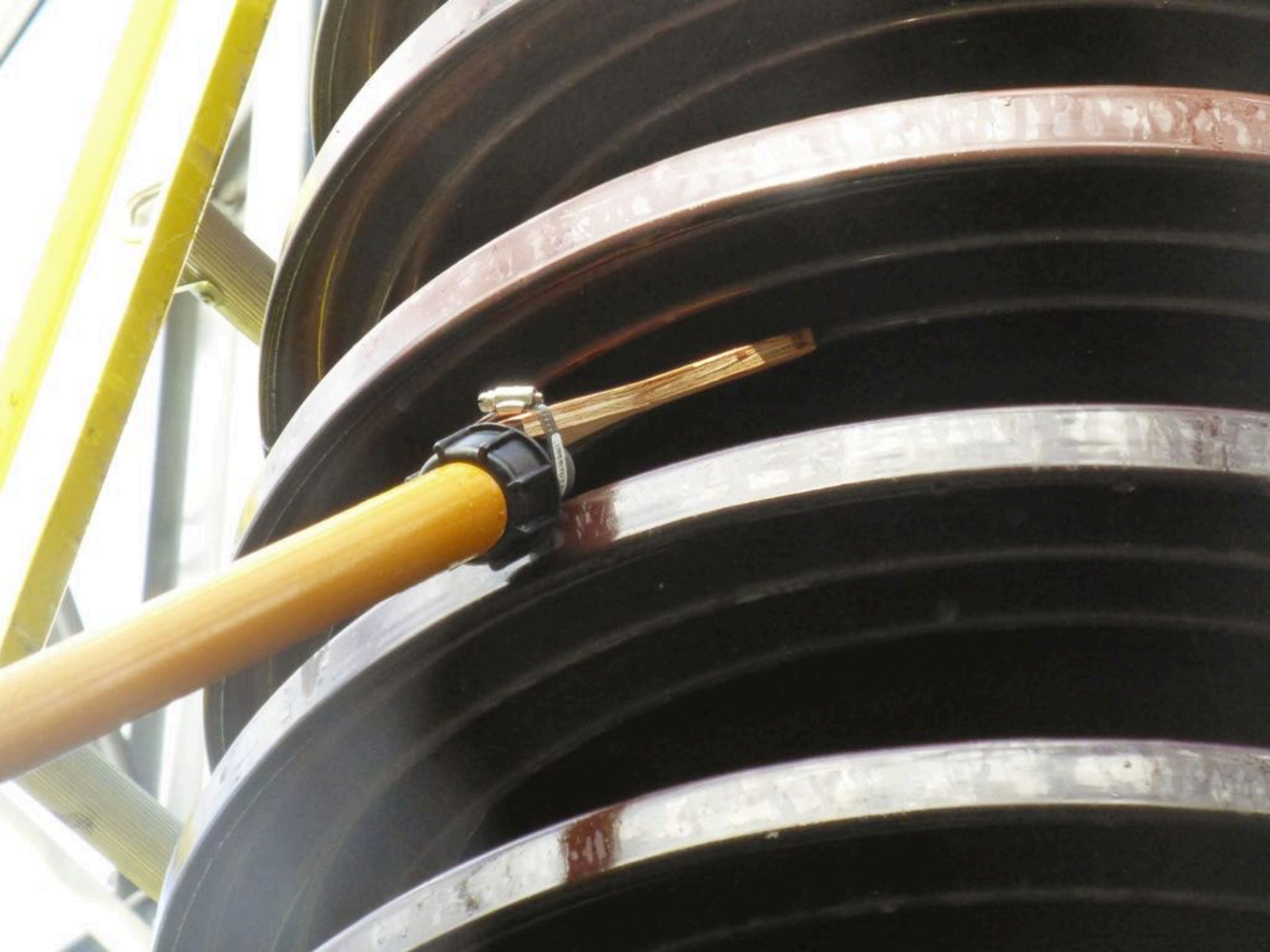

140
PORCELAIN BUSHING
OIL
FLANGE
CORONA SHIELD
HALF RING
GASKET
STUD BOLT
STEEL BASE Ø
520 Ø
RUBBER GASKET
NYLON CUSHION
SECTION B-B

Instruments B and C (held with magnets)

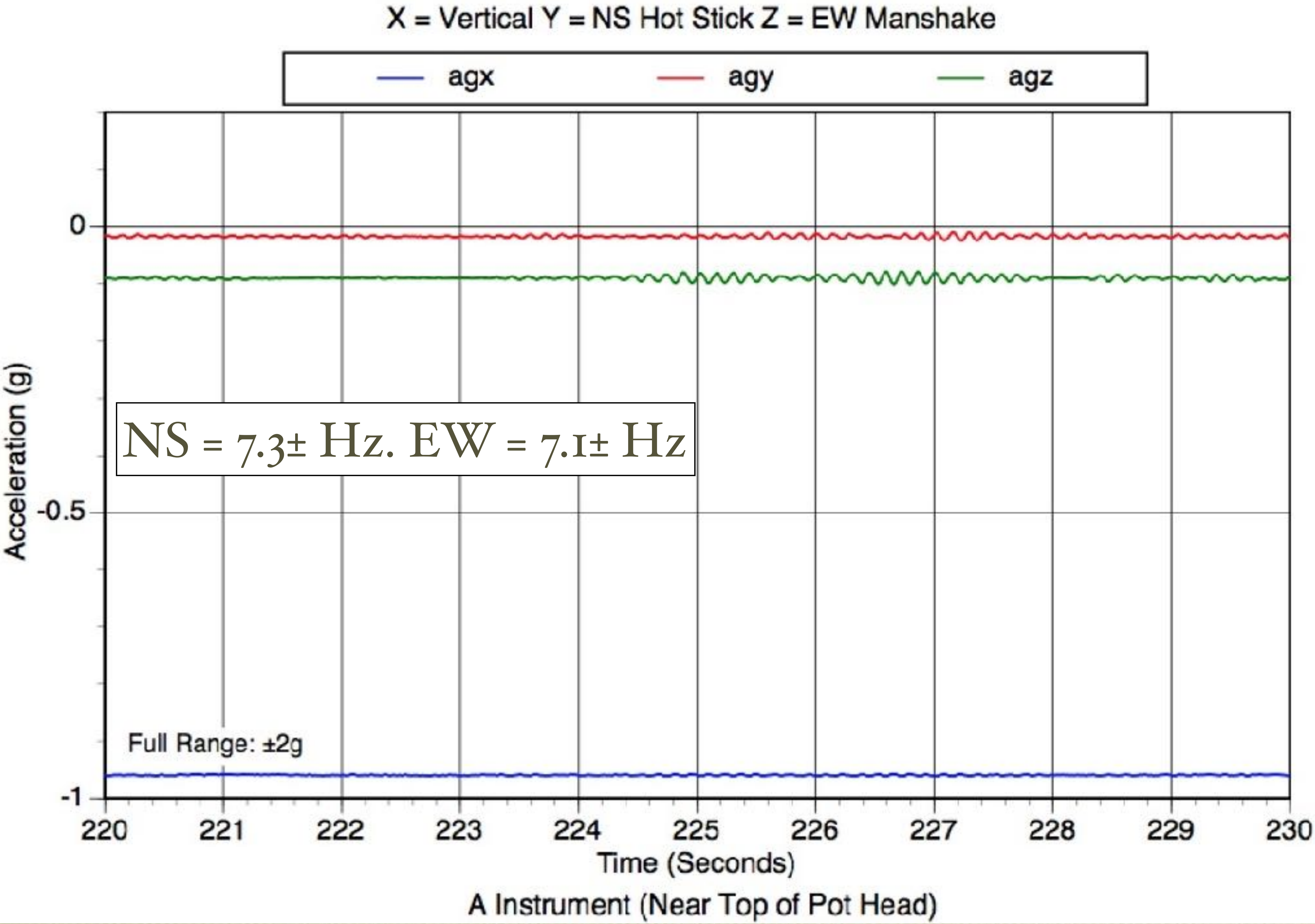
300 kV Pothead
Pirelli
1968
(CPT)

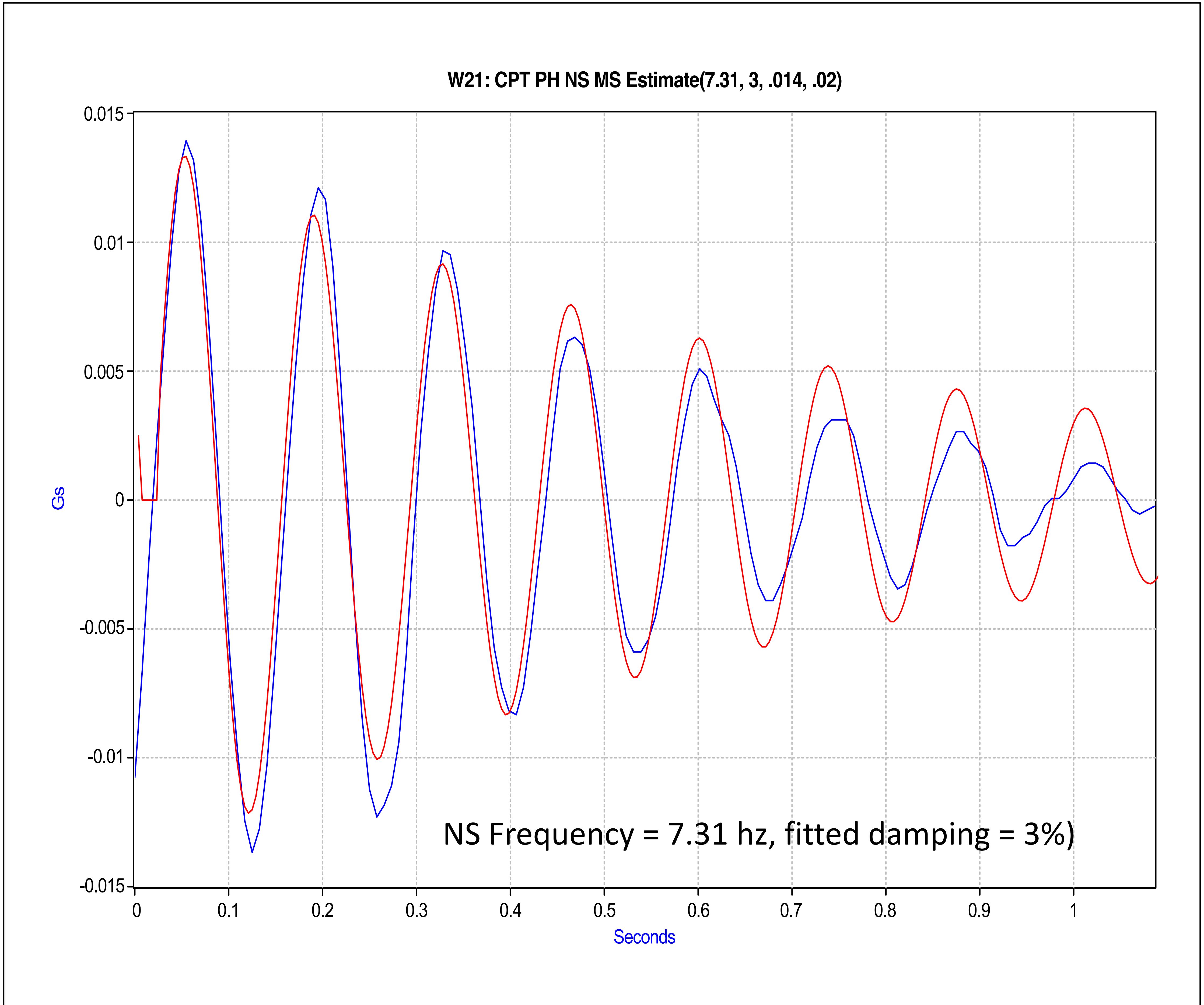






300 kV DC at CPT

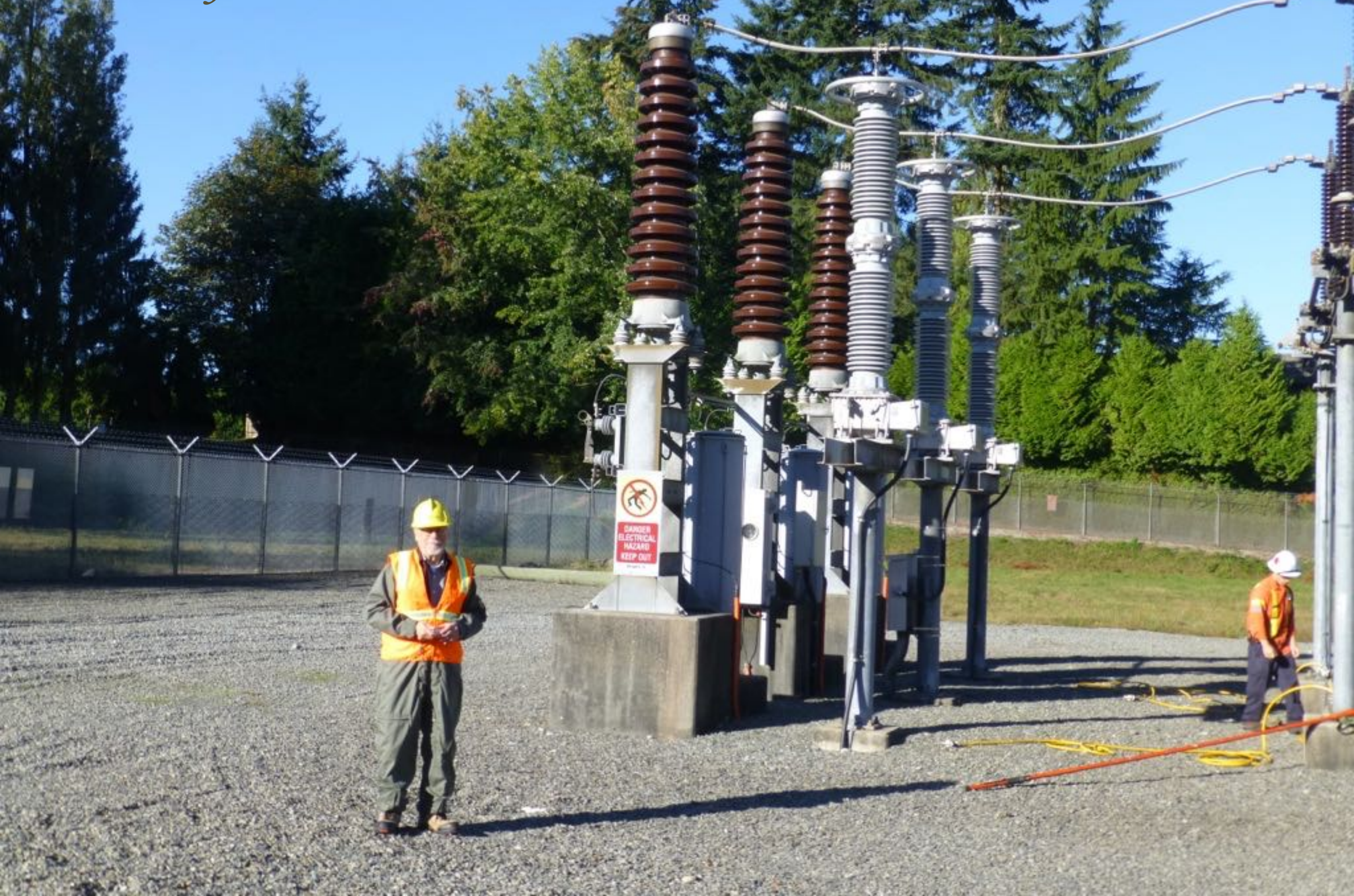



W21: CPT PH NS MS Estimate(7.31, 3, .014, .02)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
Gs
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Seconds
NS Frequency = 7.31 hz, fitted damping = 3%)

Field Test of 230 kV Porcelain Pothead (Camosun)

- Man-shake
- Sometimes clean response
- Sometimes not

Camosun
230 kV Pot Heads




DANGER
ELECTRICAL
HAZARD
KEEP OUT

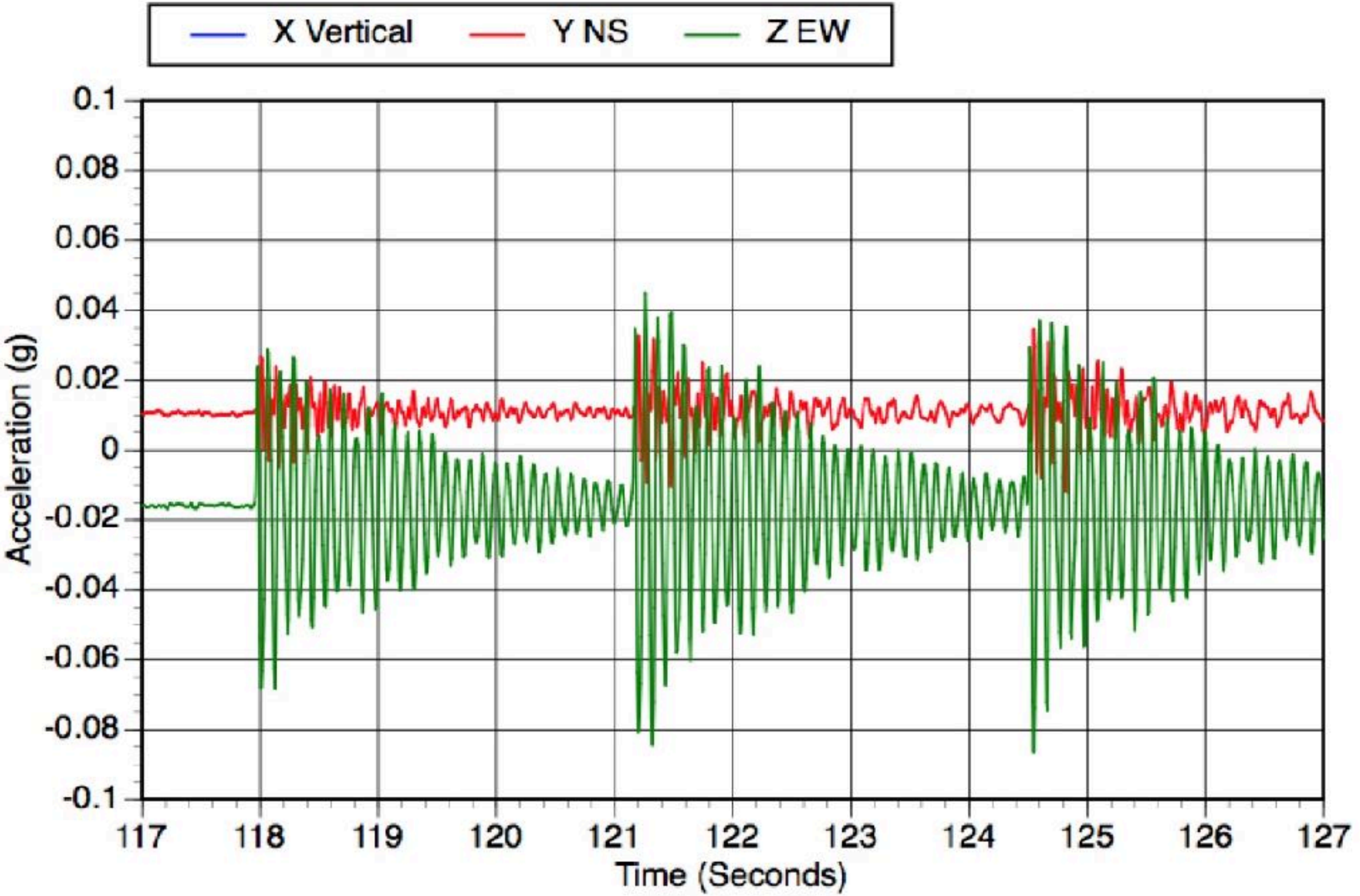
230 kV Potheads Camosun

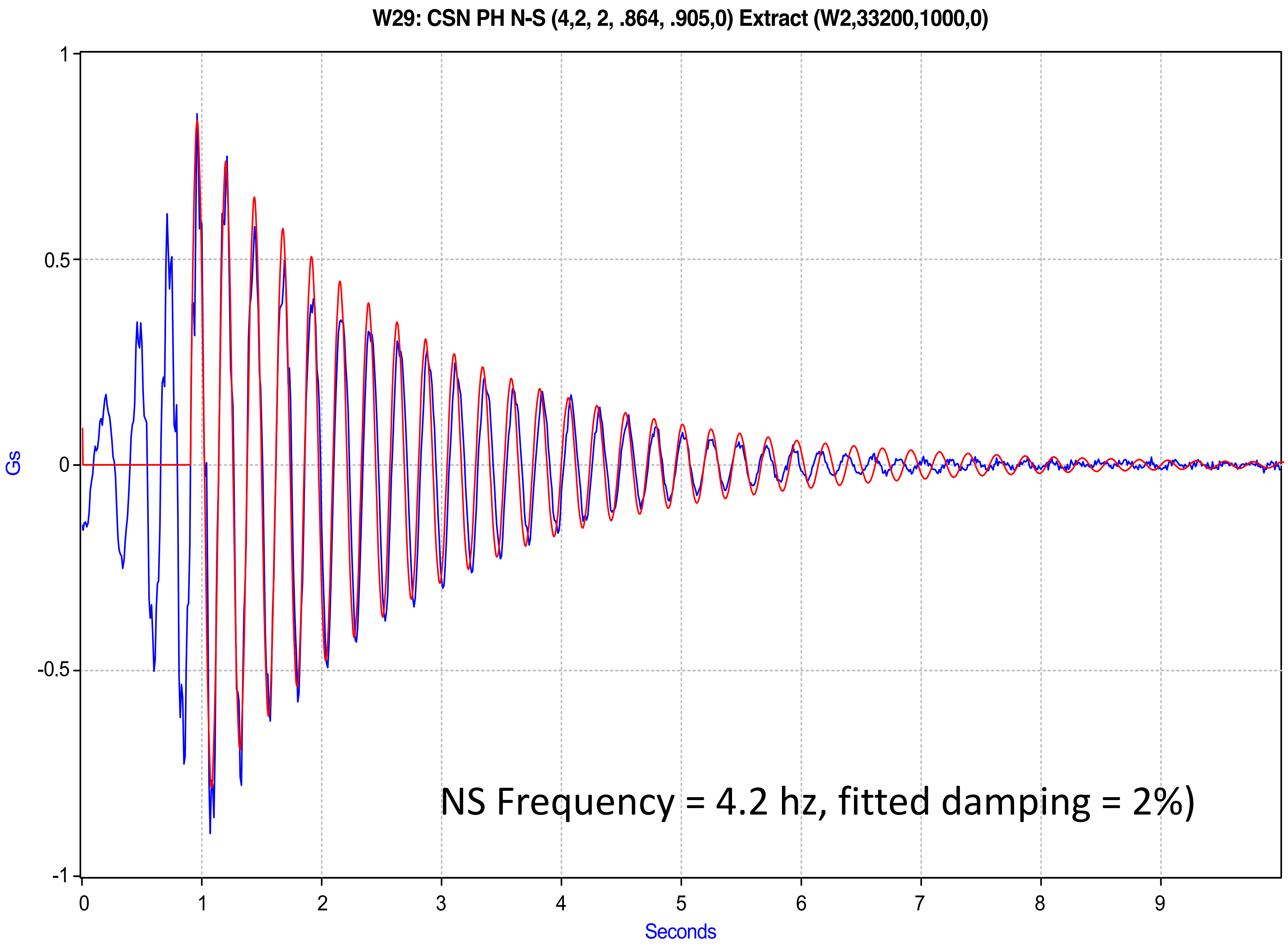

DANGER
DANGER
DANGER
DANGER
DANGER

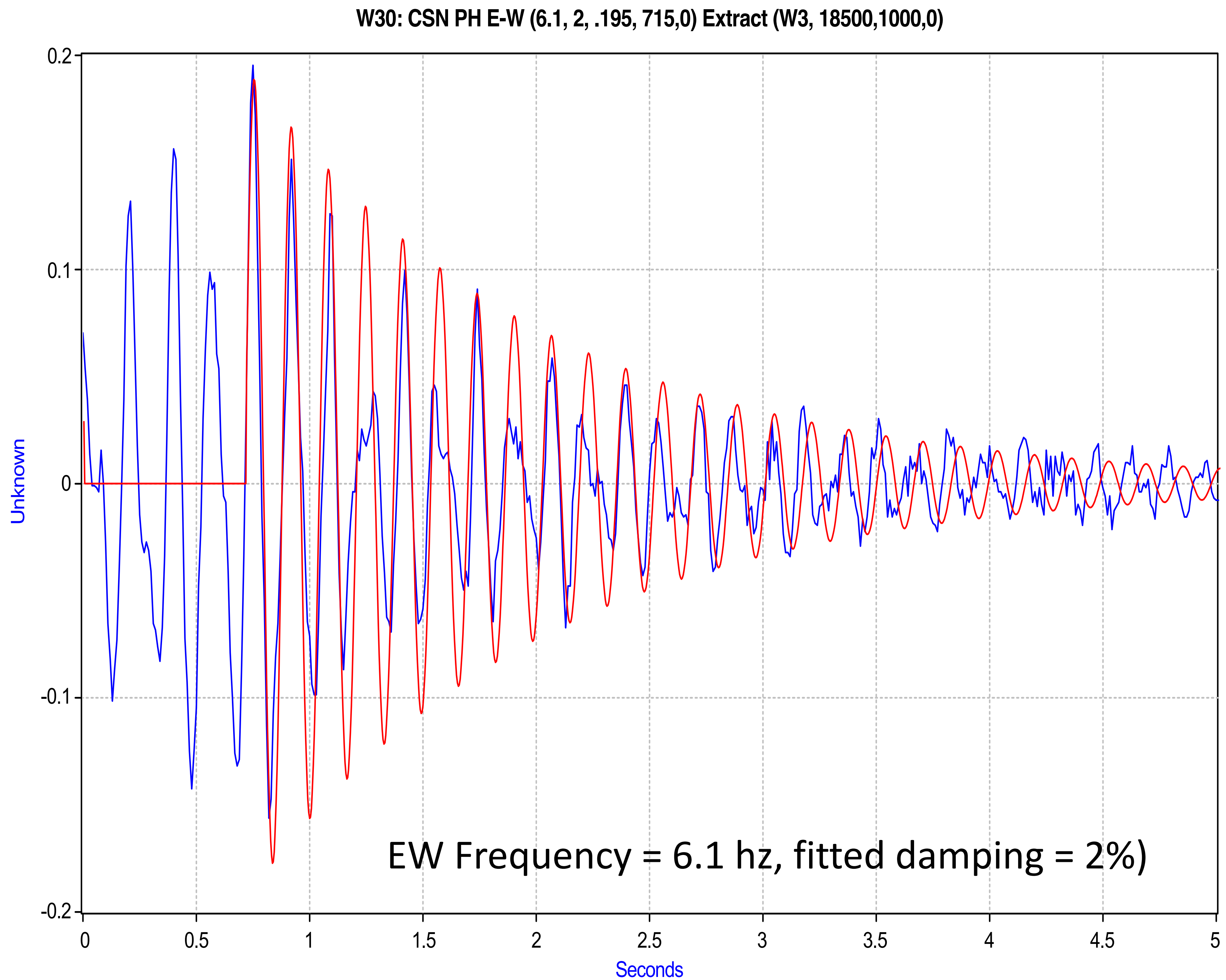
North South Man Shake

Movie

Camosun Pot Head




W29: CSN PH N-S (4,2, 2, .864, .905,0) Extract (W2,33200,1000,0)
Gs
Seconds
1
0.5
0
-0.5
-1
0
1
2
3
4
5
6
7
8
9
NS Frequency = 4.2 hz, fitted damping = 2%)



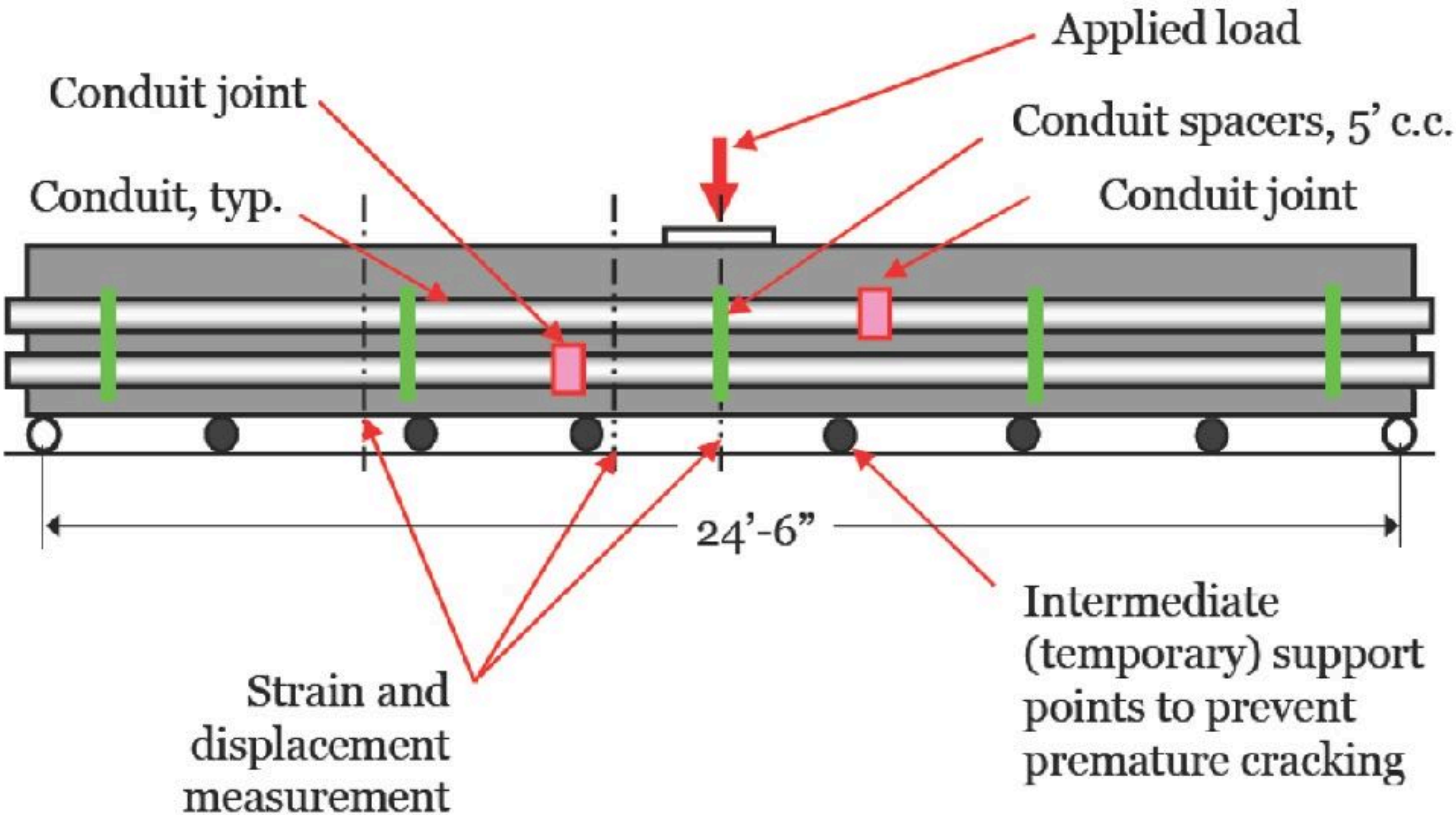
W30: CSN PH E-W (6.1, 2, .195, 715,0) Extract (W3, 18500,1000,0)
0.2
0.1
0
-0.1
-0.2
Unknown
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Seconds
EW Frequency = 6.1 hz, fitted damping = 2%)

ChCh
Feb 2011
Bromley Substation
PGA~0.5g

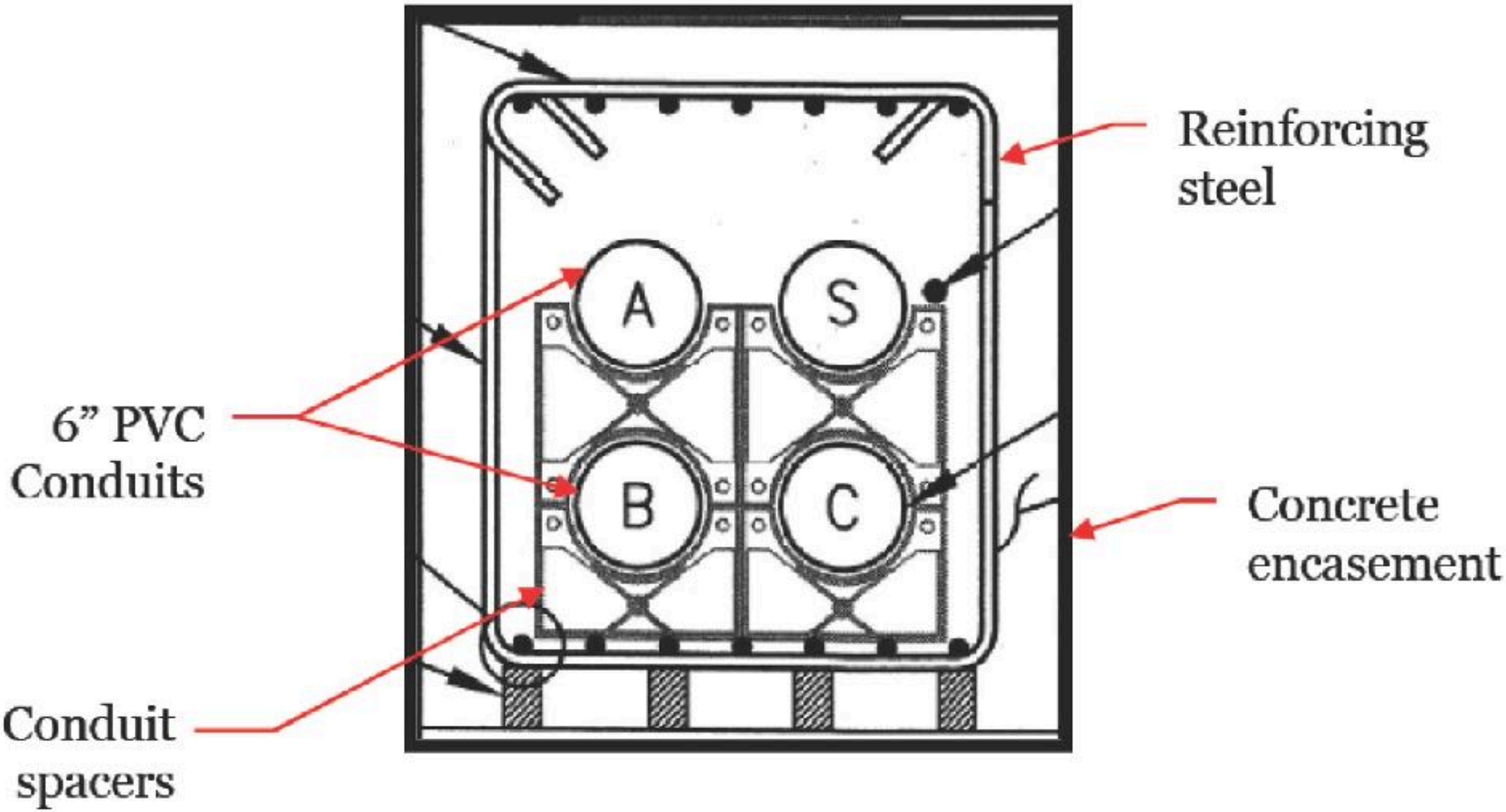
66 kV Potheads, Surge Arrestors, SF6 CB

Full Scale Tests - Berkeley
Nov-Dec 2011

Full-scale Test 31”x 34” Cross-section

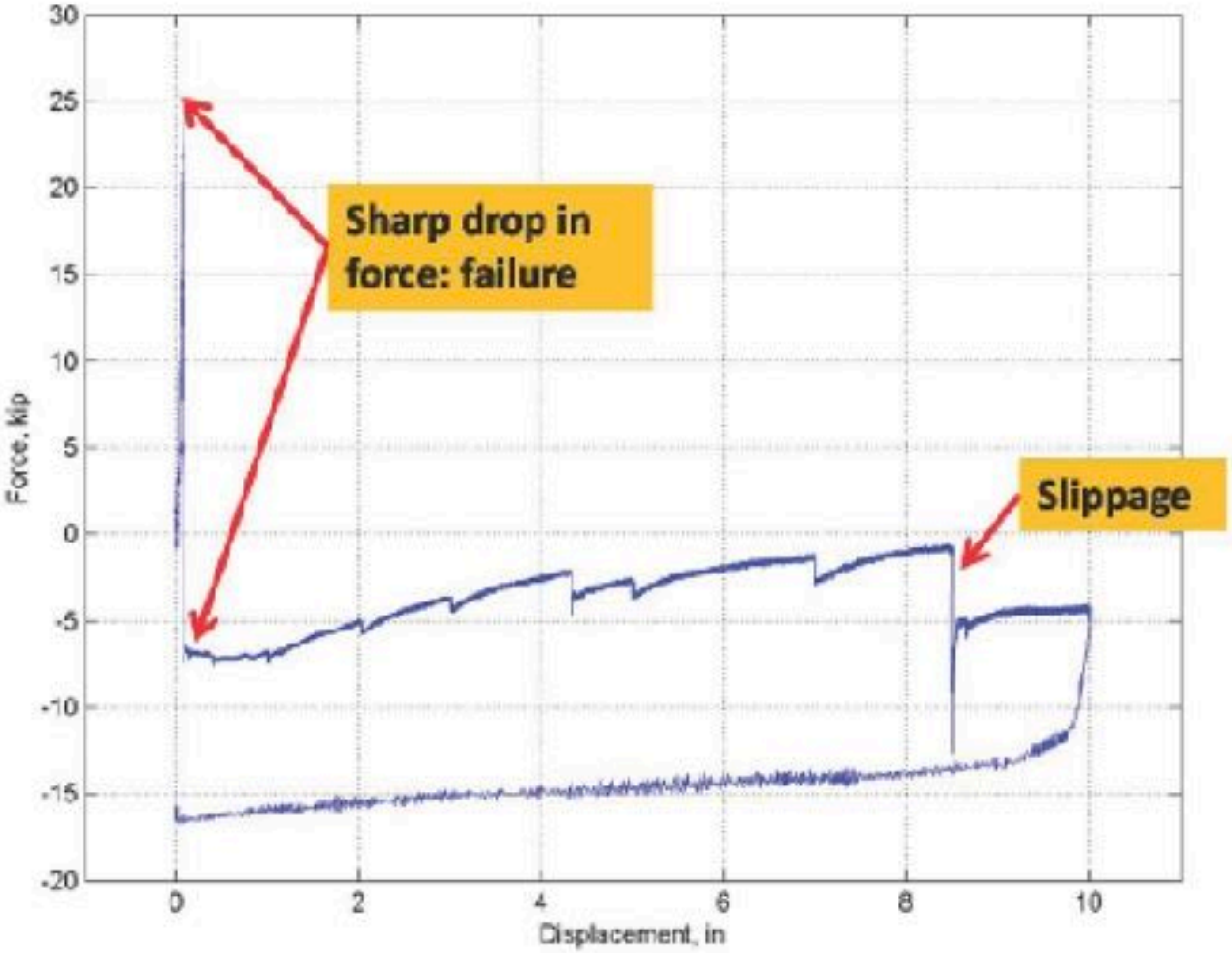


Buried Duct Bank Cross-section 31”x 34”

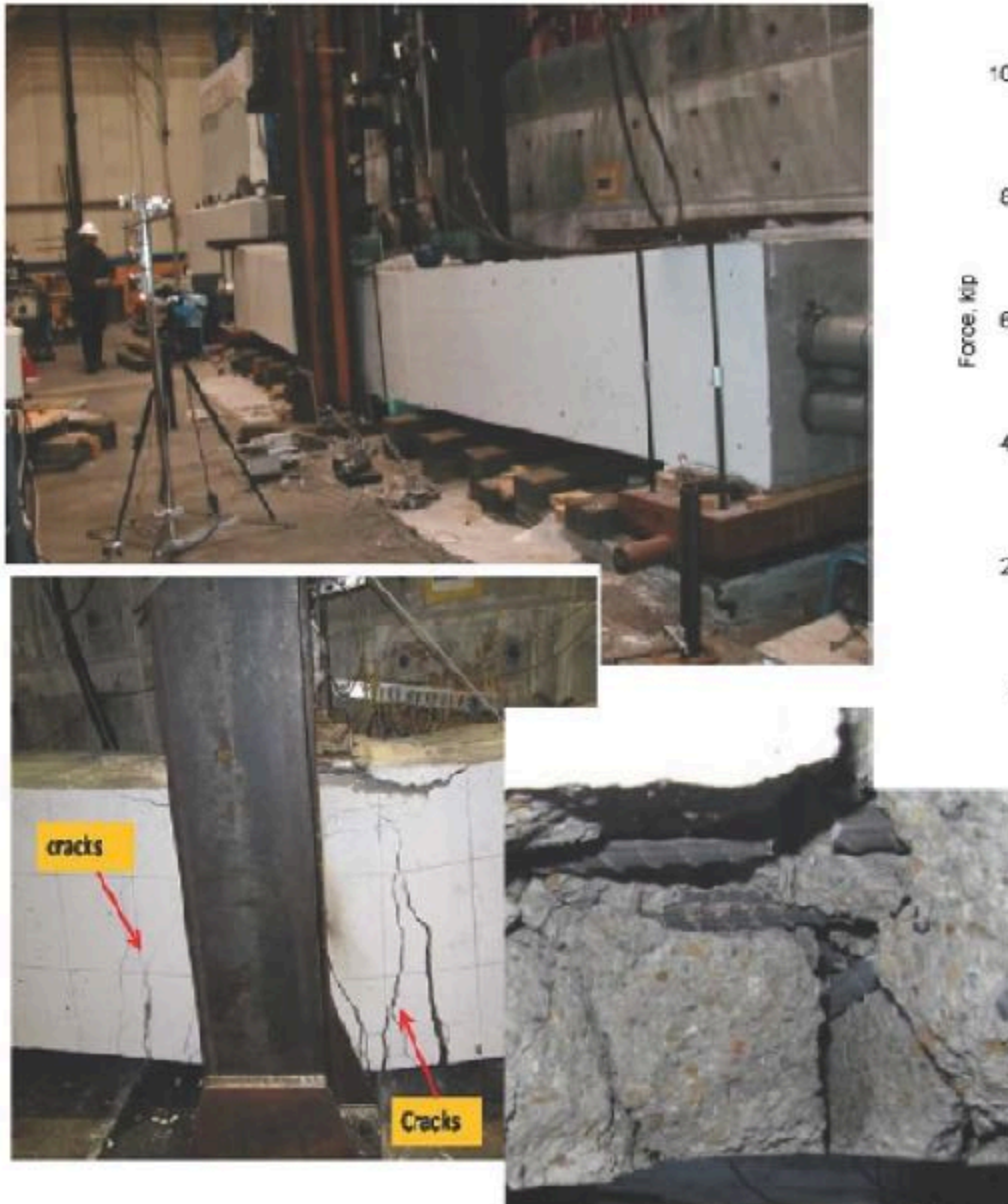


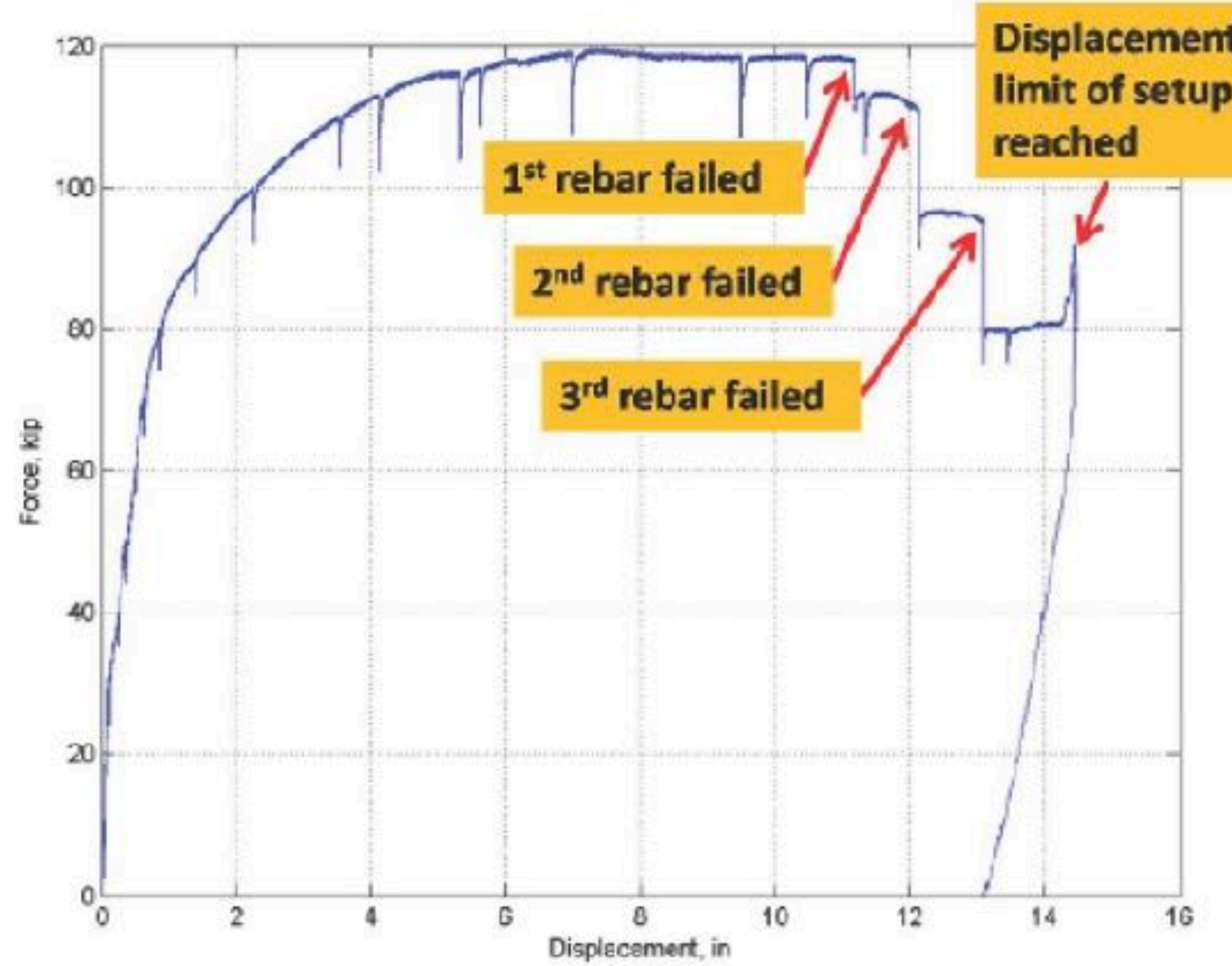
Full-scale Duct Bank - Fabrication

Unreinforced

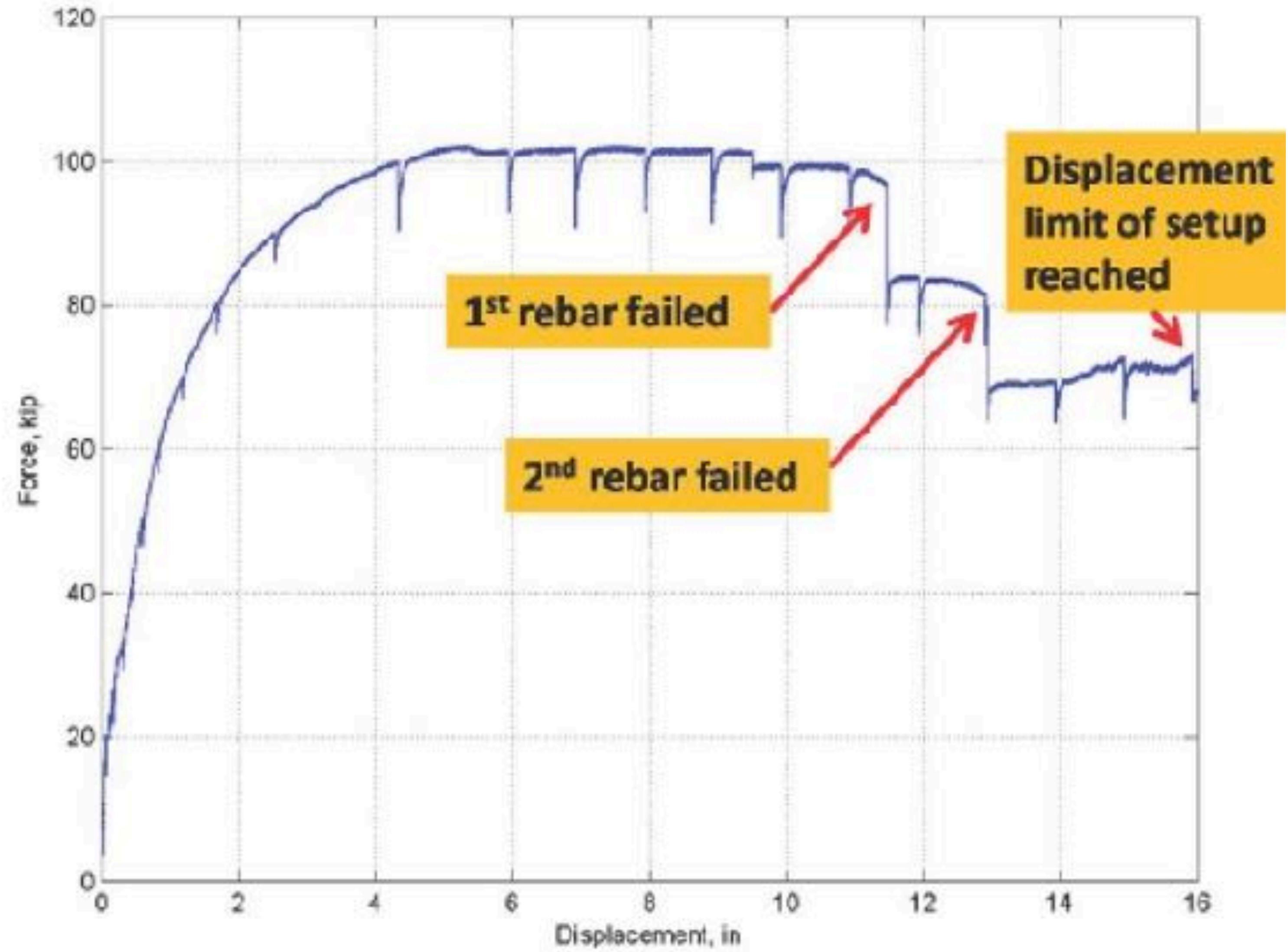


Reinforced #1





Reinforced #2

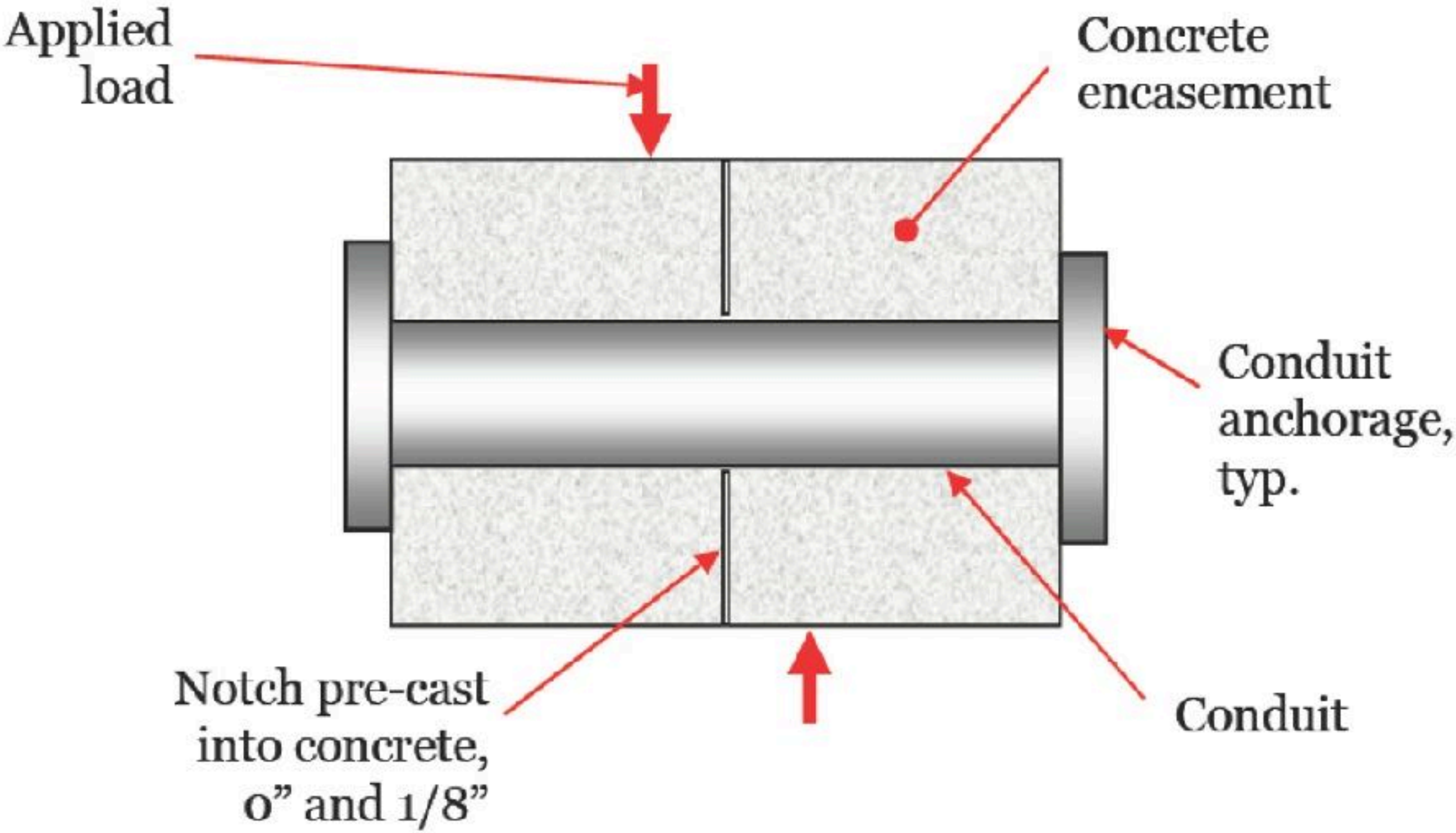


Full-scale Test Summary

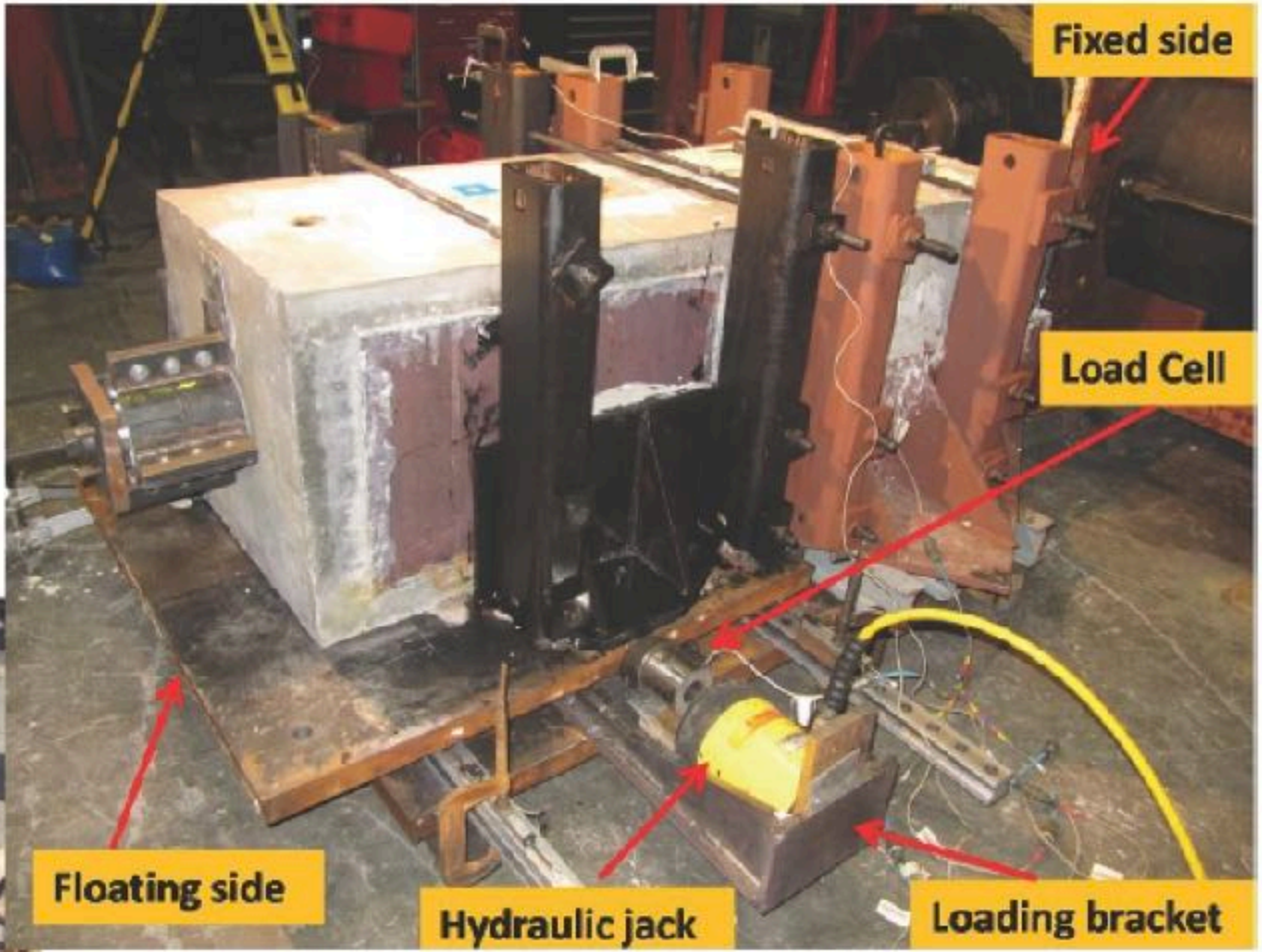
Test Description	Load (kips)	Ultimate Mid-span Displacement (inches)	Ultimate Hinge Rotation (radians)
Unreinforced	25.3	10	Negligible*
Reinforced #1 (Load about strong axis)	120	14.5	0.19
Reinforced #2 (Load about weak axis)	102	16.5	0.22

* The duct bank beam has almost no resistance to bending after initial cracking. Conduit susceptible to shear offset displacement at cracks.

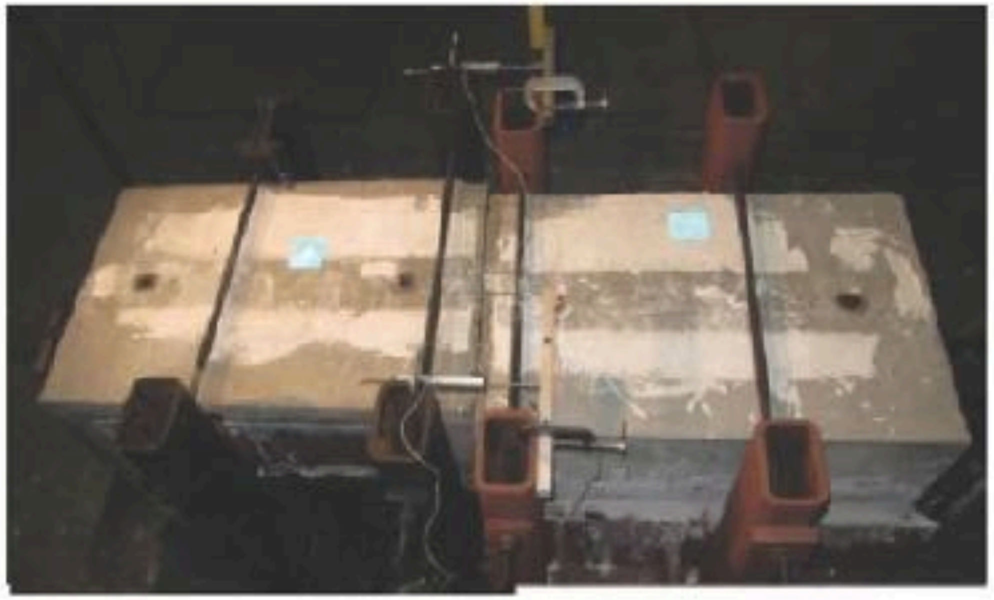
Shear Offset Test

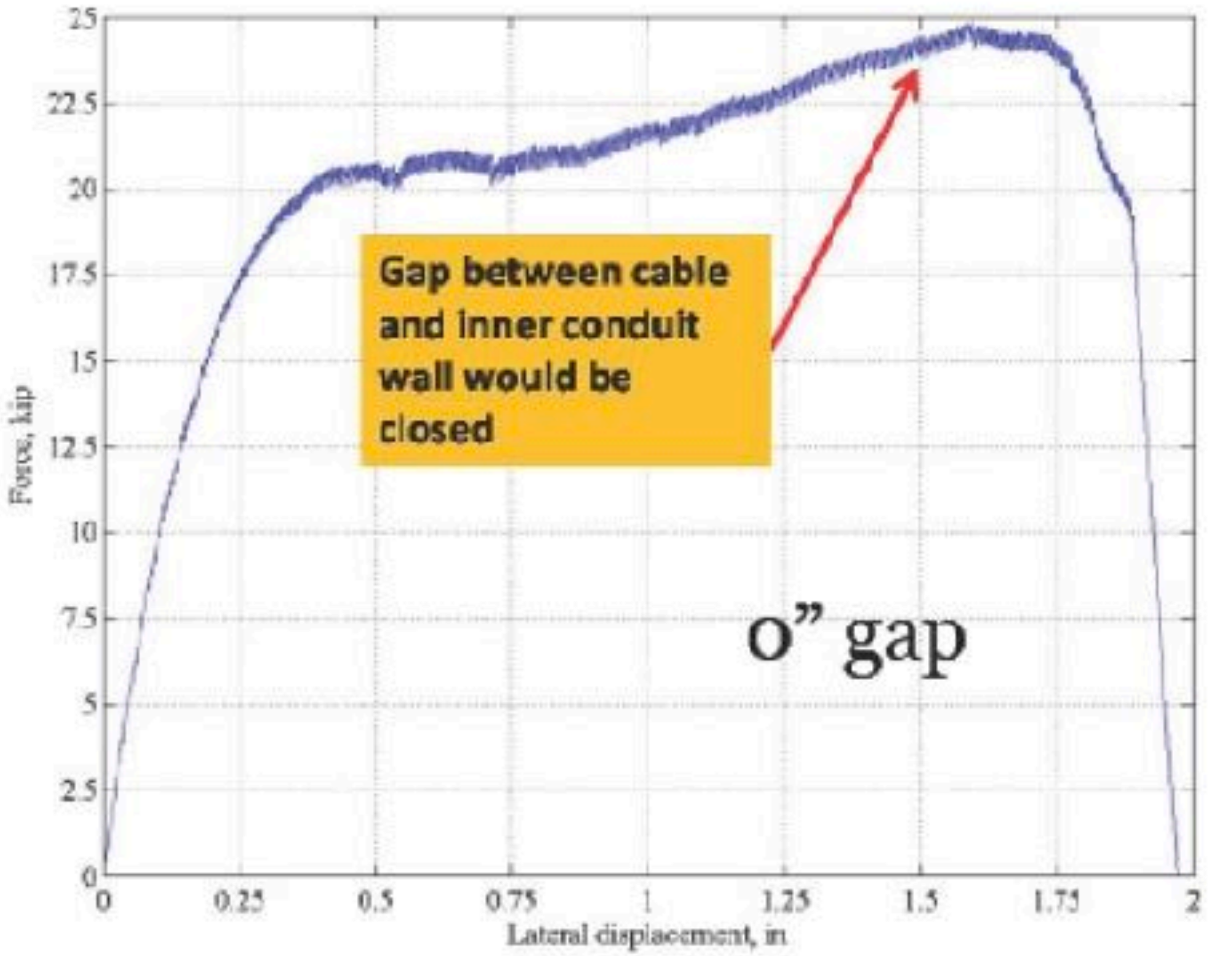


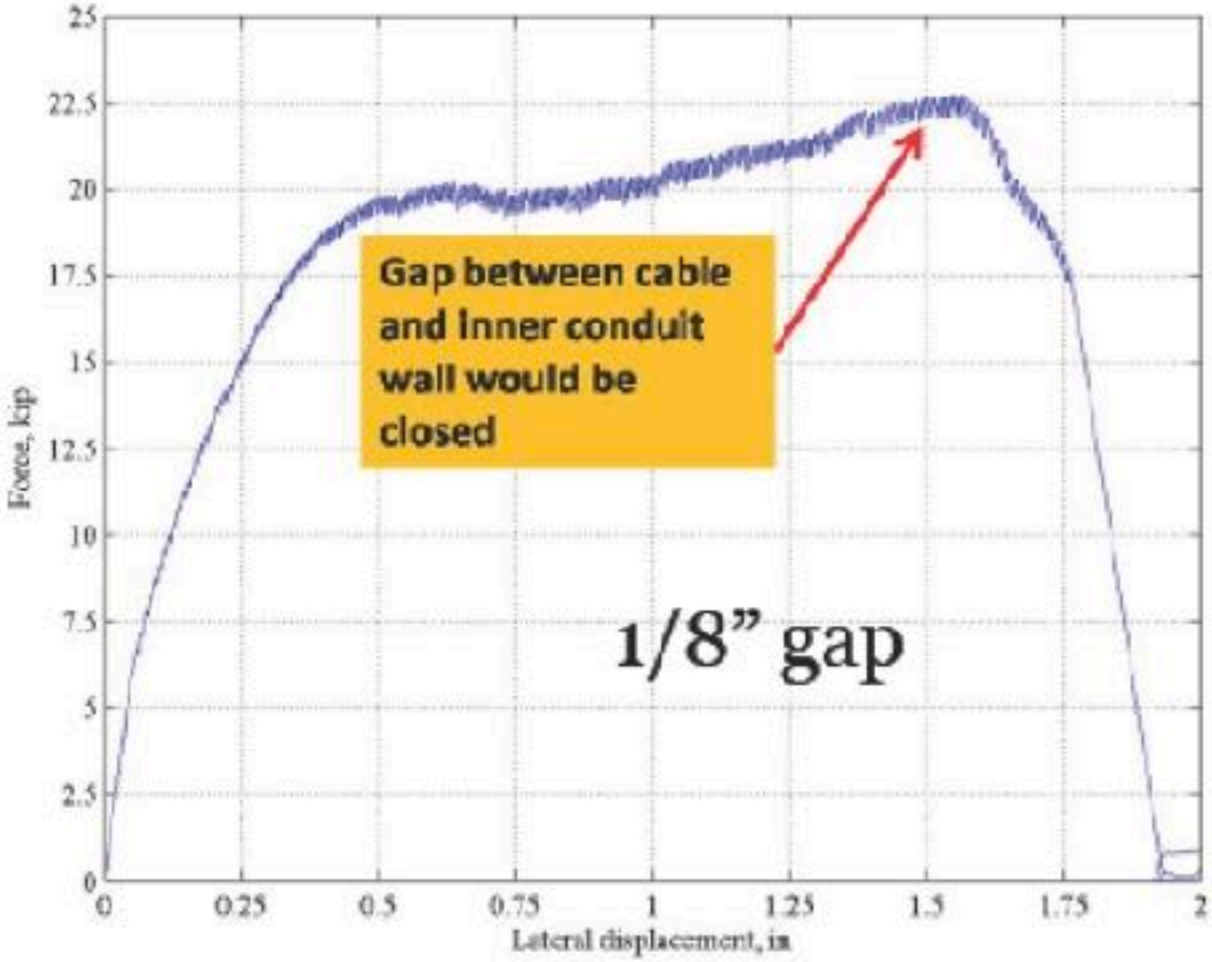
Shear Offset Test



Shear Offset Test



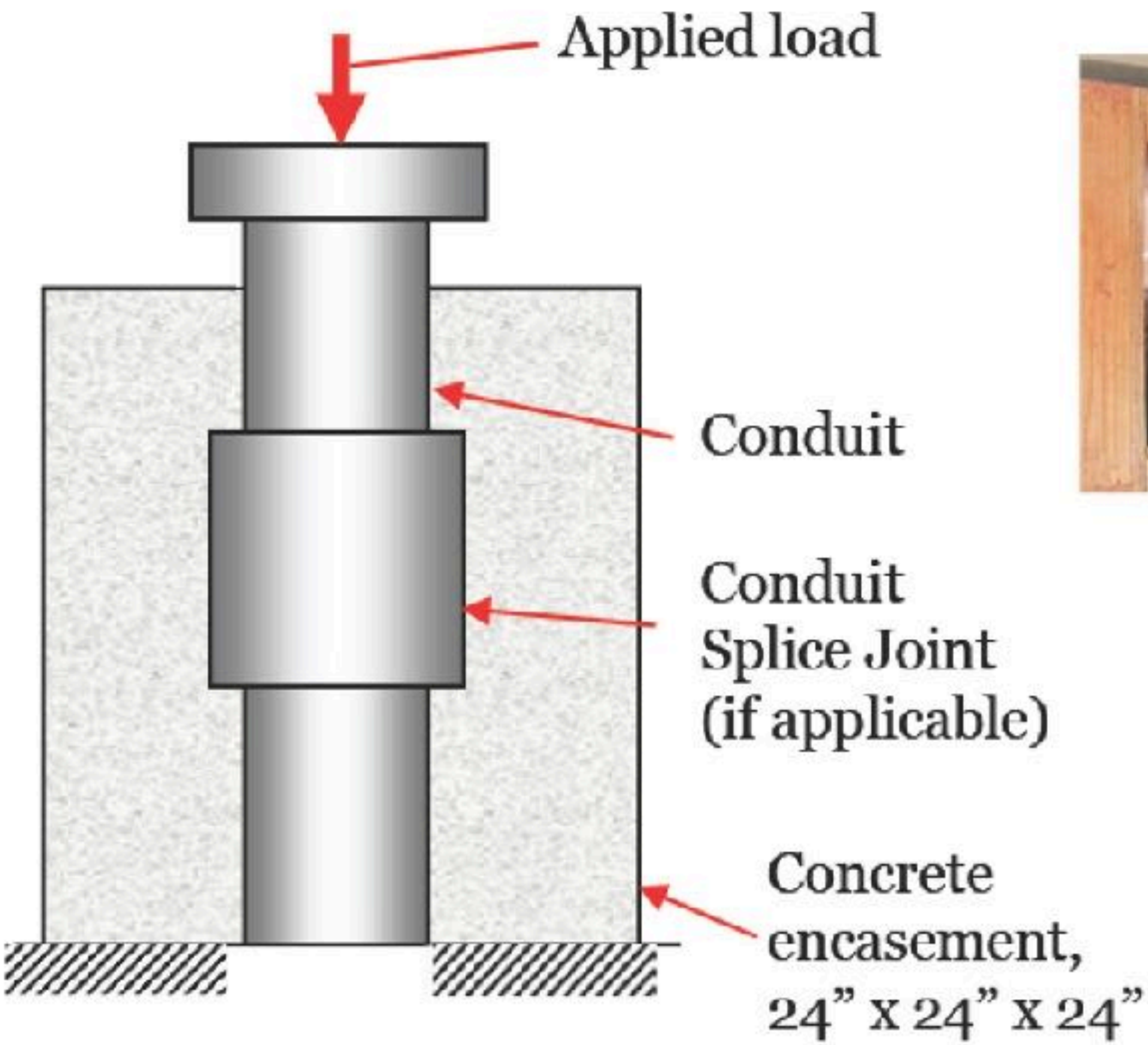




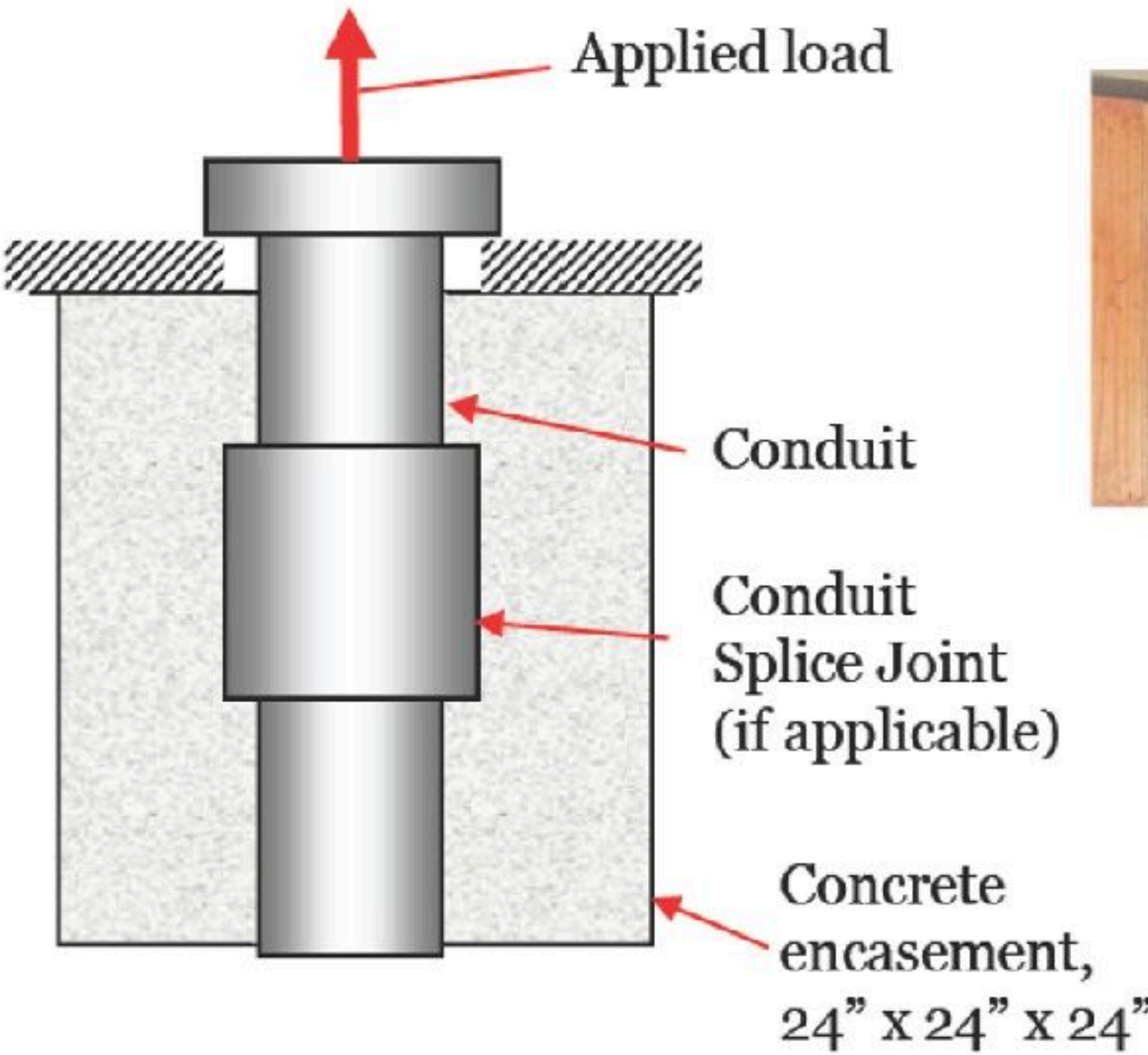
Shear Offset Test Results

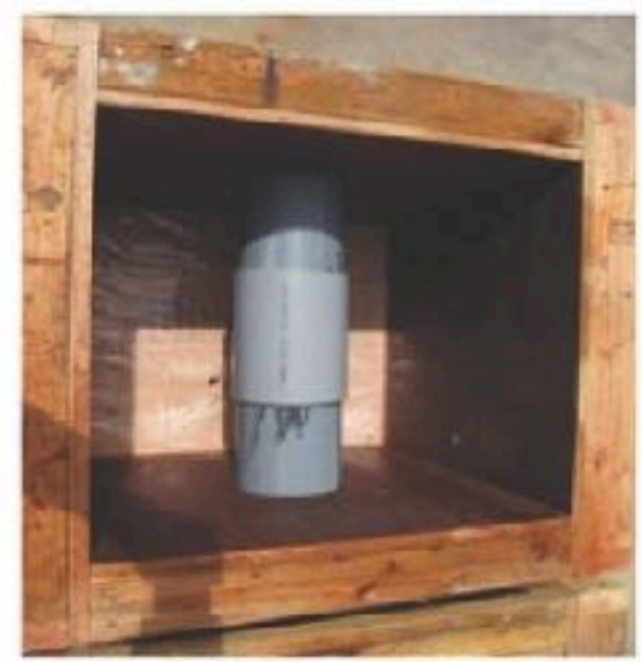
Test	Gap (inches)	Ultimate force (kips)	Displace-ment at Failure (inches)
#1	0	24.7	1.89
#2	1/8	22.6	1.76

Conduit/Concrete Bond Tests Compression)

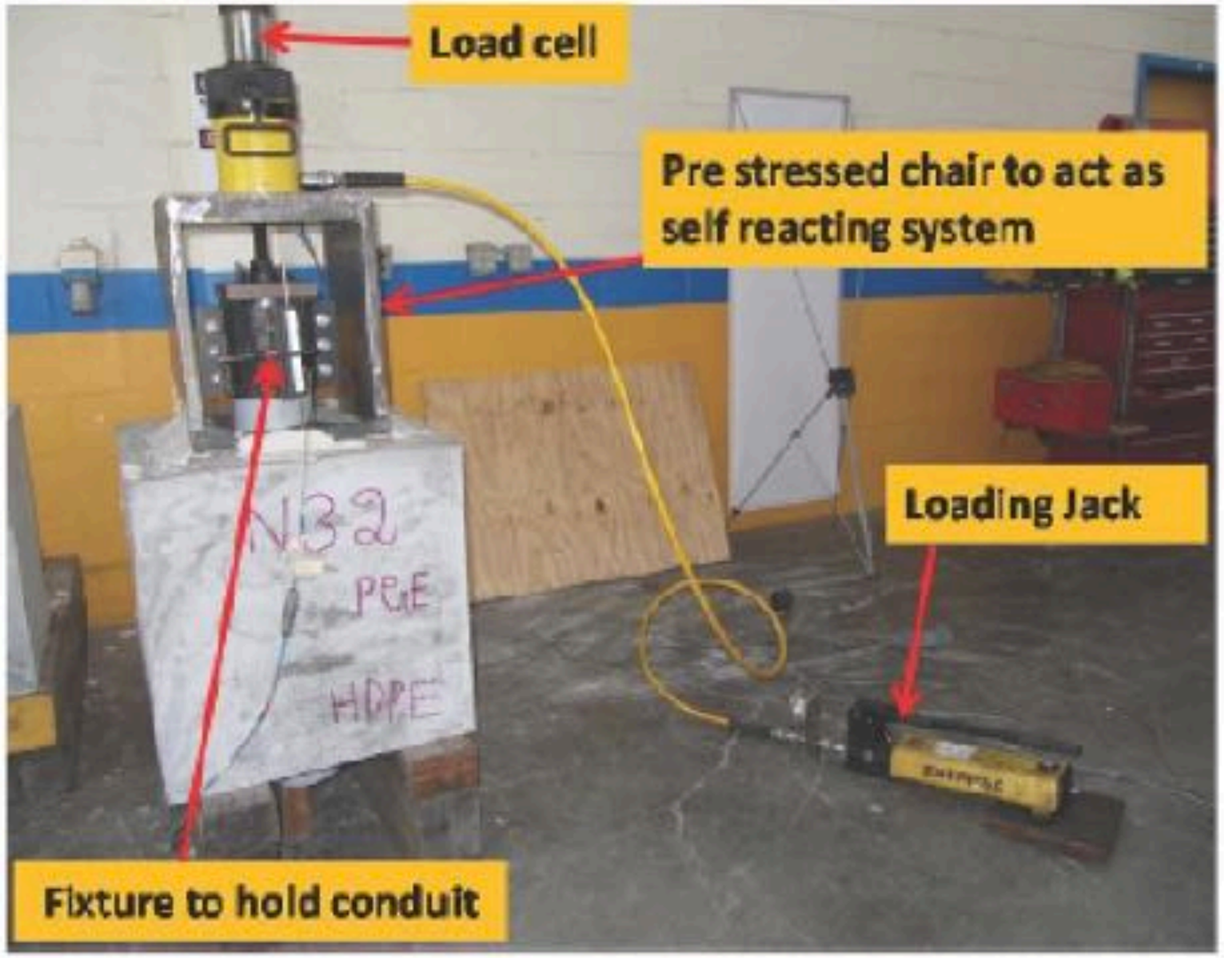


Conduit/Concrete Bond Tests (Tension)

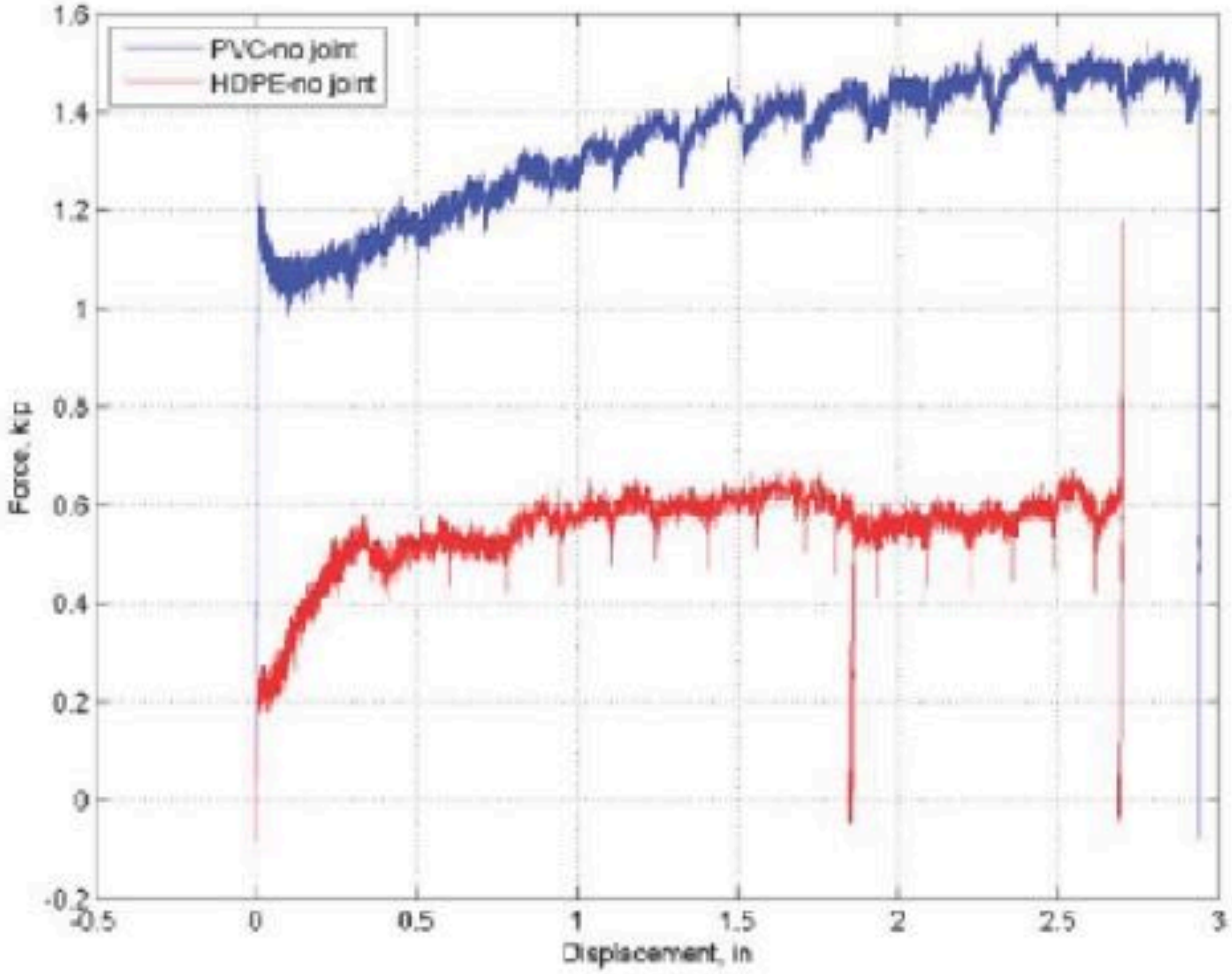




Conduit/Concrete Bond Tests (Tension with no Joint)

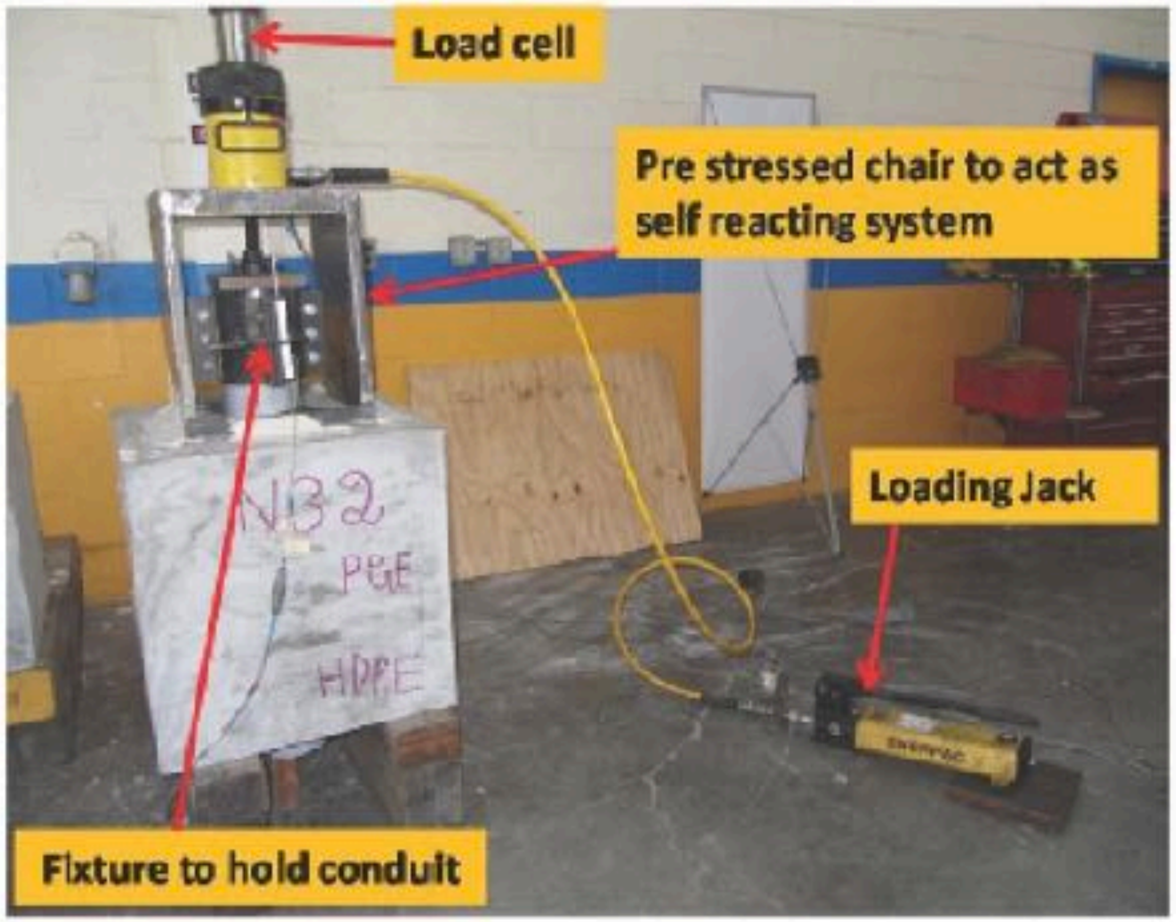


Test setup

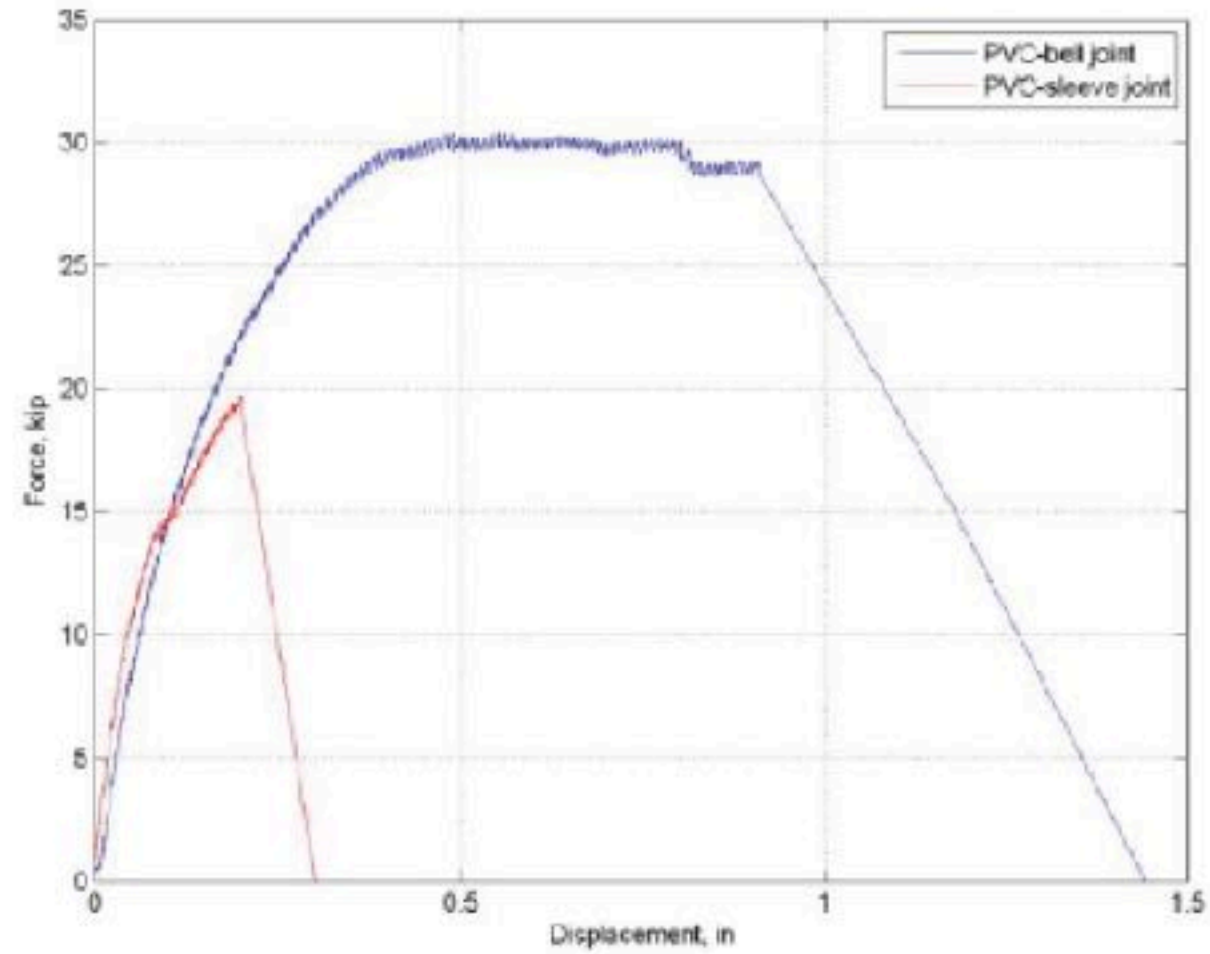


Tension tests without joint

Conduit/Concrete Bond Tests (Tension with Joint)

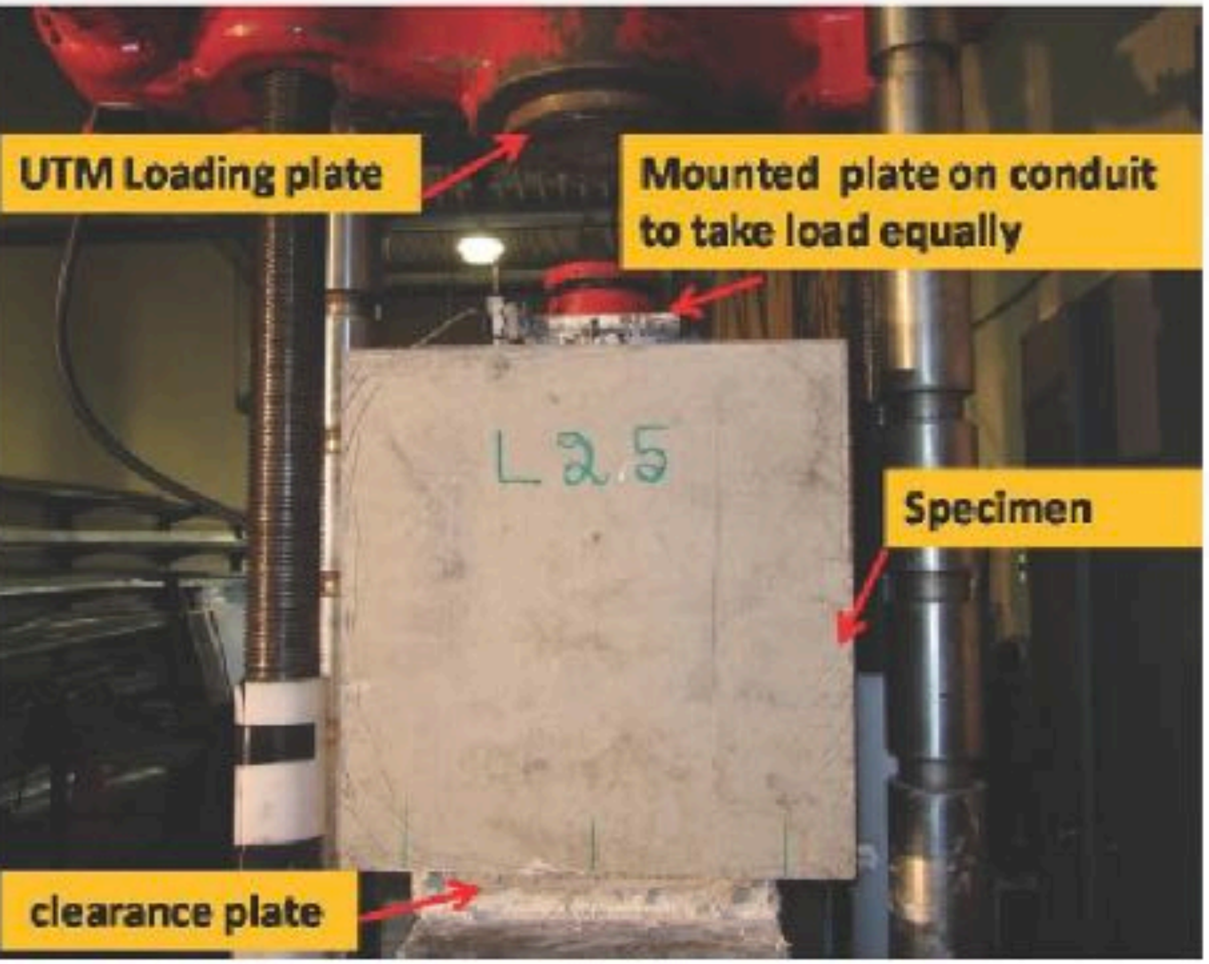


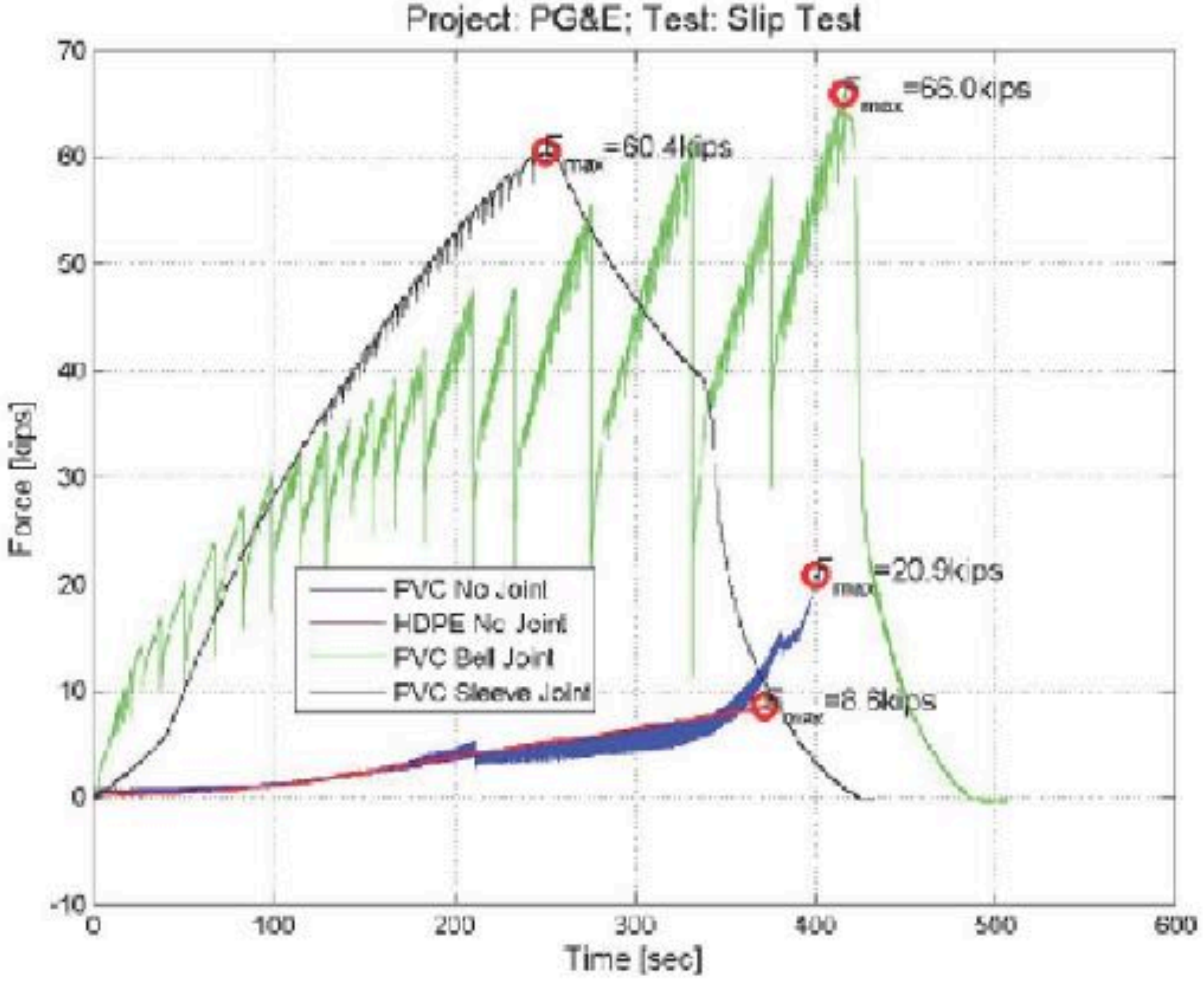
Test setup



Tension tests with joint

Conduit/Concrete Bond Tests (Compression)



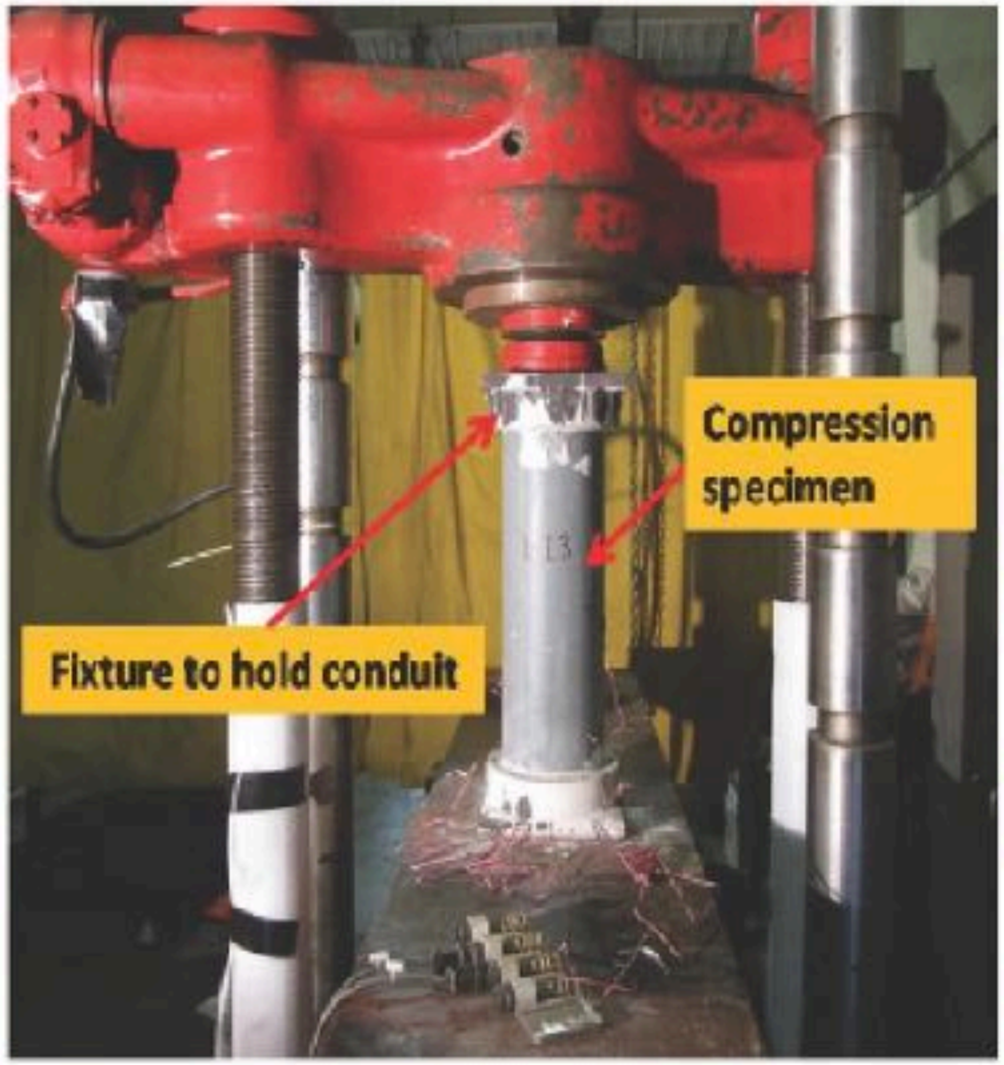


Conduit/Concrete Bond Test Results (Negative denotes compression test)

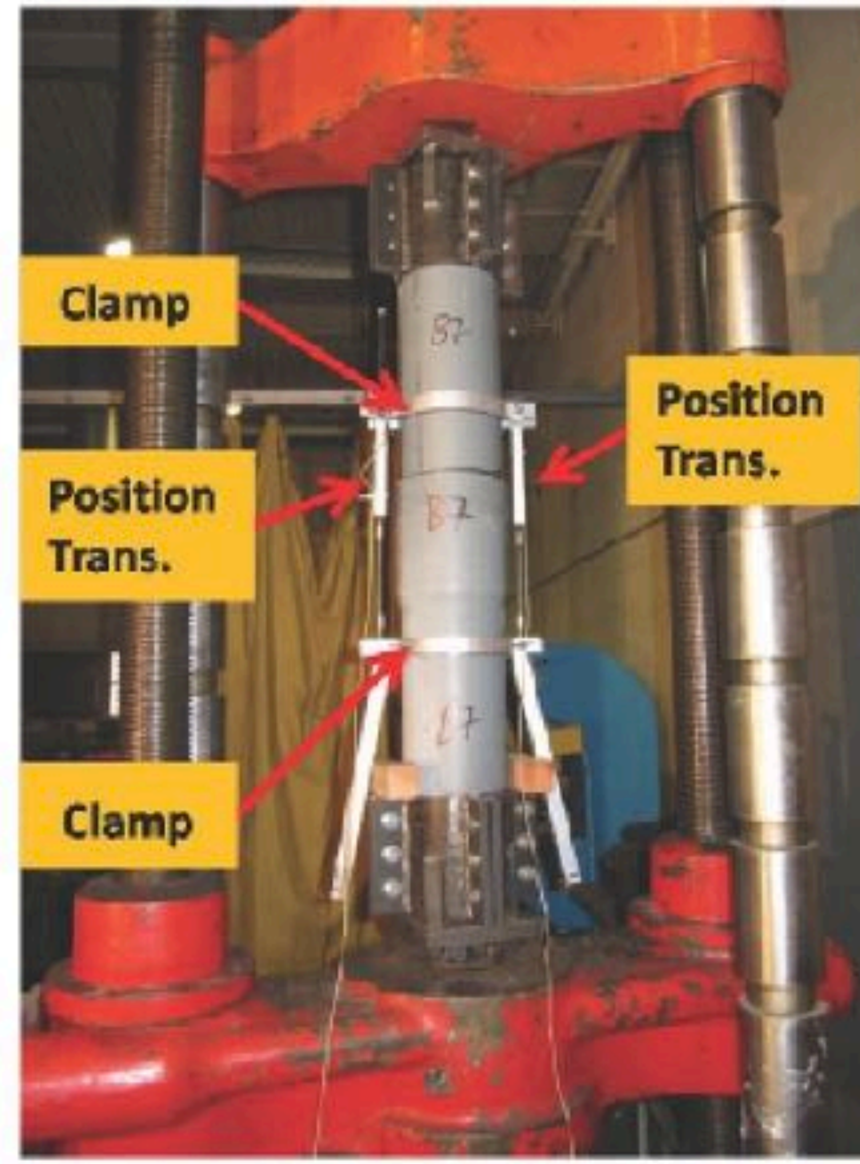
Conduit Type	Slip Force (kips)
PVC (bare)	-20.9
HDPE (bare)	-8.6
PVC with bell joint	-66.0
PVC with sleeve joint	-60.4
PVC (bare)	+1.5
HDPE (bare)	+0.7
PVC with bell joint	+30.4
PVC with sleeve joint	+19.7

Conduit Tension and Compression Tests

Specimens before



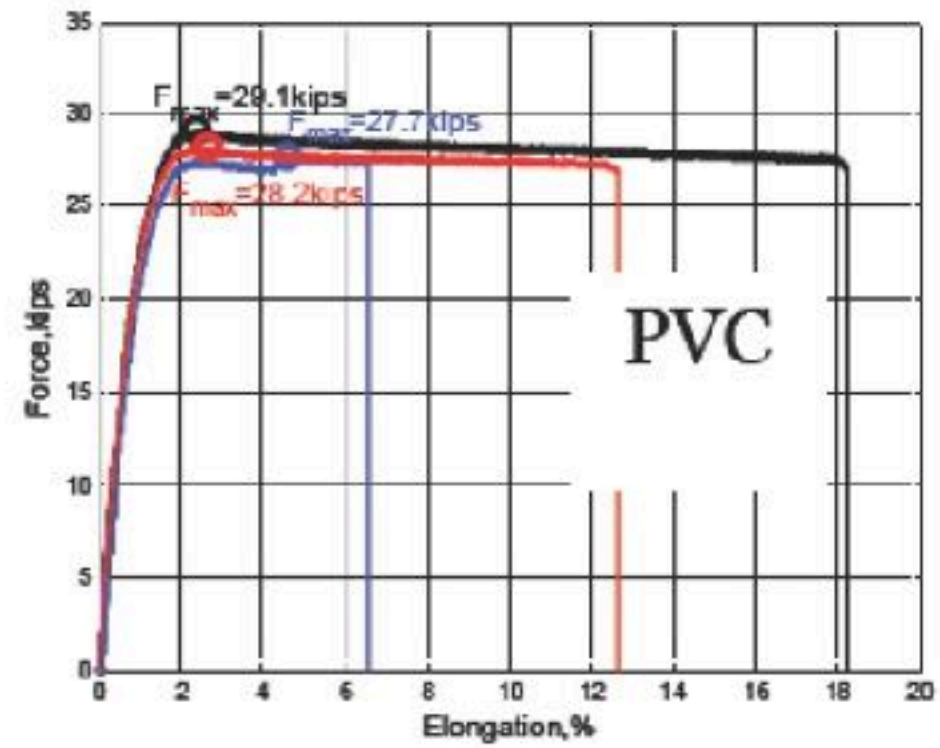
Compression test

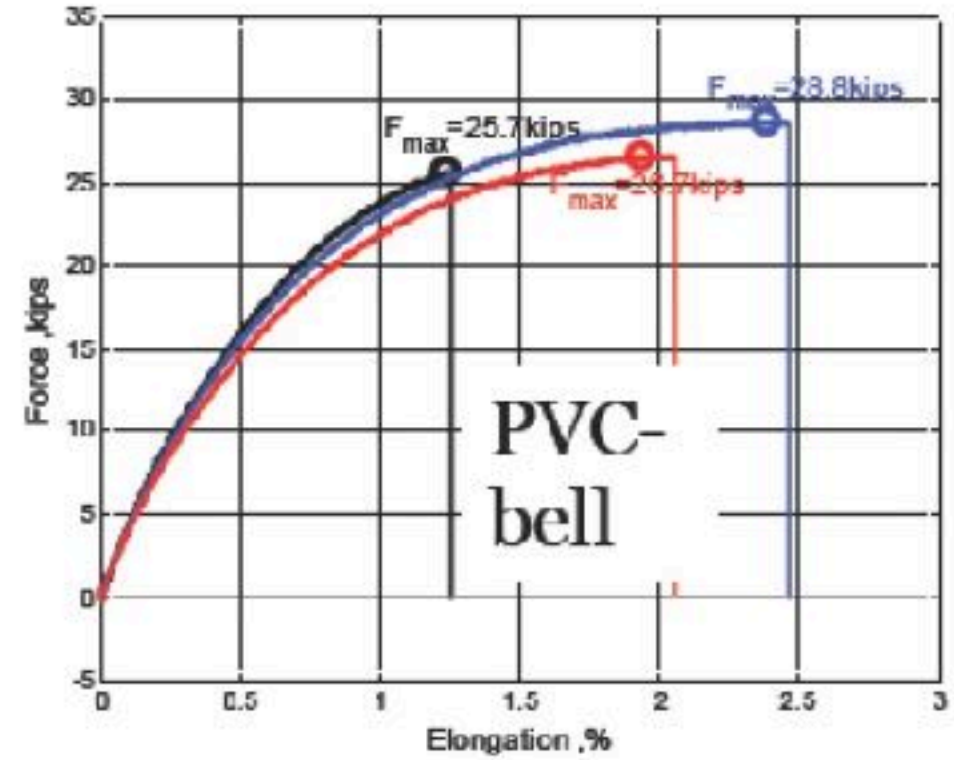


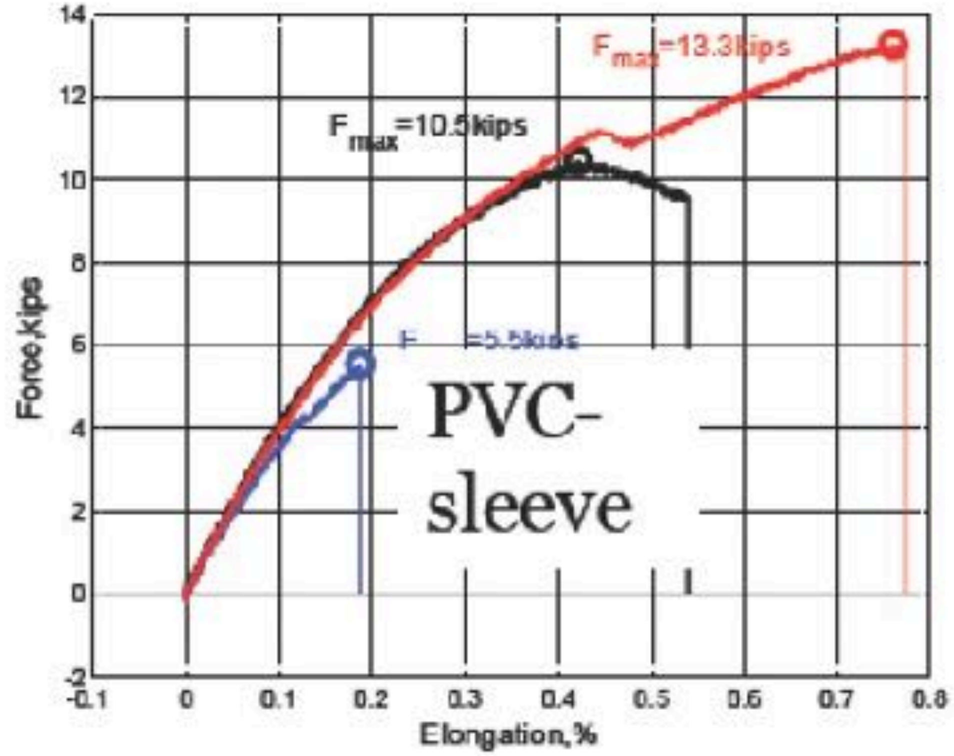
Tension test

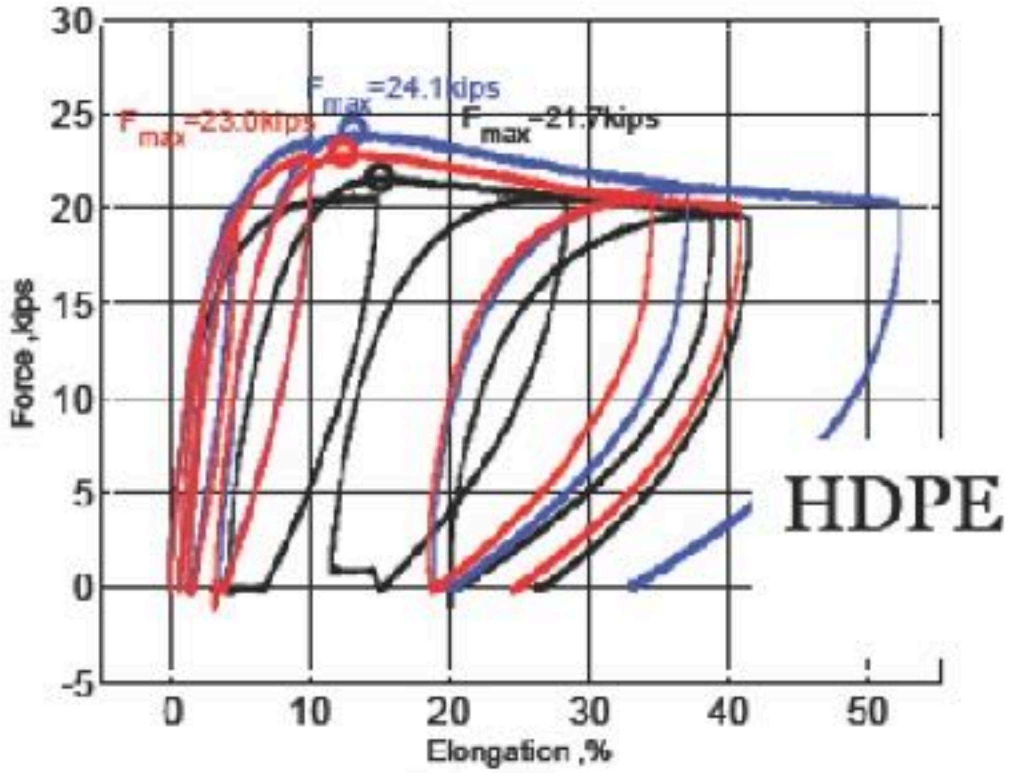
Conduit Tension Tests

Force vs. Strain



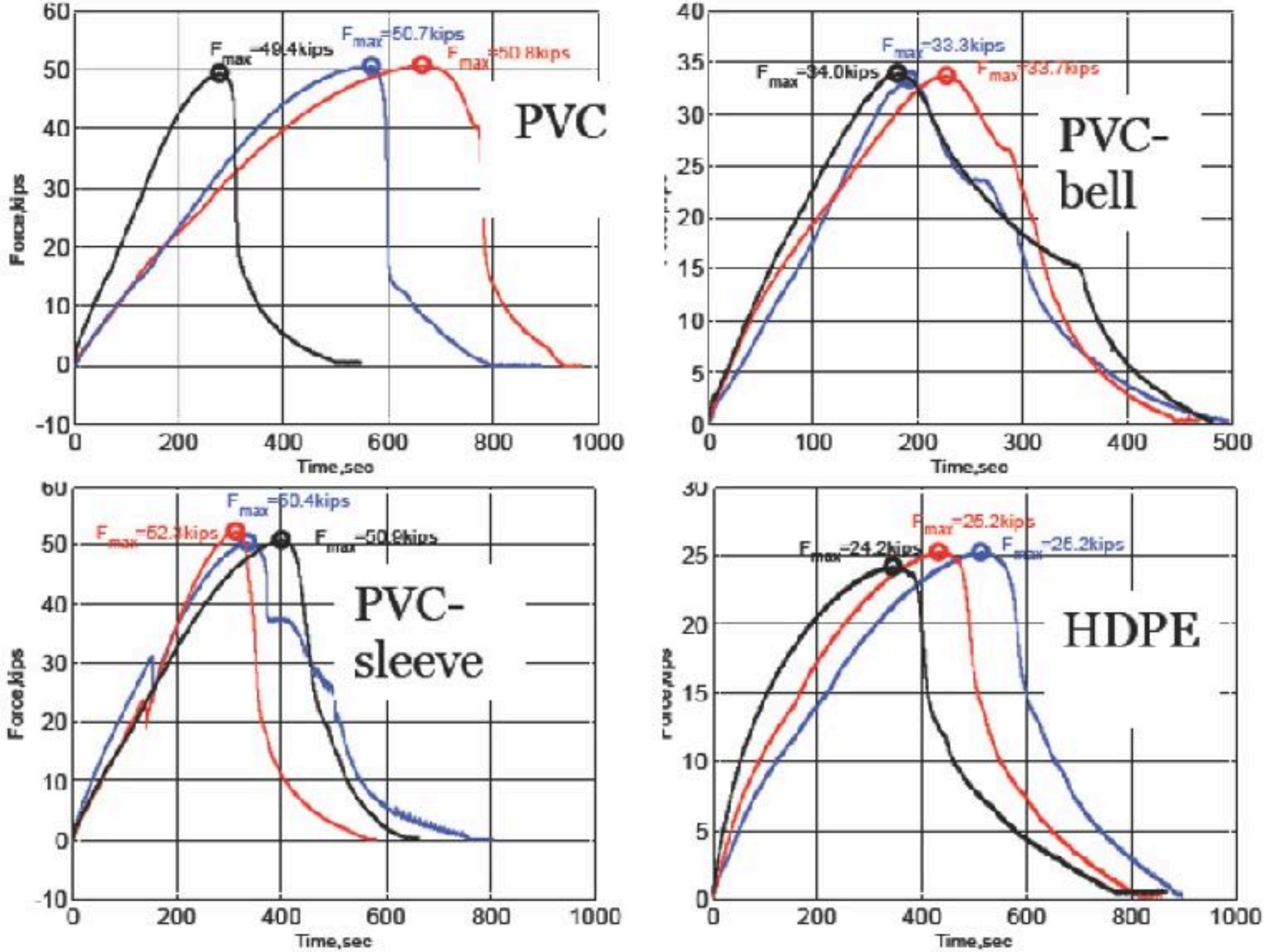






Conduit Compression Tests

Force vs. Time



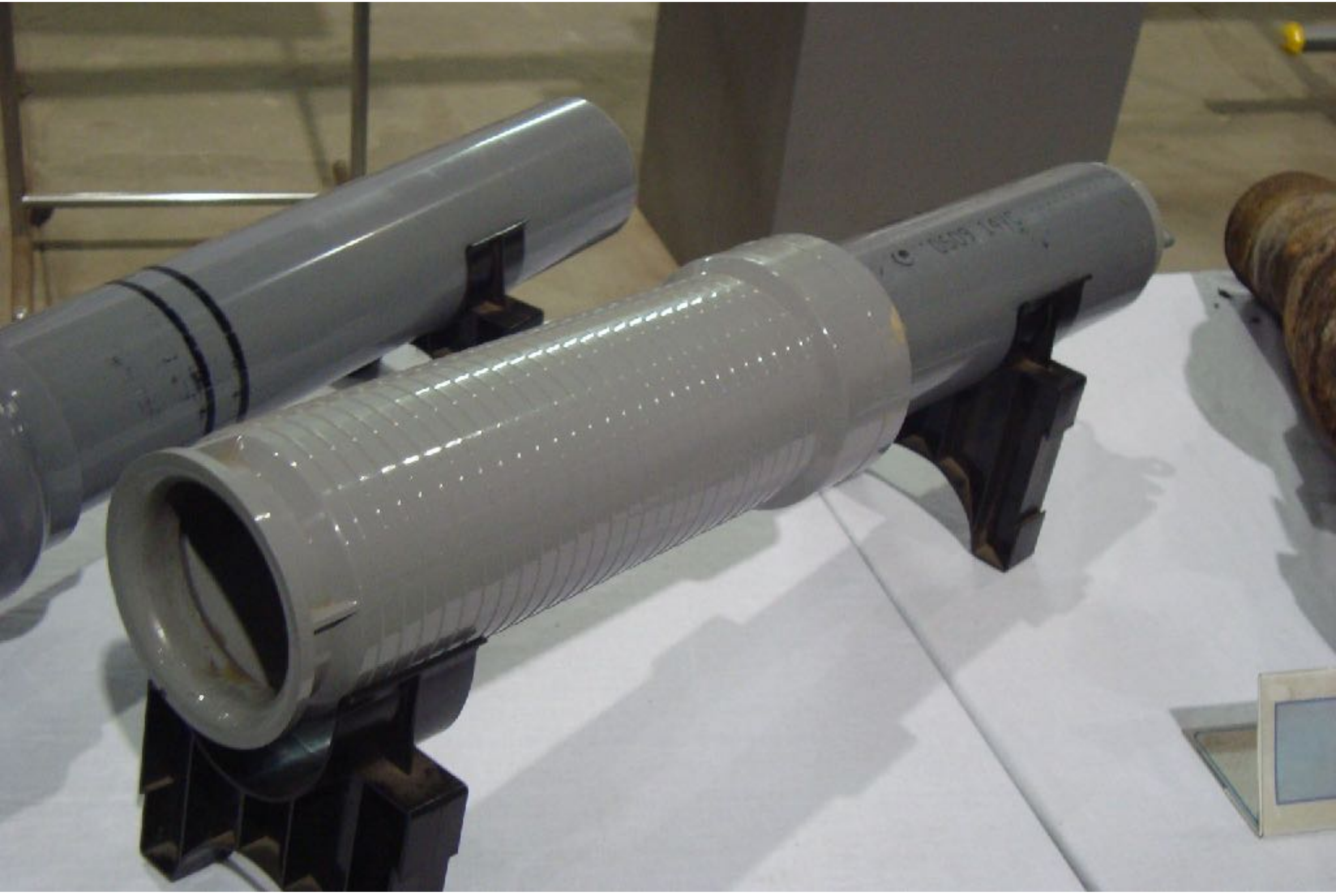
Conduit Tension and Compression

Material	Joint	Mean Comp. Cap. (kips)	Mean Tension Cap. (kips)
PVC	None	-50.3	+28.3
PVC	Bell	-33.7	+27.1
PVC	Sleeve	-51.2	+9.8
HDPE	None	-24.9	+22.9

NTT Telecommunication Research Lab, Tsukuba

- NTT does not bury their cables without a conduit
- Telecom cables bundles and power cable bundles are in separate conduits
- Moisture and telecom cables cannot co-exist particularly optical fiber cables

∞PVC-U NTT 75P-Vカン (Sナシ) 06-06
∞PVC-U NTT
∞PVC-U NTT 75P-Vカン



Summary

Buried Cables

- Direct Burial: Highly Vulnerable to PGDs of 3 inches or higher
- In Empty PVC Conduits: OK for PGDs < 6 inches if slack available. Still vulnerable for High PGDs
- Duct Banks: Non-reinforced: Vulnerable. Reinforced: Very tough
- Pull Vaults: Detailing is critical

PotHeads

- Standoffs (porcelain and composites) are vulnerable. Age can degrade(?)
- Porcelain: Yet to fail one
- Composite: Yet to fail one

Where do we Go?

- The Industry needs a Seismic Design Guide
- Cable Manufacturers: Need to provide P, M, EI, EA, Strain to failure (axial, compression, bending)
- A/E: Need to include seismic as a load case in areas with poor soil / PGDs. Then design ducts, conduits, vaults accordingly

Who Should do this?

- Cigre
- IEEE 693
- PG&E and BC Hydro
- Similar issues for Communication cables, so applies to AT&T, Verizon, T Mobile, Sprint et al