Anchorage M 7.1 Earthquake
Nov 30 2018, 8:29 am
(TCLEE 5B)

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October 15 2019

Other TCLEE Reports

- Napa California 2014 (TCLEE 1 150 pp)
- Kyushu Japan 2016 (TCLEE 2 300 pp)
- Mexico City / Chiapas 2017 (TCLEE 3 100 pp)
- Hokkaido Japan 2018 (TCLEE 4 300 pp)
- Anchorage Alaska 2018 (TCLEE 5A 19 pp)
- Ridgecrest California 2019 (TCLEE 6)

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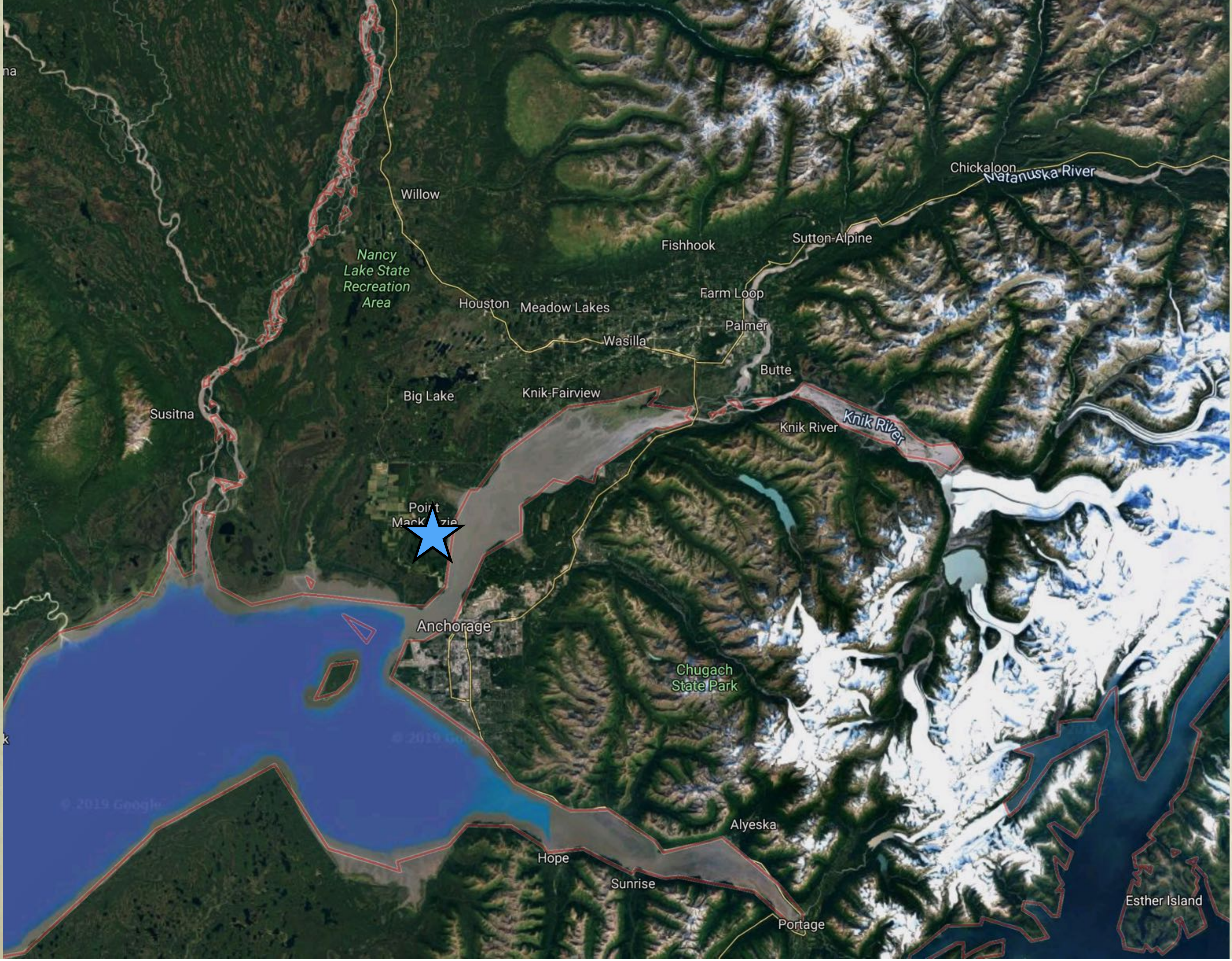

Willow
Nancy Lake State Recreation Area
Houston
Meadow Lakes
Fishhook
Sutton-Alpine
Chickaloon
Matanuska River
Farm Loop
Palmer
Wasilla
Butte
Big Lake
Knik-Fairview
Susitna
Knik River
Knik River
Anchorage
Chugach State Park
Alyeska
Hope
Sunrise
Portage
Esther Island

Quick Overview

- 3 Electric Utilities (MEA, ML&P, CEA)
- ~ 375,000 people with PGA > 0.1 g
- >23 million Customer - Minutes of outages (might be higher)
- Many failures of 230 kV, 138 kV, 115 kV substation equipment and distribution feeders

Questions

- Question 1. "Weak Seismic Design is Okay" or "Brilliant Cost Effective Seismic Design" ?
- Question 2. Is the greater Anchorage electric system ready for the next M ~9 event (like 1964)?


Susitna River
Willow
Nancy Lake State Recreation Area
Houston
Meadow Lakes
Wasilla
Fishhook
Farm Loop
Palmer
Butte
Chickaloon
Matanuska River
Sutton-Alpine
Big Lake
Knik-Fairview
Eklutna
Knik River
Knik River
Susitna
Epicenter of M 7.1 Earthquake
Knik Arm
Eagle River
Pt MacKenzie
Beluga
Anchorage
Chugach State Park
Turnagain Arm
Alyeska
Hope
Sunrise
Portage

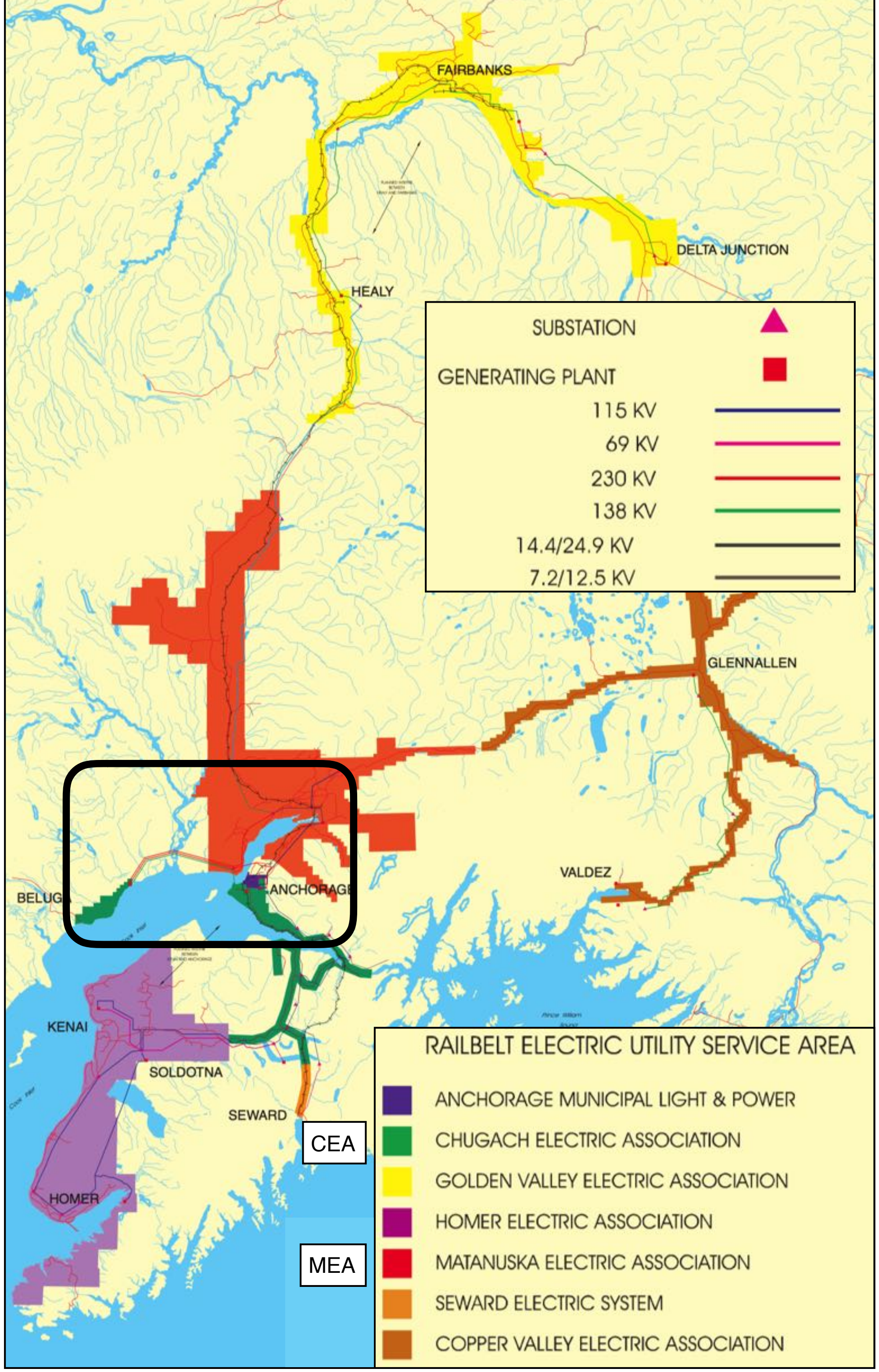
ML&P. Serves Downtown Anchorage

MEA. Serves northern suburban / rural areas

CEA. Serves southern suburban / rural areas

Geographic Area of Interest in this M 7.1 Earthquake

Population in the box
~375,000 (2018)
~125,000 (1964)



Anchorage Municipal Light & Power (ML&P)
Matanuska Electric Assocation (MEA)
Chugach Electric Assocation (CEA)
Seward Electrical System (SES)
Golden Valley Electric Assocation (GVEA)

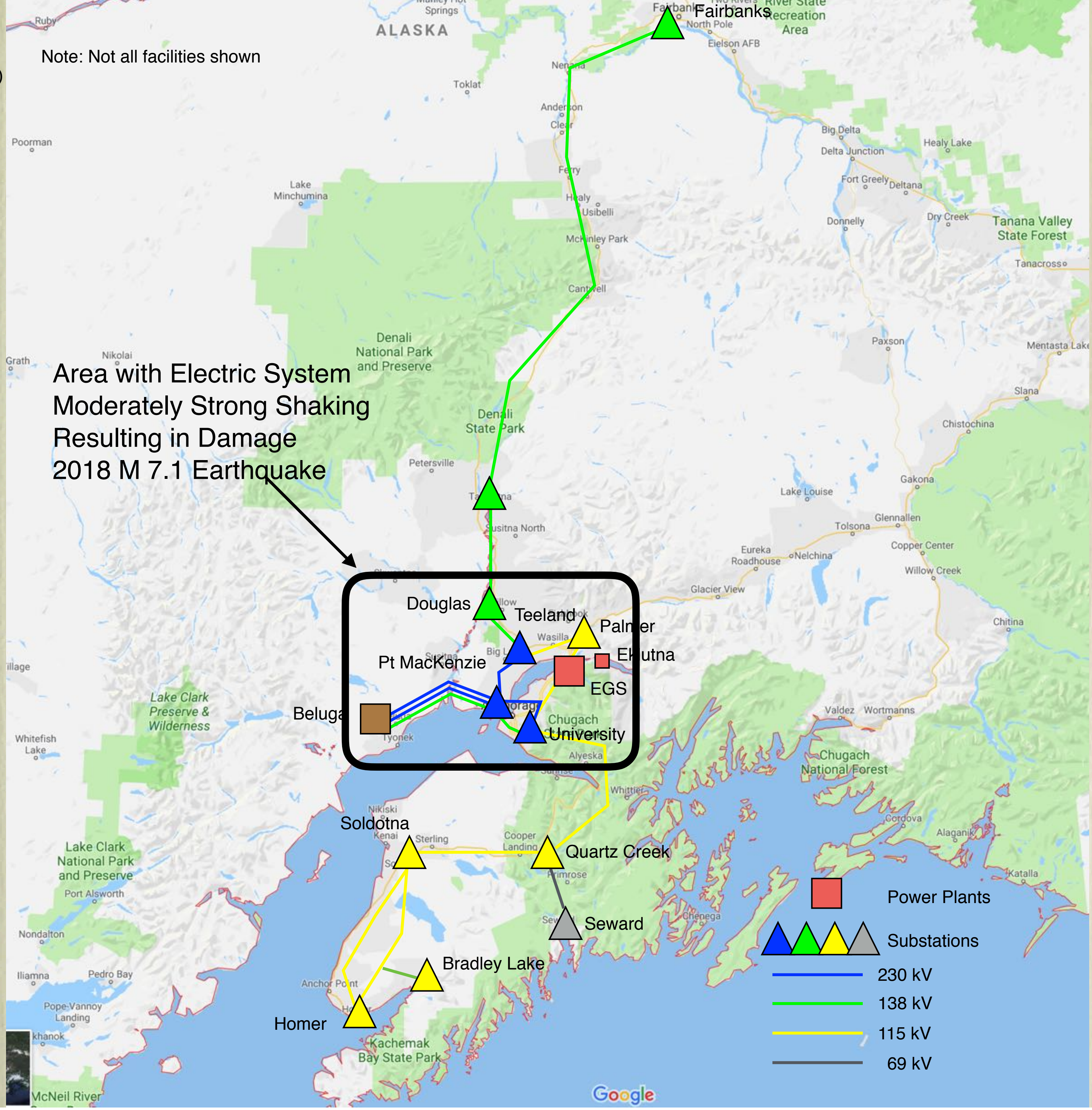
1964. Same utilities, but much smaller load and only the 115 kV grid existed

2018. New 138 kV and 230 kV transmission, much larger load, several new gas-fired power plants

2018. Little to no evidence of seismic design at substations.

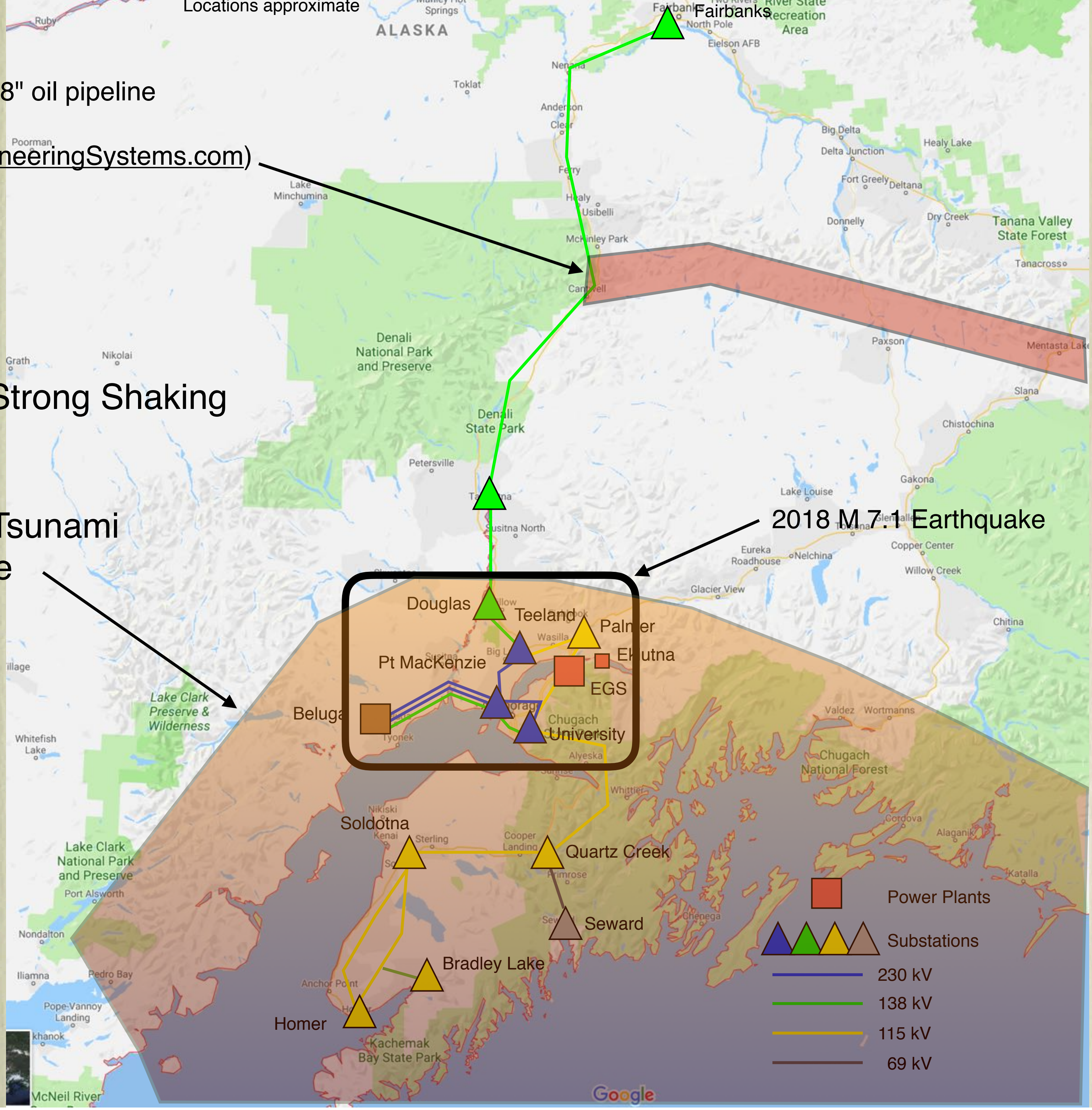
Weak bus design - widespread at nearly every substation.

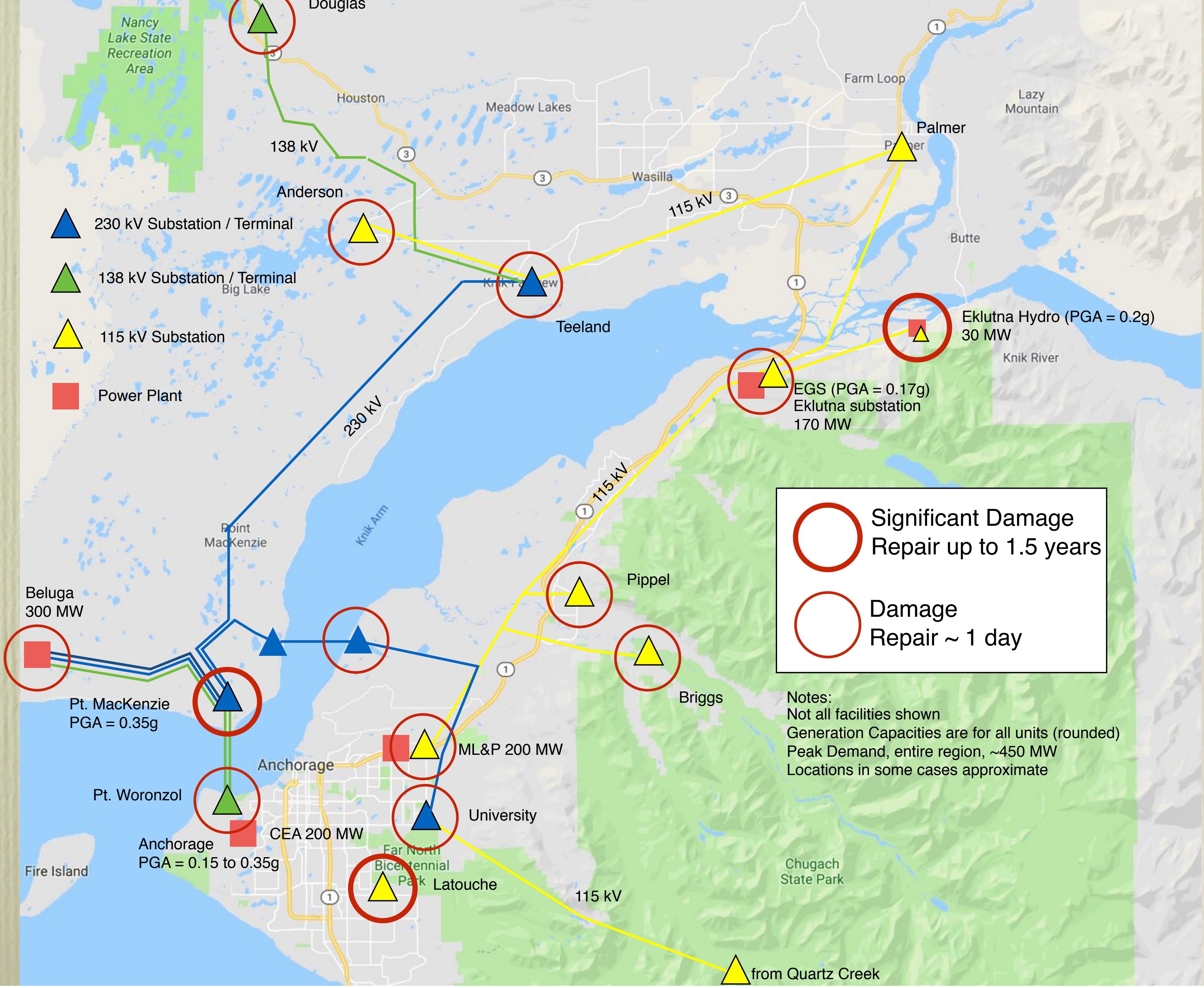
No IEEE 693 Seismic tags that I could see on recently installed (post 2005) 230 kV equipment



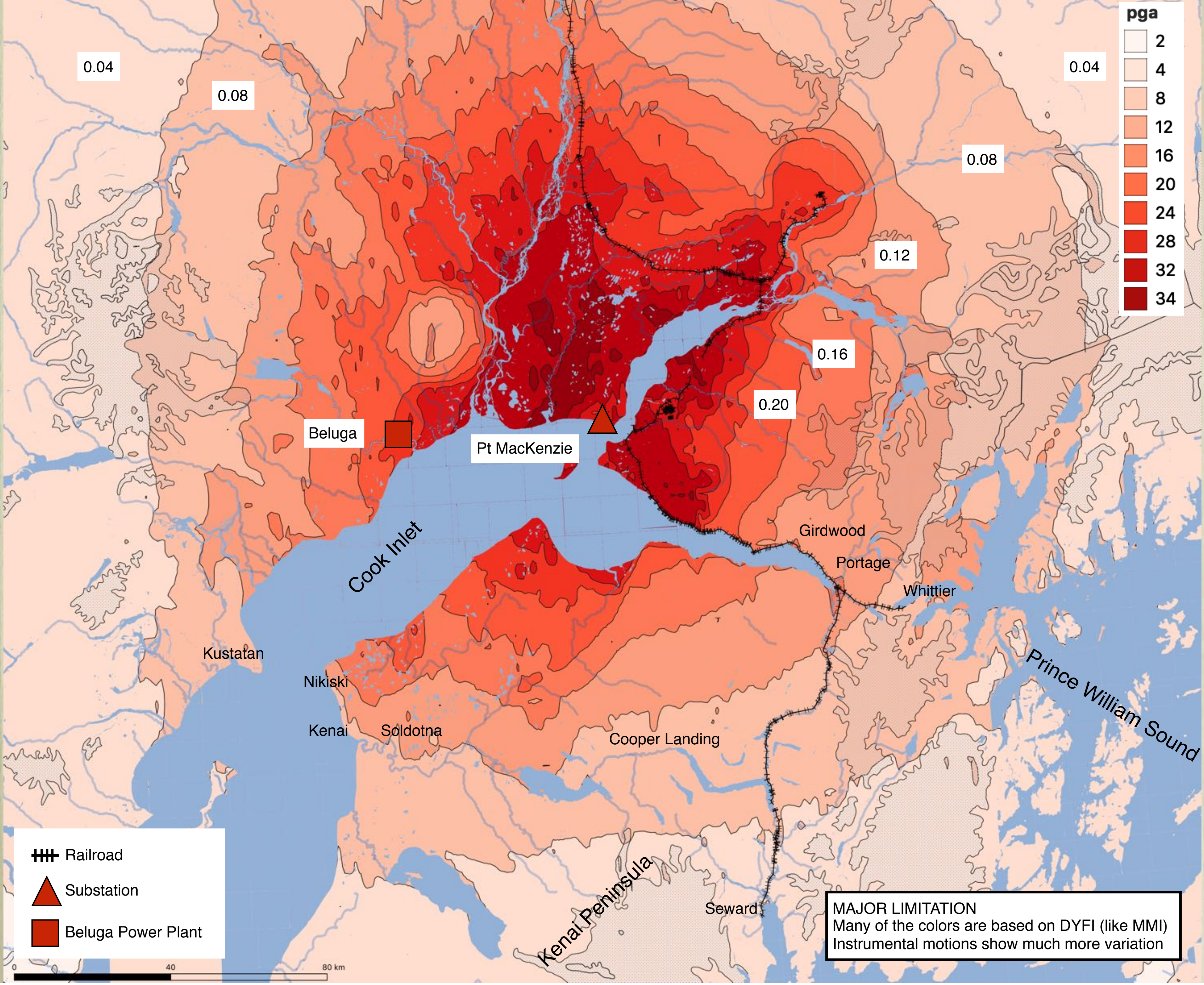
Area with ~No Electric System,
High Shaking
14 feet right lateral offset at the 48" oil pipeline
2002 Denali M 7.9 Earthquake
(Denali_M7.9.pdf at www.geEngineeringSystems.com)

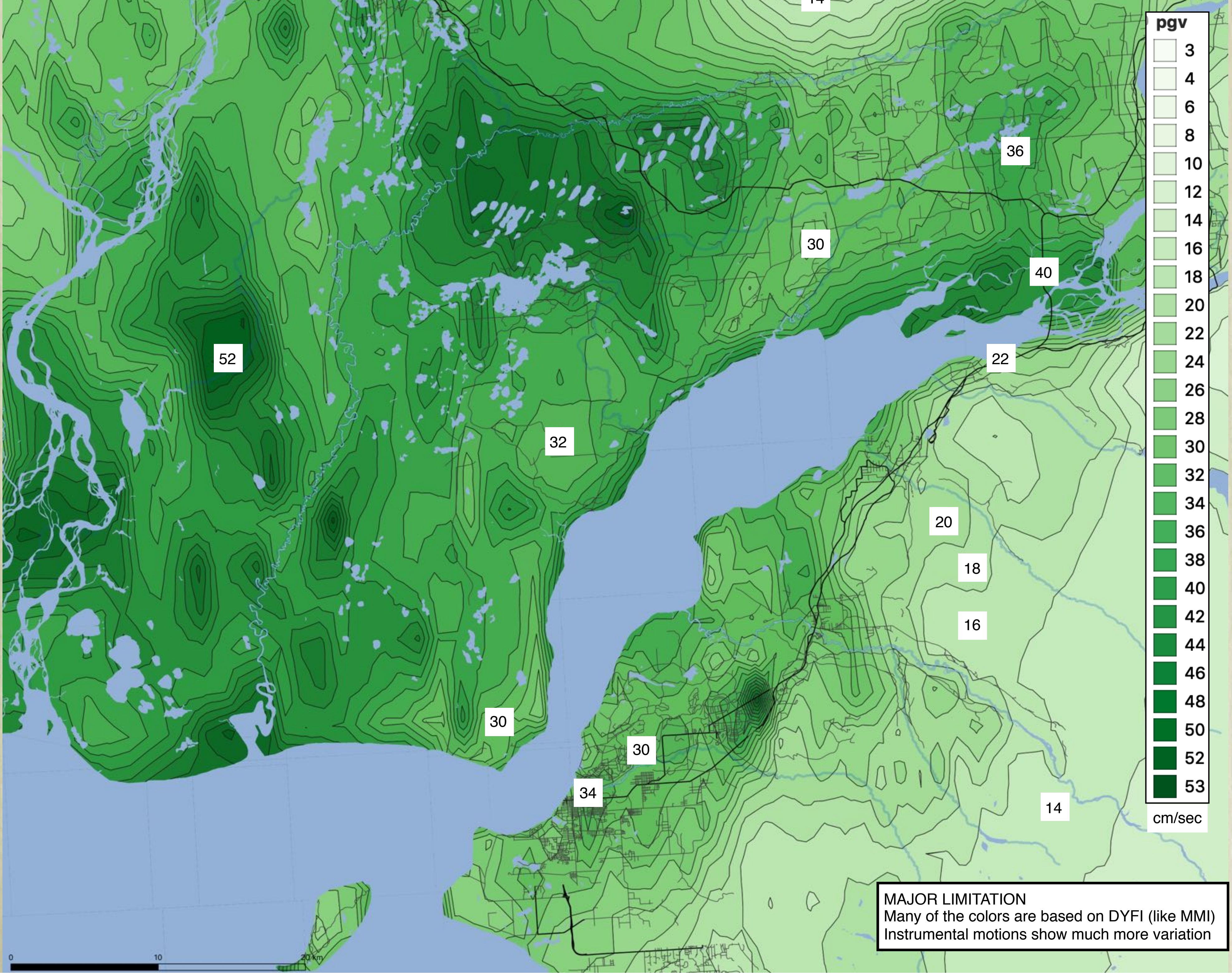
Area with Moderately Strong Shaking
Very Long Duration
Many Ground Failures
Many fatalities due to Tsunami
1964 M 9.0 Earthquake




Douglas
Nancy Lake State Recreation Area
Houston
Meadow Lakes
Farm Loop
Lazy Mountain
Palmer
138 kV
Wasilla
Anderson
115 kV
230 kV Substation / Terminal
Butte
138 kV Substation / Terminal
Big Lake
Teeland
115 kV Substation
Eklutna Hydro (PGA = 0.2g)
30 MW
Knik River
Power Plant
EGS (PGA = 0.17g)
Eklutna substation
170 MW
230 kV
115 kV
Significant Damage
Repair up to 1.5 years
Point MacKenzie
Knik Arm
Pippel
Damage
Repair ~ 1 day
Beluga
300 MW
Briggs
Pt. MacKenzie
PGA = 0.35g
Notes:
Not all facilities shown
Generation Capacities are for all units (rounded)
Peak Demand, entire region, ~450 MW
Locations in some cases approximate
ML&P 200 MW
Anchorage
Pt. Woronzol
University
CEA 200 MW
Anchorage
PGA = 0.15 to 0.35g
Far North Bicentennial Park
Fire Island
Latouche
115 kV
Chugach State Park
from Quartz Creek

Eagle River
Anchorage
Anchorage
Examples of damaged substations
7.06 km
Image Landsat / Copernicus
Google Earth
Imagery Date: 12/30/2016 lat 61.229575° lon -149.748460° elev 67 m eye alt 30.39 km


pga
2
4
8
12
16
20
24
28
32
34
0.04
0.08
0.04
0.08
0.12
0.16
0.20
Beluga
Pt MacKenzie
Cook Inlet
Girdwood
Portage
Whittier
Kustatan
Nikiski
Kenai
Soldotna
Cooper Landing
Prince William Sound
Kenai Peninsula
Seward
Railroad
Substation
Beluga Power Plant
0
40
80 km
MAJOR LIMITATION
Many of the colors are based on DYFI (like MMI)
Instrumental motions show much more variation


pgv
3
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
53
cm/sec
36
30
40
52
22
32
20
18
16
30
30
34
14
MAJOR LIMITATION
Many of the colors are based on DYFI (like MMI)
Instrumental motions show much more variation
0
10
20 km

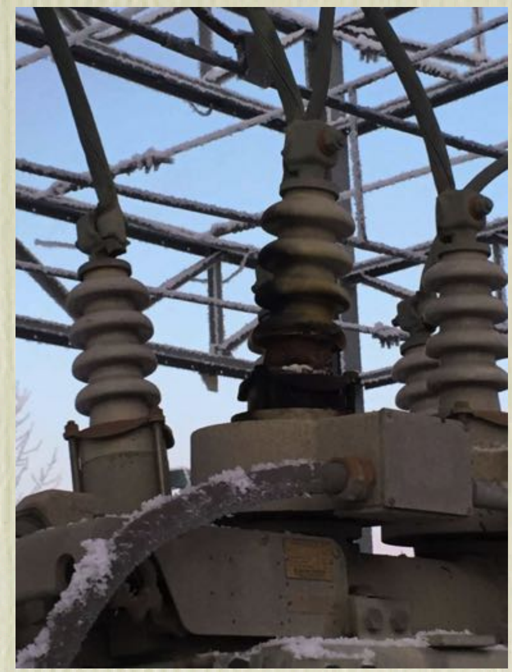
MEA

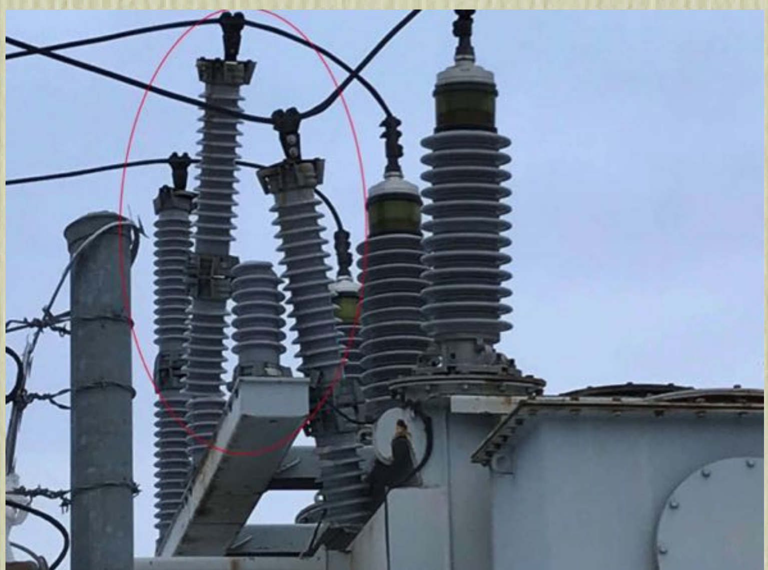
- 16 of 22 substations immediately went black.
- 4 substations had damage to high voltage equipment (115 kV)
- New 10 x 17 MW power plant: 2 of 3 step up transformers (each 13.8 x 115 kV 75 MVA) tripped. Various other damage to plant building, fire sprinkler pipes, overhead crane, gas regulator station, etc. PGA ~0.22g.
- Distribution damage.
- 42,600 of 65,000 meters (1 meter = 1 customer) were black at 11:30 am. 2,500 were black at 5 pm. 835 customers at 11:30 pm. About 15 Million CM.
- $1.1 Million Repair Cost. Mitigation? none apparent.

MEA Briggs Substation

Rigid Bus. Surge Arrestors. Transformer slid, breaking 4 bushings.
PGA ~ 0.30g

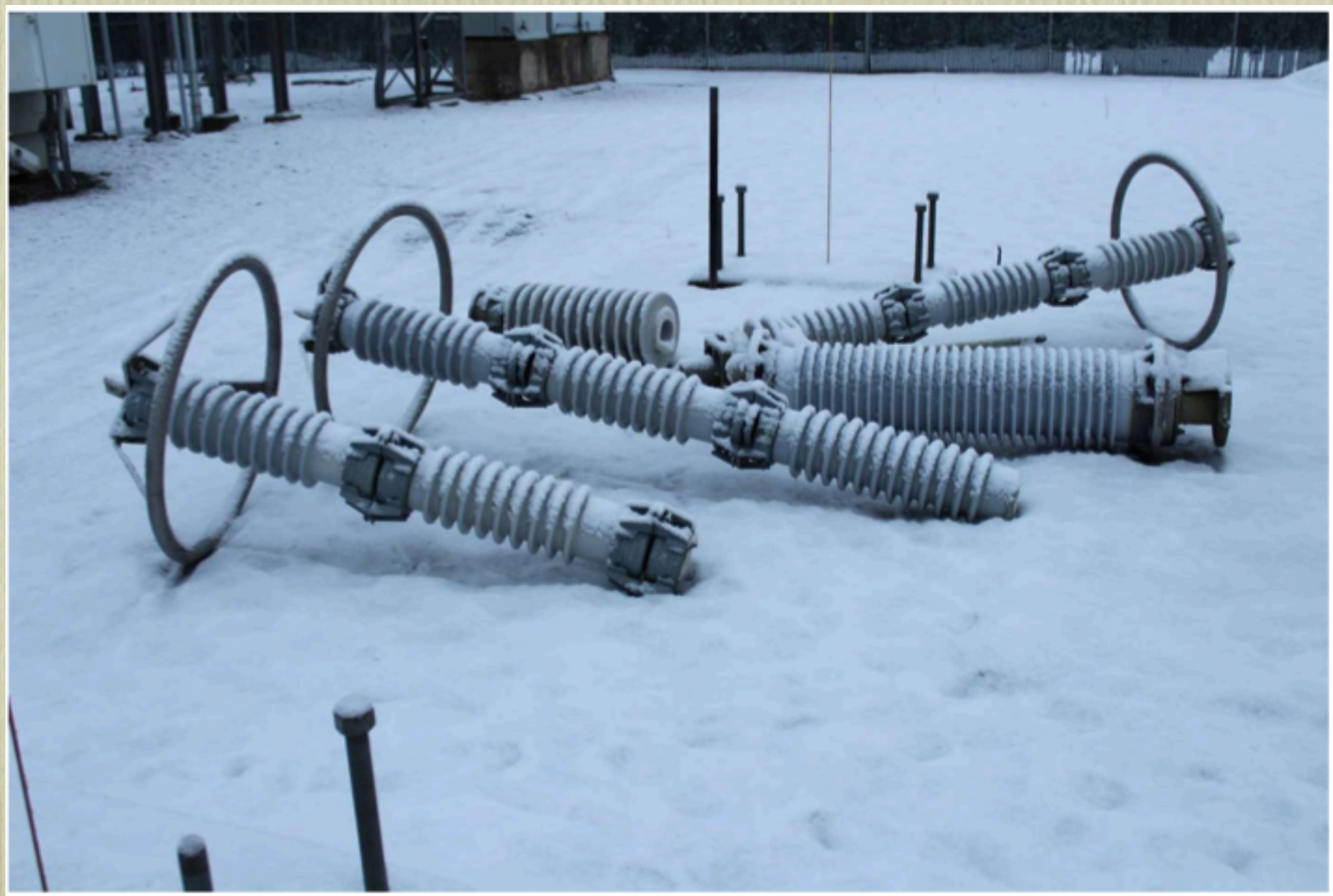
MEA Pippel Substation





Candlestick Breaker. Surge Arrestors. Bus. 15 kV DS + CB. PGA ~ 0.30g

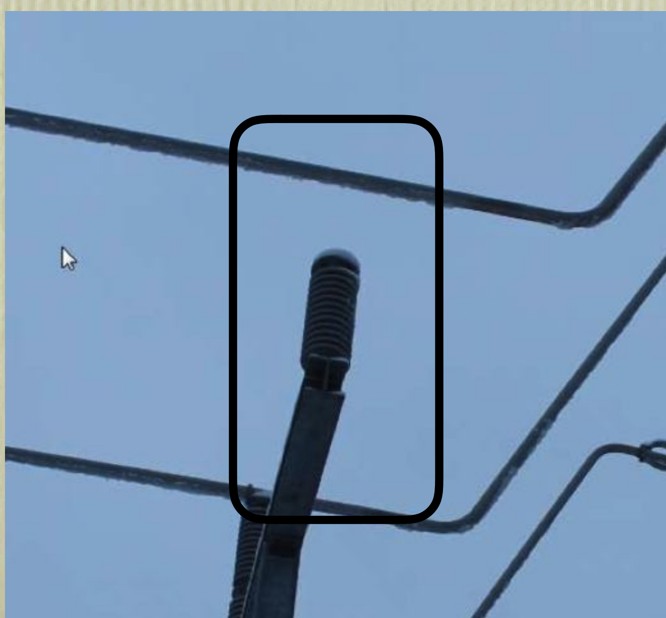
MEA Anderson Substation



Surge Arrestors. Circuit Switchers (candlestick breakers)
PGA ~ 0.30g

MEA Douglas Substation

Rigid Bus Expansion Joints, Bus Supports. PGA ~ 0.30g



Excessive differential movements leads to failures
Switch streel structures and bus supports
use I-beams, low frequencies,
twisting / torsion. All this is readily computed.
Suitable connectors are available.
Do utilities (and their A/Es) turn a blind eye?
Sunshine will expose the weaknesses.
CEA, ML&P and MEA all have work to do.

ML&P

- 3 115 kV substations tripped immediately (oil level and PT issues). Sub 6 115 kV bus damage.
- Plant 1 35 kV bus
- Plant 2A Units 10 and 11 tripped. SPP tripped.
- Eklutna PT and CT rooftop failures (3 total). PGA 0.17g
- Significant distribution damage.
- 30,800 customers. Power to 8,500 customers by 1 pm. 10,000 customers by 11 pm. All customers by 5 am Dec 1. About 10 Million CM.
- Mostly restored by Dec 1 3 am.
- $1.3 million repair cost.

ML&P Eklutna

3 of 6 PT / CT damaged. Transformers slid (a bit). Minor damage to buildings

ML&P Damage

Rigid bus

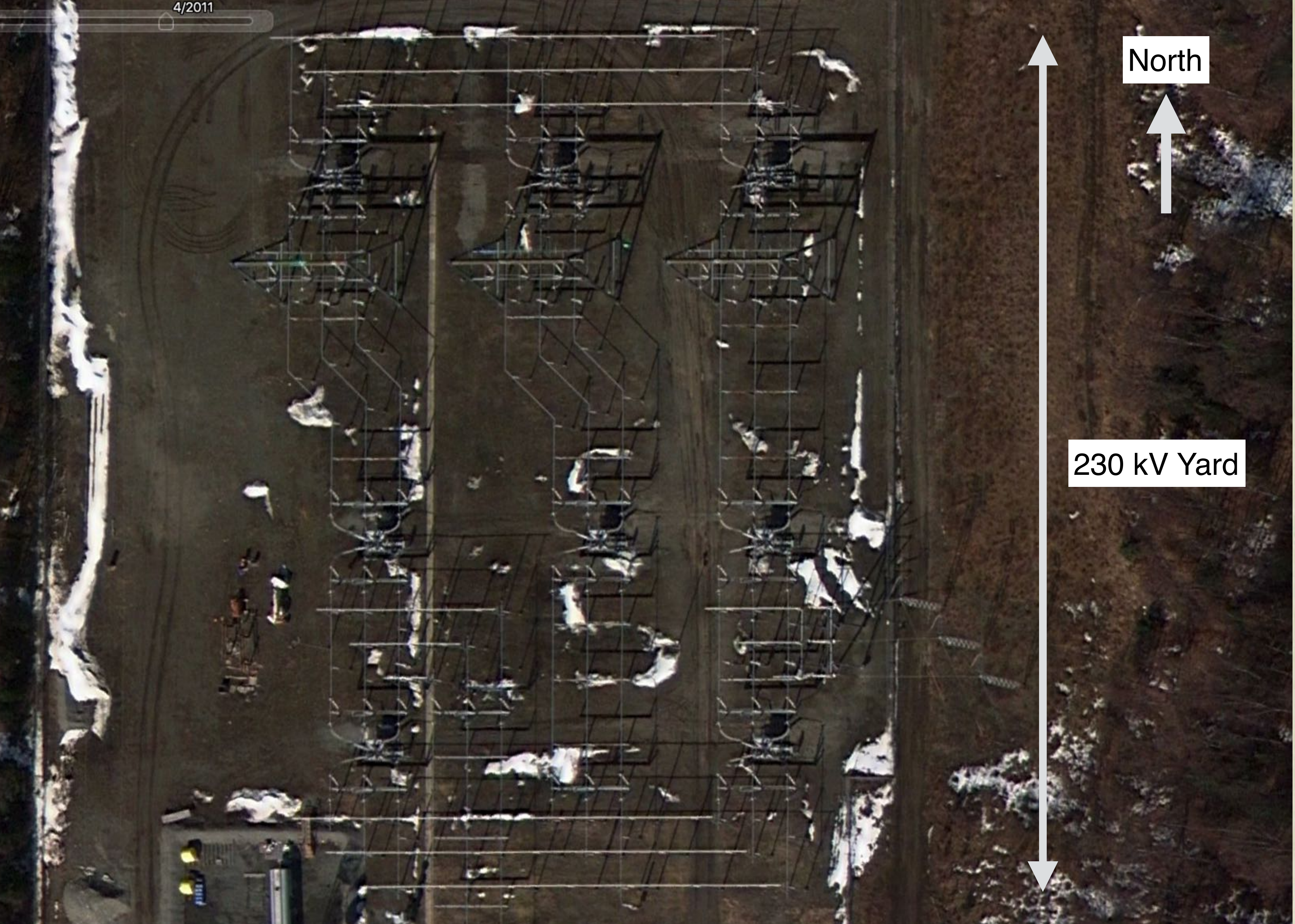
Underground TR

CEA

- 69,000 customers. 4,291 customers out at 1:53 pm. About 2 Million CM (might be low).
- Major damage at Point Mackenzie 230 kV ($2 to $7 million)
- Tilted transformers and switchgear (Latouche) $2 million.
- East Cable 230 kV terminal; Beluga power plant distribution transformer, Teeland switches, Airport foundations cracked, Pt Woronzol leaking bushings, Boniface substation, Dowling substation, University substation (settlement and broken switches), Hillside substation, Huffman substation. $0.5 million.
- Eklutna tunnel, others. $1.5 million.
- $7 million (to $12 million) repair cost.

CEA
Pt MacKenzie 2018
230 138 kV
Lat 61.2496
Long -150.0268

"Major Damage" of
230 kV Yard

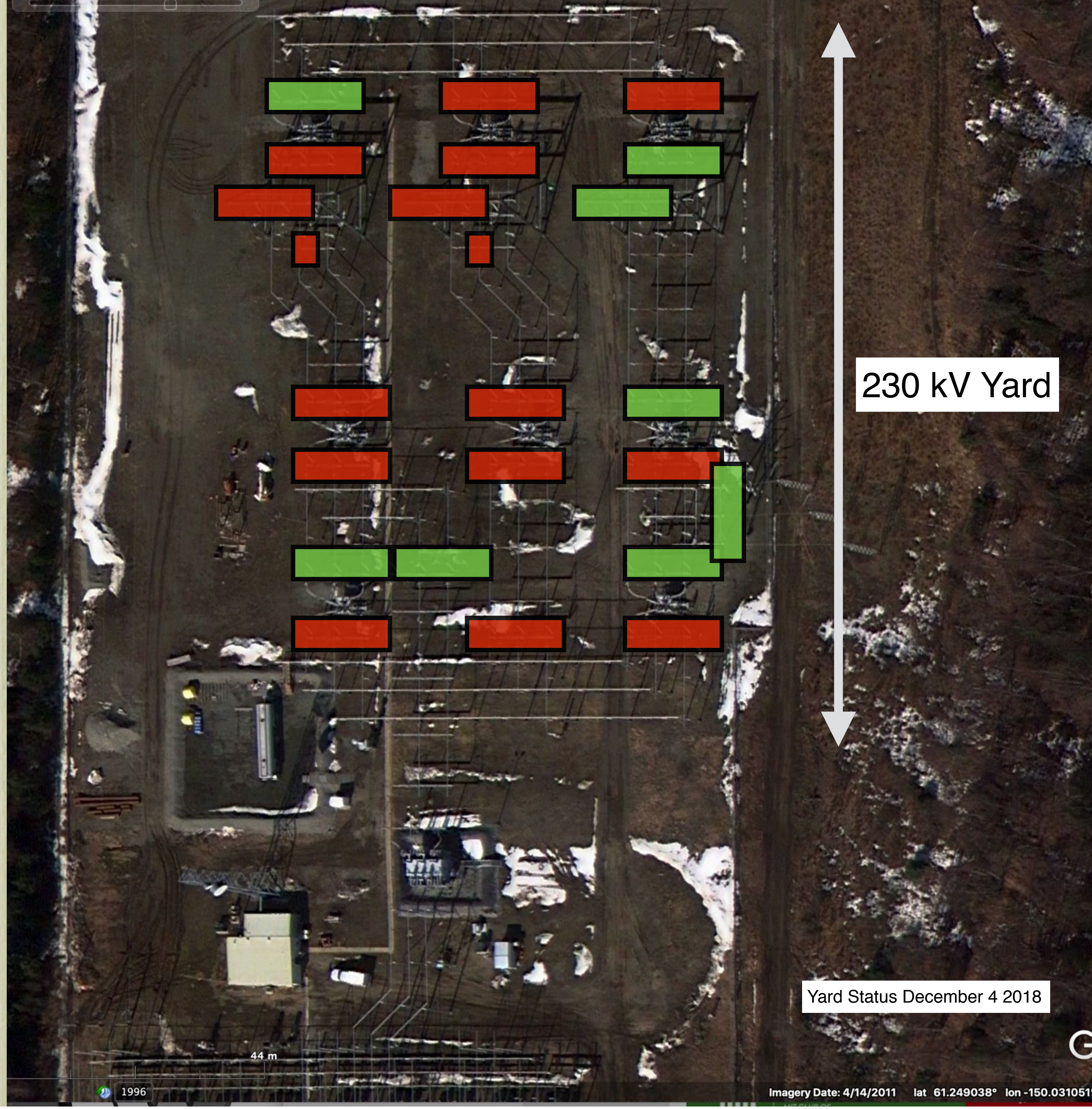

4/2011
North
230 kV Yard

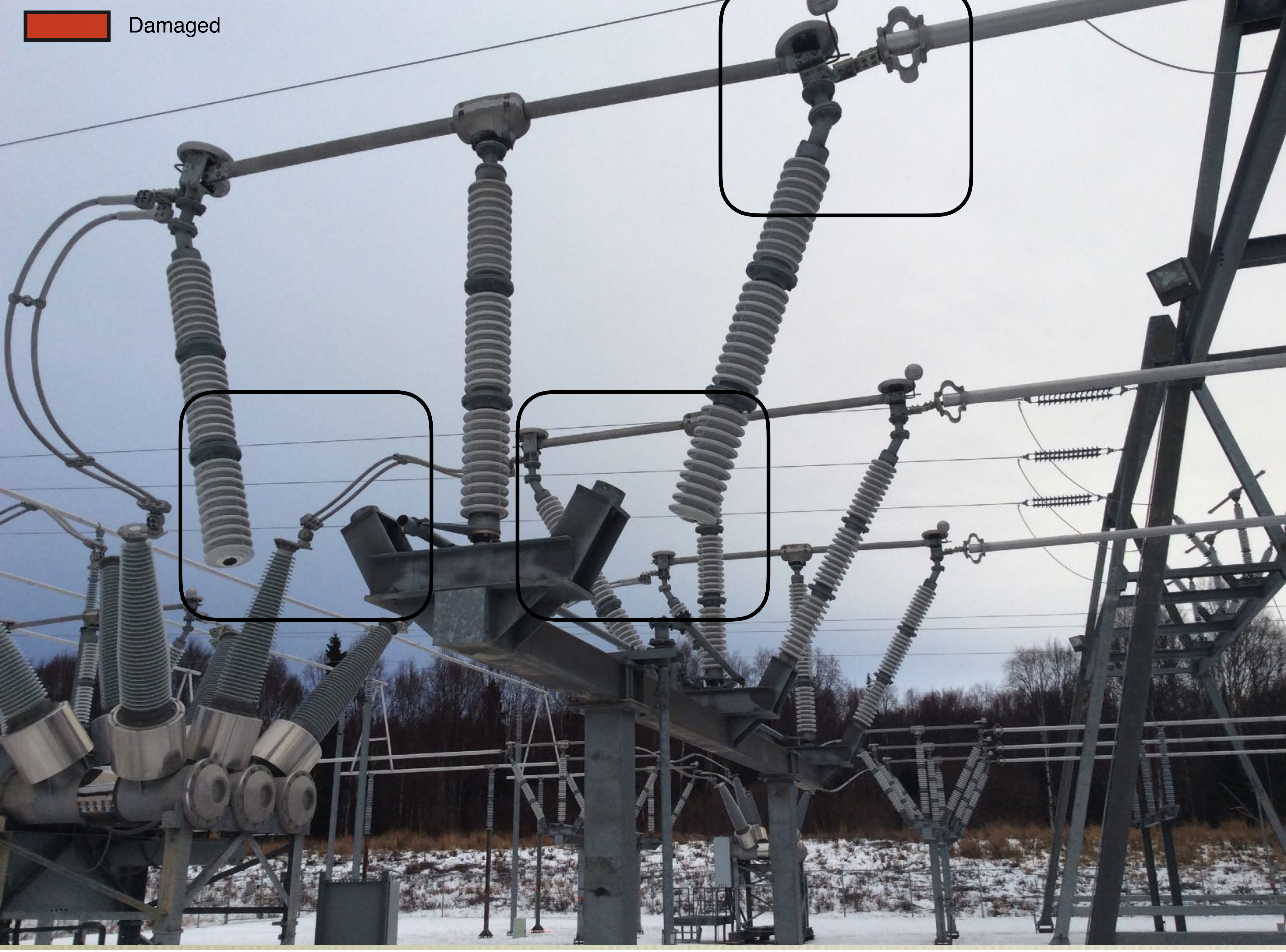
Damaged

Undamaged

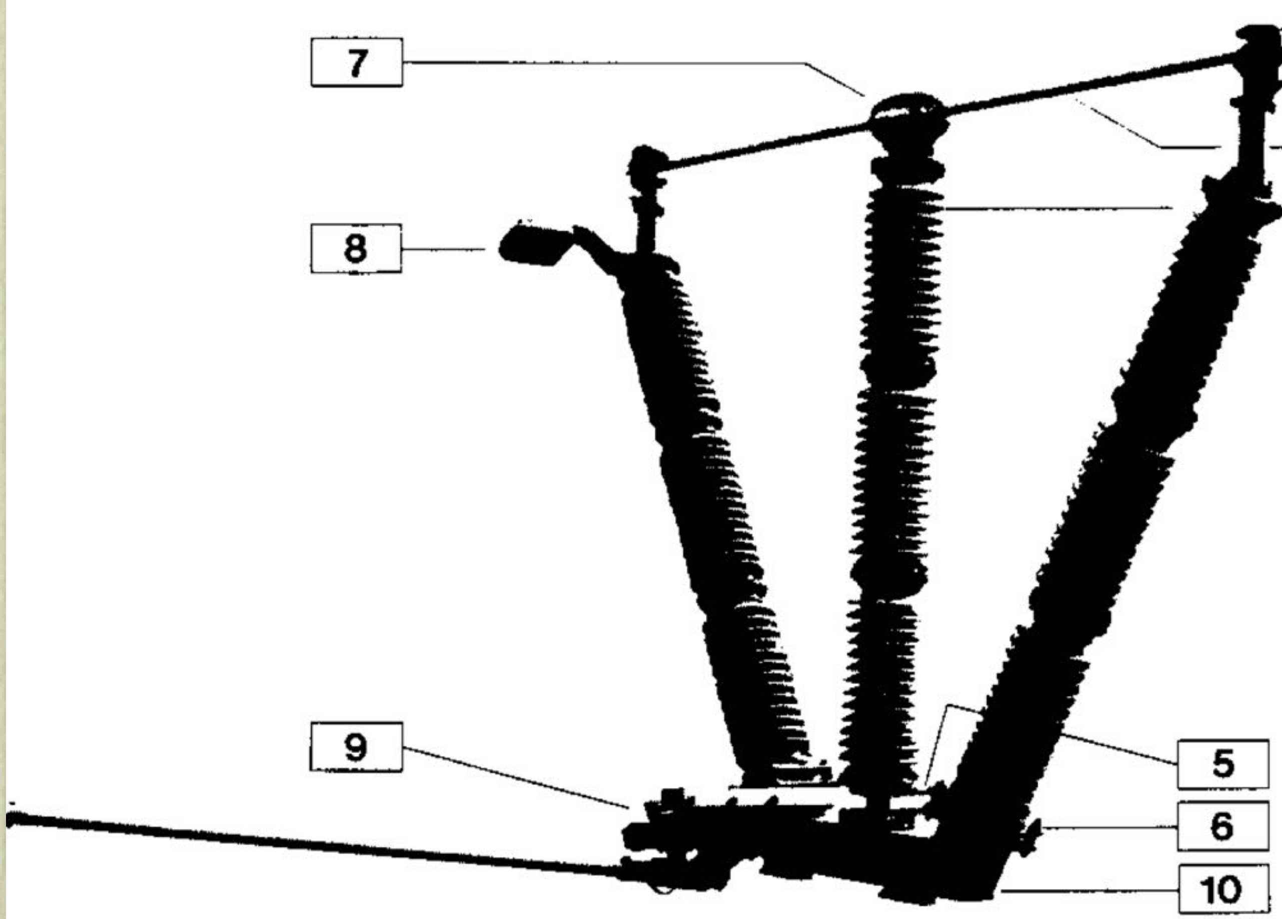
CEA
Pt MacKenzie 2018
230 138 kV
Lat 61.2496
Long -150.0268

North




Damaged

Double End Break 230 kV Switch

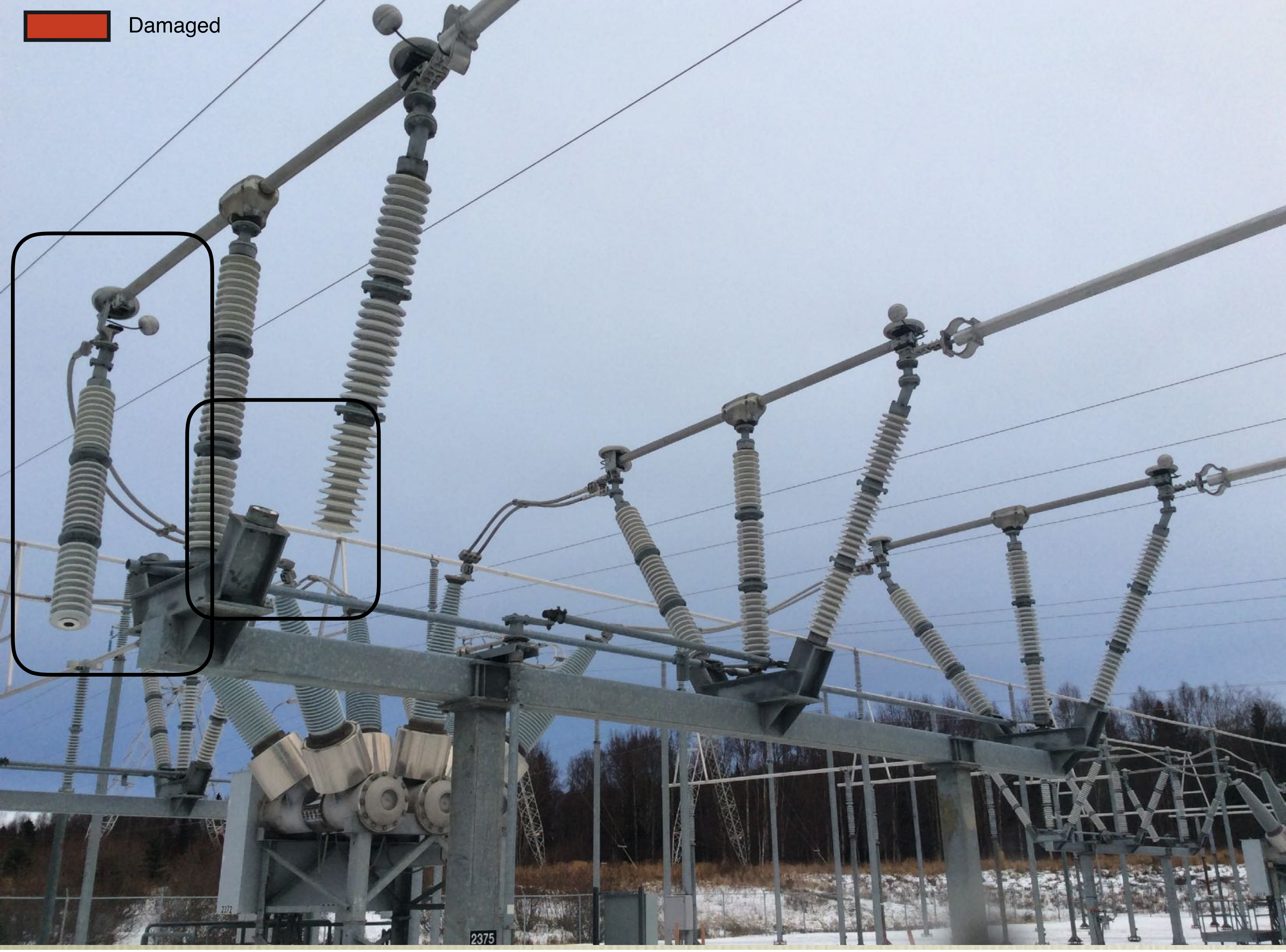


1 - Jaw
2 - Arcing Horns
3 - Switch Blade
4 - Rotating Insulator
5 - Switch Arm
6 - Jack Screws
7 - Blade Operating Assembly
8 - Grounding Switch Jaw
9 - Grounding Switch Hinge
10 - Switch Base

Figure 1 - Identification of parts. This switch is equipped with a grounding switch, which is optional equipment. 230 kV model shown. For other ratings, refer to the unit assembly and operating mechanism drawings. Items 8 and 9 may not be used on all ratings.

The switches are a hybrid between original Siemens Allis, with replaced parts by Southern States


Undamaged


Damaged
2375

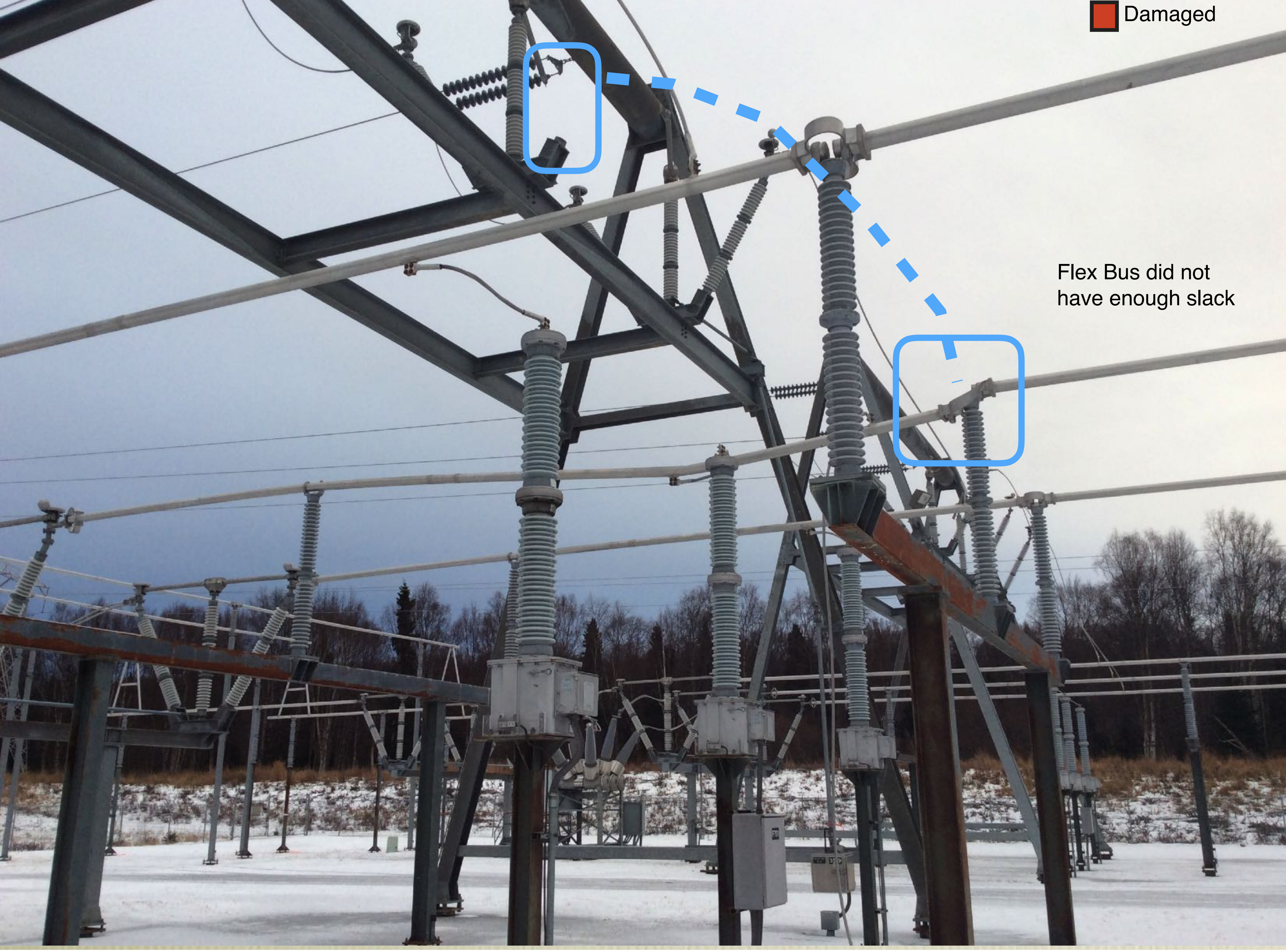
Damaged


Damaged


Damaged


Damaged
Rocking lack of stiffeners
Low frequency


Undamaged

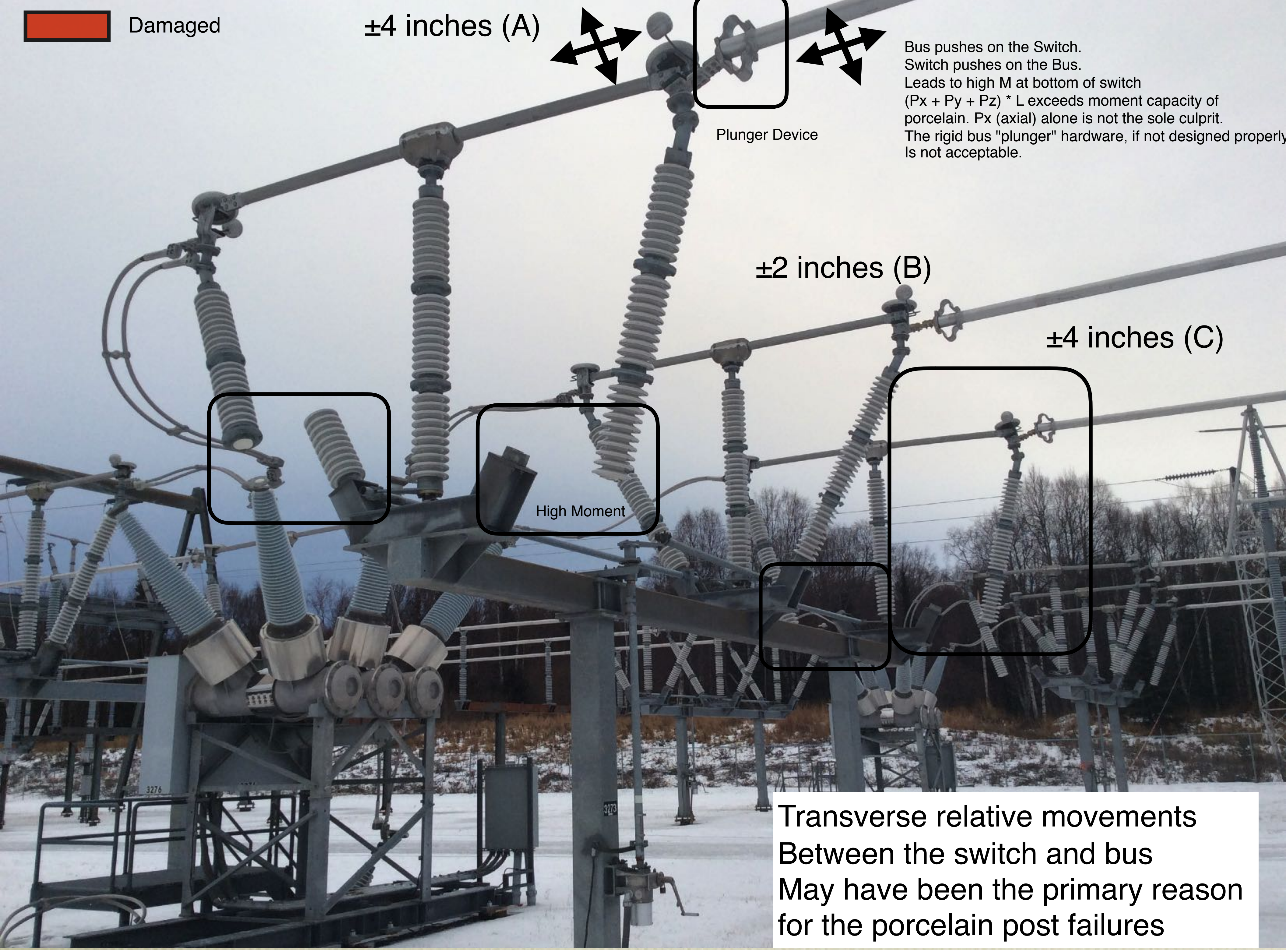

Damaged
Flex Bus did not
have enough slack

Damaged

Damaged


Damaged
3276

Damaged



Damaged
±4 inches (A)
Plunger Device
Bus pushes on the Switch.
Switch pushes on the Bus.
Leads to high M at bottom of switch
(Px + Py + Pz) * L exceeds moment capacity of
porcelain. Px (axial) alone is not the sole culprit.
The rigid bus "plunger" hardware, if not designed properly
Is not acceptable.
±2 inches (B)
±4 inches (C)
High Moment
3276
3273
Transverse relative movements
Between the switch and bus
May have been the primary reason
for the porcelain post failures


Damaged
4171

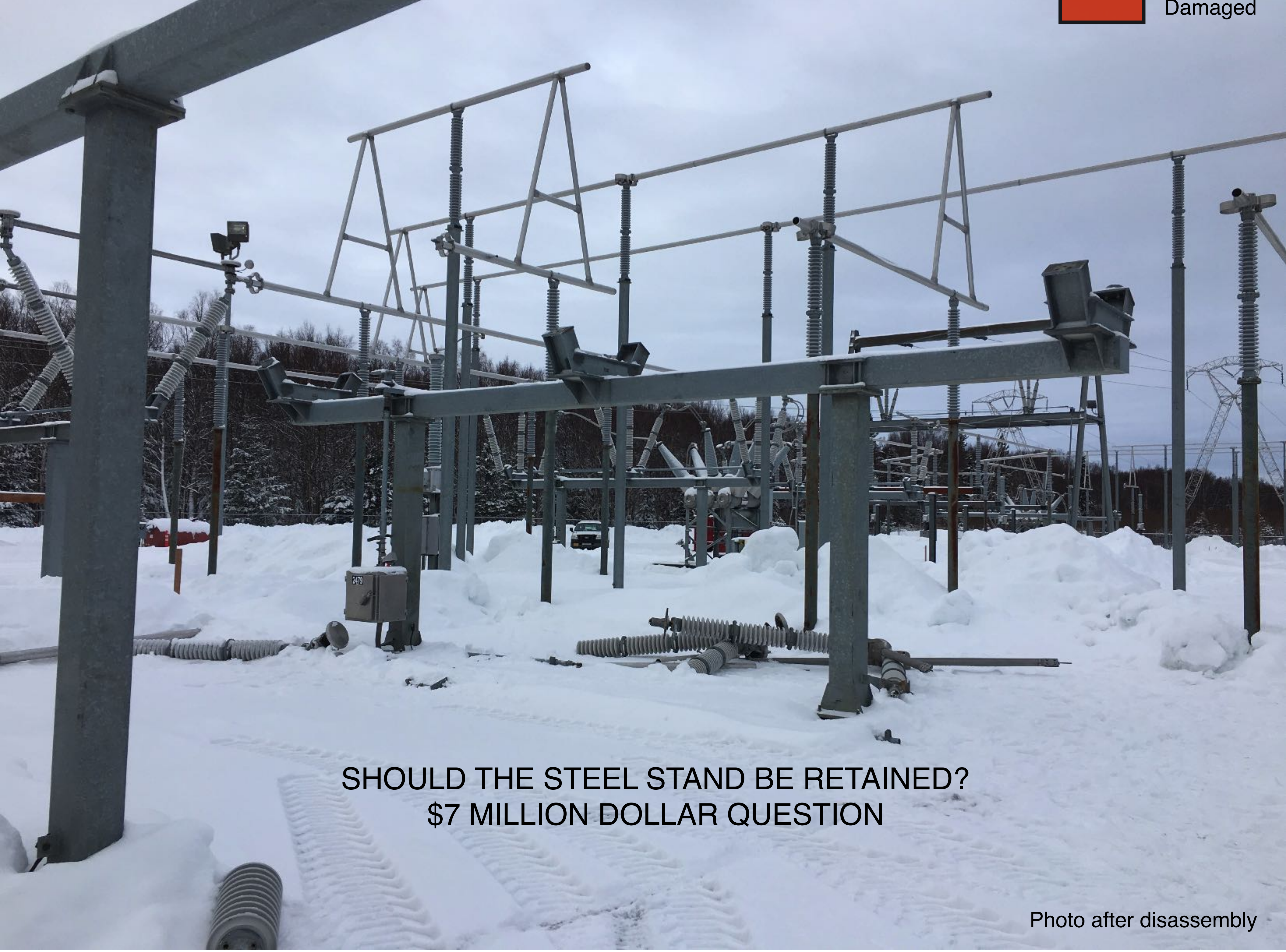


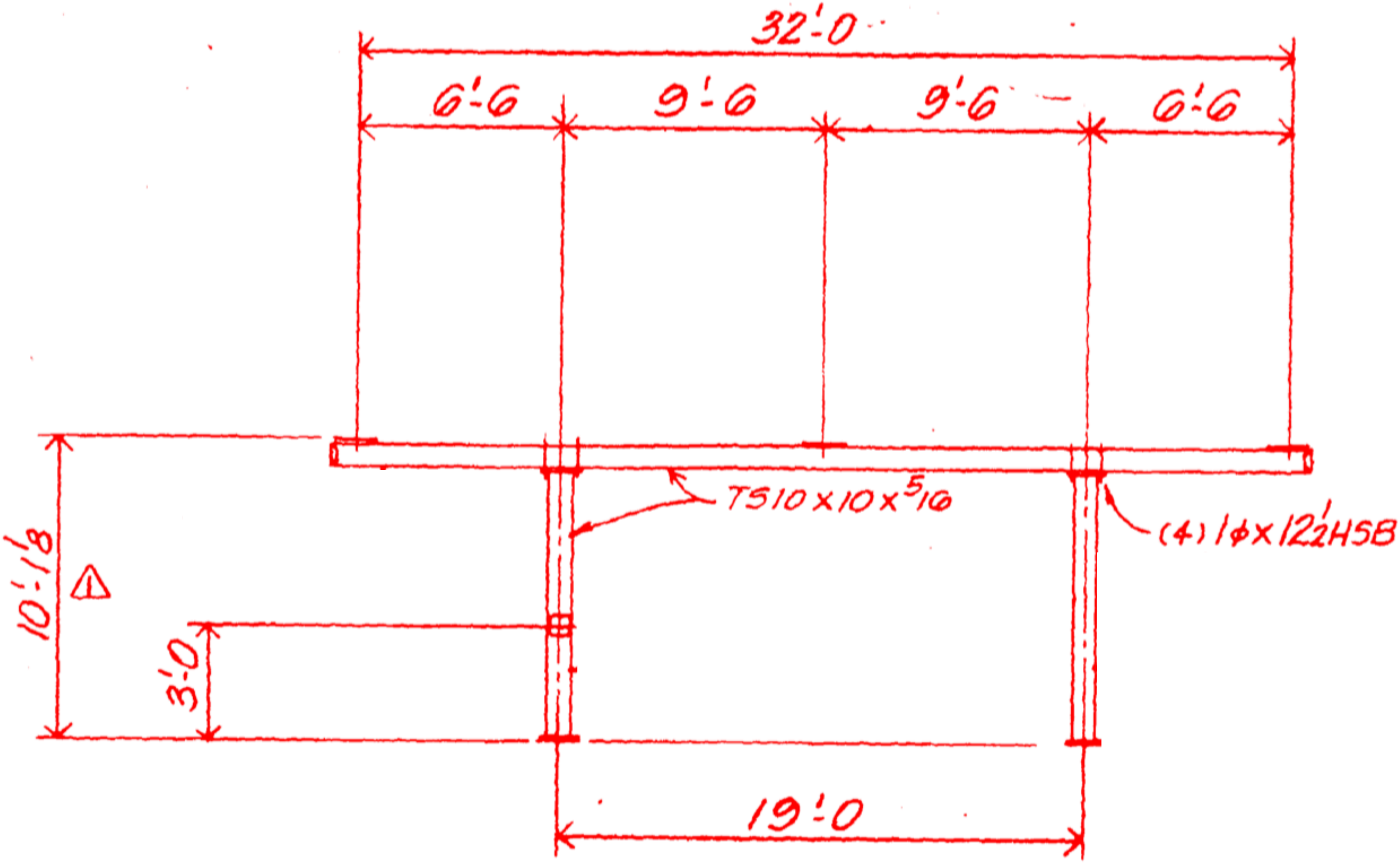
Photo after disassembly


Damaged


Damaged
2276
ALASKA
YYT 881


Damaged

No damage



SHOULD THE STEEL STAND BE RETAINED?
$7 MILLION DOLLAR QUESTION

Damage Summary

Description	Phases Damaged
Low level switch	A ø
Low level switch	None
Low level switch	C ø
Low level switch	A ø, C ø
Low level switch	C ø
Low level switch	None
High level switch	B ø
Broken connection	B ø
Low level switch	None
Low level switch	A ø
Low level switch	A ø, C ø
Low level switch	A ø, C ø
Low level switch	C ø
Low level switch	A ø
High level switch	B ø
Broken connection	B ø
Low level switch	A ø, C ø
Low level switch	None
Low level switch	A ø, C ø
Low level switch	None
Low level switch	None
Low level switch	A ø
High level switch (unique)	None
High level switch	None

Low Switches - Dynamics

Mode	Frequency (Hz)	Primary Modal Directions
1	2.4	NS
2	2.9	NS
3	4.1	EW, Vertical
4	4.8	NS
5	5.2	Vertical, EW
6	8.2	EW, Vertical
7	8.3	NS
8	8.5	NS
9	10.3	NS
10	10.9	NS
11	11.4	Vertical, EW
12	11.5	NS
13	12.2	EW, Vertical
14	12.5	NS
15	13.0	EW, Vertical
16	15.3	Vertical
17	19.4	EW, Vertical
18	19.5	Vertical, EW
19	19.6	EW, Vertical
20	29.8	NS

Table 5-5. "Switch Low" Frequencies

EW 4.1 HZ
NS 2.4 HZ

Location	NS (Inches)	EW (Inches)	Vertical (Inches)
Phase A Base	1.47	0.32	0.44
Phase B Base	1.03	0.32	0.05
Phase C Base	1.47	0.32	0.44
Phase A Top	3.78	1.41	1.63
Phase B Top	3.12	0.41	1.43
Phase C Top	3.78	1.42	1.63

Table 5-6. "Switch Low" Displacement Responses

High Switches - Dynamics

Mode	Frequency (Hz)	Primary Modal Directions
1	1.0	EW of the A Frame
2	2.5	NS, Vert
3	4.0	Vert, NS
4	4.1	EW
5	4.6	Vert, EW, NS
6	5.3	Vert, NS, EW
7	5.3	Vert, NS, EW
8	6.0	NS, Vert
9	6.9	NS, Vert
10	7.2	NS, Vert
11	7.4	Vert
12	8.3	Vert
13	9.2	Vert
14	9.6	Vert, NS
15	9.9	Vert, NS
16	10.3	Vert, NS
17	10.4	Vert, EW, NS
18	10.5	Vert
19	10.9	Vert, NS, EW
20	11.2	NS, Vert
21	11.4	NS, Vert
22	14.2	EW
23	19.1	NS
24	19.5	Vert
25	19.6	Vert
26	19.6	Vert, NS
27	19.8	NS
28	20.3	EW
29	23.3	NS
30	23.9	NS, Vert
31	24.4	NS
32	25.3	NS, Vert
33	27.3	EW
34	28.0	Vert, NS
35	32.0	NS
36	39.4	Vert

EW 1.0 HZ
NS 2.5 HZ

Location	NS (Inches)	EW (Inches)	Vertical (Inches)
Phase A Base	1.87	10.22	0.68
Phase B Base	3.60	10.22	0.80
Phase C Base	1.97	10.22	0.68
Phase A Top	1.95	10.67	0.92
Phase B Top	3.92	9.95	1.32
Phase C Top	2.02	10.67	0.92

Observations (1)

- Yard Re-build using new 4-leg supports and new IEEE 693 Switches: **$7 Million**
- Yard Re-build using original 2-leg supports and new Switches: **$2 Million**
- CEA, Switch Vendors and Local AK A/E: original leaning towards $7 million. After external review, adopting $2 million.
- This weakness is prevalent throughout the Anchorage area. An area-wide assessment with mitigation is RIPE.
- FEMA can pay. CEA, ML&P and MEA should step up to the plate.

Observations (2)

- IEEE 693 is a Guideline. Not Mandatory.
- BC, WA, OR, CA. Mitigation of the bus remains important. The West Coast is not "done".
- IEEE 693 / 1527 / SERA. Field observations and displacement calculations will uncover nearly all of these weaknesses at Anchorage substations. Fixing this is "straightforward". More than half of residual weaknesses at modern substations remain with flex bus and rigid bus adverse interactions.

More Information

- TCLEE No. 5A Report: Overview of all lifeline performance in the Anchorage 2018 earthquake
- http://www.geEngineeringSystems.com
- Free
- Detailed report. Point MacKenzie Substation. G&E Report dated July 30 2018 (104 pages). Upon request (NDA)