Storm Report
for
The City of Seattle

following
The Storm on East Marginal Way South
April 5, 2019

prepared by

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TABLE OF CONTENTS

1. Details of the Incident……………………………………………………………3

2. Materials Relied On………………………………………………………………3

3. Qualifications and Forensic Steps Taken………………………………………3

4. Weather Analysis Findings………………………………………………………5

5. Findings for Pole Loading Designs……………………………………………5

6. Findings for Pole Remaining Strengths………………………………………6

7. Causation…………………………………………………………………………7

8. Conclusion…………………………………………………………………………7

9. Appendix A – Map of Failed Pole Locations…………………………………1

10. Appendix B – Bingel CV…………………………………………………………3

11. Appendix C – Marne CV…………………………………………………………11

12. Appendix D - Winandy CV………………………………………………………18

13. Appendix E – Bond CV……………………………………………………………37

14. Appendix F – Weather Conditions Report ……………………………………50

15. Appendix G – Wood Pole Loading Report………………………………………55

16. Appendix H – Rule 250B Pole Loading Analysis Reports……………76

17. Appendix I – Rule 250C Pole Loading Analysis Reports……………162

18. Appendix J – Expected Storm Pole Loading Analysis Reports….177

19. Appendix K – Forensic Analysis of Failed Poles……………………263

20. Appendix L – Wood Pole Strength Report ……………………………289

1. Details of the Incident

On Friday, April 5, 2019 an afternoon summer storm occurred in the Seattle area with high winds and rain. At approximately 3:50 PM, Seattle City Light experienced a downed section of power line consisting of 26 poles located north and south of the Museum of Flight at 9404 E. Marginal Way South in Tukwila, WA. The map in Appendix A shows the location of the 26 poles. Security camera footage and news reports showed that one pole landed on a moving vehicle with two occupants inside. The vehicle passengers were treated and released shortly afterward from a local hospital.

Seattle City Light quickly responded with 7 crews and about 40 workers to assist with the safety of people near the scene. Subsequent efforts were focused on clearing debris and restoring power to approximately 16,500 customers impacted by the outage. By 6:00 pm all but 300 customers had power restored and all, but 13 customers were restored by Saturday morning.

The Seattle City Light called for a third-party review of the incident and asked the City Attorney's Office for assistance in contracting with multiple experts and overseeing the on-site inspection. The results of that expert review are contained in this report.

2. Materials Relied On

A. Seattle City Light Design Standard 9620.01 – Properties of Wood Poles (June 2015)
B. Seattle City Light Design Standard 9130.01 – 26.4 kV Overhead Design
C. Seattle City Light Construction Guide D9-51 – 26 KV Construction for 954 Rail
D. Seattle City Light Material Standard 5082.00 – Wood Poles, Pressure Treated, Douglas Fir
E. Seattle City Light Material Standard 5054.10 – Crossarms, Douglas Fir
F. Seattle City Light: Douglas Fir Wood Pole Material Standards History File Review
G. Seattle City Light Standard 160812 – Inspection Procedures for Wood Pole Assessment
H. Seattle City Light 2016 Pole Inspection Reports for the 26 poles involved in the incident
I. National Electrical Safety Code (NESC) 2017 edition
J. Google Earth views of previous pole construction

3. Qualifications and Forensic Steps Taken

The Seattle City Attorney's Office contacted the following experts to form the team to investigate the incident:

- Nelson G. Bingel, III - Mechanical/Structural Engineer
  Wood Pole Loading and Strength Expert
  Chairman - National Electrical Safety Code (NESC)
- David J. Marne - Electrical Engineer
  National Electrical Safety Code (NESC) Expert
- Jerrold E. Winandy - Wood Scientist
  Expert on Properties and Durability of Wood
- Nicholas Bond - Research Meteorologist
  Climatologist for the State of Washington

The Curriculum Vitae of the experts are attached as Appendices B, C, D, and E.

As the investigation progressed, it was determined that the investigation team should be led by Nelson Bingel as the focus was on the wood pole failures. This report has been authored by Nelson Bingel with input from all the team members.

The following personnel with Seattle City Light and the Seattle City Attorney's Office have worked with the experts to provide documents, additional information, and a field visit:

- Jeff Wolf and Engel Lee – Seattle City Attorney's Office
- Paul Larson – Seattle City Light - Engineering and Operations Manager
- Alan Hall – Seattle City Light - CL Team D Engineering Manager
- Tom Caddy – Seattle City Light - Supervisor South Operations

A field visit was organized for May 6 where Nelson Bingel, David Marne and Jerry Winandy were hosted by Jeff Wolf, Paul Larsen, Engle Lee, Alan Hall, and Tom Caddy. The group first visited each of the 26 poles of the rebuilt section of line on East Marginal Way South by the Museum of Aviation.

In addition to the Seattle City Light pole numbers, the poles that failed were numbered 1 through 26 for easier reference during the analysis. Pole number 1 was the farthest north pole to fail and 26 was at the southern end (Appendix A – Map).

Pole species, length and class details were collected from the replacement poles along with measured groundline circumferences and span lengths. Not all poles were reset in the location of the previous poles. Wire types and specific pole construction were also recorded along with all guying configurations. The terrain and nearby buildings and foliage that may deflect or accelerate wind loading were also noted.

The next visit was to the pole yard where all remaining pole sections that Seattle City Light could identify had been sequentially positioned for inspection in the same order as they existed when in service. The 2016 inspection reports provided the pole species, length and class and most of those could be validated from the remaining pole sections.

The setting depth of each pole was measured from the butt of each pole to the perceived groundline. The distance from groundline to the breakpoint was also recorded. The span lengths of the original construction were provided by Seattle City Light and the pre-storm pole construction would later be confirmed using Google Earth.

The pole sections were also closely evaluated for the condition of the pole near the groundline and near the breakpoint. The groundline and the breakpoint were often the same location. This analysis was to determine the amounts of decay-induced void volume, the extent of decayed wood showing some physical evidence of weakened strength, and/or sound wood near the groundline or point of pole failure. The measurements would be used to estimate the remaining bending strength at the groundline of poles with decay.

An additional forensic analysis was conducted by Nicholas Bond to determine the best estimation of the actual wind conditions that occurred during the storm. The weather data was largely obtained from the Boeing Field station (KBFI) and a private weather station in the Highland Park neighborhood. The videos provided by the Seattle City Attorney's Office were reviewed by Nicolas and a site visit occurred on June 9, 2019. The full report is attached as Appendix F, Weather Conditions Report.

4. Weather Analysis Findings

The maximum observed gust speeds at the Boeing Field station occurred at 3:50 pm and reached 29 mph. The atmospheric conditions resembled a wet microburst where heavy downpours of rain result in stronger surface winds over small areas. Fitting atmospheric soundings to the observed wind gust magnitudes resulted in an expected gust speed of 39 mph.

Another mechanism that can contribute to locally enhanced wind speeds in low-level terrain is having higher-level terrain located nearby. Although the actual resulting wind speed increases are difficult to calculate, the expert opinion is that an increased wind speed of roughly 10 mph would be reasonable in this case.

Given all the factors related to the weather conditions that occurred at the accident site, a reasonable upper bound for the wind speeds was concluded to be approximately 50-mph.

5. Findings for Pole Loading Designs

Each pole of the original construction was modeled in the pole loading software program, O-Calc Pro, using the field data, Google Earth views of the construction, and conductor types and span lengths provided by Seattle City Light. The loading requirements of this line are found in the National Electrical Safety Code: Rule 250B and 250C.

This line is in the Medium Loading District which calls for adding a radial ice thickness of ¼ inch to all conductors which adds ½ inch to the diameter of each wire. The wind is applied at a pressure of 4-lb/sq-ft of surface area; most of the surface area consists of the wires with the additional ice and the pole. Some poles had streetlights, other equipment and telecom attachments which were also added to the pole models.

A wind pressure of 4-lb/sq-ft is approximately equal to a 40 mph wind speed. The NESC requires Grade C construction for this line so the strength and load factors for Grade C were also applied.

To account for construction tolerances, a 1° line angle was added to each pole. This created some additional transverse load on each pole caused by the wire tension in the spans not directly opposing each other.

The design capacity for these poles when new exceeded the loading requirements of Rule 250B in the NESC. In most cases the design significantly exceeded the code loading requirements as shown in the pole loading summary in Appendix G, Wood Pole Loading Report.

The NESC Extreme Wind Load Case, Rule 250 C, also needs to be considered when poles extend more than 60 feet above ground. This case is intended to represent an extreme summer wind event using a wind speed of 85 mph and a wood strength factor of 0.75. Only poles 17 through 20 are tall enough to require evaluation using the Rule 250C criteria. the new pole capacity of these poles exceeded the Extreme Wind load case for Grade C construction. The capacity of the shorter poles in the line also exceeded the Extreme Wind load case.

The individual pole loading analyses are included in Appendices H through J.

Another benchmark for loading can be established by calculating the equivalent wind speed without ice on the wires that causes the same load as the Medium District load case. In this analysis, the equivalent "no-ice" wind speed was greater than the 50 mph upper limit that is expected to have occurred. Thereby, the design capacity of the poles exceeded the capacity required to support the upper limit wind speed that was expected during the storm.

6. Findings for Pole Remaining Strengths

The requirements for categorizing poles following groundline inspection are specified in Seattle City Light Standard 160812 – Inspection Procedures for Wood Pole Assessment. Table 2-1: Priority Rating (below), explains how poles are to be classified depending on the remaining strength results during the "Inspect & Treat" program.

Table 2-1: Priority Rating

Priority Rating	Maintenance Required	Description
P1	Replace	RSM is 25% or less – Pole requires Replacement – **Immediate Action Required** – Notify CITY LIGHT if pole poses an imminent public safety hazard
P2	Replace	RSM is 75% or less than and greater than 25% – Pole requires Replacement – Maintenance Required within Practical Timeframe – Not a candidate for truss reinforcement.
P3	Reinforce	RSM is 75% or less and greater than 40% – Maintenance Action Required within Scheduled Timeframe. Candidate for truss reinforcement.
P4	None	RSM is greater than 75% – Pole is Serviceable based on an above ground level sound and bore inspection only (non-excavatable). No Remedial Maintenance Required – Inspect next cycle.
P5	None	RSM is greater than 75% – Pole is Serviceable – No Remedial Maintenance Required – Inspect next cycle.

During the inspections, two sections of the 26 failed poles were found to have several adjacent poles which were severely weakened by decay at the groundline as shown in Appendices K and L, Forensic Analysis of the Failed Poles and Pole Strength Report; poles numbered 8 to 13 (6 poles) in the midsection and poles 22-24 and 26 (4 of 5 poles) at the southern end. The condition of these poles was classified as P2 during the 2016 inspection.

However, a P2 pole, per the Seattle City Light specification, may have a remaining strength ranging from 75% down to a value greater than 25% remaining strength. This range is conservative on the high end as the NESC allows pole strength to be reduced to 67% before restoration or replacement is required. The greater than 25% remaining strength is non-conservative for the P2 description in Table 2-1:

> "Pole requires replacement – Maintenance Required within Practical Timeframe – Not a candidate for truss reinforcement."

The phrase "Maintenance Required within Practical Timeframe" is completely vague and provides no level of urgency for remediation. Seattle City Light will need to revamp Table 2.1 with tighter remaining strength ranges and more specific requirements for replacement or restoration.

It was also noted that three of the poles in the line also had damage from the presence of Golden Buprestid beetles (see Appendix H, pg 2). These beetles usually only survive in a tree converted to a utility pole if the pole was not properly sterilized during manufacturing. The larvae bore holes on the inside of a pole which by themselves do not cause a significant strength reduction. However, boring larvae do spread fungal spores throughout these bore holes causing significantly more rapid fungal inoculation of the untreated heartwood. Where such beetle larvae boring holes are found, wood decay was generally more noticeable than in un-bored heartwood.

7. Causation

Poles categorized in the P2 classification may have a remaining strength ranging anywhere from 75% down to just greater than 25%. Within this 26-pole line segment there were two groups of P2 classified poles that were sequential and were in the lower portion of the strength range. Six such P2 classified poles, 8 to 13, were near the middle range of the failed poles.

The remaining strength of a pole cross section is typically calculated based on the pole failing in bending. These six poles had advanced internal decay that created a thin-walled cylinder. Instead of failing in a bending mode, these poles are likely to fail due to localized buckling of the thin wall as explained in the Conclusions of the Wood Pole Loading Report, Appendix H.

It is known that when hollow poles fail due to local buckling, the actual remaining strength is less than what is calculated as a remaining bending strength. However, it is difficult to calculate with any precision because local buckling depends on multiple shell measurements of the cross section and it varies with the height of the internal decay within the pole. The greater the height that the decay extends in a pole, the lower the expected buckling strength.

The estimated remaining strength values in Table 1 of Appendix H for poles 12 and 13 are 57% and 33% respectively. These values are based on a pole failing in bending so the actual remaining strength was likely to be less when buckling is considered.

Poles 12 and 13 were exposed in open ground as opposed to neighboring poles which had some level of sheltering or disruption of the wind from buildings and vegetation. The wind speed exposure for these poles was likely greater than most of the other poles (Figures 5 and 10 of Appendix G).

Video BOE_4_5_2019 shows that poles 12 and 13 failed first. It also shows the northward sequential failures of poles 11 through 6. The dynamic loads created by wire tension and falling poles is very significant and explains the continued failure of several poles; even poles with no decay at the north end of the line. The propagation of failures eventually ended at pole 1.

The Museum of Flight video (MOF 04.05.19 power lines and poles fall) shows pole 18 and 19 failing sequentially by a longitudinal line tension coming from north of their location. A validation of the significant additional dynamic loading created by poles falling and that the failures also propagated southward from poles 12 and 13 to pole 26. Pole 26 was the last pole in the line on that side of the street so there were no neighboring inline poles that were affected by the failure of pole 26.

8. Conclusion

The original designs of the 26 poles when installed surpassed the requirements of the National Electrical Safety Code (NESC). The weather report provided by Dr. Bond projected an upper limit of actual wind speed to be 50 mph during the storm. When these poles were initially installed, the new pole bending capacity of all poles in the line exceeded the loading that a 50-mph wind would cause.

The main issue for this line turned out to be a group of sequential poles that had significantly reduced strength due to internal groundline decay. The poles were classified as P2's during the 2016 inspection but that Seattle City Light designation covers a remaining strength ranging from 75% down to greater than 25%. Poles 8 through 13 were near the middle of the failed poles and all were in the lower range for P2's. Poles 12 and 13 failed first which created significant additional dynamic loading for poles to the north and south causing sequential failures of an additional 13 poles to the south and 11 poles to the north including 9 poles with no groundline decay.

This report and appendices are based on a reasonable degree of engineering and wood science certainty, based on forensic review in the Seattle City Light pole yard, based on my expertise in the National Electrical Safety Code (NESC), based on the documents reviewed and cited in this report, and based on my experience with wood utility pole inspection and maintenance.

I reserve the right to add, amend, or change details or opinions should further information be made available for my review or come to my attention.

Respectfully submitted,

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