kpff Consulting Engineers

Oregon Zoo Cascade Stream & Pond Exhibit

Structural Condition Assessment of Cable-Supported Roof
July 20, 2010

Introduction

In June 2010, the Oregon Zoo retained KPFF Consulting Engineers to determine the existing condition of the structural wood poles and structural steel cables supporting the steel mesh roof above the Cascade Stream & Pond Exhibit. KPFF's scope of work included a review of the existing architectural and structural drawings, a field reconnaissance of the exterior enclosure, any limited calculations as needed to support our findings, and this report summarizing our findings. Original structural calculations for the exterior enclosure were not available for review and indeed may no longer exist. Our review and the findings presented herein are limited to the structural wood poles and structural steel cables of the exterior enclosure and their connections, and only to those conditions that could be visually observed – areas concealed from view and the remainder of the exhibit is not a part of this assessment. An appendix has been included to show all of the figures referenced in the body of this report.

Structure Description

The Cascade Stream & Pond Exhibit, located within the Great Northwest section of the Zoo, was completed in 1982. The Exhibit includes a single-story building of approximately 4,500 square feet abutting an exterior enclosure to the west and south. The building consists primarily of wood frame construction at the roof supported by reinforced concrete bearing walls, and houses various indoor spaces for animals and the viewing public, animal holding and keeper support. The exterior enclosure consists of steel mesh fabric and secondary steel wire rope cables at the roof supported by primary tensioned steel wire rope cables that span between vertically-oriented 12"-diameter (approx.) pressure-treated wood poles at various locations around the perimeter. The wood poles range in height from 10'-0" to 31'-0" and are restrained at the point of roof cable anchorage by single or double steel guy-wires that extend and anchor to grade or to the building structure. The exterior enclosure covers the aviary and beaver portions of the Exhibit. See Figures 1 and 2 showing the exterior enclosure work completed in 1982.

In 2006, the Zoo engaged the services of WDY, Inc., to relocate the guy-wire anchors for two of the poles that would have otherwise encroached into the new Black Bear Ridge Exhibit completed in 2007 just to the west of the Cascade Stream & Pond Exhibit. As part of that work, the Zoo replaced the anchorage of both the guy-wires and the exhibit roof cables with a galvanized steel cap that fits over the top of the two poles. See Figures 3 and 4 for this limited anchorage work completed in 2006.

Drawing Review

The following existing architectural, landscape and structural drawings were reviewed:

- Drawings A-1 through A-14 by Jones & Jones Architects, stamped "As Built" and dated December 28, 1982.
- Drawings L-1 through L-13 by Jones & Jones Architects, stamped "As Built" and dated December 28, 1982.

- Drawings S-1 through S-7 by KPFF Consulting Engineers, stamped "As Built" and dated December 28, 1982.
- Drawing SK-5 by WDY, Inc., dated May 9, 2006.

Of note, sheet L-13 of the 1982 landscape drawings show the guy-wires and exterior enclosure roof cables to be anchored into the tops of the wood poles with the aid of a 10-gage thick by 3½-inch wide galvanized steel strap wrapped around the circumference of the pole and secured to the pole with three lag bolts. Field observations showed this as-built condition to be different than as indicated in the drawings; the actual condition is as described in the *Observations* section below.

Additionally, sheet L-13 also shows the tops of the poles to be beveled at a 30-degree angle, presumably to discourage water from falling rain and snow from infiltrating the top of the pole. The drawings do not indicate that the tops of the poles were to be treated in any way to help mitigate against water infiltration.

Except for the anchorage of the guy-wire for Pole K, which is described by detail A/S-7 of the 1982 structural drawings as an eyebolt affixed to a TS4x4x1/4 post which is bolted to a vertical wood truss member at the building roof, the as-built drawings available do not provide details of the anchorage of guy-wires into surrounding substrate. In most cases, the guy-wires were observed to be anchored into concrete deadmen at grade. The 1982 landscape drawings do refer to a structural sheet S-1A for information regarding the concrete deadmen at grade; however, this sheet was not found and therefore could not be reviewed. Sheet S-7 indicates that the guy-wires for Poles J, N, P, A and F were to be anchored to the building structure by use of an eye nut affixed to one of the 5/8-inch diameter bolts at the wood roof truss connection plates (e.g., reference detail B/S-4). Sheet S-7 further indicates that roof cables at Points L and M were to be anchored to the building structure by use of an eye nut affixed to one of the 5/8-inch diameter bolts at the perimeter glulam beam connections (reference details Q and R/S-6).

The structural design loads are shown on sheet S-1 of the 1982 structural drawings. While the design code is not mentioned, it is assumed to be the 1979 edition of the Uniform Building Code (UBC). Except for seismic loads, the code-prescribed design loads from the 1979 UBC are not significantly different than those of the current 2010 Oregon Structural Specialty Code. Code-prescribed seismic design loads have been significantly increased in Western Oregon since the original 1982 construction; however, the exterior enclosure structure is very lightweight and its required strength is therefore unlikely to be impacted by these higher seismic design forces.

Observations

A cursory walk-through of the exterior enclosure was conducted with Randy Whitworth of the Oregon Zoo on June 15, 2010. The purpose of this cursory walk-thru was to obtain a general understanding of the layout of the enclosure and to determine the accessibility for subsequent visual inspection.

A detailed walk-through of the exterior enclosure was conducted on July 1, 2010. Our visual assessment included looking for signs of decay, signs of possible insect damage, and other distress or damage. Our tactile assessment consisted primarily of prodding the wood structural elements with a 6-inch long flathead screwdriver near any point that appeared to be decayed or susceptible to decay. In all cases, the anchorage of the enclosure roof cables and guy-wires to the tops of the wood poles was observed to be constructed by either directly securing screw eye bolts into the wood poles or (more often) by thru-bolting an eye bolt to an eye nut at the opposite side of the pole. This is a departure from the use of a 10-gage thick by 3½-inch wide galvanized steel strap wrapped around the circumference of the pole as is shown on the 1982 as-built drawings. Also,

although not explicitly measured, many of the poles appeared to have tops with a beveled angle less than the 30-degrees specified in the 1982 as-built drawings.

The following are comments regarding the structure that could be observed. Pole and anchorage point identification letters follow those indicated on the 1982 structural drawings. Photographs are included in the appendix as the figures mentioned.

General

While not explicitly measured, enclosure cable sag was observed to far exceed the values indicated on the 1982 as-built drawings. The sag values on the 1982 assume a 10 psf ice load, which was not present at the time of observation. Furthermore, when pulled laterally, several guy-wire cables were observed to flutter significantly, which may indicate that the wood poles are resisting a significant portion of the enclosure roof reactions in bending that should otherwise be resisted in guy-wire tension. It is probable that the wood posts were not specifically designed to resist these reactions in bending.

The enclosure cables were observed to be wrapped in vinyl sheathing. However, in various locations along their length, this sheathing was torn and the exposed cables were observed to be rusting (see Figure 3). Also, while mostly concealed by a black vinyl material, presumably in an effort to protect them from rain, the steel rings and swage sockets used at cable intersections were observed to be rusting (see Figure 4).

Pole A

See Figures 5 and 6. Significant decay was visible at the top of Pole A. While tactile assessment was not possible due to an inability to reach the top of the pole from the enclosure roof, a large pit has formed in the center of the pole and is collecting fallen debris from nearby trees. The roof cable and guy-wire anchorages appeared to be in good condition except all enclosure and guy-wire sockets were observed to be exhibiting minor rusting. The guy-wire was observed to anchor into a different building truss panel point (western hip) than that indicated on sheet S-7 of the 1982 structural drawings (eastern hip). It is unknown if the final building design took into account this revision. The base of Pole A was not observed.

Pole B

See Figures 7 and 8. Significant dry rot was not visible at the top of Pole B and the wood provided significant resistance to the screwdriver tip. Significant distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the enclosure side) was observed, causing the eye nut to be skewed downward with the force from the enclosure cables. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has either fractured or bent within the body of the pole. On both sides, the hole through the pole has elongated to such a degree that it was visible behind the washer and the screwdriver could be pushed into the hole – this would indicate a dowel bearing failure of the wood, possibly initiated by internal dry rot. Both guy-wire sockets were observed to be exhibiting minor rusting. Neither the base of Pole B nor the anchorage of its guy-wires into the deadmen at grade was observed.

Pole C

See Figures 9 through 11. Significant decay was observed at the top of Pole C that included deep pitting, and the screwdriver was easily pushed into the top of the pole over its full shaft length. Significant distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the guy-wire side of the pole) was observed, causing the eye nut to be skewed downward with the force from the guy-wires. This distortion was not observed at the opposite (enclosure) side of the pole, suggesting

that the bolt has either fractured or bent within the body of the pole. On the guy-wire side of the pole, the hole through the pole has elongated to such a degree that it was visible behind the washer and the screwdriver could be pushed into the hole – this would indicate a dowel bearing failure of the wood, possibly initiated by internal dry rot. Both guy-wire sockets and two of the enclosure cable sockets were observed to be exhibiting minor rusting. Neither the base of Pole C nor the anchorage of its guy-wires into the deadmen at grade was observed.

Pole D

See Figures 12 through 14. The top of Pole D was capped in accordance with drawing SK-5 by WDY, Inc., dated May 9, 2006, except that a shear plate was added to receive the anchorage for the enclosure cables in lieu of the through-thickness eye bolt shown on SK-5. It was not possible to ascertain the condition of the wood pole beneath the galvanized steel cap. The cap assembly and cable anchorages appeared to be in good condition except that both guy-wire swage sockets are exhibiting minor rusting. Neither the base of Pole D nor the anchorage of its guy-wires into the deadmen at grade was observed.

Pole E

Neither Pole E, its guy wire, nor the anchorage of its guy-wire into the deadman at grade was observed in detail. From a distance, it was noted that the top of the pole was capped in the same manner as Pole D.

Pole F

See Figures 15 through 18. Visible decay was observed at the top of Pole F and the screwdriver could be pushed into the top of the pole approximately 3 inches. A large split was observed to extend approximately 3 feet from the top of the pole. The split is located away from the eye bolt and nut anchors and therefore would not be expected to adversely impact the strength of the cable and guy-wire anchorage; however, the width of the split allows water to easily reach the untreated core of the pole. Some distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the enclosure side of the pole) was observed, causing the eye nut to be skewed slightly from the enclosure cable forces. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has bent within the body of the pole. Some localized dowel bearing failure of the wood from the off-axis loading on the eye bolt was observed. Minor rusting of the guy-wire and enclosure cable sockets was observed. Some minor splintering at the soil line was observed at the base of Pole F. The anchorage of the guy-wire to the adjacent building roof was not observed.

Pole G

See Figures 19 and 20. A large through-thickness split, parallel to and intersecting the enclosure anchorage eye bolt, was observed to extend many feet from the top of Pole G. The cause of the split was likely a combination of severe dry rot at the top of the pole and lateral dowel bearing between the eye bolt and pole due to a significant difference between the direction of the enclosure cable tension load resultant and guy-wire axis. The split was observed to be approximately 1½ inches wide and, with any significant ice or snow loads acting on the roof mesh, may result in sudden detachment and collapse of this corner of the enclosure roof. Some distortion of the tail end of the threaded eye bolt was observed, suggesting that the bolt has bent within the body of the pole. Minor rusting of the guy-

wire and enclosure cable sockets was observed. There were no outward signs of decay at the base of Pole G. The anchorage of the guy-wire to the adjacent building roof was not observed.

Pole H

See Figures 21 through 23. A pit of visible decay was observed at the top of Pole H where the screwdriver could be pushed into the top of the pole approximately 2 inches. Some distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the enclosure side of the pole) was observed, causing the eye nut to be skewed downward from the enclosure cable force resultant. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has bent within the body of the pole. Some localized dowel bearing failure of the wood from the off-axis loading on the eye bolt was observed. Minor rusting of the enclosure cable sockets was observed. Neither the base of Pole H nor the anchorage of its guy-wire into the deadman at grade was observed.

Pole I

See Figures 24 and 25. While not visibly evident, significant dry rot was discovered at the top of Pole I as the screwdriver was pushed approximately 5 inches into the top of the pole. Some distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the enclosure side of the pole) was observed, causing the eye nut to be skewed downward from the enclosure cable force resultant. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has bent within the body of the pole. Some localized dowel bearing failure of the wood from the off-axis loading on the eye bolt was observed. Minor rusting of two of the enclosure cable sockets was observed. There were no outward signs of decay at the base of Pole I. The anchorage of the guy-wire to the deadman at grade was not observed.

Pole J

See Figures 26 and 27. Significant decay was observed at the top of Pole J, and the screwdriver was easily pushed into the top of the pole over its full shaft length. Some distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the enclosure side) was observed, causing the eye nut to be skewed downward from the enclosure cable force resultant. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has bent within the body of the pole. Some localized dowel bearing failure of the wood from the off-axis loading on the eye bolt was observed. Minor rusting of one of the enclosure cable sockets was observed. There were no outward signs of decay at the base of Pole J. The anchorage of the guy-wire to the building roof structure was concealed and could not be observed. The anchorage of the guy-wire to the deadman at grade was not observed.

Pole K

See Figures 28 and 29. Visible decay was observed at the top of Pole K and the screwdriver was easily pushed into the top of the pole over its full shaft length. The roof cable and guy-wire eye bolt and nut anchorages appeared to be in good condition except all three swage sockets on the enclosure side are exhibiting minor rusting. The base of Pole K was not observed. The anchorage of the guy-wire into the building roof structure was concealed and could not be observed.

Point L and Point M

The anchorage of the enclosure cables to the building perimeter at Point L and at Point M was not accessible and therefore was not observed in detail.

Pole N

See Figures 30 and 31. Significant decay with deep pitting was observed at the top of Pole N, and the screwdriver was easily pushed into the top of the pole over its full shaft length. Although not reflected on the 1982 as-built drawings, an enclosure cable was found to extend from the top of Pole N to the top of Pole P. This additional cable is threaded through and anchored to the sling link at Pole N by use of a single cable clip acting in bearing on the link and other cable sockets – this was likely not an engineered solution. Except for minor rusting of some enclosure cable sockets, cable anchorage generally appeared to be in good condition. At some of the enclosure cables in the vicinity of Pole N, the vinyl sheathing was observed to have torn or disengaged from the socket, resulting in rusting of the cable. The base of Pole N was not observed. Except for some minor rusting of the cable sockets, the anchorage of the two guy-wires into the building roof structure appeared to be in good condition.

Pole P

See Figures 32 through 35. Significant decay with deep pitting was observed at the top of Pole P. The enclosure cable from Pole P to Pole N (see "Pole N" above) was found to be severed near Pole P – it is apparent that, as with Pole N, this cable was previously threaded through and anchored to the sling link via the use of a single cable clip since the clip is still embedded within the link. Some distortion of the eye end of the threaded eye bolt was observed, causing the eye bolt head to be skewed downward with the force from the enclosure cables. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has bent within the body of the pole. On the enclosure side, the hole through the pole has elongated to such a degree that it was visible behind the washer and the screwdriver could be pushed into the hole, indicating a dowel bearing failure of the wood, possibly initiated by internal dry rot. Some minor rusting of the guy-wire and enclosure cable sockets was observed. It appears that the guy-wire anchorage was relocated from the building roof to the top of the concrete retaining wall beyond at some point after the original construction; to reach the retaining wall, the guy-wire has been extended with a 5/16-inch diameter cable connecting to a turnbuckle via a thimble and cable clips. It is unknown whether the concrete retaining wall or the anchorage of the 5/16-inch cable extension can withstand the additional 4.75 kip guy-wire design tension load indicated in the 1982 structural drawings, and drawings of the retaining wall were not reviewed. The base of Pole P was not observed.

Pole Q

See Figures 36 through 38. Significant decay was observed at the top of Pole Q, and the screwdriver was easily pushed into the top of the pole over its full shaft length. Minor rusting of the guy-wire and enclosure cable sockets was observed. The base of Pole Q was not observed. The anchorage of the guy-wire to the deadman at grade was not observed.

Pole R

See Figures 39 through 42. Significant decay with deep pitting was observed at the top of Pole R, and the screwdriver was pushed into the top of the pole nearly its full shaft length. Significant distortion of the tail end of the threaded eye bolt (as it connects into the eye nut on the enclosure side) was observed, causing the eye nut to be skewed downward with the force of the enclosure cables. This distortion was not observed at the opposite (guy-wire) side of the pole, suggesting that the bolt has either fractured or bent within the body of the pole. On the enclosure side, the hole through the pole has elongated to such a degree that it was visible behind the washer and the screwdriver could be

pushed into the hole, indicating a dowel bearing failure of the wood, possibly initiated by internal dry rot. Minor rusting of the guy-wire and enclosure cable sockets was observed. Some minor splintering at the soil line was observed at the base of Pole R. The anchorage of the guy-wire to the deadman at grade was not observed.

Pole X

See Figures 43 and 44. The top of Pole X could not be reached from the enclosure roof and therefore was not observed. Significant distortion of the tail end of the threaded eye bolt on the enclosure side was observed, and the eye nut was skewed downward with the force of the enclosure cables, suggesting that the bolt has either bent within the body of the pole. Accordingly, the hole through the pole has elongated to such a degree that it was visible behind the washer, indicating a dowel bearing failure of the wood. Minor rusting of the enclosure cable sockets and ring was observed. The eye bolt and anchorages of the guy-wires to the eye bolt was not visible from the enclosure roof and therefore were not observed. There were no outward signs of decay at the base of Pole X. The guy-wires and their anchorage to the deadmen at grade appeared to be in good condition. As indicated on the 1982 landscape drawings, Pole X was fitted with a sheave and winch to lower the portion of enclosure roof immediately adjacent to it; however, due to the height of Pole X (approximately 31 feet from grade to sheave) and the minimal slack of the enclosure cables spanning to adjacent Pole A and Pole G, it is unlikely that the roof mesh could be lowered enough to provide access without a lift or tall ladder.

Conclusions and Recommendations

As indicated in the observations above, significant decay was observed throughout the exterior enclosure structure of the Cascade Stream & Pond Exhibit. This decay threatens the continued longevity of the enclosure, and prolonged inaction could result in partial collapse of the enclosure roof and potential injury to the animals or persons within the Exhibit.

At Pole G, the large through-thickness split at the top of the pole is imminently jeopardizing the structural integrity of the associated enclosure roof anchorage. Ice or snow loading on the adjacent portion of enclosure roof could cause the anchorage to detach from the pole and result in a partial collapse of the roof, thereby endangering occupants below. Accordingly, we recommend that the deterioration of Pole G be addressed as soon as possible by removing the top portion of the pole and refitting the connecting roof enclosure anchorage (see Recommendation 4a below), or by replacing the pole in its entirety (see Recommendation 4b below). Please note that either solution will require structural design in conformance with the current Oregon Structural Specialty Code, the completion of which is beyond the scope of this report.

We further recommend that the 5/16-inch cable extension, its connections, and the concrete retaining wall to the east of the building be evaluated for the additional 4.75 kip guy-wire design tension load from the anchorage of Pole P.

For the remaining elements of the enclosure structure and its anchorage, we recommend the following measures be undertaken. In all cases, new structural elements would need to be designed in accordance with the current Oregon Structural Specialty Code, the completion of which is beyond the scope of this report.

1. Even though the poles were pressure treated prior to construction and only minimal signs of decay at the base of the poles were evident during our visual and tactile observation, the base of the poles are exposed to soil and moisture, and extensive dry rot may still exist within their cores. The base of all poles should be thoroughly tested for the presence of dry rot via resistance drilling, and the results

should be reviewed and evaluated by a structural engineer. If extensive dry rot is found, complete replacement of that pole is warranted.

2. Replace all rusting cables, guy-wires, cable and guy-wire fittings, rings, and links with galvanized hardware of equivalent capacity.

3. Where feasible, depending upon the extent of decay, temporarily remove enclosure cable and guy-wire anchorages and carve out dry rot within the cores at the tops of the poles to expose sound wood within the core. Plug the hole with solid wood, fill interstitial gaps with epoxy, and provide an even surface to the top of the pole via sanding or other means to ensure proper bearing. Add a galvanized steel cap similar to that provided at the tops of Poles D and E in 2006, and reattach the enclosure cables and guy-wires to the cap. See Figure 45; however, please note that that this sketch is not meant for construction and is only presented to clarify the scope of work involved with this recommendation.

4. Where Recommendation 3 is not feasible due to the extent of decay or splitting found at the top of the poles, either: a) cut the pole at base of the dry rot, provide an even surface to top of the cut to ensure proper bearing, add the galvanized steel cap as mentioned in Recommendation 3, and reattach the cables and guy-wires, or; b) replace the pole in its entirety.

Respectfully submitted,

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Associate

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OREGON
MARCH 9, 2004
JASON M. THOMPSON
EXPIRES: 6.30.12

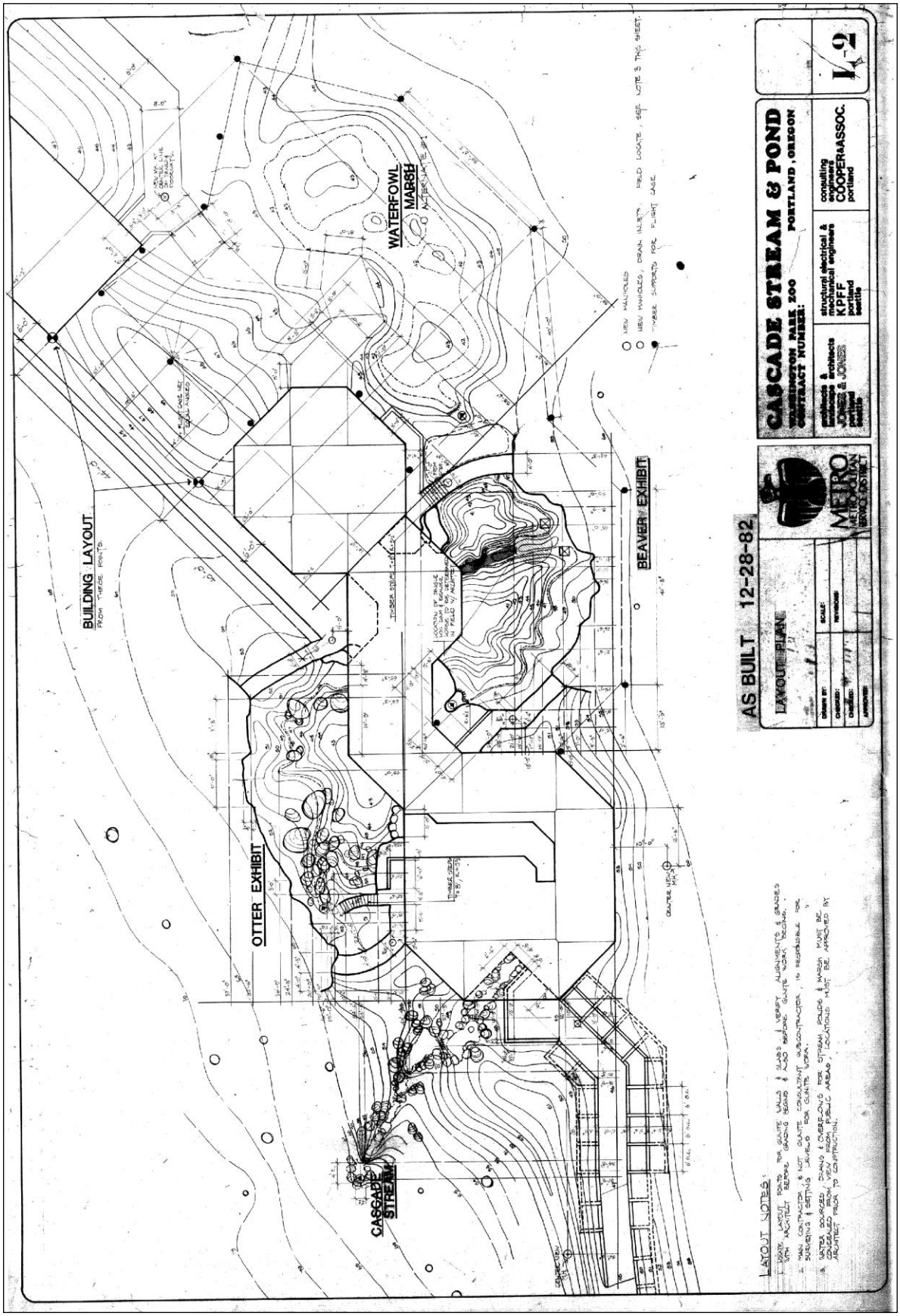

Figure 1 – 1982 Landscape Layout Plan

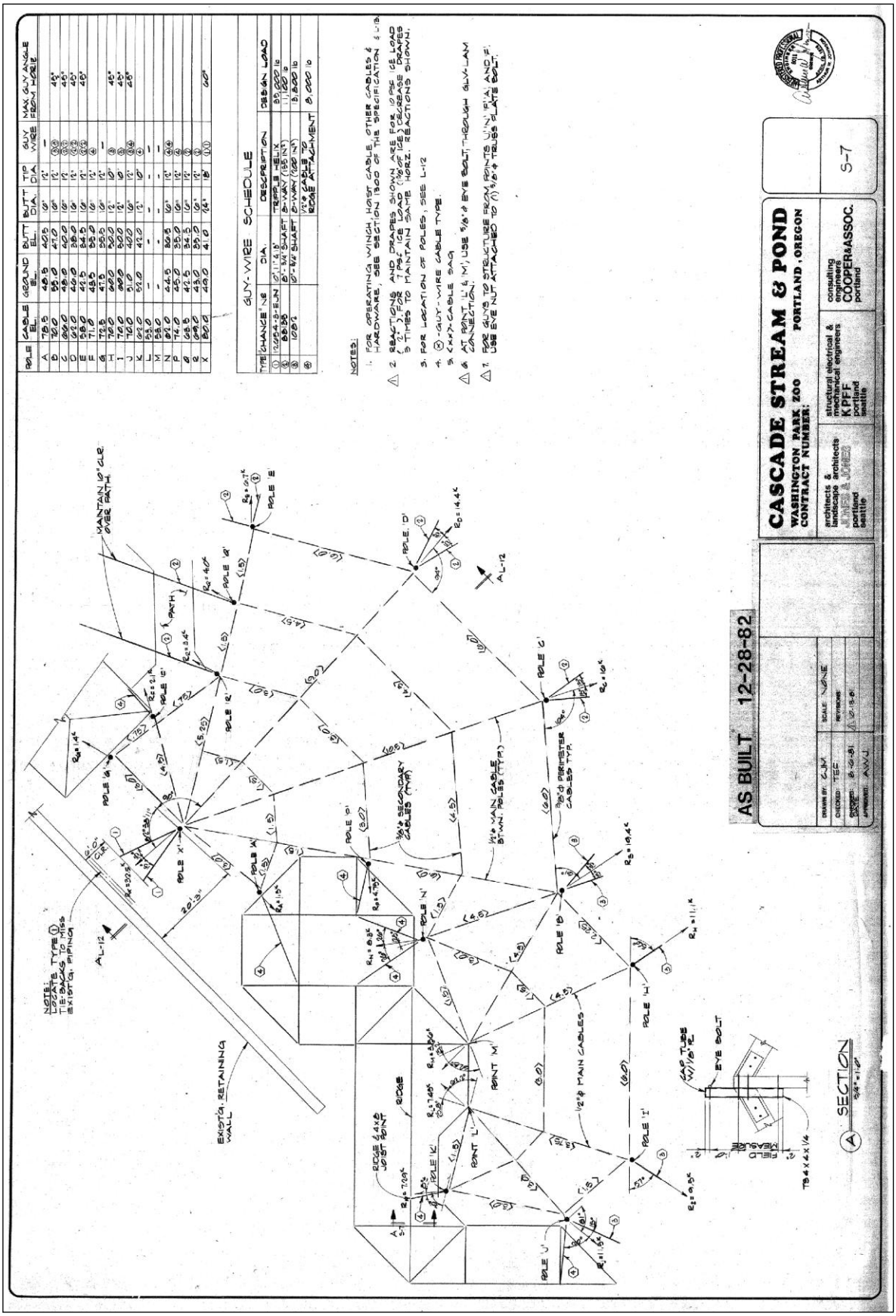

Figure 2 – 1982 Exterior Enclosure Structural Plan

Figure 3 – Tear in Cable Sheathing, Corrosion in Cable

Figure 4 – Typical Cable Intersection

Figure 5 – Decay at Top of Pole A

Figure 6 –Enclosure Cable Anchorage at Pole A

Figure 7 – Top of Pole B

Figure 8 – Enclosure Cable Anchorage at Pole B

Figure 9 – Decay at Top of Pole C

Figure 10 – Guy-Wire Anchorage at Pole C

Figure 11 – Enclosure Cable Anchorage at Pole C

Figure 12 – Top of Pole D

Figure 13 – Enclosure Cable Anchorage at Pole D

Figure14 – Guy-Wire Anchorage at Pole D

Figure 15 – Decay at Top of Pole F

Figure 16 – Guy-Wire Anchorage at Pole F

Figure 17 – Base of Pole F

Figure 18 – Enclosure Cable Anchorage at Pole F

Figure19 – Decay and Enclosure Cable Anchorage at Pole G

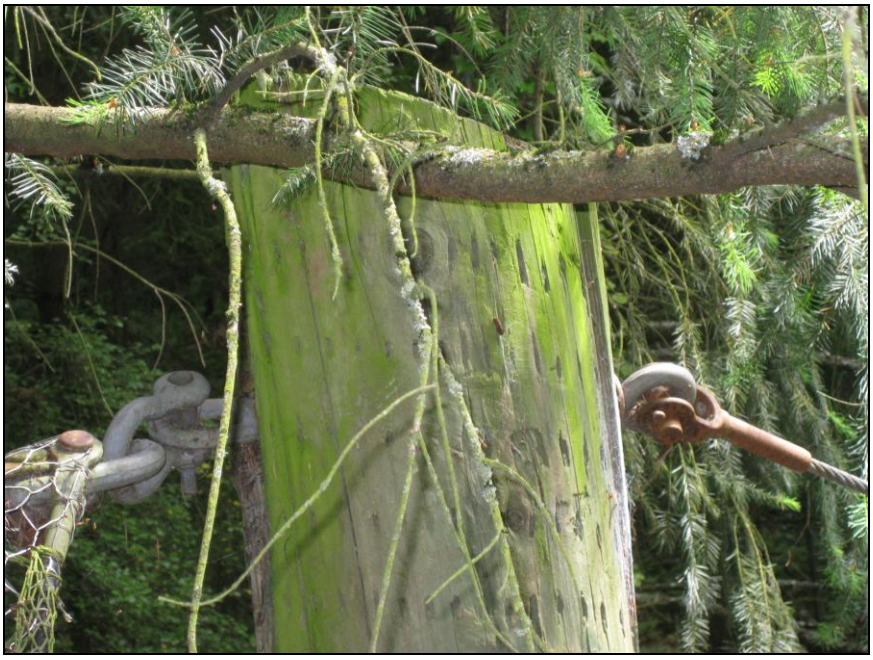

Figure 20 – Enclosure Cable and Guy-Wire Anchorage at Pole G

Figure 21 – Decay at Top of Pole H

Figure 22 – Enclosure Cable Anchorage at Pole H

Figure 23 – Guy-Wire Anchorage at Pole H

Figure 24 – Decay at Top of Pole I

Figure 25 – Guy-Wire Anchorage at Pole I

Figure 26 – Decay and Enclosure Cable Anchorage at Pole J

Figure 27 – Guy-Wire Anchorage at Pole J

Figure 28 – Enclosure Cable Anchorage at Pole K

Figure 29 – Guy-Wire Anchorage at Pole K

Figure 30 – Guy-Wire Anchorage at Pole N

Figure 31 – Decay and Cable Anchorage at Pole N

Figure 32 –Decay at Pole P

Figure 33 – Enclosure Cable Anchorage at Pole P

Figure 34 –Guy-Wire Extension at Pole P

Figure 35 – Enclosure Cable Anchorage at Pole P

Figure 36 – Decay at Top of Pole Q

Figure 37 – Enclosure Cable Anchorage at Pole Q

Figure 38 – Guy Cable Anchorage at Pole Q

Figure 39 – Enclosure Cable Anchorage at Pole R

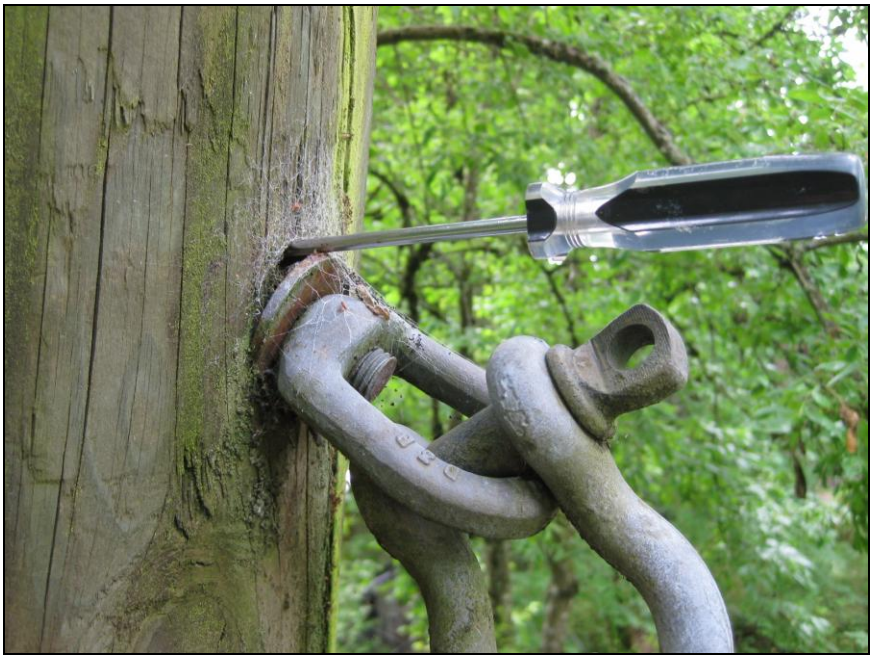

Figure 40 – Enclosure Cable Anchorage at Pole R

Figure 41 – Decay at Top of Pole R

Figure 42 – Base of Pole R

Figure 43 – Enclosure Cable Anchorage and Sheave at Pole X

Figure 44 – Enclosure Cable Anchorage and Sheave at Pole X

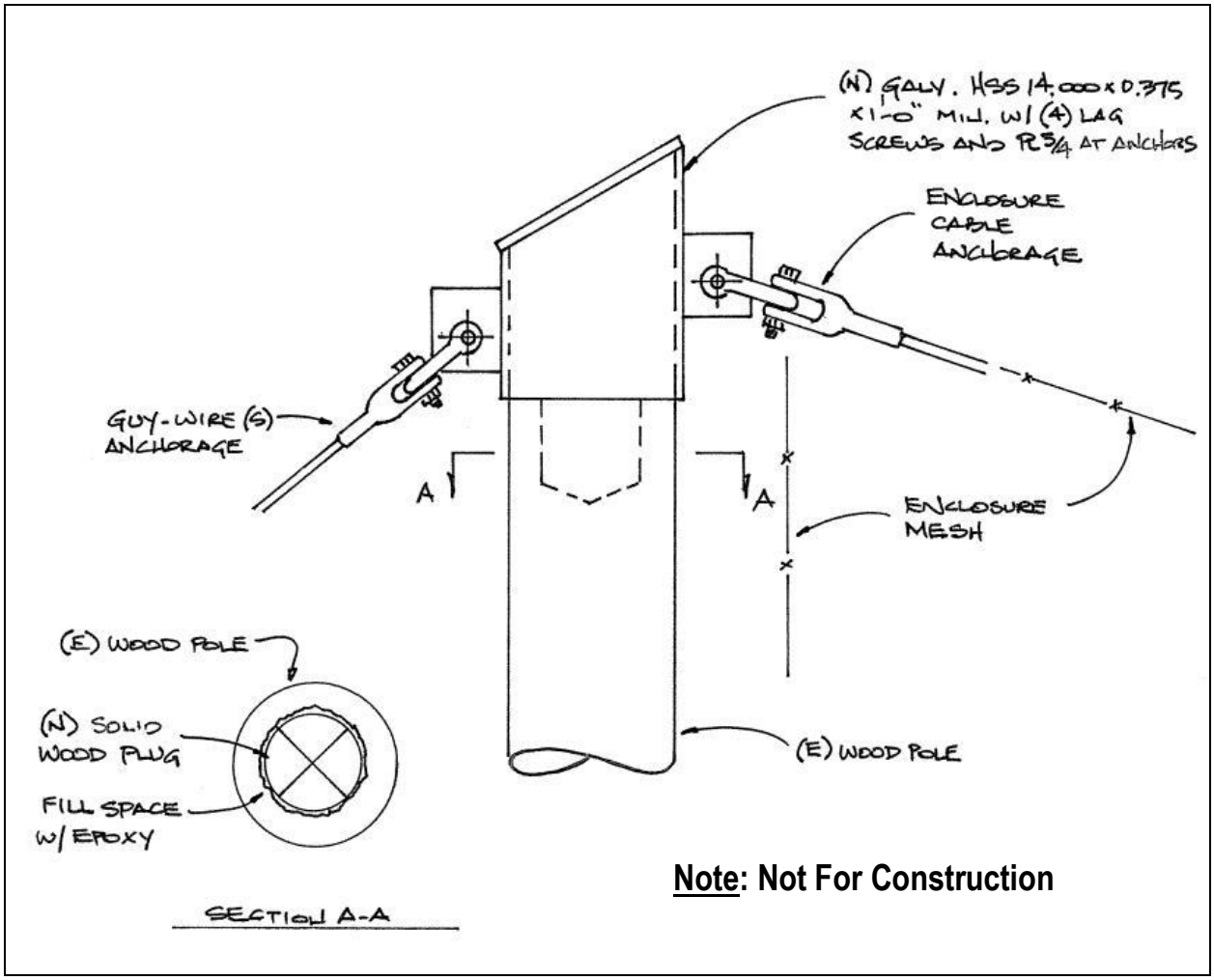

Figure 45 – Recommendation #3