PORT OF MOSES LAKE

Preliminary Condition Assessment & Structural Evaluation of Building 401 Primary Roof Structure

Prepared By:

JACOBS

Jacobs Engineering Group, Inc.

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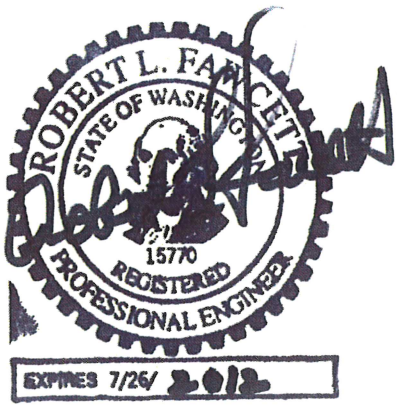

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EXECUTIVE SUMMARY

Building 401 is located at the Grant County International Airport. This building was constructed in 1942 and is currently being used as an airport hangar.

In 1998 the Port of Moses Lake retained Pacific Engineering & Design P.L.L.C. (PE&D) to evaluate the structural integrity of the Building 401. The opinion of PE& D was that the timber roof truss and lateral bracing system was failing. Their report recommended that the roof trusses and lateral system either be repaired or replaced.

Recently, the Port of Moses Lake has retained Jacobs Engineering Group to re-evaluate the structural condition and integrity of existing roof system of Building 401. This re-evaluation included reviewing as-built plans, reviewing the 1998 PE&D report, and performing a site visit to observe the current condition of the structural roof. Components observed were: roof trusses, lateral roof bracing, and associated connections. This re-evaluation also included an assessment of the structural capacity of these members and their connections considering the risks associated with the effects of checking, splitting, and cracking of these members.

Our review generally agrees with the 1998 PE&D bowstring truss findings. Our preliminary calculations indicate that even if no deterioration is present, the bottom chords and splice plates are overstressed when subjected to current code required design loadings. Many of these bottom chords and splice plates are not in pristine condition with a reduced capacity due to the splitting and cracking present in the connection areas. Because of limited redundancy of the roof structural system, a failure in any portion of the bottom chord, including the connections, carries the risk of complete progressive collapse of the building if the roof system is fully loaded to the current code mandated design loads.

Our review further indicates that portions of the lateral support system have failed due to broken "X" bracing and cracked wind struts, which has degraded the lateral capacity of the building.

Our review also indicates that the roof system has limited capacity to resist upward directed wind loads. Therefore it is important that hangar doors remain closed during wind storms and on windy days.

As a result of these deficiencies of the roof structure, we concur with the recommendations of the 1998 (PE&D) report that the roof structure should be repaired or replaced. We also have identified a promising truss repair method that can be installed with limited disruption during construction.

1.0. INTRODUCTION

Building No. 401 is an airport hangar located on the Grant County International Airport. The airport is operated by the Port of Moses Lake is located north of Moses Lake, WA. This building was constructed in approximately 1942.

Jacobs scope of work is to re-evaluate the condition and vertical load integrity of the roof structure of Building No. 401. The re-evaluation includes reviewing as-built plans, reviewing the 1998 PE&D report, and performing a site visit to observe the current condition of the structural roof. Components observed were: roof trusses, lateral roof bracing, and associated connections. This re-evaluation also includes an assessment of the structural capacity of these members and their connections considering the risks associated with the effects of checking, splitting, and cracking of these members.

References used by Jacobs in the structural assessment of the roof structure included the International Building Code (IBC) 2007, National Design Specification (NDS) for Wood Construction (2009), the American Institute of Timber Construction (AITC) Timber Construction Manuals of 1974 and 1985, the Naval Facilities Engineering Command (NAVFAC) Inspection of Wood Beams & Trusses Report NAVFAC MO-111.1 September 1985, and the Anti-Check Bolts as Means of Repair for Damaged Split Ring Connections Document by Quenneville and Mohammad, 1999.

A general overview was undertaken of the report titled "Building Structural Assessment Port of Moses Lake Building No. 401 Moses Lake Washington "dated May 15, 1998 prepared by Pacific Engineering & Design, P.L.L.C. (PE&D). PE&D visited the site, inspected portions of the structure, performed numerous calculations, and created two different repair procedures.

PE&D analyzed the roof trusses under the 1997 Uniform Building Code (UBC) for the following loads:

Roof Live (Snow) Load:	20 psf (plus snowdrift)
Wind:	70 mph Exposure C
Seismic:	Zone 2B
Frost Depth:	18 inches

PE&D assumed roof truss allowable stresses consistent with 1997 UBC values for Douglas Fir Larch No. 1 Post and Timbers.

Jacobs generally finds that the PE&D approach was appropriate for the time at which the report was generated. The International Building Code has replaced the Uniform Building Code and has undergone a series of changes. These changes do not have a substantial impact on the loadings previously analyzed.

2.0. STRUCTURE DESCRIPTION

Building number 401 is approximately 140' long by 200' wide. The wood roof structure is 1 by sheathing on 2 x 12 wood rafters supported on bow string roof trusses. The roof trusses in question span approximately 160 feet and are spaced at 20 foot on center.

The top (compression) chords of these trusses consist of continuous field fabricated curved glue-laminated wood beams. Each top chord is constructed of spaced double 5-1/4"x16-1/2" glue-lam beams. Each beam consists of 10 – 2x6's. that are glued together. Each bottom chord is constructed using spaced double 6x12 (nominal) sawn beams. Bottom chords are spliced at 6 locations on each side of the truss. Forces are transferred through these splices using 6" timber spacers between beams and 3" timber side plates that are bolted through with 4" diameter split ring connectors. Web members are typically comprised of 6x6 sawn members except for 6x8 diagonals adjacent to the truss king posts (i.e. centerline vertical web member).

Jacobs field measured several 6x12 bottom chords and web members and found the actual dressed size was smaller than the expected 5.5" x 11.5" standard dimensions. The bottom chords and the web members measured were typically 5.25" x 11.25".

3.0. FIELD OBSERVATIONS

3.1. HANGAR STRUCTURE

3.1.1. Roof Structure

Access to the roof structure was very limited during our observations. Airplanes were located around the perimeter of the structure and the man lift for inspection was not allowed to operate over any portion of an airplane.

The following roof structural observations were made by Jacobs during the May 2012 site visit and generally match the efforts made by PE&D in 1998. :

ELEMENT	JACOBS OBSERVATION	PE&D OBSERVATION
Roof rafters	A few broken and cracked roof rafters were observed.	Numerous broken and cracked roof rafters were observed.
Bow string truss top chord stitch bolts	Few loose stitch bolts were observed.	Loose stitch bolts are observed as typical.
Bow string truss top chord	Top chord appears to be in fair condition. No splits or checks noticed. Glue typically appeared brittle. Observed 2 foot long separated lower lamination near center of Truss F.	Top chord assessed as in fair condition. No splits or checks were noticed. Glue appeared brittle.
Bow string truss verticals and diagonals	Verticals and diagonals appear in good condition. However, a few members are twisted and a few split rings appear disengaged.	Verticals and diagonals were assessed as in good condition. A few members are twisted and a few split rings disengaged.

ELEMENT	JACOBS OBSERVATION	PE&D OBSERVATION
Bow string truss bottom chord heel connection	Limited access to heel connection. Observed only a few splits. No yielding at timber or steel plates observed.	Numerous splits noted. Assumed yielding of heel connection.
Bow string truss bottom chord side plate splice bolts	Side plate bolts and split rings are gapped between side plates and main bottom chord members at several locations.	Loose side plate bolts and split ring seen gapped between side plates and main bottom chord members.
Bow string truss bottom chord splice plate splits	Many side splice plate full depth splits and partial depth checks observed. Numerous splits occur along the entire or nearly the entire length of splice plates. Numerous splits are adjacent to the split ring connectors.	Many side splice plate full depth splits and partial depth checks observed. Some splits were continuous along entire length of splice plate.
Bow string truss bottom chord main members	Deep splits extend throughout the length of the splice region in close lateral proximity to the split rings at numerous locations. At several locations the split length apparently extends the entire length of the main member (approximately 20feet).	Crack and checks were observed at many locations throughout truss bottom chord members.
Bottom chord truss split summary	Observed splits in Trusses A –G.	Observed splits in Trusses B –G.
Bow string truss heel anchor bolts to concrete connection	Not observed due to lack of access.	Several loose anchor bolts observed.
Bow string truss lateral deflection of top and bottom chord	Lateral deflection observed at bottom chord is judged to be insubstantial. No top chord lateral deflection observed.	Observed "S" shaped configuration at both top and bottom chords.
Bow string truss "X" bracing	Observed racking between Truss A and B and Truss F and G.	Observed racking between Truss A and B and Truss F and G.
Framing sleeper 2x	Observed some sleepers that were bent and could possibly fall onto offices and floor below.	Observed bowed & twisted on verge of collapsing into the office structure below.
Wind bracing	Wind bracing struts between Truss A and B were observed to be cracked and failed.	Wind bracing struts between Truss A and B were observed to be cracked and failed.
Wind truss anchor bolts	No deficiencies observed, but 1998 photos confirm loose anchor bolts.	Anchor bolts were observed to be loose.
Pipe supports	Several pipe supports appear inadequate.	No comment.

The 1998 report included measurements of heel elevation and truss centerline elevation. Jacobs did not perform these measurements.

4.0. ANALYSIS

4.1. HANGAR STRUCTURE

LOADS;

The PE&D report indicates that the hangar structure was originally designed for a Basic Roof Load of 30 lbs per sq ft and a Basic Wind Load of 20 lbs per sq ft. These loads are consistent with the information presented on the as-built drawings. The PE&D report also indicates that these loads satisfy the then current Uniform Building Code (UBC) requirements enforced at the time of the report, except for wind loads. The report further indicates that the local snow load requirement is now 20 psf, which is consistent with the current City of Moses Lake code requirements.

Jacobs agrees in general with the live and dead loads presented in the PE&D report. The current wind load design requirements follow the International Building Code (IBC) guidelines. Although the IBC, which presents a more detailed wind loading criteria than the earlier UBC code, generally leads to the same wind load conclusions. It is also important to note that the wind analysis assumes that the hangar doors are closed during the design wind event. Leaving the hangar doors open risks increasing adverse wind effects on the roof.

ALLOWABLE STRESS:

The PE&D report lists several allowable stress values for the timber trusses as follows.

Extreme Fiber in Bending	= 1200 lbs per sq. in.(psi)
Horizontal Shear	= 100 lbs per sq. in.(psi)
Compression Parallel to Grain	= 1000 lbs per sq. in..(psi)
Tension Parallel to Grain	= 800 lbs per sq. in.(psi)

Except for the tension parallel to grain stresses, the above allowable stress values are consistent with the as-built drawings and the Douglas Fir Larch allowable stress values given in the AITC "Timber Construction Manual" (1974) and the current National Design Specification (NDS) for Wood Construction. Research into the historical stress values found that the allowable tensions parallel to grain values were first tabulated between 1966 and 1974. Based on the AITC "Timber Construction Manual" Second Edition (1974), as well as the current NDS, the truss bottom chords are classified as "Beams & Stringers" with an allowable tension stress parallel to grain of 675 psi. In our opinion this allowable tension stress is more appropriate than the 800 psi used by PE&D. As a result the 675 psi allowable tension parallel to grain stress was used in our preliminary calculation to assess the existing bottom chord load capacity. We increased the basic allowable stresses by the 15% duration of load stress increase allowed for snow load.

The PE&D report presents a Structural Analysis Summary identifying the live and dead load capacity and required live load capacity for roof sheathing, roof joists and various members of the Bowstring Truss.

Jacobs agrees with the PE&D report that in general the wood quality in 1942 was superior to that of the present time. The as-built drawings do not indicate grade or species of timber, though

grade stamps on timber members in Building 408 indicate WCLA Rules No. 1 was utilized. Given the amount of cracks and splits in the bottom chords and web members, in our opinion it is likely that the current condition of lumber grade and strength exhibit some degradation.

5.0. ASSESSMENT

5.1. HANGAR STRUCTURE

The PE&D report indicates that the roof joists are adequate to support roof live and dead loads with little deterioration present. Additionally, this report assessed the wood frame walls, reinforced concrete buttress, foundation and footings were generally found to be in adequate or good condition. These elements were not evaluated or observed by Jacobs as they were not included in our Scope of Work.

The PE&D report indicates that the bowstring trusses are adequate to support the required live load, if in good condition. However, there is extensive splitting of the bottom chord and splice plates and loose bolts, which leads to an elevated risk that the normal snow load could cause the chord to fail and potentially lead to a collapse of the entire roof structure.

The PE&D report indicates that the splits are a result of the wood drying out and causing the wood to shrink while the split rings and bolts restrained the affected wood members from shrinking. The report further indicates that the bolted heel connections with closely spaced bolts have led to additional splits in the bottom chord. The 1998 report recommends repairing or replacing the defective members.

The PE&D report also indicates that the lateral system has failed as evidenced by racked and broken "X" bracing, cracked wind truss struts, and other related failures.

Jacobs agrees in general with the conclusions of the PE&D report with the following exceptions:

1) In our opinion the structural capacity of the bottom chord and timber splice plates are inadequate to safely support either the original design live load of 30 psf or the code required 20 psf roof snow load based on good lumber without splits. This is primarily due to the allowable tensile stress that we determined to be appropriate.
2) Although the top chord stresses appear adequate to resist roof loads, the residual strength of the glue is questionable. Reduced glue adhesion strength could potentially degrade the top chord capacity. We recommend that the glue be evaluated to determine if the top chords have adequate capacity before any repairs are undertaken.
3) The PE&D report made no assessment of the capacity of the split ring connections. The capacity of the split rings will depend on the species and grade of wood and the proximity of the splits to the split rings. In our opinion when splits are located within 2 ¾ inches from the center of the split rings, which is the minimum 4 inch diameter split ring edge distance required by the NDS and the Timber Construction Manuals, then the capacity of the split rings would be reduced. Depending on the number of reduced capacity split rings at any given splice location; the bottom chord splice connection could control the roof load.

The PE&D report used standard nominal dimensions when computing member capacities. Measurements taken by Jacobs indicate that the members are actually incrementally smaller than the nominal dimensions used by PE&D, for example the area of a 6x12 bottom chord is reduced by about 7%. This reduction in member size leads to member capacities that are less than those determined by PE&D.

In conclusion Jacobs agrees that some of the bow string truss members have serious defects and may not be able to withstand the design roof snow loads unless repaired and/or replaced. Under full design dead and live loads, the bottom chord members and splice plate stresses exceed the critical allowable stresses even if the wood is optimistically assumed to be in good condition. Furthermore, the splits in the splice connection areas are serious and degrade the capacity of the splice. Because of limited redundancy of the bottom chord members, a failure in any one of the splices would lead to failure of the entire bottom chord and truss. Due to the lack of redundancy in the roof system, failure of any one of the trusses could lead to complete collapse of the roof structure.

We also caution that the capacity of the roof system to resist wind uplift loads is very limited. This issue is intensified if the hangar doors are left open during a wind storm. As such, it is critical that the hangar doors remain closed during wind storms and on windy days.

In addition we also observed roof pipe supports that appear inadequate to meet current code requirements.

The PE&D report on the condition of the buttress wall structure, foundation, and lean to structure are not in our Scope of Work, and therefore are not being addressed in this report.

6.0. RECOMMENDATIONS

6.1. HANGAR STRUCTURE

As a result of these deficiencies of the roof structure noted above, we agree with the recommendations of the 1998 (PE&D) report that the roof structure should be either repaired or replaced

In our opinion adding steel rods, plates, and/or channels along the full length on each side of the bottom chord, is a viable repair alternative if the top chord glue is found to be adequate. This will increase the vertical load capacity of the trusses to current code load levels. Additionally, we recommend further investigation and evaluation of the existing roof structure's lateral and uplift capacities during the final design.

A method as to how these added rods, plates, and/or channel may be installed without removing the roofing or damaging the existing bow string trusses with minimal shoring is summarized below:

1. Limit the bow string truss repair strengthening activities to the summer months to minimize risks of excessive roof loads due to snow during the repair. Snow and wind load history will need to be assessed to validate the maximum roof load during this work effort.

2. Connect new brackets to the existing truss shoes by incrementally and progressively removing and replacing a limited number of the existing 1 ¼" diameter heel connection bolts of a damaged truss.
3. The number of existing truss shoe bolts removed as brackets are installed will be predetermined and limited so as not to reduce bottom chord load carrying capacity below a reliably anticipated reduced summer month roof load demand.
4. Add new steel rods, plates, and/or channels for the full length on both sides of the bottom chord.
5. Connect the ends of the added rods or plates to the added brackets and tension as required.
6. Repeat steps 2 through 5 until all damaged truss bottom chords are repaired.
7. Replace and/or repair the damaged lateral bracing system.
8. Secure loose or damaged roof timber sleepers.
9. Upgrade deficient pipe supports that are attached to the roof structure.

APPENDIX A

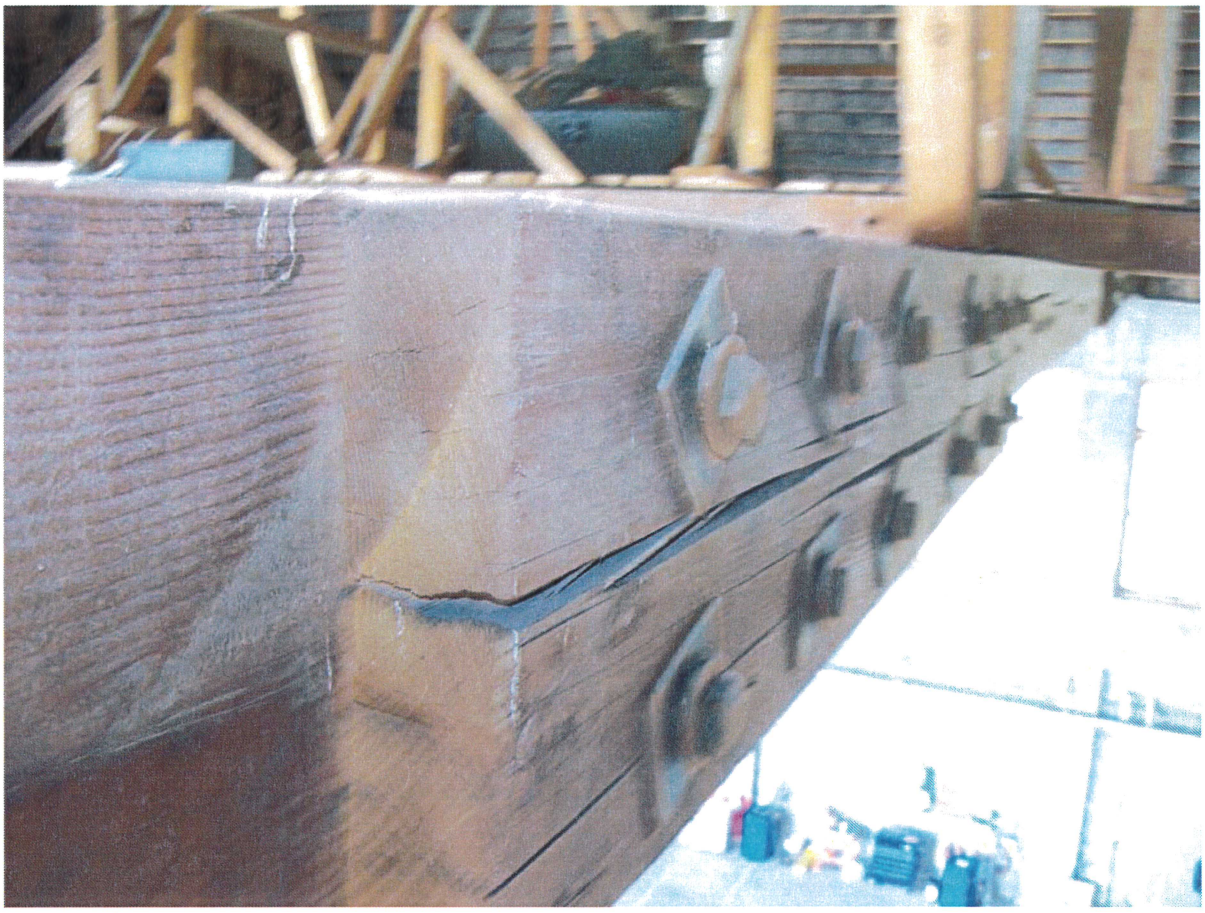
PHOTOGRAPHS

Checking in Bottom Chord (entire 20' length of board)

Longitudinal Splitting of Bottom Chord

Splitting Through Splice Plates

More splice plate splitting



More Splice Plate Splitting

Damaged top chord

Split diagonal

Additional Split Diagonals

Possible Splice Plate Movement

Broken Lateral Bracing

Racked and split lateral bracing

More split lateral bracing