500 West Big Beaver
Troy, MI 48084
troymi.gov

CITY COUNCIL AGENDA ITEM

Date: February 14, 2022

To: Mark F. Miller, City Manager

From: Robert J. Bruner, Assistant City Manager
Robert C. Maleszyk, Chief Financial Officer
Lisa Burnham, Controller
Kurt Bovensiep, Public Works Director
Brian Goul, Recreation Director
Dennis Trantham, Facilities and Grounds Operations Manager
Emily Frontera, Purchasing Manager

Subject: Standard Purchasing Resolution 5: Approval to Expend Budgeted Funds – Wagon Shop Repair Design and Construction Documents.

History

During the 1800s blacksmith shops were as common and as important as gas stations are today. This simple board and baton workshop was built at Troy Corners before the Civil War. Blacksmiths used the shop for decades. However, in 1947 the old building and adjacent farmstead became Gow's Little Acre, a collection of popular antique and gift shops. In February 1972, fire destroyed the farmhouse and singed the old wagon shop. Five years later Alex Gow retired, sold the northwest corner to a developer, and donated the deteriorated wagon shop to the Troy Historical Society. The Society raised funds to relocate the building to the Village in February 1978. Today skilled artisans continue to shape metal and wood in the shop using centuries-old tools and techniques.

The Wagon Shop is one of multiple buildings located within the Troy Historic Village campus. The Wagon Shop is used primarily March through November annually as interpretative space and as an active blacksmith shop. Classes are also held in the building to teach the art of blacksmithing.

Roof replacement was identified in the Facilities Condition Assessment and Analysis, conducted in 2018. The initial assessment by the City of Troy Facilities Staff and the Troy Historic Society identified possible structural concerns, including bowing of walls and missing knee walls. To better understand the condition of the structure, Facilities reached out OHM for a proposal to conduct a structural analysis and provide an opinion on the necessary repairs prior to the replacement of the roof.

Phase one, the structural analysis of the Wagon Shop by OHM, was approved at the October 11, 2021 meeting of the Troy City Council (Resolution #2021-10-148-J-e). On January 21, 2022 an onsite review of the report occurred and recommendations were made. The report revealed the need to remove the added loft area along with repairing and reinforcing structural elements that have failed for various reasons over time.

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Purchasing

The current contract with OHM Advisors (OHM) was adopted by City Council in 2017 for engineering and design services (Resolution #2017-06-105-J-4a). Under the current contract pricing, OHM proposes a fee of $17,000 for the development of design and construction documents, as per the attached detailed proposal.

Financial

Funds are budgeted and available in the Museum Capital Fund under Project Number 2022C0074 for the 2022 fiscal year. Expenditures will be charged to account number 401.804.804.7975.900.

Recommendation

City Management recommends granting the authority to expend budgeted capital funds to OHM Advisors (OHM), which is one of the City's professional service engineering firms (Resolution #2017-06-105-J-4a), for the Wagon Shop Repair Design and Construction Documents for a total estimated cost of $17,000 not to exceed budgetary limitations.

February 4, 2022

Mr. Dennis Trantham
City of Troy
Facilities and Grounds Operations Manager
4693 Rochester Rd.
Troy, MI 48085

RE: Proposal for Professional Services
Troy Historic Village – Wagon Shop

Dear Mr. Trantham:

In our original proposal to the City for this work, the first phase involved a study to assess the existing building conditions and provide recommendations, as required, for repairs to the building. That phase of the work has been completed and delivered to the City. We understand that the City would like to proceed to complete design documents for work to be completed by one of their contractors. In this proposal, we have outlined the scope of work, fee, schedule and terms and conditions.

This proposal's scope includes development of construction drawings and specifications to address the recommendations set forth in the attached report as reviewed on-site and a decision on approach to design made in January of 2022. The scope of work to include:

1. Remove the existing loft floor and install roof framing similar to the roof framing on the north half of the building.
2. Reinforce the distressed fractured and charred rafters at the southern half of the building.
3. Install cross-bracing at the set of northern rafters where existing cross-bracing is not secured to the rafters.
4. New support for bellows which is currently supported by the loft.

SCOPE OF SERVICES

Our Scope of Services for this work will be completed as one task:

Analysis and Repair Design of Roof structure.
During this task our team will continue the limited structural analysis of the roof framing. The roof framing on the south half of the building will be reviewed for the removal of the loft floor. Additional review of the new bellows support framing to be developed with the removal of the loft framing currently supporting it. One site visit to be included to review and verify existing geometry or conditions as the design is developed further.

Development of Construction Documents
During this task, structural drawings to express the design intent for the contractor's use in completing the repair effort will be prepared. Anticipated drawings to include:

- A title sheet with specifications in the form of general notes.
- A demolition drawing indicating which members are to be removed.
- A framing plan, sections and details of the new work to be constructed.

One formal design review on-site with contractor and final design drawings to be included during this phase.

COMPENSATION AND SCHEDULE

OHM Advisors will perform the outlined services above based for a lump-sum fee of $17,000, in accordance with our current contract with the City. OHM is able to begin work upon written authorization by the client with an estimated project schedule of 5 weeks.

No reimbursable expenses are expected or included in the fee. Neither the fee nor the schedule reflects unforeseen conditions that may arise. If unforeseen conditions are determined OHM will immediately notify owner if there is an impact to our fee.

ASSUMPTIONS, EXCLUSIONS & OWNER RESPONSIBILITIES

OHM Advisors is prepared to complete the work as outlined above per our understanding of the project, which includes the following assumptions, exclusions and identified Owner responsibilities.

- OHM Advisors point of contact for this project is Dennis Trantham
- Any additional reviews/meetings that might be required not specifically noted in this proposal will be billed on an hourly basis.
- Construction phase professional services are not included in this proposal.
- Non-structural elements/design are included such as roofing systems or flashing details.

ACCEPTANCE

Work will be done in accordance with the terms and conditions of the Continuing Services Agreement between OHM and the City. If this proposal is acceptable to you, please provide signature below or e-mail confirming us to proceed on the project.

Thank you for giving us the opportunity to be of service. We look forward to working with you on this project.

Orchard, Hiltz, & McCliment, Inc.	**City of Troy**
CONSULTANT	OWNER
(Signature)	(Signature)
Christopher Ozog	
(Name)	(Name)
Project Architect	
(Title)	(Title)
February 4, 2022	
(Date)	(Date)

Cc: Rhett Gronevelt

Wiss, Janney, Elstner Associates, Inc.
30700 Telegraph Road, Suite 3580
Bingham Farms, Michigan 48025
248.593.0900 tel
www.wje.com

January 14, 2022

Mr. Christopher Ozog
Project Architect
OHM Advisors
34000 Plymouth Road
Livonia, MI 48150

Troy Historic Village
Wagon Shop Structural Assessment
60 West Wattles Road, Troy, MI 48098
WJE No. 2021.5313

Dear Mr. Ozog:

As requested, Wiss, Janney, Elstner Associates, Inc. (WJE) performed a structural assessment of the Wagon Shop in the Troy Historic Village located at 60 West Wattles Road in Troy, Michigan. The primary purpose of our assessment and analysis was to evaluate the capacity of the roof for a planned roofing replacement effort and develop conceptual repair recommendations for any structural strengthening, if needed, for your consideration. This letter summarizes our findings and recommendations.

BACKGROUND

Building Description

The Wagon Shop is one of multiple historic buildings located within the Troy Historic Village campus. The Wagon Shop is used primarily during March through November each year as interpretive space and as an active blacksmith shop. Classes are held within the building to teach the art of blacksmithing. Located within the Wagon Shop, the bellows, used in the blacksmithing activities, are reported to be the oldest artifact on the campus.

The Wagon Shop (Figure 1) is a wood framed building that was reportedly constructed around the mid-1800s and relocated in the 1980s, after a fire event, from a local farm to the Troy Historic Village. The less than 1,000 square foot building has a gable roof with the ridge parallel to the longer sides of the rectangular footprint. A loft floor is located on the front (south) half of the building. A brick masonry chimney extends through the roof level at the west wall. There are larger window and door openings in the north and south gable end walls, and smaller window openings in the east and west bearing walls.

The gable roofing consists of cedar roof shingles supported on wood plank decking that spans between dimensional lumber rafters. Horizontal collar ties are located near the ridge at the south half of the building. At the north half, rafter ties are located at the rafter bearing elevation, and cross-bracing, located parallel to the rafters, is attached to the rafters. The roof is visibly displaced downward, most notably on the southern half of the roof.

Nominal 2x4 stud-framed knee walls are located 5-1/2 feet from the roof ridge in the loft area. The knee walls are supported on the wood plank flooring and underlying dimensional lumber joists of the loft level structure. The dimensional lumber loft floor joists span in the north-south direction between the south exterior wall and a timber beam located near the middle of the building. The timber beam has been reinforced with metal tension rods. The beam has mortise and tenon connections to timber columns located at the east and west side walls; additional 2x members have been added inset of the column surface at each end of the beam. The beam to column connection is located below the column and wall timber top plate connection. The tension rods are secured with washers and nuts against the exterior surface, at the top of the east and west side walls, and above the centerline of the interior beam.

The wood stud walls are sided with horizontal plank boards on the interior and vertical boards and batten system on the exterior. Timber top plates are present at the top of the east and west walls, and newer treated timbers are located at the bottom of the east and west walls. Similarly, a timber top plate and header is present above the door and windows at the south, gable end of the building, supporting the loft floor joists and dimensional lumber stud wall above. The north, gable end of the building is of similar construction as the south gable, though the wood header is comprised of three-ply dimensional lumber, spanning over a wide sliding door. A gutter and downspout are present on the east side of the building. The west bearing wall is visibly bowing outward.

The main level floor is an unfinished earth floor. A concrete masonry unit (CMU) foundation wall is exposed at the northeast corner of the building on the exterior.

Project Background

We understand there are plans to replace the cedar shake shingles with new roofing materials. Roofing materials being considered include new cedar shakes or a metal roof system. Concerns regarding the capacity of the existing roof structure to complete the roofing replacement project and visual observations of the condition of the center beam and side wall bowing prompted the request for a structural assessment and conceptual repair recommendations, if warranted.

FIELD ASSESSMENT

Mr. Justin Barden and Ms. Jordan Reinhardt, both of WJE, visited the site on November 15, 2021, to perform a visual assessment of the Wagon Shop. The assessment was limited to accessible portions of the roof structure where WJE measured and documented the geometry and detailing to complete a limited structural analysis. Pertinent observations from the assessment are as follows:

General Conditions

1. Multiple cedar shingles are damaged or missing. Vegetation growth is present on the roof shingles, and localized areas of decay is common along the edges of the shingles (Figure 2).
2. The roof ridge is visually displaced downward, with the south half of the roof exhibiting greater displacement than the north (Figure 3). Additionally, the rafters are deflected downward along their span most noticeably on the south half of the roof.
3. Localized char is present on multiple roof framing members, primarily within the south half of the building, though the center beam and perimeter top plates and headers also exhibit localized char (Figure 4). The measured char depth typically measures 1/16-inch, but extends up to 1/8-inch. Soot staining, but no char, is also present at some of the roof framing members.

Roof Framing

4. The roof framing supports cedar shingles that are attached to 3/4-inch wood plank decking. The roof framing is generally at an 8 on 12 slope and is approximately 7-foot in total depth, spanning approximately 23 feet between the east and west walls. The framing differs between the north and south halves of the building as described below. Refer to Figure 5 for general elevations of the two framing systems.
5. The original rafters are nominal 3x4 members spaced an average of 36 inches on-center. The collar ties, rafter ties, and cross-bracing are nominal 2x4 and 2x6 members.
    a. The north half of the building consists of eight sets of rafters, with newer, unpainted, members located between the painted original rafters, reducing the average spacing of the rafters to 18 inches on center. The painted rafters are typically 2-3/4 inches by 3-1/2 inches, and the unpainted rafters are typically 1-1/2 inches by 3-1/2 inches. The rafters of each set abut each other at the ridge; there is no ridge board. Nominal 2x6 rafter ties are secured to the rafter ends at the eaves. Nominal 2x4 cross-bracing, parallel to each rafter set, is secured to the rafter ends at the eaves and to the rafters at approximately 4-foot from the ridge, measured horizontally.
        i. At one set of rafters, both cross-bracing members are unsecured to the west rafter to accommodate the masonry chimney (Figure 6). The rafter is also notched to accommodate the chimney (Figure 7).
        ii. At the ridge, the vertical surfaces of the rafters, at the abutting ends, are not always painted (Figure 8).
        iii. The rafter ties are lapped and bolted together near mid span with four, 5/16 inch diameter bolts, except for the northmost rafter tie, which is bolted with five bolts (Figure 9).
    b. The south half of the building consists of four rafter sets. Nominal 2x4 collar ties are connected with three nails at each end. The ends of the collar tie are located approximately 3-feet from the ridge, as measured horizontally, to the original, 2-3/4 inch by 4-inch rafters. A nominal 2x4 knee wall is located near midspan of the rafters with the studs aligned with each rafter and a top and bottom plate consisting of nominal 2x4s.
        i. A set of rafters are fractured near 1x gusset plates at the ridge. The gusset plates are unique to this set of rafters. The gusset plates and the west rafter, at the fracture location, are charred up to 1/8-inch deep (Figure 10). While the rafter is charred around the fracture, the exposed fractured surface is not charred (Figure 11).
        ii. A gap is present between most rafters and the knee wall top plate (Figure 12). A gap also commonly exists between the top plate and studs or between the studs and the bottom plate (Figure 13). The nail shanks connecting the various components are visible in the gaps.
        iii. A stud is missing in the west knee wall (Figure 14).

Loft Floor Joists

6. The wood plank flooring of the loft is supported by nominal 2x8 joists spanning between the south exterior wall and center 7x7 timber beam. The joists are notched over the top of the center beam and wall top plate timber. The depth of the notch is approximately 1-1/4 inch (Figure 15), except where

the tension rods extend above the top of the center beam. In these areas, the joists were notched up to 3-inches around the tension rods (Figure 16).

7. Cross-bridging is located at midspan of the loft floor joists. (Figure 17).
8. A partial depth fracture is located near midspan of the fifth joist as counted from the east wall. The fracture extends from a knot on the bottom edge of the wood member where the fracture is widest (Figure 18).

Center Beam

9. The center beam is a hand-hewn timber reinforced with 1/2-inch diameter metal tension rods to create a composite "truss" with a 19-inch depth at midspan (Figure 19). The tension rods are secured with washers and double nuts at the top, exterior surface of the east and west walls and turnbuckles at midspan.
   a. The northwest tension rod is no longer in direct contact with the wood spacers located on the underside of the timber beam.
   b. There are two abandoned mortises on the underside, one at each end of the beam, suggesting knee braces or columns were once connected to the beam (Figure 20). Additionally, a ghosting of a past column is present near midspan on the underside of the beam (Figure 21).
   c. Checks are present in the underside and north faces of the timber beam (Figure 22).
   d. Surface char is present on the timber beam, intermittently along the span of the beam (Figure 23).
   e. A maximum beam deflection of 1-1/2 inches was measured referencing a datum, under essentially self-weight of the structure and minimal storage in the loft space.
10. The center beam is connected to 7x7 timber columns through a mortise and tenon joint with wood trennels (i.e., wood dowel "nails") visible on the sides of the beam (Figure 24). A 2x wood member, secured to the interior face of each of the columns, provides an additional 1-1/2 inches of bearing for the center beam.

Wall Framing

11. Nominal 2x4 wood stud walls are sided with horizontal plank boards on the interior and vertical boards and batten system on the exterior.
    a. Timber beams serve as top plates of the south, east, and west walls. Three, 1-1/8 inch to 1-1/2 inch by 12-inch-deep wood members span over the large door opening in the north wall.
    b. The base plates are of treated nominal 4x6 members. The wood studs are secured with nails to the wood base plates which are secured to the CMU foundation wall.
       i. In at least one location, the wood stud is spliced at the bottom, likely as a previous repair of deteriorated wood (Figure 25).
       ii. Minor water staining is present at one exposed location at the top surface of the treated base plate.
12. The top of the west wall is visibly, horizontally displaced outward on the south half of the building (Figure 26) up to 7/8 of an inch over the 9 foot height of the wall. At the center beam location, the wall is displaced inward 1/2 of an inch over the height of the wall. A 3/8 of an inch outward

displacement was measured near the location where the north rafter cross-bracing is interrupted by the masonry chimney at the north end of the west wall.

13. Localized decay is present in the exterior wood boards intermittently throughout but is more concentrated at the bottom of the battens (Figure 27).

LIMITED STRUCTURAL ANALYSIS

To supplement our site observations, WJE performed a limited structural analysis of the rafters, loft floor joists, and center beam per the 2015 edition of *The National Design Specification for Wood Construction* (NDS), as referenced in the 2015 edition of the *Michigan Rehabilitation Code for Existing Buildings* (MRCEB), to determine an order of magnitude of stresses in the members to be compared with calculated design loads as described below. Considering the lack of brittle finishes, serviceability considerations (e.g., deflection under design load, wood crushing) were not included in our analysis. Additionally, a review of the connections between members was not included in our analysis.

The allowable design strength of a wood member depends on the species, mechanical design properties, and dimensions of the wood. Based on our review of wood specimens obtained from a painted rafter, unpainted rafter, and the center beam, the wood appears to belong to the Pinaceae family; therefore, we utilized the spruce-pine-fir (SPF) species when selecting the allowable design stresses tabulated in the NDS. Although not individually reviewed and graded, based upon the general tightness of the grain, slope of grain relative to the length of the members, and the limited size, locations, and quantity of knots, we assumed No.1/No.2 grade for the rafter and joist wood members and No.1 grade for the center beam.

For the analysis, dead, live, snow, and wind loads were calculated following the prescribed procedures in the 2010 edition of the American Society of Civil Engineers' *Minimum Design Loads for Buildings and Other Structures* (ASCE 7), which is referenced by the MRCEB.

Our limited analysis considered the following imposed loading conditions:

- Load Case 1 (LC1): dead load only (10 psf design dead load)
- Load Case 2 (LC2): dead load plus uniform live load (16 psf reduced roof live load for the roof and 20psf live load for the loft)
- Load Case 3 (LC3): dead load plus snow load (21 psf sloped roof snow load)

A limited wind load analysis was completed to determine an order of magnitude wind uplift force at the rafter bearing ends. The net wind uplift on the roof structure is minimal, and is thus, not considered further in this limited analysis effort.

Refer to the descriptions and Table 1 below for a summary of the analysis.

Roof Framing

Considering the three design load cases, the combined flexural and axial demand-over-capacity ratio (DCR) for the rafters is less than 1.0, which indicates the calculated demand is less than the calculated capacity of the rafters. However, when considering reduced section of the rafters due to the observed char on the bottom surface and a side surface of a set of southern rafters, the DCR exceeds 1.0 for load cases

Table 1. Structural Analysis Demand over Capacity Ratios

	Combined Bending and Compression			Bending	
Load Case	**North Half Rafters**	**South Half Rafters**	**South Half Rafters with Char**	**Loft Joists**	**Loft Joists Under Knee Wall***
LC1: Dead Load	0.33	0.38	0.93	0.34	2.63
LC2: Dead Load + Live Load	0.54	0.62	1.55	0.93	4.00 *(Roof Live Load only; no Loft Live Load)*
LC3: Dead Load + Snow Load	0.71	0.78	1.99	N/A	5.02 *(No Loft Live Load)*

**The DCRs shown for the loft joists below the knee wall assume one joist supports all of the load from the knee wall. When assuming three joists evenly support the knee wall load, the DCR still exceeds 1.0 for LC2 and LC3.*

LC2 and LC3, meaning the calculated demand exceeds the calculated capacity. Specifically, for this analysis, the 1/8 of an inch char depth and an additional 1/4 of an inch depth of the member in the heat effected zone (i.e. the weakening of a thin layer of wood just below the char due to the rise in temperature of the wood[1,2,3]) were assumed to provide zero strength to the rafter members. Note that the analysis of the rafters assumes the knee wall provides adequate bearing and the cross-bracing of the northern rafters is attached to the rafters and rafter ties.

Based on the limited wind analysis, there is a net uplift force, up to 250 pounds, at the rafter bearing locations. Further verification of the connection of the rafters at their bearings to withstand the net uplift force is recommended, although not required by current building codes for a replacement roofing project.

Loft Floor Joists

The loft joists were analyzed for flexure. The DCR for the typical loft joists does not exceed 1.0; however, when considering full design loads acting at the knee wall on a single joist, the loft joist is overstressed with a DCR significantly exceeding 1.0. Additionally, by inspection, the depth of the typical notch at the center beam bearing is at or exceeds current limits set by the NDS. The notch depth can significantly reduce the shear strength capacity of the joist members and may limit the live load capacity of the loft floor structure.

Center Beam

Although there are two sets of spacers located between the bottom of the timber beam and the steel rods, the spacers are within 24 inches of each other and are at midspan of the beam. The two spacers

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[1] *Wood Handbook - Wood as an Engineering Material,* Forest Products Laboratory, Gen. Tech. Rep. FPL-GTR-113, 1999.

[2] White, R. H., *Analytical Methods for Determining the Fire Resistance of Timber Members*, in Handbook for Fire Protection Engineering published by the Society of Fire Protection Engineers, 2002.

[3] Schaffer, E. L. et. al., *Strength Validation and Fire Endurance of Glued-Laminated Timber Beams*, Research Paper FPL 467, Forest Products Laboratory, 1986.

would term this post-tensioning reinforcement as a “queen truss.” however, due to the proximity of the spacers to each other, the center beam analysis could consider the reinforcement as a “king truss” with a single spacer system for simplicity. The tension rods being located 12 inches above the centerline of the timber beam at the east and west walls creates an eccentric connection between the tension rods and the center beam, and involves the complexity of the mortise and tenon joinery of the original post and beam building frame.

Presuming the southern rafters are supported by the existing stud knee wall at the loft level and underlying loft floor framing, under full design load including snow loading on the roof and 20 psf live loads in the loft space, the DCR is more than 3 when only the center beam, and not the post-tensioning effect, is considered. Based upon the limit of the washer bearing against the wood on the exterior of the building, the axial capacity of the tension rods is likely not more than 1000 pounds, much less than the tensile capacity of the rods.

The metal tension rods, if adequately secured, will improve the capacity of the beam, but due to the eccentric connections of the rods relative to the centerline of the timber beam and the actual “queen truss” geometry, the actual capacity would need to be verified through advanced analysis techniques that go beyond the scope of our services.

DISCUSSION

Roofing

The existing, deteriorating shingles can be replaced with new roofing materials, either similar cedar shingles with a fire retardant or a metal roofing system. Either roofing system will not overstress the rafters under dead load only. Repair and temporary shoring or strengthening of the existing structure is recommended, however, to accommodate live loads resulting from maintenance, construction, and full design snow and wind loads.

Roof and Wall Framing

The northern rafters are adequate for the load cases considered in this analysis, mainly due to the installation of additional rafters between the original painted members and the presence of the rafter ties and parallel cross bracing members. The outward displacement measured at the west wall relates to the unsecured cross bracing at the chimney location. The unpainted vertical faces at the ridge of the original members may indicate structural movement of the rafters, but the movement may have occurred during the relocation of the building, prior to the installation of the newer rafters and bracing, or simply, the vertical surfaces were missed during the painting effort.

The observed southern roof deflections, wall displacement, and fractured rafters are consistent with the calculated DCR values being greater than 1.0. Because the support of the knee walls is insufficient, the span of the south rafters is increased, resulting in overstress conditions and excessive deflection of the rafter members, especially those affected by the fire event. Additionally, the southern rafter collar ties provide minimal restraint for the lateral thrust of the rafters due to their location relative to the ridge. Without the support at the knee wall or attachment of the rafter system to the loft floor structure, the roof thrust presents itself through the outward displacement of the timber beam at the top of the walls and the downward displacement of the ridge line. The timber top plate of the west wall is actively supporting the roof thrust, spanning between the west center and southwest corner support posts. With proper support provided, the roof thrust should be minimal, and the outward displacement of the west wall may be able to be resolved back to a near-plumbed condition.

The separation of the knee wall members between the rafters and the loft floor framing is likely related to the seasonal loading of the roof acting on the loft floor joists. Under the snow load conditions of the unheated building, the loft floor joists supporting the knee wall deflect, potentially inelastically (creep). The joists will not recover to a level condition if the deformation is inelastic, allowing the knee wall members to separate at connection points as the seasonal loading is removed and the rafters return to their undeflected condition. Additionally, the net wind uplift forces may contribute to the separation of the knee wall members. Reinforcement of the knee wall member connections to accept the uplift force at the rafter bearing locations, and either modification to the southern rafter framing system to support the demand loads, or temporary shoring of the knee wall during the winter months, is recommended.

Although the openings in the north and south walls are relatively large, the observed wall displacement is not solely related to the "racking" of the overall structure due to lateral wind forces acting on the building. The wood sheathing located on both the interior and exterior surfaces, provides rigidity to these shear walls and the walls are anchored to the foundation. The observed displacement is primarily related to the roof thrust concerns discussed above.

Loft Floor Joists

As stated in the analysis discussion above, the notch in the loft floor joists to accommodate the tension rods at the center beam will limit the capacity of the joists. However, the addition of a wood 2x ledger secured to the timber beam will alleviate the concern with the deep notches. The typical joists will then be adequate for a 20psf floor live load, but the joists supporting the knee wall above are to be reinforced, assuming there are no alterations made of the southern rafter system. The fracture through the knot of the one joist may be related to the seasonal overloading of the joists, and occurred at this joist due to the presence of the knot at the bottom edge of the member.

Center Beam

The addition of the steel tension rods at the center beam is a common method employed to gain additional capacity of a wood beam. The rods are typically installed when columns or other supports located within the length of the beam are removed. With the installation of the tension rods, the timber beam is working compositely with the steel as a "truss" with the timber beam accepting the compression loads and the steel rods accepting the tension loads of the "truss." This specific strengthening of the timber beam is not a true "truss" due to the location of the end anchorage of the tension rods relative to the centerline of the timber beam. A more detailed analysis would be necessary to verify the capacity of the center beam to support the loft floor and knee walls.

The additional 2x support provided inset of the columns at each end of the beam allows for an increase in bearing forces as compared to the original mortise and tenon joinery. The 2x members were likely installed when the center beam was reinforced with the tension rods to accommodate the increased support reaction required of the longer span of the beam.

CONCEPTUAL REPAIR RECOMMENDATIONS

Prior to replacement of the roofing, WJE recommends the following:

1. Install cross-bracing at the set of northern rafters where the existing cross-bracing is not secured to the rafters. The cross-bracing can be attached on the northern side of the rafters, avoiding interference from the chimney.
2. Provide adequate vertical support for the southern rafters. There are multiple methods in which this can be accomplished, each with its own advantage and disadvantage that will need to be considered regarding the use and historic importance of the building. Additionally, the vertical support system is to be coordinated with the lateral roof thrust resistance system. Some options available include:
    a. Replicate the rafter tie and cross-bracing system employed at the north rafters. This will prohibit use of the loft floor space, but will provide the additional strengthening for the lateral roof thrust.
    b. Strengthen the existing rafters to eliminate the need of the knee wall at midspan. The depth of the rafters in relation to how they will fit within the existing geometry constraints at the supporting walls will be challenging to accommodate. Additional strengthening addressing the lateral roof thrust will be required.
    c. Reduce the tributary area the rafters support, and thus the demand loading on the rafters, by adding adequately sized rafters between the existing rafters to reduce the spacing. Additional strengthening addressing the lateral roof thrust will be required.
    d. Replace the knee wall with a girder beam or add a roof ridge beam. The supports for either beam system will require new columns bearing onto new foundations located within the span of the window in the south wall and in the interior space, near the center beam. The girder beam method will eliminate the need to strengthen the support of the knee wall, and the ridge beam option will reduce the amount of strengthening required for the support of the knee wall, but the support columns for either option will likely interfere with the use of the building. Installation of the beams will minimize the roof thrust concern and will not require additional strengthening for the lateral roof thrust.
    e. Implement repairs and strengthen the knee wall as required; re-level, as reasonably possible, the loft floor joists; and strengthen the loft floor joists and center beam to accept the roof load from the knee walls. Additional strengthening for the lateral roof thrust will not be required with this approach but would likely involve the following:
        i. Replace the missing stud member of the knee walls, reinforce the knee wall member connections to allow for the design wind uplift force, and provide hardwood shims as necessary to ensure full bearing between the rafters and the supporting loft floor joists.
        ii. Sister the joists with wood or steel members or add support within the span of the joists. If the deformations are inelastic, a true level condition may not be achievable with the existing joists, further complicating the effort to install the new members.
        iii. Strengthening of the center beam would likely involve adding additional midspan supports, although other strengthening methods may be applicable upon further review.
    f. Provide temporary shoring below the knee walls for the planned roofing work and during the winter months annually. This will not require additional strengthening for the lateral roof thrust.

3. Resolve the lateral roof thrust of the southern rafters, as coordinated with the vertical support of the rafters as described above. Alternatives to address the lateral roof thrust include:
   a. Install collar ties directly above the loft floor elevation, making use of the floor difficult. Tension ties may be able to be added in lieu of collar ties, but further review of the wind uplift loads would be required to verify the ties will remain in tension.
   b. Connect the rafter system to the existing loft floor diaphragm. A significant amount of wood blocking, sheet metal connectors, and fasteners will be required to achieve the connection between the roof system and loft floor diaphragm and may be visible to the building occupants.
   c. Remove and replace the loft floor framing so that it is spanning perpendicular to the ridge, allowing the floor joists to also serve as ties for the roof rafters. Mid-span support will be required, which will require columns and foundations within the interior space of the building.
4. Regardless of the strengthening method(s) pursued, reinforce the distressed fractured and charred rafters at the southern half of the building by means of attaching dimensional or engineered lumber to the side of the rafters for their full length.
5. Verify the tension rods at the center support beam are snug-tightened.

While unrelated to the roof framing, WJE also recommends the following structural improvements:

6. Reinforce the fractured loft joist by means of attaching dimensional lumber on one side of the joist for the full span of the joist.
7. Replace the deteriorated portions of the exterior battens and trim along the walls.

The recommendations provided above are conceptual approaches to improve the strength of the wood roof structure and its interior supporting elements. Other repair approaches are possible, and many options provided above will greatly impact the use of the interior space or alter the historic interpretation of the structure. WJE can discuss the conceptual designs further to help with the decision-making process. Further analysis and design are required to provide member sizes and materials of the strengthening systems, complete a more detailed analysis of the center beam system, and review the header beams over door and window openings.

CLOSING

Thank you for the opportunity to assist you with this historic structure. Please call if you have any questions or would like to discuss our findings or next steps for reinforcement of the structure.

Sincerely,

WISS, JANNEY, ELSTNER ASSOCIATES, INC.

Cheryl L. Early, P.E.
Senior Associate

Justin D. Barden
Associate III

Enclosure: Figures 1 to 28

FIGURES

Figure 1. Overall view of the Wagon Shop, looking from the southwest corner of the building.

Figure 2. Localized decay (boxed areas) and lichen growth (arrows) on the roof shingles.

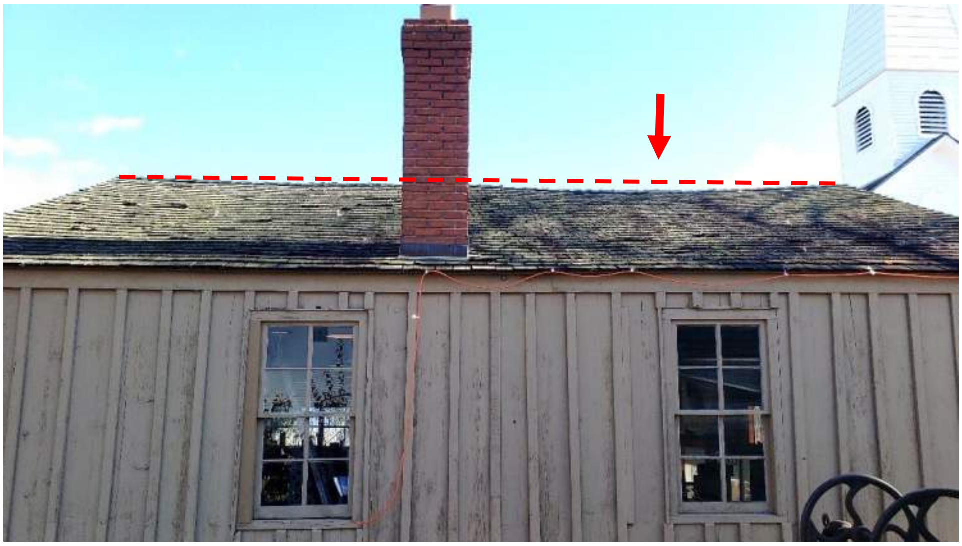

Figure 3. Visible deflection of the roof viewed from the west side of the building.

Figure 4. Char on the north wall header. The box indicated a location where char was removed.

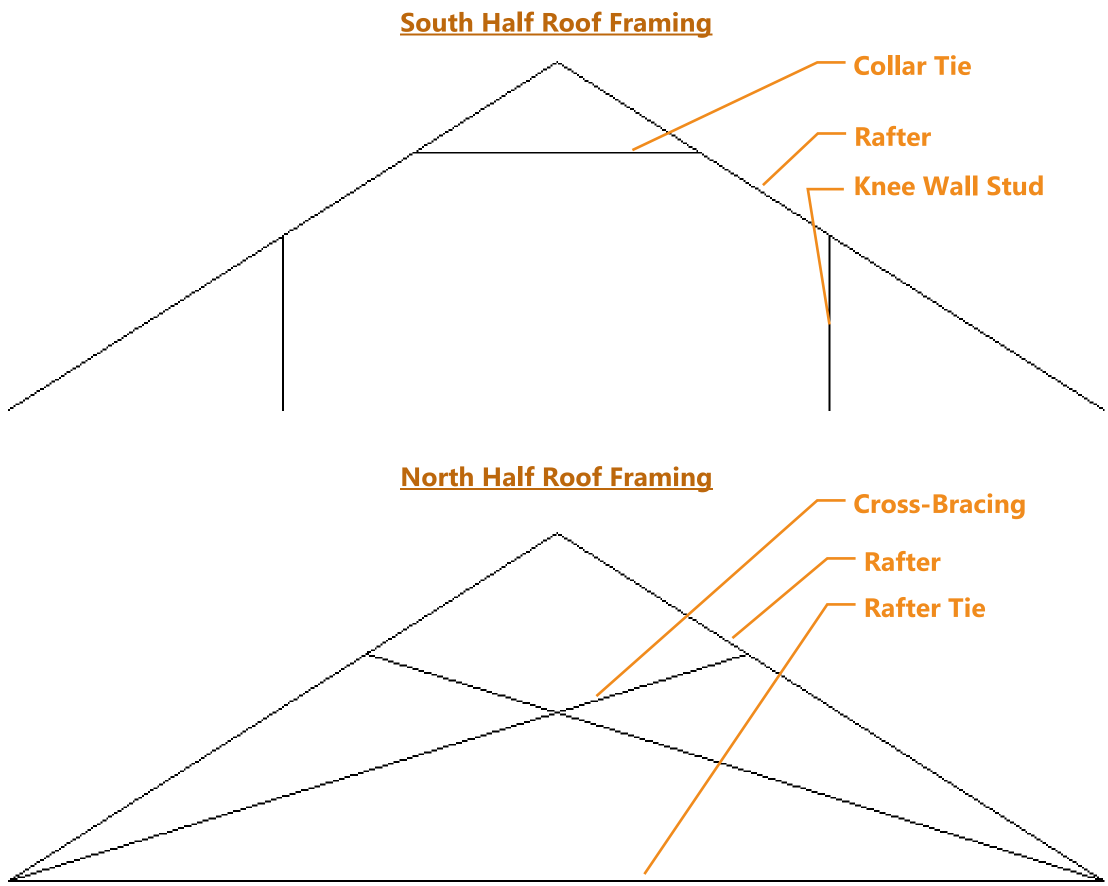

Figure 5. Typical roof framing systems. The lines represent wood members.

Figure 6. Cross-bracing is unsecured to west rafter to accommodate chimney.

Figure 7. Notched rafter at chimney.

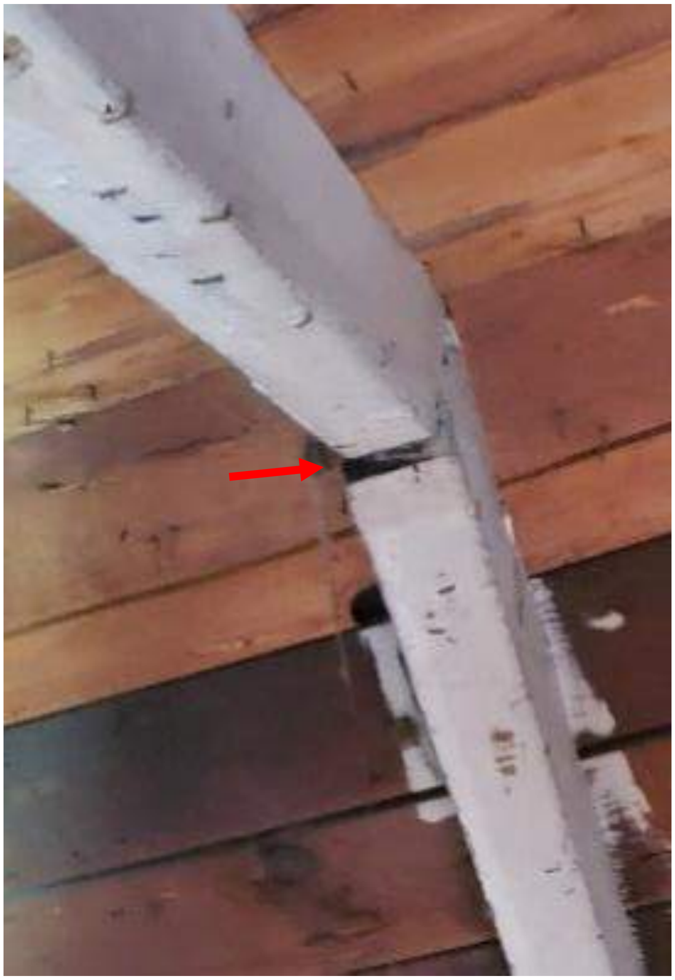

Figure 8. Unpainted end of rafters. Note paint on underside of some of the roof decking.

Figure 9. Rafter ties bolted and lapped.

Figure 10. Fractured rafter (arrow) near the ridge, where char is located.

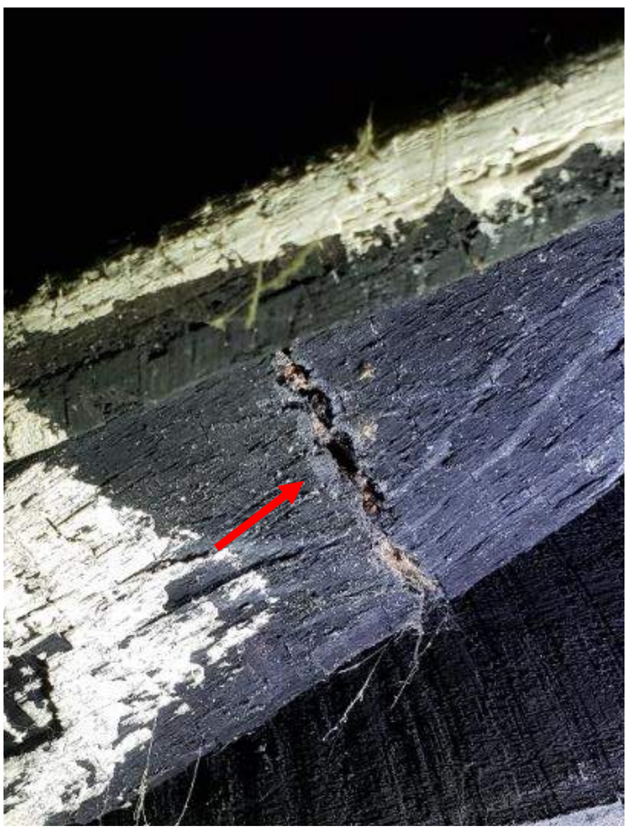

Figure 11. Up-close view of the fractured rafter shown in Figure 10. Note the absence of char and smoke staining within the fractured surface.

Figure 12. Rafter not bearing directly on a knee wall top plate.

Figure 13. Knee wall stud is not bearing directly on the knee wall bottom plate.

Figure 14. Missing stud below rafter in the west knee wall.

Figure 15. Typical notch in loft area joist bearing end.

Figure 16. Large notch to accommodate center beam tension rod.

Figure 17. Cross-bridging at the loft floor joists.

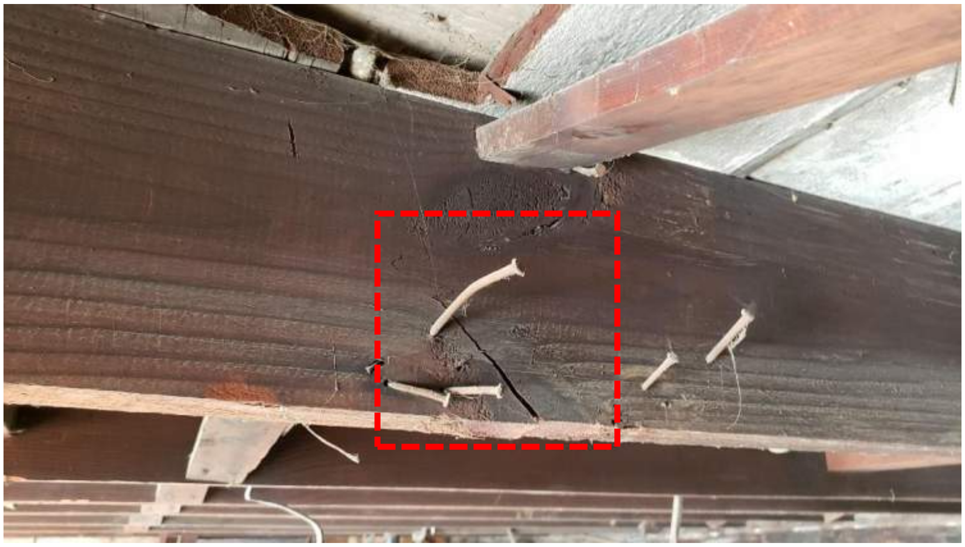

Figure 18. Fracture at loft area joint extending from knot.

Figure 19. Post-tensioned ‘truss” comprised of timber (yellow arrow) and tension rods (red arrow).


Figure 20. Abandoned mortise on center beam underside.


Figure 21. Shadow of likely previous column on underside of center beam.


Figure 22. Check on center beam underside.


Figure 23. Surface char on center beam underside.

Figure 24. Wood trennels on side of column (arrows).

Figure 25. Wood splice at a wall stud.

Figure 26. West wall of the building. The arrow indicates the approximate location of maximum outward displacement.

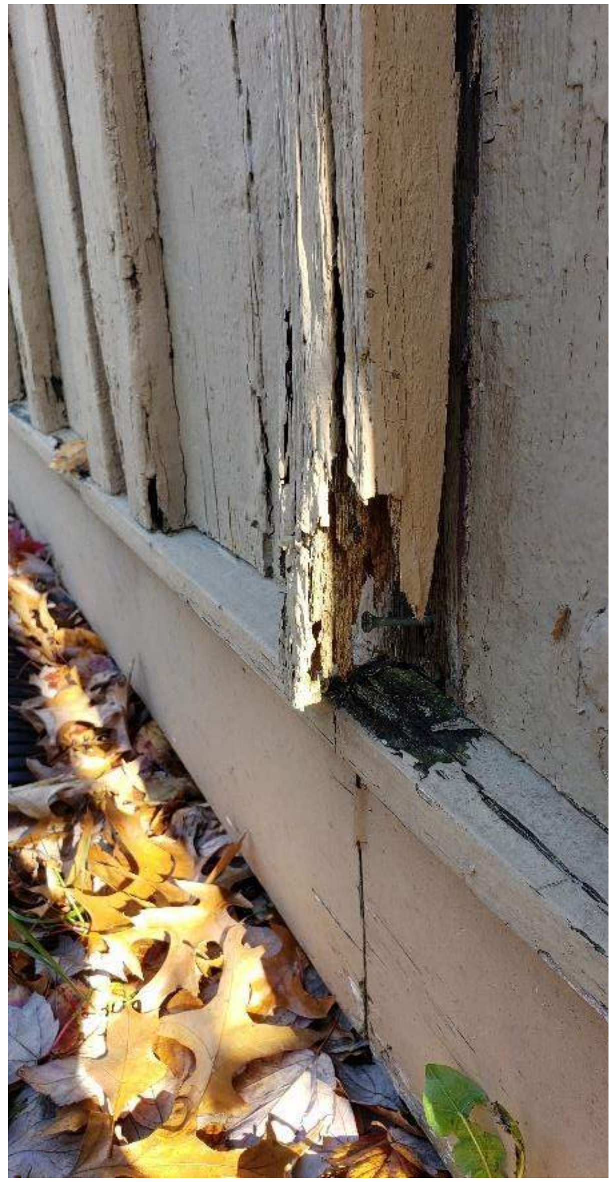

Figure 27. Decay at the bottom of batten and horizontal trim board.