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NDE investigation of the timber foundation in the historic Kennecott Mine Concentration Mill Building

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Abstract The U.S. National Park Service acquired the National Historic Copper Mine at Kennecott, Alaska, in 1998. There was uncertainty about the condition of the timber-cribbing foundation supporting the concentration mill, the largest building in the mine complex. A comprehensive on-site evaluation of the timber cribbing foundation was performed in summer 2009. The inspection process included visual assessment, species confirmation, moisture content determination, stress wave scanning test, resistance micro–drillingcore-drilling, and decay testing. Extensive deterioration was found in the timber-cribbing foundation members at the lower floors of the mill building. The upper levels of the cribbing foundation exhibited much less deterioration, especially in areas where the timber cribbing was not filled with soil. Current efforts are focusing on a comprehensive structural evaluation of the Concentration Mill Building with the goal of stabilizing and preserving this historical mining building important to the cultural heritage of early 20th-century America.

Keywords nondestructive testing, inspection, timber, substructure, crib foundation, decay detection

1. INTRODUCTION

An abandoned copper mine located in the village of Kennecott, Alaska, and within the Wrangell-St. Elias National Park & Preserve, is in the process of being fully restored and/or stabilized by the National Park Service (NPS). The mining complex includes 45 buildings with three separate mines located on the mountainsides above the village, which is located adjacent to the Root Glacier (see Figure 1). It is located approximately 5 miles beyond the east terminus of the McCarthy Road (GPS coordinates 61° 29’ 10” North, 142° 53’ 19” West).

The mining town was constructed over a a two-year period ending in 1912, and its remote site was unique for containing one of the largest concentrations of copper in the world. The copper ore initially contained over 70 percent copper, along with trace amounts of silver and gold. The mine was in service for nearly 27 years until production was ceased abruptly in October 1938. The Kennecott Mines produced an estimated 4 million tons of copper ore valued at over $200 million. For many years after the mine closed, Kennecott became a ghost town; lack of maintenance led to deterioration of the roof sections at the upper floors and caused significant damage to the building structure. The village includes several historical buildings that are in the process of being restored by the NPS, which acquired the properly in 1998.

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Figure 1 – Aerial view of the Kennecott Mine complex (left) and a northwest view of the Concentration Mill Building (right).

The hallmark structure in the historic town is the massive Concentration Mill Building shown in Figure 1 (right). The 14-story timber building was constructed in many phases between the years 1910 and 1935, with new additionsadded as the copper concentration process became more complex (NPS 2008). The building foundation consists of a separate heavy timber box crib foundation for each Wdiug level that "stair-steps" up the mountainside. Copper ore processing began at the upper level ore bins, was gravity fed to each lower level for various concentration techniques, and culminated with packaging the copper ingets for their 131-mile (211-km) rail journey to the port of Cordova. As part of the overall effort to restore and stabilize the Concentration Mill Building, the initial focus was placed on the general condition of the foundation structural systems. A more up-to-date condition assessment of the building foundation using current nondestructive evaluation (NDE) inspection tools was needed to support a structural analysis of the building system

1.1. Objective and scope

The focus of this field investigation was a condition assessment of the timber crib foundation in the Kennecott Concentration Mill Building. A team from the Forest Products Laboratory (FPL) performed the inspection over a six-day period during June 2009. The inspection included a variety of quasi-nondestructive evaluation techniques for evaluating wood members in a minimally invasive manner, which helps to preserve the historical fabric and integrity of the structure. The techniques employed included visual assessment, hammer sounding, species identification, moisture content determination, transverse stress wave scanning, resistance micro-drilling, and core removal for additional laboratory analyses.

1.2. Previous inspection work

In 1976, an inspection team from the NPS and FPL performed a cursory inspection of all the buildings at the Kennecott Mine site. Some limited inspection work was done in the Concentration Mill Buildiqg however, it was based solely on visual assessments. Tho reding inspection report (Moody 1976) fmd the basis, along with required architectural assesmen&, to establish the historic site as a National Historic Landmark in 1986.

The Concentration Mill foundation walls (as they appeared in 1976) at level 3 are shown in Figure 2 and are open-cell type consisting of square timbers measuring 25 × 25 cm or 30 × 30 cm int-ed with saddle notching. The "headers" are notched members (designated as '8" members) that are aligmd perpendicular to the face of the wall. The "stretchers" (designated as "S" members) have no natching and are aligned parallel to the ace of the wall. Timber planking is attached at the backside of the stretchers at most locations to contain the soil fill material inside the timber crib cells.

Figure 2 - Timber crib foundation wall (level 3, left) and outside (level zero, right) during the 1976 building inspection.

Some foundation wall sections along the norhternside of the structure were constructed after mining operationsbegan in 1912 and utilized tound timh for the crib foundation as shown in Figure 2 (right).

2 INSPECTION METHODOLOGY

Our field investigation employed a variety of nondestructive testing tools to provide an enhanced view of the internal integrity of the timbers. The NDE inspection included a moisture meter, hammer sounding, stress wave timer, and a resistance micro-drilling device. Initially, we established a reference baseline by collecting data with each NDE toos in areas of the building that appeared to be in good condition. Data collected in other portions of the building was subsequently compared to these “benchmark” values for each inspection tool.

We employed a five-step process during out field investigation:

Step 1 - identify areas in the heavy-timber crib foundation that are visibly damaged or show signs of deterioration using visual techniques. This step included mapping of general condition of the members.

Step 2 - utilize a stress wave timing device and/or hammer-sounding to identify suspected areas of internal deterioration based on acoustic principles.

Step 3 - utilize a resistance micro-drilling tool to probe suspected areas in order to confirm the presence and magnitude of internal decay and voids.

Step 4 - acquire core samples from several target areas for wood species identification, density measurements, and decay detection in the laboratory.

Step 5 - develop an overall condition assessment for each foundation timber based upon a combination of visual and NDE data.

Temperature and relative humidity conditions were also monitored inside the Concentration Mill Building for the duration of the inspection work.

2.1. Moisture content measurements

We used an electrical-resistance-type moisture meter (which automatically conpensates for species and temperature) in conjunction with 76-mm-long insulated pins and a hammer probe (see Figure 3) to measure the in situ moisture conditions of timber crib members at each level of the building.

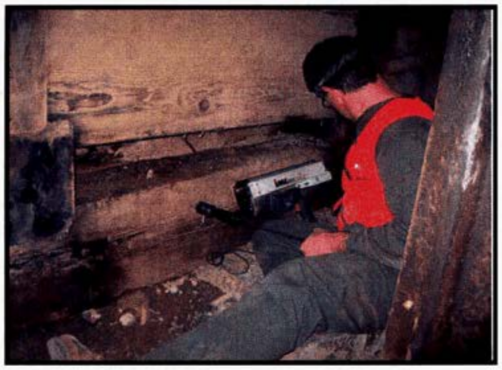


Figure 3 - Moisture content measurements being collected with an electrical-resistance-type meter.

Figure 4 – Stress wave measurements being collected using a microsecond timer device.

2.2. Transverse stress wave measurements

A stress wave timing device that measures the time it takes for sound waves to travel through the heavy timbers was used to locate internal decay pockets (see Figure 4). Spiked-transducers were carefully inserted into opposing faces (perpendicular-to-grain orientation) of the foundation timber. Then a hammer impact sent a sound wave through the member, with the timing device precisely measuring its time of flight through the targeted area. Expected readings for sound Douglas-fir timbers typically fall within the range of 457–914 microseconds per meter. We also took baseline reference readings in several sound 30- × 30-cm Douglas-fir timbers at the upper floors of the Concentration Mill Building, and they typically fell within the typical range for sound timbers. Readings above these baseline reference levels would indicate the presence of moderate to severe decay pockets or significant checking in members.

2.3. Resistance micro-drilling measurements

A resistance micro-drilling device that measures the relative density as a long steel drill bit (with a 3-mm bit diameter and a 1.5-mm shaft diameter) bores through the foundation timber (see Figure 5). The probe hole is very small and usually self-seals within a short time period. A true scaled plot of the relative resistance versus drilling depth is generated for each location (see Figure 6). The supplemental data assists the inspector in estimating the relative size and location of internal voids and decay pockets within timber-cribbing foundation members. Relative resistance profiles that have closely spaced peaks and valleys are associated with a radial drill path orientation. Relative resistance profiles that are flatter, but still well above zero drilling resistance, are associated with a tangential drill path orientation. Locations of internal checking or splitting usually are short distances of zero drilling resistance. Pockets of internal decay typically extend more than 25 mm with zero drilling resistance.

2.4. Core specimen removal and testing

In total, 28 core samples were removed from Levels 1 to 6 in the Concentration Mill Building to determine compressive stress values, examine for the presence and type of decay organism, and determine the moisture content and specific gravity of the building material. All core samples were placed in sealed glass containers to maintain the specimen moisture content. In addition, all coring holes were re-plugged with treated timber dowels to prevent an avenue for future deterioration due to moisture intrusion or insect damage. All core samples were drilled perpendicular to grain in the radial direction of the member and nominally sized at 9.5 mm diameter and 51 mm long.

For an indication of the compression (perpendicular-to-grain) behavior of the removed material, the eight core samples were compressed along the cylindrical axis of the sample and perpendicular to the grain of the wood. Prior to compression the original 51-mm-long specimen was cut to 13-mm length. This fabrication squared the specimen end and resulted in a consistent specimen length. A monotonic load was applied until a 20-percent drop in maximum load was observed or the compressive

Figure 5 – Resistance micro-milling being performed at a foundation member.

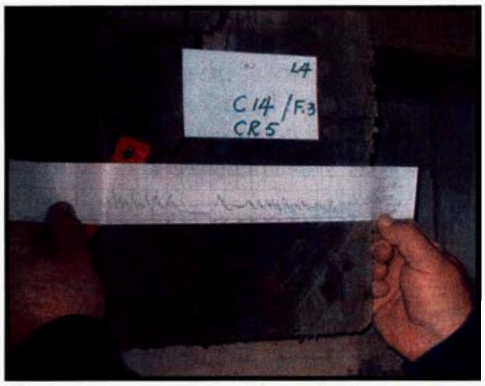


Figure 6 - Relative density plot from the resistance micro-drilling device held aligned to the drilling path.

deformation exceeded 5 mm (i.e., 40-percent specimen length). During loading, both load and machine head movement were recorded at 5 Hz. Moisture content and specific gravity values were also determined in accordance with ASTM D 4442 (2007) and ASTM D 2395 (2007), respectively. Specific gravity values were determined using the volume (prior to drying) and the oven-dry weight.

2.5. Monitoring ambient conditions

During the inspection period, we monitored the ambient conditions inside the Concentration Mill Building. We used a portable datalogger probe that measures both temperature and relative humidity preset at 5-minute intervals. It was placed at building levels 1, 2, and 3 for various time periods during the inspection work.

3. INSPECTION RESULTS

A comprehensive report detailing our inspection methods and results is available (NPS 2009).

3.1. Moisture content results

A summary of the electrical-resistance moisture content (MC) data is presented in Table 1. A total of 94 readings were taken at various locations in the timber cribbing foundation members. Most of the data were taken at probe penetration depths of 25, 51, and 76 mm, with the average moisture content value increasing from 19.7 percent (25-mm penetration) to just over 27.3 percent (76-mm penetration). The minimum values indicated a few heavy timber crib foundation members were at dry levels below 19 percent moisture content. The maximum values indicated that most of the heavy timber crib members were at moisture content readings in excess of fiber saturation levels (typically 26 percent for Douglas-fir). These electrical-resistance moisture content data generally confirmed visual observations of the timber crib substructure conditions. Level 4 moisture content readings appeared to be relatively dry and were within 16- to 22-percent levels. Level 3 moisture content readings appeared to be relatively dry, within 13- to 24-percent levels, but there were visibly wet areas during rainfall events. All remaining levels had moisture content readings in excess of fiber saturation levels. A large portion of the moisture content readings were in a range that is conducive to decay activity. Additional moisture content data were calculated from an oven-dry analysis of the increment cores removed from the heavy timber crib foundation members (see Table 2).

Table 1 - Summary of MC data (percent) collected from timber crib foundation members.

	Probe penetration (mm)		
	25	51	76
No.	31	34	29
Max.	40.0	40.0	40.0
Min.	11.2	12.7	13.5
Mean	19.7	25.1	27.3
St. Dev.	7.6	9.3	9.3

3.2. Stress wave and resistance micro-drilling results

A graphical summary of the stress-wave scanning and resistance microdrilling results for levels 2 and 4 are presented in Figure 7. There were a small percentage of deteriorated timber crib members on level 4, with most occurring between cribs 12 and 18. A larger percentage of deteriorated timber crib members were present on level 2, the terrace level containing members nearly all with advance decay.

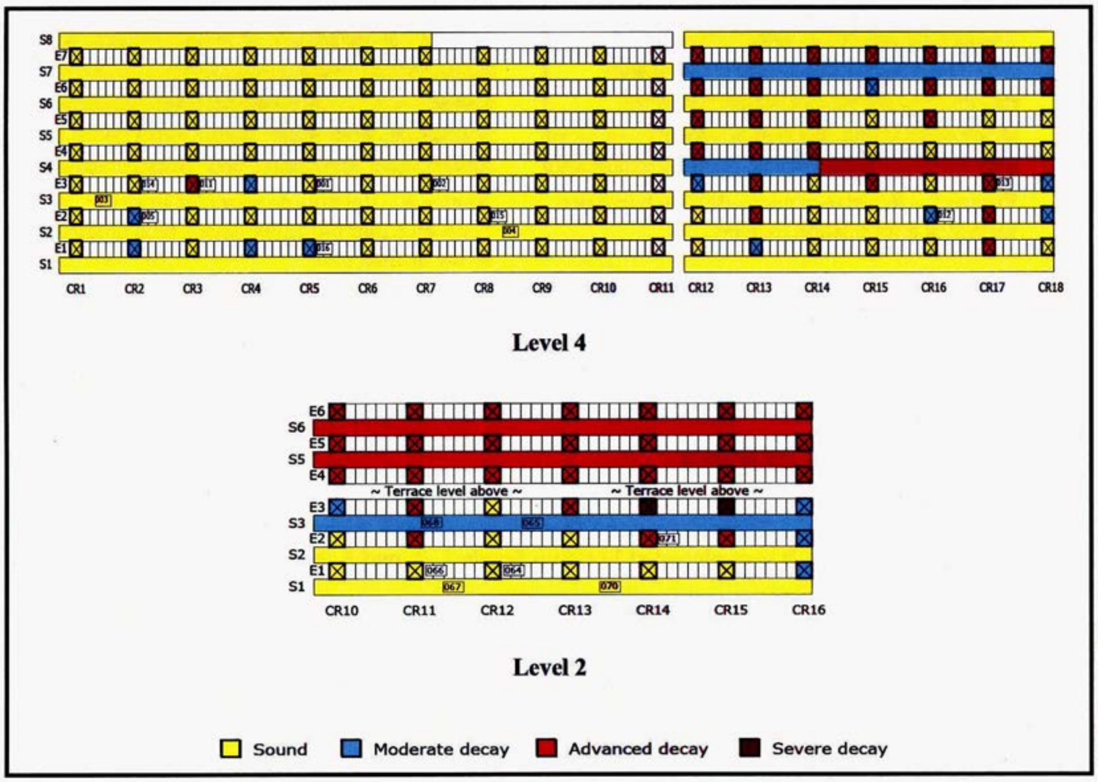


Figure 7 - Composite summary of stress wave scanning and resistance microdrilling results for levels 2 and 4.

3.3. Core sample-physical and mechanical test results

Table 2 summarizes the physical and mechanical testing conducted on eight core samples from the Concentration Mill Building. Compressive stress levels are listed for three deformation levels (0.5, 1.0, maximum). Specific gravity values, considering the moisture content, fall within the expected range for Douglas-fir. Compression perpendicular-to-grain stresses at the 1.0-mm deformation are slightly lower than published values for unseasoned Douglas-fir (ASTM D 2555,2006). Compression (perpendicular-to-grain) stress values published for unseasoned Douglas-fir of the Pacific Northwest region average between 669 and 707 lb/in^2, with a coefficient of variation of 28 percent.

3.4. Core sample-decay detection test results

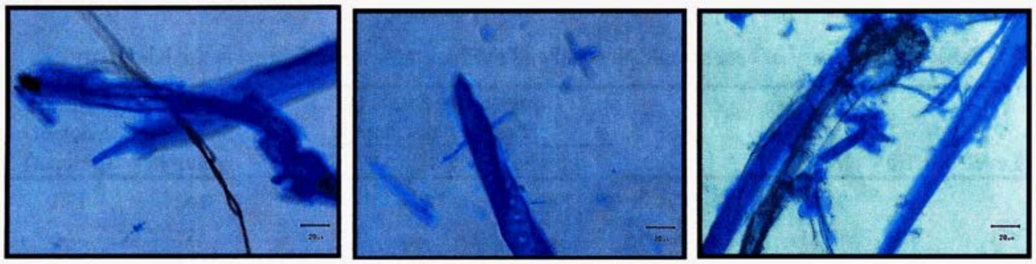
Table 3 summarizes the results of decay testing conducted on 20 core samples removed from the Concentration Mill Building. Figure 8 shows selected microscopic images of decay detected during core sample testing. Eighteen of 20 core samples exhibited some form of decay activity. A majority of the core samples showed signs of soft rot decay activity, and only two samples indicated brown rot. Soft rot decay is an early form of decay and is present typically when moisture contents are very high. Brown rot is one of the major forms of wood decay that can cause wood to crack across the grain, shrink, collapse, and be crushed into powder. Brown rot decay was detected in this level 3 core sample showing signs of segmented hyphae with clamp connections. A combination of soft rot and brown rot decay was detected in this level 5 core sample showing signs of hyphae attached to the cell wall.

Table 2 - Summary of core sample physical and mechanical tests performed in the laboratory.

Level	Crib	Member	Spec ID	Compressive Stress (kPa) at given deformation 0.5 mm	1.0 mm	Max.	Specific gravity	Moisture content (percent)
2	11	S2	Douglas-fir	2,868	3,020	6,433	0.42	17.1
3	12	S5	Douglas-fir	--	--	--	--	--
	1-2	S3	Douglas-fir	3,358	5,295	12,438	052	16.5
	2	E3	Douglas-fir	1,020	2,544	6,109	0.49	11.7
4	5	E3	Douglas-fir	3,840	3,613	7,109	0.43	122
	7		Douglas-fir	3,509	3,827	8,943	0.39	12.4
	8-9	S2	Douglas-fir	3,434	3,592	4,737	0.45	14.7
6	2	S1	Douglas-fir	2,551	3,089	6,564	051	10.0
			Average:	2,937	3,572	7,474	0.46	13.5
			COV:	0.32	0.25	0.34	0.11	0.20
			Minimum:	1,020	2,544	4,737	039	10.0
			Maximum:	3,840	5,295	12,438	0.52	17.1

Table 3 - Summary of core sample decay tests performed in the laboratory.

Level	Location of core Samples: Column	Wall	Crib	Member	Decay detected	Comments
1	Under entry stair		13	E2	Soft rot	Soft rot cavities present
	32	V	13-14	S1	None	No attack to cell wall or pith
	14 up	W	1	S3	Soft rot	Soft rot cavities present
2	20-25	K	10	E2	Soft rot	Fruiting body attached to cell wall
	--	K	12	E2	Soft rot	soft rot cavities present
2A	12-13	U	2	El	None	No attack to cell wall or pith
	14-15	M.1	6	E2	Soft rot	soft rot cavities present
3	12-13	G	6-7	S4	Brown-rot	Segmented hyphae with clamp connection
	14-15	G	9-10	S4	Soft rot	Soft rot cavities present
	14-15	G	7-8	S2	Soft rot	Soft rot cavities present
	17-20	G	14	E3	Soft rot	Soft rot cavities present
5	14-15	E	5-6	s2	Softrot	Hyphae growing out from cell wall
	13	E	3	E3	Soft rot	Soft rot cavities present
	12-13	E	2-3	S2	Soft rot	Hyphae present m pith Soft rot cavities present
	26-29	C	8	E2	Soft rot	Soft rot cavities present
	26	--	--	overhead beam	Soft rot / brown rot	Soft rot cavities present Hyphae attached-to cell wall
6	--	A	7	El	Soft rot	Soft rot cavities present
	37	A	12	El	Soft rot	Soft rot cavities present
	--	A	1	E3	Soft rot	Soft rot cavities present
	31	B.1	9	S2	Softrot	soft rot cavities present Fungal hyphae



level 3–brown rot *level 3–brown rot* *level 5–soft/brown rot*

Figure 8 - Decay organisms detected via microscopic analysis of core samples.

4. CONCLUSIONS

The following conclusions are provided from our investigation of the Concentration Mill Building's timber crib foundation:

- The timber crib foundation walls in the poorest condition, characterized by widespread severe deterioration and multiple failed members and wall sections, were found at level 2 (crib 10–16 terrace level), level 2A (crib 1-6), level 3 (crib 12–22), level 3B (all exposed sections), level 6 (crib 8–12), and level 6B (crib 8–12). The timber crib foundation walls in the best condition, characterized by many sound members with sporadic moderately decayed members, were found at level 1 (crib 2–15) and level 4 (all exposed sections).
- Moisture intrusion into the building is the leading cause of decay and deterioration in the timber crib foundation walk within the building. Many areas of the timber crib members at several levels in the building are saturated or show signs of past wetness. In addition, much of the construction debris and rock/gravel in the cribbing cells are trapping moisture adjacent to the timber crib members. It appears that much of the water may be coming from surface runoff down the hillside, as the wet areas on several levels are in general vertical alignment.
- Microscopic analysis of core samples revealed the presence of decay fungi on most levels of the building. Most decay fungi were soft rot, which is an early form of decay.
- Mechanical testing of core samples indicated compression perpendicular-to-grain values that were similar to those published in ASTM Standard D 2555.

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