METRO TESTING BURNABY

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Dear Sean,

Re: GREENWOOD SMELTER RUINS

As requested, Metro Testing Laboratories Burnaby (Metro), a division of CCMET Inc., examined selected masonry, mortar and brick samples of the BC Copper Company Smelter ruins and heritage site at Greenwood, BC (Fig.1 and Fig.2). The site work took place on 19 and 20 April 2017, followed by laboratory testing.

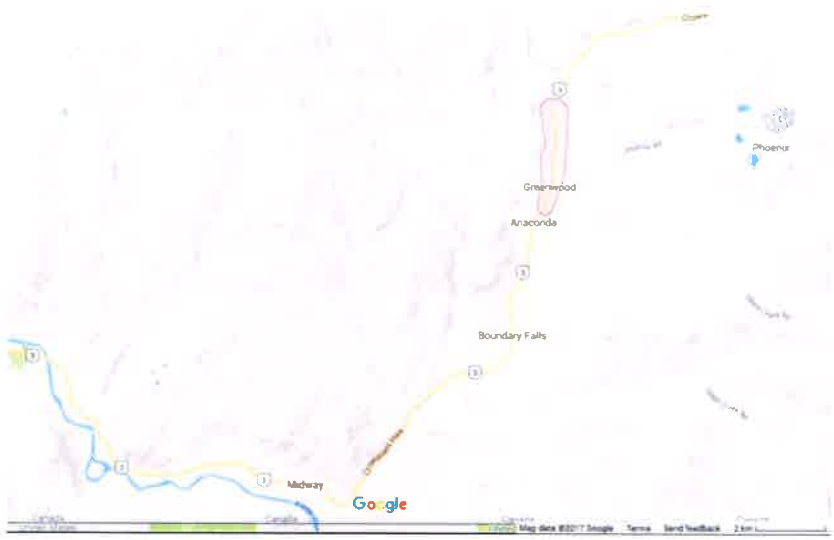

Figure 1 – Location of Greenwood (Source: Google Maps)

*Figure 2 – General view of the smelter's **flume and chimney***

The general purpose of **Metro's work** was to assist the structural engineer in determining the current status, and estimate the properties, of masonry elements (mortar and bricks) identified by the structural engineer in order to salvage as much as possible of the original buildings.

Metro's scope of work was limited to:

- Visual evaluation.
- Four in-site brick shear test as per ASTM C1531, Procedure B.
- Mortar strength determination using a Hilti DX-450 nail gun and needle penetrometer.
- Compressive strength testing of bricks removed from site.

Between 19 and 20 April 2017, Roland Heere, *P.Eng* and Alberto Martinez, *P.Geo*, both from Metro, conducted the site evaluation of the masonry walls. The evaluation was limited to two structures, the smelter chimney and the corner building, approximately 20 meters southeast of the chimney. The structural engineer, Ranko Vulic, *P. Eng.* from DJ&T Engineering, performed the overall evaluation on site and selected the structures considered relevant and safe for Metro's materials testing. During the evaluation, the weather was variable, with light rain intervals and an estimated temperature of approximately 12°C.

1.0 VISUAL EVALUATION

The clay bricks are approximately 20 cm x 10 cm x 6 cm, massive and of red colour. The bricks typically have a rough surface texture and are set in white lime mortar. The masonry is typically exposed. However, the inside of the chimney is coated with a glassy slag, very likely deposited by the smelting fumes (Figures 3 and 4). Of further note are the conditions of the bricks inside the chimney where accessible from the ground. Here the bricks had suffered spalling and delamination to approximately 3 cm beyond their present surface. In addition, masonry near the bottom had eroded by approximately one to two wythes.

Figure 3 (left) – Interior of the chimney

Figure 4 (right) – Detail of delaminated slag and bricks.

The corner building (Figures 5 and 6) had clay bricks with appearances and dimensions similar to the chimney bricks. The building's foundation was comprised of granite blocks bonded with what apparently is the same type of mortar used for the clay bricks. Compared to the chimney, the mortar at the corner building appeared to be weaker, more friable, and in some cases loose and sandy, particularly in the foundations.

The top of the chimney was observed from a helicopter. Visual observation (Figures 7 and 8) revealed loose

Figure 5 (left) – Aerial view of corner building. *Figure 6 (right) – South view of the Corner Building wall.*

bricks on the top and deteriorated mortar coating, presenting immediate falling hazards, particularly in the event of strong winds. Note that more photographs are on file.

Figures 7 (left) and 8 (right) – Top of the chimney. Note loose bricks and mortar in imminent danger of falling.

2.0 TESTING

2.1 Mortar

2.1.1 Field (Penetration) Testing

Penetration tests were conducted to determine the compressive strength of the mortar. Metro unsuccessfully attempted first the 3 mm diameter needle hand penetration test. However, the mortar was stronger than testable with the penetrometer, so we switched to the Hilti Dx-450 powder actuated nail gun (Figure 9) using different cartridges as appropriate for the specific locations (White – lowest power, Green intermediate power).

This method is based on EN 14488-2 and Sika's Shotcrete Early Strength determination procedures. Compressive strengths between 3 and 20 MPa are determined by threaded studs (Figure 10), which are driven into the shotcrete surface. The relation between the depth of penetration (h_{nom}) and the pull out resistance infers a compressive strength according to the calibration curve (*Appendix – Calibrations*). Ten readings per measurement are necessary. The measurement tool for this method is the Hilti DX 450 with green cartridges and a pull out device (Figure 11).

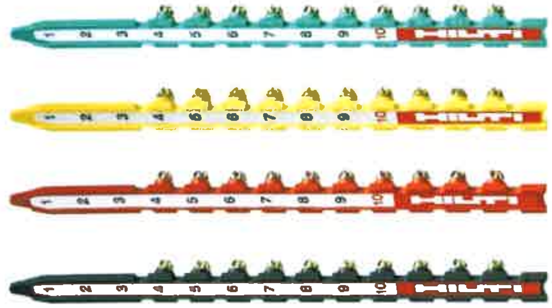

Figure 9– Hilti DX-450 Powder Nail Gun and cartridges.

Lower mortar strengths are tested with the white powder charges and only the depth of penetration (h_{nom}) needs to be determined to infer the compressive strength.

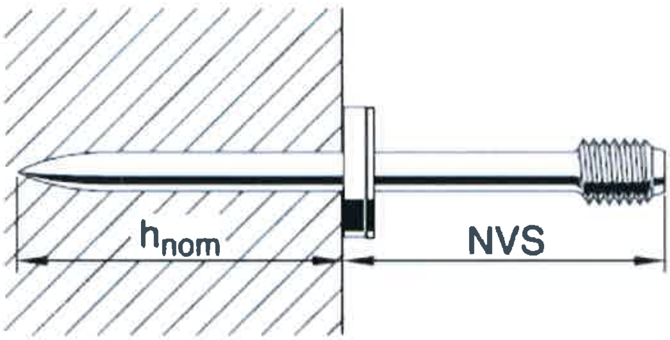

Figure 10 (left) Threaded studs used for penetration test.

Figure 11 (right) – Pull out device for Hilti studs.

The mortar strength ranges from 7 to 12 MPa in the chimney, barely 1 MPa in the Corner Building masonry walls and approximately 2 MPa in the Corner Building foundations. Results are summarized on Table 1.

2.1.2 Masonry Shear Testing

Clay brick masonry was tested for shear resistance on site. Metro was able to conduct shear tests to failure in two locations at the Corner Building. In the two test locations at the chimney, the shear resistance of the **bricks exceeded the maximum capacity of Metro's testing equipment.**

Metro conducted four ASTM C1531, Procedure B, in-situ brick shear tests (Figures 13 to 16). For each test, one brick adjacent to the test brick was removed to allow the temporary installation of a hydraulic jack and shims. The second vertical joint beside the test brick was also cleared from all mortar so as to allow lateral movement of the brick during the test. We applied a gradually increasing lateral force to the brick, using a 120 kN hydraulic ram (12T Single) and a hydraulic hand pump with a 5,000 psi digital pressure gauge. Each test was terminated when the test brick visibly moved while the hydraulic pressure was dropping, or a hydraulic pressure of 4,700 psi was achieved. Failures occurred gradually, with ample warning (i.e. fine particles dislodging from the surface well prior to ultimate load) at the Corner Building wall. Test bricks in the two locations at the chimney resisted 57 kN shear force without signs of imminent failure. Refer to the calibration chart (*Appendix – Calibrations*) for the system, to relate hydraulic pressure to test load. Results are summarized in Table 2.

Figure 13 – Detail of testing equipment and brick #1 (Corner building)

Figure 14 – Testing location #1 (Corner Building)

Figure 15 – Location and brick #2 (Corner building)

Figure 16 – Locations #3 & #4 (Chimney)

2.1.3 Lab Testing

Using a pocking knife and conducting a cursory petrographic analysis of mortar sampled at the Corner Building (Figure 12), the compressive strength was estimated to be in the 2 MPa range.

The mortar composition was determined using diluted HCl acid to estimate the nature of the binder (lime reacts strongly and dissolves completely with HCl while Portland cement reacts milder and leaves a solid residue) and by point counting under the microscope.

The mortar is estimated to contain 26% lime, 62% fine sand

Figure 12 – Lime mortar from Corner Building.

>1mm (Mostly quartz particles and minor amount of darker grains (volcanic)), and 12% air voids.

Some of the pores were filled with lime, which suggests that the porosity was originally in the 15-18% range, but reduced over time due to the autogenic[1] (**"self-healing"**) properties of lime mortars.

2.2 Clay Bricks Test

Metro collected 8 bricks from the site for compressive strength testing. The tests were performed in Metro's Burnaby laboratory. The sample included 4 bricks from the Corner Building (Samples #1, #1A, #2, #2A) and four bricks from the flume immediately adjacent to the chimney (Samples #3, #4, #5, #6).

The bricks were capped (Figure 17) with Hydrostone capping compound to ensure proper contact of the bearing plates. After the capping compound had cured, we loaded the bricks individually in Metro's Forney UTM until failure (Figures 18, 19 and 20). Results are summarized in Table 1. Additional notes are included in *Appendix – Test Results*.

Figure 17 – Capped bricks (top) from the Chimney and bricks ready to cap (bottom) from the Corner Building.

Figure 18 – Specimen #1 during compressive strength test.

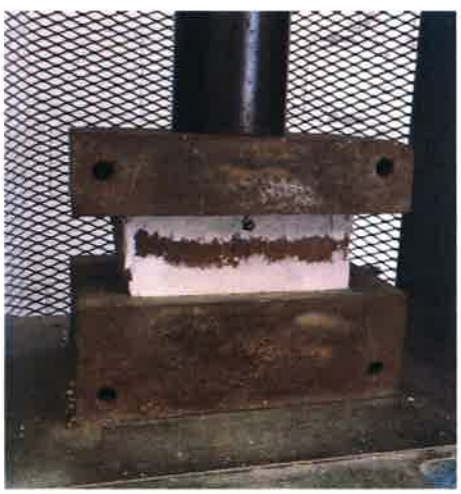

Figure 19 – Specimen #6 (Chimney) before test.

Figure 20 – Specimen #6 (Chimney) after test.

[1] *This phenomenon is expressed by the filling of microcracks by secondary products, restoring or enhancing the material's performance, thus leading to a prolonged life cycle. The main products formed during healing consist of calcite and various C–S–H/C–A–H phases.*

3.0 RESULTS AND DISCUSSION

The following tables summarize shear, compressive strength, and ASTM and CSA requirements.

Table 1 – Mortar Strength and Requirements as per ASTM and CSA

CHIMNEY						
Inside	*Avg. Pull Out Load (kN)*	2.96	*Avg. Penetration (mm)*	32	*Compressive Strength (MPa)*[1]	**12**
Outside, East	*Avg. Pull Out Load (kN)*	1.99	*Avg. Penetration (mm)*	36	*Compressive Strength (MPa)*[1]	**8**
North opening	*Avg. Penetration (mm)*	33			*Compressive Strength (MPa)*[2]	**7**
Shear Strength (ASTM C1531)	*Avg. Load (kN)*	≥ 56			*Average Shear Strength (MPa)*	**≥ 1.2**
CORNER BUILDING						
Wall	*Estimated strength based on (discontinued) penetrometer test (MPa)*					1 - 2
Wall	*Avg. Penetration (mm)*	64			*Compressive Strength (MPa)*[2]	**1**
Foundation	*Avg. Penetration (mm)*	54			*Compressive Strength (MPa)*[2]	**2**
Shear Strength (ASTM C1531)	*Avg. Load (kN)*	14			*Average Shear Strength (MPa)*	**0.3**
REQUIREMENTS (MPa)	**ASTM C270**				Type N	≥ 5.2
	ASTM C270				Type S	≥ 12.4
	CSA A179-14*				Type K[3]	≥ 0.5
	CSA A179-14*				Type O[3]	≥ 2.0
	CSA A179-14*				Type M[3]	≥ 14.0
	CSA A179-14*				Type N	≥ 3.5
	CSA A179-14*				Type S	≥ 8.5

** Requirements for 28 days old on site prepared mortar.*
[1] Compressive strength calculated according to Hilti's DX-450 Calibration Curve FX-7 for green cartridges.
[2] Compressive strength calculated according to Hilti's DX-450 Calibration Curve FX-6 for white cartridges.
[3] Types described are infrequently used in modern masonry construction. Only Type N and Type S are specified and recognized in the masonry design standard CSA S304.

Table 2 – Brick Strength

CHIMNEY				
Compressive Strength	*Avg. Load (kN)*	687	*Average strength (MPa)*	**31.7**
CORNER BUILDING				
Compressive Strength	*Avg. Load (kN)*	365	*Average strength (MPa)*	**17.6**

4.0 CONCLUSSIONS

The lowest compressive strength of the bricks is in the 17 MPa range. Any repair should be performed with a Type N or S mortar as per ASTM C270 and CSA S304.

While mortar and bricks are strong and still usable at the Chimney except where delaminated or weathered, the Corner Building's integrity is compromised. Although the bricks are fairly strong, the mortar is weak and deteriorated in many locations. Re-mortaring or deep re-pointing will be required to at least somewhat stabilise the masonry. The Structural Engineer may want to design additional measures to stabilise the wall.

We trust this report provides the information you require. If you have any questions or require further information, please call the undersigned.

Respectfully submitted,
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