STRUCTURAL INVESTIGATION OF MASONRY KILNS AT CLAYBANK BRICK PLANT NATIONAL HISTORIC SITE

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ABSTRACT
After operating for 76 years, the Claybank Brick plant was closed in 1989 and was declared a National Historic Site in 1997. The most distinctive structures on the site are ten masonry kilns that were constructed with 450 mm thick walls and 10972 mm diameter masonry domes. During operation of the brick plant the kilns had been rebuilt and repaired as required, however extreme temperatures during operation and existing soil conditions left these kilns in need of extensive rehabilitation.

In an ongoing effort to balance economy and preservation of the brick plant, four of the kilns had been abandoned and left to deteriorate, while the remaining six kilns became part of an ongoing preservation effort.

During a recent structural assessment radial and horizontal cracks, localized inward deflection of the dome, and efflorescence was observed in each of the kilns. It was concluded that the radial cracks and the outward expansion of the dome were within a safe limit. It was also concluded that the horizontal cracks and inward deflection of the roof may be early signs of localized failure, particularly individual bricks falling out of the dome roof.

This paper presents a brief history of the kilns, the findings of the structural investigation, and a discussion on how the kilns were assessed. The results of the assessment were compared to the deteriorated state of the four abandoned kilns to confirm the findings.

KEYWORDS: masonry dome, water infiltration, preservation, masonry investigation, radial cracking

INTRODUCTION
The Saskatchewan Clay products company constructed the Claybank Brick plant in 1913 approximately 100 kms south west of Regina, Saskatchewan near the town of Claybank. Clay was originally taken by cart from the hills south east of Claybank to Moose Jaw (approximately 50 kms) until a new railroad was constructed north of the site. By 1917 the brick plant consisted of a main factory, ten masonry kilns, five brick stacks, wood stock sheds and several brick buildings [1].

During operation Claybank Brick Plant had a reputation of being an efficient system and a well planned operation. Clay was mined from the hills south of the brick plant and brought to the factory for processing. The bricks were molded in the main factory and then dried in tunnels (dryers) located on either side of the factory. Hot air was supplied to these dryers by an underground tunnel that was connected to the kilns. As the kilns were fired, hot air was pulled through in-floor vents and drawn back to the factory. Once the bricks in the kilns had cooled, they were unloaded into stock sheds along the rail line, and the bricks from the dryer tunnels were loaded into the kilns.

Bricks from this plant were supplied across Canada, into the United States and possibly into Cuba. More notable buildings that used the face-brick are the Chateau Frontenac Hotel in Quebec City, and Hotel Saskatchewan in Regina. The refractory brick from Claybank was used for many industrial purposes such as locomotive refractories and combat ship boilers during World War II.

Due to changes in industry and trade agreements between Canada and the United States, the brick plant closed in 1989 after being in operation for 76 years. It was declared a National Historic Site in 1997 and has been maintained by the Claybank Brick Plant Historical Society, in partnership with the Saskatchewan Heritage Society and Parks Canada.

J.C. Kenyon Engineering was hired in 2005 to conduct a general assessment of the brick plant. Since then, annual inspections at the brick plant have been carried out to identify structural deficiencies and to provide recommendations for the preservation and restoration of the structures on site. Over the past two years the masonry kilns have been the main focus of the investigation and preservation efforts.

The investigation of the kilns included three parts:

1) A study of the history, construction, and operation of the kilns,
2) a visual assessment of the kilns, which included documentation of the observations, photos and some measurements required for analysis, and
3) numerical analysis of the kilns.

CONSTRUCTION AND OPERATION OF THE KILNS

Records indicate that the kilns were constructed on masonry or concrete footings approximately 914 mm x 914 mm in size. Vents were built into the floor of the kilns with brick, and a brick flue was constructed below ground to move recovered heat from the kilns into the dryers.

The exterior walls of the kilns were approximately 2845 mm high. When the kilns were originally constructed, the walls were thick at the base and narrow at the top where the dome was supported by the wall as verified by photos. At the narrow part of the wall a 750 mm steel band was used as a tension ring to resist the outward thrust of the dome.

Over time, these kilns were reconstructed. The last of the original kilns was demolished and reconstructed in 1951. The reconstructed kilns had a new design, which is the same form as the existing kilns (See Photo 1). Records suggest that the new kilns were constructed on the original foundations with 450 mm thick load bearing walls that were the same thickness from the foundation to the base of the dome. The steel band from the original kiln was cut into 150 mm strips and distributed along the full height of the wall, with three bands located at the dome/wall interface. The steel bands were connected with rivets and a turnbuckle that was used to tighten the steel bands as the kilns were fired.

Photo 1: Kiln #1- a typical example of the existing kilns

Documentation indicates that the dome roof of the kilns was constructed with brick in the following order, inside to out (see Figure 1):

- Layer of vertical firebrick, dipped in very liquid cement
- Layer of cement and zonolite mixture, 25 mm thick
- Layer of horizontal firebrick
- Layer of mortar
- Layer of face brick
- Three layers of parging

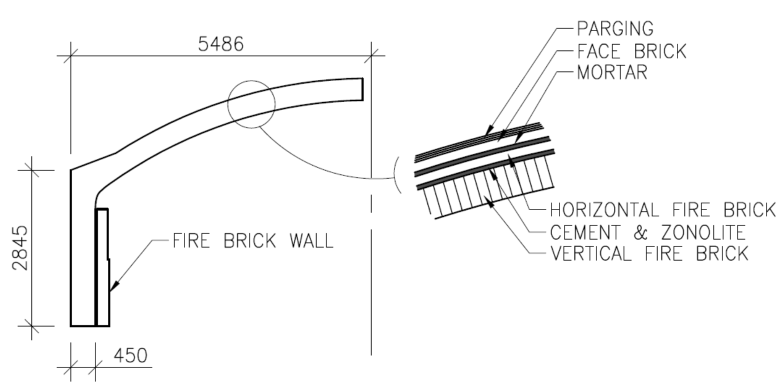

Figure 1: Half Cross Section of Kiln

The kilns were originally fired with coal through 10 small arched openings around the base of the wall, but in 1960, six of the kilns were converted to natural gas. The four kilns that were not converted remained in operation until 1971 and were then abandoned after being deemed "beyond repair".

STRUCTURAL ASSESMENT

The structural assessment of the kilns was limited to the six kilns that were converted to natural gas in 1960. The remaining four kilns had deteriorated beyond any point of repair and access to these kilns was limited.

In general the six kilns had similar deficiencies, but depending on when the last upgrades were completed, the deficiencies were worse for some kilns than others. For example, the floors had all experienced varying degrees of heaving from the expansive clays below. The firebricks in the floor had also deteriorated, but the venting through the floor could still be seen.

The exterior mortar joints had deteriorated (See Photo 2) with the joints at the top of the wall in the worst condition. No protection from rainwater running off the dome had been provided, which allowed water to run directly into the mortar joints at the top of the wall. In some locations the remaining mortar could be easily brushed away, and in other locations moss or other vegetation had started to grow.

Photo 2: Kiln #1- A typical example of deteriorated mortar joints

The steel bands were corroded and pitted, but appeared to be tight. The turnbuckles on some of the kilns were actually so tight that they had caused damage to the surrounding brick. On Kiln #4 there was a crack in one of the three bands located at the dome and wall interface. The band was still in place and it did not appear that the crack had gone through the entire band.

The dome roofs each had minor radial and horizontal cracking in the exterior cement. On Kiln #9 some of the cement had delaminated from the bricks below and there was clearly a void in the area between the dome and the wall interface (See Photo 3).

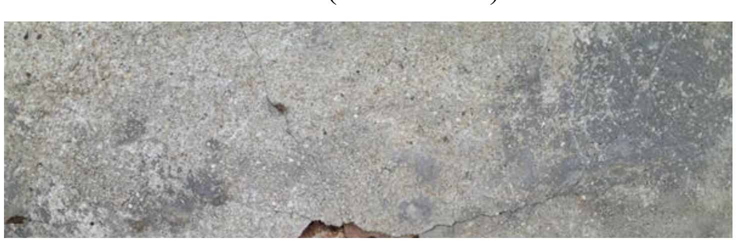

Photo 3: Kiln #9- Exposed face brick at the perimeter of the dome roof

The interior walls of each kiln could not be seen due to a protective firebrick wall that was constructed approximately 25 mm inside the load-bearing wall (See Photo 4). The firebricks were drystacked with no mortar between the bricks. The top of the firebrick wall was not level at several locations. One of the contributing factors was that the arches above the fireboxes had partially collapsed. The firebrick walls had also experienced lateral movement, but did not appear to be at risk of falling. Considering that there were no similarities between the firebrick wythe and the load bearing wythe, it was concluded that the two wythes acted independently.

Photo 4: Kiln #1- Interior firebrick wall

Each of the interior domes displayed radial cracking, which is a vertical crack that starts at the base of the dome and propagates towards the crown. The radial cracks in Kiln #1 were the most severe and were measured for further analysis. The radial cracks appeared to have some mineral build-ups at the base of the dome, which suggested water frequently leaked at these locations.

Similar to the radial cracks were diagonal cracks that suggested settlement of the wall below. These cracks were minor, but noted for future observation.

In Kiln #9 a horizontal crack was present along a portion of the dome that had deflected inwards at the base of the dome. Similarly, another horizontal crack was observed half way up the dome (See Photo 5). At location the colour of the bricks changed, which led to the conclusion that part of this dome had been rebuilt. The horizontal crack was located at the interface of the two brick types. Efflorescence was also observed at the dome/wall interface.

Photo 5: Kiln #9- Horizontal cracks half way up the dome and Deflection at the base of the dome

DISCUSSION

An ongoing challenge in preserving the structures at the brick plant is a high water table and very poor drainage. The brick plant was constructed on highly plastic clay. The expansion and contraction of the clay during wet and dry summers, and freeze-thaw cycles during the fall and spring creates constant movement of the ground below the kilns. Besides small diagonal cracks identified in the dome of Kiln #1, there was no clear indications that differential movement of the foundation had occurred.

Water penetration into the masonry structure seemed to be one of the primary causes of deterioration and structural damage. On the exterior of Kiln #4, the mortar joints had deteriorated to such a point that the brick was beginning to deteriorate, affecting the ability of the walls to resist differential movement below the foundation and effectively transfer forces from the dome to the load bearing walls and steel bands. Repointing of the brick was clearly a necessity to properly preserve the structures.

The steel bands are a key element in resisting the outward thrust forces of the dome roof. During the firing process the steel bands would have expanded faster than the brick. If constant tension was not applied during firing by tightening the turnbuckles, outward thrust of the dome would have occurred, leading to the formation of radial cracks. It became necessary to determine if the radial cracks and the subsequent expanding of the dome were within a safe limit, and if the steel bands that currently resist the outward thrust of the dome were sufficient.

The inward deflection of the domes was interesting because it appeared to correlate with water penetration that had occurred in the dome roof. The discovery of voids below the mortar around the perimeter of the dome on Kiln #9 led to the conclusion that a cavity had formed between the layers of brick within the dome. During the summer water would likely be able to escape the voids (as was seen by the efflorescence and mineral deposits at the radial cracks), however in winter months melted water would not have the ability to drain. As the captured water froze the bond between the vertical firebricks and mortar would break, allowing larger voids to form. At the base of the dome a void between the inside layer of firebrick and the horizontal firebrick would allow ice to build up against the vertical firebrick and force it inward.

After observing the deflection of the dome in Kiln #9, a further investigation of the abandoned kilns was conducted to determine if similar deflections had occurred and to identify potential risks caused by the deflection. The investigation also provided a better understanding of the potential failures that could occur in the remaining six kilns.

We were able to access Kiln #6 which was abandoned in 1971. This kiln was constructed the same way as Kiln #9 and displayed the most extensive deterioration of all the kilns (See Photo 6). For example, the exterior walls of the kiln had started to break apart due to eroded mortar joints and freeze thaw cycles, the steel bands on the lower portion of the wall were broken or loose, and the arches at the door appeared to be leaning inwards. The exterior parging on the dome had also become home to many native plant species.

Photo 6: Kiln #6- Exterior wall

Inside the kiln, radial cracks were present in the dome along with a horizontal crack that occurred near the crown. At several localized locations around the base of the dome the bricks had also deflected inwards in a similar fashion at Kiln #9. At the worst location, bricks were no longer held in place by the compressive forces of the dome and had fallen out leaving a clear opening to the outside (See Photo 7).

Photo 7: Kiln #6- Interior deflection of the walls and dome

The observations from Kiln #6 were then applied to Kiln #9. The exterior walls of this kiln did not show indications of inward deflection. However, two potential failure mechanisms had started to form. These were at the interface of the two brick types in the roof, and at the location of inward deflection at the base of the dome. From the evidence in Kiln #6, it was clear that the bricks could slide out from the adjacent bricks if they were no longer held in compression. Considering that a horizontal crack had formed in the roof of Kiln #6 (indicating a lack of compression between the bricks) it was concluded that those bricks could also slide out and fall to the ground.

ANALISIS

To determine the outward thrust and the stress in the external steel bands, the dome was divided into 36 lunes (each lune having an angle of 10 degrees from the axis of revolution) and each lune was then divided into 8 voussoirs. By calculating the properties of each voussoir, the cumulative outward thrust from one lune was determined to be 27.1 kN, thus the total outward thrust from the roof was 975 kN. As noted previously, three steel bands are located at the dome/wall interface. Using a prescribed yield strength of 210 MPa, the tensile resistance of one steel band is 808 kN, therefore assuming each band carries an equal load, only 40% of the capacity is being used.

In Kiln #1 the total width of the radial cracks was measured to get an approximate span increase. The total width of the cracks was approximately 120 mm or 0.3% of the perimeter according to original drawings. Recent research indicates that a 7% span increase in this dome would be acceptable leading to the conclusion that the base of the dome had not moved outward beyond a safe limit [2].

The inward deflection of the domes typically occurred at the base of the dome, which is the location of maximum stress. The stress in the brick was found by taking the resultant force at this location for the lune section that was used earlier. Assuming that the full thickness of the dome section is being engaged, the stress at this location is 0.08 MPa. However this assumption was challenged by the fact that the dome had deflected inwards at its base and that a potential void existed between the interior bricks of the dome and the second layer of bricks above. If this bond had been broken it was possible that the entire compression force of the dome was being resisted by the inside layer of fire brick. If this was the case, the stress in these bricks would have been 0.15 MPa; still within the compressive resistance of the brick.

PRESERVATION OF THE KILNS

Once the analysis was complete, the focus turned to preserving the kilns. Water penetration was clearly the most important and least costly external factor that the kilns could be protected against. It was recommended that mortar joints be repointed and that the cracks in the roof be filled. On one of the kilns it was necessary to remortar the entire dome of the roof.

CONCLUSION

The analysis of the radial cracks indicated that the span increase of 0.3% does not exceed what would be considered a safe limit of 7%. Furthermore, it was determined that the steel bands used to resist the outward thrust of the masonry dome are at 40% of their capacity and sufficient to resist the tensile forces from the outward thrust.

Due the number of assumptions that would be required to determine the cause of the inward deflection of the dome on Kiln #9, observations of the abandoned kilns were used to understand the potential failure mechanisms that could occur. From those observations it was determined tourists should not occupy Kiln #9 as there is potential that individual bricks could fall from the roof.

ACKNOWLEDGEMENTS

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