RESTORATION OF HISTORIC BRICKWORK CASE STUDY: THE ROUND FOUNDRY, LEEDS, UK

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ABSTRACT

The Round Foundry in Leeds was the first site in the UK where all of the trades were brought together for the production of static steam engines. The buildings, eleven in total, were built in the nineteenth century, the latest in around 1875. They included cast and wrought ironwork and massive timber roof trusses, all of which were of interest; however this paper will focus on the brickwork fabric. The buildings were largely derelict but there was a desire to bring them back into use as apartments, offices, restaurants and bars. This paper describes the investigation into the properties of the brickwork and how the site was developed to be suitable for modern use. Of particular relevance was the compressive strength of the walls of what had been at one time the massive machine assembly hall. The buildings were listed as being of historical interest and hence retention was a priority but this was in circumstances where local damage due to frost, water, salts and movement was evident. Consequently the desire to retain appeared at times to conflict with need to make commercial decisions about the value and earning potential of the buildings in the future.

KEYWORDS: historical brickwork, round foundry, sampling, testing

INTRODUCTION

The Round Foundry is a collection of 11 buildings close to Leeds city centre which formed the first site where all of the trades required to produce static steam engines were brought together [1,2]. The site is shown in Figure 1; the labelling is consistent with an earlier archaeological survey [3].

In 2001 when Ceram was first involved the site was largely derelict and although very close to the city centre it was very run down. This was clearly an opportunity for development although there was an issue as to whether investment could be justified if the likely life of the buildings once restored was limited. There were issues with the timber structure of the roofs in particular and internal wrought and cast ironwork. This paper concentrates solely on the brickwork.

Brickwork investigations can be extremely intrusive, especially in aged structures, as the retrieval of whole bricks, which are suitable for testing, can be difficult. In this investigation as the buildings were listed, sampling was minimized and efforts were made to relate the sampling to those facades intended to be retained. Consideration was given to whether hitherto internal walls would become exposed to the weather and to determine whether bricks from different buildings were the same type so as to enable samples to be taken from the less sensitive areas. This has led to conflicting demands and consequently a compromise reached but it is felt that sufficient was done to enable reliable decisions to be reached.

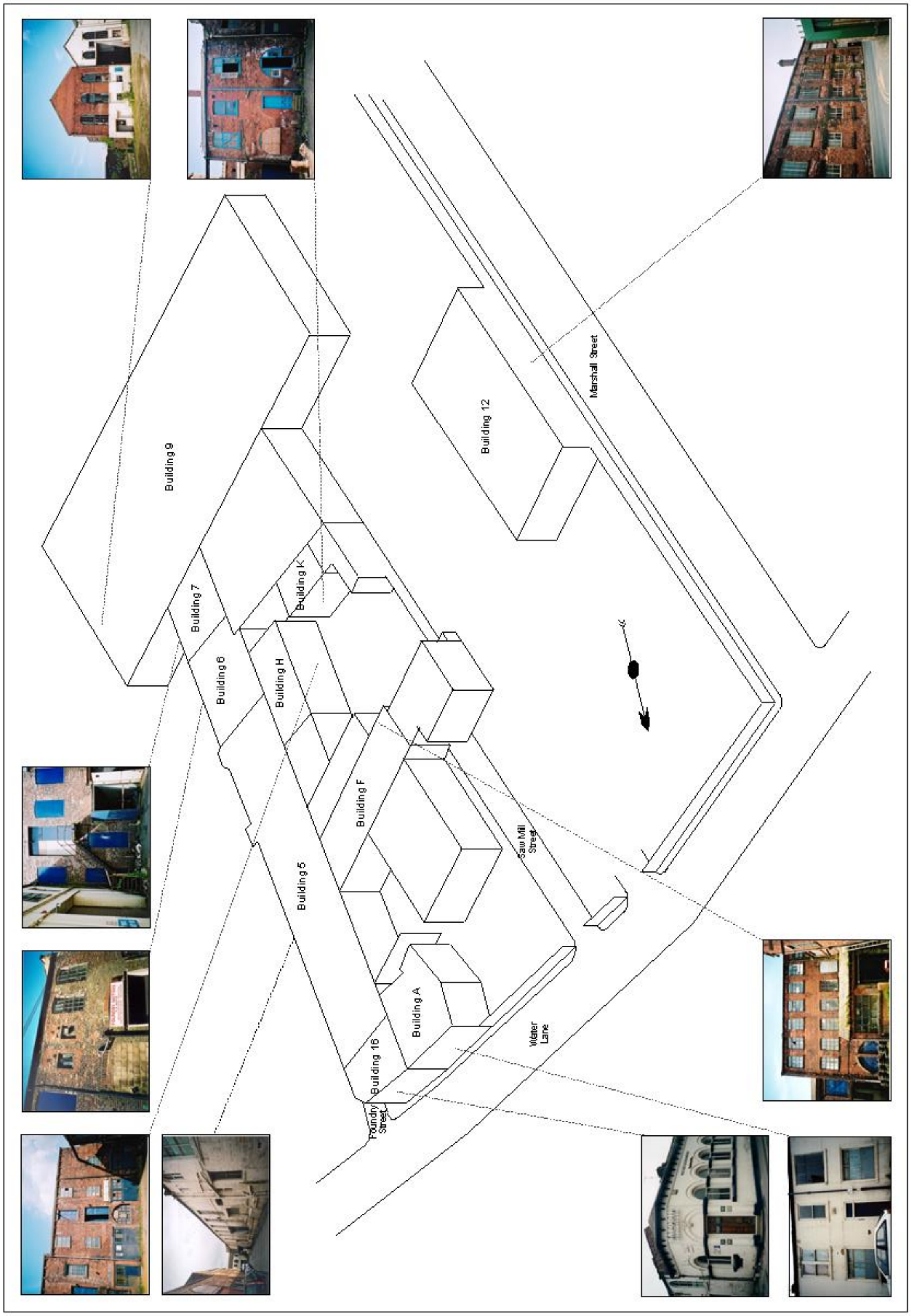

Figure 1: The Round Foundry

The next section gives an indication of the sampling and test procedures that were applied across the whole site, together with an indication of the results. Subsequent sections give additional comments on the Fireproof Mill and the machine shop which were two of the buildings of greatest interest.

SAMPLING AND TESTING

Samples of bricks and mortar were taken from all the buildings at the Round Foundry. For each building, brick samples were tested to give their 24hour cold water absorption which gives an indication of their variability and which taken together with other factors such as strength, size and colour was used to establish a measure of their quality. It was not possible to take sufficient samples to yield results that were beyond criticism in a statistical sense. However, when considered together with the physical inspection of the buildings and the known history they are sufficient to enable a balanced judgement to be taken as to the further useful life of the brickwork.

Where it has been possible to sample whole bricks for compressive strength testing their bed faces were ground flat prior to testing. This process serves two purposes, firstly to remove any mortar adhering to them and secondly to remove surface irregularities, which may lead to, localised excessive stresses. It is also the procedure subsequently adopted in BSEN 772-1 [4] the European Standard for compressive strength testing.

The bricks sampled are in general larger than those made today. The effects of brick shape on strength have been investigated during the development of EN 772-1 consequently for assessment purposes the strengths measured have been adjusted to give the equivalent strength of bricks with a current standard work size. Where it was not possible to sample whole bricks because of their friable nature, but where there was a known desire to retain a particular façade, part bricks have been taken and cubes cut from them which enables brick types to be compared with one another.

FROST RESISTANCE

The panel-freezing test is described in an authoritative paper [5]. Bricks which pass 100 cycles of freezing and thawing are deemed to be suitable for all exposure conditions, including copings, cappings, etc. bricks which fail in less than 10 cycles are considered to be suitable for internal use only. Bricks that survive for between 10 and 100 cycles can be used with confidence externally providing the provisions of BS5628: Part 3 [6] are followed. The test has subsequently been standardised as the approach to be used in Europe [7]. The test is not normally used for bricks which have been in use however it is anticipated that they will give a reasonable guide to the extent to which the useful life of the bricks which have been sampled has been expended. However as the ones tested are those that did not exhibit failure any test results must be used with a balanced judgement about the extent of any existing damage.

Making a prediction as to the likely period before frost failure occurs is extremely difficult. The classifications referred to earlier relate to the bricks surviving for what would be deemed to be a reasonable economic working life. So bricks that pass 100 cycles in the frost test would be expected to last for this period, often quoted as 60 years, in the most exposed locations. In this series of buildings the judgments made are based upon the test, the existing damage, the location (degree of shelter) and in some cases the wall thickness.

The effect of location can be considered in relation to a very useful guide produced by Hanson Brick. This classified areas as either moderately or extremely frosty based upon annual rainfall, height above sea level and frequency of frosts. Similarly a Ceram frost index based upon rainfall and frost can be useful.

Wall thickness may be important as if the aesthetics could remain acceptable following some frost damage there is less concern about some of the extremely thick walls than would be the case with modern construction.

WATER ABSORPTION

Typical values for the water absorptions from the buildings across the site are given in Table 1. They are mean values of those it was possible or desirable, depending on the future use of the building, to sample. They are very variable and most represent means from a variable set of samples. In the original work recommendations for each building were based upon specific data. The table has been included to give an indication of the overall difficulty of the task.

Table 1: Water Absorption Values

Brick Location	Water Absorption(%)
Bldg. 9 external	9.8
Boundary Wall	11.3
Bldg. K external	6.5
Bldg. 16 external	10.0
Bldg. 6 internal	8.6
Bldg. F internal	9.8
Bldg. H external	11.3
Bldg. H internal	13.2
Bldg. 12 internal	9.3
Bldg. 12 external	11.0
Bldg. 9 internal	10.8
Bldg. 9 external (apex)	5.6
Bldg. A misc.	17.7

CHEMICAL ANALYSIS

A chemical analysis of the mortars sampled at a number of locations was carried out in accordance with BS 4551 [8]. Essentially the mortars were all a mixture of dolomite and lime acting as the binder and an aggregate, the mix proportions ranged from 1:2 to 1:14. The aggregate was made up of river washed sand 0.1mm to 1.2mm in size, iron foundry slag of 0.1mm to 1.5mm in size and fine-grained siliceous sandstone 0.2mm to 2mm in size. The results from each analysis are given in Table 2. There are two distinctly different aggregate types based upon the soluble oxides they contain, the proportions are given in Table 3. An inspection does not suggest any particular relationship between aggregate type, mix proportions, age, etc, although a more detailed investigation could lead to some information of historical interest. The mortars had quite a high sulfate content and this probably reflects the atmosphere during the working life of the buildings.

Table 2: Results from Chemical Analysis of Mortar

Sample No.	Location	Aggregate Type	Mix Proportions		
			Dolomite	Lime	Aggregate
04	Bldg. A se	A	1	0.2	4.2
05	Bldg. F iw	B	1	0.4	6.2
06	Bldg. H fe ext	B	1	0.2	12.5
07	Bldg. Fe br	A	1	0.4	6.5
08	Bldg. H 1st f int	B	1	0.1	3.7
10	Bldg. H 2nd f int	B	1	0.1	9.1
11	Arch Pub 12	A	1	0.8	8.1
12	Bldg. 6 int	B	0.1	1	14.8
13	Bldg. 6/7 ext	B	1	0.2	5.5
14	Bldg. 9gl	A	1	0.1	11.5
15	Old Bldg. 9 s bw	A	1	0	6.6
16	Bldg. 12 ext	B	1	0.1	1.9
17	Old Bldg. 13 sbw	A	1	0.3	9.1
18	Bldg. 16 f ext	A	1	0.1	2.4
19	Bldg. A	A	0.3	1	12.2

Table 3: Aggregate Type

Type	Comparison %		
	Soluble Al_2O_3	Soluble SiO_2	Insoluble
A	2.1	5.2	92.7
B	0.8	2.3	96.9

COMPRESSIVE STRENGTH

In each case where a brickwork compressive strength has been quoted the tabulated values for a 1: 3 lime: sand mix have been taken from CPIII as a guide [9]. This was fairly crude, as the mix proportions taken as the total binder (dolomite + lime) to aggregate ratio was 1:2 to 1:14. However in view of the poor joint filling should strength be an issue for design in a particular situation some further investigation was warranted and recommended. It is anticipated that any calculation regarding stability would be based upon gravity. The brickwork strengths were been determined by applying a global factor of safety of 4.5 to the basic stresses in CPIII. The typical strength of the individual bricks is given in Table 4 together with a typical size which was used in the adjustment of strength for brick size.

Table 4: Compressive Strength of Bricks

Brick Location	Dimensions l x w x h (mm)	Compressive Strength (MPa)
Bldg. 9 external	234 x 114 x 80	-
Boundary Wall	234 x 110 x 70	-
Bldg. K external	237 x 113 x 87	22.8
Bldg. 16 external	239 x 117 x 85	17.7
Bldg. 6 internal	234 x 112 x 76	48.5
Bldg. F internal	235 x 113 x 74	20.2
Bldg. H external	235 x 111 x 76	28.8
Bldg. H internal	238 x 113 x 72	37.43
Bldg. 12 internal	250 x 116 x 90	-
Bldg. 12 external	236 x 116 x 75	-
Bldg. 9 (apex)	233 x 112 x 71	-
Bldg. A misc.	243 x 113 x 68	16.7

THE FIREPROOF MILL

The Mill contains a series of masonry vaulted floors, hence the description as fireproof, at each storey height. The ceilings are carried by wrought iron beams and tie rods. The ground floor consisted of 8 arches. There was a bricked in window or door opening on the back wall at the centre of each arch. The interior of the building was heavily painted which made it difficult to assess the quality of the bricks. However, their general appearance seemed to be good.

The front of the Fireproof Mill (building F on Figure 1) faces South into what was known as Saw Mill yard. The main part of the building is three storeys high (see insert on Figure 1) with a one storey lean-to extension. The extension of the building showed large patches of frost damaged bricks but also numerous individual bricks which has suffered frost damage. In total it was estimated that 25% of the bricks were damaged.

The Mill contained a cellar, which could be accessed via a manhole. There was an obvious dip in the ground floor in one of the arches and on accessing the cellar it could be seen that the arch had collapsed and had been infilled with rubble. The arches had not been painted in the cellar and could be viewed more easily. The arch consisted of a row of springer bricks running the length of the beam and a series of bricks on end forming the arch between the springer bricks. The depth of the arch being the depth of a brick. An attempt was made to take a core out of the crown of the arch on the ground floor but the core disintegrated during drilling. One arch was opened up next to the cast iron beam. The mortar was found to be powdery and non-cohesive. Full bricks could not be sampled due to their friable nature.

Since a single storey lean-to and engine house extension were to be demolished and would lead to the internal wall of the building becoming an external wall, bricks were sampled from this elevation. On exposing the mortar it was found to be black and gritty with no cohesion, having the texture of a shaley soil. The external mortar was also soft and easily penetrated with a key. It was very difficult to sample full bricks; the bricks broke easily on removal from the wall.

The brickwork in the South facing elevation, which would become exposed when the single storey extension was removed, was expected to have a reasonable working life. However there were other areas where there was quite extensive frost damage and either further testing was warranted or fairly extensive replacement was necessary. In view of the degree of damage in what is a very sheltered location the brickwork of the Western elevation it was recommended that it be replaced.

In view of the poor brickwork sampled from the ground floor arch and the evidence of a collapsed arch it was strongly recommended that an in situ loading test be carried out prior to any decision to re-use the arches in the upper floors as structural elements. In the event the arches were retained, propped and used as permanent framework for a new concrete floor.

THE MACHINE SHOP

This was the building in which machines were assembled and consisted of the remains of three buildings. Attention was focussed on the Eastern elevation of the building as much of the rest of the cladding was to be replaced (see Figure 2). The brickwork plinth to the timber clad Northern part of the building was painted white, it was 370mm thick (1½ bricks) thick. The wall was generally in English Garden wall bond, with a course of headers in every fifth course. The brickwork was in good condition with no indication of frost failure and a hard grey mortar had been used. The window cills varied, in some cases being of bullnose specials and in others timber had been used.

The brickwork in the Southern most part of the Eastern elevation (1875-1877) was painted white up to the cill level. The top triangle was relatively new, and the remainder had been repaired in various places and is in need of further repair. The rebuilt top triangle of the wall looked to be in good condition, it was one brick thick and connected to the roof structure by six straps, probably of steel along each of the two verges. There was a diagonal crack to the Southern end.

Figure 2: The Machine Shop

The Eastern wall was 510mm (two bricks) thick at the base, reducing to 380mm (1½ bricks) at the height of the cills to the main windows (4.26m). The height at which the brick changed to those for the apex is 7.8m. The arch bricks were of special shape 310mm in length with a depth of 50mm at the arch soffit and 75mm at the other end. Above the window openings the mortar which was hard to a key test had eroded to a depth of about 10mm.

MATERIALS INVESTIGATION

In view of the desire to retain this façade sampling, which left damage to be reinstated, was kept to a minimum. However, in order to try to obtain a sample of brickwork for testing an attempt was made to remove a 300mm core from the internal face of the wall near to the Southern end. The removal of the core showed a number of things. The wall construction is of two parallel leaves each one brick thick. Although each wall appeared to be cross-bonded every sixth course there seemed to be no regular connection between the leaves. The core could not be removed intact as the mortar was very weak and friable and also because there are a significant number of places where the mortar was missing. These gaps in the joints were clearly visible from the cored wall, see (see Figure 3) and were evident as water used to lubricate the core drill was emerging from joints remote from the drilling position. The mortar mix was 1: 0.1: 11.5, which confirmed that the reason for the poor performance was lack of binder. Two bricks were removed from the Eastern façade. In order to obtain representative samples of what is an important part of the cladding without being too intrusive, and in view of the fact that this building was known to be part of an earlier larger building. It was considered that the brickwork of the Southern boundary wall was of the same type as machine shop and greater numbers of bricks were sampled from that wall. The boundary wall was probably the Southernmost wall of the original larger building. Although the water absorptions in the bricks from the boundary wall were highly variable, it seems most likely that the inner leaf of the Eastern wall, the Southern boundary wall and what remains of the old North wall is of one brick type. The outer leaf of the Eastern wall was of a different, denser, larger brick type. For the purpose of future structural consideration this difference is probably unimportant.

Figure 3: Core Site

In view of the massive nature of the wall, which had clearly been built to withstand the load from another storey, now removed, attention was focussed on the likely durability of the façade rather than compressive strength. However from the cubes cut from the interior bricks which come from the core it seemed strength of about 10MPa was reasonable [10-15]. This would suggest, bearing in mind the poor nature of the mortar, a brickwork strength of no more than 2MPa. The two bricks sampled from the Eastern façade of the building and the eleven taken from the boundary wall, were tested for their frost resistance. They did survive 78 cycles before failure occurred by delamination of one of the two façade bricks, one of the eleven boundary wall bricks and no further damage occurred to other bricks during the remainder of the 100 cycles (see Figure 4). Consequently the bricks although of quite low strength were of reasonable durability, however once failure occurred it did develop quickly.

Figure 4: Frost Failure

The bricks used for the newer apex have a relatively low water absorption (5%), they are stamped Normanton in the frog and this probably means they are more recent, possibly after 1920. The same bricks are being made today from the same clay and quarry and these are known to be frost resistant and have been used in the redevelopment of the nearby Granary Wharf.

Since the work on site it is understood further consideration was given to the brickwork elevation. Although the bricks appeared to be some of the more durable from the site the mortar within the body of the wall was poor and there were numerous gaps. The fairly poor standard of construction in terms of joint filling, the poor mortar and the fact that quite extensive repairs would be required to make the corner safe, to stitch across the cracks means that repairs would be extensive. Taken together with the fairly unsightly painted band at the bottom part of the wall suggested that replacement was the best option. This was what was done and the wall was replaced forming a façade for what is now The Round Foundry Media Centre (see Figure 5) which was built in the same style as the original.

Figure 5: Round Foundry Media Centre

CONCLUSION

It has been possible to retain large parts of an historical industrial site and to replace those parts that were not suitable for retention in a style similar to the original. This has enabled a rundown inner city area to be regenerated into a vibrant mix of office, residential, professional and retail development. The evaluation of the brickwork has been by interpretation based upon archaeological information, testing to current best practice together with research data. The approach, although not well documented, has been successfully used on a number of important projects in the UK.

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