An investigation into the non-uniform decay of Hardwick Stone

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AN INVESTIGATION INTO THE NON-UNIFORM DECAY OF HARDWICK STONE

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Hardwick stone as used on the vernacular Hardwick Estate buildings decays in a non-uniform way. Typically stones at Hardwick decay cavernously leaving the mortar matrix behind. Levels of decay can vary dramatically from stone to stone with one stone showing advanced decay whilst adjoining stones are relatively intact. Ten sample buildings giving a total of 1587m² of elevations and with a good geographical spread across the estate were surveyed. Ratings were assigned according to condition. It was shown with 95% confidence that the weathering on the western elevations is significantly worse than that seen on the eastern elevations of the sample buildings. Northern elevations had high levels of stonework in good condition, while western elevations had the lowest. The prevailing wind direction on the Estate is west to north-west. The difference in levels of decay below 1 metre and above 1 metre has been shown to be significant at the 95% confidence level with a slight correlation between levels of stone decay and building height (above sea level). The survey also highlighted stone decay parallel to, but offset from, the roofline where there were no overhanging gables present. In contrast, buildings constructed with protruding cills were often observed to have areas of decay underneath the cills. Stone decay often appears to be associated with the path of the chimney.

Keywords: Sandstone; Weathering; History

INTRODUCTION

The vernacular buildings on The Hardwick Hall estate have little in common with the magnificence of the Elizabethan Hall except that most of them, and the Hall, are constructed from the same material: Hardwick Stone, originally obtained from the now disused quarry on the estate. The new quarry at Hardwick is still in operation and stone from this is used for repairs. According to the BGS data both quarries sit in an area of sandstone from the Pennine Middle Coal Measures Formation.

This stone displays remarkable decay characteristics. Some stones decay cavernously leaving the mortar matrix behind and in extreme cases an aperture to the rubble core. Parts of other stones show advanced decay whilst other parts are relatively intact and other stones show little sign of decay. These features can be seen occurring in buildings across the estate on all elevations. It was the purpose of this research to investigate the non-uniform decay of this stone, to discover whether any trends or patterns in its decay could be established and to suggest reasons for this decay. The results of this research may help with the financial and logistical planning of future estate repairs.

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RATIONALE

The mapping of stone weathering was undertaken using the classifications of weathering forms and intensities.

Consideration was given to several systems of assessing stone condition used in literature sources. "The mapping method represents a non-destructive, well established procedure, which allows the quantitative evaluation of complete stone surfaces according to type, intensity and distribution of weathering forms. It makes an important contribution to rating of weathering damage, weathering prognosis, information on causes and processes of stone weathering and to sustainable monument preservation" (Fitzner, Heinrichs and La Bouchardiere 2002, p. 224 cited Fitzner *et al* 1995). Detailed schemes such as those proposed by Fitzner *et al* (2002) in mapping of the ancient structures in Cairo allowed "detailed registration of weathering forms" and was used as a "basis for the quantitative rating of stone damage by means of damage categories and damage indices." (2002, p. 217), however these were deemed too detailed to acquire a statistically viable sample derived from the Hardwick estate buildings. Systems of condition survey detailed by Warke *et al* (2003) were also considered.

It was decided to use a system complimenting The National Trust's quinquennial structural and condition survey system, as the Trust is the body who maintains the buildings. As part of the quinquennial survey the external walls would be examined. In undertaking this research every elevation was split into a grid of 1m² areas each of which had a condition value assigned to it. Masonry in good condition that is functioning as designed was rated as 'good – requires no attention' while masonry that is showing signs of decay to an extent that it may need replacing or at least flagging up for special attention at the next quinquennial was rated as 'some decay – requires monitoring'. Masonry that had decayed to such an extent that it required replacement before the next quinquennial was rated as 'severe decay – requires replacement'. Stone already replaced due to failure was also noted. Richard Lambert, National Trust Building Surveyor, states that stone becomes critical in terms of its structural role when the decay is approaching 50% of its depth (pers. comm. November 2007).

Literature highlighted a number of areas which would require investigation. Robinson and Williams (1996, p. 137) believe that one of the most important factors affecting the degree of weathering is height: "The most weathered blocks tend to be found towards the base of walls, within the capillary fringe … Window surrounds also appear to be particularly susceptible to weathering." Figure 1 illustrates the moisture regime on a typical historical façade, after Duffy and O'Brien (1996, p. 257). They also state that the upper 25% of the façade receives 60% of the driving rain. Duffy and O'Brien. Their diagram shows that projecting cills protect the elevation below keeping them drier as a cill is designed to throw water away from the elevation. The distribution of badly decayed stone directly with relation to the cills was also investigated at Hardwick.

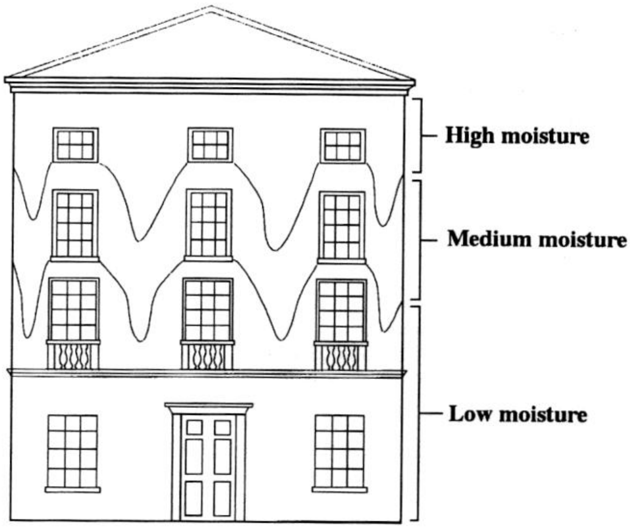

Figure 1: Inferred moisture regime on a typical historic façade Duffy and O'Brien (1996, p. 257)

All elevations were mapped in terms of the 4 categories of the quinquennial survey noted above and statistical analysis carried out on the data to discover whether perceived differences in results were significant or not. In addition to the field work, extensive laboratory work was undertaken, but is not presented in this paper.

Details of selected surveyed buildings

Norwood Piggeries

This building was built as a pigsty to house animals belonging to the occupants of Norwood Cottages. Like the cottages, it was built in 1874 (National Trust Vernacular Building Survey – 2 Norwood Cottages, 1997, p.1). The building although built as an animal shelter is now used as a garden shed. There has been no replacement of stonework to date and some of the existing stone is badly decayed, and is particularly severe and widespread on the southern elevation, Figure 2, although there is some decay evident on the other elevations. The building's roof has significant overhangs, which may have affected the manifestation of decay levels on the southern and northern elevations.

The southern elevation has the lowest proportion of stone in good condition (36%). The eastern elevation has the highest proportion of stone in good condition (69%). The average for all elevations is 55%. The northern elevation has the highest proportion of stone showing signs of decay (42%). The eastern elevation has the lowest proportion of stone in this category (24%).

Figure 2: View of southern elevation Norwood Piggeries

Figure 3: Example of cavernous weathering, southern elevation Norwood Piggeries

Figure 33 is a detailed photograph of one of the stones exhibiting cavernous decay in the southern elevation of Norwood Piggeries. In this photograph it is possible to see that the cavern passes right through the stone and it is possible to see mortar and the rubble core behind.

Rowthorne Lodge

The National Trust vernacular building survey for Rowthorne Lodge states that it was constructed in approximately 1827 (National Trust Vernacular Building Survey - Rowthorne Lodge, 1997, p.1). The central protruding section of north elevation has been extended at ground floor level at some point and is not built with Hardwick Stone. This building, although small, was finished to quite a high standard. It is generally in good condition, and there is no stonework in the worst two categories i.e. needs replacing or has been replaced. The stone showing some signs of decay on upper levels follows the path of the flues due to combustion by-products. The roofs have a slight overhang, this is more pronounced on the roof over the central two-storey section. Figure 54&5 show how the exterior stone decay appears to follow the path of the flue.

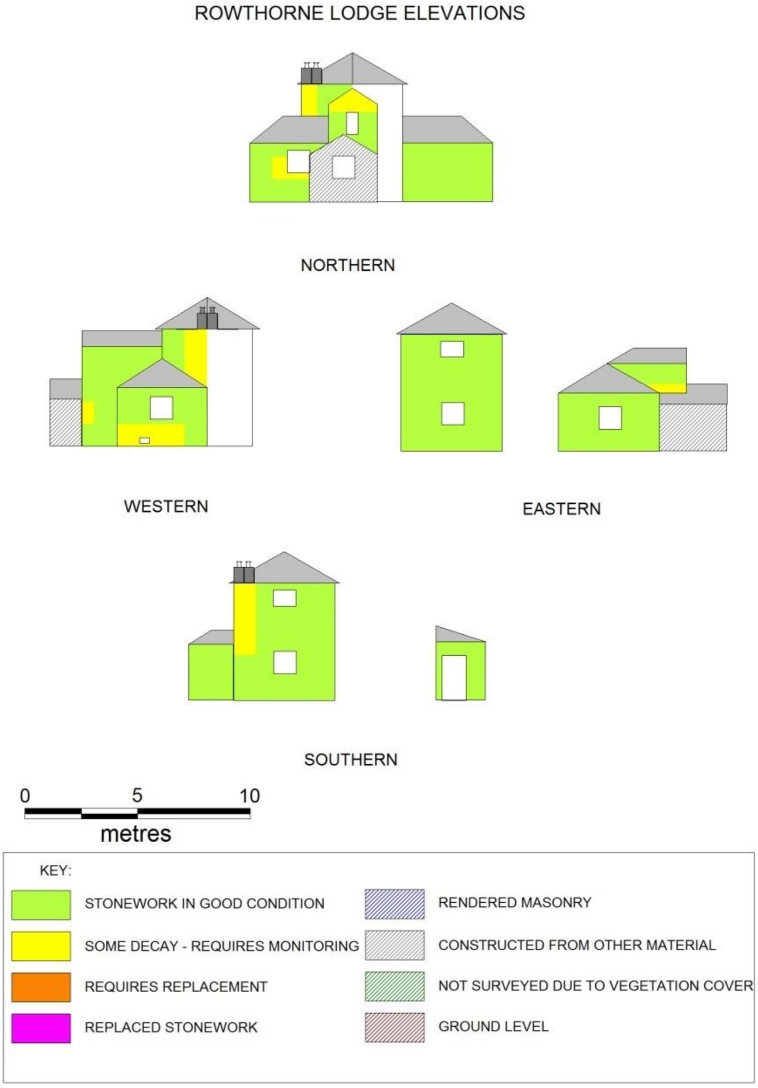

Figure 4: Elevations of Rowthorne Lodge

Figure 5: Stone decay along route of flue

The western elevation has the lowest proportion of stone in good condition (74.5%). The eastern elevation has the highest proportion of stone in good condition (98%). The average proportion of stone in good condition for all elevations is 88%. Apart from the flues the other locations where there is stonework showing signs of decay are on the northern gable, around the cill on the northern elevation and mainly at low level on the western elevation.

The Grange

This building has a date stone of 1724, although the rendered section is believed to have been constructed in the nineteenth century. There is a fair proportion of stone replacement in evidence. The roof does not overhang any of the elevations. There are a mixture of window designs, some with projecting stone cills and others that are flush. It is noticeable that the decayed stonework occurs at low level on this building and also on the central and upper sections of two of the gable ends. Interestingly the third un-rendered gable end does not show this decay pattern. Figure 66 illustrates the extent and severity of stone decay on this building.

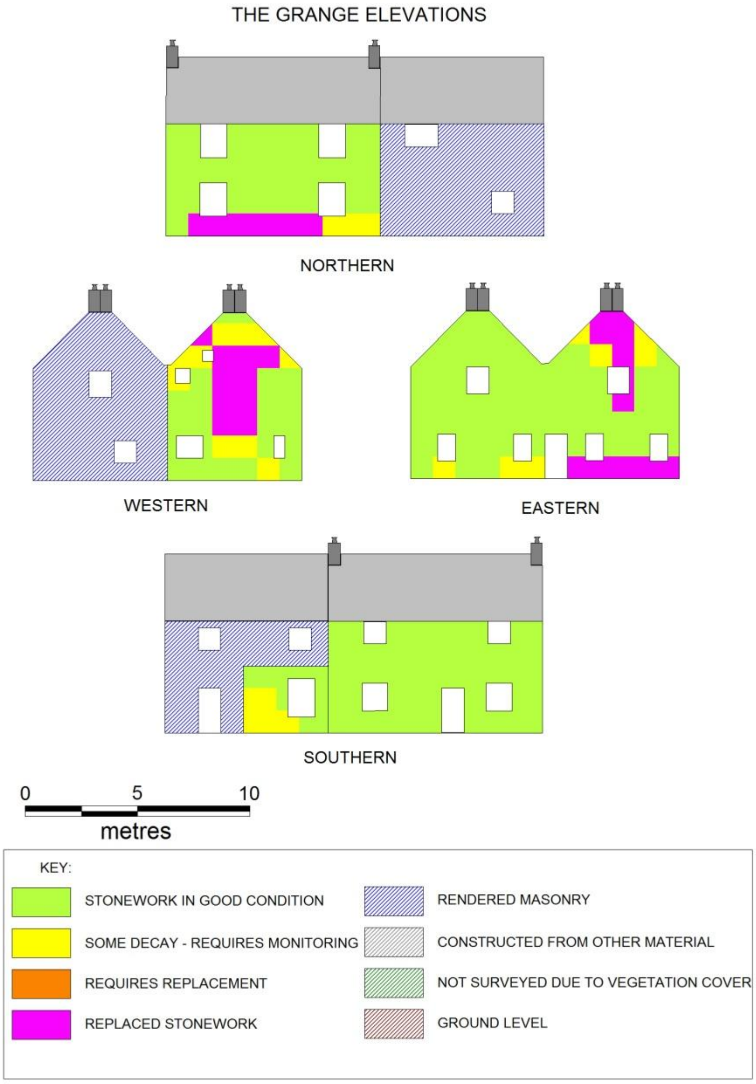

Figure 6: Elevations of The Grange

The elevation with the highest proportion of stone in good condition is the southern elevation (92%), the western elevation has the lowest proportion of stone in good condition at 52%, with an average over all the elevations of 77%. The western elevation has the highest proportion of stone that is showing signs of decay (22%) and also the highest proportion of stone that has been replaced (26%).

The Croft

This building is built around 3 sides of a courtyard, with the southern side open. It therefore forms an 'n' shape. Due to this shape the external elevations were surveyed as 'The Croft.' The southern elevation of the building facing into the courtyard was included in this survey as the southern end of The Croft is the open end. The other 2 elevations that face into the courtyard were surveyed as 'The Croft Courtyard.' Figure 7 shows the extent and severity of stone decay to The Croft, Figure 8, **Error! Reference source not found.**shows the extent and severity of stone decay on The Croft Courtyard elevations. Due to the size of this building the elevations are shown at a slightly smaller scale than others illustrated in this paper.

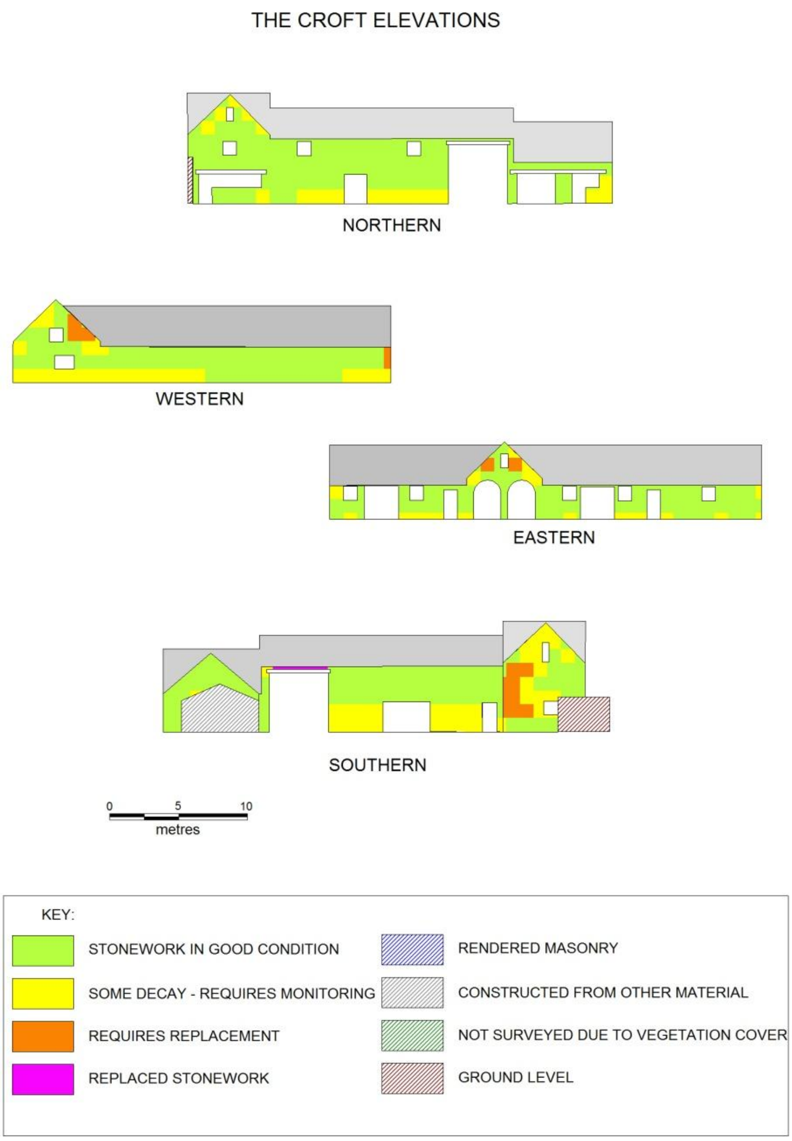

Figure 7: Elevations of The Croft

Figure 8: Elevations of The Croft Courtyard

The roofs of the Croft building are dual pitch covered with stone slates. They do not overhang any of the elevations to any significant degree. There are multiple openings to the elevations performing a variety of functions. The condition of the stonework in the elevations varies. The elevation in worst condition is the western elevation of The Croft Courtyard.

The elevation with the lowest proportion of stone in good condition is the southern elevation (64%), whereas the highest proportion of stone in good condition was observed on the northern elevation (83%) with an overall average for all elevations of 73%. The southern and western elevations have higher than average figure for stone showing some signs of decay, 28% and 27% respectively. The southern, eastern and western elevations all have some stone requiring replacement, whereas the northern elevation does not. In the case of The Croft Courtyard, both elevations have a low proportion of stone in good condition. The eastern elevation has 44% in good condition, the western elevation fairs slightly better at 52%. The average for these two elevations is 51%. The eastern elevation has a high proportion of stone that is showing some decay (56%), whereas the western elevation has 39% in the same category. The western elevation also has 9% of its stone requiring replacement.

One of the most striking features of this elevation mapping is how the spread of stone showing signs of decay appears to occur high up in the building, towards the southern end of the western elevation which may be attributable to the fact that the southern end is the open end of the courtyard and therefore this part of the building is least protected. Decay at high levels in the elevations can also be seen on the eastern gable of the southern elevation in Figure 7. Another feature of the pattern of stone decay on The Croft is that decay appears to occur on the gables of the buildings parallel to, but offset from, the roof line. This is not shown perfectly by the elevation mapping because the elevations have been split into 1m grids.

This pattern of offsetting of the areas of higher levels of decay when gables are present can be seen on other, similar, elevations on other estate buildings; notably Yew Tree Farm, The Grange and The Grange Outbuildings 1 & 2 for example. It does not occur on buildings with overhanging roofs however, Norwood Cottages and Stainsby School being good examples.

Stainsby School

This building was constructed in 1895 (datestone) as a boys school for the village of Stainsby. The extent and severity of the stone decay on this building is illustrated in Figure 9.

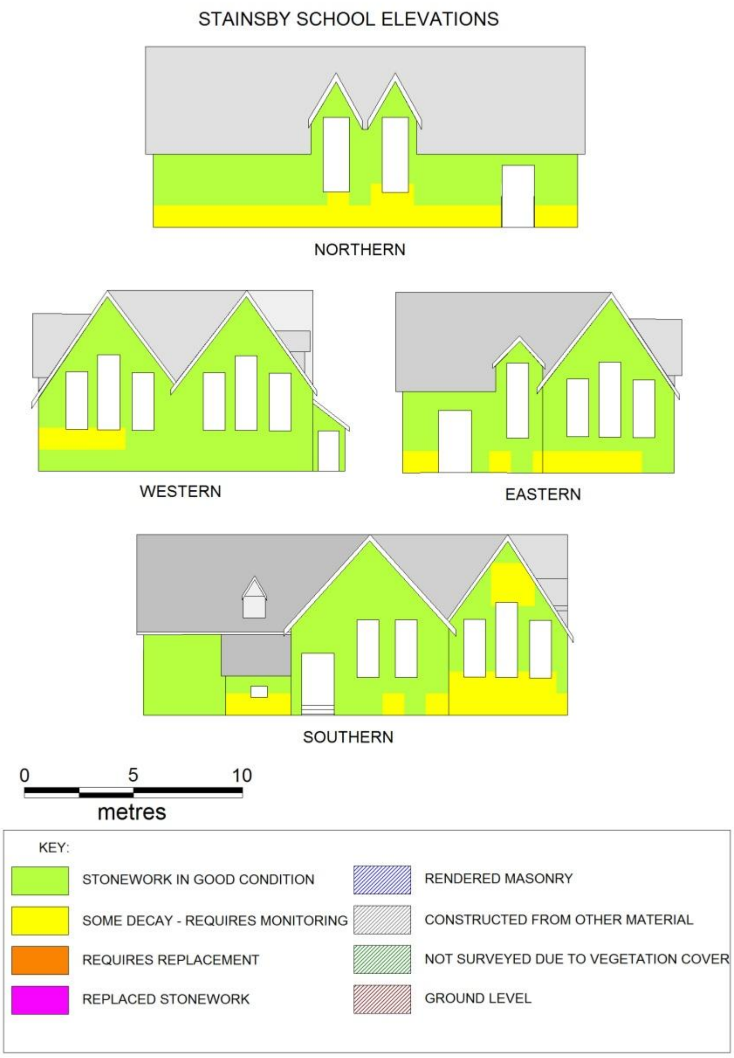

Figure 9: Elevations of Stainsby School

The building is of single storey construction with an overhanging clay tile roof. There are large windows to all elevations with projecting stone cills. Overall the stonework is in good condition. There is no stone in the worst two decay categories and much of the stone is in good condition. Where there are signs of some decay this tends to occur at low level except for some to a gable on the southern elevation and some under a cill on the western elevation. All elevations have high proportions of stone in good condition. The highest proportion occurs on the western elevation (93%), the lowest on the northern elevation (69%). The average for all elevations is 80%. The northern elevation has the highest proportion of stone that is showing signs of decay (31%). The western elevation has the lowest (7.5%)

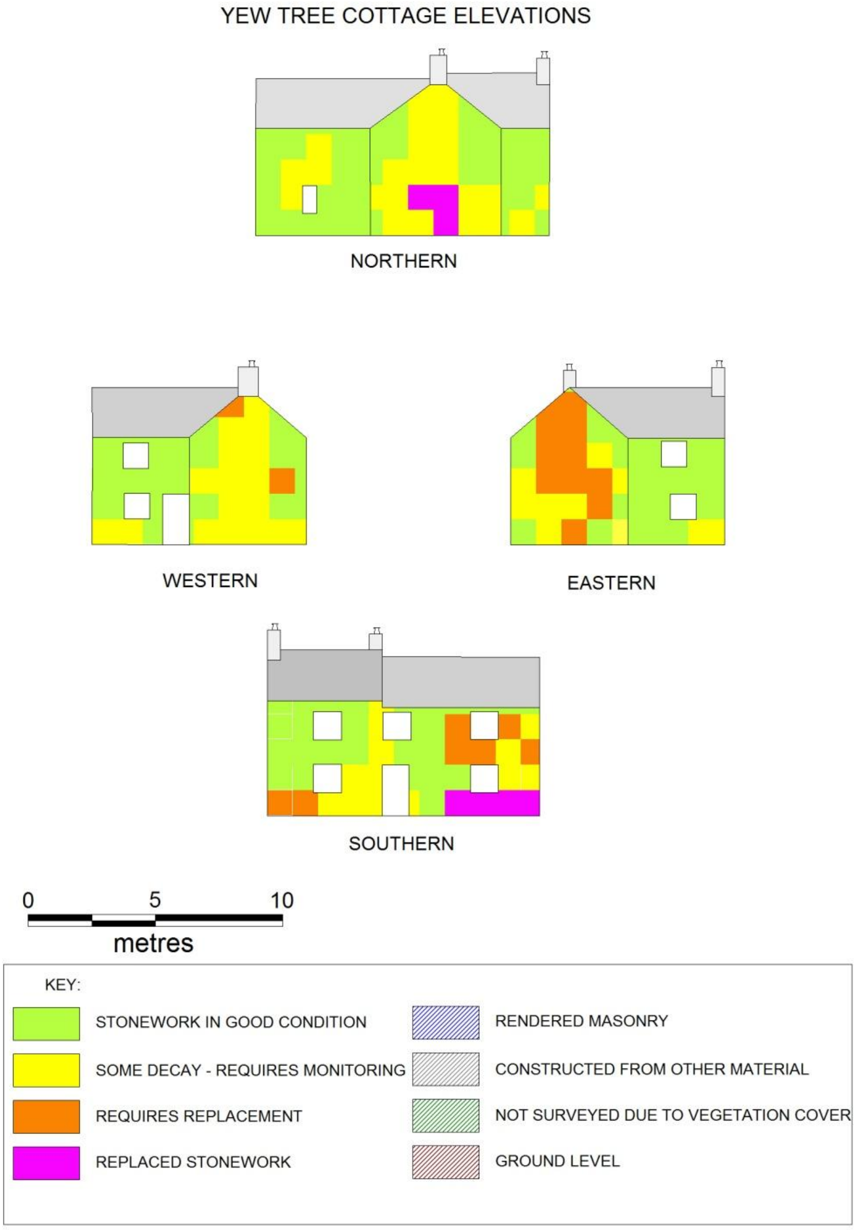

Figure 10: Elevations of Yew Tree Cottage

Yew Tree Cottage

Yew Tree Cottage is one of the older buildings that make up the sample in this survey. The National Trust Vernacular Building Survey dates it as late eighteenth century with nineteenth century alterations/extensions (The National Trust Vernacular Building Survey – Yew Tree Cottage, 1997, p.1). The roof does not have any significant overhang to any elevation. The building forms a 'T' shape and has three gable ends. There are chimneys to two of these gables and the third (eastern) appears to have had its stack removed at some point. There are windows of differing styles in this building, some have protruding cills and some are flush. This building has a lower proportion of stone in good condition compared to many of the other buildings in this survey. There is a suggestion in the Vernacular Building Survey for this property that the stone for this building came from a small quarry in the Hamlet of Astwith local to the building (The National Trust Vernacular Building Survey – Yew Tree Cottage, 1997, p.1).

This may mean that the stone in this building is slightly different to the stone used in other buildings in the sample. It does display the same weathering characteristics however. Figure 10 illustrates the severity and spread of stone decay at Yew Tree Cottage.

The proportions of stone in good condition is low for all elevations, the worst elevation being the southern elevation (48%) and the best being the northern elevation (55%). The western elevation has 50% of stone in good condition and a further 45% showing signs of decay. This leaves 5% requiring replacement. The eastern elevation has the lowest proportion of stone showing signs of decay (23%), but has the highest proportion of stone requiring replacement (27%). The southern elevation has the highest proportion of stone that has been replaced (9%).

Combined results for all buildings surveyed.

The data gathered from the buildings surveyed has been aggregated and plotted as a graph. This groups elevations of the same direction together. This data is shown graphically in Figure 11:

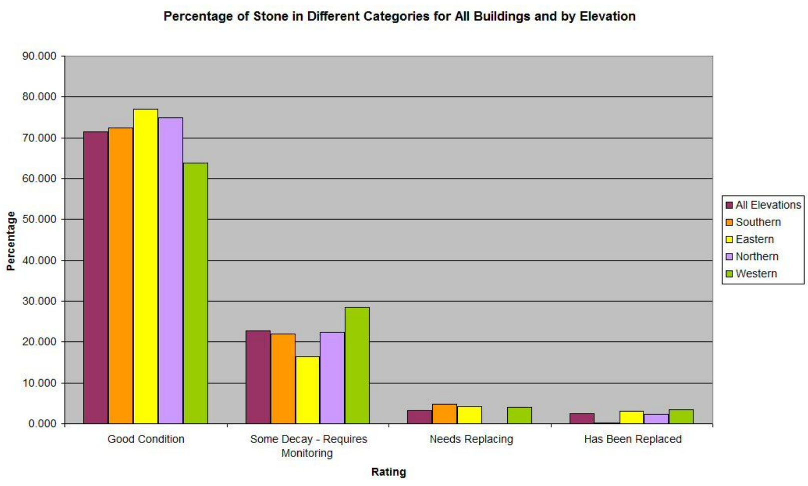

Figure 3: Graph of stone condition for all buildings

As can be seen from above the eastern elevations of the buildings surveyed have the highest proportion of stone in good condition (77%). The western elevations have the lowest proportion of stone in good condition (64%). The average for all elevations is 71%. The western elevations also have the highest proportion of stone that is showing some signs of decay (28%), the eastern elevations have the lowest (17%). The southern and northern elevations are close to the average figure for all elevations in this category both at 22%. The average is 23%. The northern elevations have no stone that requires replacement although 2% of northern elevations have already had stone replacement. The average for all elevations in this category is 3%. The southern elevations have the highest figure at 5% followed by the eastern and western elevations at 4%.

Across all elevations the average proportion of stone that has been replaced is 2.5%. The southern elevations have only had 0.3% replaced, the eastern elevations have had 3%, the northern 2.3% and the western have the highest proportions of stone replacement at 3.5%.

Given the difference between the proportion of western elevations that have stone in good condition and the proportion of eastern elevations that have stone in good condition the Chi-square test has been applied to the data to assess whether this apparent difference is statistically significant or not. The Chi-square test was used and it can be said with 95% confidence that the two sets of results are significantly different between the amount of weathering occurring on the western elevations of the sample buildings and the amount of weathering occurring on the eastern elevations. Ted Edwards, Head Warden Hardwick Hall Estate, (pers. comm. March 2008) states that the prevailing wind direction at Hardwick is west to north-west. This could help to explain the difference in weathering observed between the western and eastern elevations, however it would not necessarily explain the lower weathering seen on the northern elevations, as Figure 11 shows, the northern elevation has the second highest proportion of stone in good condition at 75%. This is an interesting finding as it may be expected that the northern elevation would receive high levels of wind and rain and low levels of insolation. Robinson and Williams (1999, p.11) investigating the weathering of Hastings Beds sandstone gravestones suggested that the more severe weathering of gravestones on their western sides could be attributed to their facing the prevailing wind, and thus being more frequently rain-soaked as well as them being sun-lit in the later parts of the day when air temperatures are highest, which may cause them to become drier than the eastern sides. This might indicate that decay is by cyclic wetting and drying rather than frost or chemical degradation.

Building's use

Part of the hypothesis for this project stated that the level of decay would be dependent on the building's use. As buildings can have many uses the buildings have been categorised into 1 of 2 classes: designed for human occupation and not designed for human occupation. The graph below shows the proportions of stonework in each category by building's use.

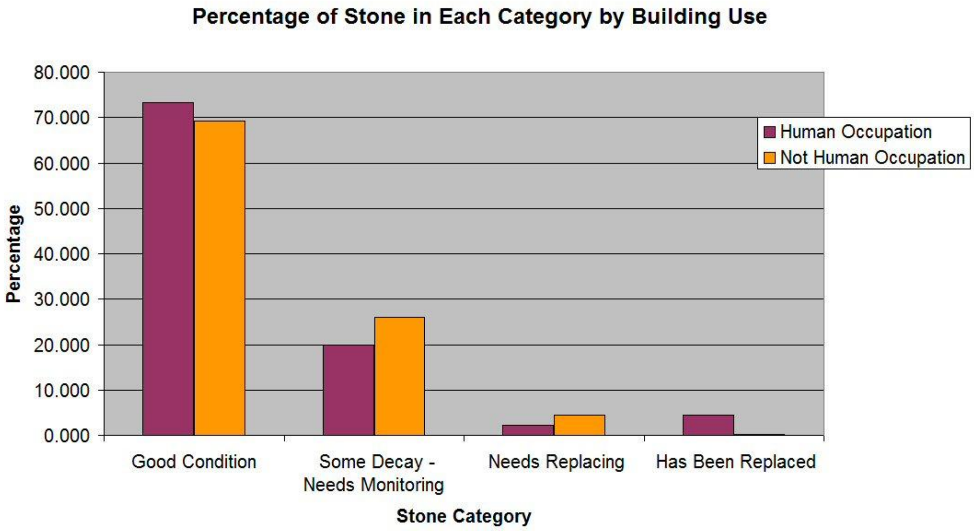

Figure 124: Graph of stone condition by building use

As can be seen from Figure 12412 those buildings designed for human occupation have a slightly higher proportion of stone in good condition than those designed for other uses 73%

and 69% respectively. Buildings not designed for human occupation have higher proportions of stone that is showing signs of decay or needs replacing. Stone replacement has been almost totally restricted to buildings designed for human occupation 4.5% compared to 0.11% for buildings not designed for human occupation.

There are various reasons as to why stone might fare better on buildings designed for human occupation. They are generally built using better materials, techniques, designs and craftsmanship in the first place. For example a number of buildings designed for human occupation have overhanging roofs which provide protection to the walls. They have more efficient mechanisms for carrying rainwater off the roof and away from the building i.e. functioning gutters and downpipes. In addition there is more likelihood of earlier and effective care and maintenance, for example a building that is occupied by humans is less likely to be damp as the occupiers are likely to take steps to rectify any dampness and the internal space will be heated. Buildings not designed for human occupation probably suffer more abuse over their lifetimes. For example: buildings that have been used as animal shelters often have contaminated masonry due to contact with animal waste which occurs over a period of many years. Water is a major agent of decay since water can transport salts into the pore spaces of stones, either from the ground or other sources; cause decay due to the freeze-thaw process and can also cause decay due to its acidity. The text above sets out a number of reasons why buildings designed for human occupation may suffer less from water penetration and therefore from salt crystallisation, freeze-thaw and acid attack. However the Chi-square test has been carried out on the data for the relative proportions of stone in good condition for human and not-human occupation. The results of the test show there is no significant difference between the two sets of data and thus the hypothesised better quality of stone in human habitations cannot be proved by the observations made.

Stone height in the elevation and relation to damage

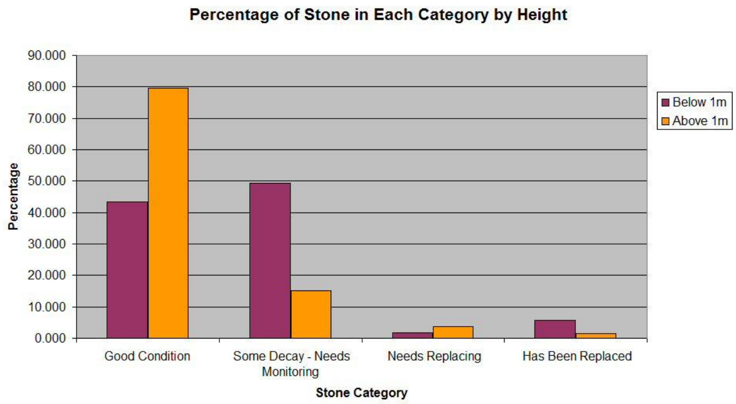

Figure 13: Graph of stone condition by height above ground level

Whilst carrying out the survey of the buildings detailed in this report it became apparent that much of the decay seemed to occur at low level; up to 1 metre in height from the ground level. The graph below illustrates the percentages of stone in the different categories for stonework below 1 metre and stonework above 1 metre in height.

Figure 1 illustrates large differences in the condition of the two sets of stone in the first two categories. Only 43% of stone below 1 metre in height is in good condition, whereas 79% of stone above 1 metre in height is in good condition. 49% of stone below 1 metre is showing signs of decay compared to only 15% of stone above 1 metre. Results for stonework that needs replacing, although low in percentage terms, are markedly different from each other.

1.6% of stone below 1 metre needs replacing compared to 3.7% of stone above 1 metre. These figures are in contrast to the results for the previous two categories. The percentage of stone that needs replacing above 1 metre is more than double that below 1 metre. This may be explained in part by the final category however. 5.7% of stone below 1 metre has been replaced compared to 1.6% of stone above 1 metre. This may be due to higher rates of decay in the low level stone. The fact that more stone at higher level requires replacement could be due to access difficulties. That is to say low level stone can be replaced by the masons without the need for scaffolding, specialist equipment etc. Therefore stone in poor condition at a higher level will probably not be replaced until there is a sufficient quantity of work required to make scaffolding and other equipment economic. The Chi-square test has been applied to the data for proportions of stone in good condition to assess whether the perceived difference in the results is statistically significant or not. The calculated value for Chi-square is 27.44. The value for Chi-square at the 95% confidence level is 3.84 Naoum (2007, p.199). Therefore it is said with 95% confidence that the two sets of results are significantly different.

With consideration of location of stone it is expected that the capillary fringe will be more at risk and that areas under the cills will be less at risk. At Hardwick it was found that weathering patterns in the capillary fringe agreed with that anticipated from the literature review, however in contradiction to accepted theory, the area directly under the cill often exhibits signs of decay.

Stone decay and height above sea level

A factor in a building’s location is its height, i.e. its height above sea level. There appears to be a broad relationship of increasingly damaged stonework with elevation, but these underlying trends may be altered by the affect of local conditions, such as tree cover or local topography for example. The Grange and outbuildings are the highest buildings in the survey at 170m, however to the immediate west there is a tract of mature woodland. It could be argued that the buildings should be afforded some protection from this plantation. Stainsby School is lower at 120m but it sits on top of a small hill, surrounded on three sides by open fields and is therefore quite exposed.

Stone decay and age of building

It might be reasonable to assume that the older a building is, the worse the observed stone decay would be Scatter graphs have been produced which plot building age against percentage of stone in the worst two damage categories, as in Figure 14.

There appears to be a general correlation between building age and the percentage of stonework in the worst two damage categories, the older a building is, the higher the proportion of damaged stone, indicating that decay continues throughout the life of the building in a progressive, although not necessarily linear, manner. Factors such as the quality of the stone used, the local topography, the building’s design, the maintenance regime will also affect the rate of decay.

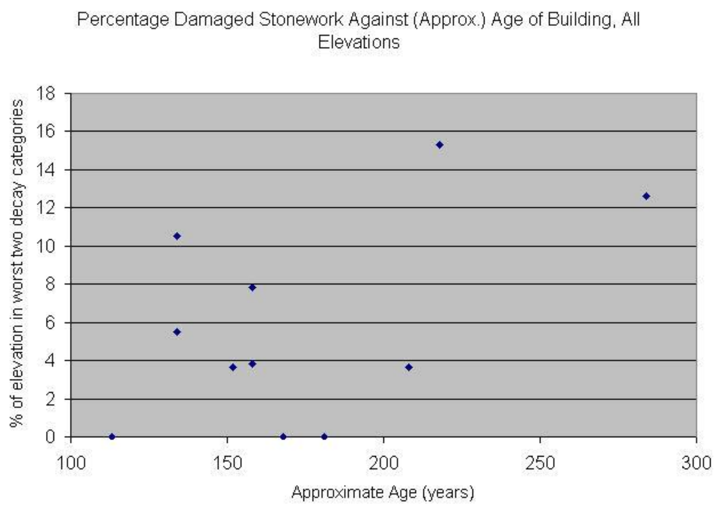

Figure 14: Graph of stonework damage against building age - all elevations

DISCUSSION

Research was proposed into the decay of Hardwick Stone due to the non-uniform nature of this decay. Secondary research has been undertaken with regard to assessing building stone condition, the causes of stonework decay and materials testing. A Selection of appropriate buildings were chosen as a sample. The elevations of these buildings were surveyed and the location and severity of stone decay on these elevations was mapped. This data has been aggregated, mapped and displayed graphically to provide a variety of statistical information.

It has been shown with 95% confidence that the weathering on the western elevations is significantly worse than that seen on the eastern elevations of the sample buildings. This may be due to the fact that western elevations are subjected to higher levels of driving rain and that the eastern elevations are more sheltered. Northern elevations had high levels of stonework in good condition. This was not necessarily expected given that the prevailing wind direction on the Estate is west to north-west. The northern elevation may experience lower levels of insolation and therefore less drying. If the northern elevations are generally damper this may mean that there is less chance of salt crystallising in stone pores. This could be an explanation for the higher levels of stone in good condition on these elevations. This could also explain why the southern elevations have the second lowest levels of stone in good condition; i.e. they have high levels of insolation and therefore experience more extreme wetting and drying cycles than other elevations.

During the survey it was noted that patterns of decay were observable across different buildings. The most noticeable of which was the concentration of decay at low level, below 1 metre in height. The difference in the amount of stone in good condition above and below 1 metre in height has been shown to be statistically significant at the 95% confidence level. Low level stone has a much lower percentage of stone in good condition (43%) than does higher level stone (79%). This is despite the fact that upper areas of elevations receive more driven rain. Water may be the cause of this low-level decay however; water running down the elevations, water splashing onto elevations from ground level and water passing up into the stonework from the ground by capillary action will affect the lower level stonework. As has been seen water is an important part of the process in the three areas of stone decay which have been tested as part of this research.

Patterns of decay on gables without overhanging roofs were also noted. This pattern is in the form of stone decay parallel to, but offset from, the roofline. This pattern was observed on a number of buildings e.g. The Croft, Yew Tree Cottage, The Grange and The Grange Outbuildings. It was notably absent from buildings with overhanging roofs, Norwood Cottages and Stainsby School for example. The reason for this decay pattern is not clear and would require further research.

The survey recorded that buildings constructed with protruding cills often have areas of decay underneath the cills. As Duffy and O'Brien (1996, p. 257) note projecting cills generally decrease the moisture in the stonework below them. Therefore this is another area that requires further investigation. Decay under the projecting cills on buildings at Hardwick is often worse than the immediate surrounding area. This could be due to something as simple as a lack of a drip groove in the soffit of the cill or there may be more complicated processes at work.

On a number of buildings stone decay appears to be associated with the path of the chimney. This may be due to the by-products of combustion leaching through the stone and causing decay. Confirmation of this and the exact processes at work would require further investigation.

Part of the hypothesis of this research stated that levels of stone decay would be affected by the building's use. This use was categorised as either human occupation or none human occupation. Possible reasons why a building designed for human occupation may have lower levels of decay have been examined (e.g. quality of materials, quality of construction, levels of maintenance, heating, rainwater goods etc.) however, the recorded difference was not shown to be significantly different. It was noted that buildings designed for human occupation appear to have had higher levels of maintenance e.g. 4.5% stone has been replaced compared to 0.12% for buildings not designed for human occupation. It is perhaps not surprising that the buildings people live in are better maintained than those used for other purposes. It may be that in practice the quality of the materials used in the construction of these buildings did not vary between buildings designed for human occupation and those not. Quarried stone may simply be classed as good enough to use or not. Similarly the quality of the construction may not have varied significantly either as most buildings would have been built by the Estate masons.

Attempts were made to identify a correlation between height of the building above sea level and levels of decay. It appears that the amount of stone decay does increase with building height. This trend seems fairly vague but there are other factors at work which also affect the level of decay. The theory behind the height/degree of decay correlation is that the higher a building the more exposed to the elements it is. There are height differences between the buildings at Hardwick. The lowest is 120m and the highest is 170m. The amount of exposure to the elements is not solely a factor of height, however. Yew Tree Cottage and The Grange occupy high positions and yet both are sheltered to a degree by their locality. In the case of Yew Tree Cottage the shelter is provided by the land, which rises to the west. In the case of The Grange there is a tract of woodland to the west. Stainsby School whilst being low lying, sits on top of a small hill with open fields to three sides.

A scatter graph was produced to see if a correlation between building age and degree of decay could be observed. This was felt to be a reasonable assumption as decay occurs over time. However the pattern was not as well defined as might be expected. It appears that there is a trend for the decay to be worse in older buildings, but this is not always the case. Norwood Piggeries, for example, is, at 134 years old, one of the younger buildings in the sample and yet it had a figure of 10.5% of stone in the worst two decay categories. Rowthorne Lodge at 181 years old, on the other hand, had 0% of its stone in the worst two decay categories. The two oldest buildings in the sample, The Grange (284 years old) and

Yew Tree Cottage (218 years old) had the highest percentage of stone in the worst two decay categories at 12.6% and 15.3% respectively. As with the height of the building, the correlation between building age and degree of decay may not be as clear a pattern as may be expected due to the other factors at work.

CONCLUSION

The building stones at Hardwick decay by cavernous weathering but this is inconsistent even in the same course of a building such that neighbouring stones may show radically different decay levels. There appears to be a correlation between the height of a building and the levels of decay present and a correlation between the age of a building and the levels of decay present. Factors such as a buildings use has been identified as having a possible affect, but this has not been shown statistically to significantly affect levels of decay, probably due to the local proximity of the source quarries. Decay is also associated with the path a flue takes, thus by-products from chimneys have a noticeable affect on levels of decay. The direction that the elevation faces affects stone decay. It has been shown with 95% confidence that western elevations have higher levels of decay than eastern, where the prevailing wind direction on the Estate is west to north-west. Stonework below 1m in height has higher levels of decay than stonework above 1m. This has been shown to be significant at the 95% confidence level. The survey also highlighted stone decay parallel to, but offset from, the roofline where there were no overhanging gables present, and gives a strong indication that even minor protection of the stone causes a displacement of decay, rather than removing it altogether and indicates the importance of saturation and drying to the decay mechanisms operating.

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