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THE FEASIBILITY OF USING SCIENTIFIC TECHNIQUES TO ASSESS REPAIR-MATERIAL SUITABILITY IN EARTHEN BUILDING CONSERVATION

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Abstract

The application of scientific techniques to conservation work has in recent years grown as a discipline, driven by a desire within the field of building conservation to better understand historic building materials. Wide ranges of historic materials are now analyzed to determine behavior and performance characteristics, which has led to advancements in the implementation of conservation work. However, the area of earthen building conservation has not yet been investigated in great detail; there is at present a large lacuna on how to select earthen repair materials, especially in terms of sacrificiality of interventions. This study directly addresses this fact by carrying out laboratory analysis of earthen materials in order to assess the feasibility of using repair materials to specify conservation work.

A case study from Buckinghamshire in England was chosen; a wychert-cob ecclesiastical building that had recently undergone repair and conservation. An identical program of material classification and performance tests was carried out on two sample materials from the building; one historic and one repair material. Through the study of laboratory results, the material characteristics and mechanical behavior of the two earthen materials were compared, and a critical analysis of the compatibility of the historic and repair material carried out. The findings of the study concluded that the repair material was unsuitable for use in this case, being incompatible with the original material. The achievement of the work was twofold; firstly it serves as verification for using these techniques to obtain comparable results that can be used to appraise material sacrificiality, and secondly it demonstrates that earthen materials are of a complexity whereby compatibility cannot be assumed using basic techniques. Work such as this highlights the need for analytical investigations in earthen building conservation, in order to ensure appropriate repair materials and techniques are used.

1. INTRODUCTION

There is currently very little scientific basis behind the methods used for repairing earthen structures, with factors, such as availability of materials and traditional building techniques, usually taking precedence. It is particularly rare for analytical investigations to be undertaken on repair and historic materials, and subsequently there is at present no standardized protocol to follow in order to understand whether a soil (adobe, rammed earth, etc.) will behave sacrificially when inserted in the historic fabric. Failure to consider this vital aspect of conservation work is in direct contradiction to the guidelines set out by the ICOMOS Charters, used to guide the selection and detailing of repair work. This work addresses this issue at a fundamental level by undertaking such an investigation on the material used to repair a historic cob earthen building in England.

Cob is a material consisting of unbaked soil, mixed to quite a wet consistency and placed directly onto the wall. Walls are built without the use of shuttering and, as such, rely on self-consolidation for strength. Following their construction, cob walls consolidate through drying and by virtue of their own weight (Ashurst and Ashurst, 1988). As the material dries the necessary cohesion to produce a hard, strong, monolithic body is achieved. Their strength is, therefore, dependent on the proportion of materials used, the thorough mixing of those materials, and the compaction of the mix through treading.

For the purposes of conservation, comparative analytical studies require work to be carried out on both new and historic material, with an approach to testing that encompasses investigation into the interaction of these materials. Furthermore, any intervention and associated technical specification must take account of the principles that guide conservation work, and that consider important factors, such as reversibility of the work and authenticity of the historic structure in question, as described in the Nara Charter (1994). Realistically, the concept of reversibility is not often possible, and so the principles of compatibility and retreatability are referred to and sought for (Van Balen, Papayianni, Van Hees, Binda, and Waldum, 2005), where compatibility requires that the intervention will have no negative consequences on the historic fabric, and for retreatability, that the present intervention will in no way hinder any future required intervention. In considering compatibility in this way, the concept of sacrificiality of repair is implied, in that when the historic and repair fabric are put under duress by exposure to environmental and other factors, the repair material is required to promote and preserve the historic fabric, and so in itself be subject to greater amounts of decay and damage.

It is this explicit sacrificial relationship that this work looks to analytically appraise, with a view to developing a methodology for the work. One such suggested methodology has been developed for repair mortars by Schueremans, Cizer, Janssens, Serre, and Van Balen (2011), which looks to overcome the disparity between specified and applied repair work that comes as a result of the many stages through which conservation work passes before completion. Here the clear process from authenticity to conceptual requirements and, finally, functional and technical requirements are addressed in an attempt to develop a methodology for satisfying and achieving the compatibility criteria above, defined and based on the original and repair mortars. It is this type of methodology, now relatively established in other fields of conservation that this work seeks to promote for the field of earthen heritage.

2. THE CASE STUDY OF HADDENHAM METHODIST CHURCH

2.1 Architectural history, building form and materials

The village of Haddenham, in which the Methodist Church is situated, presents the highest concentration of wychert buildings in the country, containing over 100 surviving examples. The material has been used throughout the village, for a range of structures from humble dwellings and boundary walls, to manor houses, villas and chapels (Pevsner and Williamson, 1994), with the Grade II listed Methodist Church (1822) being one of the tallest. The church is regarded as "an entirely standard composition (three bays, two storeys, arched windows, and a big pediment across)..." (Pevsner and Williamson, 1994). A stone facing with brick quoins up to internal balcony height articulates the façade wall, after which the wychert construction is used to produce the upper wall with its three arched windows, and finally the pediment up to the roofline. The remaining flank walls are made entirely of wychert, apart from a stone plinth used for approximately the first 3 feet above the ground. The church stands at over 7.6 m in height (McCann, 1983), and the outer flank walls are almost entirely unsupported laterally. As such, spreading from the roof and any other horizontal loading would have to be withstood by the walls in bending. The loads are likely to be substantial due to the span of the roof, showing how impressive wychert is as a building material.

The first important characteristic of wychert is that the material is predominantly clay and has high chalk content (Ashurst and Ashurst, 1988; McCann, 1983). One fact repeatedly mentioned in the literature is the very high inherent strength that wychert naturally exhibits, being held in very high regard and raised in un-shuttered lifts without requiring much strengthening and improvement (Keefe, 2005). The material is said to be particularly strong and durable if kept dry, and once dug from the ground, only fiber and water would need to be added (Pearson, 1992).

2.2 History of conservation

The history of the conservation of the Methodist church is quite complex and so, in order to give a clearer overview, is divided into three phases.

2.2.1 Phase 1: 1822 – 2003

Following its construction in 1822, the first serious recorded process of repair to the church was prior to 2003, when the internal plaster was replaced in places with cementitious materials. Furthermore, fluid-irrigation treatment against dry rot was also carried out, and this contributed to the collapse of the southwest flank wall. What had been viewed, as simply failing render was in reality a symptom of a far greater problem existing within the wall, that of excess moisture and its related effects. Removal of the internal plasters during building works disturbed the sensitive equilibrium of the wall in its dilapidated state, ultimately bringing about collapse (Oxley, 2003).

2.2.2 Phase 2: 2003 – 2008

The University of Bath became involved with this conservation work in 2007. By that time, the building had undergone a significant transformation. The collapsed wall had been rebuilt using adobes, and the whole building (apart from the façade wall) had been rendered with a mud-scratch coat and a lime based skim coat. The use of these natural breathable materials would suggest that the problems highlighted earlier had been overcome; however, the render continued to fall away from the walls. The red bricks have the advantage of being easily distinguishable as new, satisfying the requirement of readability of conservation intervention (ICOMOS, 1964), but it is felt here that a more adequate repair material could have been selected, especially considering the highly concentrated use of wychert, in England.

2.2.3 Phase 3: 2009 Onwards

The final portion of conservation work was undertaken during April and May of 2009 when a pair of trial render patches were applied to the southwest flank in an attempt to find a more suitable render mix for the building. This period of inspection highlights several possible programs of analysis applicable to the building. Firstly, the causes of failure of the render could be inspected, looking at both material compatibility and quality of construction, to determine which is the dominant factor. Secondly (and that on which this particular investigation focuses), is the repair of the original wychert-cob wall with a cob blocks, using material sourced outside of the sphere of wychert construction. Here it needs to be determined whether this seemingly incompatible material and construction method could be classified as a successful intervention in a historic structure. Additionally, through analysis of the material, it could be possible to specify suitable earthen materials based on behavioral characteristics; the feasibility of which will be assessed following this analysis.

Fig.1 Haddenham Methodist Church (credits: Victoria Stephenson, 2003)

3. TESTING PROGRAM AND RESULTS

The section provides detailed methodology information for the suite of tests carried out, the design of which was referenced to British Standard publications, but also to the work of Walker and Standards Australia (2003), Houben and Guillaud (1994), Teutonico (1988), and Fodde (2007), and is split into characterization and performance testing.

3.1 Sampling and materials

3.1.1 Historic Wychert samples (HW)

The wychert material received by the laboratory was taken from the portion of collapsed wall that had been repaired with cob blocks, and so had been piled in a near-by agricultural field. As such, the material contained a substantial amount of organic and insect contamination. A representative sample was taken from the core of the heap. Upon arrival at the laboratory, the material was sifted by hand and the contaminants removed. The material was also of very high moisture content and so, it was partially dried to prepare it for testing.

3.1.2 Repair earthen cob-block samples (rcb)

The laboratory received one repair cob block of dimensions 450 mm long x 215 mm wide x 100-mm deep. The block appeared to have been manufactured using the extrusion method, and was very dense and solid in appearance. It also appeared to have a very high fiber content.

3.2 Characterization tests

3.2.1 Mineralogy and color

A full mineralogical investigation of the samples was beyond the scope of this investigation; however, from geographical and geological information, along with some visual analysis of the samples, it is possible to give a very basic interpretation of the mineralogical origin of the material. Kimmeridge Clay, Portland Limestone and Chalk are the most likely geological sources of the material. The origin of manufacture of the repair cob block is unknown and so, color is the strongest indication of the mineralogical origin available to this investigation. Visual analysis of the linear-shrinkage samples was carried out in accordance with BS 5930:1990, Code of Practice for Site Investigations, Table 13. Firstly a hue was identified, followed by a description of the chroma of the hue, and finally, identification of the lightness of the color.

Color testing does not give an indication of physical sacrificiality of the material; however, testing was necessary to identify whether the ICOMOS principle of readability of conservation interventions was satisfied. In this case, the readability is also addressed by the instantly recognizable use of pre-dried cob blocks within monolithic cob. In summary the RCB material does satisfy the requirements, although it is this authors' opinion that a more suitable local wychert source could have been found.

3.2.2 Granulommetry analysis through sieving and hydrometer sedimentation

Gravel particles are those greater than 2 mm, sand particles from 2 mm to 60 μm, silt from 60 μm to 2 μm, and clay less than 2 μm (BS 5930:1990). The tests were carried out in accordance with BS 1377-2: 1990 Clause 9 (Methods of Test for Soils for Civil Engineering Purposes. Part 2: Classification Tests). As for sedimentation analysis, it was carried out in accordance with BS 1377-2: 1990, Clause 9.5, on material passing the 75-μm sieve.

The particle-size distribution graphs show correlation between the RCB and HW samples, and also a generally high quality of grading of the samples, without gap grading occurring. Closer inspection of the materials does, however, reduce the initially assumed compatibility of the RCB and HW, as the cob block has a clay fraction over double that of the wychert, and a combined-fines proportion of nearly 10% greater. The RCB material will, therefore, be more durable than the HW, which is unsuitable for a repair intervention, as it provides no protection for the historic fabric. The RCB material will not, therefore, act sacrificially towards the HW, making it unsuitable for use.

3.2.3 Plasticity analysis

The measurement of soils plasticity categorizes its behavior in relation to its moisture content. Measurement of the Plastic and Liquid Limit was carried out using the Atterberg Limit tests as described in BS 1377-2: 1990, Clauses 4 and 5, using the portion of the soil finer than 425 μm. The RCB and HW samples have both been classified as of intermediate plasticity by the British Standards. Alternative analysis can be found in Clifton and Wencil-Brown (1978), where the relationship between plasticity index and expansion potential is quantified. The data, taken from Seed, Woodward, & Lundgren (1962), is used for particles smaller than 2 μm, but can be used to quantify the maximum potential for expansion, accounting for the reduction in that value due to the presence of less-expansive silts and sands. From it, the expansion of the HW will be up to 4.5 %, whereas the RCB will expand up to approximately 12 %. The high clay fraction of the RCB means this value is likely to be quite accurate. In this respect, the higher expansion of the RCB

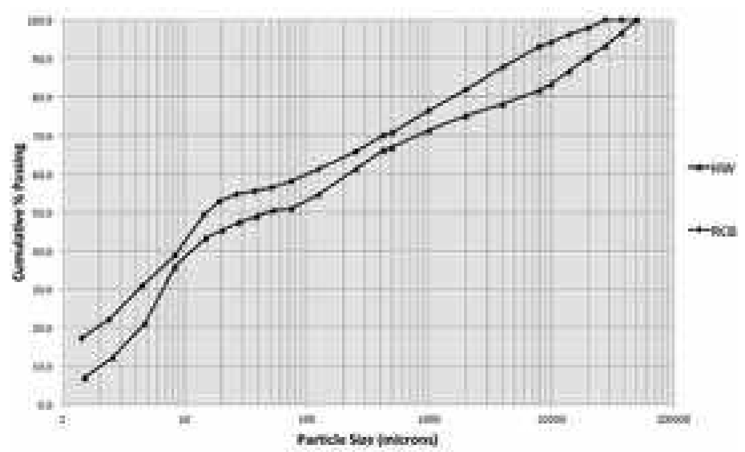

Fig.2 Granulommetry analysis of repair and historic earthen material

makes it unsuitable for use next to the HW, where it is possible it may induce stresses in the HW due to the RCB expansion in the wall; this is not sacrificial behavior. In summary, the RCB does not have behave sacrificially when assessed for plasticity and so, does not prove a suitable material for intervention in this case.

3.2.4 Chemical testing and soluble-salts analysis

a) pH analysis

Each of the samples tested were found to be alkaline in nature, indicating they contained no or very little organic material. Clifton and Wencil-Brown (1978) suggest that for compatibility of repair and historic fabric, the pH value of a repair material should be within +/- 2 pH units of the original, an indication of a difference of a factor of 100 in the concentration of hydrogen ions. The values of pH for the RCB (7.56 pH) and HW (8.39 pH) material satisfy this criterion and so, the RCB material is found to be compatible. Preservation treatments can drastically alter the pH values of soils, however, which limits the validity of the isolated test carried out in the laboratory, a factor that should be accounted for. In general, the RCB sample was found to be compatible with the HW, and thus is more likely to act sacrificially, although a rolling program of in-situ testing at Haddenham would strengthen this argument.

b) Carbonates analysis

The presence of salts in earthen-building material is generally the product of efflorescence, a deterioration mechanism common to many forms of masonry, stone and earthen construction. Most of these salts are soluble in water, with the exception of calcium carbonate, a normal constituent of calcareous stones (Teutonico, 1988). The tests carried out at the University of Bath have been adapted from Experiment 16 of the Teutonico Laboratory Manual, and determine the presence of carbonates in soil. The analysis is only qualitative, but they can give an indication of the nature and extent of deterioration potential in a soil.

Carbonates act in two different ways when present in a soil:

firstly, as a cementing agent when present in clay material of <2 μm, and secondly, as an aggregate when present in sand and gravel. In this test material classified as sand, silt and clay was tested, meaning that some discrepancies in the results can be identified. A significant difference between the carbonate content of the RCB and HW samples was found, with the repair material having no perceptible amount, and the historic containing a significant quantity. The RCB contained far less carbonates than the HW, and the very high concentration observed in the HW sample can be partly attributed to the presence of chalk in the material. Again, there will be a net migration of carbonates from the HW to the RCB until equilibrium is achieved, which will prolong the life of the historic material by reducing the salts content of it. This test indicated that the RCB will behave sacrificially, and the fact that the soluble salts and carbonate results agree supports this hypothesis.

c) Soluble-salts analysis

Analysis of soluble salts is a widely recognized component of testing for decay in traditional building materials, such as earth and fired-brick masonry. The method used here follows the test detailed in Clifton and Wencil-Brown (1978). The accuracy of this test relies on two criteria: firstly, that the moisture content of the dry sample is consistent at all times during weighing, and secondly, that the filtering system used prevents the loss of clay particles into the water containing the dissolved salts.

The soluble-salts content of the RCB sample at 0.88% is lower than that of the HW 2.42%, suggesting that when in place in the wall, migration of salts would be in the direction of the RCB. In this respect, the salts will accumulate in the RCB and this is the material likely to decay quicker through salts attack. However, the sample does not meet the criteria put forward by Garrison (1990) that repair material should contain less than 0.1 % soluble salts. The RCB material has been shown to behave sacrificially towards the HW, although a lower percentage of soluble salts would be desirable.

3.3 Performance tests

3.3.1 Erosion testing

Erosion rates in earthen architecture are used as a parameter for determining the durability performance of the structure. In earthen conservation, this behavioral characteristic is useful in determining the sacrificiality of repair material, and can be achieved through comparison of repair and historic material-erosion rates. The most comprehensive test methodology available for earthen-erosion resistance is set out in the Accelerated Erosion Test covered by the Australian Earth Building Handbook. The test uses a water-spray erosion system and "performance, in terms of erosion rate (mm/hour), is determined on the basis of pitting depth or time taken to completely penetrate the sample" (Walker and Standards Australia, 2003).

The HW samples performed better in the accelerated-erosion test, with an erosion rate of 16 mm/hour compared to the RCB erosion rate of 21 mm/hour. This indicates that the RCB material will erode faster over time, supporting preservation of the HW. These results are, however, contradicted by the fact that more weight was lost during the test in all of the HW samples, suggesting greater amounts of erosion in the wychert, which is unacceptable for conservation interventions.

3.3.2 Freeze-thaw testing

The freeze-thaw cycles carried out in this testing framework have not been designed using any previous testing methodologies; rather, they are the product of material, timetabling and equipment constraints. Reference was made to the testing carried out at Krasnaya Rechka (Fodde, 2007), and the method of wetting used here is similar, although the availability of material at that site was far in excess of that available in this case study, and the scope of the testing carried out reflects this. Furthermore, tests carried out at Krasnaya Rechka analyzed wetting and drying cycles, and freeze-thaw cycles independently. It was not possible to carry out this type of testing here due to a shortage of material, although it is advised that wherever appropriate, the tests should be separated.

In the cycles, the HW samples performed consistently worse, losing on average 2.7% more material over the course of the test. However, at Haddenham the application of a render will protect both the RCB and HW from much of the environmental conditions, so long as the render is successful. The limited availability of material determined that these tests would primarily act as preliminary work, but even here, contradiction is observed. When considering weight loss, the tests concur that the RCB would not behave sacrificially towards the HW.

3.3.3 Compression testing

Tests were carried out on a series of cubes to give an indication of the compressive strength. The pre-manufactured nature of the RCB on arrival at the laboratory meant that it was more appropriate to test cubes of the material, as opposed to cylinders, is now the accepted standard test in Britain. To ensure continuity of testing, cubes were also manufactured out of the HW sample. The test does comply with BS1881-116: 1983 (Method for Determination of Compressive Strength of Concrete Cubes), although this document has been superseded by the relevant cylindrical-compression test.

When analyzing the peak strengths of the RCB and HW material, the HW is consistently stronger, suggesting that the RCB would behave sacrificially to protect the historic fabric. However, the profiles of the compression tests suggest that the HW cubes demonstrated brittle failure at the peak load, whereas the RCB cubes behaved in a far more ductile manner. Ductility is always preferred in engineering situations, to prevent sudden and catastrophic collapse of structures. The lack of fiber in the HW cubes is, undoubtedly, significantly responsible for their brittle nature, as fibers will act to reinforce a soil mix by providing links between the soil particles that are capable of withstanding tension. Other influencing factors include the particle-size distribution of the mixes and the age of the blocks. Furthermore, the reality of the case study is that pre-dried cob blocks constructed with a mortar material will structurally behave very differently to monolithic cob. In this respect the compression testing carried out in this investigation can yield only indicative results. Preliminary results show that the RCB material is weaker than the HW, which suggests it would behave sacrificially, however the brittle nature of the HW is a cause for concern and overrides the trends in peak values. The scope for further more detailed testing is extensive within this area.

3.3.4 Shrinkage testing

Linear shrinkage and the measurement of shrinkage during manufacture using DEMEC studs were both undertaken. DEMEC measurements are regularly taken of relative movement over short gauge lengths of cracks in structures (Clayton, Simons, and Matthews, 1982). Studs are placed either side of a crack using a standard length bar and glued into place using epoxy resin. Once the glue is dry, the two points of the DEMEC gauge are placed on a standard Invar bar and a zero reading taken. The points are then placed in the studs and a reading recorded. This procedure is repeated over a period of time, and the relative movement of the studs calculated.

It is desirable that a repair material expands no more than the historic fabric, when exposed to the same moisture-content increase, as this would induce excess stresses on the historic fabric and cause considerable further damage. This is somewhat overcome by the pre-drying of the cob blocks, although the effects of water ingress post-construction will highlight this incompatibility. The linear shrinkage tests demonstrate the repair material shrunk by 3% more than the historic fabric. The higher level of shrinkage in the RCB could lead to failure of the repaired wall along the interface between the cob blocks and wychert cob, subsequently damaging the historic fabric of the building. If this were the case then the intervention of the cob block repair would be inadequate in satisfying the principles of conservation. However in general greater levels of shrinkage would be desirable in a repair material, as this is the material more susceptible to cracking. In this respect the RCB behaves sacrificially.

4. CONCLUSIONS

4.1 Assessment of the feasibility study

The structure of this testing framework has been designed in such a way that the requirements of a repair material and its relationship with the historic fabric can be addressed logically and systematically, in the hope that specification of the repair material can be clearly obtained. The tests were carried out using well-established procedures, and these can be easily referenced and repeated by other technicians. It has been shown that laboratory analysis of earthen materials can yield clear results suitable for compatibility analysis, and subsequently, a judgment over the susceptibility of one material to suffer and deteriorate because of its proximity to another can be made. The analysis has also shown that while one parameter or test may determine a repair material to be unsuitable for use, another test may contradict this. This highlights the complex nature of earthen building materials and shows that for clear evaluation over suitability to be made, specific conditions for each case study must be taken into account.

In order for this testing to move forward and become the framework for a methodology, clear testing parameters would need to be stipulated prior to testing, ideally in order of priority. A checklist of tests and behavioral characteristics could then be clearly set out, and the suitability of a material investigated in a logical and progressive manner. Results should be displayed in a technical format so that third parties can easily access the data and findings. Further work might possibly combine the test results to produce one qualitative parameter that defines suitability.

4.2 Scope for further work

This testing framework was carried out in a university laboratory, in a civil engineering department. This obviously puts constraints on the scope of tests that could be carried out, with the most important shortcoming of the tests being a lack of detailed mineralogical and chemical analysis of the samples, which is so important to understanding the behavior of earthen building materials. The first step for any further work would be to repeat the above procedures to validate the results, through the selection of different case studies with different parameters, such as geographical location or construction method. Notable areas where further work could be carried out is in the detailed analysis of organic material using thermal analysis and polarized light, the investigation of porosity and permeability using quantitative stereometry, and mineralogical analysis using X-Ray Diffraction (Houben and Guillaud, 1994). Such analysis was unavailable to this testing framework, but would form core components of any methodology to assess suitability and sacrificiality, by looking closer at micro-composition.

It was highlighted that homogeneity between constructional forms used together in the same building cannot be assumed in earthen construction, and there is further work to do here. The study of how and why conservation fabric changes over time brings a new dimension to investigation in this discipline. The development of prediction criteria for material behavior, in order to act preemptively to preserve historic fabric, would present a more complex level of methodology-protocol work.

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