By Appointment to
Her Majesty The Queen
Building Facade Restoration
and Conservation

PAYE

No. 4 THE GROVE

HIGHGATE, N6 6JU

MORTAR ANALYSIS RESULTS

CONTENTS

INTRODUCTION

All samples were retrieved by Spencer Hall ACR on Monday 15th February 2016. Samples were taken from areas which we felt were likely to be representative of the original mortars, this was focused on the external walls but included an internal chimney breast exposed during the soft strip. An additional sample (2b) was taken gratis from location 2, as two similar looking (presumed) lime mortars were uncovered and we couldn't be sure which was likely to be representative of the original. All chemical analysis was then completed by Paul D'Armada and the interpretative report compiled by Paul D'Amarda and Spencer Hall ACR on behalf of PAYE Conservation.

LOCATIONS OF SAMPLES

The list below outlines the location of sample retrieval and can be read with corresponding imagery within our attached photographic record.

Sample 1 – Internal (lime) brick mortar
Location – behind fireplace in New Master Bedroom Ensuite

Sample 2a – Internal (lime) brick mortar
Location – Reverse of external wall New Master Bedroom

Sample 2b – Internal (lime) brick mortar
Location – Reverse of external wall New Master Bedroom

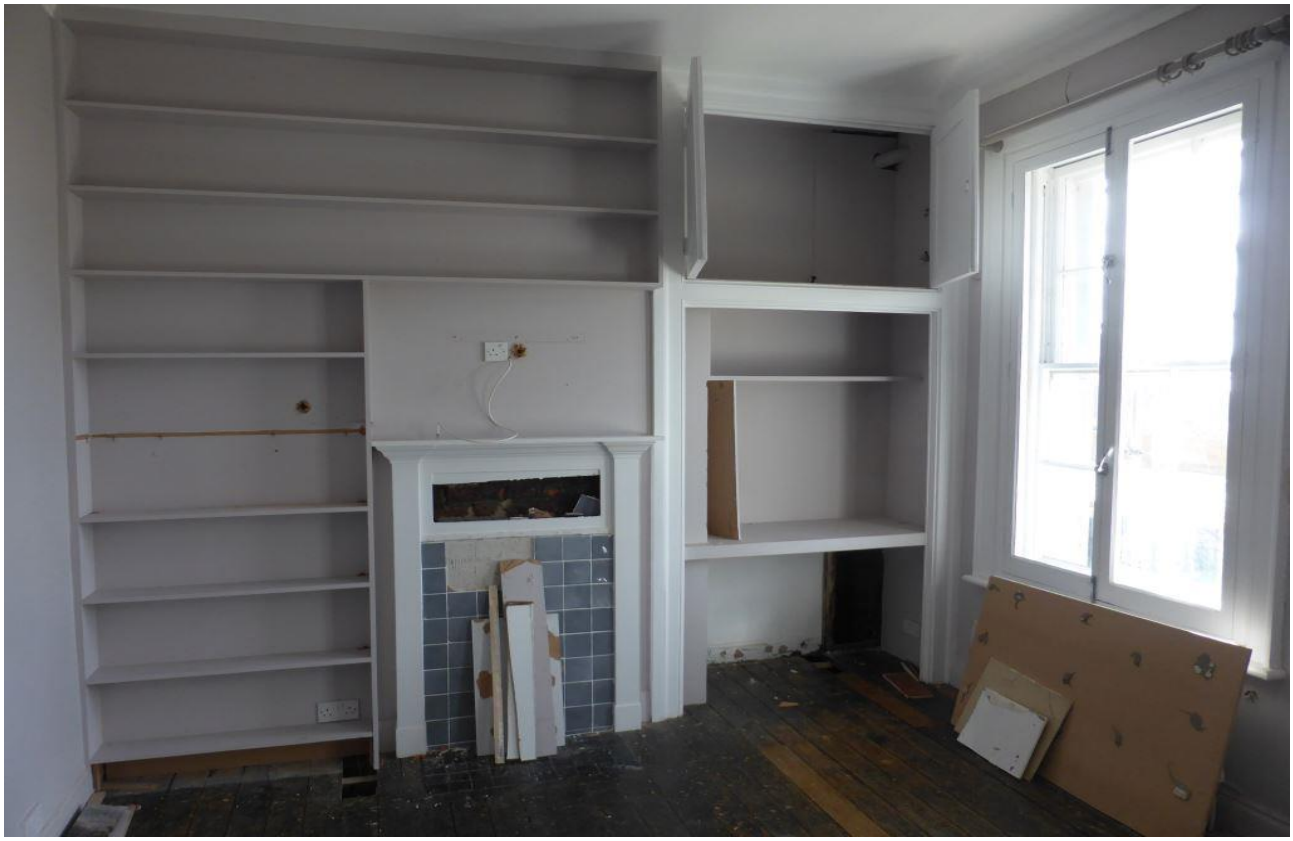
Sample 3 – External (lime) brick mortar
Location – Rear of building (see elevational drawing)

Sample 4 – External (cement) brick mortar
Location – Rear of building (see elevational drawing)

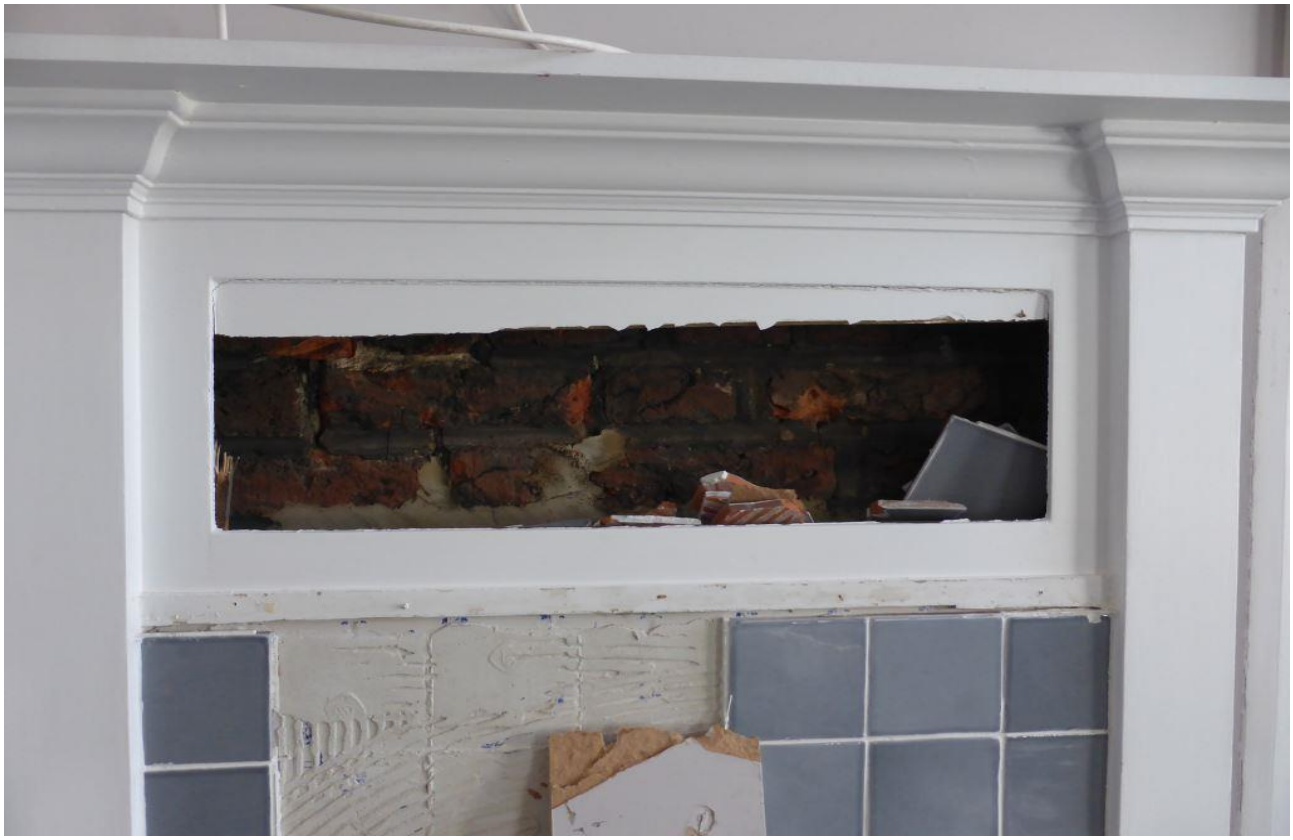
METHODOLOGY

A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques are used, in addition to polarised light microscopy, in order to determine the components and characteristics of the mortar sample, as shown in the results table:

All analysis was undertaken on the 22nd and 23rd February 2016



LOCATION OF RETRIEVED SAMPLE 1



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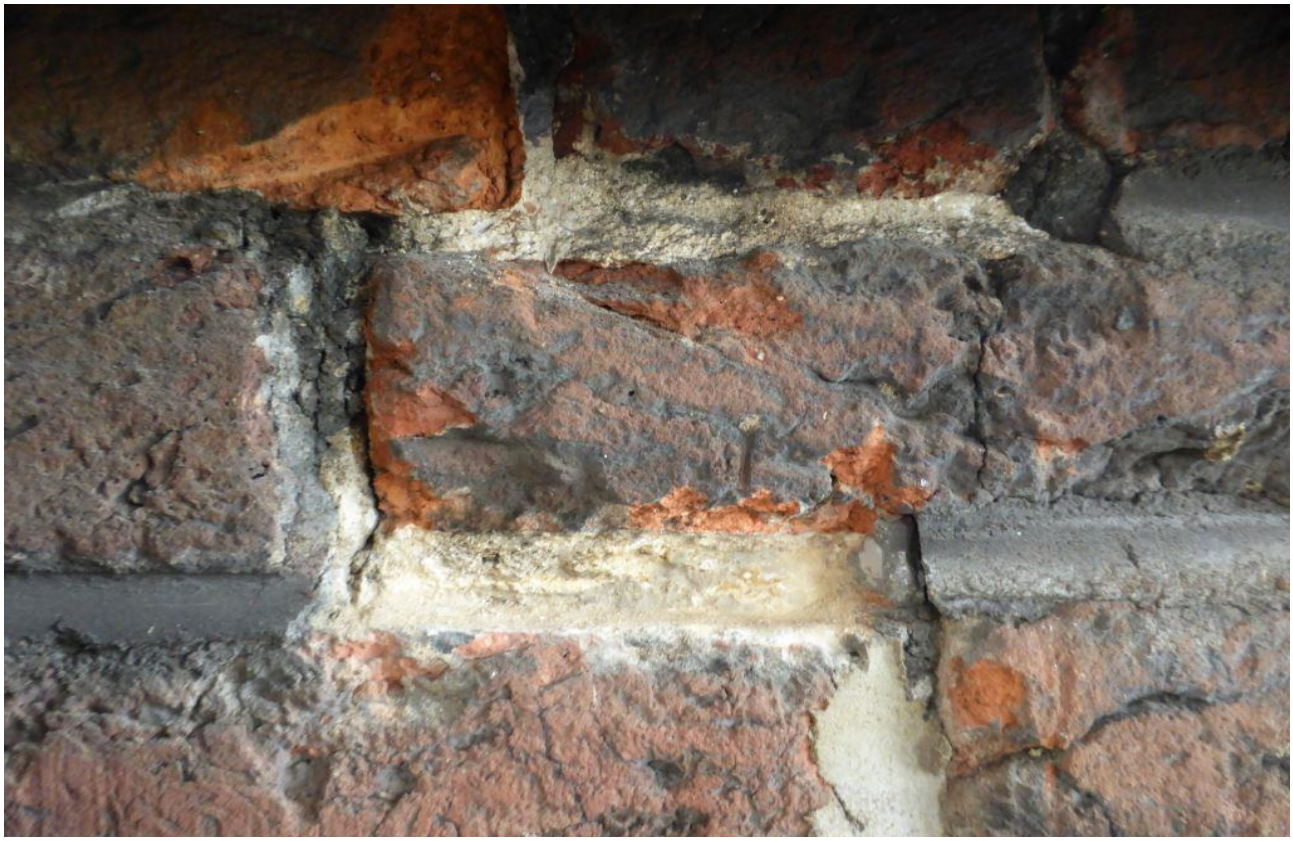
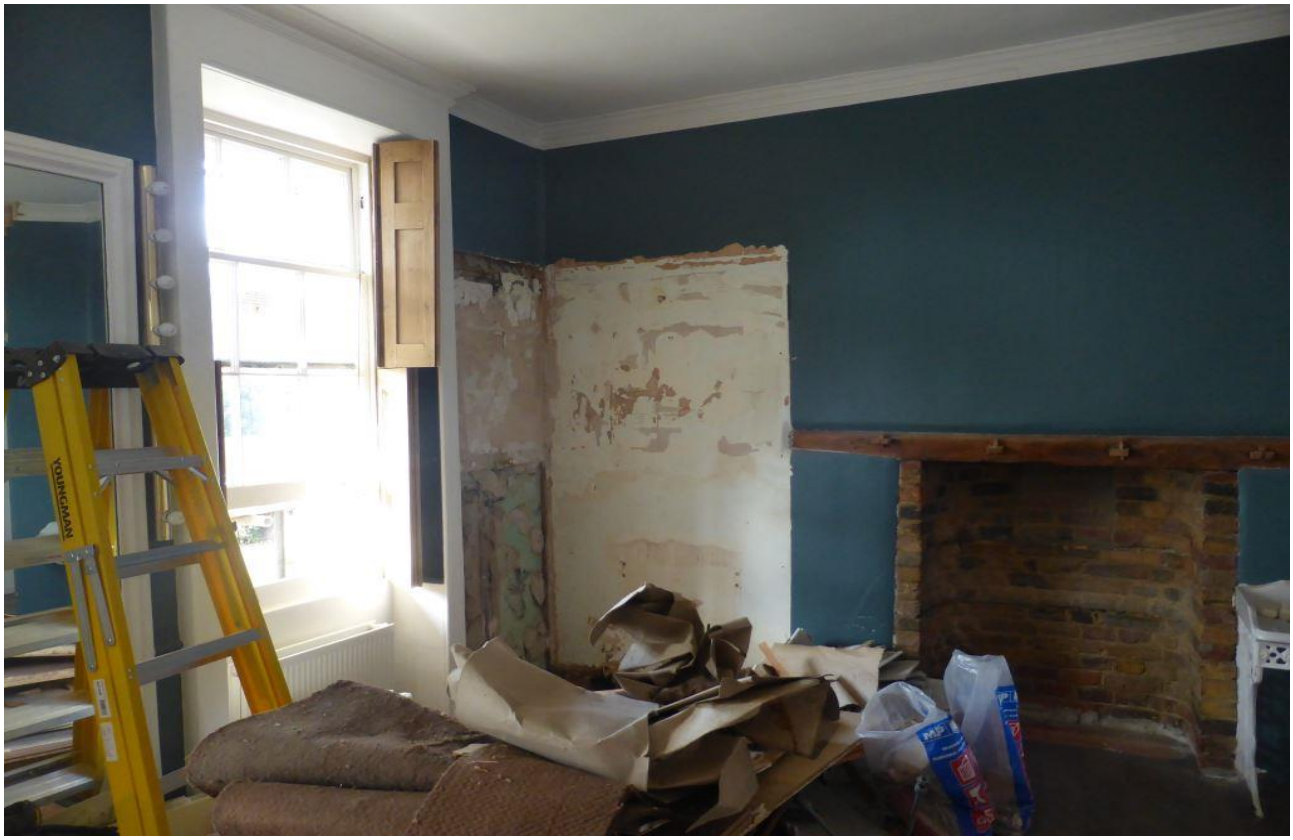
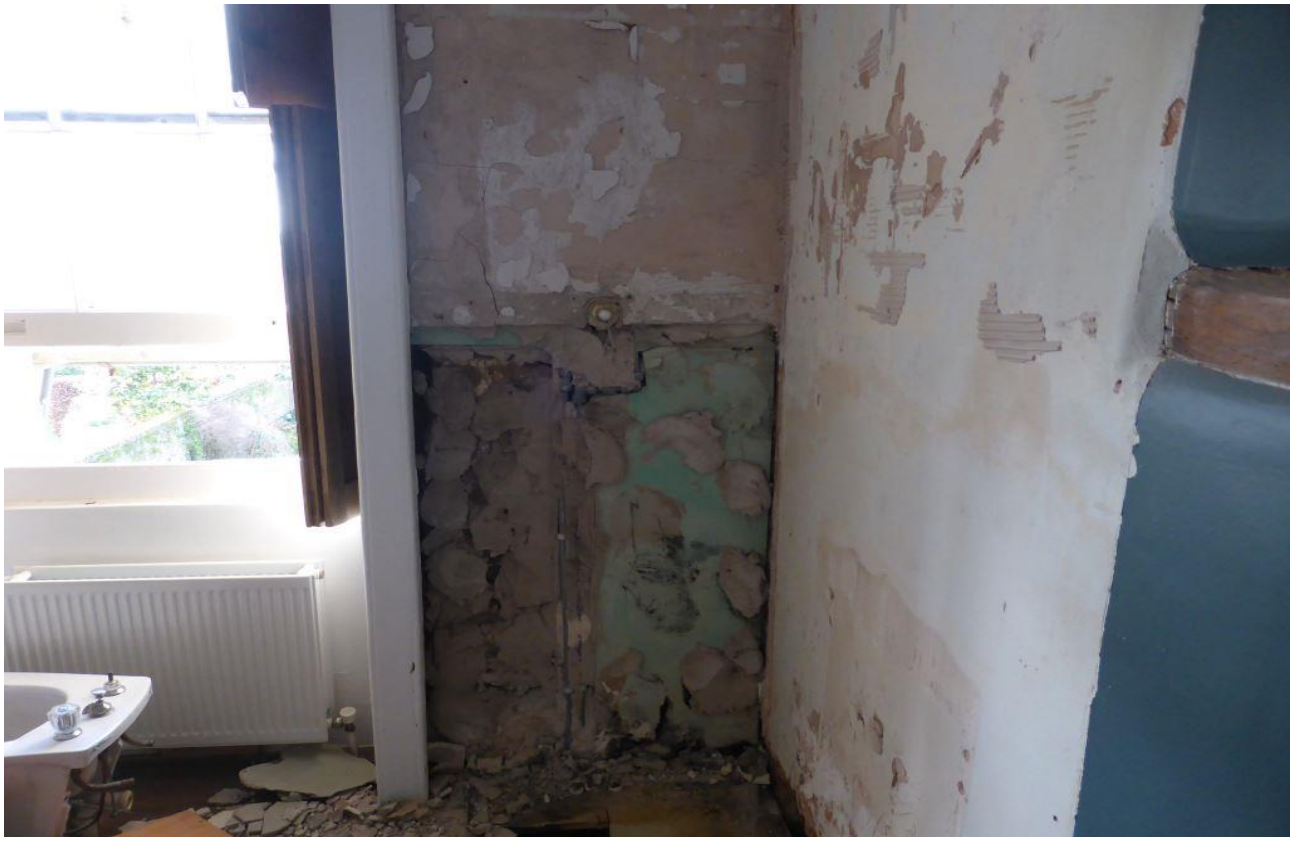


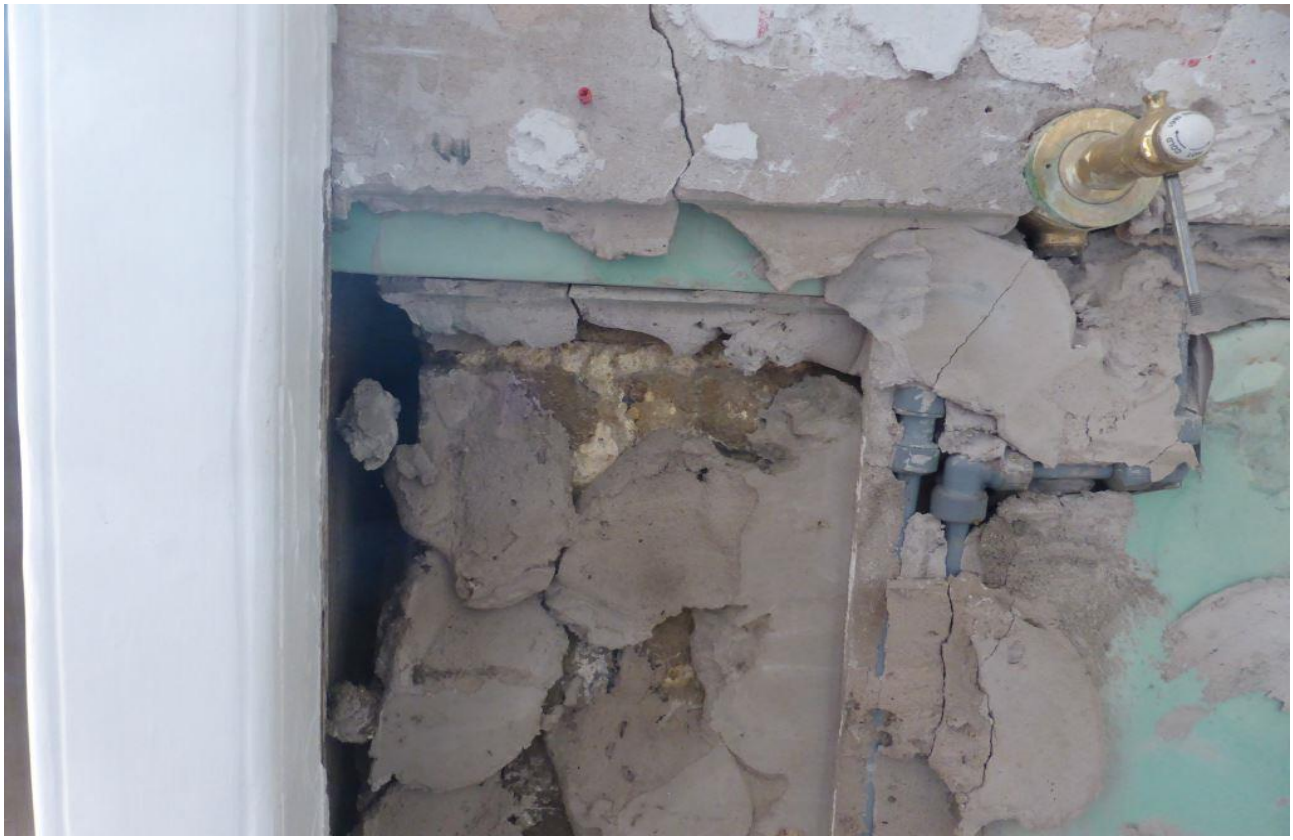
LOCATION OF RETRIEVED SAMPLE 1



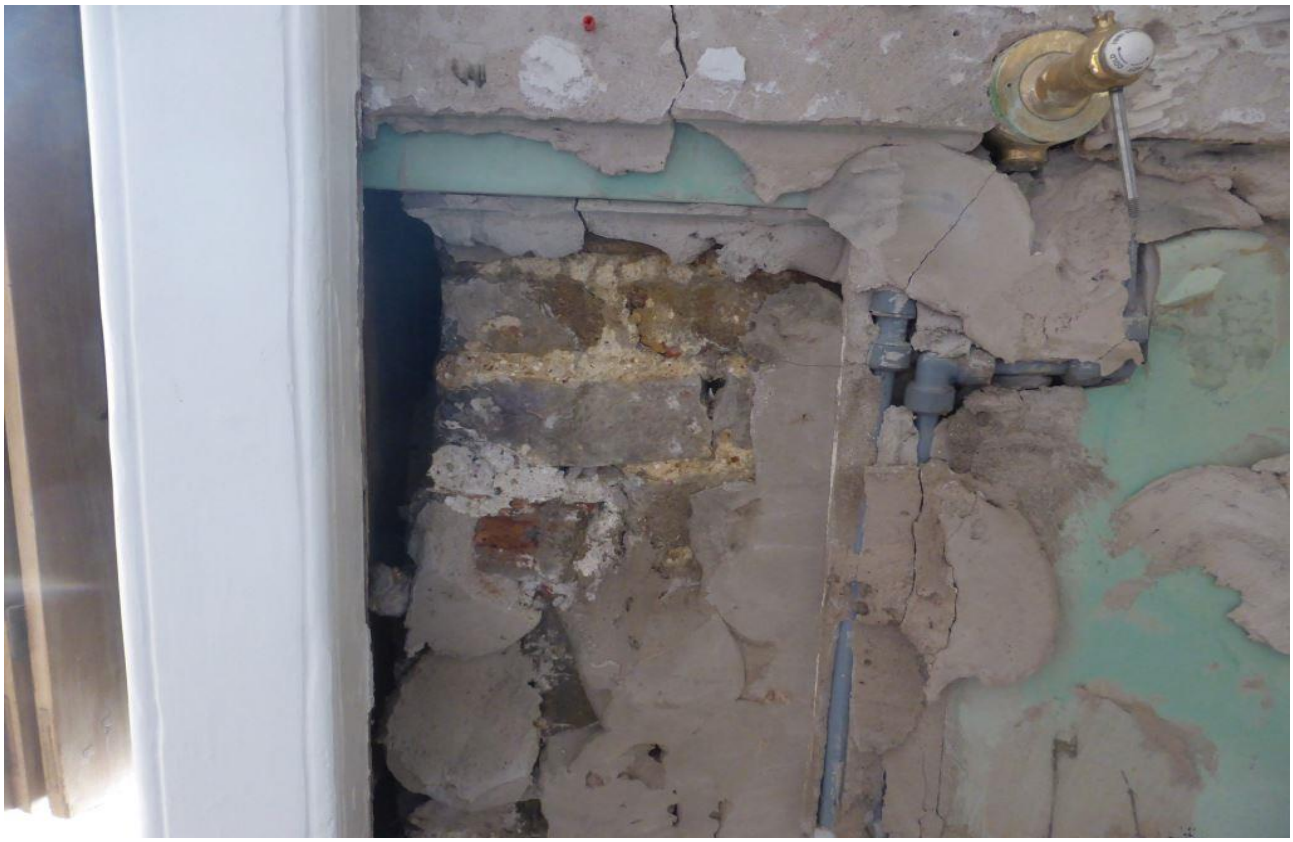
LOCATION OF RETRIEVED SAMPLES 2a & 2b



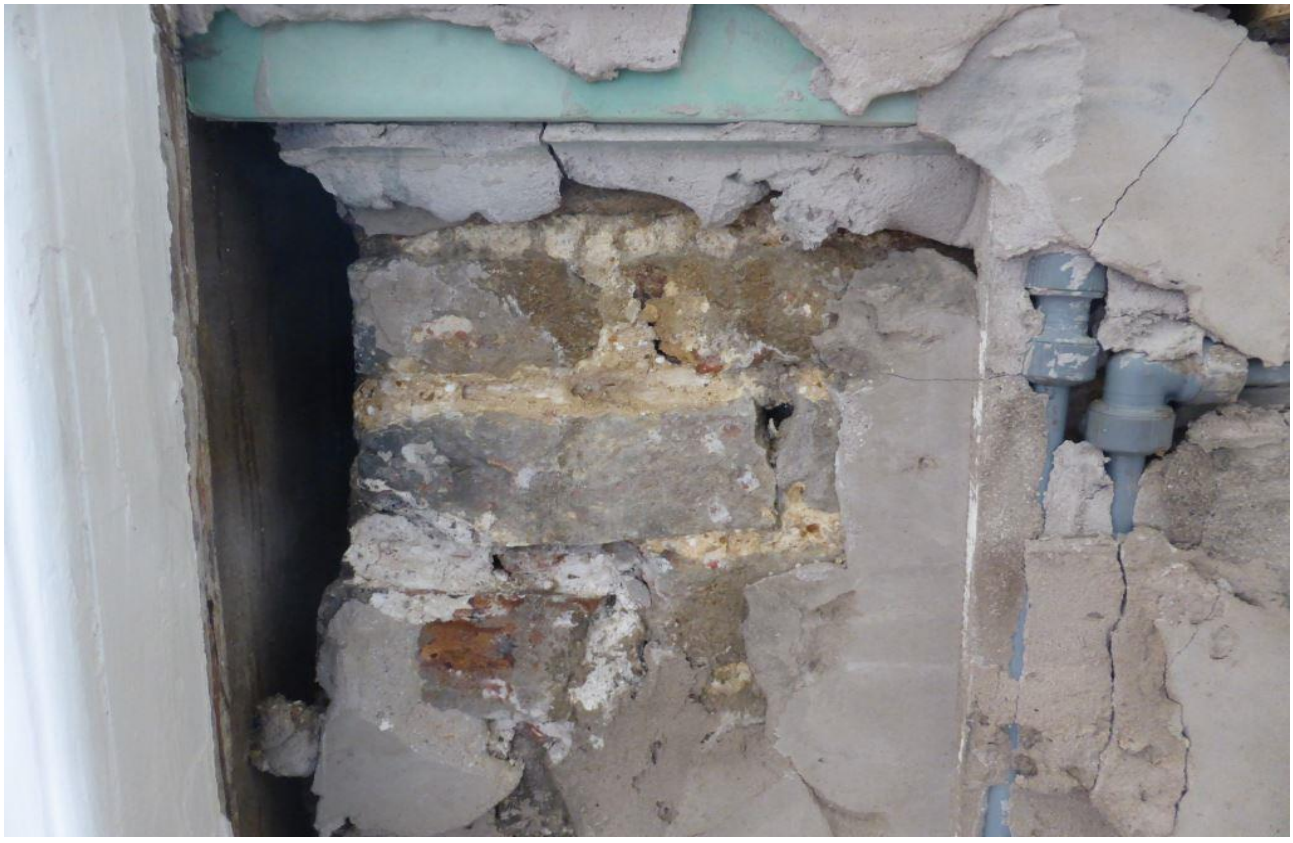
LOCATION OF RETRIEVED SAMPLES 2a & 2b



LOCATION OF RETRIEVED SAMPLES 2a & 2b



LOCATION OF RETRIEVED SAMPLES 2a & 2b

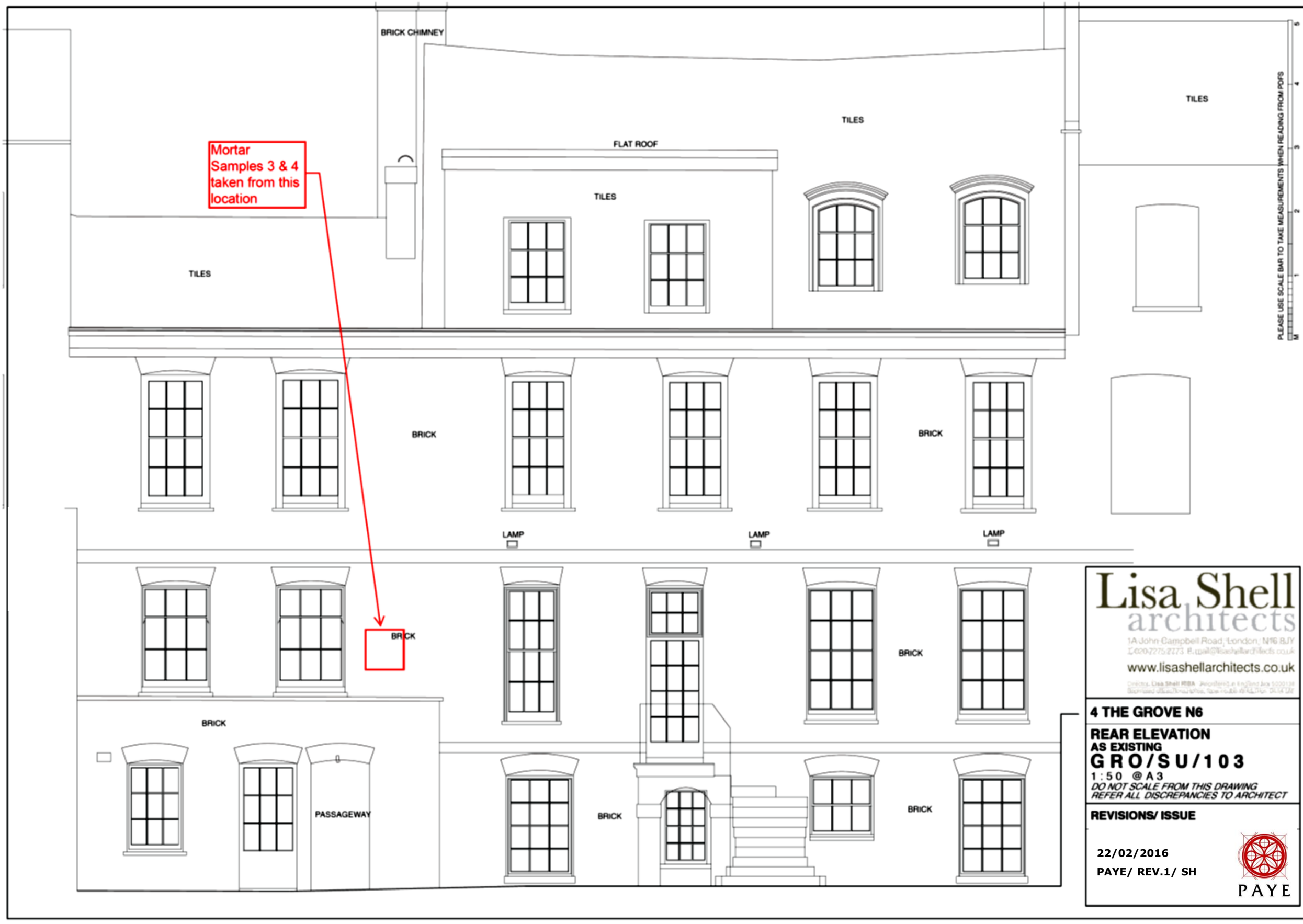


LOCATION OF RETRIEVED SAMPLES 2a & 2b

LOCATION OF RETRIEVED SAMPLES 3 & 4

LOCATION OF RETRIEVED SAMPLES 3 & 4

LOCATION OF RETRIEVED SAMPLES 3 & 4



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4 THE GROVE N6

REAR ELEVATION
AS EXISTING
GRO/SU/103
1:50 @ A3
DO NOT SCALE FROM THIS DRAWING
REFER ALL DISCREPANCIES TO ARCHITECT

REVISIONS/ ISSUE

22/02/2016
PAYE/ REV.1/ SH

PAYE

Sample 1: Internal brick mortar, behind fireplace in New Master Bedroom Ensuite.

Observations: A buff coloured, fine - coarse grained, fairly soft mortar with visible inclusions of white chalk or carbonated lime.

RESULTS:

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO_2 emission	**22.17873451**	
Dolomite %D	Calcimetry and titrimetric (EDTA)	**2**	
Aggregate	Gravimetric	**68.54520548**	
Gypsum	Barium Chloride	**2**	
Nitrates	Titrimetric/test strips.	**0.020608696**	
Chlorides	Titrimetric/test strips.	**0.103043478**	
Iron Oxides (Fe_2O_3)	Test strips/Titrimetric (potassium dichromate)	**0.6**	
pH of mortar sample	Indicator Strips/pH meter	**8**	
Mix Ratio	**Parts By Mass Aggregate : Binder (A : B)**	**2.2**	
Mix Ratio if binder was lime putty	**Parts By Volume Aggregate : lime putty**	**1.3**	
Mix Ratio if binder was HL/cement	**Parts By Volume Aggregate : Hydraulic Lime or cement**	**1.6**	
Active lime [$Ca(OH)_2$]	Titrimetric (Extracted in 10% sugar solution)	**0.00003**	
Carbonated lime in binder (degree of Carbonation)	From %$Ca(OH)_2$ in binder	**99.99**	
Cementitious Compounds	%S x 2.5	**4.55**	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	**1.82**	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	**7.72**	
CaO in Original Binder	From CaO in mortar	**62.88**	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	**14.83**	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	**-**	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	**0.28**	
Type of Binder	Dependent on the % Soluble Silica in Binder	**NHL2**	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

Sample 1 Results Continued

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	**RETAINED MASS (gms)**	**% RETAINED**	**% PASSING**	**AGGREGATE CHARACTERISTICS**
5.45		0	100	
2.465		12.97	87.02	Angular/sub rounded off-white/yellow coloured amorphous silicates (grit)
0.915		3.34	83.68	As above + clear/milky sub rounded quartz grains + occasional red brick dust.
0.567		1.67	82.0	As above
0.411		3.34	78.66	As above but mostly clear/milky/yellow quartz grains + some brown quartz grains
0.14		13.38	65.27	As above but all grains are angular
0.09		40.5	24.68	As above
<0.09		24.68	0	As above

Summary of Results and Comments:	**The aggregate:** is a fine grained golden brown coloured silica sand with about 15% by weight of coarser grit (see photomicrograph). **The Binder:** is equivalent to an NHL2 (non – feebly hydraulic lime). **The Mortar:** is buff coloured, fine - coarse grained, fairly soft with occasional visible inclusions of carbonated lime. **The Mix Ratio by volume:** is essentially a 1.5 : 1 (aggregate : lime binder)

Aggregate 1 magnification x 10

Sample 2A: Internal brick mortar, reverse of external wall New Master Bedroom

Observations: A buff coloured, fine - coarse grained, fairly hard mortar with visible inclusions of white carbonated lime.

RESULTS:

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO_2 emission	**37.17**	
Dolomite %D	Calcimetry and titrimetric (EDTA)	**1**	
Aggregate	Gravimetric	**56.21**	
Gypsum	Barium Chloride	**2.26**	
Nitrates	Titrimetric/test strips.	**0.35**	
Chlorides	Titrimetric/test strips.	**0.68**	
Iron Oxides (Fe_2O_3)	Test strips/Titrimetric (potassium dichromate)	**0.6**	
pH of mortar sample	Indicator Strips/pH meter	**8**	
Mix Ratio	**Parts By Mass Aggregate : Binder (A : B)**	**1.3**	
Mix Ratio if binder was lime putty	**Parts By Volume Aggregate : lime putty**	**0.8**	
Mix Ratio if binder was HL/cement	**Parts By Volume Aggregate : Hydraulic Lime or cement**	**0.92**	
Active lime [$Ca(OH)_2$]	Titrimetric (Extracted in 10% sugar solution)	**0.000017**	
Carbonated lime in binder (degree of Carbonation)	From %$Ca(OH)_2$ in binder	**99.99**	
Cementitious Compounds	%S x 2.5	**1.74**	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	**0.69**	
Soluble Silica in Original Binder	From %S x $(\frac{A}{B} + 1)$	**2.14**	
CaO in Original Binder	From CaO in mortar	**68.79**	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	**22.35**	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	**-**	
Cementation Index for Binder (CI)	CI ≈ $\frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	**0.07**	
Type of Binder	Dependent on the % Soluble Silica in Binder	**Non Hydraulic**	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

Sample 2A Results Continued

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	**RETAINED MASS (gms)**	**% RETAINED**	**% PASSING**	**AGGREGATE CHARACTERISTICS**
5.45		0	100	
2.465		3.50	96.49	Angular brown grit
0.915		6.14	90.35	Angular grey flint/chert, brown/yellow/rede grit, sub angular clear/milky/yellow quartz grains + red brick dust
0.567		3.07	87.28	As above, but mostly quartz grains
0.411		3.50	83.77	As above
0.14		14.91	68.85	As above but all grains are angular
0.09		30.70	38.15	As above
<0.09		38.15	0	As above

Summary of Results and Comments:	**The aggregate**: is a golden brown coloured, fine grained silica sand with about 10% by weight of coarser grit, similar to the aggregate in sample 1. **The Binder:** is equivalent to a non hydraulic lime. **The Mortar:** is buff coloured, fine - coarse grained, fairly soft with occasional visible inclusions of carbonated lime. **The Mix Ratio by volume:** is essentially a 1 : 1 (aggregate : lime binder)

Aggregate 2A magnification x 10

Sample 2B: Internal brick mortar, reverse of external wall New Master Bedroom

Observations: A soft, off-white coloured, fine - coarse grained mortar with visible inclusions of white carbonated lime.

RESULTS:

Components of Mortar	Method	Results % by mass	Results with >40% chalk/Lst. in the aggregate
Calcium Carbonate %C	Calcimetry - CO_2 emission	**48.54**	**48.54**
Dolomite %D	Calcimetry and titrimetric (EDTA)	**4.25**	**4.25**
Aggregate	Gravimetric	**43.75**	**72.91**
Gypsum	Barium Chloride	**0.43**	**0.42**
Nitrates	Titrimetric/test strips.	**0.83**	**0.83**
Chlorides	Titrimetric/test strips.	**1.04**	**1.04**
Iron Oxides (Fe_2O_3)	Test strips/Titrimetric (potassium dichromate)	**0.3**	**0.3**
pH of mortar sample	Indicator Strips/pH meter	**8**	8
Mix Ratio	**Parts By Mass Aggregate : Binder (A : B)**	**0.81**	**3**
Mix Ratio if binder was lime putty	**Parts By Volume Aggregate : lime putty**	**0.5**	**1.7**
Mix Ratio if binder was HL/cement	**Parts By Volume Aggregate : Hydraulic Lime or cement**	**0.6**	**2**
Active lime [$Ca(OH)_2$]	Titrimetric (Extracted in 10% sugar solution)	**0.000035**	**0.000035**
Carbonated lime in binder (degree of Carbonation)	From %$Ca(OH)_2$ in binder	**99.99**	**99.99**
Cementitious Compounds	%S x 2.5	**0.86**	**0.85**
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	**0.343**	**0.342**
Soluble Silica in Original Binder	From $\%S \times \frac{(A + 1)}{B}$	**0.82**	**1.77**
CaO in Original Binder	From CaO in mortar	**66.38**	**58.62**
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	**27.66**	**27.65**
Aluminium Oxide in Binder	Gravimetric (using Oxine)	**-**	**-**
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	**0.025**	**0.013**
Type of Binder	Dependent on the % Soluble Silica in Binder	**Non Hydraulic**	**Non Hydraulic/NHL2**

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume).

Sample 2B Results Continued

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	**RETAINED MASS (gms)**	**% RETAINED**	**% PASSING**	**AGGREGATE CHARACTERISTICS**
5.45		0	100	
2.465		6.35	93.64	Angular off-white/yellow grit + milky quartz grains
0.915		13.87	79.76	As above + some brown-red brick dust
0.567		9.82	69.94	As above but mostly yellow-brown/clear/milky quartz grains + occasional rounded clear quartz grains
0.411		9.24	60.69	As above + some black previously molten iron compounds (botryoidal form)
0.14		28.32	32.36	As above but all grains are angular
0.09		10.98	21.38	As above
<0.09		21.38	0	As above

Summary of Results and Comments:	**The Aggregate:** is an off-white/pale buff coloured fine - coarse grained silica sand with some possible slag material **The Binder:** is equivalent to a non hydraulic lime. **The Mortar:** is a soft, off-white coloured, fine - coarse grained mortar with visible inclusions of white carbonated lime. **The Mix Ratio by volume:** is essentially a 0.5 : 1 (aggregate : lime binder). Note: if the ratio is very low (e.g. < 1 : 1 by volume), this could mean that there is a significant amount of chalk/limestone in the mortar (added as part of the aggregate), perhaps up to 40% as shown in the results table, which will have inevitably manifest itself as carbonated lime binder in the analysis. However, no chalk microfossils (coccoliths) were found using the PLM. Alternatively, many old historic lime mortars give a mix ratio for sand : lime putty, by mass, from <1.5 – 2 : 1, (i.e. from <1 – 1.3 : 1 by volume), because they were generally 'hot mixed' as up to 3 parts of sand with 1 part of quicklime by volume (water being added). Over the years this 3 : 1 sand : quicklime mix ratio, by volume, has incorrectly been recorded as 3 : 1 sand : lime putty, by volume. We can convert a sand : lime putty mix ratio to a sand : quicklime mix ratio as follows: Aggregate : Quicklime = (Aggregate : Lime Putty, by volume)/0.44 Using this conversion factor we see that the 0.5 : 1 sand : lime by volume mix ratio may be equivalent to an original 1.2 : 1 sand : quicklime mix by volume, i.e. 0.5/0.44 : 1 = 1.2 : 1

Sample 2B Results Continued

Aggregate 2B, magnification x 10

Sample 3: External brick mortar, rear of building

Observations: A quite soft, off-white coloured, fine - coarse grained mortar with visible inclusions of white carbonated lime.

RESULTS:

Components of Mortar	Method	Results % by mass	Results with 25% chalk/Lst. in the aggregate
Calcium Carbonate %C	Calcimetry - CO_2 emission	**40.61**	**40.61**
Dolomite %D	Calcimetry and titrimetric (EDTA)	**6.8**	**6.8**
Aggregate	Gravimetric	**46.42**	**61.9**
Gypsum	Barium Chloride	**1**	**1**
Nitrates	Titrimetric/test strips.	**0.012**	**0.012**
Chlorides	Titrimetric/test strips.	**0**	**0**
Iron Oxides (Fe_2O_3)	Test strips/Titrimetric (potassium dichromate)	**0.3**	**0.3**
pH of mortar sample	Indicator Strips/pH meter	**8**	8
Mix Ratio	**Parts By Mass Aggregate : Binder (A : B)**	**0.9**	**1.6**
Mix Ratio if binder was lime putty	**Parts By Volume Aggregate : lime putty**	**0.5**	**1**
Mix Ratio if binder was HL/cement	**Parts By Volume Aggregate : Hydraulic Lime or cement**	**0.6**	**1.2**
Active lime [$Ca(OH)_2$]	Titrimetric (Extracted in 10% sugar solution)	**0.00006**	**0.00006**
Carbonated lime in binder (degree of Carbonation)	From %$Ca(OH)_2$ in binder	**99.99**	**99.99**
Cementitious Compounds	%S x 2.5	**4.9**	**4.86**
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	**1.95**	**1.94**
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	**4.83**	**6.79**
CaO in Original Binder	From CaO in mortar	**61.7**	**56.51**
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	**24.85229665**	**24.85**
Aluminium Oxide in Binder	Gravimetric (using Oxine)	**-**	**-**
Cementation Index for Binder (CI)	CI ≈ $\frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	**0.15**	**0.08**
Type of Binder	Dependent on the % Soluble Silica in Binder	**NHL2**	**NHL2/3.5**

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

Sample 3 Results Continued

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	**RETAINED MASS (gms)**	**% RETAINED**	**% PASSING**	**AGGREGATE CHARACTERISTICS**
5.45		0	100	
2.465		22.32	77.67	Angular grey chert, yellow translucent grit + bright orange-red brick dust
0.915		21.42	56.25	As above
0.567		8.03	48.21	As above + some occasional possible black iron slag material
0.411		6.25	41.96	As above
0.14		18.75	23.21	As above but all grains are angular
0.09		7.14	16.07	As above
<0.09		16.07	0	As above

Summary of Results and Comments:	**The Aggregate:** is an off-white/pale warm buff coloured silica sand with some possible slag material, similar to the aggregate in sample 2B. **The Binder:** is equivalent to a non hydraulic lime. **The Mortar:** is a quite soft, off-white coloured, fine - coarse grained mortar with visible inclusions of white carbonated lime. **The Mix Ratio by volume:** is essentially a 0.5/0.6 : 1 (aggregate : lime binder). Note: if the ratio is very low (e.g. < 1 : 1 by volume), this could mean that there is a significant amount of chalk/limestone in the mortar (added as part of the aggregate), perhaps up to 25% as shown in the results table, which will have inevitably manifest itself as carbonated lime binder in the analysis. However, no chalk microfossils (coccoliths) were found using the PLM. Alternatively, many old historic lime mortars give a mix ratio for sand : lime putty, by mass, from <1.5 – 2 : 1, (i.e. from <1 – 1.3 : 1 by volume), because they were generally 'hot mixed' as up to 3 parts of sand with 1 part of quicklime by volume (water being added). Over the years this 3 : 1 sand : quicklime mix ratio, by volume, has incorrectly been recorded as 3 : 1 sand : lime putty, by volume. We can convert a sand : lime putty mix ratio to a sand : quicklime mix ratio as follows: Aggregate : Quicklime = (Aggregate : Lime Putty, by volume)/0.44 Using this conversion factor we see that the 0.5 : 1 sand : lime by volume mix ratio may be equivalent to an original 1.2 : 1 sand : quicklime mix by volume, i.e. 0.6/0.44 : 1 = 1.5 : 1

Sample 3 Results Continued

Aggregate 3 magnification x 10

Sample 4: External brick mortar, rear of building

Observations: A fine - coarse grained, hard, grey-buff coloured mortar.

RESULTS:

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO_2 emission	**16.7**	
Dolomite %D	Calcimetry and titrimetric (EDTA)	**0**	
Aggregate	Gravimetric	**67.9**	
Gypsum	Barium Chloride	**0.4**	
Nitrates	Titrimetric/test strips.	**0.015**	
Chlorides	Titrimetric/test strips.	**0**	
Iron Oxides (Fe_2O_3)	Test strips/Titrimetric (potassium dichromate)	**0.6**	
pH of mortar sample	Indicator Strips/pH meter	**8**	
Mix Ratio	**Parts By Mass Aggregate : Binder (A : B)**	**2.12**	
Mix Ratio if binder was lime putty	**Parts By Volume Aggregate : lime putty**	**1.23**	
Mix Ratio if binder was HL/cement	**Parts By Volume Aggregate : Hydraulic Lime or cement**	**1.5**	
Active lime [$Ca(OH)_2$]	Titrimetric (Extracted in 10% sugar solution)	**0.000084**	
Carbonated lime in binder (degree of Carbonation)	From %$Ca(OH)_2$ in binder	**99.99**	
Cementitious Compounds	%S x 2.5	**14.41**	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	**5.76**	
Soluble Silica in Original Binder	From %S x $(\frac{A}{B} + 1)$	**23.9**	
CaO in Original Binder	From CaO in mortar	**88.25**	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	**21.3**	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	**-**	
Cementation Index for Binder (CI)	CI ≈ $\frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	**1.5**	
Type of Binder	Dependent on the % Soluble Silica in Binder	**Cement**	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

Sample 4 Results Continued

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	**RETAINED MASS (gms)**	**% RETAINED**	**% PASSING**	**AGGREGATE CHARACTERISTICS**
5.45		0	100	
2.465		17.60	82.39	Angular agglomerates of fine sand bound in a strong matrix (possibly older cement)
0.915		11.97	70.42	As above
0.567		15.49	54.92	As above + angular grey/brown quartz grains and grit
0.411		16.90	38.02	As above
0.14		30.28	7.74	As above
0.09		3.52	4.22	As above
<0.09		4.22	0	As above

Summary of Results and Comments:	**The 'Aggregate':** is a buff coloured material composed of either an older crushed mortar, or the result of incomplete acid disaggregation of very fine quartz grains bonded by a high strength 'cement' matrix. This would suggest a possible 'Roman' cement mortar with the fine quartz grains indigenous to the cement. **The Binder:** is equivalent to an OPC (cement) **The Mortar:** is fine - coarse grained, hard and grey-buff coloured. **The Mix Ratio by volume:** is 1.5 : 1 (aggregate : cement).

Aggregate 4 magnification x 10

SUMMARY AND RECOMMENDATIONS

We know the front of the property has been pointed with an inappropriate cement mortar (not sampled) which needed to be removed for reasons which are both aesthetic and functional. What we hadn't appreciated previously was that the rear of the property has also been pointed (or in this case, over-pointed) with a cementicious mix – see Samples 3 and 4 within above analysis.

The colour of this pointing will dramatically impact upon the overall aesthetic and we think improve the perception of the brickwork dramatically – there will however be a stark difference between the front and the rear (requiring a considered break point). Our recommendations would be as with the front to remove and replace the cementicious pointing with a suitable, permeable lime mortar.

Samples 1, 2A, 2B and 3 all appear to be subtle variations of the same original bedding/pointing mix. These mixes are very close to one another and could vary simply due to the batching on site.

Given that we are looking to match the equivalent of mortars found in samples 1, 2a, 2b and 3 and taking into consideration the time of year we understand works to be required (ie outside of the lime season). We would on reflection recommend that all repointing is completed with a base mix of something like;

1pt Feebly Naturally Hydraulic Lime (2)
1 ½ pts sieved sharp sand
½ pt fine builders sand
½ pt crushed chalk crumb

This basic recipe could then be tweaked on site as necessary to achieve a close match to colour and texture of the original. If works were to be completed well within the lime season, then we could consider the use of a lime putty binder instead of the NHL 2 prescribed. However, scaffolds and protection sheeting must remain in place for as long as necessary, adding to programme and in turn the overall cost.

We trust the above is self-explanatory, but if you would like to discuss any of the content, then please do not hesitate to contact us.