ALACAH

CONSERVATION ENGINEERING

Mortars for Damp Masonry

Overview:

Introduction and Context

I. Diagnosing Damp Towers

II. Hardening Kinetics of Traditional Mortars

III. Optimising Mortars for Technical Performance

Summary

THE DIOCESE OF BLACKBURN

THE CHURCH OF ENGLAND IN LANCASHIRE

Section Overview

Introduction & Context

Introduction & Context

Focus:
- Damp towers
- Masonry bridges
- Spires
- Open ruins

Introduction & Context

Focus:

- Damp masonry

Introduction & Context

‘Mortar failures’… traditional hot-mixed lime mortars getting a bad press…

Introduction & Context

‘Mortar failures’… NHLs by no means exempt!

Introduction & Context

Focus:

- Masonry wet to begin with
- Possibly subject to sustained water ingress / re-wetting
- Within cyclic wet/dry water line
- Beneath defective water-shedding detailing
- Skyward-facing joints
- Onerous environments

…How do we get carbonate-based binders to work with this sort of thing?

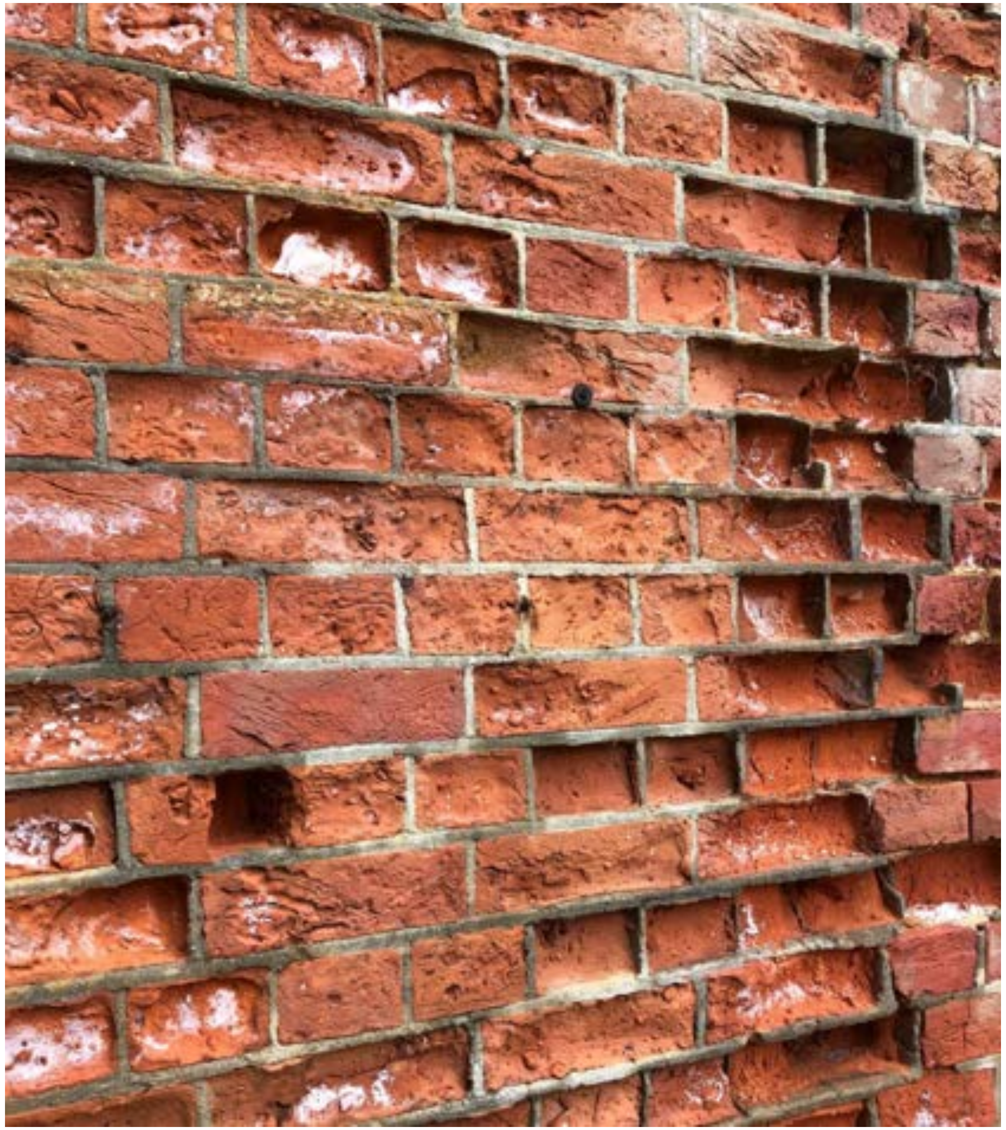
Introduction & Context

Ah! That's why we like to use NHLs, or better still, 1:1:6…
Recap: What's wrong with NHLs and 1:1:6:

- NHLs have been shown to have very unpredictable properties
- NHLs are very low in actual lime content, only a fraction when compared with authentic lime mortars, giving miserable microporosity
- 1:1:6 is very low in lime content and very brittle owing to its high cement content, letting water in and stopping it getting out

All in these properties <u>shove the drying front into the masonry units</u>, where the salt damage then occurs.

…No prizes for using cement just because it won't fall off in the first winter…



Section Overview

I. Diagnosing Damp Towers

Diagnosing Damp Towers

St Mary's Pembroke:

- Massive masonry tower, very exposed
- Free water seeping out of walls even on dry days
- Textbook 'damp tower syndrome'

Diagnosing Damp Towers

Structural and Fabric Pathology

- Thorough S1 Appraisal inside and out
- Tactile survey on the wall (rope access)
- Check water-shedding efficacy
- Reconcile all the puzzle pieces
- Don't look down!

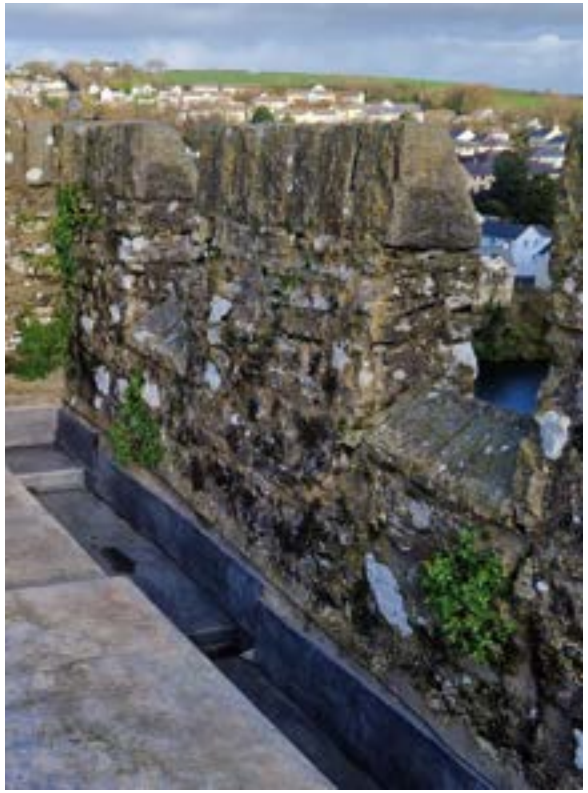
Will repointing this tower actually deal with the problem?

Diagnosing Damp Towers

Water-shedding detailing:

- Wall tops ok to the outer face, but open at the head
- Wall tops rubbish to the inner face
- Corbel course dripped ok
- Not one opening has its hood up

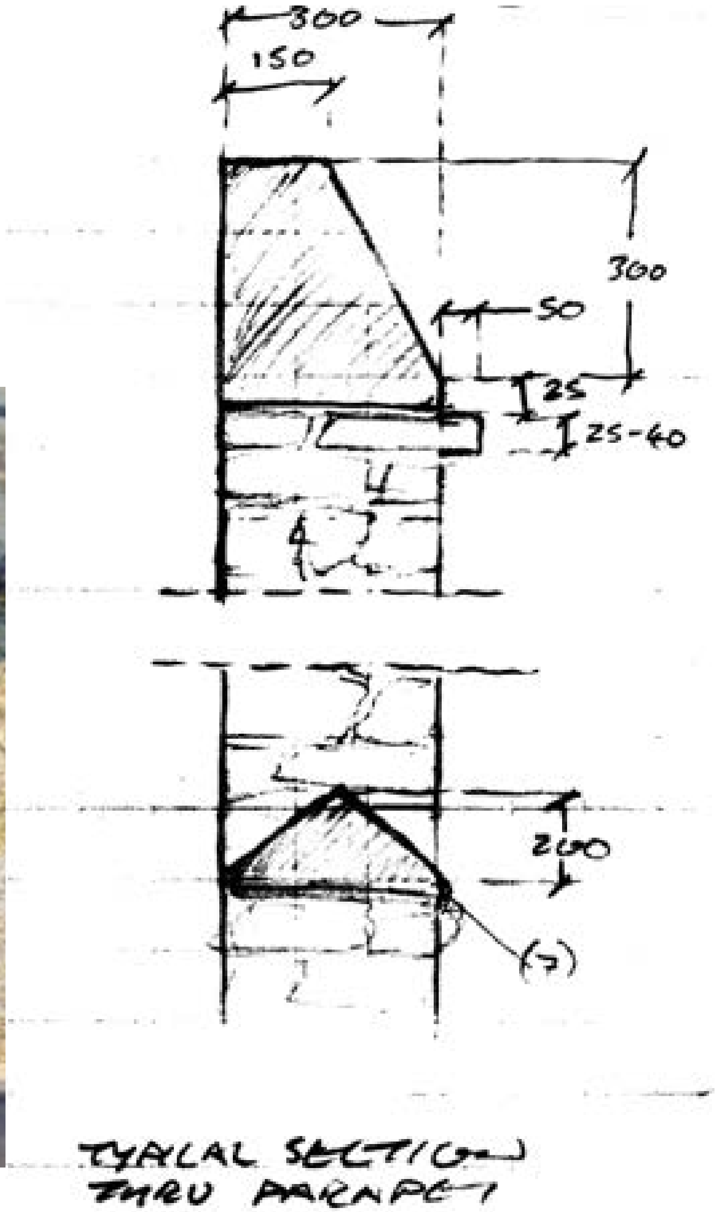


Diagnosing Damp Towers

Water-shedding detailing:

- Leadwork a joke, pressed onto the wall
- Water already in the wall thanks to skyward-facing joints
- Record the details and build the picture…



Diagnosing Damp Towers

Water-shedding detailing:

- Staircase roof flat topped with flush edge, water pouring down surfaces (look for the pond dwelling plants)
- Other than the wall top outer faces and the corbel course, no drip detailing at all
- One massive film of water clinging to the wall…

Diagnosing Damp Towers

Water-shedding detailing:

- A remedial string course…
- Actually fairly effective, although it's carbon steel so will prise the masonry apart…
- How does a string course work…?

Diagnosing Damp Towers

Masonry fabric condition:

- Aye the mortar's dreadful in places
- But just repointing will not fix the problem, and will be doomed to a monster 'lime failure'

Diagnosing Damp Towers

Fabric and structural pathology are so intertwined…

- Free water pouring down inside face of walls
- Unhappy bell-ringers
- Bell-frame dangerous condition
- All due to sustained water ingress & retentivity

Diagnosing Damp Towers

Dealing with damp towers…

- Detailing's dreadful
- Mortar condition poor
- Originally harled and limewashed

BUT.

- Attempting a re-harl today without correction of intrinsic detailing deficiencies will end in disaster

Diagnosing Damp Towers

Buxton. Effects of decay…

- Intrinsically sound water-shedding detailing loses shape
- Water is sticky, and clings to masonry
- Wet walls – gutters on the inside

Diagnosing Damp Towers

But wait – we can't throw that in the bin, it's original material!?

Diagnosing Damp Towers

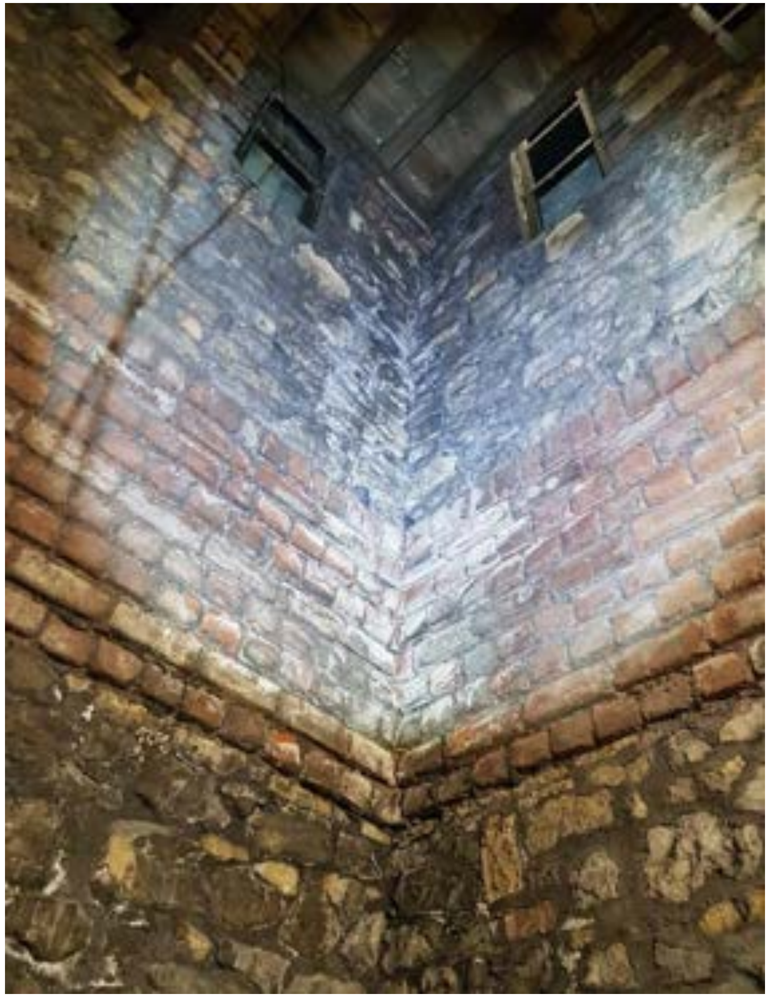
Water-shedding detailing…

- What should a coping, string course or hood mould actually do?
- How do they work?
- And if knackered, what do we do?

Tyre tread on a classic car…

Diagnosing Damp Towers

‘Breathable membranes’…



Diagnosing Damp Towers

Diagnosing Damp Towers

Literally a couple of weeks later…

Diagnosing Damp Towers

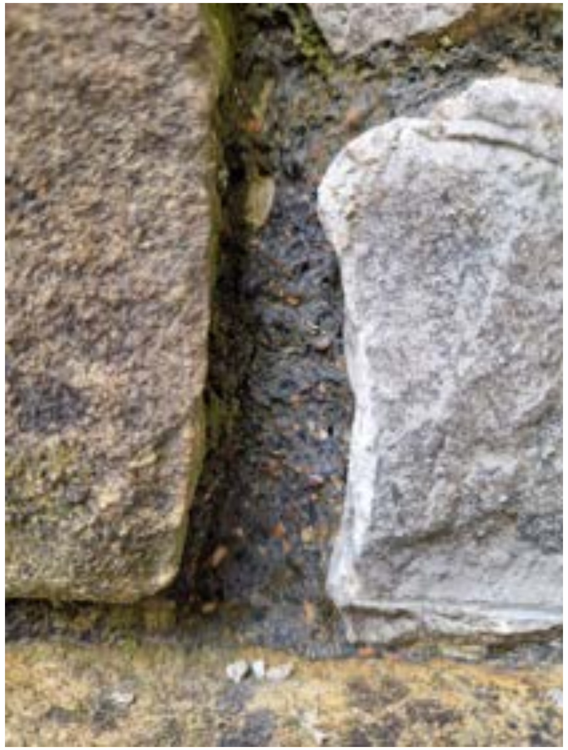
Vapour permeability is an absolute load of rubbish

See https://clach-conservation.co.uk/lime-training-%2F-r%26d for a debunking of breathability myths and an examination of convective drying

Diagnosing Damp Towers

And that's just taking off incompatible nonsense and letting the wall blow dry…

THEN we get on with the repointing ☺



Original lime-ash mortar…

Lime-ash repair mortar…

Diagnosing Damp Towers

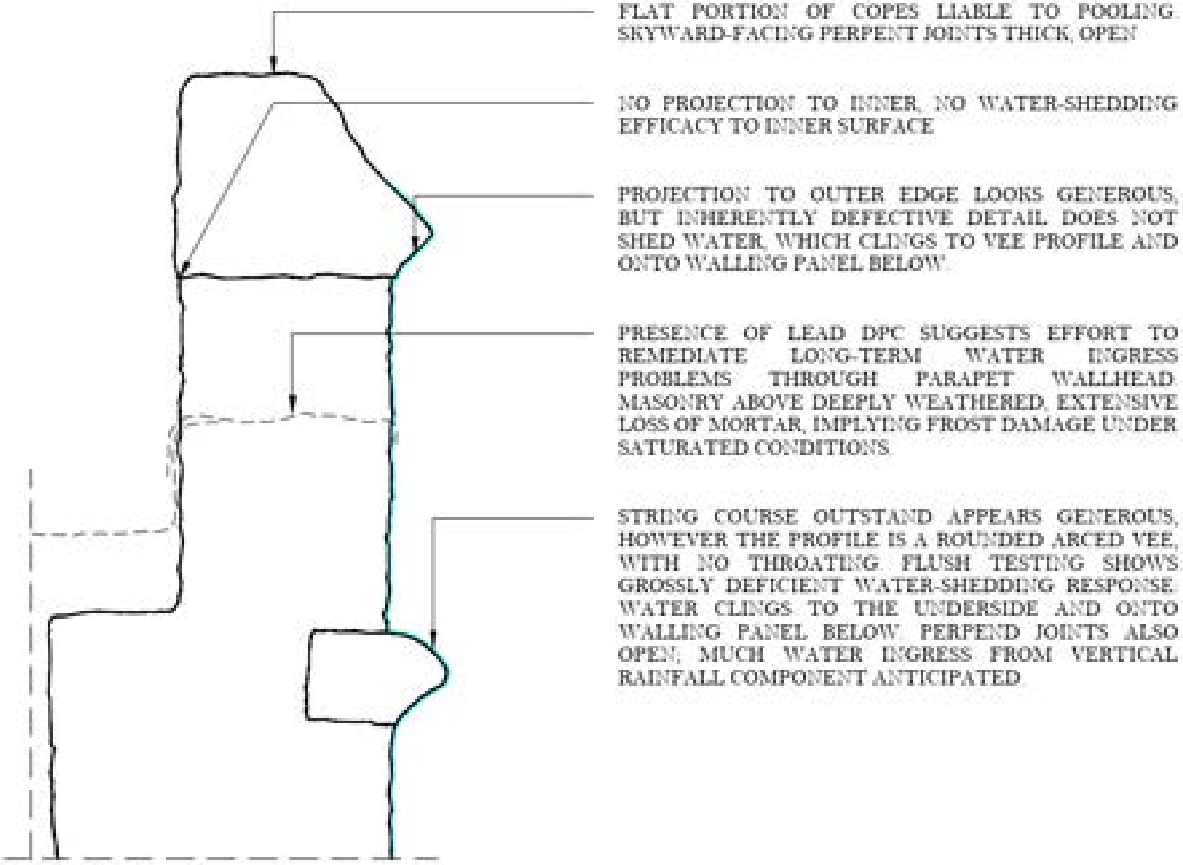
But it's Grade I…! 😱

Gorgeous. But the Victorians have a lot to answer for….

Diagnosing Damp Towers

Appraisal of water-shedding detailing…

- Copings look good, massive string course projection. OK it probably had a surface coating, but maybe just a good repoint do the job?



Diagnosing Damp Towers

Tactile appraisal with flush-testing to test initial hypothesis…

Diagnosing Damp Towers

Looks pretty but completely useless.

Diagnosing Damp Towers

Intrinsically sound detailing – but why the water ingress?

Diagnosing Damp Towers

How do copings, drip courses and hood moulds work?

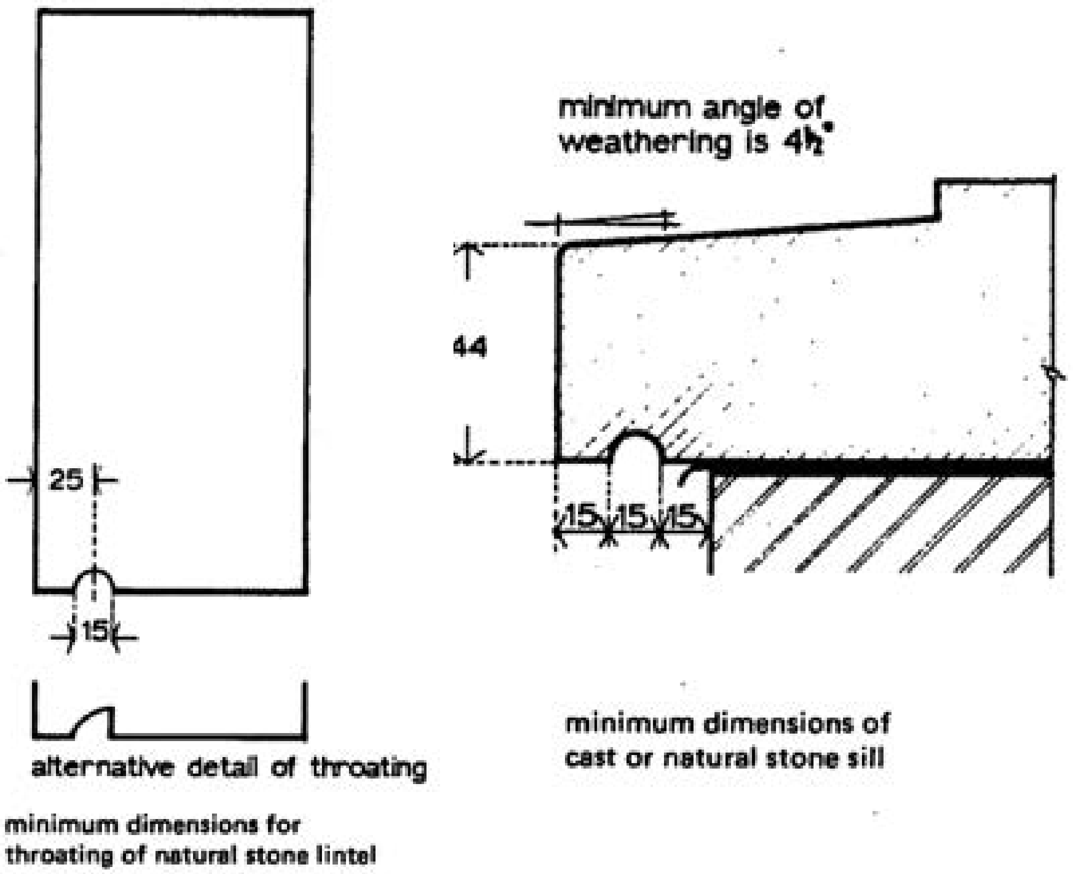
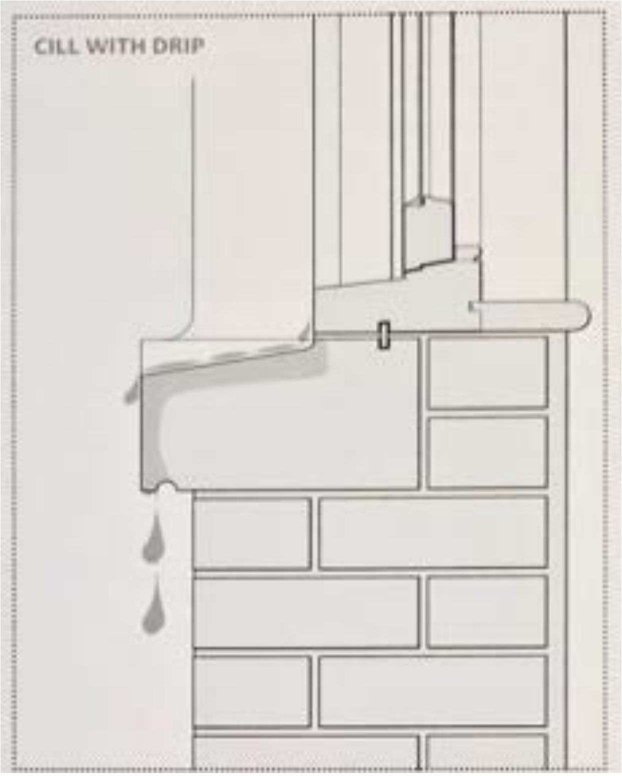
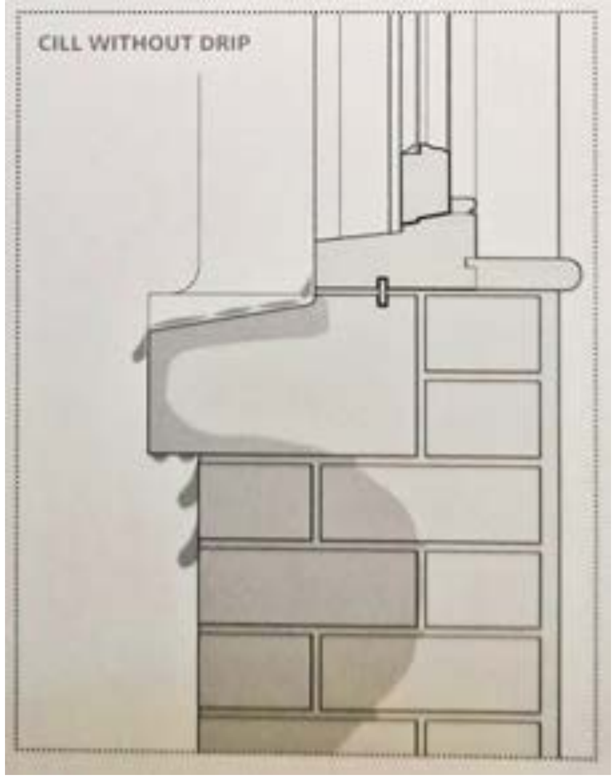


Figure 15. Sills and lintels





Diagnosing Damp Towers

How does drip detailing work?

Diagnosing Damp Towers

Traditional water-shedding detailing…

1. Intercepts film of water from structure above
2. Condenses it to a thicker film, making it heavy
3. Moves it outward away from the structure below
4. Throat forces effect of gravity to overcome stickiness of water
5. Throws water OFF the building

Diagnosing Damp Towers

Effects of stupidity…

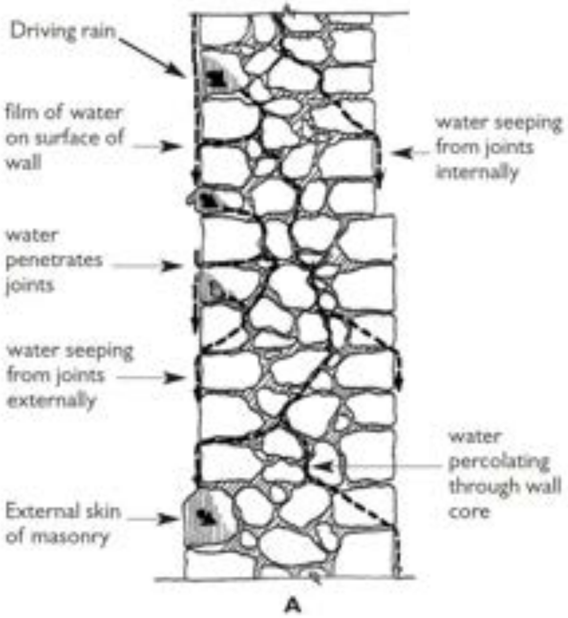
- Intrinsically sound water-shedding detailing loses shape
- Water is sticky, and clings to masonry
- Wet walls

Diagnosing Damp Towers

Diagnosing Damp Towers

So before we spec up a repointing job to a damp tower…

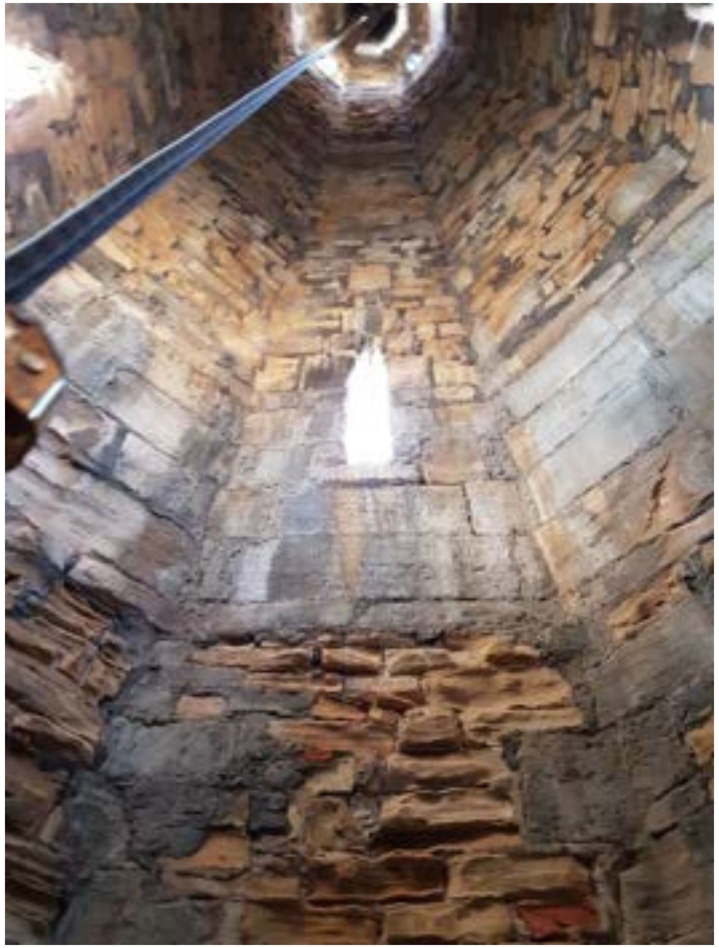
- Thoroughly understand the building
- Check efficacy of water-shedding detailing
- Plot drip-lines down the building
- Consider enhancements if intrinsically deficient
- Investigate hidden details – check the core as a liquid pathway for free water

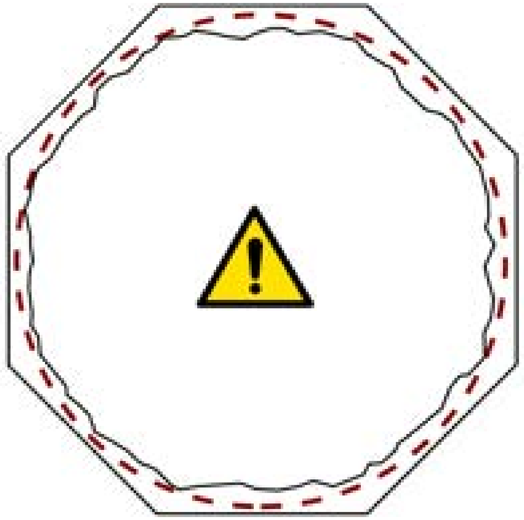


If we try and push mortar to do the job of water-shedding detailing, we are kidding ourselves on.

Diagnosing Damp Towers

But getting this mortar business right is important to keep these gorgeous old buildings going.





Section Overview

II. Hardening Kinetics of Traditional Mortars

Hardening Kinetics of Traditional Mortars

Carbonation:

1. Carbon dioxide diffuses into pore space of mortar;
2. CO_2 dissolves in pore water to form carbonic acid H_2CO_3;
3. Free lime $CaOH_2$ dissolves in pore water (reduced ph);
4. Carbonic acid carbonate ions react with calcium ions from the lime, to form calcium carbonate $CaCO_3$.

Word to the wise: moisture is essential to carbonation process. BUT!

- Carbonation 'impossible' below 20% RH…
- Carbonation impossible at 100% RH…
- Optimum RH ~60%
- Lab environment?
- Meanwhile in Scotland

AIR WITHIN PORES OF DAMP MATERIALS PRACTICALLY 100% RH…

Hardening Kinetics of Traditional Mortars

Hydraulic mortars:

1. Hydraulic limestone source or pozzolanic mortar;
2. Calcium silicates and aluminates react with water molecules to form calcium silicate & aluminate hydrates
3. i.e. "Hydration". $2CaOSiO_2$ (Belite), $3CaOSi0_2$ (Alite), $3CaOAl_2O_3$ (Tricalcium aluminate)…
4. This chemical set gives initial hardening and early strength;
5. Thereafter, carbonation takes place

Or so the story goes…

Hardening Kinetics of Traditional Mortars

Why do we gauge mortars?

Hardening Kinetics of Traditional Mortars

Gauged lime mortars:

- To make them strong
- To make them harden in damp/wet
- To resist frost

To get the best of both worlds?

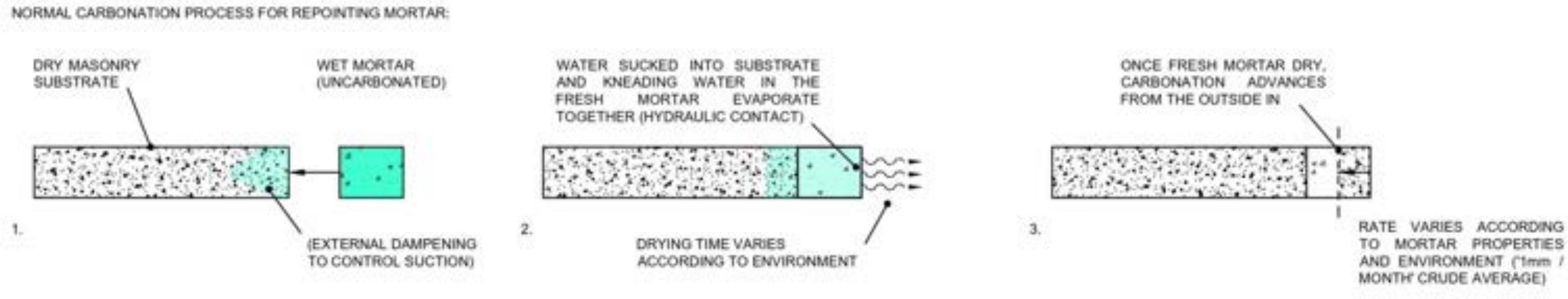
- So we use a mortar that needs to stay wet to hydrate, but needs to be dry to carbonate…

1. The early set lulls us into a sense of false security
2. We think it's 'went off', it's exposed to the elements, probably wet to begin with…
3. But the mortar's still overwhelmingly air lime and this means no carbonation
4. The more hydraulic the mix, the slower the carbonation rate…
5. The wetter the substrate is, and the more water we add to it by 'aftercare', the longer the delay in carbonation will be…

Hardening Kinetics of Traditional Mortars

Carbonation in a dry wall:

- Famously 1mm/month outside-in…



- Optimum humidity and temperatures apply
- Process significantly faster when macroporous aggregates employed

Only once the mortar has dried, and then the mortar stays dry.

Hardening Kinetics of Traditional Mortars

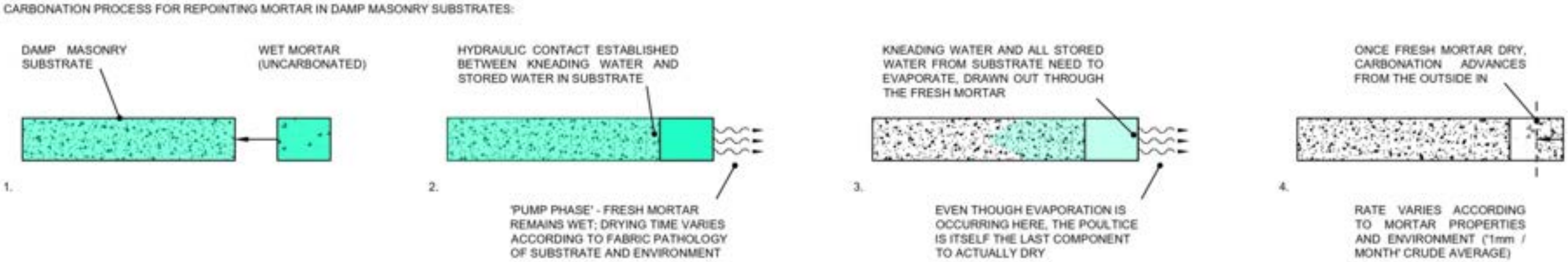
'Pump Phase'

- Mortar gets tangibly wetter after worked into the wall…

Hardening Kinetics of Traditional Mortars

Carbonation in a damp wall:

- Famously 1mm/month outside-in… Aye right



Pump phase:

- Kneading water in fresh mortar engages stored water in substrate (hydraulic contact)
- All the kneading water needs to evaporate as usual
- All the stored water in substrate is then sooked out (poultice)

Even though all the drying is occurring at the mortar surface, in a multi-layered system of porous materials, the poultice is itself the last thing to actually dry… LIME MORTAR IS A STRUCTURAL TOWEL.

Hardening Kinetics of Traditional Mortars

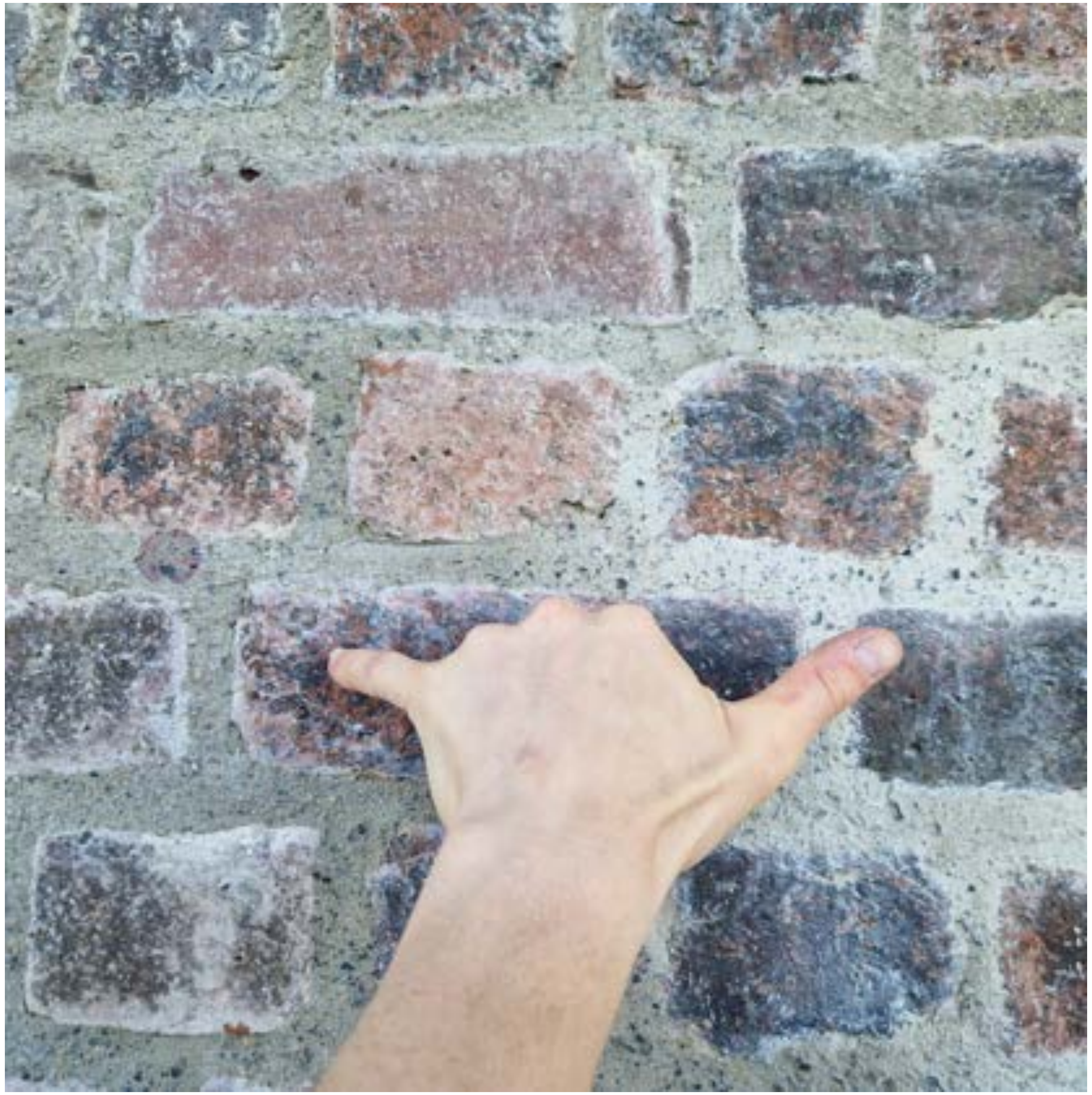
Hardening Kinetics of Traditional Mortars

Hardening Kinetics of Traditional Mortars

Hardening Kinetics of Traditional Mortars

Pump phase…

- Access to air movement essential
- Prevent further water added to the system
- Cover the wall tops, drain / drip off
- Protect the wall sides, wind but no rain allowed
- Patience
- Highly vulnerable to frost attack while it's wet and until it carbonates…



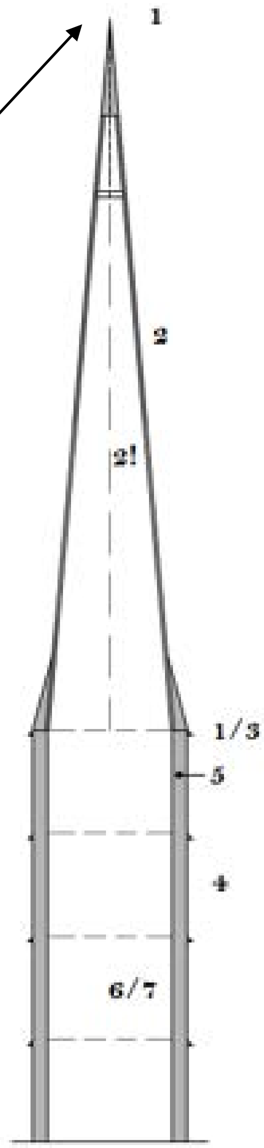
NO CARBONATION WILL BE DONE UNTIL PUMP PHASE IS COMPLETED

Section Overview

III. Optimising Mortars for Technical Performance

Optimising Mortars for Technical Performance

Wall tops, flaunching and water-shedding detailing



Optimising Mortars for Technical Performance

What can we learn from history? AKA via Nigel… ☺

Millington, 1839…

> *'All mortar, made from the ordinary kinds of lime, **requires to be kept tolerably dry** in order to insure its setting properly in the work in which it has been used; consequently it will not answer for use under water, **or in wet positions.** In these, a peculiar mortar called Cement, must be used… The material generally used in England as a cement for water-works, bridge building, lining tanks to make them water-tight, and other similar purposes, is called Parker's cement, or Roman cement'*

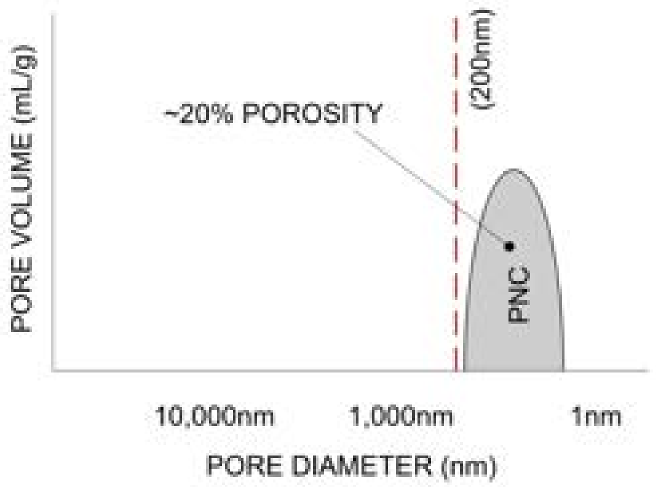
Natural cement

Water limes in the water, air limes in the air… the nuance here is stuff that is subjected to sustained wetting / long term saturation

Optimising Mortars for Technical Performance

Wall tops:

- Absorptive mortars subjected to saturated conditions will fail in frost
- Proved it in the lab
- Waterproof mortar to throw water off is therefore necessary
- High frost durability
- Intimate seal around arisses
- Low/no shrinkage
- Ideal world, low modulus…

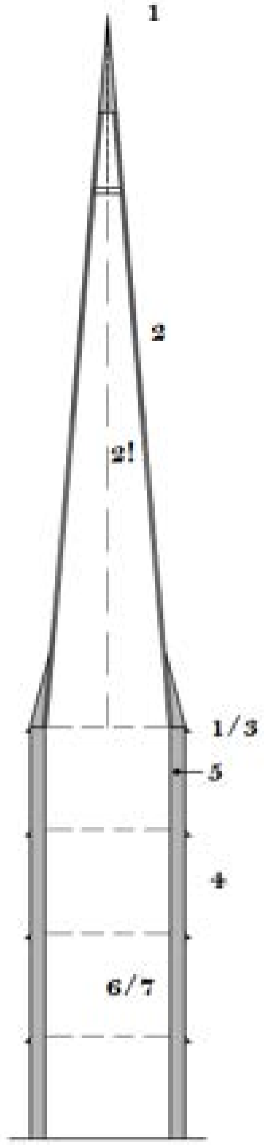


Optimising Mortars for Technical Performance

Wall tops, flaunching & water-shedding detailing typical recipes:

1. WALL TOPS (FLAUNCHING) A
•1 PROMPT NATURAL CEMENT
•2 GRIT SAND (QUARTZ)

3. DRIP DETAILING B ("1:1:6")
•1 WHITE CEMENT (CEM I)
•1 LIME HYDRATE (CL90)
• 6 GRIT SAND (QUARTZ)



Optimising Mortars for Technical Performance

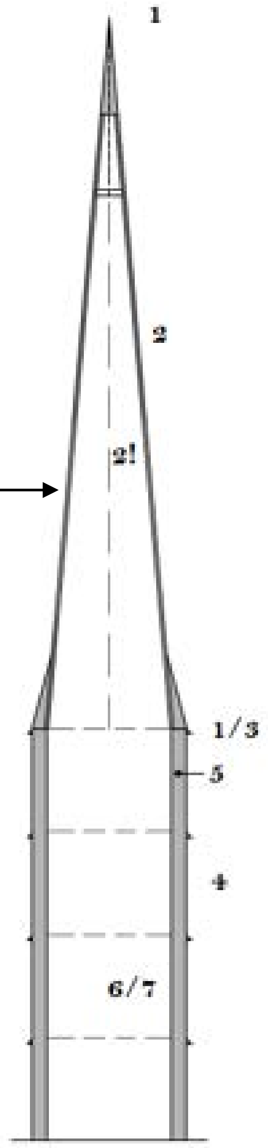
But no prizes for using a dense hydraulic mortar on wall sides…

Evaluation of NHL 'Control' Mix at Bennerley Viaduct

- NHL 5 1:2.5, quartz sand
- Set hard, tight bond
- Very slow water absorption
- Completely uncarbonated even after 1 year evaluation
- Major displacement of drying front (salt precipitation) into brick units
- Manifestly incompatible

Optimising Mortars for Technical Performance

Spire shells



Optimising Mortars for Technical Performance

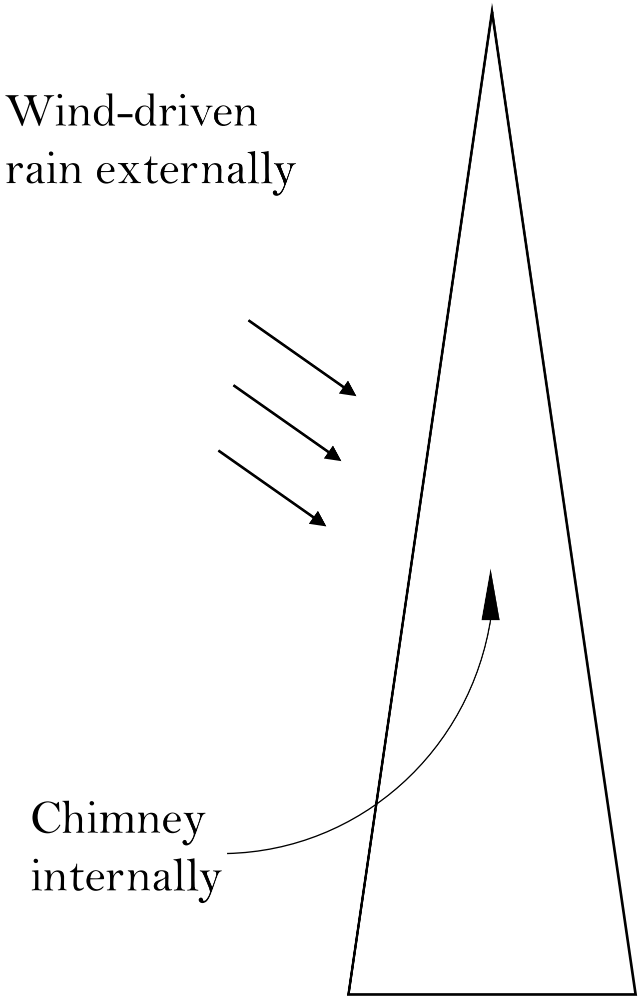
Spires.

- Subject to rapid wetting & drying cycles
- Durability important but salt management critical

Images: Phil Scorer, Vitruvius Conservation

Optimising Mortars for Technical Performance

Spires often weather worse on the inside or leeward face…



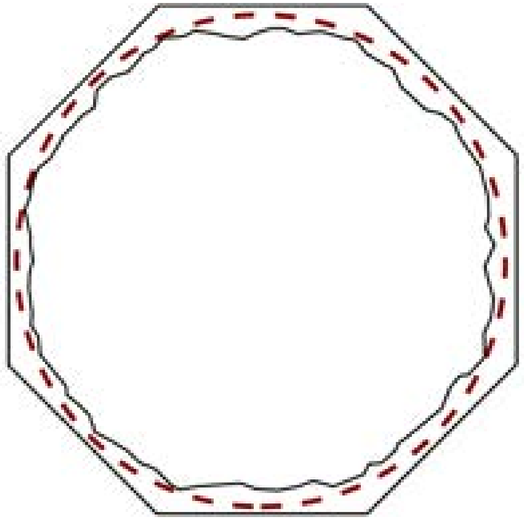
Drying front dictates where salt causes damage. Decay is primarily on the inside.
50% section loss on an already slender spire…

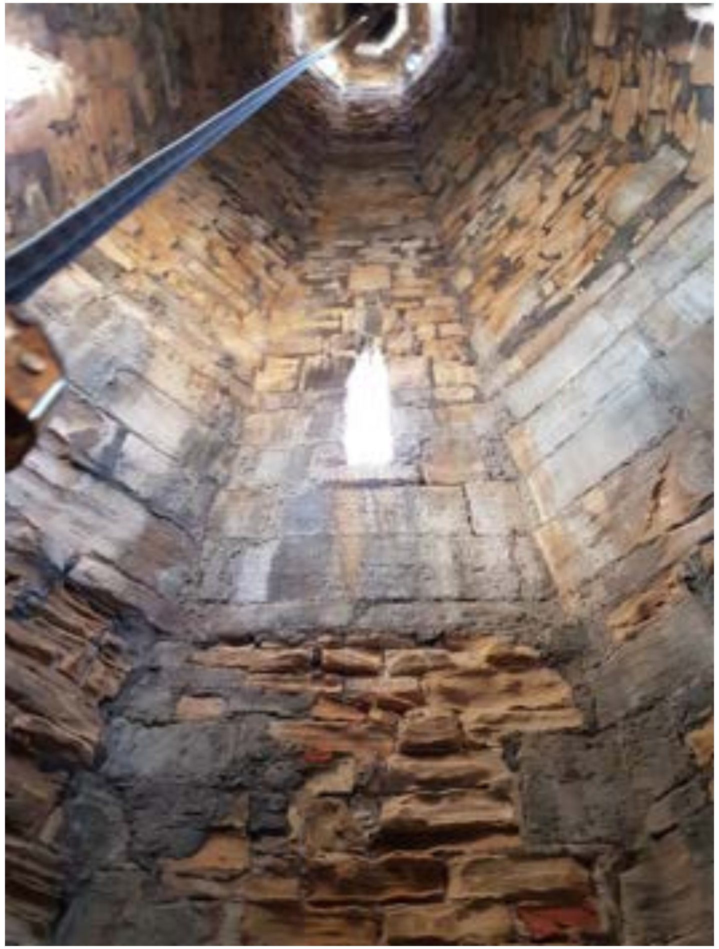
Optimising Mortars for Technical Performance

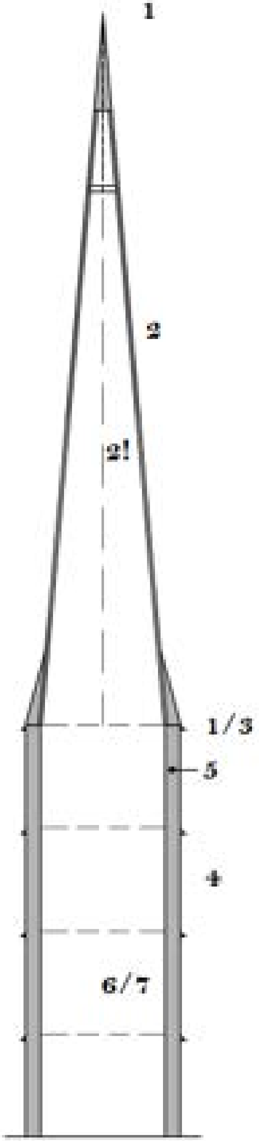
A spire shell typical recipe:

2. SPIRE SHELL

- 0.5 QL
- 1 NHL 3.5
- 2 SHARP SAND (QUARTZ)
- 1 OOLITE / PORTLAND STONE DUST





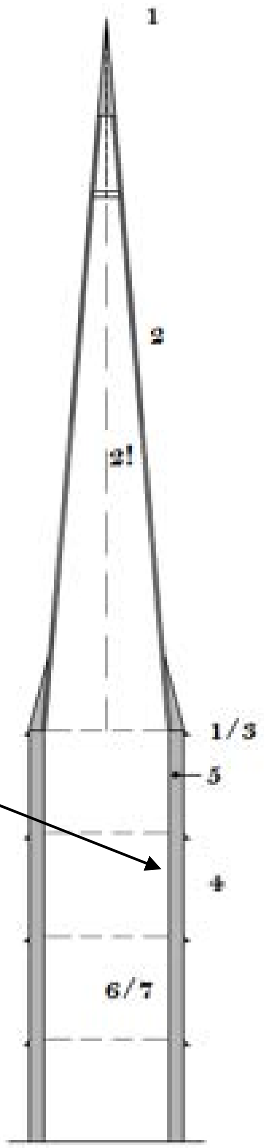


Inside needs as much attention as outside

Optimising Mortars for Technical Performance

Wall sides

(hint: there are 2…)



Optimising Mortars for Technical Performance

So, air limes for wall sides, when the wall is long-term damp and the detailing is pants?

- Desirably, a mortar with the hardening kinetics of 1:2:9, but the capillary-drying / poulticing efficacy of a hot-mixed air lime… Can we have the best of both worlds?

BENNERLEY VIADUCT: Wall tops (waterproof)
- 1 part Vicat Prompt natural cement
- 2 parts Nosterfield grit sand graded 3mm down
- Slate gallets driven into mortar bed and over-pointed

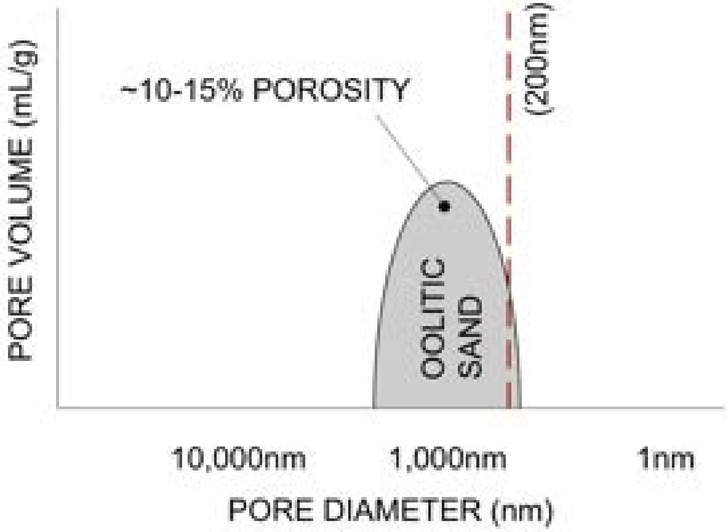
BENNERLEY VIADUCT: Wall sides (absorptive)
- 2/3 Part NHL 5 (St Astier)
- 1/3 Part CL90 quicklime (Calbux powdered)
- 2 parts oolitic limestone sand (Moreton Cullimore 3mm down)
- 1 part sieved coal ash (graded 4mm down to 1mm)

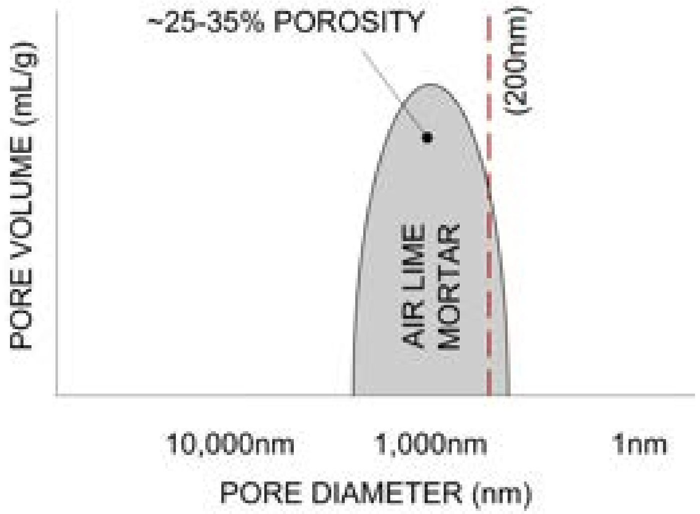
Overall mix proportions slaked lime to aggregate ~1:2.25
Microporous lime aggregate, so more like 1:1 hot mix

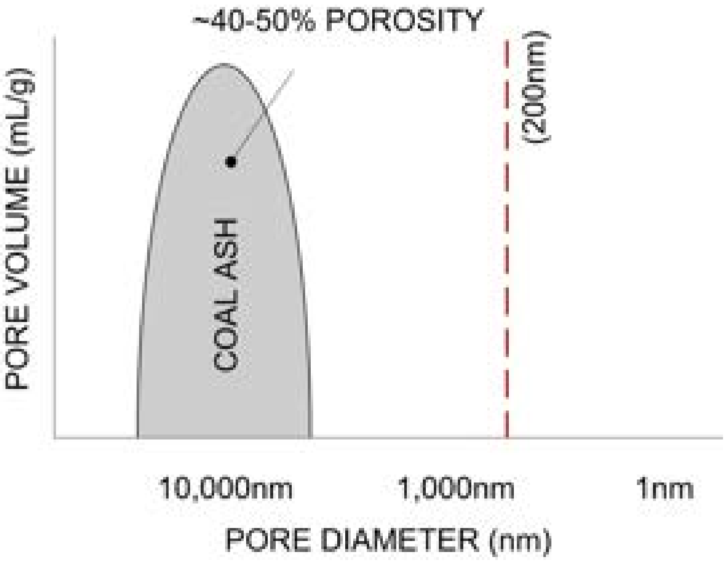
Optimising Mortars for Technical Performance

By hook or by crook…

- Reverse-engineered the microstructure of an absorptive hot-mixed lime mortar with hydraulic gauging
- Microporous limestone sand as an aggregate, to allow us to tone down the amount of quicklime in the mortar to achieve the same overall lime richness
- Macroporous aggregates to accelerate carbonation and build in frost resilience







Optimising Mortars for Technical Performance

Reverse-engineered a sacrificial capillary-drying mortar… Smashed it!

Feeling pretty smug… but it's not a magic bullet

Optimising Mortars for Technical Performance

Evaluation of fine-tuned mortars for damp substrate

CARLISLE CASTLE: wall tops
- 1:2 Prompt mortar to copings & capped thickenings each tier
- Bomb proof.

CARLISLE CASTLE: wall sides
- Gauged hot-mixed mortar with micro- and macro-porous aggregates
- Achieved 5-10x ‘usual’ carbonation rate (up to 10mm a month – really)
- Only after pump phase had run its course
- Not all detailing could be corrected… If cappings don’t drip water OFF a building, they simply move the problem further down

Optimising Mortars for Technical Performance

Broadly speaking, a stonking result.

- Ridiculous programme, scaffold lid removed and dropped November…
- Heavy driven rainfall and double-digit snap frost throughout the winter…
- For most of the work we achieved full or partial carbonation within an extremely tight timeframe
- Keep now drying out and masonry brightening up

Optimising Mortars for Technical Performance

From accelerated decay to sacrificial protection

- Damp, salty substrate
- Covered in extremely hard, dense cement mortar
- Significant decay to masonry units, especially to the inner face where preferential drying front

Optimising Mortars for Technical Performance

BUT.

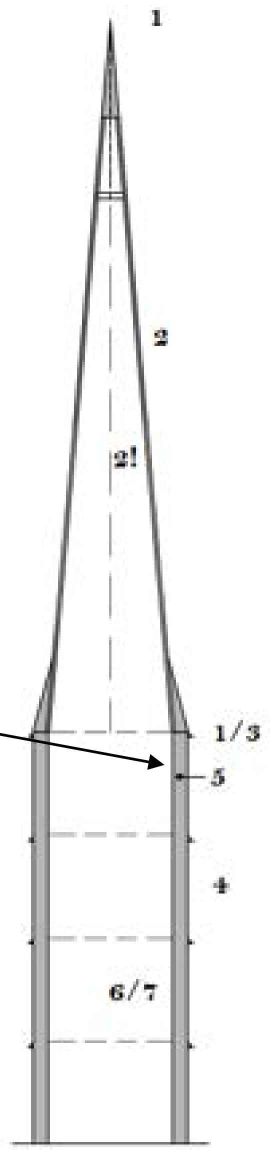
- Even though the prompt shed water beautifully, the absorptive mortar on the wall sides below the CAPPING got a beating
- Same pattern further down at each stepped thickening, CAPPED not COPED
- Copings are only effective if they are throated or sharp enough to drip
- See the immaculate condition under coped wallhead, vs capped with no drip…

It seems we cannot have the cake and eat it too.

Optimising Mortars for Technical Performance

Optimising Mortars for Technical Performance

Grouting voided rubble cores



Optimising Mortars for Technical Performance

Boiling hot lime grout for core consolidation:

- Take a voided rubble core and intimately fill void space (prevent free water percolation)
- Fill with ‘structural blotting paper’ to mop up water
- Reinstate capillary continuity between body of wall and wind outside
- Damp towers research

Typical wiggo special grout mix:

- 1 QL (POWDERED)
- 0.5 PART ARGICAL M1000 OR NHL5
- 1 OOLITIC LIMESTONE SAND OR PORTLAND STONE DUST (0/1)
- 0.5 PART SIEVED COAL ASH (2mm TO DUST)
- HOT WATER (1.5 TO SLAKE, 1.5 TO THIN)
- MAKE HOT, USE HOT, KEEP VIGOROUSLY AGITATED
- GOES THROUGH ALKATHENE TUBING, GURGLES INTO THE WALL INTO EVERY NOOK AND CRANNY

Optimising Mortars for Technical Performance

Boiling hot lime grout:

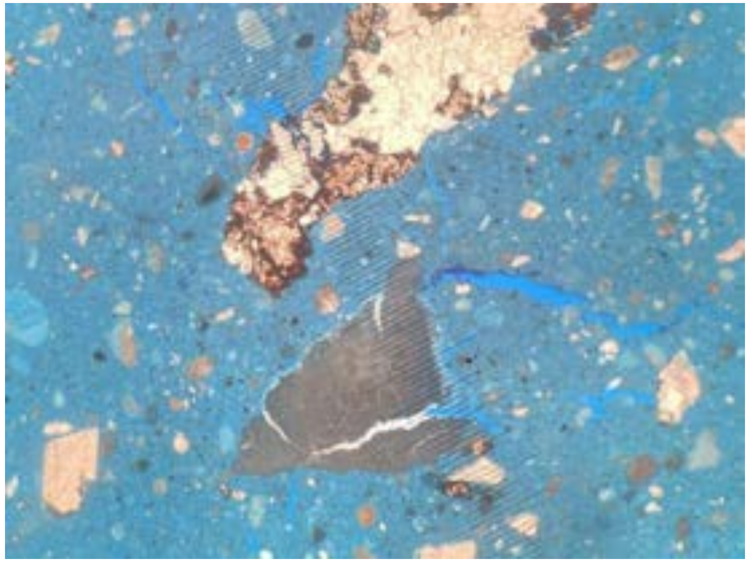
- Super lime-rich
- Flows beautifully
- Irreversible…
- Really effective wick
- Minimises water ingress
- Maximises water egress to depth
- Shrinks less than you think
- Messy
- Fun

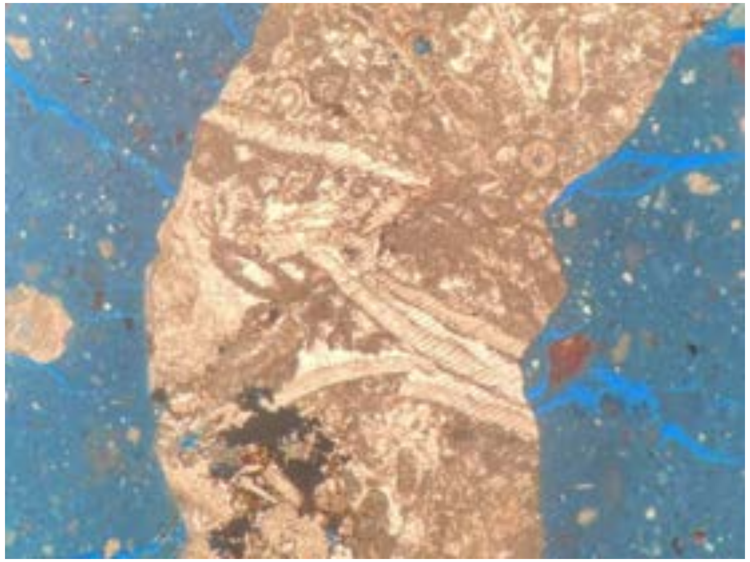
Point Count Data:

Components	Total (%)
Quartz	3
Lithic fragments (carbonate rock)	32
Lime inclusions	3
Opaque fragments	5
Other	3
Total aggregate	**46.0**
Lime Binder	50.5
Alite	0
Belite	1.5
Lime inclusions	2
Total Binder	**54.0**
Total	100
Cracks and voids	8.0
Porosity (visual)	>15%

Results of modal analysis on the sample received.

The mix proportions (by volume) are 1 part binder to 0.85 parts aggregate.





Optimising Mortars for Technical Performance

1. **Intercept ALL vertical rainfall.**
- Temporary and permanent works conditions
- Copings, string courses, hood moulds - check function
- Enhance detail if inherently deficient
- Wall tops… forget air lime – use cement

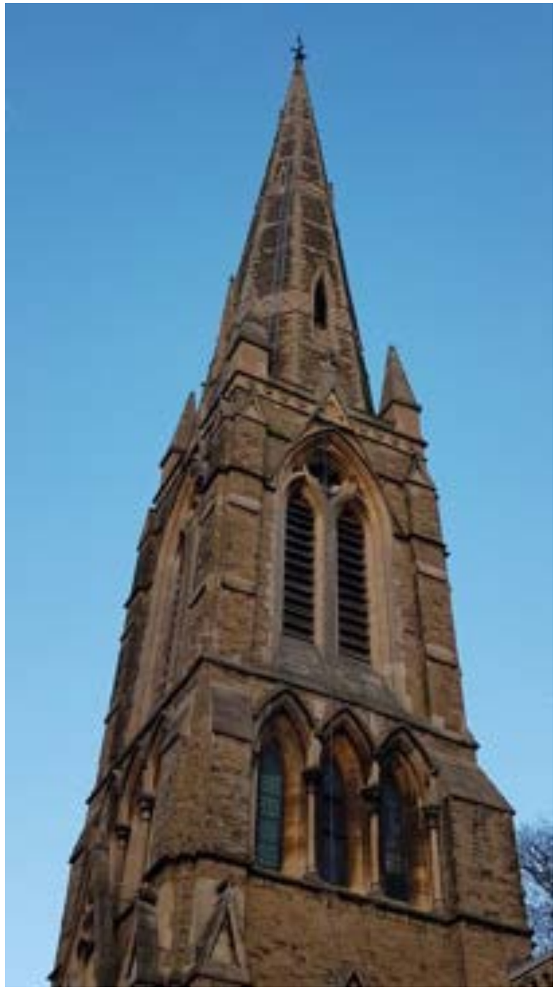
2. **Recognise pre-existing water content of substrate.**
- Turn the tap off, then let the bath drain down
- Build time into programme to dry out
- Remember lime mortar is a poultice… it's the last thing to dry!

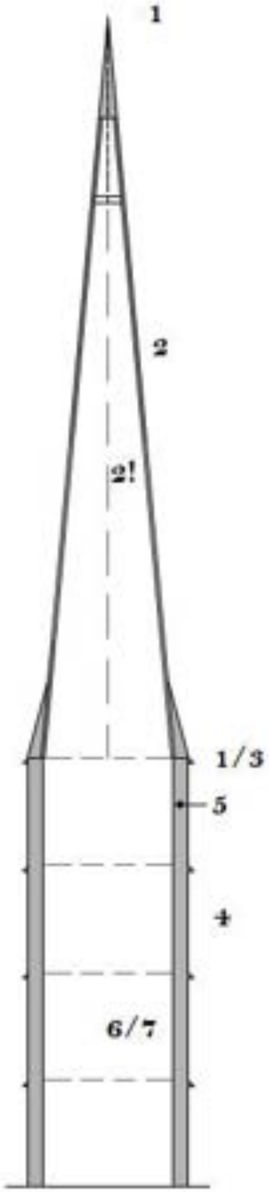
3. **Consider optimising mortar for carbonation & capillary drying.**
- Microporous aggregates accelerate carbonation but only *after* the substrate water has been sooked out

4. **Be honest with context… will an air lime ever work if context remains long term damp/saturated?**
- Opportunity to tone down free lime while maximising capillary drying (reverse-engineering a mortar… a bespoke business!)

Optimising Mortars for Technical Performance

Typical mortar recipes for church towers:





MORTAR MIXES BY CONTEXT

1. WALL TOPS (FLAUNCHING) A
- 1 PROMPT NATURAL CEMENT
- 2 GRIT SAND (QUARTZ)

2. SPIRE SHELL
- 0.5 QL
- 1 NHL 3.5
- 2 SHARP SAND (QUARTZ)
- 1 OOLITE / PORTLAND STONE DUST

3. DRIP DETAILING B ("1:1:6")
- 1 WHITE CEMENT (CEM I)
- 1 LIME HYDRATE (CL90)

6 GRIT SAND (QUARTZ)

4. WALL SIDES: AIR
- 1 QL
- 2 GRIT SAND (QUARTZ)
- 1 PORTLAND STONE DUST

WALL SIDES: FEEBLE
- 1 QL
- 0.25 NHL 5
- 2 GRIT SAND (QUARTZ)
- 0.5 PORTLAND STONE DUST
- 1 SIEVED COAL ASH (+-1mm)
- 0.5 GRITTY CRUSHED BRICK

WALL SIDES: MODERATE
- 1 QL
- 1 NHL5
- 3 GRIT SAND (QUARTZ)
- 2 PORTLAND STONE DUST

WALL SIDES: EMINENT ("1:2:8")
- 0.5 QL
- 0.5 PROMPT NATURAL CEMENT
- 3 OOLITIC LIMESTONE SAND OR PORTLAND STONE DUST
- 1 SIEVED COAL ASH (+-1mm)

5. GROUT
- 1 QL (POWDERED)
- 0.5 PART ARGICAL M1000 OR NHL5
- 1 OOLITIC LIMESTONE SAND OR PORTLAND STONE DUST (1mm DOWN)
- 0.5 PART SIEVED COAL ASH (2mm TO DUST)
- HOT WATER (1.5 TO SLAKE, 1.5 TO THIN)
- MAKE HOT, USE HOT, KEEP VIGOROUSLY AGITATED

6. PLASTER
- 1 QL (POWDERED)
- 2 FINE AGGREGATE (CONSIDER STONE DUST)
- PLENTY OF HAIR. MAKE HOT, USE HOT

7. LIMEWASH
- QUICKLIME AND WATER (1-1.5 TO SLAKE, 1.5-2.0 TO THIN)
- MAKE HOT, USE HOT - KEEP VIGOROUSLY AGITATED

Summary

Overview:

I. **Diagnosing Damp Towers**

II. **Hardening Kinetics of Traditional Mortars**

III. **Optimising Mortars for Technical Performance**

Questions

THE DIOCESE OF BLACKBURN

THE CHURCH OF ENGLAND IN LANCASHIRE

Homework

- Hot Mixed Lime and Traditional Mortars (Nigel Copsey)
- PBC: Building Environment (Curtis & Pender - HE)
- Ins and Outs of Weathering to Walls (Building Conservation Directory)
- BS 5390:1976 COP for Stone Masonry
- How Traditional Lime Coatings Work (Building Limes Forum)
- Baker Memorial Lecture 2020 (https://clach-conservation.co.uk/lime-training-%2F-r%26d)

Questions…?

www.clach-conservation.co.uk

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