ENGLISH HERITAGE

DAMP TOWERS CONFERENCE

18TH APRIL 2013

THE ROUGEMONT HOTEL, EXETER, DEVON

PROGRAMME

WELCOME

Dr. Edward Impey, Director of Heritage Protection and Planning, English Heritage

Morning everybody, my name is Edward Impey and I rejoice in the job title with English Heritage as Head of Heritage Protection and Planning.

Damp Towers! I think Chris must have had the branding consultants in for that one – that really is a corker. But obviously it's worked and I gather that the conference is at least twice over subscribed, so that's fantastic.

Welcome to everybody who is here on behalf of English Heritage and the myriads of other people that contributed to this amazing piece of work.

Why do the towers matter? Obviously towers are prominent both visually in the landscape – the most prominent type of historic monument you can think of and that's their intention, especially down here in the West Country. Builders of towers from the middle ages vied with each other to have the most ornate and the tallest tower that they could build. We are here today also because they are the most problematic and that's nothing new. Those of you, who have an interest in medieval architectural history, will know that towers had a habit of falling down and that was a kind of constant leitmotif in medieval building, but of course since then we've had conservation. I know that most conservation work is undoing the work of the previous generation of conservators and I gather that's not entirely untrue in the context of repairs done to church towers in the 1980's and how we deal with problems that those repairs have actually caused.

So today we are dealing with a huge and important issue and are at a kind of threshold of getting to grips with it through the work of this research project.

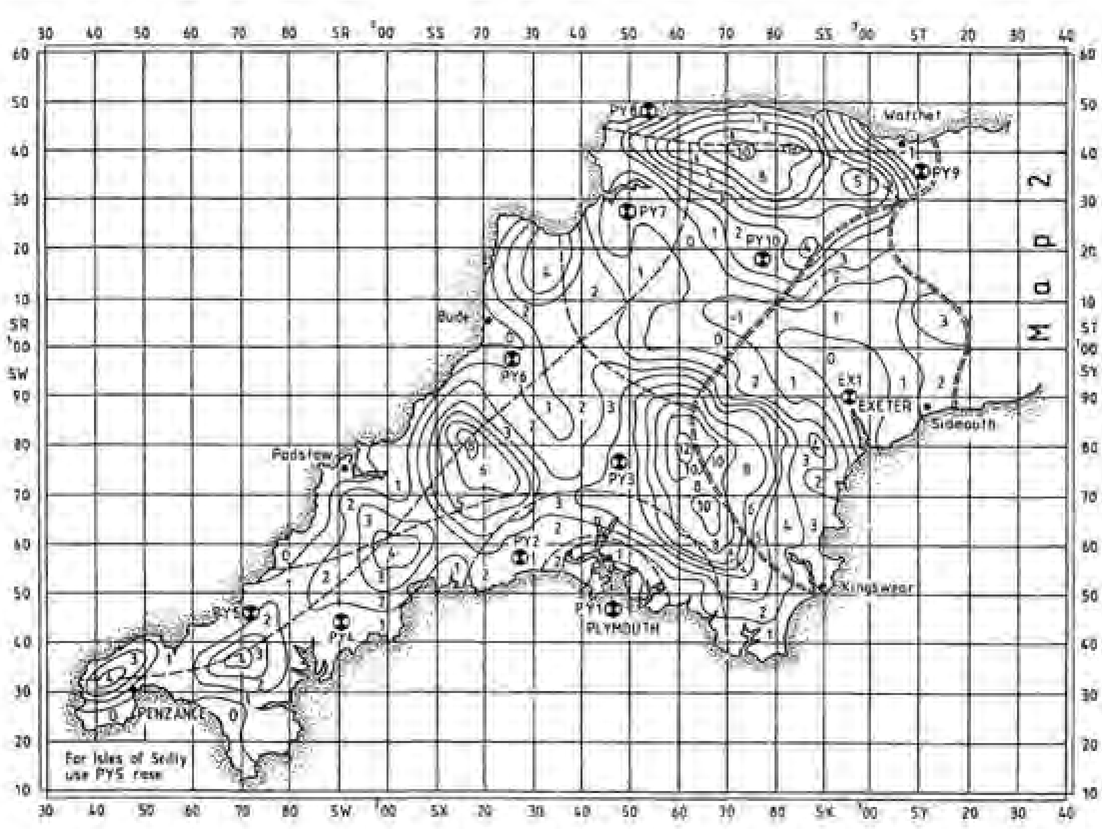
INTRODUCTION AND OVERVIEW OF THE DAMP TOWERS RESEARCH PROJECT

Chris Wood, Head of Building Conservation and Research Team, English Heritage

Good morning everybody and I'd like to add my welcome and particularly thank many of you in this room who have been so helpful to us in our project, both in terms of giving us access to the churches, and providing information, but also in some cases actually carrying out the monitoring for us. We are very grateful to you for that.

The aim for today is to tell you what we found out in our project and to discuss the issues. We're particularly interested to get your feedback. Two reasons: firstly we are intending to produce some guidance information later this year and secondly we are contemplating carrying on doing some more research in the future, so your views on this are particularly interesting to us.

We tried to divide the day basically into 2 parts, concentrating on the problems this morning and this afternoon we are going to look at more positive aspects by looking at some solutions. This introductory talk is simply me telling you what we did and why we did it. I'm going to start with some background to the research.

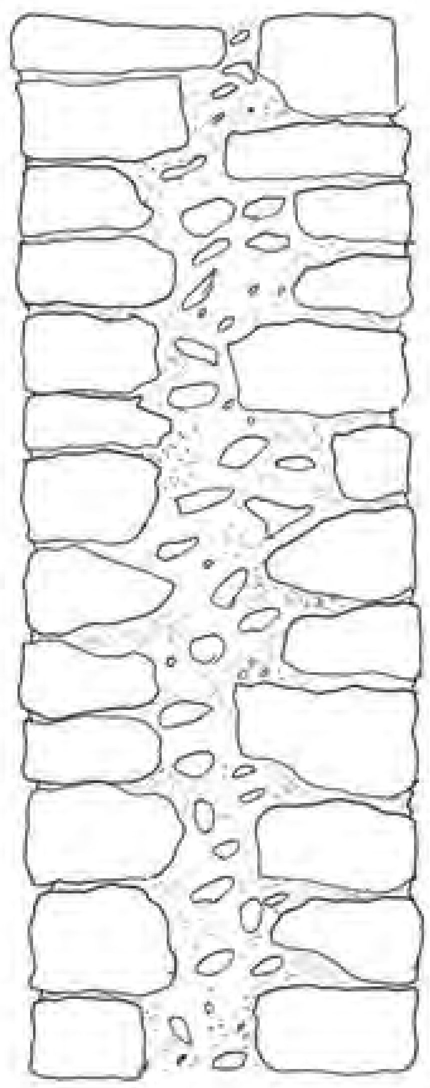


This map is taken from the BS 8104 British Standard code of Practice for assessing exposure of walls to wind driven rain. The highs are the contours at the top of the moors of Dartmoor, Exmoor and Bodmin. They are quite complex in the way they work these things out, it's changed a lot since that diagram but of course it's important to remember that in the South West there's an annual average rainfall of about 90 inches while the rest of England is about 36.

I want to start with some definitions; the Damp Towers project – actually, its real name is 'Understanding and Controlling the Movement of Moisture through Solid Masonry Walls caused by driving rain' – so you can see why we call it Damp Towers.

It obviously has a wider application than church towers. If you see the initials WDR that's the technical and academic name for driving rain (Wind Driven Rain).

Most of the walls we are dealing with are composite walls which you'll see in the diagram are basically two skins of stone and a rubble core. The quality of these varied. Some were built very well, some were built very poorly, and we think some were voided from the time they were probably first built. It's the core that holds the key to the problem.



When talking about appropriate repair it's important to remember that not only are these places of worship but also the majority of buildings you'll see are Grade-I listed and are therefore our most important and warrant the highest standards of conservation.

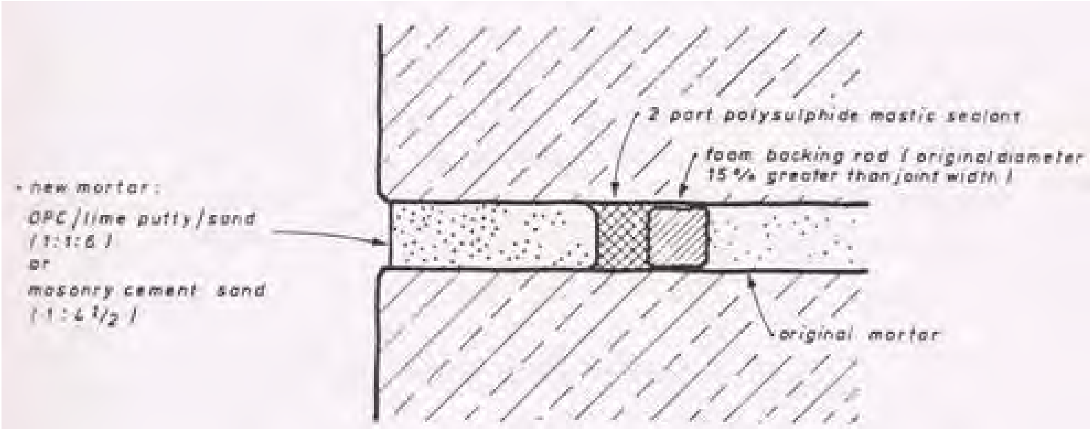
We've concentrated on these repairs – on pointing, rendering and plastering with limes because coincidentally this work has gone on at the same time as much of the lime revival.

We've also included grouting, which obviously is not a traditional repair because it probably came into existence in about the late 18th century, but it is extremely useful for void filling. It was used throughout the 19th and 20th mainly with cements, but of course we've been trying it in the last decade or so with lime.

We're not going to be talking about alternatives that have been suggested to us by lots of people. The most obvious one in the South West of course would be slate hanging, which is a good traditional method of weathering. Tree screening can be beneficial. Internal drainage, that's basically a gutter around the ringing chamber of a church. We looked at those, but not in too much depth. Neither did we consider water repellents, but if anybody wants to talk about those in questions, we will.

Very little research had looked at the problems of driving rain affecting historic structures. One of the very few I think was published was in 1982 and featured the work done at Castle Drogo by the architect Anthony Hollow with John Ashurst. Castle Drogo is a Grade 1 listed building, which has leaked from the day it was built. It occupies a hilltop on a very prominent part of Dartmoor. It was built with solid walls without any weatherings on the façades, no down pipes and a flat roof. In fairness to the architect, Lutyens, he intended to build it with a cavity wall but of course his client didn't want his medieval castle built with a cavity wall, so basically there is a solid wall with vertical damp proof course.

So their solution was to try, on one of the exposed sides, this detail here.



Essentially they cut out the cement joints, put in a foam backing rod at the back of the joint, introduced a two part polysulfide mastic sealant using a mastic gun, put an adhesive along the sides of the joint and re-pointed in a 1:1:6 mix, which was recommended at that time. I'm told for a while it was very successful.

The next bit of work we are aware of was carried out by a colleague in the Building Conservation and Research Team (as it is now called), Iain McCaig in 1988. He produced a report 'Rain Penetration in West Country Church Towers' that looked at seven Devon Churches all suffering from driving rain. Most of the churches had been subject to repairs, but there were complaints that they were now wetter after the work than they were before. His visit followed a couple days of heavy rains.

I'll show you some examples.

This is St. Peters, Ugborough, South Devon.

This is a very tall exposed tower, two metre (at the base) thick granite rubble walls. It had been re-pointed in cement a couple of years earlier. The cement pointing was pretty shallow; some bits had started dropping out. There was a lot of water coming out through the external façade and significant lime bloom inside indicating that the water washing through the core had washed the lime through and then hardened on the internal surface.

This is St. Mary's, Rattery. This had been given a rough cast render and was still leaking.

Bratton Clovelly, on the west side of Devon, again similar problem: granite rubble, cement pointing, water escaping on the outside and inside the ringing chamber.

There's an internal drainage gutter put in there and that was the only bit that was dry!

This is St. Werburgh's, Wembury, right on the south Devon coast, hence the cement render on the south elevation. It had been re-pointed in a purpose made mix in a "thoro' dry-joint" about three or four years earlier. This exhibited similar problems, with water getting in.

Lastly, St. Andrews, Whitchurch, near Tavistock, on the western side of Dartmoor, high up on a hill, very exposed, with similar problems to the others. Cement pointing which had started to crack, allowing water to get in on the inside.

Drainage channels were put in on the outside right up to the middle of the core. As you can see there's water coming out everywhere except of course from the drainage channels. The report concluded that these structures were built with impermeable stones and suffer from very high levels of exposure. This means that all the work in terms of dealing with moisture is done by the joints. Joints invariably crack and the problem is made worse, seemingly by shallow pointing using impermeable materials.

Drainage tubes have not proved very successful.

Internal gutters – again not successful.

Potential solutions recommended in the report include:

- point properly i.e. cut out and re-point at least twice the depth (being twice the width), using deep tamping
- grout
- render
- carry out internal improvements i.e. the removal of cement based mortars and replace it with lime
- improve the ventilation.

Now that was all good stuff, but it was all based on just visual observation with no sort of empirical tests. As a result of those advisory requests which essentially came from colleagues based in the English Heritage local offices (formerly known as regional offices). These gave us the opportunity to develop more information and learn about the problems and we began to target cases that we could monitor.

I'm just going to talk about one typical advisory case here because I'm going to deal with case studies in the next talk.

This is a tower in east Sussex. It's medieval in origin. It originally sat on the coast line and is now used as a museum. It had been extensively re-pointed and various other repairs carried out and 18 months later it had extensive mould and various other deposits inside. There are beams which are now ridden with death watch beetle. Essentially the problem was that a lot of moisture was getting in. Why? It's not easy to see from just looking at the façade. The weatherings have been improved, but there are no cracks or holes in the pointing. The contractor had probably used the correct mix but nevertheless, it had not worked. And this is actually one of the hardest things: determining where and how the water is getting in. Many of these towers don't look from the outside to be in too bad a condition.

The research project started in 1996. We started off by posing a few obvious questions:

- How does driving rain enter solid masonry?
- How does it move? And how does vapour move within and is it important?
- How can they be reliably measured?
- What are the differences in performance between the remedial treatments we have been talking about?
- What is the best design specification for each?
- What is the most effective at preventing moisture in these and if we can't prevent it, what is most effective at minimising wetting and maximising drying.
- To what extent is poor workmanship and specification responsible for failures?

Obviously as the project developed, more questions arose, but those are the basic ones we started with.

Throughout the project we were looking at what else had been written and done by others because we didn't want to re-invent the wheel. I have to say that I've spent a lot of time reading scientific literature and not a lot of it is much use to us. More interesting I think are some of the historical records, but again it's not easy to actually discern what had been happening in the individual churches. It's certainly very difficult to find out what repairs had gone on in previous decades – very difficult to find that information, particularly say, if the architect hasn't been there very long.

Other historical studies we looked at were weather patterns, because don't forget that when some of these towers were built we had a semi Mediterranean climate. And through the centuries the climate has been quite varied. I think the most interesting was the 18th when we had a mini ice age and that of course was when we had the Great Storm of November 1703. It was recorded by Defoe, with lots of anecdotes about what happened. It wasn't just one night – although on one night 8,000 people lost their lives and a third of the ships sunk – but it was the culmination of a whole week of almost hurricane winds and rain. There's lots of anecdotes as to what happened – twenty tons of lead were lifted from a roof and flung hundreds of yards away. It's phenomenal reading, but no specific information on what happened to our towers.

There's been a lot of driving rain studies in the Low Countries, but again this isn't terribly helpful to us because it's concentrated on cavity wall type construction and also its effect on individual blocks and bricks. There is very little done on joints which is really what we're interested in. It's also quite difficult to study these things because architectural details make a huge amount of difference to the amount of wind pressure. Someone also did research on the size of raindrops which can make a significant difference to water take up; as can the rain meters you use to collect the rain, so it's all quite complex and the results are somewhat disappointing.

We know that liquid water enters and flows easily through permeable material, whereas the flow of vapour would be extremely slow. It certainly moves when there is gravity involved – in other words it flows downwards. Rain falling onto the surface of a dry permeable material will be absorbed in the surface pores and then evaporate again as the conditions change. It can get in, though, if enough collects to percolate in, perhaps through the cracks, or run down a surface until it meets a fine crack through which it will be drawn by capillary action. If the core of the tower has voids and hollows in which any of this liquid water entering can pool, the materials around it will begin to wet: and wet materials will draw in more water. If a wall is wet, rain hitting the surface will be absorbed into it instead of stopping at the surface pores.

It is much easier to wet a material than it is to dry it again. Drying requires evaporation, and the main driver for that is air movement. This will pull out liquid moisture, but it will have little or no effect on water vapour, so to dry effectively you need a chain of pores connected to the surface and holding liquid water; the moment that chain of water is broken, and moisture must move through the pores in vapour form, drying effectively stops. Plus, of course, there are many forces pulling moisture into the pores and keeping it there. The upshot is that more water gets in than gets out again, so over time your tower will get wetter. And indeed, most of them, in England, are wet and never get dry.

There is some useful information emanating from some of the research we've looked at. For example the horizontal penetration of water in compact walls with driving rain is due to a combination of wind pressure and capillarity at the surface of the wall. Wind actually can only be blamed for bringing rain into contact with the wall and it is the surfaces' own properties that are the principle factors allowing water penetration.

Basically it's the capillary draw i.e. the suction which is more important. However you can't always see that narrow capillary in a joint – you can see a hole but the only way you're going to get water down a hole is obviously by wind pressure, which actually, believe it or not, comes second to the pressure exerted by capillary draw.

Another theory we wanted to test was whether driving rain ever passes through a well constructed wall. Moisture history is critical. The higher the initial moisture content, the more rapidly it absorbs and the faster it will move. Basically if you have water in a tower and it was already sitting there, the likelihood is that it will conduct through to the other side much more quickly.

And the last theory we wanted to explore was that badly prepared joints absorb 12 times the amount of water as good ones.

Because of a lack of relevant testing to date, we designed our own laboratory tests, carried out at Sheffield Hallam University, which Liz is going to tell you all about. To briefly summarise: the first one was a pilot test to see how effective they were. We wanted data on the impact of driving rain through mortars and the differences in their performance.

We used single skin granite walls as you can see there.

To get more realistic results we built core walls with two skins. They each weighed about half a ton and by building them on weighing balances, we could weigh moisture loss and gain.

You can see on there we have different renders and internal plasters.

We are very interested in grouting as a remedial solution. We used to hold courses down at our training centre in Fort Brockhurst and we had these ruinettes to work on. The great advantage was we were able to take the face down and see how effective the grout was.

We held a seminar to which we invited all the manufacturers along. Nothing was said during most of the day which we thought was them trying not to divulge trade secrets, but it turned out they all admitted in the end that none of them had ever seen their product in a wall. They'd never been sued so they never had to take the face down to look at them. So there was a huge lacuna of information on grouting.

During the second phase of research at Sheffield Hallam, we looked very closely at grouting.

There you see our conductivity test in which Liz put some dye in to the last runs of driving rain, so when we took the walls down we could see how the water tracked through the wall.

Pointing is obviously very important facet as well because most PCC's didn't want their tower rendered, they still wanted them re-pointed. So we, in conjunction with the Oxford University Centre for the Environment (OUCE) carried out a series of tests to see if we could come up with a pointing mortar that wetted fairly slowly, but dried very quickly. Heather will talk more about this in her presentation. We took a range of historic mortars and we also used mortars that are being more commonly used today, with a few variants, we carried out a series of tests which we will explain later and compared the results of those from Sheffield.

The last bit of testing, carried out by Colin Burns at the Oxford Field centre, was to form mortar joints using the same materials as the tests. One was the exemplar, three incorporated the common faults we often see and these were measured with sensors at the back to see how they resisted rain penetration.

In our final bit of work, last November, we revisited Iain's seven Devon Churches to see how they've got on 25 years later.

At St. Werburgh's, Wembury, which is on the south Devon coast, a conservator had been in a couple years earlier and re-pointed on the west side and also repaired some failures in the render. That now appeared to be dry.

St. Peter's, Ugborough still shows signs of internal ingress, but it was no longer running like it was. I'm not sure if that's because more mortar has dropped out and therefore more escaped from the outside.

A similar position at Whitchurch: again we can see water still escaping, but as far as the church wall is concerned this isn't a major problem.

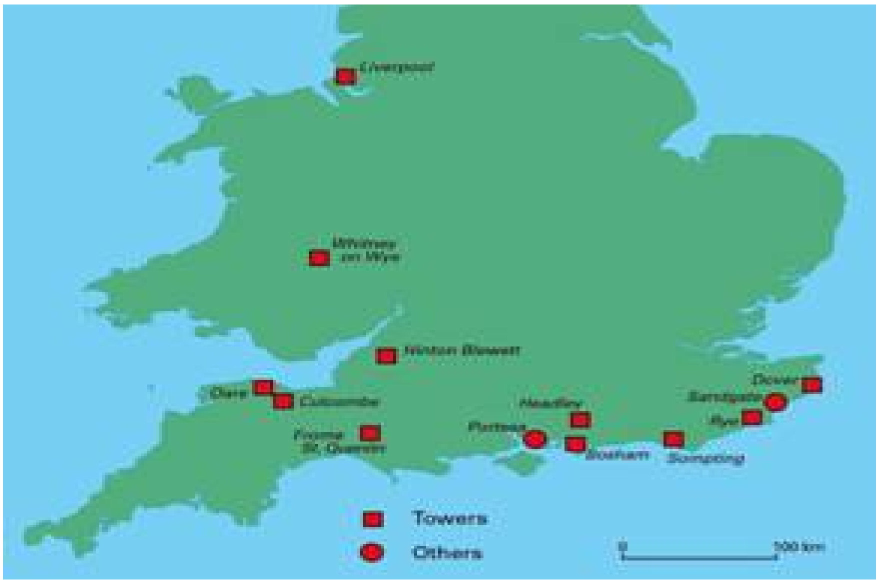
All Saints, Clovelly, on the north Devon coast which I didn't show you, and I'm afraid it seems to be worse than ever and they're still resorting to the buckets.

Thank you. I'll leave it there.

CASE STUDIES OF DAMP TOWERS

Chris Wood

I've already mentioned that we had a lot of advisory requests from colleagues out in the local English Heritage offices. We looked at well over 50 buildings. The map doesn't show them all, but we looked at a lot more in Cornwall.



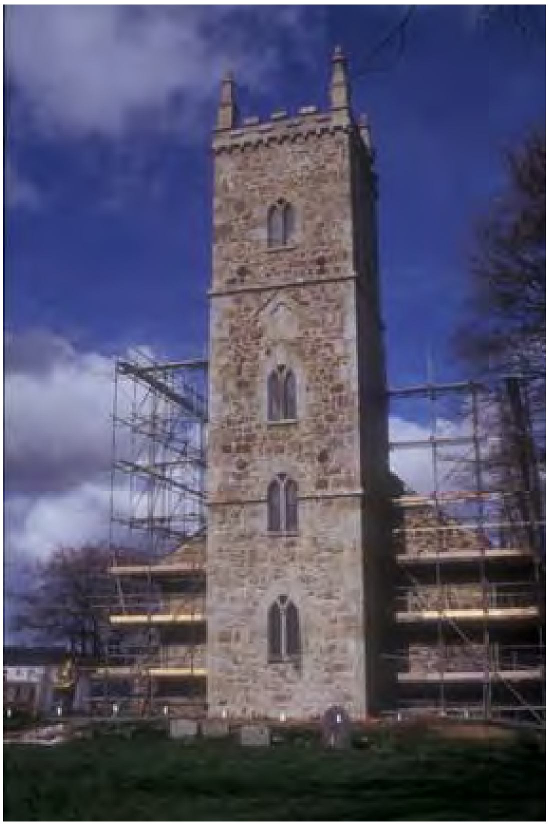
We concentrated very much on towers that we were able to monitor and I have divided this talk into three elements: looking at pointing, rendering and grouting.

Before I go in to detail, I just have to emphasise one point – although all these towers are very similar because they are built with impermeable stones and generally built with composite walls and they all suffer from driving rain, there are significant differences between all of them. For example, stone work – you've got ashlar work here, you've got a lot of rubble, you've got very thin slate material here and in some of these elevations you have what appears to be more mortar than you have stone. Joint widths, as a result vary considerably.

They also very in terms of weathering, both by design and in terms of the way they've been maintained. You've got other factors such as height, altitude, aspect. So, in other words, although there are lots of similarities in terms of the way they perform, every single tower is unique.

I'm going to start with some pointing case studies first.

This is St. Michaels Princetown – I suppose in some ways our most spectacular example. For those of you who know Princetown, that's Dartmoor prison.



Once you've visited Princetown, you'll understand exactly why they sited a prison there. Its 420 metres above sea level, it suffers a 120 inches of rain per year and most of that comes in sideways. The tower was built in the early 19th century by French prisoners of war, so not the most motivated of work forces. Cornish masons, apparently, did the dressings – it obviously wasn't built terribly well because substantial ties were incorporated in the 19th century. It was taken over by the Churches Conservation Trust in 1991 and a survey by the architect described it as "dank, dismal and very green".

That's Princetown on a warm summer's day – it was very challenging for the poor contractor who had to work there – it's bad enough for us just going for a site visit. Now the problems. These pictures are taken from old photographs and slides, because that's the vintage we were in. Essentially we've got a lot of cement pointing which was cracked. There are ferns growing inside. There's no plaster inside. The work was to re-point, carry out selective grouting, to put on a new lead roof and essentially tie the tower together. That work started in 2000. We came to visit after it was completed so we didn't see the works in progress. We were asked because it was still damp, in fact damper than when it started.

When we arrived they were working on grouting the walls. This is the south wall and that's a Devon mason with his arm into the wall which gives you some idea of the extent of the voiding. During the work, the weather was dreadful – either frost and snow or heavy rain. That guy, a very experienced Devon mason, I believe emigrated to France at the end of the year.

We've got water coming through straight away, escaping on the inside. The original intention was to use an hydraulic material (NHL5) and a very gritty aggregate, and grout with a fairly cementitious mix. At the time it was justified on the basis because the weather was not good (it was far from ideal time to be doing this sort of work), it was a very tough stone (they had to rebuild quite a bit). It was a substantial job carried out in very adverse conditions.

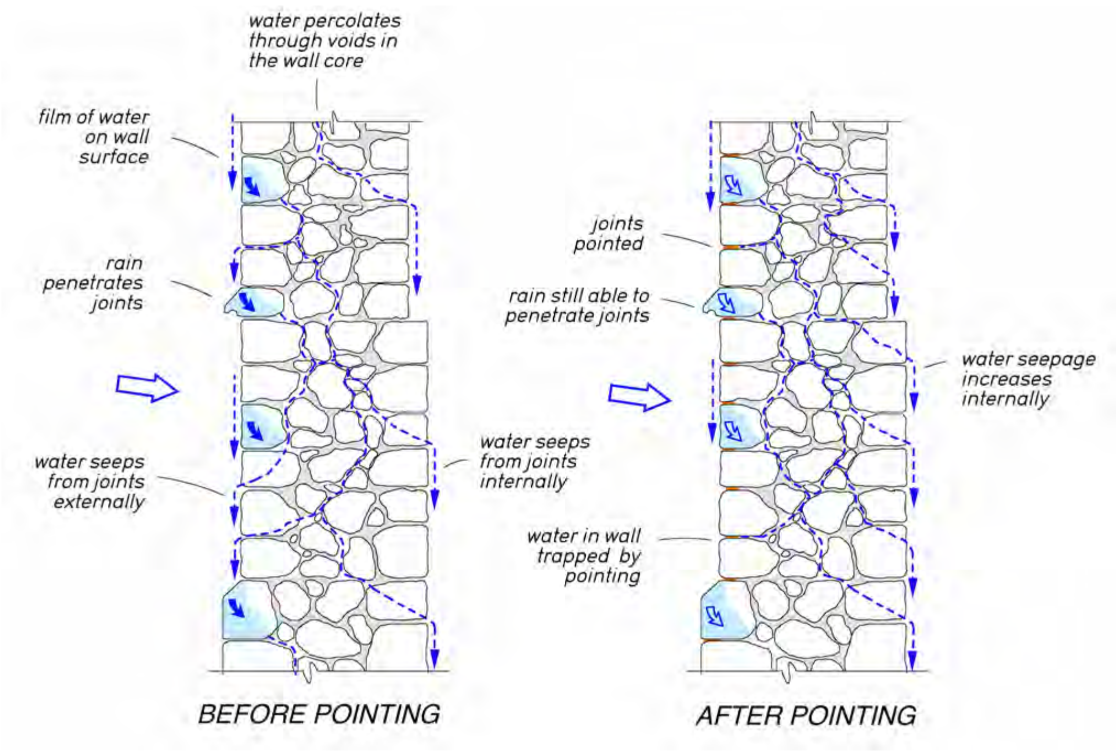
There was a question about the quality of the granite; a suggestion that there was more than one type (there were certainly five different colours) and that some of this was actually porous. Our consultant geologist, David Jefferson, did a permeability test and he took samples to confirm that there were three types. He confirmed they probably came from the prison's own quarry. All of them passed the permeability test, in other words, no water got through. He compared it with the most robust Bath stone used for the pinnacles and coping. Water went through that, so there was basically nothing wrong with the stone, so presumably it was something to do with the mortar or workmanship.

This is what it's like in November of last year – it looks like we've got neat penicillin growing up on this wall. It is a really grim state and most unfortunate. When you look on the outside there is very little evidence of bad workmanship or problems – there's no cracks in any of this pointing. We can see moss beginning to accumulate, which may mean we are getting excess moisture between the joint and stone. On the other hand it's simply that we've got a horizontal ledge that moss will sit on and it's bound to be wet. And the solution? Well, we haven't been asked fortunately, but clearly one would have to carry out some careful investigation of the core to try and discern what has actually been going on.

We move down to the north coast of Cornwall. This is St. Senara, Zennor – a very attractive tower on the north Cornish coast, subject to driving rain from three sides. This had been re-pointed with fat lime pointing with a pozzolan.

We thought the work was carried out well, but the church was still very wet inside. We had a look at the joints. One or two of the fairly shallow ones had clearly dropped out, but generally speaking the work was done quite well. The problem seemed to emanate from the stones themselves. They weren't cut 6 sides square, which meant they touched a few millimetres from the surface, resulting in only small amounts of mortar being accommodated.

When you get driving rain down there of days in duration, it can go through a few millimetres in not much time. What we think is happening here is that water is coming in, it goes into the core, some of it goes inside, some of it escapes through the cracks and missing joints on the outside. As soon as you block those with good pointing those escape routes are lost and you get all the water now being transferred internally. Now we've seen this on so many occasions where workmanship seems to have made it worse than it was before. We are reasonably confident, that that is actually what is happening.



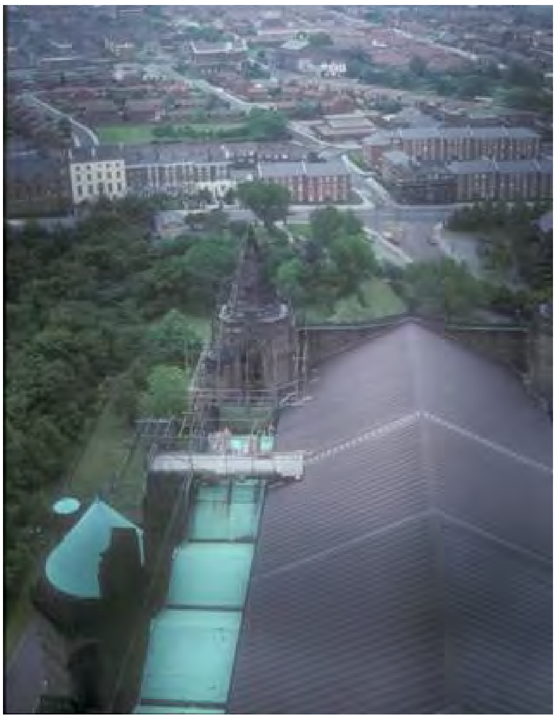
I don't want to give you the impression that every pointing job we looked at failed.

This is All Hallows, Woolfardisworthy.

You can see the lime bloom here where the rain was washing through the joints.

It was described as running internally. The works involved re-pointing, re-doing the roof and internal plaster work. Three months of moisture monitoring was carried out before anything started and this was continued throughout the work programme. The scaffolding was put up, shrouded in monoflex, to help the tower dry down. Unfortunately, such is the wind there that it had to be changed twice and the scaffold collapsed, damaging one of the pinnacles. After the work was carried out it was still really saturated because the work was done in winter. An hydraulic lime mix used to re-point. The tower was dried and the churchwarden didn't report any untoward dampness. It was monitored, though, for 15 months between 2006/7 and the readings were about 20–25%, but after the month of May when there was a lot of driving rain, it shot up to 150%. Much of it through the south turret – the staircase – where there is much thinner masonry – basically it wasn't able to resist the onslaught of the driving rain so obviously liquid water in there. We visited that last year, a decade later and clearly the pointing was successful.

In 1997 we were asked to provide some training at Liverpool Anglican Cathedral. The local team were having difficulties replicating the original pointing, but we wanted to try one of the, at the time, newfangled hydraulic limes to see if we could make it work. It was obviously a hostile environment. We were working up here, on this pinnacle, 250 feet up, from which you overlook the Irish Sea.



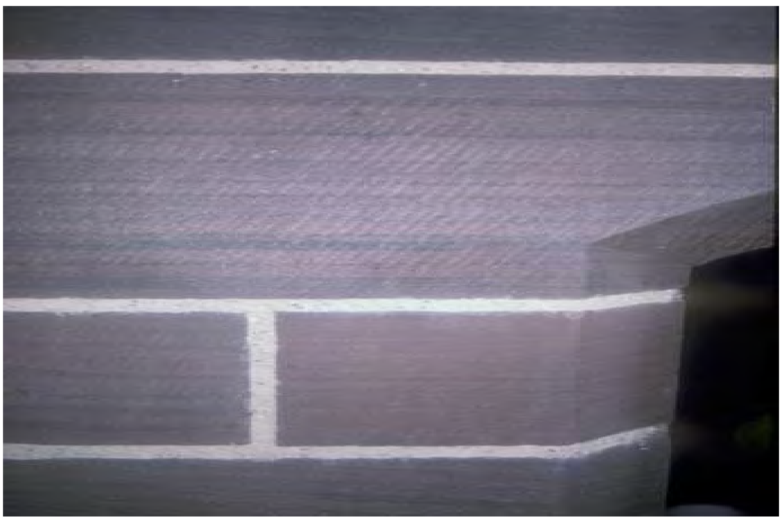
The great thing about working on 20th century buildings, you often got some evidence of how they were built and what they were built from and this was very carefully built with ash mortars.

The other lovely thing to look at on these pictures is the slightly more relaxed attitude to health and safety. That was the finished joint. They used a 1:2:9 originally or something like that. These have dropped out.

This was the mason's attempts at re-pointing – not altogether successful.

Colin's going to show you some slides this afternoon to show the extent of the damage that was caused.

We weren't able to do everything we wanted. We obviously protected the work, but we weren't able to do the finishing you'd normally expect, we had to leave it and then go away. Two years later we went to have a look and it's still as good as the day it was done.



Back to Castle Drogo. The architects together with the team at National Trust have been doing a huge amount of work trying to at last get on top of this problem and great progress is being made. One of the things that was commissioned was a series of trials. There were 5 different hydraulic lime mixes and one cementitious mix.

Timber dowels were inserted with sensors screwed in which went to the data logger on the roof, which sat alongside the weather station and that information was downloaded continuously for 15 months. The result was that the hydraulic limes all dried out well and were a lot dryer at the end of the year's monitoring. The cement stayed wet the whole time. The trials were carried out on the west elevation. They also tested to see if there was any cracking or movement in the joints as well.

The main conclusions from the pointing case studies:

- re-pointing alone is not sufficient to stop water entering from driving rain
- it's usually vital to ensure that voids in the core are identified and filled
- failures in new pointing mortars are usually due to inadequate specifications and workmanship, materials, protection or having to work at the wrong time of year.

This is Holy Trinity, Challacombe, north Devon. It's very exposed, because it's on the edge of Exmoor.

We monitored this for a year before any work started. Then it was shrouded in scaffold and monoflex and allowed to dry down for 15 months. Invasive investigations were carried out to see the state of the core and it was found to be in a very poor condition. It was an earth mortar and it didn't look promising at all.

Monitoring revealed that the whole place was saturated bar one part of the east wall.

There's the completed work. The work was carried out in the Somerset feebly hydraulic lime with Bideford grit. A very successful job – essentially the moisture levels have come down to equilibrium – about 30%. We have monitored it several times since and have been familiar with this building for about 18 years. It's continued to stay reasonably dry. When I say dry, I mean there was no liquid water inside, with levels about 30% in the core. One particular month it rose to about 60% because of driving rain, just showing that water still does penetrate through renders, But, if your core is in sound condition, it will deal with it and in this case it dried down by 30% in the next month.

Frome St. Quintin, again I want to cover in more detail this afternoon. This was rendered twice and it failed twice, so as a result various tests were carried out to establish what had happened. It was redone a third time in 2002 and through monitoring we can see that in the last decade, it's remained nice and dry.

We do get asked occasionally to look at renders that have gone wrong for one reason or another. I'm not going to go into all the reasons now. Often they're not fatal, but we'll talk a little bit more about that this afternoon. Generally speaking renders are successful in preventing water ingress. We know from talking to specifiers and contractors and looking at their work that they've had good results from both hydraulic and non-hydraulic mixes as well as employing various different techniques. The failures are often down to wet substrate, bad weather, inadequate attention or overworking.

Finally grouting. A small church on Exmoor with a 19th century tower, subjected, as usual, to a lot of driving rain. In fact it was absolutely running inside. Interestingly, they put Knapen tubes in the wall to try and get the water to drain out through there. As you know, spiders like a dry environment, so where better to put your web than in a Knapen tube because no water seems to get in there!

Anyway, English Heritage grant-aided exploratory work and damp monitoring to get a handle on the condition of the structure. It was re-pointed and grouted and seemed to be ok. Lots of stones were removed to see whether the grout had got in and it had. Problems became apparent with subsequent monitoring, so clearly, moisture was high, so we think that maybe the grouting wasn't as successful as we'd originally thought. In fact only a ton of grout was used, so this is quite low in terms of the amount of usage. The grouting that we carried out at Fort Brockhurst and also the work at Sheffield indicated that the grouting was potentially a very successful solution to our problems. We wanted to carry out some research on a real church that was suffering and we also wanted to see if we could come up with some model specifications for doing it. So at this church, St. John the Baptist Church, Stowford, we commissioned Colin Burns to work very closely with the architect and the contractor to develop the specification and work programme.

You can see from the picture there we have a lot of damp on the south elevation. It's running water here with salt damage on the inside. This tower has always been wet and Gilbert Scott suggested in 1860 that it should be grouted with liquid cement and cement plastered on the inside. By the end of this work the moisture level was down to about an average of 30%. Again, a couple of years later when we monitored, it shot up following heavy rain, but again the water didn't go to the inside and it settled down. The other good thing was that there was now an extremely well-prepared and skilled work force at the end of this project and they then worked on St. Petrock Parracombe, north Devon, again a church subject to significant driving rain.

The tower is very exposed. These are the walls, about six feet thick at the base –the architect's report said that it had been running with water and it hadn't even been raining for a week. That shows the damp ingress and the salt that's coming through here. The tower was monitored in two phases for budgetary reasons and some of these images show the dowel monitoring and there's evidence of the grouting and the tubes being prepared before the grouting process. The first operation was to repoint which was carried out successfully with hydraulic lime. We went to visit in 2012 again and it was very dry apart from a few problems near the very top which was not related to the grouting, but moisture ingress above one of the concrete ring beams.

To conclude: grouting can restore the integrity of the core – it's got to be comprehensive though if it's to be successful, and it does prevent water ingress getting to the inside face.

I just want to end though with one that has so far defeated us – this is St. Mary in Castro, Dover Castle.

English Heritage are looking after Dover Castle so we have responsibilities over the church which you see here. That by the way is the Roman pharos (lighthouse) which dates from around the 3rd century AD and that's the view over the Straits of Dover. The problem was typified by the bag full of stone dust that had been collected from around the vicar after he finished his sermon one Sunday and basically a lot of debris was coming down from the centre of the tower as a result of moisture ingress. We looked at the historical record to see what had gone on and the church was ruined since the 15th century. Gilbert Scott came along in 1862 and consolidated the top there in a cement mix. Butterfield then built this up in a hydraulic mix and brickwork in 1889.

That's a view from the inside. That isn't actually all damp that you are looking at, it's just showing a difference in the colour following the mortar and changing building pattern.

We see again from the records that quite a few campaigns of re-pointing had been carried out and most of it was pretty hard and cementitious. So basically we've got a problem of a cement laden exterior, some soft-ish sort of bricks, three or four different builds – quite complicated. We thought the first solution was to try and at least get rid of the cement. Essentially we carried out trials that showed it would take a complete day to remove about half a square metre of this cement. It was so tough – it was tougher than the flint and frankly it wasn't practical. The further you got, the worse it was. So removing that wasn't an option. So what we therefore tried to do was find out where the water was actually getting in. We had the scaffold up so, the contractor installed monoflex against that lift and waited for the rain to come from the south and we were able to observe whether any moisture went through. Eventually when we did the same on the west side, we put it over two lifts and eradicated the moisture ingress. Unfortunately, six months later, the investiture of the new Lord Warden of the Cinque Port was scheduled so I'm afraid our interest took a very poor second place and the scaffold came down. I've spoken to the new incumbent and the problems remain and that is something that will have to be tackled again in the not too distant future.

Thank you.

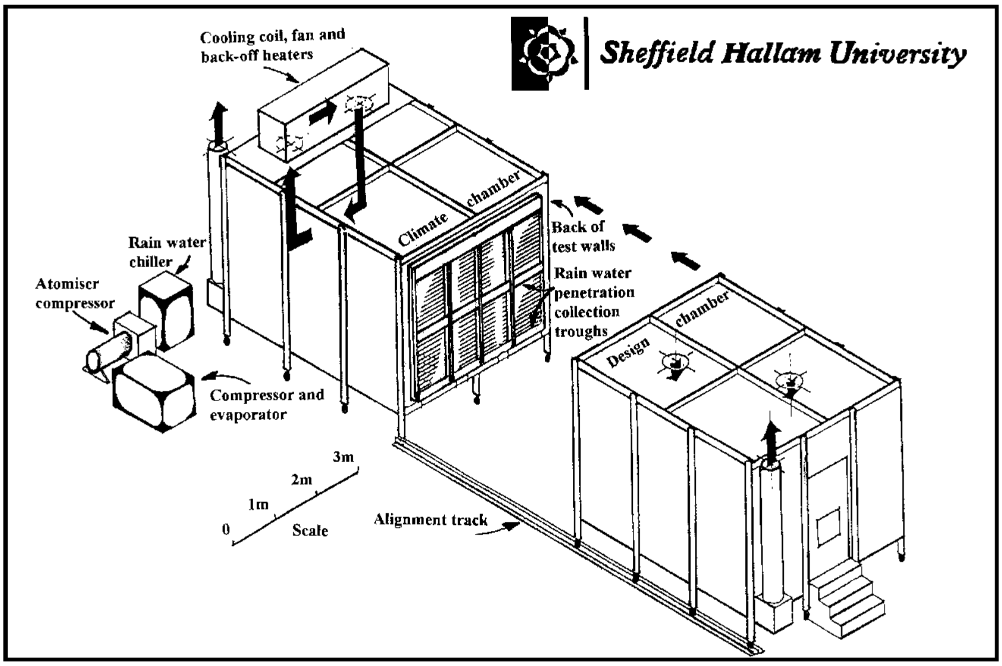
LABORATORY TESTING AND ANALYSIS

Dr. Elizabeth Laycock, Sheffield Hallam University

Good morning. Sheffield Hallam University was tasked with undertaking some laboratory work to try and explore this in an environment where we could do some destructive investigations without causing damage to the historical fabric of any of the buildings.

We started with a literature search which realistically showed very little information on driving rain through structures of historical importance. Most of the laboratory work, most of the testing works exists to rationalise and quantify the volumes or mechanisms on driving rain through modern cavity wall construction, not through solid masonry, such as you're dealing with, with these types of towers.

So, lots of work on using various laboratory methods, or starting whether a render works or whether a particular treatment works, or when it works how long until you get water penetration through the exterior skin of the cavity wall, but not really very much on these structures and obviously not very much actually quantifying the effects of pointing and rendering where you have a fixed structure. So you have one wall type that you then play about with in a laboratory condition and see what works and what doesn't work quite so well.



So this is the equipment that we were using. It's a climatic simulator and we've used it quite extensively for looking at freeze/thaw durability of various building materials, but it was also quite suitable for looking at water penetration work. In the past we've suspended work or built work within the chamber – obviously with walls of these dimensions that wasn't really feasible so we actually constructed a load bearing plinth and the walls were built in situ on that plinth. This is obviously the first stage with the small walls and Chris already showed you what they look like.

What were the aims of the first part? We did a pilot phase, relatively small scale to see whether it was feasible to try some new ideas. You'll notice some foreshadowing there that maybe some of these ideas didn't work as well as we might have hoped so you'll have to excuse my honestly in this particular aspect. What we wanted to do was simulate some driving rain on some of these walls to see what happened, which is a relatively simple experiment. In order to work out what was happening we decided to construct the walls on a polypropylene base – the idea being that the run off from the wall could be collected and we could then work out what the flow rates were, make sure that all the walls had a balanced flow rate and were all getting the same amount of water. The internal conditions here were pressurised. We put some in situ mortar in. These were built into the wall rather than being placed retrospectively in order that the water flow wasn't disturbed by subsequently drilling holes into the wall and installing equipment. And then the idea was that we would collect any run off from the back that had gone through the wall and ideally that would prove everything.

So we duly constructed the walls. That was the first wall constructed and we had Colin who constructed the walls with a little bit of swearing as we tried to help and got in the way as academics tend to do, sticking their noses in where they're not really welcome and eventually I gave up and just watched from a distance in a respectful manner.

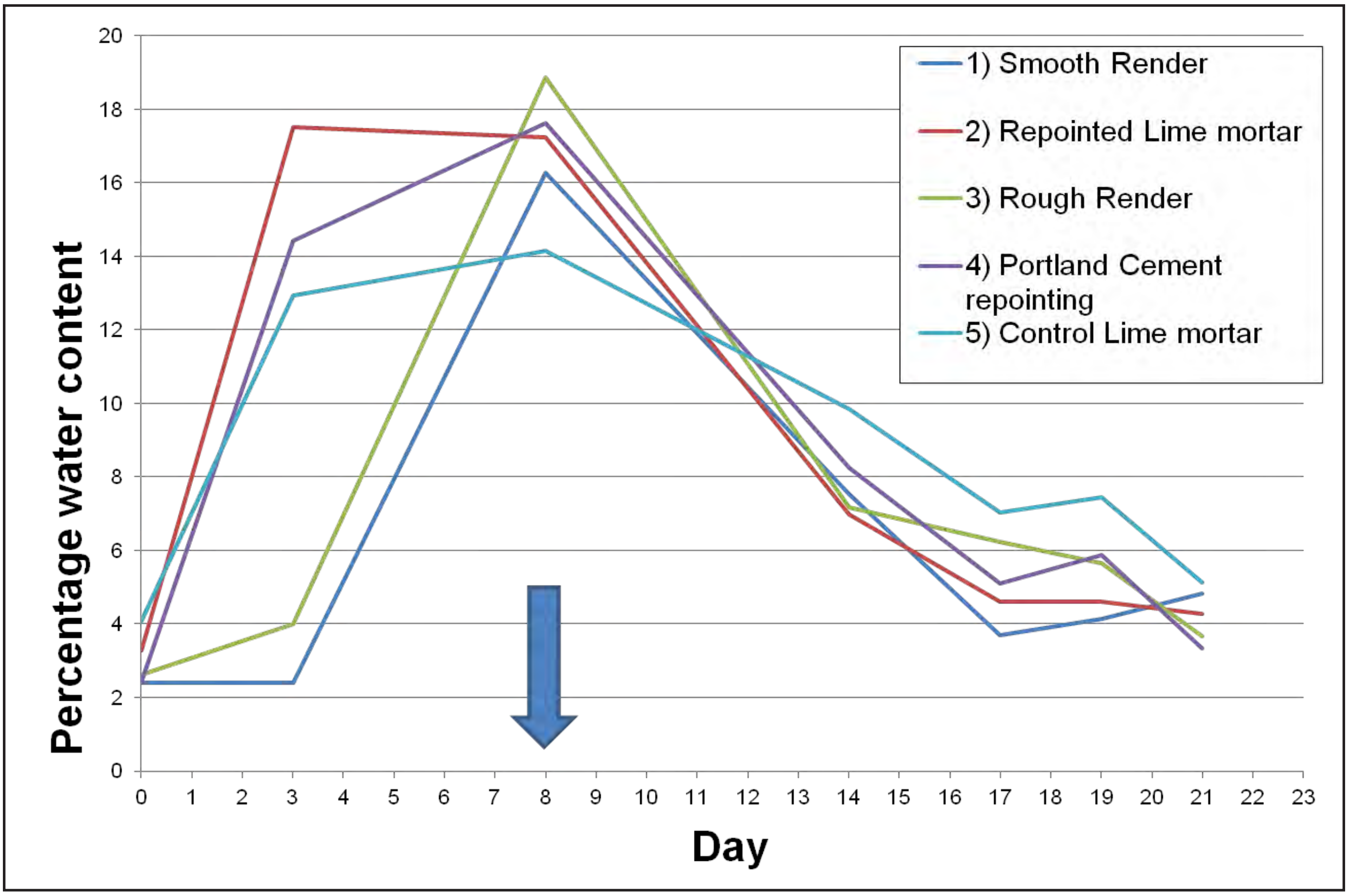
Wall 1	Wall 2	Wall 3	Wall 4	Wall 5
Fine render	Washed out mortar	Course finished render	Repointed in PC	Control Panel

So we started with wall 5, control panel and obviously Colin did the whole lot. He constructed walls that he then effectively sabotaged the joints and re-pointed them with Portland cement mortar as per worst repair practice. We had two render types, a cast finish render and a smooth finish render – details available for those of you who are particularly interested in what they were. And then another with mortar that had been washed out, to mimic the natural decay that might be expected on one of these walls. We let these walls cure; we monitored them and lovingly cared for them.

We turned on the taps on the first day, thinking it's going to take ages for this to wet up and after 6 hours they were leaking. So that sort of threw us a little bit. We weren't expecting these walls, having been built to best practice, to leak so quickly, through two skins of stone which were very mobile with a lime mortar and in 6 hours you have free water running down the back of the wall.

Wall 1	Wall 2	Wall 3	Wall 4	Wall 5
Fine render	Washed out mortar	Course finished render	Repointed in PC	Control Panel
				

Ok, so a little bit surprised, we decided to monitor the amount of water by drilling.



Obviously we had to do destructive tests and you can see that in general the walls continued to wet up, to the point where you turn the water taps off on all of the construction. Although obviously the re-pointed, that's the cement lime mortar. That's one that was re-pointed later on with a lime mortar re-pointing and even then, they were wetting up very, very quickly, within two or three days of the water being turned on and we've got free water running down the backs of these walls.

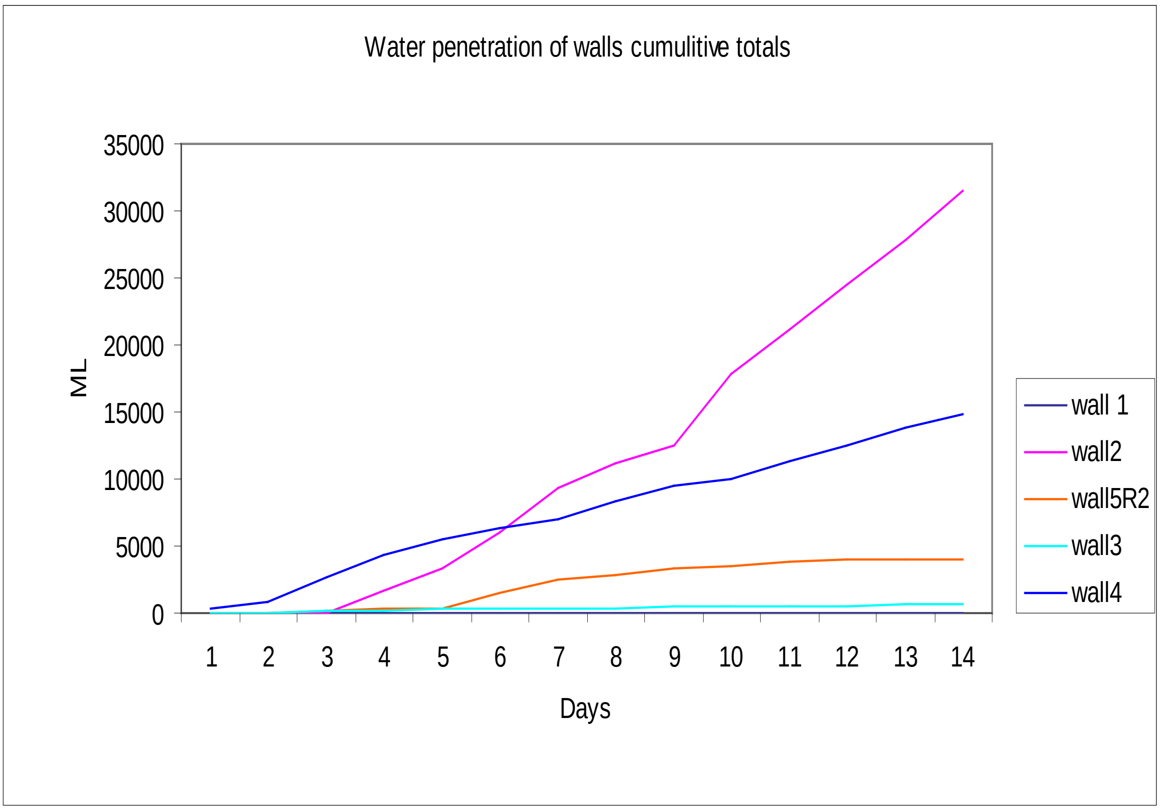
Now obviously the construction form is not quite what we would expect, they're relatively thin skinned but these are not excessive moisture conditions and these are not excessive wind speeds – about 20mph driving wind equivalent. So these are low speeds and relatively low rainfalls and we have free water with these thinner walls, so again we were a little bit upset by that. It undermined our possible preconceptions.

The sensors and this is where I must confess that it went utterly wrong. It's very nice to present a bit of research where everything has run fantastically and you have no issues whatsoever, but maybe research doesn't always run as smoothly, and certainly this one didn't. We had failures across most of the sensors. The wetness sensors that we had showed the initial water ingress and then the voltages frizzed until we started to get significant drying, they weren't that accurate over the high moisture content. The temperature sensors were great as they showed us exactly where the water front was as the water entered the wall but they didn't then show how the water left the wall or where the wetting front was, they weren't sensitive enough. The humidity sensors were pretty much a disaster. They basically showed the wetting up, registered a 100% humidity and then they continued to register 100% humidity all the way through the rest of the experiment, even when the wall was drying back. So the water vapour conditions in the wall were so relatively high even when the wall was drying that we were getting no meaningful responses from those. And although we were able to monitor free water, it wasn't really giving us enough information to be confident that we were able to have any sense of accuracy over the various interventions.

In addition, the control wall (the best practice wall) did not behave as we might have expected. It was the first one built and the general feeling after much head scratching and conferring was that the mortar may have been slightly wetter during construction of that first mix and that had had a disproportionate effect. So the decision was made to dismantle the control wall and see if we could have a better go next time, but before we did that we ran some dye tests. We started building the walls up and we hit the wall with a water soluble dye to see where the water was penetrating the wall and the preconceptions. Again you shouldn't really have them when you go into laboratory testing, but you do, based on what you feel might be the mechanisms because then you are developing the test to identify and use those mechanisms – but this was very surprising.

This indicated that there was virtually no transport through the body of the mortar, that all the transport was actually at the interface between the block and the mortar. So again, we were expecting that a perceived practice that the mortar soaked up the water and the water transmits through and the mortar becomes wet. This was indicating that at least the initial penetration is along these interfaces. So again that's very interesting.

So we rebuilt the control and everything was left to cure again and we retested it and this is just a graph of the one where the smooth render didn't allow any water penetration over the time.



So this was the second run through and we had all the other walls have then been tested twice and allowed to dry back between testing. So, as you can see no real surprises, the lime mortar joints didn't do very well, effective pointing didn't do very well, the control panel did O.K., lime rendering with an open texture did really well and obviously smooth lime did very well indeed.

So that was the first one, but again, we weren't very happy with the results. We ranked them and it did sort of generally conform to what might have been anticipated, but we wanted to have another crack at it.

So, findings. Yes we could identify that the render had a very positive effect; we could identify leakage at the back of the walls, even where these walls were built to very good practice. We were able to identify that the shelter effect of having a relatively solid wall where the front face of the mortar seems to soak up the water entirely, it just wasn't working. Free water flowing after 6 hours indicates there is no sheltering effect at all. With the normal pointing, that sheltering effect probably did happen with the render. And the other observation was even after the rain had stopped, the face of the wall looked dry and the mortar joints looked really, really dry but the walls were still saturated.

So, what do we do next? Well first of all you have a head scratchy conflab to find out why this might have happened. And I throw this out really for discussion, maybe its something to think about for the panel. The blocks were very low permeability and we've done some previous work looking at the effects that high and low suction rate units in bricks has on bond strength and it does seem to be a very strong indication that where you have a high suction rate block, the fines in the cement drawn upwards from the cement and effectively that might mean that this interface is less porous when you have a higher suction rate block. Where you have a low suction rate block you don't have this mechanism, the block floats on the mortar and obviously as you sheer the block, then perhaps you actually cause water pressure to build up and push the fines away so you make this interface slightly more porous perhaps. And again this was an idea that the project team sort of thrashed about. So this was Colin, Chris, myself and our colleague Steve Hethington sitting down trying to work out why things had happened. So, you know, perhaps the aggregate is important, perhaps the interlocking nature or the rounds of the aggregate, perhaps the block properties, in other words perhaps some of these buildings have an inherent defect before they actually reach completion. Although workmanship will be highlighted later in the talk as being extremely important; perhaps sometimes even really good workmanship can't stop this defect from occurring.

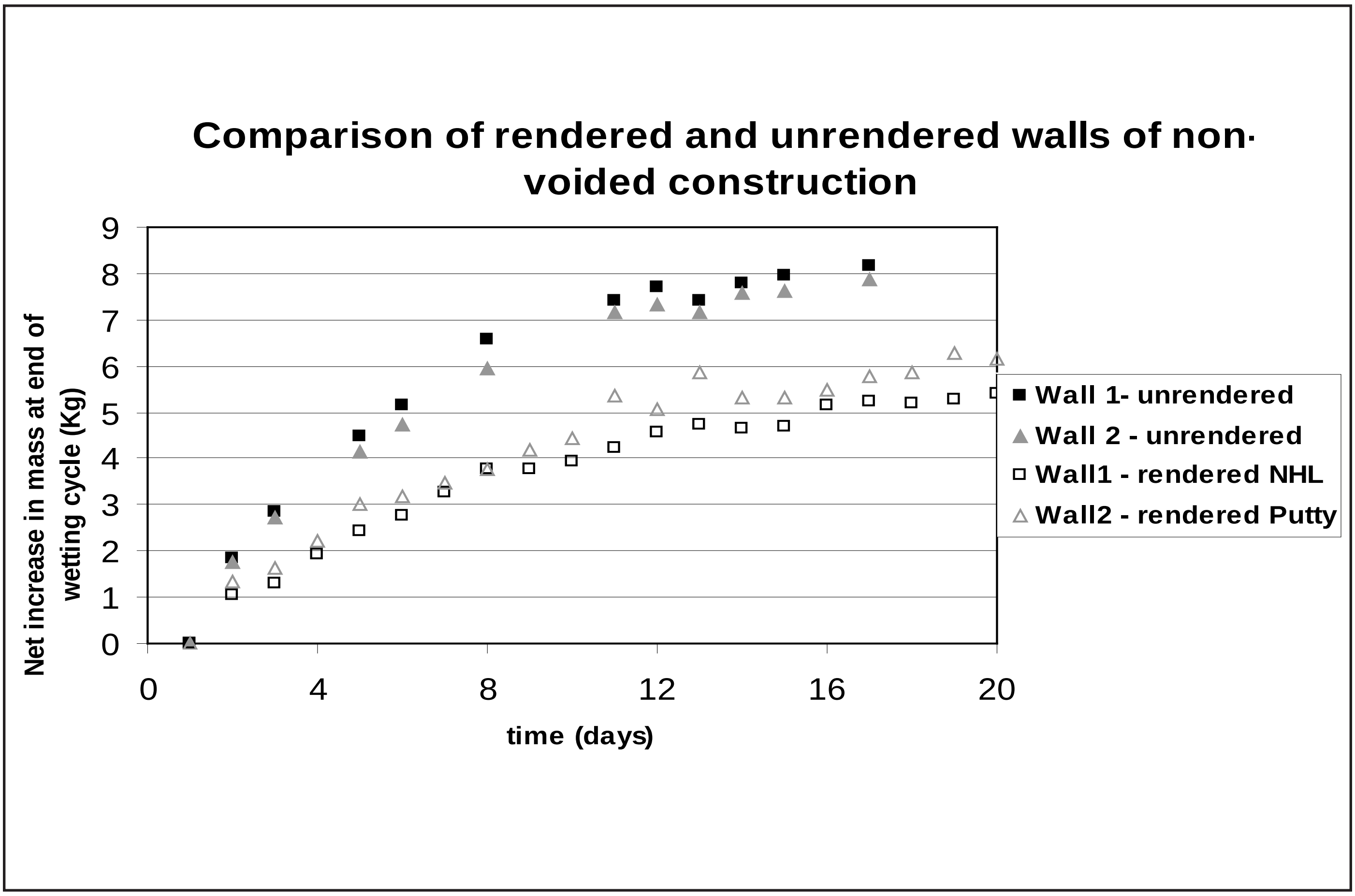
So the continuation work. Right lets build some proper sized walls, or more precisely let's ask Colin to come along and build some proper sized walls. So these were the new troughs that were constructed with a mesh over the top. We were anticipating significant water flow down through the core of the walls during driving rain. Based on what we'd seen from the previous work where water was saturating the first two skins relatively quickly. We had some very high capacity weighing scales, the walls were just over 400 kilos each and altogether Colin constructed four of them. From this we were able to monitor the water conditions in the walls throughout the wetting and drying cycles and then get a base line for each intervention. So we knew the weights of the walls, we were able to monitor them. Then we were allowed to put an intervention in, watch that dry down as it cured, then start testing again.

So here's Colin hard at work constructing the first two walls and you can see that we've got the face work and central core area. You can see the monitoring cables, we're trying a different set of sensors to see if we can get results, but we're not relying on the sensors now, we've got the balancers and that will show us.

We did a whole set of proofing and calibration work to demonstrate that the balancers were very, very accurate, even with these very high weights on them. We ran a testing programme, starting in 2004 and finishing in 2006, so that's two years of watching walls become soggy and slightly less soggy, with various interventions, things going on, things going off, things happening all the way through and then monitoring them.

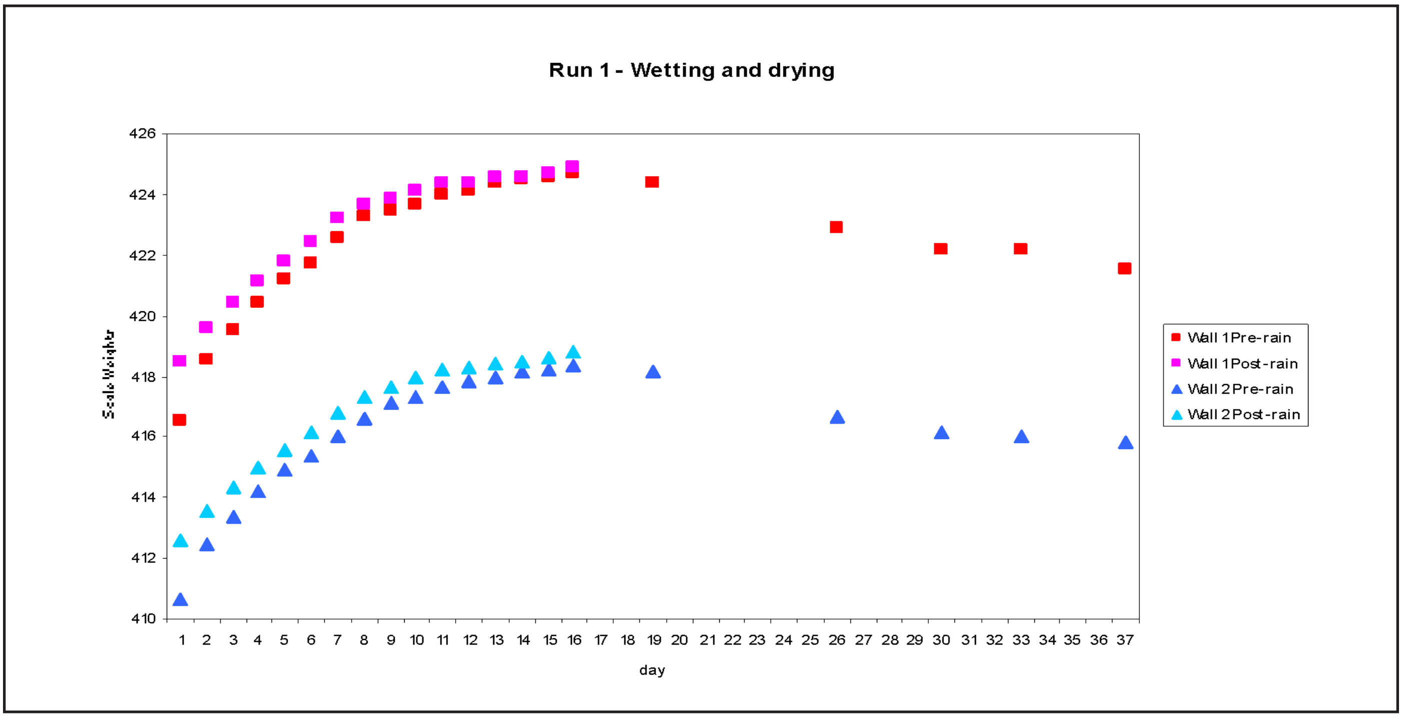
So there was grouting, there was plastering, there was rendering,. You name it, these walls were getting dressed up and being tested. And the results were very interesting. Wall 1 and 2 didn't respond in quite the same way. Obviously this is how much water they've taken over the cycle time during the raining and you can see that in general wall 1 and wall 2 went unrendered, had a similar pattern, but not quite the same. I don't think it would be reasonable to expect that they would take exactly the same amount of on water each day. But you can see that the render, regardless of whether it was an NHL or putty based render is actually extremely effective in reducing water content but it didn't stop the water content. It reduced it, but the wall is still getting wet, maybe it is not reasonable to expect any porous material to resist the ingress of water unless you are going to paint it with a water repellent and that's not something I would necessarily advise.

We also managed to monitor the drying runs. Now obviously the key thing for this is you wet the walls up – quick explanation – pre- and post-rain, obviously this is condensed snapshots of 6 hours of rain there is illustrated by the slight stagger in time.



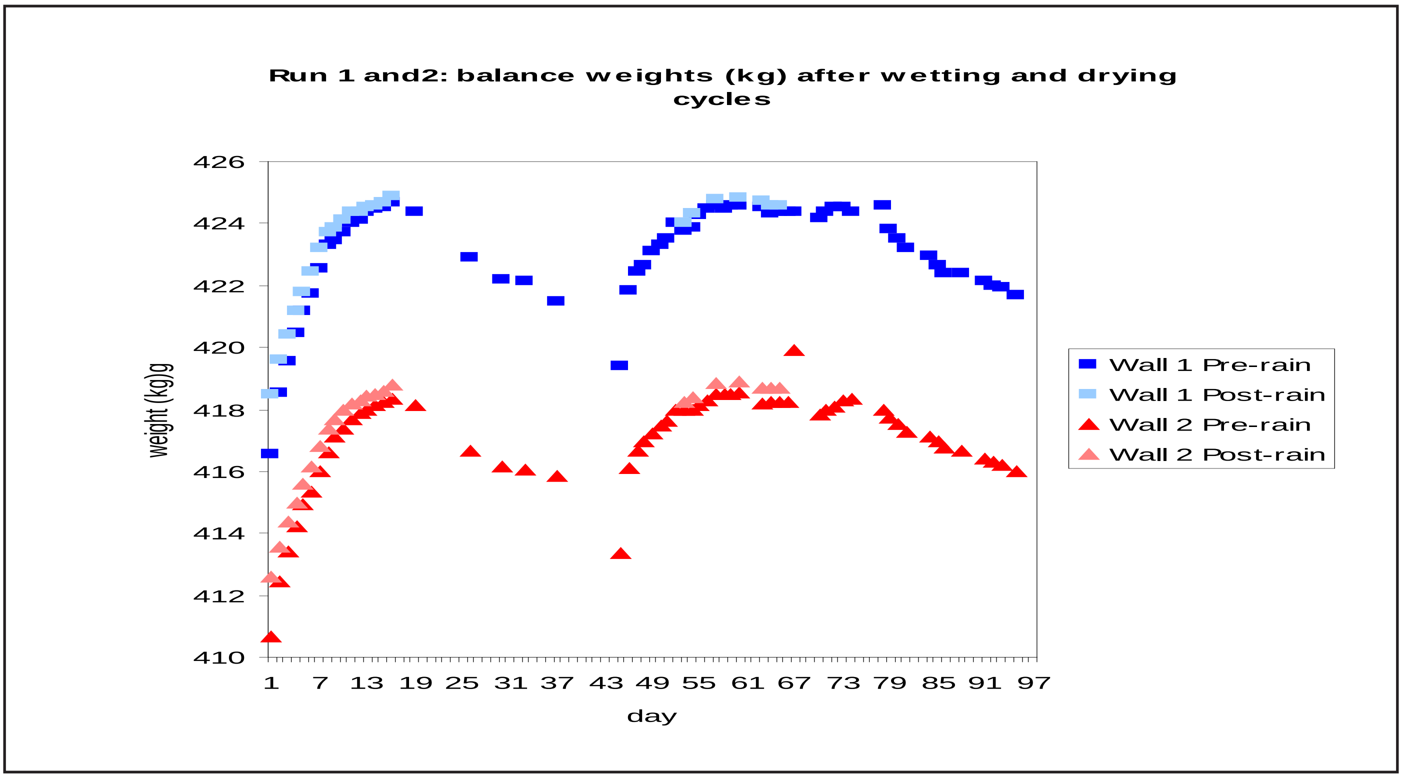
So you can see as a percentage of the overall wall mass the amount of water uptake is relatively small, you can also see, there's an indication that perhaps there is two phases of wetting. There's an initial very quick phase of wetting and then a much slower phase. But you can also see that even over time taken we're no where near saturation and indications in the field that a stable core centre saturation would be about 30%.

Obviously we would have liked to have tested to saturation, but given that we also wanted to get data on what happened with the various treatments, we had to draw a decision over only going to take it to 18 days worth of rain and monitor that. We can't carry on saturating walls until they will take no more water on, so again no experiment is foolproof.



Now, we're expecting again that the water will show a consistent tracking, so in other words the water would manifest in the middle or lower range of the panel or in the troughs and we would be able to collect it and actually there was no free water in these walls, they were dry. They took the water in, but the water was soaked up into the walls like a sponge and it did not run down the back of the walls, it did not run into the troughs.

These walls work: they do what they are supposed to do and they stop water coming through, while ever the structure is coherent. The drying rates were extremely slow.



Here are some examples of drying rates and you can see that the wetting up rates are very fast and the drying up rates – oh dear, we just ran out of time so we had to start the next cycles before we got back to this level.

We did some calculations. We worked out the we had to wait another two or three weeks to get down to those levels each time we wet up, so another month. So the number of cycles we had was an extra years worth of testing, which is lovely if someone is footing the bill but obviously is not very reasonable.

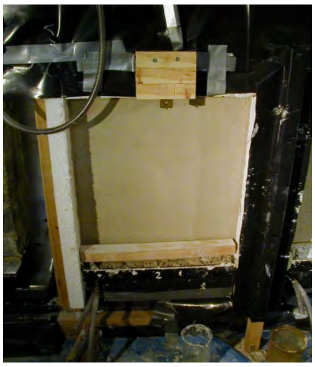
Then we decided that we wanted to test some voided walls. Now creating a voided wall in a laboratory environment is not something that seems to have been done on a regular basis. How do you create a space within a wall when you are dealing with wet mortar? Modelling balloons and inner tubes! Maybe not the most scientific method, but if you have any examples of how you might do that in the field or in the laboratory, I'll be interested to hear them.

So here are the modelling balloons. We quartered them through the walls so we could see, well, so we knew where the voiding was. The idea being that we then could link the water penetration and find the points of egress to the location of the voids and obviously when we came to point up or grout we could actually see whether the points changed. So we had a large void wall and then we had a wall with much smaller voids, effectively mimicking where the lime had been washed out and left a more gravely voided substrate. Also we used straws to mimic channelling going through the voids as if water had already started to create pathways through. So that was wall 4, with the finer voids. That was wall 3 with the courser voids.

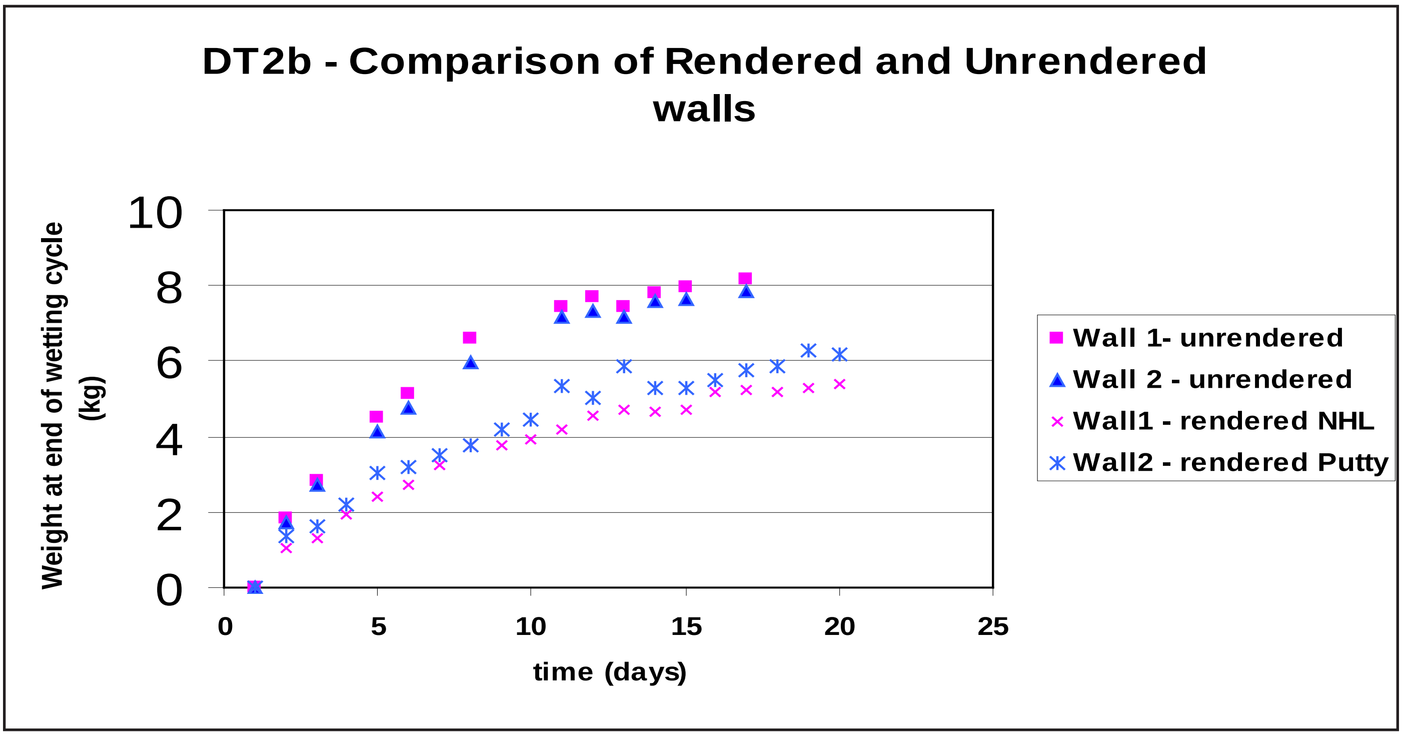
And here are some walls in progress, there's the modelling balloons, they weren't left in, I want to stress that, we didn't just leave the balloons in, oh we've got voided walls that's fine. You'll notice they are currently bonded together with some 'Heath Robinson experiments are us'. That's the masking tape, that was removed before each course was created and the end of the modelling balloons were dragged through to the back of the wall and then I had a very interesting time with a hat pin gently poking through to the balloons and carefully unravelling them so as not to disturb Colin's fantastic pointing work. Likewise, the straws were removed; no straws were left in the wall during construction.

As I've indicated earlier we put various treatments on. So this is just a quick view, the face of the walls as a snapshot in time.

Wall 1 Wall 2 Wall 3 Wall 4

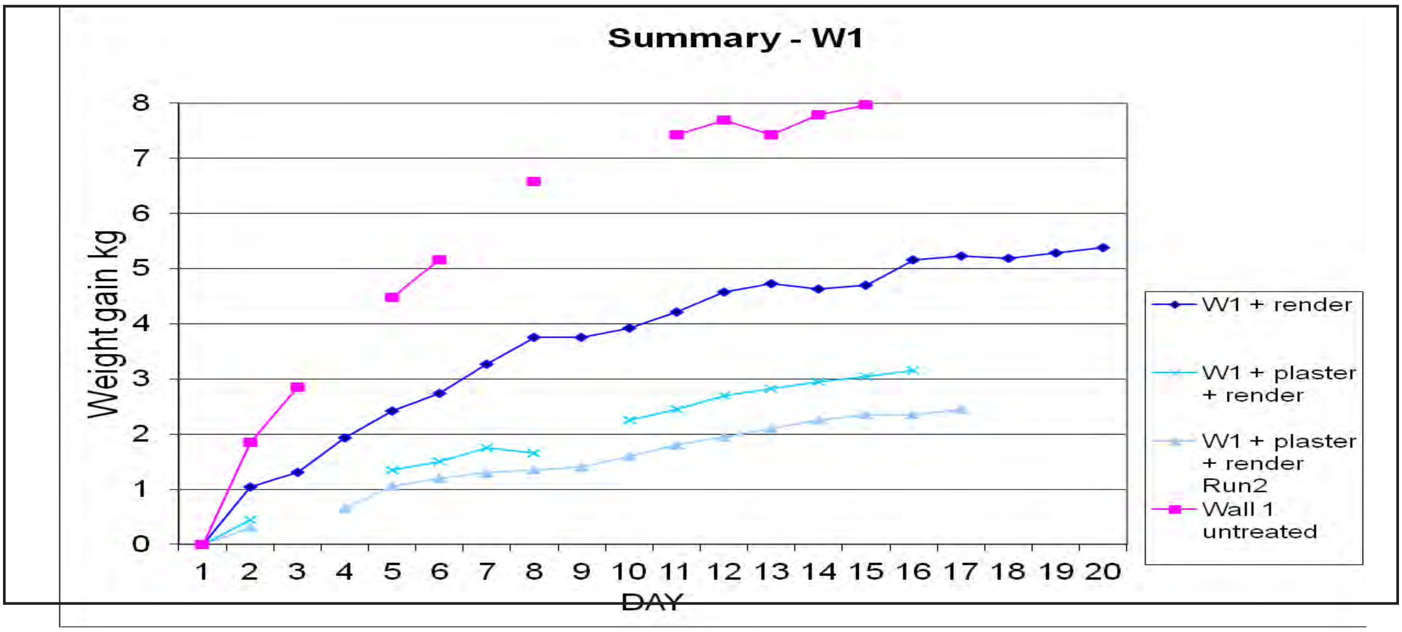
You see the two central walls, wall 1 and wall 2, those were the best practice walls. Wall 3 and wall 4, the voided walls and that's pretty much as seen in the chamber. And again there we go, rendered vs. unrendered walls.



Weight loss findings. We simulated 15 days of rain. The drying curves indicate that you would need to wait at least 1 month to 6 weeks and that's in idealised conditions. We were force drying by heating, by forcing air across the surface of the walls, giving it idealised drying conditions. So you can see from that that it's actually very easy for these towers over a period of time to build up more water than they lose. You only need a few damp summers to mean that you will get a tower that is going to be vulnerable to leakage during the winter.

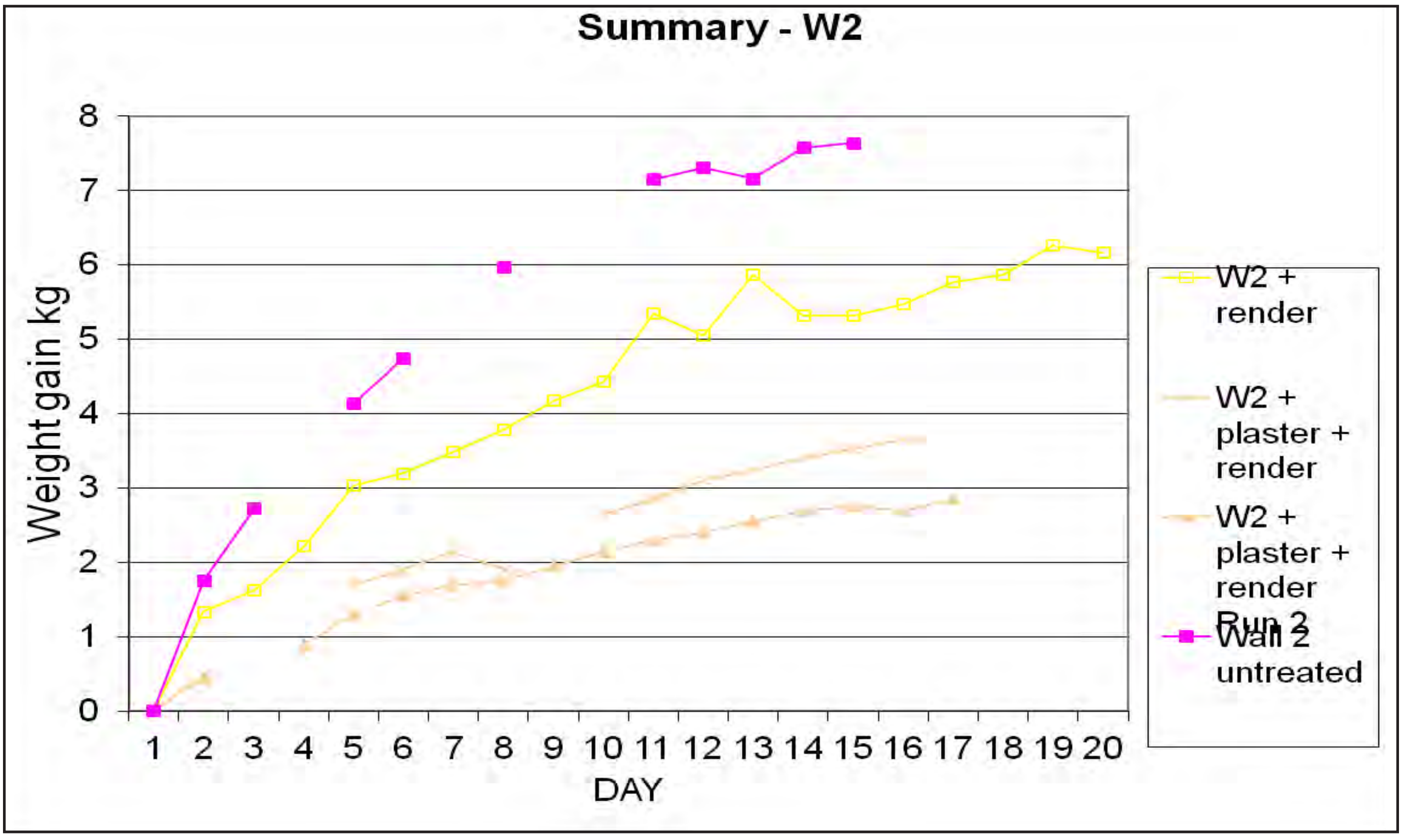
So after all this testing, lets summarise what we actually found out.

This is wall 1, one of the perfect walls. Here's the untreated wall, this is the weight gain over testing – it takes on 8 kilograms.

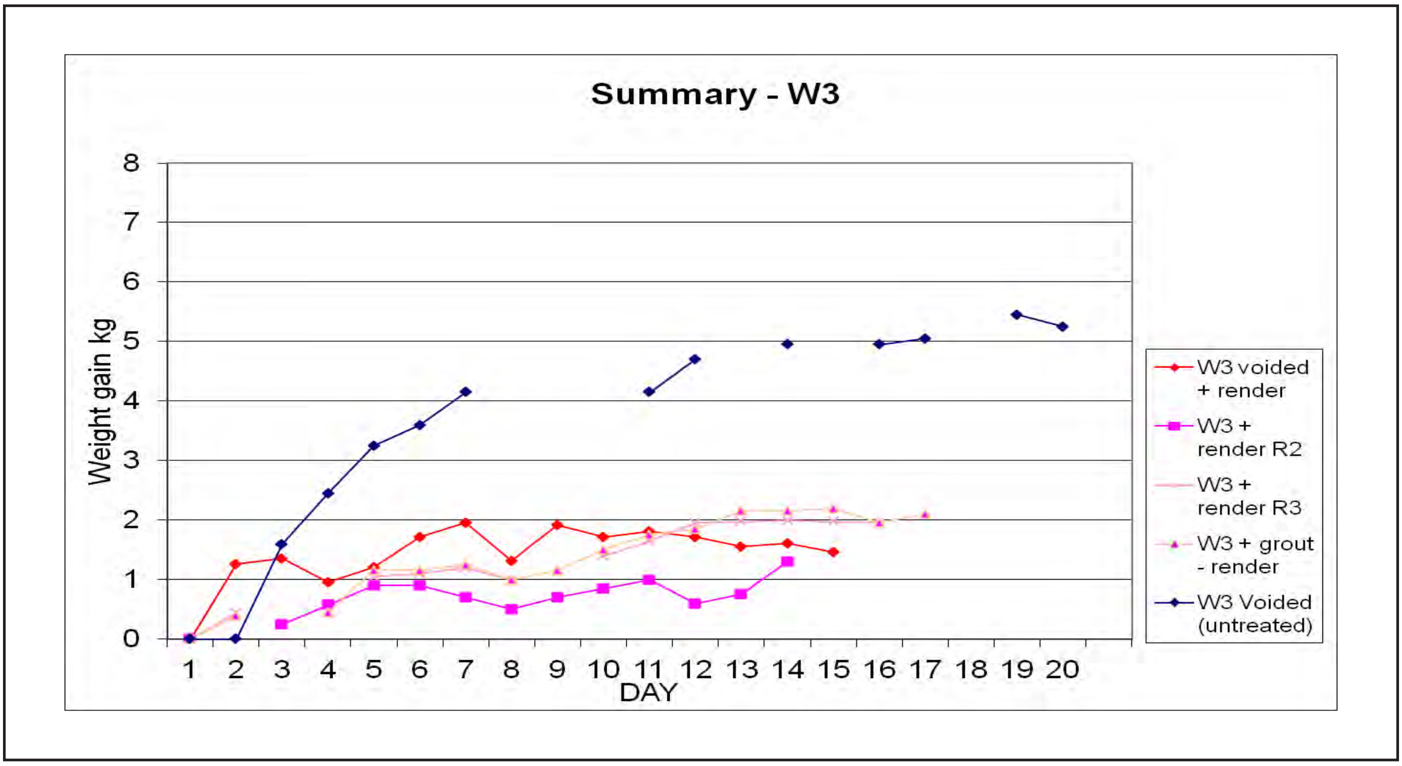


What happens if you render it? Significant reduction. What happens if you apply plaster as well as the render? Significant reduction. Now obviously wall 1 wasn't leaking, this is based purely on the weight gain of the panels.

Wall 2, exactly the same trend. There's the untreated wall with render, with render plus plaster.



Wall 3 and wall 4 a little bit more complicated because of the difficulty in actually finding where the voids were really and you can see that adding render to these was very effective, adding grout – very effective.



Same with wall 4 render and grout both very effective. Obviously we applied the render first, then the render came off, then the grout went in. We didn't have render plus grout – render or grout.

So just a quick explanation of this. The good constructions didn't get much water reduction pro rata because they were actually just soaking up the water. So it meant that the good constructions didn't actually do very well, but actually they did do very well, they did exactly what they were supposed to do. When you have large voids you get a significant water reduction with both render or grout. With small voids render is possibly slightly more effective than grout simply because of the logistics in finding where the voids are.

So in summary, it's a complex situation. It's probably more complex than I envisaged when I first started on the laboratory work. The high humidity was a big surprise, the lengths of drying times that we saw in the laboratory were extremely unpredictable. The fact is that if you have a very thin skin of wall you get significant water flow. If you have a thicker wall, double the wall, it cuts down the water flow considerably and it also maybe indicates that once your wall has become vulnerable by voiding, you're far more likely to see free water from the back – a reduced effective thickness of walls. You also have the voids potentially pressuring up under driving rain, so you have driving rain pressing against the internal skin of your building rather than the external skin. Rendering had a positive effect on it. A wall structure that is competent won't leak and a wall structure where you have voiding will leak. Thank you very much.

Heather Viles – Thank you very much Liz and now we have a half hour break for coffee and we will be back to start promptly at 12 o'clock.

LABORATORY EXPERIMENTAL WORK

Professor Heather Viles, Oxford University Centre for the Environment

I'm rather cheekily talking today on behalf of Chris and presenting some of the material that he produced while he did a Masters thesis under my supervision at the University of Oxford, associated with the Damp Towers project. His work focused on looking at pointing mortars and doing some experimental studies to evaluate different mortars. The big question, as he's already suggested, is that management of these damp towers problems through pointing requires a mortar that's slow to absorb water and quick to dry out and that was the real thing that his work focused on. The aim of his project was to evaluate the performance of a number of different pointing mortars in conducting water.

He did this by addressing two objectives, firstly to test the wetting and drying behaviour of a range of these mortars in the lab and secondly to test the performance of different mortars under different conditions of workmanship on a test wall near Oxford.

What I want to do in this talk is briefly outline the methods that he used for both of these and to summarise the results and some of the implications of these results.

Firstly, looking at the experimental testing that he did on wetting and drying behaviour. This is his little family of mortars that he with Colin so lovingly prepared and nurtured over a fairly long time in order to use them in the tests.

The basic experimental design that Chris used can be seen in this image here.

This shows a bit of drainpipe with a mortar cylinder poking out of the end and the thing to notice is that there's a large fixed head of water on the left hand side.

The idea is that you fill up the water and that forces water at some high pressure through the mortar and the idea of this is to simulate in a very basic way how driving rain might interact with the mortar joint. So clearly we can see some of the difficulties with this. It's quite a coarse scale and it's as Liz might have said a Heath Robinson-ish kind of approach, but it proved to be a useful way of testing these mortars.

To look at the kind of mixes that we used, Chris used 8 main mixes.

Mix Number	Details	Replicates (mm)		
		100	200	300
1	1:2.5 – NHL 3.5 sand	3	3	3
2	1:3 - Lime putty: sand	3	3	3
3	1:3 - Lime putty + porous particulate: sand	3	3	3
4	1:2.5 - NHL 3.5 + porous particulate: sand	3	3	3
5	1:3 - Lime putty + coal ash: sand	3	3	3
6	1:2.5 - NHL 3.5 + coal ash: sand	3	3	3
7	1:2.5 - NHL 3.5: coal ash	3	3	3
8	1: 3 - NHL 3.5 (2/3) + lime putty (1.3): sand	3	3	3
9	1: 2.5 - Lime putty (12 yr old) + wood ash	4	1	
10	Pozzament grout mix	3		

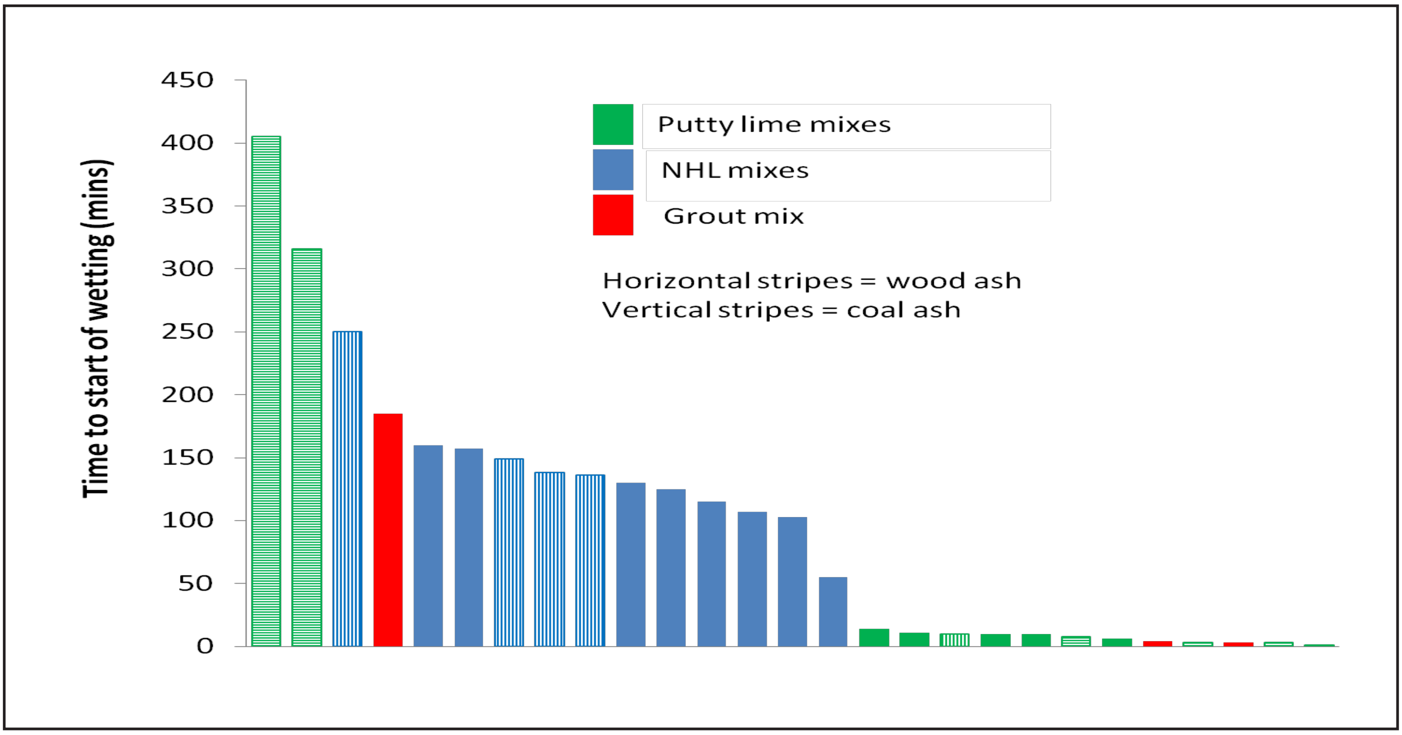
Mix 1 is what we would call the control mix: NHL 3.5 and sand at the ratios that you can see in the image. And the other mixes that he used were a range of different mixtures, some of which were based on lime putty, some of which had porous particulate in. I want also to point out that several of them had ash in; coal ash in mortars 5, 6 and 7 and wood ash in mortars 9. And he also used the grout mix that Liz explained that was used in the Sheffield Hallam experiments as well.

What I'd like you to look at is that the columns on the right hand side show that we had a number of different replicates and we had in most cases three individual test runs with three separate cylinders of mortar and each of those was 100 mm in length and there were three at 200 mm and three at 300 mm. The idea of this really was to provide some kind of representative analysis. Just using one or two cylinders and no replicates is not good experimental design. The mortars were allowed to cure for 100 hundred days and then were subjected to the experiment. Here is a list we produced of bullet points of what Chris and the team at Oxford Rock Breakdown Lab did in detail.

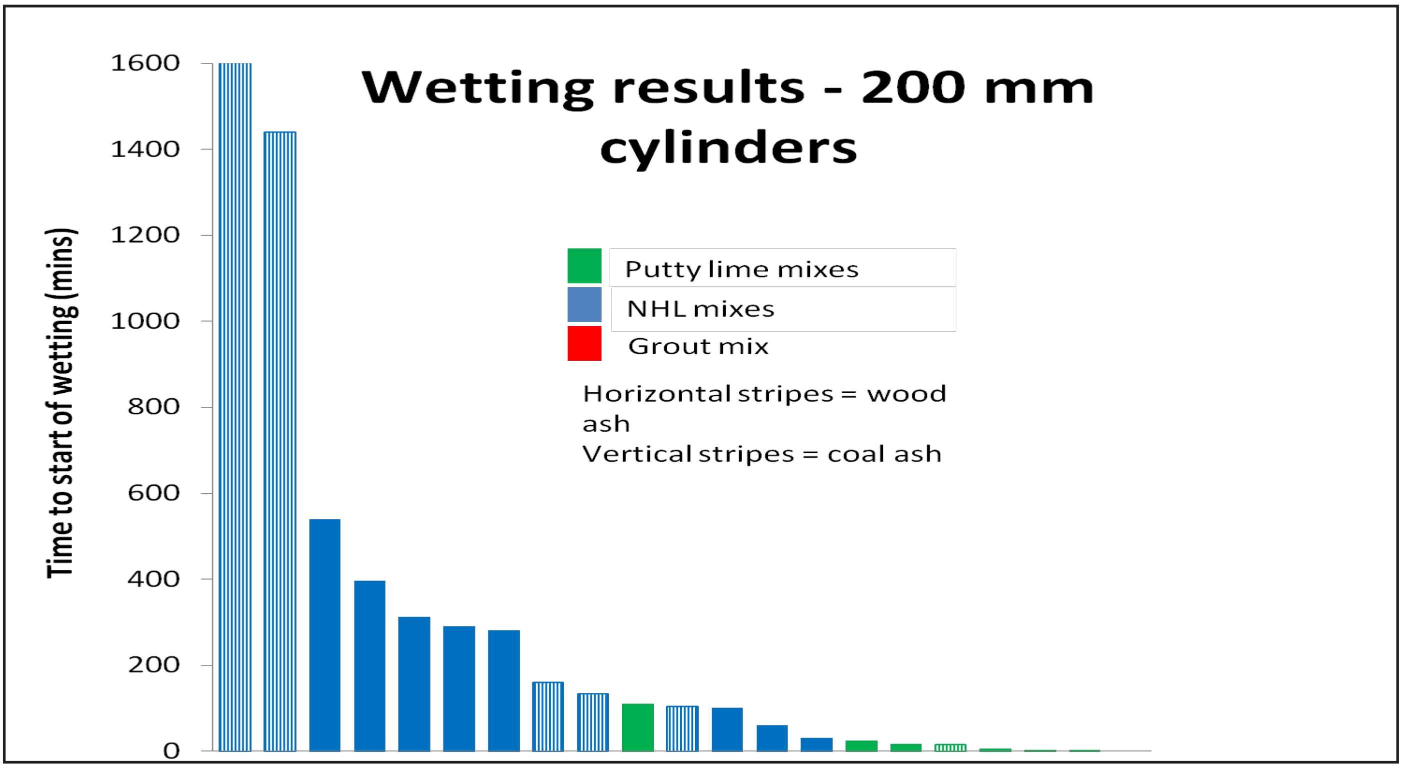
Chris and the Oxford Lab team went through a particular routine of weighing the cylinders, putting them in the apparatus, filling up the water tank and monitoring the time at which it took the water to come through the mortar and also to monitor by drawing on the outside of the cylinder the progress of the waterfront as it went through. He reweighed the cylinder at the end. Now before I tell you anything about the results I just want to talk through the experimental design for the drying experiment. He used exactly the same mortar mixes, the same cylinders again replicates of the different lengths and submerged them in water for 24 hours, weighed them, left them to dry under controlled conditions and then monitored the change in weight until ideally we got to constant weight i.e. a measure of relatively dry conditions in equilibrium with the lab conditions. And again this is a rather coarse, but effective way under lab conditions of seeing the rate at which mortars dry out.

We also did adjunct tests on the mortars to simply characterise them by looking at water absorption by capillarity following the standard test regime, as well as looking at surface hardness using the exquoted hardness tester and thanks to David Jefferson carrying out a lot of thin section petrography to tell us more about the basic make up of the mortars.

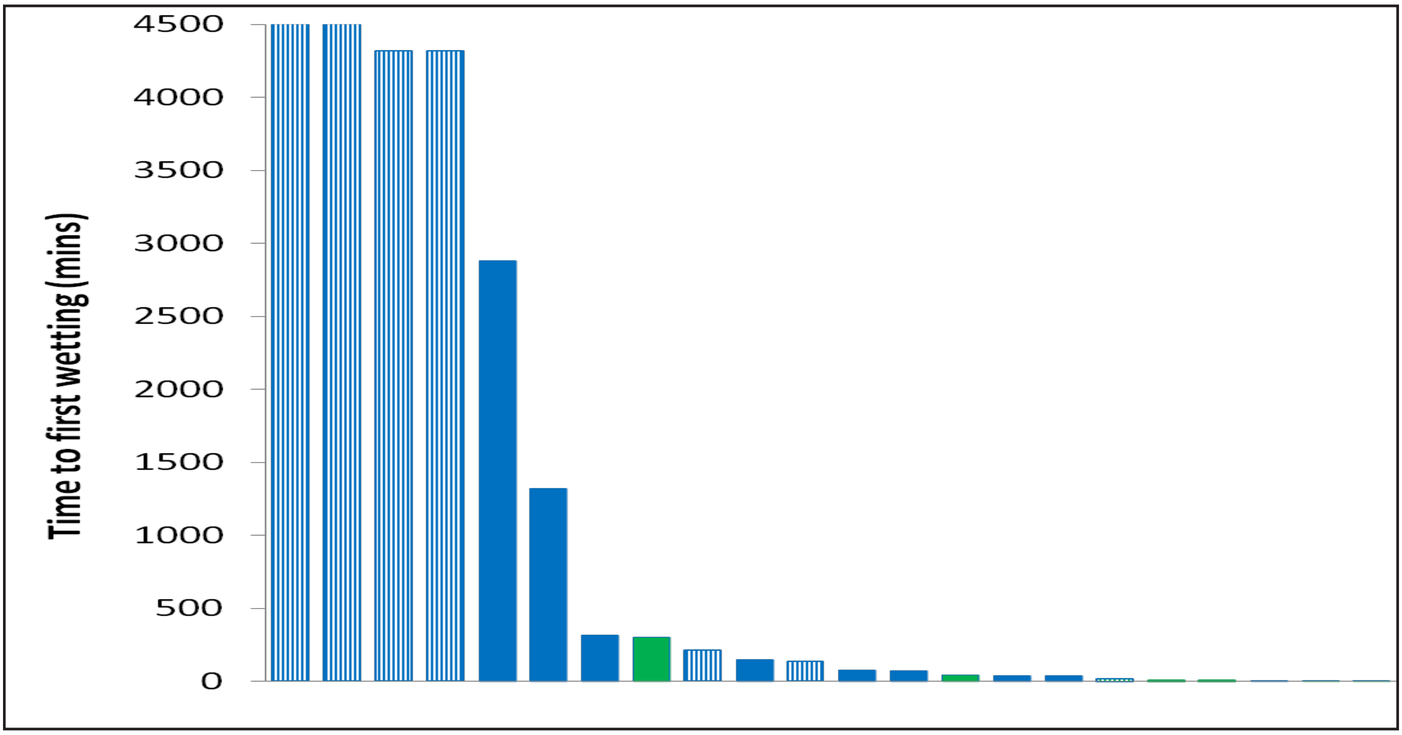
So the moment you've all been waiting for – what were the results? Well we saw a colour change as the water came through the cylinder and the entire face becomes wet. But we're not really content just to show you lots of pictures, of course being scientists, we like to show you a few graphs.



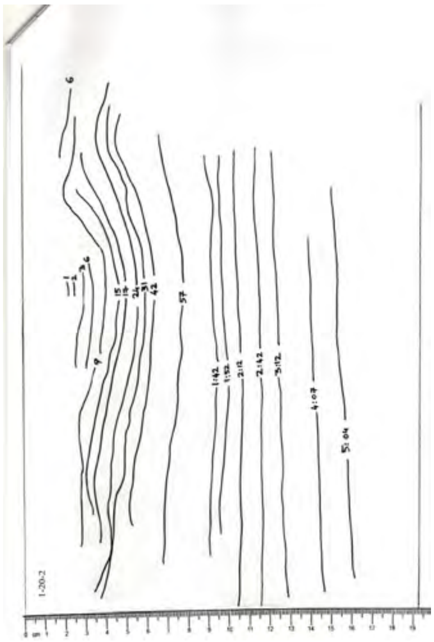
This graph firstly summarises the wetting results for the shorter (100 mm) cylinders. The thing to notice is the vertical axis shows the time taken until the face started to get wet and each vertical bar represents a different replicate of one of the mortar mixes and the colour coding there explains the different type of mortars. Don't forget that what we wanted to achieve is something that is slow to wet up and quick to dry down. And you can see here that for the 100-mm length cylinders it's the putty lime mixed with wood ash which takes the longest time to wet up, but there's a whole range of other ones, largely the blue ones, the NHL mixes with various additives, which take a good long time to wet up. In comparison the thing to note over on the right hand side of the graph is that most of the putty lime mixes actually wet up very quickly.



And we can look at similar results for the longer cylinders, the 200-mm ones where we had a more restricted range of types of mortar being tested. The thing to note here is that the ones performed best (i.e. took the longest to wet up) were the NHL ones mixed with the coal ash.

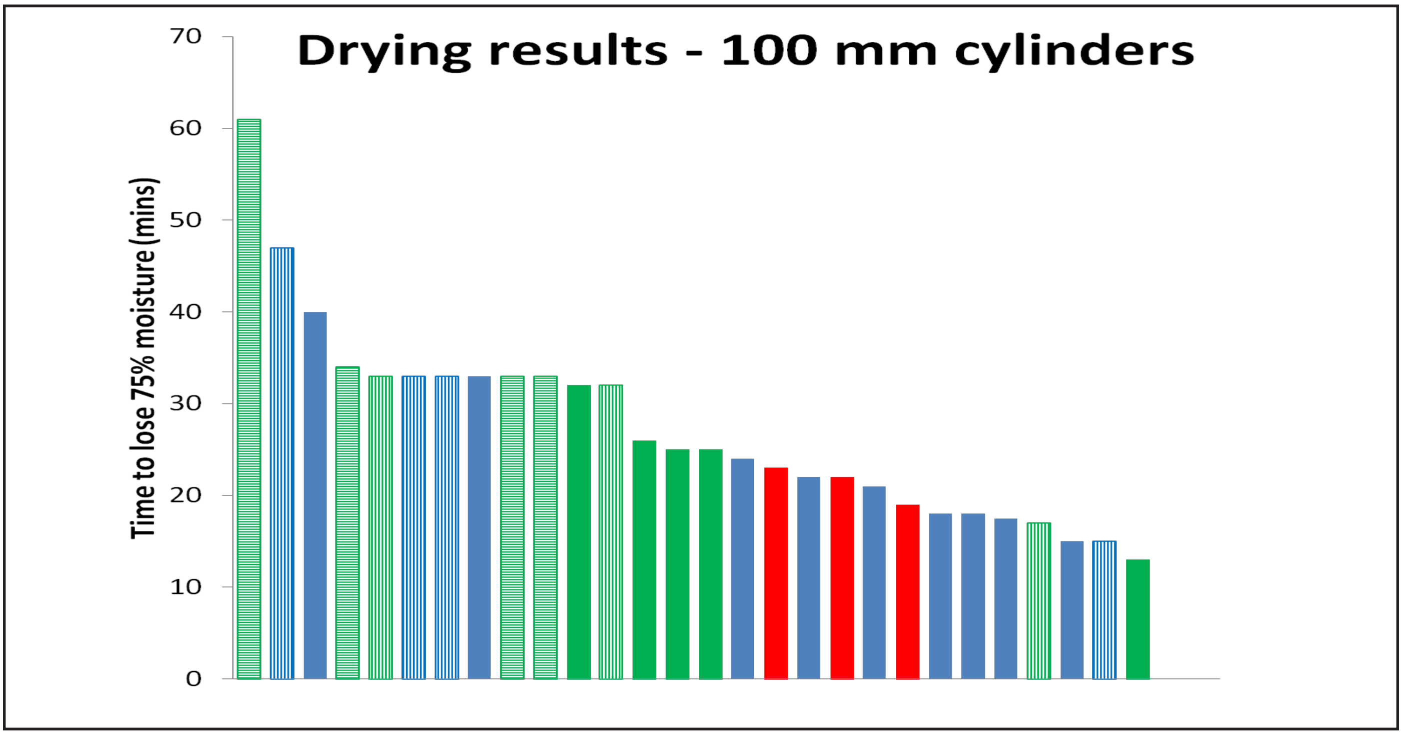


And again if we look at the 300-mm ones, we have similar results. Some of the ones with NHL and coal ash, you can see four of the replicates of slightly different varieties in the graph took a very long time to wet up.



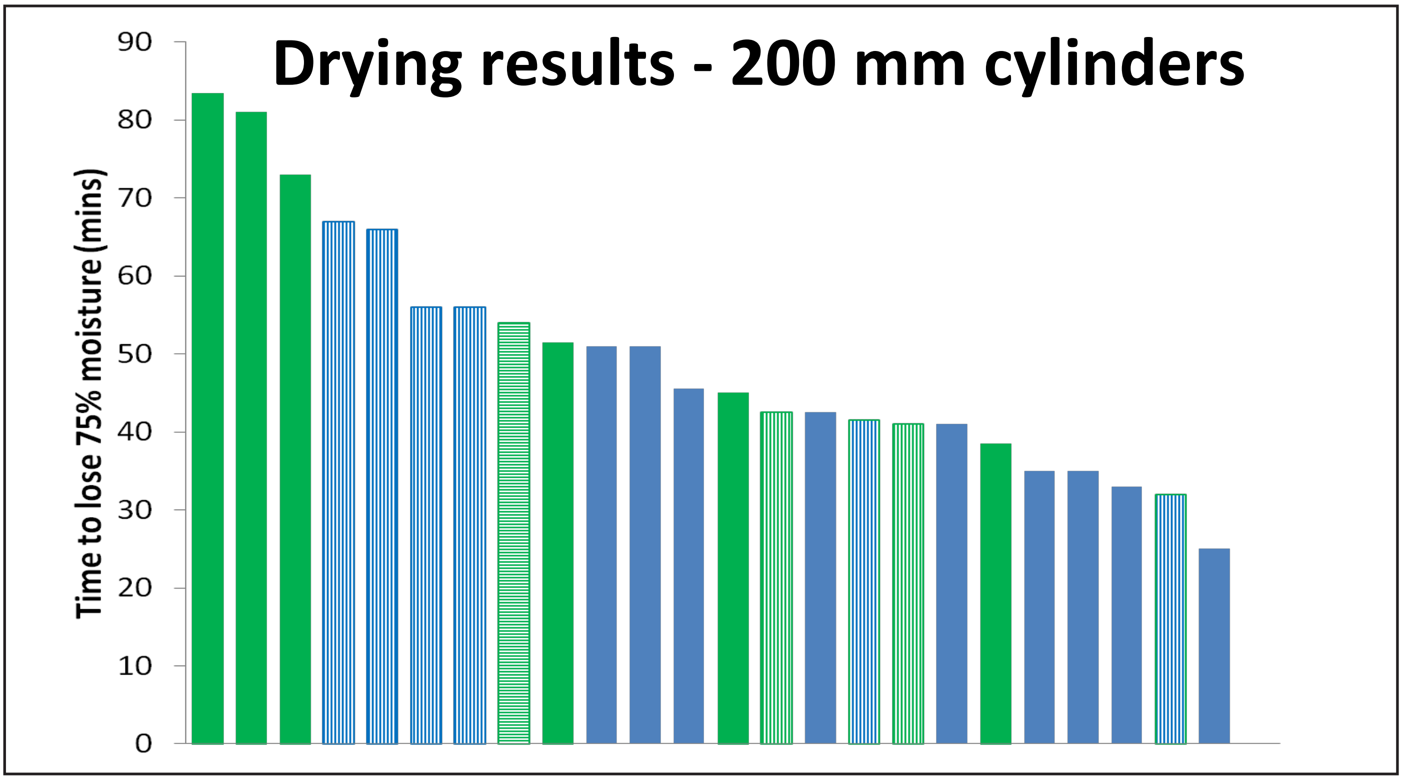
Just to show a little bit about how we monitor the nature of the wetting, these are some of the results from tracing the water front. If you look over at the image on the right hand side you can see a record of how the water front moved from the back to front of the cylinder. What you notice is that we recorded this at regular times so you can look at both the rate the water moves and also the nature of the water movement. Is it straight, showing a very even penetration or does it show some fast and some slow spots? This is a very good one; this is from mix 1 which behaved quite sensibly. If you can look at the image on the left hand side you can see an example of one that showed some very unusual wetting behaviour, as you might expect from complex mortars.

I want then just to summarize the drying results, again using a similar kind of graph.



The vertical axis shows that the time it took to lose 75% of the moisture that has been taken up by the 100-mm cylinders. Again the different bars represent the different types of mortar cylinders tested. For this aspect of the test, what we are looking for in terms of a good mortar is something that dries out quickly. So we're looking for bars that are on the right hand side of the graph, in this case, rather than on the left hand side. The most notable thing that I want to point out about this graph is that there's no clear pattern, no clear distinction in the shorter cylinders between the behaviour of the NHL and the lime putty mortars. But in general those that have the wood ash and the coal ash in seem to dry out at a slower rate than those without.

If we look at the 200-mm cylinders we can see a little bit of more a pattern occurring and in general the slowest drying times are those from putty lime mixes and those with the good, i.e. short, drying times tend to be the NHL mixes.



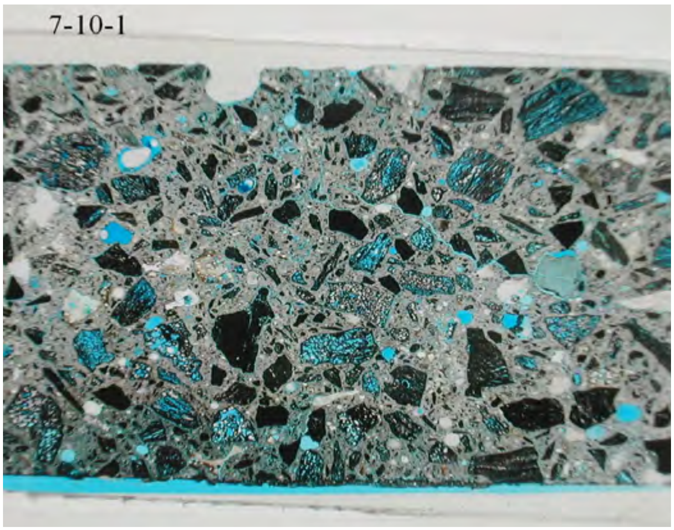
I want to show you some of the results from the adjunct tests, just so we can tell you a bit more about the description of these mortars. This is a particularly unhelpful table by the way, for which I apologise. The point I would like you to see is the fact that the mortars that are made with lime putty have a higher water absorption capacity in comparison with those using NHL and those results also reflect the hardness so the lime putty mortars are softer and the NHL ones are harder. Both of those findings are unsurprising.

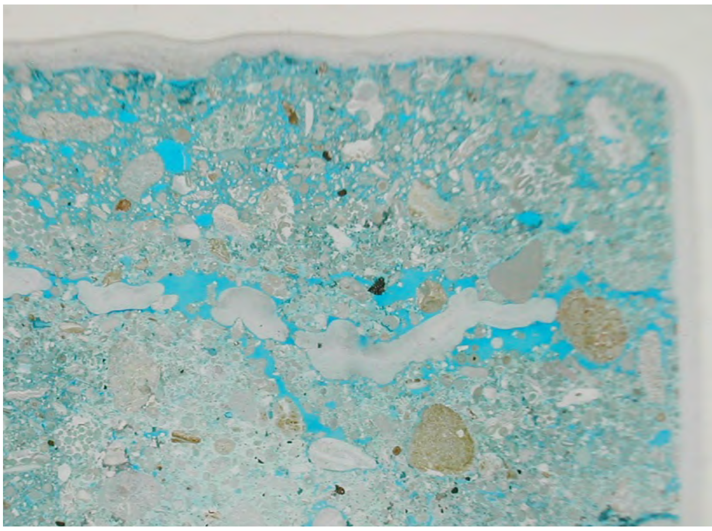
Sample	WACC (gm2s0.5)	Density (g/cm3)	Equotip hardness (Leeb)
1	129	1.96	252
2	473	1.93	220
3	575	1.81	201
4	192	1.95	257
5	484	1.62	227
6	212	1.71	338
7	183	1.4	362
8	212	2.01	285

The thin sections proved to be a really interesting part of this analysis and David Jefferson did a lot of very detailed work on which I'm going to give an extremely brief summary.

Mortar 7 (NHL mortar)

Mortar 3 (lime putty)





This image shows two types of mortars, including one of the examples of the NHL mortar with the ash added (mortar 7 on the left) and one of the lime putty mortars, (mortar 3 on the right). The blue areas are those which have been penetrated by a dye and represent the open porosity and measure of the permeability, the areas that water can pursue. It's clear that there are very great differences in terms of the nature of porosity especially the micro porosity within the binder. The NHL mortars in general, especially the ones with the ash, had very low micro porosity in the binder whereas the lime putty mortars tended to have medium to high amounts of micro porosity and this is very important in predicting their response to water ingress.

The big headline news here that Chris really worked hard towards in his Masters thesis was to create a good objective ranking. This I believe is a little bit of a dark art. I'd quite like you to question Chris rather closely at the end of this, about how he obtained the rank order shown in this image.

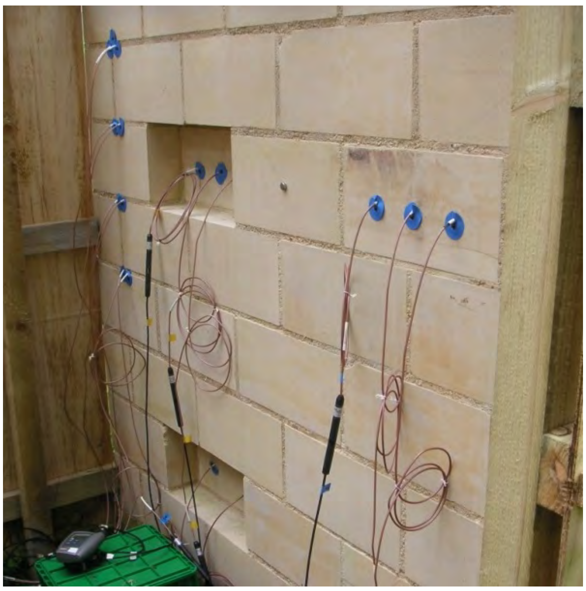
Mix	WAF	WT	WAC	D	H	T	TS	Total	Rank
1	7	8	4	18	4	6	8	55	**5**
2	5	5	3	20	2	2	3	40	**7**
3	3	3	2	7	2	3	4	24	**8**
4	15	11	4	21	4	5	7	67	**4**
5	3	3	1	19	2	5	8	41	**6**
6	22	22	3	14	10	8	5	84	**2**
7	30	28	0	21	10	6	4	99	**1**
8	23	9	4	19	6	8	3	72	**3**

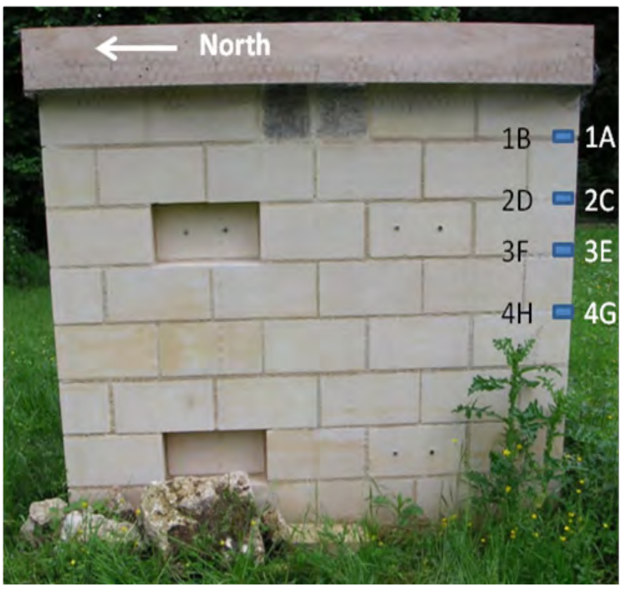
If we just focus on the red box; the mortars that came out as the highest ranked, those ranked 1, 2 and 3, were all those that were NHL and had the coal ash in. In the case of mortar 8 it was NHL plus lime putty mixed. These seem to combine slow wetting, rapid drying and other good characteristics. So we seem to have some advice that might come out of these very simple tests.

Just quickly I want to talk a little bit about the second objective, that's to test the pointing workmanship. What Colin and Chris did is to take an existing test wall built for another project, cut out some of the lime mortar joints, re-point them with various degrees of workmanship and place sensors behind so we could monitor moisture movement over a long time period and carry some very simple semi-quantitative observations of surface moisture using Protimeter surveys. There were four joints: the control joint with mix 1 of the mortars that we tested done to an open texture, finished with a churn brush. Joint 2 was the same as joint 1, but with a closed finished so to produce a flat service. Joints 3 and 4 were similar but much poorer in terms of workmanship, so the stone wasn't pre-wetted and there were various flaws in their workmanship.

To show you how we monitored this, this is the back of the wall in the image on the left hand side showing a series of relative humidity and temperature probes. As I say the relative humidity probes as Liz explained from her lab tests proved to be really inadequate. They record wetting up as soon as it gets wet, but they're incapable of recovering and don't record any drying down. The temperature probes worked very well but didn't provide much useful comparative information.

This is the condition of the joints a few days ago. The top one is joint 1– still very crisp. Joints 2, 3 and 4 lower down illustrate various states of decay over the past few years.

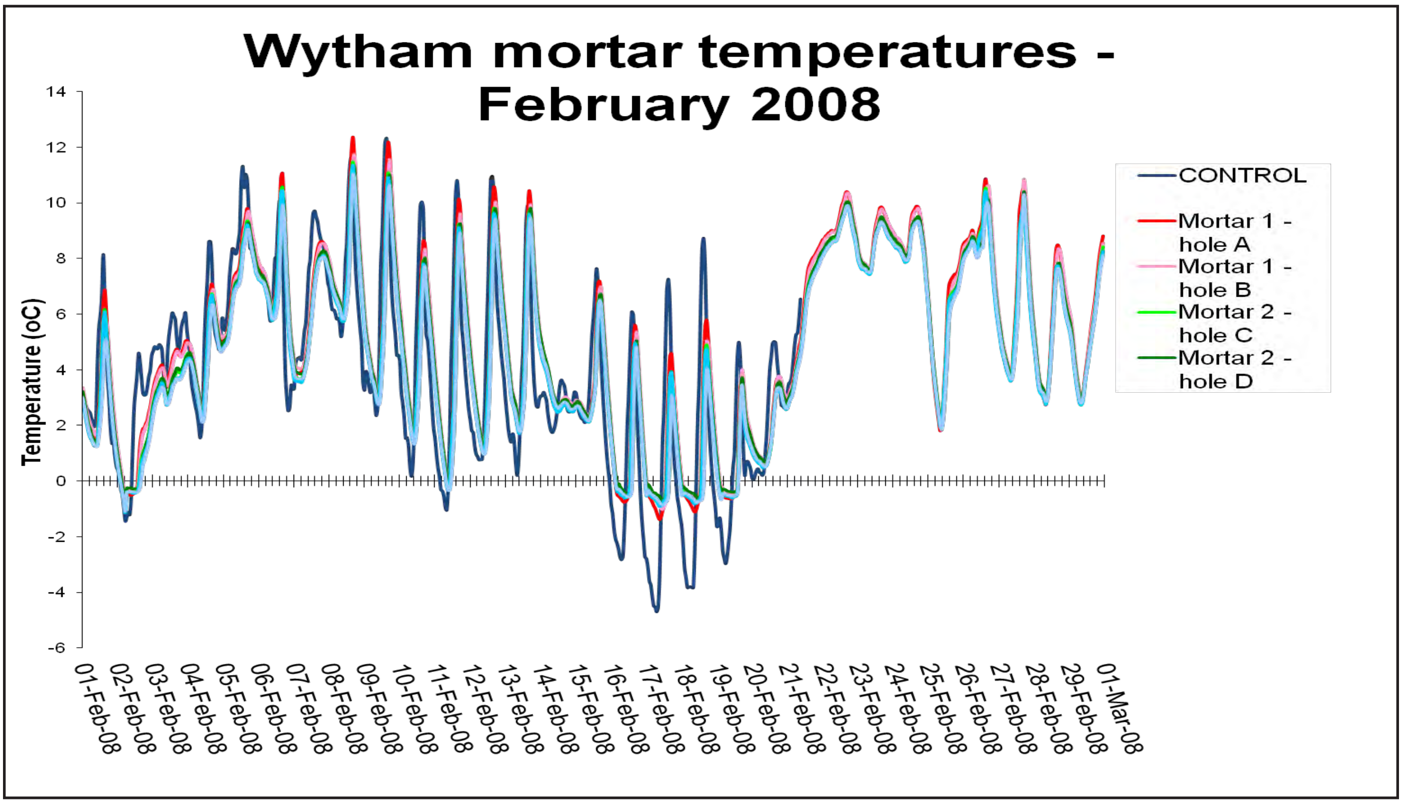




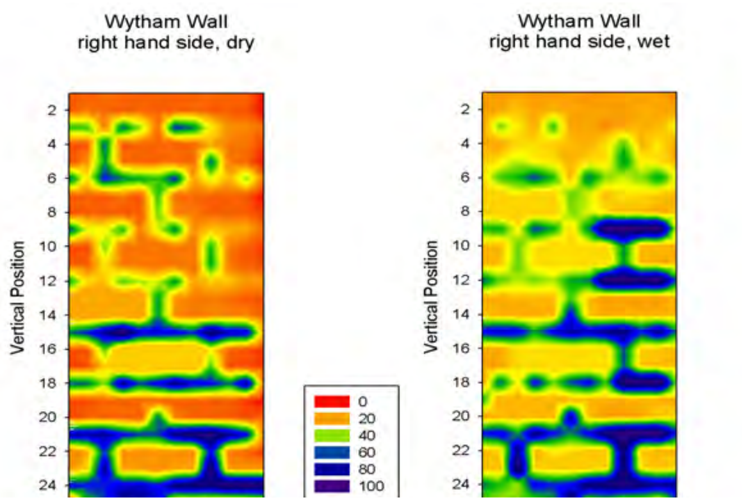
We see a slight difference with mortar 1, but I can't rule out the fact that is simply the position of the mortar at the upper joint slightly sheltered by the overhanging roof which has protected it from decay.

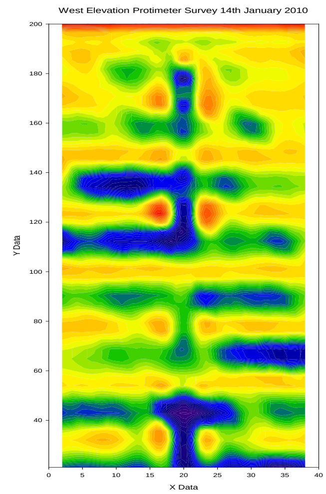
The Protimeter surveys, although very rough and ready, do give some comparative information and I urge you to look at the comparison between the dry and the wet readings here from July 2008.

The four joints are in the red box and you see the dry patches shown in the orangey colour. What I want you to notice is that after wetting the two joints at the bottom – the bad joints – 3 and 4 retain moisture much longer.

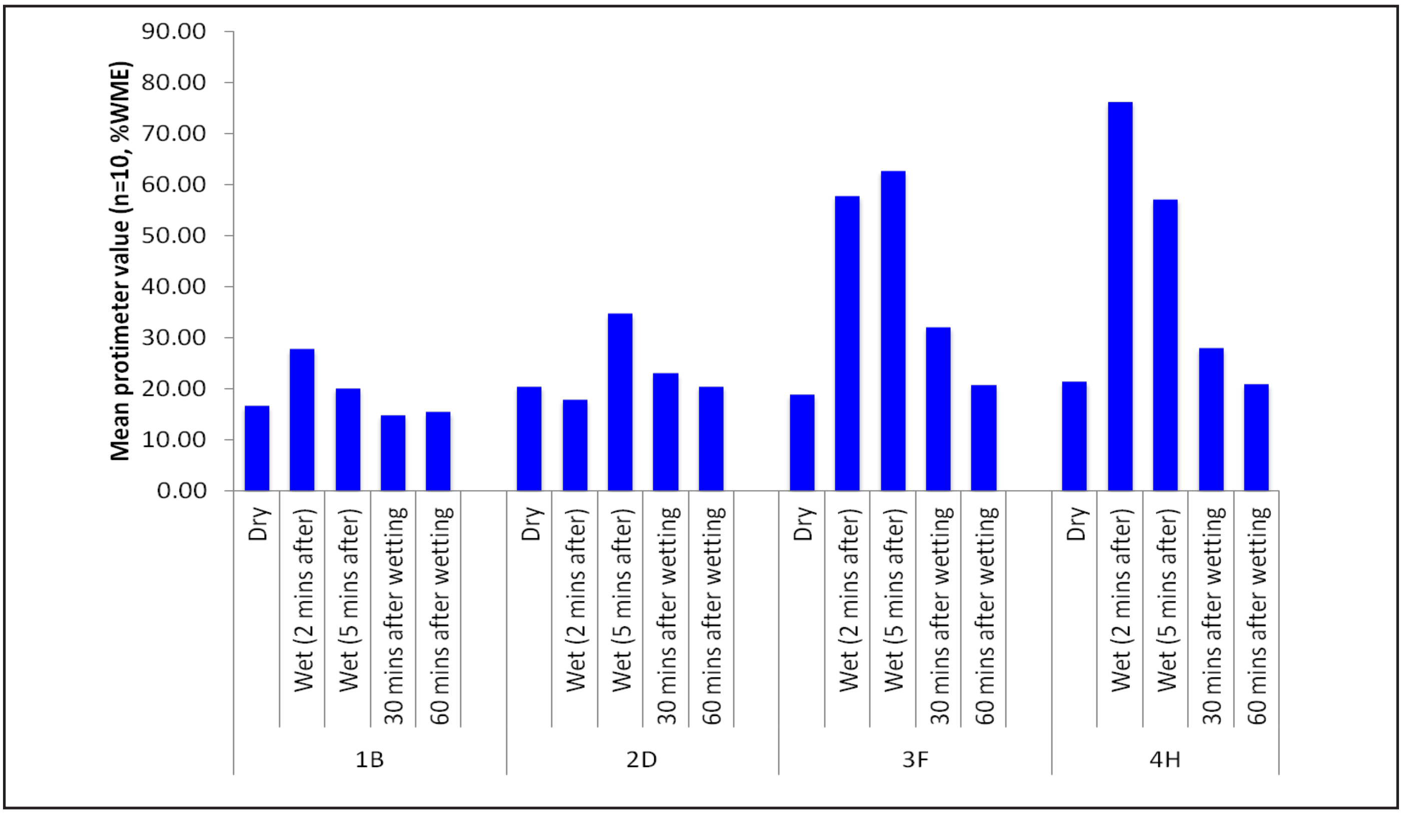


I re-did some experiments the other day using a wetting experiment spraying on some simulating driving rain and again the results are shown here.





What I want you to notice is that joints 3 and 4 are the two right hand sets of bars and I want to highlight two things – firstly that they wet up a lot (the bars after the rainfall are much higher) and secondly that they are still quite wet after 30 minutes to an hour, whereas joints 1 and 2 react much more quickly. This illustrates even in a tentative way that workmanship does make a difference to how these joints respond.



Now for some quick discussion and conclusions. In the lab our bespoke – I love that word – test methods are very promising especially if you use replicates, but they still need improvements. The ranking method, I'm sorry Chris, I think is a little crude, but does allow you to assess many different factors. The field tests are ongoing, it's a really nice opportunity to monitor mortars over several years but we still need better equipment to measure what is happening inside the mortars.

And, to finish, some acknowledgements to people who have helped with the research: Mona Edwards, Lisa Mol, Mark Page (OxRBL). Thank you very much.

IDENTIFYING AND DIAGNOSING THE PROBLEMS

Chris Wood & Colin Burns, Mason, English Heritage Consultant

I'm giving a very quick start to this talk. We are talking about identifying and diagnosing the problems. Colin is going to give the bulk of the talk; in which he'll talk about determining what is going on by observation and simple tests that you can carry out.

I thought I'd briefly mention the types of methods and tools that we used.

Heather's talked about the Protimeter. It has a limited use. It's fine in timber, its fine if it's used the way Heather showed you there. Obviously trying to walk up to a wet wall and get any sensible reading is not going to happen with one of those tools.

We tried endoscopes and boroscopes, but you've got to be very experienced and quite skilled to be able to determine what you're actually looking at when you put them into the core of the wall.

We did a lot of lab testing. This is very useful to test particularly remnants of old renders to distinguish what was originally there. Similarly with mortars, not necessarily in terms of designing a replacement, but it's good to get an indication of what materials were used.

I've already shown this micrograph David Jefferson produced. Petrography is very important, particularly if you want to identify a suitable replacement stone. It's very important to get density, porosity, permeability etc. right so as not to harm the host stone later.

Photography is absolutely essential. Good photography with dates will also be useful to the specifier/conservator as a guide, so that next time he or she goes back new shots can be taken from the same positions. That's often extremely useful for everybody and certainly for the likes of us.

We tried thermal imaging to identify voids and wet patches inside. This was no use whatsoever, simply because of the size of the stone, the scale of the walls and the fact that there was no heat differential because with no heating in the tower it was pretty much the same temperature as outside.

Monitoring: Heather's already told you, and Liz in fact did all the lab experiments, we found that wetness and RH sensors were ineffective.

We used something called electrical resistivity tomography. This isn't bad. It basically puts a signal into the wall that reflects back to the electrode and with multiple electrodes you get an image on a laptop. The problem is it's very expensive and it's not a practical thing as far as we're concerned because you'd need scaffolding to actually access the wall to get all those little round things on.

We used the timber dowel method, the oven balance method which I know has got its critics. It's very simple. Essentially what we did was just simply drilled holes into the core of the walls through the mortar joints on the inside face of the masonry.

Basically the timber calibrates to the same sort of moisture content as its surroundings. It is then wrapped in polythene and sent back to the lab. They're then weighed, put in the oven over night, dried and then weighed again and essentially you get a weight difference between the wet and the dry. We like them because they're fairly cheap and they're easy to apply. As I said we got a number of church wardens to send these back to us and put new ones in. You can access them all from the inside of the tower, you don't have to build up expensive scaffolding and it gave us the data which we required which was not necessarily data of a moisture content on a gauge, but it gave us trends of wetting up and drying on a monthly cycle.

We did try a few high tech solutions. Recently we had colleagues at English Heritage using ground penetrating radar at Portland Castle to see how that would work, Colin is going talk a little bit more about that.

In essence it didn't work, we weren't able to distinguish any cracks or voids under 25 mm. Having said that though, the radar team together are coming down to West Dean to look at some of the ruinettes, because as we know exactly where the voids are and how deep they are, it will give us the chance to see if they can refine their system so it can be of some use. Having said that of course it is very expensive and you've got to have people who are extremely competent and know what they are doing to use it, so whether it is going to be practical for us looking after church towers is debatable.

Anyhow, I'll hand over to Colin now.

Thank you Chris, for that. We are now down to touchy feely things, by way of a change. Low tech if you will. This is a church tower. In the distance, it looks in pretty good condition. However what we need to do is move in, take a closer look and this is a typical situation that we have. It has been re-pointed at some point in its history with cement mortars, but they are now giving up the ghost, they are somewhat detached and fractured. They allow an enormous amount of rainwater to be driven into the heart of the wall. Unfortunately they are also something of a barrier to ready evaporation to atmosphere from the heart of the wall. So it is a problem. It's already been mentioned but to re-emphasise, these walls are at least a metre thick. It's a composite construction, the heart of the wall is a lime mortar – please think of it as a sponge. Wind driven rain hits the face, soaks in and if the wall is complete it will get say half, two thirds of the way through that wall, the heart of the wall always have a moisture content but it evaporates back out to atmosphere when the rain stops. That's the nature of the beast. We've already heard from Liz that if we have a void within the heart of the wall then moisture can continue tracking into those voids, become pressurised and gets driven farther in until such time as it arrives internally.

The re-pointing which really started the whole thing going back in the 80s and the Research Technical Advisory Service of English Heritage, found that once a tower had been re-pointed, 18 months – two years after we would get a call saying that things had become rapidly worse, it was wetter internally now than it was before, and this is the reason that when the cement is in such poor condition and we have 50% of it left, rainwater can run back out of the face and evaporate away. When we point up, the nice lime mortar is complete, it doesn't allow evaporation as quickly, so whatever goes in goes through to the inside surface of the wall.

This particular church was re-pointed, it has been re-pointed about three years ago, but if you look at the glass windows you can see that moisture is on the inside of the glass which means that water has penetrated into the head, running down, and it still has problems.

Pointing alone was not the answer. The answer is you get a huge diamond saw, you put a cut through the wall and see exactly what's going on. Now wouldn't that be absolutely great!

But its very, very interesting to see something like that because the brickwork that you can see that's been placed there in repair at sometime has produced long, straight joints, and the ability for that bulging to occur, and brickwork replacing stonework and so on. No real ties here. So these are typical of the kind of conditions that we are trying to rectify.

How do we know we got a problem? [audience laughter]. Sometimes it's a bit of a no brainer.

Buckets. You can see the green inside – an obvious problem.

This slightly less so I suppose, but good observation on site leads you to look at the underside of arches like this and the awful condition that it's in. Obviously there's some stitching and some grouting is going to be needed.

There are a whole range of things that tell us that there is a problem from a distance.

Damp patches running down the wall. Calciferous material running from the core depositing on the face. When is the best time to do an inspection of a stretch like this? After it has rained and when its beginning to dry out because we can see all these faults like that. And you could go on and on.

Chris has already mentioned pipes that are inserted where rain water has been escaping from the heart of the wall. You've got the pipe here, seal around it and it dries up. For whatever reason they never work, only for very short periods of time, so that's a bit of a waste.

This is an obvious problem: A lot of escaping rain water carrying lime with it.

On the way down in the car Chris was saying: Colin, we must be quite clear about this, there is no blame game. We are not going to make any criticism of any practices or anything else, which is a bit of a relief because if we look closely at this little image on the left side on the down pipe, we can see an English Heritage logo!

Vegetation of this kind demands a lot of moisture and constant. You can't just turn it on and off, so the core of this wall remains very damp for long periods of time. This is in fact one I'll be showing this afternoon but typical if you've got a structure which has been cement pointed and you are looking for potential damage go to the corners first, that's where its going to get kicked off and won't be able to recover, so we are always going to get fractures which ultimately lead to situations like this: with loss of mortar, voiding and vegetation.

A pretty little granite structure. If we take a quick look inside, it's quite obvious where the ingress of water is coming from, and it's through the perpendiculars. Isn't it funny, perpendiculars are always the problem! I explain to students on occasions that mortars when they are in compression with stones and bricks on top of them keeping the weight on, perfect. Perpendiculars never get the privilege of that weight. They only ever get the weight that we apply to them, via the pointing key. So perpendiculars are usually the first to fail. And there should be a relatively simple solution for this, perhaps pressure washing out the joints, re-grouting. Here the underside is cement pointed, so whatever repairs are carried out and we leave the cement pointing there, our mortars are going to get rain from the outside and will remain in a fairly wet condition without the ability to evaporate internally.

Chris has already mentioned penicillin growing on the walls. You can see the moisture glistening on the surface. This is the inside surface of the tower, in Dartmoor, it's just so unhealthy. We were in there probably 20 minutes and couldn't wait to get out.

Some people will say that if you listened to the walls they will tell you what is required. This wall I think was screaming "Help!" It's just so damp and horrible. It needs the heart of the wall looking at. And again there's just too much vegetation.

This is a through-stone, in other words a single stone from external face to internal face. Now the tower as you can generally see is dry internally and in good condition, but this one through stone is transmitting moisture right the way through, so beware of those little rascals. You need to know about them.

We are off to the western isles of Scotland now. We'll bring to your attention to these important, circular, sandstone columns with very decorative heads. We can also see the fairly high moisture levels.

Now this is an island site, Iona. The moisture that you are seeing there is actually coming from the clerestory. Salt water is getting in, coming down through that spandrel, evaporating out to atmosphere, bringing salts (crypto efflorescences) with it, and destroying the surface of the sandstone. In a situation like this we need to resolve the issues tout suite.

Now, I visited this church, I went up onto the roof and I believe that two storeys above the ground floor were lost and subsequently rebuilt. This is up at roof level and this is the condition of the core that was built. Those small voids obviously do interconnect to some extent, and they carry and transfer rainwater down to the structure to drive that salt problem. Internally there are problems. It was suggested that they should render the external surfaces of their tower, but they weren't keen because they want to see the pretty stones! I wonder if we got rid of the moisture here whether they'd complain about the loss of vegetation. It looks rather attractive in a curious sort of way.

Chris has already shown some of these drainage systems and the ones we visited were dry!

Now for a little bit of theatre. Removing stones from the face and taking a look at the core, sometimes tells you nothing and sometimes tells you everything. Medieval construction was quite poor. There is no comparison between it and Roman. You can see that perhaps there's been a little bit of wash through, a bit of calcite there, but for the most part it has never ever had mortar in it. So that's how it started life. In my experience so far, I've never seen a core that has been washed out. I found cores in this condition, but it's a bit of a fallacy that they do wash out.

So I give you those comparisons with the voiding. Obviously here is much larger, and the influence that this is going to have when you try to grout this core is phenomenal. They are chalk and cheese. The expertise in grouting unfortunately is within the people that carry out the work. It's not in specification. How much water do we put in the grout to ensure that it will flow through the structure? You need experience for that. You need to know the size and distribution of the voids within your wall. Without that knowledge you are not even in with a shout.

Here you can see that the beds are solid, but the perpendiculars are open.

How do we know the condition of the heart of this wall? How do we even start to get the contract documents together? By going on a very large grid system and drilling into the heart of the wall. And it might sound somewhat silly, but there is an art to drilling a hole in the wall. Because if there is moisture in there and you go drilling like some kind of lunatic, all you will do is create a slurry around the drill bit, which will grip and you will loose all feeling. The whole idea of drilling is to drill gently, and when you come to a void you get a lurch. A lurch could be 20 mm, it could be 120 mm. If you have a detached face which looks good but in fact, isn't; you'll soon pick it up, with the drilling, immediately. When each hole is drilled properly and the data is recorded, including each time you get a lurch and its distance then you end up almost with a 3D picture of where those voids are and when you test it with water and you can see which ones interconnect.

That ladies and gentlemen concludes my presentation.

QUESTIONS

AUDIENCE MEMBER 1: I see quite a few of the graphs that you've done on water penetration. You've not mentioned anything to do with the natural tendency of the water in the tower to probably move downwards. When you see it coming through, you don't see the water line moving upwards, obviously it goes in, the way the water drifts downwards. I just wondered what research has been done on that.

LIZ LAYCOCK: I didn't manage in the time, to show all the data we've got. What we've shown under the driving rain conditions is why we would have anticipated that the water would generally manifest at the base of the wall. In actual fact, some of the walls, even the perfect construction, leaked at the top of the wall. Water under driving rain conditions will seek the easiest route from front to back and while that's generally, as Colin has highlighted, associated with perpendicular joints and some of the through stones that go through the wall, it doesn't always follow the expected norms of water transfer because the systems of mortar and stone are actually very complicated and it's not a simple, homogenous system, unfortunately.

The small scale test walls didn't really give us opportunity to explore the very large scale and weren't manifesting the patterns of a large scale tower, where again you'd expect the water under gravity, to migrate towards the base of the tower rather than the top. Does that answer your question?

AUDIENCE MEMBER 1: Yeah, I'm, thinking of a brickwork construction where obviously it's more consistent than you'd get on stone and that's what we're experiencing. Water is actually moving downwards in the lower 3 metres.

AUDIENCE MEMBER 2: I wonder if I could ask if any research has been done yet on the frost damage, in particular during the last two years that we've been experiencing in the West Country?

LIZ LAYCOCK: As far as I'm aware, in terms of frost damage on walls, the large scale testing has generally been on the frost resistance of brickwork and I think that's principally because it's usually where the money is. It's usually frost damaged paid for by manufacturers or at the behest of manufacturers. Research is the principal test house with brickwork. As far as I'm aware there is no laboratory frost testing of large scale composite construction as we have evidenced here. I am aware that in the literature there has been a suggestion of particular damage into the core caused by frost attack, but there is no laboratory work to back that up. Sorry.

AUDIENCE MEMBER 2: Thank you.

AUDIENCE MEMBER 3: Can I just ask the panel, am I right in thinking that we are better off considering the use of hydraulic limes as opposed to non-hydraulic limes, if we're going to do repairs to our church buildings? It's just that the research seems to suggest that we should be moving towards hydraulic limes.

COLIN BURNS: Well it's certainly safer isn't it, that's for sure. Unfortunately I think we've lost an awful lot of confidence in ourselves and in the non-hydraulic limes. I think they're capable of much more than they're producing at the moment. Having said that, you need people who know what they're doing to be able to drive them properly. I suppose the same can be said to some extent on the hydraulic. I teach on this subject at West Dean College to students all the time. The answer is water. If you've got a mortar failure almost always it's because of water – shortage of or the mortar is allowed to dry out too quickly and so on and that can affect both non- and hydraulic.

AUDIENCE MEMBER 3: I think it was the water uptake rate that I was quite alarmed to see. The non-hydraulic was taking up water and holding onto it, more so that the hydraulic.

COLIN BURNS: It does, but it's the nature of the beast. The non-hydraulic gives up the water to the atmosphere more readily than the hydraulic. It's unfortunately understandable that somebody has to be responsible for the specification and that being professionally safe is very, very important. It is just such a pity that we don't use our materials more thoroughly.

CHRIS WOOD: I would agree with everything Colin said. If you're referring to the ranking system, I don't want to be too critical, but I didn't want to include it because it's not quite as simple as saying that we want a mortar that wets up slowly and dries fast because it's doing so many other things and it depends on the circumstances. I'll be giving a talk this afternoon on renders and I'll be at pains to point out that we've seen as many good, fat lime renders as we have hydraulic renders. There's no reasoning principle why one shouldn't perform as well, if not better than the other. It comes down to very much what Colin is saying, workmanship.

AUDIENCE MEMBER 3: Whether or not it's a hot lime perhaps?

CHRIS WOOD: That will no doubt help, yes. Particularly with practitioners who are experienced in using and then tending it. And that's probably the most important factor, and I'm pre-empting what I'm going to be talking about this afternoon. In terms of the success of these renders, the actual amount of care, aftercare and tending that they're able to give. And as I say, we've got a lot of evidence that fat lime renders work just as well. They might possibly need more work and more skill, that's the other point.

AUDIENCE MEMBER 3: Thank you.

LIZ LAYCOCK: Can I just add to that the work that we did, although it was inconclusive, there wasn't a clear pattern, the lime putty render did appear to dry out in a wall construction, slightly faster than the NHL, which I realise is a different pattern than was picked up looking at the mortar systems alone.

AUDIENCE MEMBER 4: In your mortar testing the samples were tested at 100 days, so in terms of non-hydraulic mortars, the mortar wouldn't be properly carbonated, so perhaps that could have affected the test results. Do you anticipate that if similar mortars were used in an actual wall where they were allowed to carbonate for a much longer period, you might expect much better performance results than you actually got in your experiment?

CHRIS WOOD: Probably yes, is the answer to that. We spent a long time thinking how to design something and the reason we used those tubes was that we could actually see the performance. 100 days seemed a reasonable amount of time and that was all we were able to give it. There's no question that the testing protocol could be improved, particularly if we could apply the same sort of testing to the external environment and that means either a small scale wall or putting it into an existing building. And it's one of the things that we wanted to discuss this afternoon was whether people see mileage in perhaps doing additional research in certain areas because I know other agencies are very interested in the whole problem of wind driven rain and it's effects. And that is certainly an area that warrants further examination.

COIN BURNS: One of my pet hates are mortar trials and mortar cubes, which are placed out on scaffold racks at Hadrian's wall, totally exposed, and they break down. There is a comparison between one and the other, but it is totally non-representative of any situation you're going to place a mortar into. If you're going to test the mortar, test it in the wall. And we know the lime mortars, if they're working properly and they always do; as the stonework/brickwork erodes back, then so does your lime mortar. It never stays out, projecting as a cement one would do. In other words they can not take three sides exposed, so don't try it with 6. It won't work.

AUDIENCE MEMBER 5: Might you comment on two thoughts that I had. Firstly, whether it's the hydraulic or non-hydraulic lime, the results seem to be a lot better if it's mixed with ash. I just wondered whether this is with historic lime that the actual method of manufacture would have resulted in a lot of ash within the lime being mixed in with the mortar from the word go anyway. And the second thought is you've talked about voids as a mechanism for transporting water through the wall from one void to the other, but I wondered whether there is another, so the mechanism of voids creating a reservoir for water was somewhat hinted at. The comment that the water was coming out of the wall a week after the rain has stopped.

COLIN BURNS: Absolutely. If we could deal with the ash question first. I had the privilege of seeing the work of Herod over in Israel at Masada, where it is an ash lime mortar which the water systems, twice the size of this room are rendered out in, which is quite extraordinary. That's always fascinated me. The ability of wood ash in particular. What the characteristic is, I'm not sure. Perhaps this is a research project? I get the feeling that perhaps a wood ash when it becomes wet may expand ever so slightly in conjunction with a good lime putty it can become sufficiently tight to hold back water. I think the results suggest that it doesn't give the water back again either. So all of this information in a lifetime, you pack into your computer and there are all these situations where you need a mortar which is going to hold moisture back; retain moisture back or whatever.

The second part of your question: I think it was at Corfe Castle where somebody drilled into the wall and gallon upon gallon of water came out as a solid spout for about half an hour. So yes, you're going to get voids in the wall that hold moisture and give it up gently.

CHRIS WOOD: Can I just come back on the question. It is something we've discussed at great length. What is it in the ash mortars that give it these properties? We discussed with Peter Ellis. It was his coal ash that we used. A lot of people are convinced that it gives a pozzolanic set and improves it, but it gives something, we're not quite sure why it achieves what it does and it's certainly something that would certainly warrant investigation. We'd love to go to Masada and do some more work on this. But certainly the reservoirs, absolutely right and the walls at Sheffield prove that. When you've got liquid water inside, that flow that I was talking about will continue. If it's all seeped into the core and it's basically no longer in the liquid form, it doesn't.

PETE ELLIS: There's a lot of fine material in that coal ash. Obviously porosity and permeability are not only to do with the binder, they are to do with the void structure within the mortar. When you have a lot of very fine material, obviously that tends to fill the voids in the mortar . It get can get less porous and certainly less permeable and that may explain some of the results, I don't know. And certainly in terms of the rate at which it absorbs moisture. So I think that's part of it . Coming back to your point, the pozzolanic reaction depends on the amount of reactive silica within the aggregate and there isn't any, or at least there virtually none in coal ash. I tested some of those mortars from Masada and it was very clearly a hydraulic lime that was used. There was ash in it, but I don't think it was the ash that gave the mortar it's the waterproofing properties. That was my conclusion anyway.

AUDIENCE MEMBER 6: I'm interested in the use of non-destructive testing of walls. It seems to be suggested that it's not worthwhile or that it's not successful, which in my experience, having once been asked to grout a large void at a National Trust property, it turned out to be a chimney flue! And recently working on another large building where there had been considerable expense of doing non-destructive testing of the walls to find voids. When we did drilling we couldn't find any void at all. It seemed to be recording different mortars rather than voids in the structure. But can I ask the panel, or indeed anyone in the audience whether we should not be 'dissing' non-destructive testing of these walls and whether there are methods available now or that will become available that are good and not too expensive and able to be interpreted?

CHRIS WOOD: I wasn't trying to 'diss' these methods, but to point out that we had no success and that we went to something that was cheap and cheerful. No. we would be delighted if we could come up with some method of non-destructive testing which would tell us exactly what's going on inside a wall. We'll continue persevering. Can I ask you a question: did you manage to get your grout out of the chimney? We've never tried to reverse one!

AUDIENCE MEMBER 6: No, in the end we became aware of the problem when a lady volunteer at the desk, handing out tickets and her handbag was 4" deep in grout!

HEATHER VILES: Can I just say something about non-invasive and non-destructive testing. I think Chris is quite right to point out that it's proved to give enigmatic results at the moment, but that's no reason why we should stop pursuing it.

And I think there are a couple of things that we can make progress on. One is making sure that we use a range of non-destructive test in conjunction with each other. We're often expecting too much from one individual test and I think knowing what they can and can't tell you and making sure that you use at least two approaches in conjunction will help. But secondly I think there needs to be an awful lot of work just cross-checking what destructive and non-destructive testing is telling you. I think we do need to do a lot of work where we could hopefully pepper a structure or actual building with destructive testing, having previously carried out non-destructive surveys. Because I think we're asking an awful lot; we know so little these materials and the architectural context, but I really think we should make progress. It would totally stupid if we weren't able to make use of these things. They are expensive now, but they're all coming down in price. In five to ten years time, they'll be really useful bits of equipment, I suspect.

CHRIS WOOD: And that's precisely what we're going to start doing, hopefully at West Dean on one of Colin's ruinettes. We'll try Ground Penetrating Radar together with a couple of other high tech solutions!

AUDIENCE MEMBER 7: Am I right in saying that we're still dissing (if that's the right word) water repellents; even high tech, modern nano technology? I mean, for 30 years I've been told that it's the work of the devil because it will clog the stones. But is there no scope to do research on this at all? None seems to be forthcoming. I even phoned Keim in Germany to try and get some kind of good account of how their products and I failed to get anything from them at all.

LIZ LAYCOCK: I'll take that if I may, as 'lightning conductor' for all things water repellent. I'm currently sitting on the CEN technical committee for the assessment of laboratory-based methods for applications for cultural heritage and one of the standards that is going through is on water repellents in cultural heritage. A few points you should be aware of are the standards that are being applied are extremely stringent and it seems to be the thought of the various countries involved in the development of those standards that the testing regime is extremely onerous in order to prevent mis-application of these materials. The standards themselves are generally assessing the application to one particular substrate, so one of the cautionary idea that I would like to throw out is are you sure that for your particular structure that you are confident in identifying all the potential pathways that water may be entering the structure. Are you then confident that the water repellent will then prevent those pathways from being exploited after application for the rest of that structure's life?

AUDIENCE MEMBER 8: I noticed that your tests seemed to show that smooth render seemed to behave better in terms of preventing moisture penetration than a rough one which is slightly counter intuitive for, I think we've been told for years that a coarser render would be better in terms of having a larger surface area. Could you comment on that?

LIZ LAYCOCK: I think, as I say, the results were not conclusive because the renders actually had two different surface finishes. So that's why the results should be taken with a big pinch of salt. We had a smooth, lime putty and a coarse, harled NHL, so not definitive, but we can only test so many permutations within the experimental frame. So I think that it's really a factor of the interactions with the environment and the surface water, the maintenance of a wetting front through the constant presence of water in the core structures as the material wets up and dries out. And I think it's the maintenance of that wetting front wanting to export water from the front of the wall that it's such a complex system that realistically I wouldn't put money on the results as they stand to give any definitive answer without further work.

AUDIENCE MEMBER 9: I was going to ask on the same subject on the drying out of the render. Obviously if you've got a greater surface area, drying out should be faster and therefore the result, you talked about that those samples may not be representative. You talked about the smooth render not absorbing as much water or any water, where as the porous render absorbed little, but it's surely in the drying out that one should see the difference.

COLIN BURNS: I'd just like to pick up on the previous point about closing down the surfaces rather than opening up or harling. Closing down a lime based surface to me with any metal implement is sacrilege and very, very dangerous. You are in effect in my view anyway, creating two zones: you've got the body of your mortar and then when you close it down bringing all the fats up and you provide a skin which is going to work differently to the underlying mortar. You are likely to get a shedding of the skin in those circumstances. It also prevents moisture from evaporating out as quickly, in my viewl. So, no, we're not advocating that you close down surfaces at all.

AUDIENCE MEMBER 10: Hello, just to pick up on the silane thing. I know that in Germany it is used a lot on their historic buildings. Alte Pinakothek in Munich is coated every few years. But in most British circumstances, you only get one go at it. I worked on one building that has had silanes coated on the outside. It probably got washed off within two years in exposed condition. But, I was very interested and my main point, to see your mortar samples in plastic pipes because the photos showed that there was extra moisture at the interface. I think one of the things I'm taking from this morning is that you can not get that bond between mortar and impervious stone. That seems absolutely crucial point for mortar penetration in a wall. You've talked about mortars, the actual mortar itself doesn't seem to be the problem so much, in terms of the overall priority. It's got to be how well the joint between the stone and the mortar is working – that seems to be the main bone of contention, I think.

COLIN BURNS: I couldn't agree more. In fact, porous stone surfaces, one of the little things I do with students is take two chalk blocks which are dry and take two chalk blocks which are moist and put exactly the same mortar between them and make a little sandwich, leave them overnight and ask a student to pick them up in the morning. The dry one you'll simply lift the block away, leaving the mortar on the other block below. Where they've been moistened, you can pick up both blocks by picking the top block up alone. You can hold it sideways, so you prove that bond – in porous materials – that's fine with chalk. When it comes to impervious, even surfaces, I believe we have something of a problem. It was well illustrated with the black dye at Sheffield Hallam and that was particularly prevalent in the perpendiculars. Again, those perpendiculars are going to let us down every time. And work as hard as you may, I think they're always the weakness in the wall. I don't know that there is any answer to it. You can be as thorough as you can conceivably be, that's the best you can do.

CHRIS WOOD: One of the points is that we're talking about impermeable stones, there's not a lot of point putting water repellent on the stone. What we're really talking about is putting it on the joints. And of course, long term, joints are supposed to be sacrificial. Whether they will continue to function in the same way when they're covered with an effective nano-lime type material is open to speculation. I had a look at a lot of the testing that was done in Europe which was done on water repellents and it worked quite successfully – admittedly this was on brick – but after one or two of them broke down, what they found was exponentially, where there was break down, the amount of water that was then taken in at those points was quite colossal. Even though it is only little part areas of the surface. And with water repellent there, although they claim to be breathable materials, we're talking about liquid water getting out. Whether they do or not effectively is a moot point. And this whole question about a breathing material and how well they're tested and to what extent we get rid of any extraneous water or liquid, in my view, has not been tested, or at least I haven't seen any tests that give me any confidence that long term they are an answer.

EDWARD IMPEY: Right, on that uplifting note on how we know nothing, we'll end this session!

GROUTING: GOOD PRACTICE

Colin Burns

What I'm going do is talk you through the grouting process and show you this in practice as well at Stowford Church.

We have been quite fortunate since 1973, running training courses at Fort Brockhurst, and introducing students to basic grouting procedures, as you shall see here.

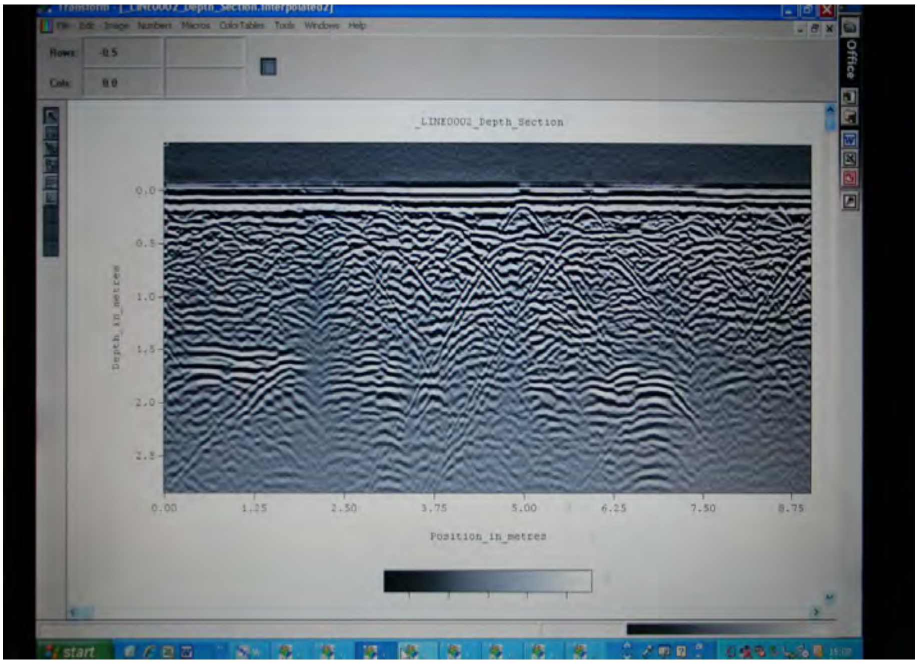
We are using a diaphragm pump and a pressurised pump on this occasion. That first single image encapsulates the grouting process. It's quite a tricky one to get photographically, but you can see there the wooden pegs and the cotton wool. Some people are occasionally surprised by the cotton wool, but it's absolutely the best medium to use when grouting because it allows the water from the grout to pass through and obviously thickens the grout at the interface. So it's fantastic for stemming leaks.

Now in the process of filling these walls up they become totally filled and useless, unless we take the face down, excavate them and re-run the process, which is what we have to do.

So there is the grout behind the face work which is been taken down, and we learn so much from this. It's a unique position for us to be in. We can look at the various grout types. What we have always used to date are the heritage grouts which are lime based. We have a range of grouts. A tarmac product, LPB221 which is basically hydrated lime, PFA and bentonite and would you guess in the proportions of 2:2:1. We have heritage grout 1.5 which is referring now to the crushing strength at 28 days strength and we have Heritage Grout 7, which is a bit of a beast. St Paul's mix as developed by English Heritage – it carries cement – it's an animal. I wouldn't use it anywhere, well maybe underground.

So these are the grouts. We learn how to use them, what their characteristics are, what their strengths are, and when you have to remove the core as it is I can assure you that even with the weakest, the LPB221 just acting as a void filler it's a hells of a job getting that out of the wall. So I advise that you think of them, unless it's a structural problem, as a void filler and you don't need a great deal of strength with them.

The other thing is how much water do you put with them? The manufacturer will tell you for a 25kg bag to put 20 litres of water. That is to get to that strength which is already quoted, say 1.5. In reality you'll never get that into the wall, it's too thick, and I'll be able to show you that in a while.



Chris has already made mention of non-destructive methods, so I'm not going to go over this too much. This particular image shows the read out that has to be interpreted.

What I can tell you is that that's the face of the wall, that's the rear face of the wall, and obviously that's the core of the wall. If it means something to you put your hand up immediately! I knew that there was an empty perpendicular and said "could you tell me that that perpendicular is empty" and they said "No, sorry, can't, too fine, too small, need a bigger hole please". [audience laughter]

So it takes us back to the fact that we've got a building in front of us with a problem, without any hi-tech solutions, how do we find out? And as I suggested earlier, drilling gives us a really good insight to the condition of a core, whether it's totally solid or whether it's voided, and by careful drilling we can determine at what depths and what size the voids are.

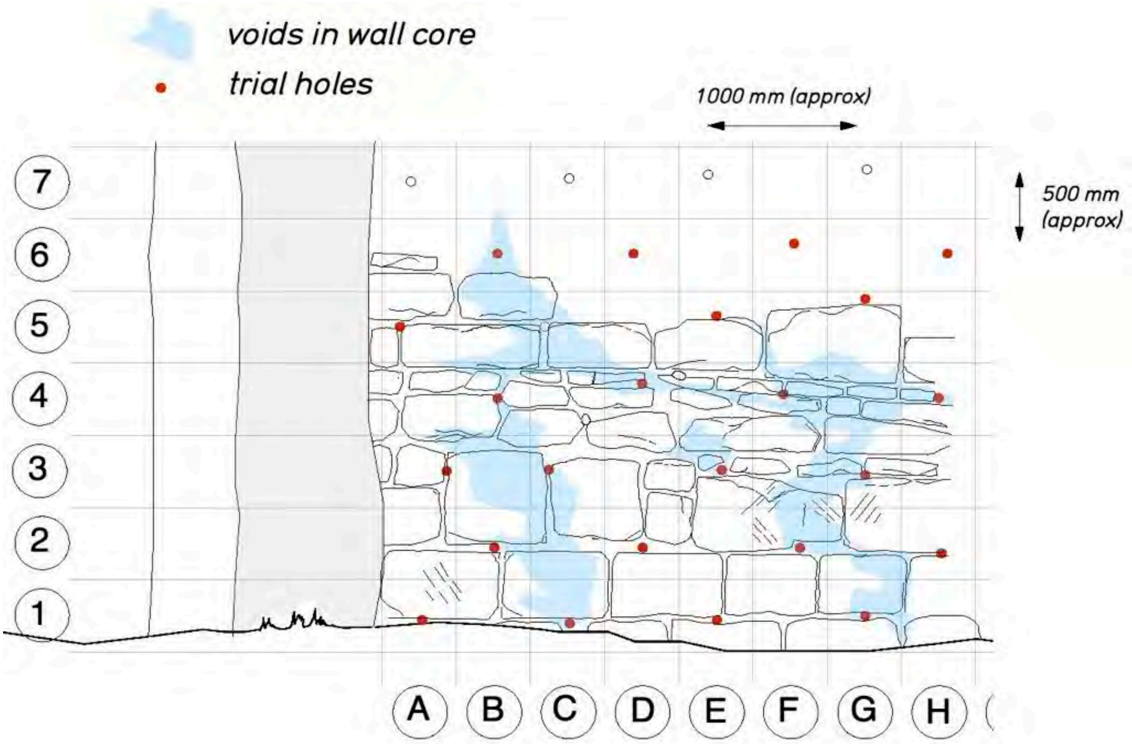
Now we come to Stowford Church and the tower at the back. This is where we carried out full scale grouting of the whole tower. Chris has already alluded to the fact that it had a very good contractor. I would venture to suggest that today if we wanted to grout this tower that there isn't a contractor you could go to with a fully trained up team to carry out that grouting work. It doesn't happen regularly enough. And whilst we trained up a team on this particular project in the short period afterwards, life being what it is, they disperse and go their separate ways, go to other companies and are no longer a team, so grouting whilst it is often the solution is very difficult.

I've mentioned the grid system already. On a separate piece of paper you record every drill hole, and not every drill hole of course will pass a void, in which case it's a blank, leave it, block it off, in fact. Just concentrate on the ones that are open and interconnected.

You need everybody in the team to have the same grid system image, in order to start the grouting process.

Before you start the grouting process you have to get your wall core in a condition to accept the grouting. We did this deliberately at Fort Brockhurst where we underdid the pre wetting process and then injected grout. In essence inside the face we ended up with like a mushroom-like effect: the grout spread out, de-watered and that's your lot. It will not go any farther. Game over in that particular grout hole. So you've got to be able to get that water consistency right. Therein lies the success.

You can see on this image. Let's say I drill a hole there. I'm going to cross the void there, I'm going to cross another void there, might be quite a long one, on occasions there will only be one, or indeed none.



A typical condition, as I mentioned earlier, you go near a corner if you want to see how the walls are performing with cement pointing in it. A step fracture there, loss of cement pointing, vegetation, all those signs – a problematic core.

In order to pre-wet the core we set up these interconnected tanks with a supply pipe from right the way down the height of the scaffold, teed off on every level so that we can flood the core and test and see where these holes interconnect. So that is essential as is the supply to them. Unbelievably this little pump pumps water back to the top and keeps it full at all times.

Because of the condition of this particular tower and the condition of the cement pointing, it's not sound enough to use as a barrier to escaping grout. We couldn't ever hope to stem the flow of the grout from the core to all these holes. So the decision had to be made that we would test, pre-wet, rake out, re-point in advance of grouting. Quite unusual, because you'll have to re-point from the ground up rather than coming down as is the traditional way. Because your grouting will always, start from the ground upwards. You never grout downwards. You could get air pockets, you could pick up loose debris in the core, bring it into a narrow neck and block. So always grout upwards. That loose material when you are going upwards goes into suspension, falls out of suspension quite quickly and your grout can carry on its passage through the wall.

So at this stage we've raked out the joints and we pre-tested the wall with water. Where the water escapes at the bottom point we insert these little plugs. That's where we are going to introduce the grout, at the bottom of the void, in each one. Some of these interconnect; some don't, but that you'll have on your plan.

Now all the pointing is done. We've got these little bits of hose. They, by the way, are drilled to nearly a metre deep. If we drill with a 25 millimetre diameter masonry bit and then we put a smaller diameter, something like a 15 millimetre diameter hose, you'll see that if you feed that hose right to the back of the hole and then inject grout its going to feed back down the hole. In doing so it will pick up any fissures and voids within the length of that hole and feed into them.

The other thing is that we always precede grouting with water. We wet the core up; we cannot over wet it because what you'll find that when you start grouting water will float on the grout. It will precede it through the wall, and that is good news because it's wetting your surfaces and you're going to get good grout flow.

The other thing we learned, (I've been able to take faces down), is that all the voids in the wall are not the same size! Well what a surprise! What we have are fine fissures and large voids. How do we satisfy that, in terms of water content? The only way I've been able to deal with it is to start with water, then we go in with a grout which is very runny, it could be 50 litres per bag, so it's a very thin grout. That is then followed up with a heavier grout. How heavy? I can't tell you. There's no table that we can look up. We have to work from experience. Knowing what your grout will flow like and down what size of fissures. But that chosen system, the thin material gets pushed out preferentially when the heavier material comes up into the larger voids, and we get a satisfactory result. Because there's so much water involved, when we are grouting the wall what you should see is water actually coming through either the fabric (not in this case, its far too dense), but certainly through your mortar; and it will 'bleed' water; and that is as it should be.

In this particular face, you can see that the cement mortar is in such a condition that it can retain the grout satisfactorily and a repair here and there as we get small leaks, so straight into the holes with the hosepipe.

This is the equipment that I favour – farmyard engineering. It's a diaphragm pump and you pull the handle and it pumps grout. Surprisingly it's quite delicate and if you get blockage or any resistance you can actually feel it; and if you can't feel it there is in fact a gauge on here, and that's probably as high as you want to see it go.

I always remember, many years ago back at Fort Brockhurst, we had a group of Americans down for a month, they were grouting and we were getting near the top of the void and this beefcake I'm not joking, he lifted about that much (300 to 400 mm) of the masonry as a wall cap, up, and the grout flew out, and guess what? I got it ! He thought it was ever so funny. It is dangerous. You have to gently ease the grout into the void, because you've got interconnecting voids and your grout is not just going straight up, it's going in, back and along. You have to give it time to do that. You are going to get leaks. Now if I got a leak down here somewhere and we are pumping at a ridiculous rate we are getting a head of grout up here, I can shout "STOP!" and they'll stop pumping, but I have still got that head of grout which is going to escape. It creates a lot of problems, believe me. So a gentle approach is the right approach.

This is the material itself. We are always mixing in dustbins with a power paddle. These guys you can't see, but they've got hard hats on and masks and goggles and PPE kit! They finished mixing and they've taken it off.

So this is the condition of the grout. That is at the manufacturer's recommendation of 20 litres per bag. I hope you can see that that one is too thick. There is no way we are going to get that through the wall, so more water is added to it. This is simply a receiver, which keeps the grout in suspension.

So let's start counting shall we? We have two men on the pump: you've got two men mixing. That is a continuous process when you get going. We have a man on this handle, to keep it agitated; we need a man at the face for any leaks. We need a man with a radio, inside in case you get any leaks. Now we are starting to total up the number of people here. So you can see that the cost of grouting is not cheap.

From my experience going back three years I'd say, the cost of grouting a cubic metre, everything in, scaffolding, the whole business: you are looking at between £1,200 and £1,500. Each bag here is worth £25. It goes nowhere! So it's an expensive business. You need to know that you have to do it, and if you are going to do it and spend that much money, for goodness sake, let's get it right! The contractor's dream of drilling a hole in the wall, injecting a nozzle and just pumping, and hey, I'm making money! They do say that. I heard it said. It's been said to me. I'd say keep them away; you don't need that kind of person.

The farmyard engineering comes with connections like that. The hoses are so heavy it's ridiculous, so a conversion was made by the contractor here to reduce it right the way back to the size of a garden hose. Now that with a piece of copper tube in the end you can go along and plug into every grout point in the wall. Quite a simple, but foolproof method.

The impressive thing is that the grout pump is operated from the ground level at all times. There is no need to lift it up the scaffold. Having said that if you see that delivery hose that we had that going through, quite a weight of grout in that! So the hosepipe proved very useful.

Now we are underway, all the preparations done, the pointing, the finishing, there's our bit of copper pipe, we plug in and we start grouting. Gently as I said, preceded with water, a thin coat and then a thicker coat. And in no time at all – hey! We got our first little hint, that grout is coming out. So this is not only a grout injection point it's a proving point. So now a little wooden dowel, a bit of cotton wool would be put in there to seal it up. What we learnt is once you have started grouting in a hole and all the time that it keeps flowing around that hole, stick with it. If you look at textbooks and you go along plugging all the way, it doesn't work. By the time you are messing around its de-watered and you can't get any more flow.

It had to happen didn't it! I won't tell you what British Waterways calls this, but it's a leak! Here's the governor, showing the boys how to stop the leak! As I said this was actually a very, very good team. So a simple cotton wool, stick it into the hole, de-water and on we go. And there it is in action, simple and very, very effective.

You have to chase the grout off of the face wall. It is one thing you can tell the client before you ever start with grouting is that they are going to lose the beautiful lichens that they are so fond of, for a few years at least because this stuff I'm afraid is so alkaline. They just die.

And that's what we end up with: a nice wet surface. The cotton wool we tend to leave until the next day before removing them, and then repair with mortars. And I've put this up so that you can see the glistening effect up here, that's what you expect to happen. It has to de-water.

Now, my preferred way of working, if it is possible, and in this case it worked quite nicely because of the re-pointing, is to grout for a day and then leave it for a day, in order for the grout to de-water and reduce in volume, so that the next time you come back you can start and build on that again.

Now because we had to point from the bottom up, we started about a month prior to grouting taking place. But obviously we didn't re-point the whole tower so when we had a day off from grouting, we could do pointing, so that worked very nicely, moving up the tower.

That stone has been displaced by the weight of the grout. Now we weren't being silly, we were being quite conservative with the height that we were lifting each day; and yet this moves. In a sense it's nice as it gives you a photo opportunity to show you how well the grout has got round the back of that stone – ain't that lucky! That's a very serious point as the grout has flowed around beautifully. Now you can see it at the back of the stone also.

So we go day on, day off, to allow de-watering to occur. Now when you get to the top of your structure you've got a bit of a delaying tactic that we need to employ because we've got to let it settle down in order to get it topped right up. If you don't you are going to pay the price; and I guess if I'm honest I've got to say to you that we kind of paid a price there. I'll come back to that. So what we see in the face at the end of all this when we pull our grouting plugs out and repair them with little mortar dabs – they're not finished there, but they will be.

In order to check how thorough we were, at random we removed stones and just looked at the sockets and the grout which had flowed round the back of the stones. Everything appeared to be tickety-boo!

I did come slightly unstuck inasmuch as we didn't completely fill at the head and did have to come back and you can see all the cotton wool between the roof timbers and the wall that was removed afterwards obviously. But it was a very successful experience. One thing you must expect is the fact that water within a wall is subject to gravity and all that water is going to come down and out so we are getting a nice green build-up there because of the high levels of moisture over a period of time.

That is the way that we worked on this particular tower. This is not the general specification for any grouting that is been carried out. Every job you go to in conservation is different.

Well that is the tower as it looked a couple of months ago. That's five years after the event.

And that pretty much concludes the grouting process. Thank you very much.

RENDERING SOLUTIONS

Chris Wood

We decided that Colin would actually go through the grouting process in detail because we've never seen anything published on it before. I don't propose to do the same with rendering, not just because Colin was rude about my attempts at rendering in the past, one of them still survives on one wall, but the idea for this afternoon is for me to go through some of the experiences that we have gleaned from our Damp Towers research.

I'm going to look at historical use primarily for performance. I'm going to go into much more detail on the case studies I flipped over very quickly this morning, looking at materials and problems that occurred and also the thorny question of appearance.

On the question of historical use we still get asked, particularly by members of PCC – are you serious that you want to render the old towers that we've always known to be faced in stone? I mean there is no doubt in our minds that the vast majority of towers in England were either rendered or had some slurry coat or certainly limewash.

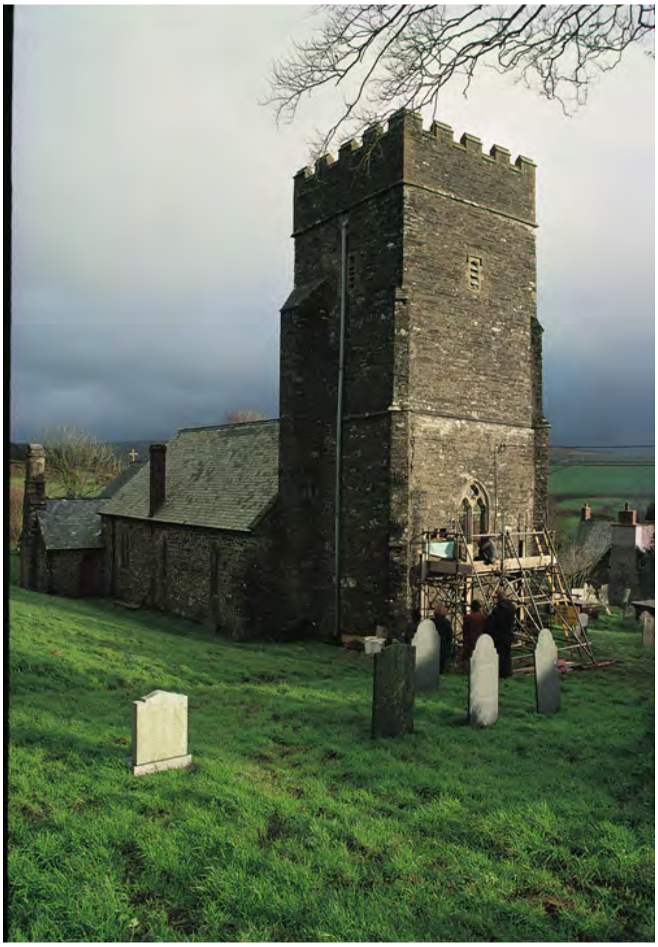
A lot of the prints you see from before the 19th century, like this one from the 18th century. This is the Church of St. Mary's, Sompting in Sussex. It shows very clearly that it was rendered and if you read past tomes particularly of a rural nature you'll see all sorts of references to obligations of parishioners to whitewash the tower, which implies there was some sort of limewash on those.

That is the tower of Sompting on the left today; it is actually one of the most important Saxon churches in England. That is a unique roof, the Rhenish Helm roof. It's of great historical interest, but as far as the PCC is concerned they've only ever seen it in that form clad with flint. If we look on the right hand side, there is very clear evidence of the main body of the church that parts are still rendered and it clearly was.

If you look at the photographs of the 1950's, clearly they have problems. You've got here the south transept clearly with a cement render and cement render at the base of the tower.

We were asked to go and have a look at this problem back in 1996 and that was the inside of the south transept and that's how it appeared for a considerable amount of time, every time they limewashed it, essentially that's what they got. They were reluctant to consider rendering, we did suggest 'well, why don't we render this and then we'll monitor it' because we had been monitoring the tower and the main parts of the church and clearly they were getting driving rain in but again, as I say, there was a reluctance and there were certainly one or two members of the congregation who were local builders and convinced that cement was the answer. So anyhow, we got a local flint contractor, who did quite a good job. What we suggested to him – as an experiment let's re-point half this gable using a mix with hydraulic lime binder and we'll monitor it and compare it with the cementitious one on the other side and see what happens. I know this is not desperately scientific because you only need to isolate one side from the other, but we had to try and come up with some compromise that they were going to accept. We monitored using the wooden dowels with sensors in them, reading data. It was an interesting experiment. It showed quite clearly that our hydraulic lime did dry out far more appreciably than the cement, but unfortunately it didn't prevent that sort of nasty appearance there coming back time and time again, which as far as I'm concerned vindicated our view that the only solution here I'm afraid, is to render.

This tower sits 200 feet above sea level, about a quarter of the mile from the south coast. That's it actually a couple of weeks ago in fact. I'm afraid the picture doesn't do it justice, but already within three months the staining started to appear again.



This is Holy Trinity Church, Challacombe ,which I mentioned very briefly this morning. This is situated on the northern part of Exmoor, fairly close to the coast. It suffers acute driving rain problems. It's built with a locally shillety sandstone. This was its condition in 1994 when we were asked to go and have a look at it. There was a scheme to carry out various works but colleages in the SW team managed to persuade the PCC that rendering was the solution to adopt in this instance. You can see the condition of the walls.

This slide shows a drying elevation with very clear dark marks to indicate where the moisture is escaping through the cracks and patches of cement and obviously you've got the same at this window.

On the inside, that's our collection of ferns in the west window – this was a church still in use don't forget.

On the left hand side just some of the mould. There was mould everywhere which is not very surprising since that's pretty hard plaster on the inside. That's up in the belfry absolutely covered in lime bloom. So what we did as part of the grant aid, was to monitor the walls with the timber dowel method for a whole year. Essentially what it shows is that the whole tower was absolutely saturated, bar a small part of the eastern wall. Fairly invasive investigations took place on the west wall there. The initial conclusion here was in fact that the core had suffered some sort of washout – it appeared to be voided. There was a lot of earth material within the core and the thought was that major grouting would be required, but after a year of monitoring the tower was then shrouded in monoflexed scaffolding and kept up for 15 months. The cement joints were knocked out both externally and internally and basically this thing was allowed to dry down – 6 foot gap at the base of the scaffold was not covered by the monoflex to allow the wind to flow.

Whilst that was going on, it gave the architect a good chance to do a thorough survey and investigation of the walls. He found a purple replacement stone that had been added sometime in the 19th Century that seemed quite porous and not doing very well, so those were all removed and replaced with a tile creasing that you can see there.

He also found evidence under the string courses of some earlier render which was used as the basis for coming up with 6 different mixes for potential re-rendering.

That was that on the west wall and that was allowed to weather for a year before the decision was made on which mix to use.

Broadly speaking when the project started off virtually the whole thing indicated saturation point. That's actually after only 10 months. The moisture levels were reduced down from an average of around 60% down to about 30% which is round about the time everyone felt confident enough to go about the render works.

The actual mix that was selected was the Somerset hydraulic lime, which used to be called feebly hydraulic, and the weakest of the lot. That was mixed in with a local, Bideford grit and stone dust, in portions of 2½ to 1. Rendering started in May with the dubbing coat, the second coat went on in June and the third in July – they were all applied green on green. Two months were spent tending this, keeping it sprayed, so it dried down very, very slowly and then 5 coats of limewash were added. This was the finished result.

We kept the monitoring going and by this time the monitoring was between 25% and 30% which is as low as we thought we would ever get it.

That's as it appears in the landscape. It's our view that these towers are meant to be obvious beacons for the local parishioners to go and do their celestial duties, but certainly in the west country a lot of these towers, particularly those visible from the coast were regularly lime washed as an aid for navigation.

And that's as it appears 6 years after it was finished. Obviously it suffered the ravages of the south west climate, but it's on the west elevation. There is a loss of a bit of limewash.

I hope you can see the lovely texture on the finished render. The architects kept the monitoring going and we still had the average level of about 27%. We were measuring this in 2006–2007, during the month of May. It was tremendously wet and the moisture level went up to 68–70% on the western elevation, but came down pretty quickly afterwards and as I said this morning, despite this actually being a thick covering, a render isn't a barrier, moisture did percolate through to the core. The core had been repaired properly – it was solid and any water then flowing through had evaporated away to the outside air.

That's the inside and we've almost completely lost the greenish hue – very pleasant.

When we had a meeting back in 1994, it was actually too cold and uncomfortable to sit in that church, even on a warm summer's day. This was in February in 2006. It was freezing outside, but we actually sat down and had a discussion, it must have been for three quarters of an hour. What I regret about this project is not recording the temperatures during any of this work. The reason why this is of interest is that I'm involved a lot with the Green Deal at the moment, by which the government hopes to galvanise the construction industry. We're trying to persuade them to fund repairs because currently it is only new work and replacements that are eligible. The thermal benefits from repairing a building are significant, as this work shows.

Last year, a final look. Much the same: visibly dry on the inside. There was an extremely wet period before we came to visit. Quite interesting, we were up in the belfry and a huge amount of gale force wind blowing through, you think naturally ventilated that's great, actually the natural ventilation or the wind up there is probably about 95% humid so in actual fact what we're getting in there is not fresh dry wind, but a lot more moisture and the atmosphere was very moist.

So additional lessons that we learnt from the Challacombe experience – good protection being essential during works in these exposed locations. The architect closed off the chancel arch, which was important because it allowed the church to be used but also allowed very good air flow on both sides of the tower wall which was so beneficial in helping it to dry it down. I think Jonathan Rhind's (architect) view was that 6 months would be enough for drying down but we allowed 15 months. It's also essential to have things like parapets and string courses repaired, which he and the contractor went through great pains to do well.

It's important to tend the finished project. Two months was spent spraying down that final finish before it was lime washed and the scaffold struck. So in other words before that render has to face the ravages of the south west winds and rain, it's as reasonably well cured as it's going to be.

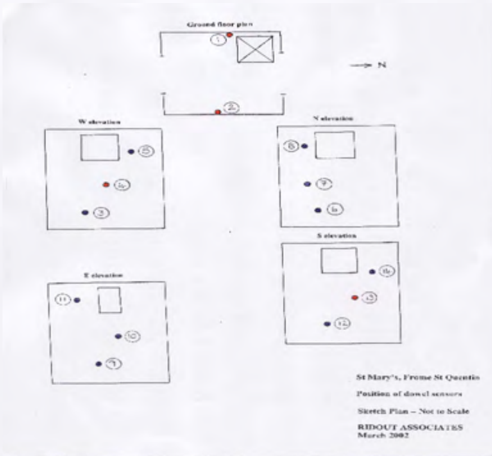
This is the other church that I mentioned before, this is in fact in Dorset. Allegedly this is the wettest parish in the county. The church sits quite high up on a hill. It's exposed to significant, direct rainfall, it has got a long history of moisture penetration problems. I think in the 1980s all the panelling had to be removed because of severe dry rot. The decision was made to render. That was carried out in about 1990, but the rendering actually followed grouting because of the extent of voiding which they found, they grouted it first and a few months later it was rendered. It was rendered in a putty lime mix and had a very good contractor working on it. He found traces of old render which he analysed and replicated. Unfortunately, it failed the following winter. The assumption was that there was something wrong with the render and basically the frost got it. It was done again a couple of years later and it failed a second time. So after this we were asked to come and have a look to see if we could offer any advice. The obvious thing to do was to discuss the matter in depth, but also carry out a few basic tests and essentially what you're seeing here is the phenolphthalein being used.

Phenolphthalein will identify uncarbonated parts of the render and as you can see from that maroon colour there clearly is a lack of carbonation. The interesting thing was that the render that had actually sat on the flint seemed to be reasonably well carbonated. It was the render that was over the joints that was uncarbonated, so naturally it was something to do with the walls of the church. I think our conclusion was that following rendering you have hundreds of gallons of water in the core of the wall and that water is obviously going to transpire or diffuse out over time and this is what we think was going on here, and this is what caused a perfectly good render mix, well applied, to actually fail, after grouting.

The architect went over there to see exactly what had been done and as a result again that was shrouded in scaffolding. The old joints were knocked out; the old render was taken off, and it was allowed to dry down. Monitoring took place again to test the moisture levels.

St Mary's, Frome St Quintin

	07-Dec-00	22-Feb-01	03-May-01	04-Jul-01	07-Sep-01	15-Nov-01	23-Jan-02	20-Mar-02
1.1	61.0	43.8	42.0	33.7	39.6	42.9	32.7	40.7
2	71.7	59.6	67.5	75.2	61.7	44.5	42.6	41.4
3	67.8	68.2	70.4	93.9	80.6	35.8	41.0	46.2
4	49.2	46.8	39.0	54.5	43.8		26.0	36.7
2.1	61.6	86.0	71.0	68.8	47.4	28.2	67.0	54.8
2	51.4	80.6	61.5	40.4	34.8	28.3	59.2	44.4
3	74.3	101.9	66.6	73.0	38.5	27.9	68.9	41.8
4	66.9	88.5	61.4	77.0	50.0		61.9	52.9
3.1	26.6	33.1	40.6	30.8	29.0	26.0	28.5	30.9
2	25.7	28.2	31.7	30.7	28.9	26.7	28.1	30.4
3	26.2	51.2	50.0	36.3	29.8	24.7	26.7	30.5
4	29.4	43.1	36.6	30.1	26.2		26.8	28.6
4.1	36.0	63.2	47.4	39.5	29.3	25.7	33.3	39.2
2	51.1	81.7	51.4	41.7	26.1	25.1	32.3	35.8
3	56.1	88.8	62.6	38.2	27.9	23.0	29.5	35.9
4	46.3	73.9	49.2	29.2	24.8		28.2	31.3
5.1	74.6	58.3	35.7	32.7	27.7	26.3	28.5	30.3
2	69.3	57.0	33.4	33.0	26.9	25.6	25.7	30.3
3	44.3	35.0	31.5	29.9	26.0	23.7	23.5	28.3
4	27.0	28.7	26.9	27.9	22.9		24.5	25.4
6.1	23.4	36.4	26.3	30.3	24.4	24.7	27.2	29.4
2	24.3	35.6	26.6	29.8	23.7	25.1	26.7	28.4
3	24.2	35.7	27.0	31.0	24.4	23.0	26.2	29.2
4	22.0	29.7	24.9	27.5	22.2		23.6	28.4
7.1	43.1	48.9	34.7	35.5	30.1	26.3		
2	46.3	56.0	39.6	40.2	35.0	27.0	34.5	31.3
3	40.6	40.4	33.0	32.4	26.9	24.4	35.9	31.2
4	24.0	29.1	27.8	25.2	23.4		25.7	26.9
8.1	22.2	29.0	28.3	28.1	26.7	24.2	28.8	29.5
2	20.5	28.8	27.4	29.4	25.4	23.6	27.4	28.2
3	19.6	26.4	26.0	28.1	24.3	20.3	26.4	27.1
4	18.7	23.0	21.9	23.9	20.8		24.3	23.9
9.1	22.3	35.6	28.4	29.7	23.3	27.2	26.4	29.0
2	23.4	32.0	29.4	30.8	26.6	26.7	26.7	29.2
3	24.0	44.0	34.5	31.3	29.2	23.4	25.9	28.9
4	21.2	31.3	26.3	27.1	23.7		23.2	25.7
10.1	35.4	44.9	36.2	36.2	26.3	23.3	30.1	31.1
2	37.4	36.2	32.4	30.4	24.4	24.3	30.5	31.1
3	33.8	31.8	29.7	29.5	25.6	21.8	29.3	29.3
4	24.5	27.3	26.8	28.5	21.8		25.9	27.3
11.1	23.2	34.5	30.4	31.6	23.9	25.9	26.7	27.5
2	25.2	34.0	30.0	31.1	24.0	25.8	26.0	27.4
3	23.8	30.7	26.6	29.5	24.2	20.1	24.5	27.0
4	20.1	25.7	22.1	23.0	18.6		20.1	23.2
12.1	29.4	40.4	32.4	33.8	27.9	27.2	28.3	30.7
2	30.4	43.1	33.7	33.3	28.3	27.4	28.1	30.8
3	29.2	55.3	46.7	36.1	35.2	26.2	37.7	30.3
4	28.7	60.2	59.5	35.3	43.1		41.0	31.5
13.1	27.1	60.6	63.5	68.1	29.6	26.5	32.1	36.4
2	29.3	70.5	63.1	81.6	37.4	28.7	36.0	48.5
3	33.5	71.7	68.1	80.2	47.1	28.3	37.3	55.6
4	29.2	63.8	63.5	64.3	34.1		37.0	41.3
14.1	40.6	53.8	43.0	38.8	36.9	27.4	missing	30.5
2	52.1	74.1	40.3	41.1	32.7	30.0		32.1
3	54.2	73.3	46.8	74.3	38.2	28.8		35.7
4	45.4	65.6	39.4	67.6	41.2			32.8
Average	37.3	49.8	40.6	40.9	31.3	26.7	32.0	33.2

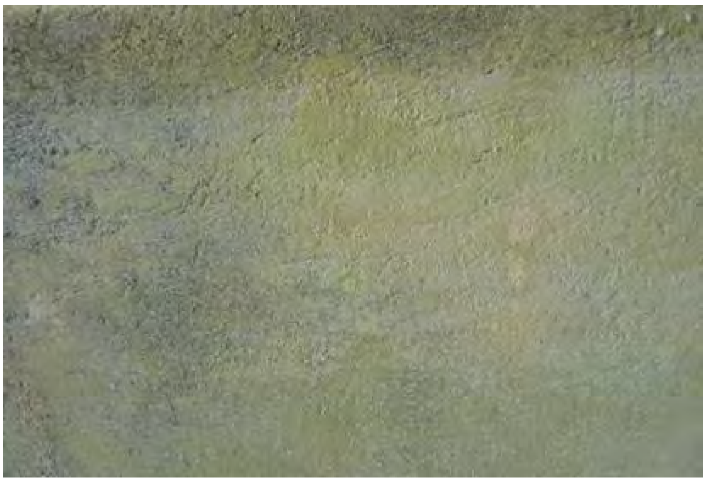


At the start it was still saturated from the grouting. You can see red marks on the first column that indicates that we have a saturated situation and that actually went on for some time – these lowers ones down at the base – and it isn't until we get about here that they begin to settle down. We're talking about 18 months, until we get to a position where re-rendering can be contemplated again. This mix was changed this time because of the two failures. They decided to as near as possible replicate the mixture used at Challacombe, using the Somerset hydraulic lime, that used to be called feebly hydraulic lime. Even the dubbing coat which was in a putty lime was taken off because they didn't want to put a stronger coat on top of a weaker first coat.

So the trials took place. A wooden float was used. Firstly that brings up the laitance. The churn brush was used to open it up again and the trowel used to take off the excess. So at the end of the process you end up with a nice textured finish and this was well tended. In fact that finish was tended again for about 6 weeks, spraying every day to allow it to slowly carbonate. Then a slurry coat was added and that was one part lime, one part hydraulic and part of aggregate. Then it was given four coats of limewash and allowed to dry and all the moisture has disappeared.

That's the finished result in 2002. A lovely texture and colour. Almost immediately the tower began to dry and all algae disappeared.

That's what it looked like at the end of last year, slightly similar to Challacombe in that it's beginning to suffer the ravages of the weather. The weathering was not holding back all the moisture so we're beginning to get the algae deposits, never the less very attractive and very effective.



There's a close up of the attractive texture there, again. A nice dry tower, but a very wet church. The rest of the church unfortunately is cement pointed and it's quite cold and unpleasant, but the tower is most pleasant.

Just in case you get the impression, that somebody asked the question this morning 'Are you just working with hydraulic limes?', the answer is definitely no. We've seen a number of examples of excellent work done by very good contractors using non-hydraulic limes.

Another couple of examples I wanted to show you. This is another one from Sussex – Holy Trinity Church, Bosham. A very famous historical church, it's actually depicted in the Bayeaux tapestry. This is where Harold left in 1064 for his aborted trip to Normandy and allegedly the daughter of King Canute is buried there. Back in the 1980s it had been rendered with this cementitious mix which had started to come off. It was stripped back, an appearance the PCC wanted to keep, highlighting the sandstone and round the other side, flint. Basically a decision was taken to render it. So the contractor did his best to make this as surreptitious as possible. He found traces of the original which was coloured pink.

This is putty lime, so the contractor added brick and chalk dust as well as aggregate to make the mix. Several render panels here. The render was applied as a single coat because the idea was to follow the contours as much as possible – this is the idea of making it as surreptitious as possible. That was quite an arduous process because some of these coats were about 13mm deep in parts. In order to slow the drying and cracking it was basically pressed down as opposed to being wood floated and they had to continue keeping that up for several days.

There is the completed job, I think very successfully managing to follow the contours; a very successful piece of work.

Kings Nympton, north Devon. Quite elevated and very vulnerable to driving wind and rain from this elevation. It had been rough cast rendered in 1995. Basically it was rendered again, using putty lime which they blended with a little bit of the Somerset feebly hydraulic lime. I would have thought it made little difference to the fact it's non hydraulic because the percentage is quite small. Anyhow, it's been there for 15 years, very successfully. There are some minor bits of loss there where there's a bit of splash back and the frost has got it, but otherwise another commendable piece of work.

Of course it's not just materials, there are different techniques as well. This is a church in Somerset, again subject to a lot of driving rain. We were asked to come and have a look at it by the architect at the end of the job. Apparently before the repair started it had running water on the inside so it was in a really perilous state. Substantially voided, they grouted it and decided to render. After our experiences at the Dorset church, we were quite interested to come and see how this performed.

That's basically the render process. Here he's using a render gun to apply the dubbing coat which proved very effective, particularly as the stones were very smooth and it was a very quick efficient way of doing it, with far less loss of material than occurs with floats. The next two coats were done in the traditional way.


That's the wooden float finish and finishing off with the tamping of the brush just to bring out the texture.


Anyhow, the finished job – very attractive. They've tended it again for a good 6 weeks, spraying it continually to make sure that it dried out as slowly as possible. The PCC wanted a very bold and dramatic colour scheme which they got in five coats of limewash. Here, you've got moisture appearing on the external face of the render. Presumably we think that this may just be the tower drying out because having been grouted we have hundreds of tons of water finding its way out – better coming out through the external elevation than the inside, as far as we were concerned. Perhaps nothing to worry about at the moment, but it will be very interesting to see how this one fares.

1998 2012

As I say different types, different techniques. We've got the rough cast render on Rattery which Iain looked at in 1988. Water is still getting in and it has problems up here in the gutters. That actually is a nice dry tower that we visited in 2012, that's absolutely fine.

The earlier discussion mentioned rough casts. I think our view is that this is an exemplary way to finish off. It is a very traditional way. It certainly opens up the texture of the render and it's got to enhance drying.

That's again a nice dry tower, in south Devon. We did come across problems: I'm not going to go through them, but often they're not fatal. For example, the assumption is that there is a bit of a detachment of the top coat – with the view that the whole thing is going to come off but this is often not the case. If you need details on basic repair mixes, it's all available in our latest publication, Practical Building Conservation: Mortars, Renders and Plasters which is available now from Ashgate Publishing Group.

Our conclusions were that renders were widely used up to the 19th century. Lime based renders are certainly effective at preventing the ingress of rain. We recommend that the condition of the core is assessed before work is undertaken. Techniques vary, but we've seen good results from all and failures that we've actually had to examine over the last 18 years can easily be down to either a wet core, workmanship problems, working at the wrong time of the year, inadequate protection or just bad luck. Because no matter how much attention is paid, this is not an exact science and basically if you're very unfortunate with the weather it may be beyond your control. I think it was 2005, we had two periods where we had excessive amounts of rain for about three or four weeks followed by severe frost in November and again in February. We had numerous calls to go and look at failed renders and mortars. Even the strongest mixes suffered, including 1:3 cements and some of the NHL 5 mortars failed, so in short there is an element of luck in it.

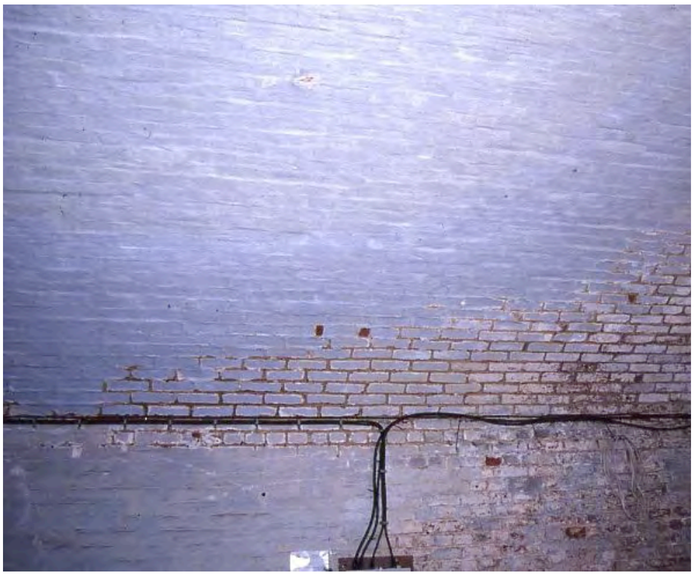
Thank you.

POINTING: GOOD PRACTICE

Colin Burns

Let's take a look at what we need from a lime mortar.

Fort Brockhurst: always came up with the goods photographically. This is inside one of the casemates inside the training centre. As you can see we have a problem. There was an early asphalt roof that failed, and we have moisture ingress.



And here we see after many, many years of limewash build-up, the moisture is moving through, carrying salts through, getting that crypto efflorescence to the back of this limewash and its being burst off the face of the joint. That's exactly what we want – the joints are working. A relatively simple task now is to rake out the defective lime based mortars, and replace it with a nice soft mortar. It is a sacrificial material. We must keep that in mind. This business of pointing it up to last the next 40 years, is rarely achievable.

Fort Brockhurst again. The lime mortared joints and you can see nice lichen which covers the whole face of that joint. In other words moisture is going into the wall it transfers in what I refer to as the drain in the wall, which is the joint, and it moves out to atmosphere. So the joint stays in a slightly wetter condition than the brick.

Now then let's whip that out, lets put some cement pointing in the end of that drain in the wall as I refer to it, and see what happens.

This is literally three paces from the last photograph. It's the same elevation. Same brick, same everything. The only lichen you can see is at the junction between the cement and the brick. It's not on the cement, it's on the brick, its keeping the arris of that brick in a wet condition, its carrying salts with it no doubt, so we're going to get a bit of a breakdown of that arris. We are also going to get a bit of frost damage on the arris, which is why they're going to round off and why that cement will eventually drop out. It is as simple as that. I think that these are some of the most graphic images that I have ever seen to show how a joint should work and how cement is a problem to us.

Same site, still at Fort Brockhurst, I apologise for the fact that this is brick and perhaps you should be concentrating more on stone. The principles of what I'm speaking of here apply to both. So here we have lenses of brick attached to cement pointing carried out by the military. Just a flick of the little finger and off it drops; those are not salts, they are spiders and little nests. You can see that the original mortar is of a good depth! There's nothing wrong! Why did they re-point that in the first place? That is always the question. If it is cement and you think it's got to come out, test it. Can you get it out without doing damage to the fabric? If you can't, leave it alone. Nature will take care of it in fullness of time.

Just a few uglies!

Granite: a great material I know, but cement sees it off. It's instantly repairable this, not a problem!

This was actually quite amusing. This was in Bradford and it was British Waterways training that we doing at the time. I was speaking to the workers about the errors of strap pointing and how wrong it was. One of the operatives said to me "why do you keep on about our strap pointing? It's a tradition." I asked how far this tradition went back in time. "10 years that I know off" he replied. That put me in my place!

It's visually awful isn't it?

Same elevation, re-pointed / not re-pointed. Look at the difference. On the right there we can see the brick, the colour of the brick, nice bit of shadow, all I can see is pointing on the left. It shouldn't be that way. It has a secondary role to play, visually as well.

A nice bit of Portland stone being ruined! Cement again flush pointed simply because of a bit of water was percolating through, and we'll stop that Hah!! And they certainly did, to the detriment of the fabric itself.

A more recent job that I was involved in after the work was completed. A bit of re-pointing has gone on here. You don't need me to show you just how ineffective that is, there's no depth to it. The cutting out was achieved by use of an angle grinder and I've got all sorts of images of the damage done, but I'm not going to bore you with that. Simply just a really ordinary job carried out with a total lack of attention to detail. Why that's left wide open, I really don't know. But this smearing I'd draw your attention to because we have one of those 'brush it all over' materials. So it's a silicone which is applied very soon after the pointing was completed, so they picked up some of the white cement, pasted it, deposited onto the surface and Bob's your uncle.

Now the whole reason here of course was to keep water out. That is that wall. So the perpendiculars are totally empty, they are not addressing that at all, they can't afford to they say, so they are doing a quick point, paint it over and leave it alone.

Just one or two tricks of the unscrupulous contractor. This is a British Waterways accommodation bridge. It was cement pointed; it had the same old problems. This is quite a few years back, they spent £7,000 on the re-pointing here, and we were going to run a training day on the bridge, and I see this and I bring to their attention the fact that what the contractor had actually done was taken a broad, blunt, tool, laid it against the face of the old cement and gave it a jolly good wallop and sent it back in by a couple of millimetres. You take a fairly fine sand and cement and slick over the top, get a signature, take the cheque and run like hell! Now I always suggest in specifications that you describe the depth that you want these joints cut out to, and that when that work is completed you get a call so that you can go out and inspect it. Now if you do that, this cannot happen. It's so simple, but the lady who was responsible for this attacked me, vigorously, saying that she had better things to do than driving around the countryside looking at what contractors are doing!

Another Fort Brockhurst. I was asked to pop across and have a look on the Keep. The architect wasn't terribly happy, I guess looking at this you wouldn't be either! The first question was:

"Do you have appropriate tools!"

"Oh yes mate," he says "no problem, ready made supply."

"Really?"

"Yes."

"Where from?"

"DIY."

Reaches into his pocket and comes up with a screwdriver. God, bad enough – it's a Phillips! What he is doing here is giving us a good 'V 'cut, put mortar in, and it's going to fall out. I had to feign interest in the sandstone lintel so leaned there just to get a shot of all of the brick which is knocked out by this inappropriate method.

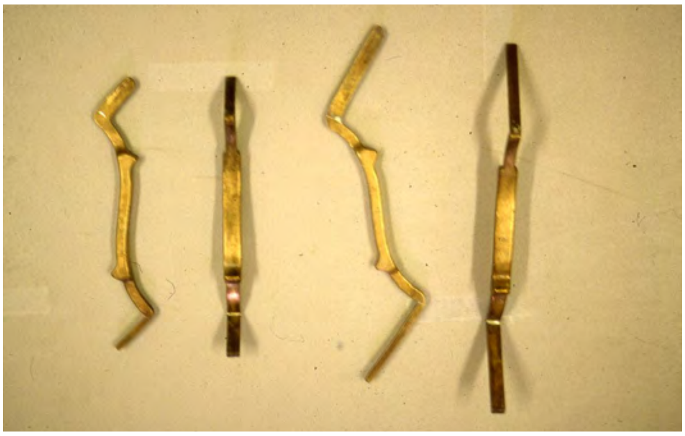
Liverpool Anglican Cathedral. Chris mentioned this earlier. This is the way that the contractor found the joints. We've got ash, lime, bedding mortar, cement, probably around 25mm, which is failing, you can see. The specification said that it would be a 3:1 with lime. The lime can be putty or hydrated. You choose. So they spoke to their suppliers who said "go for the hydrated, then its dry, we have dry sand, we'll blend the two together, put it in bags and deliver it to site. You add a bit of white cement mortar, mix it up, off you go". Brilliant. Thank you.

If you choose a hydrated lime in its powder form and as soon as you put water in it to convert it, basically to a putty, it reduces in volume. You probably have 60–70% of the lime you should have. So we don't have a 1:3 we have 0.6–0.7:3 or 1:4–3¾, so we have a lower lime content.

So the boys start work. This is the damage that they caused. You'll be pleased to know that they used the proper tools. They used hammers and chisels, and this is one of my contentions, put a hammer and chisel being the correct tools, in the wrong hands that's what you can get. Conversely put a power tool in the hands of a good man and you can get success.

Now what happened here is the contractor couldn't use the mortar. There wasn't enough binder with it. So they said: I know what it is. It's that sand, that gritty sand that they got there. Its rubbish, difficult to work with. If we go with a finer sand it will make it much better. Let's do that…and they did. So we go for the finer sand and a finer sand demands more binder. They didn't get it, so it got worse. The only way you have any effect in terms of workability now is water, which is what they did and its why it is as sloppy and horrible as that. So just a little cautionary tale.

And as Chris has shown, we went in with a hydraulic and showed them how to cut out correctly and how to point properly.



These are the kind of tools. It can be as sophisticated as this, it can be a piece of angled hard wood. It doesn't matter what you use provided you can apply pressure to the mortar once you face it within the joint.

Let's be clear about this. We are pointing, we are not building and the mortars that you use for both are completely different. What I can get away with building mortar probably wouldn't survive as a pointing mortar. When we are pointing we are going to cut a little groove out, that's it. Take a look at a cross section. Work out in our own mind how much moisture there is in that section, work out how quickly they can be drawn into the background or lost through atmosphere. If you don't care for it and it dries too quickly you've lost it. The other thing is that its going to have no additional weight on it, as it would when first constructed. When you place that mortar into the joint the only weight that goes on it is what you give it from the face, with a proper tool and apply some weight to it to get those aggregates to snuggle down properly.

So that's the correct way to cut out. That's the kind of finish we want, correct depth, being roughly twice the size of width of the joints squared at the back, cleaned out, wetted up, get a reservoir of moisture into that wall, if you don't you are in trouble.

Placing. Now I confess my work looks scruffy there because it's placed, it's ironed in the line of the joint and the mortar either side, commonly referred to as snots, remain there, untouched. And providing that they remain untouched you don't get any lime binder onto the face of the brick or stone? Its called working cleanly.

Just a small metal tool, drag the surface down to the arris, churn brush finish means striking the wall with it, to cut back and expose the aggregates and compact the mortar, no tramlines, none of this dragging through [laughs]. I'm sure we've all seen it.

There's also in this particular case. This is the Swan at Bradwall – all those good jobs you get every now and again because on the window sill you can't see a big pint of Guinness. Makes the job go swimmingly well!

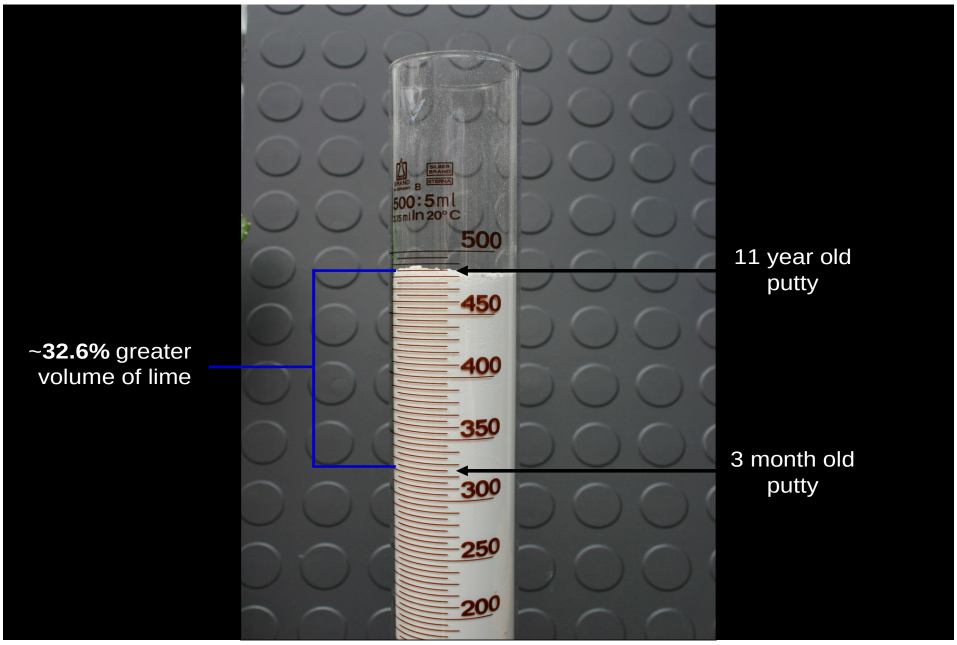
Just up there, there is a hint of penny struck in the joint, if you can see it. But that's how it was finished. The contractor unfortunately started ripping that out and putting cement mortar in its place, so the conservation officer stopped him.

Now we've done everything correctly, we've cut out properly, we've pre-wetted, we've designed a really nice mortar, we've placed it properly, compacted it, finished it – it looks an absolute treat. If we walk way now it's going to die. We have got to maintain the moisture levels for days, even weeks, to some extent. As Chris was saying, it's a matter of luck with the weather. It could be such that you wouldn't need to keep spraying, it could be such that you need to protect against wind and apply moisture. One thing we must understand is that we need moisture and carbon dioxide from the atmosphere to carbonate the mortars, even on a hydraulic. Now when we mist spay and look at the surface we can see the water glisten, then it will disappear, it's getting drawn through your mortar into the background. It is being displaced by air in other words carbon dioxide. You are accelerating the carbonation process and keeping in the moist conditions that can set it properly. All very, very simple, and should be totally understood by all practitioners.

That's the kind of condition that we want to see our mortars in. Not those that you have to hold the pointing key up the other way so that it doesn't come off because it's so wet, and often the contractor will do that.

Just a quick comparison.

On the left three month lime putty. On the right is some that I've got: 11 years old. More like a cream cheese. So I measured them in tubs, exactly the same volume, I put them in an oven overnight and dried them out completely, which gives you a product like this with little tiny lumps in it and you take it to a mortar and pestle and take it down to a fine powder. Why?



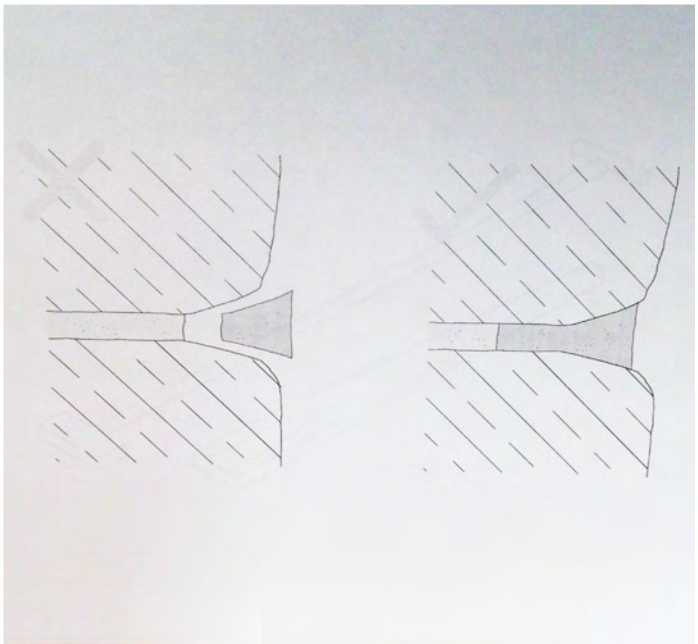
Because there is a difference between a three month and 11 year old and I wanted to prove what it was. That is what is yielded from a three month old, that is what is yielded from the 11 year old, and that is the difference between the two. So when we have prescribed mixes whether they'll be I:2½ or 1:3, please tell me what is the one part? Because you don't know and I don't know how much water there is in that particular putty.

A quick word on hydraulics. When we are working with hydraulics, if you mix your hydraulic in the correct proportions, which is normally 2:1 and you add water. This one of the most unpromising materials I have ever used. It is a powder that needs to convert to putty, so you can work with it. For it to convert to putty, it takes time. So I personally mix the afternoon before and allow it to soak overnight, in airtight bins.

I was training a team in southern Ireland several years ago and I said to them, when I go home Monday morning knock me up a mix, put it back in the tub, and do that every day until Friday, then find somewhere to put it in the wall and we are going to see how it performs. And they got part way through the week and they had to go somewhere else. And it was actually 16 days after initial mix that they came back and said "Oh God! Colin's mortar!" They tipped it out and it was very firm, but green and moist, and they could cut it open with a shovel. So they did and threw it back in the mixer, but said we had to add a bit more water with it but it worked a treat! Now I carry that sample with me and it's like bell metal; after all those days.

We simply don't know enough about how far we can stretch these materials. I am not advocating mixing it and waiting for 16 days. All I am saying is that material is capable of dealing with that and still give you a very good result. When I worked with English Heritage Building Research Establishment on the Smeaton project, trying all kinds of mortars, and I asked on a NHL 3.5 St. Astier mix, could we instead of putting it straight into the moulds for curing and testing, that we leave it out, and we left out for 3 ¼ hours. Then we remixed it and put it in the moulds. Now the result of that was, that from that point in time through to that strength over that period in time, it went in a straight line the normal mix. When we delayed it for 3 ¼ hours started from the same place but it took a different line. Still reaching that same strength at the end of the day, from what was retarded initially. Very, very important and very damn useful on a hot summer's day.!

How typical is that in this neck of the woods? It's just so typical, I can't tell you. I'm sure the specifications probably asked for 30 mm of rake out and re-point, and if we take it from the face it's a recipe for disaster.



Let's take a look here. What we have on your left is what you saw on the wall: it's given up, it's falling out. On your right is what I suggest it should be. We shouldn't be measuring from that point back to that point, for the raking out. What we should do is go to that point within the joint, so that we are within the bed joint then measure back. That should be the depth of your rake out, as mortars want something to hold on to.

I mean these are just basic, I know it's obvious, so why are we getting so many failures?

And finally, curing. Whether it's putty or hydraulic, they all need to be cured. Regarding hydraulic, I had a number of situations where I had to condemn whole towers. It's not a nice thing to do, and if you are as small as I am, you'll be kicked out and thrown off the scaffolding quite easily. So it's not something I like to do, but let me tell you what to look for: carry a little metal bar and when somebody has re-pointed with a hydraulic in particular, they say how do you like to finish on that then? Yes it looks quite nice thank you! Put your thumb on it, its really, really hard and firm. Take a big metal bar and drag it across the surface. If you get a slight hollow sound take a chisel and cut it out. What you'll find and it's so easy to do – what an unscrupulous contractor will do, let's put it that way. Place the mortar in, get the finish, then walk away and leave it. Now there is a hydraulic set, which is easy to guarantee of course, and you will end up with 2 possibly 3 mms of hard outer shell. Behind it you've got powder, because it dried out too quickly. Sound will tell you and colour will tell you. If it's looking too white, then it's too good to be true, because that's another indication that it's dried out too quickly. You need to be aware of all those things.

Now a bit of plastic sheeting. I'm not quite sure why the wet hessian is hanging over the top of the plastic sheeting, but I don't particularly care. The plastic sheeting is there which is keeping the drying winds off, holding the moist atmosphere overnight until you get back into control the following day. Strip that away and water mist if necessary or not whatever the case may be. Care for it, for some period of time.

So nothing startling there. What you've basically done is taking you right back to basics, simple steps, and they are steps I'm afraid you cannot duck. That's it: obey it or lose it.

That concludes. Thank you very much.

OUTPUTS SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Chris Wood

I'm going to tell you what the outputs from today are going to be and what we are going to do perhaps in the future. Then we are going to go straight into the questions and answers session because there are probably lots of issues from this afternoon's talks that people will want to ask.

We are intending to produce a transcript, which will be up on the English Heritage website in due course. We are also hoping to get a guidance note produced some time later this year.

We're going to produce Research Transactions, because obviously we have 18 years of work in this project. It'll be a very detailed volume of all the testing you've heard about today, plus most of our case studies.

In this last questions and answers session we are particularly interested if you have any views on what issues you might think we might research in the future, to do with the damp towers problem. We haven't made any commitments to the future, but obviously we've built up a certain amount of information, and as it's always the way with research, the more you find out, the more you realise you don't know and the more areas of potential research you can open up. There are other agencies in the UK that are also confronting this problem and we may even be able to do some combined work in the future.

If you have any further comments, please feel free to email Clara.

QUESTIONS

AUDIENCE MEMBER 1 – There's two parts to my question. The concrete pointing you use in brickwork and you find you can't get it out that easily, when it does come out eventually you said nature takes its course. Is it likely to take the arris with it in certain cases?

COLIN BURNS – How old is the cement that's the first question. Because if it is relatively young – 10 or 20 years perhaps – and if it's in good order, this is a very tenacious material that's holding onto the stone or brick. If you try to remove it, you could take fabric with you. If it's a bit older and it's become detached the scenario that I showed up there that is probably salts and frosts which have taken away part of your arris in which case the cements can fall out quite readily. Does that answer the question?

AUDIENCE MEMBER 1 – Yes and no. Is it likely to damage the arris, say you decide to wait for 20 years for nature to take its course. When nature does take its course is it likely to damage the arris, and also if there's damage is it right to take it out?

COLIN BURNS – I think I mentioned earlier on, if you have to take it out, do a trial. Always do a trial in any event is my advice to see whether you can safely remove it without causing damage to an arris. Now again, correct tools and technique come into it. When I am faced with a cement joint, I actually take a very broad tool which is blunt and make sure that I am inside the arris line and I just give it a bit of a bump with a hammer, give it a shock, then I employ a tungsten tipped quirk and quirk back, and those blows that I put in, come into play and the shock that they've provided often detaches cement from the arris of the stone or brick. If it doesn't then you can still work on those and take that off as well. So there are ways and means when you know what you are doing, which brings us back to quality of people and their education.

AUDIENCE MEMBER 1 – Ok sorry, just the part two. A visual of inspection of pointing. I had a young professional the other day. We got to the pointing and straight away she said this is lime mortar because the aggregate was quite visible, so she assumed straight away that it was lime mortar. I wasn't so sure to be quite honest. Is it possible to tell without doing some sort of scientific analysis?

COLIN BURNS – Visually I would say no. Put a bit of cement in and you can fool anybody I think! Not that I wish to do so. It's a difficult one because if you got a good hydraulic that's gone off very, very well and you take a chisel to it to test it. That way you would have a job to know the difference between a really good hydraulic and weak cement. Acid? Is that going to give us answers?

AUDIENCE MEMBER 2 – No you can't tell with acid, because cements carbonate over the fullness of time too.

COLIN BURNS – Yes, because the degree of fizz that you are going to get is not quantifiable is it? The answer is No.

AUDIENCE MEMBER: Peter Ellis – I mean obviously sometimes you can tell because the lime mortar is very, very soft and if you can crumble it in your fingers then it is clearly a lime mortar and very unlikely to be a cement mortar, but with certain harder mortars hydraulic limes or cement or cement lime blends its almost impossible to tell without analysis. And even then it can be difficult. There is no quick test. The harder the mortar, the slower it is to carbonate. If you do a carbonation test with phenolphthalein for example, it might give you an indication but it would still depend on subjective conclusion. There is no simple test to do that.

COLIN BURNS – Not the most satisfactory answer, but that's the way it is.

AUDIENCE MEMBER 3 – Can I ask a question related to Challacombe church? You said that although there was wind through the tower it wasn't drying. At the end downstairs, in the body of the church there seemed to be a dramatic improvement in the whole church interior and I just wondered if ventilation had a part to play there if not in the tower. Does ventilation improve the environment?

CHRIS WOOD – Well the short answer is 'Yes'. Since the work has been done, the ventilation and the regime have been improved. All the evidence I can go by are the irregular visits and the monitoring that had to be done. So I can't tell you on a very regular basis whether there is not the occasional condensation problem down in the body of the church. I mean I haven't seen it myself and the architect will be able to tell you more accurately the answer to that. I really wanted just to point out that sort of phenomenon in the tower, of what would seem to most people to be a lovely drying condition simply because you have this roaring gale. The fact is that if you have such high levels of humidity there is an awful lot of moisture in that air. Its not absolutely as beneficial as ventilation, and the evidence was quite stark. You get a very cold surface like cement pointing and there was clear condensation. If that had been granite wall it may well have been pretty wet because granite seems to be very cold to the touch as well.

AUDIENCE MEMBER 4 (architect for Challacombe church) Could I add to the last point. The inside of the church was coated with a delightfully shocking pink vinyl emulsion which was removed and then limewashed, and the plaster underneath it was a lime plaster. The damaged areas on the west wall of the church were re-plastered and the remainder of the original plaster underneath the vinyl paint was unaltered. So it was the removal of the vinyl paint that improved condensation in the remainder of the church. There are no new windows in the church. There was a howling gale through various areas and ventilation is transitory. Could I just add a couple of things about the timescale of the pointing removal. The moisture monitoring occurred right at the very beginning of the project, as soon as the scaffolding went up on the very damp tower. Then in the 15 months that the scaffolding stayed in place, the moisture levels were recorded as dropping. During this 15 month period the maximum level of moisture drop was over the first six months and after that period the drying curve dropped fairly substantially. The pointing was removed both inside and outside the tower and the west window of the tower was removed, so you had this funnel the whole way through and which is why we blocked off the chancel arch, so you did get a howling gale up through the middle of the tower. Thank you.

AUDIENCE MEMBER 5 –We've concentrated today on damp towers. I just wondered if you've done any research on dry towers to see what we could learn from those. That's just a thought to leave you with. The two questions are for Colin. The first is on the water testing, the flushing out that you did to start with. I assume that you did it from the top and therefore could you not get a build up of water pressure within the core of the tower and get some pushing out? The other is about the height of the grout lifts, something you might have said, but I missed that, perhaps you could tell us what the height of the grout lifts was.

CHRIS WOOD – In answer to your question about dry towers, of course we certainly monitored those that dried out afterwards. We didn't set out with that intention and we haven't done as a comparable, more fortuitous perhaps.

COLIN BURNS – Regarding the flushing out, 'No' is the answer. Initially we start from the bottom and then in that way you can plug the holes again with cotton wool and dowels, and dam the water and in that way you can test and pre wet and this is actually something you have to repeat from time to time during the grouting process, because the thing will de-water as it does take some time, so no I'd start from the bottom and work up. The second part of the question: grout lifts; I did miss it during my talk. I made copious notes and typed them out beautifully and haven't looked at them once! I don't know why I bothered! If we have a really good large granite masonry wall with small joints, you could quite easily go up 2–3 metres, , no problem whatsoever, because then there is no pressure, there's not the volume of grout there. If we changed that, let's say we got a wall consisting of small masonry units, or small flints, in a degraded lime mortar you may go as little as 200 mm high and if you went any further you would probably blow the face off. So this comes down to experience and judgement. Sorry, everything takes us back to knowing what you are doing and having had some experience of it before. Does that answer your question? Thank you.

AUDIENCE MEMBER 6 – My question is regarding render. A number of churches you've sheeted up to allow the tower to dry before rendering and yet its imperative that you allow the render to dry very slowly so you would think that actually having a wet tower to begin with might be beneficial, but you said part of the reason for failure is because of residual moisture from grouting that would have gone on in the past. Do you therefore need a dry tower which you then wet to create suction or what's the problem with it being damp?

CHRIS WOOD – Perhaps the word damp was the wrong word I mean it's not defined. We are talking about something that is basically too wet, inhibiting the carbonation of the dubbing coat to start with or the render coat or the float coat; one of the three. It's really down to a question of quantity. It's not an exact science. When we were monitoring the towers and I was showing you those figures that were saturated, I mean clearly that's far too wet to contemplate rendering on top of that, but once we were getting down to percentage terms, 30% or maybe up 40% perhaps, that's when you have the opportunity to make a start.

AUDIENCE MEMBER 6 – Thank you

AUDIENCE MEMBER 7 – I was hoping to ask a question about owning up to mistakes that have happened in the past. In Northern Ireland we have filled one of our monuments with a polyurethane filler in the core of the building and I suppose it's maybe owning up to problems we've had as agencies and maybe using them as means of creating best future practice for government departments. It's a slurry that's been pumped into one of our monuments and really it's probably an irreversible thing but its something that should be studied as a means of ensuring we don't do the same thing with other buildings in the UK.

EDWARD IMPEY – The question was partly whether we should institutionally own up to mistakes we made in the past and learn from them.

CHRIS WOOD – That would take a week! I'm afraid a lot of our monuments were filled with extremely strong concrete, and we've tried to remove it. It's extremely difficult. It will be fairly destructive to try and do it and I'm afraid it's left in there. We monitor and try to do the best we can. I'm not sure if there is any work we can actually do to try and reverse the sort of thing that you've just described.

EDWARD IMPEY – I suppose we can publish a bumper book of mistakes, with all the things we've done badly over the years, and learn from them.

CHRIS WOOD – Like you said we hold our hands up. We've done a number of things wrong. That's how we learn of course by making mistakes. I know its no consolation.

AUDIENCE MEMBER 8 – I have a question for Colin about the grouts that you used. Do you always use propriety grouts and do they always contain cement?

COLIN BURNS – In general terms I always use propriety grouts. On-site mixing I think it's fraught with dangers, both in terms of health & safety and getting the proportions right. Do they always have cement? No. The heritage grouts that I mentioned which are Heritage Grout 7, Heritage Grout 1.5 and LPB221. They have no cement whatsoever, its just hydraulic lime, PFA , bentonite and a few fillers and flow agents and secret ingredients that a contractor will not divulge to you or anybody! (audience laughter) And the big problem with them is that whilst they are good, their flow characteristics are really good, their shrinkage values seem to work exceedingly well in composite walls, bless them, the supplier, greedy so and sos won't do anything less than one ton at a time which is a big shame. I know there is a contractor down in this neck of the woods that is considering trying to produce himself in relatively small quantities a lime based grout for use in such buildings. Power to his elbow, I hope he pulls it off.

AUDIENCE MEMBER 9 – Could I ask a question about the percentages that you've been quoting. You're been saying 30% 40%, 60% etc. Are you referring to the Protimeter percentages of the dowels themselves or have you been testing the actual water content of the mortar?

CHRIS WOOD – These are the moisture content of the dowels which we hope it's calibrated to the moisture content of the masonry within the holes. Certainly there is somebody in our team who's been doing this sort of monitoring for decades and he has complete confidence that as a system it is reasonably accurate and calibration is fairly reliable. But the figures that I've been quoting, yes the moisture content of the timber dowels, subjected to that oven/balance treatment.

AUDIENCE MEMBER 10 – Today nobody seems to have addressed the largest component of mortar mixes: the aggregate. Do you not consider this to be important in selection or are you going to address this in another item?

COLIN BURNS – We weren't talking about mortar designs today particularly although of course it is absolutely critical. Unfortunately these days because of the purity of our limes we tend to employ cement technology. Now if you want to go back and start looking at historic mortars you will find that they were made up from the most unpromising materials, some of which would never be used today! I can think of one particularly, which is virtually a silt. The whole of the core of Byland Abbey in North Yorkshire is constructed from it, in a hot lime method. You wouldn't do that today. We would be looking at 5 mm down, sharp well-graded aggregate.

These prescribed mixes that I've been reeling against is 1:3. Why 3? I mean if you test a sand the most simplest test on dry sand put it in a one litre container: Get one litre of water and pour it in till it reaches the top, which gives you an idea (some idea) of the voids available within that sand. I've done this many times and I've never seen one come out at one to three yet. One to 2 ¾ (three quarters) that's very, very common, so I actually think that we tend to under do the binder content slightly on modern mortars. Also if we look at historic mortars they are not just silica sand necessarily. Very often we've got porous limestone fragments within it, and you can call that porous particulate if you will, or deliberately crushed brick, in Roman technologies. Fantastic!

These are little reservoirs within your mortar, which fill with water in the mixing initially. That water is given off during curing. When you are mist spraying they fill with water then give it off again gently. It's an aid to curing. Its provides resistance against frost. Once it's in place its resistant against salts growths because we got all those little voids there, that these elements can act within. So I personally like a good sharp silica sand, well graded, but mixed with a percentage of crushed limestone, a limestone which has fairly high shell content because that gives us the rigidity and strength from it together with a bit of porosity within the mix. That makes in my view, generally speaking a first class mortar great aid to cure. I could go on. Does that satisfy you sir?

AUDIENCE MEMBER 10 – Partly!

COLIN BURNS – What part doesn't it?

AUDIENCE MEMBER 10 – When you said we could probably go all afternoon!

COLIN BURNS – We could indeed! I'm game!

CHRIS WOOD – When we sat down and decided or tried to work out our programme for today, we could have filled three days with items that would be of interest to most of this audience. The practicalities are that we tried to restrict it as best we could to the most relevant. I mean aggregates are terribly important, but they themselves probably deserve at least a good day if we are really going to do it justice.

AUDIENCE MEMBER 11 – Do you have any plans for research into what we referred to today as the 'hot lime mixes', which are the more traditional mortars, and could you give us English Heritage's position on that of gauge mortars with putty and hydraulic?

CHRIS WOOD – You know I was thinking about that this morning. I think the moratorium has been lifted now hasn't it! Interestingly, I spent a lot of time talking to Colin and over the years since that moratorium was introduced we got far more experience on how to blend these things as you say or mix them, and the consensus amongst practitioners involved, was that they've had successful results! Are you going to say something on this Alison?

ALISON HENRY (Senior Architectural Conservator, English Heritage (EH)) – I just wanted to comment on the published EH guidance on hybrid mixes. The guidance in the Practical Building Conservation volume on Mortars, Renders & Plasters which is the first statement that EH has issued since the moratorium, is that on the whole there is no need now to use hybrid mixes because there is a good range of different binders of different hydraulic strengths available on the market. I think at the time the moratorium was imposed there was a far more restricted range of lime binders available, so if people wanted to create a feebly hydraulic lime they were doing it up by blending a stronger hydraulic lime with a non hydraulic one. I think the situation has changed: there are more products available plus a wide range of pozzolans, and I think on the whole EH's view is that there is no need to take the risk of blending materials. Research done under the Foresight Project, which was done at Bristol University did quite a lot of research on this and they did calculate the loss in strength that would arise if say an NHL3.5 was blended with different proportions of non-hydraulic lime. There is a graph / curve from which you can infer some of the properties of your hybrid mix, because this was always the problem: people were blending these mixes but didn't know what the performance characteristics would be of the mortar that they were producing. So on the one hand EH is saying you don't really have to do this, there is a wide range of products available, on the other hand the Foresight Project found out if you do have to do it at least here is a way of calculating what the performance characteristics might be if you do that.

AUDIENCE MEMBER 13 – I think the other thing is that if you are doing it to improve, for example the workability of a hydraulic lime mix, which is one of the main reasons for doing it as I understand, then the addition of a small amount of putty to a hydraulic lime mix, in proportion of I think about 10% is considered acceptable, although there will be some slight loss in strength. So you are substituting improved workability, but the price you pay is slightly loss of strength.

COLIN BURNS – May I say a couple of words on that and also ask a question: Alison you made that statement about mortars. Is this mortar for re-pointing or mortar for building work?

ALISON HENRY: It was mortars in general

COLIN BURNS – There is a huge difference between those two. Nobody shoot me, but I was asked to build, construct four walls in Oxfordshire, 3 meters long, 2 ½ meters high,1metre wide composite walking structure. I said "Fine I can do that. What mortar would you like to use?" They said: "Colin do what you like". So I did. St. Astier will guarantee their material with putty forming up to 10% of the total binder. I pushed the boat out and put 75% hydraulic, 25% putty. I'm pushing it ridiculously OK! To one of those mixes I put in a proportion to a small part of wood ash in to soak up some of the free lime that I had thrown in. So this is experimental. All these walls are there to put grass on the top of them so it's not the issue. This was 4–5 years ago. The walls are built on clay in a slight hollow, the idea being that they were going to wait and come up with problems that these kinds of walls do. We had a hell of a winter and I had a few concerns shall we say. We went through that winter with no problems at all. It's been through subsequent winters which as we all know have been quite extreme, and they are as good now as the day they were placed. Now that is as a mortar in building. If I'd used the same mortars in re-pointing I would suggest they would fail, because they are different animals and with all the moisture that is within that wall, that's given off very, very slowly and gently and the curing process is brilliant. Now I am not advocating its use in those proportions, all I am telling you is I've used it and that's the result.

CHRIS WOOD – That's very good.

It is now gone 4:30, the time we are due to finish. I repeat the invitation if you got any more comments or points you want to make, by all means email us. As I said, we're particularly interested in looking at potential further research, so the question about hot limes is something we'll think about, and I think it just remains for me to thank my colleagues for contributing and if you'd give them a round of applause that would be great.

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