Medieval mortar and the constraints of formwork

Extract from The Template-makers of the Paris Basin, Leura, 1989.

There are three important aspects of mortars: the fabrication of the materials, the amount of shrinkage, and time needed for initial set.[1]

Modern mortars are made from cement or lime. Cement can set harder than the materials it joins, so that movement in the structure may not be taken up in the joints but in unsightly rupturing of the stones themselves. Lime mortar, being invariably weaker than stone or brick, will be the first to crack when there is settlement, so that the movement takes place along the joints. This leaves the base material of the construction unharmed. Cement mortar is rarely used today in renovations.

Modern mortars are hydraulic, for they set through the interaction between lime and water. The process was invented by the Romans, though rarely used by their successors until the eighteenth century. In the Middle Ages chalk or limestone was quarried in lumps which were burnt in a kiln to remove the carbon dioxide and the water. The chemical removal of the carbon dioxide ensured that the calcium and magnesium carbonates in the stone would not recombine until carbon dioxide was added, thus preventing setting. After burning, this material is called quicklime.

The quicklime was then placed in pits and slaked with water, causing a violent reaction as the water boiled and sent steam into the air. During this process the lumps of chalk broke down into a uniform, soft and rather greasy paste, which was then strained and put into bins. It has a fatty consistency like putty. To ensure that the entire mass was thoroughly slaked, it remained in the pits for at least two weeks, though two months was considered better. Properly prepared and protected from the air under a thin layer of water, the lime remained fatty, which is the word we use when it is easy to work.

Drying should not be confused with setting. Water did not help the material set, but made it plastic enough to be worked. The set occurred through contact with carbon dioxide in the air.[2] The hydration we expect from modern limes did not occur, because after the boiling, little hydrocity was left. This is why the lime mortar that has been isolated in pockets of the construction away from the air has remained unset indefinitely.[3]

However, the disadvantage of quicklime is that it shrinks as the moisture evaporates. Even if sand is added, the shrinkage is only slightly reduced. Consequently, in bulk construction (as in thick walls and vaulting cells) there was a maximum permissible rate of construction so the core could achieve some degree of set before being loaded. Even in the thinner beds between courses of ashlar the setting took a long time, though it was accelerated by adding materials which contained air, such as crushed tiles or bricks, carbon, volcanic ash, and at times animal blood or urine. These necessary delays had to be taken into account in every building, and are mentioned in some contracts for towers.[4]

In constructing walls, the slowness of the set produced two practical problems. First, as more stones were placed onto the wall, the mortar in the lower courses could be squeezed out. Second, in thick walls where the space between thin slabs of ashlar facing were filled in with rubble and mortar, the newly placed wet fill could push outwards and dislodge the facing. If the mortar beds were too thick, the strength of the mortar became critical to the stability of the building. It has been suggested that the collapse of the crossing tower at Winchester in the eleventh century could be attributed to the enormously thick joints, which can still be seen in those parts of the tower which remain.[5]

To minimize compression of the mortar, spacers such as oyster shells were sometimes placed in the bed joints. Pebbles and the larger aggregate in the mortar may have been intended to serve the same purpose but were less predictable. No evidence has been found in the Paris Basin for spacers before the sixteenth century.[6]

These difficulties were greatly exacerbated in arches and vaults where the stonework had to be supported on centring. The purpose of centring was to support the voussoirs until an initial set had occurred. This set had to be at least sufficient to hold the weight of the stones without allowing the mortar to be squeezed out of the joints. The time needed for this set and the amount of the shrinkage is a little difficult to calculate, yet it is imperative to our understanding of the erection process to know something of these problems.

When the cloister arches were rebuilt at Canterbury it was discovered from the geometry of the voussoirs that the arches had settled about 15 mm. over a span of four meters.[7] If the arches had been loaded before settlement was complete, the voussoirs would have dropped away leaving a big crack between the arch and the spandrel over it, which would then have been unsupported. This settlement would have been noticeable in masonry, and the cracks would have allowed the frost to penetrate between the voussoirs. If the span had been greater these cracks could have caused major structural distress.

It was calculated at Chartres that the shrinkage was in the order of 8 percent of the mortar joint.[8] What this meant in real total shrinkage would depend on the cumulative thickness of the mortar beds. In an arch with fifty voussoirs and joints each measuring 10 mm, the total lateral movement at the crown of the arch would have been 40 mm. Whatever the actual amount, it was many times greater than the shrinkage in modern mortars and could not be ignored.[9] Thus the builders had to allow enough time for the initial shrinkage to be complete before the centring could be struck.

There was an optimum moment for decentring. If struck too early, the mortar would compress under the load of the voussoirs, and the arch could distort and possibly collapse. If the centring was left so long that the mortar had fully hardened and the joints became unyielding, any jolt during decentring would break the bond between the mortar and the stones. Rain, the sudden onset of a frost or a dry hot spell, would all affect the timing.[10]

After referring to a number of experts, Fitchen wrote, "It was in the great vault itself (for which all the rest was, in a structural sense, only preparation) that the uncertainties of the mortar became critically focused at the time of decentring, endangering the collapse of all."[11]

I know of no experiments in making mortar in the medieval way, nor in using it to erect arches or vaults. However, in the literature and in the view of many practical men in the profession,[12] the general opinion is that the time between laying and striking would have been a minimum of three months in warm weather, increasing to as much as twelve months under some circumstances. Besides Pliny's well-known view that "the older the mortar, the better the quality," (which is supported by Vitruvius and Alberti) I add the following:

Abraham: "in walls of medium thickness the final set can be figured in years,"[13]

"three months, maybe more, even 6 months," John Ashurst in conversation;

"the setting time is very slow, and takes a year or a year and a half,"[14]

"fresh mortar must be left for half a season, perhaps nine months, if it is to be hard. But if the mortar is more than two years old it sets more quickly, perhaps in three months," Baker in conversation;

"conditions from place to place were so varied that he could not be specific, but three months would probably be minimal", Georges Duval;

"would never consider less than three months, six may have been safer, but if the mortar had been left on the ground for two years the setting time could be shortened to 3 months", Brian le Mar;

Robert Mark "the general success of medieval builders with long monolithic shafts shows they must have been in the habit of waiting until the mass of coursed construction had settled before fitting (them)",[15]

"the decentring can take place as soon as the lime mortar has taken on some consistency, but not before it has completely dried out in the mass, a condition that requires a minimum of six months and sometimes much longer".[16]

The setting time needed is born out in the fifteenth century accounts for the construction of Barcelona Cathedral. The men were paid on March 15 to set one keystone of the high vaults and just three months later, on June 20, the first payment was made towards purchasing materials for construction of the cells, which would not have commenced before the centring had been struck.[17] The setting time would also have been affected by the quality of the materials. Limestone and chalk are found in most of France, but their hydrocity, burning and puddling characteristics vary. Brick and volcanic ash were not available everywhere, and some stones were more absorbent than others. The quality of the materials usually depended on what was immediately available.[18]

It would appear that there were two periods of delay, one when the arches were being supported by the centring, and another while the voussoirs were settling after the centring had been removed and before the arches were loaded. The arches were first laid up on their centring and left until the mortar had had time to harden. Then after the centring was removed, the voussoirs would ease themselves onto their mortar beds, closing the cracks in the joints. This would have been a long process. Some weeks were needed, a minimum of four and perhaps more.[19] In discussions with the foreman at Westminster Abbey who re-laid the southern flyers in 1989, French hydrated lime was used. These arches were left for six weeks before the formwork was struck. Medieval lime was not dissimilar, but as their quality control was poorer, prudent setting-time would have been longer.

Only after the mortar had been given time to compress and the arch had settled into its final position could the cells or the walling which rested on them, be installed. If the superstructure was built too early, there would be differential settlement and the arches could afterwards drop away from the cell leaving a space between them.

There is contemporary evidence for this second stage in Abbot Suger's description of a particularly violent storm: "The force of the contrary gale hurled itself against the ... main arches which were not yet held together by the bulk of the serveries ... nor supported by any scaffolding."[20] He states that neither the cells not any

scaffolding was in place, not even the supports needed to erect the cells nor any platforms for the workmen. The storm must have struck during this pause between the operations of striking and loading.

Thus, in the construction of any vault or arch, there were two stages when the master may have had to direct his men either to some other part of the job or, in small buildings, to leave. Though vaults may have been the more complex, these delays were necessary over all types of openings, including windows and doors. The Sainte-Chapelle workshop may have been disbanded on more than one occasion: possibly twice for each of the two vaults, and twice more for the arches over the windows of the two chapels.[21] It may be that the same conditions applied to the laying up of the cells too, especially where they were to be loaded with triforia or other stories.

The implication for medieval buildings from these conclusions is significant: As there would always have been pauses in the construction program around archways, therefore, in all but the largest jobs, we should expect changes in the construction teams. It is useful to know that junctions between different teams of men will nearly always occur at the vaults and archways.

As local conditions and the changing weather would have made it difficult, if not impossible, to plan in advance a date for recommencing work, few promises could be made to assure the builder's return at some agreed date in the future. As client and master mason had to await the unpredictable, and as no firm arrangements could be made for the continuation of the work, few builders could have been expected to keep their men in readiness for some unknowable future commitment. In small projects, once the ribs had been laid, both the master and the client would have expected the men to be taken off the job and put to work elsewhere. It is little wonder that, as at the Sainte-Chapelle, the contractors employed on later stages of the vaults were different from the first.

We should remember that these technical matters were normal, to be found in all buildings, and though many churches were large enough and sufficiently complex for the master to put his men to work on another part while they waited for the mortar to set, everyone would have taken these necessary pauses for granted. The junctions between campaigns at the level of the vaults may be confirmed in nearly every building in the Paris Basin, and are amongst the most easily recognized. Thus, construction paused wherever centring was used: under vaults, window and door arches. Unless there was other work for the men to do, every voussoir forced a new campaign.

To return to the Sainte-Chapelle, some may find it hard to believe that the king would have engaged either in such ad hoc and uncoordinated construction or that he would have relied on temporary engagements that required the employment of so many masters on the one building. Beliefs are memes. The evidence must be allowed to speak, and from that, and that only, should we derive our conclusions. So this may be the place to address two issues: Was there a supervising architect over the various masters, and would the king not have had a permanent team of builders?

If there was one supervisor overseeing each group of masons, he allowed each to prepare all their own templates. He left the dimensions and the geometry to the men on the job. It is important to realize that this meant that the major structural decisions were also left to them, as structure cannot be conceived apart from dimension. Finally, he left the arrangements for the dado arcades to the crews. Therefore, what supervising did he do? At the most he created the overall concept, but if he did so without also cutting the templates, can we call him master mason? Is it not simpler, and closer to what we know of France at this time, to credit this role to the client's representative on the site, be he clerk of works or head of the building committee?

On the second point, the king may have had a permanent team of builders, but the evidence shows that at the Sainte-Chapelle he did not rely on them. The question stems from a priori assessments of motives, not from data. If the changes to dimensions, templates and geometry show there was a change in masters, then we must conclude that their motives were not ours, for the king did not call back the first team when the time was right. The evidence must be primary, for only then will it enrich our knowledge of the past. Here it shows us the exciting prospect that the men of the Middle Ages may have had a different view of architectural control and personal artistic integrity from ours.

Mortar was one of the crucial, if not the crucial limitation to building progress. It affected every job without exception, for not only was the decentring of vaults delayed, but also windows and doors, and indeed any form involving arches. This may be why lintels over doorways were so often made from large single blocks of stone, for then the opening could be finished as if it were a wall rather than an arch. These delays seem to have been a real factor in determining the masters' relationship with their clients and their work. If they knew their tenure would be short-lived, they might not have felt as much responsibility for the overall design as for their smaller part in it.

[1] Much of my understanding of what follows is indebted to John Ashurst's lucid booklet, to Brian le Mar and Peter Long, both *Magister fabricae* at Canterbury, to Georges Duval, Inspecteur Général des Monuments Historiques, Guy Nicot, architect in charge of restorations at Chartres, and my long-time collaborator, Dominique Maunoury, architect. Also, Viollet-le-Duc, *Dictionaire raisonné*, vi, 402-403, and those mentioned below.

[2] In view of the effect of air on mortar, if quicklime is left outside exposed to the air it will 'air-slake', the lumps gradually crumbling to powder while increasing in volume.

[3] Brunet, "Restauration", 73, for example, describes the innermost parts of the vaults at Soissons which remained unset after 700 years.

[4] Salzman, *Building*, 445, refers to the Berkeley Castle contract of 1372 for a bell tower that restricted the builder to a maximum of twelve feet per year.

[5] Suggestion by R. W. Baker who is restoring the statues on the west front at Wells cathedral. Thick joints may have been used in earlier buildings to allow the facing to settle with the core, whereas from the mid-twelfth century very thin joints became common with a correspondingly slow construction rate as the core had to settle before the next course could be laid.

[6] From discussion with Georges Duval and Guy Nicot.

[7] Discussed with Brian le Mar, who said that none of the stones were so worn that the original geometry could not be calculated from the inclination of the lateral faces of the voussoirs.

[8] James, *Contractors*, 440 and 481.

[9] Mark, *Gothic structure*, discusses all three types of shrinkage and the different times required for each, 13-15, 77.

[10] McMaster, *Bridge*, 71, on easing instead of striking. A 19th century technique, probably not used in Middle Ages.

[11] Fitchen, *Gothic cathedrals*, 262-65.

[12] Medieval recipes for cement may be found in Thompson, *Liber de Coloribus*, 29; and Smith and Hawthorne, *Mappae clavicula*. I thank Donald Royce-Roll for these references.

[13] Abraham, "Probléme de l'ogive", 36.

[14] Marcel Aubert, quoted by Fitchen, *Gothic cathedrals*, 214.

[15] Mark, *Gothic structure*, 70.

[16] Ranquet, "Origine français", 45.

[17] Libras de la Olera, folio 50v and 63v for 1418. I am indebted to Dorothy Kostuch for this valuable reference.

[18] Viollet-le-Duc, *Dictionaire raisonné* ,vi, 402-403 on different qualities of mortar.

[19] Le Mar, Nicot and Maunoury all found from experience that weeks rather than days would be needed.

[20] Panofsky, *Suger*, 109. The sentence has been slightly reorganized for clarity.

[21] "34 Sainte-Chapelle"..