Chapter 15

Solid as a Rock: Poured Lead Joints in Medieval Masonry

Jennifer S. Alexander

Although lime-mortar is the preferred jointing material for stonework, it is not the only one that was used by masons. Lime-mortar has particular qualities, distinct from those of modern cements, that give it advantages in building. It is not designed to bond stones together into a solid, monolithic mass, but to provide a flexible layer between the stones, to keep them separate from each other and to allow for a certain amount of movement. This can be seen in numerous buildings where settlement has occurred and there is deformity in the stonework, but the wall has not failed. The limitation with lime-mortar is that it takes some time to set. This is chemically a two-stage process in which the primary setting takes place reasonably quickly, but the second stage can take considerably longer to achieve. Effectively, the joint is made once the first stage has happened, but support will be needed for arches and vaults during this process, and the mortar has not reached its full strength until it has set fully.[1]

There are some situations in which it is necessary to make a joint that sets instantly, or to make an inflexible joint, and both of these can be achieved by the use of poured lead joints. Lead also can be used with dowels and cramps to ensure that ferrous metals are protected from damp and thus from expansion leading to spalling.[2] The concept of rigid joints is one that applies in a number of circumstances; in the construction of copings, attachment of pendant bosses, fixing of ridge-ribs and other horizontal sections of masonry, and in the joining of sections of shaft to achieve desired lengths. Some of these joints can be made by other means, such as dowels and cramps dropped into shaped cut-outs, but lead joints have been found in all of these applications, and further, poured lead has also been used to fix shafts into position when it has been necessary to make that installation after the main construction. Modern builders use cement grout in these

[1] Robert Mark, *Experiments in Gothic Structure* (Cambridge, MA, 1986), pp. 18–19.

[2] Examples of this can be found in the spire of Salisbury, where cramps were run in with lead to make the joints, and iron bars wrapped in sheet lead were used to brace the top of the tower. John Reeves, Gavin Simpson and Peter Spencer, "Iron Reinforcement of the Tower and Spire of Salisbury Cathedral," *Archaeological Journal* 149 (1992), pp. 380–406.

conditions, but it was not available to medieval builders, and building textbooks of the 1920s still refer to "lead plugging," which the description reveals to be poured lead jointing.[3]

Early Use of Lead in Joints

The technique of using poured lead has a very long history, although the lead is usually found associated with other metals. Scholars working on ancient Greek buildings have noted poured lead joints used to fix dowels between column drums at the Temple of Zeus at Olympia and at Delphi, with the molten lead poured through a bird's mouth joint at the edge of the blocks.[4] Similarly, marble statuary from the period of the sixth century BC to the first century AD has been found to be jointed with dowels run in with lead.[5] The huge vertical stone slabs used for the cisterns at Housesteads Roman Fort in Northumberland still retain the lead that sealed the corner joints, with iron bars providing the support. However, lead used on its own has been found in buildings from the second century AD. Roman builders at Corbridge and Chesters in England used a form of jointing in which lead run in narrow channels formed an interlaced grid across the stone blocks, described as forming "lead tie-bars." The excavators also reported clamps apparently made of lead, as well as the more usual use of lead to secure the butterfly-shaped clamps and bar clamps in stonework for the bridges of Hadrian's Wall.[6] In the early medieval period, Simeon of Durham reported that the stone cross brought by the monks from Lindisfarne to Durham in the tenth century had its cross head re-attached using lead as the jointing mechanism, and Richard Bailey has suggested that the mortise and tenon joints found on a number of Viking Age crosses in the northern England would have been secured using molten lead.[7]

At Canterbury, according to a late twelfth-century chronicle, lead was used with iron and cement to bind together the blocks of the tomb-shrine raised over Thomas Becket's burial in the crypt before its removal into the new cathedral choir in 1220; as John Crook has recently observed, this was to make the saint's tomb strong enough to protect his body from theft.[8]

High Vault Joints

In medieval buildings, poured lead jointing has been found in a number of situations where a monolithic construction is necessary, for example in the micro-architecture of tomb canopies such as that of Cardinal Beaufort in Winchester Cathedral. However, it also occurs in the construction of vaults with ridge ribs from the Gothic period.[9] At Lincoln Cathedral, the ridge rib of the nave high vault from the second quarter of the thirteenth century shows it clearly (Fig. 15.1). The vault of the west block is on a different alignment to that of the nave, and so the last section of ridge rib has been left out and the joint faces of the bosses are visible. The characteristic leaf-vein arrangement of the channels for the lead to run in are clearly visible, together with the pouring hole at the top, and the drilled holes that allow the lead to seep into the block and form an immovable key to resist lateral movement. The advantages here are threefold: the section of ridge rib can be assembled with the boss before the joint is made on the centering, the poured lead joint sets almost instantly so the joint is fully made, and finally, the joint is extremely solid. Mortar pointing completes the job, and the whole process then becomes invisible. It is only on disassembly that it is evident, as at St Albans, where a boss with its lead in place has been recovered in excavation. Restoration work at Exeter Cathedral has revealed that the nave high vault from the mid- fourteenth century has lead joints used in this way.[10] In these instances the poured lead has formed the whole jointing mechanism; drilled holes in the faces of the bosses and ribs have allowed the lead to run into the block and have not contained dowels. The remaining lead has spread between the two jointing faces. Where dowels have been used in joints, the amount of lead is considerably less and has been limited to the area around the dowel.

In the case of the St Albans boss, the lead joint was still attached, but this is unusual since most excavated or dismantled stonework has had the lead removed; many examples can be found of sections of architectural features that show pouring channels clearly, but lack the associated lead. Lead has always been a costly material that is easy to recycle, so it is unlikely to have been left in abandoned or dismantled stonework. Evidence for its removal, and for the

3 See, for example, H. B. Newbold, *House and Cottage Construction*, 3 vols (London, c. 1925), vol. 2, p. 65.

4 A. K. Orlandos, *Les Matériaux de Construction et la Technique Architecturale des Anciens Grecs*, 2 vols (Paris, 1966), vol. 1, pp. 114–21.

5 Amanda Claridge, "Ancient Techniques in Making Joins in Marble Statuary," in Marion True and Jerry Podany, eds, *Marble: Art Historical and Scientific Perspectives on Ancient Sculpture* (Malibu, 1990), pp. 135–62; see also Brunhilde S. Ridgway, "Metal Attachments in Greek Marble Sculpture," in ibid., pp. 185–206, for a report of an early example of the use of a poured lead joint on a stone figure sculpture.

6 P. T. Bidwell and N. Holbrook, *Hadrian's Wall Bridges*, English Heritage Archaeological Report no. 9 (London, 1989), pp. 124–33.

7 Symeon of Durham, *Opera Omnia Historia Ecclesiae Dunhelmensis* 1, ed. T. Arnold, Rolls Series 75 (1882), p. 39; Richard N. Bailey, *Viking Age Sculpture in Northern England* (London, 1980), p. 242.

8 John Crook, *The Architectural Setting of the Cult of Saints in the Early Christian West c. 300–1200*, (Oxford, 2000), p. 259.

9 By its nature, this type of jointing is very hard to see when it is in place, and it is only on the rare occasions when vaults are dismantled that it is likely to be evident. It would be expected that it would mostly occur in Gothic buildings, and that has been the case so far.

10 I am grateful to Dr Richard Morris of Warwick University for bringing the St Albans boss to my attention. Details of the Exeter vault construction observed during restoration have been published by John Allen, "Restoration and Archaeology in Exeter Cathedral," *Devon Archaeology* 1 (1983), pp. 1–5.

thoroughness of Henry VIII's commissioners in Yorkshire, is documented at Rievaulx, for example. An inventory of the materials of the dissolved abbey made in 1538/9 itemizes "the lede of the joyntes of pyllers and other placys, of as much as is defasid of the ppremysses there, now is fastenyd within stonys not lose, sold to … Benson of York for xxvi s."[11] Not all the lead was taken; some can still be seen in the joints of the tannery vats at the south end of the east claustral range, perhaps because the tannery continued in use beyond the Dissolution.

Window Tracery

Masons constructing window tracery from sections of stone also used poured lead joints in construction. The recent restoration of the west window at York Minster found that the mortar jointing of the fourteenth-century tracery disguised lead joints.[12] Equally, the cloister arcade at Salisbury Cathedral was held together by lead joints, as the extensive restoration of the early 1990s showed (Fig. 15.2). Bases and capitals were linked to shafts and tracery by lead; it also provided a bed for the horizontal iron bars that supported the upper sections, and the tracery units themselves were further jointed in this manner. Tracery has long been recognized as a separate unit within the window, distinct from the moulding of the arch head, and modern architects introduce flexible joints between the tracery and the window arches to maintain this separation. By creating a monolithic structure, using lead joints for the tracery and then fitting the assembly into the window head with mortar, the medieval builder achieved the same result.

En Délit Shafts

A further use for poured lead joints is found with *en délit* or monolithic shafts, particularly Purbeck ones. As early as 1753, William Price, surveyor to the fabric of Salisbury Cathedral, wrote:

> I have from many observations found, that most of the marble shafts … were fixed after the work was raised, and in a manner settled. And this may be found … that the marble bases, and capitals of the pillars have a socket in each, for the little shafts to be fixed in afterwards, and run in with lead, instead of being fixed with mortar.[13]

11 Glyn Coppack, "Some Descriptions of Rievaulx Abbey in 1538–9: The Disposition of a Major Cistercian Precinct in the Early Sixteenth Century," *Journal of the British Archaeological Association* 139 (1986), pp. 100–33, at p. 111.

12 Derek Phillips, "The Tracery of the Great West Window at York Minster," *Journal of the British Archaeological Association* 152 (1999), pp. 24–48, at p. 38.

13 Francis Price, *A Series of Observations … upon the Cathedral-church of Salisbury* (London, 1753), p. 63.

Price attributed this to the problems of using monolithic shafts (which allow for little or no settlement) around a coursed pier core in which appreciable amounts of settlement are permitted through the mortar joints.[14] At Worcester, the writings of John Leland confirm that the Purbeck shafts were added to the piers after construction. In describing the work of Bishop Giffard (1268–1302), Leland observed that Giffard ornamented the piers of the east end of the church with marble columns. The choir is acknowledged to have been started in 1224, and was sufficiently advanced by 1232 for King John's monument to be installed, so the piers must date from the mid- to late 1220s. A building break can be seen in the choir, but it is not thought to have caused a lengthy interruption to the work.[15] Giffard's addition of the Purbeck shafts would therefore have taken place at least 40 years after the piers had been built, which would have allowed plenty of time for any settlement to have occurred.

Price's observations also apply to wall arcades that have separate shafts. In numerous examples, from the late twelfth century until the phasing out of these shafts in the early fourteenth century, the capitals and bases have clearly been built with the main walling and the monolithic shafts only added after any settlement had taken place. In these cases, lead can be seen between the neck of the capital and the top of the shaft, with a hole bored through the bell of the capital for the lead to be poured. When it is done skilfully, it is hard to see, and ground-level arcades tend to have been done with greater care than those higher up. Derek Phillips has described the creation of these joints as a four-stage process:

1. setting lead pads as spacers between the joint faces
2. packing around the joint with clay
3. pouring molten lead into the joint through an aperture, using a clay funnel or a pouring hole through the stone, with a bleed hole to let air escape
4. smoothing mortar over the joint.[16]

The lead pads used as spacers become invisible in use, but the clay packing is still evident at Lincoln, where traces of it remain trapped behind the shafts. The consistency of the clay is important, since it has to be damp enough to stick, but

14 At Salisbury, the height of the piers built in this way required that the *en délit* shafts be made up from lengths of Purbeck marble, and considerable care was taken to disguise these joints (see further below). Curiously, the central pier of Lichfield's chapter house has poured lead joints between the coursed drums of its centre core, but not evidently at the fixings of the surrounding monolithic freestone shafts. This may have been because the central pier supports a complete, vaulted, upper storey as well as its own vault.

15 John Leland, *The Itinerary, parts ix, x and xi*, ed. Lucy Toulmin Smith (London, 1910), p. 227. For a discussion of the date of the east end of Worcester, see Barrie Singleton, "The Remodelling of the East End of Worcester Cathedral in the Earlier Part of the Thirteenth Century," in Alan Borg, ed., *Medieval Art and Architecture at Worcester Cathedral*, *British Archaeological Association Conference Transactions* 1 (1978), pp. 105–15.

16 Phillips, "York West Window," p. 38.

not too moist or spitting will occur when the hot lead reaches it. The lead has to be molten; in its pure state it melts at 327.5° C, and it is then highly mobile, which is why the clay collars are necessary, but it cools extremely fast and makes a tight bond with the stone that requires considerable force to break. In order to allow for a longer working time, the stone can be heated, and the building accounts for Rochester Castle in 1367–69 include payment for coal bought "for cementing the stones." This process risks scorching the limestone, which turns it pink. Derek Phillips found evidence of such scorching on the tracery stones at York.[17] Medieval masons also dealt with this problem by carrying out the pouring in stages, creating a series of layers in the lead, and this gave them a longer working time (Fig. 15.3).[18]

Purbeck shafts of any length will have been made up of sections, and these too have been found to be lead-jointed, but the processes at work are not always clear. At Rochester Cathedral, for example, the monolithic Purbeck shafts of the clerestory arcade in the presbytery have the pouring hole clearly visible at the rear of the shafts (Fig. 15.4), but other examples seen have been neatly trimmed to make the joint inconspicuous, and pouring holes have not been evident. Modern practice is to offer up these shafts into position supported by a frame, create the joint and then turn the shaft round so that the pouring hole is not visible. This may have also been a method used in the medieval workshop, but it is possible that the masons devised a spout-less form of pouring. In this, the clay collar would have been moulded into a cup shape around the joint, which would have needed spacers to hold it apart, and the lead poured into the cup would have been taken into the joint by gravity.

Brass Shaft Rings

In a number of cases, a brass ring has been fitted over the joint, or if the architecture permits, a heavier annulet covers the join. Lincoln, for example, used annulets, whereas Salisbury used brass rings for some shafts and annulets for others. The effect of using brass rings is to make the shafts look monolithic,

17 L. B. L. [Rev. Lambert Larking], "Fabric Roll of Rochester Castle," *Archaeologia Cantiana* 2 (1859), pp. 111–32, at p. 120; and Phillips, "York West Window," p. 38.

18 Mixing tin with the lead, to create solder, gives a melting point of 183° C without affecting the working properties of the lead, which would have been a much better working temperature when dealing with stone. However, the hardness of the recovered lead joints that have been examined suggests that any inclusion of tin would have been at a much lower concentration than the one part lead, two parts tin used for solder. Lead-tin alloys have been known since Roman times. In the twelfth century, Theophilus described the soldering process in detail, and purchases of tin for solder are recorded in the Exeter fabric accounts (on which, see further below). Theophilus also gives instructions for casting lead for window cames and makes no mention of any addition to the lead in the melting process; Theophilus, *De Diversis Artibus*, trans. John G. Hawthorne and Cyril Stanley Smith (New York, 1979), pp. 69–71.

because the rings, particularly when unpolished, are inconspicuous, and they are used to great effect in the Trinity Chapel at Salisbury. There, the vault of the three-aisled hall church appears to be supported solely by groups of four thin Purbeck monolithic shafts. Peter Draper has described the shafts as "daringly slender," and has pointed out that all the load-bearing, or apparently load-bearing, shafts in the cathedral employ these rings. By contrast, the decorative window shafts have the heavier annulets, which suggests that the master mason was responding to visual as well as structural requirements.[19]

It is possibly a different aesthetic aspect that was noted by Leland at Worcester. His description of the work of Bishop Giffard, mentioned above, also includes the detail that Giffard's Purbeck shafts were joined by brass rings that were gilded ("columnellis marmoreis cum juncturis aereis deauratis").[20] The reference to gilding establishes that these rings were meant to be clearly visible. The rings, or their replacements, are still extant at Worcester on the Purbeck shafts that surround the freestone cores of four pairs of piers, while the rest have Purbeck annulets (Fig. 15.5). There are two pier types at Worcester, and shaft rings occur on both types, as do the annulets, with no discernible pattern in their distribution between choir and presbytery.

At Westminster, the five nave piers west of the crossing built by Robert of Beverley, between 1260 and his death in 1285, have brass rings used for the shafts of the piers of the main arcade. The respond shafts in the aisle bays have rings as well.[21] Shaft rings continued to be used in the fourteenth century. The building accounts for Exeter list metal rings bought for marble columns between 1310 and 1321; the rings were bought in small quantities, the largest number at any one time is six, and the sizes clearly varied, as did the cost. The price for "four metal rings for the columns" in 1310 was 4 shillings, six metal rings cost 12 shillings the following year, and two years later three "large metal rings" that were part of an order for marble columns from Corfe cost 16 shillings. Two final entries, in 1319 for three rings "for marble columns" at a cost of 7 shillings, and in 1321 for "one brass ring" at 3 shillings complete the accounts that we have.[22] The variation in the price suggests that the rings were of different sizes, and possibly some were more complex than others, but their sites of use are not specified. Most of the Purbeck at Exeter is coursed; there are few monolithic shafts in the building, except in the Lady Chapel and in the transepts, where they have been added to the remodeled

19 Peter Draper, "Salisbury Cathedral: Paradigm or Maverick?," in Laurence Keen and Thomas Cocke, eds, *Medieval Art and Architecture at Salisbury Cathedral*, *British Archaeological Association Conference Transactions* 17 (1996), pp. 21–31, at p. 22.

20 Leland, *Itinerary*, p. 227.

21 Christopher Wilson, "The Gothic Abbey Church," in Christopher Wilson et al., *Westminster Abbey*, New Bell's Cathedral Guides (London, 1986), pp. 22–69, at p. 66.

22 Audrey Erskine, ed., "The Accounts of the Fabric of Exeter Cathedral: Part 1, 1279–1326," *Devon and Cornwall Record Society* ns 24 (1981), pp. 50, 59, 72, 109, 130. The accounts are not continuous, however; the period from 1279 to 1299 has very few documents, and of the annual accounts from 1300 to 1317, eight are missing.

Romanesque walls. Moreover, a certain amount of Purbeck was replaced in Scott's restoration in the 1870s. However, metal rings can still be found in the Lady Chapel, where the Purbeck corner shafts and vault shafts have brass rings, making a total of 16 small rings. The Lady Chapel is a single-storey building that was built at the end of the thirteenth century and its roof leaded in 1304, so a date within the next twenty years would be likely for the insertion of these shafts and their rings.[23] The six monolithic shafts in each transept now appear to have metal rings, but these resemble repairs, especially in the case of the shaft next to the nave south aisle, which has a total of six rings randomly ordered on the shaft.

Wax, Pitch and Resin

Medieval building accounts frequently refer to wax, pitch and resin in connection with jointing, or cementing, stone. Salzman's pioneering study of the medieval building industry cites examples of the use of these materials from accounts which he interprets as evidence for a very specific type of cement used in wet conditions. He was able to demonstrate that the practice continued for a long period, but noted that no trace has been found in any existing building of this type of cement.[24] Further examples suggest that the materials were used as part of the lead jointing process; at Porchester Castle, for example, the building accounts for 1396 include payments for pitch and resin to join the stonework using metal ("soldur petrarum"). At Winchester Castle this was specifically associated with leadwork; in the 1258 account roll, items bought for the plumbery include tallow, wax and pitch, with brushwood to found lead for the clamps of the tower.[25] The Exeter accounts reveal that considerable amounts of wax and pitch were bought for cement in each building season, with, very occasionally, resin as well, and large quantities of tallow.[26] All of these materials share a common use as fluxes to prevent the oxidization of metal surfaces in soldering, and as such will have been used extensively where leadwork involved that process. One obvious use is in the soldering of lead window cames to assemble stained glass, or in lead pipework, but fluxes were also used when metal clamps or dowels were run in with lead. It is in this context that references to the use of wax, pitch and resin in "soldering" stones should be understood, since stone-to-stone joints, or poured lead joints alone, would have no need of fluxes.

In conclusion, poured lead joints provided masons with the means of creating rigid structures, either to speed up building operations in the case of vaults, to

23 Ibid., p. 35.

24 L. F. Salzman, *Building in England down to 1540* (Oxford, 1952), pp. 153–4.

25 Barry Cunliffe and Julian Munby, *Excavations at Porchester Castle, Volume 4: Medieval, the Inner Bailey* (London, 1985), pp. 156, 176; H. M. Colvin, ed., *Building Accounts of King Henry III* (Oxford, 1971), p. 185.

26 Erskine, "Exeter Fabric Accounts," for example, pp. 25–6.

create lengths of monolithic shafts from sections, or to allow for subsequent insertions of *en délit* shafts to piers or wall arcades. It is a hazardous and skilled operation that is rarely practised today, but it enabled the medieval building masons to create the visual aesthetic that the master mason or his patron required. Then, as now, we perhaps fail to appreciate the skills of the people involved in translating the plans and drawings of the designers into the solid reality of the buildings.

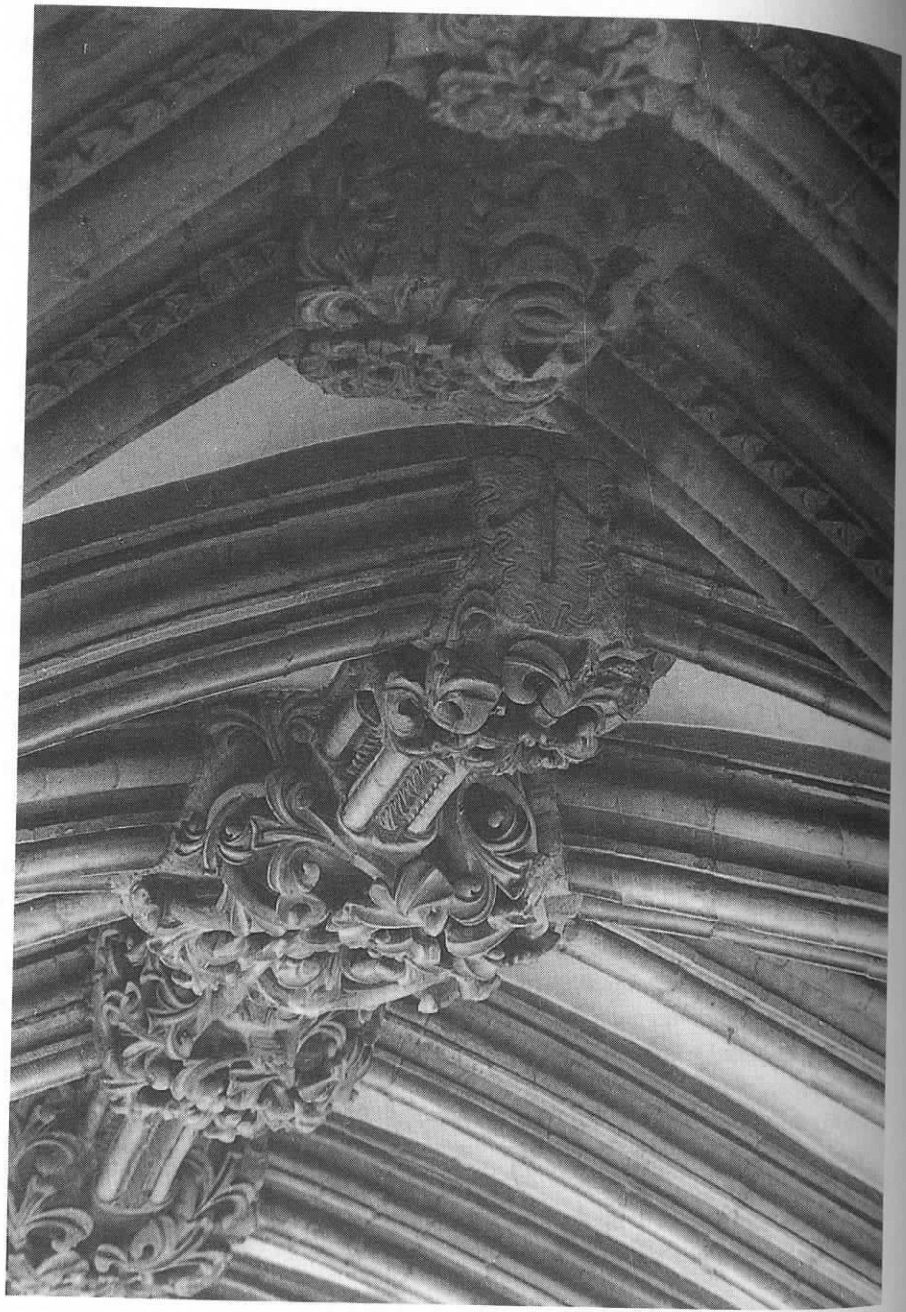

Figure 15.1 Lincoln Cathedral nave high vault west end; pouring channels in vault boss jointing face (photo: author).

Figure 15.2 Salisbury Cathedral cloister; dismantled section of tracery showing lead joint in place (photo: author).

Figure 15.3 Limestone shaft from Lincoln Cathedral with partially dismantled lead joint. Note pouring hole on left (photo: author).

Figure 15.4 Rochester Cathedral presbytery; Purbeck shaft with poured lead joint and pouring hole evident on right (photo: author)

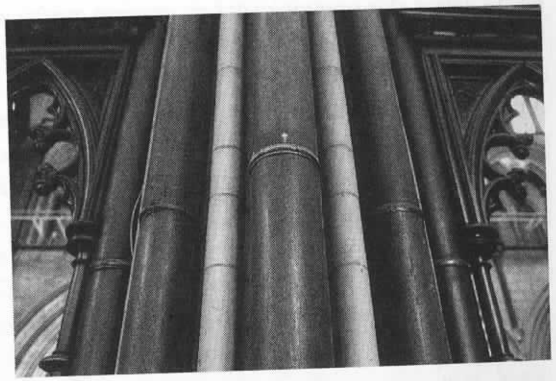

Figure 15.5 Worcester Cathedral choir; gilded brass rings covering the joints in the Purbeck shafts (photo: author).