ST LEONARD'S TOWER: SOME ASPECTS OF ANGLO-NORMAN BUILDING DESIGN AND CONSTRUCTION

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The free-standing structure known as St Leonard's Tower, West Malling (NGR TQ 6761 5707) is generally believed to have been built under the patronage of Gundulf, Bishop of Rochester (1077-1108). Many brief descriptions of the tower have been published since the late eighteenth century, the most informative of which was written by Clark in 1884.[1] He concluded: 'It is much to be desired that the Kent Archæological Society should take this curious tower in hand, and obtain proper plans and elevations of so very remarkable a building ...'.

Large-scale plans and internal elevations of St Leonard's Tower were eventually drawn up for the RCHME in 1989 (**Fig. 1**),[2] which reveal an unambiguous example of disciplined, if somewhat irrational, modular construction. This is of some significance for the debates surrounding early medieval architectural principles, the respective roles and capabilities of patrons, master masons and builders and, potentially, for the clarification of Gundulf's reputation as 'one who was knowledgeable and effective in the work of masonry'.[3] However, the attribution to Gundulf is an assumption based on circumstantial evidence that has yet to be assembled in a coherent form. It is nevertheless timely that McAleer, in his recent and exhaustive study of the somewhat similar 'Gundulf's Tower' at Rochester Cathedral, suggests that the Rochester tower was built under the patronage of Gundulf's English predecessor, Bishop Siward.[4]

PROVENANCE: THE CIRCUMSTANTIAL EVIDENCE

St Leonard's Tower takes its name from an adjacent church or chapel which was first recorded in *c.* 1120-30 and demolished in the eighteenth century.[5] The tower remained unrecorded until shortly after the

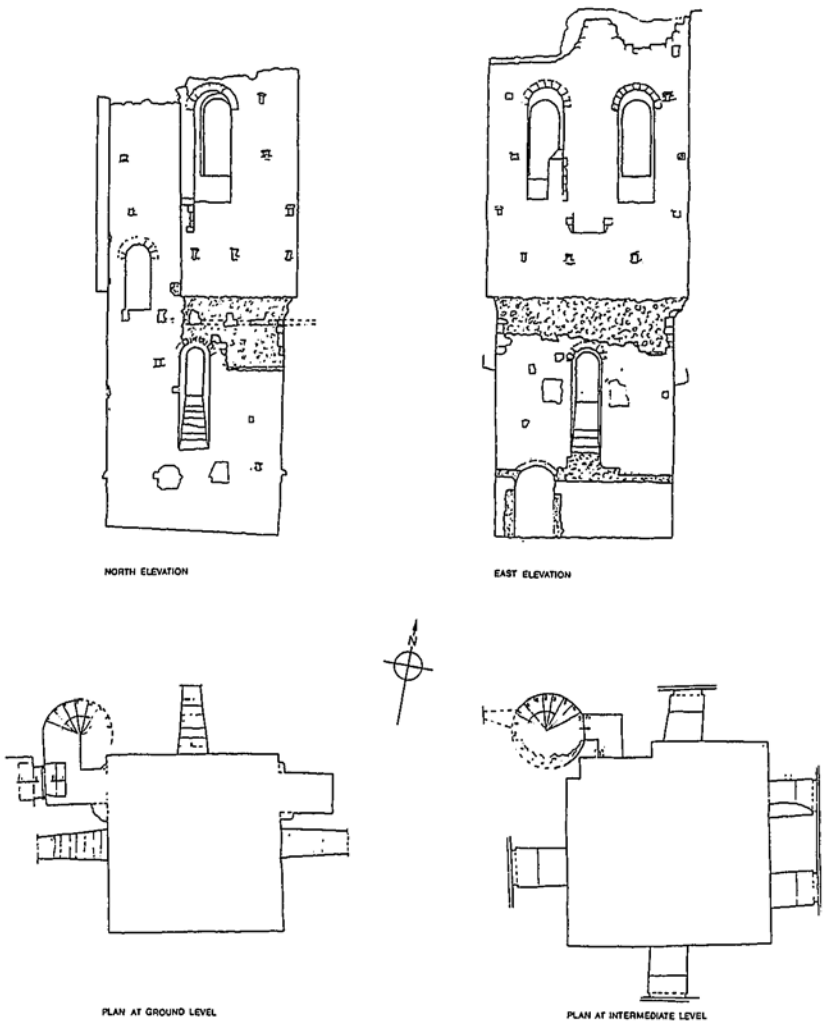

Fig. 1 Plans and internal elevations of St Leonard's Tower.
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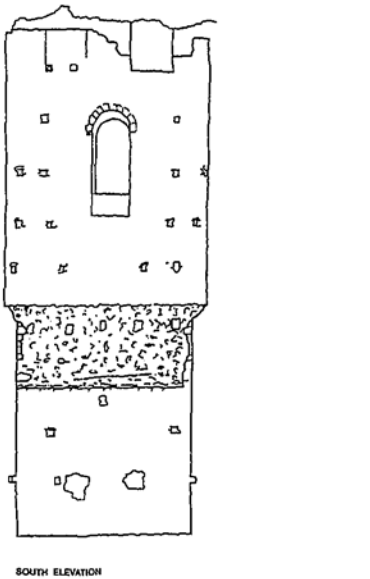
demolition of the chapel, when antiquarians recognised it to be more like a keep or *donjon* than a church tower. By the early 1860s the tower had become attributed to Gundulf, primarily because of its proximity to Malling Abbey (Gundulf's nunnery, founded *c.* 1090/1093), the remains of which stand about 700m to the north-east



of the tower.[6] Since Gundulf governed the nunnery and established the town around it,[7] popular legend would have it that he erected St Leonard's Tower to protect the abbey and/or the road through West Malling to Rochester. More certainly, however, West Malling was the only estate belonging to the bishopric to have a natural and

prolific supply of building stone – a resource which probably determined the location of the nunnery and the existence of the tower.[8]

The manorial evidence is more compelling, if not entirely conclusive: West Malling was divided into two manors when Gundulf endowed the nunnery with a substantial part of the estate. The remainder – the borough or precinct of Ewell (named after the springhead at St Leonard's) – is reasonably assumed to have been Gundulf's demesne and St Leonard's its administrative centre. The borough of Ewell continued to be held by the bishops of Rochester (as tenants-in-chief) until it was also given to Malling Abbey in 1441.[9] However, the nuns had seemingly taken possession of St Leonard's Chapel by the mid twelfth century, implying a separate endowment by Gundulf or one of his early successors.[10] It is therefore debatable whether any person other than Gundulf would have had a compelling reason to build St Leonard's Tower.

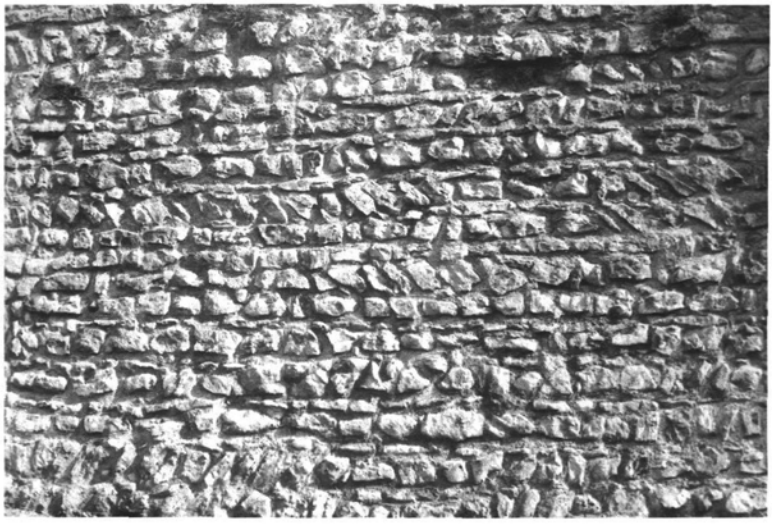
MASONRY STRUCTURE: GENERAL DESCRIPTION AND INTERPRETATION

Clark's 'curious tower' was probably so-called because it had generous windows and was entered through the basement, apparently without a fore-building. Nevertheless, apart from commentators who have preferred to interpret the building as a defensible church tower, the tendency has been to over-rate its apparently defensive features. At the same time, descriptions of the tower have been fairly superficial and often contradictory. The following commentary is therefore intended to supplement earlier descriptions, though at the risk of repeating or contradicting much that has already been written.

The tower is square in plan with thick walls of ragstone rubble interspersed with levelling courses of thinner masonry (**Plate I**) and plain, round-headed, tunnel-vaulted openings throughout. Calcareous tufa was used selectively for the ashlar work, with grey material used for internal surfaces which were presumably intended to be plastered, and white or cream-coloured material reserved for window dressings and quoins.

The standing remains comprise a high plinth of shelving ragstone bedrock which was raised with sloping masonry on the south and east sides, forming a solid base which is *c.* 3m (10ft) high on the east side. (A detailed analysis of the measurements is set out below.) The tower contained a clay-floored basement and a first-storey chamber, the latter indicated by sockets for a timber floor. The walls were originally set off internally at *c.* 0·45m (1·5ft) above the joist level, the offset subsequently being removed. While this may be indicative of

PLATE I



St Leonard's Tower: typical coursed ragstone walling (south face).
Photograph: author

an error or a change of plan, other disturbances to the masonry in the basement suggest that the upper chamber was intended to have a solid floor supported by an east-west tunnel vault, which was abandoned before completion.[11]

The uppermost parts of the tower have been slighted, leaving remnants of inner sills in the south and west elevations suggesting that a further storey has been removed. The overall external dimensions of the tower are *c.* 10m (34ft) square with walls *c.* 2·06m (7ft) thick. The present maximum height above the plinth is *c.* 18m (61ft) and the original height would not have been less than 22m (75ft).

The basement is lit by inwardly-splayed openings with multi-stepped inner sills, centred high in the north, east and west faces. The steps have been interpreted as exits to an external platform or gallery, though they are crudely constructed and might only have been intended to form deep splays. The evidence for external galleries, meanwhile, consists of small, widely spaced putlog holes which appear (from the ground) to be suitable only for the support of lightweight scaffolding.

PLATE II

St Leonard's Tower: window seat and tufa brackets (circled).
Photograph: author

The windows of the upper chamber are (more or less) parallel-sided, with deep, single steps to the inner sills and rebates for shutters. The openings are also high above the (first) floor level and are more numerous than in the basement: two in the east face and one in each of the north, south, and west faces. The north-eastern opening in the east face has a stone 'seat' built into the inner sill which tapers towards the outer end to allow the shutter to be opened or closed (**Plate II**). The feature is located above a blocked eastern entrance to the basement (see below) and might therefore have been used by a watchman or doorkeeper.

The tower is divided externally into three stages by slight offsets and tufa stringcourses marking the outer sills of the windows. The north-east, south-east, and south-west angles are clasped by pilasters, and a pilaster strip runs up the centre of the south face to the sill of the upper window. Decorative features are otherwise limited to rows of plain, round-headed recesses or niches articulating the south and east faces and incorporating the centred lower window opening in the east face (**Plate III**).

PLATE III

St Leonard's Tower: blind recesses in the south and east faces.
Photograph: M. Gadd

The north-west angle is buttressed to contain a tunnel-vaulted helical stairway with mural lobbies at the basement and first-floor levels. The stairway has been removed above first-floor level but the vice wall, which is wholly constructed of dark grey tufa ashlar blocks, is preserved for the remaining height of the building. The surviving treads, which are of ragstone and tufa with traces of a rendered surface,[12] are well preserved and apparently little used.

An original entrance to the tower is indicated by a straight, tunnel-vaulted passage through the north end of the east wall at the basement floor level. The passage is blocked at its outer end and has been so since at least 1772, when an illustration of the tower's east side showed it in its present ruinous condition.[13] The tower is now entered by a *c.* 1870s round-headed portal in the west face,[14] opening into the mural lobby at the foot of the stairway. Photographs from the mid-nineteenth century show a gaping hole in the position of the portal and substantial damage to the base of the adjacent vice buttress[15] which was probably inflicted during the evident slighting of the whole structure, perhaps in the seventeenth century (Civil War

period?) or earlier. The repair work appears to have involved the restoration of a slightly larger portal, evidenced by an external step that is wider than the present portal and conforms to the scale of measurement used throughout the construction of the tower (see below). Since the eastern entrance gave access to the basement at a point remote from the stairway and if – as seems most likely – the basement was intended as a storage area, the provision of a private entrance to the stairway might well have formed part of the original plan.

The basement was divided by a low-level timber floor, indicated by opposing pairs of large beam sockets in the north and south walls and associated wall-plate channels in the east and west walls. This has frequently been interpreted as the first floor of the tower, though the features are clearly not original: the channels are crude insertions which run through putlog holes and bisect the heads of doorways, whilst the large sockets indicate that beams were inserted with little regard for precise measurement. Timbers associated with these features might, however, have been recovered from the original structure: similar pairs of sockets at the higher level of the basement windows in the east and west walls evidently held massive beams (*c.* 0·5m (20in.) wide by 0·6m (2ft) high), their lower surfaces set at the level of the lower stringcourse and having equidistant spacing (*c.* 1·5m; 5ft) between the sockets and the adjacent walls.

Function: a re-assessment

The location of St Leonard's Tower was determined by the springhead and its decorative features were evidently restricted to those faces that were on public view. The original curtilage probably extended northwards for a short distance to a steep-sided combe but the location is more prominent than defensible. The blocked eastern entrance, which opened onto a natural platform of ragstone,[16] is almost invariably interpreted as a defensive feature, though this cannot have been the case when the tower was built: the platform was an extension of a natural terrace on the north side of the tower at the level of the basement floor (the ground on the north side of the wall being considerably higher than that on the south side) which is now concealed by the garden wall of the adjoining property (*Malling Place*). The garden wall, which abuts the north-east angle of the tower and has been interpreted as a curtain wall, is of several constructions and incorporates the north wall of St Leonard's Chapel; it is therefore conceivable that the wall originated as a property division resulting from the donation of the chapel to Malling Abbey.[17]

Internally, the apparent lack of a water supply, latrines and a

fireplace argues against domestic use, though a private chamber might have existed in the destroyed uppermost part of the tower. A formal function for the first-floor chamber is nevertheless indicated by the provision of a relatively wide stairway (see below) and by the two large windows - including the 'window seat' - in the east face, below which are the remains of two tufa brackets (Plate II). The brackets evidently flanked a larger structure - possibly a throne, altar, or a hearth, though there is no clear evidence of a smoke vent for the latter. An administrative or ceremonial function for the first storey (perhaps an audience chamber) therefore seems preferable, in which case the 'doorkeeper' function of the window seat would be most appropriate.

PLANNING AND CONSTRUCTION

St Leonard's Tower is a modular building in the sense that virtually all the construction work was governed by two units of measurement: multiples of 9in. (0·23m) for lesser dimensions and of 3·75ft (45in.; 1·14m) for major dimensions:[18] the eastern entrance passage is 7·5ft high and slightly less than 4ft wide; the external step to the western portal (though not certainly original) is 3·75ft wide by 1·5ft deep by 9-10in. high; the external buttresses for the vice are 7·5ft wide and project 1·5ft; internal vice buttresses are 7·5ft wide (north wall) and 2·25ft wide (west wall); the lower mural lobby is 3·75ft wide by 7·5ft long and originally *c.* 7·5ft high (the lobby floor having been raised to the level of the first tread on the stairway); the upper mural lobby was 7·5ft high (reduced by a 10in. step) and is 3·75 ft wide; the vice has a diameter of 7·5ft with walling of 9in. courses; the vice loops occur at 17·5 and 32·5ft (15ft apart, and 7·5ft below and above the internal offset) to correspond with the geometry of the stairway, which rises 15ft in one turn (the vaulted ceiling of the stairway is 7·5ft above the treads and a further 7·5ft of infill above the vault maintains the pitch of the stairway; see below). The upper stringcourse is 37·5ft above the plinth; joist sockets are centred at 3·75ft intervals; tufa brackets in the upper chamber are 7·5ft above the internal offset; upper window openings are 3·75ft wide; internal heights of window openings (i.e. the overall height before steps were built in) are 11·25ft in the lower chamber but slightly greater in four of the five upper windows. The basement floor is 18·75ft square (less 2in.); the walls of the basement are 7ft thick (set off by 1·5ft in the first-storey chamber) but are increased to 7·5ft by the pilasters, making the external plan up to 33·75ft square (measured on the south side). Finally, a horizontal beam slot, buried in the north wall, is 22·5ft above the plinth level. Major dimensions that do not conform to the module are the heights

of the internal offset (25ft) and the lower stringcourse (14ft), and the widths of the pilaster strips (3-3·5ft).

While any evidence for modular design in early medieval architecture is of considerable interest, the point of immediate significance is that the major scale was not applied to determine the heights of the lower stringcourse and the internal offset; why not, for instance, 15 ft and 22·5 ft respectively?[19]

It can hardly be coincidental that a hemi-cylindrical vault would have fitted neatly into the vertical space between the stringcourse and the internal offset, allowing some 20in. for the thickness of the vault and a solid floor above it. On this interpretation, the height of the lower stringcourse denoted the springing level for the vault, corresponding, as we have seen, with the level at which massive beams were inserted – arguably to support the formwork and the weight of the vault during its construction. The internal offset might then have been designed firstly to support a temporary working platform and secondly to indicate the final level of the solid floor (**Fig. 2**). Before

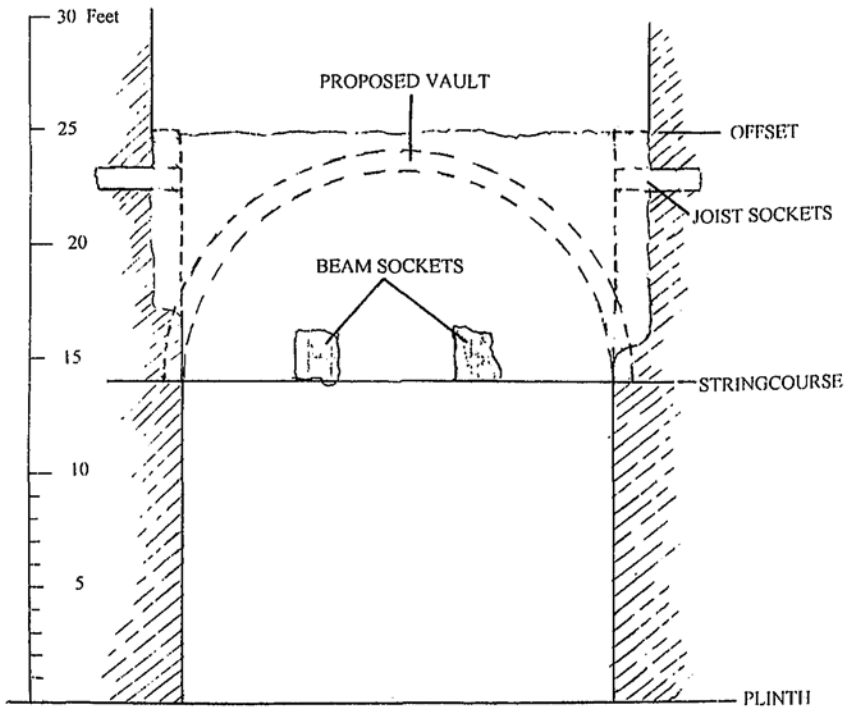


Fig. 2 St Leonard's Tower: Section showing proposed vault over the basement.

considering the physical evidence for the attempted construction of a vault, however, it is necessary to describe the construction of the vice.

Construction of the vaulted helical stairway

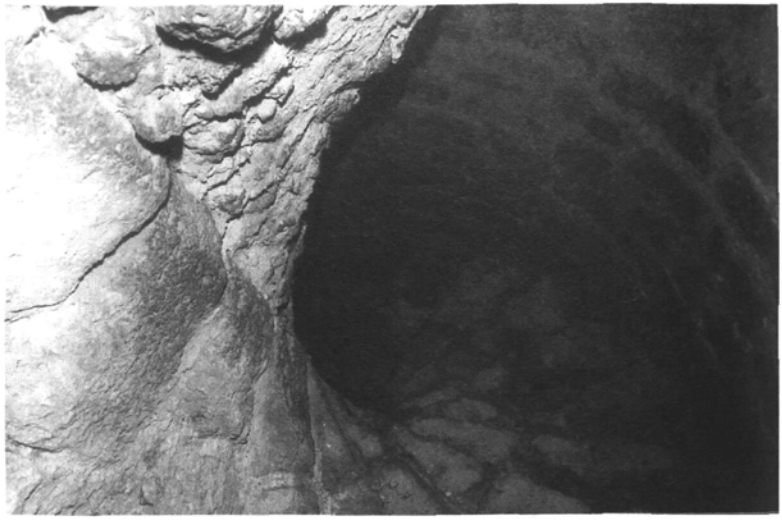
The basic requirements of the helical stairway are to provide sufficient headroom, treads of sensible dimensions and suitably orientated access to upper floor levels. The knowledge of geometry and level of planning required of medieval architects to satisfy these requirements should not be underrated.

In the tunnel-vaulted stairway the need for planning and expertise is emphasised by the separate construction of the vice wall and the stairway: the vice wall and surrounding masonry (usually with loops at predetermined positions) were built first around a timber cylinder or drum. The lower treads, for the first three-quarters of a turn, were built around a central newel post and supported by the floor; higher treads were then constructed on the infill of a vaulted ceiling over the lower treads such that the finished stairway formed a helical tunnel around the newel post.[20] Thus no stair building or vaulting work could be started until the vice wall and surrounding masonry had been completed to a considerable height, and perhaps not until building work had reached first-floor level.

As already indicated, at St Leonard's Tower the geometry of the vice conforms to the module used throughout the building; the 7·5ft internal diameter of the vice was therefore the theoretical maximum which could be contained within the angle of the walls. The diameter of the vice distinguishes it from the narrow, claustrophobic examples found in parish church towers and in the upper parts of some major churches; it is also distinctive, if not unique, in being constructed without a newel post (**Plate IV**) - presumably to create more internal space.[21] The newel-less method of construction was self-evidently effective, but the diameter and placement of the vice had a number of unfortunate consequences.

First, the vice wall was built with its perimeter touching the internal angle at basement level and buttressed to maintain the wall thickness above the level of the internal offset. However dangerous the arrangement might now appear, the immediate consequence was that a vault could not be supported in such close proximity to the vice. Secondly, the vice was accessed by a rectilinear, dog-leg mural lobby or passage entering and occupying the first (south-west) quadrant of the stairway; the disciplined plan of the lobby thus brought it almost to the outer line of the west wall, resulting in the bizarre decision to bend the line of the wall to accommodate it.[22] Thirdly, the external

PLATE IV



St Leonard's Tower: newel-less stairway.
Photograph: author

vice buttresses were built to the prescribed dimensions without any recognition of the alteration to the line of the west wall, resulting in a total lack of correlation between the vice and the surrounding walls (**Fig. 3**).

Accurate construction of the stairway was partly dependent upon the construction of the vice wall, where 9in. courses were intended to correspond with, and thus regulate, the height of the treads.[23] The stairway, rising 15ft in one turn, should have reached a height of 22·5ft in the 1½ turns needed to coincide with the first-floor lobby in the north wall or 26·25ft in the 1¾ turns needed to make an exit in the west wall (i.e. above the ground-floor lobby). However, cumulative errors in the courses, which were adjusted periodically with thinner stones (**Plate V**), caused the stair builders to gain an extra 9in. in the first turn. Subsequent courses (and steps) settled down to a regular pattern but earlier errors were not corrected and the height of the lobby floor was then increased with an additional step to just under 23·5ft to compensate for the extra height gained by the stair builders.

Since the geometry of the stairway corresponds with the height of

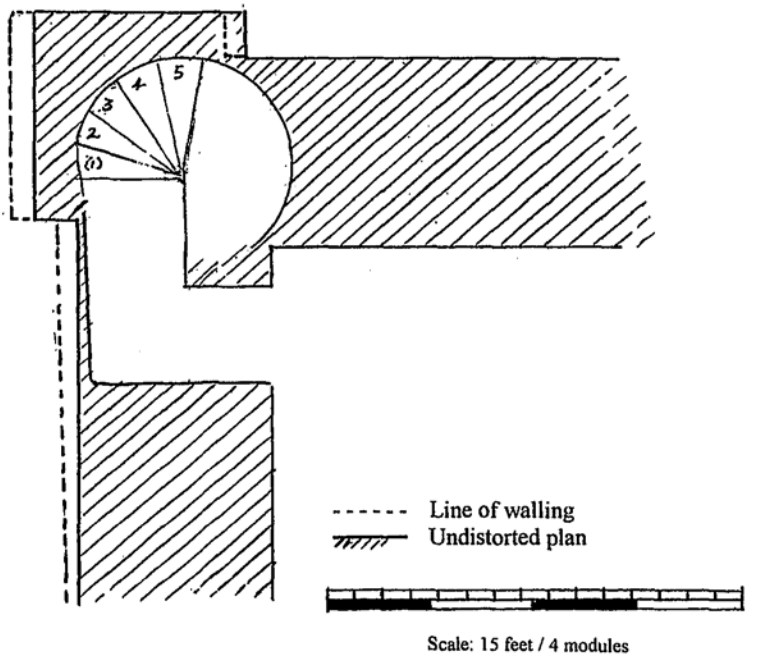
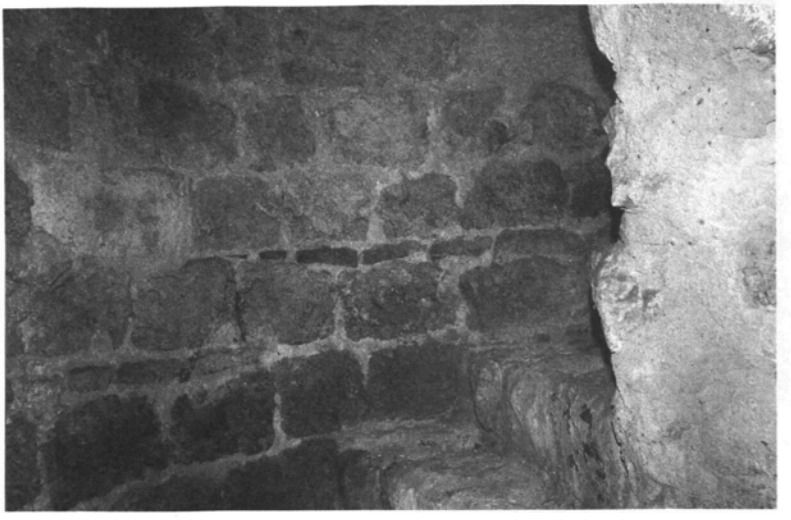


Fig. 3 St Leonard's Tower: plan of north-west angle (basement floor level), showing alignment of the west wall and angle buttresses.

the lobby, rather than that of the offset (25ft), which was later removed, and since the floor joists also correspond with the lobby, we are left to ponder the building sequence and the intended position for the lobby. If the original intention had been to make an exit in the west wall, corresponding with the level of the offset, the discrepancy noted above plus the extra height gained on the stairway would have amounted to a difference of 2ft, which, with hindsight, could probably have been adjusted with steps down into the lobby. The point, however, is academic. There is no evidence for drastic rebuilding to move the lobby to its present position; the construction of the stairway to first-floor level evidently followed the simultaneous construction of the lobby, the adjacent walls and the offset. Thus, while the builders followed instructions to build an offset at 25ft, they (or the stair builders) were bound by the geometry of the stairway to build a lobby in the north wall at 22·5ft.

There is some indication, however, that a lobby in the west wall had been planned. The upper west window, which has no apparent reason

PLATE V



St Leonard's Tower: typical levelling courses in the vice wall.
Photograph: author

not to be centred, was eccentrically but neatly placed as if to accommodate a lobby and an internal buttress of the standard width (7·5ft) beside it. At the same time a (presumably) centred window in the north wall appears to have been rebuilt to accommodate the internal buttress in that wall, resulting in the inner and outer jambs of the opening being badly misaligned. Either way, it was the standard width of the buttress, rather than that of the lobby (only 3·75ft), which dictated the eccentric position of the window opening!

Construction of the first floor and major vault

The evidence for the planning and attempted construction of a vault can now be summarised: firstly, the modular design of the tower was spatially adapted for that purpose; secondly, the insertion of large beams at a non-modular level is significant for springing and suitable for the support of formwork and the weight of vaulting and, thirdly, material was removed from the basement walls in preparation for the work. At first sight this might be dismissed as masonry robbing;

PLATE VI

St Leonard's Tower: removed masonry at the internal offset level (south and west walls). *Photograph*: author

however, most of the material was removed systematically and evidently for a structural purpose. First, and because of the discrepancy between the height of the lobby and the offset, the latter was reduced in height in all four walls to a point below the level of the floor joists. Facing stones were then removed from the south wall, the removal terminating in a horizontal line at the level of the tops of the large beam sockets (**Plate VI**). A smaller socket at the south-west internal angle, corresponding with the bottoms of the beam sockets (i.e. the level of the stringcourse and the proposed springing level) suggests that facing stones were being removed to that level and that the work of removal was incomplete. In the opposite (north) wall the removal of facing stones was terminated at a slightly higher level (actually, 7·5ft below the offset) though a neat hole at the north-west internal angle again corresponds with the level of the stringcourse. In this case the hole penetrates the vice wall (which, as we have seen, almost touches the internal angle) at an open section of the stairway. It appears, then, that the vaulting work was abandoned at this point, firstly because a vault would have encroached into the stairway, and

secondly because the weight of a vault against the stairway would have caused the collapse of both structures.

On this interpretation the floor joists, which were deeply embedded in the walls and must therefore have been inserted during the course of construction, present the appearance of a permanent floor because the builders were unaware of the significance of the offset; the geometry of the stairway dictated the position and level of the first-floor lobby, hence it was evidently the correct height for the floor joists. If the builders were unaware of the significance of the offset they were probably also unaware of the intention to build a vault, which would probably not have been attempted until the building was roofed and watertight.

CONCLUSION

The apparently experimental nature of the stair- and vault building at St Leonard's Tower is consistent with McAleer's conclusion that it was a slightly later and more sophisticated version of 'Gundulf's Tower' at Rochester Cathedral,[24] which was constructed without a vice and (possibly) without a ground-floor entrance. The few original measurements that can be recovered from the much-restored remains of the Rochester tower suggest, however, that its dimensions differed from those at St Leonard's, and that a similar modular system was not employed for its construction. Indeed, preliminary investigations suggest that, with the possible exception of the plan of the first Norman cathedral church at Rochester, the scales of measurement evidenced at St Leonard's Tower are conspicuously absent from early medieval buildings elsewhere.[25] This raises the possibility that the modular system was a function of the design, rather than of local craftsmen and local measurements.

In any event St Leonard's Tower may be summarized as an experimental design, which was executed with minimal supervision from the architect. Typically, plans and elevations might have been worked out at full scale close to the building site and would necessarily have been available to the builders for the duration of the project, which at St Leonard's probably lasted for at least five or six years.[26] In practice, however, a combination of unsuitable terrain around the Tower and an apparent lack of communication between architect and builders suggest that the necessary planning was carried out elsewhere. Thus, having designed the building, the architect might have transmitted instructions to an overseer or master mason on a seasonal basis, making only occasional visits of inspection.

Some such hypothesis might then explain the generally disciplined but sometimes irrational actions of the builders, who evidently followed instructions without question. This would not rule out the existence of an independent architect, though it rather suggests the work of an innovative patron who was heavily committed elsewhere.

ACKNOWLEDGEMENTS

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NOTES

[1] G. T. Clark, 1884, *Medieval Military Architecture* II, London, p. 293.

[2] Historic Buildings and Monuments Commission AS1/1. Scale: 1:50.

[3] R. Stalley, 1999, *Early Medieval Architecture*, Oxford, pp. 103-5 (citation at p. 105).

[4] J. P. McAleer, 1998, 'The so-called Gundulf's Tower at Rochester Cathedral', *Antiquaries Journal*, 78, 111-176 (esp. 156-9). McAleer provides useful comparisons with St Leonard's Tower, but gives only a superficial account and analysis of the latter. He concludes, mainly on the basis of style and the inclusion of a helical stairway at St Leonard's Tower (not evidenced in the Rochester tower) that St Leonard's was 'possibly (?slightly) later and more sophisticated ...'.

[5] G. Ward, 1932, 'The List of Saxon Churches in the Textus Roffensis', *Archaeologia Cantiana*, xliv, 39-59 (esp. 53). The 'recent' demolition of the chapel is implied in J. Thorpe, 1788, *Antiquities in Kent, within the Diocese of Rochester*, London, pp. 128-130.

[6] J. H. Parker, 1863, 'The Buildings of Bishop Gundulph', *The Gentleman's Magazine*, CCXV (September 1863), 256-7 (esp. 256-7).

[7] R. Thomson (ed.), 1977, *The Life of Gundulf, Bishop of Rochester* (Vita Gundulfi), Toronto, fol. 74v.

[8] C. Flight, 1997, *The Bishops and Monks of Rochester 1076-1214*. KAS Monograph Series VI, pp. 182-3; 187. Flight speculated that ragstone and tufa might have been transported from Malling for the construction of Gundulf's cathedral at Rochester. Surprisingly, however, he did not associate the availability of building materials with the choice of location for Malling Abbey.

[9] A. M. Oakley, 1990, *Malling Abbey 1090-1990*, West Malling, p. 45.

[10] *Calendar of Charter Rolls* V (1341-1417) p. 62. An inspeximus of Edward III (1347) confirms a grant to the nuns of an annual, five-day fair by William de Ypra (*c.*

1150). The full text (unpublished) concludes: 'through his charter to God, St. Mary, St. Leonard, and the nuns serving God there'. Subsequent charters (from the late twelfth century onwards) confirm the possession of the church of St Leonard by Malling Abbey.

[11] See below. Parker 1863, *op. cit.* (see note 6) p. 258, interpreted the evidence as a 'destroyed' vault.

[12] The writer is grateful to Alan Stevens for pointing this out.

[13] Thorpe 1788, *op. cit.* (see note 5), plate XXVII, dated 1772. The blocking is most clearly illustrated in D. Renn, *Norman Castles in Britain* (second edition, London, 1973), plate XLVII - the photograph having been taken before the masonry was re-pointed in the 1980s.

[14] Clark 1884, *op. cit.* (see note 1), p. 292, described the portal in 1884 and it appears in drawings and photographs of slightly earlier date.

[15] An illustration of the Tower in Parker 1863, *op. cit.* (see note 6), based on a photograph in the KAS collection, shows the damaged masonry prior to the construction of the present portal.

[16] Most of the platform has been quarried away. Removal of natural stone from the north-eastern corner is indicated by the remaining bedrock foundation beneath the tower and the northward termination of the man-made plinth, which corresponds with the southern extent of the blocking to the eastern entrance.

[17] Details of the remains of St Leonard's Chapel and other features associated with ancillary buildings on the north side of the tower will hopefully be published in the near future.

[18] The measurements, which are subject to variations of up to 2-2·5in. (50-60mm), have been taken from the 1:50 scale drawings (see note 2) and confirmed, where possible, in the building. The original basement floor level is identified as the top of the plinth, corresponding with the threshold of the eastern entrance to the basement.

[19] The limited scales employed by the builders and the relative precision of measurements achieved in the coarse masonry work arguably rule out any possibility of miscalculation.

[20] The construction method was used until the introduction of 'keyhole shaped' monolithic treads in the early thirteenth century. For a fuller account, see D. Parsons, 1982, 'The Romanesque Vices at Canterbury', in *Medieval Art and Architecture at Canterbury Cathedral before 1220*, B.A.A. Conference Transactions (1982 for 1979) No. 5, pp. 39-45.

[21] The treads were laid tangentially with the innermost stone of each tread overlapping the one below it and supporting the one above it.

[22] The passage to the stairway could, of course, have been angled to overcome this problem – as it was in the similar (and presumably slightly later) tower at Holy Trinity Church, Dartford. The Dartford tower (also attributed to Gundulf) has walls *c.* 5·5ft thick and a vice of *c.* 6ft in diameter which was also placed close to the internal angle.

[23] Various methods were employed to regulate tread heights in the construction of vaulted stairways. Measured ashlar blocks, facing stones or newel drums were usually used in high-status buildings.

[24] McAleer 1998, *op. cit.* (see note 4).

[25] A paper is currently in preparation by the author on the metrology of the early Norman cathedrals at Canterbury and Rochester.

[26] D. Renn, *op. cit.* (see note 13), pp. 25-6. Analysis of expenditure on castle keeps suggests that they were erected at the rate of 10-12ft per season.