II
The Design of Hadrian's Wall and its Implications

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THIS paper gathers together some of the evidence for the design of the original broad wall from Newcastle to the Irthing, and examines some aspects of the design which have been the subject of discussion or where a fresh examination throws light on old problems and raises new ones. The implications of the conclusions reached on technical building considerations for the function of the Wall are brought out. The authors are grateful to Dr. D. J. Breeze for some useful comments, and for the data reproduced in Appendix 2.

The Curtain Wall

The broad wall seems to have been designed with a width of 10 Roman feet (9′ 8″, 2·96 m) and for the first sixteen Roman miles may have been completed to something like that gauge; it is generally recorded as being between 9′ 1″ and 9′ 6″ (9·36–9·8 Rf, 2·77–2·89 m), with the preponderance being slightly in favour of the lower figure.[1] The best physical evidence for the height comes not from the curtain wall itself but from the walls of milecastles 37 and 48. A detailed review of this evidence appears in Appendix 1, where the conclusion is that the design height of the wall top, measured from the top of the foundations, can be reckoned at a minimum of 14′ English (14·4 Rf, 4·27 m), and almost certainly 14′ 6½″ (15 Rf, 4·44 m).[2] Thin bonding courses were provided at intervals of four or five feet. It seems reasonable to suppose that the curtain wall was built to the same height although, using a 5′ module, the possibility that it was only 10′ high should not be entirely excluded, even though a wall as high as it was thick would be an oddity. A height of 15′ would seem more probable, and is assumed to be so in the following pages.

Bidwell and Holbrook[3] calculate the height of the broad wall, adjacent to Willowford bridge, at between 11′6″ and 13′2″ (11·86–13·6 Rf, 3·5–4·0 m). The calculation is based on the stepping of the core, but there are problems inherent in the use of this evidence. First, the vertical height of the stepped core is no more than 2′6″ (0·75 m), a very small length of slope from which to project the finished height having regard to the variation in the size and shape of the stones; as the authors acknowledge, there was some doubt about which gradient to use. Working from their Fig. 41 it is not difficult to arrive at a height of 15′4″ (15·8 Rf, 4·67 m). Secondly, using the core in this way implies that the gradient of the core followed very closely the gradient of the stepped walling stones which supported it, something which does not seem particularly likely. Thirdly, even if the facing stones were present, the variations in their size make a smooth gradient aiming straight to the wall top somewhat unlikely, especially over so short a length; no more than four courses would have been needed to support that height of core. In the light of these reservations, it would seem best to disregard this stepping of the core as evidence for the height of the broad wall.

In order to calculate the scale of the work account must be taken not of a possible design drawing, but of what was actually built to the original design, where this is known, and an average width of 9′3″ (9·54 Rf, 2·82 m) seems to be a fair one to take for this purpose. With a height of 15 Roman feet, the volume of material for forty-five miles of curtain wall alone without parapet is just over one million cubic yards, using rather more than ten million facing stones.

The first thing to strike the observer is the sheer irrationality of the size—a height to width ratio of 3:2 looks to be intended to withstand a battering ram, which is one thing the Romans were unlikely to have faced in north Britain. The excessive thickness is not likely to have been based on fears of stability for the Romans were well practiced in building techniques. The use of clay rather than mortar for bonding the core, at least in places, is unlikely to have been the reason.[4] The generous size may have been chosen simply for the sake of emphasising its impressive appearance.

An immediately obvious reason for the thickness is that it was to accommodate a patrol walk, but if that were so why was it possible during the construction of the Wall to reduce the width to 8′ (2·44 m)? As will be shown, 1′ 6″ (460 mm) would have sufficed for the parapet (the question of a rear parapet is discussed below). If the remaining 6′ 6″ of an 8′ wall would have accommodated patrols, the original 10′ gauge would seem to have been selected on the basis of a hopeful guess, an unlikely scenario in an army well used to building military works. The 6′ (1·83 m) wall at T26b is sunk a little in to the broad wing wall in the same manner as the 8′ and 7′ walls which override the wing walls at MC48 and T29b respectively, suggesting that a 6′ gauge was also used in the Hadrianic programme, despite recent attempts to revive the notion that this width is diagnostic for the Severan rebuild.[5] There would be room on this narrow wall for one armed man to walk along behind the parapet, but it would be difficult for two men with shields to pass comfortably, bearing in mind that the walkway would be only some 4′6″ (1·37 m) wide with a fifteen foot drop on one side if there was no rear parapet. It is not a question of only a short length of narrow wall; some 30 miles—Wallsend to Newcastle and Wall-miles 22-49—were built to less than the original ten foot gauge. Not only is the severe reduction in width a partial abandonment of monumental impressiveness but, if patrols were part of the original scheme, it implies a change of use.

The provision of bridges at Chesters and Willowford, only wide enough to carry a walk and yet of monumental proportions and on the line of the wall,[6] strongly suggests that a walk along the top of the wall was part of the original plan. It is difficult to see them as simply intended to allow foot patrols to cross the rivers dry-shod without any reference to a wall-walk, for in that case simpler structures behind the wall line would have been more likely. At Willowford, this footbridge seems to have been repaired on two occasions which might suggest a continuing need for it, though it is the original form and siting that are important; later rebuilding would tend to be on the same line from simple inertia. The evidence from the bridges would support an original desire to provide a walkway on top of the Wall, a walkway which, like the turrets and milecastles, lost some, perhaps most, of its importance when the forts were built on the line of the Wall.

The building up in stone of the recesses left from the demolition of unwanted turrets some time after the return from Scotland is perhaps an indication that an existing wall-walk had to be maintained, although the same result could have been achieved more quickly and easily by throwing across a bridge of two beams with cross-slats. Making good in stone may also have been related more to tidying up and consolidation of the wall than to a patrol walk. The stability of the Wall, up to eighty years old by this time, would not have been improved by the work of demolishing the turrets. At each end of the recess there will have been a ragged scar 3′ wide with a stone missing from every other course where the bonded turret wall had been removed; something had to be done about that at least, and the thickness of the wall at the recess was as little as 3′ (920 mm). The blocking of the turret recesses could have been to aid stability at this weak point. The blocking wall at T33b was not built on sound foundations[7] and later subsided, which would have made its use as a walkway somewhat uncomfortable unless repaired at the top; the subsidence is undated but movement of this sort tends to take place sooner rather than later. The alleged provision of an outside staircase at Peel Gap Tower,[8] after the tower had gone out of use, also suggests that a wall-walk existed, but even if the idea of a fixed staircase can be accepted a similar provision ought to have been provided at the sites of other dismantled or disused turrets and none has yet been recognized. The implications of keeping a wall-walk without the use of turrets for shelter and accommodation need working out before the concept can be accepted on the evidence so far presented. The possibility that the narrowing of the wall led to a diminution in the use of its top as a patrol walk remains.

As the Wall has not survived to full height there is no firm evidence for the way in which it was finished off. The most recent survey of the options appears in the 1985 Horsley lecture[9] in which are offered the options of the traditional flat wall-walk with either crenellated or straight parapet, and a sloping top which is more satisfactory from the point of view of longevity, as rain water would be rapidly shed instead of ponding and percolating into the core. There is no reason why a sloping top should not have its apex on the centre line, with an equal slope to north and south, except that the existence of the string course on the north side only (see below) suggests an asymmetrical top. A single slope running down from north to south at an angle of 10° would necessitate a retaining wall above the string course, raising the height of the north face of the wall by 1′ 6″ (460 mm) (fig. 1). The sloping top could have been finished with rough slabs arranged to overlap like roof tiles.

A traditional parapet would not only imply a patrol walk but would also have made a very considerable addition to the labour. The difference in material content is not great—a parapet 1′ 6″ wide[10] by 5′ high has a volume of 59,300 cubic yards, whereas a single slope would require 56,000 cubic yards for the full 45 miles. The difference lies in the facing stones, 534,000 being needed to form the retaining wall for a sloping top, while a double faced parapet called for the working of some 3,500,000.

If the wall were flat-topped it would presumably be finished off with flat stone slabs, preferably set at a slope sufficient to encourage some of the water to run off but gentle enough to give a secure footing to the soldiers; reconstructions commonly show large straight sided rectangular slabs like paving stones, carefully worked to give tight joints. The labour involved in producing these would be considerable,[11] and it may be that random crazy paving was more likely to have been chosen. In either case water would penetrate the wall core as the mortar joints inevitably cracked and perished, but if the surface were well maintained this would not necessarily be a rapid or particularly destructive process.

From the growing body of evidence from a number of places on the Wall[12] it would seem that on the north side of the wall the topmost bonding course was replaced by a projecting string course to emphasize the change from the main body to the superstructure, whether this was a sloping top or a parapet. On the analogy of York legionary fortress,[13] the string course would have been fixed with the flat side uppermost,[14] which to those familiar with medieval drip courses strikes an illogical note; unless fixed with a slight tilt, the top surface would collect water which would then be attracted into the wall, and the chamfer on the lower side would encourage any overflow from the top to run down the face of the wall. But however illogical, this form was being repeated by the Romanesque cathedral builders on, for example, the west front of Lincoln where its unachievable intention seems to have been to protect the great frieze. It is likely that the string course on the wall was fixed with the chamfer on the lower side as suggested in the report of the 1926 excavations at Heddon (note 12).

The existence of the string course does imply some sort of superstructure; neither the retaining wall for a sloping top nor a parapet wall would be out of place. The latter might be the more likely superstructure to merit a string course, but as this suggests a patrolled walk

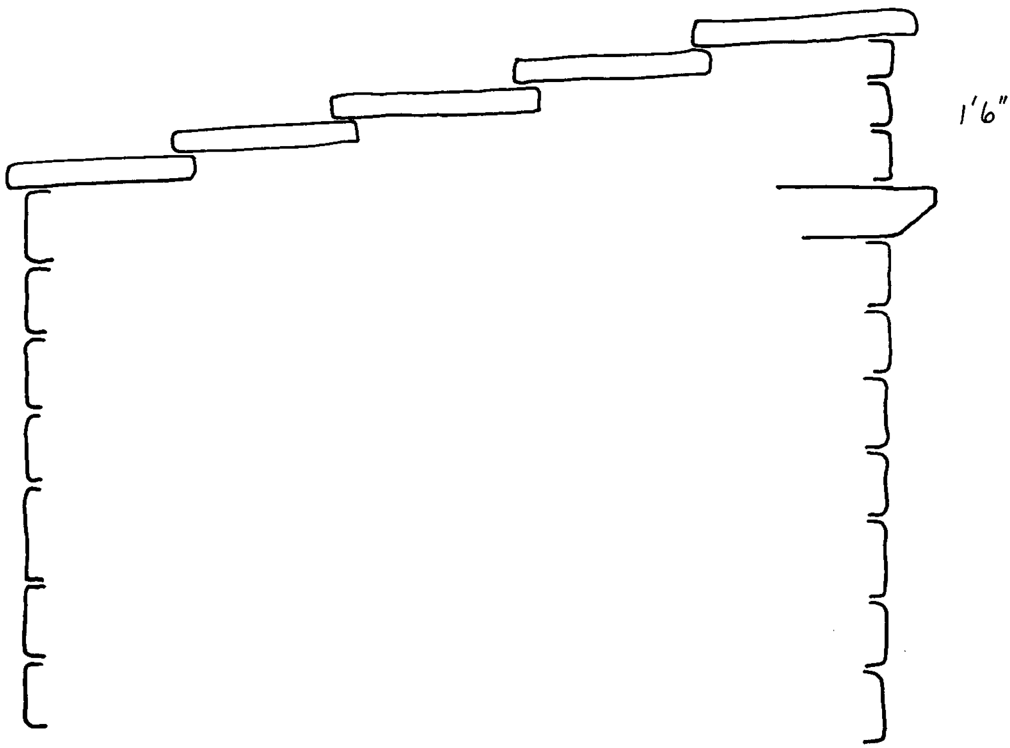

Fig. 1 (Not to scale)

one would expect a parados (or rear parapet)—desirable in view of the fifteen foot drop—as well, which ought also to call for a string course at the rear. Evidence for a string course at the back of the wall would suggest the existence of a parados, but no chamfered stones have been found on the south side of the wall and a parados must remain only a possibility. It would restrict further the space available for the wall walk, leaving just over 6′ on the 9′ 3″ (as built) broad wall and as little as 3′ on the extra-narrow wall, if the width of each parapet is taken as 1′ 6″ (fig. 2).

The stones from Cawfields tentatively identified as parapet stones,[15] two of them L-shaped in section with a short horizontal "toe" and one ?broken cubical stone (fig. 3), are an unnecessary elaboration for the base of a parapet. This would normally be built as a simple wall rising from the top bed of the string course as at York, and suggest (there is no scale) either a very slim parapet of through stones or one built with unduly heavy stones which is unlikely, as suggested above (note 10). As these stones would have to go above the string course, the level of any wall-walk would be raised above the fifteen foot mark by an amount at least equal to the depth of the toe, an unnecessary addition. This is not to say that these stones did not form part of a parapet, but in the absence of dimensions and details of the surface finish, which might have confirmed the existence of a parapet, its size, and perhaps some indication of the activities taking place on the wall top, the identification must remain open. If they were indeed worked as carefully as the drawing in the report suggests, there must be a degree of unease about their function; they look far too good to have formed a part of the wall unless in a very special feature. In this context, there is nothing special about a parapet.

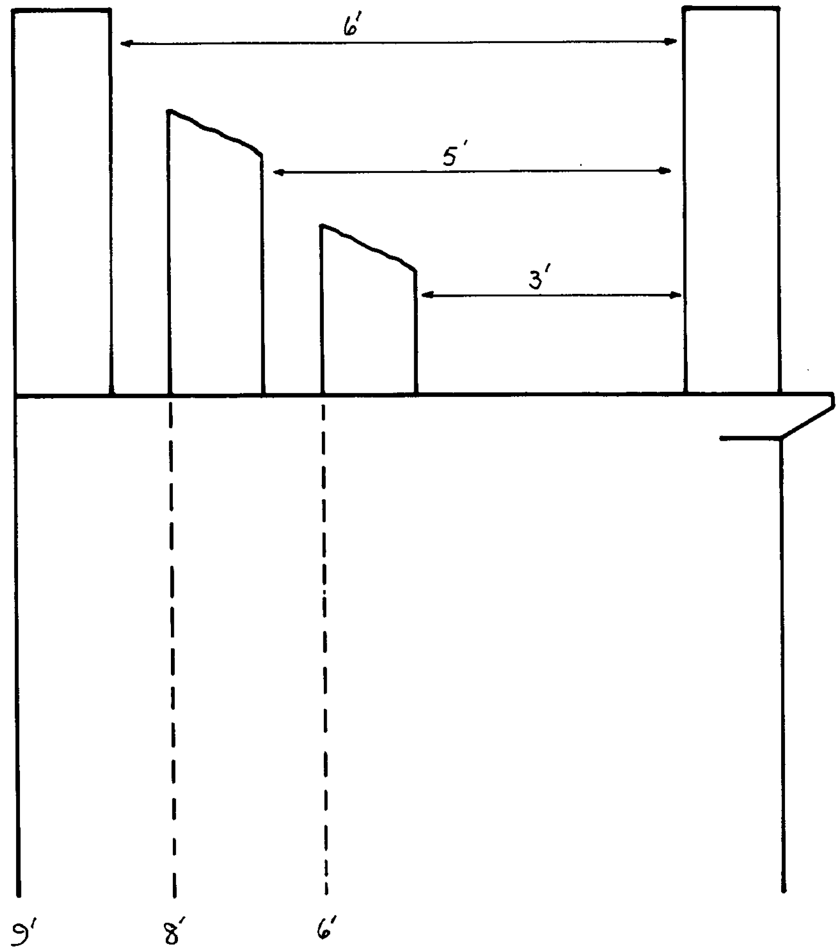

Fig. 2

If there were indeed a parapet it remains to consider what form it might have taken, which in turn depends on its function. A simple barrier to prevent men falling off would take the form of a plain wall perhaps 3′–5′ high with a coping of some sort to prevent water percolating into it. Reconstructions traditionally show crenellations, which are not a decorative effect but have a practical purpose related to both defensive and offensive action. The merlons are to provide cover for a soldier under attack from missiles, while the embrasures are low enough for the soldier both to view the enemy's activities and to discharge his own missile before dodging back into cover. A height of 4′ (1·22 m) above the wall top for the embrasures is low enough to allow for aiming and throwing a javelin, with a height of at least 5′ 6″ (1·68 m) for the merlons. The reaction of the legionaries on being asked to build 36,000-odd merlons is almost as interesting as their reaction to the whole idea of a 45 mile long stone wall of monumental proportions.

The presence of crenellations would presuppose that the wall was designed to be manned as a fighting platform. The arguments against

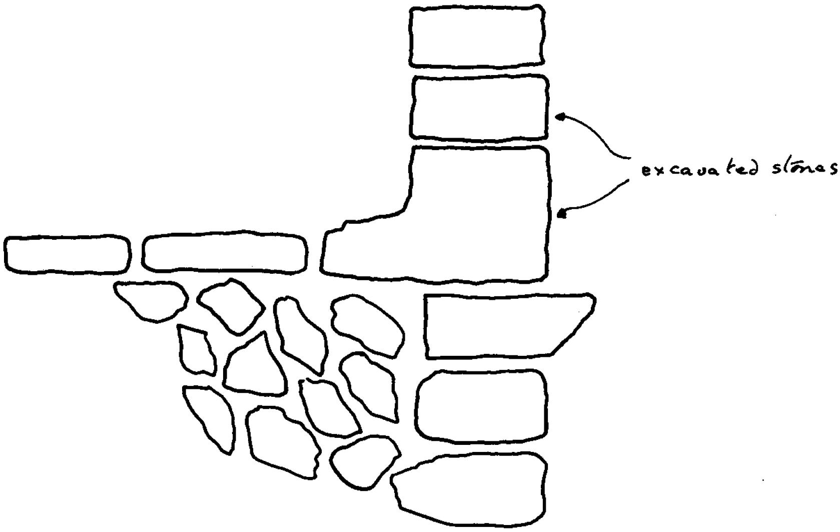

Fig. 3

this have been well rehearsed,[16] and if crenellations existed we must fall back on the rigidity of the military mind. Only the discovery, in association with the curtain wall, of unquestionable merlon copings with distinct returns worked on them is likely to settle the question of a wall parapet and its form. A century of excavation has failed to produce a single published stone which can unequivocally be identified as a merlon coping from the line of the curtain wall well away from other structures. If there is general agreement that there is no evidence for crenellation on the curtain wall, there must be agreement that their absence is a strong presumption against the intention to fight from it. The situation is different in the case of fort gateways, milecastles, and turrets, at least nominally defensible structures, where apparent merlon caps have turned up; the significance for these in relation to the roofs of these structures is discussed below.

A note of caution must be sounded here. Any apparent merlon coping, that is traditionally a chamfered stone with at least one return (fig. 4a), found in the vicinity of fort gateways must be treated with reserve. Where towers project from the line of the wall or where the face of the gate is recessed between

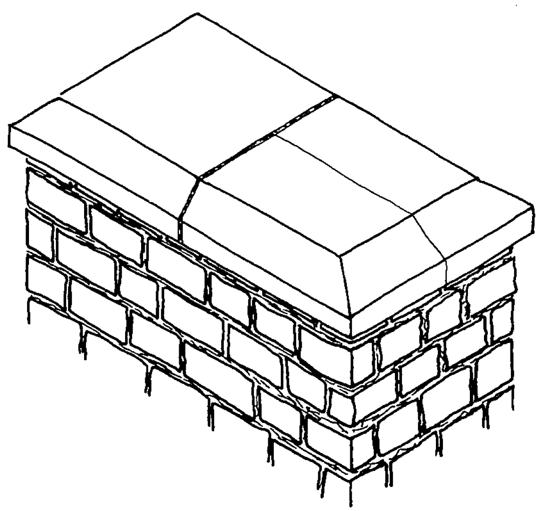

Fig. 4a

the towers,[17] the string course would very likely have been continued up to and perhaps across the face of the towers. This would give either two or four stones with external returns having a similar form to part of a chamfered merlon cap (fig. 4b). Also, the possibility that turrets and milecastle towers had a second string course, perhaps to mark the storey

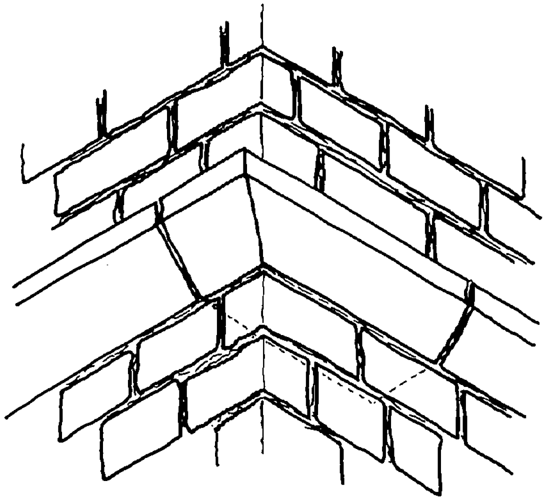

Fig. 4b

height and having four stones with external returns, should not be overlooked. The identification must depend on whether one bed had clearly been mortared and the other had been exposed to the weather for a considerable period of time. Complete caps, with a chamfer on all four sides, are less of a problem, except that two of those so far published indicate merlons of no more than 2′ wide (610 mm),[18] barely sufficient to offer serious shelter. In fact there is no need for a merlon cap to have had a chamfer at all—a simple flagstone set at a slight tilt would suffice—but evidence from forts, milecastles, and turrets indicate a Roman preference for worked and chamfered caps; it is the latter that one would expect to find along the wall in conjunction with a dressed string course.

What emerges from this analysis of the curtain wall is a picture of a running barrier, standing some 15 Roman feet high, probably but not certainly flat-topped, with a low parapet, not crenellated. There is a strong suggestion that a wall-walk was provided originally; it is far from certain that an effective wall-walk could have been preserved when the wall was narrowed to 8′ or even 6′ as early as the time of Hadrian.

The Milecastle Gateways

These gateways present the most interesting design features of any part of the Wall; different designs seem to be the work of three different legions and are a clear statement that each legion had its own interpretation of the purpose of the work they had been asked to do. Hadrian's instructions cannot have been very detailed, limited perhaps to the number and frequency of milecastles and turrets.

Taking the milecastles from the stone wall sector where dimensions are known, it appears that (ignoring the anomalous size of 47 and 48) they were designed to have internal dimensions of 50 by 60 Roman feet (14·78 by 17·74 m) with a wall thickness of nine Roman feet,[19] although very few were actually completed as planned. The average width of the gate passages is 11′ (3·35 m) which, as there are no signs to the contrary, must represent the internal width of the towers over the gates. The depth of type I and II gates (see fig. 5) was about 9′ (2·74 m), in this case being the external dimension. The voussoirs at milecastle 37 are 1′ 6″ from front to back, which must represent the thickness of the north and south walls, and it would be both reasonable and structurally acceptable to take the east and west walls as being the same. This gives a tower of 14′ by 9′ (4·27×2·74 m) externally and 11′ by 6′ (3·35×1·83 m) internally for types I and II; type III, projecting beyond the broad wall, had an external measurement of 14′ by 11′ (4·26×3·85 m) and an internal measurement of 11′ by 8′ (3·85×2·44 m). The identical substructure of the north and south gates does not of itself guarantee towers over both; the large squared stones of the piers have no relevance to the existence of towers which, as demonstrated by the nature of the turrets, could be built entirely in walling stones. The ground plans are related more clearly to arched gateways rather than to towers although, as will be shown, types II/IV and III carry a hint that the designers had towers in mind.

As can be seen at milecastle 37, milecastles clearly had arches over their entrances, the pivot holes being placed behind the arch to

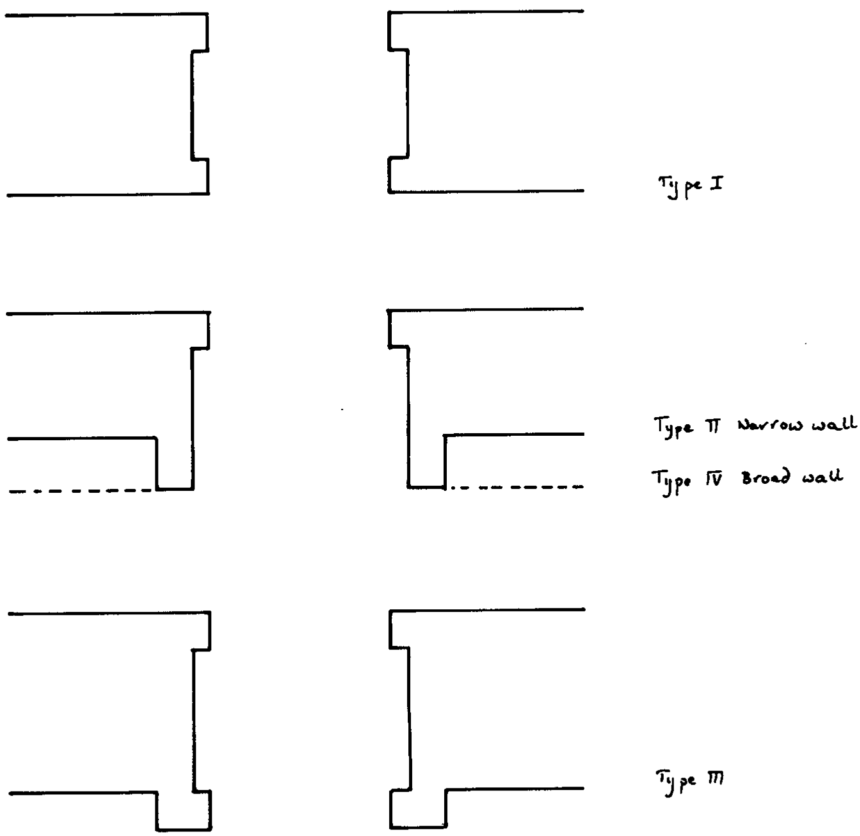

Fig. 5

avoid the doors fouling the voussoirs. The doors will have been flat-topped, with the upper pivot being a projecting stone of the sort visible at the south gate of Chesters fort. The walls of the gate passages must have risen vertically, as may still be seen at milecastle 37, so as to allow the doors to open; a barrel vault, unless springing from a point higher than the top of the doors, was out of the question. Most likely the passages were covered with a plank decking carried on timber joists.[20]

The design of type I gateways, with two pairs of responds in the thickness of the wall, arched at inner and outer ends with the passage walls rising vertically above the springing line, can be seen very clearly at milecastle 37 and is to that extent straightforward. Piers and passage walls are here built with large reasonably square-cut stones to give a truly monumental style, the builders of at least some examples of this type of gate being seemingly more concerned than the other legions to give a grand effect.

By contrast with the simplicity of type I, type II gateways with only one pair of responds present certain problems. There is very likely to have been an arch sitting on the responds at the outer end of the passage, but the provision for an inner arch is open to a degree of doubt. The Handbook,[21] following earlier writers, records that type II gateways, found only in conjunction with narrow wall, have one pair of responds, with the piers and passage walls built in small masonry, noting on the following page that type IV, found only east of the North Tyne in broad wall, is usually built of large masonry. F. G. Simpson described "... a simple continuation of the passage wall, which forms the rearward treatment of type II."[22] The same author also noted that "In type II the passage was arched at the outer end only."[23] The existence or otherwise of a rear arch, to say nothing of the implications thereof, has been largely ignored by later writers; although the excavator of MC 27 points out that "... piers or responds for an arch ... are absent from the rear",[24] he did not go on to speculate about what might have taken its place.

It will be seen below that the study of these gateways is hindered by the terms "large masonry" and "small masonry", terms which are of only the smallest value. For example, to apply the description of type II gates "piers and passage walls in small masonry" to the north gate of MC 39 implies that there is no distinction between the styles of masonry used in the two elements of the gate. This is clearly not so; it is true that the responds are built of stones which are smaller than used in, say, MC 37, but they are dressed to smooth faces with carefully worked beds. Even though they are only slightly bigger than the squared rubble of the passage walls they are of a much superior quality and designed for a different purpose. The relatively small bed heights used in the responds are more likely to be due to restricted bed heights in the quarry rather than to a deliberate design change although, as always when considering physical aspects of the Wall, the amount of evidence available for comparison is very small indeed.

There is another small problem. There is a difference between a "respond" or projecting half-pier (as may be seen supporting the front gate arches), and a "pier" which is normally a freestanding support for an arch but which may be built flush as part of a wall. The distinction has not been seen as significant in Wall studies (and the first of the present writers has been as guilty as anyone of using the two terms indiscriminately), but as will be shown there is now a need for discrimination. In milecastles of type II, there are no inner responds but some at least seem to have had inner flush piers at the junction of the passage wall and the inner face of the milecastle wall.

There are eight possible examples of type II/IV gateways known from the Wall—9, 27, 33, 34, 35, 39, 40, and 47. Although little detail is given, by studying the excavation reports and the accompanying photographs, it is possible to make a judgment on how the inner ends of the passage walls were constructed. The following list gives a summary.

MC 9 First course of squared stone pier survives[25]
27 First course of squared stone pier survives[26]
33 Two/three courses of squared stone pier survive[27]
34 Recorded as type II without details[28]
35 Recorded as type II without details[29]
39 No evidence of original style survives in rebuilt gate
40 No information published about the inner end of the passage[30]
47 "... backward projection had also been built in 'large masonry' "[31]

The evidence from three milecastles, 9, 27, 33, shows reasonably conclusively, and evidence from one, 47, suggests, that at least four of these eight type II/IV gateways were originally provided with inner piers of squared stone built flush with the passage walls. The evidence from the other four is non-existent but there seems no reason to doubt that all these gateways had responds at their outer ends and flush piers of large squared masonry at the inner. The available evidence also indicates that it is by no means certain that type IV passage walls were always in large squared stones rather than coursed rubble.

What was the purpose of these inner piers? The obvious answer is for the support of an inner arch, for it seems to have been the practice of the legionary builders to provide solid piers under arches,[32] and it may not be too illogical to expect the presence of a pier to suggest an arch.

However, the span and height would have been greater than in the outer arch. The increase of 6–9″ (150–225 mm) in the height would not be visually significant but the increase of 12–18″ (300–450 mm) on the span would have caused problems for the builders. The wooden centre made for the outer arch could be re-used for an inner arch only if it were raised 6″ on its supports (stilted), in order to maintain anything like a semi-circular profile, and if the voussoirs were held off the centre towards the crown with suitable wedges. This would be a quite possible but highly inconvenient operation, carried out twice at each milecastle. It is also probable that the centre would have been too narrow to be supported on the impost caps of the inner piers, and would have needed additional, ground-based, support.[33] The alternative of making a second centre would again be an extra labour, simply to provide a larger inner arch for which no material advantage can be seen.

It may be that a second arch was never intended, and that the upper stages of the tower were to be supported on a timber lintel. Assuming the tower to have had 18″ thick walls as suggested above, the lintel, which supports only that portion of the wall forming an equilateral triangle over the span, would have to carry a load of some 4·8 tonnes. A 1′ 6″ (450 mm) square oak lintel will carry this load with ease[34] and for a good many decades if not centuries. Solid piers may have been thought desirable for the same reason they were used under an arch, that is, the better to carry the concentration of weight.

The suggestion that a timber lintel may have been used instead of an arch must raise the possibility of a timber superstructure above the level of the curtain wall, and for the extension of a similar construction to the upper stages of the turrets. The idea is not a new one,[35] but the discovery of stone window heads at MC 39 and T44b[36], and parapet stones at some turrets, argues very strongly against the idea.

The fact that there is a flush pier rather than an inner respond in the gateways of Housesteads fort carries a suggestion that it may have been designed by the legion which built type II/IV milecastle gateways. A similar design appears in the entrances to the near-contemporary amphitheatre at Caerleon, built by Legion II. If these similar, and on the Wall unique, designs were the responsibility of one legion, it would be necessary to re-allocate type II/IV gateways to Legion II Augusta.[37]

Type III milecastles, with the inner pair of responds projecting into the milecastle, are structurally similar to type I except that, even in conjunction with broad north walls, the inner piers project some two feet into the milecastle. An obvious reason for the design of this extra-long gate is in order to increase the floor area of the tower, the necessity for which is not immediately apparent. A floor area of 66 square feet (6 m^2) was not found inadequate for an observation platform in the other gateways; one wonders whether this legion had some further function in mind for the tower, sufficient to justify the additional work entailed in providing an extra 22 square feet (2 m^2) on each floor, or whether they alone were concerned merely with the stability of a narrow tower. Whatever the reason, the ground plan of this type of gateway appears to be designed with a tower in mind. As the same plan appears in both north and south gates of several milecastles it must be assumed that both gates were furnished with towers and presumably, therefore, other milecastles also had two towers.

The building of the inward projections in type II gateways even more strongly reflects the existence of towers—there is no other obvious reason for maintaining the original length of these gates after the wall had been narrowed. If type I gateways on the other hand had ever been built in conjunction with narrow north walls, they would also have projected into the milecastle, but not specifically to maintain the size of a tower; a gate with two pairs of responds of the width normally found has to be a minimum of about 9′ deep in order to give room to open the doors fully.

The existence of two towers presupposes a lookout on each tower as well as, during the day time, manpower available to man the gates if needed. Jim Crow has suggested that the pivots at milecastles are smaller than those at forts, not only because the gates of the former were lighter but because they were used far less frequently.[38] However this may be, the original design allowed for traffic to pass through the Wall and in fact the gateways would seem to have been the *raison d'être* of the milecastles, and therefore the number of men stationed there must have reflected the need for them to be opened on some sort of regular basis. Two men on each gate and one on each tower during the day, with perhaps one man patrolling the Wall towards each adjacent turret, calls for a minimum of six men on duty at any one time, and perhaps eight if the patrols were each of two men. But the available evidence points to barrack accommodation for eight men only. Jim Crow has argued for sixteen at Housesteads milecastle (37) but only on the assumption that the barrack had no back wall other than the milecastle wall, a unique arrangement. A table of comparative sizes is given in Appendix 2. The Crow hypothesis is easier to work with in regard to manning the milecastle, but more evidence is needed. If eight is the correct figure, the gate guard may have to be reduced to one man each, and the wall patrolling left to the men in the turrets, so a total of four men on duty at any time in each milecastle would just about suffice if each man were to work eight hours on and eight hours off duty.

This would be a high intensity regime, especially as there would be the ordinary fatigues of cooking, cleaning, and similar military duties to be performed. In order to maintain efficiency, sentries have to be relieved at frequent intervals; taking early twentieth century practice into account, "Sentries will be relieved every two hours; but at night, in cold or inclement weather they may . . . be relieved every hour."[39] Current practice is for night duty to be divided into four three-hour shifts. A garrison of four men on duty and eight off (though perhaps not entirely free of military duties), working in total eight hours on and sixteen hours off would be a more reasonable estimate for a milecastle garrison, with the twelve men sharing eight bed spaces under the time-honoured military "hot bed" system.[40] It may be assumed that these garrisons would be relieved, at not infrequent intervals, from their parent unit. Evidence from Dura[41] shows that detachments might be away from their units for as much as three years or more, but there the distances involved were as much as 170 miles, and frequent rotation would have been logistically difficult. The Wall turrets and milecastles were nowhere more than four or five miles distant from the forts which may be presumed to have supplied the detachments, and regular relief would have been a simple matter. The milecastles may also have been bases for patrols working the countryside in advance of Hadrian's Wall, as suggested by J. C. Mann,[42] but this question, and the numbers which may have been involved, raises issues greater than can be dealt with here.

The height of the towers is a matter for calculation and inspiration. The first-floor height must have been fifteen feet in order to clear the arches and the top of the doors, and this would also have made for easy access to the top of the milecastle walls. One could argue for one storey above the wall top, surmounted by a flat roof for observation: the general utility of flat roofs is discussed below, but there are also arguments relating directly to milecastles. Milecastle 39 has yielded fragments of stone heads from at least two windows, which are more likely to have come from a gate tower rather than from barracks which, whether in fort or milecastle, do not provide evidence of having had stone-arched windows. These finds suggest that an upper floor had some function other than a covered access to a flat roof; a single slit window would have given sufficient light, combined with the open access trap to the roof, for the sentries to negotiate a familiar ladder. The windows are unlikely to have been in connection with accommodation, for there was sufficient room for this in the milecastle itself, and if living space had in fact been needed in the towers the floor area would probably have been increased to match that of the turrets, for which see below.

The most probable explanation for the windows is that they were for observation purposes, and this argues for a second floor; without one there would be little point in building towers over the gates, for a sentry might just as well stand on the wall top. To maintain a five foot module internally as well as externally, first and second floors were perhaps each of ten feet, but this is not strictly necessary. A first and second floor each of seven feet, with a one foot thick floor between them would have been sufficient for accommodation and observation giving an eaves height of thirty feet (Roman measurement).[43]

Turrets

The typical turret measures about 20′ (6·10 m) over the east and west walls, which vary between three and four feet thick (915–1220 mm); it may be that the thickness was less in the upper parts, perhaps reducing by half at wall top level which would bring them into line with the thickness of milecastle tower walls as calculated above. As usual the height is the most difficult to determine. Parker Brewis reconstructed T18a with an eaves height of 25′ (7·62 m), giving a first floor of ten feet (3·05 m) plus a diminutive attic for a look-out;[44] the picture of a sentry lying down or squatting for his spell of duty needs no further comment. In fact, given that all the towers are equidistant one from another, the turrets should have been of the same height and roof form as the towers over the milecastle gates in order to maintain a consistent observation level. A fifteen foot storey matching the milecastle towers may be assumed, again making a straightforward connection with a putative wall-walk; there could equally well have been an additional floor inserted between the ground floor and the wall top, but the detail is of no great significance for the height of the turrets.

Taking the internal size as 14′ square, the floor area of the average turret, at just under 200 square feet, is very much greater than the area of the milecastle towers: three times the area of type I and II towers and over twice the area of type III. The plan of the milecastle towers is to some extent dictated by the design of the gateways, being no wider than required by the width of the gate passage and in two out of three cases being no deeper than the width of the broad wall. There is no evidence that their relatively small area gave rise to problems in reaching the required height, and there is no structural reason why the turrets should not have been built to a similar plan. But instead of a regular series of similar sized towers they alternate in a large-small-large-large-small sequence. As, unlike the variations in milecastle design, the variations between turret and tower are not due to the whims of individual legions there should be some other rational explanation. Milecastles have barracks available for accommodating the look-outs, and it seems not unreasonable to suggest that a major factor in the design of turrets must have been the need to provide living space. This suggests that they offered at least overnight accommodation, raising the questions of whether the men manning them came from the nearest milecastle and whether the accommodation available in turrets should be *added* to the total of sleeping places in milecastles, rather than a bed-space being provided both at a parent milecastle and the turrets. The 200 square feet (18·6 m^2) floor area of the turrets gave sufficient accommodation, by comparison with auxiliary barracks in forts and in milecastle 9 (see Appendix 2), for more than merely overnight shelter for one or two men. A turret could offer ample accommodation on its two floors for the bedding, arms, and equipment of eight men, with scope for food preparation.

In turrets 18b and 26a there was a need for two renewals of the floors during Period 1a,[45] and there is much evidence of the build-up of cooking hearths; Lindsay Allason-Jones's survey of small finds points up the widespread presence of quernstones, gaming counters, and the domestic implements of a soldier's life.[46] All these factors indicate an occupation in strength, and of an intensity more appropriate to a group of men, outstationed from forts, probably for limited periods, than to patrols sent out along the wall top from milecastles and using the turrets as sentry boxes, and this is what one would expect if the turrets were part of a chain of signalling and observation posts.

A detachment of eight men in a turret would allow for wall-top patrols, if these are to be accepted, as well as for a lookout at the top of the turret, assuming one man on lookout and one patrolling to each side. Working thus would give each man eight hours on duty and eight off, with rotating shifts. Objections to this intensity of duty have been made above and twelve men in each turret would allow for four men on duty and eight off, changing over every eight hours and sharing bed spaces.

Reconstructions of turrets indicate a degree of speculation about the form of the door and windows; the latter may technically have been any shape the individual legions cared to make them (the arched window head preserved in T44b indicates the preference of at least one legion), but the doors must have had flat lintels. The reason for this is simple; the outward[47] opening doors were pivoted towards the outer side of the threshold (about 6″ (150 mm) from the outer edge and 1–1¼″ (25–30 mm) from the east jamb in the case of T26b[48]) and in order to turn required a slab carrying the upper pivot hole to project into the doorway vertically above the lower one. With a flat-topped door the upper pivot hole would conveniently have been formed in the lintel, but with a round-headed door the upper pivot would either have to project at the springing line of the arch, with a large slot cut out of the door edge to accommodate it, or for the pivot hole to be formed in a voussoir; in the later case, the pivot would have to continue the line of the door edge as a tangent to the curve of the door top, and as it would meet the steepest part of the arch the hole would be a most awkward and unsatisfactory shape. Furthermore, fitting the door would have been somewhat difficult and, because the pivot hole comes some 6″ inside the front of the arch, there would have to be excessive clearance between door and arch in order fully to open the door. If an arch were felt to be essential, a possible but bizarre alternative would be to have the door cut off straight at the springing line and pivoting in the base of a wooden or stone tympanum beneath the arch.

There may have been a gallery around the turret as reconstructed in the 1985 Horsley lecture.[49] Such a feature would have facilitated all-round observation from a gable-roofed turret and there is good evidence from Trajan's Column[50] for their use. Lindsay Allason-Jones tends to discount the possibility on the grounds of the absence of nails from many sites,[51] but nails (i.e. building nails) are in fact more widespread and more clearly grouped by location than are hobnails which must have been lost in every turret. One would expect nails to have been used in the structure of the first floor of every turret, yet they have been found in only ten out of the 27 turrets analysed. Finds of all types of artefact are few however, and the question of galleries may remain open.

A significant feature of turrets is the existence of wing walls against those turrets where the curtain wall was brought up in narrow gauge. The wing walls are of just the right length to allow the turret to be built up in advance of the curtain wall to at least a height of 15′, from which point they would rise independently, with a full raking joint down to foundation level. This would require the provision of some 3,000 feet (915 m) of scaffolding at each site, and if this were ever done would involve a considerable waste of effort on the part of the builders. The most efficient use of resources would have been for the builders to put up as much of the turret and wing walls as was practical without scaffolding before moving on to the next turret, completing the upper stages when scaffolding for the curtain wall arrived on site. The planning seems to have been less than perfect.

Having said that, there is no evidence that the wing walls were anywhere actually used to build a turret to full height; the best evidence for the sequence comes from T26b, where the broad wing wall on the east side reached a height of only 4′ 6″ (1·37 m) before being overridden by the narrow curtain wall which bonds with the turret wall. This clearly shows that the turret had reached a height of no more than 4′ 6″ before dislocation and the decision to narrow the curtain. The fact that the west wing wall meets broad curtain wall indicates that the curtain builders had started to complete the curtain wall in broad gauge before the turret had been taken any higher than a few feet. The wall is a full 10′ wide at the west end of the present enclosure 150′ (46 m) west of the turret, showing that a considerable amount of broad wall had been built. However, as the excavator of milecastle 27[52] found no more than broad foundation at a point 14′ (4·27 m) east of its north-east corner, the full extent of broad wall superstructure built in this area is unknown.

So, either the length chosen for the wing walls was coincidence or, more likely, the actual builders had seen the impracticality of the plan. It is frankly impractical to consider the building of *any* part of the Wall as an isolated structure to a height of more than about five feet without exceptionally good reasons; the unnecessary haulage of scaffolding from site to site is alone sufficient to rule it out. It has been suggested that some wing walls were carried up to the height of the curtain wall on the grounds that "some wings walls can still be seen standing to a considerable height, without the narrow face riding over them."[53] This is not so. Where abutted by the narrow wall, in no case does a turret wing wall stand higher than 4′ 8″ (1·42 m) above the foundation; the only "wing wall" to stand higher than this is at the west side of T27b, where broad curtain wall meeting the turret disguises the original height of the wing wall. Wing walls can never have been built to full height as a part of an independent turret; practical considerations as well as the small amount of evidence available indicate that they would have been built up in stages, as described below.

We are perhaps still too much influenced by the elegantly simple statement of Sir Ian Richmond[54] that "In every known case the incidental structures were built first". They may well have been *started* first, but there is no evidence that any of them were *finished* before the arrival of the curtain wall; such small evidence as exists supports the notion that a start was made on the structures, perhaps to fix their positions, but that they were taken no higher than a man might reach. Many discussions of the sequence of building above the broad foundation appear to envisage the curtain wall arriving as a fifteen foot entity; the closest to the truth is the "horizontal building" referred to by C. E. Stevens[55] where he suggests, on the basis of the vertical contiguity of centurial stones, that in a few places at least the Wall was built up in a series of "layers". This is exactly what must have happened along the entire length of the wall for purely practical reasons, and the same must apply to the building of the various structures. There will probably have been three "layers" built with two lifts of scaffolding. A delay would be likely after the first four or five feet had been built and then, with the arrival on site of scaffolding, the second and third stages would follow closely upon one another. Any change recorded in the unit responsible for a given stretch of wall is most likely to be related to the pause after stage one.

It may be noted in passing that where broad curtain wall is recorded east of T26b, there are rarely more than a very few courses and there is no evidence that the broad gauge was ever built to a height of more than five feet. The number of narrow walled milecastles east of the Tyne certainly indicates that many of the structures in this sector were far from finished at the point of dislocation. This has implications for the building of milecastles and for the extent to which the legionary lengths had been completed at the point of dislocation.[56]

Roofs

Roofs of turrets and milecastle gate towers may have been either flat or pitched. Each school of thought has its adherents, basing their judgment on excavated evidence or lack of it, on sculpture, and on models. From the structural point of view the pitched roof in gabled or hipped form presents no problems; such roofs would have been a straightforward exercise in providing a weatherproof covering to the building, assuming of course that this was an essential requirement. As noted above, the reason for the much larger floor area of the turrets is very likely to have been to provide semi-permanent accommodation for soldiers, and the probability then is that a watertight roof was called for, something that would be very simple with tiles, stone slates, wooden shingles or thatch.

Flat roofs present problems. In a northern European climate they are, and always have been, an abomination to be avoided wherever possible; their popularity over the last fifty years or so has had every thing to do with architectural fashion (and initial economy in domestic contexts) and nothing to do with practicality. Even in the last decade of the twentieth century, with modern science and materials, it is axiomatic that flat roofs leak; it is only in the last few years with the use of the latest plastics that builders have been prepared to offer serious guarantees against leakage.

The best technology available to the Romans is given by Vitruvius.[57] Although he is strictly speaking of floors in the open air, they are clearly supported on joists above ground level and he is concerned to prevent water penetration from above; flat roofs are what he appears to have in mind. He recommends two layers of boarding at right angles, a layer of two-foot tiles laid with waterproof joints, topped with at least one foot of concrete, on top of which the finished surface—he suggests brick—is laid at a slope of two digits in ten feet. Inevitably, as the beams and the building settled, and with the natural movement of the building, the concrete and the joints between the slabs would crack and the roof would leak. It might not happen immediately, and it might not leak very much, but it would leak. Now, it is true that in modern domestic buildings with electrical installations and plastered and papered walls, leaks are perhaps a more serious matter, if only aesthetically, than in soldiers' accommodation with rough stone walls. But apart from the inconvenience, the roof timbers would rot, especially where the ends were built into the wall and the roof would have to be dismantled and rebuilt, perhaps after as little as five years. The Romans were not inexperienced as builders, and would have been aware of the problems long before the Wall was begun. Flat roofs are more appropriate to Rome than to Rudchester.[58]

The only reason for insisting on a flat roof is if some significant purpose could be found for it. A thirty foot tower allows for two low stories above the wall top, raising the eye line to around 28′ above ground level. One may argue that this is not enough, but a flat and leaky roof would add only another seven feet or so to the eye line in return for structural problems. Looking over a flat plain, the horizon from an eye height of 20′ is about 11,653 yards, from 28′ about 13,375 yards and from 35′ about 14,730 yards; the increase from 20′ to 28′ gives an increase in view of around 15% and from 28′ to 35′ only about 10%.[59] The law of diminishing returns applies, the Romans would have been empirically aware of this and would surely have required a better reason than a marginal increase in field of view before opting for flat roofs.

Here the use of flat-roofed turrets and milecastle gateways as *tormenta* (catapult) emplacements[60] must be considered. Quite apart from the fact that a view of an artillery-based wall defence has more in common with medieval siege mentality than second century Rome, there are physical objections to the Donaldson scheme of "interlocking arcs of fire". First, the Wall was not particularly high, and any small group of reasonably active men could on a dark night have scaled the wall at a distance from a turret and then, should they have wished, captured the turret at leisure by attacking from the rear and thrown the *ballista* into the ditch. Secondly, they could also have crossed the wall in broad daylight, for considerable stretches of wall in the central sector would have been invisible from both turret and milecastle. Thirdly, two thirds of the milecastle towers would have had a roof platform no more than six feet wide, which would make the operation of a *ballista* cramped, though perhaps not impossible. Fourthly, one protected a city or town in this way because it was a clearly defined and usually small entity, and normally very few troops would be available for its defence. The Wall on the other hand was immensely long, protected very widely scattered economic and social units, and had large bodies of troops immediately available to take the field, which was the preferred Roman method of dealing with attacks or insurrection.

To lock the troops into a defence of the Wall was an admission of failure. Fifthly, it is certain (see below) that at least some turrets had pitched roofs, leaving an immediate gap in the chain.

There are further organizational problems. There is no evidence for auxiliaries possessing *ballistae* at this period. They were held by the legions, an arrow-shooter per century, a stone-thrower per cohort. The provision of nearly 240 arrow-shooters, the complete firing-power of four legions in small catapults, with crews, in late sources given as eleven per machine, placed at least one mile ahead of supporting infantry in the first Wall plan, seems a military absurdity. Even if the auxilliaries had been equipped similarly to the legions, for which there is no evidence,[61] this would mean the arrow-firers of 40 or more units. Catapults seem to bulk larger in the modern mind than the ancient literary evidence warrants.

Returning to the design of the roofs, iconographic references are small; the one which seems best to be attempting a pictorial representation is Trajan's Column, where the towers[62] show pyramidal thatched roofs. It seems likely that they served the same function of watch and signal towers (for signal towers must be able to watch if they are to have anything useful to signal) as the turrets on Hadrian's Wall. If the Danubian towers could have pitched roofs, why not the Wall turrets?

Pitched roofs may be gabled or hipped (that is where a sloping section of roof replaces the gable end). A hipped roof on a square plan gives a pyramidal roof, which form the turret roofs may have taken. The rectangular milecastle towers may have had a hipped roof, running up to a short ridge, or both they and the turrets may have had conventional gabled roofs.

The orientation of a gabled roof must be considered. The rectangular towers over the milecastles will very probably have had an E–W ridge, on the grounds that a ridge is normally parallel to the long axis, but with the square plan of a turret there is no restraint on the direction of the ridge and a preference for N–S or E–W must rest on convenience of the users. An E–W ridge is to be preferred on two grounds. The north facing slope would encourage rocks and other missiles to fall clear of the Wall whereas a N–S ridge might allow them to fall onto a wall-walk; whether we should be looking at an enemy standing throwing rocks at the turrets is another question altogether. Secondly, an E–W ridge would have a similar protective effect in respect of the weather, the rain from the eaves drip falling clear of the turret rather than on to the wall top, where it would ultimately encourage water penetration. Of course the southern slope would discharge water in front of the turret entrance.

Turning to look at the physical evidence on the ground, this inevitably is neither consistent nor entirely in accord with the above. The only confirmed finds of any kind of roofing material in turrets have been stone slates[63] and tiny fragments of clay tiles.[64] These last have admittedly been so small as to be insignificant, but nothing at all suggesting a flat roof has so far come to light. The stone slabs from T29b and T44a[65] were in both cases found in conjunction with stone slates and so are unlikely to have been part of a flat roof. Broken slabs of the lime concrete recommended by Vitruvius would not be greatly sought after for re-use and if they ever existed some trace should have turned up. Laying stone pavings straight on to the roof timbers would simply have exacerbated the problem of waterproofing and if any bituminous material had been used some indication should have survived. Both wooden shingles and thatch, which are what the Column indicates,[66] are short lived materials and the least likely to leave archaeological trace.

Reference has already been made to the scarcity of finds of nails from turrets.[67] On a flat roof, the cross boarding would have been spiked to the joists with at least one nail at each junction. If we take 6″ by 2″ (150×50 mm) boards and joists 2′ (600 mm) apart every roof would use well over 400 nails between 3″ and 5″ (75–125 mm) long and there is no sign of such quantities in widespread use. On the other hand, a gabled roof might be expected to use a large number of even longer nails, and there is no sign of these either. Nails would also have been needed for fastening shingles or stone slates on those turrets so roofed. Perhaps the majority of towers were capped with roofs made up of untrimmed poles lashed with withies and covered with thatch.

Thus far, the evidence is not inconsistent with pitched roofs on the towers, with no suggestion of flat roofs. A complication comes with the evidence of merlons caps from both turrets and milecastles, implying a parapet and thus at least some space behind it for soldiers to stand. The evidence is however not entirely unequivocal. The corner of a chamfered stone was found "amongst the fallen rubble" at MC 39;[68] a complete capstone was found next to the Peel Gap tower;[69] at T7b[70] what seems to be a complete cap is shown in a photograph as being inside the turret, without comment; at T51b[71] the complete capstone was unstratified and the precise find spot is not given; at Cote Howe tower[72] (16a) on the Cumberland coast, with no curtain wall, what appears to have been half a merlon cap can only have come from the tower. The piece from MC 39, if indeed it is a part of a capstone and not part of a string course part-way up the tower, is not particularly significant as a milecastle is quite likely to have had a crenellated parapet all round its walls; there is no indication that it definitely came from the gate tower.

The finds from turrets are a different case; there the capstones (and in this context no other conceivable use for rectangular stones with a single chamfer on all four sides comes readily to mind) must have come either from the turret or the adjacent curtain wall. Neither of these options finds any favour in the light of the arguments above, but it must be allowed that, in the absence of capstones from the line of the Wall, at least four turrets had at least a walkway around the edge of the roof; there would still be the possibility of a pyramidal roof in the centre shedding water to a combined walkway and gutter on the narrow wall top, but there would hardly be room, and this may be an excess of special pleading.[73]

There is another possibility. The advantage in using a flat roof for observation is the all round visibility available from any point on the roof. There is no reason why a flat-roofed tower, complete with parapet, should not have a thatched or tiled roof carried above it on four corner posts; with overhanging eaves only small amounts of rain would be blown on to the floor. A floor thus sheltered would be comparatively easy to waterproof—thick boarding with well caulked joints would suffice. This would be a somewhat elaborate system of roofing and visually unattractive, but it does at least fit all the available evidence and provide an efficient look-out point. It is perhaps an option to be borne in mind.

To sum up, there are two turrets where roofing slates have been found, 29b and 44b, one where fragments of tile have been found, 18b, and four, 7b, Peel Gap, 51a, and tower 16a, where merlon caps have been found inside or near the turret. Perhaps, among other variations in design, some turrets had pitched roofs and some had flat (leaky) roofs although, as noted above, the topmost observation platform should have been at the same level in all cases. The question must remain open for the present. Its resolution is not helped by the lack of serious, extensive, published excavations along the curtain wall, or by the well established tendency to restrict details of finds of undecorated masonry to a passing mention in excavation reports, or chance appearance in photographs; fortunately, the situation is beginning to change.

Manpower

The possible accommodation available in milecastles and turrets has already been considered, but not all the implications. A major headache must have been finding the men to man the system. If the milecastle and turret garrisons were drawn from the forts on the Wall, and Lindsay Allason-Jones has produced the first firm evidence suggesting that this might have been the case,[74] each fort had to supply the men for seven milecastles and fourteen turrets, a total, using the lower figures given above, of 252 out of a theoretical 480 in the case of a *cohors quingenaria peditata*, a serious drain on the efficiency of the unit. If the

Crow hypothesis were to be accepted the requirement would be for 336 men. The evidence from Vindolanda[75] for the *cohors prima Tungrorum* which had the number of centurions appropriate for a quingenary cohort, yet with a large detachment away which brings it up to 751, a number of men appropriate for a milliary unit, suggests that there is much to learn about establishment and actual strengths. Under war conditions of course there would be no case for keeping units in the forts, still less for manning milecastles and turrets.

Water supply was a daily necessity and no permanent supply to these small garrisons has been discovered. A few, like MC 48 and T27a were very close to water courses and as plans developed some will have benefited from the newly built forts with their aqueducts but most must have had to rely on more distant sources. The British army in 1914 reckoned on one gallon per day for drinking and cooking on active service.[76] In the Roman army wine would take the place of some of this, but the garrison of a turret would still have to be supplied with a weight of 80–120 lbs (36–54 kg) of potable liquid per day, and of a milecastle some 160–240 lbs (73–109 kg). One solution would be a regular delivery, by mule from the Stanegate forts or from the Wall forts before the building of the Military Way in the 160s; for a fort to supply all its outstations would take thirty mule loads over distances of up to four or five miles, a small but daily irritant to a commander trying to run a fighting unit with its numbers perhaps already seriously depleted. More likely, the men might have been required to collect their own water and wine from whatever source.[77]

The food supply would have been less of a problem, as men outstationed for short periods, perhaps up to a week or ten days, could easily have taken most of their rations with them, but some transport might still have been required. The lack of ovens at the turrets may indicate that baked foods were prepared at either milecastles or forts. Again, the men may well have fetched rations themselves in their off-duty hours, or supplemented their diet by trapping.

Relationship of Structures to the Wall

Having reviewed the design of the curtain wall, milecastles, and turrets it remains to consider the way in which they were physically related to each other.

The milecastles were enclosures offering protection to the men guarding the gates, and as such will have been defensible stations, although twelve or even twenty-four men defending a circuit of some 260′ (80 m) would have been under some pressure; it is probable that their walls were topped with a crenellated parapet as at forts. In order to present a complete defensive circuit, this parapet logically should have crossed the wall-walk to join the curtain wall parapet, for it would have been relatively easy for an enemy to scale the curtain wall. Such a complete parapet would have barred the garrison from access to the wall-walk for patrolling, assuming of course that this was a part of their normal function. The only access to the top of the curtain wall was, so far as is known, at the turrets by means of an internal ladder and from inside the milecastles by means of steps leading to the top of the milecastle wall as found at Poltross Burn. It may be noted in passing that, unless there was a loose ladder leading to a high-level door in the tower above the gateways, such steps[78] were the only means of access to the gate towers; there were presumably doors leading from the towers to the wall top.

There are thus two possibilities for the junction between milecastle and curtain wall; either any patrols were carried out solely by the turret garrisons or the parapet was incomplete at its junction with the curtain wall. It seems unlikely that a gap was left, and it may be presumed that there was some form of blocking available, whether this took the form of a pivoted gate or a movable wooden fence. A moveable barrier would look less incongruous than the formal arched gateway closed by a solid door as suggested by M. J. Moore,[79] but bearing in mind that an enemy would be on a level with the base of the parapet a stout doorway is perhaps to be preferred. A lintel is more likely than an arch, with the door pivoting in the manner described above for the turret doors. A gateway of whatever type might have looked aesthetically more pleasing if the milecastle parapet had risen to a similar height at a point a little way short of the curtain wall. It must be emphasized however that all this is entirely supposition, and it may be, for reasons which are not understood, that there was no direct access from the milecastles on to the curtain wall. Possibly the milecastle garrisons were not responsible for any patrols there may have been along the wall top.

The access between the turrets and the curtain wall is less problematic. There would have been no difficulty in having a doorway leading from the turret directly on to the wall top and such a doorway would be likely to have the same form as the entrance door on the ground floor.

Although forts are strictly outside the scope of this paper the connection they had with the curtain wall may be of significance when considering the way in which they related to the every day use of the wall. In every case the curtain wall joins the forts at either a corner turret or a gate tower, which *may* suggest that there was access from the wall-walk through a doorway into the tower. A need for such protected access could explain in part both the projecting north-west angle tower at Greatchesters and the repositioning of the north-east angle tower at Housesteads. However this is once again entirely supposition; there is no evidence to support either direct access from fort to wall, or a deliberate bar to such access.

Summary

A number of points have emerged from the above consideration of the practical problems of building the Wall and its associated structures, and the scanty physical remains. What consequences follow for the concept of the Wall's function as set forth in the Seventh Horsley lecture?

What is envisaged is a wall, built in stone in the east and central sectors, with milecastles every Roman mile flanked by turrets spaced at one-third of a Roman mile intervals. The forts remained on the Stanegate, the natural east–west line of communication. The units based in them may have supplied the troops which manned milecastles and turrets, on a rota basis, but were given no function in the operation of the Wall system, in which controlled admission through the milecastle gateways and observation of unauthorized crossings from the turrets and milecastle towers were the key elements. The strength of the curtain wall lay in its forbidding passage by hoof or wheel except at the authorized and controlled gateways. Prevention of any passage by men on foot was impossible to achieve. Although theoretically the wall does not need to be flat topped and patrolled, a case can be made out for it being both. In that case a parapet was probably provided, but it was in all probability not crenellated, and was not a fighting top for reasons expounded in the Horsley lecture. The notion of catapults mounted on the towers with intersecting arcs of fire is ingenious but even more improbable for a variety of reasons.

The building of forts on the line of the Wall and the creation of the Vallum is clear evidence that the original plan was flawed. It was necessary to have fighting units available on the Wall line, able to move freely into the lands north of the Wall, and also responsible for supervising movement through the Wall complex. The key element in such passage was now the Vallum crossings, closely supervised by the forts, not the milecastle gateways. Although the milecastle gateway was tried again on the Antonine Wall, in conjunction with forts on the line of the wall from the beginning, it was there found necessary during the actual building to replace perhaps half the milecastles by small forts. It seems that control required troops, in sufficient numbers to combine as a fighting force, based close at hand rather than full units as much as three miles away. On Hadrian's Wall the turrets were to be largely abandoned by the end of the second century, and although the milecastles were retained they had their gateways narrowed or eliminated.

The effects of these changes on the use of the

Wall itself are more difficult to understand. The narrowing of the curtain wall is normally seen as a device to save time and effort in view of the commitment to building forts on the line. It should not have changed the way in which the Wall was supposed to function. The narrowing to eight feet does not require any such change, but the narrowing to six feet does bring into serious question the wall-walk. It is difficult to see how a wall-walk could be useful or practical without the shelter of turrets, still less why a turret might be eliminated but a stair put in, as suggested by J. Crow at Peel Gap.[80] It would be good to be sure if turrets were discarded for the Antonine Wall, or whether they existed but have not shown up archaeologically, which is a theoretical possibility. If the original plan for the Wall was so flawed that turrets were unnecessary and broad milecastle gateways unsatisfactory, it did take Rome some time to realize the mistake, but little could be done while Hadrian ruled, and Pius's Scottish adventure meant that serious consideration of Hadrian's Wall only became possible in the 160s, although there are hints in the Antonine Wall that some lessons had been learned.

The above review has been conducted largely from the practical point of view of the builders and from examination of such scanty remains as have survived. The solutions must lie in the material available for study, although clearly not everyone will agree with the interpretations here put forward. The Wall remains fascinating as a technical achievement, and more detailed and informed analysis is required to bring out this achievement. As far as function is concerned, there are issues on which building evidence could be decisive, if it were to hand. Such issues are the form of the wall top, the existence and form of the parapet, the roofing of turrets and milecastle towers. Other factors are important, notably the nature of the Roman army, its strategy and tactics, and the inescapable fact that the first scheme did not include forts on the Wall.

But it is the contention of this paper that on simple considerations of the practical problems of building and the material evidence it is possible to establish a strong case for the six-foot wall being in some places Hadrianic, possibly implying a change of use in the wall top; for a wall parapet (if it existed) without crenellations; for towers with windows for observation over both north and south gates of milecastles; for neither milecastles nor turrets having reached full height before the curtain builders arrived; and for turrets as providers of primary accommodation rather than simply secondary accommodation for men based in milecastles.

APPENDIX 1

The Height of the Wall

It was noted on page 1 that the best evidence for the height of the curtain wall comes from the milecastle walls, in particular milecastles 37 and 48. The calculations in respect of both milecastles first appeared in F. G. Simpson's 1911 report of the excavations at milecastle 48,[81] and this seems an appropriate point to examine the evidence afresh. It will be seen that there are a great many unknown factors and that a good many assumptions have to be made.

The rough stonework of the three steps found at MC 48[82] may represent the finished surface of the treads, or there may have been flagged treads of unknown thickness on top of the surviving rough stonework. As found, the height of the first step is about 9″ and the average rise between the first and third steps (the second is imperfect) is 8″. The width of the treads is 11″. The length of the retaining wall allows for eighteen steps. Simpson took the lowest height of riser, 8″, as the average for the full flight and thus arrived at an internal height for the east wall of 12′. On account of the slope of the ground, the external height of the north wall would have been 14′ (14·4 Rf, 4·27 m). If, on the other hand, the average rise had been 8½″, the internal height of the east wall would have been 12′ 9″ and the external height of the north wall 14′ 9″ (15·2 Rf, 4·5 m). There is no way of knowing whether the builders were using the internal or external height as their reference, although it is likely in a defensible work that the external height would have been the more important. The use of three steps (one sixth of the total), only two of which are complete, in order to compute the height of the wall may be somewhat unsafe. In defence, it may be said that a flight of steps is usually regular to promote ease of use.

The steps are secondary (for they block a drain in the north wall), but the excavator considered them to belong to the first Wall period.[83] The broad wing walls abutted by narrow curtain wall show that completion of this milecastle followed the decision to reduce the thickness of the curtain wall (see above page 40). The construction of the steps thus belongs to the post-broad wall building phase, even if the milecastle walls were completed to the original gauge.[84] If it can safely be assumed that the curtain wall and the milecastle walls were finished to the same height, the figures given above suggest that there is no reason to suppose that the narrow wall, like the broad wall, was not built to a height of 15 Roman feet.

The survival of the piers and impost caps at the north gate of MC 37 makes it possible to calculate the height of the archway; Simpson's figures are here reproduced:

	ft.	ins.
From the top of the original pivot stones to top of imposts	6	8
Height of arch (span 10 feet)	5	0
Height of voussoirs	2	0
	13	8

To this figure he suggests adding the flagging of the wall-walk and of any intervening masonry between the crown of the arch and the flags. In fact this point is not relevant as the crown of the arches would have been concealed in the north and south walls of the gate tower. However the height of the arch is still important in relation to the string course, discovered since his report was published and discussed above page 29. It is not certainly known whether this feature was continued across the face of the milecastle, but there is no change in the wall-line against which it could conveniently be stopped and the logical likelihood is that it was a continuous feature. It is suggested above (fig. 2) that the string course marked the transition from wall to parapet and that the top of the string course was at the same level as a wall-walk; if this is accepted the relationship between the string course and the outer gate arch becomes significant. Reconstructions of gateways vary in their choice of relationship—the string either rests directly on the voussoirs or is separated from them by one or more courses of masonry.[85] Aesthetically, at least one course of masonry is desirable but not in practical terms essential. Assuming that the string course rested on the voussoirs, and assuming that it maintained a constant height across the face of curtain wall and milecastle, the height of the upper surface would have been about 14′ 2″ (14·6 Rf, 4·32 m).[86] If there were one course of stone between the string course and the arch it would have raised the height by not less than 5″, bringing the total height to 14′ 8″ (15·1 Rf, 4·47 m) or a little more (see fig. 6).

There is another factor to be considered. Simpson's elevation drawing of the gate of MC 37 takes into account all the essential structural points, including the upper pivot blocks set into the passage walls.[87] The doors, each shown as about 5′ 5″ wide have a turning moment which tends to draw the pivot blocks out of the wall. The position of the lower pivot blocks allows the doors to have been up to 6″ thick; accepting Jim Crow's point that milecastle doors were comparatively light,[88] and giving ample clearance against the back of the responds, each door may be taken as having an average thickness of 3″. The height of the doors will have been at least 11′ 8″, allowing 1″ ground clearance at the bottom and 1″ overlap at the highest point of the arch. If made of oak, the weight of each leaf would have been about 870 lbs. The horizontal component of the force thus acting on the upper pivot is about 185 lbs; it is this pull which must be countered. No upper pivot block has survived from a milecastle, but they were presumably of stone as may be seen at Chesters fort. If they projected 9″

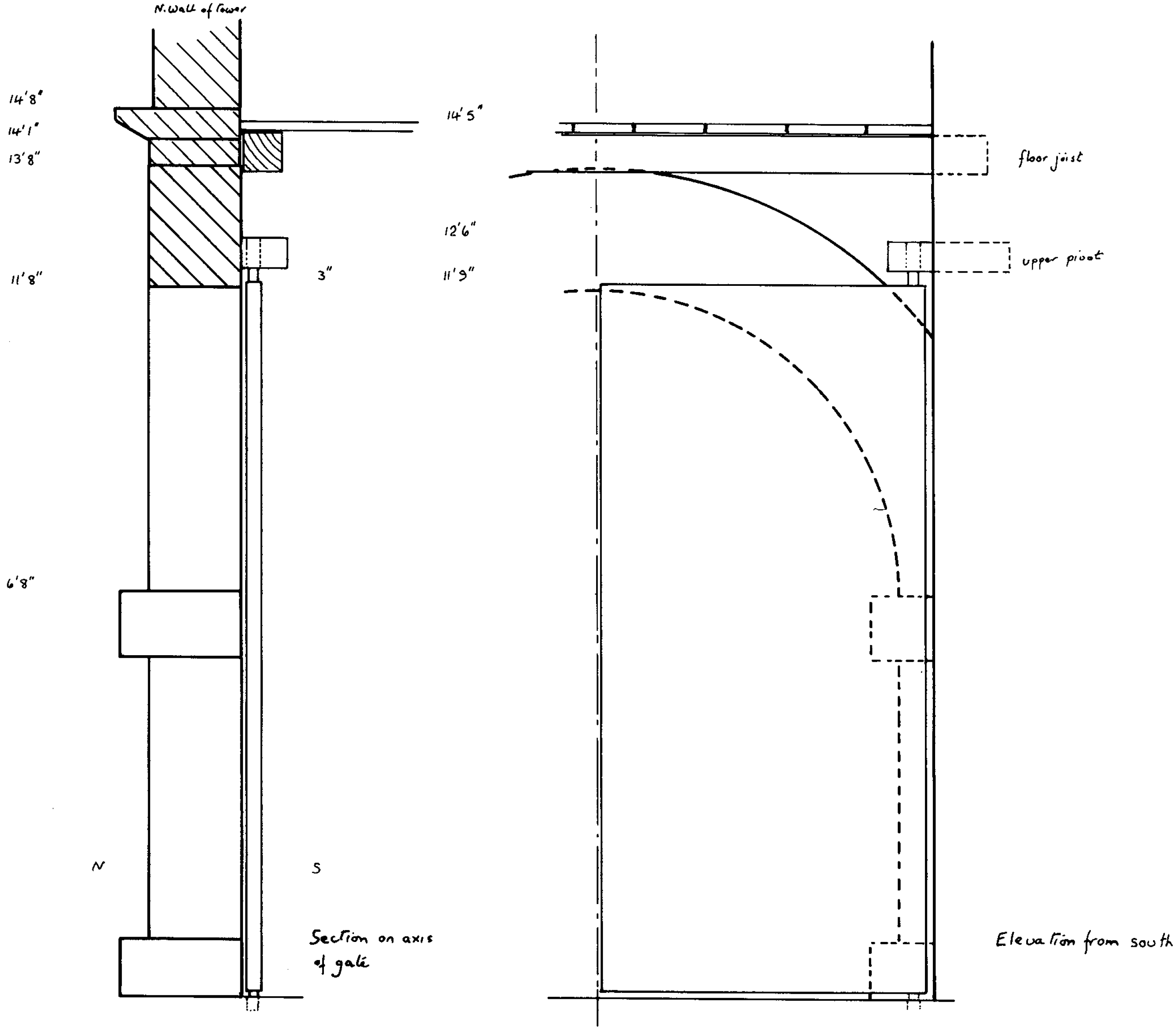

Fig. 6 North Gate, Milecastle 37

from the wall the overall size may have been 2′ long, 9″ wide and 6″ thick, weighing in the order of 112 lbs, leaving 73 lbs of the required counterweight to be found in the weight of superimposed masonry and the strength of the mortar. If the passage walls, which at about this point become the side walls of the gate towers, were continued straight up in coursed rubble masonry there would be no need to consider the point any further—the pivot blocks would easily be held in place. But there is a complication in the form of the tower floor, which as Simpson suggests in his drawing will have been carried over the passageway on wooden joists running east–west. There would thus have been a joist in the wall above the pivot blocks to carry the northern edge of the floor. If this joist had been placed immediately above the pivot, the latter would probably have held in place owing to friction and the tensile strength of the lime mortar, which is about one ton per square foot.[89] However, there would inevitably have been some shrinkage of the beam and there would be constant shocks to the pivot from the banging of the doors and some sideways pull unless the pivots and the hole were perfectly round. In these circumstances it would have been prudent to have at least one course of stone between the pivot blocks and the beams. A course of stone just over 6″ thick would have countered the pull, without taking into account the strength of the mortar, but any movement or shock affecting the pivot block would have broken the hold of the mortar and for safety a stone of perhaps twice this figure should be allowed, say 13″. The Roman builders would have been empirically aware of the need for the pivots to be well secured and most of their buildings have large factors of safety. Giving 3″ clearance between the doors and the upper pivot blocks to allow for fitting the doors, and following Simpson in allowing 8″ beams and 2″ boarding, the height of the tower floor comes to 14′ 5″ (14·9 Rf, 4·39 m) (see fig. 6).

In the light of the above review of the evidence for the height of milecastle walls, it seems a near-certainty, despite the large number of assumptions, that their original design height was 15 Roman feet (14′ 6½″, 4·44 m) and it is very probable that the curtain wall was similarly designed. Minor variations from site to site are to be expected, as it is clear from the evidence for the width of the curtain wall that the builders were not greatly concerned about inaccuracies of a few inches.

APPENDIX 2

Barrack accommodation

There is considerable variation in the size of barrack blocks in milecastles, something which is not closely related to the work of different legions. The following table gives the internal area of the usual two rooms together including the partition wall, except in the case of milecastle 48.

The maximum figure for milecastle 37 depends on the barrack making use of the east and south walls of the milecastle, something which is not recorded elsewhere. Ignoring the exceptional milecastle 48, the others are not far removed in size from the *contubernium* in Housesteads fort. The largest, the only timber barrack, is some 30% larger than the fort barrack and could theoretically have accommodated ten or eleven men without making use of the hot bed system. On the same basis, a turret could have held at least twelve men.

	Size in feet	*Area (sq. ft.)*
Housesteads fort, barrack xiv	25 × 11	275[90]
Milecastle 9	20½ × 11	225[91]
37 (max)	36 × 16	576[92]
37 (min)	29 × 10	290
48 (eight small rooms)	13 × 12½ each	1300[93]
50TW	30 × 12	360[94]
Turret (two floors)	14 × 14 each	392

NOTES

[1] J. C. Bruce *Handbook to the Roman Wall* (13th Edn Newcastle 1978 ed. Charles Daniels) 16 and passim; there is no obvious reason for the slight reductions from its apparent planned width. Measurements given in feet, which are convenient for the study of the wall, are in imperial measure unless otherwise indicated. Fractions of an imperial foot are given in inches, and of a Roman foot (Rf) as a decimal. Metric equivalents are approximate, to within 10 mm, and are not given where they seem superfluous or would lead to unnecessary repetition.

[2] A height of between 14′ 6″ and 15′ 6″ (4·42–4·73 m) for the fort walls is given in a well reasoned argument by I. A. Richmond and F. A. Child, "Gateways of Forts on Hadrian's Wall", AA^4 xx (1942) 134–54. Bede (*Hist. Eccl.* 1, 12) records the Wall as standing eight feet wide and twelve feet high (2·44, 3·66 m).

[3] P. T. Bidwell and N. Holbrook *Hadrian's Wall Bridges* (English Heritage 1989) 58–9 and fig. 41.

[4] The presence of an earthy bonding material, especially from early excavations, may sometimes be the result of lime leaching out. The present writer, in dismantling walls no more than 100 years old, has found narrow ashlar joints to be full of earth and grass roots. No doubt lime was present, but it was not readily discernible. A similar suggestion is made in J. C. Bruce *The Roman Wall* (1851) 91, but this is not to suggest that clay was not used to build some parts of the wall.

[5] Charles Daniels (ed.) *The Eleventh Pilgrimage of Hadrian's Wall* (Newcastle upon Tyne 1989) 51. The excavator of milecastle 48, CW^2 xi (1911) 404–5, was quite clear that there had been no reconstruction from the foundations of the 6′ 11″ wall east of the milecastle.

[6] Bidwell and Holbrook op. cit.

[7] R. Miket and V. Maxfield "The Excavation of Turret 33B (Coesike)" AA^4 l (1972), 156.

[8] Charles Daniels (ed.) *The Eleventh Pilgrimage of Hadrian's Wall* (Newcastle upon Tyne 1989) 53. A solid staircase could have been comfortably accommodated against a 12′ (3·66 m) wall but would have been awkwardly steep against a 15′ wall. A ladder would hardly have needed a continuous platform extending some 10′ 6″ (3·20 m) from the south face of the wall; its foot could safely have been placed no more than 5′ (1·53 m) from the higher wall. The wall here was always narrow.

[9] Brian Dobson "The Function of Hadrian's Wall, *Seventh Horsley Lecture* (1985)" AA^5 xiv (1986) fig. 4 facing p. 15.

[10] The figure is suggested by Richmond and Child, op. cit. This size suggests that the parapet would have been built of two contiguous skins; if built entirely of through stones, each one, at perhaps 12″×18″×7″ (305×450×180 mm) would weigh about 130 lbs (59 kg), an unreasonable weight for two men to fix continuously. Also, working two faces on a single stone takes more than twice the time taken to work a single face. The apparent merlon cap from T51b (see note 70) was 18″ (460 mm) wide, suggesting a parapet width of 14–16″ (350–400). That from the Cumberland coast tower 16a (note 71) was only 13″ (330 mm) wide.

[11] If each slab were 2′×2′ (620×620 mm), a convenient size to handle, four would be needed to cover the width of the wall behind the string course. This amounts to some 9,700 slabs per mile with some 68,000 linear feet of reasonably clean joints; 437,000 slabs and 3,000,000′ (915,000 m) of joints from Newcastle to the Irthing. Each slab might take three times the labour of working one facing stone, adding about 10% to the building programme.

[12] E.g. Heddon, AA^4 iv (1927) 116–18, AA^4 xxxvi (1958) 58–9; Rudchester and Chesters, AA^4 i (1925) 103; Peel Crag, Grace Simpson (ed.) *Watermills and Military Works on Hadrian's Wall* (Kendal 1976) 115–16 and fig. 26; Peel Gap, *Britannia*, xxii (1991) 59 and fig. 3 (58).

[13] *JRS* xv (1925) pl. xxvi.

[14] At Wörth, most conveniently illustrated in Anne Johnson *Roman Forts* (London 1983) 70, fig. 43, the chamfer seems to have been uppermost on the collapsed fort wall.

[15] AA^4 xlvi (1968) 73–4.

[16] B. Dobson op. cit., 5–8.

[17] E.g. Housesteads, Greatchesters, Birdoswald, Haltonchesters, South Shields.

[18] T7b, AA^4 vii (1930) 174 plate xli fig. 2, where the scale appears to be a three foot folding rule, and T51b AA^4 xliii (1965) 182.

[19] The most convenient summary is R. Hunnysett "The Milecastles of Hadrian's Wall—an alternative identification" AA^5 viii (1980) 95–107.

[20] These points are clearly illustrated, without comment, by F. G. Simpson in Grace Simpson op. cit. plate xi facing 124, and by Richmond and Child op. cit. (note 2) fig. 2 facing p. 137.

[21] *HB* 23.

[22] AA^4 xiii (1936) 259.

[23] AA^4 viii (1931) 309. As F. G. Simpson seems to have had a clearer understanding of the function of structures than most of his contemporaries and successors, it is surprising that he never went on to consider the implications of this statement.

[24] *AA*[4] xxxi (1953) 171

[25] *AA*[4] vii (1930) pl. xliv fig. 1, facing p. 174.

[26] *AA*[4] xxi (1953) pl. xx figs 1, 2, facing p. 174. The passage wall on the east side seems to have been built in large squared rubble, the west side in perhaps rather better masonry.

[27] *AA*[4] xiii (1936) 263 fig. 2, and observation on the ground before recent damage.

[28] *JRS* xxxviii (1948) 84.

[29] Ibid. The exploratory trench appears to have been on the narrow north wall where the later excavators found no trace of a gate (*AA*[5] xii (1984) 36, 38, and fig. 3); the same excavators believe that the gateway in the broad south wall was of type IV.

[30] *WMMW* 89 and fig. 15.

[31] *AA*[4] xiii (1936) 271 and fig. 7.

[32] As noted by Richmond and Child, op. cit., 139.

[33] The impost caps would normally be ideally suited to act as supports for the centre, *contra* Julian Bennett, "The principal gateways of masonry forts on the Hadrianic frontier in England" in Bidwell, Miket & Ford (Eds) *Portae cum Turribus* BAR 206 (Oxford 1988), 121. The majority of the weight of the voussoirs is carried by that part of the cap which rests on the piers, rather than by the centre resting on the overhang of the cap.

[34] *Molesworth's Pocket Book of Engineering Formulae* (London 1910) 136, 139.

[35] First raised by J. P. Gibson, *AA*[2] xxiv (1903) 15.

[36] *Britannia* xiv (1983) 290. They were found reused in the wall, but it is difficult to see where else they might have come from originally.

[37] Cf. P. R. Hill "Hadrian's Wall: some aspects of its execution" *AA*[5] xix (1991) 33–9, where it is shown that legion II did not *necessarily* design type I gateways.

[38] James Crow "Notes on the North Gateway of Milecastle 39" in Bidwell, Miket & Ford (Eds) *Portae cum Turribus* (BAR 206 1988) 148.

[39] *The King's Regulations and Orders for the Army* (HMSO 1912), para. 948, covering duties of guards and piquets on permanent stations.

[40] Pseudo-Hyginus 1, where a "hot-bed" system is envisaged in the statement that only eight tents are pitched per century as two *contubernia* will be on guard duty at any given time.

[41] P. Dura, 100 and 101. For a discussion of outstationed troops see David J. Breeze "The Roman Fortlet at Barburgh Mill" *Britannia* v (1974) 144–51.

[42] "The Function of Hadrian's Wall" *AA*[5] xviii (1990) 53.

[43] James Crow op. cit. 143–53 reconstructs the gate tower with two stories above the Wall and a flat roof but gives a height only for the curtain wall.

[44] Parker Brewis "Conjectural Reconstruction of Turret No. 18a" *AA*[4] ix (1932) 198–204.

[45] C. C. Woodfield "Six Turrets on Hadrian's Wall" *AA*[4] xliii (1965), 89f, 130f.

[46] Lindsay Allason-Jones "Small finds from turrets on Hadrians Wall" in J. C. Coulston (ed.) *Military equipment and the Identity of Roman Soldiers* (BAR International Series 394, Oxford 1988)

[47] *AA*[4] ix (1932) 199.

[48] *AA*[3] ix (1913) plate II facing p. 56.

[49] B. Dobson op. cit. (note 9) fig. 4 facing p. 15.

[50] Scene i, Lepper and Shephard Frere *Trajan's Column* (Gloucester 1988) plate iv.

[51] Op. cit. 218f and fig. 7.

[52] *AA*[4] xxxi (1953) 168.

[53] Dorothy Charlesworth "A re-examination of two turrets on Hadrian's Wall" *AA*[5] i (1973) 98.

[54] I. A. Richmond "Hadrian's Wall, 1939–1949", *JRS* xl (1950) 44.

[55] C. E. Stevens, *The Building of Hadrian's Wall* (Titus Wilson 1966), 17, 28, 60, 75 and passim.

[56] Cf. R. Hunnysett op. cit. (note 19). The evidence, reasoning, and effect is fully reviewed in P. R. Hill "The Construction of Hadrian's Wall", forthcoming.

[57] *The Ten Books on Architecture*, Book 7, Chapter 1.

[58] The flat roof over the reconstruction of Northgate, Manchester consists of boarding, reinforced (Portland cement) concrete, sheathing felt, and two layers of asphalt, finished with stone slabs, a specification based on but far in excess of Vitruvius. John Walker, "The reconstructed Roman remains at Castlefield" in Bidwell, Miket & Ford (Eds) *Portae cum Turribus*, BAR 206 (1988) 97–8.

[59] Table of Horizon Distances, to be found in any Nautical Almanac.

[60] G. H. Donaldson "Thoughts on a military appreciation of Hadrian's Wall" *AA*[5] xvi (1988), 125–37.

[61] Cf. D. Campbell, *BJH* 186 (1986), 117–32.

[62] Lepper and Frere op. cit. plate iv.

[63] T29b *AA*[3] ix (1913) 60 and T44a *AA*[2] xxiv (1903) 14.

[64] T18b, *AA*[4] xliii (1965) 99. The excavator did not consider that one fragment of imbrex and two other small pieces made a tiled roof.

[65] *AA*[3] ix (1913) 60.

[66] Lepper and Frere op. cit. plate iv.

[67] Note 46.

[68] James Crow op. cit. (note 38) 151.

[69] Ibid.; also J. G. Crow, *Britannia* xxii (1991) 61 and fig. 4 (60).

[70] *AA*[4] vii (1930) plate xli fig. 2 facing p. 174.
[71] *AA*[4] xliii (1965) 171, 182.
[72] *CW*[2] lvi (1956) 65 and fig. 1 facing p. 64.
[73] This solution is also put forward by Julian Bennett op. cit. (note 33) 137, but unfortunately there is no evidence for this construction.
[74] Op. cit. 219.
[75] Robin Birley *The Roman documents from Vindolanda* (Carvoran 1990), 22f, document T 1987/841.
[76] *Field Service Pocket Book* (HMSO 1914), 52.
[77] In the Aalen Limesmuseum is a water-bottle uncannily like the British army pattern, P. Fitzinger, *Limesmuseum Aalen* (Stuttgart 1983) Taf. 23. A similar one from Newstead is illustrated in D. V. Clarke, D. J. Breeze, G. Mackay *The Romans in Scotland* (National Museum of Antiquities of Scotland 1980) 21.
[78] As the steps at Poltross Burn are secondary, and no clear sign of a staircase has been found at other milecastles, it may be that this was not the usual form of access.
[79] D. J. Breeze *The Northern Frontiers of Roman Britain* (London 1982), 81 fig. 14. The door as shown in the reconstruction would not open for the reasons given above for arched turret doors. The problem of protecting the access to the milecastle from the wall-walk and the possible solution, was first pointed out to Dr. Breeze by Mike Moore who prepared the illustration.
[80] Op. cit. (note 8) 53.
[81] *CW*[2] xi (1911) 390–461.
[82] Ibid. 420–21.
[83] Ibid.
[84] P. R. Hill "Hadrian's Wall: some aspects of its execution" *AA*[5] xix (1991) 37.
[85] Hesselbach fort, illustrated in Anne Johnson, op. cit. (note 14) 91 fig. 67, and Housesteads fort, Richmond and Child op. cit. (note 2) fig. 2 facing p. 137.
[86] *AA*[4] xxxvi (1958) 59 gives the height of the chamfered stones as about 5½″, to which must be added at least ½″ for the mortar joint.
[87] Grace Simpson op. cit. (note 12) plate xi facing 124.
[88] Op. cit. (note 38) 148. Richmond and Child, op. cit. (note 2) 140, suggest that the fort gates were 4″ thick.
[89] G. H. Blagrove *Dangerous Structures* (London 1906) 57.
[90] *AA*[4] xxxix (1961) 282.
[91] *AA*[4] vii (1930) pl. xlii facing p. 174.
[92] J. G. Crow *Housesteads Roman Fort* (English Heritage 1989) 33. See also plan in Charles Daniels (Ed.) *The Eleventh Pilgrimage of Hadrian's Wall* (Newcastle upon Tyne 1989) 55.
[93] *CW*[3] xi (1911) 422.
[94] *HB* 214.