Cymdeithas Waliau Cerrig Sychion
Cangen Gogledd Cymru

Dry Stone Walling Association
North Wales Branch

STONEWORK

A technical guide to standards and identification of common faults in dry stone walling

DSWA is registered as a charitable organisation (289678)

COVER PHOTO: A new roadside wall within 2-3 years of having been built.
Written by Sean Adcock on behalf of North Wales Branch of Dry Stone Walling Association, 2012.

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PREFACE

This guide tries to exemplify some of the basics of construction, identifying common faults which occur in dry stone walling, and why these may be considered to be weaknesses. It is intended as a tool to aid those commissioning work, in either drawing up specifications, establishing a best practice against which faults can be identified, or actually identifying the faults themselves. This includes farmers and private landowners, as well as those working on publicly funded or large scale projects, who accept such work to be of sufficient high quality for payment. It should facilitate a fuller understanding of faults and hence increased awareness of, and ability to identify, these during the inspection process. It will also be of value to dry stone wallers wishing to improve the quality of their work.

Variations in local practice and stone type mean that it is not possible to develop a catch-all specification for dry stone walling. Understanding how and where specifications might need to be varied should be aided through the highlighting of common problems, and descriptions of best practice, contained here. Careful reference to the main body of the text should aid with adapting general specifications for a specific situation although for any specific project it is always advisable to have expert local advice. The Dry Stone Walling Association of Great Britain (DSWA) should be able to suggest suitable contacts.

The guide is a development of the original *"Stonework"*, a basic guide to standards produced by the North Wales Branch of DSWA in the1990s, plus a technical appendix from a report compiled for North West Wales Trunk Road Agency (NWTRA) working for the Welsh Assembly Government, by Sean Adcock. For specific queries relating to the booklet please contact the author via DSWA - Lane Farm, Crooklands, Milnthorpe, Cumbria, LA7 7NH Tel: 015395 67953 Email: information@dswa.org.uk.

INTRODUCTION

A dry stone wall is a stone wall built without recourse to the use of binding agents such as mortar. The stones are held together by gravity and friction and the wall is reliant on good craftsmanship to ensure stability. On occasion a concrete foundation may be allowed (normally on freshly made up ground), with all the stonework above ground being dry stone. Where vandalism is a problem it might be necessary to mortar the top stones.

This booklet looks at standard "doubled" dry stone walls, essentially walls with two independent faces separated by a core of much smaller stone. Additional factors need to be considered for other structures such as single walls, Galloway dykes (where there is a single sitting atop a double), and structures with an earth core such as Cornish hedges and Welsh cloddiau. Brief mention is made of retaining walls as most of the factors included here would apply to them; however additional advice should be sought where they are structural.

Much of the strength of a wall is internal and there is no substitute for inspecting work as it progresses. However many faults can be assessed from the outside and guidance is also given on how to recognise these. The fact that you can identify a fault does not necessarily mean the wall will fail. It is important to remember that an occasional fault does not necessarily make a wall bad; no waller, however good, has built every wall perfectly.

Bad faults are generally created by very poor wallers and rarely do they stop at one. As you progress through this guide you will see that in many of the photos illustrating one particular fault you can normally find others. Essentially faults are the result of bad technique and so the existence of one suggests the possibility of others. In addition, as many faults are hidden, if you can actually see a number it would generally suggest that they are likely to be compounded by hidden ones, exacerbating the problem. Consequently if an obvious fault exists, it is as well to look closely for others. Most capable craftsmen would be less likely to create the obvious faults in the first place. Whilst individual faults can be a problem it is usually a combination or concentration of them which leads to catastrophic failure.

It should not be inferred from the content of this booklet that the majority of wallers are incompetent and need watching like a hawk. Rather its purpose is to highlight what can go wrong, inform readers on what could and should be achieved, and to help produce excellent work.

Photographic examples are included within the text. A photo gallery of all the pictures contained here, plus extra examples can be found in the "Standards" section of www.dswales.org.uk., along with a glossary of walling terms. *"A Guide to the Commissioning, Inspecting and Assessing of Dry Stone Walling",* a leaflet containing the main points of this booklet has been produced by the North Wales Branch on behalf of DSWA of GB.

SPECIFICATIONS

The DSWA's free "Technical Specifications leaflets" are available online at www.dswa.org.uk, and on the North Wales Branch website: www.dswales.org.uk. These include very basic information which might form the basis of a specification, however dry stone walling is not a homogeneous craft; different stone types demand different techniques which become incorporated in local traditions. You might get the impression that faults in one area are normal practice in another. Often this is a question of degree, with other factors mitigating the potential weakness, in effect negating the problem. Thus it is not possible to describe a universal best practice across the British Isles and care should be taken not to remove local practices through the attempted implementation of a standard -blueprint of what is "correct". Variations must be allowed for but they complicate assessment. Understanding when and where rules apply and how they should be applied is key to assessing stonework and understanding whether a waller doesn't know any better, or is maybe even trying to pull the wool over your eyes. It has been said *"Rules are for the guidance of wise men and the blind obedience of fools." (*Solon the lawmaker of Athens 559BC)[1]

Clear written specifications should include information on all aspects of the work, such as timescales, groundwork, site access, traffic management, and public access. Such site specific details are best left to those commissioning the work. It is recommended that aspects of stonework such as quality - including finish, line, batter, tightness, throughs, copes; and technical aspects such as - patterns, ties and jointing; should be drawn up in consultation with suitably knowledgeable wallers.

Where replacement stone is used, this should match the stone of the immediate area in order to maintain the vernacular. Sawn faces in particular can detract from appearance (as seen in figure1). Care also ne eds to be taken when sourcing fresh stone as some stone types need to be left to weather prior to use. For example some freshly quarried oolitic limestone will

Fig.1. Inappropriate stone used in repairs Caithness (left), Cotswolds (right)

delaminate if exposed to frost before it has "cured". It should also be borne in mind that many stones will change colour as they weather. Further advice on these issues is best sought from local experts, the DSWA is happy to suggest suitable contacts.

Hopefully this booklet will help with negotiating these difficulties. It contains only limited technical advice as this is best dealt with in detail within other publications such as the British Trust for Conservation Volunteers *"Dry Stone Walling: A Practical Guide"* or the DSWA's own less detailed *"Dry Stone Walling: Techniques & Traditions"*. However if you have any queries please contact

Sean Adcock (the author) or your local branch, both via DSWA of GB, who can also suggest other local experts who can offer advice.

QUALITY

Quality is not solely about what a wall looks like; a well built wall combines structural strength with neatness of finish. Unfortunately it is possible to make stonework look good without the end result being structurally sound, and consequently quality in a wall can be difficult to assess. Good craftsmanship involves the marriage of structure and neatness to produce an end result that is both strong and looks good. A good craftsman does not charge more simply because the end result is neater and looks better, but primarily because the whole wall has been built soundly, will last longer, and also looks neater than a poorly built wall.

A distinction is often made between more utilitarian walls (such as those on farms), highly visible projects (e.g. roadside) and show walls (e.g. gardens); and the relative qualities applicable to each. Whilst different degrees of craftsmanship might be required on such projects this essentially relates to finish rather than structure. The basic faults identified herein represent bad practice regardless of the type of wall in which they occur. All walls should be built structurally sound regardless of their actual function.

The DSWA operates the only nationally recognised, tiered certification scheme available in the craft, details of which are included in APPENDIX A. In addition it produces an annual *"Register of Certificated Members and Sources of Stone"*, which lists all professional members by region and certification level. This is available in print from the DSWA Office and Branches. There is an electronic version on the DSWA website (www.dswa.org.uk).

WALL CONSTRUCTION

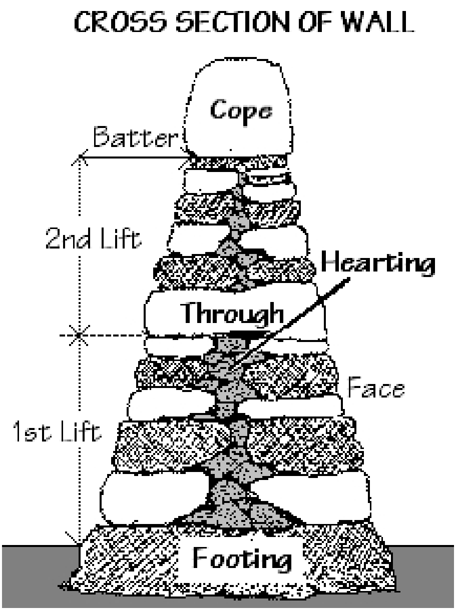

Fig.2. Typical wall cross section.
After DSWA's *"Techniques & Traditions"* p.15.

Unless subjected to an outside force such as cattle or a motor vehicle, walls can only really fall down as a result of gravity during ageing. Stones move as the wall settles. Many problems in walls occur where there are differences in settlement between adjacent sections or from one side to the other. How much the wall settles is not only dependent on the ground but also on the internal structure of the wall. Most aspects of wall building are geared towards either reducing or controlling this movement. Foundations are dealt with after basic building techniques, since most of the principles which apply to the main body hold true there.

BUILDING

When placing a building, or "face", stone on a wall the waller will be trying to achieve several things at once. The more of these that are achieved, the stronger the wall will be, so that a good starting point in assessing how well a wall is built is to try and identify what each stone should be trying to achieve and why these factors might be important. A good starting point for this are eight principles identified in the British Trust for Conservation Volunteer's *"Dry*

Stone Walling'[2] and listed with some paraphrasing below. The waller should aim to meet each of these with the placement of each individual stone. Whilst it is not always possible to adhere to every principle with every single stone it does follow that, if you can identify where these principles are badly broken, then there will be faults in the wall.

i Grading: largest stones at bottom.
ii Length into wall, avoiding tracing (ie running long axis along the wall).
iii Contact: place each stone so that it is touching its neighbours, below and to the sides for as much of its surface as possible.
iv Place each stone in a way that does not make it unduly difficult to build alongside and on top of it.
v Break/cross joints.
vi Stone placement /structure. Sit stones solidly with a minimum of wedging.
vii Set stones to the true horizontal.
viii Taper the outside surfaces of the wall to the correct batter.

Remember that some of these principles cannot be assessed once the wall is completed and, as much of the strength of a wall is internal, there is only so much you can see from the outside.

(I) <u>GRADING</u>

Grading is the placing of larger stones towards the bottom of the wall, smaller stone to the top. In coursed walls the stone is set in regular layers of very similar heights, in random walls the layers comprise stones which vary far more in size especially with regard to their heights. However random does not mean placing any size anywhere, for example the vast majority of larger stones should be lower in the wall and, whilst stone size generally decreases with height, it is not necessary for every stone higher in a wall to be smaller than those below it.

Oversized stone should always be used in the footing, unless its length and shape are such that it will make a suitable throughstone.

Not all coursed walls have layers which diminish in thickness very strictly with height. In parts of the Cotswolds, for example, where the face heights of the stone might only vary by a few centimetres, there is little wrong in having a slightly thicker course over a thinner one. As such the thickness of subsequent courses is random, and the pattern known as "random coursed".

There are other related reasons for having a well graded distribution. Smaller stones placed towards the bottom of a wall are more likely to become displaced. Larger stones require more space, especially if the long axis is to be placed into the wall and this fits better in the lower, wider wall. Generally a big stone on top of a layer or two of smaller stones is vulnerable and unstable compared to a layer or two of small stones sitting on top of a big or oversized stone.

In a well structured wall not only is stone graded according to height it should also have an even distribution along a wall. Again this tends to apply more to random walls as by definition stones in a coursed wall will be of a similar face height along any given course.
For example if you are rebuilding a 5 metre section of wall and have five large boulders it is often tempting to group them, (especially on slopes) but structurally it is likely to be better to spread them along the length. Similarly filling a gap between two large stones is better done with 2 or 3 medium size stones rather than half a dozen small ones. As a practice such grouping alone is unlikely to destabilise a wall, however it can indicate a poor building process and other faults are likely to be present.


Fig.3. Two walls of similar glacial stone used very differently

Figure 3 shows two walls a few hundred metres apart on opposite sides of a road, built at the same time by different contractors. The wall on the left has poor stone distribution as well as a number of other faults. The wall on the right built of the same stone looks very different because of the way the stone has been used rather than the stone itself. For example good grading and less tracing usually makes stone look smaller since a large stone high up looks bigger than when set lower alongside similarly sized neighbours; whilst stones set end-in have smaller faces than if "traced"("tracing" is dealt with in detail under LENGTH INTO WALL).

In this case the difference is enhanced by the fact that on the right good sized coping stones were set aside before building began. On the left these have likely been "walled in" with the coping just constituting whatever was left over. In addition, excessive "pinning" (small stones in the wall face – see STONE PLACEMENT/ STRUCTURE:*Pinning*), and a lack of "tightness" (gaps and ill fitted stones – see CONTACT), have exacerbated the different look.

Fig.4. Oversized stones high in wall, carboniferous limestone

There are other implications with these stones size which can be ascertained from relative dimensions.

In figure 4 the 2 large stones highest up the wall have faces of around 25-30cm high and are about twice as long along the face. They are very close to the wall top and in this example the wall is only 40cm wide below the cope. Hence, as they are about as long as the wall is wide, assuming they are not throughstones, they must be traced. Then there are two possibilities: either they are standing on edge (i.e. their base depth into the wall is less than their height - see STONE PLACEMENT/STRUCTURE: *Vertically set stones*) and therefore highly unstable - especially given they are traced**;** or they leave relatively little space (much less than 15cm) for building the second skin on the far side as in figure 5, which would consequently be weak, and likely to peel away.

Setting stone on edge can be regionally acceptable. In some areas they are known as “shiners”, although this can refer to any stone with a large surface however it is set in the wall’s face. Stones used in this way should have a good flat base set on a good surface (maximising contact and friction) and reach at least a third of the way across the wall. They should not be top heavy so they are usually longer than they are tall, which has tracing implications (see LENGTH INTO WALL). This practice is dealt with in greater detail under STONE PLACEMENT/STRUCTURE : *Vertically Set Stones*.

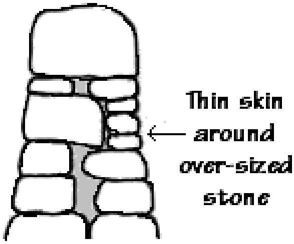

Fig.5. Oversized stone high in the wall

Fig.6. Jumpers, oolitic limestone

In many regions which have regular stone, the coursing is broken by a jumper (figure 6), a large stone, which jumps up two or sometimes 3 courses/layers. Beyond the technical aspects of changing course size these stones are appropriate as a local practice as long as:

- They have good length into the wall and are not traced or vertically set on edge.
- They do not result in a thin, unstable opposite face.
- There is good stonework above and below.

(II) LENGTH INTO WALL

A key aspect in a wall’s strength is the placing of stones with their longest axis pointing into the wall, a general rule of thumb being that any single stone should reach at least a third into the wall.

Stones placed with their long axis along the line of the wall (as in figure 7), are known as "traced" stones. “Tracing" is a frequent fault in cheaper work since traced stones complete more of the length of the wall so fewer stones have to be placed, and it is easier than trying to fit them lengthways into the wall where stones on the opposite side of the wall will have to be painstakingly fitted around them. Individual traced stones are sometimes referred to as “stretchers”.

Ideally all building stones should be placed with their longest axis into the wall, “tail-in”. The stones placed length in are sometimes called “headers”, and said to have good “bite”. Placing them this way greatly reduces their potential to become displaced during settlement. Traced stones lower in the wall tend to be more of a potential weakness than those higher up as the forces are larger, whilst narrow traced stones are particularly easily dislodged.

It should be noted that with some stone types, most notably laminates such as slate, tracing can be unavoidable. In these cases a specialised structure (dealt with below), is required.

Fig.7. Excessively traced stone (1.2m level)

Tracing often produces a neater wall than could otherwise be achieved, but its strength is suspect. Within most walls the tracing of occasional stones is acceptable. However the grouping of traced stones alongside, or on top of, each other can create a greater weakness, as can a proliferation of traced stones sprinkled liberally throughout the wall.

Fig.8. Excessive grouping of traced stones

Examples such as those shown in figures 8 and 9, can only really be assessed through inspection as work progresses. From the outside, given the width of the wall, it would not be possible to determine that the stones are traced, although a skilled inspector familiar with the local stone can normally guess at the problem. Where rounded stones are excessively traced as in figure 9, you will normally find at least one face stone which can be moved or easily dislodged.

Fig.9. Face view and inside view of an extremely badly traced wall

With many stone types it is possible to get a good idea from the general dimensions of the wall and the relative visible dimensions of a stone, whether many are traced, especially extreme examples as shown in figures 7 and 10. If the length of the stone's face is more than about half the width of the wall at that height the stone is likely to have been traced. The occasional apparently traced stone might just stretch well into the wall. You then have to consider whether this has necessitated the use of insubstantial stone to build around it (as in figure 5).

Given the concentration of long stones in the left picture of figure 10, plus the fact that they are out of character with the general stone type and shape (as illustrated by the right hand picture), they are almost certainly traced. Given the stone type – generally small angular limestone - it is likely that these are valuable throughstones used as traced building stones, exacerbating the fault.

Fig.10. These two photos are taken close by in the same wall. The right hand photo is indicative of walls in the immediate area. This suggests that many of the through-stones were traced as building stones, in one short section (left)

In extreme examples the weakness created by the relative instability of the traced stone is compounded by the fact that because of their length they do not always sit securely on the several stones below. Consequently the lower stones are relatively easily displaced and, if they move, the traced stone is even more unstable. This problem usually referred to as the problem of “1 on 3” (see CONTACT).

In some areas with very flat stone, which ensures excellent surface contact above and below, increasing friction and reducing potential displacement (see CONTACT), tracing is acceptable. It is also acceptable with some stone types which disintegrate if dressed (thick slate and shales).

In these instances there are likely to be local approaches such as only tracing stones which fit ⅓–½ across the wall. In addition the tracing of adjacent stones, stones opposing each other on both sides of the wall, or tracing one stone on top of another would be minimised. Good use would normally be made of the space opposite a traced stone, with the incorporation of stones as long (into the wall) as can be fitted into the available space. The layer above any traced stone should compensate for the weakness created by tracing, with each traced stone normally tied back on the next layer. Tie stones or bonders, which run more than half way into the wall would also be more prevalent, and the frequency of throughstones (discussed in THROUGHSTONES) increased.

Care needs to be taken in jumping to the conclusion that a wall is unduly traced as stone types, such as the sandstone found in Caithness can produce what looks like a traced wall. The wall in figure 11 is actually well built. It is obviously “tight” (close fitting, see CONTACT). What cannot be seen is that many of the building stones are triangular in plan, allowing them to be set with tails almost as long as, if not longer than, their faces. Whilst the stones have long faces they can still reach ½, sometimes to ¾ the way across the wall, occasionally to within a few centimetres of the other face. The problem outlined with figure 5 is avoided because the intrusion is only a point which can be walled around with another triangular stone. When this is repeated on subsequent layers a large number of the building stones are in effect ¾ throughs (see THROUGHSTONES) and the whole structure is well tied.

Fig.11. “Illusory” tracing, coal measures sandstone, Caithness

These examples lead to several corollaries:
- The flatter the stone the less serious the problem of tracing, always assuming the wall is built with good stone contact.
- The further into the wall the stone stretches, and the thinner (face height) the stone, the less the problem.
- The more irregular or rounded the stone, the narrower the stone, or the taller the stone the less stable it will be.
- The less the stone extends into the wall the more likely it is to work loose.
- Where the stone used is more rounded there will be much less contact and any traced stones will inevitably work loose.

(III) <u>CONTACT</u>

How well the stones fit together in the face of a wall is referred to as "tightness" with "slackness" as the self explanatory opposite. A "slack" face (figure 12, right) with more gaps has more potential for movement during settlement, not only because the stones could move into the gaps, but also because there is less friction between stones to hold them in place. In a reasonably well built wall the amount the wall can settle within itself will be very limited, greatly reducing the potential for collapse. Where the face is very slack smaller stones can often be simply pulled out by hand (see also figure 3, left picture).

Fig.12. 2 sections of wall from very similar carboniferous limestone, showing a tight face (left) and relatively slack face (right)

The effective degree of tightness that can be achieved can vary with stone size and type (see figure 13, the back cover also shows 3 sections of tight wall of differing stone types). In all cases stones should be butting against their neighbours, but, for example, a wall built of regular/flat stone should be tighter than one built of irregular stone, and rounded stone is likely to appear slacker than squarer stone. Smaller stone should result in a tighter build than larger stone - a 5cm^2 `gap` is not a problem where the butted stones have 200cm^2 faces; where they only have 100cm^2 faces it is of far more concern, as illustrated in figure 14.

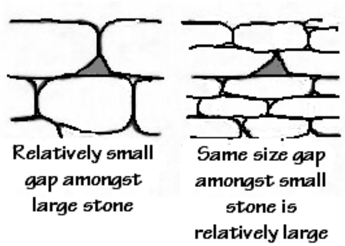

Fig.13. Gap size is relative to stone size

Fig.14. Relatively large gaps in sawn sandstone wall

The area of contact at the top and bottom of stones is the most crucial stone contact within a wall. Whilst a stone only needs one good point/line of contact with each of the stones under it to sit relatively securely and hold the lower stone in place, the greater the area of that contact the more securely will the stone be held, and the less likely it is to be displaced. This tightness is perhaps one of the most overlooked aspects of wall building and tends to be put down as neatness rather than strength. All other things being equal, the better the stone contact the stronger wall. Figures 16 and 17 illustrate how different the end result can be with the same stone.

If there is good contact between the edges of adjacent stones there is far less scope for movement during settlement: a key aspect of good wall building that can only be effectively assessed during construction. It is quite easy to create a tight looking wall from the outside whilst creating a slack wall on the inside. It is easier to butt points (figure 15) than to get good fits in every plane. Of course this weakness can be mitigated by other factors such as those outlined in the Caithness example seen in LENGTH INTO WALL.

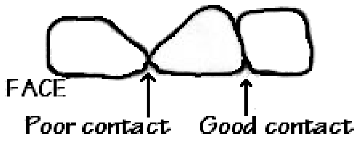

Fig.15. 'Point' contacts should be avoided

Whatever the case there should be some squaring of the inside touching edges even if only a few centimetres. This greatly reduces the risk of pivoting. Good hearting within the internal V shaped voids also works against movement, but overall is unlikely to produce as much as the actual contact of building stones.

Fig.16. Above and below 2 sides of same field walled with glacial stone from field clearance. The top wall is built by trainees the lower wall by a Master Craftsman

Fig Fig.17. Left and right, sections of same oolitic limestone wall built by different contractors

In some instances small gaps are filled with small stones or pins, giving the appearance of tightness. This process is discussed in more detail under STONE PLACEMENT/STRUCTURE : *Pinning.*

Where a stone fails to sit on one below it a "letterbox" results, several can be seen in figure 18. This is often the result of a traced stone bridging three stones which do not quite provide a level surface to build on. In some instances a stone just does not make any contact with the one below, and is called a "floater", as it appears to float over the lower stone as shown in figure 19.

Fig.18. "Letterboxes" and loose stones

Fig.19. "Floater"

Letterboxes are frequently, although not exclusively, created by trying to sit one stone over three, a practice that is often frowned upon for this reason. It can be very difficult to get a 1 on 3 stone to sit on and hold all three stones as it will tend to either rock on the middle stone or miss it completely. For this reason it is advisable to check the solidity of all of the stones under a 1 on 3 stone. Whilst a 1 on 3 stone is not necessarily traced, if they are frequent within a wall it is often a good indicator that stones are being traced. In addition it should be noted that where a 1 on 3 stone is present, any movement in the wall below will result in one of the three no longer being securely held, unless all three move by the same amount. In figure 7 at least two of the stones, the white one and the thin one, are not gripped by the traced stone. Whilst 1 on 3 cannot always be avoided, especially the more irregular or rounded the stone, if it occurs frequently within a wall it usually indicates a poor building process and other faults are likely to be present. Whatever the case you would not expect to see, on average, more than one per square metre of wall face.

(IV) SUBSEQUENT BUILDING

The way stones are placed affects subsequent building. It is no good having a stone that meets all the other criteria but cannot be readily built on. Stones with badly sloping or rounded top surfaces can initially look good but tend to create major problems as they try to shed the next stone placed on them. This aspect of building must be borne in mind during construction. It is usually the case that a difficulty in placing a stone lays in faulty construction one or more layers below. The following are examples:

- Small steps between stones usually necessitate the use of inappropriate undersized thin stones or slivers to provide a level for the next stone (See STONE PLACEMENT/STRUCTURE: *Shims/Plates)*, or result in a stone placed at an angle to the layer, with only one or two points of contact and gaps.

- Acute/obtuse angles between stones can result in inappropriate gaps, or poorly placed stone to counteract the problem.

When building a layer the waller should think of what will follow, like chess each move limits or expands future options. The waller should try to get back to a flat top, making it easier to build the next layer. Good, accurate hammer work can reshape stone and make layering easier, avoiding the need for flimsy shims and plates, which are better saved for use in the top layers.

(V) CROSSING JOINTS

Stones should have a good bond to distribute forces and tie stones together, similar to brickwork. One stone should sit on two, and two on one. The more evenly spaced the joints, the better the wall, ideally (again as with bricks) half on one, one on half. During settlement the stones either side of a joint have less holding them in place than do stones which overlap. Where the stones are set so that there is no bond this is known as a "plumb", or vertical, joint. A plumb joint through two layers is not normally frowned upon, unless they proliferate as is the case in figure 20. They tend to be more common/ acceptable where regular types of stone are used in random walls. The double joints in these instances avoid the necessity of using lots of thin stones (See STONE PLACEMENT/STRUCTURE: *Shims/Plates)* to compensate for small steps, levelling the step in two rather than one as shown in figure 21).

Fig.20. Wall riddled with "plumb" joints

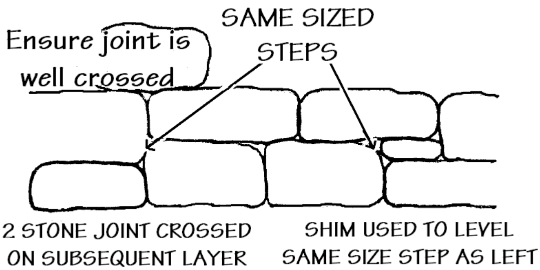

Fig.21. Shims versus double joints

Consequently this might not be a serious fault with this particular type of stone, although you would still expect to see good crossing of joints generally, without grouping of acceptable joints. Two or three per square metre of face would generally be more than enough, with no plumb joints through more than two layers/courses.

Given that this acceptance of plumb joints is to avoid the necessity of thin levelling plates you would not expect to see double joints in a coursed wall, and the jointing in figure 22 is particularly poor. Given the regularity of the stone it could have been avoided with a simple small shift of stones along the course.

Fig.22. Excess of double joints in Permian red sandstone

Plumb joints through three or more layers are referred to as "running joints". They occasionally have regional names such as "galloping joints" and the French have a striking term for this fault "Coups de Sabre"[3], literally blows of a sabre, loosely - sabre cuts or slashes.

Fig.23. Running joint in irregular sandstone

Fig.24. Running joint in regular limestone

Figures 23 and 24 show bad running joints, such joints are a severe weakness, creating a seam in the wall which is likely to widen as the wall settles. The longer the joint the greater the weakness, which *"increases geometrically for each additional uncrossed joint in a vertical line"* [4]. As such any joint running for half the height of a wall is a major weakness, complete joints such as in figure 24, are of considerable concern.

There are some rare circumstances where walls appear to contain running joints, but in fact do not. These can occur on slopes where the wall is built in sections to reduce the chance of catastrophic failure of long sections, and occasionally on flat ground to demarcate ownership/responsibility for repair. In these instances the joint is actually a de facto wall end built with “ties” and “runners” (SEE WALL ENDS), and as such not a weakness.

In some instances where irregular shaped stone is used, an apparent running joint in the face might be broken behind the face, leading to a “false joint” where strength is not really compromised. It is not unknown for builders to claim this of any running joint. However as a defence it would normally only apply to two stone joints, or a three stone joint where the middle stones have the false joint. False joints tend to be rare so you would not expect a running joint to contain two or more false joints. Even if the joint did contain a number of false joints it would tend to indicate a faulty building process. This “excuse” cannot be used as a widespread defence for joints in a wall as a craftsman would be unlikely to keep repeating the “error”.

Masonry (i.e. mortared) walls often contain expansion joints which can appear to be running joints. These are not necessary in dry stone work because the wall should be flexible enough to cope with seasonal movement.

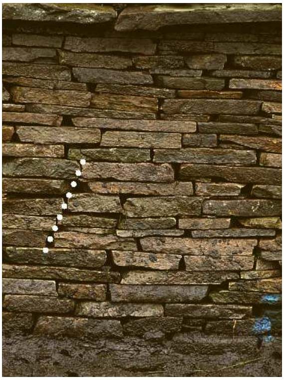

Fig.25. Diagonal running joint (left of centre), in sandstone wall

Fig.26. Diagonal running joint (centre), in glacial fieldstone wall

Not all running joints are plumb. Where several vertical joints are only slightly crossed, with each stone only just lipped onto one below, it creates a poor bond, and can be almost as serious a weakness as a vertical joint. This poor bond gives rise to two other forms of running joint, the “diagonal” joint and the “zipped” joint.

Diagonal joints should be relatively easy to recognise with regular stone (see figure 25). With irregular stone there can be a tendency to see them everywhere, even when absent.

There are several distinct diagonal running joints in figure 26. The key to identifying them is that there are a series of slightly offset joints in one direction; where even allowing for the shape of the stone they barely overlap (see also just right of centre in figure 31). In figure 27 you can see what appear to be diagonal joints. A close look at where the ends of the stones are relative to those below, shows that they actually overlap by a significant amount and so are not in fact a weakness at all. The more rounded/triangular the stone the more you will see these “phantom” joints.

Fig.27. “Phantom” diagonal joints

Zipped joints occur where there is a limited overlap which alternates, and are illustrated on a variety of stone types in figure 28. As the overlap is small the joint sequence is never really crossed. Similar to phantom diagonal joints, if the stones are small or square, with one sitting on half or almost half, what might appear to be a zipped (or diagonal) joint is not. With both diagonal and zipped joints the overlap is limited compared to the size of the stone.

Fig.28. (l to r) Zipped joints in (l to r), glacial field stone, sandstone, oolitic limestone

Neither diagonal nor zipped joints are as serious as plumb joints, however they still represent a serious weakness, generally indicate that the overall walling quality is at fault, and could be indicative of other problems.

Occasionally you will find joints broken with relatively thin or insubstantial stones. There is actually a good chance that these stones will crack on the line of the joint during any settlement and as such in terms of assessing the severity/length of joint their presence should be ignored.

Running joints either side of a stone result in "stacking", where a series of stones are effectively just piled on top of each other, as shown in figure 29 (and notable in figure 31 too), creating a section of wall lacking integral strength. Again the French have a particularly descriptive term for this: “La pile d’assiettes”[5] literally a pile of plates, and describe the practice (with a degree of paraphrasing) as ‘reflecting a serious lack of competence and an unacceptable fault.’[6]

In an ideal world, as noted, beyond sitting one stone on two and two on one you should aim for half on one and one on half. Smaller overlaps reduce the cohesion of the face and so overall poor jointing needs to be avoided.

Fig.29. Stacking in regular shaped limestone

(VI) STONE PLACEMENT/STRUCTURE

Stones should be placed so that they sit securely with a minimum of wedging. Any wedging should be at the back or sides (within the wall, not in the face) only, not as in figure 30. While to some extent this can be assessed after completion, the basic principle that a stone should not be rocking when you try to place another on top of it, can only be assessed during construction.

Ideally longer (into the wall) building stones would be placed on top of shorter ones and vice versa. In this way you try to cross the joints inside the wall as far as is practically possible for any given stone type. This reduces the possibility of two completely independent faces.

Pinning

Pinning can mean several slightly different things, all variations on a theme. The strictest interpretation is the use of small stones inserted, rather than built, into the face of the wall to secure larger stones (figure 30). It is also used where small stones are sprinkled liberally and hence inappropriately, throughout the structure (figure 31). Sometimes it is used to describe any small stones in the face especially where they are ill fitting or loose (as in figure 3). Frequently the pins will pop out during settlement and, since they were securing what was probably an ill fitting or loose stone in the first place, this might be a serious weakness.

Fig.30. Front pinning

To further confuse matters, in some areas the wedging of the tails of stones is also called pinning.

Fig.31. Badly built pinned wall Brora, Sutherland

In much of Scotland pinning has been a widespread practice. The practice here varies slightly from the previous interpretations in that the larger face stones are not reliant on the pins for their stability; the pins only fill small voids in the face, hammered into place once the wall (or a section of face) has been built. Supporters of the practice argue that the pins are hammered in with care so as not to force stones apart, if they fall out the wall is no weaker than it was because stones were not reliant on them for stability, but if they stay in place the wall has less potential for settlement. The key is still to build as tight as is possible and then pin small holes, not just build loosely and pin later, this is just poor workmanship. On balance there seems to have been an over reliance on pinning at times, rather than a concentration on tight building. Consequently pinning nowadays, is more generally frowned upon. If it is present, then assessment needs to consider carefully if the wall is built sufficiently tight.

Plates/shims

Plates or shims, are thin stones used to level off a small step, allowing the placing of the next building stone without it rocking. They are acceptable if they sit well, are firmly held, and do not proliferate. Plates can also refer to large (and fragile) thin stones in a face.

Fig.32. An excess of plates in sawn sandstone wall

If there are many of them in a wall as there are in figure 32, (and this is not the vernacular as it might be with some slates and mudstones), then it tends to suggest poor stone selection and a lack of attention to detail on the part of the builder, pointing towards the likelihood of other problems.

They can also be a weakness and should be checked to see if they are loose. They should be firmly gripped, have good length into the wall, and should sit well. Flat shims on flat stone should not present too much of a problem, however less regular shims, especially on less regular stone, are likely to sit with one or two points of contact. Each of these will be a pressure point increasing the likelihood of the stone cracking and moving. It is then more likely to become loose itself, or to destabilise the stone above, or both. The thinner the shim, or the lower it is in the wall, the less acceptable is its use. Wherever placed they should not extend along the wall beyond the stone they are shimming.

Vertically set stones

As a general rule stones are set flat rather than on edge, with their largest surface forming their base. This facilitates their sitting securely and distributes weight/forces efficiently. A stone set on edge (sometimes referred to as "edge bedded") is easier to displace as it is not well held by gravity and friction. The greater the height of the stone relative to its footprint and the extent to which it runs into the wall, the more unstable the stone, with traced stones set on edge being particularly unstable.

Fig.33. Stones traced on edge. It can be seen that length of pencil into wall is less than if it was held up the face.

Setting stones in this way is a common practice in mortared walling and cladding where the mortar, to some extent, holds the stone in place. As a practice is not generally transferrable to dry stone walling. It is however, a regional practice on Skye where it is often argued the basalt blocks are so heavy they are not easily displaced. This argument is probably only sometimes true, such as when comparing the heaviest of stone with the lightest (e.g. Skye basalt is 50% heavier than oolitic limestone). It is also commonplace in Aberdeenshire walls in order to accommodate large granite blocks. Generally there is not a huge difference in densities of stone type. The relative differences with regard to stone contact and friction are likely to be far greater, and hence more significant. In practice a less dense stone might sit more securely than a dense one. As such it is a practice best avoided. If employed, a good footprint with good stone contact below, with further good contact to the sides and from subsequent building must be achieved.

This aspect is particularly difficult to assess after construction. In the example shown in figure33, even if we could not see the top of the stone, the actual height of the stone is measurably more than half the width of the wall so the is either set on edge (compounded by tracing), and/ or there is a ridiculously narrow space left for the second skin, as in figure 5.

As with traced stone this fault becomes more serious the narrower the stone or the lower it is set in the wall. In general terms it is usually a very serious fault which should be avoided during construction.

Soldiers/book-ends

Occasionally relatively thin stones are set on edge to fill a narrow gap between two stones. Whilst not a generally accepted practice (since stones placed this way are technically less stable than those laid flat), provided the stone is tight with its long axis into the wall it is not entirely unacceptable. There could, however, be implications if the stone has a grain and this is set vertically, as such stones can be more prone to damage through weathering.

Fig.34. A proliferation of soldiers

If the use of these “bookends” is widespread (as in figure 34) it would tend to suggest a generally poor technique, as the waller should not let such gaps keep developing. In this example it is not really helping with the crossing of joints, which tends to be the usual reason for their use. This is similarly the case with those in figure 8, where it actually creates bad joints.

Provided the stone is the right height and is held well from both sides, then a problem is unlikely to occur. This is easier said than done. In effect you face the same problems as with 1 on 3 stones (see CONTACT). There are also considerations with frequency. This is a practice which is probably acceptable every few weeks rather than a few times every day/square metre. It is easily avoided just by ordering the stone better, and points to bad technique.

Triangular/wedge shaped stone

Where any cross sectional part of a stone is triangular this end should be set as the stone`s face.

If the triangular cross-section is set within the wall, weight from above will work on the wedge shape of the stone to force it out of the wall (see figure 35). This can only be assessed during construction, and only then if observed in practice.

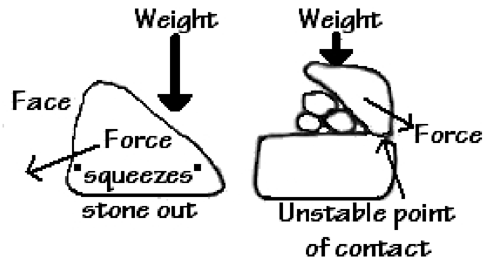

Fig.35. The problem of triangular profiles

Towering/Stacking

The practice of building up several layers on one side before changing sides is a bad practice as it tends to create voids which are difficult to pack (see HEARTING). It also tends towards tracing as it is not really possible to lay stones length in on top of shorter ones. As such a much weaker structure is likely to result, with the two faces far more independent than if the tails of stones from opposite sides frequently interlock.

(VII) <u>SET TO TRUE HORIZONTAL</u>

Generally stones should be set to the horizontal rather than sloping. In keeping the stones flat the gravitational forces are better transferred onto the stones below, helping to bind stones to each other. Sloping stones exert shear forces on stones below. This can serve to open joints or force stones out of line. Similarly building the wall`s layers or courses to follow a slope rather than the true horizontal can mean that the weight of each stone is trying to force it downhill. Hence special care needs to be taken when working on slopes (especially slight ones where there seems to be more of a tendency for wallers to build with the slope).

Where the wall is regularly coursed it might be the only possible method of construction although this rarely applies to random walls. It has been suggested that with coursed walling *"once the angle gets over ten degrees* [about 1 in 6] *it is advisable to lay the courses horizontally"*[7]

Figure 36 shows two sections of the same wall just a few yards apart, but built by different contractors. If the wall on the left wasn't within a 'normal' layered wall it could almost pass for polygonal walling (below). Sometimes, especially with flatter stone poor workmanship can create undulations or waves within the layering. Generally this should be avoided, and unless a deliberate well constructed artistic feature, tends to be indicative of poor workmanship elsewhere. There are some rare regional exceptions to this rule. These include herringbone, slanted

Fig.36. Adjacent garden walls of same stone type, incorrectly set to level in left photo

(Purbeck) stonework, sloped coursing (as noted earlier), vertical stonework, and polygonal styles. Generally these styles should be obviously different to basic random or coursed patterns, and in keeping with the vernacular style. If in doubt consult your local Branch of the DSWA.

The polygonal pattern, however, is worth some consideration here as it can appear at first glance to be poorly built random. It is not unknown fore some to claim that their poor random stonework is deliberately polygonal. However, truly polygonal walling, whilst common around the Mediterranean, is very rare in Britain. As a style it is typified by tight stonework and very few small stones, as shown in figure 37.

From a structural viewpoint, if the whole wall is built polygonally and adheres to all the other "standard" rules, then it isn't a problem. However, it should not be used as an excuse for poor workmanship. If the wall is not tight and has many small stones, it is either a poor polygonal wall, or little more than a badly built standard wall, with a lot of badly skewed stones.

Fig.37. Polygonal wall, Mallorca

(VIII) LINE AND BATTER

Another important consideration is "line" (how straight/even the face is along its length) and "batter" (slope of the face, how even the face is as it narrows from bottom to top). Essentially line is along and batter is up. Paying attention to these is not merely meant to make the wall look good, but will add to the wall's durability and, in stock proofing terms, its effectiveness.

Fig.38. A severe bulge is a fault in both line and batter

Essentially the "A" shape adds to a wall's structural stability; the more vertical a face the more likely the wall is to topple during settlement. Bulges in the face mean that it will take less for the wall to fall down as some of the stones are already effectively part way out of the wall. Irregularities in the line and batter also dramatically increase the likelihood of stock, particularly some breeds of sheep, being able to get over the wall. Dips or depressions in the face effectively mean the upper part of the depression is too vertical, or that some stones are overhanging those below. As can be seen in figure 38 a bulge is often a fault in both line and batter.

Structural integrity should not be sacrificed for perfect line/batter. If a stone sits and fits better only slightly out of line that is fine, provided the overall effect of the wall is straight and even, with no distinct dips and bulges. Unfortunately a good line and batter are often achieved by tracing stones and/or by using stones which do not butt up to their neighbours.

A wall with good line and batter looks even when viewed along its length, with a consistent slope from the foundation stones to the cope (figure 39). Throughstones and cover-bands will look even along a distinct line. If the wall does not look even then you should be closely scrutinising the rest of the work.

Fig.39. Good line and batter

Even if a wall is perfectly flat and straight, it doesn't necessarily follow that one or both of the line and batter are actually right. If one side slopes more than the other it is likely that the batter is wrong on one side – or both. There are some regional and technical exceptions to this, check with your local DSWA Branch. Also if both sides have the same batter but the wall is wider at one end than the other the line is wrong. If a wall has different batter at either end on the same side then the batter is wrong.

Worrying about this can seem a little finicky; however the ideal, strongest, wall has a perfect line and batter. A running joint is a fault, so is a lopsided batter. In practice small variations are of little concern, and the most important consideration is that the batter is consistent.

A good waller will keep discrepancies in line and batter to nearly zero. Faults here can stem from bad placement of stone, poor foundation, compensation for traced stone etc, basically from breaking the building principles detailed in the earlier part of this booklet.

In some respects having a good line and batter is important in the long, rather than short, term. If a wall is built straight and flat in the first instance then you can tell if it is moving/settling over time. If a wall is well built you would not normally expect to see any significant change for many years. If it is badly built and is going to be a problem, then the development of bulges will be the first sign you see, other than an actual collapse. In terms of maintaining a wall you can only accurately assess if a problem is developing, how bad it is and whether or not remedial action is needed, if its shape was consistent in the first place.

Wall Dimensions

There are several inconsistent formulae promulgated for wall dimensions[13]. In practice dimensions will be affected by local traditions and the stone type.

Walls with large foundations stones have to be built wide enough for these to fit together. In addition, generally the larger the stone the more vertical the wall has to be in order to avoid steps in the batter. Similarly squarer stone tends to need a more vertical batter. The net result tends to be wide bases, limited batter and consequently a wide top which in turn can lead to coping problems (below). Generally with this type of stone the footing needs to be as narrow as can reasonably be achieved without necessitating lots of tracing, with the wall battered as much as reasonably practical with the specific type of stone (whilst not creating steps which sheep could use to climb the wall).

Batter is most properly referred to as a ratio, such as one in eight - written as 1:8, which means for every 8cm in height the wall batters in 1 cm on each side. 1:6 is arguably the most common batter, 1:10 is generally as vertical as it gets, outside of very flat stone which might be built to 1:12.

Technically longer stone can be built with a more vertical batter, as can flatter stone, with the converse also true - so shorter and/or more rounded stone needs more batter.

Overall wall height also has a role to play. It might be appropriate to batter taller walls more for a given stone type as it is certain that the lower a wall (all other things being equal), the less likely it is to fall down. Hence in the Cotswolds, where many walls are traditionally quite low and the stone if not traced lends itself to a more vertical structure, the walls tend to be built with a batter of around 1:10.

A small deviation of a few centimetres from batter is often dismissed as irrelevant. However it can be a significant change with serious implications on overall stability. The more vertical the batter the more significant any variation as it is a greater proportionate change than for more battered walls. If a wall is specified to be about 1:12 (just under 5° of batter) and is built vertical it is obviously a serious mistake. The error however is essentially the same as if building a wall which should be around 1:6 (just under 10° of batter) at around 1:12.

For most walls something around 1:7 is acceptable, a little either way likely to be of little significance. The more vertical the wall the more thought/questioning of how appropriate the batter is, is required. A batter less than 1:8 should be questioned, with less than 1:10 requiring very reasoned justification.

The simplest way of measuring the batter on walls on inspection is to mark a spirit level 80cm from one end. Hold it vertical against the footing (avoiding dips and projections) and measure in from the mark (that is 80cm above ground level). The face stone should be around 11 or 12cm (around 1:7) from the level, ideally no less than 9cm and certainly no less than 8cm (1:10), unless of course that is the specified batter.

HEARTING

Hearting, often called "packing", is the small stone used to fill voids in the centre of a wall. By filling the voids it reduces the potential for movement of the face stones and the possibility of the wall falling in on itself during settlement. It is particularly important in preventing the movement of any wedges stabilising the tails of the building stones. It should progress alongside the placing of building/face stones, avoiding voids and the serious problem caused through not placing enough hearting before placing longer stones onto the wall, so that whilst the very point of the tail might be wedged and hearted, voids are still left under the stone.

Fig.40. Voids were left as wall was built.

The hearting should be thoroughly packed in, not thrown or shovelled in, and placed in a way that minimises gaps or voids. This can be one of the more time consuming aspects of wall construction, but it is easily skimped on as it cannot be seen from the outside. Its importance in the long term should not be underestimated: as the wall settles the hearting is integral in preventing the collapse of the wall. It needs to be placed as each layer progresses, so that the tails of stones are not sitting over voids which cannot then be filled adequately, as in figure 40. The largest stone possible should fill any given gap with as much contact with the building stones as possible. In turn any remaining gaps are then with the largest stones that fit.

Individual hearting stones should not be loose, nor get in the way of subsequent building. Angular stone is best as it binds better than rounded pebbles. Small round fill is generally a bad idea since if it gets under a face stone it can act like ball-bearings making it easier for the stone to be displaced. It should also be set essentially flat and not on edge where, in extreme cases, it can act as a wedge pushing out the face stones when weight is applied from above. The use of small gravel and stone, or fines, is unacceptable. In the long term it is likely to settle more than substantial stone leaving voids and, as with rounded stone, its granular nature can act similar to ball bearings if it gets between stones. This considerably reduces stability speeding up some of the processes involved in the degradation of all walls.

Whilst this is another internal aspect best assessed during construction, following completion if you squat and look directly at the face you should not be able to see any daylight through the wall since this means that at that point there is no hearting. It is worth bearing in mind that not being able to see daylight does not necessarily mean a wall is well hearted especially if the face stones are reasonably tight and of smaller stone. For daylight to show you obviously need two gaps opposite each other (i.e. lining up) and also no hearting between them.

Sometimes a wall's inside can be so well built in places, in terms of stone contact and interlocking of faces, that it is difficult to fit hearting in. This is largely dependent on stone type, and can be a particular problem with larger and/or squarer stone. Whilst the resultant lack of hearting is a fault, it is not necessarily a major one The tightness of the interior and consequent reduction in the potential for movement arguably compensates for it. In the foundation this tightness is normally seen as the ideal (unless there are specific drainage requirements), although here it rarely causes problems with hearting. As an excuse for a lack of hearting it is only really acceptable if it is sporadic, and only if the wall is obviously otherwise well built.

In 2007 Bath University carried out experiments to examine how retaining walls reacted when subjected to certain loads[8]. As part of this experiment they tested various grades of building, the quality was in part measured by the amount of stone used for a given volume of retaining wall, with a less well built, looser, poorer hearted section containing less stone and more air. Built from Cotswold limestone with generally good stone contact, whilst the poorer walls did have looser faces, empirical observation suggested a significant amount of the decrease in stone was in respect of hearting, and the care taken with its placement. The initial, extremely well built and packed wall, proved very difficult to destroy. The subsequent poorer sections reacted and bulged far more dramatically. However the decrease in stone/ increase in air, was only a few percentage points. This would seem to suggest that a small increase in tightness and hearting makes a considerable difference to strength. This might have particular implications for less regular stone where the voids between stones are greater and more difficult to fill. A glimpse of daylight every few metres might be little to worry about, but any greater frequency and you should be questioning how well hearted it is as a lack of hearting is a very serious weakness.

FOUNDATIONS

If the foundations do not settle or move significantly, there is limited scope for failure of the wall. It would seem to follow that most wall failures are at least in part the result of movement in the foundation. Given this, inspection of foundations can be critical, it is impossible to assess them once the wall has been built.

In new walls the foundation (or "footing") should be laid in a levelled trench, with all vegetation and loose soil removed, down to firm ground. Where there has been a pre-existing wall the trench may only need to be 10-15 cm deep. Otherwise it might need to be 20 cm or more.

Whilst there is a presumption that the largest stones are used in the foundation (see GRADING) it should be noted that surface area in contact with the ground is more important than sheer volume. Whilst a large blocky stone might make a good footing a thinner stone with a greater footprint is likely to be better (depending on how easy it is to build opposite and alongside).

Fig.41. Flat/level, interlocking footing

Each stone should butt up tightly to its neighbours. The foundation should be an even width along the length of the wall, with as level and flat a top surface as is practical with the available stone (as figure 41).

Tracing can be a particular problem with foundations as traced stones are more likely to tip, as are shorter stones in general. If there is a need to use shorter foundation stones, then these should be matched with longer stones on the opposite side of the wall as can be seen in figure 41. Runs of a number of short stones next to each other should be avoided. Any gaps should be well packed with suitably sized stone (see HEARTING).

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Each foundation stone should sit solidly, secured with stone wedges rather than compacted soil. If you are inspecting the foundation during construction then none of the stones should wobble when walked upon, and stones should not move if (reasonable) weight is applied to their outer edge.

Each stone should sit on its largest surface (large flat surfaces are less likely to tip or move), and as noted, the resultant surface of the footing should be as flat as possible. This will of course be partly determined by the stone size and shape: irregular stone will make a more irregular footing and boulders will lead to steps.

If the steps are small, they can be brought to even height by digging the taller stones into the soil. This is preferable to using too many thin building stones to level the foundation course. This is also the best method for using irregular stones. The trench can be excavated to accommodate irregularities rather than using a profusion of wedges. A stone set properly on dug out ground should be more stable than a stone held in places with wedges.

If an old wall is being repaired, the foundations should be reset if they have moved or tipped. Many collapses of old walls are the result of uneven settlement of the foundation, yet all too frequently the original foundations are not removed as this is usually the single most time consuming aspect of rebuilding. The result is that the problem is merely covered up rather than rectified. However, if the original stones are solid, do not slope and are not significantly projecting from the desired line, it can be best to leave them in situ, as it is far from certain that once moved they will be as solid.

In some areas the foundation stones project by a few inches beyond the main body of the wall in what is known as a scarcement (or scarsement) as shown in figure 42. This is a regular even coursed ledge rather than just the use of oversized stone which are not in the correct line as is the case in figure 43. A few extra inches of width on foundations spreads the weight over a wider area. This decreases settlement on soft ground, but requires good, flat stones.

Fig.42. Wall with a scarcement

Fig.43. Original boulders left in situ and out of line, providing springboard for sheep

Fig.44. Inappropriate footing set on edge

Another regional variation is the setting of extra large stones, on edge. This can be particularly unstable and as a technique should only be used where the local vernacular is specifically being retained, and then only sparingly (not as shown in figure 44, where only one stone is not on set on edge). Such stones should ideally be set into the ground by half their height or more, have a good footprint and sit on solid ground. Thin stones set on edge rarely stay upright unless almost entirely buried.

On slopes it is necessary to step the foundation in order to maintain setting to true horizontal. Depending on the angle of the slope and the size of stone, this will either need to be a series of short stepped platforms; or a sequence of steps, often necessitating the sitting of one foundation partly on another. The less regular the stone the more likely such stones will rock. All the basic principles for a standard flat foundation apply. Care needs to be taken with levelling the steps for subsequent building and inspection should particularly note the tendency for bad joints to develop, and/or the inappropriate use of shims.

In some parts of the world the foundation is set on a gravel/small stone sub-layer. This is rare in Britain but does occur in some areas for example where ground water is prone to flow under or through the wall, or where new walls are being built up on made up ground (especially clay). Generally this consists of a 10-15cm. layer of something similar to “MOT Type 1” granular sub-base (c.40mm to dust, or “washed” if water flow is required) and should be mechanically compacted. Specific advice should be sought as to exact specification and appropriateness if such a sub-base is being considered.

THROUGHSTONES

There are a range of local terms, such as “thruffs”, “binders”, “throughband”, for single stones which completely traverse the width of a wall, connecting the two faces. More generally they are known as “throughstones” or simply “throughs”. This tying of the faces helps prevent bulging during settlement, notably where the building stone is quite small resulting in two independent skins separated by a band of hearting. They also maintain *"the wall`s equilibrium by distributing the weight of the upper layers equally onto both faces below"* [9].

The style and spacing of throughs varies from region to region. In many areas they project from one or both sides of the wall, in some areas (as seen in figure 45 they are set flush with the face. In many areas they are spaced, but in some they form complete rows, with each subsequent stone butting against the previous one. As usual the local style should be duplicated.

If spaced, they will normally be at regular centres of about a metre. That is they are spaced at regular intervals measured from their centre line across the wall, rather than the space between them. If spaced further apart they will do little to tie the faces of the wall as a whole. If available in sufficient numbers they can be spaced closer, although structurally it is best if they are still at regular intervals. If one row is employed this should be around half way up. For taller walls (over 1.2m plus coping) there should be 2 rows at about ⅓ and ⅔ height, with the centres staggered from the lower to upper course. Whether you take the height of the wall as before or after coping makes little practical difference, except with lower walls with a taller cope, where the measure should be below the cope.

Fig.45. Regularly spaced flush throughs on a slate wall

Where throughs project they would normally all be at the same height. However, the fact that stones protrude from a face is not a guarantee that they are actually throughstones, as it is not unknown for building stones to be deliberately poked out to maintain a pattern of throughs. This can only be detected during construction unless particularly badly done (e.g. the stone can be moved).

The projection should only be around 5-10cm. If throughstones project too much, stock, especially cattle, can rub on them and the leverage is likely to cause problems in the wall.

Where the practice is to set throughs flush with the face of the wall they would still tend to be all at about the same height, provided the stone is workable. For stone which doesn't dress well - such as harder stone (granite) or stone which shatters (some slate, shale and mudstone for example) - there tends to be a little more variation in positioning with each stone set at a height where its length matches the width of the wall. In these instances care has to be taken to maintain some sort of regular spacing. Those placed particularly high or low in the wall should be discounted in terms of any pattern as they are best regarded as long building stones rather than throughs. Given the irregularity in spacing it is best to try and incorporate more than one per metre if available, and it is important to avoid bunching them in groups rather than sprinkling them liberally through the wall.

All throughs should be set at right angles to the face. If not and there is settlement with the potential for bulging, then there is a good chance they would pivot and not actually tie the faces until after the wall has bulged and they are at right angles. An angled through is better than nothing, but it is a far from ideal and with a little care can be easily avoided.

They should also be set level; otherwise they will act like a slope shedding the stone set on them. Care has to be taken to ensure that all voids under the stone are well packed: this tends to be a particular fault associated with "slabbier" throughs. Another problem with these is getting them to sit securely on all the stones under them (similar to the problem of '1 on 3' seen in CONTACT). They should hold all stones securely and not be front pinned. Where the throughs form a continuous band they should interlock with their neighbours ensuring that there are no gaps at the face where building stones are not gripped.

Throughs are not always available in walls. Where this is the case care should be taken to ensure that ¾ "throughs" are regularly used, and care needs to be taken in their selection and placement.

Also known as a "horizontal key", "interlocking headers"[10] or "galf stones" (northern England), ¾ throughs technically come in sets of 3 where the tail of one stone is held in a "pincher grip"[11] by the tails of two stones on the opposite side of the wall, as shown in figure 46. This method however does not work well with thicker stone as the top stone of the triplet tends to be too far up the wall to be either practical or function particularly well with regard to pinching. In the triplets the top stone also serves to hold the smaller stone used to build around the tail of the middle stone, and can afford to be a little shorter than the others thus allowing space to build around it.

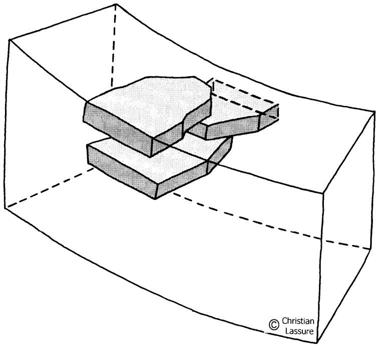

Fig.46. Illustration of horizontal key showing tail *"held in a pincher grip by the tails of two headers"* laid in opposite face. By kind permission. Christian Lassure *"Building a drystone hut: an instruction manual"*. 2nd Edition, C.E.R.A.V., 2009. p.15

The problem of building around the tails means that the length of ¾ throughs is fairly critical (see figure 47). Structurally they must exceed half width by some margin, but if they go too far their far end is difficult to build around without compromising the integrity of the opposite face. This is slightly mitigated in the case of more pointed stone such as the Caithness sandstone seen earlier (LENGTH INTO WALL). Apart from this case it is probably better that they are slightly shorter rather than longer. ¾ is essentially the ideal compromise length and a three quarter through should be just that, not a six tenth or nine tenth through.

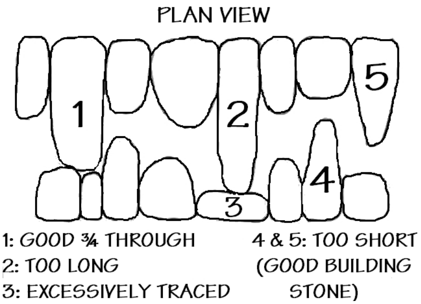

Fig.47. Appropriate and inappropriate use of stones as ¾ throughs

Just as with standard throughs the spacing of ¾ throughs should be planned and regular.

A single stone stretching ¾ across the wall is not a ¾ through; it is just a long building stone. ¾ length stones set next to each other are better than nothing, but do not really constitute ¾ throughs. Again they are essentially just good building stones. In order to create sufficient friction in order to bind, the stones need to be set on top of each other.

Where tracing is an accepted practice (see LENGTH INTO WALL) then correct structure, that is good usage of the space opposite the stretcher plus ties on the traced stones, will create a lot of de facto ¾ throughs. You would expect the wall to have 5-10 tie stones per square metre of face (depending on thickness of stone), but you would still expect regular throughs. To help compensate for the stretchers, the throughs would normally be more closely centred along a layer/course with the gap between courses also reduced. Generally a maximum of 75cm centres, with a course every 30/40cm.

With some stone types, larger boulders or long triangles, the natural structure of the wall when correctly built, results in a lot of individual stones stretching more or less ¾ across the wall. The natural consequence of this is numerous ¾ throughs essentially by accident rather than design. In these walls there is much less emphasis placed on planning the throughs or ¾ throughs. This is fine provided the wall is uniformly well built using stone length in. Again there is no substitute for inspection during the building process.

COPING

Known as*, inter alia*, “cams”, “tops”, “toppers”, “copes”; the coping stones are the wall’s top stones and serve to seal the top of the wall, holding the final layer of each skin in place, binding them together.

Many styles and regional variations of coping exist (a reasonably comprehensive description of which can be found in BTCV’s *“Dry Stone Walling.”* [12]) As a start you should be able to compare the coping on the wall being built with that of the surrounding area and/or consult with the local Branch of the DSWA if you have any queries – there are often many variations within a small area, so deciding what is appropriate often requires a local expert. Most forms comprise upright stones, occasionally slabs are set flat on the wall top. These are generally known as covers and in many instances the vertical stones sit on a horizontal cover.

At risk of over generalising, the following principles would apply to most types of coping. Provided the top of the wall is narrow enough and the coping stones wide enough (which should not be too much of a problem with a new wall of suitable stone), then each stone should sit securely on top of both faces. Stones should not be simply piled on top of the wall (as seems to be the case in figure 48). Each stone should sit solidly on its own base, the top layer of both faces of the wall and fit tightly, each stone placed to maximise contact with its neighbours in order that they lock together. Irregular stones make poor coping. The extent to which the coping stones are subsequently pinned or wedged varies considerably, depending on local practice.

Fig. 48. Ill fitting, gappy coping.

In many areas the gaps between the tops of stones are wedged/pinned to help lock the cope, with care being taken not to force the stones apart (this should not be able to happen if the stones are well placed in the first instance). Sometimes any gaps on either side of the coping are wedged to help secure the stones, reducing the potential for movement during settlement, again taking care not to force the stones apart. In some instances a lack of wedge stones results in this being neglected. In areas where this pinning is the norm neglecting it is only really acceptable where the stones have very good complementary fits, and should not really be the case with new walls, since wedging is normal practice and stone ought to be provided for it. The absence of pinning in the coping tends to occur more with more regular coping (often sandstone and gritstone walls), and in areas where the stones are set at an angle. Here each stone sits on, and securely holds, its neighbour.

Most coping styles follow a pattern, such as a relatively level top, or sometimes random styles where there are taller and shorter stones regularly spaced, sometimes alternately as in Figure 3 (right hand picture). Even in random patterns you would not expect to see groups of shorter or taller stones. A distinction can be drawn between such random coping (even where the tall and short stones alternate), and more formalised alternating or “castellated” copes, where the tall stones are of a fairly uniform size as are the shorter spacing stones, and “buck and doe” copes where heights are reasonably uniform but thickness varies. Most walls when originally built would have had a cope that resulted in a reasonably regular top line when viewed from a few yards away. The fact that many walls in an area would not appear to have been built this way is due more to subsequent settlement and movement, rather than the original building. Figures 11, 12(left), 17, and 22 show particularly good coping, whilst figure 10 (both examples), shows particularly bad coping.

When rebuilding an existing wall, whilst the original cope stones might have gone, it is usually possible to find sufficient replacement from within the wall. With collapsed walls they need to be carefully retrieved and sorted from amongst the stone pile. If a wall is being dismantled and rebuilt, the original coping should have been added to with replenishments selected from within the wall to replace damaged and smaller stones. An indicator of good practice is the laying out of cope stones in a row before building commences. This can be time consuming, and selection of larger stones from within the wall can then slow the actual building process as smaller stone is used in the reconstruction. However, a poorly coped wall is of little use: if the coping stones become displaced there is nothing holding the top of the two faces of the wall together. Stones inevitably come off the wall (livestock accelerates the process) and so a compromise in building stone quality has to be made, unless there is a ready source of replacements. If stone is imported to replenish the cope it is usually best, aesthetically, to mix the new stone in amongst the old rather than construct whole sections from new stone.

A common fault with poor rebuilds is to "wall in" a lot of the potential copes as they are usually useful, easy to use building stone. This can be seen in figure 3 (left hand example) where it would appear that the coping has been formed by little more than piling whatever was left over from the building process onto the top.

Fig.49. Good 'double rubble' coping left, poor rubble coping right.

In some areas the coping is just rubble which does not stretch across the wall (as shown in figure 49), or rubble placed on covers or half covers (found on wide walls where each side of the wall has a smaller cover roughly extending half way across the top). However a proper rubble coping should not just be the leftovers piled on the wall top. Essentially it consists of smaller stone which should still be set to a good line with each stone complementing its neighbour, and wedged together. It will often not span the wall so it usually requires two rows (often only one if set on a cover), usually alternating larger stones on opposite sides, interlocking the tails wherever possible. This type of 'double rubble' coping requires quite a wide topped wall. For example, if the rubble is around 20cm high then the individual stones need to run more than 20cm across the wall to have any degree of stability. So a nominal 20cm rubble top would normally sit on a wall at least 45/50cm wide at the top. Most cope, including rubble, is still best set using a line, this ensures stone is used to its best advantages (e.g. not sitting shorter stones in dips). The line does not need to be strictly adhered to but the effect should be to produce a relatively 'crisp' line to the top/tallest stones when viewed from several yards away.

Fig.50. Poorly structured and poorly fitted rubble coping

Figure 16 (bottom) shows what can be achieved with double rubble, whilst figure 16 (top) is acceptable, and figure 50 shows a front view of part of the wall shown in figure 49 (right) and is totally unacceptable. Whilst all rubble copes essentially use leftovers, the careful selection and setting aside of some good longer stones suitable for helping to key and lock the whole, coupled with resisting the temptation to use up every flatter stone for building, can make a great difference to quality.

On many walls the coping is set centrally: that is, on a 40cm wide wall a 35cm cope would be set with 2-3cm of wall top beyond either end; a 45cm cope would either be trimmed to 40cm or projected equally on both sides dependant on local practices. Where the wall top is wider than the majority of copes this is usually indicative of an overly vertical batter. However, in some areas the nature of the stone results in walls too wide for a single cope, but not wide enough for a double cope (similar to double rubble, but with full sized copes). In these instances the stones are normally set to one side of the wall. This is generally the lower side if one exists. They often project by 3-5cm to improve stock-proofing and create space for additional stones on the back. The back is then filled with large wedges/small copes. With these walls the levelling stones on the back, should ALL be good headers in order that their tails are still trapped by shorter copes. Longer copes should not be grouped as this leaves little space for wedges, they are better spaced apart providing keys for the wedges/small stone. Whilst the copes should still fit well it is not uncommon to allow for them to splay a little and then fit slightly longer stones than the norm in from the back, facilitating keying.

In some areas a “coverband” sits between the top of the wall and the coping (as can be seen in figure 22, although they are often more regular in size). The same basic rules apply for their setting as for throughstones. These “covers” completely span the wall top, often with a slight projection, binding the faces. They can facilitate the setting of shorter copes which would not otherwise span the whole width. Where the covers vary in thickness they facilitate the creation of an even topped, vertical cope, through the use of copes of varying heights. Some walls have a “slab cope” similar to a cover but without the associated vertical stones. Depending on local practice, both slabs and covers may either be set to create a level top or set on a levelled wall irrespective of their own thickness. In either case the same principles as apply to slabbier throughstones apply here

All coping stones should be checked by trying to gently rock them from side to side and front to back. There should be no movement. Rubble coping needs to be treated more gently as in most instances it would not be overly difficult to exert enough pressure to move the stones however well laid. There should however be no discernable movement under reasonable pressure. A similar principle can be applied to taller copes, or bucks with small does, where leverage can again make it relatively easy to loosen them. When testing the coping care should be taken as there is a risk that dislodging a cope on a badly built piece of wall, will bring the wall down.

RETAINING WALLS

These are walls (built across slopes) which support or protect earth banks, and the structure will vary depending on stone type and local traditions. Smaller stone should always be used to form a double skin wall that is essentially free-standing in its own right. A distinction needs to be made between these and those where the wall is built with a good outer face and a rough second internal skin, in effect very well organised large hearting. Larger stone, and stone which has greater length into the bank, is frequently used to form a single skin wall.

Generally the same principles apply to the stonework in retaining walls as for a free-standing walls, however as they are by their nature more structural than free standing walls, faults tend to be regarded more seriously. In particular there can be little excuse for tracing of face stones as not only is this questionable in structural situations, there is generally more space for the building stone, and little stopping every stone being lain as a header. With doubled retaining walls there is less emphasis placed on the internal skin and more tracing is generally permitted on this face as they cannot slip out.

Considerable care needs to be taken with filling behind the face of the wall. Where there is a back skin of stone any soil filling behind this should not be compacted as it can impede the free flow of water. In areas where soil is present within the structure it is important that it is kept off the building stone ensuring good stone to stone contact. Ideally there should not be any soil in the hearting and it should certainly not be used to form the basis of the fill. In some single skin structures it does form the basis of the fill, and in these instances should be well compacted as it is part of the structure, although this has implications on the free flow of water.

It is usually the case that a retaining wall would be built with a wider foundation, and slightly more batter than would be used with the same stone in a free-standing wall. Advice should always be sought on the suitable dimensions where the wall has a structural function.

WALL ENDS

There are a myriad of 'standard' features associated with dry stone walling, within this booklet we shall only deal with wall ends, also known as cheeks and sometimes heads.

Figure 51 shows a standard textbook wall end with alternating runners (stretchers) and ties. Given that the end has to contain traced sone care needs to be taken to ensure a good all-round tight structure and a good key to the main body of wall without running joints, or even two stone plumb joints (see CROSSING JOINTS). Long runners should have tie stones or throughs near their internal ends to prevent pivoting.

Stretchers should run well into the wall otherwise the end stones can be easily displaced as in figure 52. Here it would appear that the problem could have been easily avoided as apparently suitable end stones have been used (and even then, poorly) in the main body of the wall.

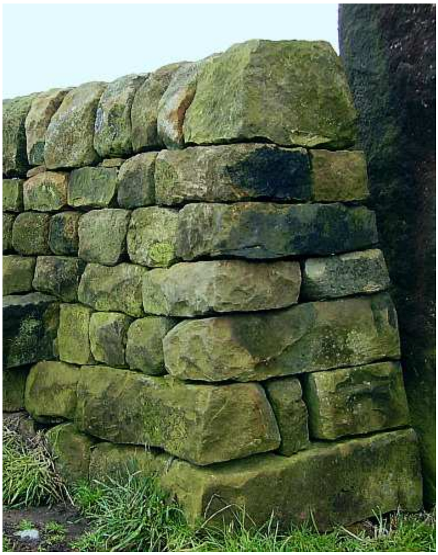

Fig. 51. Textbook sandstone wall end

Fig.52. Poorly tied wall end with a lack of runners/stretchers.

The tie stones should run across the whole width of the end as can be clearly seen in figure 51 and unlike the one half way up the end in figure 53. They should not poke out even in areas where that is the norm with throughs, as they are relatively easily dislodged if rubbed or caught by stock.

The end should be the same shape as the rest of the wall, again unlike the one in figure 53, and also those shown in figures 54 and 56. The runners are far more likely to become displaced if the wall is too vertical.

In areas with a lack of good ties and runners, you usually find "broken tie" ends, where the end is constructed by a series of alternating L shapes, as shown in figure 55. Stone length is always an issue with these types of ends. Running joints must be avoided and good stone contact maintained in order to ensure the stones are held as securely as is reasonably practical.

Figure 56 shows very bad jointing and too vertical a batter. There is very little effective tying across the end or into the wall. The two corners are in effect independent piles of stone.

Fig.53. Poor ties and batter in wall end

Fig.54. Poorly constructed "broken-tie" wall end

Fig.55. End and side view of reasonable broken tie wall end.

Fig.56. End and side view of badly tied 'broken-tie' end with insufficient batter.

APPENDIX A
CRAFTSMAN CERTIFICATION SCHEME

All internet references correct as of April 2012.

The DSWA recommends that only suitably qualified wallers are employed on projects to which end it operates the only national, graded, practical skill tests for walling - the *Craftsman Certification Scheme*. Current qualifications have been specifically designed in conjunction with Lantra Awards and sit within the Qualifications and Credit Framework (QCF). As well as being stand alone qualifications, they also form the technical certificate for the modern apprenticeships.

Fig.57. Intermediate tests, Derbyshire Eco-centre, Wirksworth

The Craftsman Certification scheme has four levels:

Initial - Able to undertake minor works, having demonstrated their ability to rebuild gaps in free-standing dry stone walls.

Intermediate - Able to undertake most general walling work to a good standard, and have demonstrated their ability to construct a sound, free-standing dry stone wall which includes a cheek-end.

Advanced - A level indicating high technical skill. Have a proven ability to build set pieces of work with an emphasis on finish and quality including construction of retaining walls, curves.

Master Craftsman - A high level of quality and technical expertise. Have a proven ability to produce quality work to a high standard in a variety of commercial conditions including the construction of a full range of features, e.g. steps, stiles, pillars, arches, etc.

The Initial, intermediate and advanced levels parallel the levels 1,2 and 3 of the LANTRA awards scheme, further details of which can be found at www.lantra-awards.co.uk.

Fig.58. Initial Test North Wales

More detailed information can be found in the DSWA booklet *"Craftsman Certification Scheme*" available from DSWA and its branches, and also online at www.dswa.org.uk, and at www.dswales.org.uk. The DSWA also keeps a register of the certification level of its professional members. Printed copies are available from the DSWA and its Branches, details of all professional members are available on line at www.dswa.org.uk.

REFERENCES

[1]Also "Rules are for the obedience of fools and guidance of wise men" Attributed to Douglas Bader. Both retrieved from http://www.g4jnt.com/Notices.pdf 17.12.2010. Various forms of similar wording have variously been attributed to Bertrand Russell, Oscar Wilde *inter alia*

[2] Brooks, Adcock, Agate. "Dry Stone Walling.". BTCV, 1999. p.51

[3] Rouviere. M. "La Restauration Des Murs De Soutènment De Terrasses". Parc National de Cevénnes, 2002. p.28

[4] Brooks, et al 1999. p.54

[5] Rouviere.M. 2002 p.28

[6] Rouviere.M.2002. p28. Literally "l'empilement systématique des pierres alternance de joints coupés reflète un manque flagrant de compétence ce défaut est inacceptable"

[7] See Mundell.C, McCombie.P. F., Heath.A., Harkness.J. and Walker.P. "Investigation of bulging, bursting and toppling in dry-stone retaining walls" in *Stonechat 18.* Summer 2009.
See also http://www.bath.ac.uk/ace/dry-stone-2/ retrieved 19.12.2010

[8] DSWA. "Dry Stone Walling Techniques & Traditions". DSWA, 2004. p.67

[9] Brooks et al, 1999. p.55

[10] Lassure. C. "Building a drystone hut: an instruction manual". 2nd Edition, C.E.R.A.V., 2009. p.15

[11] Lassure.C. 2009. p.15

[12] Brooks et al, 199. pp.132-139.)

[13] Whilst several attempts have been made to give a basic blue print for the dimensions of a dry stone wall by and large these lead to confusion. It is widely promulgated that the base width should be twice the width below the cope. Occasionally this is taken further:
"The base width should be twice the width of the wall measured immediately beneath the copestones. By adding these two widths together you can get an approximate measure of the height of the wall before the cope is put on", DSWA, 2004. P.15
"a general rule of thumb, the base width of a wall should be half its height, measured from the top of the coping. The top width, below the coping, should be half the base width". BTCV, 1999. P.58 (not in earlier editions). A similar formula is promulgated by Dr.P.Jarvis in "Dry Stone Walling on the Ffestiniog Railway". 1993, p.8.

The two 'formulae' actually give markedly different results; the first is 1:6, the second around 1:8 although it will vary for every wall depending on the height of the coping. (This would of course not be the case if height was measured from base to below cope when it would always give 1:8).

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"STONEWORK" is also available electronically in the "Standards" section of www.dswales.org.uk where an expanded photo gallery of examples of faults can be found.

S.Adcock. Cover,3(both),4,7, 8, 9(both),12,16(both),18,19, 20, 22, 24, 25,26,27,28 (left), 29, 30, 33 36(both),37, 38,39, 41, 43,45, 48, 49 (both), 50, 52, 53, 54, 55, 56, 57, 58

N.Aitken	1 (left), 31	K.Blackwell	1 right,6, 17(both),28(right)
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R.Tufnell	42	T Wragg	10(both),

Thanks to all those who submitted photos included on the website but not in this publication.

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