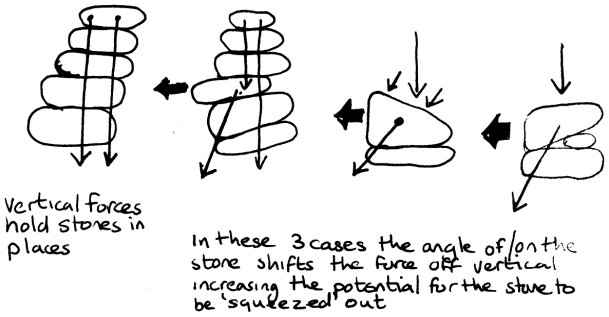
Masterclass: settling the argument.

I was recently asked to comment on the efficacy of/necessity for a cover band, in any situation other than on a wall for which you have either insubstantial or insufficiently wide copes to span its width, and whether or not they actually make a wall stronger. So I started thinking, and eventually my cogitations quite literally settled.

Settlement

I would argue that in order to understand walling it is necessary at least to have a grasp of what's going on in the process of settlement, so to start by simplify greatly… Each stone exerts a downward force dependent on its mass (weight x gravity - strictly speaking acceleration due to gravity). Stone is held in place by the force on it (essentially weight and gravity) and friction. As long as the force remains downward stones remain in the wall. To be displaced a sideways force greater than the downward force has to be exerted on the stone. This can be an outside force such as a rampaging cow, or the internal downward forces being translated into lateral forces through angles or tipping. For example a stone sloping into or out of the wall can lead to a partial translation of this downward force into a sideways one, and hence the stone has the potential to be displaced. Without a sideways force it CANNOT be displaced.



The way stones combine creates a line of thrust and as long as this stays within the wall, the wall stands up which I don't have the time or space to go into here, but is well covered in "Stonechat 10" (Available at £1.50 or viewable at http://www.dswa.org.uk/north-wales-g.asp).

As the forces are downwards all walls will almost inevitably settle to some degree, although this might be minuscule. Thus all the basic principles of building from setting stones flat, maintaining batter, running axis of stone into wall, tight face, good hearting etc., play some role in maintaining the maintaining equilibrium of the forces in play. So most of what we do when walling is done to mitigate the effects of gravity and settlement. Essentially good building reduces the potential of stones to move during settlement and keeps the forces in line so to speak. To expand a little, as a wall settles the stone moves. If the wall is tight (close fitted stones) there is less scope for movement (and settlement within the wall) and increased friction through contact means there is less chance of displacement. Good fits within the wall similarly reduce the potential for movement and increases friction. Placing stones length in means that any movement during settlement is less likely to displace a stone, if there was no movement then the fact that a stone was traced wouldn't matter, if it's not moving its not falling out. Hearting holds wedges in place, so they cannot move destabilising the building stones, it also reduces the potential for movement of the building stones. Throughstones distribute loads so that settlement is likely to be more equal on both faces; they also reduce the potential for the two faces to move away from each other. Similarly crossing of joints helps distribute the load evenly within a face so that individual stones do not become loose and subsequently displaced during settlement exacerbating the process. The `A` shape also helps distribute loads more evenly (see *"Stonechat 10")* and reduces potential displacement in that bulges are already partially displaced (as are overly vertical walls) as are the stones above depressions.

A wall can settle principally in 2 ways:

Sinking into the ground

Movement of stones to close gaps. (Unless every stone fits perfectly with every other stone there is in the very least potential for movement)

Assuming a wall is well built, with stones sitting well on those below them, the greatest potential for settlement is the ground. The amount of settlement will depend on the weight of the wall and the relative softness of the ground compared to the wall (i.e. if the ground is as hard as the wall (bedrock) the wall can only settle in this way if the stone itself is compressed which is incredibly unlikely, so this is not really a factor. As an aside in order to be crushed under its own weight a wall would need to be well over a mile high.

Foundations

This is why footings/foundations are so important. At its simplest large flat based stones distribute the load of the wall better, reducing potential settlement. However if we were able to take a given piece of well built wall and move it from site to site differences in settlement would be determined by the differing ground conditions. This fits into the debate on how deep footings should be dug, to which there is of course no easy answer. At one end bedrock means the wall cannot settle (except within its actual stonework) at the other freshly dug soil contains a lot of air and is easily compressed, and the wall will sink and move. Similarly sitting a wall straight on turf will kill the turf and its root matter, this will decay and the wall will settle.

So ideally all walls should be sat on (flat) bedrock, but as with everything else in walling we have to compromise, so the answer as to how deep is, until a suitable substrate is reached. Unfortunately there is no definitive answer as to what a suitable substrate is (unless we always excavate as far as bedrock) and hence no definitive depth.

A corollary of this is that we do need to be wary of made up ground unless it is highly mechanically compacted. This is probably a good point to consider heresy. If flat bedrock is best, why not recreate it? Personally I like the idea of setting walls on a concrete strip footing; I've done it a couple of times. If the footings can't move and you do a good job with the building little can go wrong. Even if you do a bad job with the building there is much less that could go wrong than would otherwise be the case.

As an alternative to concrete on another site (made up ground, clay) we used 15cm of MOT type 1 (granular sub-base 40mm to dust) on Terram. This was mechanically compacted 10 years on there had been no obvious signs of movement whilst part of an original wall on the site was dismantled and rebuilt (the footings had tipped) with resetting of footings and increased height. The footings were set directly on the `disturbed` clay and it subsequently collapsed in 2 places.

Differential Settlement

Settlement is the enemy of wallers. However if a length of wall settles uniformly the internal forces will remain in equilibrium, the wall might sink into the ground up to its coping (I've seen uninterrupted lengths of wall dropping a foot or more in height across boggy ground, presumably having sunk but remaining a cohesive unit) but it doesn't necessarily fall down. A wall falls down when different parts settle at significantly different rates (in this respect stone displacement is just excessive settlement of a single part of the wall). This is differential settlement.

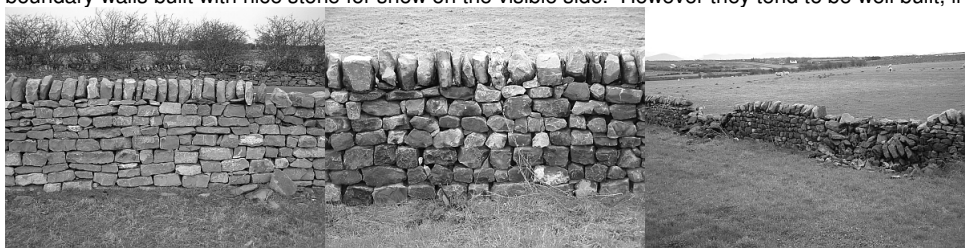
So when the lateral force exceeds the force holding a stone in place (vertical force and friction) it becomes displaced (or partially displaced), essentially it is settling more than the stones below and alongside. This can be caused by any one or a combination of factors, such as - poor stone use/placement; the shape of stones; differential ground conditions (i.e. soft/hard spots), etc.

This has implications for the overall internal structure of a wall. Theoretically, to produce the perfect wall we need to distribute everything equally to ensure the whole wall settles in same way, if 2 adjacent bits of wall settle differently then there is the potential of collapse. An extreme example of where this goes wrong is one I have come across in the real, rather than theoretical world. One section of wall had lots of throughs (probably 6 or 7 randomly distributed through a section around 1.5m high and about as long). The piece alongside it didn't have any throughs and collapsed. Whilst this might have been partly due to fact that it had no throughs the actual collapse was more likely facilitated by the fact that the piece with all the throughs could barely move exacerbating (and maybe even creating) the differential settlement.

Throughs and covers from Nortumberland near Haddon on the Wall, the wall below both having settled more than the cover/through. © John Shaw-Rimmington

I have often played with the further heresy that throughstones (which I looked at in detail *in "Stonechat 12"*) might be more trouble than they are worth. They can weaken a wall if grouped as discussed, that is why such emphasis is placed on their even distribution. Unless you have a complete band however (which has problems of its own as outlined in *"Stonechat 12"* and re-visited here later) they must to some extent promote differential settlement. Of course there are so many variables involved that they might just be cancelling out other problems. Where the wall is essentially two skins separated by a band of hearting then they are likely to make it act more as a single entity, but it is important to remember they play a role in distributing loads in addition to their binding function. There are just too many variables to be confident with theories. I don't lose too much sleep if I don't have any, but then I'm never happy when they are absent from walls especially those built from less substantial stone. On balance I tend to think they are for the best, but not the sacred cow that most would advocate.

Another example of an unbalanced structure is this section of the notorious A55 dualling side road improvements on Anglesey. If you try to look past the generally appalling stonework (see next page) the two sides of the wall demonstrate very different structures primarily through different stone size and shape, notably larger in the first photo. Within a couple of years of being built the result was the third photo, as one side peeled away from the other. This is potentially a problem with many estate boundary walls built with nice stone for show on the visible side. However they tend to be well built, if



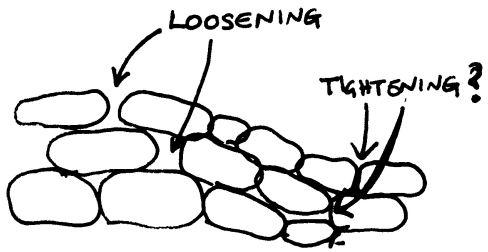
A55 side road wall showing field side (left) and roadside (centre). The joints are striking but the unbalanced nature of the stonework in terms of size, shape and general build probably led to the collapses (right) which occurred soon after completion. All © Sean Adcock

you reduce the potential for settlement you necessarily reduce the potential for differential, whereas the poor overall structure of the A55 wall meant excessive settlement was inevitable and the differential use of stone meant collapse was more a question of when rather than if and as it turned out the when was more easily measured in tens of months rather than tens of years.

Do walls tighten as they settle?

It is often said that walls tighten as they settle; whilst this might essentially be true it is I think a gross over-simplification of the process, and seems to imply that walls get stronger as they settle. If a wall does indeed tighten as it settles the face must have fewer gaps and this only really works if the wall is badly built and there are letterboxes/gaps below stones and/or poor contact between adjacent stones, without these gaps there can be no settlement unless there is lateral movement (i.e. along, in, out) of stones. This lateral movement means the wall's integrity is weakened (unless it was so badly built that the movement have rectified an original problem!).

A further aspect of this is the concept of differential settlement (which we shall look further in due course). If stone `A` to the right of stone `B` settles sideways by a mm more than `B` then the wall to the right of `A` or below `A` might be tighter, however the wall to the left of `A` will be looser. This is `differential settlement` which is what ultimately causes collapses (other than those created by outside forces, cars, bulls, kamikaze sheep, ramblers).



So a wall could conceivably tighten as it settles especially if it was badly built in the first place, however for this to be an improvement the overall shape must be maintained. If there is to be tightening there must be movement and once there is movement this by its very nature is likely to include movement out (likely line of least resistance) or in (if the wall is poorly hearted), and most likely a weaker structure. If the wall maintains its shape and some of it is tighter, some of it must necessarily be looser. If it is looser it is weaker, if a wall is only as strong as its weakest point it is now overall weaker.

A slight tangent to this is the notion of tightness itself which we tend to use as a reference to the walls face, but all walls have an internal structure which has a degree of tightness all of its own (how well the internal faces fit, how well hearted it is). If this is loose especially with regard to hearting. In poorly hearted walls or walls with a high hearting content (i.e. two faces separated by a distinct band of hearting) then the hearting is likely to settle more than the face stones (another form of differential settlement) and the wall collapses in on itself.

If we get settlement out from the face (bulge then the internal structure must be looser, exactly how this works needs further thinking about lateral forces and interaction of face stones such as separation/reduction of contact).

Getting back to the wall collapsing in on itself this might in some respects maintain 'tightness' but not a good wall. Essentially if a wall is built with no hearting it could conceivably tighten into a pile of stone on the ground! You can reach a point where the term `tightness` actually has no relevance.

Should we build gaps higher?

Another idea I have seen touted is that gaps should be repaired proud of the adjacent wall. In my not so humble opinion in most instances this idea is plain daft.

If the footings are okay and we leave them in, then how likely is the wall to settle as a result of the ground conditions? Probably not at all, unless it is built badly. Even if the footings are reset it seems fair to assume that the ground below them is reasonably compact (unless particular soft spot, drainage problem etc.) and significant settlement unlikely, if a sound footing is re-laid.

The wall is only likely to significantly settle if it is badly built, if it is build well settlement will be minimal. If the line and batter on either side is matched it can probably only be built higher if it is built with a loose face or lack of hearting. The need to build it higher then becomes self fulfilling. I suppose it could be argued that the problem with gaps is having enough stone to get up to height if they are well hearted and built tight, so they cannot always be built well and so are likely to settle. I would counter that it is at least as logical to build them well and if necessary lower than the adjacent wall, and then

wait for the wall either side to settle more! If the waller is any good it is just as likely as the repaired bit settling more, and even if it is going to settle more how could you ever work out how much?

Are tall walls more or less stable?

A well built tall wall ought to be stronger than a well built low wall in that if everything else is equal the lower parts have more weight on them and so are more securely held. This is fine if everything is in equilibrium but once that equilibrium is disturbed they of course have more weight on them which might mean they are more likely to be forced out. Once you start to get problems they are magnified in taller walls. It is also worth noting that as a wall settles there is more potential for movement of stones further up the wall as their equilibrium is disturbed. The taller the wall the greater is this potential. This is well illustrated on the A55 where badly built low walls are still intact whilst most of the major failures have occurred in the taller walls.

Coverbands

So what's all this got to do with coverbands, I hear you ask, or had you forgotten that's how this diatribe started? Do coverbands strengthen a wall?

Arguably a wall is only stronger if a technique reduces settlement or reduces potential movement during settlement (that is leaving aside the need for strength in the respect of withstanding lateral forces from outside – rampaging cattle and tourists etc.)

Covers need to sit on everything under them otherwise the levelling stones are not gripped and hence potentially easier to displace, the larger the cover the more problematic achieving this becomes.

A large cover band can prevent the wall from acting as a unit, skewing the way loads are transferred. If the stones under a cover settle away from it creating a gap as seen here (the cover effectively creating a bridge/lintel) then they are no longer securely held and are hence more likely to become displaced than if there were individual cope stones settling with the wall. In the example shown the wall below the cope is settling faster and hence bulging. This brings about the possibility that if you have a bridged cover it could suddenly drop into the gap if the support at either end slips. This would place a sudden load on the stones below making collapse more likely especially if the wall is bulging. (There is a possible argument that the cover is reducing the load on the bulge/problem below it reducing the potential for collapse in the short term, as along term argument for stability this seems a little specious).

The wall nr Llanrug is settling away from the over long slate cover. At the extreme right there is a distinct bulge, all within 18 months of construction © Sean Adcock

In *"Stonechat 10"* it is suggested that coping acts similar to pinnacles, a heavy weight on top of a structure which helps deflect sideways forces downwards (typified by pinnacle atop flying buttresses in gothic architecture) keeping them within the pillar/wall. Initially I accepted the argument, thinking about covers has however led me to re-examine them. Heyman ("The Stone Skeleton: Structural engineering of masonry architecture" (Cambridge University press 1997 pp 88-91) points out that compared to the overall weight of these buttresses the weight of the pinnacle is relatively insignificant and would therefore have relatively little effect except on the wall/pillar immediately below the pinnacle (i.e. without the pinnacle there would be no downward force on this point).

In order to move the wall sideways force must be greater than the downward force created by mass and sufficient to overcome friction too. This is why it is relatively easy to push a wall over near the top (little downward force from mass of wall above to counteract the lateral one) compared to the bottom (much greater downward force from mass of wall above).

A cover plus coping might act like a pinnacle above the wall top levelling, it might actually have slightly more effect than an equivalent height of wall as the relative volume of wall might contain more air and therefore effectively be less dense and lighter. However structurally it adds little if anything more to stability than would just stopping the wall without coping to the same finished height.

Coping adds strength in that the individual stones are bigger than levelling stones and therefore require more force to dislodge them, plus a well constructed cope will have a greater friction co-efficient than the wall top levelling, again increasing the force required to dislodge it. It should be noted in both cases this is coping relative to wall top levelling, if it is coping compared to the equivalent height of wall top (i.e. the top 25cm of building compared to a 25cm cope) then the mass and friction are not necessarily going to be much different.

A cover could conceivably lead to a more even distribution of weight, as does a throughstone. This however is not likely to be of particular note given the lack of weight above to be distributed and is unlikely to do much more than a good cope in this respect too. It would however probably be of some use in this respect if sited below smaller copes or rubble. A type of coping dealt with in detail in *"Stonechat 14"*. However by and large covers are far more common in areas where you have regular stone and tight fitting copes

Maybe covers reduce potential movement of the topmost stones but beyond that do they really strengthen a wall any more than a decent cope. I'm un-convinced, their value appears to be where there is poor and insubstantial coping, and as to strengthening a wall this surely is not significantly different or more than good coping.

Enough for now, these masterclasses are getting a little too theoretical. More in terms of practicalities is needed! However if you don't tell me what you want I will probably just keep theorising until the cows come home. So really it's down to you dear readers.

Sean Adcock.