MASTERCLASS – Planning part 4

Grading Revisited and Joints

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Talking about planning ahead I had intended to end this series in this issue with a final instalment, not so much about planning, rather covering a couple of bits missing from the first three instalments, often of an analytical and theoretical nature, or tangents to them which did not seem to fit properly at the time – and if I don't mention now might never get an airing. However I discover that covering two major aspects in detail leaves little space for the bits and bobs. There's plenty of space in this issue, but this article is long enough without all the bits and bobs. So rather than split it into two equal bits, I'll deal with the substantive parts here and come back next time... By then the rest will probably have expanded. Lots of text and few illustrations I'm afraid. Just like a badly planned wall I now have to somehow finish off with all the left over bits, and it will not look pretty....

<u>Ceteris Paribus</u>

Frequently within this series (and elsewhere) I have used the phrase 'all other things being equal' this is a loose translation of the Latin 'ceteris paribus' which literally translates as *"with other things the same"*.[1] It's a phrase I first came across in Economics 30 something years ago, it occurs frequently within my wittering and for the un-initiated it's probably about time I tried to explain its importance. As well as being used within the economics field it is also prevalent in many areas of scientific enquiry where you are trying to look at the relationship of two variables and in order to do so have rule out the influence of anything else which if it occurred would affect that relationship. Basically you are simplifying the situation in order to examine basic concepts and relationships. It crops up in walling analysis because a wall is a complex structure with very many interacting factors and without it, it's not possible to describe fundamental concepts.

A simple example might relate to tracing (running the longest axis of a stone along the wall line). In splendid isolation a traced stone will always be less stable than if its placed length in, and so all other things being equal the wall will be stronger if it is placed length in. However in reality things are rarely equal. Whilst if placed length in itself it will be more stable, its overall effect on the wall might be destabilising. For example, it might leave insufficient space to build round it well on the opposite side of the wall. Had it been shorter perhaps a better stone could have been used opposite it, individually neither might be as stable as the first but the overall effect is likely to be more stable. Similarly you might run a stone in whilst creating a joint, it might also be difficult to build onto or alongside, it... and so forth. Basically you just have to ignore all the complicating factors and at least initially look at a principle/idea in splendid isolation to see if it has any value. Obviously applying it is another matter.

<u>Grading</u>

In part 1 (*Stonechat 26*) I said that *"Generally a big stone on top of a layer of two smaller stones is vulnerable and unstable compared to a layer of two small stones sitting on top of a big or over sized stone."* In hindsight this was a bit of a throw away comment as I was leading up to another aspect of poor grading to be covered in part 2 (*Stonechat 27*).

My good friend John Shaw-Rimmington questioned this notion on his immensely popular Blog *"Thinking With My Hands"* (see http://thinking-stoneman.blogspot.co.uk/2013/01/shaken-not-stirred.html Friday, January 4, 2013)

The post did generate some debate on Johns site, and I think it is worthy of consideration here.

John took the idea of gravel in a bucket stating *"Listing the bucket to one side, and then vigorously shaking its contents of small random size stones will eventually cause the larger stones to all come to the top. It is evident that the stones in the bucket have now found a more settled, more stable state."*

I'm not entirely convinced as to the cause and effect of this with relation to walls. They are neither contained as the gravel is, nor (the odd earthquake and maybe roadside) shaken about. I would need further convincing that it necessarily equates to the gravel in the bucket being more settled and stable, although it might be the case. However even if it is, I'm not sure it can be applied to walls.

This phenomena, sometimes known as 'the muesli effect' (and by scientists as granular convection), probably relates mostly to dry stone walling in that it is likely one suggested reason (especially in colder climes) for stones rising to the surface of fields. They need clearing which sometimes leads to walls. The process is not fully understood by scientists, the most popular (and easiest to explain) ideas are that it could be that some form of convection (similar to that found in liquids) is taking place, especially within confined containers, the currents lift all the particles (contents) and are strongest at the edges, weakest at the top, and so the larger particles get lifted near the edges but left behind at the top. Another idea is that vibration causes the smaller particles to fill the voids between the larger ones, which cannot then sink back down and so are in effect slowly 'jacked' up. Can either really be said to apply to walls? It's perhaps amusing to think of all those cowboy walls where the cope stones have been built in and the wall finished with rubble eventually ending up properly coped!

John further opines that *"Smaller stones in the wall will naturally continue to find ways to slip down between,(hence get lower than) the bigger ones below them. Therefore large stones might often be better bedded in a wall on a selection of a smaller stones to begin with, rather than having the smaller stones (especially if they are much smaller) placed above them, complying with the natural selection of sizes per height exhibited in the previous 'bucket of stones' example*."

I can concede that hearting does settle within a wall but of course the face stones are in no way acting in this manner. The settlement of the stones is I would contend is more gravity and void originated than the result of any granular convection - which requires larger stones to effectively rise, not just smaller ones to percolate down. Granular convection requires gaps between the bigger particles which are larger than the particles which are going to move down. There is limited scope for this in a well packed wall, where most gaps are going to be smaller than the small hearting. If the wall settles and the gaps widen, then there might be some scope, but I have yet to take down an old wall where I could definitely say the hearting gets smaller rather than larger as you get closer to the footings. It should also be born in mind that placing the majority of building stones with length in also reduces the potential for any substantial settlement of the hearting. All this said I have limited experience of working in areas where the walls are often two skins separated by a substantial hearting core, as for example, would be the case in some limestone districts.

Having rather ungenerously rubbished the argument so far it has however made me think hard and long. Whilst I think the reasoning is highly suspect, it might be possible that the 'widely' perceived notion that larger stones higher are not as stable, is maybe a little taken for granted.

It occurred to me, and indeed John points out that Galloway Dykes have smaller stone near the bottom, larger near the top, they work – although possibly for quite unrelated reasons to those being considered here (things are complicated by singling and setting stones on edge) . My analysis is as ever directed at flat laid doubled walls, so I'll avoid looking any further in the Galloway direction, we'd also have to consider other forms of 'wedge' walls, polygonal stonework and more. However another, not quite uniquely, Scottish phenomena is 'random brought to courses' particularly 'common' in Deeside, and well illustrated in Callandar's excellent "Dyking in Deeside". [2]

These walls contain a lot of large stones, practicalities (and sometimes simply style) might preclude strict coursing. After a less than entirely regular layer of large stones you still have a lot of large stones to use up. This can present difficulties in getting them to sit without creating joints. Rather than employing lots of plates/shims the next layer is (usually) built reasonably thick (the occasional thinner stone will be employed), 'to a course' evening out the irregularities and providing a good level base on which to set the rest (or another layer) of larger stones.

Fig.1. Although built in Nant ffrancon this wall built from reclaimed house stone, (some tracing but every third stone on the second large layer is a through) gives an idea of the Deeside style

If you think about it, it's an efficient, structural way of using the stone, you can get a few jointing issues and 1 on 3's which if you're not careful could theoretically compromise the structure, but as with all things if you are aware and plan, need not be that debilitating.

There is also the fact, as one of John's readers points out, that we put large coping stones on the top, and a couple mention large throughstones. In this instance I think this comes down to what can perhaps best be described as other things not being equal. There use tends to be more specific and not necessarily applicable throughout the structure. There are specific technical reasons why we use large coping stones, and normally set them on edge, they are performing a specific function at a specific point. Any technical weaknesses/problems tend to be outweighed by the advantages, and there tend to be very good reasons why we don't set large stones vertically on edge lower down.

Similarly large throughs can cause problems - mostly highlighted in the Throughstones Masterclass in *Stonechat 12,* and touched upon in the Differential Settlement Masterclass in *Stonechat 20*). They are also very different entities to individual stones in one face, and so the mechanics will work differently, most importantly any weaknesses are (all other things being equal) usually considered to be outweighed by their benefits (essentially load redistribution and tying). In other words, as with coping, they tend to be more right than they are wrong. They may well be too big for where you put them, but as I keep saying you cannot adhere to every 'rule' with every stone, and they do have the (perhaps key) principle of length in - "in spades"! Similarly coping stones perform a function, if they are oversized they can certainly cause problems, obviously in displacing stones when placing (but that's neither here nor there within this analysis), but also over time, (which is) but that could equally be more to do with how well the smaller stones beneath are set. This I thinks is key to a couple of the contributions on John's blog.

Nick Aitken's response might have some relevance. Even if it doesn't I'm going to repeat it simply because I enjoyed his turn of phrase! *"When a big stone decides it wants to play elsewhere it will move easier when there is a pile of minions below it, small enough to respond to his whims and fancies and be bullied out of the way."*

Similarly John Scott added to the debate with a striking metaphor – his stock in trade I think. I first met him when I popped in on him and John instructing in San Francisco. He came up with a brilliant description of a stone's arris which he related to an (almost literal) eureka moment involving his heavily pregnant wife lying in the bath, that is by the by and I can't tell it the way he does. In this instance *"I can carry my kid on my back much longer than she can carry me. You could argue that a wall would have more kids to support me, but those mosh pit crowd-surfing moments that happen at raves or Nuit Blanche only last until the crystal meth wears off!"*

Actual strength of stone is something I will be looking at later in this article, and whilst Nick and John Scott might essentially be correct and not so long ago I would not have questioned it, they are concepts that I think need a little more scrutiny.

Whether or not a large stone displaces those below it will be in part affected by how well set the smaller stones are. All other things being equal smaller the stone, the less stable it will be, if for no other reason than it has less length into the wall. Remember walling is not just about now but also about the long term. Much of what we do is controlling movement in long term – hence length in.

However I'm not so sure we should get too carried away by the idea of larger stones forcing the smaller stone below them out. Getting back to basic principles the force acting on the stones below the larger stone will essentially be the same as if it were made up of half a dozen stones forming the same shape and volume. The forces acting on a small stone will be much the same if we have a given wall made out of small stone, as to having the same stone in the same wall but with a group of stones replaced with one larger one of similar shape and volume. If we replace one stone with several there will of course be some air which would reduce effective mass, the actual points at which the force is distributed might also vary. The minutiae gets complicated but essentially there need not be any great difference in practice. Length into the wall as ever will come into practice (another thing not being equal). A large stone might tie small ones, small ones are unlikely to tie a big one. Although this will largely depend on relative lengths in. It is as well to remember that size isn't just about face size it's also about length into the wall (which is one reason that slate walls for example often look badly graded) and relates as much to volume as face area. Larger stones probably have more potential to act on the back of shorter stones, forcing them out. A large stone with a smaller footprint than 'smaller' stones below it, will be less of a problem. Again a case where all other things aren't equal.

Somewhere in this mix 'centre of gravity' will come into play. This is a concept I always struggle with so I'm not going to go into any great depth of analysis here. I think it will be different (or at least act differently) with a large stone compared to an agglomeration of smaller stones. It is also possible that a single stone will be less stable (all other things being equal) than group of stones of the same length in, individually. It's a headache area. The situation however will be the same for a given stone wherever it is placed in the wall (provided its orientation is the same). Indeed if it is placed higher in the wall it will actually have less force attempting to tip/ move it – it is possible to conceive of situations where on balance (maybe a very appropriate word) a stone might be better higher up than lower down. This however does not mean that in general this is likely to be the exception rather than the rule. It is also possible that a larger stone is more likely to resist these forces than the half a dozen substitutes, this in itself will be greatly influenced by other factors such as contact/friction.

Just to complicate the issue further you can often (stone type and shape), all things being equal, build a tighter wall with smaller stone. If there are less voids lower down, might this reduce the potential for settlement? It might if we have the same length in with the smaller stone (again- maintain the building stone footprint regardless of face size) and do indeed have more stone less air. You have to bear in mind that even if you can fit smaller stone together more closely, this does not necessarily mean that the overall result is tighter. The cumulative 'gap volume' between say six stones filling the same space as two larger stones, would still have to be less than the volume of the (probably) fewer gaps you'd have between two large stones.

So smaller below bigger need not be that bad. But getting back to John's argument I am concerned by the idea that smaller below bigger somehow relates to 'natural selection'. Whilst it relates to granular convection and might explain stones rising to the surface in fields, these are specific cases. If they weren't we'd have a landscape littered with huge boulders. John is also relates this to the idea that a large stone will be better bedded on smaller stone. This might sometimes be the case but again I would suggest it is the exception to the rule. I would also question the cause/effect nature of the argument. Even if it is the case the logic of John's argument is that the smallest will support the biggest that is what granular convection does. However in a bucket, muesli container, even a field, the smallest are ultimately constrained in some way and cannot be forced out the edges. In a wall they can, and even if there was substance to John's notion there would still be a point where small is too small. The aphorism "gravel travels" applies here. We can bed stones on pea gravel hearting very well. Fill the middle with river gravel and placing the next stone becomes so much easier. We can fill every nook and cranny, nothing initially moves. This does not equate to a nice solid wall, as mentioned earlier much, if not most of what we do is about reducing potential movement and controlling that which does occur... ultimately gravel travels, and even acts as the stone equivalent of a lubricant.

Should size of stones decrease in proportion to height of a wall? In terms of potential problems with fitting around it especially if it stretches well into wall, and to a lesser extent getting a large stone to sit on smaller stones, the significant jointing problems which can result (outlined in *Stonechat 27*), which I doubt most people consider/realise. We also have to ask if the smaller stone has sufficient length in, and does using smaller stone lower down mean using more hearting than if we'd used a larger stone - in effect increasing the number of moving parts and with them the potential for movement. With smaller stone which is also thin, we risk cracking if its lower down, a topic dealt with later.

On balance I think larger stones are better employed lower in the wall for all sorts of reasons outlined in the last few issues, however I question the idea that just because it's bigger is one of them, as with all walling it will depend on the individual circumstances. By definition a random wall requires stone distribution to be random. As with everything it becomes a question of degree. Rules have to be broken, walling is about striking a balance. Rules can be broken but little and not often.

In this instance we perhaps have a good example of the instance that the better a wall/waller, the less a problem it can be when you do 'cheat'. The potential for a large stone to displace smaller ones, and the very notion that a group of smaller stones can have a similar mass to one large stone is largely dependent on contact and air space. Hence it will be more of a problem in poorer, loosely built walls, that is there is much more relative mass working on a much less stable wall.

Jointing

In part 2 dealt I dealt with jointing - there are one or two bits that didn't fit neatly there, which I'd better get out of the way before I grind to a halt, and so I'll crowbar them in here.

Fig.2. Joints broken by relatively thin stone

One on two and two on one is all very well, but in itself not always sufficient.
Running joints always show a lack of forethought, planning, checking or even recognition of what you are doing.

Here in the centre of the picture is a case perhaps not so much of thinking ahead, more thinking back, basically realising what you are doing. Having one joint directly above another just one layer away is not necessarily wrong, it's all about context. Good chunky stones sitting well, with even jointing - sat half on half, great.

Whilst crossing joints is one of the golden rules of walling, depending on the stone sitting across the joint, and the stones on either side of the joint all sorts alternatives for pressure points can arise. Basically an unsupported stone has the potential to crack. Simply crossing a joint will almost inevitably mean part of the stone is unsupported, it's the way it is and need not, indeed rarely should be, a problem.

Stone is incredibly strong under compression. We do not have to worry about the stones in a wall being crushed by the stones above them. Gordon in *"Structures : or Why things don't fall down"* explains that a vertical pile of stone would need to be over 2km high before it was crushed under its own weight, and that tapering (as in a wall) means we could build taller still... *"... this is more or less how mountains work. Mount Everest is... about 8 kilometres high and shows no sign of collapsing"*.[3] To paraphrase Gordon if you could build a wall high enough you'd have more problem with lack of oxygen than crushing of the foundation stones. Stone in tension is another matter.

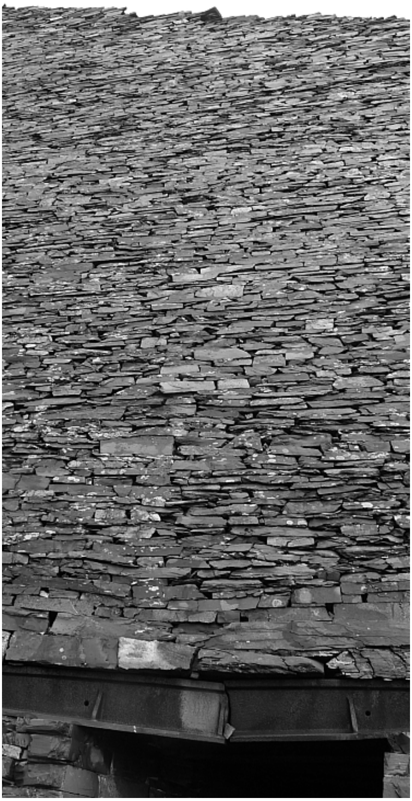

Fig.4a. Cracked cast iron lintel in C4 Incline, Dinorwic Quarry. The result of running joints, or is a vivid imagination at play?

There is a detailed explanation in *Stonechat 9,* however to attempt to simplify compression is where stone is being pushed in literally compressed, tension is where it is being stretched. In this respect a stone crossing a joint is best compared to a lintel. The upper surface of the lintel is being compressed whilst the lower surface is being stretched. Cracks develop through a combination of high pressure and weak point. Stresses will (all other things being equal) be at their highest at the centre of the gap being bridged, a crack might develop offset from this if the stone has a weakness off to one side relative to its centre. If we have thick, flawless stone the problem is reduced. However the problem of stone's weaknesses is illustrated by the historic lack of lintels over large spans and the development of corbel and voussoir arches. You cannot just make the lintel stronger by increasing its size and hence the span. As you make a lintel thicker so you increase its weight, and the force it is exerting on itself, and so it cracks under its own weight. Not relevant for our wall but hopefully an interesting aside!

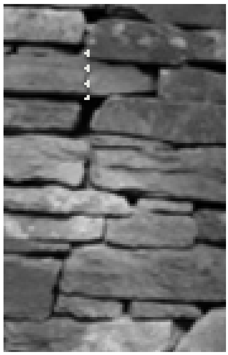

Fig.3. Close up of top left of Fig.2. Crack highlighted.

What is important is that crossing voids (or joints) is not something stones are good at and so crossing joints with thin stones, is not such a good idea; if the stone is much thinner than the ideal vis-a-vis grading, that's worse; if it sits poorly it's more of a problem; low in a wall, where there is more pressure, it's a problem waiting to happen. There is an obvious weakness to the centre of fig xx. At first you might think this is hardly criminal, but look to top left of fig.2 carefully, fig.3 is a close up of this area, the white dots highlight where a stone has actually cracked. The way the stone is sitting and how the joints line up has created a pressure point and the stone has cracked. Whilst a running joint didn't originally exist a plumb joint has been turned into one. Ideally avoid crossing joints with 'overly' thin stones, and if for some reason you have to then offset the joints.

In fig.3. the situation is probably exacerbated by the fact that we now have a four stone joint, each joint increases the potential for pressure on the stones below, concentrating the forces at work, and if there are any more pressure points and (possibly largely dependent on the stone type), more cracking. This is a major consideration with jointing, poor jointing fails to distribute the forces evenly, it can in fact concentrate them. A running joint immediately above the foundations can concentrate more pressure on one footing, this stone is then more likely to move than it would have been, exacerbating the potential for differential settlement. Poor jointing can contribute to differential settlement not only on the ground but within the body of the wall itself. This is why diagonal and zipped joints are also of concern even if arguably not as severe as plumb joints.

Time for another aside – the role of mortar. Whilst it seems it is often used as such in masonry, mortar is not a glue (other than to a peripheral side effect). It purpose is to ensure the loads over joints are spread evenly, avoiding the potential of high points to create pressure points, evening out stresses across a joint, filling voids and reducing tension. This is a mjor factor why engineers prefer mortared masonry to dry stone, you can rely on, or at least make fairly reasonable assumptions as to how loads will be transferred within mortared masonry, which you cannot make in dry stone work where there is far more potential for variables.

The problems of running joints are difficult to illustrate, but I did come across this wall (fig.4a) in Dinorwic quarry where a 12" cast steel lintel has been cracked by the weight of the wall above. To my eyes you can make out a diagonal 'ish' joint above the fracture (fig.4b)– it might not be complete but if it is concentrating forces within sections of the wall the short breaks in it would be insufficient to redistribute any forces and so ultimately a severe pressure point has hit the lintel which has cracked very close to its centre. Of course given the weight of stone and a flaw in the lintel it could have cracked anyway.

Fig.4b. Highlighted Running Joint?

It could also be a little 'chicken and egg', it is possible that the lintel has cracked leading to an opening of the joints above, the diagonal might just be in the mind's eye – I can't make up my mind if there is another running off to the right a little way up, effectively intersecting the first and exacerbating the situation. Perhaps we see what we want to see. However I am fairly certain that the lintel itself is a replacement and not original to the structure. Which I would like to think suggests there is indeed a problem which has had a rather ineffective sticky plaster added rather than applying a cure.

Fig.5. Clearly visible separation of a diagonal joint at Opus 40

This 'chicken and egg' scenario was one I encountered recently at Opus 40, Harvey Fites creation at Saugerties near Woodstock in upstate New York. The site is riddled with diagonal joints, and where these occur within otherwise generally tight walling they are quite obvious (fig.5).

Some parts of Opus 40 are undoubtedly on the move, in places the terracing/made up ground, is quite tall/deep. It could be that some parts are settling more causing joints to open, it is as, if not more likely that joints are concentrating forces and where this coincides with a softer ground or poorer footing the problem is exacerbated, increasing differential settlement and opening the joints, which in turns only makes the problem worse and more concentrated.

Whilst most wallers recognise that they shouldn't create joints I wonder if many realise why and what effect they have on the forces within the wall (as well as weakening the bind between adjacent stones, once more increasing the potential for movement, and failing to control it if it does occur.

I shall finish by repeating one of my mantras yet again. Having a fault is not necessarily a problem, what is a problem is that people don't realise it is a fault, or if they do, do not plan how to compensate and so the fault is compounded. That is when problems occur and walls fail.

NOTES AND BIBLIOGRAPHY

[1]See Wiki. http://en.wikipedia.org/wiki/Ceteris_paribus (October 2013)

[2] Callandar. R. *"Drystane Dyking in Deeside".* (Aberdeenshire) 1986

[3] Gordon.J.E. *"Structures : or Why things don't fall down"* (Penguin 1991) p.172