Drystone regulations: boon or bane?

Norme per i muri a secco: seccatura o vantaggio?

Des normes pour la pierre sèche: fléau ou bénédiction?

Trockenmauer-Normen: Fluch oder Segen?

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I. Introduction

Most drystone structures are built by craftsmen using traditional knowledge. Experience is passed on with training schemes and review by other wallers in order to maintain quality, i.e. durability and appearance. Many structures are low and not very safety-relevant in the case of failure. Deformations are acceptable to a certain extent. For these reasons, building regulations are often not applied, or only in a very general manner.

In some countries, wallers' associations primarily regulate the craftsmen and not the walls, e.g. the Drystone Walling Association of Great Britain with training courses and certificates of competence. Similar organisations in France and Switzerland are following this route, also USA, Canada and Australia. In Germany the focus is on both documenting local traditions and producing literature for amateurs and landscape professionals alike. In other countries so far, the thrust is more in documentation and preservation than training builders, although local builders' groups or experienced firms may also be found.

In the case of high retaining walls, there are strong safety issues. Many such walls are built using engineering practices to specifications drawn up by the client, e.g. a road department or railway. Others are built on the strength of experience alone. Many advanced structures such as housing, sea walls or bridges have been built or supervised by experienced experts of the time, in some cases military or civil engineers. Some of these structures are quite old yet still in use.

In between the simple low and engineered high walls we find countless medium sized retaining walls supporting agricultural terraces or hill roads. Although failures could be dangerous, they seem to occur "gracefully", e.g. stone by stone or at least slowly with ample warning (O'Reilly&Perry 2009). Such

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predictable failure modes are common with natural "low-tech" building materials, at least with structures of a human scale. Of course there are also catastrophic failures due to landslides or severe earthquakes and flooding.
For all these reasons, technical regulation is not very widespread. This has the advantage of low cost: ordinary people can build walls without extensive education or training. It has the disadvantage that drystone is often not taken very seriously compared with cement and mortared work and that it is difficult to define legally if work has been done well or poorly.
Today this is slowly changing. Especially drystone retaining walls are treated as "gravity walls" which can be designed and regulated by engineering-type methods. National and international building code and/or secondary regulatory bodies are beginning to feel responsible for regulating drystone. This paper examines the implications of this.

II. History

Building regulations go back a long way. Around 1770 BC the Babylonian king Hammurabi imposed the code known under his name. It has 282 laws and five of these ensured sound buildings using a weighted "eye for an eye" principle:

Fig. 1: Hammurabi's Code, inscribed on both sides of a basalt stone over 2m high, presently in the Louvre. (Photo Mbzt, Wikimedia, CC-BY)

- 229. If a builder build a house for some one, and does not construct it properly, and the house which he built fall in and kill its owner, then that builder shall be put to death.
- 230. If it kill the son of the owner, the son of that builder shall be put to death.
- 231. If it kill a slave of the owner, then he shall pay slave for slave to the owner of the house.
- 232. If it ruin goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.
- 233. If a builder build a house for some one, even though he has not yet completed it; if then the walls seem toppling, the builder must make the walls solid from his own means.

Also the Bible has a building regulation of a more modern type. Moses 5 (Deuteronomy), chapter 22, verse 8, says:

- When you build a new house, make a parapet around your roof so that you may not bring the guilt of bloodshed on your house if someone falls from the roof.

Today's building codes are more complicated. They are not only about justice and safety, but also about setting standards in order to facilitate interoperability and business. They are also about power and control, furthering the aims of the rule-makers, and about money.

This paper cannot supply a history of rule development, just give a few examples. Retaining walls, dams and arches have always been intriguing problems for physicists and engineers. They also interact with the ground they stand on or the soil they retain. Numerous theories were developed and some resulted in specifications, e.g. for the thickness of retaining walls. The calculation of earth pressure devised by the famous physicist Coulomb is still used today, after modifications and improvements by others. The military engineer de Vauban devised rules for building fortification walls; many of these are still around in French cities. The military engineer Burgoyne had four 6 m high drystone walls built and tested in Ireland in 1834; these experiments are extensively covered in many drystone research papers and the results still used today, because they remain the largest research walls ever built.

III. Ways of specifying drystone walls

There are several ways of specifying drystone walls: by experience, by calculation, and by rules. And by their combinations.

Specification by experience

As with most natural building materials, drystone walls can initially be specified to some extent using "common sense", intuition and "trail and error". Poorly built or under-dimensioned walls will fail quickly and the builder will eventually acquire enough experience in order to build sound walls. This experience can be passed on to others orally, with written "rules of thumb", and with training. Drystone-walling itself involves much tacit or implicit knowledge, which, like learning to ride a bicycle, is a skill which cannot be entirely acquired through the use of explicit rules. Farrar (2006) has examined the drystone wallers' learning experiences in great detail.

This method works well with traditional construction and especially with freestanding walls, where there is really no alternative. It doesn't work well with new structures outside the wallers' usual scope or experience .

Specification by calculation

In theory the use of physics allows the calculation of all physical forces and hence specifying new walls of any type or size. A camera and computer could even scan available stones and specify the optimal placement of each one, provided the forces of usage and the properties of the adjacent soils are known. In practice much of the needed data is not available. This is especially so with freestanding walls, where the usual causes of failure are not due to forces which are easy to calculate, but rather due to weathering, ingrowing plants, climbing animals, or humans who remove stones. How can such things be calculated?

With retaining walls things are clearer. The civil engineering and soil sciences know a great deal about the interaction of the forces involved. Only one wall face need be exposed to weathering, animals and humans, so the calculable factors are greater than then incalculable ones. Computers can solve complicated equations or use numerical methods (very many calculations of arbitrarily small regions). Statistical mathematics can predict the frequency of occurrences quite outside the scope of human experience, e.g. seldom failures.

The scientific principle means that, in theory, anybody can examine any proposition or calculation to see if it is correct. In practice, much jargon is used and equations are not presented in a way that most people can easily follow. Some problems are so intractable, that they are not yet completely solved. Statistics can get complicated and the results are very sensitive to the initial assumptions. Some properties, e.g. the cohesion of soil, vary greatly, so results can contain huge uncertainties. The calculation of failure probabilities can only be done if the right data is available. Even when it is, there is no guidance on which failure probabilities are acceptable, as this is a matter of human judgment and not physics.

Geotechnical and physical modeling software is available, but not yet a "Design your own drystone wall with three clicks"-program. Last but not least, while computer programs can deal well with highly standardised materials such as bricks or brick-like stones, the calculation of individual irregular stones as mentioned at the beginning of this section, is probably not really an option in practice. The properties of most drystone wall will always depend strongly on the skill, experience and intuition of the human builder.

For these reasons, physical calculations do allow the design of extraordinary structures of any size and safety implications over any desired time-scale, but they should always be checked by other methods in case of wrong assumptions or errors. The scientific method is never dogmatic but invites constant scrutiny and proposal of improvements.

Specification by rules

Building rules, regulations or norms are actually meant to bring together experience and science and formulate easy to understand specifications. While this has been done successfully for drystone with some books, it has not worked out that way for national and international building regulations. Equations, while basically simple, are often presented in ways which only trained engineers can understand. Often they use inconsistent systems of units or no units. Assumptions and simplifications are often undocumented, methods sometimes presented in a dogmatic "we know best" way. Factors which have little to do with each other are mixed together. Safety factors are applied generously and sometimes repeatedly. The rules are drawn up by committees of people of which some have vested interests, e.g. for furthering their businesses. When much is at stake, committees are "stuffed" in order to win over controversial issues.

Building rules work well within their own professional context and with predictable building materials. They don't work well with lay builders (too complicated and expensive) or scientists (too simplistic and physically inaccurate), or outside their intended scope. They cannot completely take into account the great variability offered by drystone. Here "failure" or "unsuitability" is difficult to define. For example, to which extent is wall sagging or bulging permissible before the wall is considered to be failing or unsuitable?

IV. The new role of building codes for drystone

Historically specifications for great drystone works were drawn up by large clients, such as road and rail authorities. Today's projects are much smaller and builders can get guidance from numerous books published in the last few years and decades. These describe traditional wall-building and dimensioning by rules-of-thumb. A few give tables or graphs based on research or building codes.

There is an increasing tendency for organisations and individuals to try to pass off responsibility to someone else. Especially local authorities are worried about being sued when something goes wrong, as today people are more likely to sue even regarding trivial or nonsensical issues, not only in the USA. Therefore customers often demand work done in accordance with national or international building codes. As these don't apply very much to the specific nature of drystone, sometimes other guidelines are specified.

In 2004 the Swiss Federation of Dry Stone Masons (SVTSM) published specifications for drystone walls (SVTSM 2004). Probably unique in Switzerland, the Canton of Baselland maintains own drystone guidelines for cantonal (i.e. main) roads (Tiefbauamt Baselland 2010). In Germany, guidelines published by FLL (2012) will be used.

However, such guidelines themselves try to pass on legal responsibility with phrases such as "consult a qualified engineer" or "building codes X, Y, Z, etc. apply in any case and most be followed." The SFDSM specifications state that "heavily loaded retaining walls must be calculated by an engineer." The guidelines of Baselland only apply to walls under 1.5 m height in uncomplicated situations. The FLL guidelines list 24 national and European regulations to be followed.

Thus the committees making rules for bodies such as SIA (CH), UNI (IT), DIN (DE), BSI (GB), or EN (EU) are left being held responsible for things outside their main field of experience. Accordingly some cases (e.g. free-standing drystone walls) may be left out entirely and others lumped together with other wall types, e.g. cemented retaining walls. In the absence of exact data, generous safety factors are applied and compounded. These walls seem to be over-specified compared to historic ones. Conversely, modern engineers regard the latter as under-specified.

V. Specific examples

Voidage

In order to specify the dimensions of a retaining wall you must calculate its weight, which means knowing its voidage, i.e. void volume compared to total volume. For years German rules (DIN) required to assume 50%, then they switched to 25%. Swiss rules (SIA) first made no assumptions, now they specify to use the actual voidage and if unknown, 33%. Scientists like to do actual measurements: McCombie (2012) gives values of 23% to 46% for tightly built to loosely built limestone walls, respectively. These values are similar to those found by other researchers. Theoretically the densest packing of perfect and uniform spheres gives about 23%, suggesting that boulder walls are more solid than they look.

Stone Overlap

Many drystone constructions rely on the horizontal overlapping of stone layers in order to give the structure tensile strength due to friction. The SVTSM (2004) guidelines specify that two stones of vertically adjacent layers overlap at least 20% relative to the larger stone – implied in the lengthwise direction of the wall. The FLL (2012) guidelines require at least 33% and in addition at least 10 cm. Inspection of existing walls indicate that even those considered well-built have numerous overlaps less than 33% and even some less than 20%. The 33% requirement is thus completely and the 20% requirement slightly unrealistic. Physically it seems plausible that the more overlap the better, but this also depends on other factors and doesn't apply to all wall types.

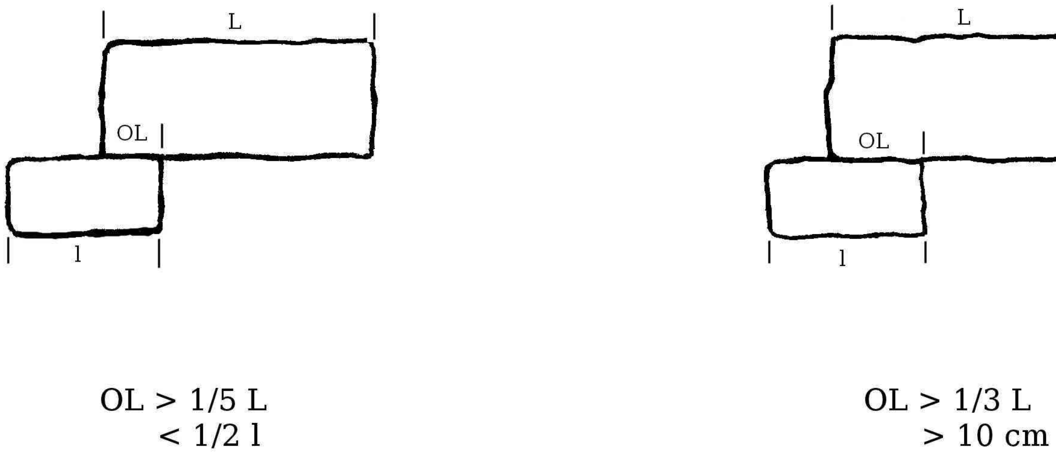

Fig. 2: Stone overlapping. On the left is the minimal overlap as specified in Swiss drystone guidelines, on the right as specified in German drystone guidelines.

Soil and friction properties

In order to calculate earth forces you must know various values which are in practice difficult to measure or which vary greatly and unpredictably. One of these is cohesion and this is often assumed to be zero even when the soil is clearly cohesive. Such an assumption constitutes a kind of hidden safety factor.

Thrust line:

The stability of a wall against tipping or toppling over can be expressed by the eccentricity of the thrust line or resultant of the wall's summed forces where it passes from wall to ground. This also influences several ways the ground could fail and the wall could deform. Some codes such as DIN and derived guidelines such as FLL (2012) only allow a relatively small eccentricity, e.g. one sixth (17%) of the foundation width, others one third (33%). (One half (50%) would mean the impending toppling over of a monolithic wall and the local failure of the ground under the wall's toe.) This method only works for "ordinary" rather upright wall shapes; for special or highly tilted shapes it can be meaningless. For drystone walls the patterns of deformation and failure are more complex than for monolithic ones. The oversimplification and mixing of different things preclude a "correct" specification. It seems that regarding tipping, present German walls must be built with twice the relevant safety factor of present Swiss or French walls!

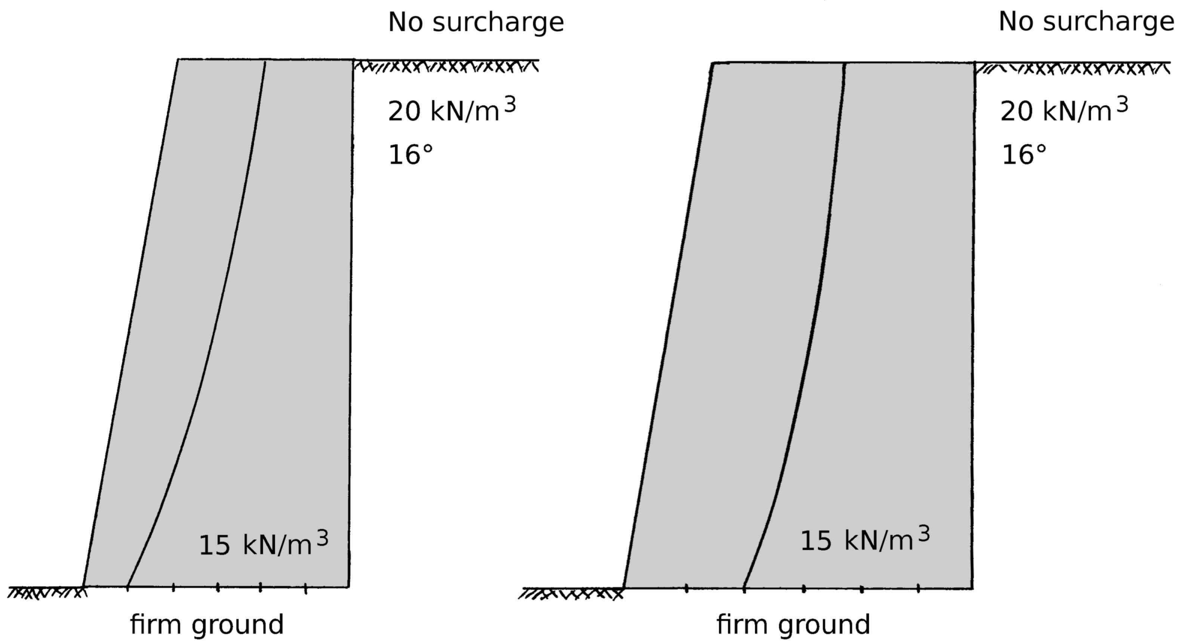

Fig: 3: Position of Thrust line. On the left is a retaining wall cross section with a thrust line having 1/3 eccentricity. This is an actual calculated example for retaining extremely unstable soil, e.g. mud, while the base soil is considered firm. On the right is the same example with only 1/6 eccentricity as specified in German regulations. It must be considerably wider and would require over 30% more stone to build.

Safety factors:

These govern the probabilities of deformation and failure. Where loss of life or high costs are incurred through failure, a probability of under one in a million is sought, and corresponding safety factors are derived, with which the calculations are multiplied. (In contrast people accept thousands of times more fatalities in fields such as road traffic and pollution.)

At the other extreme, the failure of a structure without safety consequences can often be tolerated with 100% certainty after its designed lifetime, as can some deformation.

Building regulations do differentiate between deformation and failure and between categories of loading and of difficulty, i.e. "simple cases" - e.g. retaining walls of under 2 m height in uncomplicated conditions-, "normal cases", and "difficult cases". While the different cases are not treated entirely the same, it appears that in building rules no variation of safety factors is intended. Thus the safety calculations for a low garden wall seem the same as for a high wall supporting a railway. Low walls tend to be over-specified and yet many still deform too much. This can happen if they are built poorly or subjected to the creep of soil, i.e. slight but strong ground movements which accumulate over long periods of time. They are also more sensitive to loads e.g. from vehicles.

Modern regulations try to follow scientific statistical methods by applying different partial safety factors to all values. This quickly gets so complicated that lay persons cannot use such regulations. For these it is better to use the traditional concept of a single total safety factor per calculation. But which value to use? One finds everything between about 1.2 and 3. The former means the structure can survive 20% more than its intended load, the latter 3 times its intended load. Or not deform, as the case may be. On top of these explicit safety factors however come the hidden ones and many designers apply additional ones of their own in order to avoid failures at all costs. Therefore actual safety factors are often several times what codes actually require.

Other designers do the opposite: they calculate as closely as they can and save every bit of material possible. "If it never breaks, it's too strong!"

VI. Implications for drystone

Applying building regulations rigorously to drystone walls can make them overweight and thus more expensive than need be. This occurs for reasons described above and because engineers used to standard engineering materials do not appreciate fully how a structure made of simple unconnected stones can exhibit ductility and tensile strength. More expense is incurred if the regulations are so complicated that professional engineers are required to implement them. Or even to access them, as the regulatory bodies finance themselves by selling copies, so they are not generally available for free, in libraries or at nominal cost.

While this results in many very sound and safe walls, it may also be counterproductive. Some builders will not bother at all and attempt ambitious structures without any guidance, which could then be particularly unsafe. Others will give up entirely and not use drystone or even gabions, to which much of the above applies. Forms of walls which cannot be regulated may lose status. Drystone walling could end up as a luxury.

VII. Solutions and Conclusion

The use of walling books and websites can make rules and methods available at nominal cost and and be at least somewhat understandable. However the builders or clients do have to decide themselves *which* of these to consult. E.g. in France CAPEB (2008) gives design graphs for retaining walls worked out with safety factors of 1.2 and 1.5 against sliding and overturning, respectively, with *no* external loads, whereas in Germany FLL (2012) provides graphs worked out with 1.5 and approximately 3, *with* external loading, being based on DIN rules. In Britain one of the most recent research papers by McCombie et al. (2012), suggests a safety factor for 1.5 against sliding and thrust lines corresponding to a safety factor of approximately 1.5 *or* 3! O'Reilly&Perry (2009) describes the fluctuations of safety factors depending on year, country and author.

There are thus considerable differences. Which rules should one use?

You could use Swiss regulations (SIA), which are a bit shorter and more readable than DIN or EN (Eurocode) regulations and do not yet go for the mandatory thrust line corresponding to a safety factor of approximately 3. They also contain articles which in effect state that you can do what you like or what the client wants if you know what you are doing and can show it by calculations or experiment. However the same other limitations apply as with all modern regulations: they are meant to be used by professional engineers.

The DSWA offers brochures, magazines and books, the section of North Wales also "Stonechat", with a great deal of practical information. Brooks & Adcock

(1999) have written a well-know handbook. Stiftung Umwelt-Einsatz Schweiz published a small "bestseller" in 1996 and are working on a new one for 2013. However all of these do not contain any specifications other than the rules of thumb. The scientific literature, on the other hand, gives advanced methods of calculation. However the equations given are aimed at the scientific community, not builders. I have attempted something in between. In (Schmidt 2013) motivated builders will find information for working out retaining walls which are just about usable without mathematical proficiency, including a spreadsheet which works out earth pressures and safety factors. These are ideal for medium-sized walls where strict application of national building regulations are not yet mandatory.

To conclude, building regulations can help make retaining walls strong and safe, but often overly expensive. Other guidelines can result in more economical retaining walls and they also give more assistance with freestanding drystone walls. None of the methods described seem to take account of soil creep which might occur especially with low walls subjected to frequent freezing-thawing cycles. None of the written information can replace natural or acquired skill and experience, strong hands and and a good eye! Hopefully walling traditions can be retained and regulations used for furthering rather than impeding the craft.

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