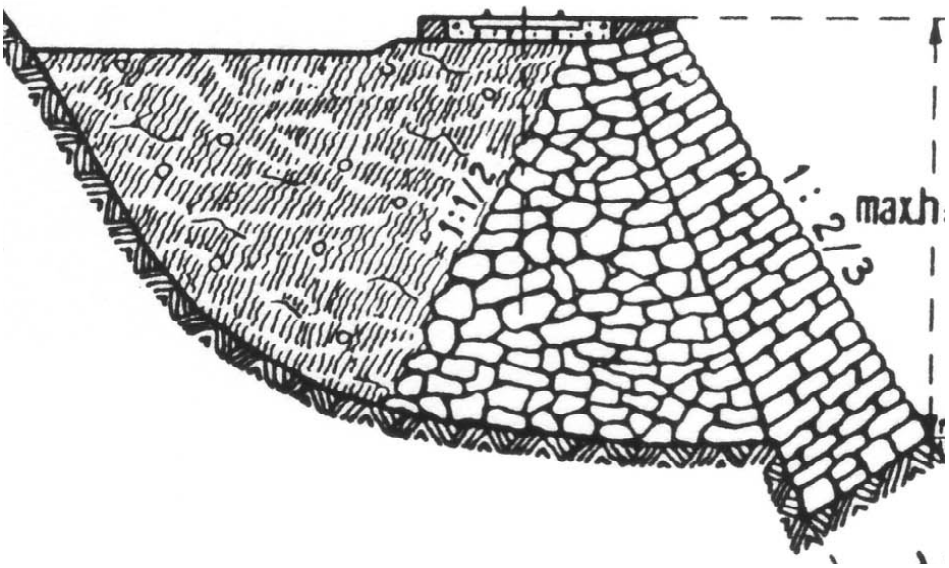
Retaining walls in dry stone masonry



Gerhard Stoll
Trockenmaurer / Dipl. Arch. ETH/SIA
Hüeblistrasse 28
8636 Wald

+41/55/246'34'55
+41/78/761'38'18
gstoll@bluewin.ch
www.stonewalls.ch
www.trockensteinmaurer-verband.ch

1. Terminology

In the literature a bewildering number of different terms for "retaining wall" are to be found. Their use is not uniform and that can lead to misunderstandings. Terms like "lining wall", "supporting wall", "revetement wall", "stone packing", "stone paving", "burr wall" are used.

E. Schmidt, "der Erdkunstbau auf Strassen und Eisenbahnen" von 1871:
"Under a revetement or lining wall one understands a masonry body which has the purpose confine a masses of earth, rock or sand possibly vertical. The term "lining wall" can be used very generally.
Walls which reach to the summit of embankments are called "lining wall", while walls those which don't reach the full height are called "retaining walls". On the Brenner railway "retaining walls" is the term used for walls which retain an artificial backfilling, "lining walls" are those walls which are built in front of solid subsoil or rock. Plessner calls a wall which carries a railway dam on a steep slope a "retaining wall", a wall which prevents the existing slope to slide on the track or which dimishes the cut a "lining wall". Finally a wall which is only built to protect the toe of a slope from slipping or being washed away or to allow a steeper angle of the backfilling is called by him a "revetement".

From such and many other examples it follows that the use of the terminology is ambiguous".

Freiherr von Röll, "Enzyklopädie des Eisenbahnwesens", 1921:
"Retaining- and lining (revetement-) walls":
The covering of empankments with masonry structures serves for:
a) the protection of earth- masses which themselves stand firm but are prone to erosion by downpour or wind.
b) support of slopes which are steeper than the natural slope than the natural embankment. Arrangements of the latter kind are mostly justified by the necessity to achieve savings in width of used terrain either because of too steep a slope or because near roads, watercourses or other features have to be spared , or because of the high costs of the ground. Stone packings (up to max. 100% of incline), dry stone walls (up to max. 66% of incline) and mortared walls (max. 0% of incline, vertical) are associated with increasing steepness of the supporting mass to the retaining walls under point b).

We use the following terms:
Retaining wall
Generic term of all walls which support a backfilling or which support their own weight.

Traditional built retaining wall
Dry stone retaining wall which is constructed of a face of carefully laid stones. The stones used for the face are are usually of medium to large size carefully graded and placed by hand to fit. The backfilling consists of smaller stones, laid in horizontal planes behind the face.

Load bearing retaining wall
Retaining walls on which pressure is exerted by the supported material by water or by a additional load (e.g. traffic). The weight of the supported material acts on the masonry.

Lining walls / revetement walls
Revetment walls are built in front of firm subsoil or stable bedrock to prevent erosion. They do not have to carry other loads than their own dead weight.

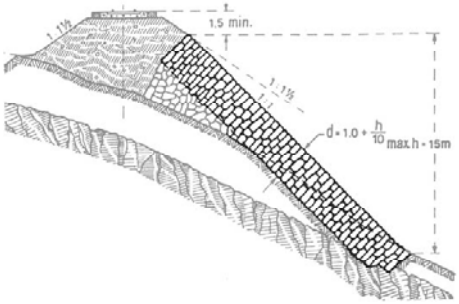


figure 1:
example for a stone

"Steinsatz" (cf fig. 1):
Mixing of paving and retaining wall. The inclination of the surface is not steeper than 1:1 (45°). It is considerably thicker than a paving. The weight of the masonry acts on the subsoil.

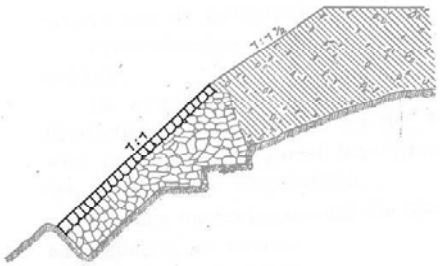


figure 2:
example of a stone paving

stone paving (cf. fig. 2)
Protection of flat slopes with stone masonry reaching under frost depth (in cold climates). The maximal inclination is not bigger than 1:1 (45°). The weight of the masonry acts on the subsoil.

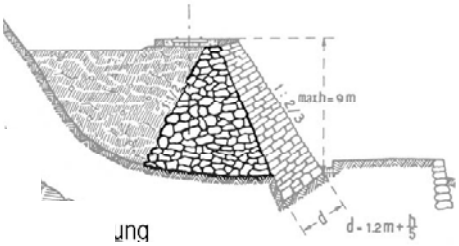


figure 3:
example of a stone packing behind a dry stone retaining wall.

stone packing (cf. fig. 3)
Built between the trapezoid of a gravity wall and the subsoil without a bond between masonry of the retaining wall and the stone packing. Makes possible the reduction of the section of the gravity wall.

2. Introduction

figure 4:
dry stone retaining wall of the railway Martigny-Chamonix near Finhaut, Switzerland

Many people think, that dry stone retaining walls are relatively instable structures which can be used only for small walls. It is often forgotten that in the 19-th century, at the moment of the industrial revolution, the building of dry stone walls experienced a last climax. At that time great infrastructure buildings in the Alpine space (e.g., the Gotthard railroad, road constructions over alpine passes, but also the first big protection buildings against avalanches) were built. Many of these retaining walls and protective walls serve to this day. Before this time dry stone masonry was planned and built by experienced masons. Now the dimensions of the dry stone masonry for these load bearing structures was calculated by engineers. This use of engineered dry stone masonry, the second important theme of dry stone masonry besides the traditional use in agriculture and vernacular architecture, originates in the devloppement of military engineering in the age of enlightement when french military engineers fathomed the theoretical bases of the traditional building techniques.

The construction style of engineered dry stone masonry differs substantially from the traditional way to build dry stone walls for agricultural terracing or freestanding boundary walls on pastures.

3. Traditional building style

building dry stone retaining walls with one carefully set facing.

When building a retaining wall the traditional way only the exterior face is constructed of carefully laid stones. The stones used for the face are are usually of medium to large size carefully graded and placed by hand to fit. The backfilling consists of smaller stones, laid in horizontal planes behind the face (cf figure 5 and 6)

figure 5, left:
section through a retaining wall built the traditional way.

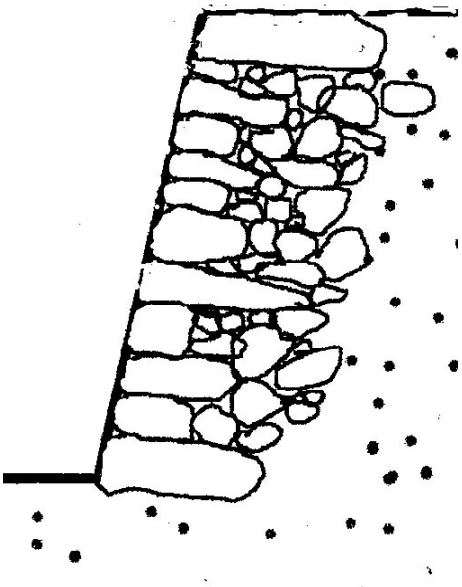


figure 6, right:
example of a retaining wall with only one carefully set face, Chemin, VS, Switzerland

4. Building style for engineered dry stone walls

building load bearing gravity retaining walls with dry stone technique

By contrast stand stand the retaining walls dimensioned and calculated by an engineer to carry a defined load . The dimension of this gravity walls can be determined computationally considering thrust of the retained material, superimposed load, dead weight of stone material and geometrical form of the planned retaining wall (). The load-carrying capacity of the subsoil must be also taken into consideration. The calculation produces a trapezoid-shaped cross section which is broader at the toe than at the top (cf. fig. 7).

Often the face of this trapezoid section is inclined towards the slope with a batter of about 20 - 30%. Retaining walls in very steep terrain can also be built with a vertical face without a batter. The wall height which is thus saved compensates by far for the increased masonry section which ha to be built. In addition a wider road can be realized (cf fig.10).

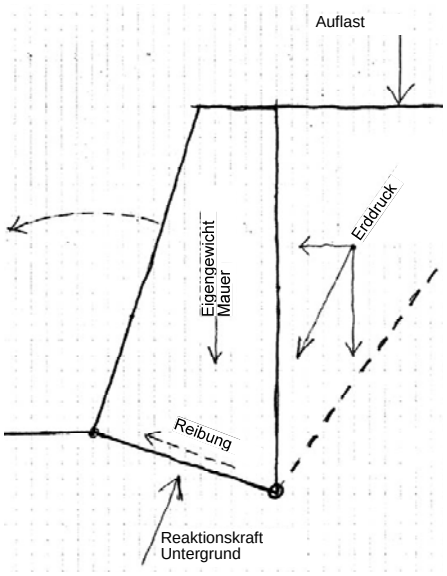
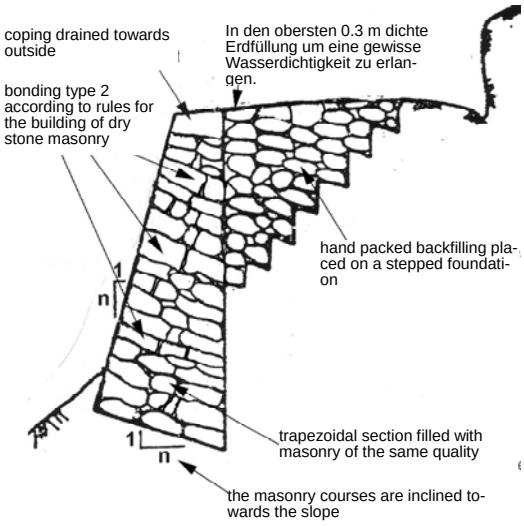


figure 7, left:
statical system of a gravity wall.

figure 8, right:
Zweischalig gebaute Stützmauer einer Erzverladeanlage auf Naxos

The calculated section is filled with good masonry stones (weight normally min. 5 kg) with impeccaple bonding (cf. rules for the construction of dry stone masonry, bonding type 2). In practise the masonry is built from the face inwards. The masonry courses are built like a paving and each course is finished before the next course is started. However, the courses don't have to be levelled off. One through stone per m2 face has to be inserted (cf. rules for the construction of dry stone masonry, bonding type 2), (cf. fig. 9



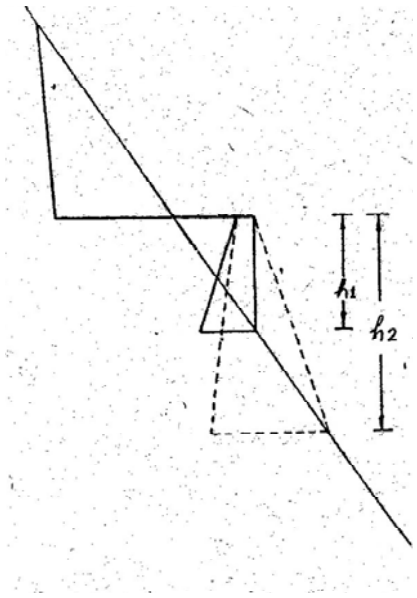


figure 9,left:
schema of a retaining wall built with a trapezoidal section.

figure 10, right:
Effect of batter on the height and volume of a wall built on a slope.

and 11).

As a rule stones used as binders and strechers are alternated. In the masonry courses laying over one another a binder should lay on a stretcher and vice versa. stone-quality and intended look of the face (face bond) can alter this relation. When using a great number of small stones of an irregular shape it is necessary to use more stones as binders than when using flat, regular and big stones.

figure 11:
building a gravity retaining wall

Between the trapezoidal gravity wall and the subsoil a carefully stacked stone packing is inserted. Form and size of the stones for this packing don't matter much. However ist is important to pack the stones as compact as possible to prevent later settlements. Besides this stone packing acts as an drainage.

The stability of a gravity wall can be augmented with the following features:

5. Construction details for load bearing retaining walls

5.1 Projecting foundation

Projecting foundation
A projectiing foundation, built in bond with the rest of the wall augments the surface of the area over which the weight can be transferred in the ground and it protects the subsoil from erosion if water from heavy downpour flows over the wall.

5.2 Inclination of bedding planes

Inclination of the foundation and of all bedding planes against the slope

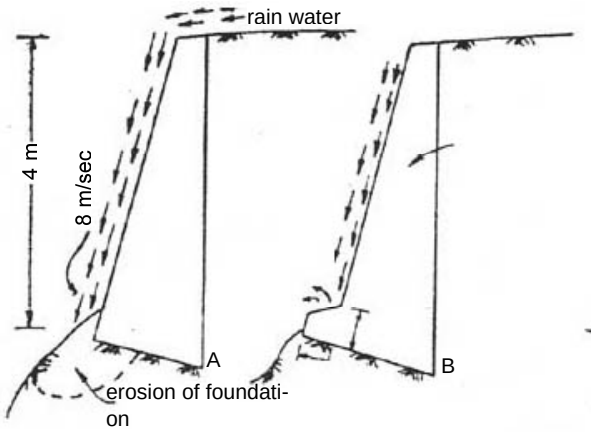


figure 12:
function of projecting foundation
A: without projecting foundation
B: with projecting foundation

5.3 Size of stones

Size of stones matters
The use of big stones (weight over 5 kg) and the consequent renunciation of small wedges in the face adds stability. This is particularly important when building retaining walls carrying roads with traffic which are exposed to vibrations.

5.4 Stepped subsoil of the back packing

The subsoil of the backbacking should not be simply an inclined surface corresponding the slope. It must be prepared as a stepped surface, so that the weight of the back packing can be better transmitted in the subsoil. Otherwise there is the risk that the mass of the back packing has the tendency to slide on the slope and the whole weight acts on the retaining wall.

5.5 Drainage

Although in a dry stone wall water can drain through the open joints there can appear a problem with retained water. Conceivable is a plugging up of the joints with silty material or in cold climate a freezing of water in the joints. Therefore it is recommendable to pay attention to the proper drainage of the dry stone structure. A proved measure are scupper holes with an opening of minimal 0.3 x 0.3 m (so that a cleaning of these openings is possible). foundation ditches inclined towards the slope have to be drained with rubble filled slits going down under the frost depht (for cold climates).

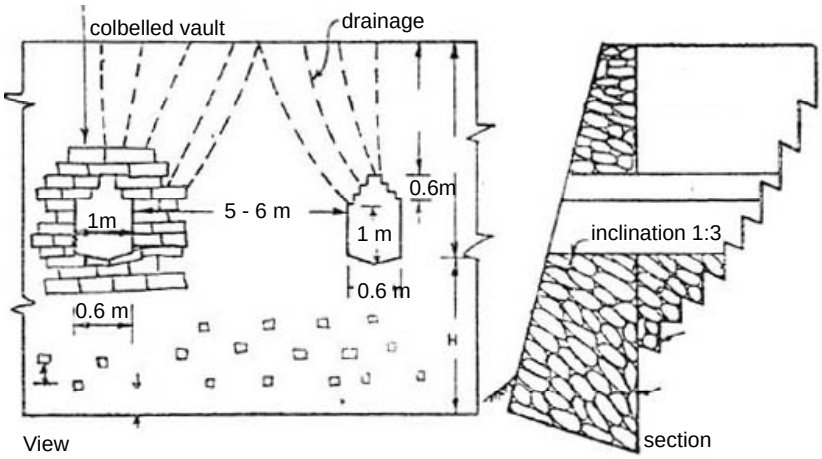


figure 13:
Scupper holes

6. Problems / damages

6.1 Tension fissures

When building high walls (from approx. 4 m height) there can emerge the problem of the rupture of single stones due to "stress peaks". The transmission of load in a dry stone structure is not steady but occurs trough the touching points of the stones. As a result of that it can happen that the stones are not only compressed but have to bear a bending force. As stone generally can bear heavy compressive loads but only small bending forces stones thus stressed often break (cf. fig.14 and 15). To prevent this problem the bedding faces of the stones have to be matched as good as possible. The bigger the touching surface, the better is the evenness of load transmission. It is also possible to level off the masonry courses with small stone chips to equalize irregularit ies. This levelling course contributes to a even load transmission but if an excessive amount of this fine material is applied there is the danger, that it acts as a ball bearing and reduces the important friction between the individual stones.

figure 14, left:
retaining wall of church-yard in Savogno near Chiavenna (I).

figure 15, right:
detail of broken cor-nerstones near wall base

figure 16, left:
bulging of a retaining wall with only a thin face of carefully laid stones

figure 17, right:
opening of the vertical joints because of bul-ging (Scudellate, Valle Muggio,CH). Possible cause for the damage is the lacking connection between the masonry face and the backfilling, an insufficent number of throughstones,traditional single masonry face construction in spite of the great height.

7. Literature:

1 Vereinigung Schweizerischer Strassenfachmänner (VSS) (1944):
Normalien für Bergstrassen.

2 Schweizerischer Baumeisterverband, SBB (1946):
Richtlinien für die Ausführung von Natursteinmauerwerk, entsprechend den besonderen Bestimmungen der SBB.
2. Auflage.

3 Reddi, T.G.K. (1982):
A plea for vertical front-faced retaining walls in hill-roads
Indian Highways, March 1982.

4 Arya , Dr. A.S. / Gupta, V.P. (1983):
Retaining Walls for Hill Roads, (incl. Discussion and correspondence); 48-6
Indian Roads Congress Journal, Vol.44-1/44-4, Paper Nr. 356.

5 Villemus, Boris (2000):
Reppis, Étude des murs de soutènement en pierre sèche du Luberon
Parc Naturel régional du Luberon.

6 Ménard, Jack (2000):
Murs de soutènement routiers en pierre sèches
Parc Naturel régional du Luberon.