

Stabilization of historical retaining walls using soil-nailing methods

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ABSTRACT: Germany is rich on historical retaining walls. Many castles, churches, and old towns are surrounded by walls, and many of these walls become more and more instable. For the stabilization of collapse-endangered historical retaining walls the soil nailing technique is very common since its invention about 20 years ago, because it allows to increase the stability without changing the views of the walls, and without digging up the backfill. The paper deals with the principle of the measures, the dimensioning rules, and the practice of the works. Some examples illustrate the method.

1 INTRODUCTION

Historical retaining walls form a big part of the views of Germany's ancient towns, castles, and church environs. They have been built in former centuries following a minimum principle: only as much stone and mortar as absolutely necessary was used, and great attention was paid to an effective drainage of the backfill. In a statical view all these walls are gravity retaining masonry walls. Because of their construction the walls cannot satisfy the safety requirements and the stability standards for new retaining structures. Weathering of the mortar and the stones, the pressure of the roots of trees and shrubbery, and the clogging of the backfill void volume and the drainage ways extort stabilization measures from the owners of the walls (mostly churches, aristocracy, public administrations, or railway authorities). Many of the historical walls are protected as historical monuments, and therefore their view may not be changed.

The soil nailing technique gives the possibility to increase the stability of the old masonry gravity walls without changing their views, and without digging up the backfill.

2 SOIL NAILING - ASPECTS OF CONSTRUCTION SUPERVISION

After the invention of the soil nailing method into the German ground engineering practice (Stocker & Gäßler 1979) the German Institute for Building Techniques (DIBt) gave certificates of approval to a number of construction companies. The certificates contain the required safety factors, dimensioning rules, testing procedures, and required material

properties of the nails. When the first 1:1 scale tests were carried out in order to investigate the failure behaviour of nailed walls, and when in 1985 the first certificate of approval was given to BAUER company nobody thought about using the method for more than building pit sheeting work in combination with a shotcrete facing. The principle of this scope is shown in Figure 1, and Figure 2 shows a characteristic construction of this type.

In the meantime the use of soil nailing methods exceeds widely this area of application. Especially for the stabilization of historical retaining walls the specifications of the certificates of approval are not applicable. Many of these walls, especially along railway lines, are lining walls, which means, that they have been constructed in order to protect a rock slope surface against weathering. As backfill material crushed rock of low quality was used, and the walls themselves are only thin shells of dressed stone. Figure 3 shows the typical arrangement of the stones even of high lining walls. The wall shown in this figure had collapsed suddenly and caused a derailment and death toll.

Other walls, especially in rural areas, have been built using every kind of stone available including bricks and rubble stones, and then plastered as shown in Figure 4. The direct value of these walls (regarding their importance for the preservation of ancient monuments) is not very high, but they have some importance for the outward appearance of the villages. So they have to be preserved, and nailing is an appropriate method for increasing their stability.

Not seldom during the investigation of the state of the walls it becomes obvious that parts of them have failed once before, and then had been reconstructed.

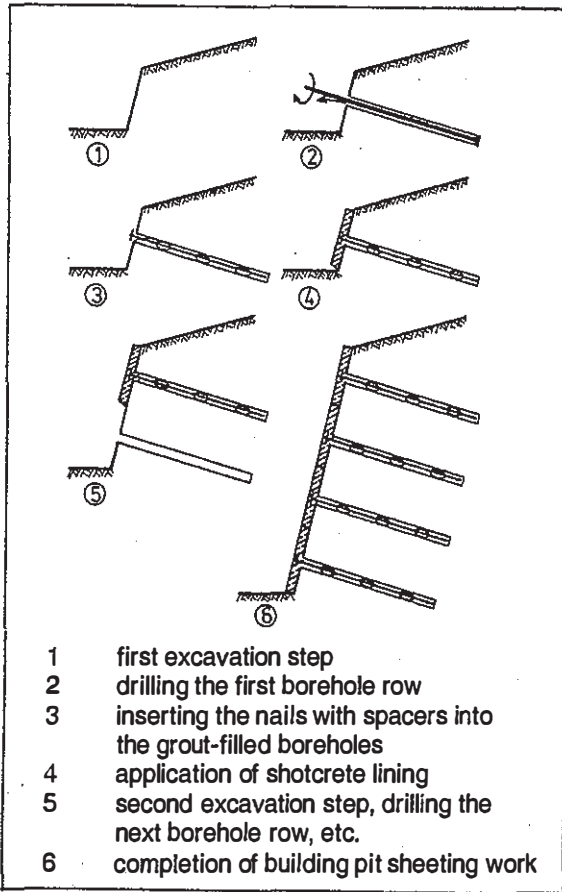


Figure 1. Soil nailing for building pit sheeting work: execution steps.

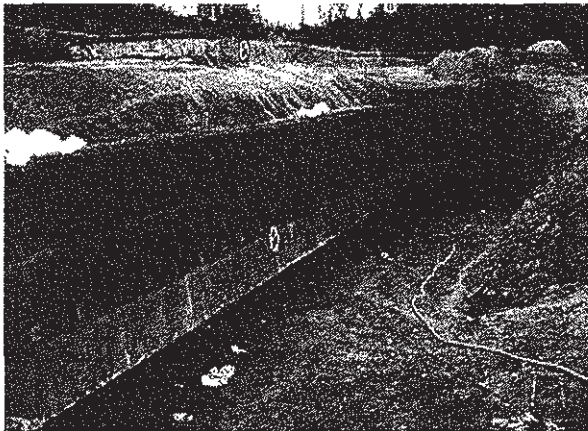


Figure 2. Building pit lining (shotcrete facing and soil nails).

In general the wall substance is bad and cannot be bettered significantly (which means, e. g., a certification against punching of the nail heads in the old masonry normally cannot be done). So the stabilization of ancient retaining and lining walls is a task which has to be solved with intelligence and empathy, and usual standards for new constructions are not very helpful in this job.

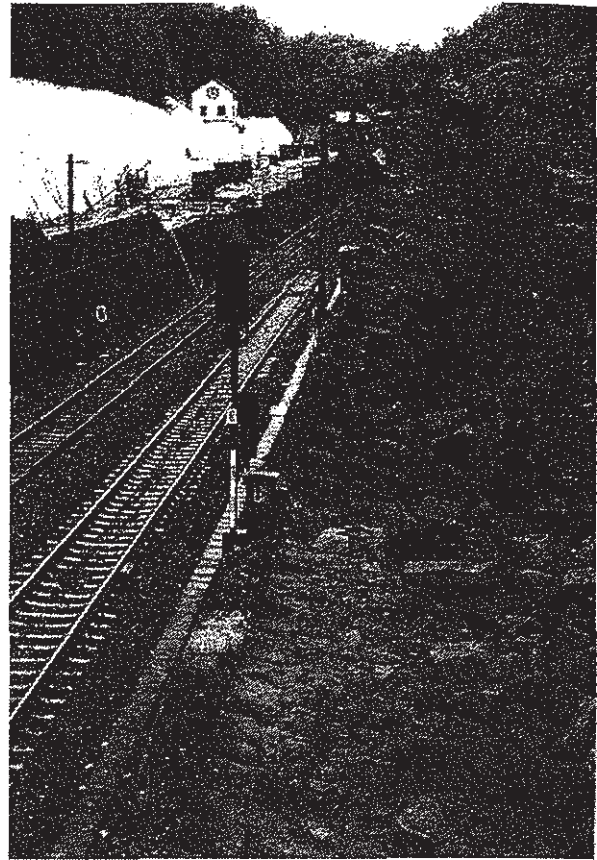


Figure 3. Collapsed lining wall beside a railway line

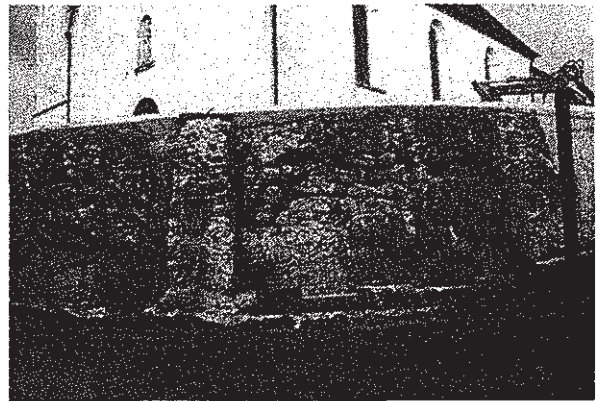


Figure 4. Medieval retaining wall constructed using various types of stones.

3 DIMENSIONING METHODS

As mentioned above the certificates of approval of the German Institute for Building Techniques regulate the dimensioning of soil nailing measures when the method is used, together with a shotcrete facing, to stabilize the walls of building pits in soils, etc.. The stabilization of historical retaining walls is not a part of these regulations.

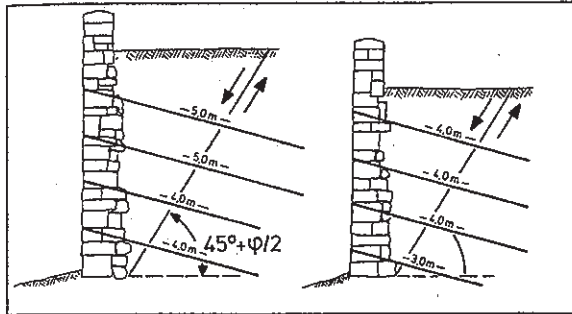


Figure 5. Failure mode for the dimensioning of the nails.

The dimensioning of the soil nails is executed normally using the wedge of the active earth pressure behind the wall as loading element, and traffic loads, if they cannot be excluded (Figure 5). The nails are handled, in the statical analysis, as anchors penetrating the slip plane. In reality they reinforce the backfill of the walls which explains that the nail-head forces straining the old masonry are generally very small.

The wall substance mostly does not allow to calculate the bearing capacity of the masonry for taking over the nail head forces. So in many cases the iron plate of the nail heads is put on a larger stone, or concrete bedding, without calculation and proof of its bearing capacity. Until now the authors have not heard of any case where a soil-nail stabilized retaining wall has failed later, or showed damages, because of lack of bearing capacity of the masonry for the nail head forces. If there is any doubt on the load capacity it is always possible to test the deformation and bearing behaviour of the masonry around a nail head executing load tests using hydraulic hollow cylinders as shown in Figure 6.

4 EXECUTION OF STABILIZATION MEASURES

There is no possibility for making an estimate about the stability reserves of already deformed historical retaining walls, but in general they are very small. There are a number of walls which collapsed suddenly when the stabilization works just had started. Obviously the concussions caused by the drilling bit had been enough to exhaust the stability reserves. The collapses in all cases the authors know happened very quickly and without any warning. Fortunately until now no death had to be lamented. In order to avoid accidents high and obviously collapse-endangered retaining walls must be supported before starting any drilling activities. Of course stays and supporting posts restrain all works in front of the wall, and for that reason construction companies try to do with little when having an order. Therefore the submission records should contain items for the supporting measures.

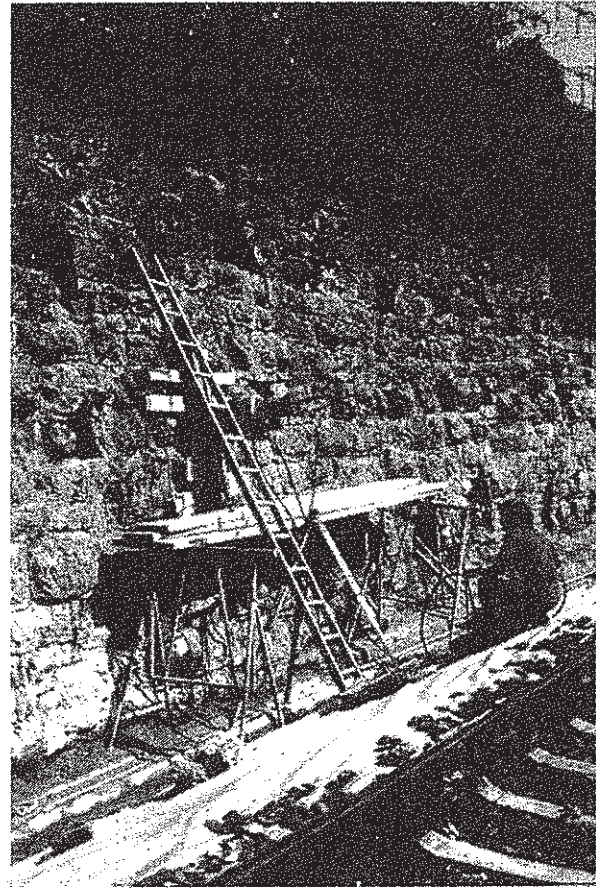


Figure 6. Load test on a soil nail head stabilizing a historical retaining wall.

Sometimes another aspect makes it difficult to execute nailing works in the neighbourhood of churches. Churches were built in former centuries in Germany on the top of hills within the communities whenever possible. Very often this position required the construction of retaining walls which now need, after a number of centuries, an improvement of their stability. In some parts of the country it was common to bury the dead as close as possible to the church, which means that graves are often situated directly behind the retaining walls surrounding the graveyards around the churches. One has to know that in order for not disturbing the calmness of the dead.

The nail screen obtained from the statical analysis is transferred to the wall facing. Vertical and horizontal nail distances between 1.5 and 2.0 m are customary. The locations of the drill holes are chosen bearing in mind that the nail heads should be covered later by the masonry again. Drilling diameters between 80 and 150 mm are used, and the nails with their spacers are plugged into the borehole filled with cement grout. Usually steel nails (threaded construction steel bars BSt 500 S-GEWI) with double corrosion protection are used. The nail heads (plates and screws) are mounted and then covered by the stones

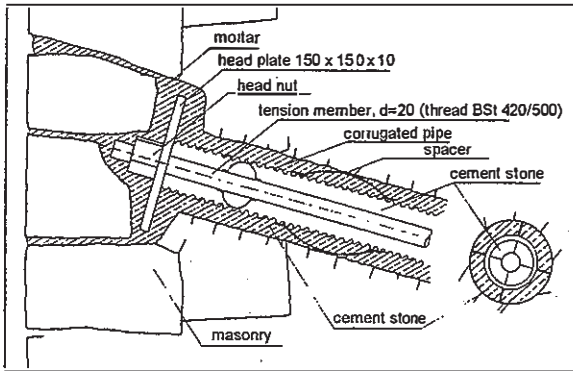


Figure 7. Nail head construction in masonry.

taken out from the wall before the beginning of the measures.

Many walls have lost the mortar in their joints in the course of time, and the masonry and the backfill is interspersed with cavities. The wall substance usually is strengthened as follows. In a first step the joints are released as good as possible from trees and bushes, which in many cases have contributed to the wall destruction, and all loose joint fillings are cleared away. Then the joints are refilled with mortar as completely as possible using a shotcrete machine which is more effective than filling them by hand. In many cases a special mortar containing trass cement is used. Immediately after the beginning of the hardening the surface of the wall has to be cleaned by hand using water and brushes, a procedure which may be repeated once or twice to get a stone-faced wall again. Drainage holes of course must be preserved during these procedures and cleaned as good as possible. Then the cavities and the rear unfilled ends of the joints are "injected" (better: filled again) carefully and with only low pressure with cement grout. Figure 7 shows a typical nail head performance inside an old retaining wall. As an example on Figure 8 the cross section of an old retaining wall stabilized by soil nailing is shown. The wall substance was in such bad condition that it was necessary to cover it using a sprayed concrete lining, also in order to protect an old church foundation against sliding movements towards the wall. Figure 9 shows the drilling works for stabilizing this wall.

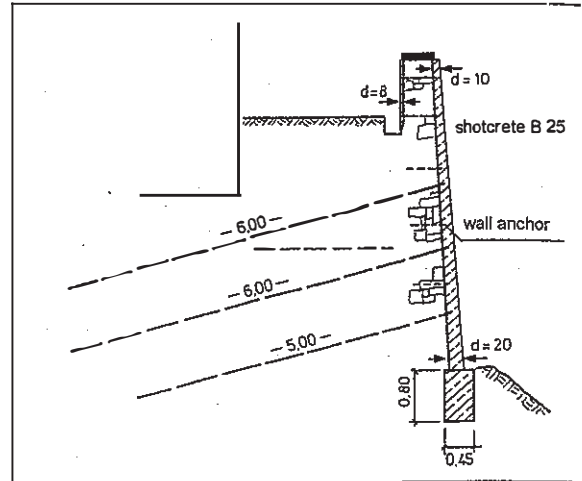


Figure 8. Cross section of an old retaining wall supporting a church building.



Figure 9. Drilling works on the wall shown in Figure 8.

The combination of improving carefully the wall substance and reinforcing the backfill using double corrosion-protected soil nails guaranty a further lifetime of some hundred years more for ancient retaining walls.

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