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Stabilization and surface protection of steep slopes using soil nails and prefabricated concrete part linings

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ABSTRACT: The report gives an overview of the German practice of the stabilization of steep slopes using long soil or rock nails instead of prestressed anchors for the stabilization of rock slopes. The nails connect the slide-endangered rock masses with the stable underground and reinforce the front areas of the slopes. The nail heads are, at the same time, used for setting up different systems of prefabricated concrete part lining walls. These walls, in a distance of 0.75 to 1.5 m ahead of the slope surfaces, are filled and backfilled with soil, and then vegetated. The report demonstrates a number of different systems, deals with the dimensioning principles, and gives some instructions for the execution of such stabilization works.

1 INTRODUCTION

Breast or lining walls have to protect the surfaces of stable rock slopes against weathering and to prevent roads or railways from being endangered by rock-fall. They are charged by their dead weight and by the pressure of the backfill between the slope surface and the rear side of the wall. Lining walls have been constructed in the course of the railway works since approximately 1850 very often and up to heights of 10 and more meters using natural stone or brick masonry. Nowadays it would be nearly invaluable to construct optically pleasing natural stone masonry walls in the course of modern traffic way construction. On the other hand high and bare concrete walls are not very popular in Germany because of the activities of the environment protectors.

So in many cases gabbion walls or polygonal masonry walls are used to protect rock surfaces against weathering, as shown in Figure 1 and Figure 2. In a (theoretically) statical point of view all these piled up revetment walls may be constructed up to nearly unlimited heights, as long as they have a dip of less than 90°, and are piled up very exactly. In practice the construction height is limited by unavoidable imperfections at a slenderness of about 1:8, depending on the dip of the lined slope and the exactness of the geometrical execution of the slope surface and the shape and size of the piled elements. If the elements are prefabricated concrete parts, they fulfill the conditions of exactness in size and shape, and high revetment walls may be built without anchoring or nailing as long as the rock slope itself is stable. The Figures 3 and 4 show such a revetment wall shortly after it's construction and 12 years later.

Figure 1. Polygonal masonry lining wall.

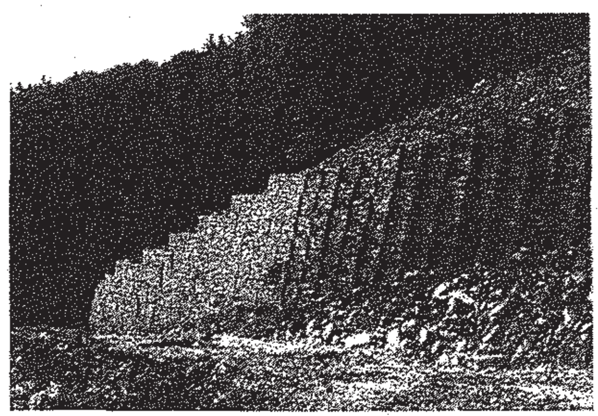

Figure 2. Gabbion lining wall of 11 m height.

Figure 5 shows a nearly 60 m high rock slope with berms. The single slopes between the berms are completely lined with concrete revetmet walls of 11m height. The cutting made some problems during it's construction caused by a joint system dipping to

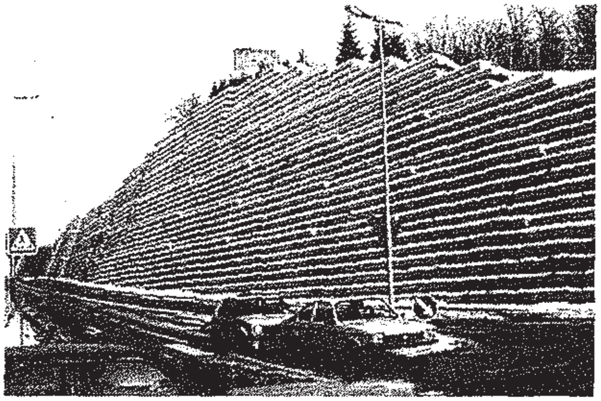

Figure 3. Revetment wall of 22 m height.

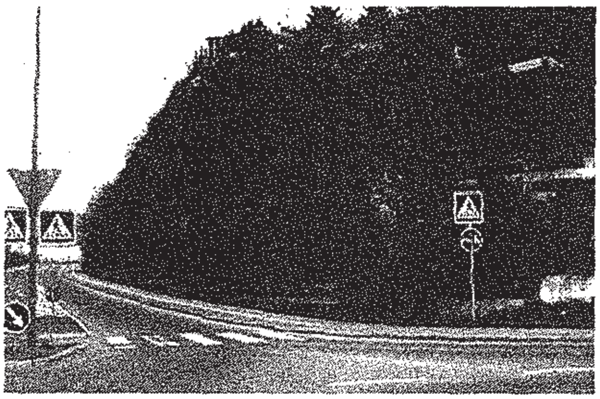

Figure 4. Revetment wall after 12 years.

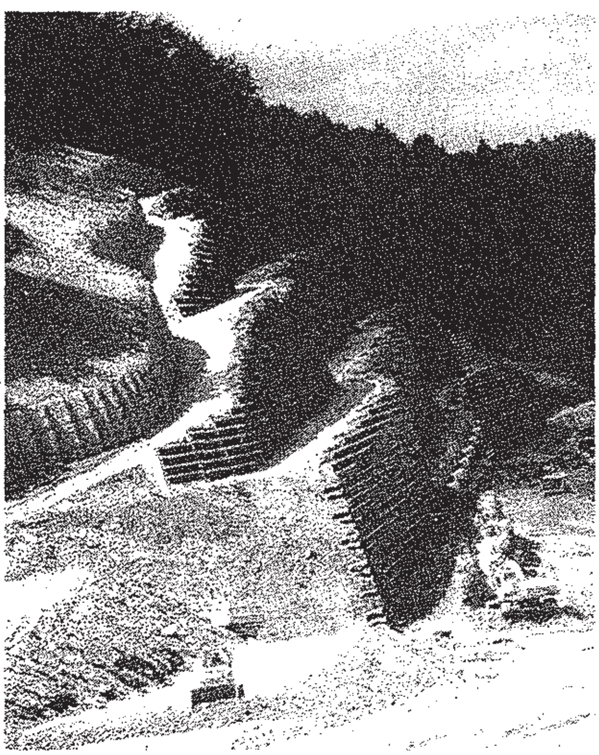

Figure 5. Surface of a deep cutting protected against weathering by prefabricated concrete parts.

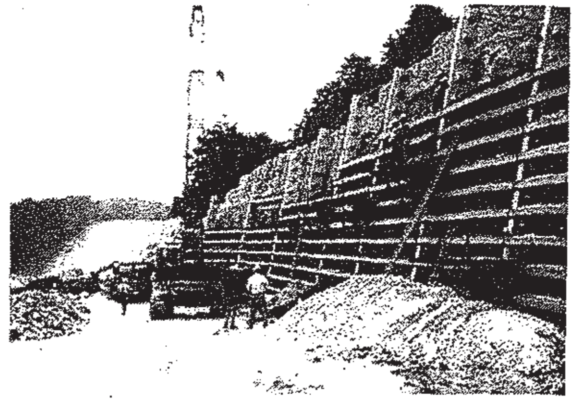

Figure 6. System of vertical and horizontal concrete parts fo ing the lining wall.

the cutting and striking parallel to it (Denzer Wichter 1987, Wichter et al. 1990). Therefore it h to be stabilized using more than 4.000 heavy a long prestressed rock anchors.

After the successful construction of the cutt shown in Figure 5 a number of similar systems l been developed, firstly as pure unanchored grav revetment walls according to the specifications the German highway authorities. Very soon it came usual to combine the concrete part lining wa with slope stabilizations using soil nailing meth when the global stability of the slope was insu cient. All common systems are composed of verti columns (so-called lisenes) put in bucket foun tions and fixed in a distance of 0.5 to 1.5 m ahead the slope surface using the nail heads as anchorag Between these columns horizontal beams are ranged in vertical distances between 0.75 and 1.2 as may be seen in Figure 6.

2 CASE HISTORIES

2.1 *Stabilization and protection of a cutting slop mica slate*

The construction of a new federal highway mad necessary to cut a natural slope in mica slate i length of 380 m and an excavation depth of m mally 20 m. The mica slate is, in a geological vi a very old rock and was extremely stressed by tectonics during it's existence.

The geological reconnaissance showed that mica slate was extremely jointed and fissured, weathered especially in the surroundings of some cal faults. The orientation of one joint set was rected nearly parallel to the road and dipp downslope in different angles. So it became ne sary to install a stabilization from the beginnin the excavation works in order to avoid later surp when the excavation had proceeded and the dept the cutting would have made it difficult to reac

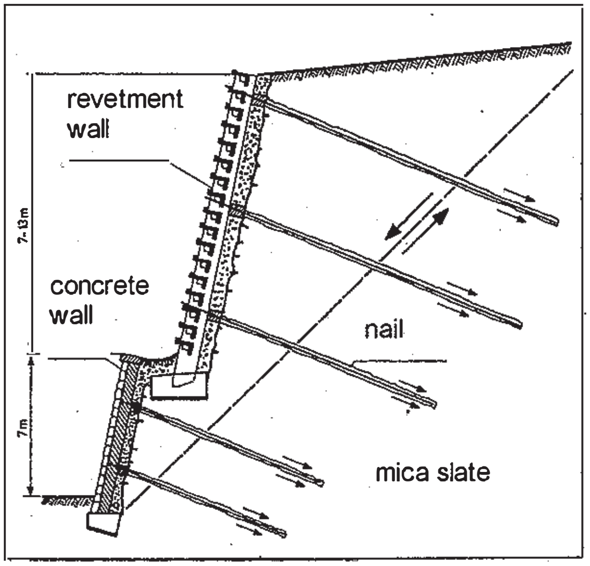

Figure 7. Assumed sliding wedge for the determination of the required nail lengths.

was decided to reinforce the slope using long soil nails in a grid of approximately 2.5 x 2.5 m. The lengths and the cross-section of the nails was determined assuming that a sliding wedge could move most disadvantageous on a slip plane activated when the excavation was nearly finished as shown in Figure 7.

Threaded construction steel bars of 63.5 mm diameter (steel quality BSt 555/700) and with lengths up to 20 m were used to secure that the slope (which beared some buildings behind on the top) would remain stable on the whole. The nails were arranged vertically in a way that their ends standing out of the slope surface could be used for anchoring the prefabricated lining wall elements later. It was not quite easy to determine the correct starting points for the boreholes (which were points in the air), and great exactness was necessary because later the prefabricated concrete parts had to be threaded on the outstanding nail ends.

The weathered and jointed rock surface between the nails was stabilized during the works to protect the workspace using steel mesh, shotcrete, and short soil nails of 22 mm diameter. About the installation of these elements was decided at the site after each excavation step using lining classes (similar to the way used in tunneling) with different shotcrete thickness and nail lengths. Figure 8 shows the slope surface during the excavation works. After the end of the excavation works the prefabricated vertical elements were installed and fixed, as shown in Figure 9. Then the cast beams (which were, in the cross section, z-shaped) were placed between the columns on consoles. Finally the lining wall was backfilled, and the vegetable mould was brought on the beams. Figure 10 shows the wall after it's completion.

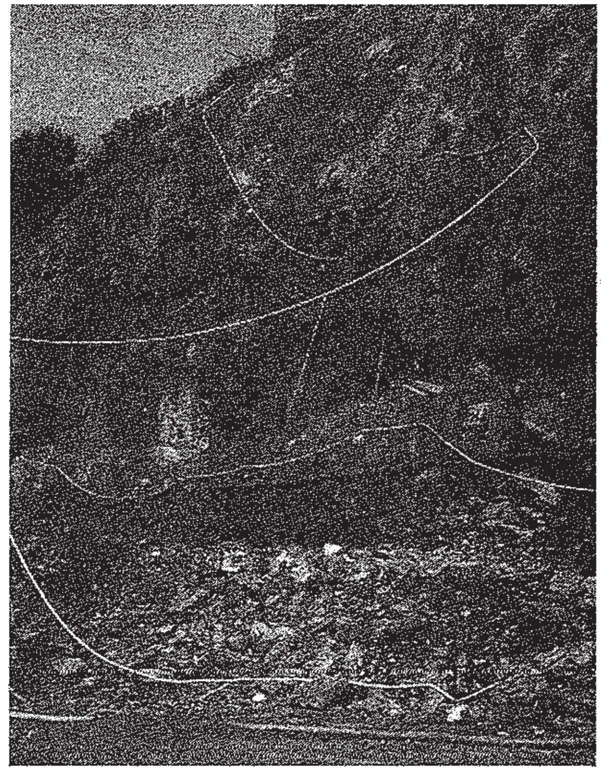

Figure 8. Slope surface with shotcrete and steel mesh lining and soil nails.

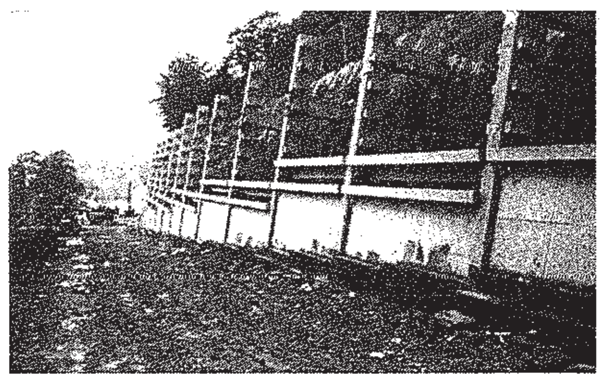

Figure 9. Installation of the prefabricated vertical columns and horizontal cast beams.

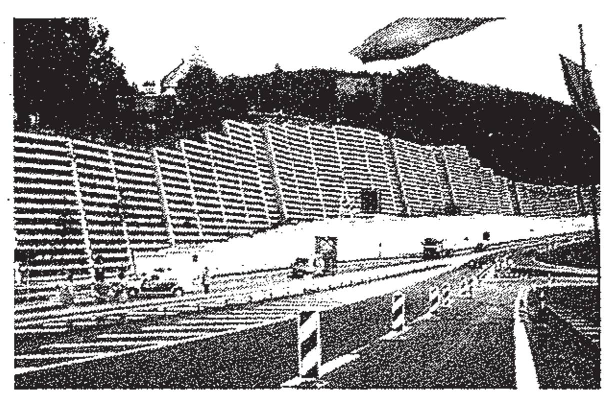

Figure 10. Lining wall after the end of the works.

2.2 *Stabilization of a Keuper Marl slope*

In the course of the improvement of the access roads to the city of Stuttgart (situated in a deep circular valley) a cutting into a steep natural slope became necessary. The slope was formed by the siltstones and claystones of the Keuper formation with an intercalated sandstone layer.

For the stabilization of the slopes the concrete part system was used which had already been used for the deep cutting shown in Figure 5, but a new technique for the abutment construction was developed. The vertical beams were supported using prefabricated concrete abutments kept in place by a part of the nails (Ø 50 mm threaded tie bars / GEWI-bars). The nail grid was 2.5 x 2.5 m, and the nail length was between 7.7 m and 11.3 m, depending on the height of the cutting slope. Figure 11 shows a cross section of the system (horizontal beams not linked) and the nail grid. The Figures 12 to 14 are photographs of the wall during and after construction.

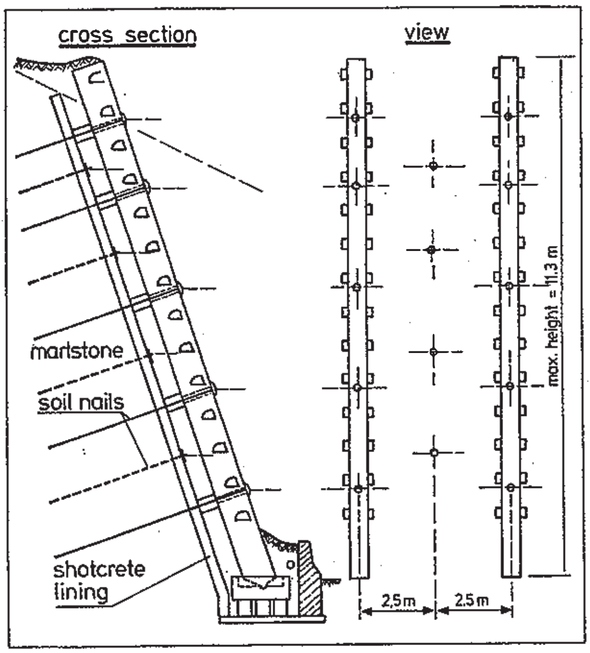

Figure 11. Cross section and nail grid of the wall system.

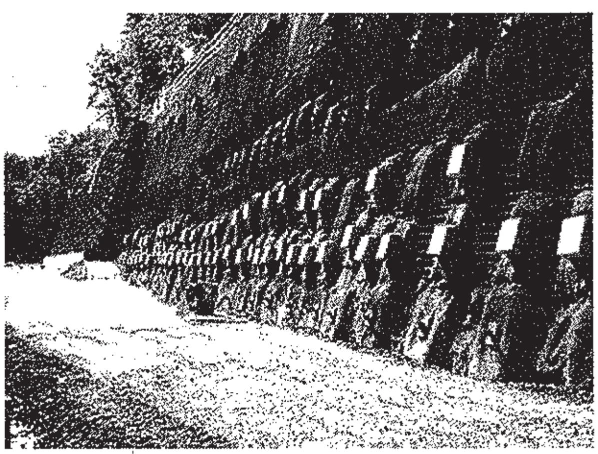

Figure 12. Nailed cutting slope before the construction of the lining system.

2.3 *Stabilization of a sandstone slope*

A cutting in a sandstone rock slope became necessary at the end of a road bridge over the river Main. In the sandstone slope a gravity induced joint system was found which dipped to the slope surface and

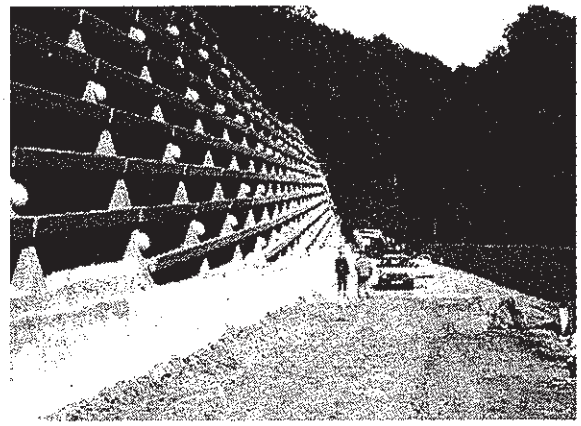

Figure 13. Revetment wall after completion.

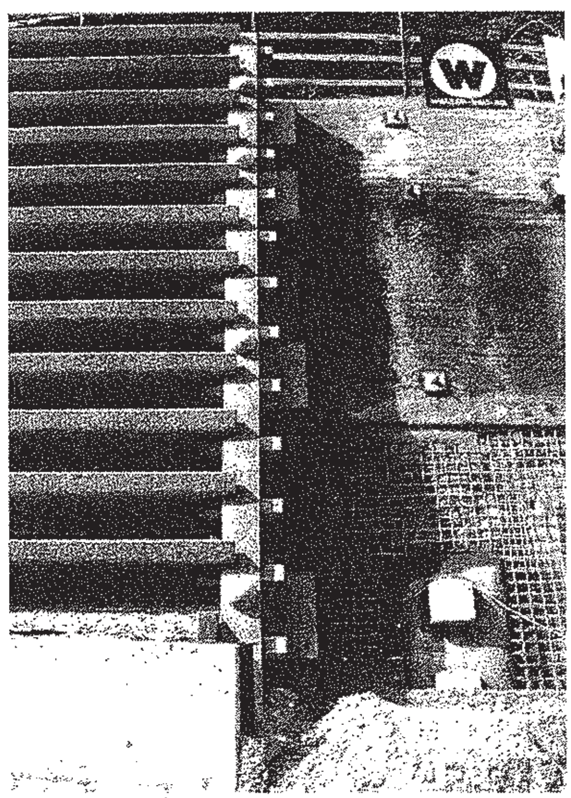

Figure 14. View of the concrete part system and the shotcrete lining.

striked parallel to the slope as shown in Figure 15. Joint systems of this type are very often found especially in sandstone rock. So it became necessary to stabilize the slope already during the excavation using threaded GEWI-bars of 50 mm diameter and lengths up to 12 m. In order to protect the workers against rockfall during the excavation sprayed concrete was used to seal the cutting surface. This concrete lining was kept in place using nails of 28 mm diameter.

Because the area is intensively frequented by tourists the road construction authorities had to cover the concrete shell with a "green" construction. The system always shown in the last chapter was used, and the cutting slope of 18 m height was divided by a berm in two slopes of less height. Figure 16 shows a photograph of the slope during the excavation works, Figure 17 the double corrosion protected soil nails.

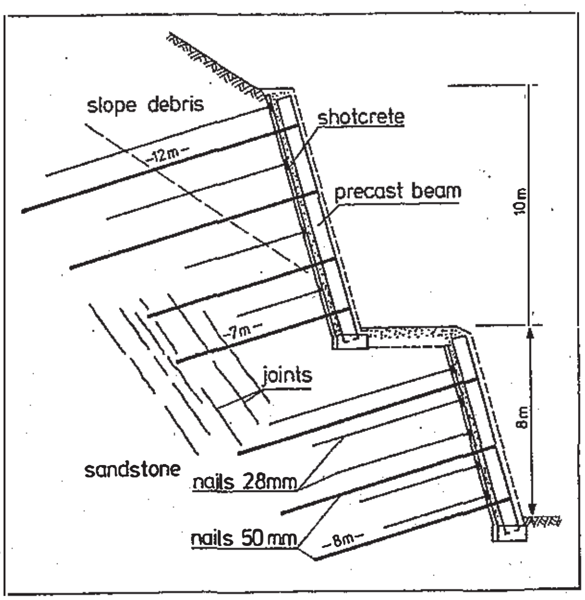

Figure 15. Schematic cross section of the cutting slope.

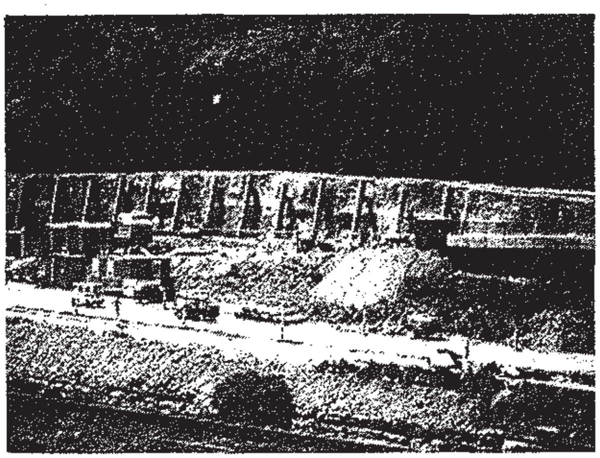

Figure 16. Sandstone slope during the excavation.

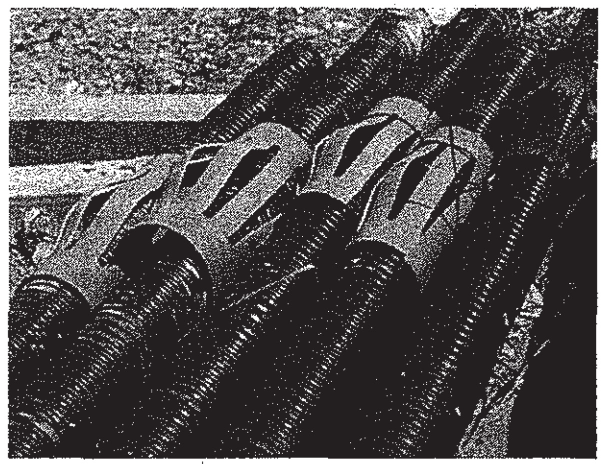

Figure 17. Double corrosion protected soil nails.

3 EXPERIENCES

3.1 *Nailing before setting up the lining*

The experiences have shown that it is possible to survey the starting points for the boreholes exactly enough to string the vertical concrete columns later. This is the condition for dividing the activity of the excavation from the setting of the lining wall, which makes the construction works easier and less costful. In the interest of an obstacle-free workspace ahead of the rock slope the nails should have bell and spigot joints directly before the shotcrete surface. Otherwise there is always the risk of damaging either the nails or the machinery working ahead (or hurting the personnel).

3.2 *Type of nails*

The first precast lining walls used prestressed bar anchors for their support. It may be advantageous in cases where the backfill produces pressure worth mentioning to prestress the front part of the nails before backfilling, and such draw the vertical concrete beams on their support. Otherwise the backfill pressure may produce a split between the part and its support which may be not good for the corrosion protection of the steel nails.

3.3 *Corrosion protection*

The majority of the nails used in Germany for long term constructions is double corrosion-protected. It is useful in the interest of a workman-like performance to test the intactness of the corrugated plastic sheathings of the nails measuring the electrical resistance between steel nail and surrounding ground. It should be higher than 0,1 Megaohm.

Threaded GEWI tie bars may be used for long term purposes also with a simple corrosion protection (cement grout of at least 2 cm thickness) when the working stress is reduced.

3.4 *Construction details of the concrete parts*

The construction of the concrete parts, especially the horizontal beams, needs a good knowledge of the loads caused by the pressure of the backfill and the deadweights of the beam itself and the fill. Otherwise the beam may overturn to the one or the other side. It is not easy to place the reinforcement necessary for the control of the bending moments and shear forces in the cross-section of the horizontal beams, and at the same time fulfill the requirements of the concrete cover. The beams are stressed by oblique bending, and dimensioning them needs experience and exactness.

The horizontal precast concrete parts for bended revetment walls are of very different size (the parts have to be shorter the higher their place in the wall is) and need a very exact performance. Walls of this type therefore are no low cost constructions.

3.5 *Excavation and blasting*

Although there is no recorded damage on the nails caused by blasting in their neighbourhood it should be avoided to blast.

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