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Stabilization of slopes and landslides using soil nailing methods

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ABSTRACT: Landslide-endangered slopes and active landslides are often stabilized in Germany using soil nails. In general two soil nailing methods are used. One method is characterized by a combination of soil nailing using steel tubes as nails, and cement grout injection. The other method uses threaded tie bars as tendons in grout-filled boreholes. The report describes some examples for the two nailing methods, and their advantages and disadvantages.

1 INTRODUCTION

The injection nailing method is characterized by a combination of soil nailing and cement grout injection. Perforated steel tubes of 1.5" or 2.0" diameter are inserted into vertical or inclined boreholes and used as injection channels for the injection of the surrounding soil. The tubes remain in the boreholes as reinforcement nails, and in some cases additionally steel rods are inserted into the tubes before the stiffening of the cement grout begins. The nails are cut some 50 cm below the ground surface, and the ground may be used again for agricultural purposes, such as vineyards, etc. The stabilization effect is a combination of increasing the shear strength of the soil by the effort of the grout, and the nailing or dowelling effect of the steel tubes penetrating the slip plane. The method is very common especially for the stabilization of landslides under difficult conditions because the machinery needed may work even in very steep slopes. The stabilization effect of the grouting depends on the permeability of the soil, and of course it is difficult to estimate and nearly impossible to calculate.

The second method uses threaded steel bars of 32, 40, 50 or 63.5 mm diameter to reinforce the slopes. The nails (simple or double corrosion-protected) are brought into boreholes filled before with cement grout. After the setting of the grout the nails connect the slide mass with the stable underground by skin friction. This method is also characterized by the circumstance that no concrete or steel parts, such as anchor plates, at the ground surface are needed. The nails are cut below the ground surface, and they transfer their forces by skin friction into the slide mass or slide-endangered soil body. Usually nail distances of about 2.5 x 2.5 m are used, and measures with nail lengths up to 24 m have been carried out. The method described has won great actuality after the German reunification when for a large number of old railway embankments in the former communist part of Germany a construction method was needed for the improvement of the stability of the embankment slopes before higher velocities of the traffic on the top could be allowed.

2 LANDSLIDE STABILIZATION USING PIPE INJECTION NAILS

2.1 *Stabilization of a steep slope in Devonian schists*

The landslide occurred in a natural slope near the Mosel river which had an inclination of 30°. The slope was traversed by a new highway, and the area had not been known as prone to sliding before the beginning of the excavation measures. Anyhow the steepness of the slope required the construction of a gabbion wall (length 90 m; max. height 12 m) at the valleyside of the road in order to relieve the slope of the weight of an otherwise required fill. The ground was a heavily jointed Devonion schist. Near the ground surface the joints were widely opened due to gravitational movements of the rock mass. The groundwater level varied locally and was found in depths between 1.7 m and 13.0 m below the ground surface. Some borings showed a complete loss of circulation. The landslide had an estimated cubic content of 370.000 m^3.

The landslide started moving after the road was finished. Reconnaissance drilling showed various faults in the subsoil where the rock was mylonized to a soil (friction angle 22°, cohesion 2.5 N/cm^2, from direct shear tests). Multishot measurements showed a slip plane in about 17 m depth below the

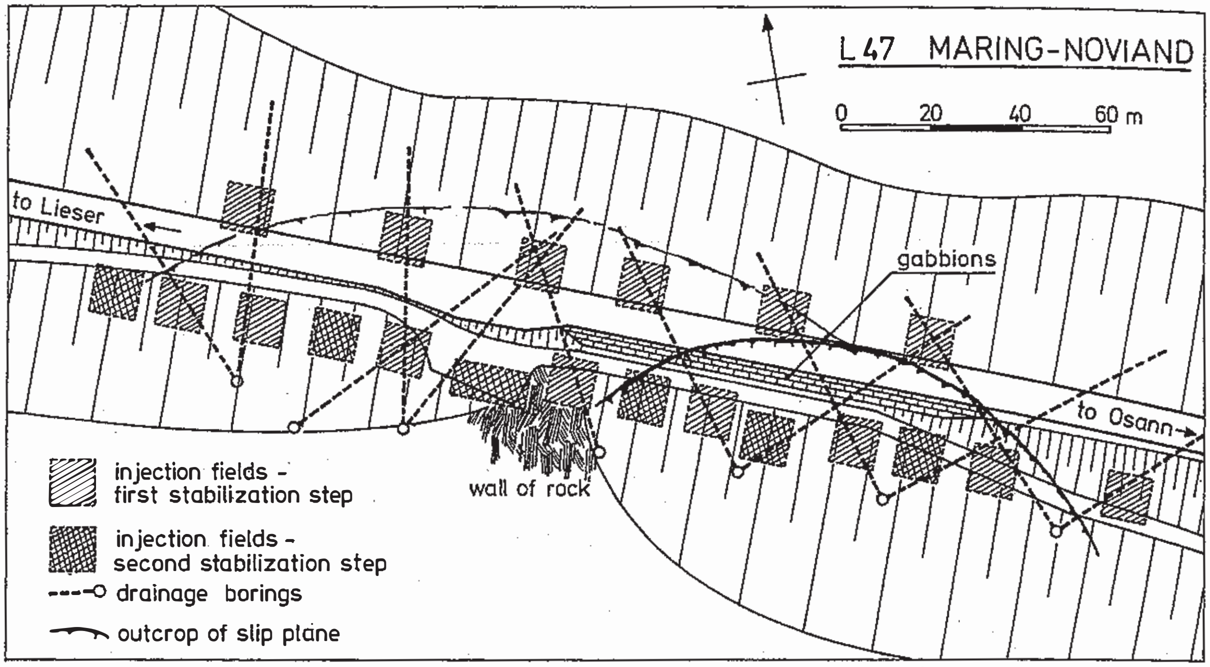

Figure 1. Plan view of the area and the stabilization measures.

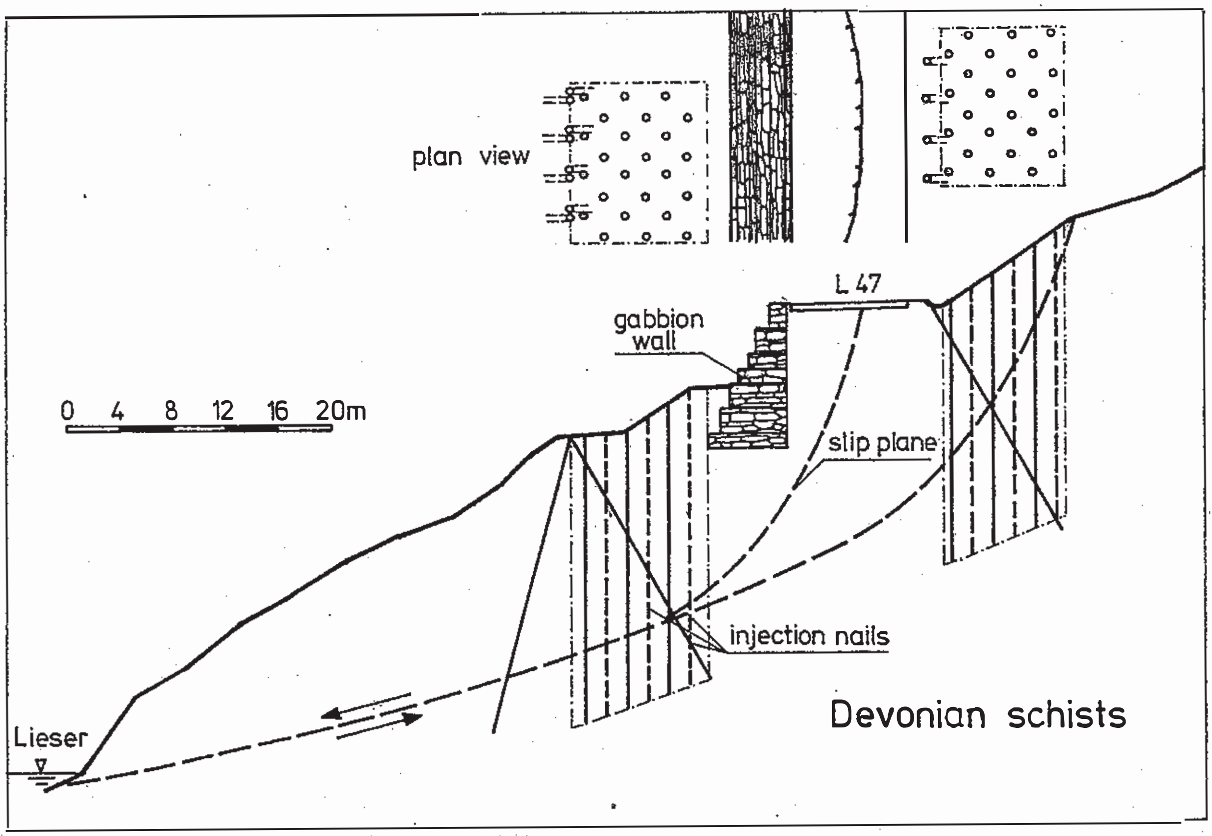

Figure 2. Cross section of the slope.

road. The maximum velocity of the landslide was appr. 2.2 cm/month, the average velocity 8 mm/ month, changing with the amount of precipitation and the season.

The landslide was stabilized using 2"-pipe injection nails which were arranged in groups of roughly 30 pipes each, and drainage borings. The stabilization was planned to be carried out in three steps. In each step only a part of the totally planned number of nails was installed, and the stabilization effect was observed using inclinometer measurements. Only the first two steps were carried out. Figure 1 shows a plan view of the area and the stabilization measures, Figure 2 a cross-section of the slope and the stabilization measures, and Figure 3 a photograph of the situation during the stabilization works.

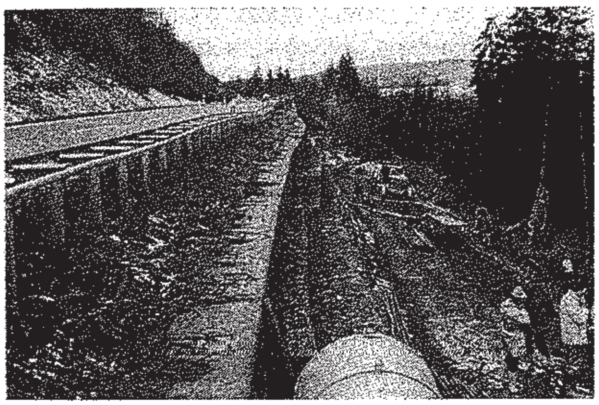

Figure 3. View of the landslide area (with deformed gabbion wall) during the stabilization measures.

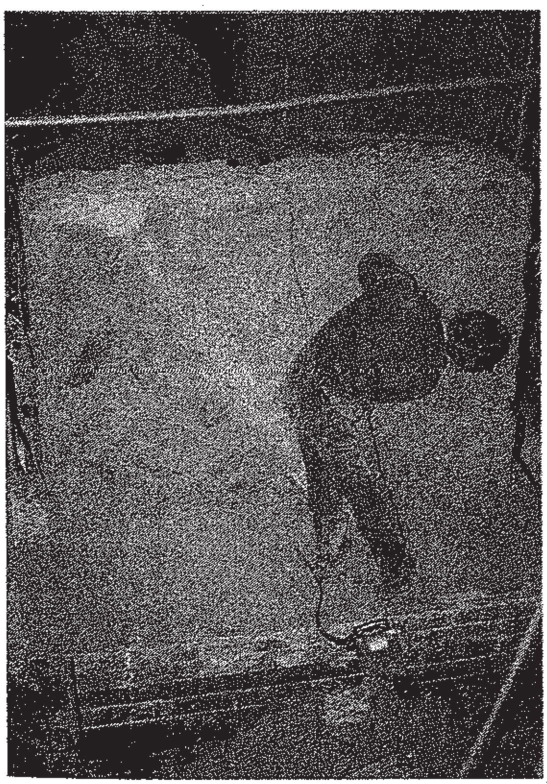

Figure 4. Direct large scale shear test on an injection nail in loess soil (shear box size 2x1x4m, upper shear frame removed).

2.2 *Large scale shear tests on injection nails*

In the past the soil nails very often had been arranged vertically because of easier drilling, and because there had been the imagination that the nails would act as small piles, or dowels. Large scale shear tests (Figure 4) on nails have shown that this is not the case. The nails should be arranged as good as possible in the direction of the most intensive shear extension as shown in Figure 5. The stabilization effect of the injection nails was found to be significantly higher when the nails were arranged correctly as shown in Figure 5 (Wichter, Meiniger & Gay 1991).

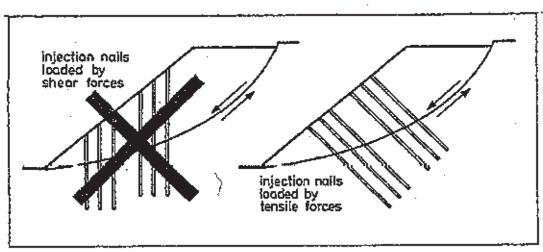

Figure 5. Wrong and mechanically correct arrangement of the injection nails.

3 SLOPE STABILIZATION USING TIE THREADBAR SOIL NAILS

3.1 *Stabilization of a cutting slope under extremely bad ground conditions*

For the construction of a bypass highway in the area of Stuttgart a cutting slope of 17 m height had to be excavated. The ground conditions were difficult. Under an overburden of loess and loess clay of some 5 m thickness an extremely water-bearing stratum of claystones and limestones was explored (see Figure 6) belonging to the geological formation of Lias α. Below this a stratum of partly weathered Keuper Marl followed known in Southern Germany as extremely landslide-endangered as soon as it comes in contact with water.

Because of lack of space at the top of the cutting to a private area and building the slope angle of the upper part of the slope (1:1.9) had to be chosen steeper than it was desirable from a geotechnical point of view, and the lower part of 8 m height was decided to get a reinforcement using soil nails in a grid of 1.40 x 1.80 m, and a shotcrete lining of 4:1 slope angle. The soil nails (double corrosion-protected steel bars BSt 500/550 S, $\varnothing$ 50 mm) had lengths up to 23 m which were determined using circular

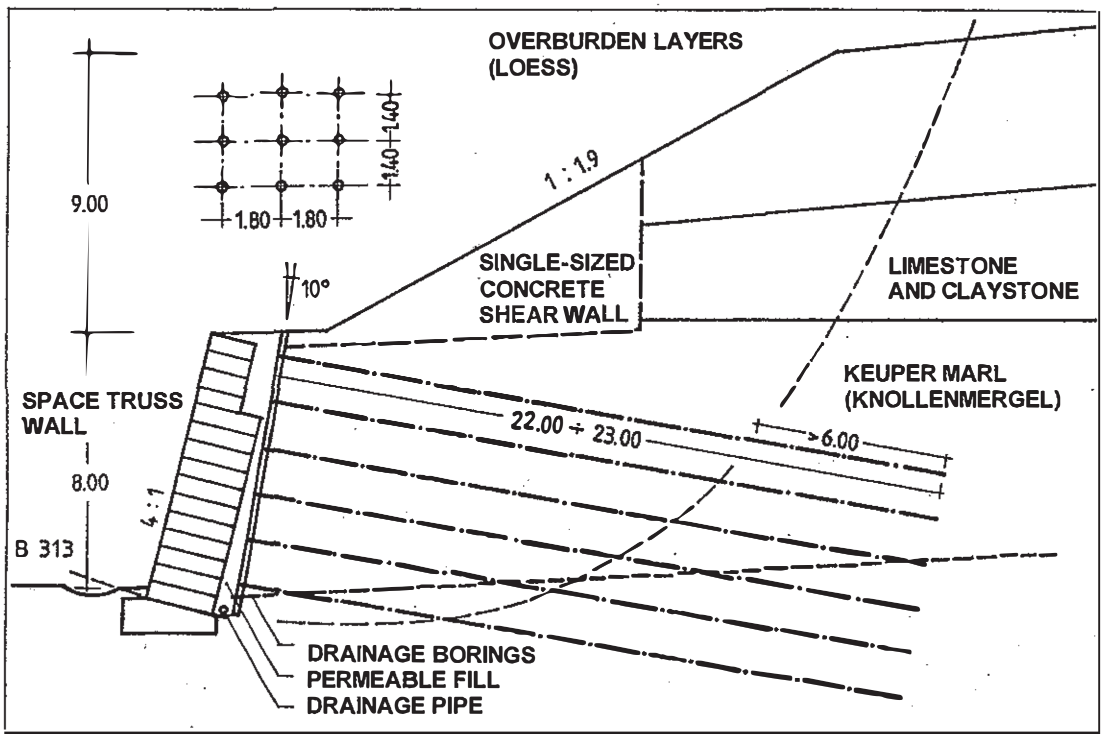

Figure 6. Sectional drawing of the cutting and the nailing measures.

Figure 7. View of the slope during the nailing measures.

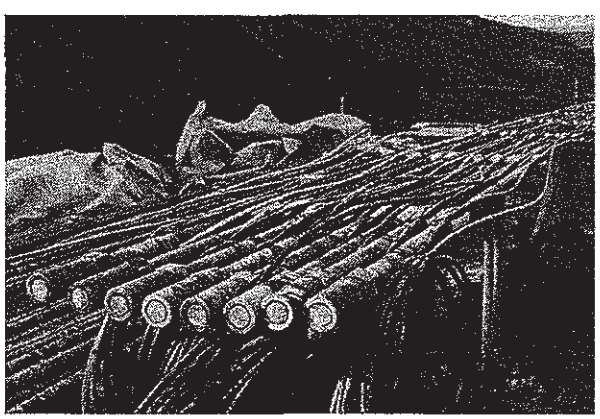

Figure 8. Soil nails with pipes for postgrouting.

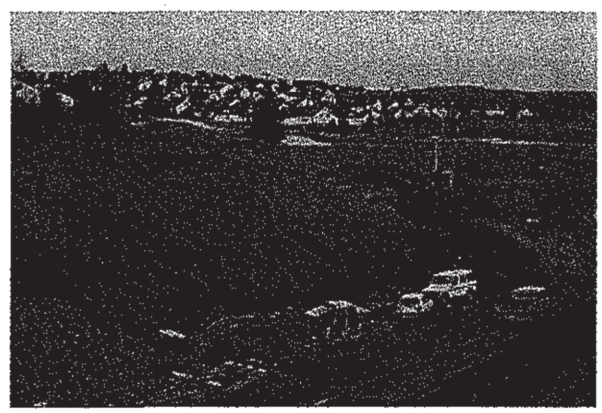

Figure 9. Landslide beside the stabilized slope.

slip planes as failure mechanisms. The shotcrete facing was later covered with a lining wall of prefabricated concrete parts.

Figure 7 shows a view of the slope during the nailing works, Figure 8 the preparation of the nails. As it may be seen on Figure 9 in the neighbourhood of the reinforced slope landslides occurred during a heavy rainfall which forced the authorities additionally to extensive stabilization measures.

3.2 *Stabilization of a cutting slope beside an express railway*

During the excavation works of a cut-and-fill-tunnel for a new express railway slope failures occurred.

The failures were caused by reactivated fossile slip planes in the Keuper Marls following the bedding planes dipping to the cutting. The slope failure necessitated extensive anchoring measures (see Fig. 10) before the tunnel could be constructed and the cutting was refilled (Fig. 10, the measure described here was executed at the right-hand side of the picture).

Immediately joining the western tunnel portal, and under the same geological conditions, the railway was planned to run in an open cutting. The dip of the planned uphill slope was only a bit less than the dip of the failed slope. The danger of new landslides was obvious. Therefore the railway authorities followed the proposal to stabilize the slope by reinforcing it using soil nails. Figure 11 shows a cross-section of the slope and the stabilization measures. The soil nails (threaded steel bars Ø 50 mm, double corrosion-protected) were arranged in a grid of 2.5 x 2.5 m and had length up to 24 m. The stabilization was supplemented by a system of drain-bores, and is surveyed using extensometers. Figure 12 shows the slope surface and the drilling measures for the nails using a special drilling machine. The measure has been described in detail by Samaras, Gäßler & Wichter (1988).

3.3 *Increasing the slope stability of railway embankments*

Many German railway embankments have been built between the years 1850 and 1900. Because of the lack of heavy machinery in those times the fill material normally was not compacted very intensive, and the embankment slopes were built very steep. In the course of the advance of the railway network (especially after the German reunification in 1990) the

Figure 10. Tunnel, filled and anchored cutting.

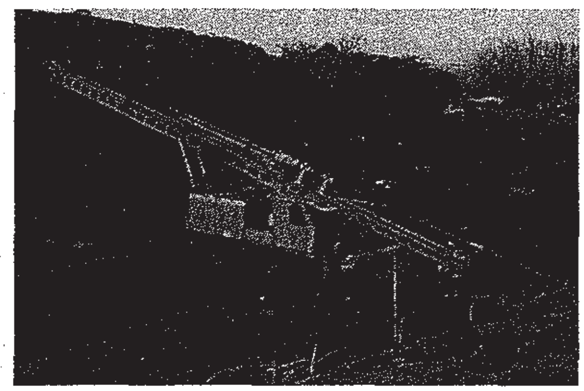

Figure 12. Slope stabilization using long soil nails

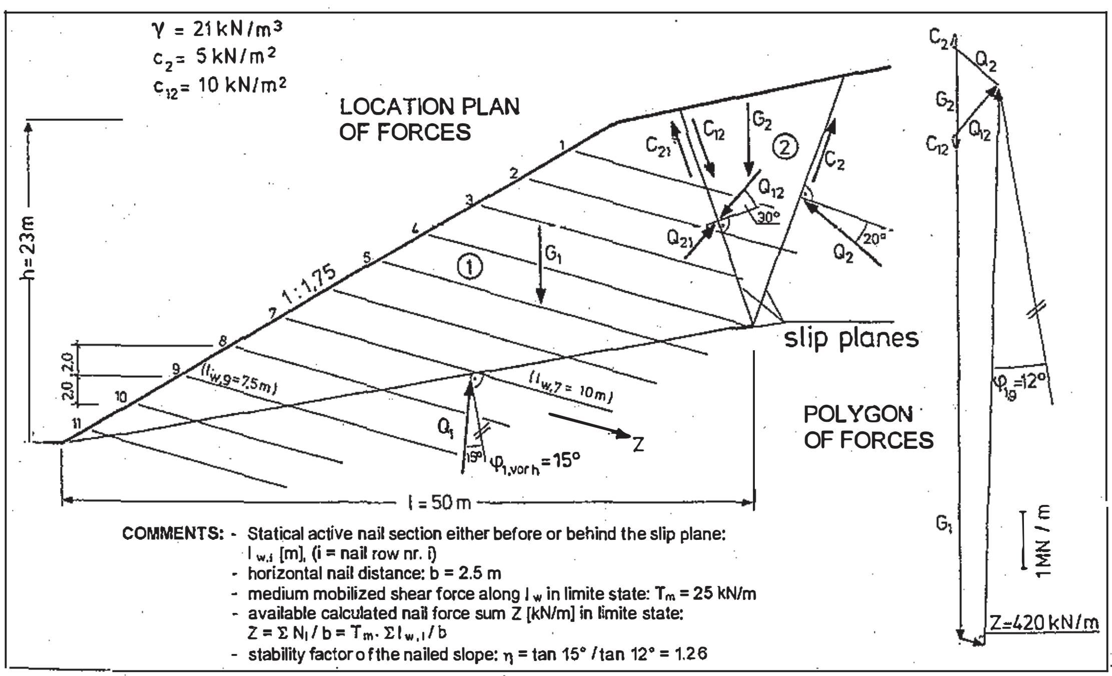

Figure 11. Cross-section of the slope, the reinforcement measures, statical analysis.

stability of many embankments has to be checked and is found often to be not high enough for modern security demands. Following the technical specifications of the German Railway (Deutsche Bahn AG) new embankment slopes have to have a stability factor of $\eta = 1.4$ against sliding (when a lamella method is used). For old embankment and cutting slopes the specifications (DB AG 2000) say.

4 ESTIMATION OF THE STABILITY OF EXISTING EMBANKMENT AND CUTTING SLOPES

(1) This item is valid for the estimation of the stability of already existing slopes and cuttings which are in use without damage and are maintained according to modulus 836.0900 (*a part of the specification*).

(2) If an embankment or cutting is in use and has been without damage, and if it is maintained according to modulus 836.0900 (*a part of the specification*), and if for the future the straining will not be higher than in the past, it may be assumed that it is sufficiently stable and sufficiently able for use.

(3) If an embankment or cutting is in use and has been without damage, and if it is maintained according to modulus 836.0900, but if for the future the straining will be higher than it has been in the past, a competent and experienced expert in geotechnics has to make investigations about the amount of change of straining and it's consequences for the stability of the embankment or cutting.

(4) For embankments or cuttings in use without damage and maintained according to modulus 836.0900 lower stability factors may be allowed than for newly built embankments or cuttings. Only an expert in geotechnics may determine the reduced stability factors. They have to be substantiated and to be made on record.

Even if these specifications allow the choice of stability factors lower than $\eta = 1.4$ there are many embankments with stability factors between $\eta = 1.00$ and $\eta = 1.10$ which need an improvement of their stability. For these embankments very often reinforcing their slopes using soil nails is the most economical method. All measures which need ground beside the railway outside the embankment area, such as landfills, are in many cases impossible to enforce because of the objections of nature and environment protectors.

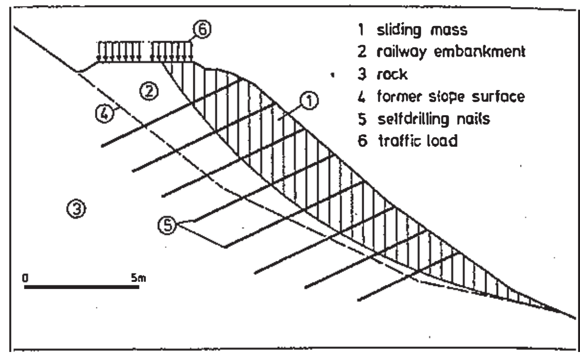

Figure 13. Principle of increasing the stability of railway embankments using soil nails.

The soil nails are arranged normally in the embankment slopes in a grid of 2.5 x 2.5 m, and their length is obtained from stability calculations using circular slip planes and lamella methods. Because of the lower costs and easier handling in many cases self-drilling pipe nails with lost bits are used. The drilling rod remains in the borehole as a tendon, and cement grout is used as a drilling fluid which connects the nails with the borehole wall. The main advantage of these nails is that the machinery necessary for their installation is not very heavy and can be used even on very steep and wooded slopes. The drilling machine is attached to a vehicle at the top of the embankment, or a light-weight drilling rig is fixed on the boom of an excavator or crane having already the dip of the nails. Figure 13 shows the principle of stabilizing railway embankment slopes with soil nails.

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