



# Stabilization of Slopes Vulnerable to Landslides Trough Tubular Anchors

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## Abstract

*This paper presents an anchor of a new design, whose properties have been selected to retain the advantages of a tubular anchor over the other anchor types and at the same time, ensure its adaptation to specific conditions associated with slope stabilization. The proposed anchor consists of a steel tube filled with expanding cement mortar. The outer diameter of the tube is 2-3 mm less than the diameter of the borehole, a groove is cut on the outer surface of the tube. A metal rod is placed in the center of the tube at the outer end of which a support plate is installed, and a tie wrench is fixed. The length of the metal rod is equal to the depth of the bore hole, while the length of the steel tube is at least half the length of the borehole. In the process of solidification and expansion of the solution, pressure is created on the walls of the bore hole. Under the influence of pressure, the pipe is opened around the groove and close contact is achieved between the pipe and the borehole surfaces. As soon as the solution hardens, the steel tube is firmly embedded in the concrete, after which the anchor reaches operational capacity. Preliminary tests of the proposed anchor showed that it has a high clamping force (for hard rock conditions - 46-75 kN/m and for soft rock conditions 32-36 kN/m). He has other advantages, namely it does not require special equipment for installation, the inside of a tube is filled with hard concrete-like mass, which hampers the process of corrosion and increases shear strength.*

*Keywords: stabilization, slopes vulnerable, landslides, tubular anchors*

## Introduction

Recent years have seen a significant increase in the frequency of landslide-induced natural disasters in many countries of the world. It is expected that the number of such landslides will increase together with the growing scale of infrastructure development, which further heightens the need for the development of landslide prevention methods. At present several methods are used to ensure the protection of landslide-prone areas, namely [1,2]:

- Changing slope geometry.
- Installation of water drainage system.
- Increasing ground stability by means of chemical or thermal impacts.
- Using support walls or concrete piles.
- Anchoring.

Anchoring appears to be the most applied method for stabilizing rocks. According to experts, it is the most effective and efficient method for ensuring slope stability. The principle of slope stabilization with anchors is based on the development of bonding forces between the moving mass and the bedrock. A schematic diagram of anchoring slopes is shown in Figure 1.

Currently, cement-ground anchors, as well as mechanical and chemical anchors, are most often used to eliminate landslides. Table 1 shows the design of such anchors and their disadvantages. Analysis showed that tubular frictional anchors can be especially effective for stabilizing landslide-prone slopes. Compared to mechanical anchors, a tubular anchor can develop bonding forces along the entire length of the anchor. It is characterized by high clamping properties. These features are important for securing reliable stabilization of block-type slopes.

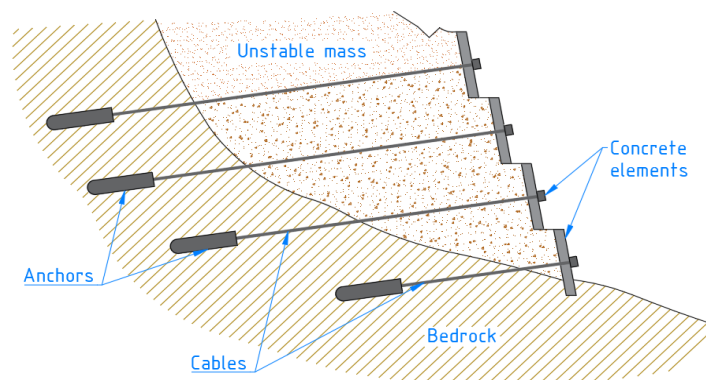


Fig. 1. A schematic diagram of anchoring slopes according to [3].

Tab. 1. The text of the table caption will be here.

Anchor category	Design, installation	Disadvantages
Cement-ground	Anchors are 15 to 32 mm diameter bars, inserted in 30 to 60mm bore holes. They are generally between 3.00 and 6.00m long, and are bonded along their entire length with cement mortar.	<ol style="list-style-type: none"> <li>1. Difficulty of applying anchors to weak soil and installation in deep;</li> <li>2. Low resistance of anchor on the shear force due to low resistance of reinforced concrete bars to the cross strength;</li> <li>3. Low working capacity in the aggressive environment. In particular, concrete corrosion may cause full or partial loss of the anchor's working capacity.</li> </ol>
Mechanical	1-4 m long steel bar with a diameter of 20-25 mm. It is fitted into a borehole by means of a special wedge element.	Can be used only in medium-to-strong rock; the working tensile load is limited.
Chemical	Cartridge of epoxide solution is injected into a borehole; after hardening of the solution a steel bar is firmly fitted into a borehole.	Limited length and tensile capacity of the bolt

Until now, tubular anchors have not been used for stabilizing slopes, but in recent years they have been widely used for supporting tunnels, connecting concrete structures and other purposes [4,5,6]. A tubular anchor has a simple design. It consists of a stainless steel tube and a lower base plate. The tube is placed in a borehole drilled in advance either by a rotary hammer drill or a high-pressure pump (Figure 2).

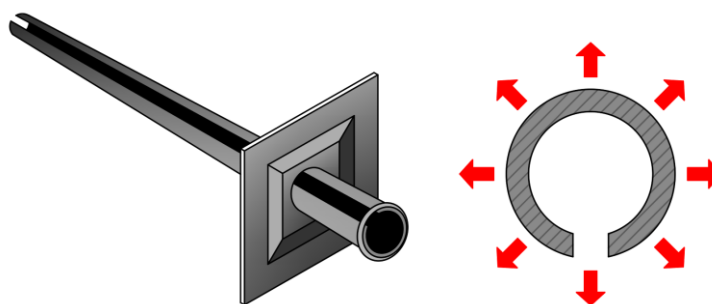


Fig. 2. A tubular anchor "Split-Set" according to [7].

Tubular anchors increase the stability of massifs under a combined impact of the bonding and friction forces between the pipe and borehole walls. The fastening force, which commonly determines. However, tubular anchors currently available on the market have shortcomings that restrict their application to the stabilization of landslide-prone slopes. These shortcomings are caused by the limited length of anchors and the difficulty of their installation, especially in closed spaces or in conditions of emergency. In addition to that, designs of such anchors are characterized by a relatively low resistance to shear force and a high risk of corrosion.

This paper presents an anchor of a new design, whose properties have been selected so as to retain the advantages of a tubular anchor over other anchor designs and at the same time, ensure its adaptation to specific conditions associated with slope stabilization.

### Design and Instalation of Anchor

The proposed anchor consists of a metal tube (1) filled with expanding cement mortar (2). The outer diameter of the tube is 2-3 mm less than the diameter of the bore hole (3); a groove (4) is cut on the outer surface of the tube. A metal rod (5) is placed in the center of the tube and borehole at the outer end of which a support plate 6 is installed and a tie wrench (7) is fixed (Figure 3). To

prevent the solution from flowing out of the tube before solidification, a plug (8) is installed. The length of the metal rod is equal to the depth of the bore hole, while the length of the metal tube is at least half the length of the borehole.

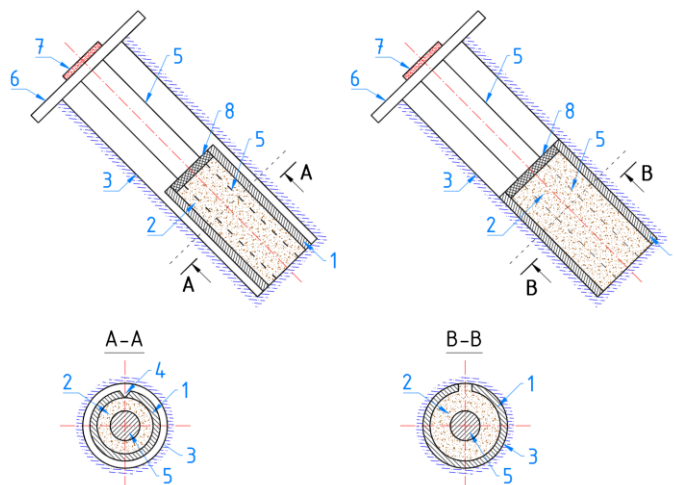


Fig. 3. A) Anchor after its placement in a borehole; B) Anchor after the hardening of expandable material. steel tube (1); expandable solution (2); borehole (3); groove (4); steel bar (5), steel plate (6); screw nut (7); pipe plug.

A steel pipe with a diameter of 42-48 mm with a wall thickness of 2-4 mm is used for manufacturing anchors. The metal tube diameter is 16-20 mm. Cement-like powder known as "non-explosive breaker" is used as an expanding agent (Bristar, Dekspan, KREK.AG, Kayati, NRV-80, etc.). During solidification, the aqueous solution expands, generating high pressure on the walls of the well. The technology for embedding anchor into a borehole is simple: 1. Boreholes are drilled in the slope area to be protected according to the predefined layout scheme; for example, with 2-4 m intervals in a checkerboard pattern. Boreholes shall be drilled to the level that is 0.5-1 meters deeper than the weak ground layer; 2. Prepare a solution of expanding composite; 3. The inner cavity of the tube is filled with solution of expanding composite and a metal rod is placed in it; 4. A tube and a metal rod placed in it are inserted into the borehole before the solution hardens. A metal base plate is put on the end of the metal rod which, in its turn, is fixed with a tension wrench.

#### Study of Pressure Acting on Anchor Tube Walls During the Expansion of the Solution

The following methodology was applied to determine the pressure acting on the walls of the anchor pipe during the expansion and hardening of the solution: A 60cm long stainless-steel tube with a diameter of 38 mm was filled with expanding solution. The pressure on tube walls was determined by the following formula:

$$P = \frac{2\Delta \cdot \delta \cdot E}{(2 - \mu) \cdot r^2}, \text{ kg/cm}^2$$

Where, P is the pressure on tube walls, kg/cm<sup>2</sup>; Δ- tube diameter during expansion, cm; δ - tube wall thickness, cm; E - stainless steel elasticity module, kg/cm<sup>2</sup>; μ - Poisson's ratio for tube material; r - tube radius, cm. The tube diameter was measured every 2 minutes with accuracy of 0,01 mm (Figure 4).

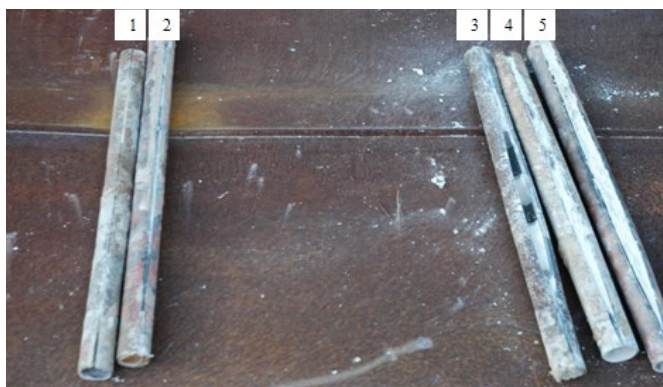


Fig. 4. Steel tube before activation (1,2) and after activation (3,4,5).

Time dependent pressures are shown in Figure 5. Experiments showed that the pressure developed on the tube walls is 45 MPa within 16-20 hours at a ratio water/expanding agent of 0.34.

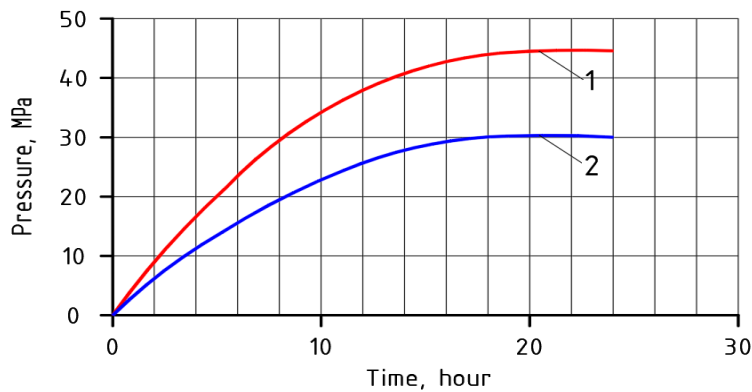


Fig. 5. Time dependent pressures

### Determination of the Clamping Force of an Anchor

Testing was conducted in the drift of the Itkhvisi mine of Georgia Manganese Ltd. The area of the cross-section of the drift was 8,6m<sup>2</sup>. Boreholes with the diameter of 42mm were drilled vertically into the roof of the drift for installing rock bolts. The total length of the rock bolt was 1.4-1.8m. A mixture of expanding material and cement with a ratio water/agent=1:3 was used. 6 anchors with the length of 1.4-1.6 m were tested in the zone of stable rocks, 3 anchors with the length of 1.8m were tested in a tunnel zone where ceiling rocks are relatively weak and a system of cracks is visible on the surface.

Sequences of operations:

- drilling of boreholes;
- preparation of working agent;
- filling of a tube with working agent;
- installation of an anchor in a hole;
- making measurements and conducting observation.

The clamping force of an anchor was measured 24 hours after installation with a dynamometer DUP-20 accurate to ±2 kN. Clamping force developed with the help of a hydraulic device. It has been established that the installation of one anchor takes 1.5-2.5 min on average (without mechanization), while the activation of a rock bolt requires 10-45 min.

The results of measuring the clamping force of a rock bolt are given in the table below (Table 2).

Tab. 2. Anchor properties and the results of the clamping force measuring (Ratio water/agent 1:3).  
Ratio of Expanding Material/Cement, %: 80/20

Type of rock	Length of an anchor, m	Clamping force, kN (average)
Hard (sandstones with the compression strength being 25-30MPa)	1,6	102.6
	1.4	81.3
Soft (sandstones with the compression strength being 12-15MPa)	1.8	58.6

Industrial testing showed that high clamping force and less time needed for the installation of an anchor as compared to the currently applied rock bolts are the advantages of the proposed design.

### Conclusion

A friction tubular anchor of new design was developed. Compared with the anchors currently used to stabilize the slopes, the proposed design has advantages, namely:

- it has a higher clamping force (for hard rock conditions - 45-75 kN/m and for soft rock conditions 30-35 kN/m);
- it does not require a pipeline/tube and special equipment for installation;
- the inside of an anchor tube is filled with hard concrete-like mass, which hampers the process of corrosion and increases shear strength;
- it can be used in limited conditions and in emergency situations, while the length of the anchor is not limited.

### Acknowledgments

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