International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
 ISBN 90 6191 820 0

Proposal for design and construction of reinforced cut slope with steel bars

N.Sano
Laboratory of Japan Highway Public Corporation, Machida, Japan

T.Kitamura & K.Matsuoka
Japan Highway Public Corporation, Tokyo, Japan

ABSTRACT: This paper describes the outline of a reinforced cut slope with steel bars in "The guide of design and execution of reinforced earthwork" compiled by the Japan Highway Public Corporation. For the reinforcement method on cut slopes, steel bars are mainly used as reinforcing materials. Applicable conditions, method of survey, design and construction are given in the guideline. The design method based on the past experiences or the one based on the calculation of stability is chosen depending on the scale of the expected failure. As for the construction method, a procedure is given and the main points are the control of construction work, and the field observation.

1 INTRODUCTION

Our concern in the report is to introduce an outline of reinforcement methods of natural ground in "The guide of design and execution of reinforced earthwork" by Japan Highway Public Corporation. Although some parts of mechanism and design technique in this method has still not been made clear, this method will be widely used for construction of roads, especially in mountainous districts. Here, when the method is applied for a design on the basis of present technical level, only a general idea for the design is suggested. Consequently, if the design is to be executed, it is necessary to study it well.

2 OUTLINE OF REINFORCEMENT METHOD

2.1 Features of reinforced earthwork

To strengthen natural ground with reinforcing materials, steel bars and similar materials are installed into the ground. These members provide tensile reinforcement and/or shearing reinforcement, and reinforced ground and the reinforcements act effectively with each other.

The features of the reinforcement method are as follows.

① Reinforced slopes excavated in stages can largely control the looseness of natural ground due to excavation.

② The method is very safe and economic because the length and intervals of reinforcing materials can be changed properly during excavation while conditions and deformation of the ground are observed.

③ For a delayed deformation after completion of the reinforced slope, counterplans and additional reinforcements are easily applied.

④ Because reinforcing materials are comparatively short and light, they are suitable for application even at sites which large machinery can not enter.

2.2 Selection of method and materials

The reinforced earthwork method has various features as described above, and is used for various applications as shown in Figure 1. It is necessary to select the proper method and materials on the basis of site conditions (including temporary or permanent use), resistance force necessary for reinforcing materials, reliability of design method, and durability and economical efficiency. General cautions on selection of reinforced earthwork are as follows.

① For permanent slopes, it is desirable to avoid designing steep slopes with the reinforced earthwork method. Eventually, it can be thought that application of the reinforced earthwork method is to complement the stability of a slope with the usual gradients.

② On long-term durability and deterioration of reinforcing materials, such as that caused by weathering of the ground,

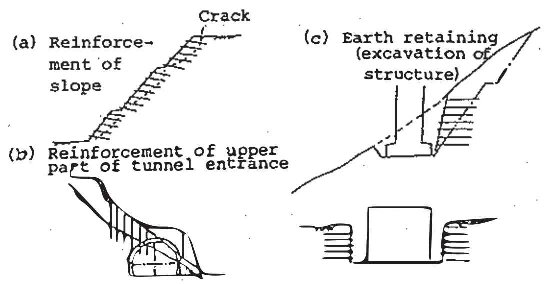


Fig.1 Application example of reinforcement method for natural ground

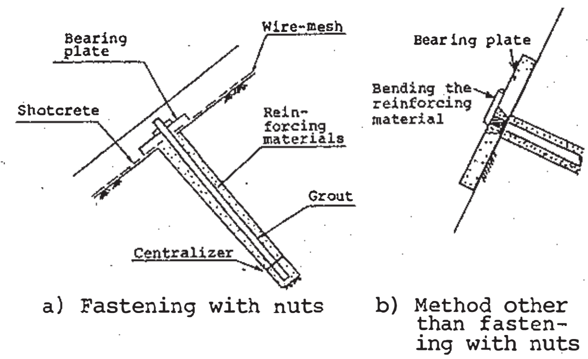


Fig.2 Basic structure of reinforcement method for natural ground

some problems remain because the zone of reinforced ground is rather shallow. Consequently, it is necessary for repairing techniques or methods for that trouble to be considered in advance and its consideration is reflected in the design.

③ It is necessary to select appropriate materials for the reinforcement purpose, though there are many kinds of reinforcing materials.

2.3 Basic structure

As shown in Figure 2, the basic members of the method are divided into three sections: reinforcing materials, grout and bearing plates. As reinforcing materials, rock bolts, steel bars, steel pipes and others are used. Cement mortar, cement slurry and other materials are generally used for grout. By connecting the bearing plate to the reinforcing material, the reinforcing effect can be increased; however the quantitative evaluation of the effect has not been done yet. In a case of the cut slope, sometimes shotcrete is used for surface protection; however, various types of slope protections, such as concrete crib work, have been used.

2.4 Applicable slope types

In this guide, whether or not reinforced earthwork with steel bars can be adopted, depends upon the estimated extent of surface slope failure.

Further, it is important for the design method to be based on the idea of estimating the shape of failure zone of the slope.

Since slope failure is caused by a combination of natural ground conditions, slope shape and external force, their combination should be used in estimating the extent and shape of the failure zone.

3 SURVEY

3.1 Geological survey

Generally, cut slopes do not consist of homogeneous soil; they consist of heterogeneous soils. Most of them show complicated geological sections. Difference in the section changes the sliding force and the sliding shape, which are the basis upon which the length, interval and direction of reinforcing materials are decided. Therefore, in the case of designing reinforcement, it is necessary to find the soil properties, and to survey geological formations (section and shape of layer).

3.2 Pull-out test

In reinforced earthwork, it is important to estimate pull-out resistance, and this is also an indefinite factor. The tensile force of reinforcing materials used for design, is decided by means of a pull-out test of the reinforcing materials before construction. Since the pull-out resistance of reinforcing materials is affected by the construction methods, such as types of ground, qualities of grout, grouting method and types of drilling, the test shall be carried out on the same conditions of those of the construction. In this case, since it is supposed that the pull-out resistance is not proportional to the length of the reinforcing materials, it is necessary to test reinforcing materials of different lengths.

4 DESIGN

4.1 Design procedures

Figure 3 shows the basic flow of the design selection of reinforced earthwork with steel bars. From the slope conditions and from the standpoint of whether a small failure occurs or not, the design is decided; one is a design based on experience. The other is a design in which mechanical stability is confirmed by means of stability analysis. The small failure shown in Figure 3 is the case in which there is a possibility of failure of around 2 m depth.

Furthermore, since the application area of the empirical design overlaps the application area of concrete block retaining wall works or relatively simple retaining wall works, proper use of these methods should be considered carefully.

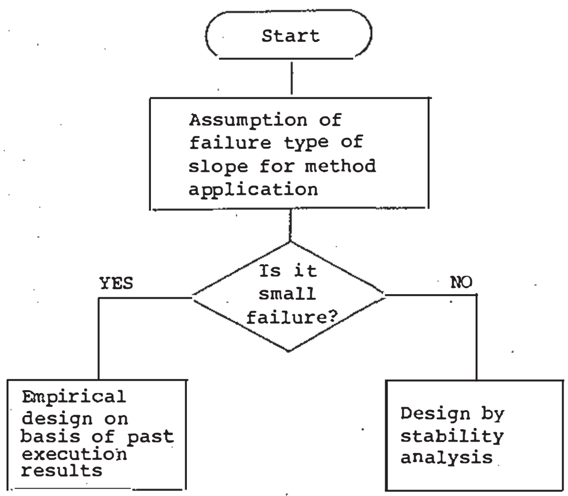


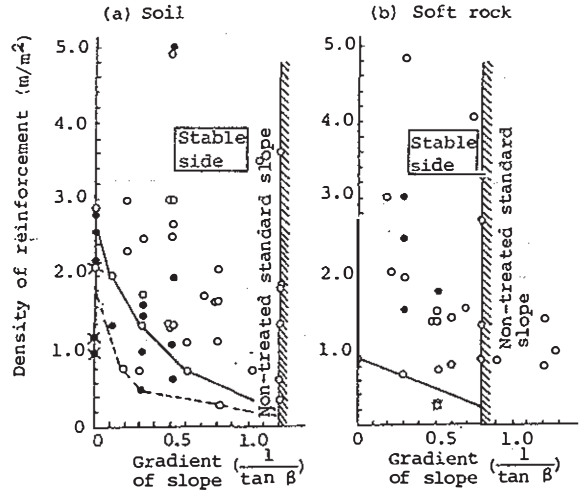
Fig.3 Flow of design procedures

4.2 Empirical design method

According to statistics of the relation between frequency of failure occurrence and failure depth of the steep slope, about 80% of the failures occur with a depth of 2 m or less. This means that relatively short reinforcing materials can restrain against most of the failure. For the ground which leg-drill with short rods can drill, this method is very effective because of its simplicity and economical efficiency.

Further, for the decision of lengths and intervals of reinforcing materials, Figure 4 is instructive. Reinforcement density in the figure is a value that is obtained by dividing the total length of inserted steel bar by the cut slope area. The limiting line of the execution result is the border between the stable side and the unstable side from the data of actual works.

Reinforced earthworks for these failures can be decided based on experience without special calculation because there are small differences, according to past experiences. Table 1 shows the specification of the empirical design method based on past executions.



●: Temporary work
o: Permanent work
×: Deformation
—: Lower limit line of the execution result
----: Temporary limit line

Fig.4 Comparison of the reinforcing effect of soil and soft rock

Table 1. Specifications of empirical design

Parameter	Range
Drilling diameter	ø40mm (equivalent to leg drill)
Diameter of steel bars	D19 ∿ D25
Length of steel bars	2m ∿ 3m
Density of reinforcement	one bar/2m^2
Angle	from horizontal to right angle

4.3 Design method by stability analysis

4.3.1 Standard of design

The design method by stability analysis is based on the ultimate equilibrium method except in special cases. And, the results of this method have to satisfy at least the specification shown in Table 1.

(1) Safety factor

The safety factor of reinforced earthwork shall be considered, on the failure of reinforced slopes and reinforcing members.

① Planned safety factors for failure of a reinforced slope

Planned safety factors for failure of a

reinforced slope are treated in the same way as the case of a slope without reinforcement; it shall have an FS of 1.2 or more.

② Material safety factors of reinforcing members shall be considered as the material characteristics and pull-out resistance of steel bars, etc.

a. Material characteristics

Material characteristics shall be confirmed for tensile force and shearing force. The allowable stress shall be one of the values described in "Concrete Standard Specifications (Japan Civil Engineering Society)."

b. Pull-out resistance of reinforcing materials

In principle, the pull-out resistance should be determined after conducting the pull-out test. The safety factor of allowable pull-out force is 2.0 basically, however, in case of temporary works, the safety factor can be lowered to 1.5.

c. Others

On factors of shotcrete and members of reinforcing steel bar head, although safety factors are not clear, needed stability may be secured according to the construction method described later.

(2) Decision of reinforcing mechanism

This guide explains the design method based on tensile reinforcement or shearing reinforcement from among the several reinforcing effects. A detailed evaluation of each reinforcing effect is given in the following paragraphs.

a. Evaluation of tensile reinforcing materials

The tensile force of reinforcing materials which acts on slip surface is shown in Figure 5.

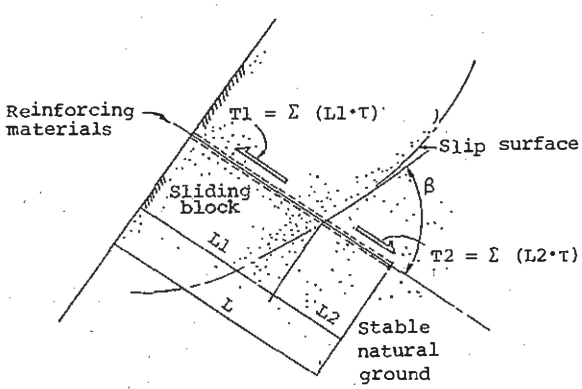


Fig.5 Evaluation of tensile reinforcing materials

Where, the length of sliding block is L1, the length of stable natural ground is L2, the allowable pull-out resistance of each soil layer is τ.

The maximum tensile force obtained from the sliding block is T1. The maximum tensile force obtained from the stable natural ground (pull-out resistance) is T2. The allowable tensile force is T3.

The above items can be considered, and the one with the smallest value is adopted.

b. Evaluation of shearing resistance of reinforcing materials

Although reinforcing materials basically shall be evaluated for tensile materials, reinforcing materials shall be evaluated as shearing resistant reinforcing materials in a case where slope ground consists of rock.

4.3.2 Stability analysis

(1) Study by circular slip failure

Study by circular slip shall be applied in a case where sliding surface is expected to be circular. On a slope which consists of uniform soil, and there is no external force to control the sliding shape, the sliding surface becomes a circular arc.

In the case of cohesive soil and sandy soil ground, the reinforcing materials are not sheared simply because the slope is not a simple sliding surface. Rather, it is thought that tensile force controls most of reinforcing effect, and tensile resistance reaches its limit before the shearing resistance acts effectively. Consequently, in a stability calculation, it is thought that the tensile force of reinforcing materials is acting on the base of sliding block of reinforces the ground.

(2) Study by wedge type slip failure

The study by wedge type slip shall be applied in the case where the sliding surface is considered to be a straight line. In case the cut slope consists of rock with many fissures, joints and bedding, the slope slips down, or is pushed out along these fissures. In that case, most sliding surfaces are regarded as straight lines. It is thought that not only the tensile force, but also the shearing force, acts on the reinforcing materials arranged throughout the sliding surface.

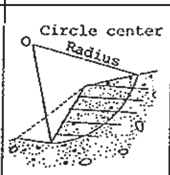
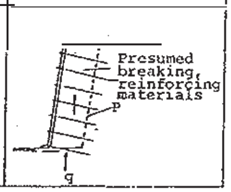
Consequently, the stability analysis is studied from the balance of the sliding force, shearing resistance of the soil on the sliding surface and the shearing resistance of reinforcing materials. Reinforcing materials shall be well arranged inside the sliding surface.

(3) Study by earth pressure

The study by earth pressure shall be applied to the place where gravity retaining wall or concrete block retaining wall works are to be constructed.

The study is based on a method in which reinforced natural ground can be replaced by a gravity retaining wall, which has some limitation. For the imaginary wall, the same stability analysis (check for sliding, overturning and bearing failure) that is used for gravity retaining wall, shall be performed. However, in this case, it must be confirmed that there is no external slip failure slide at the outside of the reinforced ground. In addition, a stability study for slide in the reinforced area is based on items (1) and (2) already mentioned.

Table 2. Relation between sliding shape and calculation technique

Calculation technique	① Study by circular slip failure	② Study by wedge type slip failure	③ Study by earth-pressure
Model example			

5 CONSTRUCTION

5.1 Construction procedure and considerations

5.1.1 Construction procedure

First, an operation, which is drilling and insertion of reinforcing materials and grouting and fixing of head plate, shall be done after the top of the slope (the first stage from top of slope) is excavated. After that, the same operations are repeated with inserting the reinforcing materials in one or two lines. As shown in Figure 6, the excavation in each stage shall be the depth at which the slope is able to stand alone. The depth shall be decided by the test excavation or by the observation of earthwork during construction; generally its height should be 1.5 to 1.7 m on the basis of construction efficiency. When the excavation depth is great, even in the case of natural ground which is able to stand alone, scaffolds become necessary when reinforcing materials are inserted.

The reinforcing effect is provided by tensile force and shearing force of reinforcing members caused with release of stress or small displacement of ground at the time of excavation. Consequently, steel bars shall be installed and shotcrete shall be applied as soon as possible after excavation to avoid loosening of the slope by release of stress or erosion and weathering.

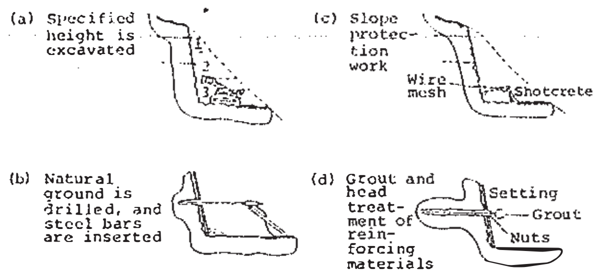


Fig.6 Details of reinforcing method

5.1.2 Drilling and inserting reinforcing materials

The cost and schedule of reinforcing earthwork are greatly influenced by drilling. Drilling efficiency is controlled by ground conditions and construction and scaffolding conditions. The type of drilling machine is limited by the above conditions. Since the properties of soil and geology of the natural ground are very complicated, drilling tests should be done in advance whenever possible.

After drilling, reinforcing materials with grout tube are inserted. After that, the holes shall be grouted as soon as possible before the hole-wall collapses (or after grouting, reinforcing materials can be inserted). Reinforcing materials shall be handled so that rust, oil and dirt, which reduce adhesion, do not adhere to them.

5.1.3 Slope protection work

As shown in Figure 6, slope protection shall be done as soon as possible after cutting the slope. In the case where the slope fails, sometimes small failure will precede large failure. Therefore, when slope protection is done, first of all, it is very important to protect against small failures. For this purpose, slope protection work must be done. Although there are many kinds of slope protection, shotcrete with concrete or mortar should be suitable because these methods can be executed immediately. The effects of the shotcrete method are to unite the earth with the reinforcing materials; heads of reinforcing materials are bound with earth. The reinforcing materials are also bound together. At this time, drain pipes or drainage ditches shall be provided to restrain water remaining in the slope when necessary.

5.1.4 Grouting and head treatment

Except where steel bars are driven into slopes directly, cement milk or cement mortar shall be grouted at low pressure before or after the steel bars are inserted. At that time, quality control of the grout materials and control of the grouting volume shall be done. Further, loosening of the natural ground by grouting pressure must be avoided, and an impermeable zone shall be made by grout leaked into the natural ground. Before grouting, any slime in the holes must be removed.

In a case where the head of reinforcing materials is fastened by nuts, plates shall be set at the head of steel bars, and they shall be fastened with nuts 24 hours after grouting. The torque shall be such that plates make contact with the slope tightly, but a large tensile force shall not occur in the steel bars.

5.2 Execution management

The items covered by the execution management are the shape, dimensions and quality (Japanese Industrial Standard) of the reinforcing materials, combination and strength of the grout materials, as well as the pull-out resistance of the reinforcing materials. The pull-out resistance of the reinforcing material must satisfy the design value within three days after construction.

5.3 Field observation

Reinforced earthwork with steel bars has unsolved problems, and it will be necessary to deal with the change of natural ground conditions. Consequently, an observational procedure like New Austrian Tunnelling Method of tunnels is recommended. In the case where an excavated slope is large and unstable without some protection works, or an influence on important structure in the vicinity of the slope is foreseen by excavation, survey by instruments is recommended. Further, when design is done by stability analysis, since there are still some unsolved problems, at least the surface displacement, the axial tension of reinforcing materials and the underground displacement shall be monitored. In the case of empirical design, the surface displacement shall be measured.

6 CONCLUSIONS

This report summaries research works performed by the committees listed in the References. So far, though various research on reinforced earth with steel bars has been examined, some unanswered questions remain. However, since a favorable effect of the method for slope reinforcement is expected, it is desirable for the questions to be solved through the accumulation of future construction and test results.

REFERENCES

1) Research Committee of the Reinforced Earthwork Method. 1986. A Study of the Reinforced Earthwork Method. Tokyo: Express Highway Research Foundation.
2) Committee of the Reinforcing Method with Steel Bars for Slopes. 1986. A Study of the Reinforcing Method with Steel Bars for Slopes. Fuji: Japan Construction Method and Machinery Research Institute.
3) Research Committee of Measures for Slope Works and Slope Stability on the Highway between Yatsushiro and Hitoyoshi in Kyushu. 1986. A Study of the Reinforcing Method with Steel Bars. Fukuoka: Expressway Technology Center.
4) Compilation Committee of the Reinforced Earth. 1986. The Reinforced Earth. Tokyo: The Japanese Society of Soil Mechanics and Foundation Engineering.