

5.5 Design and Construction of Ground Anchor Works

Ground anchors are reliable, but costly compared with other countermeasures. This method has been applied increasingly to artificial landslides to cut off the toe of the landslide. Compared with rock bolts and soil nailing, ground anchors have a relatively large resistance to sliding force and are therefore used to stabilize relatively large-scale slope failures.

5.5.1 Purpose

Ground anchors are intended to prevent landslides through the tensile strength of high tensile strength steel wire or bars installed across the slip surface.

5.5.2 Design of Ground Anchor

When the slope of a landslide area or sliding surface is relatively steep, ground anchors are more effective. Figure 5.5.1 gives a typical example of a landslide stabilized with ground anchors.

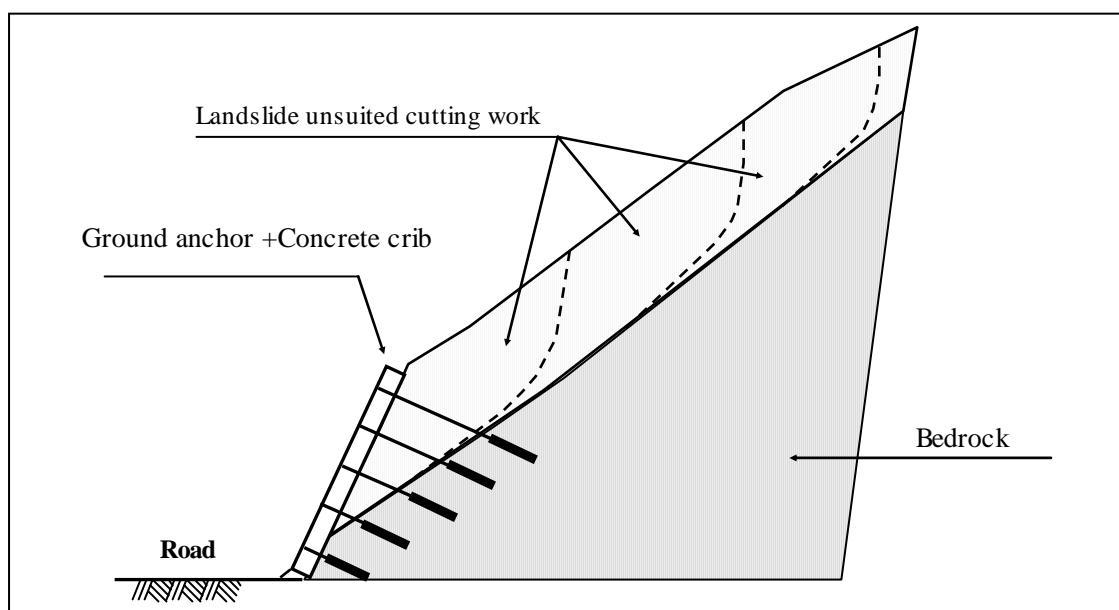


Figure 5.5.1 Typical Example of a Landslide Stabilized by Ground Anchors

(1) Design Procedure

Figure 5.5.2 shows the design flowchart for ground anchors. Important considerations for ground anchors are the bearing capacity of the ground under the bearing plate and the bond strength between the anchor grout and rock at the attachment point. In planning ground anchors, a bond strength test at the attachment is to be carried out.

Further, in planning and designing ground anchors, at least the following site tests should be performed at intervals of 20 to 30 m.

- a) Bond strength test at fixation part (extraction test)
- b) Bearing capacity test of soil mass under the bearing plate

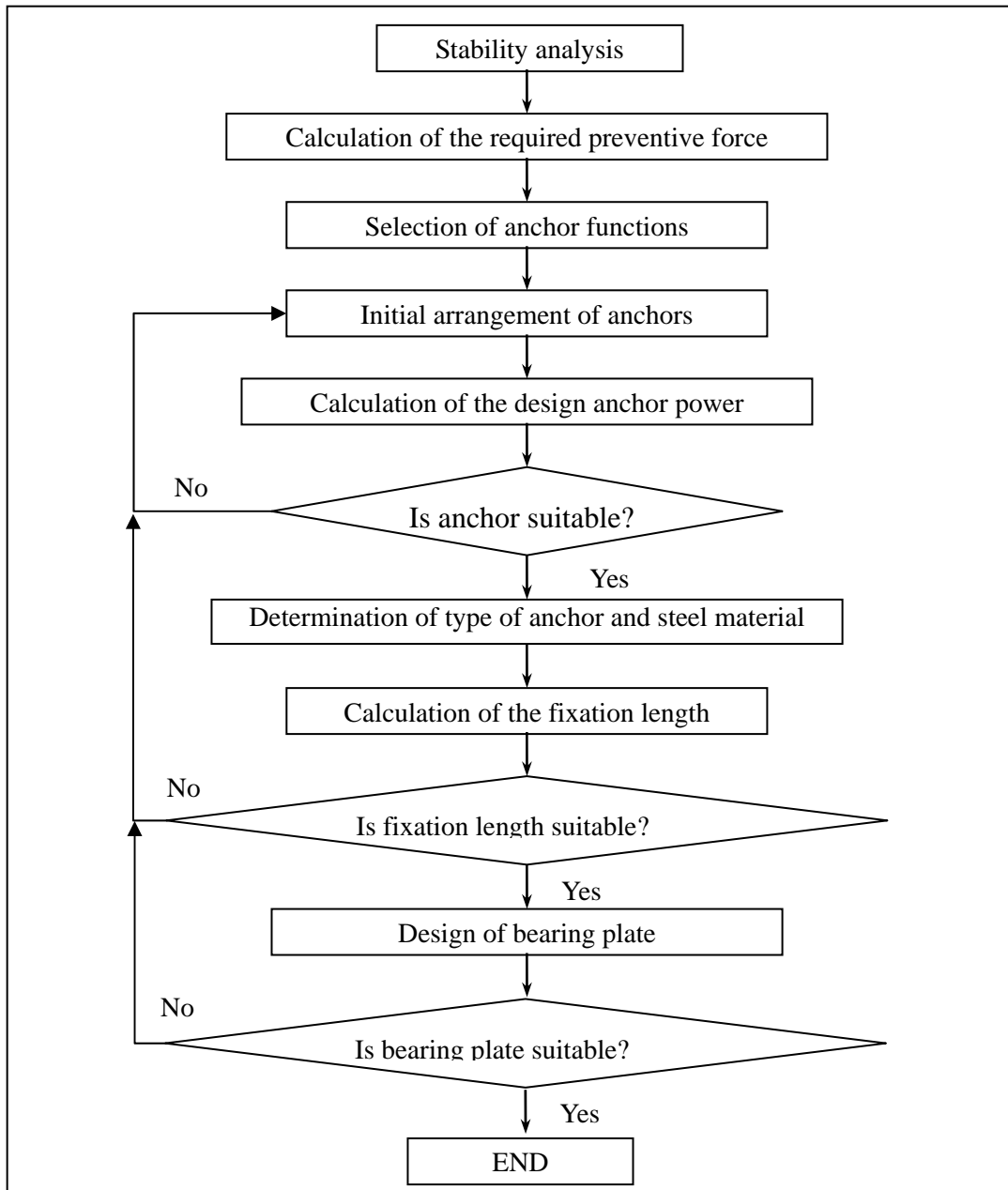


Figure 5.5.2 Design Flowchart for Ground Anchors

(2) Stability Analysis and Calculation of the required Preventive Force

The required preventive power of the anchors shall be obtained from the following Equation, as

schematically shown in Figure 5.5.3.

$$P = \frac{(PF_s - F_s) \times \sum T}{\cos(\alpha + \theta) + \sin(\alpha + \theta) \times \tan \phi}$$

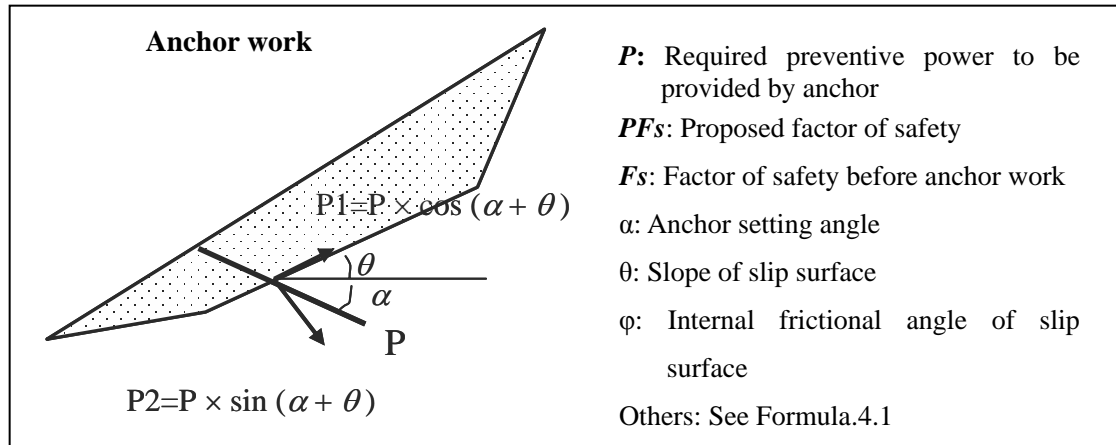


Figure 5.5.3 Schematic Diagram of Effectiveness of Anchor Works

(3) Selection of Anchor Functions

Anchors are installed to achieve the following two objectives (Figure 5.5.3):

- a) Increase the resisting power against shear force by applying stress normal to the sliding surface (clamping effect, P2 shown in Figure 5.5.3), and
- b) Decrease the sliding force of a landslide by using steel members as anchors (straining effect, P1 shown in Figure 5.5.3).

Therefore, an anchor has two kinds of mechanical effects: a) a clamping effect (P2) - To increase the resistance against shear force by applying a force normal to the sliding surface; and b) a straining effect (P1) - To decrease the sliding force of a landslide by using steel members as anchors.

The effect of anchor should generally be selected, in terms of geometry of the shape of sliding surface, as follows:

- a) Select the clamping effect when sliding surface is gentle and deep
- b) Select the straining effect when sliding surface is steep and shallow
- c) Select both effects when sliding surface is at the middle conditions

(4) Arrangement of Anchors

The position, direction and intervals of anchor installation shall be determined during the initial stage of design.

- a) In principle, ground anchor work should be planned on the lower slope of a landslide or unstable area, as conceptually shown in Figure 5.5.4. In addition, when the slope of a landslide area or sliding surface is relatively steep, ground anchors are more effective.

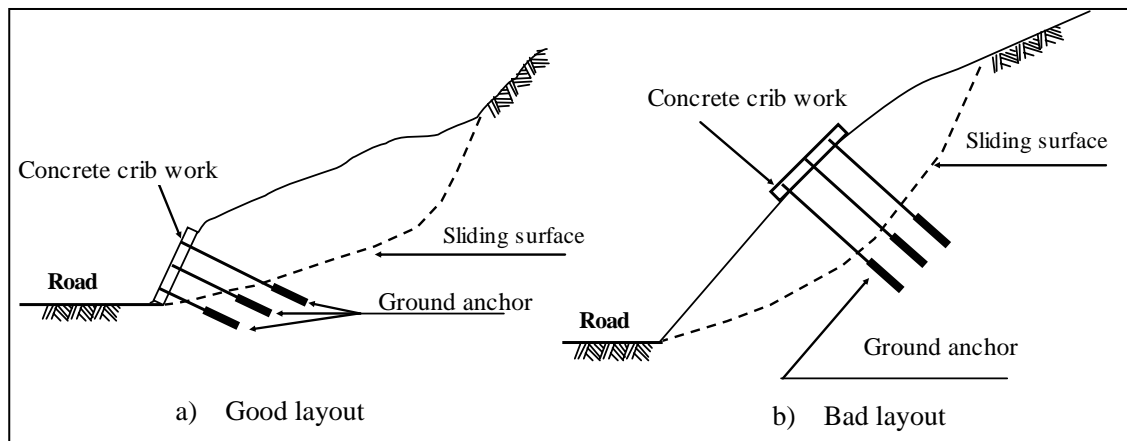


Figure 5.5.4 Conceptual Layout of Ground Anchors

- b) The direction of anchoring should be parallel to the direction of movement of the landslide. The driving force of a landslide in the direction of movement is the biggest.
- c) The inclination of the anchors in a range from $+10^\circ$ to -10° from horizontal plane must be avoided for the reasons related to anchor installation, such as residual slime, bleeding of grout, etc.
- d) Ground anchors should be installed at a spacing of at least 2 meters or more in rows. Anchor interval should be determined based on the interaction between anchors, which can be verified by reviewing anchor power, diameter of anchors, depth and ground properties.

(5) Calculation of Design Anchor Power

The design anchor power (T_d) is calculated by using the following formulas:

$$T_d = \frac{P}{\sin(\alpha + \beta) \cdot \tan \phi + \cos(\alpha + \beta)} \cdot \frac{B}{N}$$

Where,

$$P \text{ (kN/m}^2\text{)} = \text{Required preventive power}$$

α (degree) = Anchor setting angle (the angle to a perpendicular axis)

β (degrees) = Angle of slope of the sliding surface

ϕ (degrees) = Internal frictional angle of sliding surface

B (m) = Interval between anchors in horizontal direction

N= Number of anchors set in vertical direction

(6) Determination of Type of Anchor and Steel Material

Generally, the type of anchor is determined by comparing the tension strength of steel material with the skin frictional resistance between the ground and the grout as well as the allowable adhesive stress between the tendon and the grout.

(7) Determination of Fixation Length

Figure 5.5.5 gives the structural description of an anchor.

Fixation length should be 3 to 10 meters. If the fixation length is longer than the upper limit, 10 m, the allowable anchor force will be largely decreased. When the obtained anchor power at fixation length of 10 m can not meet the allowable anchor extraction force, the anchor power can be increased by enlarging boring diameter, not by extending fixation length

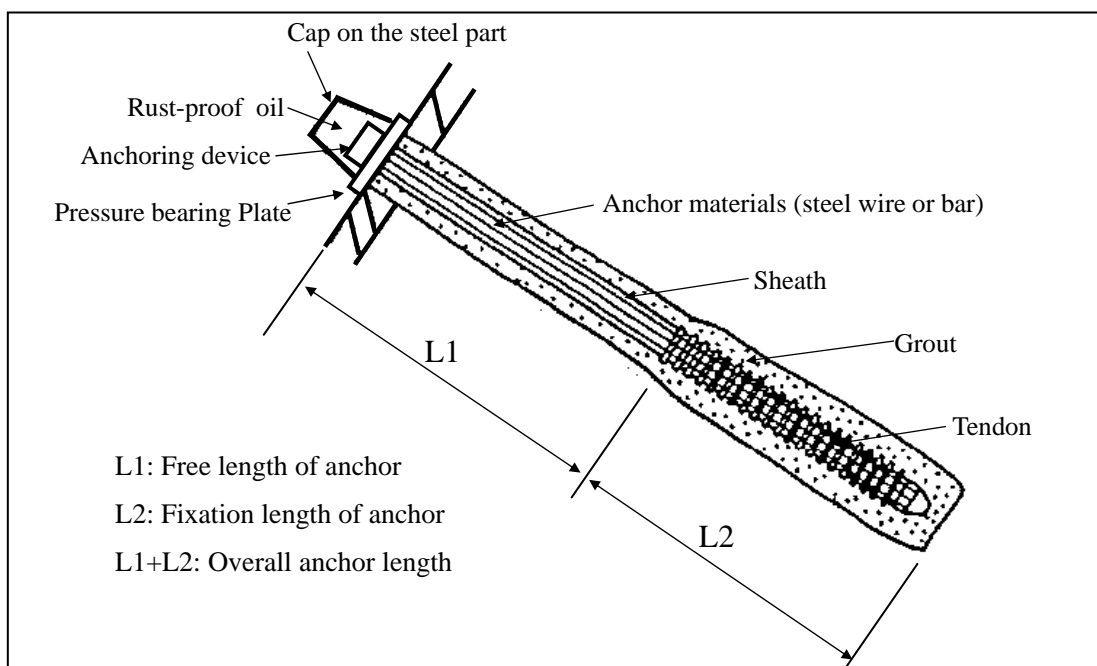


Figure 5.5.5 Outline of Anchor Structure

In addition, the free length of an anchor should be more than its fixation length or more than 4 m. If the free length of an anchor is too short, stress will be applied to an anchored structure by anchors themselves via the ground or sufficient bearing capacity against pull-out force can not be obtained because the shear resistance of the ground or the weight of a soil mass is small. The free length of an anchor should be determined so that the coupling portion of anchors is secured firmly to rigid bedrock in an unmovable stratum deeper than sliding surface. The rigid bedrocks for fixing the anchors should be confirmed through borehole investigation.

To allow the design anchor power to meet the allowable anchor extraction force, the length of contact between the ground and the grout must be compared with that between a tendon and grout. Whichever is longer should be defined as the fixation length.

$$l_{sa} = \frac{T_d}{3.14 \times D_s \times \tau_{ab}}$$

$$l_a = \frac{f \times T_d}{3.14 \times D_a \times \tau_{ag}}$$

Where,

l_{sa} (m) = Required length between the tendon and the grout

l_a (m) = Required length of contact between the soil and the grout

T_d (N/piece) = Design anchor power

D_s (m) = Diameter of a tendon

τ_{ab} (N/m²) = Allowable adhesive stress between the tendon and the grout (Table 5.5.1)

f = Safety factor (generally be defined as 2.5)

D_A (m) = Diameter of the anchor

τ_{ag} (N/cm²) = Skin frictional resistance (Table 5.5.2)

Table 5.5.1 Recommended Allowable Adhesive Stresses

Standard Ground Design Strength (unit: N/cm ²)		240	300	400
Type of tendon	1. Prestressing steel wire	80	90	100
	2. Prestressing steel bar			
	3. Standard prestressing steel wire			
	4. Multi-standard prestressing steel wire			
	5. Deformed prestressing steel bar	160	180	200

Notes: (1) 1 kgf/cm² = 10 N/cm², (2) unit: N/cm².

Source: Modification from Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

Table 5.5.2 Recommended Skin Frictional Resistance of Anchors

Type of Ground		Frictional Resistance (N/cm ²)	
Bedrock	Hard rock		150 to 250
	Soft rock		100 to 150
	Weathered rock		60 to 100
	Mudstone		60 to 120
Sand and gravel	N value	10	10 to 20
		20	17 to 25
		30	25 to 35
		40	35 to 45
		50	45 to 70
Sand	N value	10	10 to 14
		20	18 to 22
		30	23 to 27
		40	29 to 35
		50	30 to 40
Cohesive soil	Representative Cohesion C		10C

Notes: (1) 1 kgf/cm² = 10 N/cm².

Source: Modification from Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

(7) Design of Bearing Plates

Cribs, plates or cross-shaped blocks set on the surface of the ground are used as pressure bearing plates. The most appropriate pressure bearing plate is selected in consideration of specifications, operational efficiency, cost-effectiveness, maintenance, landscape, etc.

Especially, ground anchors should be designed perpendicular to the pressure bearing plate, if necessary, by providing a pedestal or anchor head block concrete, as shown Figure 5.5.6. If ground anchor is oblique to pressure bearing plate, shearing force will occur around the pressure bearing plate, and then possibly cut the ground anchor.

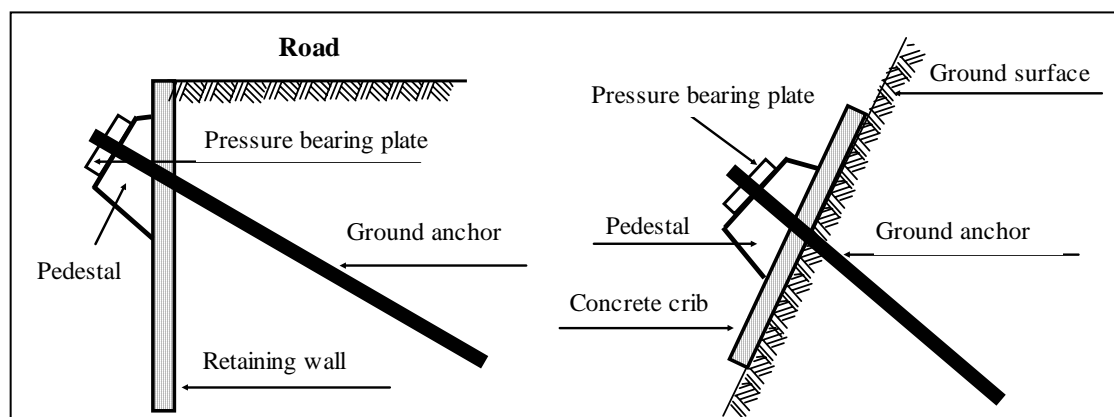


Figure 5.5.6 Conceptual Layout of Ground Anchor Head

5.5.3 Notices of Construction

In constructing ground anchor work, special care should be given, in view of topography, geology, structural effect of anchor, to the following points:

- a) The initial tensile force should be equal to the design anchor power when the clamping effect is chiefly required, whereas, to 40% to 80% of the design anchor power when the straining effect is chiefly required. Moreover, in general, the initial tensile force would be reduced by 10% in about 6 months after installation, and therefore, the anchors should be tightened again. The anchoring device should not be fixed by welding.
- b) Pulling-out test should be conducted to examine the ultimate friction force of anchor for the purpose of inferring the bond length or yield strength between bedrock and grout at intervals of 20 to 30 m.
- c) Corrosion protection should be provided for the entire anchor, including anchor cap, anchoring device and encapsulation of the free length and fixation.
- d) Anchor installation should be avoided in landslides that are in motion at the moment. If the landslide is moving, other countermeasures such as subsurface drainage and earth work should be preceded to stop the movement of landslide. Because, if the anchors are installed while the landslide is moving, earth pressure (or driving force of landslide mass) will act on the anchors while their installation is still under way, thereby resulting in stress concentration and application of earth pressure exceeding that proposed in the design, and the anchors will be destroyed one by one before they begin to function as groups of anchor system. Moreover, during anchor installation (drilling) the use of large quantities of water will activate landslide movement.