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THE DESIGN AND CONSTRUCTION OF EARTH WORKS IN STEEP WET TROPICAL ENVIRONMENT

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Abstrak

Peristiwa kelongsoran lereng yang menyebabkan tertimbunnya badan jalan sering terjadi di beberapa tempat di Indonesia pada jalan yang dibangun di daerah pegunungan pada *terrain* yang curam dan dengan tanah dalam kondisi basah, seperti yang sering terjadi di daerah Sumatera Barat. Demikian pula badan jalan yang dibangun di atas tanah timbunan sering mengalami longsor, terutama pada musim hujan, seperti yang terjadi di jalan Tol Cipularang Jawa Barat. Hal ini banyak disebabkan pada tahap perencanaan tebing maupun kemiringan timbunan tidak memperhatikan atau mempertimbangkan sejumlah hal seperti : sifat-sifat dari material dasar yang dipergunakan untuk timbunan; air tanah dan rembesan; dan konstruksi timbunan. Makalah ini membahas komponen-komponen perencanaan tersebut sebagaimana pemakaiannya pada perencanaan dan pelaksanaan pekerjaan tanah yang permukaannya miring.

Kata kunci : *kelongsoran, lereng, timbunan, jalan*

Abstract

The incident of natural slope sliding which causes the body of the road buried often occur in some place in Indonesia on roads which are constructed under wet conditions and in mountains terrain, as it often occurs in West Sumatera. In addition, the sliding also occurs in the body of the road which is constructed over the embankment, for example sliding in Cipularang Toll road of West Java which recently often occurs. The occurring of slope sliding are caused by the design of fill and cutting of terrain or the making of the slope without taking into account some factors like: the properties of the foundation material for embankment; ground water and seepage; the properties of the fill material; and the embankment construction of. This paper would discuss these design components applied to the design construction of earthworks on sloping ground.

Keyword: *slope, sliding, fill, road.*

INTRODUCTION

Background

Many roads in Indonesia are constructed under wet conditions and in mountainous terrain, and in every rainy season the incident of natural slope sliding are often occur on the most of the roads in those condition. The slope failures is cause by improperly design and constructions and not take into account some factor like the properties of the foundation material for embankment; groundwater and seepage; and properties of the fill material. The example of slope failure, which still in the memory is the slope sliding, occurs in around station 94 of Cipularang Toll Road. The body of the road which constructed over very high embankment has failed just a couple months after constructed or soon after the first rain come down in a torrent. From the investigation are know that the sliding occur cause by ground water and lack of sub-soil drainage system. Other examples of slope sliding occur by ground water and lack of sub-soil drainage system. Other examples of slope sliding often occur in West Sumatera, in West Java, and in many other places, which cause beside by the above factors also because of improperly design and construction. Many cases of slope sliding in both fill of road embankment or cutting of terrain are a background of the topic this paper.

The aim

The aim of this paper is to describe and explain the components and factor of design of slope construction like the properties of the foundation material for embankment; groundwater and seepage; properties of the fill material; and the embankment constructions itself.

A Literature Review

Slide of the rotational and translational type are generally amenable to one of the simple stability analysis, provided the geometry, soil strength, and pore pressure conditions can be satisfactorily defined. It is rare to be able to confidently analyze other types of instabilities such as flow, spreads, or falls, although observational-probabilistic techniques may prove to be of some significant predictive use to the geotechnical engineer and engineering geologist.

The selections of materials for earthen embankments and the detailed constructions control on the placement and compaction of the remolded soil lead to a relatively homogeneous soil mass. It is more likely that the type of instability will be a rotational or shallow translational failure. Natural slopes, however, will fail in a manner dictated by the geological feature of the deposit as well as the strength and geometry of the slope. Clearly, the latter situations can be very complex and has led to very detailed studied of the numerous types of failures which have been observed.

Engineers have tended to concentrate on the details of the applied machine analysis, yet the most difficult problem are commonly the selections of the appropriate shear strength parameters, the variability, and the field pore pressure state.

It is commonly accepted that many major slope failures occur by a mass of soil sliding along a curved surface of rupture. Failures or instability of this type have been observed in slopes of both normally and over consolidated clays, in shale’s and in man-made earthen embankments. In certain circumstances structural features such as bedding, bedrock geometry, fissures, joints, and defects may control, to some extent, the shale of the rupture surface, but it is often possible to approximate the shape by an arc of a circle or a composite surface of two or more geometrically different shapes.

The features of a rotational slide are:

a. The steep escarpment at the upper end of the slide which may progressively collapse with time;
b. A remolded mass of soil at the toe of the failure surface
c. A depth, D, to the total length of the slide, L, of the order of 0.15 to 0.33;

d. A rupture surface of limited thickness, usually a few centimeters;
e. A velocity during the mass movement of the soil of the order of 0.20 to 0.30m'/minute.

Successive slip refers to a series of shallow rotational slides typically in fissured over consolidated clays. Varnes (1978) and Fukuoka (1953) described features of some of the successive slide.

The scope of the paper

The scope of this paper covers the design requirements and construction of embankment and cutting terrain for road construction in wet conditions and in the mountains terrain. The design requirements discuss embankment foundations, ground water seepage and sub-soil drainage and the properties of fill materials.

METHODOLOGY

The methodology on describing and explaining the topic of this paper is based on the comprehensive study of some literatures concerning to the methods of slope stability analysis. All of the methods used to describe the stability of a slope are based on either the limit equilibrium or the limit state analyses. There are variations in the details procedures for predicting the factor of safety as a result of the different approximations or assumptions. In order easy to understanding, discussion will be grouped into five main of chapter analysis, namely General Fill Stability; Embankment Foundations; Groundwater seepage and Sub-soil Drainage; Properties of Fill Materials; and Embankment Constructions. Prior to the all of those chapters are introduction is a background, the aim of the paper and a literature review.

GENERAL FILL STABILITY

The mountainous terrain consists generally of parent rock which is overlain by residual soil on the higher slopes, and by colluviums and other debris on the lower slopes. In steep terrain fills are founded at the base of the slope, the height of fill being dictated by the vertical alignment of the highway. Fills are consequently constructed such that the main part of the fill is founded on either the parent rock or residual soil, whilst the toe of the fill is founded on *colluvium* and general soil debris. A typical section is shown in figure 1.

The drainage properties of the soil or rock foundation have a marked influence upon the overall stability of an embankment constructed on sloping ground. The permeability of rock masses will be dictated by the size and spacing of joints whilst the soil overburden will have a permeability which is controlled either by relic joints or by the permeability of the soil itself.

For residual soils, which have been formed in-situ by the chemical decomposition of the parent rock, the soil structure is relatively open and the permeability of the soil can be expected to be an order of magnitude higher than the same soil in a remolded state, i.e. when placed and compacted as fill. Consequently the placing of fill has effect of cutting off any seepage paths which outfall on the existing ground surface. This effect can also occur where fill is placed in existing stream beds at the bottom of deep gullies. Water flowing along the stream may not be fully collected by a culvert and the excess water, flowing in depressions and joints in the rock which forms the stream bed, becomes trapped by the placement of fill. The result is the development of high pore pressures along the base of the embankment which may cause failure of the fill.

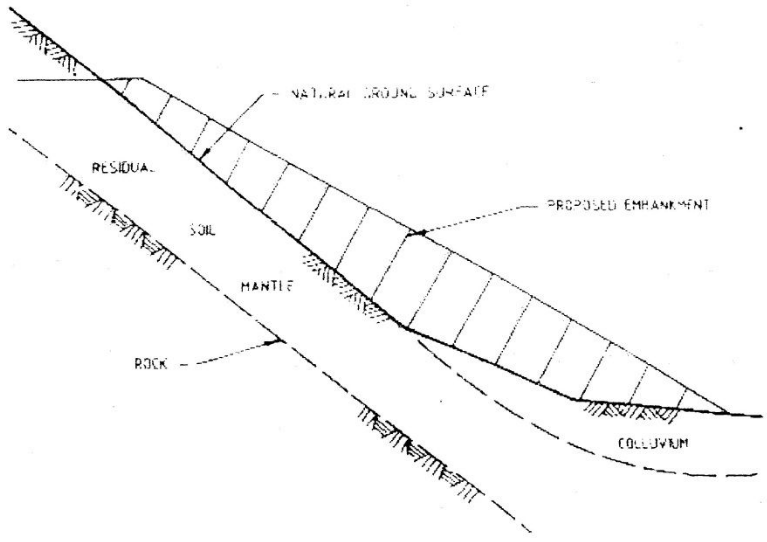

Figure 1. Typical of fill section

Provision must therefore be made, in the design of the fill to ensure that ground water can drain from beneath the fill.

Prior to constructing an embankment an assessment must be made of the strength of the embankment foundation and off the fill material. The foundation which supports the embankment toe must be checked to ensure that failure of the toe will not occur. The strength of the embankment material has to be determined for a density which is reasonable for the type of construction and the climatic conditions prevailing at the site.

EMBANKMENT FOUNDATION

Embankment is constructed with average side slopes which are usually within the range of 1 Vertical to 1 ½ Horizontal and 1 Vertical to 2 Horizontal or about 34° - 26°. The natural ground which forms the toe foundation must therefore slope at less than these values. The natural ground slope beneath the remainder of the fill may be munch steeper and can be vertical.

In steep terrain where natural side slope are often of the order of 35° - 40°, the toe of an embankment will be located at the base of the natural slope close to the valley floor. (One effect of this is to limit the design gradient of a highway to the average gradient of the river valley).

On steep slope, landslides will occur from time to time as part of the natural process of erosion. The landslide debris *(colluvium)* accumulates at the base of the slope and will often from the foundation upon which the embankment is built (figure 1). The *colluvium* may exist as a well consolidated formation or it is necessary to excavates test pits into this material. Loose materials should be removed and replaced at a higher density. If the material has a low shear strength it must be removed and replaced with more suitable material. For embankment constructed of relatively strong material upon a much weaker foundation failure will be by sliding along the weak layer under the active pressures generated by the embankment material. For fill material which is suitable for the construction of embankment the toe should be founded upon material which has un-drained shear strength greater than 40 KPa.

GROUND WATER SEEPAGE AND SUB-SOIL DRAINAGE

High pone water pressures resulting form trapped groundwater are a major cause of failure in fills built on sloping ground. To prevent the development of pore water pressures it is necessary ti provide sub-soil drainage below and within the body of the fill. The design of the sub-soil drainage must consider areas where seepage occurs or is likely to occur from the existing ground surface, and the quantity of water to be removed.

Consider first the location where sub-soil drainage should be provided. Each fill site must be inspected both before and after any necessarily clearing of vegetation. This should preferably be done after heavy rain. Seepage which is visible on the ground must be recorded. In additional seepage can be expected to occur at any of the following locations:

a. <u>Changes in Slope</u>

The capacity of the ground to carry water is proportional to this slope. As the slope out, its capacity reduces until it is unable to carry all of the ground water. The excess water leaves the soil and either evaporates or continues down the slope as surface water.

Seepage may also occur where the slope becomes steeper if the steep slope also reduces the thickness of the soil cover. The reduction in soil thickness reduces the effective flow area and excess water will leave the soil at the surface.

b. <u>Rock/Soil Interface</u>

The permeability of any underlying rock is controlled by the number and size of the joints. For reasonably intact rock masses the permeability will be less than the overlaying soil. The rock interface forms a barrier to the flow of water which is forced to flow along the surface of the rock. Where the rock outcrops on the natural slope, seepage can be expected to occur.

c. <u>Thinning of the Soil</u>

In steep terrain it is not uncommon to find rock outcropping in the stream beds. Moving away from the stream and up the valley sides the soil cover increases in thickness. Groundwater flowing down the slope, through the soil mantle will be forced to the surface as the soil mantle becomes thinner.

The most efficient form of sub-soil drainage is a drainage blanket constructed against the existing slope as in figure 2. This type of drainage system has the following advantages:

- It will intercept seepage water at all locations along the natural ground surface.
- It will provide drainage for rainwater which enters the new fill preventing the development of pore pressures within the embankment.
- When constructed upon steeply sloping ground the capacity of the drainage blanket is much higher than horizontal sub-soil drains.
- Construction of the blanket is straight forward and can be placed along with the normal filling operation.

To be effective the drainage blanket must satisfy the following conditions:

- It must cover all areas where seepage can be expected.
- It must be thick enough to carry the estimated volume of seepage water.
- It must be suitably graded to ensure that erosion of the natural soil into the drainage material is prevented

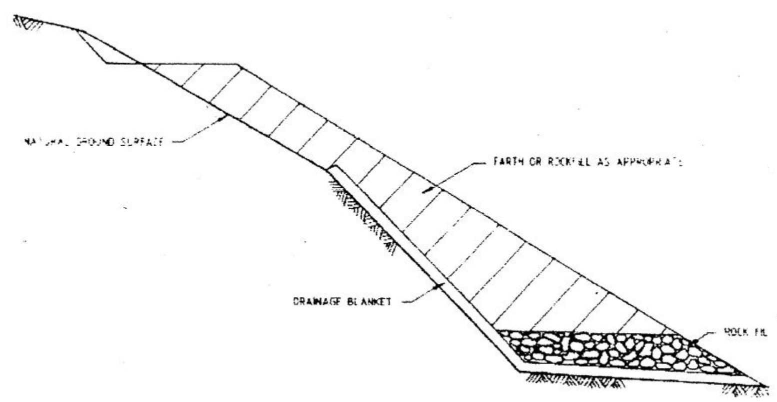

Figure 2. Typical drainage blanket

Discussing each of these conditions in detail

The area to be covered by the drainage blanket should be determined on site. By reference to the points discussed above, drainage should be provided on side slopes:

- To cover all visible seepage points.
- To cover all interfaces between soil and rock.
- To cover the area below a significant flattening of the slope.

It is recommended that the drainage blanked should, as a minimum, extend to 50% of the fill, and at a maximum the drain should finish at least 6 meters from the top of the sub-grade (measure along the ground surface).

The required thickness of the blanket can be estimated from the permeability of the drainage material, the slope of the drain, and the estimated quantity of seepage water. The quantity of seepage water can be estimated from the permeability of the soil and the measured catchments area.

There is also a minimum thickness for the drainage blanket which is dictated by construction requirements. This has been found from experience to be about 600mm.

The capacity of the drainage blanket can be estimated using Darcy's:

$$V = Ki$$

Where: V = velocity of flow

K = coefficient of permeability

I = hydraulic gradient

Estimation of the quantity of seepage water to be catered for can be very difficult if carried out thoroughly. For roadwork a vigorous analysis of groundwater flow is usually not required.

Rainwater entering the soil will do so at a maximum rate which is equal to the soil permeability (i.e. the hydraulic gradient is unity). The permeability of the soil can be obtained, approximately, from its grading or more accurately from filed test.

The absolute maximum quantity of water which can be carried by the soil foundation is:

$$Q = V \times A$$

Where: Q = flow

V = velocity = K in this case

A = catchment's area

If this quantity of water can be adequately carried by the minimum drainage blanket thickness there is no need for further calculations.

If the minimum drainage blanket is not sufficient for the estimated quantity of water, the estimated capacity of the soil mantle can be refined by using the relationship:

$$Q = K \sin \theta \, t \text{ (per unit slope width)}$$

Where θ is the natural ground slope and t is the total thickness of soil overlaying rock. Once again if this value is less than the capacity of the minimum drainage blanket thickness no further work is required.

Where the volume of seepage water is higher than the capacity of the drainage blanket it is necessary to estimate how much of this water will be intercepted by the drainage blanket. Simple flow nets can be used for this purpose. For example where the toe of an embankment is close to a river at the bottom of a slope, a high percentage of the groundwater will be intercepted.

It is important to ensure that the drainage blanket under the toe of the fill has adequate capacity. The capacity of a drain on a slope of 1 Vertical to 1½ Horizontal is 12 times that of a slope of 1 Vertical to 2 Horizontal.

The drainage of the drainage blanket material should allow the maximum possible permeability without allowing either the natural material or the embankment fill material to erode through the drainage blanket.

To prevent erosion of the natural soil it is normally recommended that the D_{15} size of the drainage material should be not greater than 5 times the D_{85} size of the surrounding soil. However for plastic soils with PI of over 25% a value of 8 times the D_{85} size is satisfactory. It is also recommended that the coefficient of the drainage (ratio of D_{60} to D_{10}), be not greater than 20.

To ensure a realistic increase in permeability between the drainage material and the soil it is recommended that the D_{15} size of the drainage material should be at least 5 times larger than D_{15} size of the soil. (Note: D_{85}; D_{60}; D_{15}; D_{10} is the diameter of particle of drainage material at which 85%, 60%, 15% and 10% of the soil by weight is finer).

PROPERTIES OF FILL MATERIALS

A completed embankment must satisfy two basic requirements; it must be structurally stable and must not be subject to excessive settlements after completion of the pavement surfacing. The overall stability of the embankment is a function of the strength of the soil and the groundwater condition. The time required to complete the settlement of the embankment is a function of the permeability of the permeability of the embankment material and the excess pore pressure present at the time of completion of earthworks.

Provided that adequate sub-soil drainage has been installed it is reasonable to assume that fully drained condition will apply with zero pore pressures once any construction pore pressures have dissipated. Hence the pore pressures which develop during the construction of an embankment control both the initial stability of the fill and the amount of settlement which takes place completion of the earthworks. During the early stages of a major earthwork project it is important to determinate whether or not construction pore pressures are likely to be a problem. This can be done by simply measuring the increase in pore pressure in the embankment material due to placing additional fill material. Any increase in pore pressure should then be monitored to establish the rates at which these pressures dissipate. Alternatively the settlement of an embankment can be recorded at different levels within the fill over a period of time. The data obtained from the measurement of settlement with time gives an accurate estimate of the rate of pore pressure dissipation within the fill.

The development of high construction pore pressure will be a problem only where continuous rainfall makes it impossible to prevent saturation of compacted materials and where fills are very high (over 0 meters). Where this situation occurs drainage layers must be built into the embankment as construction proceeds to accelerate the rate at which water is expelled from the fill. Internal drains may be formed using either rock blanket or manufactured drainage materials which are placed in the fill during construction.

The design of the embankment side slopes should use drained soil strength parameters and the highest pore pressures which can be expected during the construction of the fill. The strength of the soil should be measured on soil samples compacted to a density which can be expected on site. The normal range of densities specified for the lower parts of an embankment is between 90% and 100% of the standard (2,5kg rammer) compaction test. Higher densities should always be specified for the top meter or so below the sub-grade.

EMBANKMENT CONSTRUCTION

The first step in the construction of fills in step terrain is the provision of access. Access is required initially to haul out any timber or other vegetation which may have to be removed from the slope. Having cleared the slope, the toe of the embankment must be benched to provide a foundation suitable for placing the drainage blanket. It is recommended that whenever possible the lowest three meters of the fill should be constructed using rock fill. This will ensure that the toe of the fill is adequately drained.

The slope above the toe must be progressively cleared above the advancing fill. Clearing should ideally be carried out between access tracks to prevent loose soil and vegetable material from sliding down the slope and contaminating the fill. Where a drainage blanket is to be provided against the natural ground, all loose and unsuitable material must be removed.

Compaction of the ground prior to placing rock fill is not necessary, see figure 3.

Fill material should be placed directly from cut without the use of intermediate stockpiles. In this way the fill can be placed at or close to the optimum moisture content for compaction, see figure 4.

Compaction must be carried out as the material has been placed and the surface of the fill should be left sealed and profiled to prevent pounding of water on the fill. Provided that these precautions are taken, earthworks can proceed during dry periods with only minimal delays resulting from rainfall.

Adequate temporary drainage must be provided above cleared slopes to prevent the washout of unprotected slopes and earthworks.

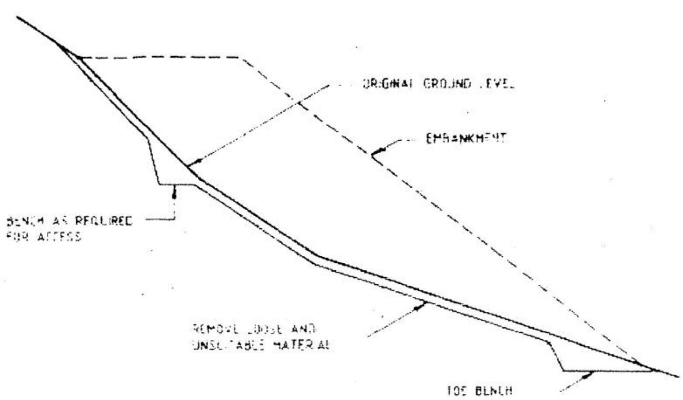

Figure 3. Slope clearing and preparation

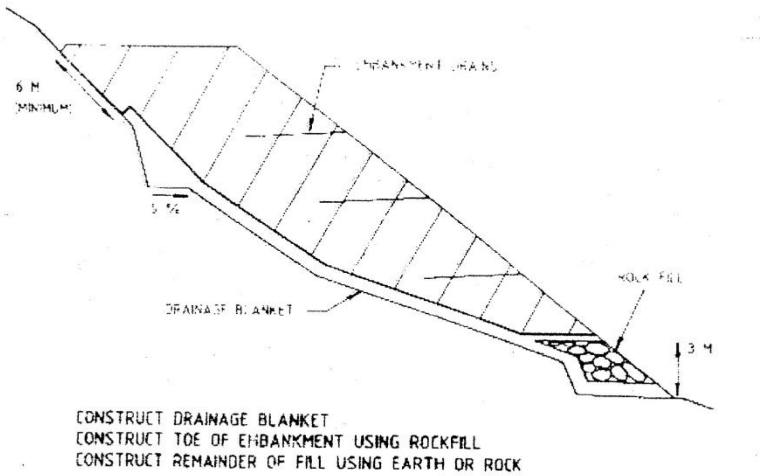

Figure 4. Embankment construction

CONCLUSION

The design and construction of earthworks in steep wet tropical environments requires an appreciation of the importance which groundwater plays in the stability of earthworks. Measures are required to ensure that groundwater is satisfactorily drained from below and within major embankment both during and after constructions. The degree of compaction to be specified for the earthworks must take account of the difficulties which will be encountered during the project as a result of heavy or relatively continuous rainfall. The use of regular sub-soil drainage during the construction stage will may otherwise occur as water trapped in the fill is slowly released.

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