A Simple Design Chart of Drainage Works for Embankment

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ABSTRACT: The embankment on the natural slope is often damaged by the heavy rainfall. A simple chart of drainage works for embankment was made by seepage analyses and stability analyses by PWRI. It was verified as a case at Yamaguchi. This chart can ease for engineers to evaluate the instability and select the proper countermeasure by inputting embankment conditions and hydrological information.

1 INTRODUCTION

IPCC (Intergovernmental Panel on Climate Change) has reported at Fourth Assessment Report that danger of serious damage will certainly rise by global warming due to the human activity. Temperature, flood of the river, abnormal weathers such as typhoons and hurricanes will influence.

It is predicted that the sea level will increase gradually by the increment of 120 to 200cm at the end of this century. National Disaster Warning Centre in Thailand is warning that Bangkok will sink in the sea by 2020 if the government does not consider some measures about global warming and the subsi-dence within several years.

Therefore, DOH and PWRI will start to develop the new costless soil improvement techniques for 5 years from 2010, which is for raise of road embankment height against the water depth increase, which will be occurred by the see level increase or flood. The water depth by the flood should be examined to find the area, where the road height would be raised.

Such surface water increases together with groundwater, which might also occur slope instability more frequently than before as seen in Figure 1.

The authors have studied a simple procedure to find the proper drainage countermeasure to lower water table. This design chart could be used as the preliminary examination of necessity of drainage works for the similar embankments at many places in Thailand and Japan.

Figure 1: Embankment collapse in Yamaguchi by heavy rainfall due to Typhoon No.14 in 2005.

2 SIMPLE PROCEDURE TO FIND PROPER DRAINAGE WORKS

2.1 *Verification of effectiveness of seepage analysis by experiments*

Drainage works are expected to effectively improve stability of embankment. This was confirmed by the experiments although conducting a small embankment on slope, which is only 4 m high. Water table at the natural ground part was set to be constant in these tests. Two cases of tests, where the lengths of blanket were set to 1/4 & 1/2 slope length. The longer the blanket is and the more stable the embankment is as the water table would be lowered.

As the seepage numerical analysis could be coincided with the experiments very well, it can be concluded to be able to use numerical analysis for investigations of the change of water conditions by drainage works.

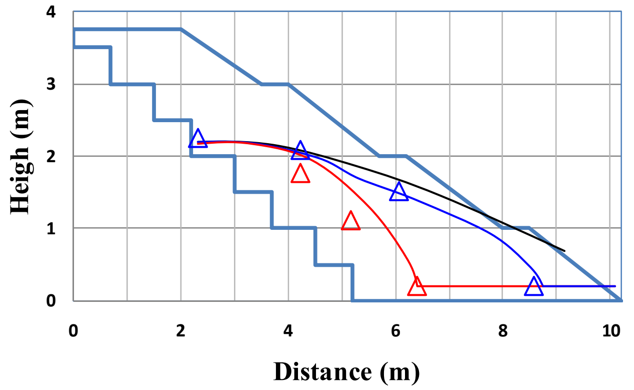


Figure 2: Comparison of water table between observations and computations, for setting blankets(□and□:measured values).

2.2 *FE seepage analyses*

To make a simple design chart of drainage works for embankment, seepage FE (Finite Element) analysis of two embankment models with blanket and lateral pipe was conducted on the various conditions.

(1) Model embankments:

Assumed embankments are with a standard slope of 1:1.8 on the natural slope with 30 degree as seen in Figures 2 and 3. Embankment height H1 varies from 10 m to 50m by the increment of 5m. Top width is 8m and the each steps of embankment are 1m width at the each height after interval of 5m.

Height of water table at the natural slope H2 was set to be 3 kinds of 0.3H1, 0.5H1 and 0.8H1.

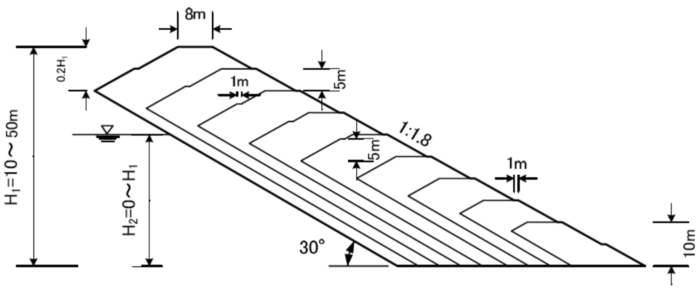


Figure 3: Comparison of water table between observations and computations.

The permeability of saturated embankment ks is 1×10^{-5}m/sec. The unsaturated soil properties are considered by the Van Genuchten Mualem equations (1) and (2). The parameters are summarized in Table 1.

$$S_e = \frac{\theta-\theta_r}{\theta_s-\theta_r} k\left[1+(\alpha\psi)^n\right]^{-m} \quad (1)$$

$$k = k_s S_e\left[1-\left(1-S_e{}^{\frac{1}{m}}\right)\right] \quad (2)$$

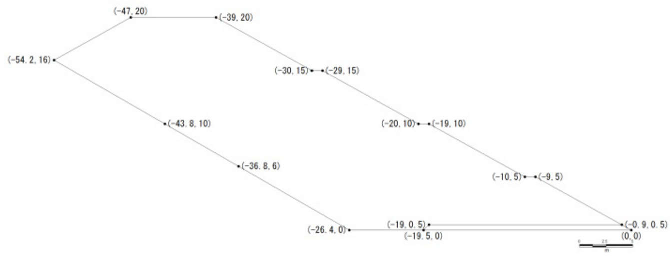
Table 1: Unsaturated soil properties

ks (m/sec)	θs	θr	α(1/m)	n	Ss (1/m)
1×10^{-5}	0.365	0.0	5.74	1.629	0.0001

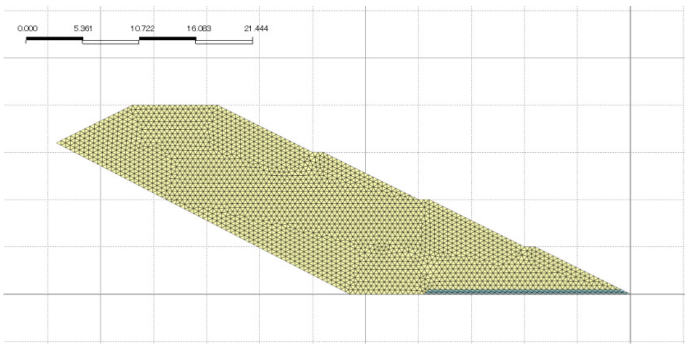
Note) m=1-1/n, The Ss is specific storage capacity.

(2) Modeling of blanket

Blanket was set on the base line of embankment from the surface of embankment. Two scales were modeled in thickness of blanket as seen in Table 2. Length of blanket is defined uniquely for the slope length embankment. The coefficient of permeability of saturated blanket is a constant of 1.0×10^{-3}m/s, which is 100 times faster than that of embankment. Example of grid model and FE mesh are shown in Figure 4.



(i) Main grids



(ii) FEM mesh

Figure 4: Embankment model with blanket (embank-ment height is 20m)

Table 2: Cases of blanket model.

	Scale of blanket
Series-1	Half length of lateral length of slope (thickness is 50cm)
Series-2	Half length of lateral length of slope (thickness is 100cm)

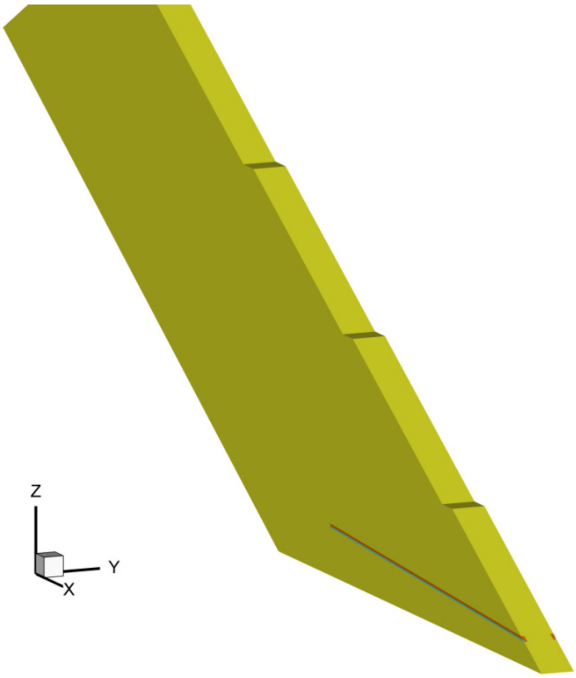
(3)Modeling of lateral pipe

Two cases of lateral pipes were modeled in Table 3. The pipe diameter is 60mm and its inside is modeled vacant. The pitch between pipes is 1m.

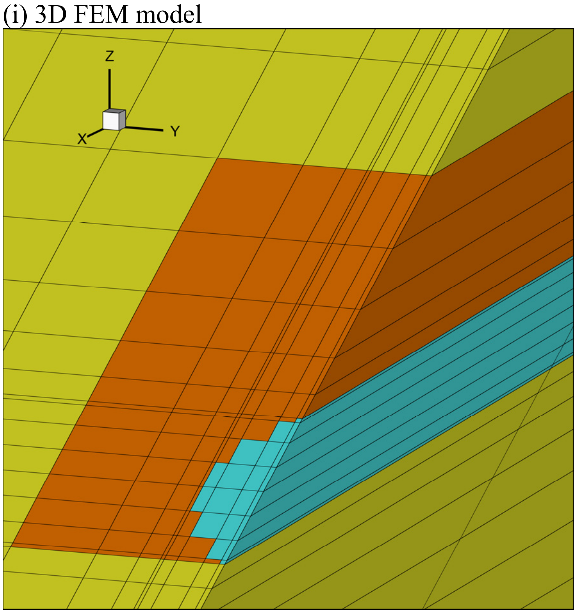
An example embankment model with lateral pipe is shown in Figure 5. As seen in this figure (2), the boxy area is the buffer area of slow down of drainage, where two kinds of permeability were assumed. This modeling is necessary because all computational points on the pipe surface would be assumed as seepage points to allow unrealistic perfect drain-age in the analysis.

Table 3: Cases of lateral pipe model.

	Scale of blanket
Series-3	Half length of lateral length of slope (Pipe is covered with the buffer area with 1/2 permeability of embankment)
Series-4	Half length of lateral length of slope (Pipe is covered with the buffer area with 1/5 permeability of embankment)



(i) 3D FEM model



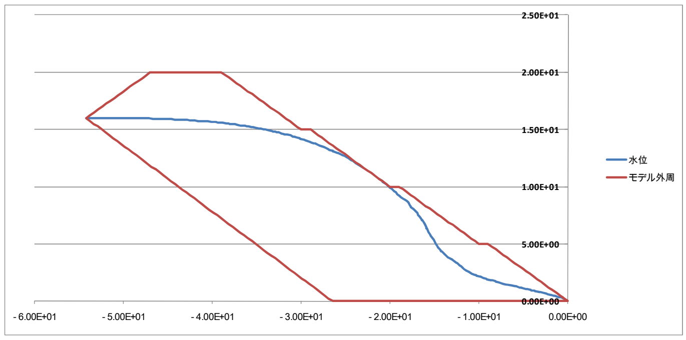
(ii) Around pipe

Figure 5: Lateral pipe model of embankment with the height of 20m (Series 3 & 4).

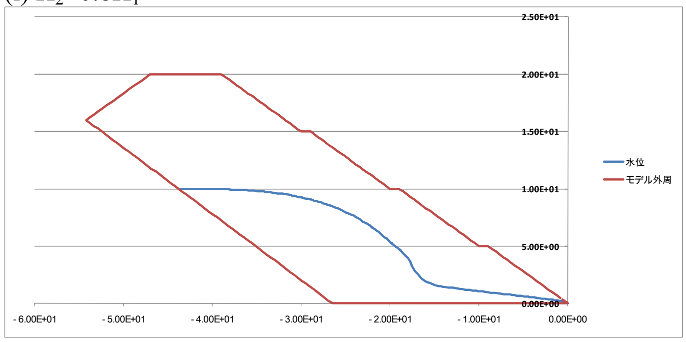
2.3 *Results of seepage analyses*

(1) Embankment with blanket

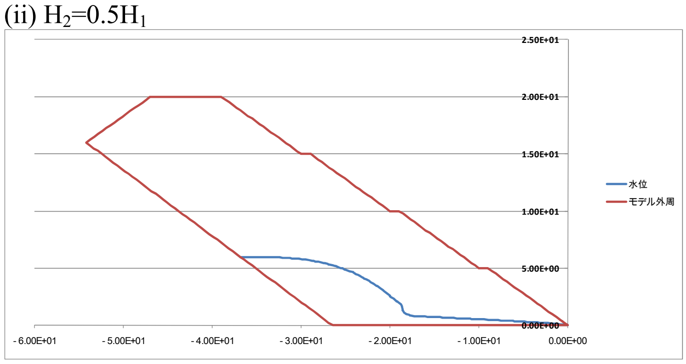
Example results of seepage analyses with blanket are shown in Figure 6.



(i) $H_2=0.8H_1$



(ii) $H_2=0.5H_1$



(iii) $H_2=0.3H_1$

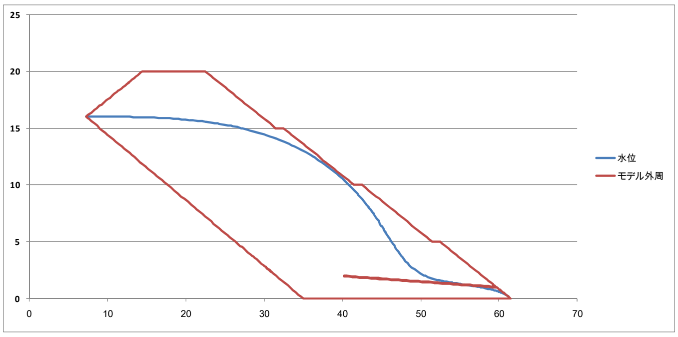
Figure 6: Results of 20m high embankment with blanket (Sereis-1).

(2) Embankment with blanket

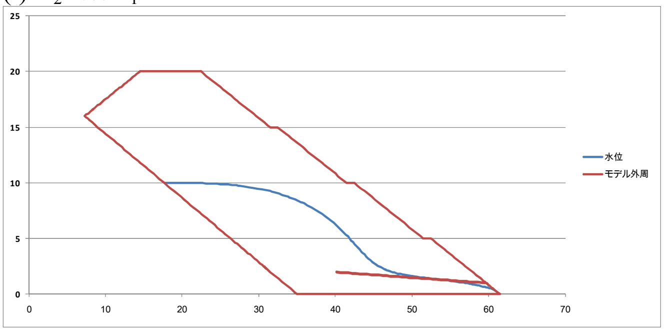
Example results of seepage analyses with pipe are shown in Figure 7. Lateral pipe is effective to decrease water table height very well at each case similarly with those with blanket. However, in case of higher embankment, the effectiveness of drainage becomes worse.

2.4 *Safety by circular stability analysis*

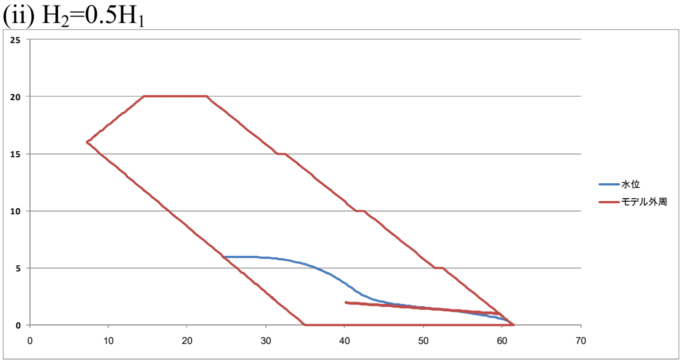
Safety factors of embankments were computed by the circular stability analysis using the above seepage results. The used soil properties of embankment are as shown in Table 4.



(i) H_2=0.8H_1



(ii) H_2=0.5H_1



(iii) H_2=0.3H_1

Figure 7: Results of 20m high embankment with lateral pipe (Series 3).

Table 4: Material soil properties for stability.

Soil type	Compaction degree and grain		Unit weight γ (kN/m^3)	Frictional angle Φ (degree)	Cohesion c (kN/m^2)
Sand	Well compacted	Well distributed in grain size	20	35	0
		Similar grain size	19	30	0
Sandy soil	compacted		19	25	10

As examples, contour maps of safety of Series 1 & 3 between the distance to embankment top from the water table (H_1-H_2) and the embankment height (H_1) are obtained in Figures 8 & 9. Series 2 & 4 are also similarly obtained as well as the case of non-treatment.

Increase of safety was evaluated simply by these contour maps for the embankment using blanket and lateral pipe. From these, it is easy to obtain safety factor at any height of embankment and water table. In these figure, safety factors of the cases with non treatment can be obtained from the values on the line with 45 degrees.

Generally from these figures, the safety factor becomes larger when embankment height becomes taller and water table becomes lower for the both cases of using blanket and lateral pipe. If the embankment is stronger, the safety factor becomes larger.

2.5 *Flow chart to decide drainage countermeasures using safety contour map*

Using these results, it is easy to define the countermeasures by imputing 1) shape and material and 2) hydrology information.

It is possible without any computations to find the safety factor of the current embankment without drainage and the increase of safety factor with drainage works.

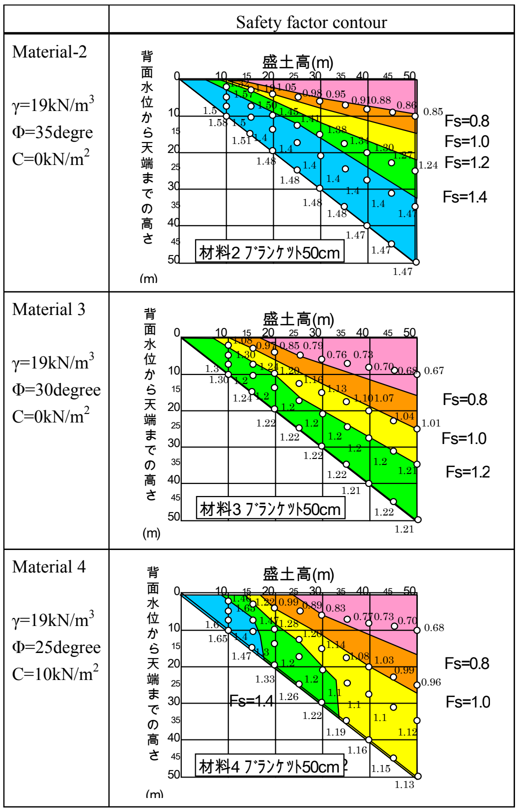


Figure 8: Safety contour map of 20m high embankment with blanket (Series 1).

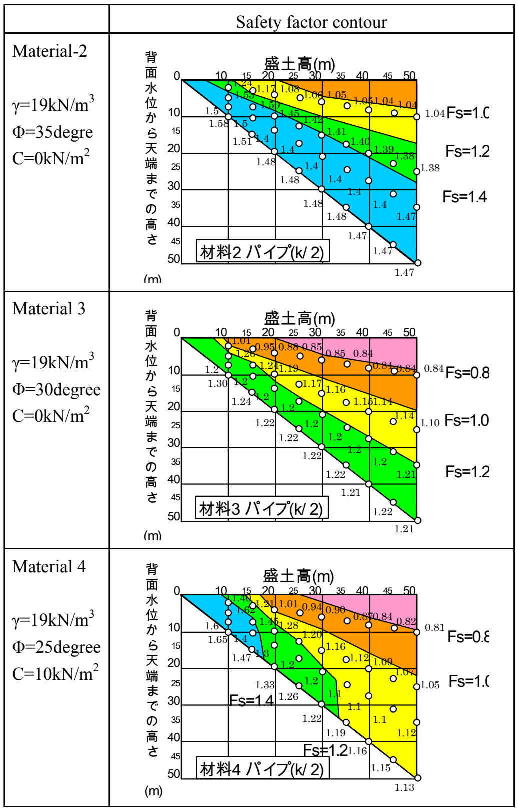


Figure 9: Safety contour map of 20m embankment with lateral pipe (Series 3) (Lateral axis: embankment height H_1 ; Vertical axis: the distance to the embankment top from the water table H_1-H_2).

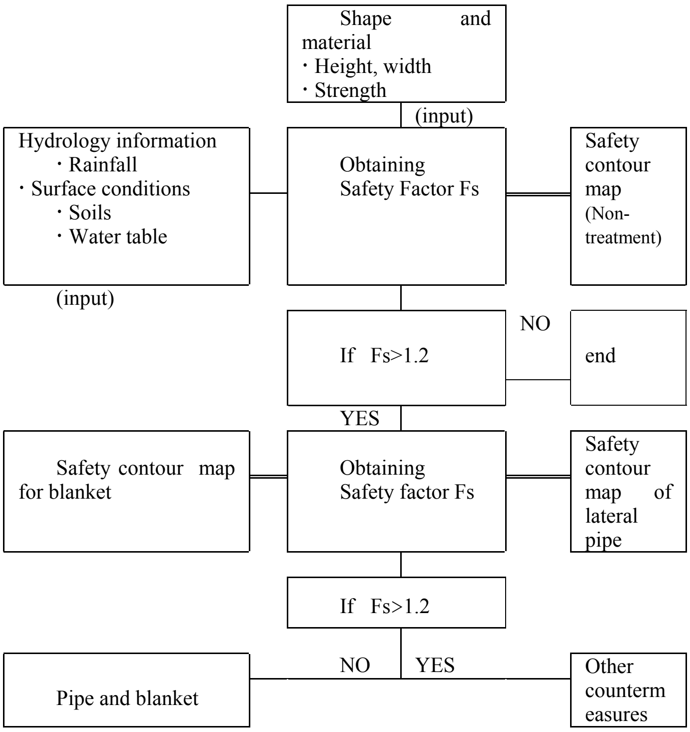


Figure10: Flow chart to find countermeasures using the safety contour map.

3 APPLICATION OF THE SIMPLE DESIGN CHART TO ACTUAL SLOPE COLLAPSE

3.1 *Typhoon No.14*

Typhoon No. 14 attached Yamaguchi prefecture Japan in 2005, with heavy rainfall, which is summarized in Table 5. Maximum rainfall of 500mm was recorded although once 200mm rainfall had been experienced. A large land collapse was occurred at the several embankments on the Sanyo Express Highways at Hataki Iwakuni City Yamaguchi. Photo 2 shows the picture of the typhoon from satellite.

Table 5: Rainfall recorded by AMEDAS.

Location / Rainfall (mm)	Rakan zan	Hirose	Shinoi	Wada	Iwaku ni	Kuga	Shimo matsu
Accumulated	540	397	313	357	347	444	322
Daily	472	352	244	337	295	382	293
Max per hour	59	55	31	47	47	45	31

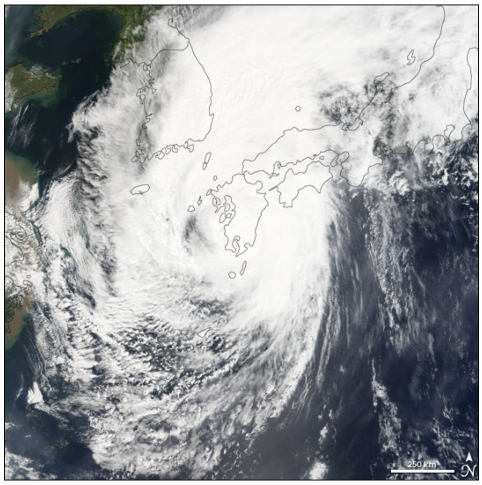


Figure 11: Picture of Typhoon No.14 from Satellite.

3.2 *Reasons for the embankment collapse*[3)]

Underground drainage facility of corrugate pipe was installed in this area, which was designed on the standard rainfall of 50mm/hour. From the rainfall record by the typhoon, the record seems to almost satisfy the design standard. However, it was found that drainage system was not good to flow water smoothly. The collapsed section is shown in Figure 12. The height of embankment is 23m and the top height from the base line is 30m. And the soil properties are investigated at the collapsed section as seen in Table 4. The water table is assumed in this figure from the stability analysis. By the intensive investigations, it was concluded that any drainage countermeasure is not enough and all embankment must be replaced with gravel material.

Table 6 shows the all soil properties obtained form soil investigations.

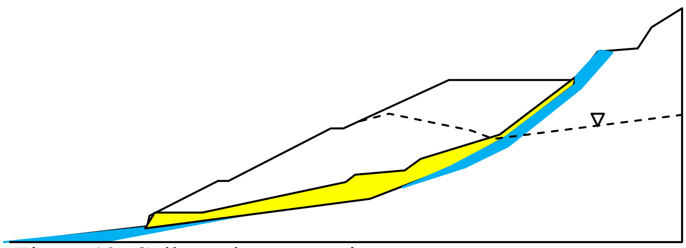


Figure 12: Collapsed cross section.

Table 6: Soil parameters obtained.

Location	Unit dry weight γd (g/cm^3)	Total stress base*		Permeability (m/sec)
		Cohesion Cu (kN/m^2)	Frictional angle φu(degree)	
Embankment	17.6	25	13	1.8×10^{-5}
Talus cone	20	35	12	1.9×10^{-5}
Weathered rock	19	122	21	6.5×10^{-6}
Bed rock	20	302	0	1.0×10^{-10}

*:Undrained triaxial compression test.

3.3 *Application of the simple design chart and monitoring of water table*

From Figure 12, it can be found that the H_1 is 30m and H_1-H_2 is about 9m. From Table 6, the embankment material seems to be very similar to Material-4. Therefore, from Figures 8 & 9, it can be found the safety factors are almost less than 1.0 for the both cases of blanket and lateral pipe. Then, it is concluded that this section can not use such normal countermeasures. This coincides with the final judgment by the disaster committee that the embankment material must be replaced with gravel.

In using this chart, it is quite important to measure and predict the water table height. Several methods to measure water table include: infrared rays exploration, physical exploration, electricity exploration, boring and well to measure water table.

4 CONCLUSION

The following conclusions have been developed.

A simple design chart of drainage works for embankment has been proposed to check quickly safety of embankment on natural slope at heavy rainfall.

This chart explains that blanket and lateral pipe reduce water table in the embankment to improve safety. By using this chart, it is possible to select the countermeasures as the preliminarily work.

If height of embankment becomes very tall with high water table, the drainage efficiency of blanket and lateral pipe goes worse not to improve the safety enough.

ACKNOWLEDGEMENT

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REFFERENCES

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