PROCEDURE FOR EMBANKMENT DESIGN IN MOUNTAINOUS AREAS WITH HEAVY RAINFALL

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ABSTRACT

The current design procedure for an embankment constructed in a mountainous region does not take into account the influence rainfall run-off from the surrounding valleys in the quantitative determination of a safety factor.

A number of road embankments in the mountainous areas of the Noto Peninsula failed due to the heavy rainfall in July, 1985. After site investigations were completed, it was found that those failures may have been triggered mainly by the rainfall run-off from the surrounding valleys. It is therefore considered unneglectable in a geotechnical engineering practice to introduce the degree of influence of rainfall run-off on the stability of embankments in mountainous regions.

This paper describes a proposed design procedure for embankment in mountainous area making it possible to evaluate the safety factor considering the influence of rainfall run-off. In this proposed design method new indices are defined in order to quantitatively determine both the rate and amount of rainfall run-off. Thus proposed design procedure is effective to determine both the optimum safety factor against heavy rainfall for the embankments and the most appropriate countermeasures to be taken immediately, if necessary, for embankments already constructed. It is shown that this methodology is quite suitable and easy to apply from a practical engineering point of view.

Key words : design procedure, embankment in mountainous area, heavy rainfall, slope sliding (IGC : E 6/H 9)

INTRODUCTION

Generally, highways and railroads through mountainous regions are constructed with sequence of cuts of slopes and embankments filling valleys. It is important in mountain-

ous areas to evaluate exactly the embankment stability against heavy rainfalls.

Instability of embankments due to heavy rainfalls are found to be triggered mainly by the infiltration and the erosion of the embankment and in addition, by both the

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rainfall run-off on ground surface and in underground seepage from the surrounding valleys. The former condition has been investigated in the past with current design procedures, however, the latter has neither been considered nor the influence on embankment stability is only roughly estimated. The main reason for this ignorance is the difficulty in run-off analysis to evaluate quantitatively the rainfall inflow into the embankment location. As is well-known, seepage and run-off analyses are still not well established because they have various uncertainties such as inevitable analytical errors in idealization of the complex actual ground conditions and behavior. At the present stage, the current design procedure requires the appropriate channels or ditches near the toe of the embankment slope to prevent rainfall inflow into the embankment. However, the influence of this inflow on safety factor remains unknown. The stability analyses of embankments in mountainous areas have not yet been prepared quantitatively taking the rainfall run-off from the valleys into account.

Several road embankments in mountainous areas of the Noto Peninsula have failed due to the heavy rainfall in July, 1985. After investigation of each failure location, it was evident that almost all embankment slides were caused by the water run-off from the surrounding valleys during/after the heavy rainfall. It was recognized that the topographical conditions is one of the important factors to be considered in the design of embankments in mountainous areas.

This paper proposes a methodology to make it possible to calculate a safety factor for an embankment based on the topographical conditions at the location of the embankment. The major results obtained from the application of this methodology to the actual failure records of the embankments are as follows: (i). Many of embankment failures in which the size of embankment cross section and surrounding topographical condition are different from each other could be reasoned out by reducing the safety factor depending

on the rainfall run-off from the main valleys overlooking the site of the embankment slide. (ii) By adapting the proposed design method, increasing degree of instability of an embankment in a mountainous areas

Fig. 1. Distribution of rain clouds on June 30, 1985

Fig. 2. Contour lines of cumulative rainfall

under the heavy rainfall conditions can be predicted. It was concluded that this proposed design procedure seems to be effective from the viewpoint of engineering practice and can contribute to the establishment of the optimum design and construction methods for embankments in mountainous areas.

HEAVY RAINFALL CONDITIONS

During the rainy season in 1985, it happened to heavily rain in Noto Peninsula, Japan, resulting in serious damage to the region (Takase et al., 1985). Fig. 1 shows the distribution of rain clouds detected by a radar system. Many thick rain clouds with an intensity of rainfall in excess of 30 mm/h

had passed over the area intermittently during this rainy season. The contour lines of cumulative rainfall from June 22 to July 13 in the Noto Peninsula region are shown in Fig. 2. The whole region is covered by contours of 500 mm~900 mm, experiencing the heaviest rain of 800 mm~900 mm in the narrow (neck) portion of the peninsula. Fig. 3 indicates the intensities and the cumulative rainfall in the Hakui and the Nanao districts located in the narrow (neck) portion of the peninsula, where a number of embankments in mountainous area have failed. In these districts, the heavy rainfall intensity over 50 mm/day was observed nine times at intervals of one to four days from June 22 to July 13. This rainfall was concentrated

Fig. 3. Rainfall in the Hakui and Nanao districts

Fig. 4. Extreme-value distribution function of cumulative rainfall during rainy season

particularly in the period from June 30 to July 13 being classified as the so-called J-pattern type of cumulative rainfall. It is considered that this J-pattern type may cause various disasters such as slope failures, landslides and debris flows. In fact, the occurrence of embankment failures in the 1985 rainy season started immediately after July 5.

The cumulative distribution function $F(y)$ of the extreme-value distribution (Gumbel, 1957) for the cumulative rainfall y during the rainy season is shown in Fig. 4, where $\bar{F}(y)$ equal to $(1-F(y))$ suggests that the occurrence probability of heavy rainfall in 1985 was nearly one-occurrence in 25 years, because the $\bar{F}(y)$ value obtained by setting

$y=717$ mm of 1985 is about 0.04. This figure was prepared from the rainfall data observed in Kanazawa City from 1941 to 1985 rainy season. Unfortunately, it is not possible to calculate the occurrence probabilities of the heavy rainfall of 1985 in the two districts due to the lack of the past rainfall records. The cumulative rainfall during the rainy season of 1985 in the Hakui and the Nanao districts went up to more than 800 mm and 900 mm respectively. Since these values are substantially higher than that which occurred in Kanazawa City although the two districts are not far apart from Kanazawa, it is certain that the occurrence probability of such heavy rainfall in these two districts should be estimated to be less than $1/25$, that is, a

Fig. 5. Locations of mountainous road embankment failure and cutting slope failure

very rare heavy rainfall occurrence.

EMBANKMENT FAILURES

Geological Conditions

The Noto toll road along which several embankments failed due to the heavy rainfall in July, 1985, penetrates through the length of Noto Peninsula. The geological conditions around this road are shown in Fig. 5. Major portion of the toll road passes through the volcanic rock zone, but some parts of the road pass through zones of the Tertiary sedimentary rocks and the alluvial soft clay. Almost all of the failed road embankments were located in the volcanic rock zone as shown in Fig. 5. These embankments had been constructed using weathered volcanic rock materials, the soil properties of which are described later. The locations of cutting and natural slopes failed due to the heavy rainfall are also plotted in Fig. 5. The cutting slopes are of 2 m to 12 m in height and about 30° to 60° in average gradient. It is seen in this figure that slides of cutting slopes have occurred mostly in the Tertiary sedimentary rock zone. This is the case for the natural slope failures as well as the large debris flow. These facts are consistent with the results reported from the many disaster investigations (i.e. Ogawa et al.,

1987; Kawamura, 1985, 1987) and will provide useful information for future prevention against heavy rainfall disaster.

A Group of Failed Embankments

The Noto toll road passing through the mountainous area is nearly 40 km long and has over 180 embankment fill sections. Fig. 6 shows the frequencies of the heights of all the existing embankments as well as of the embankments failed with slip surface passing within the embankment slope (the so-called shallow slide) and with slip surface passing over crest (the so-called deep slide), respectively. The embankments higher than 20 m, (the so-called high embankment), exist at 40 locations along the length of the road. The number of failed embankments is 16. The height of these failed embankments is 10 m to 30 m. 60% of failed embankments are high embankments. The fill materials are loam of volcanic rocks or sandy loam and the dry density of which ranges from 1.3 Mg/m³ to 1.4 Mg/m³.

Fig. 7 shows a typical section with dimensions of 11.5 m in crest width, 33.7° to 26° in slope gradient with 6 m of height difference between berms. The berm width is 1.5 m with a U-type drain ditch. The embankment slopes are generally protected by vegetation. The drain ditch near the

Fig. 6. Frequencies of height of constructed embankments and failed embankments along Noto toll road

toe of the slope is 25 cm wide and 20 cm deep. At the location where much rainfall inflow was expected, a larger surface drainage of 60 cm $\times$ 40 cm in inner size was placed.

Failure Mechanism

The site investigations, indicated that the embankment failures were caused by erosion

near the toe of the embankment slope and infiltration of the water to the eroded part. This phenomenon is naturally triggered by the rainfall run-off from the surrounding valleys. Fig. 7 shows an example of a failure location where the embankment height was 18 m. The plane around the failed embankment is shown in Fig. 7 (a). The level contours, the valley and ridge lines were

Fig. 7. Typical failed embankment, (a) Plan, (b) Cross section

specified by using aerial photographic projections, the (1/10,000) map and by actual site survey. In Fig. 7 (a), several small valleys are seen around this failed embankment, as shown by the broken lines. It is apparent that the rainfall run-off will build up in intensity along these valleys and flow close into the toe of the embankment slope. The cross section of embankment and valley (A-A section in Fig. 7(a)) is shown in Fig. 7(b) indicating that a small slide along the broken line primarily occurred near the toe of the slope. The shear strength had decreased by the water. The weight of the fill material increased due to seepage water infiltrated from the opposite toe of the opposite side of slope, and from the boundary between the original ground and the fill material. After the small slide at the toe, a secondary failure occurred along a large slip surface shown by the chain line in Fig. 7(b). Such a mechanism is thought out based on the site investigations just after sliding. The findings are as follows. (i) Though the actual rainfall had stopped several hours before the failure, the infiltrated water gushed out both at the small slide near the toe and near the large slip surface within the slope shown in Fig. 7(b). (ii) The water content of the fill material located above the slip surface was not very high, it was lower than the liquid limit. It is obvious from the above findings (i) and (ii) that the high water content zones and the dominant paths of the infiltrated water exist in the embankment material not uniformly but locally. (iii) Considerable deal of dead leaves and trees which seemed to have been carried by the water from the valley stayed on the branches of low trees located near the embankment, on the other side of which we had the failure of the embankment slope. The embankment failure seems not to be triggered by seepage water uniformly infiltrated over embankment from top to bottom. The failure must have been caused by the water laterally infiltrated from the toe of slope, flowed through consequently formed water paths and finally gushed out

Fig. 8. Plane figures of locations of embankment failures

from the slope where the slide occurred (Matsuo, 1979). The mechanism of embankment failure must have been strongly dependent on the characteristics of rainfall run-off through the surrounding valleys.

Fig. 8 indicates the topographical features around some other sites of embankment failure. In Fig. 8(a), the failure of a so-called "high embankment" 27.4 m in height occurred on July 11. This slide was of the scale more than 60 m in length with an earth volume of 38,000 m³. The site investigation confirms again that the main valleys looking down the side of the embankment, at the other side of which the failure occurred, must have played a role in this embankment failure. The rainfall run-off through these

Fig. 9. Relationship between embankment height and safety factor on Noto toll road

valleys was large in its volume and rapid in its velocity because the drainage basin area is large and the surrounding mountain slopes are steep. A similar failure of a "high embankment" of 31.3 m in height is shown in Fig. 8(b). A short and steep valley is looking down the embankment. The factor of safety against failure of this embankment was lower even before the rainfall. The rainfall run-off velocity was also high. Thus, each embankment failure is considered to have occurred due to the influence of the rainfall run-off from the surrounding valleys. Hence, prediction of the embankment failure and the choice of the appropriate countermeasure in future should be done based on the evaluation of the characteristics of rainfall inflow from the valleys, which are blocked by the embankment.

Degree of Influence of the Surrounding Valleys on Stability of Embankment

As already mentioned, these road embankments were designed with a standardized cross section. The results of safety factor F_s for embankment stability calculated using the circular arc method in terms of the total stress are shown in Fig. 9. Fig. 9 also indicates that the reduction of the cohesion c and the internal friction angle ϕ from

solid curves to dotted curves caused by the rainfall action, such as the infiltration, the seepage and the erosion will make the safety factor lower than 1.2 for high embankments. In Fig. 9, the safety factor of the embankment highest (35.8 m high) among all the embankments along this road is seen to be more than 1.2 under conditions of $c=10 \text{ kN/m}^2$ and $\phi=30^\circ$. This seems to support the appropriateness of the standardized cross section from the viewpoint of current stability analysis. The dry density γ_d of embankment material for all the failure locations was between 1.3 Mg/m^3 and 1.4 Mg/m^3 , as already described. The shear strength of $c \geq 10 \text{ kN/m}^2$ and $\phi \geq 30^\circ$ was obtained from direct shear tests on the soil of the dry density same to that in the site, 35% to 42% in water content and 85% to 90% in degree of saturation which are of the same order of those in the actual compaction controls of embankment construction. Therefore, the safety factor of embankment prior to the heavy rainfall is estimated as high as over 1.2. The standardized cross section of embankment is considered appropriate. The safety factor of the 16 embankments which failed due to the heavy rainfall in mountainous area, however, should have been in the range of 1.3 to 1.6 as seen in

Table 1. Indices for characteristics of rainfall run-off

distinction		(i)	(ii)	(iii)	(iv)	(v)	(vi)
class	score	f	L_0 (m)	l (m)	S (°)	E (°)	A (m ²)
1	0.1	0.3 under	800 over	90 over	4 under	10 under	10,000 under
2	0.2	0.3~0.4	600~800	90~75	4~8	10~15	10,000~20,000
3	0.3	0.4~0.5	400~600	75~60	8~12	15~20	20,000~30,000
4	0.4	0.5~0.6	200~400	60~45	12~16	20~25	30,000~40,000
5	0.5	0.6~0.7	100~200	45~30	16~20	25~30	40,000~50,000
6	0.6	0.7 over	100 under	30~15	20~24	30 over	50,000 over

Fig. 9.

A quantitative examination of the influence of rainfall run-off from the surrounding valleys on the embankment stability has been made. The researches in which the characteristics of rainfall run-off of small drainage basin are investigated by using topographical condition factors have been published (i.e. Wisler and Brater, 1959; Strahler, 1964). The small drainage basin area denotes with under 5 km². These papers describe that the more the topographical condition factors of drainage basin are known, the easier the distinction of characteristics of rainfall run-off is to make. In this paper the quantitative factors for the topographical condition, in the other words, for the characteristics of rainfall run-off through valley, are chosen as many as possible. Each factor with its own degree of influence on the characteristics of rainfall run-off has been often applied in the fields of hydrology and run-off approaches. The characteristics of the rainfall run-off such as the rate and amount were taken into consideration using several indices as shown in Table 1. The indices proposed to indicate the rate of run-off are shown as follows: (i) the so-called form factor of the drainage basin f equal to A/L_0^2 where A denotes the drainage basin area and L_0 the length of the main valley, (ii) L_0 , (iii) the length of mountain slopes l equal to $A/2L$ where L denotes the total length of all valleys of the drainage basin area, (iv) the average gradient of a main valley s , (v) the average gradient of mountain slopes E , (vi) the drainage basin area A as an index representing the run-off amount of valleys. The

weighted score for each index is allocated in 6 steps. Each step is defined by equally dividing the difference between the maximum and minimum values observed in actual failure sites into six classes.

The characteristics of the rainfall run-off is expected to be represented by a summation F of the scores of these indices. The greater the F -value is, the larger both the rate and amount of run-off are, and hence, the more dangerous to the embankments in mountainous area.

The values of indices at the location of an embankment can be obtained from the (1/10,000) topographical maps accomplished by a help of stereophotography together with the actual site investigations. The embankment height H , the design safety factor F_s of embankment under conditions of $c=10$ kN/m² and $\phi=30^\circ$, the cumulative rainfall amount R up to the time of slide occurrence, the value of each index, the F -value and the date of failure are summarized in Table 2 which quantitatively describes the characteristics of rainfall run-off at the failure locations. The value of R is calculated based on data from June 19. The reason for this is as follows. As seen in Fig. 3, the rainfall pattern is of a typical J-type which is known as the type dangerous to slope stability. Slope instability resulted from this J-type rainfall is generally considered to be caused both by the rainfall amount on the actual date of slide occurrence and the so-called antecedent rainfall amount, that is, the sum total of rainfall up to the day before slide occurrence. The antecedent rainfall amount is defined either as the sum total of rainfall during a few weeks prior to the day of

Table 2. Total score amount of rainfall run-off indices in failed embankment

failure site		H (m)	F_s	R (mm)	characteristics of rainfall run-off							failure date
					f	L_0 (m)	l (m)	$S(^{\circ})$	$E(^{\circ})$	A (m ²)	F -value	
deep slide	No. 1	23.4	1.36	788	0.52	176	37.48	7.12	16.18	16,992	2.1	7/13
	No. 2	15.0	1.48	445	0.38	420	48.40	12.27	27.12	66,800	2.4	7/6
	No. 3	18.0	1.42	428	0.52	160	41.30	21.03	18.28	13,200	2.4	7/5
	No. 4	11.5	1.60	635	0.68 0.83	150 210	50.70 87.10	23.15 19.92	27.77 28.60	15,200 36,600	2.7 2.6	7/8
	No. 5	24.0	1.35	634	0.50	160	39.60	19.65	19.65	12,672	2.3	7/8
	No. 6	21.0	1.38	882	0.56	1,080	94.40	7.03	20.13	656,900	1.8	7/14
	No. 7	19.5	1.41	636	0.41	128	26.30	18.43	24.60	6,720	2.4	7/9
shallow slide	No. 2	27.4	1.32	728	0.42	1,100	83.60	3.40	24.40	50,628	1.7	7/11
	No. 3	27.5	1.31	584	0.43	672	46.90	4.47	27.02	192,704	2.2	7/8
	No. 5	12.0	1.59	766	0.47	176	26.80	12.38	18.03	145,942	2.3	7/11
	No. 7	15.0	1.48	636	0.86	60	25.83	15.93	6.68	7,500	2.4	7/8
	No. 8	19.3	1.39	465	0.83	60	18.80	8.93	31.22	2,368 3,000	2.8	7/5
	No. 9	10.0	1.61	636	0.65	320	32.10	9.90	18.28	66,816	2.6	7/8
	No.10	31.3	1.30	636	0.28	320	38.70	10.62	21.68	29,120	2.0	7/8
	No.11	16.6	1.45	636	0.69	136	22.60	9.80	24.03	12,672	2.5	7/8
	No.12	27.0	1.33	766	0.28	300	33.30	4.40	2.60	25,300	1.6	7/11

 H : embankment height S : safety factor R : cumulative amount of rainfall F -value: the sum total of weighted scores of indices (i) to (vi) in Table 1

Fig. 10. Relationship between rainfall run-off and reduction of safety factor for embankment failure

slide occurrence, or as the sum total of rainfall accumulated after four continuous days of no rainfall (i.e. Honda, 1986). In the case described here, the cumulative

amount of rainfall from June 19 seems to be reasonably considered as the antecedent rainfall, because this simultaneously satisfies both of the definitions of antecedent rainfall amounts.

The relationship between F -value, the characteristics of rainfall run-off at the embankment failure locations, and the reduction of safety factors for those embankment due to the run-offs are shown in Fig.10, in which the reduction of safety factor of embankment ($F_s-1.0$) denotes a difference between the design safety factor F_s calculated under conditions of $c \geq 10$ kN/m² and $\phi \geq 30^\circ$ and unity at the time of failure. It is obvious from this figure that the greater the F -value is, the larger the reduction of safety factor will be. Fig.10 demonstrates that an embankment with sufficient safety factor for stability may be not always safe if a dangerous valley with a rapid rate and large amount of run-off is blocked by the embankment. Contour lines of the cumulative rainfall amount R drawn in Fig.10 suggest that the more the cumulative rainfall amount R for the same F -value is, the larger the reduction of safety factor of the embank-

Fig. 11. Relationship between $(F_s-1.0)/R$ and F -value

ment is. Thus, embankment stability is strongly dependent on the rainfall run-off from the valleys and the antecedent rainfall amount before the occurrence of a slide. The failure locations No.2 and 3 do not seem to fit with the contour lines in Fig. 10. In these two sites, the failure occurred with extremely deep slip surface, suggesting that these two sites are of exceptional case.

Based on Fig. 10, the relationship between $(F_s-1.0)/R$ and F -value is replotted in Fig. 11. The cross sections of embankments, the heights of embankments and the characteristics of the blocked valleys are different from each other, and yet, many embankment failures under such different conditions are plotted along one curve in Fig. 11. It is apparent that the rainfall run-off from the surrounding valleys must affect the stability of embankments in mountainous area very strongly. This curve obtained by using the method of least squares assuming an exponential function is given by the following equation :

$$\left(\frac{F_s-1.0}{R}\right) = 0.053(e^F - 1.0) + 0.181 \quad (1)$$

Eq. (1) is interpreted as follows : a reduc-

tion of safety factor for the embankment due to heavy rainfall is triggered both by the action of rainfall over the embankment itself and by the rainfall run-off from the valleys blocked by the embankment. Assuming the reduction of safety factor due to the rainfall over the embankment itself is proportional to the reduction of safety factor due to the cumulative rainfall amount R . The reduction of safety factor due to the rainfall over the embankment itself may be expressed by the second term of Eq. (1). On the other hand, a reduction of safety factor due to the rainfall run-off can be represented by the first term of Eq. (1). Eq. (1) therefore seems to be reasonably interpreted resulting in the intuitively acceptable contribution of the rainfall to the reduction of safety factor. The existing embankments in the mountainous areas along this road plotted in the region under thus obtained curve in Fig. 11 have the design safety factors F_s less than $\{0.053(e^F - 1.0) + 0.181\}R + 1.0$. These existing embankment may have a potential of slide occurrence due to the future heavy rainfall. The sizes of channels or the ditches along the embankment toes used to diverge the rainfall run-off in the sites described here were determined

Fig. 12. Evaluation of Eq. (1) from Fig. 11

based on the current design procedure, and yet we had such a number of slides. If we design the drain channels and ditches following the current design procedure, then the design safety factor F_s for the embankment should be taken higher than the value calculated by the curve in Fig. 11. That is, the value $(F_s - 1.0)/R$ of the embankment should be plotted in the region above the obtained curve in Fig. 11. It is very important, therefore, to establish a better method of design for embankments in mountainous areas so as to make it possible to guarantee a reasonable safety factor against failure due to the rainfall run-off from the surrounding valleys.

Fig. 12 is presented in order to examine whether the result shown in Fig. 11 is correct or not. In Fig. 12, both the data of the failed embankments (Table 2) and the embankments which have not failed (Table 3) are plotted comparing the design safety factor F_s and the value of $\{0.053(e^F - 1.0) + 0.181\}R$. Table 3 lists the measured values of topographical indices, embankment and

rainfall conditions for the existing non-failure embankments located near fairly dangerous valleys. It became evident after investigation of failed embankments that even the embankment slopes facing to upstream of the valleys were closed to failure in case that the F -values are extremely high. The embankments which did not fail are plotted shown above the solid straight line indicating that safety factors were more than unity even under the heavy rainfall. Therefore, it is clear that the regression curve of Eq. (1) proposed by using the actual data from embankment failures receives reasonable support from the data on embankments which have not failed. The dotted straight line obtained from the regression analysis of the non-failure embankments is shown in Fig. 12. This dotted line is given by Eq. (2).

An appropriate design safety factor F_{s*} can be determined by substituting the F -value and the given value of R into Eq. (1). For example, the value of F_{s*} becomes about 1.5 under conditions of $F=2.5$ and $R=650$

Table 3. Total score amount of rainfall run-off indices in non-failed embankments

location No.		H (m)	F_s	R (mm)	characteristics of rainfall run-off						
					f	L_0 (m)	l (m)	S (°)	E (°)	A (m ²)	F -value
1	R. S.	12.0	1.58	808	0.28	1,390	49.03	5.67	25.68	539,300	2.0
	L. S.	9.0	1.68								
2	R. S.	17.0	1.46	808	0.55	240	40.91	7.83	14.47	31,500	2.1
	L. S.	10.0	1.65								
3	R. S.	9.1	1.68	902	0.51	230	58.70	10.00	24.17	27,000	1.9
	L. S.	12.5	1.57								
4	R. S.	11.2	1.60	902	0.35	550	57.98	9.35	24.23	106,520	2.2
	L. S.	9.8	1.65								
5	R. S.	9.0	1.68	902	0.48	420	51.27	12.83	24.63	85,100	2.4
	L. S.	5.9	1.80								
6	R. S.	13.1	1.56	808	0.45	180	40.83	9.43	26.53	14,700	2.3
	L. S.	10.2	1.65								
7	R. S.	13.5	1.54	808	0.58	220	50.36	9.58	24.60	28,200	2.2
	L. S.	13.1	1.56								
8	R. S.	24.2	1.36	902	0.20	810	62.23	3.56	24.18	131,100	1.6
	L. S.	11.8	1.58								
9	R. S.	18.3	1.44	902	0.28	680	50.53	4.60	24.63	129,350	1.9
	L. S.	16.1	1.48								

R : cumulative rainfall amount to 7/13 on the end date of rainy season

R. S. : right side for Anamizu

L. S. : left side for Anamizu

mm which correspond to dangerous valleys and heavy rainfall, respectively. The value of 1.5 is considerably larger than the safety factor of 1.2 normally adopted in the current design procedures (Highway earth work series-manual for slope protection-, Japan Road Association, 1972). This means that design safety factor of embankment in mountainous area should be of the order of 1.5 when considering the influence of rainfall run-off in the surrounding valleys even in case that drainage facilities designed by a conventional design procedure and placed near the toe of the embankment slope. On the other hand, when $F_s=1.2$, the size of the drainage facilities should be much larger than that required by the current design method. It is stated in the current design code that if there is a possibility of flood or scouring around an embankment due to a heavy rainfall, the safety factor of embankment may be taken as more than 1.2~1.3. However, the method of stability of embankment in mountainous area taking the effect of heavy rainfall run-off through surrounding valley is not specified in the code. The stability analysis with full consideration on the influence of rainfall run-off seems to be of primary importance in engineering practice in future.

CONCLUSIONS

In the Noto Peninsula, many slides of embankments in the mountainous area were triggered by heavy rainfall in July, 1985. All of the embankment failures occurred after the rainfall had been accumulated up to more than 450 mm. The investigation carried out after the embankment failures led to the following conclusions :

(i) Stability analysis carefully applied to the actual embankment failures indicated that some evaluation of the influence of heavy rainfall on stability of the embankment was needed.

(ii) It was obvious that the slide occurrence had been strongly dependent on rainfall run-off from the surrounding valleys as

well as on the accumulated amount of rainfall prior to the actual instability of embankment.

(iii) The current design procedure of embankments in the mountainous area should be modified if there are some dangerous valleys with a large rate of rainfall run-off and a large accumulation of rainfall.

(iv) A unique design method is proposed making it possible to quantitatively consider the degree of influence of actual rainfall run-off from surrounding valleys on the embankment stability. Under present situation where the seepage and run-off analyses still have various uncertainties, the proposed design method based on an evaluation of the characteristics of rainfall run-off can contribute to the establishment of a practical design procedure for embankments in mountainous areas.

(v) This procedure was found useful in picking up dangerous slopes of potential landslide occurrence (Ogawa and Kawamura, 1989).

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