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Sept~~ember~~ 1977

ON THE STABILITY OF DAM SLOPES WITH WINTER FILLS OF INDIVIDUAL DAM ZONES

(Zur Standsicherheit von Staudammboschungen mit Winterschuttung Einzelner Dammzonen).

Karl-Heinz ~~K.H.~~ Brummer

CRREL-TL-641

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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German Standard TGL 21 239, Sheet 3 (1), valid in the GDR, permits dam construction materials to be installed under frost only when the prescribed tightness and adequate bonding in the construction joints of the fill can be achieved. To solve this problem of winter construction with natural earth packing materials, extensive studies (2) were performed in the VEB special construction combine on hydroconstruction in Weimar. In this connection, the VEB water economy planning in Halle received the commission of demonstrating

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) the stability of dam slopes, with the objective of understanding the stability-reducing effect, under winter conditions, of filled dam zones consisting of cohesive earth materials. The effects of frost reduce the sheer strength in the construction joints of the fill layers of the cohesive earth material. Advance calculation of this effect on the stability of dam slopes is a necessary basis for deciding the implementability of winter fills and the associated economic considerations. The greater permeability of construction joints subject to frost is another important effect. These must be evaluated according to the method described. ~~in (3).~~ In this report, the effect of planned winter fills on the stability of slopes on two dam cross sections with different construction shall be explained. In this report, the effect of planned winter fills on the stability of slopes on dam cross sections with diffrent construction shall be explained.

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ENGLISH TITLE: ON THE STABILITY OF DAM SLOPES WITH WINTER FILLS OF INDIVIDUAL DAM ZONES

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NOTICE

On the Stability of Dam Slopes with Winter Fills of Individual Dam Zones

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Contribution from the VEB Water Economy Planning

Standard TGL 21 239, Sheet 3 (1), valid in the GDR, permits dam construction materials to be installed under frost only when the prescribed tightness and adequate bonding in the construction joints of the fill can be achieved. To solve this problem of winter construction with natural earth packing materials, extensive studies (2) were performed in the VEB special construction combine on hydroconstruction in Weimar. In this connection, the VEB water economy planning in Halle received the commission of demonstrating the stability of dam slopes, with the objective of understanding the stability-reducing effect, under winter conditions, of filled dam zones consisting of cohesive earth materials. The effects of frost reduce the shear strength in the construction joints of the fill layers of the cohesive earth material. Advance calculation of this effect on the stability of dam slopes is a necessary basis for deciding the implementability of winter fills and the associated economic considerations. The greater permeability of construction joints subject to frost is another important effect. These must be evaluated according to the method described in (3).

In this report, the effect of planned winter fills on the stability of slopes on two dam cross sections with different construction shall be explained.

Example 1: Earth-Stone Fill Dam

For the dam shown in cross section in Figure 1, it was planned, while construction was in progress, to fill the clay packing zone together with its bordering transition zones under winter conditions. The construction operators here anticipated that the maximum height of the winter fill zone would be 2.0 m, and that this fill zone could lie at a dam height in the range from 17.60 m to 27.60 m.

Characteristic Data for Earth Materials

Results from laboratory studies on frozen clay samples were available for the calculation. But their extent was small and their information was inadequate. The only fact that could be obtained from these results was that the pore water pressure hardly differed from unfrozen specimens, but that the measured shear strength was reduced (4). In order not to have to rely at the very beginning still further on laboratory capacities which are availably only to a limited extent, shear strength parameters were assumed in order to check whether significantly reduced values leave intact the required stability level of the slope on the water side.

The effective friction angles ψ' of the fill material of the individual dam zones are given in Table 1. An effective cohesion c' was assumed for the clay. The values ψ' for the shear parameter combinations (1) and (2) emerged from the assumed relative displacements and their mutual compatibility from one dam zone to another, according to the recommendations in (5). Because of the variability of the devices used to determine the shear strength of individual dam construction materials (large and small box shear device, triple axis device), no direct relationships exist between the specimen displacements. Accordingly, specification of the shear strength of different dam zones must in this case be evaluated only as an approximate solution. In combination (3), the value min ψ' for clay corresponds to a specimen displacement $\Delta h_0 / \Delta h$ = 20% of the UU_p experiment in the triple axis device.

For clay slate and greenstone slate, the specified values represent the maximum effective friction angle max ψ'. The calculation takes into account an assumed reduction in shear strength, in consequence of the effect of frost, by decreasing the friction angle ψ' for clay by 30% and by 50% (see Table 2). The magnitude of the pore water pressure remained unchanged with respect to existing earth-static calculations.

Table 1: Effective Friction Angle for the Fill Material of the Dam Zones

Kombination 1	Wirksamer Reibungswinkel φ' 2		
	Lehm 3	Tonschiefer 4	Diabas 5
(1)	39,3°	29,6°	32,5°
(2)	38,3°	36,4°	37,0°
(3)	34,9°	37,0°	42,0°

1. Combination; 2. Effective friction angle ϕ'; 3. Clay;

4. Clay Slate; 5. Greenstone slate

Table 2: Reduced Friction Angle for Clay (Example 1)

Kombination	0,7 φ'	0,5 φ'
(1)	27,3°	19,6°
(2)	26,8°	19,1°
(3)	24,4°	17,5°

Calculations Performed and their Results

The demonstration of stability for the case of winter fill was performed only for the load case "construction status" and the shear parameter combinations (1) and (2). Under these conditions, the smallest reliabilities had already resulted in existing calculations for fill operation under normal weather conditions.

Friction Circle Method after BISHOP

The friction circles were studied according to this method by means of an EDP program (6). A selection of them has been entered into Figure 1. Corresponding to the inclination of the slip lines for radii R_1 through R_3 in the investigated range of dam heights, the winter fill zone lying at the various heights was associated with the existing lamellar division. Depending on the position of the friction circle, the reduced shear parameters for layers 10 through 13 had to be introduced into the present calculation. Small geometric deviations are here of subordinate significance. The results are shown numerically in Table 3 and graphically in Figure 2. The lowest safety level min η for the combination (3) for unreduced shear strength has here also been entered into Figure 2. Calculations showed that the required stability $\eta \geq 1.3$ continues to be met if the decrease in shear strength is not more than 50%. From the results (4 other friction circles were investigated), the following trend in part appears: As the position of the winter fill zone in the investigated range of dam height becomes lower, the stability declines to a greater extent than for a more elevated position. These deviations, however, are only small and without practical significance for construction.

Slip Wedge Method (Block Method)

For the calculation performed in accord with (7), the investigated slip lines are given in Figure 3. The reduced shear parameters were associated with the horizontal and inclined section of the slip line running in clay. The results of the shear parameter combination (3), which up to now has most often been used in practice, as well as for combination (2) are cited in Table 4. The stability for combination (1) is less than 1.3, since here the time-dependent decrease of the pore water pressure has not been used.

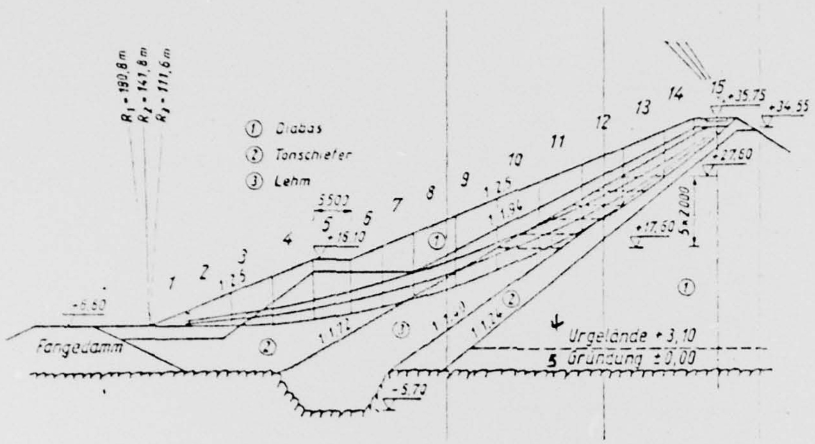


Figure 1: Dam Cross Section and Calculated Friction Circles for Example 1

1. Greenstone slate
2. Clay slate
3. Clay
4. Primary terrain
5. Foundation

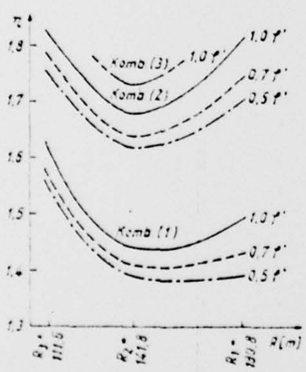


Figure 2: Course of the Stability Level min η for 3 Friction Circles (Figure 1) after Winter Fill of a Portion of the Clay Packing

Kennzahl 1	Radius 2	Lamelle 3	Kombination (1) 4			Kombination (2) 5		
			1,0 φ'	0,7 φ'	0,5 φ'	1,0 φ'	0,7 φ'	0,5 φ'
00 01		—	1,49					
01 01		—				1,81		
02 01		11		1,43				
03 01		11					1,74	
04 01	$R_1 = 180,8$	12		1,46				
05 01		12					1,78	
06 01		11			1,39			
07 01		11						1,70
08 01		12			1,45			
09 01		12						1,77
00 02		—	1,44					
01 02		—				1,68		
02 02		10		1,41				
03 02		10					1,65	
04 02		11		1,41				
05 02		11					1,65	
06 02		12		1,41				
07 02		12					1,64	
08 02	$R_2 = 141,8$	13		1,41				
09 02		13					1,65	
10 02		10			1,40			
11 02		10						1,63
12 02		11			1,40			
13 02		11						1,63
14 02		12			1,39			
15 02		12						1,62
16 02		13			1,39			
17 02		13						1,63
00 03		—	1,62					
01 03		—				1,82		
02 03	$R_3 = 111,6$	11		1,57				
03 03		11					1,78	
04 03		11			1,55			
05 03		11						1,75

Table 3: Stability Level η for 3 Friction Circles with Reduced Friction Angle for Clay

1. Identifying Number

2. Radius

3. Layer

4. Combination 1

5. Combination 2

Figure 3: Slip lines in the investigation after the slip-wedge method in Example 2

1. Slip line

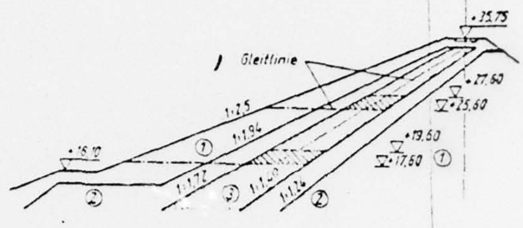


Figure 4: Dam Cross Section and calculated friction circles in Example 2

1. Winter fill 1
2. Winter fill 2

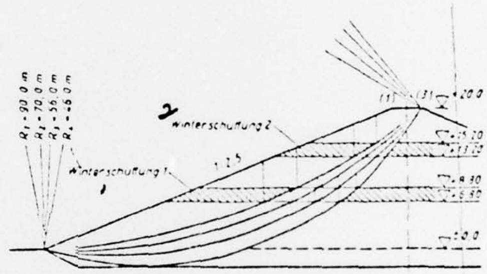
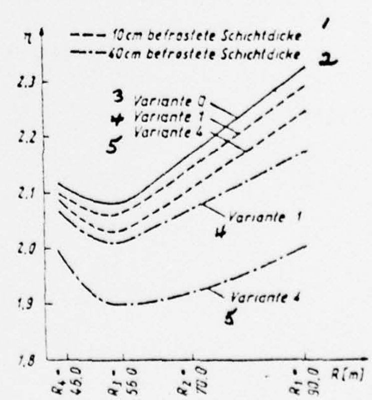


Figure 5: Course of the stability level η for 4 friction circles (Figure 4) after winter fill in zones 1 and 2

1. 10 cm frozen layer thickness
2. 40 cm frozen layer thickness
3. Variant 0
4. Variant 1
5. Variant 4



Example 2: Homogeneous Earth Dam

The dam shown in Figure 4 consists of cohesive earth material with fill layers of 0.4 m. For this dam, the stabilities of the slope were calculated with winter fill zones 1 and 2. Furthermore, the assumption was made that the entire dam was filled under winter conditions. The pore water pressure in the calculated load case "construction status" is assumed constant at 30% of the superposed weight.

Data for the Earth Material

The natural shear strengths as well as the ones reduced as a consequence of frost effects are given in Table 5. It has here been taken into account that the value φ' is reduced less as a result of frost than the cohesion c'. From the reduced shear strengths cited in Table 5 (Variant 1 through 4) and from the natural values for Variant 0, the weighted average over the entire layer thickness of 40 cm was formed for a frozen layer thickness of 5 cm and 10 cm.

Friction Circle Method according to BISHOP (6)

The calculations and results are selectively shown in Figures 4 and 5. The lamellar division was constructed differently, depending on the position of the winter fill zones with respect to the individual friction circles. The above-mentioned figures make it possible to compare the stabilities in the case of winter fill periods 1 and 2 with those in the case of normal fill technology (Variant 0). With 5 cm frozen layer thickness, the stability for Variant 1 min η amounts to 2.07, and for Variant 4 min η amounts to 2.06. Accordingly, in this case, the only essential factor for the stability is whether a frozen layer of 5 cm or 10 cm thickness is built in with each fill layer. For further comparison, the results of a complete winter fill of the dam (R_1 through R_4 in Figure 4) are listed in Table 6.

Gleit-linie	Kombination (2)			Kombination (3)		
	1,0 φ'	0,7 φ'	0,5 φ'	1,0 φ'	0,7 φ'	0,5 φ'
+ 25,60	1,57	1,45	1,32	1,54	1,40	1,33
+ 17,60	1,50	1,36	1,28	1,48	1,36	1,30

Table 4: Stability level η for 2 slip lines with reduced friction angle for clay

1. Slip line   2. Combination 2   3. Combination 3

Variante	Reibungswinkel φ'	Kohäsion c'
0	34,0°	3,0 Mp/m²
1	34,0°	0,5 Mp/m²
2	30,6°	0,5 Mp/m²
3	27,2°	0,1 Mp/m²
4	17,0°	0,0 Mp/m²

Table 5: Reduced shear strength for clay (Example 2)

1. Variant   2. Friction angle φ'   3. Cohesion c'

Variante	Befrostete Schichtdicke	
	5 cm	10 cm
0	2,08	2,08
1	2,00	1,92
2	1,98	1,88
3	1,94	1,81
4	1,88	1,69

Table 6: Stability level η with complete winter fill (for friction circles see Figure 4)

1. Variant   2. Frozen layer thickness

Slip Wedge Method (Block Method)

Since preferred horizontal slip lines may be present, especially in the area of the winter fill zones 1 and 2, further investigations were performed according to the block method (8). The slip lines lying at the height 6.80 and 13.20 bend down with various slopes to the summit points 1 and 3. Under these assumptions, stabilities min $\eta \geq 1.3$ resulted e.g. for Variant 4.

Conclusions

The calculation of the effect of winter fills of cohesive earth materials in reducing stability is possible with the usual methods for calculating the stability of slopes. The construction of the dam cross sections can here be different. By means of BISHOP's method, which has been programmed for data processing (6), the practically possible variants of shear strength reduction can be well handled. But optimization for slide faces in the form of a circular arc, in accord with (9), offers more effective opportunities for utilization.

The calculations for winter fills which have been explained above provide no generally valid results, but they permit corresponding estimates for similar dam cross sections. Definitive investigations must be performed on the basis of dam geometry, of specific earth materials data pertaining to the effect of frost, and of the planned extent of the winter fill. If the technical and technological construction preparations for winter fills with cohesive earth materials are made in time, this factor will increase the continuity of building implementation and will make possible optimum utilization of the construction machines utilized for dam construction.

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