OIL SHALE 1993, Vol. 10, No. 2-3

https://doi.org/10.3176/oil.1993.2/3.07

J.-R. PASTARUS

CALCULATION OF THE SLOPE STABILITY OF NON-HOMOGENEOUS WASTE PILES

The mineral wealth of Estonia is located in a densely populated and rich-farming districts. Mining and processing of different resources as well as the resulting accumulation of waste piles, especially in the depleted open-pit area, sharply disturb the environment. Weathering, leaching and self-ignition of waste piles may cause an intensive pollution with toxic chemical substances of both litho- and hydrosphere. For instance, dictyonema argillites (oil shale) overlapping the phosphorite seam at the Kunda phosphorite deposit (Fig. 1) contain sulphides, titanium, vanadium, etc.

Dictyonema argillites accumulated in waste piles and being undergone thermal destruction are the main suppliers of the chemical pollutants to the environment. In open-pit waste waters, the concentration of some toxic chemicals exceeds the allowed levels and the leaching process may last for hundreds of years. More over, through the hydrosphere these toxic chemicals enter the food chain and their accumulation in plants may result in raizing of their concentrations those being 1.5—21.8 times higher as compared to numbers for plants growing at natural conditions [1].

One of the possibilities to protect the environment is to place a layer of dictyonema argillites between the barrier layer and thus to reduce its weathering and seepage tc the level allowed for the leaching water (Fig. 2). This barrier layers Hxst consisı of ocally available material. At the above-mentioned Kunda deposit, it is clay, its seam thickness about 2.5 m. Two additional layers (0.2—0.3 m thick) of crushed limestone will raise the pH-value of the seepage water. To protect the barrier layers and to use the low-quality limestone seam in overburden of the deposit, a 10—15 m thick layer is placed on the top of a waste pile. Here appears the problem of stability of a non-homogeneous waste pile.

The first step in the decision of the above problem is determining the plastic, or elastic, height of waste pile. Assuming a Mohr-Coulomb failure criteria for rock material, the conditions of plasticity are calculated as in [2, 3]:

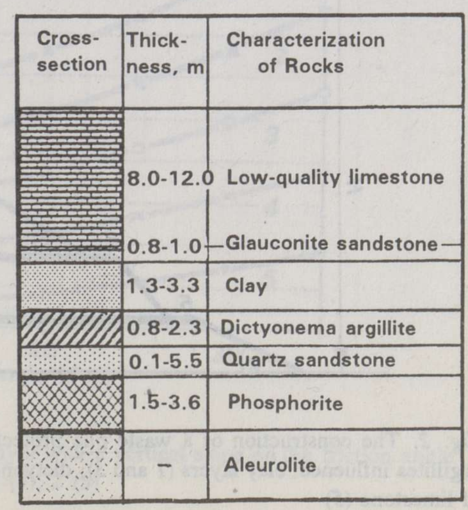

Fig. 1. The cross-sections of overburden at the Kunda deposit

$$H_p = \frac{2C\cot(45° - \varphi/2)}{\gamma(\sin^2\alpha + \nu/1 - \nu\cos^2\alpha)} \tag{1}$$

where C = cohesion, MPa;
φ = angle of friction, degree;
γ = density of the rock, MN/m^3;
α = angle of slope, degree;
ν = Poisson's ratio.

If the waste pile height is more than the value of H_p a zone of plasticity appears in the bottom layer. Subsequent increasing the height of a waste pile the stress remains constant but dimensions of a plastic zone increase. In case the waste pile height exceeds the H_p value it is necessary to take into account the plastic behaviour of the rock. The investigations have demonstrated that the plastic zone appears if the factor of safety is equal to 4—5 [2].

For the practical application and the analysis of the plastic behaviour of the rock it is convenient to divide the above formula (1) into two parts:

$$H_p = H_{90}\,K_\alpha \tag{2}$$

where H_{90} = the height of a vertical slope, m;
K_α = coefficient of stability.

The second step is determining the stable, or critical, height of waste pile at which the layers lose their stability. The methods applied for the stability analysis of waste pile are basically derived from the methods originally developed for the analysis of

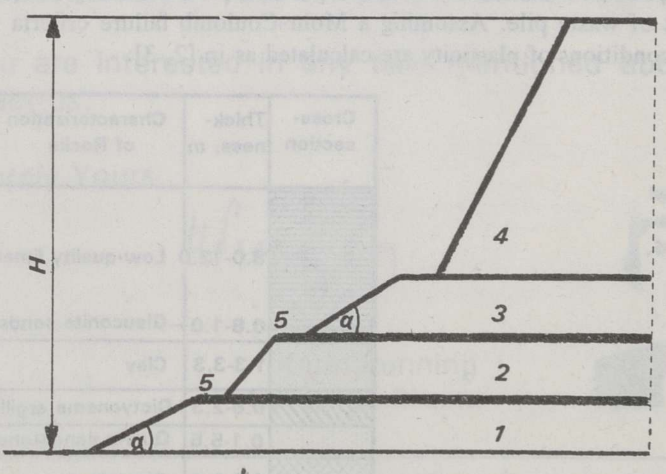

Fig. 2. The construction of a waste pile protecting the environment from the dictyonema argillites influence: clay layers (*1* and *3*), dictyonema argillites (*2*), limestone (*4*), thin layers of limestone (*5*)

the slope stability. They are based on the solution of the equations of equilibrium where the shape of the shear surface is important. There are two main groups of the above solutions for the cylindrical failure surfaces and for the plane ones. The shape of the shear surface depends on geological and rock mechanics parameters as well as on geometrical dimensions. The investigations have demonstrated the increasing of the radius of cylindrical surface if the strength parameters of the rock decrease. In such cases the cylindrical failure surface approaches to plane one [2].

The stability of waste pile can be calculated using the expression presented in [4]:

$$H = \frac{2C \sin\alpha \cos\varphi}{\gamma \sin^2(\alpha - \varphi)/2} - 2\gamma_1/\gamma_2 h \tag{3}$$

where γ_1, γ_2 = density of layers, MN/m^3;

H, h = thickness of layers, m.

Since the calculations of the equations (1)—(3) are cumbersom and time-consuming, their results are presented in Figs 3 and 4, and in the Table.

These figures characterize the plastic limit of thickness of a clay layer with a vertical slope and the stability coefficient for layers with various slope angles correspondingly.

The mechanical parameters of clay are as following: C = 20 kPa, $\varphi = 10°$, $\nu = 0.4$ and $\gamma = 22$ kN/m^3. In these calculations the thickness of a clay layer with vertical slope is equal to 2.1 m and that of a clay layer having slope angle 30° is equal to 2.6 m (Figs 3 and 4). In case the height of a waste pile or the thickness of a clay layer exceeds 2.1 m and 2.6 correspondingly, a plasticity zone appears in a bottom layer.

The Table presents the stable height of a waste pile depending on the slope angle and the thickness of top layers. In case the slope angle is 30°, the stable height of a waste pile is 28.9 m, if the thickness of top layers is 5 m, the above height is 18.9 m. If the thickness of top layers is over 14 m, the bottom layer of clay loses its stability.

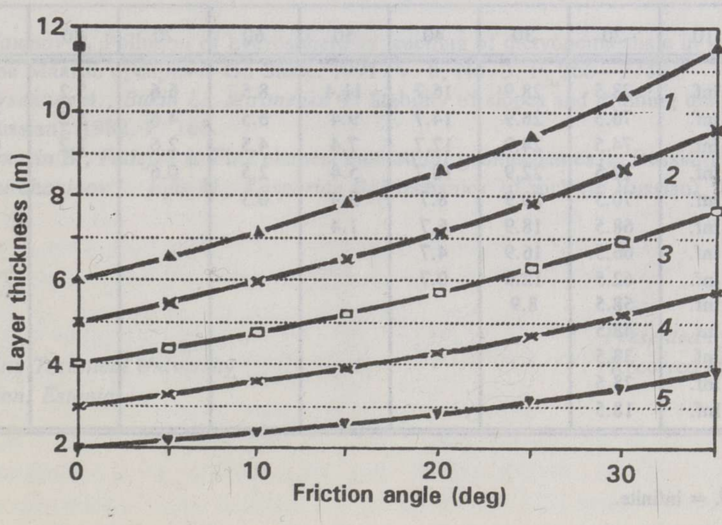

Fig. 3 The dependence of the thickness of a layer with a vertical slope on the friction angle and $2C/\alpha$ ratio; $2C/\alpha$ = 6 (*1*); 5 (*2*); 4 (*3*); 3 (*4*); 2 (*5*)

Summing up, the maximum tolerable geometrical dimensions of a waste pile and its layers are calculated using the suggested method. At the same time, in fact these parameters depend on the quality of the rocks overlapping the phosphorite layer and on the mining technology.

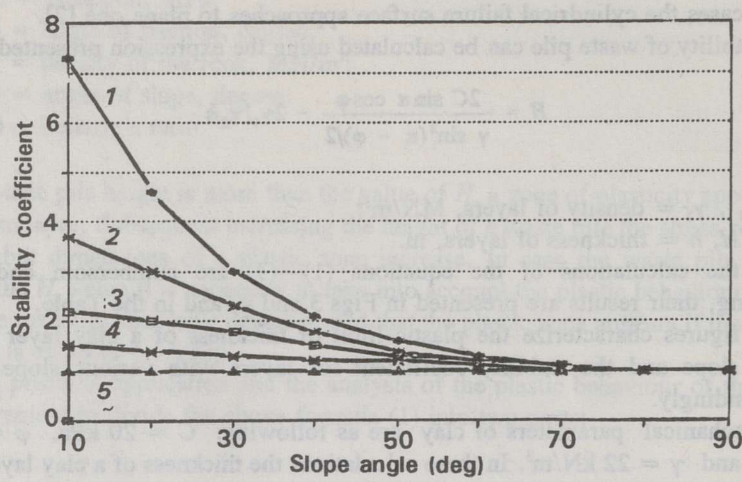

Fig. 4. The dependence of the stability coefficient on the slope angle and Poisson's ratio: Poisson's ratio is equal to 0.1 (*1*); 0.2 (*2*); 0.3 (*3*); 0.4 (*4*); 0.5 (*5*)

The Stable Height of a Waste Pile

Slope angle, degree	Layers thickness, m								
	10	20	30	40	50	60	70	80	90
0	Inf.	78.5	28.9	16.7	11.4	8.5	6.6	5.2	4.2
1	Inf.	76.5	26.9	14.7	9.4	6.5	4.6	3.2	2.2
2	Inf.	74.5	24.9	12.7	7.4	4.5	2.6	1.2	0.2
3	Inf.	72.5	22.9	10.7	5.4	2.5	0.6		
4	Inf.	70.5	20.9	8.7	3.4	0.5			
5	Inf.	68.5	18.9	6.7	1.4				
6	Inf.	66.5	16.9	4.7					
8	Inf.	62.5	12.9	0.7					
10	Inf.	58.5	8.9						
15	Inf.	48.5							
20	Inf.	38.5							
25	Inf.	28.5							
30	Inf.	18.5							

N o t e. Inf. = infinite.

Ю.-Р. ПАСТАРУС

РАСЧЕТ УСТОЙЧИВОСТИ ОТВАЛОВ СЛОЖНОГО СТРОЕНИЯ

Резюме

В Эстонии полезные ископаемые разрабатываются главным образом в пределах густонаселенных районов. При этом вопросы защиты природной среды встают особенно остро, и тем более для мест, где часто встречаются слои глинистого диктионемового сланца (рис. 1). Выщелачивание, самонагревание и самовозгорание его отвалов становятся причиной интенсивного загрязнения окружающей среды — как лито-, так и гидросферы — большим числом вредных химических соединений.

Чтобы свести на нет пагубное экологическое воздействие диктионемового сланца, его слои целесообразно изолировать, заключая между слоями глины (рис. 2). При таком подходе к этой проблеме возникает вопрос об устойчивости подобного отвала.

Решение осуществляется в два этапа: определяют (а) упругую, или пластическую, высоту отвала и (б) устойчивую, или критическую, высоту отвала. Для этого разработана методика расчетов и доказана справедливость использования предложенных формул определения устойчивости.

Результаты исследования представлены в виде графиков (рисунки 3 и 4) и таблицы. Доказано, что пластическая высота глинистого отвала в случае вертикального откоса равна 2,1 м, в случае откоса с углом 30° — 2,6 м. Устойчивая высота глинистого отвала, имеющего откос 30°, составляет 28,9 м. Если мощность надстилающих пород превышает 14 м, слой глины теряет устойчивость.

Резюмируя, можно сказать, что максимально допустимые мощности слоев и высота отвала определяются по вышеизложенной методике. Действительные же параметры зависят от качества пород в покрывающей толще пласта фосфорита и от технологии ведения горных работ.

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Presented by E. Reinsalu
Received March 17, 1993

Tallinn Technical University
Tallinn, Estonia