Dynamic Computation of the Development of Earth Slides

Calcul dynamique du développement des éboulements des terres

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SUMMARY

This paper presents a trial dynamic computation of the development of a rapid earth slide. The time-space relationship thus obtained corresponds with actual observations.

SOMMAIRE

On presente dans ce rapport un calcul préliminaire dynamique du développement d'un éboulement rapide des terres. Les relations ainsi obtenues correspondent bien aux observations réelles.

IN SOIL PROBLEMS there persist some relics from those "by no means obsolete" times when soil mechanics did not exist as a separate branch of engineering science. Then, any soil mass was treated as a stiff massive body in the mechanics of buildings and no attention was paid to the intrinsic peculiarity of soils wherein they change their volume and the internal mutual arrangement of their particles when submitted to the action of external forces. The well-known procedure elaborated by Fellenius for examination of the stability of slopes is essentially based on the principle that the investigated mass of earth is a stiff block.

The senior author has had an opportunity to observe several times that in the case of an earth slide, even one with quick development, many surface fissures always appeared at first near the upper edge of the slide and after a moment the slope collapsed. Never in such cases were fissures observed at the bottom edge of slope, preceding the collapse.

A trial examination from the dynamic point of view of the phenomena occurring during a quick earth slide is presented in this paper.

It is obvious at first glance from Fig. 1 that the right-hand portion of the sliding earth mass cannot be stable if left alone while the left-hand portion not only is maintaining itself, but also is supporting the right-hand one. We assume that in the case of failure the whole block of earth does not tear away at once from the stable mass, but the separation proceeds downwards gradually.

As an example, a case is presented of the slide shown in Fig. 1. According to Fellenius' proposal the failure line is considered as an arc. In the following examination of a slope 6 m high we assume: (1) that a shearing movement of 4 mm is sufficient to destroy the links of cohesion and in consequence then only the friction counteracts the shearing stresses; (2) that the shearing movement does not begin at once over the whole surface of shear but begins in that place where the increase of the shearing stress over the resistant strength is distinct; (3) that the first limited movements produce local soil consolidation only; (4) that after the rupture of links of cohesion in the weakest part of the sliding surface the nearest left-hand sector acquires an increase of shearing force while its shearing resistance

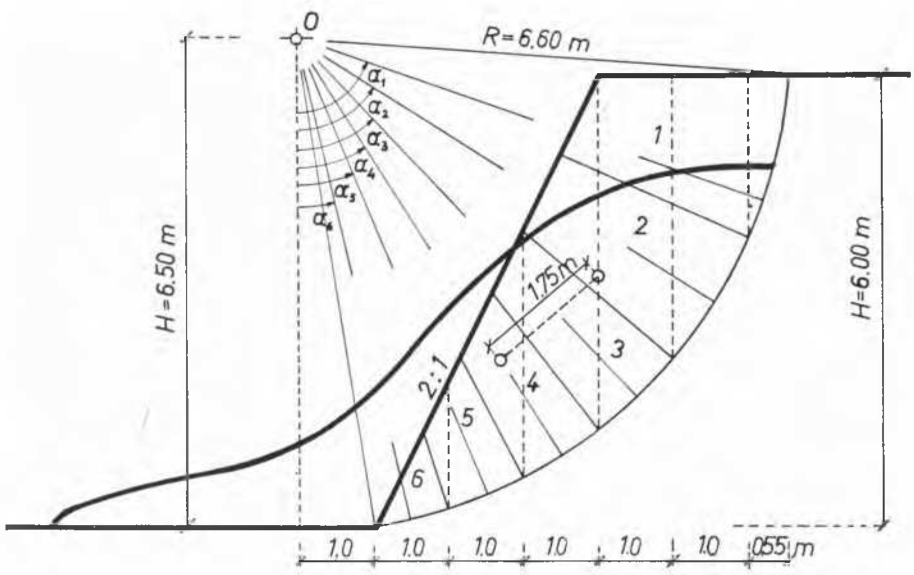

FIG. 1. Example of slope failure.

remains unchanged—therefore its stability becomes worse, it slides immediately, and its links of cohesion are cut; (5) that the mathematical analysis is illustrative and does not pretend to any strict exactitude.

The slope shown in Fig. 1 is not stable. The analysis performed according to Fellenius by the formula: $\tan \Sigma w \cos \alpha + \Sigma cl \leqslant \Sigma w \sin \alpha$ confirms this statement. In this formula w = weight of each successive vertical slice; α = angle between the tangent to failure line and level plane; ϕ = angle of internal friction; c = cohesion; 1 = length of failure line of each slice. Assuming $\phi = 18°$, $c = 0.1$ kg/sq.cm., and $\gamma = 1.6$ ton/cu.cm., we obtain 15.07 tons < 15.25 tons, which means the slope is unstable.

For examination of the time progress of failure the mass of collapsing earth is divided by radial planes into six sectors. Each sector is acted on by the driving force $w' \sin \alpha$, the resisting friction force $w \cdot \cos \alpha \cdot \tan \phi$, and the cohesion force cl, where w' denotes the weight of each sector. The residual force $S_r = w' \sin \alpha - w \cdot \cos \alpha \cdot \tan \phi - cl$.

The numerical values for the six sectors are given in Table I.

TABLE I. STABILITY OF SLOPE SHOWN IN FIG. 1

Sector	α	w' tons	$w' \sin \alpha$ tons	cl tons	w tons	$w. \cos \alpha \cdot \tan \phi$ tons	S_r tons
1	70° 30′	7.45	7.0	2.2	1.0	0.1	4.7
2	56° 40′	6.6	5.5	1.9	4.8	0.85	2.7
3	42° 30′	4.4	3.0	1.4	6.8	1.6	0
4	32°	3.3	1.75	1.2	6.9	1.9	−1.4
5	22° 20′	2.2	0.8	1.1	4.4	1.3	−1.6
6	13° 50′	0.84	0.2	1.0	1.4	0.45	−1.25

At the beginning, only sectors 1 and 2 will move. By projecting the acting forces on the tangent to the failure line of the second sector, we have the resulting force $S = 4.7 \cos (70°30' - 56°40') + 2.7 = 7.25$ tons acting at sectors 1 and 2 of summary weight $w' = 14.05$ tons. We obtain the acceleration $p = 981.\ S/w' = 506$ cm/sec^2. The time required for sliding on the distance of 4 mm is $t_1 = \sqrt{[(2 \times 0.4)/506]} = 0.04$ sec.

Afterwards we compute the stability in the next moment of sector 3, by projecting all forces on the tangent to the failure line of sector 3. After the cohesion related to sectors 1 and 2 is lost, we have the resulting force $S = (4.7 + 2.2) \cos (70°30' - 42°30') + (2.7 + 1.9) \cos (56°40' - 42°30') = 10.55$ tons. This force is acting on sectors 1, 2, and 3 of total weight $w' = 18.45$ tons. The acceleration is $p = 981 \times S/w' = 571$ cm/sec^2. The time of sliding along 4 mm is $t_2 = \sqrt{[(2 \times 0.4)/571]} = 0.04$ sec.

The next sector beginning to move is 4. We assume that the cohesion on the border of sectors 1–3 is lost. Proceeding as above, we obtain $S = 6.9 \cos (70°30' - 32°) + 4.6 \cos (56°40' - 32°) + 1.4 \cos (42°30' - 32°) - 1.4 = 9.8$ tons, acting at the weight $w' = 21.75$ tons of sectors 1–4. The acceleration $p = 981 \times (9.8/21.75) = 442$ cm/sec^2. The time $t_3 = \sqrt{[(2 \times 0.4)/442]} = 0.04$ sec.

Proceeding in the same manner with sector 5 we obtain: $S = 6.9 \cos (70°30' - 22°20') + 4.6 \cos (56°40' - 22°20') + 1.4 \cos (42°30' - 22°20') - (1.4 - 1.2) \cos (32° - 22°20') - 1.6 = 7.9$ tons; weight $w' = 23.95$ tons; acceleration $p = 981 \times (7.9/23.95) = 323$ cm/sec^2. Time $t_4 = \sqrt{[(2 \times 0.4)/323]} = 0.05$ sec.

The computations for sector 6 give the following values: $S = 6.9 \cos (70°30' - 13°50') + 4.6 \cos (56°40' - 13°50') + 1.4 \cos (42°30' - 13°50') - 0.2 \cos (32° - 13°50') - (1.6 - 1.1) \cos (22°20' - 13°50') - 1.25 = 6.4$ tons; weight $w' = 24.8$ tons; acceleration $p = 981 \times (6.4/24.8) = 253$ cm/sec^2. Time $t_5 = \sqrt{[(2 \times 0.4)/253]} = 0.06$ sec.

The trial studies have indicated that the sliding earth mass will stop at the distance shown in the Fig. 1, after the centre of gravity moves a distance of 175 cm. By taking the acceleration over this distance as having a mean value 126 cm/sec^2 (between 253 cm/sec^2 and zero at the point of stoppage), we get the time $t_6 = \sqrt{[(2 \times 175)/126]} = 1.67$ sec.

Summing the received partial times we receive $T = (t_1 + t_2 + t_3 + t_4 + t_5) + t_6 = 0.23 + 1.67 = 1.9$ sec.

It appears that this trial computation agrees quite well with the phenomena observed in nature.