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PRELIMINARY STUDY OF KARST COLLAPSE. FORECAST METHOD

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Resum

L'objecte d'aquest treball és analitzar diversos mètodes de predicció d'enfonsaments càrstics. S'estableixen dos models de predicció, en diferents condicions, d'acord amb el principi d'equilibri límit.

Es contrasten ambdós models amb les dades procedents de Yulin, Guilin, Guangxi i d'altres llocs. Els resultats de l'aplicació d'aquests models mostren l'existència de concordància entre el resultat calculat pel model i la realitat. Així, els dos models es poden usar en la predicció d'abisaments càrstics i en l'estimació de l'estabilitat de la cobertura superficial del terreny.

Aquesta nota s'ocupa detalladament de la relació entre els models i els factors que influeixen en ells, en base a la situació dels coneixements actuals; també s'apunta, més generalment, el contingut dels esmentats mètodes quant a la predicció d'eventuals abisaments. Per acabar, la predicció d'enfonsaments ha estat realitzada a San Lidian, Guilin, Guangxi, usant els dos models.

Abstract

The object of this paper is to discuss forecast methods of karst collapse. According to limit equilibrium principle two collapse forecast models are established in different conditions of the level.

Two models are checked by the data in Yulin, Guilin of Guangxi and other places. The checking result show to be consistency between the calculating result by the model and reality. So the two models can be used in forecast of karst collapse and estimation of the cover stability.

The paper dealt in detail with the relationship between the model and its affecting factors in the light of actually situation and also generally point out the collapse forecast content. Finally the collapse forecast is carried out using the two models in San Lidian, Guilin, Guangxi.

Introduction

Karst collapse is the most projecting problem of environmental engineering geology in covered karst area. Collapse serious consequences have been widly paid attention to. In order to avert and reduce collapse and losses the research on different aspects of collapse has been done. The collapse genesis and type research are focal point, the collapse forecast research is the gap yet. Therefore it is necessary to do collapse forecast.

The formation of collapse is a complex process. The cover up karst cave slack and peel with the groundwater erosion, vacuum draw erosion, aero-erosion etc, to form the soil cave, the one extend continuously up until collapse with gravity.

Karst collapse result from many factors such as karst development degree, groundwater fluctuation, cover thickness and its physical mechanic property. These factor affect the formation of collapse.

Premise condition

Premise conditions of establishing model are assumed in the paper, they include:

1. Karst developed under cover and there are karst cave;
2. The collapse to be assumed cylinder;
3. There is flowing groundwater; and
4. The cover may be slacking or peel.

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Model establishment

According to different conditions of groundwater level two models of collapse forecast are established.

1. The First Model

The first model is established in the condition of confined water. In this case, there are several acting force of the cover. They are:

1) gravity of soil body

$$G = \frac{\pi r\left[(y - vt) - \left(\frac{H - vt}{l_0 + 1}\right)\right] D^2 + \pi r_1 \left(\frac{H - vt}{l_0 + 1} + M\right) D^2}{4}$$

2) internal friction force

$$F = \pi D \int_0^{\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)} \left(\frac{1 - \sin\varphi}{1 + \sin\varphi}\, \mathrm{tg}\varphi\ rh + 1000c\right) dh + \pi D \int_{\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)}^{(y - vt)} 1000c\,dh =$$

$$= \frac{1}{2}\pi r D\, \mathrm{tg}\varphi \frac{1 - \sin\varphi}{1 + \sin\varphi}\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)^2 + 1000\,\pi c\, D\,(y - vt)$$

3) buoyancy

$$N = \frac{\pi D^2 r_w\,(H - vt - \triangle H)}{4}$$

The state to be forced in cover show in Figure 1.

Thus according to acting direction of force the first collapse forecast model is:

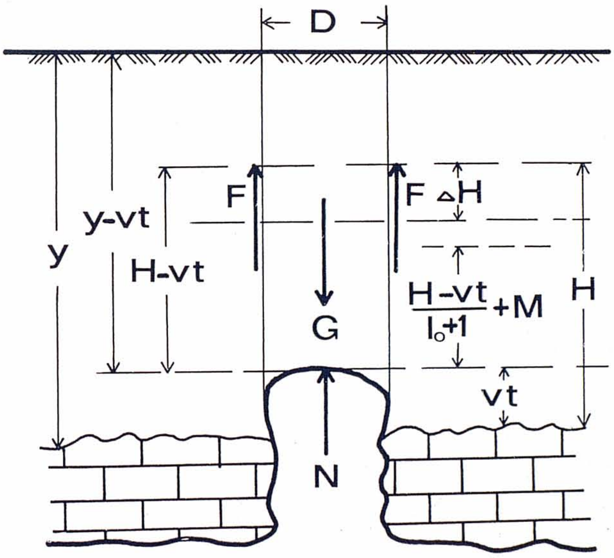

Figure 1. Sketch forced cover.

$$K = \frac{F + N}{G} = \frac{2r\, \mathrm{tg}\varphi \frac{1 - \sin\varphi}{1 + \sin\varphi}\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)^2 + 4000c\,(y - vt) + D r_w\,(H - vt - \triangle H)}{D r\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right) + D r_1\left(\frac{H - vt}{l_0 + 1} + M\right)}$$

.... (1)

where,

K = equilibrium factor;
D = diameter of assuming collapse (cm);
y = covering thickness (cm);
H = groundwater level (cm);
$\triangle H$ = groundwater level amplitude (cm);
r = natural unit weight (g/cm^3);
r_1 = saturation unit weight (g/cm^3);
r_w = water specific gravity (g/cm^3);
c = internal cohesion (Kg/cm^2);
φ = internal friction angle (degree);
t = time of collapse formation (year);
I_0 = initial hydraulic gradient (I_0 assume 1.11 in the paper);
M = capillarity height (cm) (measured volume is about 100 cm); and
v = slacking or peel rate (cm/year).

2. The Second Model

The model is established in the condition that the groundwater is unconfined. In the case there are three main force in the cover. They are:

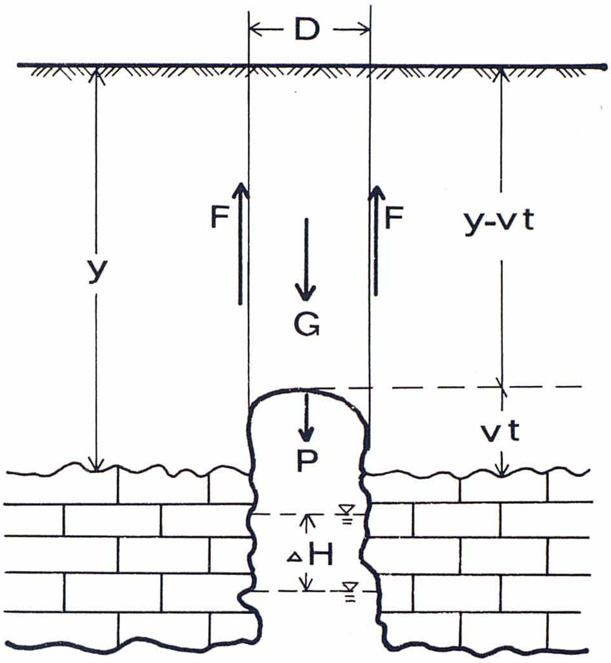

Figure 2. Sketch forced cover.

1) gravity of soil

$$G = \frac{\pi r D^2 (y - vt)}{4}$$

2) internal friction force

$$F = \pi D \int_0^{(y - vt)} \left(\frac{1 - \sin\varphi}{1 + \sin\varphi} \operatorname{tg}\varphi\ rh + 1000c\right) dh = \pi D \left[\frac{1}{2} r \operatorname{tg}\varphi \frac{1 - \sin\varphi}{1 + \sin\varphi} (y - vt)^2 + 1000c (y - vt)\right]$$

3) attraction from the change of groundwater level

$$P = \frac{\pi D^2 \triangle H\ r_w}{4}$$

The state to be forced in the cover show in Figure 2.

According to the acting direction of force the second model is established. It is:

$$K = \frac{F}{G + P} = \frac{2r \operatorname{tg}\varphi \dfrac{1 - \sin\varphi}{1 + \sin\varphi} (y - vt)^2 + 4000c (y - vt)}{r D (y - vt) + r_w \triangle HD} \quad \text{.......... (2)}$$

Model analyse and discussion

Above two models are established now following to only analyse the first model.

The model (1) show that: if $K > 1$, the cover is relative stable state; $K = 1$, the one critical state; $K < 1$, the one unstable state (that is collapse).

1) The Relationship between the Equilibrium Factor (K) and Covering Thickness (y)

Assuming other variable value to be no variation experct the covering thickness (y), the K is a function of the y. To seek the derivative for the y and to identify monotone increasing or decreasing of the function show that the K is a monotone increasing, that is, the K is increasing with the y. For example, measured data are:

$\triangle H = 384$ (cm),
$H = 705$ (cm),
$r = 1.85$ (g/cm^3),
$r_1 = 2.06$ (g/cm^3),
$c = 0.13$ (kg/cm^2),
$\varphi = 13$ (degree),

letting $t = 0$, $D = 447$ (cm) and assuming y to be variable, the calculating result show that the larger the cover thickness, the larger the K is. If the cover is more than 11 meter, the cover is no collapse in present (Table 1).

y (cm)	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
K	0.91	0.95	0.99	1.03	1.08	1.14	1.20	1.26	1.32	1.38	1.44	1.51
y (cm)	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	
K	1.57	1.64	1.70	1.77	1.84	1.90	1.97	2.04	2.11	2.18	2.25	

Table 1. The relationship between the equilibrium factor (K) and the covering thickness (y)

According to preliminary statistics of collapse number with covering thickness in Guilin. Collapse number mainly distributed over the cover that its thickness is less than 10 meter and show that the less the thickness, the more the collapse number is (Table 2). This phenomenon is consistency with the result calculating by model.

2) The Relationship between the Equilibrium Factor (K) and Groundwater Level (H) and Amplitude

To seek derivation for the H and $\triangle H$ and to identify monotone of function show that the K is monotone decreasing, that is, the K is decreasing with the increasing of H and $\triangle H$. It also show that the larger the $\triangle H$ and H, the easier the collapse is in cover. This conclusion is consistency with reality. In face, the water is a active factor in the forming course of collapse. It not only directly affect the physical mechanic property of cover, but also exert influence on the collapse formation by its action. According to incomplete statistics 80 % of collapse number are related to draw-off. As draw-off are made with larger drawdown, the $\triangle H$ is larger and K value is less. Therefore, the cover produce easily collapse. In addition, the cover often produce collapse after heavy rain. The reason is that the level rapidly rise with the larger value of H soon after heavy rain and that the groundwater level rapidly fall with larger value of $\triangle H$ in several day.

3) The Relationship between the Equilibrium Factor (K) and the Physical Mechanic Property (c and φ)

c and φ are main index representing physical mechanic property. The model show that the K is decreasing with decrease of c and φ value. Therefore, the less the K, the easier the collapse in the cover is.

4) The Relationship between the Equilibrium Factor (K) and the Slacking and Peel Rate (v) or Time (t)

The first model show that the equilibrium factor (K) is decrease with the increase of slacking (or

covering thickness range (m)	0 - 5	5 - 10	10 - 15	> 15
collapse number	94	46	11	0
percentage (%)	62.3	30.5	7.2	0

Table 2. Statistical data of relationship between collapse number and covering thickness

peel) rate (v) and time (t). It is say the faster the slacking or peel rate, the easier the collapse in the cover is. Thus the cover can be transformed stable state into unstable with time. That is, there is a evolution in collapse formation.

Model check

Can the model use in collapse forecasting or not? How do we check the model? The most efficacious and simplist method to check the model is comparing the result calculating by the model with the reality of collapse in the cover. This paper check the model by the reality data in Yulin, Guilin and other places.

The checking result show that the area of larger equilibrium factor is no collapse at present, and the collapse is always in the area of equilibrium less than 1 (Table 3).

It also show that the result of calculating by the model is consistency with reality, and the model can be used in collapse forecast.

Collapse forecast

The main content of collapse forecast are:

1. collapse site or range;
2. collapse time; and
3. drawdown causing collapse.

Collapse site and range is important forecast content. There are three methods and techniques to determine distribution of karst cave or soil cave under the cover. They include: (1) airborne remote sensing, ground geophysics and direct ground investigation. The discussion about the methods and techniques have gone beyond the scope of this paper. Therefore, here is no more discussion.

Will the cover that is stable at present is stable or not? It must be forecast. Letting $t = 0$ and analysing cover stability is status quo estimation; letting $K = 1$ and solving t is forecast, the t is the need time that the cover transfred stable state into unstable. There are two case in forecast. The first case is that the forescast result show that the cover may be collapse using the first model, if $H \geqslant vt$. The second case is that the cover may be stable if $H = vt$. In the case, at first, the t is equal to $\frac{H}{V}$, then using the second model forecast, finally two time add together to make total time from stable to unstable.

For example, at the 9th site in Sanlidian, Guilin, the data are:

$\triangle H$ = 420 (cm)
H = 713 (cm)
r = 1.99 (g/cm^3)
r_1 = 2.06 (g/cm^3)
y = 1498 (cm)
c = 0.47 (kg/cm^2)
φ = 20.5 (degree)
l_0 = 1.11 (empiric value)
v = 0.20 (cm/year, assuming value)
D = 345 (cm, statistical value)

According to above analyse stage and putting each value into the first model, the K is 3.08 if v product t is equal to H. This result show that the cover will be stable, the time is equal to 3565 year. Then putting y being equal to 785 cm (1498-713) into the second model and letting K to be equal to 1, seek time (t), the t is 3355 years. That is the cover need about 6920 years transforming stable state into unstable (That is collapse).

For the covered karst area suppling groundwater in order to avert or reduce collapse production the limit drawdown must be controlled, this aim may be realized by controlling amplitute $\triangle H$ at critical state that the K is equal to 1.

site			$\triangle H$ (cm)	H (cm)	y (cm)	r (g/cm³)	D (cm)	φ (⁰)	c (kg/cm²)	K	reality
Yulin		1	280	129	379	1.94	(500)	11.4	0.15	0.57	collapse
		2	280	699	919	1.94	(500)	11.4	0.15	0.80	
		3	280	294	544	1.94	(500)	11.4	0.15	0.70	
		4	280	284	1234	1.94	(500)	11.4	0.15	0.85	
		5	280	1034	1284	1.94	(500)	11.4	0.15	0.70	
Guilin		6	600	425	850	1.91	230	21	0.04	0.88	
		7	124	360	734	1.82	423	19	0.02	0.44	
	Sanlidian	8	413	580	1706	1.96	(345)	23.4	0.43	3.52	no collapse
		9	420	713	1498	1.99	(345)	20.5	0.47	3.28	
		10	220	1770	2649	1.95	(345)	18.1	0.64	4.01	
		11	385	1034	1789	1.78	(345)	24	0.42	3.12	

Table 3. Comparing data between status quo estimation and reality. (r_1 assume all 2.06 (kg/cm³), The data with brackets is quoting one)

Conclusions

Karst collapse result from many factors. Two models based on affecting factor such as covering thickness; physical mechanic property of soil; groundwater level fluctuation; time can be used in collapse forecast. The model analysis show that collapse is produced easily as the covering thickness (y) and the c or φ value representing the physical mechanic property of soil is less, the amplitute larger, and the cover can be transform stable state into unstable (collapse) with time.

Collapse forecast is a new topic of engineering stability evaluation. Forecast key is to define the distribution of karst or soil cave and to measure slacking or peel rate of soil etc. All of these are pending further discussion and study in practice.

References

ZHANG ZHONGYIN: «On Bond Water Dynamics Problem».