THE SAFETY OF BUILDINGS CONSTRUCTED ABOVE CAVITIES

Barlangok fölé épülő létesítmények biztonsága

KÓSA Attila

A Magyar Karszt- és Barlangkutató Társulat társelnöke
1149 Budapest
Kövér Lajos u. 46.

Associate president of the Hungarian Speleological Society
Kövér Lajos u. 46.
1149 Budapest, Hungary

Abstract

In the knowledge of the rock mechanical properties of the limestone bedrock and having the survey of the critical cave complete with plan, profile and cross sections, the topography of the surface as well as the design of the building to be erected the described method is suitable for determining the zones of subsidence hazards for buildings and for the caves with a good safety margin.

Összefoglalás

A földalatti üregekre nehezedő hegynyomás és a kialakuló feszültségmentes mag háromcsuklós tartóval helyettesíthető. A „C" pont a mag tetőpontja. A pont egy bizonyos határmélység (m_o) alatt (1. ábra), felett, ill. a felszín felett helyezkedhet el. Amennyiben a C pont az m_o alá esik, a barlang állagára a felszín semmiféle terhelésének nincs hatása. Ha a C pont az m_o fölé, de a felszín alá esik, a felszín felé haladva egyre növekszik a felszíni terhelés hatása (3. ábra) és az A-B boltozati vállaknál (1. ábra) törés következhet be, a felszíni épületekre veszélyzóna alakulhat ki (5. ábra). Ha a C pont a felszín fölé kerül, a terhelés a kőzet elhanyagolható húzófeszültségét veszi igénybe és különösen veszélyes beszakadási zóna alakul ki.

A C pont „z" mélységének a kiszámításához a kőzetmechanikai jellemzők (γ, φ, β, σ_H) ismerete szükséges. Ismert üreg- vagy barlangrendszer esetében így a veszélyzónák kiszámíthatók és grafikusan ábrázolhatók a felszín topográfiai térképén.

To determine overlying rock pressure and the stress free zone above underground cavities, K. Széchy applied a three hinge impost to calculate active forces. Széchy placed the upper hinge *„C"* at the apex of the arch of the stress free zone and the hinges *„A"* and *„B"* on the virtual imposts on either side of the cavity at a distance *„Δ"*. These three points determine the elliptic profile of the stress free zone. (Fig. 1)

According to Széchy the stress free zone can be defined above any cavity and the shape of this zone determines potential upward development in static conditions. Conditions change only if the rock pressure increases or the elliptic borderline intercepts the ground surface. The former may happen if a load, e.g. a building is constructed over the cavity whilst the latter may occur if the ground surface becomes closer to the cavity e.g. by natural denudation or man made excavation. None of these has any effect on the state of a cavity if it is located under a certain „depth limit". Three kinds of statical assumptions can be investigated where:

a) Point *C* is located under the depth limit
b) Point *C* is located above the depth limit
c) Point *C* is located very close to or above the ground

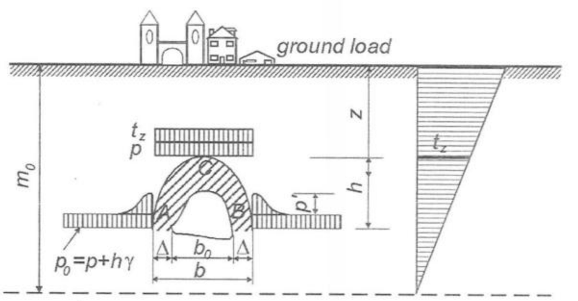

Figure 1

a) According to Jáky the depth limit will be

$$m_0 = 4b\left(1-\frac{b}{2a}\right)$$

where *b* is half the width, and *a* is half the length of a rectangular loaded area. In case of a 10 x 10 m base area the value for $m_0 = 20\ m$. In cavities where the *C* point is located deeper than 20 m the ground load will have no effect. The calculation concerns point *C* however, and not any point in the cavity itself. Therefore, the location of point *C* must be determined first.

According to Széchy if the largest horizontal extension of the cavity is b_0, its extended width is *b*.

$$b = b_0 + 2\Delta = b_0 + 2\frac{\beta b_0}{4} = b_0\left(1+\frac{\beta}{2}\right)$$

as according to Széchy $\Delta=\beta b_0/4$ and $\beta=0{,}3\text{~}0{,}5$ in the case of inflexible rocks within a rock strength, thus $b=(1{,}15\text{~}1{,}25)b_0$. The apex of the stress free zone above the widest dimension of the cavity will be:

$$h = \left[1{,}13\left(1+\frac{\beta}{2}\right)^2 - 0{,}5\right]b_0 = (1\text{~}1{,}3)b_0$$

or in the least favorable cases $h=1{,}3b_0$ and $b=1{,}25b_0$.

If the height and width of a cavity is virtually equal, point *C* will be located on the ceiling. In the case of a vertically elongated cavity profile (Fig. 2) point *C* may be located in a cavity space that is impossible to calculate using the laws of statics. Thus the ellipse of the stress free zone has to be shifted upward to a position where point *C* can be located in solid rock to present an accurate point.

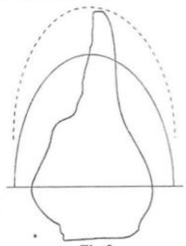

Fig.2

b) Point *C* is located above the depth limit

$$p_0=p+h\gamma\ ; \qquad p'=\frac{1}{\beta}p_0$$

Stress at the impost will be:

$$\sigma_p=p_0+p'=p_0+\frac{1}{\beta}p_0=p_0\left(1+\frac{1}{\beta}\right)=\left(p+h\gamma+t_z\right)\left(1+\frac{1}{\beta}\right)$$

Thus, if point C is situated above the depth limit, stresses resulting from ground loads (decreasing with depth) will be added to the rock stresses. The value of p_0 is the function of two reverse variables. (Fig. 3)

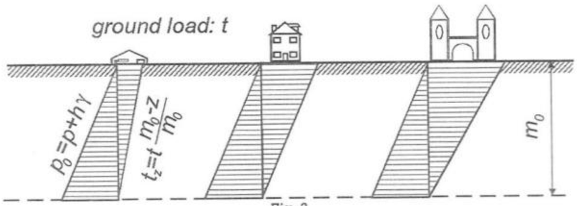

Fig. 3

No physical change occurs in the cavity if $p_0+t_z>\sigma_H$ or stresses at the imposts do not exceed the rock strength. Rock stress is analysed in Fig. 4.

If $p_0 > t$ the cavity is located higher, stresses at the imposts are less and the „*t*" load is safe.

If $p_0=t$, the stress does not change to m_0.

If $p_0<t$, the stress increases towards the ground surface and it may be that $p_0+t_z>\sigma_H$. The „*z*" critical depth should be calculated. There should be no cavity located above that level, because it would endanger the safety of the building: Deformations may occur in the cavity shifting the C point above the ground surface.

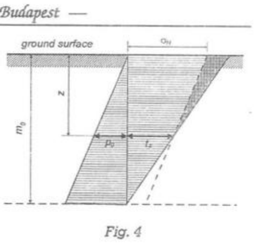

Fig. 4

$$p_0=p+h\gamma=\gamma z\left[1-\frac{z}{b}tg^2\left(45^o-\frac{\varphi}{2}\right)tg\varphi\right]+\gamma h$$

where z=0, there $p_0=0$; where $z=m_0$, there $t_z=0$

$$\frac{tg^2\left(45^0-\frac{\varphi}{2}\right)tg\varphi}{b}=\vartheta$$

consequently: $p^0=\gamma_z(1-z\vartheta)+\gamma h$ and $t_z=\left(1-\frac{z}{m_0}\right)t$

At the critical *z* depth $t_z = \sigma_H$, where σ_H is the compressive strength of the limestone.

$$p_0+t_z=\vartheta_H$$

$$\gamma_z(1-z\vartheta)+\gamma h+\left(1-\frac{z}{m_0}\right)t=\sigma_H$$

$$\gamma z-\gamma z^2\vartheta+\gamma h+t-\frac{t_z}{m_0}=\sigma_H$$

$$-\gamma\vartheta z^2-\left(\gamma+\frac{t}{m_0}\right)z+\left(t-\sigma_H+\gamma_h\right)=0$$

$$z_{1,2}=\frac{\gamma+\frac{t}{m_0}\pm\sqrt{\left(\gamma+\frac{t}{m_0}\right)^2-4\gamma\vartheta\left(t-\sigma_H+\gamma_h\right)}}{2\gamma\vartheta}$$

Out of the two roots the more unfavourable larger one should be accepted. Where the composition of the rock (γ, ϕ, σ_H) and the geometry of the cavity (dimensions and location) as well as the load on the ground are known the potential hazards of the cavity can be calculated.

c) If according to the calculations point *C* is located above the ground and a building is raised above the cavity, the load or part of it will burden the stress free zone instead of the virtual imposts. The tensile and shear strength of the rock will be loaded where they are considerably weaker than the compressive strength and these values are also very uncertain due to the inhomogeneity of the rock.

In this latter case the cavity poses grave hazards for construction and vice versa. There are technical solutions but out of natural conservation respects such hazardous areas should be avoided by development.

After taking into consideration theoretical aspects it is worth considering practical applications. In a karst area where any kind of construction is considered, serious research should precede the project, this is more important in the case of large scale construction. In the case of residential construction this aspect is usually forgotten. In the case of a known cave (known previously or discovered by construction related excavation) the procedure to be followed is relatively simple.

A survey of the cave should be completed with plan, profile and cross sections. (Fig. 5, a virtual simplified case) The survey of the ground surface should be superimposed on the cave map. The elliptical border of the stress free body should be calculated at the available cross sections. The resulting *C* points are drawn into the profile and computed to a continuous curve. Using the latter and the cross sections the tentative zones of hazard can be drawn.

The applied method is suitable for determining the zones of hazard with a good safety margin. The original formulas of Széchy and Jáky were worked out with high safety margins. The value of β is a number depending on the rock quality and it is quite imprecise. The theoretical value is 0.3-0.5 for solid rock according to Széchy, but he himself recommends using 1.0 for safety reasons. The study of case histories of collapses may cast more light on this value. Collapses in sandy clay during the construction of Budapest underground railway showed β=2 values on average, thus the number 0,5 seems to be safe for solid rocks.

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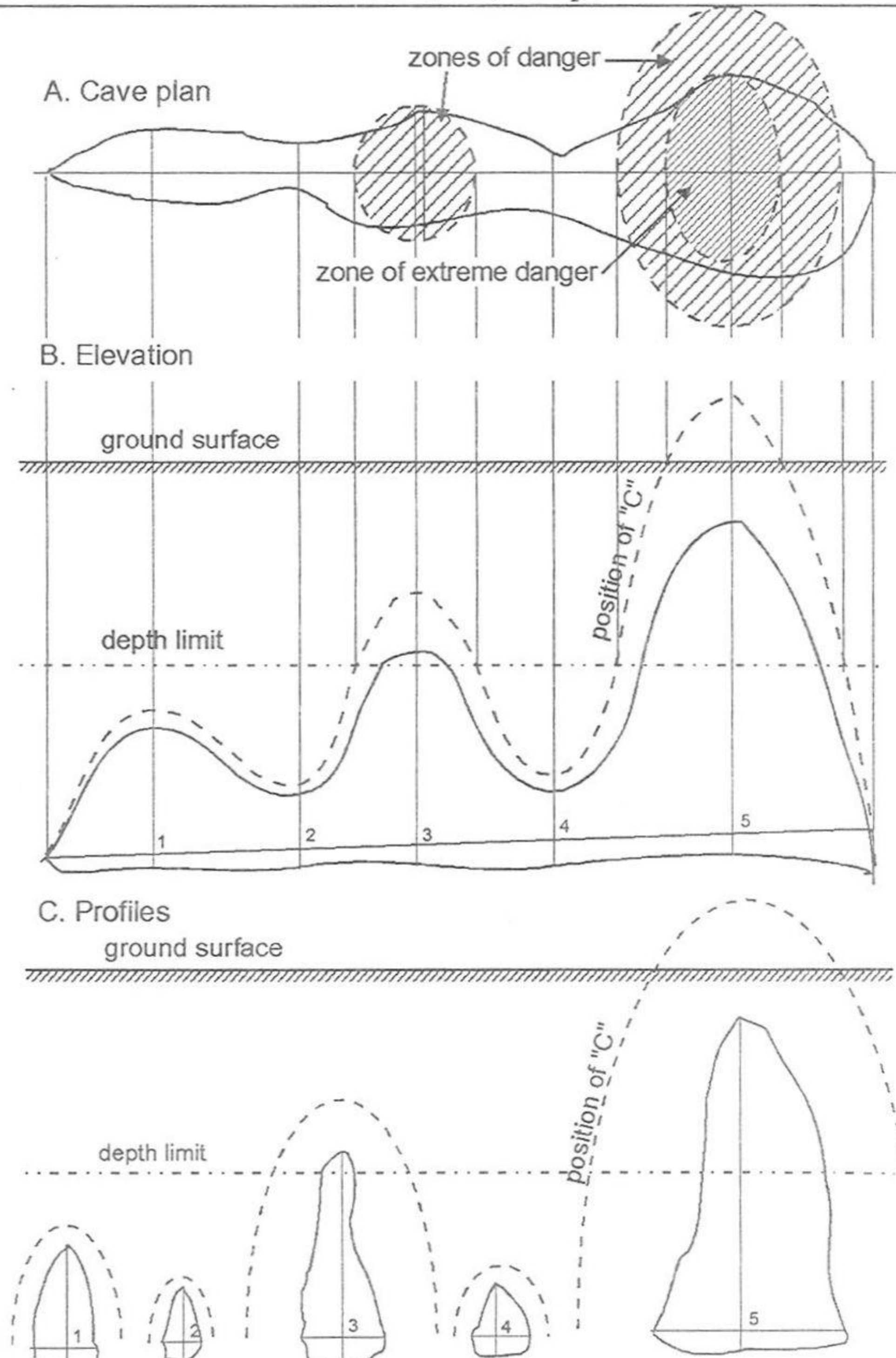

A. Cave plan
zones of danger
zone of extreme danger
B. Elevation
ground surface
depth limit
position of "C"
1
2
3
4
5
C. Profiles
ground surface
depth limit
position of "C"
1
2
3
4
5

Figure 5