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Functional catastrophe analysis of collapse mechanisms for deep tunnels based on the Hoek-Brown failure criterion

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Introduction and problem description

- The estimation of the roof stability of deep tunnels primarily lies in determining the shape and dimension of the collapsing blocks which can actually collapse from the roof of the tunnel.
- O nly the gravity field is considered, regardless of the tectonic stress field.
- The behavior of the rock mass is elastic-perfect plastic and obeys the Hoek-Brown failure criterion.
- The changes in the geometry of the collapsing block can be regarded as insignificant through the onset of the collapse.

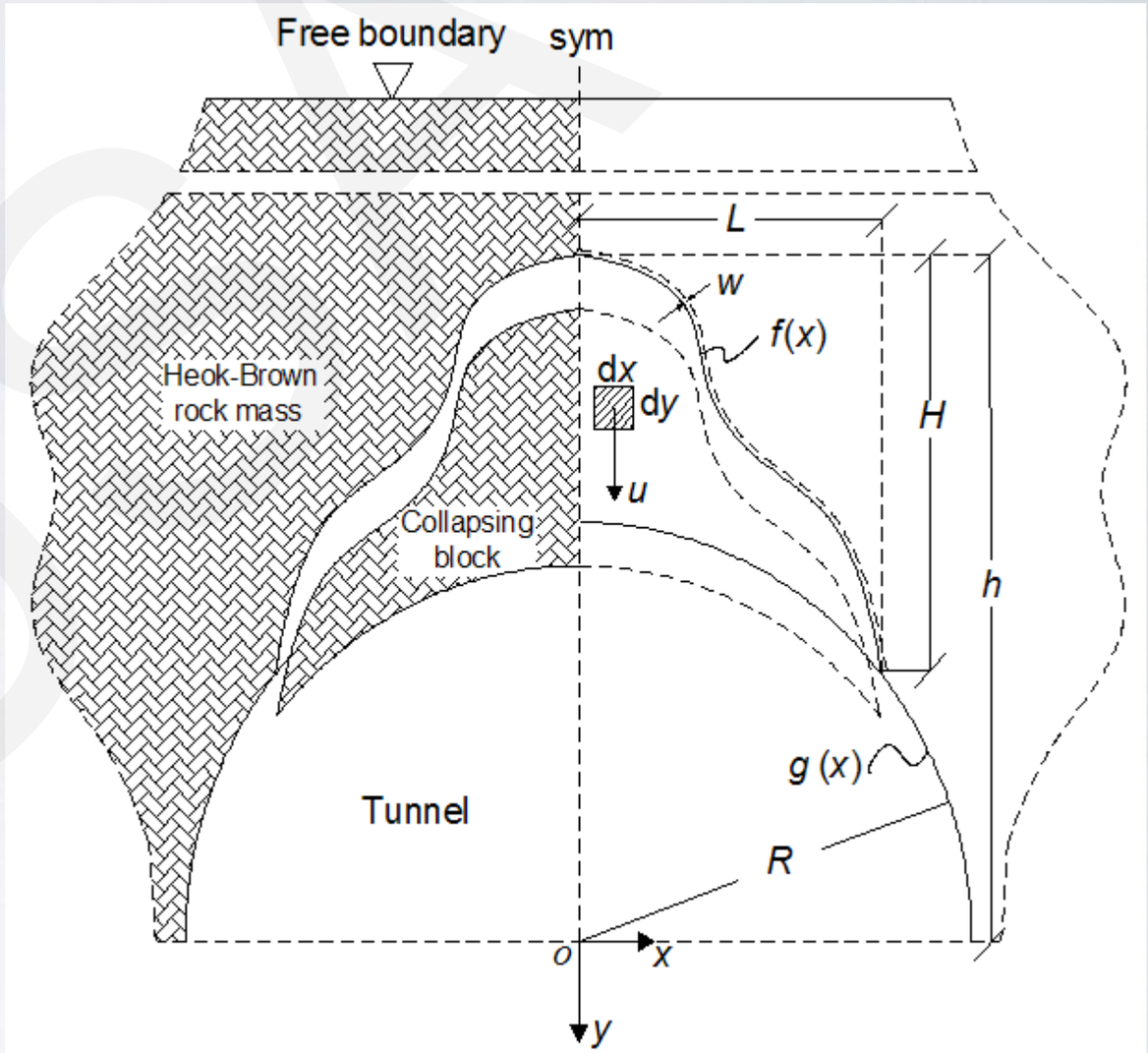


Fig. 1 Collapsing pattern of the deep tunnels

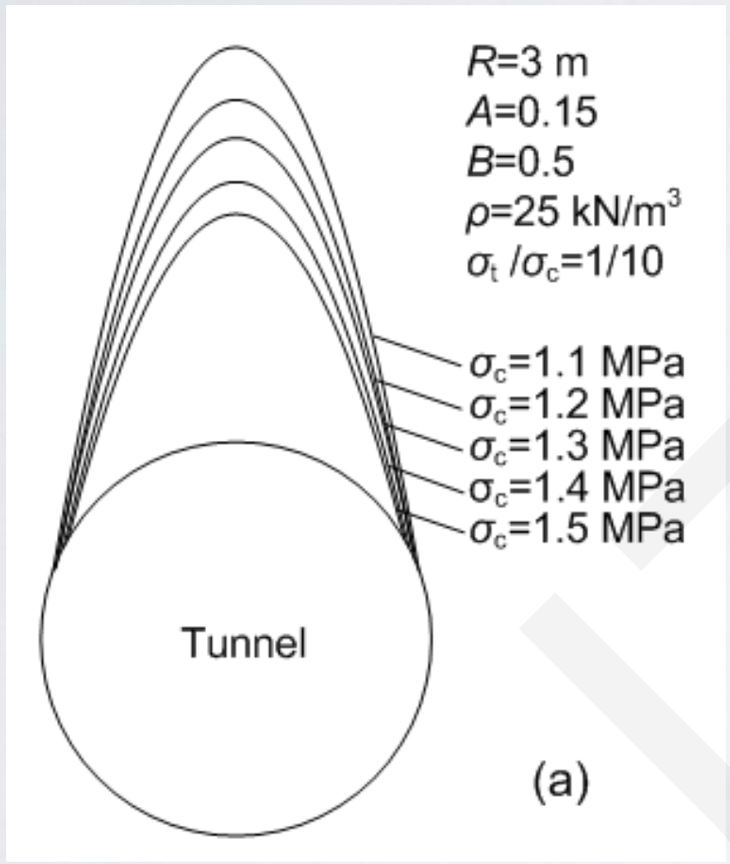
Proposed analytical results

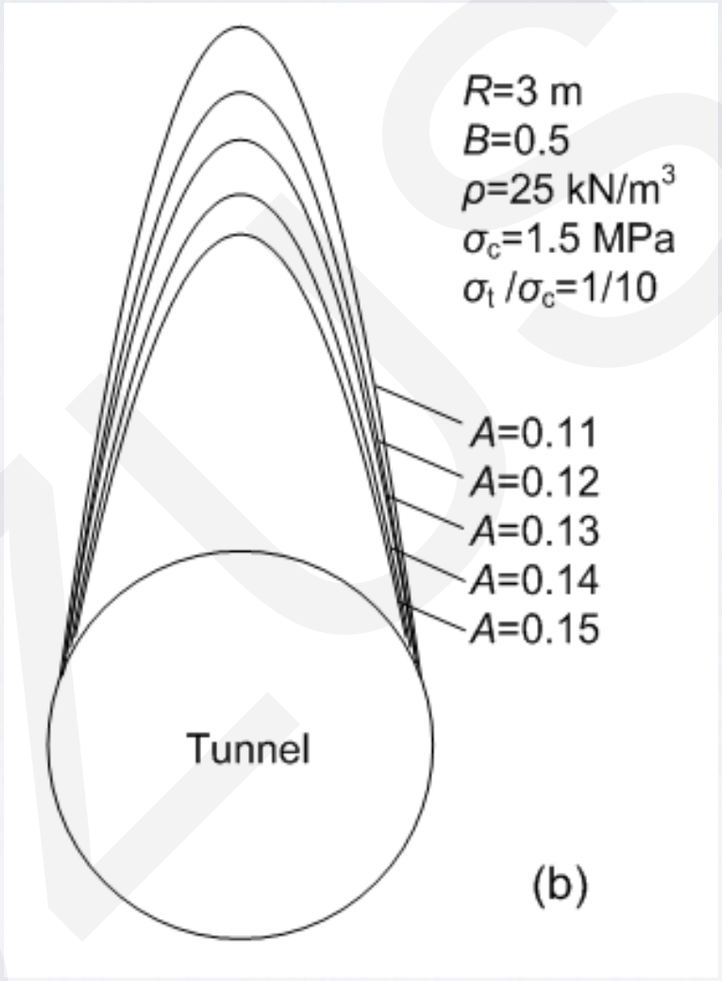
- First, it is important to obtain the total potential of the studied system: $J[x, f(x), f(x)]$ and then to obtain the $F[x, f(x), f(x)]$. Note that $f(x)$ is a function describing the outline of the collapsing block.
- Second, using Eqs. (8) and (9), a group of differential equations about $f(x)$ can be obtained. By integrating the differential equations, the shape curve (f(x)) of the collapsing block can be obtained.
- Last, the unknown constants in $f(x)$ can be determined by boundary transversality conditions and geometric compatibility equations.

$$\begin{cases} \dfrac{\partial F}{\partial f(x)} - \dfrac{\partial}{\partial x}\left(\dfrac{\partial F}{\partial f'(x)}\right) = 0, & (8) \\ \dfrac{\partial^2 F}{\partial f(x)^2} - 2\dfrac{\partial}{\partial x}\left(\dfrac{\partial^2 F}{\partial f(x)\partial f'(x)}\right) + \dfrac{\partial^2}{\partial x^2}\left(\dfrac{\partial^2 F}{\partial f'(x)^2}\right) = 0. & (9) \end{cases}$$

$$\begin{cases} f(x) = A^{-2}(\rho/\sigma_c)x^2 \\ \qquad -\left(\sigma_t/\rho + \sqrt{R^2 - L^2} + L^2/\sqrt{R^2 - L^2}\right). & (29) \\ P = 2\int_0^L \rho[g(x) - f(x)]\mathrm{d}x \\ \quad = -2\rho\left(\dfrac{L}{2}\sqrt{R^2 - L^2} + \dfrac{R^2}{2}\arcsin\dfrac{L}{R}\right) - \dfrac{2\rho}{3A^2}\left(\dfrac{\rho}{\sigma_c}\right)L^3 \\ \quad + 2\rho\left(\sigma_t/\rho + \sqrt{R^2 - L^2} + L^2/\sqrt{R^2 - L^2}\right)L. & (32) \end{cases}$$

The effects of rock mass parameters on the collapsing block shapes of deep tunnels





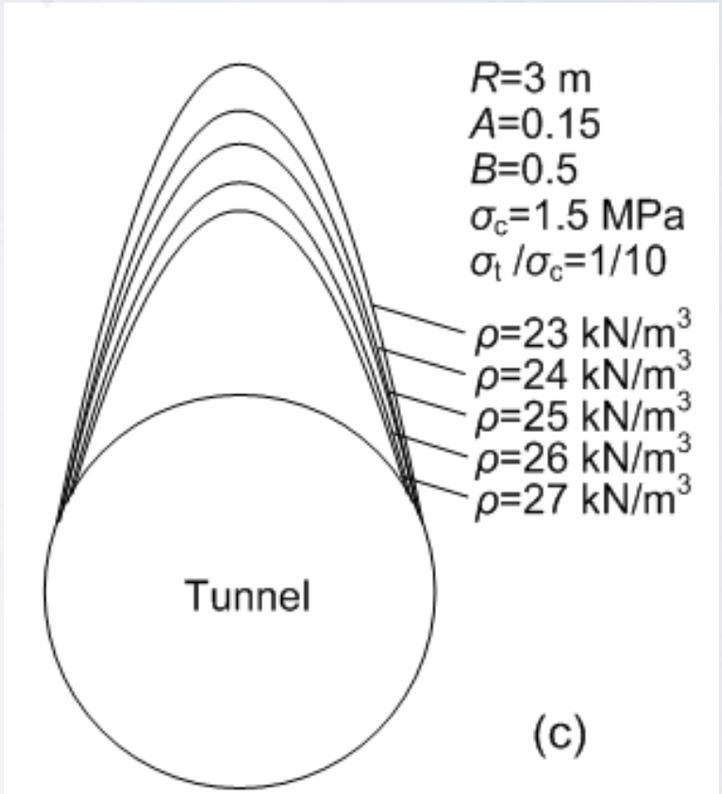


Fig. 3 Shapes of collapsing blocks vs. different rock parameters

Validation of the analytical solutions

To validate the analytical solution, the results obtained in this paper are compared with those obtained by both an empirical method and a model test. By analyzing the natural arch theory proposed by Protodyakonov (1907) and the results of a plane strain model test, it can also be concluded that the outline of the collapsing blocks is in the form of a parabola. The agreements indicate the validity of the proposed method.

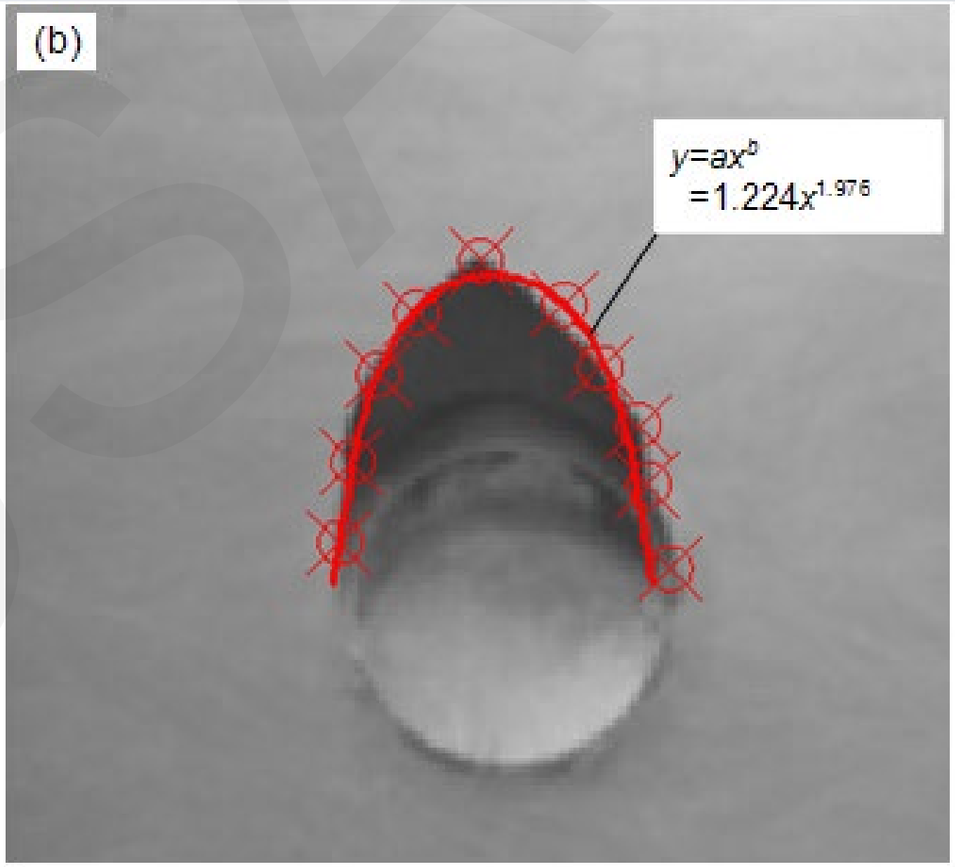


Fig. 9 Nonlinear curve fitting of the collapse observed in a model test

Conclusions

1. Based on the nonlinear Hoek-Brown failure criterion, an analytical solution of the shape curve for the collapsing blocks of deep tunnels is derived using the functional catastrophe theory. The obtained formulas can not only be used to predict the height and width of the collapsing block under unsupported conditions but also give a direct estimate of the overburden on the tunnel lining.
2. According to the functional catastrophe theory, a judging criterion is proposed to distinguish whether the roof collapse of deep tunnels will or will not occur. The influences of rock mass parameters on the shape curves of collapsing blocks in deep tunnels are obtained.
3. The proposed analytical solution is verified by both the empirical method and the model test. The agreements indicate the validity of the proposed method.