International Journal of Rock Mechanics & Mining Sciences 78 (2015) 336–349

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

A numerical procedure for the fictitious support pressure in the application of the convergence–confinement method for circular tunnel design

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ARTICLE INFO

Article history:
Received 6 February 2015
Received in revised form
25 June 2015
Accepted 3 July 2015

Keywords:
Fictitious support pressure
Circular opening
Tunnel face effect
Finite difference method
Strain-softening behaviour.

ABSTRACT

In the vicinity of a tunnel face, the fictitious support pressure represents the support pressure acting on the periphery of the tunnel provided by the rock mass itself. It is an indicator of the self-supporting capacity of the rock mass.This paper aims at solving the fictitious support pressure on a circular tunnel with hydrostatic initial stress field. A numerical procedure for the fictitious support pressure is proposed for the elastic-perfectly-plastic, elastic-brittle, and strain-softening rock masses. The procedure is composed of two steps: first, the ground reaction curve (GRC) and the longitudinal deformation profile (LDP) are solved by a modified numerical approach; in this step, the finite difference method is utilised to derive the strain components, the stress components, and the radius of the plastic zone; then, by coupling the GRC and LDP, a fictitious support pressure is obtained by a simplified approach. By using the proposed procedure, the influencing factors of the fictitious support pressure, such as the critical plastic softening parameter, the rock mass quality, the dilatancy angle and the initial stress condition are studied individually. The results indicate that the effect of the critical plastic softening parameter on the fictitious support pressure, especially for the rock mass with good quality is obvious. For a rock mass with strong dilatancy behaviour, the fictitious support pressure ahead of the tunnel face decreases rapidly. The elastic assumption of the rock mass behaviour will underestimate the stress relief factor by a large extent.

1. Introduction,

The convergence–confinement method (CCM) is a widely used tool to estimate the load imposed on the support. It suggests that in the vicinity of a tunnel face, part of load is carried by the face itself; this is called the tunnel face effect[1]. The fictitious support pressure is a surrogate for the presence of the tunnel face effect.

Based on whether the fictitious support pressure is considered or not, the existing studies deal with the CCM mainly by two approaches. By the traditional approach[2–6], the intersection of the support characteristic curve (SCC) and the ground reaction curve (GRC) is regarded as the equilibrium point of the ground-support system. The GRC can be estimated by the analytical approach for the elastic-perfectly-plastic and elastic-brittle rock mass [7-9], and the numerical approach for the strain-softening rock mass[10-12]. The SCC can be obtained for the shotcrete, steel set and ungrouted bolt by the empirical equations presented in Ref. 1 and the composite support in Ref. 4. The traditional approach provides a convenient tool to optimise the support design. However, the dissipation of the tunnel face effect or the decrease of the fictitious support pressure is not reflected by the traditional approach. Moreover, the support structures and rock reinforcement in practical cases can be fairly complex. In most cases, the rock bolts are non-uniformly distributed; and different types of support are installed. In this aspect, the elastic stiffness of SCC is difficult to represent the support properties.

The improved approach can overcome the above limitations. It introduces the fictitious support pressure and analyses the mechanical behaviour of the support-ground system more realistically[13-19]. Before the support installation, the rock mass is assumed to be supported by the fictitious support pressure. After the support installation, as the tunnel face moves forwards, the previous fictitious support pressure is gradually unloaded and the support or reinforcement deforms and carries the load. This stage can be realised by the numerical method. A wide range of support types can be simulated.

For the studies with the improved approach, the fictitious support pressure at the tunnel face was usually simplified as 50–70% of the initial stress based on the assumption that the rock

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http://dx.doi.org/10.1016/j.ijrmms.2015.07.001
1365-1609/

mass is an elastic material and undergoes a displacement of approximately 30–50% of the final displacement[13-17]. Actually, the fictitious support pressure is found to be influenced by the mechanical characteristics of the rock mass such as the plastic softening behaviour, the dilatancy behaviour, the initial stress conditions and rock mass quality. The fictitious support pressure at a certain distance to the tunnel face should be predicted as it directly relates to the load on the support during the tunnel excavation. However, it is regrettable that the fictitious support pressure in the aforementioned studies is estimated in an overly simplified way.

The objective of this paper is to bridge the gaps between the methods. It mainly covers three parts: to develop a numerical procedure for the fictitious support pressure of a circular tunnel; to validate the proposed procedure by comparing with the numerical results of other studies, and; to study the influencing factors of the fictitious support pressure, such as the critical plastic softening parameter, the rock mass quality, the dilatancy angle and the initial stress condition.

2. Problem statement

2.1. Improved approach to apply the CCM (convergence–confinement method)

The interaction between the rock mass and support by the improved approach is shown in Fig. 1. The longitudinal deformation profile (LDP) is the radial displacement which occurs along the longitudinal direction of an unsupported excavation. The ground reaction curve (GRC) is defined as the decreasing internal pressure and increasing radial displacement at the periphery of the circular tunnel. The derivation of GRC is a two-dimensional problem under the plain strain condition. The cross-section A–A′ is used to discuss GRC. As illustrated in Fig. 1, before the initial stage, the pressure on the rock mass is the fictitious support pressure p_f, and p_f at a certain location x can be solved by coupling LDP and GRC. For intermediate and final stages, the pressure on the rock mass is provided by the tunnel face and the support, which is the sum of the fictitious support pressure p_f ($p_{f,int}$ and $p_{f,fin}$) and the support pressure p_s ($p_{s,int}$ and $p_{s,fin}$). The ground-support system reaches equilibrium for every excavation step. Thus, p_f and p_s are variable in the process. When the tunnel face effect disappears at

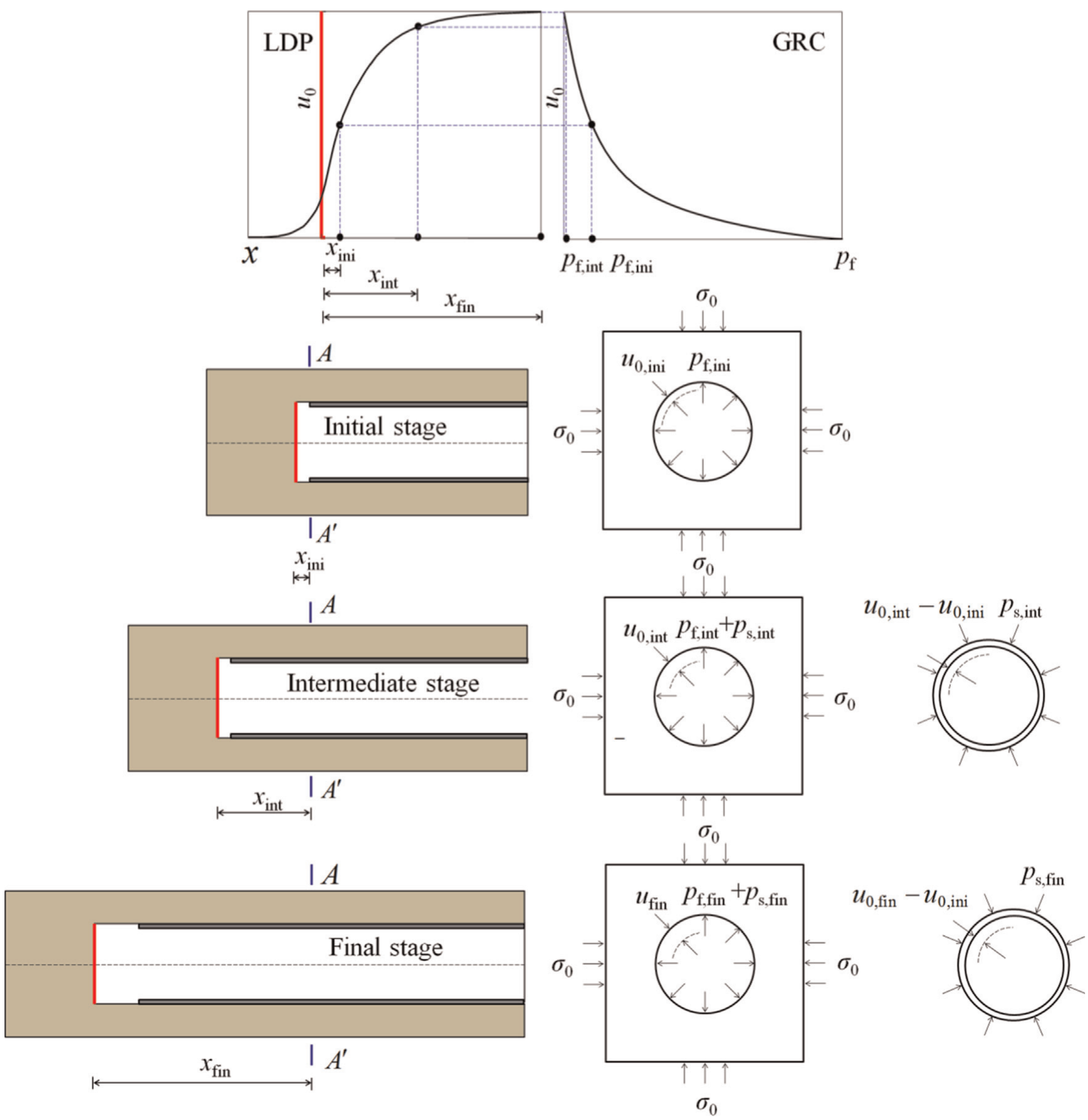

Fig. 1. Interaction between rock mass and support by improved approach.