ROCK MASS CONSTANTS and NATM

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1. Introduction

The concept of the NATM is to construct a tunnel on the basis of scientifically established principles and ideas, which have been proved in practice. The most important principles is that, the essential bearing component part of a tunnel is the surronding rock mass. Therefore Rock Classification and Rock Mass Constants play an important role in this concept.

2. Estimation of Rock Mass Constants

It is very difficult if not impossible to calculate the exact values of the rock mass constant. Based on the Engineering Classification of Rock Mass for New Austrian Tunneling Method and using more than 450 set of the datas which were obtained from various tunnels across Japan where NATM were applied, a series of equation which relates the values of rock mass constant to the velocity of elastic wave is proposed(table 1). Knowing the measured values of the rock mass constants and these calculeted values, estimeted equations for rock mass constants were found by using the theory of random function as follows:

$$\left.\begin{aligned}\rho=\rho^*(1+\varepsilon_\rho),\quad \sigma=\sigma^*(1+\varepsilon_\sigma)\\ E=E^*(1+\varepsilon_E),\quad \nu=\nu^*(1+\varepsilon_\nu)\end{aligned}\right\}\quad (1)$$

$$\left.\begin{aligned}\varepsilon_\rho=(\rho-\rho^*)/\rho^*,\quad \varepsilon_\sigma=(\sigma-\sigma^*)/\sigma^*\\ \varepsilon_E=(E-E^*)/E^*,\quad \varepsilon_\nu=(\nu-\nu^*)/\nu^*\end{aligned}\right\}\quad (2)$$

Table-1 mass constants with respect to elastic velosity

			correlation	RMS	χ^2
Specific weight density g/cm³	a	$\rho=0.1032\ V_p+2.155$	0.834	0.1004	0.875
	b	$\rho=0.4203\ V_p^{1/2}+1.741$	0.851	0.0954	0.796
	c	$\rho=2.064\ V_p^{0.1636}$	0.859	0.0932	0.764
	d	$\rho=1.978\ V_p^{1/4}+0.09956$	0.859	0.0931	0.762
Compressive strenght kgf/cm²	e	$\sigma=161.3\ V_p-102.4$	0.693	264.4	2.075×10^4
	f	$\sigma=-48.39\ V_p^2+576.4\ V_p-888.3$	0.759	222.4	1.620×10^4
	g	$\sigma=22.83\ V_p^{2.107}$	0.622	307.5	3.439×10^4
	h	$\sigma=16.83\ V_p^2+244.2$	0.629	265.5	2.636×10^4
Young modulus kgf/cm²	i	$E=1.382\times10^5\ V_p-3.325\times10^5$	0.837	1.325×10^5	8.081×10^6
	j	$E=8.156\times10^2\ V_p^{3.633}$	0.852	1.361×10^5	1.443×10^7
	k	$E=2.351\times10^4\ V_p^2-6.345\times10^4\ V_p+4.939\times10^4$	0.864	1.221×10^5	9.987×10^6
Poisson ratio	l	$\nu=2.608\times10^{-2}\ V_p+0.3818$	-0.629	0.0472	1.878
	m	$\nu=0.3407(1/V_p)+0.1780$	-0.645	0.0465	1.775
	n	$\nu=0.4501(1/V_p)^{0.3002}$	-0.645	0.0465	1.815
	o	$\nu=0.4729(1/V_p)^2-0.0303$	-0.652	0.0461	1.762

Where ρ, σ, E, ν and ρ^*, σ^*, E^*, ν^* are the expected and rondom error values of the mass density, compressiv stenght, Young modulus and poisson ratio of rock mass. These values are shown in table 2.

Table-2 Error random values by χ^2 test

	1	2	3	4	5
ε_ρ	5.137**	0.353**	8.023**	10.307*	2.187**
ε_σ	4.632**	7.592**	2.389**	8.751*	8.750**
ε_E	13.940*	4.886**	1.358**	35.578	1.844**
ε_ν	12.335**	5.980**	0.704**	4.737**	3.052**

*1% confidece level, **5% confidence level

3. Effect of the crack

One of the factors which influences the values of rock constants is the existence of crack. For considering the effect of the crack under different conditions, the ratio of the stresses in horisental and vertical direction , and the displacement of a rock mass when the crack exists and when the crack does not exist were calculated by using no tension method. We call these ratio as: Rx, Ry and Rd, where $Rx=\sigma cx/\sigma nx$, $Ry=\sigma cy/\sigma ny$ and $Rd=Dc/Dn$ (σcx, σcy, Dc are the stresses and displacement when crack exist and σnx, σny, Dn are stresses and displacement when there is no crack). It was seen that the ratio of vertical pressure with respect to the horizental pressure; rather than each of them seperately, the angle of the crack, the distance between the crack and the mechanical properties of the crack have an effect on these ratios. For different ratios of the vertical pressure to the horizental pressure the values of Rx and Ry , with respect to the angle of the crack first decrease and when this angle is almost equal to 45° it starts increasing. But the shape of Rd is quite differnt when the pressure ratio is greater than one, equal to one or smaller than one. When the crack were in vertical or horizental direction, the rock mass layer were acting almost indepently of each other, and therefore the values of Rx and Ry were almost equal to one. Using multi-rgression analysis the effect of each of the above mensioned parameters were studied and the following equations are proposed:

$$Rx=1-e^{-1.26}\left[(Pv/Ph)^{.504}(\varphi(\pi/2-\varphi)^{3.85}(Ks/E)^{.179}(Kn/E)^{-.717}(d/L)^{-.676}\right] \qquad (3)$$

$$Ry=e^{-.342}\left[(Pv/Ph)^{.0137}(\varphi(\pi/2-\varphi)^{-.458}\,e^{1/E(1.68\,Kn+.00003/Ks)}(d/L)^{-.00272}\right] \qquad (4)$$

$$Rd=e^{-3.94}\left[(Pv/Ph)^{.163}(\varphi(\pi/2-\varphi)^{-2.408}(Kn/E)^{-.512}(Ks/E)^{-.042}(d/L)^{-.715}\right] \qquad (5)$$

Where Pv and Ph are the vertical and horizental pressure; φ is the angle of crack; Ks and Kn are the shear ans normal stiffnes of crack; d is the distance between the cracks; E and L are the Young modulus and the lenght of the model of the rock. The R-square values for eq. (3), (4), (5) are equal to .900, .848, .861 respectively.

Knowing the relation between stresses and displacements when the crack exist and when the crack dos not exit and also knowing the estimeted equation for rock mass canstants the values of the Stresses and the displacements at any point of the rock when NATM is applied can be obtained by using Stocastic Finite Element .

Reference

T. Chishaki, M. Taguchi, T. Hirata, M. Saito, H. Takasaki and A. Aikawa : Engineering Classification Of Rock Masses for New Austrian Tunneling Method Memoirs of the Faculty of Engineering Kyushu University : Vol. 44, No. 1