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Back Analysis of Field Measurements Around the Tunnel with the Application of Genetic Algorithms

유전자 알고리즘을 이용한 터널 현장 계측 결과의 역해석

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요지

본 논문에서는 역해석 방법 중 직접법의 성능에 큰 영향을 미치는 최적화 과정을 인공지능의 한 기법인 유전자 알고리즘을 이용하여 역해석 프로그램을 구성하였다. 유전자 알고리즘 및 역해석 기법의 효용성을 검증하기 위하여 과거 역해석 연구 사례 중의 하나인 Gens et al(1987)과 동일한 암반조건을 가진 모델에 대한 역해석을 실시하여 그 결과를 비교 · 검토하였다. 경부고속철도 터널 현장의 내공변위 및 천단침하에 대한 계측자료로부터 최종 내공변위의 예측함수를 결정하는 방법으로 터널의 총 변위를 분석하였다. 이를 역해석에 필요한 입력자료로 활용하여 역해석을 실시하고 터널 주변 암반의 거동을 반영할 수 있는 지반의 특성치를 구하였다. 각 현장 시험에서 얻어진 지반의 특성치와 비교한 결과 본 연구에서 적용된 유전자 알고리즘을 이용한 역해석 방법이 유의한 수준의 결과를 도출하고 있다는 사실을 확인하였다.

Abstract

In this study, the back analysis program was developed by applying the genetic algorithm, one of artificial intelligence fields, to the direct method. The optimization process which has influence on the efficiency of the direct method was modulated with genetic algorithm. On conditions that the displacement computed by forward analysis for a certain rock mass model was the same as the displacement measured at the tunnel section, back analysis was executed to verify the validity of the program. Usefulness of the program was confirmed by comparing relative errors calculated by back analysis, which is carried out under the same rock mass conditions as analysis model of Gens et al (1987), one of back analysis case in the past. We estimated the total displacement occurring by tunnelling with the crown settlement and convergence measured at the working faces in three tunnel sites of Kyungbu Express railway. Those data measured at the working face are used for back analysis as the input data after confidence test. As the results of the back analysis, we comprehended the tendency of tunnel behaviors with comparing the respective deformation characteristics obtained by the measurement at the working face and by back analysis. Also the usefulness and applicability of the back analysis program developed in this study were verified.

Keywords : Back analysis, Field measurements, Genetic algorithms

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1. Introduction

The methods used in the displacement back analysis of geotechnical engineering projects can be broadly divided into two types, namely inverse method and direct method (or optimization method). For numerical modeling, the conventional procedure is to solve the system equation for displacements, based on known material parameters and loading conditions. The inverse method, such as that suggested by Sakurai and Takeuchi (1983), is the inverse of the above procedure. It numerically solves some of the material parameters or loading conditions based on observed displacements. Rapid numerical solution is one of the advantages of the inverse method. In order to obtain the inverse of the system equation, a number of simplifying assumptions are often made, including uniform material, uniform or linear geostress field and one-step excavation.

For the optimization method, the summed squared errors between the calculated displacements and their corresponding observed values are usually used as the objective function. The solution of the objective function is based on some optimization techniques to determine a set of material parameters or loading conditions that make the value of the objective function a minimum. As the system equation is only used as a constraint equation and no inverse procedure is needed, this optimization method is more appropriate for geotechnical engineering applications. However, the optimization of the objective function is accompanied by a large amount of parameter adjustments, with each parameter adjustment requiring at least one calculation. And observed displacements could be noisy and the objective function for back analysis could be multimodal. When a routine optimization method such as the Powell method is used, the results might depend on the initial values as well.

The above drawbacks could be solved by using a genetic algorithm (GA) as the objective function optimizer in this paper.

The GA simulates the mechanism of natural selection and natural genetics, and is a universal function optimizer. It outperforms both the gradient techniques and the various forms of the random search on difficult problems, such as optimization involving discontinuous media, noisy observation data, multiple dimensions and multimodal objective functions.

In this study, The optimization process which influences the efficiency of the direct method was modulated with genetic algorithm, and then the whole back analysis program was combined with the boundary element method code as a tool of forward analysis. The modulated genetic algorithm program also was combined with FLAC, a commercial finite difference program. This back analysis program was applied to estimate the geotechnical parameters in the case of weak rock mass in the Kyung-Bu Express railway tunnel and to analyze tunnel deformation characteristics.

2. Genetic Algorithm (GA)

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. In every generation, a new set of artificial creatures (strings) is created using bits and pieces of the fittest of the old. While randomized, genetic algorithms are no simple random walk. They efficiently exploit historical information to speculate on new search points with expected improved performance.

A simple genetic algorithm is composed of three operators (Srinivas et al, 1994) : 1. Reproduction (or selection), 2. Crossover, 3. Mutation

Reproduction is a process in which individual strings are copied according to their objective function values, f (biologists call this function the fitness function). Intuitively, we can think of the function f as some measure of profit, utility or goodness that we want to maximize. Copying strings according to their fitness values means that strings with a higher value have a higher probability of contributing one or more offspring in the next generation. This operator is an artificial version of natural selection, a Darwin's survival of the

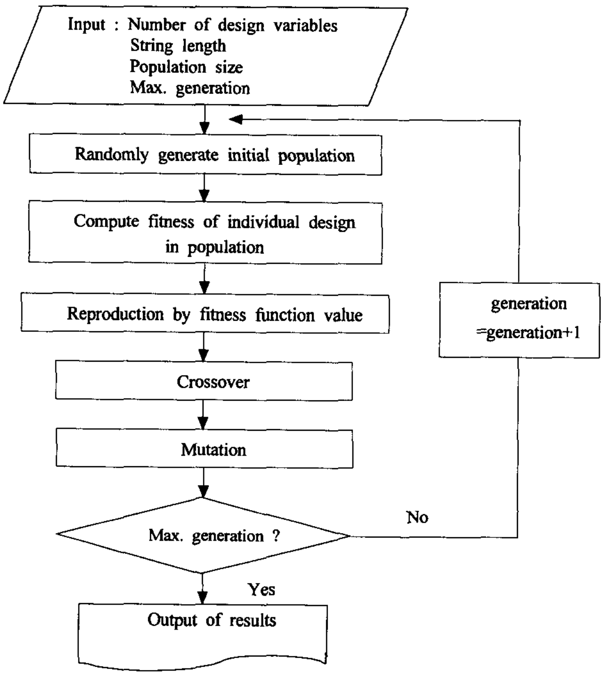

Fig. 1. Flow chart of optimization process

fittest among string creatures.

After reproduction, Crossover may proceed in two steps. First, members of the newly reproduced strings in the mating pool are mated at random. Second, each pair of strings undergoes crossing over as follows : an integer position k along the string is selected uniformly at random between 1 and the string length less one $[1,\ l-1]$. Two new strings are created by swapping all characters between positions $k+1$ and l inclusively.

In artificial genetic systems, the mutation operator protects against an irrecoverable loss. In the GA, mutation is the occasional (with small probability) random alteration of the value of a string position. This simply means changing 1 to 0 and vice versa. By itself, mutation is a random walk through the string space. When used sparingly with reproduction and crossover, it is an insurance policy against premature loss of important notions. Fig. 1 shows the process of the genetic algorithm.

3. Verification of the Back Analysis Model

3.1 Analysis Model and Ground Properties

To verify the efficiency of back analysis program in this study, The results of this study are compared with that of Gens' back analysis model (Gens et al, 1987, Ledesma et al, 1996), one of back analysis case in the past.

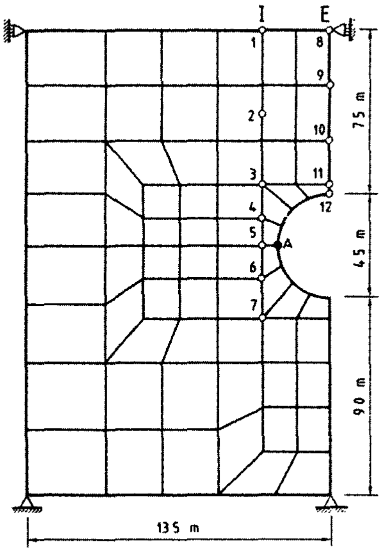

Fig. 2. Analysis model of Gens

For numerical analysis, the model shown in Fig. 2 is used to simulate the boundary condition and ground properties, assuming that the ground is isotropic and elastic and the circular tunnel is located at 9.75m depth. Table 1 shows the ground properties used in Gens' back analysis model. Elastic modulus and initial field stress ratio are the searching target values of this back analysis.

Table 1. Physical properties value used in Gens' analysis model

Physical properties	Value
elastic modulus (MPa)	10
initial field stress ratio	1.0
poison's ratio	0.49
specific weight (kN/m)	20

Table 2. Computed displacements used as measurements in model

horizontal movements		vertical movements	
point	displacement(mm)	point	displacement(mm)
1	3.16	8	-35.98
2	5.56	9	-39.05
3	20.38	10	-49.35
4	35.50	11	-63.27
5	45.50	12	-70.48
6	39.20		
7	24.27		

The Computed displacements used as measurements in model are shown in Table 2.

3.2 Results of the Back Analysis

Table 3 shows the results of back analysis using genetic algorithm. Comparing Gens' with GA's results, it can be known that the result of back analysis using genetic algorithm is fully corresponding to the true value comparing with Gens' results. Therefore, we can make sure that this back analysis model using genetic algorithm is more effective to estimate the geotechnical properties around tunnel. Fig. 3 shows the distribution of fitness function values in genetic algorithm optimizer.

4. Back Analysis of Field Measurement

4.1 Geological Outline

The project area, a part of the Kyeongki Gneiss Complex, is comprised of mainly gneisses, igneous rocks intruded later, and alluvium. The gneiss formations dipped generally toward south east, and toward north east in the west part of the area. The rocks in mineral components are similar to granitic rock, and its metamorphic facies belong generally to amphibolite facies.

Table 3. Comparison between Gens' and GA's results

	Gens et al (1996)		Genetic Algorithm (GA)	True value
	1	2		
E	9.2MPa	9.4MPa	10.18 MPa	10MPa
Error* of E	6%	8%	3.8%	
K_0	0.99	1.3	1.038	1.0
Error* of K_0	1%	30%	3.8%	

$$* \text{ relative error} = \frac{\text{true value} - \text{back analysis result}}{\text{true value}} \times 100$$

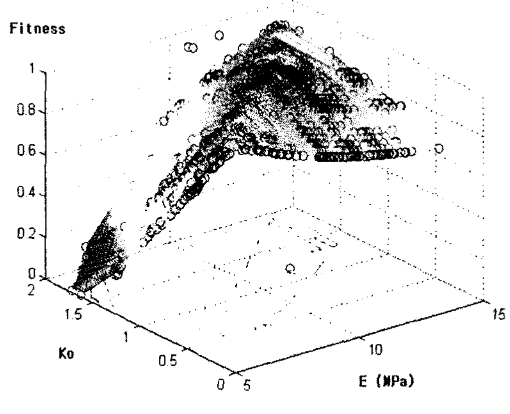

Fig. 3. The distribution of E and K0 for fitness function

4.2 Boring Test

In order to verify the ground conditions around the tunnel, a total of 23 bore holes with core drilling test were performed in the project area

4.3 Rock Classification of the Project Area

Table 5 shows that the rock mass encounted at each boreholes was classified by RMR.

4.4 Field Measurements and Tunnel Model

The items of field measurements to decide the input data for back analysis are upper half covergence and crown settlement. Fig. 4 shows the tunnel cross section and measuring points for field measurement in this study (where, UH:Upper half convergence, CS:Crown Settlement).

4.5 Analysis of Field Displacement Measurement

In this study, a regression analysis was performed for field measuring displacements to estimate total displacement, C_m and non-measuring displacement, C_0. The example of regression analysis of field measurements is

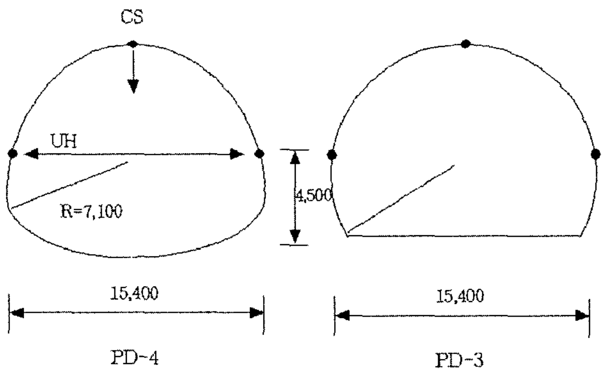

Fig. 4. Cross-section of tunnel and measuring points

Table 4. The results of boring test

tunnel name	hole No.	fill layer	colluvium	alluvium	base rock				Total (m)	S.P.T
					weathered soil	weathered rock	weak rock	hard rock		
A tunnel	TB-1		2.3		9.2	16	14.5	3.0	45.0	10
	TB-2		2.3		4.4	6.3	3.3	30.2	46.5	5
	TB-3	2.0	1.5		3.3	2.7	7.2	9.6	26.3	4
	TB-4	5.0			3.3	6.7	4.4	7.3	26.7	5
	TB-5	3.8			2.7	6.9	9.8	3.8	27.0	6
	TB-6	1.8			1.5	6.0	10.7	8.6	28.6	3
	TB-7			0.3	7.3	11.7	5.7	14.8	39.8	8
B1 tunnel	TB-8		2.0		10	6.9	7.1	4.0	30.0	8
	TB-9				7.5	13.0	6.9		27.4	10
B2 tunnel	TB-10	6.8				7.7	1.5	20.5	36.5	6
	TB-11	3.2			3.3	8.3	7.6	9.9	32.3	7
	TB-12	7.3			10.7	11.5	0.7	8.8	39.0	12
	TB-13	13.4			6.3	8.8	4.3	6.0	38.8	13
	TB-13-1	13.8		0.9	8.0	9.5	2.0	4.8	39.0	12
	TB-14	7.3			1.4	8.5	1.8	11.6	30.6	5
	TB-15	7.4			4.2	12.6	12.0	2.4	38.6	10
	TB-16	1.4			4.6	6.2	11.7	15.1	39.0	5
C tunnel	TB-17		2.8		4.7	2.0	4.3	10.9	24.7	4
	TB-18			3.2		1.5	10.3	8.2	23.2	1
	TB-19	2.8				1.0	10.3	8.4	22.5	1
	TB-20		1.7			1.8	1.0	19.4	23.9	1
	TB-21		1.2			1.5	4.3	15.0	22.0	1
	TB-22		1.0		5.5	7.3	3.2	5.5	22.5	4

Table 5. Rock mass classification of boring hole

Tunnel	boring hole No.	RMR grade	classification
A Tunnel	TB-1	IV	Poor
	TB-2	II ~ III	Fair ~ Good
	TB-3	III ~ IV	Poor ~ Fair
	TB-4	IV	Poor
	TB-5	IV	Poor
	TB-6	IV	Poor
	TB-7	III ~ IV	Poor ~ Fair
B1 Tunnel	TB-8	IV	Poor
	TB-9	IV	Poor
B2 Tunnel	TB-10	III ~ IV	Poor ~ Fair
	TB-11	III ~ IV	Poor ~ Fair
	TB-12	II ~ IV	Fair ~ Good
	TB-13	III ~ IV	Poor ~ Fair
	TB-13-1	II ~ IV	Poor ~ Good
	TB-14	II ~ IV	Poor ~ Good
	TB-15	III ~ IV	Poor ~ Fair
	TB-16	III ~ IV	Poor ~ Fair
C Tunnel	TB-17	III ~ IV	Poor ~ Fair
	TB-18	IV	Poor
	TB-19	III ~ IV	Poor ~ Fair
	TB-20	III	Fair
	TB-21	III ~ IV	Poor ~ Fair
	TB-22	III ~ IV	Poor ~ Fair

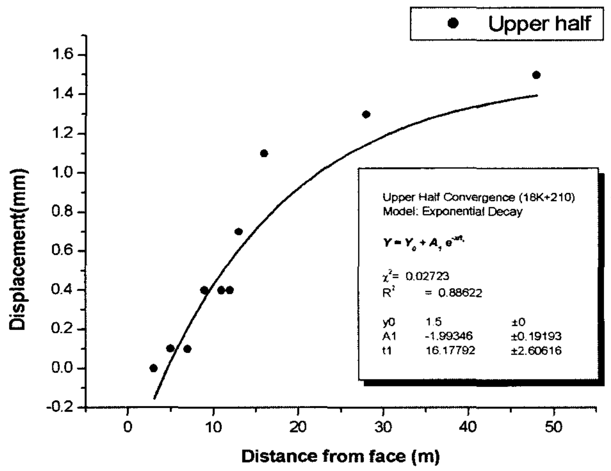

Fig. 5. Convergence fitted and measured in tunnel

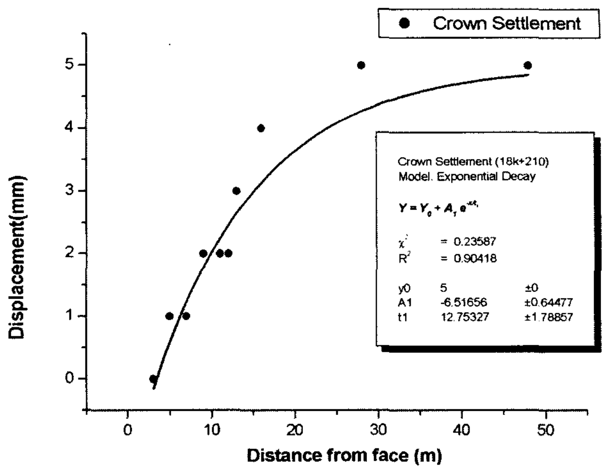

Fig. 6. Crown settlement fitted and measured in tunnel section

shown in Fig. 5 and Fig. 6.

From the analysed results, the values of total and non-measuring displacement for the field measurements can be obtained by selecting the regression model, one of the exponential decay models which has high adjusted R^2. The regression model is as follows;

$$C(x) = Y_0 + A_1 e^{(-x/t_1)} \qquad (1)$$

where, Y_0, A_1, t_1 are respectively the regression constant.

The total convergence C_{tot} can be calculated by tunnel excavation as follows;

$$C_{tot} = C_{x\infty}(1+\alpha_0) \qquad (2)$$

where, $\alpha_0 = \frac{U_a}{C_{x\infty}}$

$U_a =$ convergence before access of tunnel face

In this study, assuming $U_a/U_t = 0.3$ and $\alpha_0 = 0.428571$ based on the results of previous research papers(Hanafy et al, 1980, Vassilev et al, 1988, Panet et al, 1982 and Sulem et al., 1987), the total convergence C_{tot} of tunnel site was obtained. Tables 6~8 show the result of regression analysis on the displacements measured in tunnels A, B, and C. d_0 is the distance from the tunnel

Table 6. Results of regression analysis on the displacements measured in tunnel A

	measuring points	d_0 (X/D)	C_m (mm)	C_0 (mm)	$C_{x\infty}$ (mm)	$C_0/C_{x\infty}$ (%)	C_{tot} (mm)
18K+210	UH	0.32	1.5	0.493	1.993	24.8	2.848
	CS	0.32	5.0	1.517	6.517	23.3	9.309
18K+230	UH	0.19	1.5	0.667	2.167	30.8	3.096
	CS	0.19	5.0	2.581	7.581	34.0	10.830
20K+670	UH	0.97	1.5	1.487	2.987	49.8	4.268
	CS	0.97	4.0	6.181	10.182	60.7	14.545
20K+685	UH	0.13	8.9	9.324	18.224	51.2	26.034
	CS	0.13	5.0	5.180	10.180	50.9	14.543
20K+730	UH	0.13	1.3	0.447	1.749	25.7	2.498
	CS	0.13	6.0	1.239	7.239	17.1	10.342
20K+760	UH	0.84	2.4	6.484	8.884	73.0	12.692
	CS	0.84	5.0	9.938	14.938	66.5	21.340
20K+810	UH	1.10	2.5	28.842	31.342	92.0	44.774
	CS	1.10	4.0	46.147	50.147	92.0	71.639

UH : Upper Half Convergence, CS : Crown Settlement

Table 7. Results of regression analysis on the displacements measured in tunnel B

	measuring points	d_0 (x/D)	C_m (mm)	C_0 (mm)	$C_{x\infty}$ (mm)	$C_0/C_{x\infty}$ (%)	C_{tot} (mm)
21K+590	UH	0.45	1.1	0.500	1.600	31.261	2.286
	CS	0.45	6.0	3.990	9.991	39.945	14.273
21K+610	UH	0.45	1.5	1.560	3.060	50.977	4.371
	CS	0.45	6.0	5.434	11.434	47.523	16.334
22K+875	UH	1.04	0.5	843.528	844.028	99.941	1205.754
	CS	-	-	-	-	-	-
22K+950	UH	0.97	1.0	42.509	43.509	97.702	62.156
	CS	-	-	-	-	-	-
23K+285	UH	0.13	3.2	1.581	4.781	33.075	6.831
	CS	0.13	3.0	0.279	3.279	8.510	4.684

UH : Upper Half Convergence, CS : Crown Settlement

Table 8. Results of regression analysis on the displacements measured in tunnel C

	measuring point	d_0 (x/D)	C_m (mm)	C_0 (mm)	$C_{x\infty}$ (mm)	$C_0/C_{x\infty}$ (%)	C_{tot} (mm)
26K+490	UH	0.32	1.0	4.080	5.080	80.313	7.257
	CS	0.32	2.0	8.159	10.159	80.313	14.513
26K+520	UH	0.13	0.9	0.228	1.128	20.186	1.611
	CS	0.13	4.0	1.293	5.293	24.426	7.561
26K+580	UH	1.49	1.0	10.783	11.783	91.513	16.832
	CS	1.49	4.0	150.978	154.978	97.419	221.397
27K+915	UH	0.65	0.4	0.025	0.425	5.769	0.606
	CS	0.65	4.0	41.972	45.972	91.299	65.674
27K+955	UH	0.39	0.6	0.466	1.066	43.726	1.523
	CS	0.39	3.0	2.331	5.331	43.726	7.616
28K+065	UH	0.13	3.4	0.408	3.808	10.703	5.439
	CS	0.13	3.0	0.366	3.366	10.708	4.800

UH : Upper Half Convergence, CS : Crown Settlement

face normalized by the tunnel diameter.

5. The Estimation of Physical Properties of Rock Mass Using Back Analysis

5.1 Estimation Methods of Rock Deformation Modulus

Rock deformation modulus in the project area was estimated according to the methods given as follows;

a. rock material deformation modulus measured in laboratory test

b. rock mass deformation modulus estimated from RMR

c. rock mass deformation modulus obtained from elastometer test in bore hole

b. rock mass deformation modulus calculated from this back analysis with genetic algorithms (assuming that initial field stress ratio K_0 is 1.0)

Table 9 shows the result of estimation of rock mass deformation properties around the tunnel. Especially, the value estimated from RMR is calculated by the empirical equation as follows;

① Bieniawski's empirical equation(1978)

$$E_m = 2RMR - 100 \quad (GPa)$$

Serafim and Pereira's empirical equation(1983)

$$E_m = 10^{\frac{RMR-10}{40}} \quad (GPa)$$

Table 9. Estimation of rock deformation modulus in tunnel section (unit : MPa)

bore hole No.	Lab. test	Ave. RMR	estimated from RMR				bore hole test	Max. Fit	Con. Fit
			①	②	③	④		K0=1.0	
TB-1	21918	25.25	2406	893	988	3271	1157	1002	3237
TB-2	40482	58.50	16312	17478	8609	25582	2099	7604	38807
TB-3	27164	25.40	2427	912	1235	4100	618	642	2068
TB-4	--[1]	20.25	1804	409	--[2]	--[2]	118	150	197
TB-5	9660	24.50	2304	802	417	1361	588	749	698
TB-6	11229	25.50	2440	925	513	1707	569	234	255
TB-7	9924	34.80	4168	2779	747	2682	1893	808	2346
TB-8	27733	26.00	2512	990.	1305	4374	2305	659	2439
TB-9	35019	24.00	2239	746	1467	4746	539	490	1187
TB-10	25811	35.25	4278	2909	1987	7137	1726	1659	9566
TB-11	9336	36.00	4467	3134	746	2680	1000	1099	686
TB-12	48101	48.00	8913	8677	6650	22541	196	--[3]	--[3]
TB-13	46876	31.67	3481	1990	3006	10673	137	--[3]	--[3]
TB-13-1	19623	30.00	3162	1644	1152	4044	500	--[3]	--[3]
TB-14	33460	49.75	9857	9850	4983	16599	363	--[3]	--[3]
TB-15	22840	29.75	3117	1596	1323	4635	186	--[3]	--[3]
TB-16	24026	36.00	4467	3134	1919	6898	530	583	619
TB-17	26645	39.00	5309	41603	2459	8810	1373	1687	2110
TB-18	16897	24.25	2271	774	718	2335	892	1099	5699
TB-19	30077	30.25	3208	1693	1790	6295	461	794	3219
TB-20	33990	45.25	7608	7041	4171	14468	2354	1565	5366
TB-21	38932	34.75	4157	2765	2922	10493	1402	1099	3225
TB-22	21231	30.00	3162	1644	1246	4376	618	665	752

[1] the absence of elastic modulus E_i obtained from the laboratory test

[2] unable to estimate E_m from reduction factor due to the absence of E_i data.

[3] the absence of field measurement data

② Aydan's empirical equation(1997)

$$Em = 0.0097 \cdot R^{3.54} \quad (MPa)$$

③ Nicholson and Bieniawski's empirical equation (1990)

$$E_m = E_i \cdot \frac{1}{100} \cdot [0.0028RMR^2 + 0.9\exp(\frac{RMR}{22.82})]$$

④ Mitri et al.'s empirical equation(1994)

$$E_m = E_i \cdot 0.5 \times \left[1 - \left\{\cos(\pi * \frac{R}{100})\right\}\right]$$

5.2 Characteristics of Rock Mass Deformation Modulus

Fig. 7 shows comparison of the various estimative value for rock mass deformation modulus according to the bore hole No. around the tunnel site.

As shown in Table 9 and Fig. 7, it can be seen that the values of rock mass deformation modulus are listed in order of magnitude as follows : ① rock material deformation modulus measured in laboratory test, ② rock mass deformation modulus estimated from RMR, ③ rock mass deformation modulus obtained from elastometer test in bore hole.

According to the results of the paired t-test, the values of rock mass deformation modulus from back analysis with genetic algorithm are similar to the value of

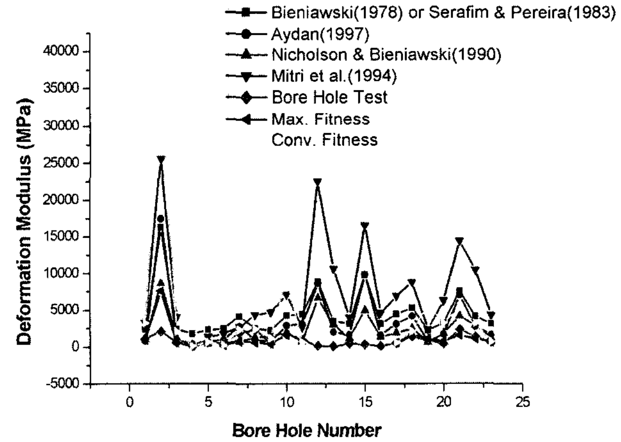

Fig. 7. Deformation modulus of tunnel sections

elastometer test more than any other values.

Fig. 8 shows the comparison of the various estimative values for rock mass deformation modulus according to RMR around the tunnel site. As shown below, the results of deformation modulus by Bieniawski (1978), Serafim and Pereira (1983) and Aydan (1997)'s empirical equation have the tendency of increase with increasing RMR, but the results of deformation modulus by Nicholson & Bieniawski (1990) are scattered a little. It can be due to elastic modulus of rock material in laboratory test.

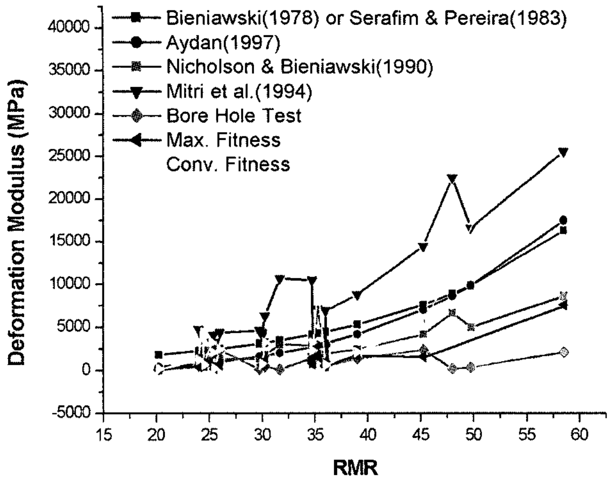

Fig. 8. Deformation modulus for RMR in tunnel

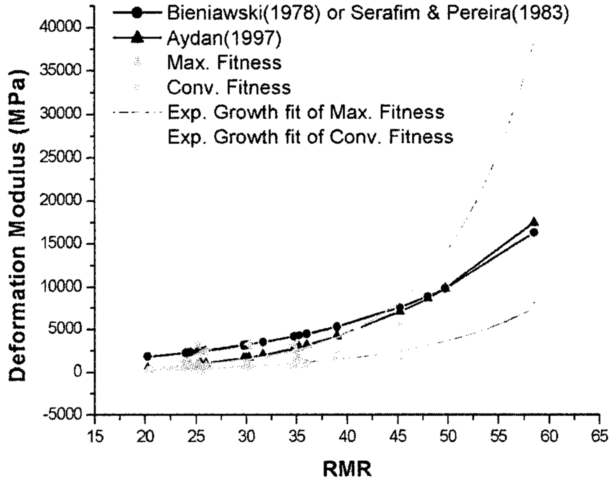

Fig. 9. Deformation modulus fitted and measured in tunnel

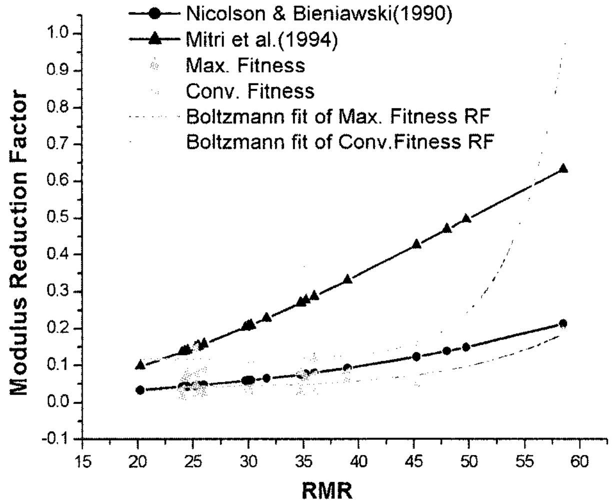

Fig. 10. Modulus reduction factor fitted for RMR

Fig. 9 shows rock deformation modulus according to RMR. As shown, we can consider the tendency of rock mass deformation modulus as exponential function as follows. That is, rock deformation modulus calculated from the results of maximum fitness in back analysis with genetic algorithm is noted as "▲" and can be expressed as equation (3).

$$E_m = 55.42 \exp(RMR/11.94) \quad \text{(MPa)} \qquad (3)$$

It can be noticeable that this expression is fully corresponding with the result of back analysis because the adjusted R^2 of this regression model is 0.9437.

In Fig. 9, rock deformation modulus calculated from the results of convergence fitness in back analysis with genetic algorithm is noted as "◀" and can be expressed as equation (4) and the adjusted R^2 of regression model is 0.9180.

$$E_m = 44.95 \exp(RMR/8.67) \quad \text{(MPa)} \qquad (4)$$

Fig. 10 shows Modulus Reduction Factor(MRF) according to RMR. As shown, we can consider the tendency of MRF as Boltzmann regression function, one of the sigmodal functions. That is, rock deformation modulus calculated from the results of maximum fitness in back analysis with genetic algorithm is noted as "▲" and can be expressed as equation (5). It can be noticed that this expression is corresponding poorly with the result of back analysis because the adjusted R^2 of this regression model is 0.6139.

$$E_m = E_i \cdot \left[\frac{0.668}{1 + e^{(RMR-68.89)/-8.16}} + 0.0385\right] \quad \text{(MPa)} \qquad (5)$$

As shown in Fig. 10, rock deformation modulus calculated from the results of convergence fitness in back analysis with genetic algorithm is noted as "◀" and can be expressed as equation (6) and the adjusted R^2 of regression model is 0.7975.

$$E_m = E_i \cdot \left[\frac{0.644}{1+e^{(RMR-66.70)/-4.03}} + 0.1165\right] \quad (\mathrm{MPa}) \quad (6)$$

6. Conclusion

In this paper, to overcome the drawbacks of other back analysis method in the past, a genetic algorithm was applied as the objective function optimizer in direct method.

Through the verification of back analysis model and comparison with Gen's results, it can be known that the result of back analysis using genetic algorithm is fully corresponding with the true value of rock mass properties in ground model. Therefore, we can make sure that this back analysis model using genetic algorithm is more effective in estimating the geotechnical properties around than any others.

In case study of field measurement for tunnel in Kyungbu Express railway, rock mass deformation modulus from back analysis with genetic algorithm is similar to the value from elastometer test more than any other values. Moreover, we can consider the tendency of rock mass deformation modulus to RMR as exponential function and Modulus reduction factor to RMR as sigmodal functions.

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