Predicting Roadway Surrounding Rock Deformation and Plastic Zone Depth Using BP Neural Network

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Abstract. It is a complex nonlinear problem to analyze the interaction between bind and the deformation of surrounding rocks and the depth of plastic zones as well as the deformation caused by destruction. This study tackles this problem by taking into account the size of roadway section, burial depth, rock parameters and the in homogeneity of surrounding rock. The software, namely--FLAC^{3D} has been used perform the numerical analysis. The sample data that affect the deformation and plastic zone size of the surrounding rock have been investigated. The BP Neural Network Predictive Model has been developed to solve the nonlinear mapping issue. With the strength of the artificial neural network, the prime deformation and the plastic zone range of the surrounding rocks caused by the roadway excavation were obtained. The developed predictive model has further been tested with a case study on the roadway with the Jalainur northern iron ore. The predictions of the ore's deformation and plastic zone range of surrounding rock are found to be consistent with the field observations.

Introduction

With the rapid development of social economy in China, the exploitation and utilization of underground resources is becoming more and more popular. As for underground mining, in order to ensure the safety in production of mine, how to maintain the stability of surrounding rock after the roadway being excavated is the chief problem to be addressed, therefore, researches on the stability of underground roadway surrounding rock are being paid more and more attention to. It is essential to take a further research on the distribution laws of stress field and deformation of surrounding rock after roadway's excavation to ensure the stability of roadway surrounding rock, on the bias of which reasonable and effective prevention measures are taken to achieve the stability and safety of rock engineering (Wright C et.al 2000).

Predicting the deformation and plastic zone depth of surrounding rock caused by roadway excavation with which the thesis starts, difficult to be described due to the complex relationship among various factors affecting the deformation and plastic zone depth of roadway surrounding rock, is an extremely complicated nonlinear mapping issue (Liu C L et.al 2002). In order to solve it, factors causing the deformation and plastic zone depth of roadway surrounding rock was fully analyzed and systematically studies, and the BP Neural Network Prediction Model of the deformation and plastic zone depth of roadway surrounding rock was built with the aid of artificial neural network's capacity of solving nonlinear problem in this thesis(Funabashi K.1989).

Analysis on the Deformation of Roadway Surrounding Rock

According to features of vertical-wall arched roadway, main factors causing the deformation of its surrounding rock are, section size of roadway arch rise r, wall height h）, burial depth (H), development degree of the joint and crack of surrounding rock(cohesion inhomogeneity degree D), rock parameters （E, μ, c, φ）. The thesis analyzed the effects of the deformation of roadway surrounding rock caused by the above eight factors respectively with software FLAC^{3D}(Liu B).

As can be seen from Fig. 1& Fig. 2, when roadway arch rise and vertical wall height are 2 m, 2.5 m, 3 m, and 3.5 m respectively, the roof settling, floor moving-up and wall displacement of roadway increase gradually with the increasing of roadway arch rise and vertical wall height, among which, floor moving-up is the largest deformation with an obvious change, wall displacement the second, and roof settling the last.

As can be seen from Fig. 3, when burial depth of roadway is 200 m, 400 m, 600 m, and 800 m respectively, roof settling, floor moving-up, and wall displacement of roadway increase gradually with the increasing of roadway burial depth, among which, floor moving-up is the largest deformation, wall displacement the second, and roof settling the last.

In order to describe the development degree of the joint and crack of surrounding rock, the thesis defines the inhomogeneity degree, whose index is cohesion and with the characteristic of random distribution in surrounding rock, as the inhomogeneity degree of rock in terms of numerical simulation. As can be seen from Fig. 4, when the inhomogeneity degrees of roadway surrounding rock are 0.1, 0.3, 0.5, and 0.7 respectively, roof settling, floor moving-up, and wall displacement of roadway increase gradually with the increasing of the inhomogeneity of surrounding rock, and these three deformations are approximately the same.

As can be seen from Fig. 5, the deformation of roadway surrounding rock decreases with the increasing of elasticity modulus. When elasticity modulus increases from 1 GPa to 5 GPa, roof settling, floor moving-up and wall displacement of roadway decrease greatly; while when the elasticity modulus of roadway surrounding rock keeps increasing from 5 GPa to 10 GPa and then to 15 GPa, the curves run gently showing that the deformation of road way decrease smoothly. So it is perceived that variations of low elasticity modulus have a severe influence on the deformation change of roadway surrounding rock.

As can be seen from Fig. 6, the deformation of roadway surrounding rock increases with the increasing of its Poisson’s ration, but the deformation curves run smoothly, which shows that the changes of Poisson’s ration affect the deformation change of roadway surrounding rock little.

As can be seen from Fig. 7, the deformation of roadway surrounding rock decreases with the increasing of the cohesion. When cohesion increases from 0.5 MPa to 1 MPa, roof settling, floor moving-up, and wall displacement of roadway decrease greatly; while when the cohesion keeps increasing from 1 MPa to 1.5 MPa and then to 2 MPa, the deformation of roadway decreases gradually slowly and the curves run gently. So it can be seen that variations of low cohesion has a serious effect on the deformation change of roadway surrounding rock.

As can be seen from Fig. 8, when the internal friction angles of roadway surrounding rock are 200, 250, 300, 350 respectively, the deformation of roadway surrounding rock decreases with the increasing of its internal friction angle, and the curves drop smoothly, which shows that variations of low cohesion has a little influence on the deformation change of roadway surrounding rock.

Construction of BP Neural Network Prediction Model on the Deformation and Plastic Zone Depth of Roadway Surrounding Rock

The BP Prediction Model built with the help of MATLAB neural network toolbox in this thesis is,

net=newff(input, output, 12, {'tansig','tansig'},'trainlm','learngdm').

Training on it was conducted through 90 sets of “input-output” samples obtained by FLAC^{3D}

numerical simulation, so as to equip it with study function. The whole training process is accomplished through train function, which means adjusting the weight and valve-value matrixes of each layer one by one through forward calculation on input variables and reverse propogation of errors, so as to achieve the required training accuracy.

As seen from Fig.9 and 10, only 138 training steps are needed to reach the set network training target 0.00001 through the BP Neural Network Prediction Model built in this thesis, which shows that the Model has the characteristic of good adaptability.

Analysis on the Prediction Results of the Deformation and Plastic Zone Depth of Roadway Surrounding Rock Based on BP Model

Function of neural network built in this thesis is tested by comparing errors between the output of neural network and the known output of test sample, based on the built neural network model and the training and study on the 90 sets of “input-ouput” samples, and taking the input of the other 7 groups of test samples as the trained and designed neural network (Grabec I 2004). Input data of the test samples are shown in Table 1.

Prediction error and error percentage of neural network can be gained by comparing the neural network’s predictive output values of roof settling, floor moving-up, wall displacement and the plastic zone depth of roadway surrounding rock of the test samples with the results of numerical simulation.

Tables 1 show the comparison of the predictive values of roof settling, floor moving-up, wall displacement and the largest plastic zone depth with the results of simulation.

As seen from Table 2, the largest absolute error of the roof settling gained through the built BP neural network is 1.41 mm, the smallest 0.02 mm, and the error percentage is between -4.7 % and 0.83 %.

As seen from Table 3, the largest absolute error between the predictive value of floor moving-up and the results of numerical simulation is 3.16 mm, the smallest 0.45mm, and error percentage is between -4.07 % and 4.26 %.

As seen from Table 4, the largest absolute error between the predictive value of wall displacement and the results of numerical simulation is 1.68 mm, the smallest 0mm, and the error percentage is between -6.5 % and 1.9 %; meanwhile, Table 5 shows that the largest absolute error between the predictive value of the plastci zone septh of surrounding rock and the results of numerical simulation is 0.12 m, the smallest 0.01m, and the error percentage is between -9.33% and 2.92%.

In conclusion, errors between the built BP neural network’s predictive results of roof settling, floor moving-up, wall displacement and the largest plastic zone depth and the results of numerical simulation is accepted, and meets the requirement of error precision, which proves the reliability of neural network model.

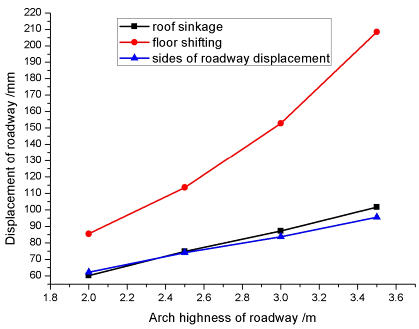


Figure 1 Relationship between the deformation of roadway surrounding rock and the arch rise

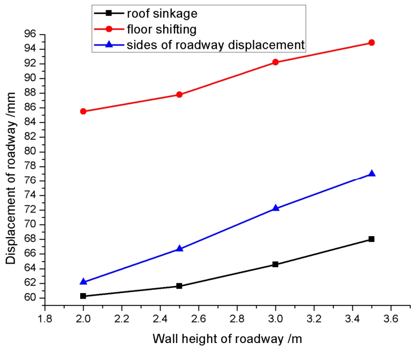


Figure 2 Relationship between the deformation of roadway surrounding rock and the wall height

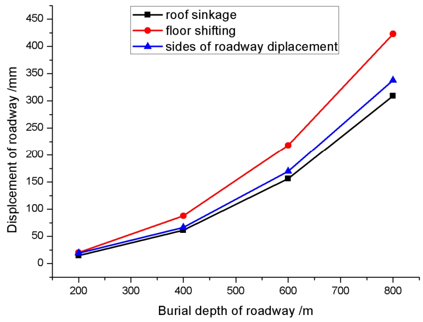


Figure 3 relationships between the deformation of roadway surrounding rock and the burial depth

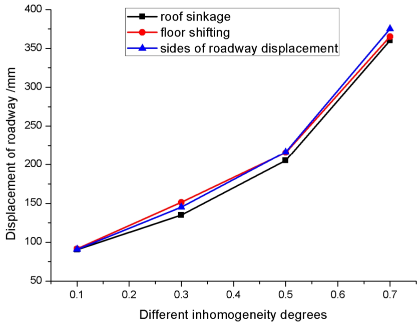
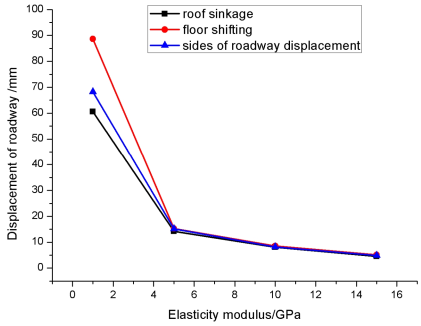
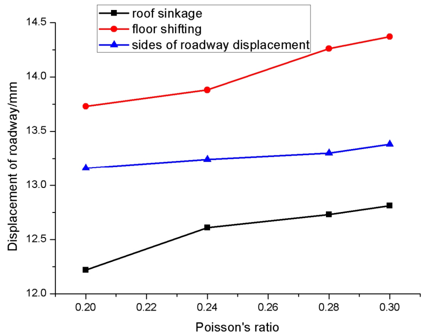


Figure 4 Deformation curve of roadway surrounding rock under different in homogeneity degrees



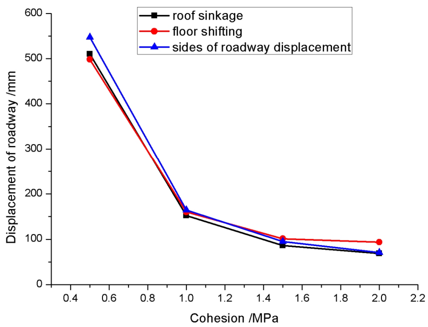
Figur

e 5 Relationship between the deformation of roadway surrounding rock and the elasticity modulus



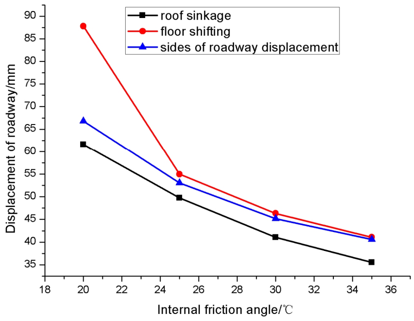
Figur

e 6 Relationship between the deformation of roadway surrounding rock and the Poisson's ratio



Figur

e 7 Relationship between the deformation of roadway surrounding rock and the cohesion



Figu8 Relationship between the deformation of roadway surrounding rock and the internal friction angle

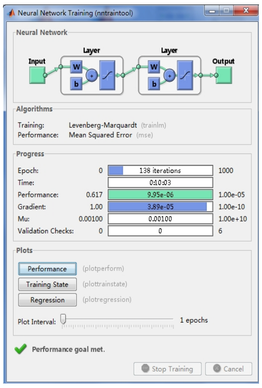


Figure 9 Training of single-hidden layer neural network

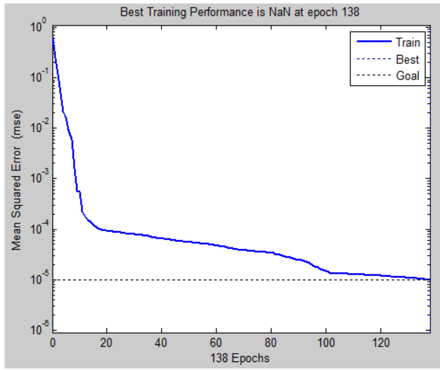


Figure 10 Error curves of neural network training

Table Legends

sample	Arch rise *r*/m	Vertical wall height *h*/m	Overlying rock load *p*/MPa	Elasticit y modulu s*E*/GPa	Poisson's ration μ	cohesi on *c*/MPa	Internal friction angle $\varphi/^0$	Inhomogeneit y degree *D*
1	3	2	10	1	0.2	2	20	0
2	3.5	3	5	1	0.2	2	20	0
3	2.5	3	15	5	0.28	2	30	0
4	3.5	3.5	10	1	0.2	2	20	0
5	2.5	3.5	10	5	0.28	2	30	0
6	3.5	3.5	5	1	0.2	2	20	0
7	2	2.5	10	1	0.2	2	20	0.5

Table 1 Input data of the test samples

sample	Predictive value /mm	Simulative value /mm	Error /mm	Error percentage /%
1	87.23	87.21	0.02	0.02
2	28.54	29.95	-1.41	-4.71
3	11.76	11.88	-0.12	-1.01
4	112.41	113	-0.59	-0.52
5	7.56	7.5	0.06	0.8
6	29.23	30.1	-0.87	-2.89
7	204.15	205.1	-0.95	-0.46

Table 2 Comparison between neural network's predictive value of the roof settling and the results of numerical simulation

sample	Predictive value /mm	Simulative value /mm	Error /mm	Error percentage /%
1	151.51	152.8	-1.29	-0.84
2	55.1	57.44	-2.34	-4.07
3	16.04	15.59	0.45	2.87
4	201.81	202.6	-0.79	-0.39
5	11.82	11.34	0.48	4.23
6	51.53	50.48	1.05	2.08
7	218.16	215	3.16	1.47

Table 3 Comparison between neural network's predictive value of floor moving-up and the results of numerical simulation

sample	Predictive value /mm	Simulative value /mm	Error /mm	Error percentage /%
1	84.35	84.19	0.6	0.19
2	27.83	27.31	0.52	1.9
3	13.89	13.89	0	0
4	114.39	114.2	0.19	0.17
5	9.31	9.955	-0.645	-6.85
6	28.88	30.26	-1.38	-4.56
7	214.92	216.6	-1.68	-0.78

Table 4 Comparison between neural network's predictive value of wall displacement and the results of numerical simulation

sample	Predictive value /m	Simulative value /m	Error /m	Error percentgae /%
1	2.47	2.4	0.07	2.92
2	0.68	0.75	-0.07	-9.33
3	2.43	2.34	0.09	3.42
4	2.63	2.62	0.01	0.38
5	1.39	1.51	-0.12	-7.95
6	0.8	0.79	0.01	1.27
7	5.83	5.8	0.03	0.52

Table 5 Comparison between neural network's predictive value of the plastic zone depth of roadway surrounding rock and the results of numerical simulation

Conclusions

In order to construct the BP neural network model predicting the deformation and plastic zone depth of roadway surrounding rock, through studying the stress changes in surrounding rock mass caused by roadway excavation with numerical simulation, and analyzing deformation laws of roadway surrounding rock incurred by different factors, main conclusions of the thesis are as below,

(1) Deformation change laws of roadway surrounding rock under different factors are, main factors influencing the deformation of roadway surrounding rock are burial depth, arch rise of section, elasticity modulus, and cohesion.

(2) Analyzing factors caused the deformation of roadway deformation, results show that the largest error percentage of test data model is less than 10%, which proves the reasonability of BP neural network prediction model. On basis of the above analysis, applying the prediction model built, and taking the level-extension roadway of Jalainur northern iron ore as research background, prediction on the deformation and plastic zone depth of this roadway surrounding rock was conducted, and its results consist with the field monitoring one. Therefore, BP neural network prediction model constructed in the thesis is realizable to some extent and can provide a foundation for the selection of support patterns at the later stage.

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