Water leakage classification of expressway operationa tunnel based on BP neural network

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Abstract. In this paper, factors influencing the tunnel leakage are analyzed synthetically, based on present situations of water leakage of operational highway tunnel in Chongqing area. Standard of tunnel leakage grade is determined and index system of tunnel leakage model is established by choosing physical geography, surrounding rock, underground water, lining and drainage facilities as the first grade indexes and choosing 12 factors such as vegetation, annual precipitation, and tunnel depth as the second indexes. Xiu-shan tunnel and Zheng-yang tunnel are selected as evaluation model of training sample from 66 operational tunnels in Chongqing area. The results are the consistent in comparing the neural network evaluation and manual evaluation. It is shown that this model has good applicability in grade evaluation of tunnel leakage, and classification of tunnel leakage could be done quickly and accurately.

Introduction

With sustainable development of infrastructure in China, the scale, the number and the complexity of tunnel engineering is significantly increasing in recent years. However, as the number of road tunnels increase, the tunnel environment, especially underground water environment, becomes more and more complex, resulting in a not optimistic operational condition of highway tunnels [1,2] . Tunnel leakage is ubiquitous in operational tunnels. Tunnel diseases should be classified according to the extent of tunnel leakage after leakage happened, then measures could be taken. However, the severity of expressway tunnel leakage is abstract and fuzzy conception, which is difficult to evaluate by normal conceptions [3]. There are many theories and methods in grade evaluation of tunnel leakage [4], such as fuzzy mathematics, grey theory, and distance discriminated analysis theory, etc. The comprehensive analysis on factors influencing the tunnel leakage disease is conducted in this paper, based on present situations of tunnel leakage in expressway operational tunnel in Chongqing. The standard of tunnel leakage grade is determined and the index system of tunnel leakage model is established.

Evaluation principles of BP neural network

Back Propagation neural network is a multilayer feed-forward network trained by back-propagation algorithm, which contains three or more layer structures. BP neural network includes input layer, hidden layer and output layer [5-6]. The analysis process is divided into 7 steps as follows.

1) Determining the evaluation standard of highway tunnels leakage grade according to research contains and investigation materials.

2) Selecting several road tunnels with different leakage grades, and grouping the evaluation data and leakage grade correspondingly. Input and output samples could be obtained, and learning samples of BP neural network could be built.

3) Building B P neural network model, and obtaining the optimal structure of neural network through substituting learning samples. Then determining the number of input neurons, inter neurons and output neurons.

4) Training B P neural network model.

5) Evaluating the leakage grade of tunnels. By substituting each evaluating data of highway tunnels into trained BP neural network, obtaining the leakage grades.

6) Evaluating the leakage grade by evaluation standard according to manual method, and then obtaining the leakage grade at present.

7) Comparing and analysis the leakage grade obtained from manual evaluation and BP neural network evaluation. If the results are consistent, it shows that the evaluation is successful. If the results are not consistent, adjusting learning samples and structure of BP neural network model and repeating form the first step until the evaluations are consistent.

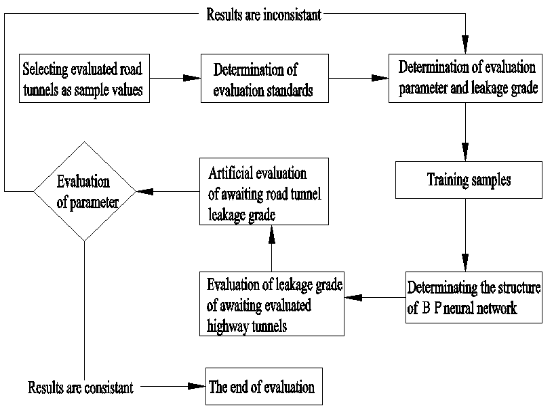

Fig.1 Safety evaluation analysis flow chart of operational tunnels

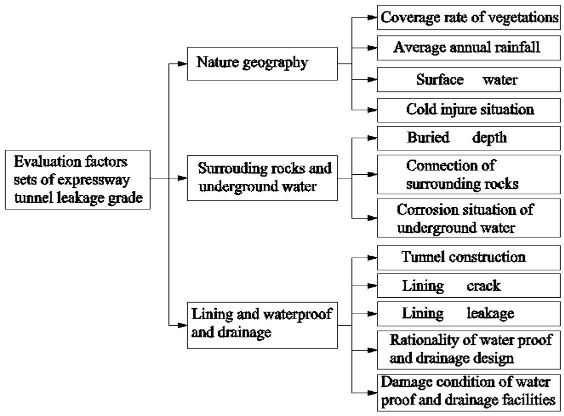

Fig.2: Grade evaluation factors of tunnel leakage

Building of evaluation index system

Based on the investigation materials, combined with cause analysis of tunnel disease and related materials [7-8], three factors as the first indexes, namely natural geography, surrounding rock and facilities of lining, and waterproof and drainage are selected. The first indexes are concretely divided into 12 the second indexes(X1, X2, X3…X12), using parallel index system. The construction of system is illustrated in figure 2.

According to the thought of discriminate analysis and referring research results [7], classifying the 12 factors influencing tunnel leakage by quartering method, and discriminating the influence of tunnel leakage grade by each factor. The discrimination of main factors is displayed in table 1.

Table 1 Grade evaluation table of tunnel leakage factors

Classification indexes	I	II	III	Ⅳ
Values of each factors	0.875	0.625	0.375	0.125
Vegetation coverage rateX1	100%～90%	90%～60%	60%～30%	30%～0%
Average annual rainfall X2	＜200mm	200mm~600mm	600mm~1600mm	＞1600mm
Surface water X3	No surface water	There is miniature surface water Q＜5m3	There are middle and small rivers and lakes	There are large rivers and lakes with large surface water
Cold injure damage X4	＞0℃	0℃~-10℃	-10℃~-25℃	＜-25℃
Tunnel buried depth X5	＜100m	100m~500m	500m~1000m	＞1000m

Connection of sock crack X6	Crack undeveloped, and permeability coefficient of aquifer k＜0.001	Crack opening，and permeability coefficient of aquifer0.001＜k＜0.5	Karst crack developing, permeability coefficient of aquifer 0.5＜k＜10	large karst cave and underground river in karst fault zone, permeability coefficient of aquifer k＞10
Corrosion of underground water X7	Underground water is non-corrosive，pH＞7.9	Underground water is slight corrosive，7.9＞pH＞5.5	Underground water is corrosion，5.5＞pH＞4.0	Underground water is strong corrosive，pH＜4.0
Tunnel construction X8	Perfect	Good	General	Bad
Lining cracks X9	Crack width＜0.2mm；Crack density＜0.1	Crack width 0.2mm~1mm；Crack density 0.1~0.5	Crack width 1mm~3mm；Crack density 0.5~1	Crack width＞3mm；Crack density＞1
Lining leakage X10	Slight infiltration appeared without leakage; leakage number＜5	Severe infiltration and dripping appeared; leakage number5~20	Inrush current appeared; leakage number20~50	Inrush current appeared; leakage number＞50
Design of waterproof and drainage facilities X11	Reasonable	Relatively reasonable	General	Unreasonable
Damage of waterproof and drainage facilities X12	Free form damage	slight	medium	severe

The diseases grade of high tunnel leakage in Chongqing are divide into 4 grades in the aspect of tunnel leakage grade, based on standard and related references at home and aboard and the analysis of advantages and disadvantages of various division methods [3-8], considering the widely use of quartering method simultaneously.

$$V = \{V_1, V_2, V_3, V_4\} = \{\text{Ⅰ}, \text{Ⅱ}, \text{Ⅲ}, \text{Ⅳ}\} \quad (1)$$

Where: V1 represents no leakage or slight leakage. V2 represents medium leakage. V3 represents relatively severe leakage. V4 represents severe leakage. The means of each grade are shown in table 2.

Table 2: Grade classification of tunnel leakage

Leakage grade	Judging content	Output set value
Grade Ⅰ	Tunnel operation is safe, without leakage or with slight leakage. Driving safety will not be influenced in this grade. Just keeping monitory.	1,0,0,0
Grade Ⅱ	Tunnel operation is basically safe, with medium leakage. Driving safety will not be influenced in this grade. However, safety signal is given and long-term monitory should be kept to find whether the leakage would develop. Warning should be given in time, if tunnel leakage grade develop and approach the standard of grade Ⅲ.Increasing monitory frequency and strengthening daily maintenance is suggested.	0,1,0,0
GradeⅢ	Tunnel operation is unsafe, with severe leakage, and the leakage keeps developing. Driving safety is threatened in this grade, and tunnel structure will be damaged if the leakage keeps developing. Maintenance with lane semi-closed in the condition of continuous traffic. Increasing monitory frequency and strengthening maintenance by corresponding measures timely is suggested	0,0,1,0
GradeⅣ	Tunnel operation is unsafe, and structure is severely damaged because of leakage. The leakage keeps developing. Driving safety is threatened in this grade, and the traffic should be interrupted. Increasing monitory frequency and taking maintenance measures is suggested.	0,0,0,1

Building of evaluation model

Zheng-yang tunnel and Xiu-shan tunnel are selected as evaluation model of training sample from 66 operational tunnels in Chongqing area. The result could be found in table 3. Tunnel leakage grades are evaluated by BP neural network compiled on MATLAB. The target convergence degree installed in model is 0.001, and the convergence degree is below 2.1953e-5, showing that learning samples have been indentified totally by network and mapping relationship between influence factors of leakage and leakage grade is built. This network could completely classify the tunnel leakage degree quickly and accurately.

Table 3: Leakage Grade Evaluation in neural network

Name of tunnel	Left of right line	values	Leakage grade
Zheng-yang tunnel	Left line	0,0.998,0.002,0	II
	Right line	0,0.995,0.007,0	II
Xiu-shan tunnel	Left line	0,1,0.012,0	II
	Right line	0,0,0.99,0.03	III

The results of neural network evaluation and field investigation evaluation are consistent, conforming to the actual field situation, showing that this model is effective. It could help to classify the tunnel leakage diseases quickly and accurately in Chongqing area, and it is beneficial for tunnel operating and management department to take targeted measures.

Conclusions

This paper introducing BP neural network model and classifying the degree of tunnel leakage disease on the base of the collected materials of operational highway tunnel leakage disease in Chongqing area. The conclusions in the process are as follows:

1) The leakage disease of operational expressway tunnel is widely ubiquity in Chongqing area, therefore it is necessary to build the quick evaluation system and then take corresponding measures.

2) Three aspects and 12 influence factors of tunnel leakage are selected, and tunnel leakage disease are divided into 4 grades, and then evaluation indexes system of leakage is built, based on comprehensive investigation and analysis of 66 leakage tunnels in Chongqing.

3) Selecting Xiu-shan tunnel and Zheng-yang tunnel as testing samples of neural network model. The results of neural network evaluation and field investigation evaluation are consistent, showing that this model is effective. It could help to classify the tunnel leakage diseases quickly and accurately in Chongqing, and it is beneficial for tunnel operating and management department to take targeted measures.

References

[1] PU Chunping. Study of Tunnel Lining Cracks and Leakage and Treatment [D]. Shanghai: Master Degree Thesis of Tongji University, 1998.
[2] FANG Licheng, DU Bin, ZHANG Xiaofeng. Atlas of Disease Prevention and Control of Tunnel Engineering [M]. Beijing: Electric Power Press of China, 2001
[3] Luo Xin, XIA Caichu. Current situation and problems of classification of tunnel diseases [J]. Chinese Journal of Underground Space and Engineering, 2006, 2(5): 877 – 880.
[4] PENG Zu zeng, SUN Wenyu. Fuzzy mathematic and application [M]. Wuhan: Wuhan University Press, 2000: 69-80
[5] A. KocbayR, Kilic. Engineering Geological Assessment Of the Obruk dam site (Corum, Turkey) [J] . Engineering Geology,2006, 87: 141- 148.
[6] Keunedy MP, Chua L.O. Neural networks for nonlinear programming. IEEE. Trans. CircuitsSystems, 1998,35:554-562
[7] PAN Haize, HUANG Tao, YANG Haijing, et al. Arid Land Geography (in Chinese), 2009, 32(1): 145–151.
[8] WANG Daoliang, Xiao Bo, Yang Biao. Research on influencing factors of leakage water in integral multi-arch tunnels [J]. Technology of Road and Transport. 2011, 12 (6):88-92.