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Evaluation Analysis on Anti-cracking Performance of Semi-rigid Base Courses Based on Grey Relational Grade

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Abstract

The theory of grey relational grade was applied to calculate the relational grades between the maximum dry shrinkage strain and some evaluation indices of cracking resistance to dry shrinkage, and the relational grades between the maximum thermal shrinkage strain and some evaluation indices of cracking resistance to thermal shrinkage. The study results indicate that the relation between dry shrinkage energy anti-cracking coefficient and the maximum dry shrinkage strain and the relation between thermal shrinkage energy anti-cracking coefficient and the maximum thermal shrinkage strain of base materials are much better. This paper also draws a conclusion that it is more reasonable to evaluate the anti-cracking performance of semi-rigid base courses adopting dry shrinkage energy anti-cracking coefficient and thermal shrinkage energy anti-cracking coefficient. The conclusion has great direction on the design of bituminous pavements with semi-rigid base courses, and the results also indicate that grey relational analysis is a simple and effective method in the evaluation of anti-cracking performance of semi-rigid base course materials.

Keywords: Grey relational grade, Semi-rigid base, Anti-cracking performance, Evaluation index

1. Introduction

Semi-rigid base course have been applied in high-grade highway widely in China because they have many advantages, such as high strength, better integrity, better water stability and so on. However, with more application of such base courses, their problem of cracking becomes more and more prominent and the problem has affected the performance of highway. Nowadays, great research has been done on the cracking mechanism of semi-rigid base courses all over the world. Generally, the deformation caused by dry shrinkage and thermal shrinkage of semi-rigid base course is thought to be the factor leading to their cracking. And some research has presented some methods to improve the anti-cracking performance of semi-rigid base course materials on the basis of the mechanism of cracking (Zhang, 1991, pp.16-21). Whereas, the research on how to evaluate the anti-cracking performance of semi-rigid base course materials reasonably is very rare. According to the research achievements throughout the world, there are many kinds of evaluation indexes of the anti-cracking performance of semi-rigid base courses. Commonly used evaluation indices are dry shrinkage coefficient and thermal shrinkage coefficient, dry shrinkage anti-cracking coefficient (wet endurance coefficient) and thermal shrinkage anti-cracking coefficient (temperature endurance coefficient), dry shrinkage anti-cracking index (anti dry shrinkage endurance index) and thermal shrinkage anti-cracking index (anti thermal endurance index), dry shrinkage energy anti-cracking coefficient and thermal shrinkage energy anti-cracking coefficient (Yang, 2002, pp.13-15). Among these indices, there isn't a certain answer about how to choose a more reasonable index.

Reasonable evaluation index not only should reflect the deformation ability of semi-rigid materials in tensile stress, but also should reflect the shrinkage performance of materials and it should have better relation with the maximum dry shrinkage, thermal shrinkage strain, which lead to the cracking of materials. Therefore, this essay has analyzed the relation between the anti-cracking indices on dry shrinkage and the maximum dry shrinkage strain and the relation between the anti-cracking indices on thermal shrinkage and the maximum thermal shrinkage strain. Accordingly, the more efficient evaluation indices of semi-rigid base course materials have been decided.

2. Method of grey relational analysis

2.1 Mechanism of grey relational analysis

Grey relational analysis is the important content of grey system theory and it ascertains the difference and proximity among the series through the curve formed by the reference series and the compared series (Wang, 1987). The curve with much closer geometry shape has closer change trend and its relational grade is larger. Relational grade shows how close the compared factor is to the reference factor. The most important influencing factor to the reference factor of the system, which has the largest relation with the reference factor, is found through the calculation of relational grade. Grey relational analysis doesn't need large amount of specimens and model distribution of the data and its calculation is very simple.

2.2 The approach of calculation of grey relational grade

(1) Choose reference series X_0: $X_0 = \{x_0(1), x_0(2), ..., x_0(n)\}$

Comparative series X_i: $X_i = \{x_i(1), x_i(2), ..., x_i(n)\}$, $(i = 1,2,3,..., m)$

(2) Seek for the initial values images of the series. The series , which have different units or initial values, have to be dealt with when doing relational analysis in order to make the series nil-dimension and eliminate the influence of each index dimension. This paper deals with the data applying initializing method. Then, the initial value image is as follow:

$$Y_i = \{y_i(1), y_i(2), ..., y_i(n)\} = \{\frac{x_i(1)}{x_i(1)}, \frac{x_i(2)}{x_i(1)}, ..., \frac{x_i(n)}{x_i(1)}\}, \quad (i = 0,1,2,..., m) \tag{1}$$

(3) Seek for the difference series Δ_i:

$$\Delta_i(k) = |y_0(k) - y_i(k)|, \qquad (i = 1,2,3,..., m), \quad (k = 1,2,3,..., n) \tag{2}$$

$$\Delta_i = \{\Delta_i(1), \Delta_i(2), ..., \Delta_i(n)\} \qquad (i = 1,2,3,..., m)$$

(4) Seek for the relational coefficient $\xi_i(k)$:

$$\xi_i(k) = \frac{\min\limits_i \min\limits_k \Delta_i(k) + \rho \max\limits_i \max\limits_k \Delta_i(k)}{\Delta_i(k) + \rho \max\limits_i \max\limits_k \Delta_i(k)}, \quad (i = 1,2,3,..., m), \quad (k = 1,2,3,..., n) \tag{3}$$

where $\min\limits_i \min\limits_k \Delta_i(k)$ and $\max\limits_i \max\limits_k \Delta_i(k)$ are called dipolar minimum margin and dipolar maximum margin, respectively. ρ is discrimination coefficient whose value is selected from 0 to 1 and is often selected to be 0.5.

(5) Calculating relational grade. In order to concentrate the information in every relational coefficient to be compared easily, we seek for the relational grade γ_i of curve X_i to curve X_0 applying a method of seeking average, which is as follow:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \qquad (i = 1,2,3,..., m), \quad (k = 1,2,3,..., n) \tag{4}$$

3. Grey relational analysis of evaluation index of anti-cracking performance of semi-rigid base course materials

The maximum dry shrinkage strain and the maximum thermal shrinkage strain of semi-rigid base course materials are chosen as reference series to found two grey relational analysis models. The first model regards dry shrinkage coefficient, dry shrinkage anti-cracking coefficient, dry shrinkage anti-cracking index and dry shrinkage energy anti-cracking coefficient of materials as compared series. The second model regards thermal shrinkage coefficient, thermal shrinkage anti-cracking coefficient, thermal shrinkage anti-cracking index and thermal shrinkage energy anti-cracking coefficient of materials as compared series. Table 1 and Table 2 show maximum dry shrinkage strain , the maximum thermal shrinkage strain of several kinds of semi-rigid base course materials and several groups of above-mentioned evaluation index values of anti-cracking performance. The evaluation index values of anti-cracking performance are acquired through the calculating of the experimental data, which comes from reference (Jiang, 2001), by the before-mentioned calculation means. The experimental period is 90 days.

3.1 Grey relational analysis of anti-cracking indexes about dry shrinkage and maximum dry shrinkage strain

After the series in table 1 has been dealt with applying initializing method, we can get the following series of relational coefficients according to Eq. (3). (When calculating: $\rho = 0.5$. After calculating: $\min\limits_i \min\limits_k \Delta_i(k) = 0$, $\max\limits_i \max\limits_k \Delta_i(k) = 0.565$):

$\xi_1 = \{1, 0.613, 0.615, 0.545, 0.400, 0.407\}$

$\xi_2 = \{1, 0.725, 0.670, 0.559, 0.350, 0.412\}$

$\xi_3 = \{1, 0.682, 0.695, 0.712, 0.413, 0.333\}$

$\xi_4 = \{1, 0.956, 0.837, 0.688, 0.413, 0.523\}$

Take upper relational coefficients into Eq. (4), and we can get the following relational grades.

$\gamma_1 = 0.596$ (Relational grade of dry shrinkage coefficient and maximum dry shrinkage strain);

$\gamma_2 = 0.619$ (Relational grade of dry shrinkage anti-cracking coefficient and maximum dry shrinkage strain);

$\gamma_3 = 0.639$ (Relational grade of dry shrinkage anti-cracking index and maximum dry shrinkage strain);

$\gamma_4 = 0.736$ (Relational grade of dry shrinkage energy anti-cracking coefficient and maximum dry shrinkage strain).

The corresponding relational grades series is: $\gamma_4 > \gamma_3 > \gamma_2 > \gamma_1$. This indicates that dry shrinkage energy anti-cracking coefficient has best relativity with the maximum dry shrinkage strain of semi-rigid base course materials. Therefore, we can evaluate the resistance to dry shrinkage cracking of semi-rigid base course materials applying dry shrinkage energy anti-cracking coefficient.

3.2 Grey relational analysis of anti-cracking indice3 about thermal shrinkage and maximum thermal shrinkage strain

After the series of table 2 has been dealt with applying initializing method, we can get the series of relational coefficients according to Eq. (3). (When calculating: $\rho = 0.5$. After calculating: $\min_i \min_k \Delta_i(k) = 0$, $\max_i \max_k \Delta_i(k) = 0.479$):

$\xi_1 = \{1,0.589,0.582,0.348,0.508,0.361\}$

$\xi_2 = \{1,0.494,0.789,0.454,0.360,0.385\}$

$\xi_3 = \{1,0.699,0.464,0.523,0.333,0.418\}$

$\xi_4 = \{1,0.905,0.360,0.446,0.937,0.923\}$

Take upper relational coefficients into Eq. (4), and we can get the following relational grades.

$\gamma_1 = 0.565$ (Relational grade of thermal shrinkage coefficient and maximum thermal shrinkage strain);

$\gamma_2 = 0.580$ (Relational grade of thermal shrinkage anti-cracking coefficient and maximum thermal shrinkage strain);

$\gamma_3 = 0.573$ (Relational grade of thermal shrinkage anti-cracking index and maximum thermal shrinkage strain);

$\gamma_4 = 0.762$ (Relational grade of thermal shrinkage energy anti-cracking coefficient and maximum thermal shrinkage strain).

The corresponding relational grades series is: $\gamma_4 > \gamma_2 > \gamma_3 > \gamma_1$. This indicates that the thermal shrinkage energy anti-cracking coefficient has best relativity with the maximum thermal shrinkage strain of semi-rigid base course materials. Therefore, we can evaluate the resistance to thermal shrinkage cracking of semi-rigid base course materials applying thermal shrinkage energy anti-cracking coefficient.

4. Conclusions

There are many evaluation indices of anti-cracking performance of semi-rigid base course materials nowadays. This essay introduces several kinds of common evaluation index systems simply, and calculates the grey relational grades of anti-cracking indices about dry shrinkage and maximum dry shrinkage strain, and the grey relational grades of anti-cracking indices about thermal shrinkage and maximum thermal shrinkage strain through examples by applying grey relational analysis method. The analytic result shows that the evaluation index system of dry shrinkage energy anti-cracking coefficient and thermal shrinkage energy anti-cracking coefficient, witch is based on dry shrinkage energy, thermal shrinkage energy and limit anti tensile energy, can well evaluate the anti-cracking performance of semi-rigid base course materials. The same semi-rigid base course materials may have different resistance to dry shrinkage cracking or to thermal shrinkage cracking. Therefore, we should take the dry shrinkage energy anti-cracking coefficient and thermal shrinkage energy anti-cracking coefficient into account synthetically when evaluating the anti-cracking performance of semi-rigid base course materials.

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Table 1. The values of anti-cracking indices about dry shrinkage of semi-rigid materials

Semi-rigid materials	Maximum dry shrinkage strain (10^{-6})	Dry shrinkage coefficient(10^{-6}/%)	Dry shrinkage anti-cracking coefficient (%)	Dry shrinkage anti-cracking index	Dry shrinkage energy anti-cracking coefficient (%)
Cement stabilized macadam A	120	27.27	4.95	0.87	4.33
Cement stabilized macadam B	111	30.08	4.05	0.92	3.95
Cement fly ash stabilized macadam A	141	27.22	5.13	1.13	4.85
Cement fly ash stabilized macadam B	132	23.56	4.34	0.86	4.21
Lime-fly ash macadam A	197	33.22	5.53	1.08	5.33
Lime-fly ash macadam B	185	30.84	5.64	0.85	5.56

Table 2. The values of anti-cracking indices about thermal shrinkage of semi-rigid materials

Semi-rigid materials	Maximum thermal shrinkage strain (10^{-6})	Thermal shrinkage coefficient (10^{-6}/°C)	Thermal shrinkage anti-cracking coefficient (°C)	Thermal shrinkage anti-cracking index	Thermal shrinkage energy anti-cracking coefficient (°C)
Cement stabilized macadam A	672.6	9.52	14.18	0.88	1.97
Cement stabilized macadam B	680.3	11.21	10.86	0.98	2.04
Cement fly ash stabilized macadam A	652.2	10.87	12.84	0.61	2.75
Cement fly ash stabilized macadam B	674.1	13.81	10.12	0.69	2.56
Lime-fly ash macadam A	880.2	14.67	12.53	0.73	2.61
Lime-fly ash macadam B	843.5	15.97	12.35	0.81	2.43