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Performance improvement model of cement pavement in seasonal-frost regions

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Abstract. The paper evaluates the performance improvement of cement pavement in seasonal frost regions. The typical diseases of cement concrete pavements in seasonal frost regions are proposed through the analysis of measured data, and the influence factors of pavement performance mutation value in those regions is determined. The application conditions of the model are obtained by the response surface test method; the road performance improvement model is established by the regression analysis method. The goodness-of-fit and significance state of the model were tested, while the validity of the model was verified by comparing it with the evaluation results of the existing model. The results identified the typical diseases of cement concrete pavement in seasonal frost regions: broken slabs, staggered platforms, cracks, exposed aggregates, broken corners and potholes. The mutation value of pavement performance is most sensitive to the impact of road damage index, running quality index and anti-skid performance index before pre-maintenance, that is under pre-curing conditions. The evaluation effect of the model for improving the performance of cement concrete pavement in seasonal frost regions is good, and the interpretable part of the improvement by the model is 99.2 %; the fit of the improved evaluation value and the measured value is 0.991, and the model is high fitting. The evaluation effect of the proposed model is better than the existing model, and the determination of the model is of great significance to the pre-maintenance of cement concrete pavement.

1. Introduction

Due to the harsh climate environment and the rapid increase in traffic, the cement concrete pavement inevitably gets cracks, peeling corners, dislocation and other diseases. The diseases not only reduce the quality and life of the cement concrete pavement, but the improper implementation timing of the pre-maintenance can even cause the destruction of the road structure and increase the maintenance cost [1]. Therefore, the accurate prediction of the instantaneous improvement value of pavement performance under preventive maintenance conditions is of great significance for the reasonable determination of the pre-maintenance timing and prolonging the service life of the road surface [2, 3].

Internationally, some studies have been conducted on the evaluation of performance improvement of cement concrete pavement under pre-curing conditions, most of which are analyzing the impact of certain

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maintenance measures on the improvement of pavement performance. Sarkar [4, 5] analyzed the improvement degree of pavement performance by different pre-maintenance measures based on road data, and believed that pre-maintenance measures such as thin-layer overlays can effectively improve pavement performance. Yoo [6] made a preliminary evaluation of the test path and obtained the annual growth rate of the flatness index. Idal [7–9] studied a 5000-mile section of Indiana, and evaluated the degree of improvement of pavement performance by different sealing materials. On the basis of tests, Labi [10, 11] established an evaluation model of pavement performance improvement based on the grinding of joints and uplift parts as the basic maintenance measures, and quantified the improvement value of the pavement performance by this maintenance measure. Mandapaka [12–14] compared the advantages and disadvantages of crack sealing methods, and proposed that using waste rubber powder as a sealing material can improve the performance of the road surface to a higher degree.

Existing results on the improvement of pavement performance mainly focuses on pre-curing technology, pre-curing materials, etc. There has not been a large-scale research on the improvement of cement concrete pavement performance, and relatively complete and mature research results have not yet been formed. Farhan [15–18] evaluated different pre-maintenance performance improvement metrics, and determined that the deterioration rate reduction (DRR) and the average annual deterioration rate (AADR) can be used to express the improvement value of road performance. Priya [19, 20] studied the performance deterioration law of cement concrete pavement under the condition of pre-maintenance, and believed that the pavement performance jump value (PJ) is the most effective mathematical index for evaluating the effect of road pre-maintenance. Ker [21] established a performance improvement model of cement concrete pavement under pre-curing condition by taking the flatness index as a parameter. However, as a representative parameter of pavement performance evaluation, the flatness index is relatively one-sided, and the impact of climate factors on pre-curing measures is also taken into account. Therefore, the performance improvement model of cement concrete pavement under the pre-curing conditions suitable for the climatic characteristics of seasonal frost regions needs to be further improved.

In this paper, the typical disease types of the pavement are screened through the disease data of the cement concrete pavement in the seasonal frost regions, and the pavement performance indicators that are more sensitive to the pre-maintenance measures are found as parameters. In addition, an improved model for the use of cement concrete pavement under the condition of pre maintenance suitable for seasonal frost regions is established, and the practicability and effectiveness of the model are verified by comparing it with the prediction level of existing models.

2. Methods

2.1. Screening of maintenance measures

For the types of diseases on cement concrete pavement, domestic and foreign experts have conducted relevant research. Haghnejad [22] evaluated the damage degree and disease distribution of cement concrete pavement by manually drawing the disease distribution map by board, and believed that the most typical diseases are cracks and broken slabs. Saxena [23] proposed broken slabs, cracks, broken corners, staggered platforms, mud, joint filler damage and potholes are the most common types of diseases based on actual engineering data. Jung [24] investigated the pavement damage conditions of several expressways and confirmed that the pavement has corner peeling and arching. Santos [25] detected voids and cracks in the road based on ultrasonic technology. Rao [26] conducted live inspections on cement concrete roads and found that repair measures would also damage the pavement. Based on the research results of the above-mentioned documents, it can be seen that cracks, broken corners, broken slabs, mud, staggered platforms, joint filler damage, repair damage, potholes, corner peeling, arching, voids and exposed aggregates are the diseases that appear on cement concrete pavement.

Cement concrete roads in seasonal frost regions are subject to the coupling effect of traffic load and freeze-thaw cycles. Therefore, in order to screen out the disease types of cement concrete pavement with the characteristics of seasonal frost regions and accurately select the maintenance measures, it is necessary to verify whether the disease status of cement concrete pavement under the influence of seasonal frost regions is different from that of ordinary climate.

Under the environmental conditions that ensure the same disease status as mentioned above, we selected the similar construction year, the same survey year, similar traffic flow, and the pavement performance of the three road sections in the seasonal frost regions, short-term frost regions and non frost regions for testing, and the selected detection index is pavement performance index (PQI). The value range of the pavement performance index is between 0 and 100, and the closer the index value is to 100, the better the pavement performance is. Long-zhou highway section in Guangdong Province, China is selected in non frost regions, Qi-yang expressway section in Jiangsu Province in China is selected in short-term frost regions, Zhao-zhao highway section in Heilongjiang Province, China is selected in seasonal frost regions. 15 sections are selected for each of the three roads, with piles number of K117-K131. In Fig. 1, the abscissa is piles number, and the ordinate is pavement performance index.

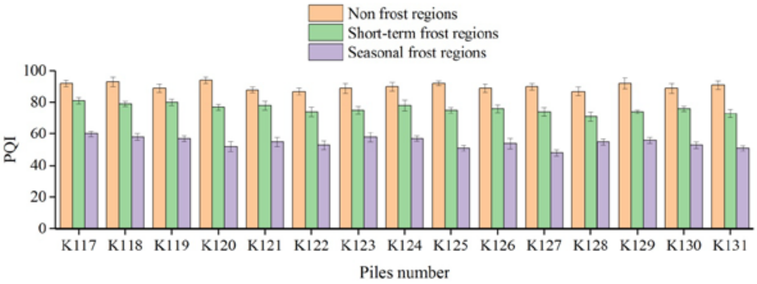

Figure1. PQI of different regions.

In Fig. 1, the PQI corresponding to different stake numbers in three different regions are different. For example, at K120, the maximum PQI ratio between the non frost regions and the seasonal frost regions is 1.81, and the ratio of the short-term frost regions to the seasonal frost regions is 1.48, which indicates that the PQI reduction in the seasonal frost regions is significantly higher than that of the short-term frost regions. The decrease of PQI in short-term frost regions is significantly higher than that in non frost regions. Most of the PQI in the non frost regions is between 85 and 100, and the road performance is excellent. The PQI of 15 piles number in the short-term frost regions varies from 70 to 85, because the cement concrete pavement in the short-term frost regions will affected by freezing and thawing and accompanied by a small amount of snow, the PQI in this case is slightly smaller than the PQI of the non frost regions. The PQI of the road in the seasonal frost regions is significantly lower than that of the other two highways, because the number of annual freeze-thaw cycles in the seasonal frost regions is more than that in the short-term frost regions, and freeze-thaw effects have a greater impact on the performance of concrete, which will cause concrete damage such as deterioration of compactness and strength reduction. Therefore, there are more serious diseases such as cracks inside roads in seasonal frost regions. At the same time, due to the influence of the weather in the seasonal frost regions, the road surface in the cold season is snowy. In order to ensure driving safety, deicing salt or snow melting agent is usually thrown on the road surface, resulting in corrosion of the surface layer of the road. The use of snow shovel will also cause the road surface to wear, so the road performance is relatively low.

Based on the above analysis, the climatic factors in the seasonal frost regions have a significant impact on the road performance. In order to properly maintain the cement concrete pavement in the seasonal frost regions, the types of diseases with the characteristics of the seasonal frost regions should be considered. According to the above analysis, the PQI value of cement concrete pavement in seasonal frost regions is the lowest compared with that in other regions. The reason is that there are many types and severity of diseases of cement concrete pavement in seasonal frost regions under the influence of freeze-thaw, and the pavement performance is poor. At the same time, according to the research results of Haghnejad [22] on freeze-thaw cycle, it is found that under the influence of freeze-thaw, the most sensitive changes of pavement are cracks and exposed aggregates. Therefore, cracks and exposed aggregates are typical diseases of cement concrete pavement in seasonal frost regions. In order to screen out the types of cement concrete pavement diseases with the characteristics of seasonal frost regions, combined with the existing research results above, 12 diseases were finally selected for preliminary screening of the main diseases in seasonal frost regions. The 12 diseases were numbered, and the numbers were D1～D12, as shown in Table 1.

Table 1. Disease number and name.

Number	Disease name	Number	Disease name	Number	Disease name
D1	cracks	D5	staggered platforms	D9	corner peeling
D2	broken corners	D6	joint filler damage	D10	arching
D3	broken slabs	D7	repair damage	D11	void
D4	mud	D8	potholes	D12	exposed aggregates

Using the actual road condition data of Zhao-zhao Highway in Heilongjiang Province, China, group analysis of pavement diseases was carried out, and the key diseases of cement concrete pavement in seasonal frost regions were screened out by using statistical package for Social Sciences (SPSS) software. The principle of group analysis method is to divide many factors into different groups. The factors in the same group have strong similarity, and the differences between the factors in different groups can be reflected, so the characterization of each factor can be observed and analyzed. The specific group analysis process is to calculate the group distance between various factors. The smaller the group distance is, the stronger the similarity will be, and the more probable is that they fall into the same group. Then, the group distance between different groups is calculated, and the two groups with the smallest group distance are merged into a group again. Repeat this step until the number of groups is reduced to one, and the grouping is completed.

In this study, Euclidean distance method was used to calculate the group distance between the factors, and the group average linkage method was used to calculate the distance between groups, and then the most reasonable number of group was determined according to the silhouette index method. After the analysis and calculation of SPSS software, the 12 factors are finally divided into 5 groups. The diseases in the group with relatively large influence degree and scope on the road condition in the distribution diagram can be determined as the main diseases, and the group classification is shown in Fig. 2.

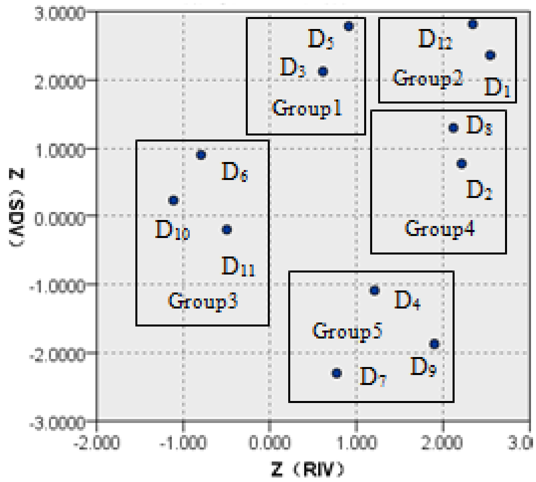

Figure 2. Group distribution.

In the group analysis diagram, RIV represents the average value of the scope of influence and SDV represents the average value of the intensity of influence, both of which are important. In order to eliminate the dimensional relationship between them and make them comparable, the standardized formula proposed by Kaufman and Rousseeuw is used to standardize the two indexes. The standardized two indexes are represented by Z (RIV) and Z (SDV).

In Fig. 2, the abscissa represents the influence scope after standardization, and the ordinate represents the influence intensity after standardization. The larger the Z (RIV) and Z (SDV) values of the disease, the greater the scope and intensity of the influence on the road conditions, indicating that the disease is the main disease affecting the cement concrete pavement in the seasonal frost regions. In Fig. 2, the values of Z (RIV) and Z (SDV) of group 1, group 2 and group 4 are positive, while the values of Z (RIV) and Z (SDV) of group 3 and group 5 are negative. This indicates that the six diseases in group 1, group 2 and group 4 have a wide range and large degree of influence on road conditions, so these six diseases belong to the main diseases. The six factors included in the other two groups have a smaller range and degree of influence than the six diseases in group 1, group 2 and group 4, so they are secondary diseases. After analyzing the group distribution results of 12 disease types, six disease types including broken slabs, staggered platforms, cracks, exposed aggregates, broken corners, and potholes have been identified as the main disease types of cement concrete pavements in seasonal frost regions and the pavement maintenance can be carried out for these six main diseases.

2.2. Model parameters

After the maintenance measures are taken for the above-mentioned diseases of cement concrete pavement in the seasonal frost regions, the performance of the pavement will be improved, which is embodied in the immediate performance improvement and the slowing down of the performance deterioration rate. The degree of change of the above indicators is usually characterized by the pavement performance jump value (PJ) [19]. According to China's "Highway Technical Condition Evaluation Standards", the evaluation indicators of cement concrete pavement performance include road damage index (PCI), road running quality index (RQI) and anti-skid performance index (SRI). Therefore, under different maintenance conditions, a model between PJ and PCI, RQI and SRI can be established to measure the degree of improvement in the performance of cement concrete pavements in seasonal frost regions.

During the implementation of maintenance measures, PCI, RQI and SRI will change. Therefore, in order to determine the parameters of the performance improvement model of cement concrete pavement in seasonal frost regions, it is necessary to analyze the correlation between PCI, RQI, SRI and PJ before and after maintenance. The index with strong correlation with PJ is used as a parameter for model establishment. Pavement performance data refer to Soares's research [27]. The symbols of PCI, RQI and SRI before and after maintenance are respectively represented as PCI_b, PCI_a, RQI_b, RQI_a, SRI_b and SRI_a. The correlation between PJ before and after maintenance and each index is shown in Figs. 3–8.

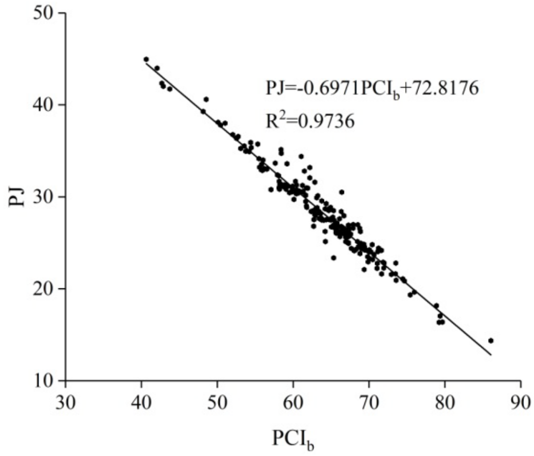

Figure 3. The fitting trend of PJ and PCI_b.

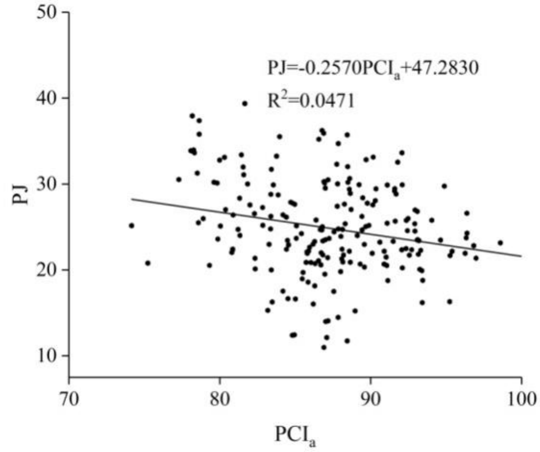

Figure 4. The fitting trend of PJ and PCI_a.

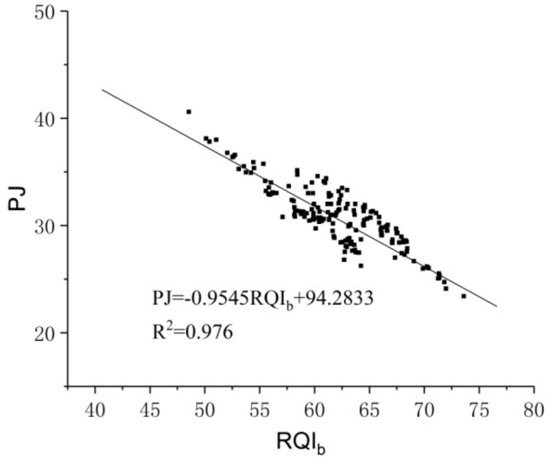

Figure 5. The fitting trend of PJ and RQI_b.

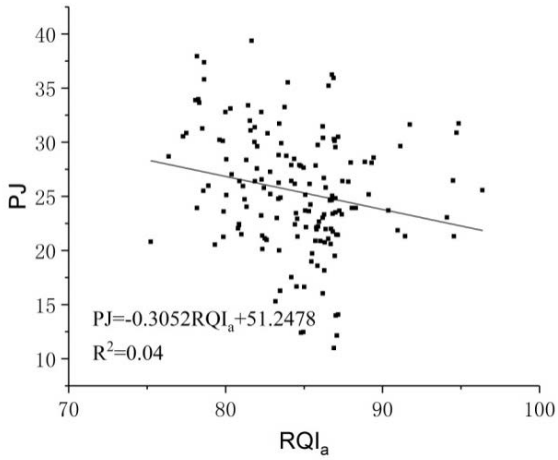

Figure 6. The fitting trend of PJ and RQI_a.

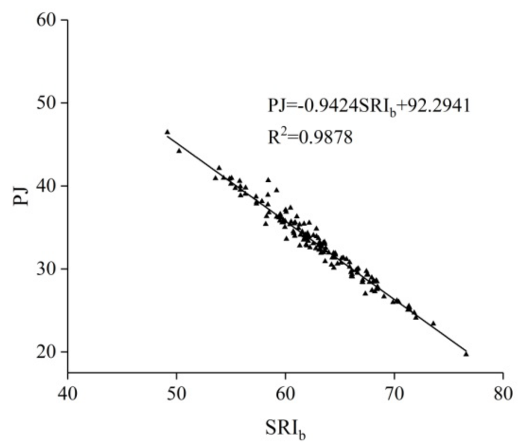

Figure 7. The fitting trend of PJ and SRI_b.

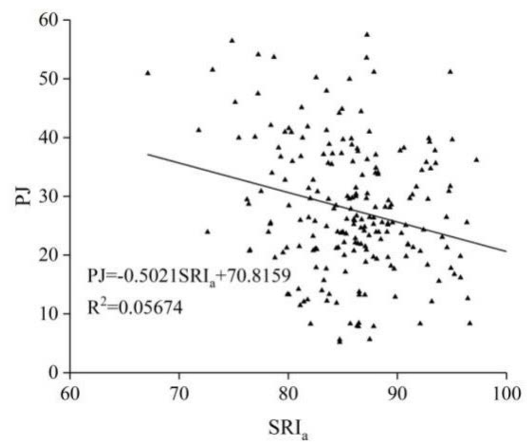

Figure 8. The fitting trend of PJ and SRI_a.

From Fig. 3 to Fig. 8, it can be seen that the decisive coefficients (R^2) of PJ and PCI_b, PCI_a, RQI_b, RQI_a, SRI_b and SRI_a were 0.9736, 0.0471, 0.9928, 0.1312, 0.9878 and 0.0567, respectively, indicating that PJ was significantly correlated with PCI_b, RQI_b and SRI_b, and not significantly correlated with PCI_a, RQI_a and SRI_a. Therefore, the parameters of pavement performance improvement model were determined as PCI_b, RQI_b and SRI_b.

2.3. Model establishment

According to the above research results, PCI_b, RQI_b and SRI_b are linearly correlated with PJ respectively. Therefore, the performance improvement model of cement concrete pavement in seasonal frost regions under pre-curing condition is determined as a function form, as shown in Eq. (1):

$$PJ = \lambda_0 + \lambda_1 PCI_b + \lambda_2 RQI_b + \lambda_3 SRI_b, \tag{1}$$

where $\lambda_0, \lambda_1, \lambda_2$ and λ_3 are constants; PCI_b is the road damage index before maintenance; RQI_b is the road quality index before maintenance; SRI_b is the anti-skid performance index before maintenance.

From the typical road sections in the seasonal frost regions, select 20 road sections of 3 roads, including A, B and C, for disease detection, and apply 140 sets of measurement data of 14 road sections to build the model, and 60 sets of measurement data for the remaining 6 road sections to perform model validation.

According to the obtained data, using SPSS analysis method, PJ (y) as the dependent variable, PCI_b (X1), RQI_b (X2) and SRI_b (X3) as independent variables to perform linear regression analysis of the model. The significance test results of the model are shown in Table 2. The regression mean square value is 345 times the residual mean square value, and the F value is 344.892. The value is large, indicating that the change of the dependent variable is caused by the change of the independent variable rather than the test error. The independent variable has a high degree of interpretation of the dependent variable. The Sig. value is 0.024, which is less than 0.05, indicating that the linear regression of the model is significant, and a regression model can be established between the independent variable and the dependent variable.

Table 2. Regression model of ANOVAs.

	Sum of Squares	df	Mean Square	F	Sig.
Regression	614.206	3	204.735	344.892	0.024
Residual	0.594	1	0.594		
Total	614.8	4			

After the F test shows that a linear model can be established, it is necessary to determine whether the independent variable has a significant influence on the dependent variable, so the regression coefficient must be tested for significance. The significance test of the regression coefficient is shown in Table 3. In Table 3, the partial regression coefficients corresponding to X1, X2 and X3 are all negative values, indicating that PCI_b, RQI_b, and SRI_b are all negatively correlated with PJ. The reason is that with the increase of PCI, RQI and SRI, the PJ value decreases. Therefore, the better the pavement performance is, the smaller the space for performance improvement after pre maintenance, and the smaller the performance mutation value. The absolute value of the critical value (t) of the bilateral test is all greater than the significance level, and the significance value of Sig. is less than 0.05, indicating that the independent variable has a significant influence on the dependent variable, so the two coefficients are all retained in the model.

Table 3. Coefficient of regression model.

Parameter	Partial regression coefficient	Partial regression coefficient standard error	Standardized partial regression coefficient	t	Sig.
Constant	86.102	1.491		6.893	0.016
x_1	–1.057	0.059	0.489	4.026	0.028
x_2	–2.324	0.143	0.348	5.246	0.007
x_3	–1.845	0.032	–1.149	–3.294	0.019

The results of the goodness of fit test are shown in Table 4. R^2 is the determining coefficient between the dependent variable and the independent variable, and the adjusted R^2 is the ratio of the mean square deviation to eliminate the influence of the number of independent variables. The closer R^2 and the adjusted R^2 are to 1, the fitting effect of the regression equation the better. The adjusted R^2 of the model is 0.992, which is close to 1, and the error of the standard estimation is only 0.025, indicating that the goodness of fit of the model is relatively high, and the dependent variable can be explained by the model accounting for 99.2 %.

Table 4. Summary of regression models.

R^2	Adjusted R^2	Standard estimated error
0.997	0.992	0.025

Substituting the coefficient values in Table 2 into Eq. (1) can get an improved model, as shown in Eq. (2):

$$PJ = 86.102 - 1.057PCI_b - 2.324RQI_b - 1.845SRI_b. \quad (2)$$

2.4. Analysis of the applicable conditions of the model

In the climatic environment of the seasonal frost regions, the severity of the disease will affect the values of PCI_b, RQI_b and SRI_b. Therefore, in order for the model to have a higher evaluation accuracy, it is necessary to determine the applicable conditions for the extent of 6 diseases such as broken slabs, staggered platforms, cracks, exposed aggregates, broken corners, and potholes. The response surface test was designed according to the number of disease types and the degree of quantification range, and the changes of PCI_b, RQI_b and SRI_b under different disease levels were observed. Taking the impact of six diseases on PCI_b as an example, a response surface test was designed. The response surface test with 6 factors and 3 levels is selected, and the coding levels are –1, 0 and 1. According to Perez's research [28], the disease degree is quantified. The quantified value of disease degree corresponding to disease number and coding level is shown in Table 5.

Table 5. 3 factor coding levels and values.

Number	Disease name	–1	0	1
A	broken board	50	72	94
B	staggered platform	30	61	92
C	crack	60	78	96
D	exposed aggregate	63	80	97
E	broken corner	49	72	95
F	hole	33	57	81

When the coding level of cracks, exposed aggregates, broken corners and potholes is 0, the response surface of the designed broken slabs and staggered platforms to PCI_b is shown in Fig. 9. With the increase of the degree of broken slabs and staggered platforms, PCI_b gradually decreases. When the degree of damage of the broken slabs is between 50 and 72, the decrease of PCI_b is significantly greater than the decrease when the degree of disease is between 72 and 94. The reason is that there will be traffic flow on the road. Excessive or overload conditions make the internal stress of the slab greater than the maximum bearing capacity of the concrete, and then irregular cracks will cause the slab to break. During this process, the road surface condition drops sharply. At this time, PCI_b is the most sensitive to changes in the degree of broken slabs and has the highest response. When the disease degree of the staggered platforms is between 30 and 61, the decline of PCI_b is smaller than that when the degree of the disease is 61 to 92. The reason is that the road can still be used normally when the height difference between adjacent pavement panels is small. When the panel sinks unevenly, it will seriously affect the normal use of the road, and the road condition will quickly drop to the minimum. Therefore, when the degree of staggered platforms is above moderate, PCI_b has the highest response to the degree of staggered platforms.

When the coding level of broken slabs, staggered platform, broken corners and pothole is 0, the response surface of design cracks and exposed aggregates to PCI_b is shown in Fig. 10. When the crack degree is above 78, the inclination angle of the response surface increases significantly compared to the angle below 78. The reason is that the freezing and thawing effect of the seasonal frost regions makes the pores of the concrete larger with irregular cracks, and in the late freeze-thaw period, the concrete capillary pores are seriously damaged, and the cracks expand greatly. At this time, PCI_b is more responsive to the cracks. When the degree of exposed aggregates is less than 67, the slope of the response surface is greater. The reason is that in the early stage of exposed aggregates, the tires are strongly worn when the vehicle is running, and the road performance has been greatly reduced. As the exposed aggregates gradually deepens, the actual contact area between the tire and the road surface constant, the change range of PCI_b tends to be gentle, therefore, when the degree of exposed aggregates is below moderate, PCI_b has a higher responsiveness.

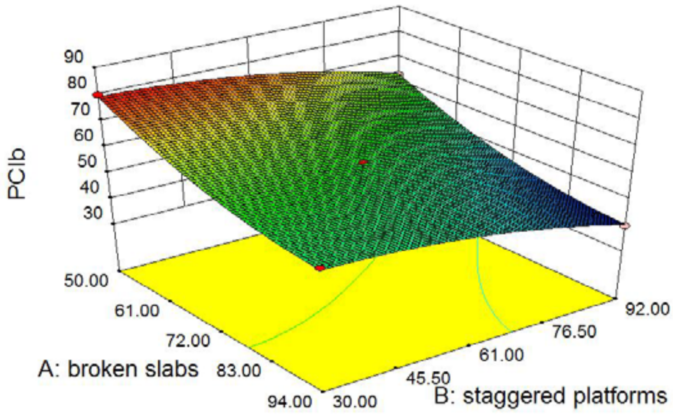

Figure 9. A and B response surface to PCI_b.

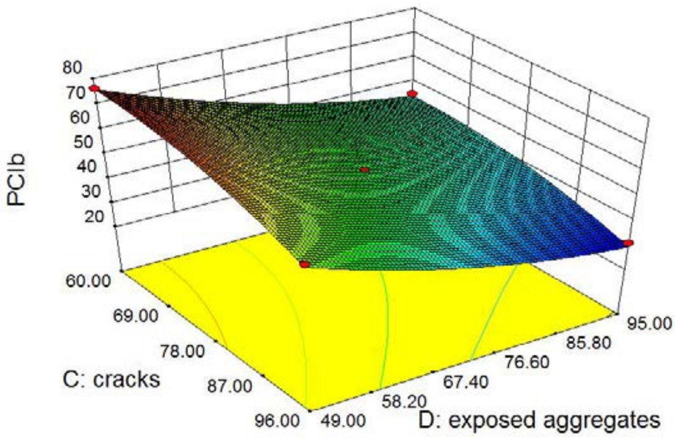

Figure 10. C and D response surface to PCI_b.

When the coding level of broken slabs, staggered platforms, cracks and exposed aggregates is 0, the response surface of design broken corners and potholes to PCI_b is shown in Fig. 11. When the degree of broken corners exceeds 76, the response surface gradually becomes flat. The reason is that the slab corner is the weakest part of the cement concrete slab. Under the seasonal frost regions climate, it is affected by freezing and thawing, and the compactness of the slab corner becomes worse. If the corner is broken, the road surface condition becomes worse. On this basis, if the corner of the road surface is increased, the road surface condition will not drop significantly. At this time, PCI_b has a low response to the corner. When the pothole degree is above 37, the slope of the response surface is larger. The reason is that when the pothole degree is large, the pavement will collapse under the load, which seriously affects the normal use of the road surface, indicating that the pothole degree is above medium, PCI_b is more responsive to the degree of potholes.

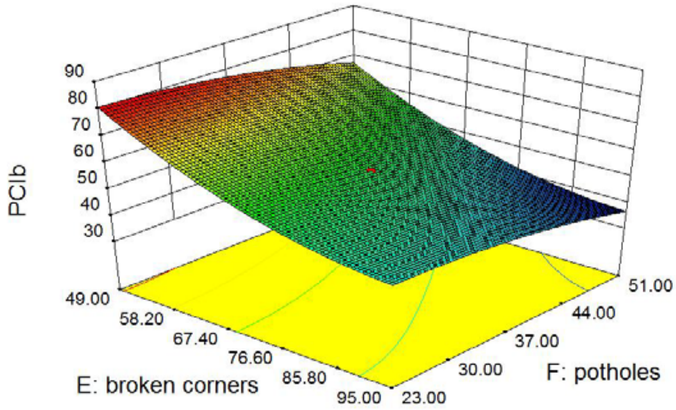

Figure 11. E and F response surface to PCI_b.

Combining the above analyses results of the response surface, we can see that if the response surface becomes flat: it indicates that PCI_b has a low response to the disease within the disease degree corresponding to the surface. At this time, the accuracy of the performance improvement model for the cement concrete pavement is low. If the slope of the response surface is large, the PCI_b changes significantly, and the corresponding disease degree will be more suitable for model evaluation. In the same way, the same response surface test is performed on the effects of RQI_b and SRI_b on the six diseases to determine the degree of disease that the model is applicable to. L stands for for mild, M for moderate, and H for severe. The final test results are shown in Table 6.

Table 6. Applicable conditions of the model.

Disease name	PCI_b	RQI_b	SRI_b
broken slabs	L,M	L,M	M,H
staggered platforms	M,H	M,H	L,M
cracks	M,H	M,H	M,H
exposed aggregates	L,M	M,H	L,M
broken corners	L,M	L,M	M,H
potholes	M,H	M,H	M,H

3. Results and Discussion

After establishing a model for improving the performance of cement concrete pavement in seasonal frost regions under pre-curing conditions with the PCI_b, RQI_b and SRI_b model parameters, the practicality of the model needs to be verified. We selected a section of Highway A in the seasonal frost regions, collected the detection data of the road performance mutation value of this section in the past 8 years, and fit the measured value with the evaluation value of the model in this paper and the existing model. Comparing the degree of fit, we judged whether the model established in this paper is better than the existing model. The fitting result is shown in Fig. 12.

In Fig. 12, the abscissa is the actual measured value (Vm) of the road performance abrupt change, and the ordinate is the model evaluation value (Vp). The model evaluation value of Labi [10] and the measured value fit the determination coefficient (R^2) of 0.955, and in Ker's study [21], it is 0.904, while the R^2 of the improved model established in this paper is 0.991, which proves that the performance improvement model established with the PCI_b, RQI_b and SRI_b parameters has the best fitting effect.

The samples of the same road section will make the test lack randomness, and the test results may have large errors. Therefore, the 6 road sections of the three roads A, B and C are again selected for verification by the actual measured road performance mutation values in the same year, as shown in Fig. 13. In Fig. 13, the edge of the radar chart is clockwise in turn with the numbers of the 6 road segments, and each layer has a fixed range of sudden changes. It can be observed that the broken line of the model evaluation value established in this paper is the closest to the broken line of the measured value, and the broken line of the other two models is relatively far from the broken line of the measured value. The reason is that the model established by Labi did not consider the influence of seasonal frost regions climate on the performance of cement concrete pavement; the parameters of the model established by Ker were not comprehensive enough and the evaluation accuracy was low. Therefore, after comparison and verification, it can be known that the performance improvement model established with PCI_b, RQI_b and SRI_b model parameters has a high evaluation level and good practicability.

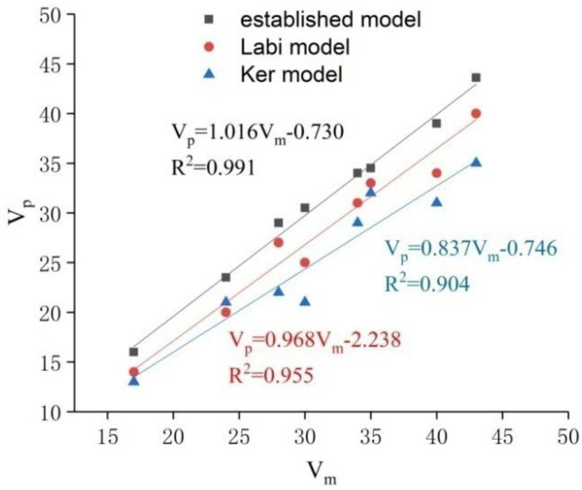

Figure 12. Fitting of PJ value.

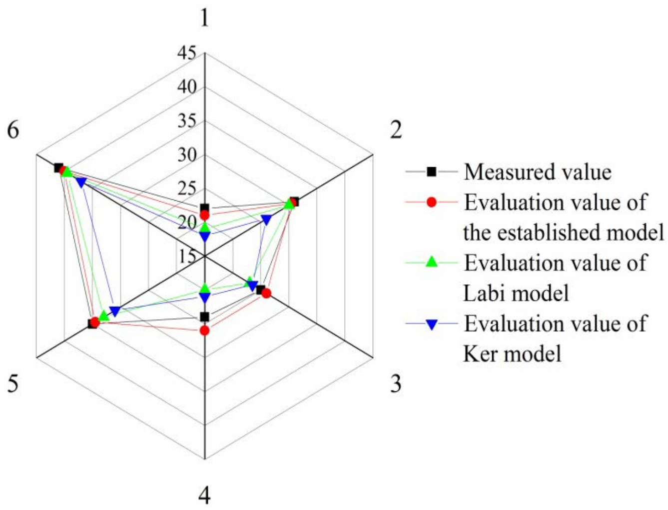

Figure 13. Histogram of PJ value.

4. Conclusions

1. Climatic factors have a significant impact on the performance of cement concrete pavement. The main disease types of cement concrete pavement in seasonal frost regions include broken slabs, staggered platforms, cracks, exposed aggregates, broken corners and potholes. The fitting correlation coefficients of PJ and PCI, RQI and SRI before maintenance are 0.9736, 0.9928 and 0.9878, respectively, and the correlation is obvious. The fitting correlation coefficients of PJ and PCI, RQI and SRI after maintenance are respectively 0.0471, 0.1312 and 0.0567, and did not show a significant correlation.

2. Using PCI, RQI and SRI before maintenance as model parameters, a pavement performance improvement model under the pre-cured condition of cement concrete pavement in seasonal frost regions was established. The coefficients after regression analysis were –1.057, –2.324, and –1.845. The deterministic coefficient of the performance improvement evaluation model is 0.992, and the Sig. value is less than 0.05. The model has a high goodness of fit and a significant regression effect, which has statistical applicability.

3. The applicable conditions of the model for improving the performance of cement concrete pavements in seasonal frost regions under pre-curing conditions are proposed. For PCI_b, it is lighter for broken slabs, the degree of exposed aggregates and broken corners, and heavier for the staggered platforms, cracks and potholes. For RQI_b, the degree of broken slabs and broken corners is lighter, and

the degree of staggered platforms, cracks, exposed aggregates and potholes is more severe. For SRI_b, the degree of staggered platforms and exposed aggregates is lighter, and the degree of broken slabs, cracks, broken corners and potholes is heavier. The extent of the above diseases is the most suitable condition for the model, and the model has the best evaluation effect.

4. The evaluation effect of the established model for improving the performance of cement concrete pavement in seasonal frost regions under pre-curing conditions is better than previous models, and it is more practical. In different periods of the same road section and the same period of different road sections, the performance improvement model and the improvement evaluation value of the existing model are respectively verified with the actual improvement value. The determination coefficient R^2 of the improvement model established in this paper is 0.991. The determination coefficients R^2 of Labi and Ker models are 0.955 and 0.904, respectively, which are lower than the R^2 value of the improved model, with its improvement evaluation value more accurate than that of the existing model as well.

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References

1. Zhao, Q., Cheng, P., Wang, J., Wei, Y. Damage prediction model for concrete pavements in seasonally frozen regions. Magazine of Civil Engineering. 2018. 84(8). Pp. 57–66. DOI: 10.18720/MCE.84.6
2. Al, Z., Al, B., Daou, A., Chhade, R.H., Chehab, G., Asce, A.M. Experimental and Numerical Assessment of the Behavior of Geogrid-Reinforced Concrete and Its Application in Concrete Overlays. American Society of Civil Engineers. 2018. 30(12). Pp. 1–10. DOI: 10.1061/(ASCE)MT.1943-5533.0002542
3. Fediuk, R.S., Mochalov, A.V., Bituev, A.V., Zayakhanov, M.E. Structuring Behavior of Composite Materials Based on Cement, Limestone, and Acidic Ash. Inorganic Materials. 2019. 55(10). Pp. 1079–1085. DOI: 10.1134/S0020168519100042.
4. Sarkar, A., Hajihosseini, M. The effect of basalt fibre on the mechanical performance of concrete pavement. Road Materials and Pavement Design. 2019. 0(0). Pp. 1–12. DOI: 10.1080/14680629.2018.1561379. URL: https://doi.org/14680629.20-18.1561379.
5. Hezhev, T.A., Zhurtov, A.V., Tsipinov, A.S., Klyuev, S.V. Fire resistant fibre reinforced vermiculite concrete with volcanic application. Magazine of Civil Engineering. 2018. 80(4). Pp. 181–194. DOI: 10.18720/MCE.80.16
6. Taylor, P., Yoo, J. Cost-effective selection and multi- period scheduling of pavement maintenance and rehabilitation strategies. Engineering Optimization. 2008. (May 2013). Pp. 37–41. DOI: http://dx.doi.org/10.1080/03052150701686937
7. Idal, M.A. V. Rehabilitation Performance Prediction Models for Concrete Pavements. Transportation Research Record. 1999. (99). Pp. 137–146.
8. Zhao, Q., Cheng, P., Wei, Y., Wang, J. Factors effecting the recovery process of self-repairing concrete. Magazine of Civil Engineering. 2019. 88(4). Pp. 52–59. DOI: 10.18720/MCE.88.5
9. Attoh-okine, N.O. Combining Use of Rough Set and Artificial Neural Networks in Doweled-Pavement-Performance Modeling — A Hybrid Approach. Journal of Transportation Engineering. 2002. (June). Pp. 270–275.
10. Labi, S., Sinha, K.C. Life-Cycle Evaluation of Flexible Pavement Preventive Maintenance. Journal of Transportation Engineering. 2005. (October). Pp. 744–751.
11. Klyuev, S.V., Klyuev, A.V., Vatin, N.I. Fiber concrete for the construction industry. Magazine of Civil Engineering. 2018. 84(8). Pp. 41–47. DOI: 10.18720/MCE.84.4
12. Ullidtz, P., Ph, D., Harvey, J.T., Ph, D., Asce, M., Sivaneswaran, N., Ph, D., Asce, M. Mechanistic-Empirical and Life-Cycle Cost Analysis for Optimizing Flexible Pavement Maintenance and Rehabilitation. JOURNAL OF TRANSPORTATION ENGINEERING. 2012. 138(5). Pp. 625–634. DOI: 10.1061/(ASCE)TE.1943-5436.0000367
13. Taylor, P., Bosurgi, G., Trifirò, F. A model based on artificial neural networks and genetic algorithms for pavement maintenance management A model based on artificial neural networks and genetic algorithms for pavement maintenance management. International Journal of Pavement Engineering. 2007. (July 2013). Pp. 37–41. DOI: 10.1080/10298430500195432
14. Fediuk, R.S., Lesovik, V.S., Mochalov, A.V., Otsokov, K.A., Lashina, I.V., Timokhin, R.A. Composite binders for concrete of protective structures. Magazine of Civil Engineering. 2018. 82(6). Pp. 208–218. DOI: 10.18720/MCE.82.19
15. Farhan, J., Fwa, T.F. Pavement Maintenance Prioritization Using Analytic Hierarchy Process. Transportation Research Record. 2009. Pp. 12–24. DOI: 10.3141/2093-02
16. Chootinan, P., Chen, A., Horrocks, M.R., Bolling, D. A multi-year pavement maintenance program using a stochastic simulation-based genetic algorithm approach. Transportation Research Part A. 2006. 40. Pp. 725–743. DOI: 10.1016/j.tra.20-05.12.003
17. Klyuev, S.V., Khezhev, T.A., Pukharenko, Y.V., Klyuev, A.V. Experimental study of fiber-reinforced concrete structures. Materials Science Forum. 2018. 945. Pp. 115–119. DOI: 10.4028/www.scientific.net/MSF.945.115
18. Rezaei, M.R., Kordani, A.A., Zarei, M. Experimental investigation of the effect of Micro Silica on roller compacted concrete pavement made of recycled asphalt pavement materials. International Journal of Pavement Engineering. 2020. 0(0). Pp. 1–15. DOI: 10.1080/10298436.2020.1802024. URL: https://doi.org/10.1080/10298436.2020.1802024
19. Priya, R., Srinivasan, K.K., Veeraragavan, A. Sensitivity of Design Parameters on Optimal Pavement Maintenance Decisions at the Project Level. Transportation Research Record. 2008. Pp. 47–54. DOI: 10.3141/2084-06
20. Chou, J., Le, T. Reliability-based performance simulation for optimized pavement maintenance. Reliability Engineering and System Safety. 2011. 96(10). Pp. 1402–1410. DOI: 10.1016/j.ress.2011.05.005
21. Ker, H., Lee, Y., Wu, P. Development of Fatigue Cracking Prediction Models Using Long-Term Pavement Performance Database. Journal of Transportation Engineering. 2008. Pp. 477–482.

22. Haghnejad, M., Modarres, A. Effect of freeze-thaw cycles on the response of roller compacted concrete pavement reinforced by recycled polypropylene fibre under monotonic and cyclic loadings. Road Materials and Pavement Design. 2020. Pp. 1–17. DOI: 10.1080/14680629.2020.1794942. URL: https://doi.org/14680629.2020.1794942
23. Saxena, P., Tompkins, D., Khazanovich, L., Balbo, J.T. Evaluation of Characterization and Performance Modeling of Cementitiously Stabilized Layers in the Mechanistic – Empirical Pavement Design Guide. Transportation Research Record. 2020. Pp. 111–119. DOI: 10.3141/2186-12
24. Jung, Y.S., Zollinger, D.G. New Laboratory-Based Mechanistic – Empirical Model for Faulting in Jointed Concrete Pavement. Transportation Research Record. 2011. Pp. 60–70. DOI: 10.3141/2226-07
25. Santos, J., Ferreira, A. Pavement Design Optimization Considering Costs and Preventive Interventions. Journal of Transportation Engineering. 2012. Pp. 911–923. DOI: 10.1061/(ASCE)TE
26. Rao, C., Darter, M.I. Enhancements to Punchout Prediction Model in Mechanistic – Empirical Pavement Design Guide Procedure. Transportation Research Record. 2013. (2367). Pp. 132–141. DOI: 10.3141/2367-14
27. Soares, R., Haichert, R., Podborochynski, D., Berthelot, C. Modeling In Situ Performance of Cement-Stabilized Granular Base Layers of Urban Roads. Transportation Research Record. 2013. 2363. Pp. 88–95. DOI: 10.3141/2363-10
28. Pérez-acebo, H., Mindra, N., Railean, A., Rojí, E., Mindra, N., Railean, A., Rojí, E. Rigid pavement performance models by means of Markov Chains with half-year step time step time. International Journal of Pavement Engineering. 2017. 8436. Pp. 1–14. DOI: 10.1080/10298436.2017.1353390.

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