Establishment of criteria for determining preventive maintenance requirements of cement pavement

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Abstract: In order to obtain the criteria for preventive maintenance of cement pavement in military airport, based on the basic assumption of flatness-dynamic load interaction in the decay process of cement pavement, derivative inflection point is adopted. The method solves the relationship between the International roughness index (IRI) and the pavement damage index (L), and obtains the IRI critical value of the cement pavement when the L decay is the fastest. After the analysis and verification, the judgment standard of the cement pavement IRI is obtained. This paper analyzes the related research results of the preventive maintenance standard range of pavement condition index (PCI), summarizes and concludes the judgment standard of pavement PCI, and gets the PCI-IRI relation based on L-IRI and PCI-IRI relation, and finally gets the judgment standard of L. Based on the current situation that our army still mainly adopts the three-meter ruler for flatness test and a large number of measured data, a three-meter ruler average gap and a pavement IRI correlation relationship are established, which realizes the conversion between the two. Based on the current situation of less accumulation of performance test data of cement pavement in military airport, the damage condition and flatness data of several cement pavement in similar environment are fitted and analyzed by using the method of space generation time, and the specific parameters of the model are obtained.

1. Introduction

Preventive maintenance is an advanced maintenance concept, which means to reasonably and take corresponding maintenance measures for the existing pavement system on the premise that the pavement is in good condition. However, the maintenance work of the airport pavement of our army is still in the stage of "either bad or repair, neither bad nor repair". The time of overhaul or reconstruction usually comes ahead of schedule. Therefore, it is of great practical significance to carry out the research on the judgment standard of preventive maintenance of cement pavement in military airport.

At home and abroad, the research on preventive maintenance standards is mainly focused on asphalt pavement, and some research results have been obtained[1]. Wang Xiangfeng proposed the road condition standard for preventive maintenance of ordinary highway asphalt pavement by analyzing the road damage status index and road driving quality index test data of typical road sections in Sichuan Province over the years[2]. Ziari, H adopts packet data processing method and establishes neural network model to obtain preventive maintenance standard of flexible pavement[3].

However, as the cement concrete pavement is a rigid pavement, its bending strength is low and the compressive strength is high, so its continuity and integrity are not as good as asphalt pavement. It is impossible to copy the research results of the preventive maintenance judgment standard of asphalt pavement completely. Therefore, it is necessary to carry out the research on the corresponding
preventive maintenance judgment standard in combination with the characteristics of cement concrete pavement. So far, there has been relatively little research in this area. This paper intends to systematically study the criteria for preventive maintenance by using methods such as summary induction, derivative inflection point and regression analysis, and establish a criterion for quantitatively guiding the preventive maintenance of cement pavement in military airports.

2. Determination of preventive maintenance demand criteria

2.1. Cement pavement international roughness index judgment standard

2.1.1. Solution of IRI criterion based on derivative inflection point. Unevenness is the inherent characteristic of cement concrete pavement. When an aircraft travels on the unevenness pavement, it will generate additional dynamic load on the pavement. The more uneven the surface is, the higher the dynamic load is, the faster the damage rate of the surface will be. There is a critical value in the process of flatness decay, and the critical value is not the time when the damage degree is the most serious, but the time when the acceleration of the development of the damage is the most. If the critical value is obtained and corresponding preventive maintenance measures are taken in the vicinity, the attenuation of the pavement performance can be most effectively mitigated.

According to the research results of pavement performance at home and abroad, combined with the analysis of the actual changes of pavement performance in some areas of China, sun Lijun[4] proposed the classic pavement decay equation as follows

$$PPI = PPI_0 \left[1 - \exp\left(-\left(\frac{\alpha}{y}\right)^\beta\right)\right]$$  \hspace{1cm} (1)

Where: $PPI$ is the service performance index; $PPI_0$ is the initial service performance index; $y$ is the road age; $\alpha$ and $\beta$ are model parameters, the size of parameter $\alpha$ reflects the length of the road service life, and the value of parameter $\beta$ determines the road decay mode. When $\alpha$ and $\beta$ take appropriate values, the $PPI$ decreases with the increase of $y$, and the rate of change shows a trend of first fast and then slow. That is, there exists a certain $y$ value, so that $PPI$ declines at the maximum rate. By using different ($\alpha, \beta$) combinations, different road decay processes can be fitted.

Zhou wenxian[5] adopts this model to study the relationship between pavement $PCI$ and pavement $IRI$. The relationship between the two is as follows

$$PCI = 100 \left[1 - \exp\left(-\left(\frac{7.54}{IRI}\right)^{2.82}\right)\right]$$  \hspace{1cm} (2)

In this paper, with reference to the practices of Sun Lijun and Zhou Wenxue, the relationship between the pavement $IRI-L$ is established.

$$L=100 \left[1 - \exp\left(-\left(\frac{a}{IRI}\right)^b\right)\right]$$  \hspace{1cm} (3)

Where: $a$ and $b$ are model parameters.

Based on the current situation that our military still uses the three-meter ruler for flatness testing, this paper intends to use $IRI$ to describe the flatness of the pavement. Therefore, the three-meter ruler and $IRI$ test vehicle are used for the flatness test of several cement concrete pavements of the same type in our army, and the data of several groups of $IRI$ and $S$ are obtained. By fitting the data of $S$ and $IRI$, the conversion relationship between them is obtained as follows.

$$IRI = 0.9043 \times S - 0.0606$$  \hspace{1cm} (4)

$R^2=0.8164$. Its conversion relationship diagram is shown in Figure 1.
To establish an $L$-$IRI$ relationship that conforms to the actual situation of our military airport pavement, it is necessary to obtain data on the long-term performance of the pavement. However, our military airport pavement has less historical data and the time series of data is not long. Therefore, this paper introduces the time-space conversion method, analyzes the performance data of several airport pavements with similar environment in our military, and obtains data of 50 sets of $L$ and $S$. The formula (4) is used to convert $S$ into $IRI$, and finally the fitting relationship between $L$ and $IRI$ is

$$L=100\left(1-\exp\left[-\left(8.42/IRI\right)^{-2.46}\right]\right)$$

(5)

$R^2=0.8874$. Its conversion relationship diagram is shown in Figure 2.

In order to obtain the $IRI$ corresponding to the point with the largest change rate of $L$, the second derivative of formula (5) is obtained, and the formula of the second derivative of $L$ is

$$L'= -100\alpha^b \exp\left[-\left(\alpha/IRI\right)^\beta\right]\left(\alpha^b \beta IRI^{-2}\beta-2-(b+1)IRI^{-\beta-2}\right)$$

(6)

Where $L''$ is the second derivative of the pavement damage index $L$, $\alpha = 8.42$, $\beta = -2.46$. To more clearly describe the $L$-$IRI$ relationship, the relationship graph is shown in Figure 3.
As can be seen from Figure 3, the second derivative of the $L$-IRI function has an inflection point. When the IRI reaches this value of 3.2, the decay rate reaches a maximum, and the preventive maintenance effect is best.

2.1.2. Determination of IRI criteria for pavement. Flatness, as a macro index reflecting the flatness performance of pavement, usually its attenuation rate is relatively slow. If the upper limit value is selected to determine the preventive maintenance demand of pavement, the result may be contrary to the actual situation. For example, the flatness of a certain surface is relatively good, but other single indicators may have reached the threshold. If the prevention of preventive maintenance is determined by the upper limit of the flatness, it will lead to the conclusion that preventive maintenance is not required. Therefore, this paper suggests that only the lower limit standard should be set for the IRI criteria, which is used to make a preliminary judgment on the preventive maintenance needs of the pavement from the IRI perspective. Whether to prevent preventive maintenance in the end is also required to be combined with other indicators.

As can be seen from the previous section, the IRI at the fastest attenuation of the pavement is 3.2 m/km. Substituting it into equation (4), inversely calculating $S=3.605\text{mm}$, which roughly corresponds to the limit value of “good” and “medium” in the GJB 2264-1995 standard, which is consistent with the corresponding results of the highway. Therefore, this paper takes 3.2 m/km as the lower limit value of pavement IRI judgment standard, and finally the IRI preventive maintenance criterion is $\text{IRI} \leq 3.2\text{m/km}$.

2.2. Judgment standard of pavement damage index

2.2.1. Standard Range Analysis of Road Surface PCI. At present, there is no research on the criteria for preventive maintenance of pavement PCI, and the research on PCI preventive maintenance standards for asphalt pavement at home and abroad is relatively mature. Therefore, this paper summarizes the relevant research on the PCI preventive maintenance standard of road surface, refers to its experience method to determine the preventive maintenance standard, and puts forward the determination standard of PCI applicable to pavement. In order to combine with the actual situation of the army, the PCI of the pavement is transformed into the pavement damage index through a certain conversion relationship, and the judgment standard of the pavement damage index is established. Summarize the standard research results of some roads PCI at home and abroad, as shown in Table 1. The evaluation criteria for road damage are shown in Table 2.
Table 1. Standard range of road surface PCI

| Researcher        | PCI  | Corresponding evaluation level |
|-------------------|------|--------------------------------|
| Wang Jiashu[1]    | 85-95| Excellent                      |
| Li Na[6]          | 60-85| Good, Medium                   |
| Zhang Liang[7]    | 70-90| Good, Excellent                |
| He Guangbing[8]   | 82-88| Good, Excellent                |
| Shanghai[9]       | 85-95| Excellent                      |
| Li Mingzheng[10]  | 70-95| Good, Excellent                |

Table 2. Evaluation standard of road surface damage[11]

| Evaluation level | PCI  |
|------------------|------|
| Excellent        | ≥85  |
| Good             | 70-85|
| Medium           | 55-70|
| Poor             | 40-55|
| Bad              | ≤40  |

According to the analysis of the research results of the above-mentioned pavement PCI standards, the general researchers think that when the pavement damage level is "excellent" and "good", it is the right time to carry out preventive maintenance. By averaging the upper and lower limits of the PCI preventive maintenance standards obtained by each investigator, the average standard range of PCI is (78.1, 90.3). As can be seen from Table 10, the upper limit value 90.3 is in the "excellent" range, and the lower limit value 78.1 is in the "good" range. The pavement is more stringent than the road surface requirements. Therefore, this paper strictly takes 75 as the lower limit and 95 as the upper limit, and finally determines that the range of the standard for the PCI of the pavement is (75, 95).

2.2.2. Conversion relationship between pavement PCI and L. At present, there is no research on the relationship between the PCI and L transformation of the pavement. In order to establish the correlation between the PCI and the L, the IRI is introduced as an intermediate variable in this paper. The PCI-L relationship of the pavement is determined by the IRI-L relationship and the IRI-PCI relationship.

According to equation (5), the relationship of pavement IRI-L is established. Ling Jianming[12] carried out statistical regression analysis on the PCI value and IRI value of the survey units of the main runway of Shanghai Hongqiao Airport from 2000 to 2003. The correlation between PCI and IRI is obtained.

\[ IRI = 23.007 - 4.684\ln PCI \] (7)

However, the formula is mainly applicable to asphalt pavement. At present, there is no literature to directly conduct a large number of regression statistics on the relationship between PCI and IRI on cement pavement. Therefore, based on the PCI-IRI relationship model of Ling Jianming, this paper takes 50 groups of PCI-IRI data from four military airports, corrects and fits the model, and obtains the PCI-IRI relationship formula of cement pavement.

\[ IRI = 18.82 - 3.64\ln PCI \] (8)

R²=0.9763. Its conversion relationship diagram is shown in Figure 4.

Figure 4. PCI-IRI Fitting correction diagram
Combining formula (5) (pavement **IRI-L** model) and formula (7) (pavement **PCI-IRI** model), through calculation, the relationship between **PCI-L** is obtained as follows

\[ L = 121.9 - 26.11 \ln \text{PCI} \]  \hspace{1cm} (9)

\( R^2 = 0.9568 \). It shows that the fitting effect is good, and the transformation diagram is shown in Figure 5. Formula (9) can be used to convert the pavement **PCI and L**, which shows that it is feasible to deduce the **L** judgment standard according to the preventive maintenance standard of pavement **PCI**.

2.2.3. **Determination of judgment standard of pavement damage index.** Through the above analysis, it is found that the standard range of pavement **PCI** is (75, 95). Through the correlation transformation of pavement **PCI-L**, it is preliminarily found that the standard of pavement **PCI** is (3%, 10.5%). According to the classification standard of the appearance quality of cement concrete pavement of military airport (as shown in Table 3), the boundary value of "excellent" and "good" is 2.0%.

| Evaluation level | Excellent | Good | Medium | Poor | Bad |
|------------------|-----------|------|--------|------|-----|
| Damage index (%) | < 2       | 2 - 5 | 5.1 - 15 | 15.1 - 20 | > 20 |

According to the **L-PCI** conversion relationship, the grading standards for the appearance quality of military airport pavements are relatively strict. If **L** = 2.0% is used as the upper limit of the judgment standard, the preventive maintenance timing will be too advanced, which is not conducive to the determination of the optimal timing of preventive maintenance. Therefore, based on the actual situation, this paper takes 3.0% as the upper limit of the **L** criterion. Substituting the lower **IRI** standard value 3.4 obtained in section 2.1 into the formula (9), the corresponding **L** = 10.16%, which is consistent with the initially obtained 10.5%, proves that the result is reasonable and reliable. This paper takes 10% as the lower limit of **L** criterion. The final determination standard of **L** is (3%, 10%).

3. **Judgment standard of preventive maintenance demand**

Based on the above analysis on the evaluation indexes of preventive maintenance from the International roughness index and pavement damage index, the judgment standard of preventive maintenance for cement pavement of military airport is determined, as shown in Table 4.

| Preventive maintenance evaluation index | judgment standard |
|----------------------------------------|-------------------|
| Flatness                               | \( \leq 3.2 \text{ m/km} \) |
| Pavement damage                        | pavement damage index | (3%, 10%) |

4. **Conclusion**

Aiming at the current situation that the historical data of military airport pavement performance is less accumulated, the method of space generation time is used to fit and analyze the damage and flatness
data of several cement pavements with similar environment in our military. The specific parameters of the model are obtained. On this basis, the research on the criteria for preventive maintenance of cement pavement in military airports is carried out.

Based on the basic assumption of the interaction between flatness and dynamic load in the course of the decay of cement concrete pavement, the derivative inflection point method is used to solve the $\text{IRI-L}$ relation of pavement, and the critical value of the $\text{IRI}$ of pavement with the fastest decay of $L$ is obtained. Through the analysis and verification, the judgment standard of the $\text{IRI}$ of pavement is obtained. This paper analyzes the research results related to the range of $\text{PCI}$ preventive maintenance standards, obtains the judgment standard of pavement $\text{PCI}$ through induction and analogy, and obtains the $\text{PCI-L}$ relationship based on $L-$IRI and $\text{PCI-IRI}$ relationship formula, and finally obtains the judgment standard of $L$.

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