This paper is part of the Proceedings of the 14th International Conference
on Structures Under Shock and Impact (SUSI 2016)
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Applicability study of an airport cement concrete pavement structure based on aircraft movements

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Abstract

It is necessary for airfield managers to ensure that airfield pavement is used sustainably and to predict pavement service life accurately. According to the specification for design of airport cement concrete pavement, this paper adopts a reversed design method to study the applicability of an airport cement pavement structure, which constructs a limit state equation based on the number of aircraft surplus repeated action. What's more, there are 4 confirmed key calculative parameters that have an effect on evaluating the applicability of airport cement pavement structure, i.e. load transfer coefficient, equivalent modulus of elasticity of foundation, thickness of pavement slab and flexural tensile strength of concrete. Taking some airport for example, the standard referenced values of pavement structure parameters have been set in advance. The level of 4 parameters variation selects 5% respectively. Then their effect of aircraft movements is analyzed correspondingly, i.e. the rank of influence degree is that: flexural tensile strength of concrete>thickness of pavement slab>load transfer coefficient>equivalent modulus of elasticity of foundation. In the meanwhile, with the effect of surplus aircraft movements analyzed deeply in different areas versus different types of aircraft, we can find that the distribution of aircraft movements in different areas of airport pavement is different in the same type. And where the most surplus movements take place is the central section of the runway. What's more, it is necessary for the airfield pavement to limit

WIT Transactions on The Built Environment, Vol 160, © 2016 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SUSI16101

the movements of aircraft with heavier tire pressure and a larger designed dynamic load, which has greater pavement fatigue damage than any other aircraft.
Keywords: airport, cement concrete pavement structure, bearing capacity, aircraft movements.

1 Introduction

Airport pavement performance will gradually become poorer with the growth of service time. For instance, the roughness of the airport pavement descends [1], which can increase aircraft tire wear and fuel consumption and reduce aircraft mechanical capacity. Besides, it has an effect on the pavement damage rate indirectly. Therefore, after an airport has been operated for many years, whether the airport pavement structure can still meet the needs of bearing capacity and aircraft movements of a new-type aircraft becomes one of the primary concerns about using this airport [2].

The pavement remaining useful life not only can be obtained through surplus aircraft movements divided by predicted yearly aircraft movements of the designed aircraft, but also can be predicted by making use of trend deduction methods (such as neural network method [3], gray prediction method [4]). In 2001, Ling Jian-ming *et al.* [5] established the model for predicting the remaining service life of cement concrete pavement. In 2004, Wang Wei [7] made use of Miner's law to perfect the method for calculating remaining useful life of airport cement concrete pavement, so as to work out the remaining service years of the pavement in a convenient way. In 2007, in order to find a method for predicting a reasonable remaining service life of the composite pavement, Zhou Zheng-feng *et al.* [9] respectively compared and analyzed various designing methods for the pavement, and finally recommended that PCI decay models should be adopted to predict the remaining service life of the pavement. In 2009, based on the gray system theory and the data collected, Wang Guanhu *et al.* [10] used the damage degrees of pavement as control targets for the service life of the pavement, and then predicted the service life of the pavement [9]. Meanwhile, by means of Miner's law and reliability designing methods, Li Le *et al.* [11] predicted the remaining movements of the pavement based on the designing specifications for the airport cement concrete pavement. In 2010, Bianchini and Bandini [12] acquired the parameters of performance of the existing pavements through FWD test data and established the fuzzy neural network model to predict the performance of the flexible pavement. In 2012, He Peng-yuan [13] established the equivalent conversion method in the area of wheel load by finite element simulation analysis. The method for calculating the pavement remaining life has been improved.

Whether the pavement bearing capacity can meet the normal usage determines the aircraft operating requirement for the pavement structure. The purpose of which is to confirm how many aircraft movements can ensure pavement structure out of functional damage. For this, with evaluation of the movements as the main conclusions, this paper proposes a method for the structural applicability evaluation. Since the pavement structure, load level area and the construction history vary at different regions of the airport pavement, so the degrees of the pavement damage are different. Therefore, the airfield pavement needs to be partitioned before conducting the evaluation of the pavement structure applicability. According to the loading conditions of different regions of the pavement, the pavement can be divided into such different parts as end of the runway, middle of the runway, taxiways, aprons, etc. Then the remaining movements of the pavement can be calculated respectively.

2 Calculation of the remaining movements of the pavement

In order to evaluate the applicability of airport pavement structure accurately, it is the need to conduct the on-site examination of the pavement structure quality. The purpose is that the remaining movements can be used to assess the applicability of pavement structure on the premise that the new pavement structure parameters are acquired after the airport has been put into use for a period of time. Remaining aircraft movements of the pavement N_j can be calculated according to Equation (1).

$$N_j = \frac{1000 N_e T}{\eta N W_t} \tag{1}$$

where N_j refers to remaining movements of the pavement, η is the passage rate when the aircraft runs within the passage width, which is determined by the type of aircraft, W_t is the tire width which is obtained by the actual measurement, If there is no measured data, $W_t = 8.3A^{0.5}$, A is the ground contact area of a tire, N is the wheel number of a main landing gear; T is the passage width, which is confirmed according to different types of aircraft and the regions where the aircraft runs, and N_e is the number of aircraft surplus repeated action, which can be calculated according to Eq. (2).

$$N_e = \sqrt[0.024]{\frac{f_r / \gamma_r - \sigma_{tpr}}{0.8\sigma_p}} \tag{2}$$

where γ_r is the reliability coefficient; σ_{tpr} is the warping fatigue stress of the temperature at the critical load position; f_r is the tensile strength standard values for the cement concrete bending; σ_{pr} is the load fatigue stress, which is generated by loads of aircraft at the location of critical load (the middle of pavement slab edges), which is calculated by Eq. (3).

$$\sigma_{pr} = k_f \sigma_p \tag{3}$$

where k_f is the fatigue stress coefficient under accumulated fatigue versus the surplus aircraft movements, σ_p is the maximal stress, which is produced by designed loads at the location of critical load.

3 Effects of pavement structure parameters and analysis based on different pavement areas

There are plenty of parameters that have the effect on the pavement structure. These parameters can be roughly divided into two categories: one is those obtained through measuring and data query, such as plate length, the maximal temperature gradient T_α, concrete Poisson's ratio μ, subgrade Poisson's ratio μ_0; the other is those obtained through the on-site tests, such as load transfer coefficient T_w, equivalent modulus of elasticity of foundation E_j, thickness of pavement slab h, flexural tensile strength of concrete f_r etc. The following is a brief analysis of an airport.

The location of airport belongs to natural zoning for highway IV. There is A-type aircraft running on the airport. The length of pavement slab situated at runway and parking apron is 5m. And the length of pavement slab situated at taxiway is 4m. The standard referenced values of T_α, μ and μ_0 are 90°C/m, 0.15, and 0.35 respectively. T_w, E_j, h, f_r are obtained by the raw data of the airport, core-drilling inspection or lading plate test. In order to analyze the rank of influence degree for calculating parameters, the standard referenced values of calculating parameters decrease by 5% or increase by 5% correspondingly. The calculation parameters of A-type aircraft are inquired, which are shown in Table 1. Among them, since the dynamic load coefficients at different regions are different, the corresponding dynamic load and load radius on a main wheel are treated differently according to the different regions. The target reliability of 95% is selected. The variation level is low, and the reliability coefficient is chosen as 1.2. According to the pavement structure parameters, the environmental parameters and the load parameters obtained above, the maximal flexural tensile stress and temperature warping fatigue stress at the critical load position are determined in the paper. Finally according to Eq. (1), the surplus aircraft movements of the pavement structure at different pavement areas are worked out, as shown in Tables 2–5. In the meanwhile, the changing patterns for

Table 1: Load parameters at various regions of the airport pavement.

Load parameters	A dynamic load on the main wheel (kN)		Main wheel tire pressure (MPa)	Load radius (m)	
	Middle of the runway	The ends of the runway, taxiway, apron		Middle of the runway	The ends of the runway, taxiway, apron
A-type aircraft	150.48	188.10	1.23	0.1973	0.2206

the remaining movements of the pavement structure can be obtained. These movements vary every time the parameters are calculated. Take the middle of the runway for example (as shown in Figure 1). The distribution of this aircraft's remaining movements at various regions of the airport pavement is displayed in Table 2.

Table 2: Remaining movements of the middle of the corresponding runway under the effect of different calculating parameters.

Parameter / Rate of change	T_w	E_j (MPa)	h (m)	f_r (MPa)
-5%	25672	44512	8988	4742
0	51861	51861	51861	51861
5%	106038	59975	245764	533002

Note: the basic values of T_w, E_j, h, f_r are respectively 0.63, 90, 0.25, 4.85.

Table 3: Remaining movements of the end of the corresponding runway under the effect of different calculating parameters.

Parameter / Rate of change	T_w	E_j (MPa)	h (m)	f_r (MPa)
-5%	23035	39939	6766	5285
0	46533	46533	46533	46533
5%	95143	53813	266181	497845

Note: the basic values of T_w, E_j, h, f_r are respectively 0.64, 100, 0.26, 5.00.

Table 4: Remaining movements of the corresponding taxiway under the effect of different calculating parameters.

Parameter / Rate of change	T_w	E_j (MPa)	h (m)	f_r (MPa)
-5%	22517	40230	6765	3805
0	46872	46872	46872	46872
5%	98859	54205	270234	362308

Note: the basic values of T_w, E_j, h, f_r are respectively 0.65, 85, 0.27, 4.65.

Table 5: Remaining movements of the corresponding apron under the effect of different calculating parameters.

Parameter / Rate of change	T_w	E_j (MPa)	h (m)	f_r (MPa)
-5%	50613	90427	11177	10035
0	105357	105357	105357	105357
5%	222210	121840	841557	967169

Note: the basic values of T_w, E_j, h, f_r are respectively 0.65, 95, 0.27, 4.95.

The degrees of the effect of various calculating parameters are measured by the ratio between the relative changing rate of the remaining movements of the pavement structure and the relative changing rate of various calculating parameters [14], wherein S_i is used to show the effect degrees of i calculating parameters, as is displayed in Eq. (4).

$$S_i = \left|\Delta J_i / J_i\right| \Big/ \left|\Delta x_i / x_i\right| \tag{4}$$

where ΔJ_i is the difference value between the movements of the corresponding pavement structure where the variation value of i calculating parameter is and the pavement structure movements where the benchmark reference value is, J_i is the aircraft movements under the standard referenced value, $\left|\Delta x_i / \Delta x_i\right| = 0.5$ is the relative changing rate of i calculating parameter.

With the variation value of various calculating parameters and the movements of the corresponding pavement structure according to Table 2 introduced into the above equation, the effect degrees of various calculating parameters for the movements of the pavement structure can be obtained as is shown in Table 3. The larger S_i is, the greater effect J_i exerts on x_i under such conditions.

Table 6: Effect degrees of various calculating parameters.

Calculation parameter	T_w	E_j	h	f_r
Effect degree -5%	10.25	2.83	17.15	18.09
Effect degree 5%	21.54	3.13	101.06	169.43

It can be seen from the above table that the degrees of the effect that these five calculating parameters produce on the remaining movements of the pavement structure are in the order of f_r> h> T_w>E_j. And the effect of f_r is far greater than the other four calculating parameters. f_r and h whose effects are among the top three greatest are obtained by on-site core drilling. Therefore, when the evaluation of the pavement structure suitability based on the movements is made, the on-site drilling core test must be conducted. The effects of T_w and E_j are smaller, so in case time is not allowed, the value can be taken for the on-site lading plate test according to the circumstances. And when T_w, E_j, h, f_r increase, the remaining movements of the pavement structure will increase in number.

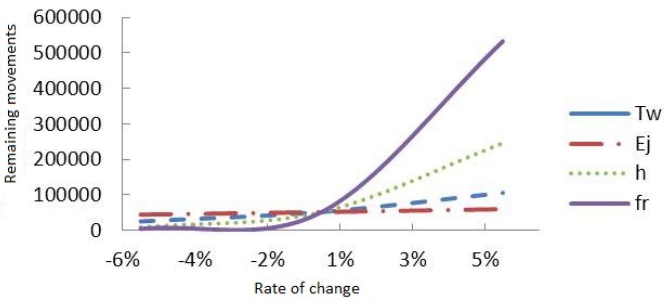

Figure 1: N_j with the change of every parameter in the middle of the runway.

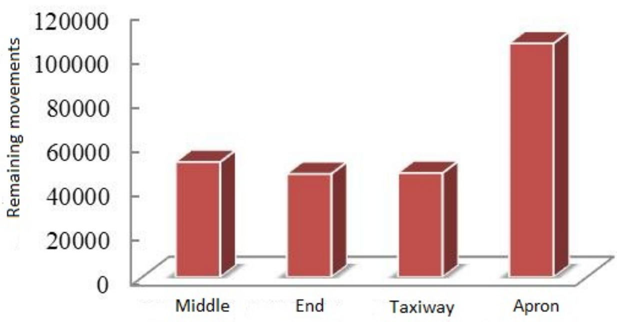

Figure 2: N_j of A-type aircraft at various airport pavement areas.

In the middle of the runway, as the aircraft passes at high speed, and the wing lift is great, so part of the aircraft gravity is offset, reducing the effect of the aircraft wheels on the pavement [5]. Therefore, compared with other regions where there are more remaining movements, the performance of the pavement turns out to be the best, which is consistent with the actual situation. Seen from this case, the aircraft with heavier tire pressure and larger designed dynamic load produces greater fatigue damage to the pavement, to which enormous importance should be attached. Besides, necessary restrictions should be imposed on the movements.

4 Conclusions

This paper identifies five calculating parameters which impact the movements of the pavement structure, and makes an in-depth analysis of them. Then the order of these five calculating parameters is determined based on their effect degrees. That is concrete flexural tensile strength of concrete>thickness of pavement slab>load transfer coefficient>equivalent modulus of elasticity of foundation. Also the paper gives an analysis of the effects on pavement structure movements at various regions, namely, when load transfer coefficient, composite resilient modulus of foundation, slab thickness of concrete pavement and concrete flexural tensile strength increase, the remaining movements of the pavement increase; while concrete bending strength elastic modulus increases, the remaining movements of the pavement structure decrease. And this provides an important theoretical basis for the applicability assessment based on the movements of the pavement.

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