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An Exploration into the Frost Resistance Evaluation Indices of Airport Concrete Pavement

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Abstract: In view of such characteristics as design standards and use requirements for the airport concrete pavement, analyses are made of the existing domestic frost resistance evaluation indices of concrete. The results suggest that the decline of relative dynamic elastic modulus to 60% and 5% of mass loss ratio in the test specimens, as stated in the current evaluation method of concrete freeze-thaw tests, are not rational evaluation indices with regard to the freeze-thaw damage to the airport concrete pavement. So it is considered more advisable to establish the flexural strength loss ratio of test specimens and the extent to which their surface scales off as the frost resistance evaluation indices of airport concrete pavement. For which purpose, the fast-freeze method is adopted to conduct a freeze-thaw damage test on concrete specimens. And, according to the correlation between the flexural strength loss and the decline of relative dynamic elastic modulus as well as that between the degree of surface scale-off and the mass loss ratio during the freeze-thaw process, the thresholds for specific evaluation indices of airport concrete pavement are supposed as follows. After 300 cycles of fast freezing and thawing, the relative dynamic elastic modulus of concrete specimens is no less than 75% (the correlative flexural strength loss ratio of the specimens is no greater than 46%), their scale-off area is somewhere between 1/3 and 2/3 of the whole surface, and their mass loss ratio no less than 1.0% (moderate scale-off).

***Key words**: Airport concrete pavement; Degree of surface scale-off; Flexural strength loss ratio; Frost resistance evaluation indices; Mass loss ratio; Relative dynamic elastic modulus.*

Preface

At present, China usually adopts the fast-freeze method, as in The Methods of Testing the Long-Term Performance and Durability of Common Concrete (GBJ 82-85), to examine the frost resistance of concrete. The decline of relative dynamic elastic modulus to 60% and 5% of mass loss ratio are specified as the thresholds for the freeze-thaw damage to the concrete. At which point the number of freeze-thaw cycles is just prescribed as the durability grade to evaluate the frost-resistant property of concrete. In this field of the country, the Procedures for Testing the Highway Engineering Cement and Cement Concrete (JTG E30-2005) also adopts the same frost resistance tests and evaluation methods. The defects of such indices, as adopted to measure the damage that frost does to concrete, lie in both the failure to take account of the actual circumstances under which the concrete is used and the belief that the frost resistance is a basic property of concrete that has nothing to do with the actual circumstances of its use. In reality, however, the same concrete is frost-resistant under some circumstances but far from adequate to meet the frost-resistant requirements under other circumstances [1]. As Powers once explained, concrete in itself is not born with such an intrinsic trait as frost resistance or durability, and any attempt to measure its frost resistance from this perspective would turn out to be in vain [2]. And moreover, the type of concrete intended for airport pavement, unlike those used in architectural structure, adopts flexural strength as its design index. And, unlike those used in highways, such concrete also needs a rigid restriction on the surface scale-off or mass loss because of the requirements for the smoothness of its surface. Thus, in response to such characteristics of the airport concrete pavement as the design specifications and the working circumstances, new frost resistance evaluation methods should be formulated, and a further study be made on the corresponding evaluation criteria for the freeze-thaw damage to the airport concrete pavement.

Up to now in China, no definite index requirements have yet been brought forward for the frost resistance durability of the airport concrete pavement. Much of such pavement will suffer a structural damage after 50~150 freeze-thaw cycles, thus falling short of the demand for its service as designed. This paper is, therefore, intended to probe into whether or not it is rational to continue to use the evaluation indices and thresholds for the freeze-thaw damage to the concrete, as prescribed in the existing frost resistance tests, to evaluate the frost resistance of airport concrete pavement.

Determination of Evaluation Indices for the Frost Resistance of Airport Concrete Pavement

To determine whether or not the airport concrete pavement suffers any freeze-thaw damage, two aspects need considering: the structural bearing capacity and the functional performance of pavement. As far as the structural bearing capacity is concerned, on the one hand, the flexural strength is adopted as the design norm for the airport concrete pavement. Besides, the flexural fatigue strength of concrete specimens is adopted as the basis for prediction of its service life. In contrast to that, architectural concrete, as designed mainly to withstand the self-generated compressive stress of the structure, adopts the compressive strength as its design standard; the

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Table 1. Results of Concrete Freeze-thaw Tests [3].

Freeze-thaw Cycles	0	25	50	75	100	125
Relative dynamic elastic modulus (%)	100	88	83	74	64	47
Compressive strength (MPa/%)	38.8/100	35.2/91	33.8/87	32.9/85	24.7/64	15.1/39
Flexural strength (MPa/%)	8.40/100	7.24/86	4.84/58	4.11/49	2.83/34	1.66/20

assessment of its failure in bearing capacity depends largely on whether or not its compressive strength meets the standards as required. Thus, there exists a distinct difference in this aspect between the two types of concretes. With functional performance, the airport concrete pavement needs strict requirements for both the smoothness and the scale-off extent of concrete surface, which in turn serve as key evaluation criteria to determine whether or not the pavement fails in function. By contrast, there are definite specifications for the protective layer of architectural concrete structure; and the thickness of reinforced protective layer acts as the basis for the evaluation of its structural function. Clearly, there also exists a significant difference between the two types of concretes. It is better for the flexural strength loss ratio and the degree of surface scale-off to take the place of the dynamic elastic modulus and mass loss ratio as the evaluation indices of airport concrete pavement. Considering that the adoption of the flexural strength loss ratio as the evaluation index will increase the pilot workload and that the dynamic elastic modulus reflects the non-destructive index of the material, there is the need to establish a right correlation between the flexural strength and the relative dynamic elastic modulus. In effect, the flexural strength loss ratio, as the evaluation index of frost resistance, can be measured through the decline of relative dynamic elastic modulus; and the extent of surface scale-off can be determined through both the scale-off area of the whole surface and the mass loss ratio [2].

Applicability Problems with the Thresholds for the Current Frost Resistance Evaluation Indices

Cheng Hong-qiang [3] et al. from Zhengzhou University adopted six groups of specimens (three pieces per group) to test the effect of freeze-thaw cycles on the concrete strength, with the results as shown in Table 1 and Fig. 1.

With the increase of freeze-thaw cycles, as seen from Table 1, the downward trend of concrete flexural strength does not agree with that of its compressive strength. There is a greater loss ratio with its flexural strength [4]. As can be inferred from Fig. 1, the flexural strength drops to around 70% when the relative dynamic elastic modulus declines to 60%, thereby failing to meet the requirements for the bearing capacity of pavement. Thus it can be seen that the evaluation indices of frost resistance, as set in the existing standards, are far from sufficient to make an accurate assessment of what damage has been done to the airport concrete pavement. So the thresholds for freeze-thaw damage to the airport concrete pavement should be specified according to the requirements for its bearing capacity.

The existing test methods refer to the mass loss ratio of concrete as one of the frost resistance evaluation indices, and prescribe 5% of mass loss ratio as the threshold for the freeze-thaw damage to the concrete. If such loss only changes the appearance of concrete

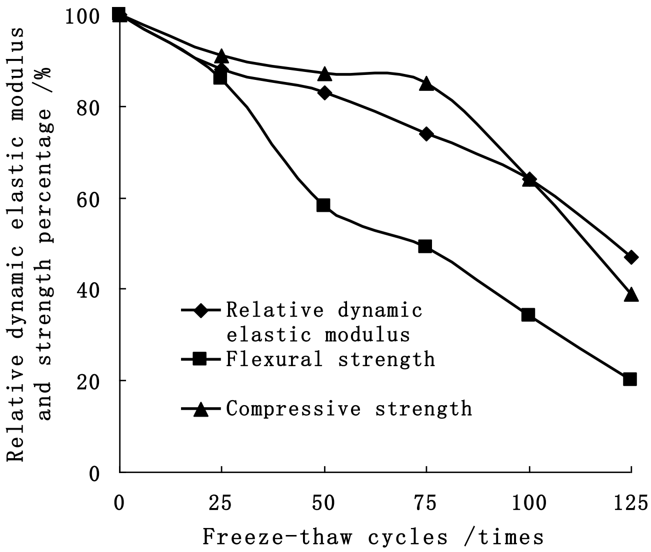


Fig. 1. Effects of Freeze-thaw Cycles on the Strength of Concrete [3].

without affecting its structural safety, it is rational to set 5% of mass loss ratio as the threshold for freeze-thaw damage to concrete. As set in the United States, "The deicer-scaling resistance test method (ASTM C672) divides the severity of surface scaling into six grades: Grade 0 stands for no scaling, Grade 1 stands for slight scaling (no coarse aggregate exposed), Grade 2 stands for somewhere between the slight scaling and the moderate scaling, Grade 3 stands for moderate scaling (with some coarse aggregate exposed), Grade 4 stands for somewhere between the moderate scaling and severe scaling, and Grade 5 stands for the severe scaling (the entire surface of coarse aggregate exposed)" [5]. Through test studies, Marchand and Pigeon established a correlation between the grades of deicer-scaling and the amount of scaling [6], as shown in Fig. 2. If 5% of mass loss ratio is converted into 2.67 kg/m^2 of scaling volume (in terms of 100 mm × 100 mm × 400 mm, with the density of concrete assumed to be 2,400 kg/m^3), as can be seen from Fig. 2, the scaling grade of concrete is somewhere between grades 3 and 4, suggesting that a considerable amount of coarse aggregate is exposed. Since there is a strict requirement for the smoothness of the airport concrete pavement, the exposure of considerable coarse aggregate is bound to affect the smoothness of pavement so much as to bring about failure in its functional performance. Thus, it is rather irrational to simply set 5% of mass loss ratio as the threshold for the freeze-thaw damage to the airport concrete pavement.

Freeze-Thaw Tests on the Airport Concrete Pavement

The materials and equipment used for the freeze-thaw tests on concrete are tabulated in Tables 2 and 3, respectively.

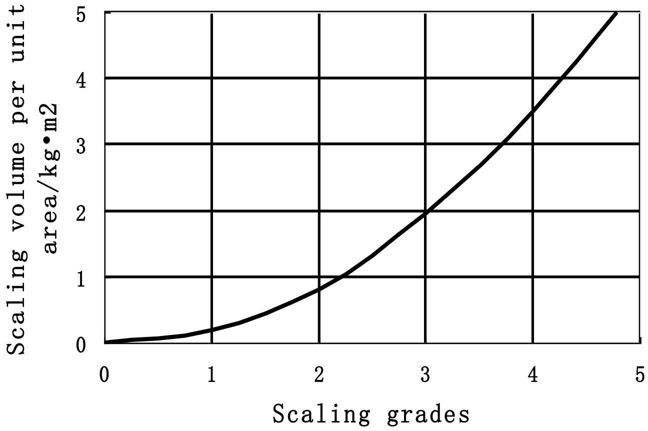


Fig. 2. Correlation between the Deicer-scaling Grade and Scaling Volume Per Unit Area [6].

Mix Proportion and Test Methods

The test herein adopts three types of concretes with different mix proportions: the ordinary concrete (PT), concrete mixed with 0.7% of air-entraining water reducer (YJ07), and concrete mixed with 1.5% of air-entraining water reducer (YJ15). The concrete of each proportion is made into 5 groups (15 groups in total, 3 pieces per group) of frost resistance specimens (100 mm×100 mm×400 mm). The specimens received a 24-day standard conservation first and then were immersed in the sample water of 20 ± 3 for four days. After that, the specimens underwent both strength tests and frost resistance tests. Results of tests on the concretes of three different proportions are as shown in Table 4.

Table 2. Test Materials.

Test Materials	Source and Specifications
Cement	Qinling-Brand High-early Strength Portland Cement (P.O 42.5R)
Fine Aggregate	Medium-coarse Bahe sand, with Fineness Modulus of 2.91and Density of 2660 kg/m^3
Coarse Aggregate	Jingyang limestone Gravels, with the Density of 2670 kg/m^3, Diameters between 5 ~ 40 mm, and the Grading Qualified
Admixture	Polycarboxylate-based Air-entraining Water-reducing Agent, Made in Xianyang Admixture Plant
Water	Drinking Water

Results and Analyses of Concrete Freeze-Thaw Tests

Results of Freeze-Thaw Tests

The results of freeze-thaw tests on the three types of concretes are shown in Tables 5 – 7.

The Effect of Freeze-Thaw Cycles on the Dynamic Elastic Modulus and the Flexural Strength of Concrete Pavement

Table 3. Test Equipment.

Test Equipment	Source and Use
TDR-type Fast Freeze-thaw Test Device	Made in Tianjin Huida Test Instrument Factory, used to make fast freeze-thaw tests on concrete
DT-10W dynamic elastic meter	Made in Tianjin Huida Test Instrument Factory, used to measure the dynamic elastic modulus of specimens

Table 4. Test Results of Flexural Strength with Concretes of Different Mix Proportions.

Concrete Type	W/C Ratio	Cement (kg/m^3)	Admixture (%)	Air Content (%)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Sand Ratio (%)	Design flexural Strength (MPa)	Measured flexural Strength (MPa)
PT	0.45	320	—	—	636	1352	32	5.0	6.5
YJ07	0.45	320	0.7	3.0	636	1352	32	5.0	6.4
YJ15	0.43	320	1.5	5.5	640	1360	32	4.5	4.9

Table 5. Results of PT Concrete Freeze-thaw Tests**.**

Test items	Freeze-thaw cycles / times				
	0	50	75	100	150
Relative dynamic elastic modulus loss ratio (%)	0	4.5	10	20	46.5
Flexural strength loss ratio (%)	0	3.0	23.4	38.6	71.4
Mass loss ratio (%)	0	0.1	0.1	0.2	0.6
Extent of scaling	The surface stays sound, with no sand and gravel exposed	1/5~1/4 of surface scales off, with no sand exposed	1/3~1/2 of surface scales off, with no sand exposed	1/2~2/3 of surface scales off, with a small amount of sand exposed	3/4~4/5 of surface scales off at a depth of less than 1mm, with sand and some gravels exposed

Notes: One group of specimens is chosen in order to undergo the test respectively after the freeze-thaw cycle(s) of 0, 50, 75, 100, and 150.

Table 6. Results of YJ07 Concrete Freeze-thaw Tests.

Test items	Freeze-thaw Cycles / Times				
	0	175	200	350	500
Relative Dynamic Elastic Modulus Loss Ratio (%)	0	4.5	5.1	9	21.8
Flexural Strength Loss Ratio (%)	0	10.9	21.1	30.8	55.0
Mass Loss Ratio (%)	0	0.4	0.6	1.0	1.8
Extent of Scaling	The Surface Stays Sound, with No Sand and Gravel Exposed.	1/5~1/4 of surface scales off, with sand and individual gravels exposed	1/2~3/5 of surface scales off, with sand and a small number of gravels exposed.	3/4 of surface scales off at a depth of less than 1 mm, with sand and a lot of gravels exposed	The whole surface scales off at a depth of 1~2 mm, with a lot of aggregate exposed

Notes: One group of specimens is chosen in order to undergo the test respectively after the freeze-thaw cycle(s) of 0, 175, 200, 350, and 500.

Table 7. Results of YJ15 Concrete Freeze-thaw Tests.

Test items	Freeze-thaw Cycles / Times				
	0	225	300	400	550
Relative Dynamic Elastic Modulus Loss Ratio (%)	0	0.1	1.9	4.5	5.0
Flexural Strength Loss Ratio (%)	0	4.8	7.3	12.1	19.9
Mass Loss (%)	0	0.2	0.4	1.4	2.0
Extent of Scaling	The surface stays sound, with no sand and gravel exposed	1/6~1/4 of surface scales off, with no sand exposed	1/3 of surface scales off, with a small amount of sand and individual gravels exposed	3/4 of surface scales off at a depth of around 1mm, with sand and many gravels exposed	The whole surface scales off at a depth of 1~2 mm, with a lot of aggregate exposed

Notes: One group of specimens is chosen in order to undergo the test respectively after the freeze-thaw cycle(s) of 0, 225, 300, 400, and 550.

The Effect of Freeze-Thaw Cycles on the Dynamic Elastic Modulus and the Flexural Strength of Concrete Pavement

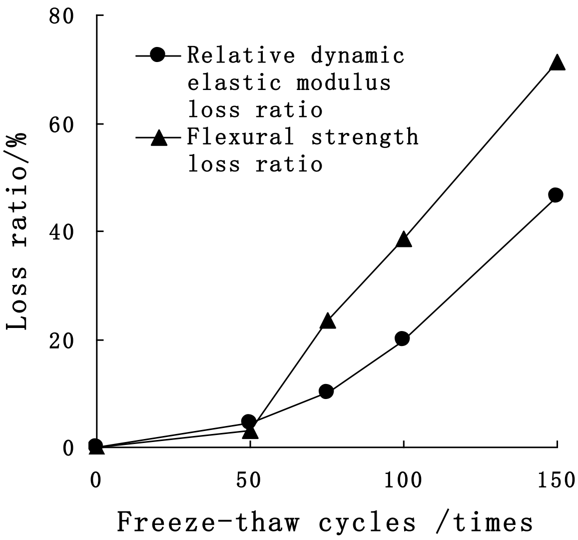
As seen from Fig. 3, the relative dynamic elastic modulus declines along with the drop of strength in three different proportions of concrete, which indicates that the relative dynamic elastic modulus is better able to reflect the degrees of deterioration in the course of freeze-thaw cycles [7]. With the standards for the existing fast-freeze method, however, the evaluation index of concrete frost resistance refers to the decline of relative dynamic elastic modulus to 60%. When the PT concrete suffers 40% of relative dynamic elastic modulus loss ratio, as can be approximately calculated from Fig. 3 (a), its flexural strength loss ratio goes up to 63.3%, thus making it impossible for its bearing capacity to meet the requirements for the structural strength of airport concrete pavement. But even after so many freeze-thaw cycles, the relative dynamic elastic modulus loss ratio of other two types of air-entrained concretes does not yet reach 40%. When the dynamic elastic modulus loss ratio of YJ07 and YJ15 concretes does reach 21.8% and 5%, respectively, their respective flexural strength loss ratios go up to 55% and 19.9%, suggesting that the loss ratio of the specimens' flexural strength is significantly greater than that of their dynamic elastic modulus [8].

The Effects of Freeze-Thaw Cycles on the Mass Loss and the Surface Scale-off of Concrete Pavement

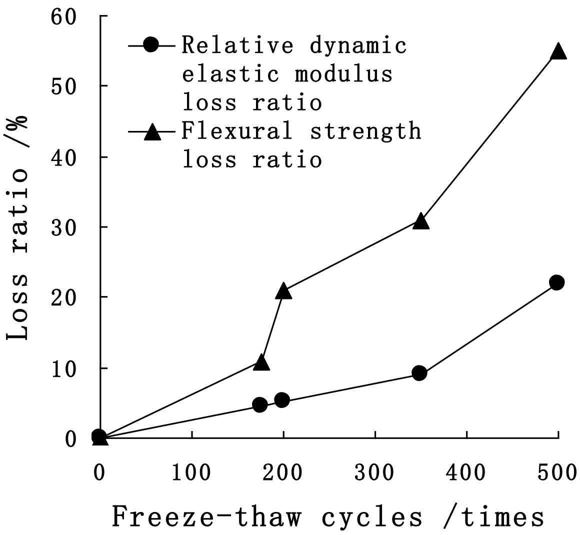
As shown in Fig. 4, three curves are drawn according to the mass loss ratios after different freeze-thaw cycles to indicate the mass loss trends of the three types of concretes. Three types of concretes (PT, YJ07, and YJ15) suffer little mass loss and no scaling-off at the initial stages of freeze-thaw cycles. But as the freeze-thaw cycles increase, so does the mass loss ratio as well as the scaling-off area and depth of the three types of concretes, with the mass loss ratio of PT much greater than those of the other two types. When the mass loss ratio goes up to around 0.4%, as seen from Fig. 5, the mortar surface of concrete specimens suffers slight scale-off without any aggregate exposed. When the mass loss ratio reaches around 1.0%, the mortar surface of concrete specimens suffers severe scale-off, with a small amount of fine aggregate exposed and a scaling depth of around 1 mm. And when the mass loss ratio goes up to about 2.0%, the whole mortar surface of concrete specimens scales off, with a large amount of aggregate exposed and a scaling depth between 1mm and 2 mm.

Determination of the Thresholds for the Frost Resistance Evaluation Indices of Airport Concrete Pavement

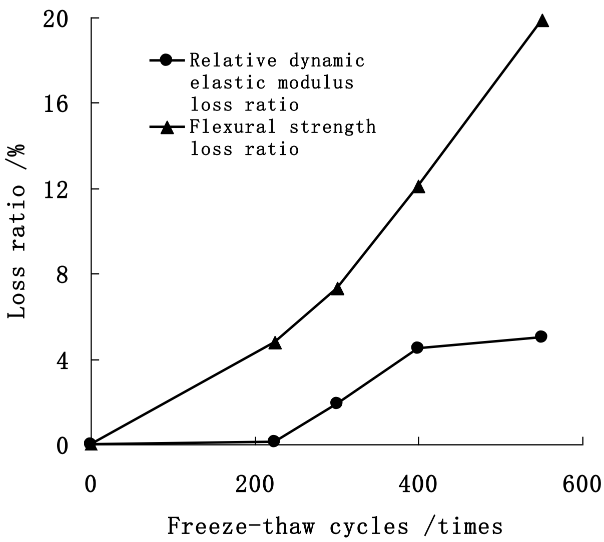
Whether higher or lower thresholds are set for the freeze-thaw damage to the airport concrete, pavement will produce a direct effect upon the evaluation of its frost resistance. In view of that, the determination of the thresholds must take into account the



(a) **PT**



(b) **YJ07**



(c) **YJ15**

Fig. 3. Effects of Freeze-thaw Cycles on the Dynamic Elastic Modulus and the Flexural Strength of Concretes.

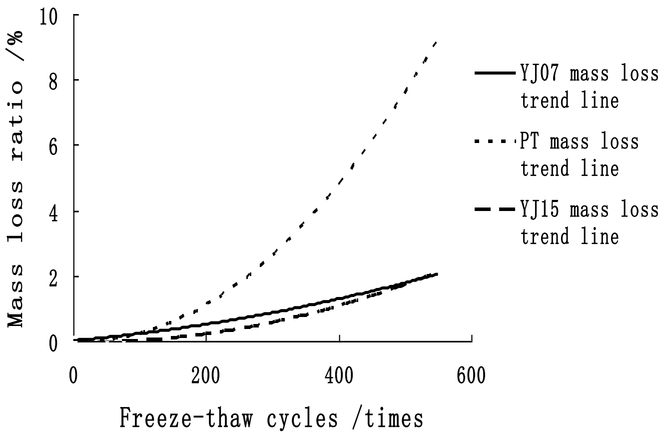


Fig. 4. Effects of Freeze-thaw Cycles on the Mass Loss of the Concrete Pavement.

(a) YJ15 Concrete.

(b) YJ07 Concrete.

(c) YJ15 Concrete.

Fig. 5. Concrete Specimens: (a) after 300 freeze-thaw cycles, mass loss ratio: 0.4%(0.21kg/m^2); (b) after 350 freeze-thaw cycles, mass loss ratio: 1.0%(0.60kg/m^2); (c) after 550 freeze-thaw cycles, mass loss ratio: 2.0%(1.05kg/m^2).

characteristics and requirements of concrete as well as the actual circumstances under which it is used.

The Threshold for the Flexural Strength

In northern cold regions of China, the design for the airport pavement must take into account the impact of freeze-thaw damage on the fatigue life of concrete in order to make sure of its service life [9]. So the principle on which to determine the threshold for the effect of freeze-thaw damage on the design fatigue life of concrete is as follows. In designing the service life of concrete under freeze-thaw circumstances, the residual value of its flexural strength should be no less than the fatigue stress of pavement. According to *The Design Specifications for the Military Airport Concrete Pavement* [10], the load fatigue stress produced by the design load at the point of critical load is calculated with the formula as below:

$$\sigma_p = \sigma_s\left(0.944 - 0.077\lg N_e\right) \tag{1}$$

where, σ_p stands for the bending fatigue strength of cement concrete, with MPa as its unit; σ_s stands for the design bending strength of cement concrete, with MPa as its unit; and N_e stands for the

Table 8. Statistics of Flight Sorties.

Years	Sorties Per Year/times of Take-off and Landing					Average Sorties Per Year/times
	Dalian	Shenyang	Urumqi	Harbin	Lanzhou	
2006	56,374	48,931	51,602	33,863	21,902	42,534
2007	63,416	56,879	59,284	40,194	28,107	49,576

Table 9. Evaluation Standards for Surface Scale-off of Airport Pavement.

Grades of Damage	Evaluation Standards
Slight Grade	The Surface Scales off, with the Scaling Area no Greater than 1/3 of the Pavement surface
Moderate Grade	The surface scales off, with the scaling area between 1/3 and 2/3 of the pavement surface
Serious Grade	The surface scales off, with the scaling area accounting for 2/3 of the pavement surface, or with a scaling depth of greater than 3mm

accumulated design impacts of aircraft on the pavement within the design service life.

Under normal circumstances, there are around 200,000 times of take-off and landing on a military airport built in northern cold regions, whereas the times of take-off and landing on the civilian airports concerned in the past two years are as shown in Table 8. As can be derived from the statistics conducted on the five cities for the last two years, there are around 50,000 sorties per year on average in the major cities. In which case there are supposed to be about 2,000,000 aircrafts in total that take off from and land on the airport within its service life. As derived from Eq. (1), therefore, the fatigue stress coefficient of the military airport pavement is 0.54 within its service life, i.e., 46% of flexural strength loss ratio, whereas the fatigue stress coefficient of the civilian pavement is 0.46, i.e., 54% of flexural strength loss ratio. For the sake of prudence, this paper establishes a 46% of drop in flexural strength as the threshold for evaluation of freeze-thaw damage to the airport concrete pavement.

The Threshold for the Relative Dynamic Elastic Modulus

If the flexural strength loss ratio of specimens is determined as the evaluation index of freeze-thaw damage to the airport concrete pavement, such direct determination will greatly increase the pilot workload. In addition, the dynamic elastic modulus is not only characteristic of concrete strength but also descriptive of its non-destructive testing index. So according to the correlation between the flexural strength loss and the decline of relative dynamic elastic modulus, as established in the paper, the measurement of flexural strength loss ratio of freeze-thaw concrete specimens can be effected through controlling the corresponding drop of their relative dynamic elastic modulus. When the flexural strength loss ratio of concrete specimens rises to around 46% because of freeze-thaw damage, as seen from Fig. 3, the relative dynamic elastic modulus of PT concrete and YJ07 concrete declines, respectively, by 25% and 18%. Since the frost resistance of air-entrained concrete is better than the ordinary concrete and such evaluation indices are intended for all kinds of the airport concrete pavement, the frost resistance of ordinary concrete is determined as the standard. Thus the threshold for evaluation of freeze-thaw damage to the airport concrete pavement is determined as follows. After 300 cycles of standard freezing and thawing, the relative dynamic elastic modulus loss ratio of specimens is no less than 75% of their initial value.

Thresholds for the Surface Scale-Off of Concrete Pavement (Mass Loss Ratio)

As specified in the existing *The Design Specifications for the Military Airport Concrete Pavement* [10], the extent of surface scaling is divided into three grades, as shown in Table 9.

As described in Table 9, the “moderate scaling” grade, as in the standards, refers to the status whose service needs nothing but better maintenance. So this paper proposes that the “moderate scaling” be set as the threshold for the surface scaling of airport concrete pavement, i.e., the peeling or scaling area accounts for 1/2 - 2/3 of pavement surface, with a scaling depth of less than 1 mm (sand coming out and some of the coarse aggregate exposed). With the two better types of air-entraining concretes, as seen respectively from Table 5, Table 6, and Table 7, 1/3 - 3/5 of specimens’ surface scales are off when their mass loss ratio is around 0.5%, with sand coming out and a few gravels exposed. And 3/4 of their surface scales are off when their mass loss ratio is about 1.0%, with a scaling depth of around 1 mm, with sand coming out and a lot of gravel exposed. The whole surface of specimens scales are off when their mass loss ratio is around 2.0%, with a scaling depth of 1-2 mm and much coarse aggregate exposed. In terms of what is stated about “moderate scaling” above, the threshold for the mass loss ratio of airport concrete pavement is better established as follows. After 300 cycles of standard freezing and thawing, the scaling area should be somewhere between 1/3 and 2/3 of specimens’ surface and their mass loss ratio is less than 1.0%.

Conclusion

Currently, *The Long-term Performance and Durability Tests for the Ordinary Concrete* specifies that the relative dynamic elastic modulus of specimens drops to 60% or their mass loss ratio reaches 5%. Such indices are no longer applicable to the evaluation of airport concrete pavement that has already adopted the flexural strength and the surficial function as its design characteristics. But in view of such characteristics as the design standards for the airport concrete pavement and the requirements for its service, this paper proposes that the flexural strength loss ratio of specimens and the extent of their surface scale-off should replace the relative dynamic elastic modulus and the mass loss ratio as the freeze-thaw evaluation indices of airport concrete pavement. For the sake of which, the fast-freeze method is adopted to conduct a freeze-thaw test on the three different proportions of concretes. And according to the correlation between the flexural strength loss ratio and the change of relative dynamic elastic modulus as well as that between the extent of surface scale-off and the mass loss ratio during the freeze-thaw process, the freeze-thaw damage to concrete can be evaluated as stated in the fast-freeze method. So it is proposed that the freeze-thaw damage evaluation indices of airport concrete pavement be determined as follows. After 300 cycles of freezing and thawing, on the one hand, the flexural strength loss ratio of concrete specimens is no greater than 46%, which can be indirectly measured through the decline of relative dynamic elastic modulus. In which light, the relative dynamic elastic modulus loss ratio of the specimens is no less than 75%. The extent of surface scale-off, on the other, is visually assessed as "moderate scaling." In which case, the scaling area of the freeze-thaw specimens is somewhere between 1/3 and 2/3 of their whole surface whereas the mass loss ratio is less than 1.0%.

This paper is just an exploratory research in which the number of freeze-thaw specimens is limited. So further researches and proofs still remain to be made in order to confirm the rationality of evaluation indices advanced herein.

References

1. Li, Z.-H., Ba, H.-J., and Deng, H.-W. (2006). Evaluation of the study on the test method about the frost resistance of concrete and the appraising parameter, *Concrete*, 6, pp. 9-11 (in Chinese).
2. Xu, D.-H. and Xu, M. (2002). *An Introduction to Concrete Material Science*. Standards Press of China (in Chinese).
3. Cheng, H.-Q., Zhang, L.-S., and Li, X.-P. (2003). The influence of freeze-thaw for the strength of concrete. *Henan Science*, 21(2), pp. 215-216.
4. Yang, S.-M. and Zhou, S.-X. (2008). Discussion on test methods about freeze-thaw resistance of concrete and its appraising parameters, *Concrete*, 4, pp. 27-28 (in Chinese).
5. ASTM C672 (2003). Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.
6. Marchang, J., Pleau, R., and Pigeon, M. (1996). The assessment of the deicer salt scaling resistance of concrete-Part1: statistical evaluation of the variability of ASTM C672. *Cement, Concrete, and Aggregate*, 3, pp. 66-78.
7. Zhao, X.-L., Wei, J., and Huang, Y.-Y. (2003). The comparison of evaluation indexes for durability degradation of concrete in freezing-thawing cycles. *J. Huazhong Univ. of Sci. & Tech* (Nature Science Edition), 31(2), pp. 103-105 (in Chinese).
8. Shang, H.-S. and Song, Y.-P.. (2008). Behavior of air-entrained concrete under the compression with constant confined stress after freeze–thaw cycles. *Cement & Concrete Composites*, 30, pp. 854–860.
9. Wang, X.-C. and Hou, R.-G. (2007). Structure design of long-life pavement. *Journal of Traffic and Transportation Engineering*, 7(6), pp. 46-49 (in Chinese).
10. GJB 1278-91:21, Design Standards for Military Airport Concrete Pavements (in Chinese).