ALTERNATIVE METHOD TO PREDICT RESIDUAL SERVICE LIFE OF CONCRETE AIRFIELD PAVEMENT WITH EMPHASIS ON RUNWAYS

ALTERNATIVE METHODE ZUR VORHERSAGE DER RESTNUTZUNGSDAUER EINER START- UND LANDEBAHN AUS BETON

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SUMMARY

After inspection of the runway of a regional airport, the question has been raised about the residual service life. There exist several international methods for predicting the life of a runway. However, they depend on data, which here were not available. On the other hand, it was known from earlier inspections that the concrete suffered from alkali-silicate reaction (ASR). Therefore, the present paper uses the detection of a crack due to ASR in the middle of the depth of the pavement, which is assumed to determine the limit of serviceability of the runway. An analytical model is proposed to calculate the remaining service life.

ZUSAMMENFASSUNG

Nach der Inspektion der Start- und Landebahn eines Regionalflughafens stellte sich die Frage nach der verbleibenden Nutzungsdauer. Es bestehen mehrere internationale Methoden dazu, die jedoch auf Daten beruhen, die hier nicht vorhanden waren. Andrerseits war von früheren Inspektionen bekannt, dass der Beton an einer Alkali-Kieselsäure-Reaktion (AKR) litt. Daher benützt der Beitrag die Entwicklung eines für die AKR typischen Risses als Versagenskriterium. Zur Berechnung der Restnutzungsdauer wird ein analytisches Modell vorgestellt.

1. INTRODUCTION

Surface distress of concrete airfield pavements is potentially a much more serious concern than for concrete highways and local concrete streets, because of the risk of foreign object debris. Concrete that is spalled from joints, cracks, and popouts in an airfield pavement is considered foreign object debris, and could cause damage if ingested into aircraft engines. The planning of renewal measures requires a tool that makes it possible to determine the prediction of service life of the airfield pavement. This would also make it much easier for the airport operator to plan maintenance requirements from a financial, personnel and aviation safety point of view. It is difficult that damage evaluation is slow at the beginning. But with the increasing degree of damage it is becoming faster and faster.

Several models for prediction of life of concrete pavements have been examined which concern the various parts of an airport such as the apron, the taxi-way and the runway [1]. The results of measurements with the FWD and HWD (Falling Weight Deflectometer and Heavy Weight Deflectometer) together with the deterioration and repair inventory and some laboratory test results are the basis for the evaluation method for cement concrete airfield pavement condition index (APCI) [2]. A literature review discusses various fatigue models for concrete airfield pavements, which assume a logarithmic decay of the performance with time [3]. Similar results are found in [4]. A manual for “Best Practices for Airport Portland Cement Concrete Pavement Construction (Rigid Airport Pavement)” is presented in [5], which is aimed at the prevention of damages. It includes the materials, the execution, the operation, and the maintenance of rigid pavements.

The models cited above are based on all kinds of damages which can be observed visually or rely on deflection measurements. The statistical treatment of the facts leads to the judgement of the current state and to a predicted service life of the structure. The damages have different weights and the sum of all elements leads to a validation number between zero and one hundred. It is up to the investigator or the judging authority to stipulate the weights and to comment on the result.

Another way for the prediction of the remaining service life of a pavement is to use a thorough inspection of the crack pattern. There are corner cracks, edge cracks, longitudinal cracks, delamination, crazing or map cracking, and maybe others. The cause for these damages must be discussed. They can be due to shrinkage, to temperature, to overloading, due to bad execution, to unsuitable components of the concrete.

One severe cause of deterioration is the so-called alkali-silica reaction (ASR). The first symptoms of ASR in a concrete pavement are often cracks starting at and running perpendicular to the transverse of longitudinal joints. Map cracking often appears first at the corner of pavement slabs. As ASR advances, the cracks spread around the perimeter of the slabs (Fig. 1).

Fig. 1: Cracking following the perimeter of pavement slabs. Additionally the left figure includes the patching of the transverse joint and the right figure the patching of the corner

No cracking occurs in the center of the slab (Fig. 1, right). The reason that the region around the joints is more prone to cracking is, first, there is often more moisture available at the joints, second, there is less restraint to expansion close to the join, third, mechanical stresses to vehicular loading are higher at the joints [6]. In many cases, spalling at joints is likely to continue and may require patching. In severe cases, extensive patching can only delay the time until a major repair or replacement is required.

One type of crack, which does not have much attention in the past, is the interior cracking which leads to partial delamination [7] and on the surface to corner cracks. It is this crack, which is considered as main cause for failure of the slab, and it will be subject of the following deliberation.

2. INTERIOR CRACKING PARALLEL TO THE SURFACE

During the inspection of the Portland cement concrete runway of a regional airport, interior cracks parallel to the surface have been found by removal of pavement slabs (Fig. 2 and Fig. 3) and by coring (Fig. 4). It is the sign of delamination.

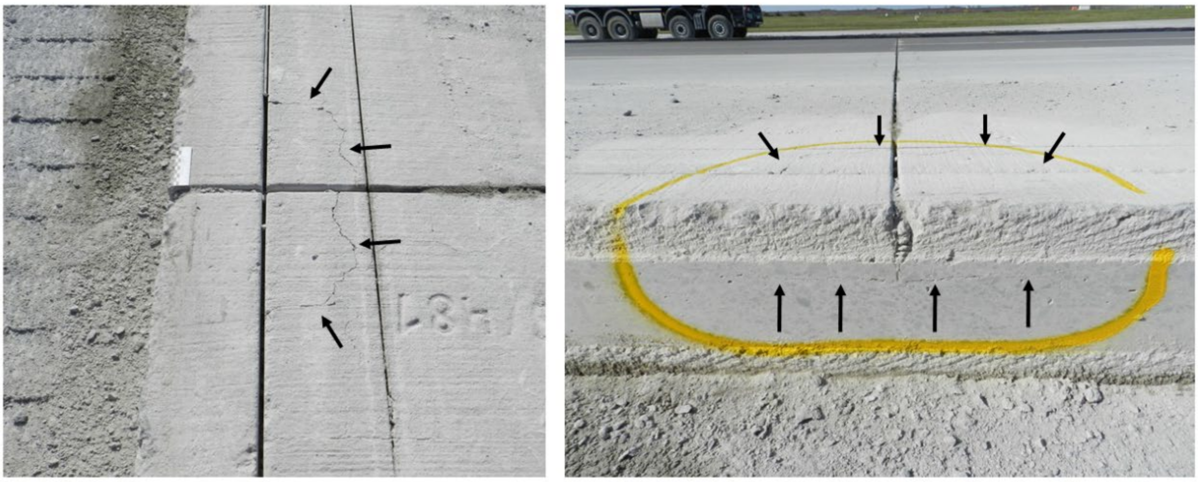

Fig. 2: Corner cracks (black arrow) on the surface of pavement slabs (left) with the corresponding interior crack (black arrow) of the slab (right)

Fig. 3: Interior cracks parallel to the surface (left and right figure). In the left figure, the interior crack led to a corner crack, which had to be patched

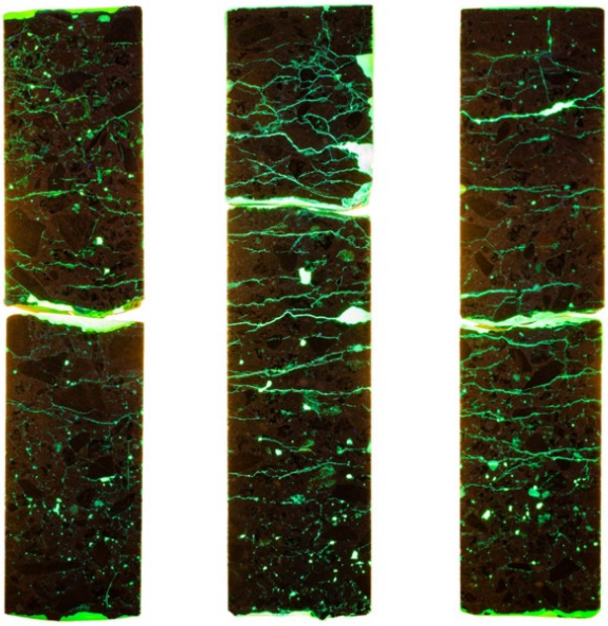

Fig. 4: Drill cores with internal cracks parallel to the surface under UV illumination. The three drill cores were taken at a distance of 26 cm from the longitudinal and transverse joints

As spoken before, the delamination leads on the surface to diagonal cracks near the corner of a concrete slab may develop, forming a triangle with a longitudinal and transverse joint often (Fig. 5). Usually these cracks are within 20 to 60 cm (approx. 0,66 ft. to 1,97 ft.) of the corner of the slab. With further deterioration, more cracking develops. Eventually the entire broken area may come loose (Fig. 6).

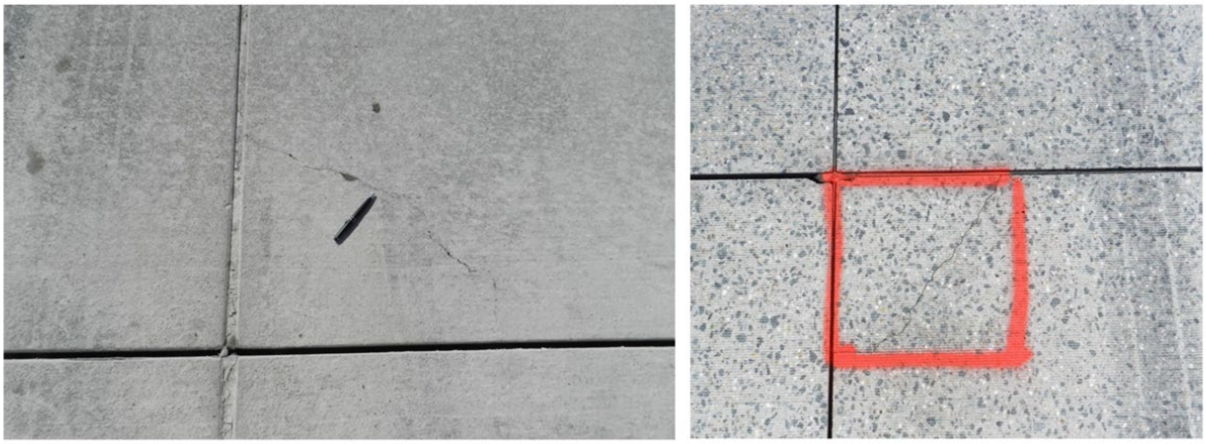

Fig. 5: Corner cracks, forming a triangle with a longitudinal and transverse joint

Fig. 6: Further deterioration, more cracking develops (left figure). Broken area may come loose (right figure)

The crack appeared to be due to ASR in combination with the loading of aircrafts mainly during take-off and landing. The cracks were emanating from transverse joints and propagate along longitudinal joints. They can lie in the middle of the slab height or higher or deeper, they can follow the boundary of a concrete layer if the slab has been constructed as two-layer slab, but they can also be caused by differential temperature or differential expansion due to ASR and alkali penetration from the surface. Runways are treated by deicing chemicals during winter time.

A horizontal crack in a beam or slab splits the cross-section into two, which has an influence on the stiffness and stress. The stress in the outmost fiber is given by

$\sigma = M/W \sim 1/h^2$

with M bending moment, W section modulus and h height. If we assume the crack running in der middle of the height the section modulus is only a quarter of the original. If both halves are considered to carry the load together the stress is doubled compared to the solid beam.

The deflection is given by

$\delta = M/(EJ) \sim 1/h^3$

If we assume the former constellation (crack in middle of the slab, both remaining slabs are carrying the load) the deflection is four times as large as if the slab was uncracked. The two slabs will also slide on each other along the crack.

Of course, this reasoning is only valid for complete delamination. In the state of incomplete delamination, one has to analyze the real situation. However, this is not the subject of this paper. In any case, the stresses get larger than in a solid slab.

3. LIMIT STATE

It is assumed that the crack parallel to the surface (delamination crack) determines the failure (limit state). From [8] follows that this crack has been caused by ASR together with the loading of aircrafts and it will propagate during airfield operation. It is assumed that it has the length of 1 cm at the beginning and will propagate exponentially with time, the loading being independent of time, i. e. the loading in the future will be same as in the past. This assumption must be made because the load spectrum is not known and the length of the crack has been measured only once. At time t the mean crack length is r and it will grow as follows

$$r = e^{kt}$$

or, as logarithm, $ln\ (r) = kt$

with k a constant which is calculated from the measurement data. Failure occurs, when a corner crack exists (for example Fig. 5). The distance of the corner to the intersection of the crack with the longitudinal or transverse joint is 20 cm to 60 cm as mentioned before.

Example: For corner crack, the distance of 60 cm between the corner and the intersection of the crack with the joint after 18 years after execution were assumed. With the measured mean crack length of 26 cm (by coring, Fig. 4) the constant k becomes

$$k = ln\ (26) / 18.$$

The total life is then given by

$$t_u = ln\ (60)\ x\ 18 / ln\ (26) = 22{,}6 \text{ years}$$

and the residual life t_{re} = 22,6 – 18 = 4,6 years. A safe remaining serviceability time can be predicted taking account of a safety factor $\gamma = 1.5$ which yields 3,1 years.

2nd example: For corner crack, the distance of 20 cm between the corner and the intersection of the crack with the joint after 18 years after execution and crack length of 8 cm (assumption) were assumed. The total life becomes

$$t_u = ln\ (20)\ x\ 18 \,/\, ln\ (8) = 25{,}9 \text{ years}$$

and residual life becomes t_{re} = 25,9 – 18 = 7,9 years. With safety factor 1.5 the predicted life is 5,3 years.

As the damage increased exponentially after 18 years after execution the damaged concrete slabs of the runway was renewed for safety reasons after 25 years after execution. Both calculations for the residual life were between the inspection and the renewal of 7 years.

Economic efficiency studies have shown that a fundamental renewal of the concrete pavement should be considered if the failure rate is between 10% and 20% of all concrete slabs [9]. Generally, in the case of airport runway and due to the safety risk, renewal should take place when temporary repair of the exponentially occurring damage is no longer possible in terms of time.

4. ASSUMPTIONS MADE

Several assumptions are hidden in this analysis which have to be justified.

1) The crack parallel to the surface (delamination crack) is a special one caused by ASR. It is regarded as failure inducing criterion.
2) If one inspects visually a slab there are corner cracks, edge cracks, longitudinal and transverse surface cracks. These cracks are local phenomena and do not cause total failure whereas the delamination crack affects the loading capacity of the whole slab.
3) The precise location of the crack is not known since only a limited number of measurements were taken.
4) Further, it is assumed that the crack propagates in the same way as before. One must admit that the crack at the boundary of the slab precedes the crack front in the middle of the slab (sickle-shaped crack).

5) The loading is taken independent of time. This means that all influences which may impair the slab are considered implicitly, such as temperature, ASR, shrinkage, variation of aircraft loading. The effects which caused the crack so far will continue.
6) The exponential crack extension is similar to the Paris equation [10] for the prediction of fatigue failure. There, the stress-intensity factor increment follows a power law.

The aim of the exercise was to formulate an analytical method which is simple and physically speaking sound. Since only a single measurement campaign was carried out it was necessary to use a function with only one unknown. If in the future more measurements were available the constant k could be calculated more precisely.

5. CONCLUSION

Several models have been examined which predict the life of airfield pavements. They are based on measurements with the FWD and HWD (Falling Weight Deflectometer and Heavy Weight Deflectometer) and/or on the regular visual inspection of the pavements. In this paper another way is chosen.

a) The inspection of the runway of a reginal airport has shown a crack in the concrete pavement which runs parallel to the surface about in the middle of the height which leads to delamination.
b) The interior cracking leads to corner cracks on the surface of concrete pavements.
c) This crack has been identified as a crack due to ASR (alkali-silica reaction) together with the aircraft loading. This crack is considered to be decisive for the service life of the pavement.
d) Based on one single measurement campaign, a simplified model is presented which allows to predict the residual service life of the pavement. It assumes an exponential crack growth with time.

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