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Combination application of FWD with GPR in the detection and evaluation of airport pavement

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Abstract. This paper mainly through the falling weight deflectometer (FWD) with ground penetrating radar (GPR) combined application way for two kinds of detection means, combined the quality safety inspection and evaluation of pavement with three typical airports, an application example of the sums up two main nondestructive pavement testing equipment composite application advantages and complement each other, both to provide technical reference and draw lessons from for pavement testing, but also for the management and development of the airport and industry provide the basis for evaluation and decision basis.

Keywords. Falling Weight Deflectometer (FWD), Ground Penetrating Radar (GPR), Pavement testing and evaluation, Nondestructive testing.

1. Introduction

With reforming and opening up, in the end of 2015, China has built 210 civil airports, completed a total of 8.566 million aircraft movements, and according to incomplete statistics, the area of Chinese civil airport runway has been more than 80 million m2. Under the "along the way" and other grand strategy, the number of civil airports will remain a high growth, ushering in a broader market and a rare opportunity, and the civil aviation infrastructure especially in the field of pavement security evaluation and detection the market and demand show more and more prominent.

Flight area of airport is the most important and main functional area, which is generally accounted for more than 70% of the total area of airport, such a broad area mainly shoulder aircraft taking off and landing, taxiing, parking and other important tasks. Pavement as the most basic facility of flight area is playing a role in ensuring the safe and effective operation of flight area, hence it is the key to elaborate the great efficient operation of platform. But with the operational time passing away, also under the influence of environment and load, the condition and performance of pavement will gradually decline, even appearing serious diseases, which will continuously increase pressure for operating and airport road surface maintenance personnel's workload. On the other hand, with the busiest airport aviation business volume increasing and varied natural environment influencing, the night suspended will be longer and shorter, in this situation how to detecting and evaluating the overload operation of pavement more efficient has become an important problem. Therefore, in order to better monitor and timely and effective maintenance and manage the pavement conditions of flight district a right consciousness of “healthy and for treatment” should be established to detect the pavement condition and “take effective” treatment" for “disease”.

Through the detection and evaluation of pavement two important purposes that is to explore and analysis the existing problems and to take maintenance and improvement measures to solve the problem are reflected.

2. Application review and theory

Road surface detection, including damage detection and nondestructive testing, at present the nondestructive testing with characteristic of fast, efficient, wide coverage and other advantages are gradually replacing the damage detection which shows low efficiency and high limitation. Structural testing is often directly related to the safe operation of road surface, therefore, structural testing is particularly important, deflection and radar testing are the better way of structural testing.

2.1. Weight deflectometer

The falling weight deflectometer (FWD) is currently in the pavement engineering field widely used as nondestructive testing equipment, it can through the determination of pavement deflection evaluate pavement and the strength of the foundation. FWD by drop hammer simulates load application process when vehicle being on road surface, and by the sensors distributing in different distances away from the load center to record deformation response under the load (as shown in Figure 1), so as to evaluate the foundation strength and structure of pavement. The main indicators include: pavement bearing capacity *ISM*, load transfer coefficient LTEδ, void coefficient T.

$$ISM = P / D0 \quad (1)$$

In the formula: *P*——load of bearing plate; *D0*——center deflection of bearing plate.

$$LTE\delta = D\text{unload} / D\text{load} \quad (2)$$

In the formula: *LTEδ*—load transfer capacity factor (%); *D*unload—measured deflection (UM) of sensor in the 15cm distance position from the plate not being affected by the load to the joint (um); *D*load—measured deflection of sensor in the 15cm distance position from the plate being affected by the load to the joint(um);

$$T = b \times t \quad (3)$$

$$b = 0.5 + 0.5 \times LTE\delta \quad (4)$$

In the formula: *b*—constraint coefficient; *LTEδ*—Load transfer capacity coefficient

$$t = D02 / D01 \quad (5)$$

In the formula: *t*—original void coefficient; *D*02—center deflection of the bearing plate of plate edge measuring point; *D*01—center deflection of the bearing plate of plate in the measuring point;

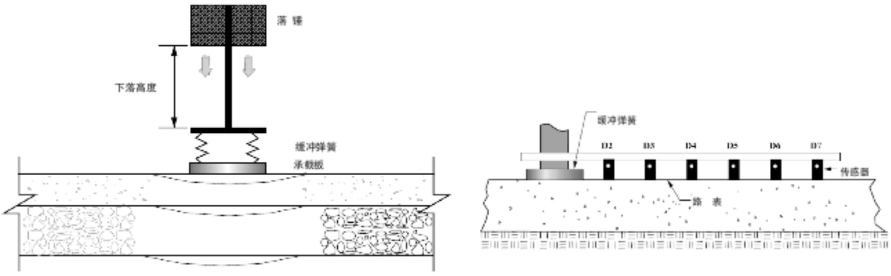


Figure 1. Schematic diagram of deflection test

2.2. Ground penetrating radar

From the eighties of the twentieth century, ground penetrating radar being characteristic of flexible degree, high precision, widely use gradually developed into the main detection methods in engineering geophysical field.

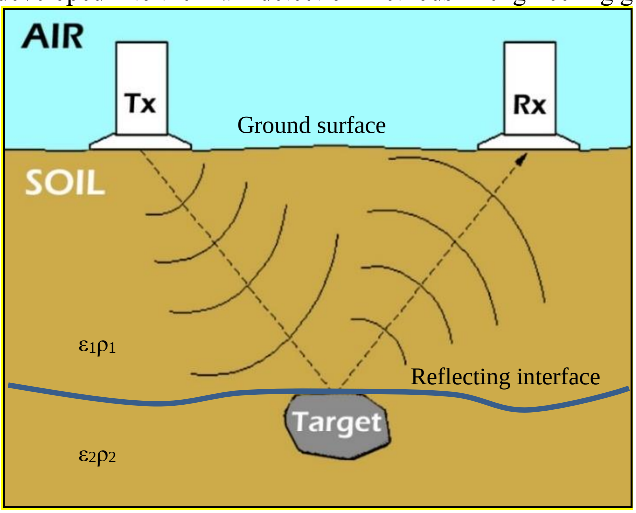


Figure 2. Schematic diagram of GPR principle
T - transmit antenna; R - receiving antenna; e - dielectric constant; R - conductivity.

GPR[1] (Figure 2) in the travelling direction through the T antenna emits pulse electromagnetic wave which will along the ground or depth direction continuously issue. In a homogeneous medium, electromagnetic wave propagates with a certain speed, while faced with electric different stratum or object, such as voids, pipelines, broken zone, karst caves and aquifers etc., the electromagnetic wave will be reflected to the ground or detection point and received by R antenna and recorded by the host, getting the two-way travel time t which includes launching through the reflection of underground interface back to the receive antenna. When the velocity of underground medium is known the position, depth and geometry of object can be obtained by the measured accurate t value combining with processing and analyzing the frequency and amplitude of reflected electromagnetic wave.

Generally speaking, the main frequence of ground penetrating radar antenna used in the engineering quality detection is generally relatively high, and the medium is mostly nonmagnetic and mainly based on displacement current. Therefore, when calculating the propagation velocity of electromagnetic wave in underground medium, only need considering the dielectric constant can get the electromagnetic wave propagation speed

$$V \approx \frac{C}{\sqrt{\varepsilon_{\gamma}}} \quad (6)$$

In the formula: C —electromagnetic wave propagation speed in vacuum, C=0.30m/ns (speed of light); ε_{γ} — Relative dielectric constant of medium.

Penetration depth and resolution of ground penetrating radar are mainly determined by the frequency of radar wave and the electrical properties of underground medium. The lower the frequency is, the greater the penetration depth is; the lower the conductivity is, the greater the penetration depth is, and vice versa. The higher the frequency is, the higher the resolution of ground penetrating radar which can reach the centimeter level or even higher at the present stage is.

3. Application cases and analysis

3.1. Detection zone status

The combination between bottom radar and heavy hammer type bending sink instrument is mainly detecting the road surface of Haikou airport runway, Tianjin airport runway and Chongqing airport.

There is 3 ~ 5cm obvious wrong table in landing section of the Haikou airport runway and severe damage in the caulking material, as shown in Figure 3, and the survey data shows that there is subgrade replacement in the section.

Figure 3. Caulking material damage and dislocation

In the northern end extension section of the Tianjin airport runway for the transition zone between the cement and asphalt road surface there is not flat condition and the caulking material damage, as shown in Figure 4.

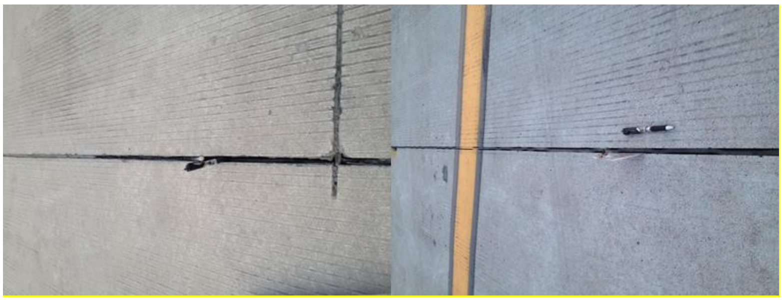


Figure 4. Caulking material damage

For Chongqing Airport B slide on the tarmac near seat section the pavement structural damage is most evident in the form of diseases including corner crack, broken plates, dislocation, etc., as shown in Figure 5.

Figure 5. Dislocation angle breaking plate

3.2. Test results

The examples of specific results of the falling weight deflectometer (FWD) and ground penetrating radar (GPR) detecting the pavement above area is shown in Figure 6 to Figure 8, and the relevant test data and image results are shown in Table 1 to Table 2.

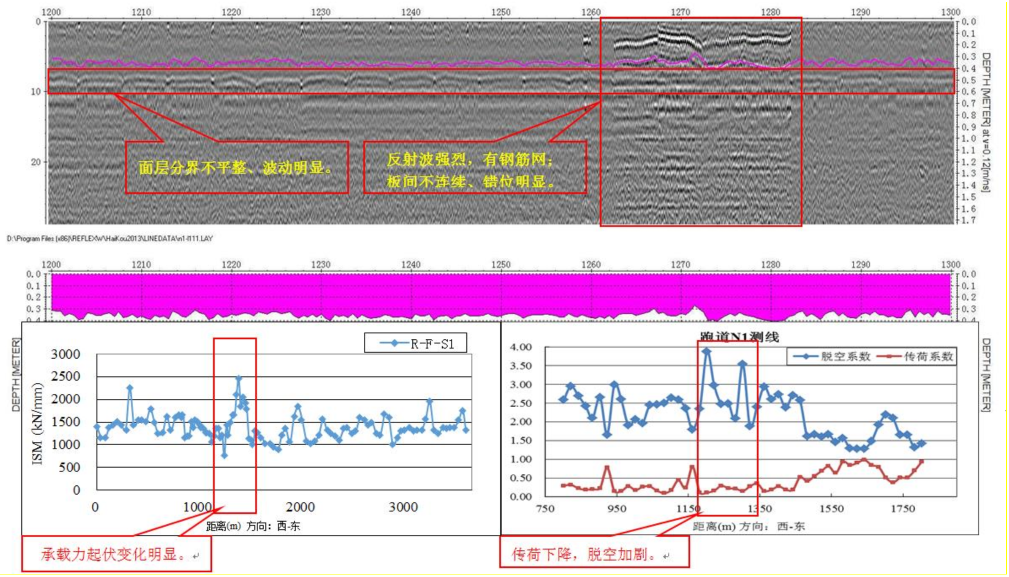


Figure 6. Haikou airport runway deflection and radar detection schematic

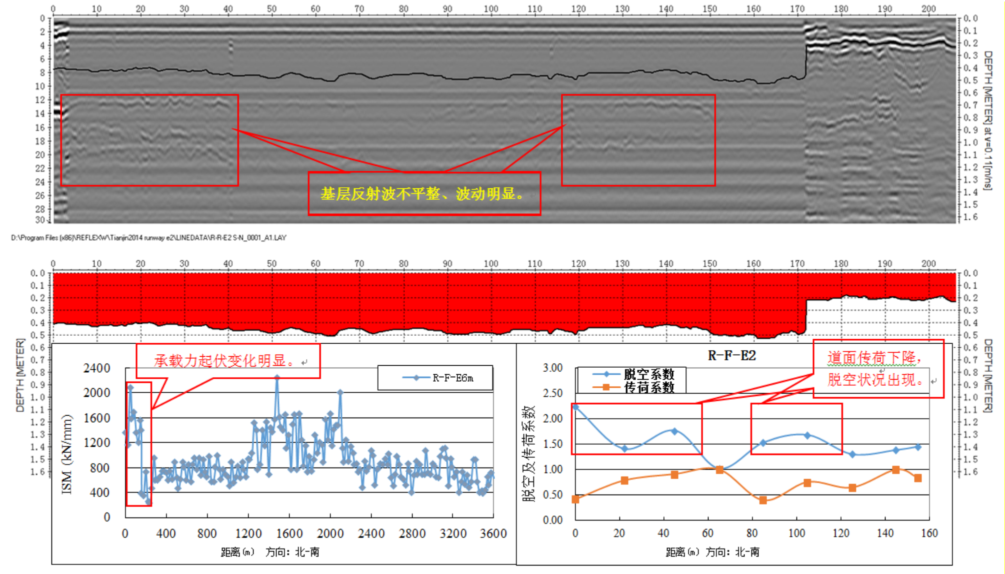


Figure 7. Tianjin airport runway deflection and radar detection schematic

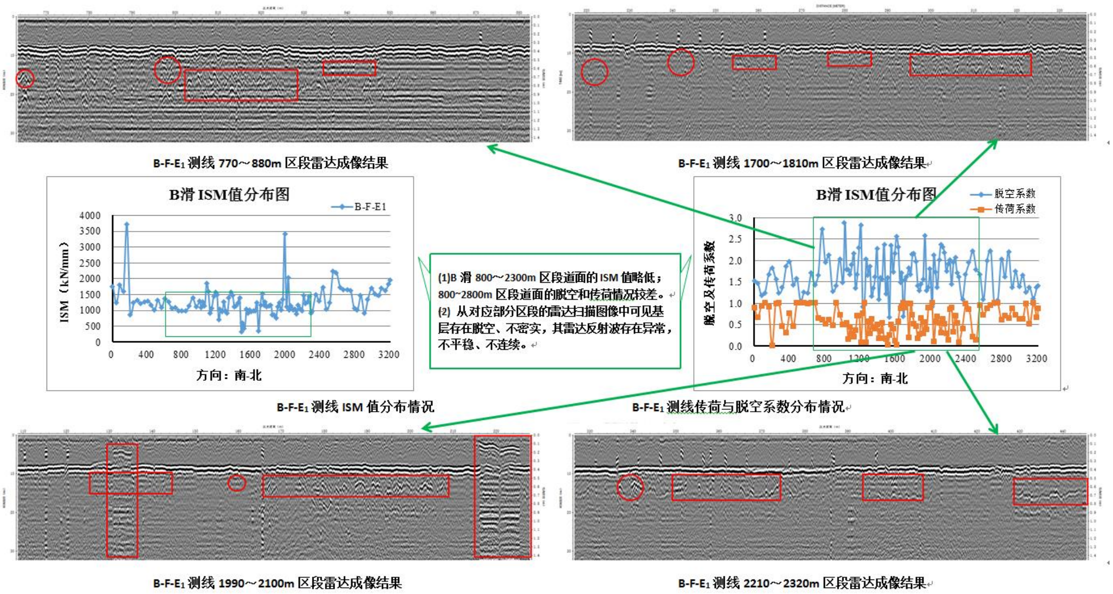
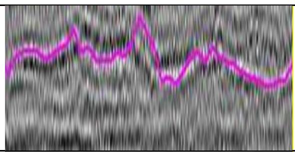
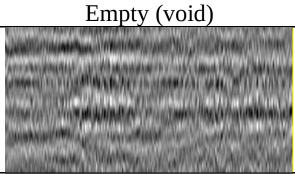
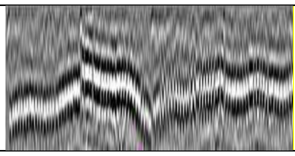
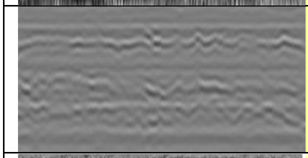
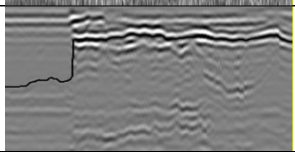
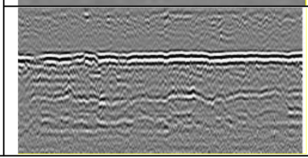
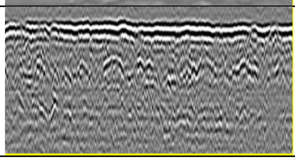
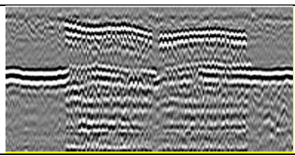


Figure 8. Chongqing airport runway deflection and radar detection schematic

Table 1. Reflect situation of deflection data

Airport	Area	ISM value (kN/mm)	load transfer coefficient				void coefficient		
			good	moderate	bad	worse	Not void	Slight void	Dutuo empty
Haikou	Feature area	1000~2500	46.4%	21.8%	25.4%	6.4%	18.2%	53.6%	28.2%
Tianjin		400~2000	44.4%	44.4%	11.2%	——	55.6%	33.3%	11.1%
Chongqing		500~1500	33.0%	22.0%	22.5%	22.5%	38.0%	40.0%	22.0%

Table 2. Reflect situation of radar image

Airport	Area	not smooth for reflected wave	Empty (void)	Steel mesh deformation
Haikou	Feature area			
Tianjin				
Chongqing				

3.3. Analysis

For the detection, the data and test results are analyzed as follows:

Haikou airport runway dislocation zone (main landing strip) as former replacement ditch area is a weak foundation. With the running time increasing and aircraft frequently loading, there is significant fluctuations in the pavement bearing capacity; the load transfer between the plates because of the caulking material aging decreases, meantime as more rainfall in the region, the load together with rain cause void generation, then there pavement dislocation appears.

Tianjin Airport northernmost 200m is at the junction between the cement concrete pavement and asphalt concrete pavement and the different structural forms result in pavement bearing capacity change significantly; the extended part of pavement due to lack of caulking material results in a slight void pavement.

3, Chongqing Airport B-slip (butt apron near seat section) appear more structural damage. The joint filler between the pavement shows damage and aging, and the load transfer between the plates larger declines, and there are frequent loads, resulting in the pavement moderate void being particularly prominent and the road surface foundation supporting being deficient, and thus leading to structural damage of pavement.

3.4. Combination application

The FWD and GPR in the quality and disease detection of road surface, although each has advantages, but there are some deficiencies. The effective combination of two detection means can better elaborates its advantages, make up for each other's deficiencies in order to achieve a better detection results. The advantages and disadvantages of the combinations are compared as shown in Table 3.

Table 3 Comparison and evaluation application of FWD and GPR detection

Testing Equipment	Testing Objective	Detection Results	detection and evaluation application		Combined application
			Advantages	Disadvantages	
FWD	Road structure evaluation	Data	●Less affected by external factors; ●data objective good at statistical analysis; ●high test efficiency, Strong adaptability for the test object and strong continuous operation ability; Data result processing simple; ●perfect evaluation system;	●The operation precision is limited; ●The data reflect belongs to an indirect result.	1) make up for the limitation and deficiency of each other; 2) improve the ability to compare and analyze; 3) enhance the reliability of results; 4) stronger test adaptability, be up to more difficult task.
GPR		Image	●image intuitive and easily identify ●high test efficiency, high operation accuracy,strong continuous operation ability.	●the external factors is more and complex; ●The data processing is complicated; ●The lack of perfect evaluation system; ●being easily influence by equipment precision, weak adaptability of the test objects.	

3.5. Decision-making application

To sum up disease test results of airports, considering the resources and investment situation of airports, taking a targeted repair and corrective measures to solve the existing problems, reduce security risks and improve decision-making and management efficiency of airport operations.

Table 4. Decision-making application of airport detection results

Airport	test results	repair and rectification	input	notes
Haikou	Ground track panel Wrong / void	Grouting in disease area	Million level	Strong pertinence Save expense
Tianjin	Junction of pavement structure Asphalt pavement is not smooth Cement pavement void	Inclusion the overall reform plan of western road surface	Billion level	Whole matching transformation
Chongqing	B slide (apron gate butt section) Obvious structural disease Obvious Pavement moderate void	Grouting in disease area Plan change board	Ten million level	Strong pertinence Save expense

4. Conclusion

In this paper, the following conclusion is made by the application of FWD and GPR in the case of civil airport pavement detection and evaluation.

Application and effect: make up for the deficiency, elaborate their respective strengths, improve the reliability of comparative analysis; at the same time, enhance and expand the scope of application areas, work depth, etc..

Reference: the combination of two kinds of non-destructive testing methods can be used as a reference for other testing projects and improve the detection accuracy and efficiency.

Evaluation and decision-making: intuitive and clear detection results can provide better judgment and decision-making basis for the management, resulting in the scheduling arrangement and management of limited funds, manpower, resources more reasonable and efficient.

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