

Application and Analysis of Ground Penetrating Radar in Non-destructive Testing and Evaluation of Civil Airport Runway

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Abstract. Driven by the strong civil aviation strategy for powerful nation, the civil aviation industry has continued to develop rapidly. The pavement of the running and sliding system has also been subjected to a sustained high load, accelerating the destruction of the pavement. In order to ensure the safe and comfortable operation of the aircraft, it is necessary to conduct a quasi-evaluation of the performance of the road surface regularly, which provides routine decision-making for pavement maintenance and repair. In this paper, the ground penetrating radar (GPR) is used to evaluate the pavement defects at several selected representative airports in China. GPR is also compared with other detection methods. The result shows that GPR has the advantages of high detection speed, high working efficiency, strong visibility of assessment results and having little impact on the airport's safe operation, which is suitable for non-stop operation of the airport.

1. Introduction

In recent years, with the development and drive of the strong civil aviation strategy for powerful nation, the civil aviation industry has maintained a momentum of rapid growth, with new breakthroughs in both the volume of transportation and infrastructure. According to the preliminary statistics of relevant departments of the Civil Aviation Administration of China in 2017, the total turnover of China's civil aviation exceeded 100 billion ton kilometer for the first time. The civil airport comprehensive system layout has been continuously improved. By the end of 2017, there have been 11 new civilian airports, with a total number of 229^[1]. With the increasing demand for air transport, the state and industry have put forward higher requirements for the security of airport infrastructure, especially the airport flight area runway pavement. The running and sliding system of the flight area pavement is the most fundamental infrastructure for providing and guaranteeing the operation of aircraft. Therefore, the safety detection and evaluation of the flight area pavement is of great significance in ensuring the airworthiness of the runway pavement and providing the airport management department with routine decision-making for pavement maintenance and future reconstruction and expansion.

The characteristics of airport flight area pavement detection and evaluation are as follows: high safety requirements, tight time, and heavy tasks. The application of more non-destructive testing methods is the fundamental guarantee for the reliable and efficient completion of operations. The ground penetrating radar (GPR) is one of the important methods used in non-destructive testing in recent years.



2. The working principle of GPR

GPR is an advanced geophysical prospecting technology using high-frequency electromagnetic waves, the characteristics of which are as follows: having no damage to the object to be detected, strong anti-interference ability, intuitive and accurate measurement results, and high work efficiency^[2]. Based on the continuous improvement of software and hardware, the application of GPR is becoming more and more extensive in the field of non-destructive testing.

The working principle of GPR^[3] (as shown in Figure 1) is mainly to transmit pulsed high-frequency electromagnetic waves to the target object through the transmitting antenna. When the electromagnetic waves encounter a target object of electrical property difference during the course of travel (such as the pavement voids, cracks, pipelines, etc.), the electromagnetic waves are reflected and received by the receiving antenna. By processing and analyzing the GPR data, the type, size, and location of the target object can be inferred and identified based on radar waveform, electromagnetic wave intensity, amplitude and two-way travel time and other parameters.

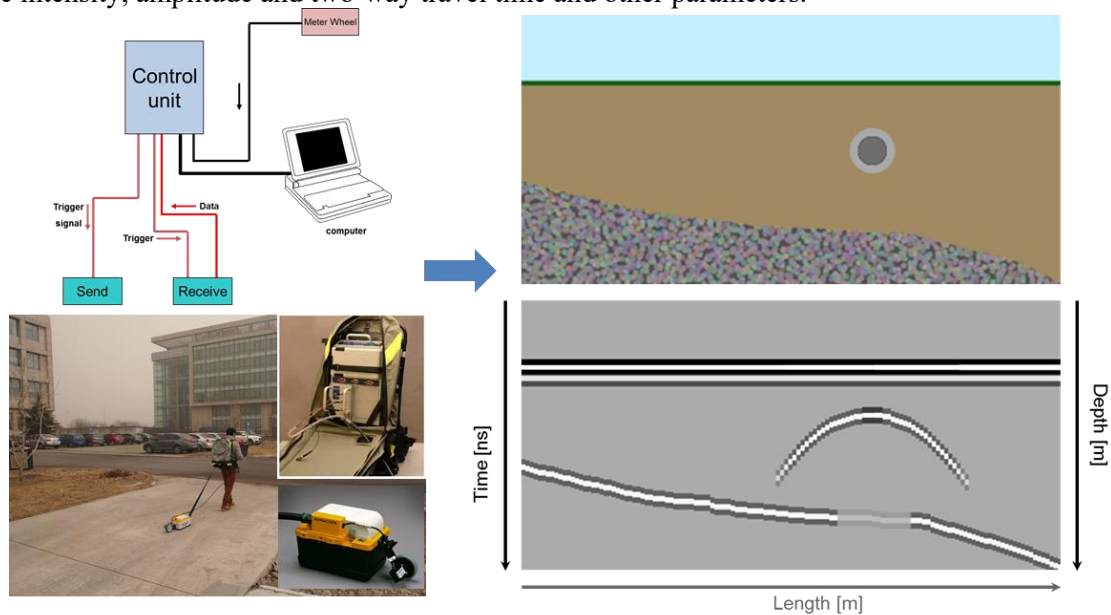


Figure 1. The working principle of GPR.

In general, the basic frequency of the ground penetrating radar antenna used in the detection and evaluation of project quality and safety is generally relatively high (800~1600MHz), and the medium encountered is mostly non-magnetic and mainly displacement current. Therefore, when calculating the propagation speed of electromagnetic waves in an underground medium, only the dielectric constant needs to be considered, and the propagation speed of electromagnetic waves can be obtained:

$$V \approx \frac{C}{\sqrt{\epsilon_r}} \quad (1)$$

Where C is the propagation speed of electromagnetic waves in vacuum, $C=0.30\text{m/ns}$ (light speed), and ϵ_r is the dielectric constant of the medium.

The penetration depth and resolution of GPR technology mainly depends on the frequency of radar waves and the electrical properties of underground media. The lower the frequency, the greater the penetration depth; the lower the conductivity, the greater the penetration depth, and vice versa. The higher the frequency, the higher the resolution of GPR^[2].

3. Application analysis

In 2017, the number of airports with a domestic passenger throughput of more than 10 million is 32, and the throughput of most busy airports still maintains a high-speed growth trend. This paper selects

three airports with similar passenger throughput in Central China: Zhengzhou, Changsha, and Wuhan airports. Through the use of GPR, non-destructive testing of the three airport runway pavement structures is conducted, and the radar imaging results are compared, analyzed and evaluated. The passenger throughput rankings of the three airports with a passenger throughput of more than 20 million in 2017 were as shown in Figure 2^[1], and Table 1 shows the basic information of the airports.



Figure 2. Twenty million passenger throughput airport ranking.

Table 1. Basic information of the three airports ^[4].

Airport name	Used time (Until 2017)	Runway level	Pavement structure	Flight take-off and landing (times)	Average annual growth of take-off and landing (2012 ~ 2016)	Main aircraft type	Remarks
Zhengzhou	20 years	4E	cement concrete	178054	13.98%	A320 B738	——
Changsha	28 years	4E	asphalt concrete	167910	7.60%	A320 B738	Covered in 2007
Wuhan	22 years	4E	cement concrete	175669	8.54%	A320 B738	——

The selected airports are typical busy airports in China. Due to the large number of flights and the heavy safety guarantee task, the time for the safety inspection and evaluation of the pavement is limited. In order to ensure fast, efficient and accurate work under conditions of tight schedule and heavy tasks, the application of non-destructive testing equipment such as GPR is reliable. This GPR test is a ground-affixed test. The main equipment includes a Swedish MALA ProEx main engine, an 800MHz radar antenna and a main wheel. The survey lines are mainly arranged along the main wheel track band, and are generally in the range of 3 to 6 m on both sides of the runway center line.

3.1. Examples of radar detection at each airport

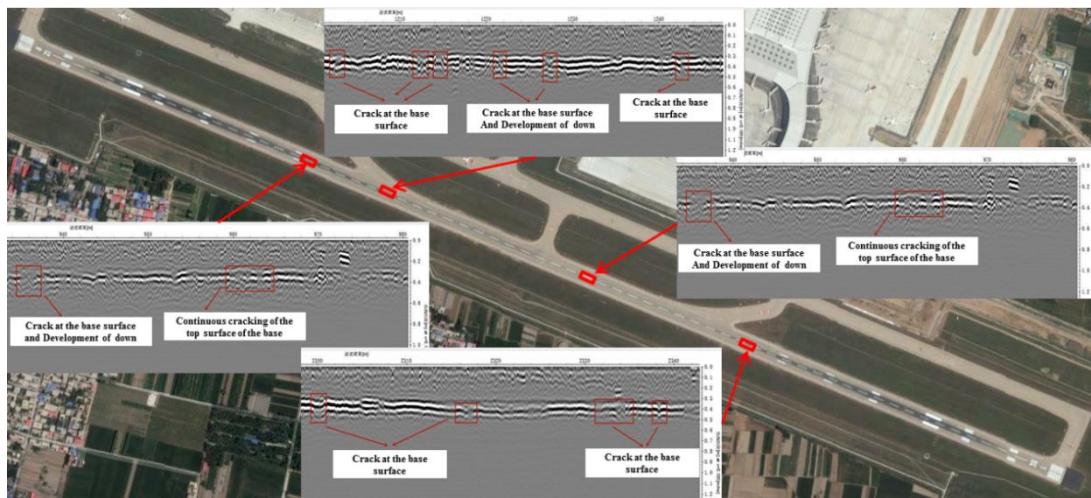


Figure 3. The example of Zhengzhou Airport south runway radar detection.

The radar detection results at the south runway of Zhengzhou Airport are shown in Figure 3. The radar image analysis is as follows: the surface and basic layer of main landing area, fast glide area and linking taxiway area in the runway, the radar wave reflection image shows a weak signal, and it is not continuous to the image of adjacent areas. The analysis results show that the overall structural damage of the runway is not much, but there are continuous cracks in the top surface of the base layer in some sections of the pavement structure and may extend downwards, and there is also the risk of interlayer void and some other damages.

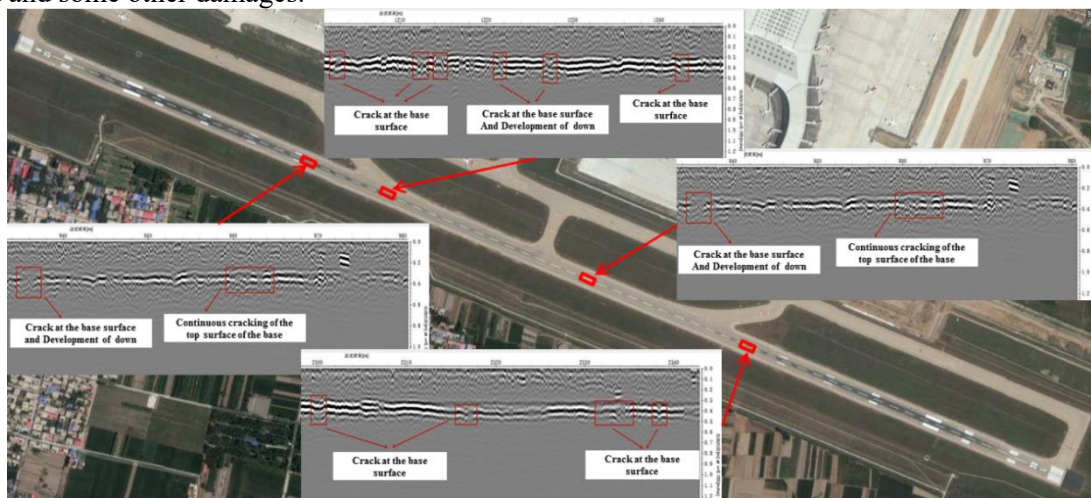


Figure 4. The example of Changsha Airport west runway radar detection.

The radar detection results at the west runway of Changsha Airport are shown in Figure 4. The radar image analysis shows that the amplitude of radar wave reflection fluctuation is obvious at the junction of the northern section of the west runway (the thickness of the extended northern section is different from that of the original pavement). The radar reflection between the whole asphalt concrete pavement surface(covered in 2007) and the original pavement surface is relatively continuous, without any misalignment or obvious abnormality in structural interlayer.

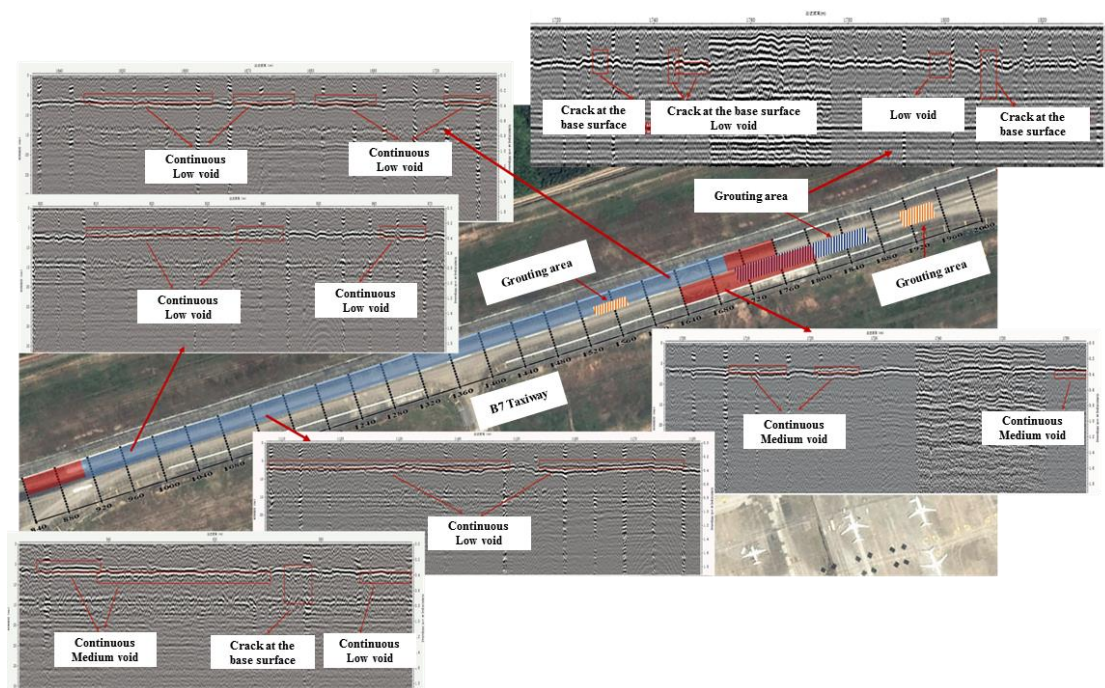


Figure 5. The example of Changsha Airport west runway radar detection.

The radar detection results at the west runway of Wuhan Airport are shown in Figure 5. The radar image analysis shows as follows: The west runway of Wuhan Airport is in contact with the fast glide. The signal of radar wave reflection image is weak within a certain range of the intersection area of west runway and fast glide and the entering and leaving runway area (original grouting area), and the fluctuation amplitude is obvious and the overall coherence is poor. The analysis results show that there is a continuous void between the surface layer and the base layer in the area, and the void is mild to moderate. Some of the base layers in central section have cracked and have a tendency to deteriorate.

Through radar detection, a summary of the of the airport runway structure void status (the main structural defects) for the three selected airports is presented, as shown in Table 2 below.

Table 2. The runway structure void status of the airports.

Airport name	The proportion of void in detection area (%)			
	East survey line		West survey line	
	No void	Void	No void	void
Zhengzhou	81.18%	18.82%	45.03%	54.97%
Wuhan	54.12%	45.88%	65.12%	34.88%
Changsha	Mainly detect the asphalt structure (covered in 2007)			

As shown in Table 2, after the Changsha airport runway was covered, it differs from the other two airport in pavement structure types. After detecting the concrete pavement of Zhengzhou and Wuhan Airport by radar and analyzing the image, it is possible to more conveniently count the void part and quickly grasp the void status of the runway pavement.

In addition to the overall control of the pavement structure and the visibility of various defects, the operating efficiency has been greatly improved in the applications of radar detection at the selected airports. Combined with the operating time of the above three airports, the operational efficiency of radar and other nondestructive testing equipment is shown in Table 3.

Table 3. The operational efficiency of GPR and other non-destructive testing equipment.

non-destructive testing equipment	Available operation time and required operation time of the three airports (hours per day)					
	Zhengzhou Airport		Changsha Airport		Wuhan airport	
	Time available	Time required	Time available	Time required	Time available	Time required
GPR	3~3.5	1.4~2	3.5~4	1.2~2	3~3.5	1.4~2
Falling weight deflectometer		4.5~9		4~8		4.5~9
Other equipment		> 10		> 10		> 10

As shown in Table 3, the selected airports' daily operation time is very limited, basically 3 to 4 hours; In the same conditions, the GPR equipment is at least 50% more efficient than other non-destructive testing equipment.

In summary, from the application of radar detection in the selected three airports we can see as follows: 1. In the same conditions, the operating efficiency of GPR is much higher than other non-destructive testing equipment. 2. The comparison of radar applications and image analysis at different airports shows that: 1) There are more pavement defects on the main landing area, fast glide area, linking taxiway area and other areas with variation structural of pavement than anywhere else in the runway. 2) As the service time increases, various defects will occur on the airport pavement under the influence of heavy traffic loads and the geological and environmental conditions of the airfield, including but not limited to voids, small holes and cracks at the base surface, corner cracks, broken plates, dislocation, etc. 3) When defects continuously occur at the cement concrete pavement and it is not conducive to the safe operation of the pavement, the pavement surface should be reconstructed in due course. For example, the west runway of Changsha Airport has been covered and rebuilt 18 years after it was put into operation. The airport runways of Zhengzhou and Wuhan have been put into operation for more than 20 years. With the continuous increase in transportation volume and the continuous appearance of pavement defects, the pressure of operation and maintenance is increasing day by day, and they are also facing an urgent demand for pavement renovation.

3.2. Summary of radar image analysis

Combining the detection of selected pavement with the evaluation of project applications, we summarize the typical radar images showing structural defects or hidden objects through the comparison and analysis of radar reflection wave images. Such typical situations includes: 1. Pavement voids, small holes or non-dense: There are usually obvious changes in the phase and amplitude of the waveform, showing strong anomalous negative phase reflectance anomalies. 2. Cracks: There are usually horizontally or longitudinally perforative or continuous reflection anomalies. 3. Rebars: There are usually small, obvious arcuate waves. 4. Pipelines: There are usually a spike-like wave anomalies in a hyperbolic form. Finally, the corresponding radar images are summarized as shown in Figure 6^[5] for reference of other similar projects.

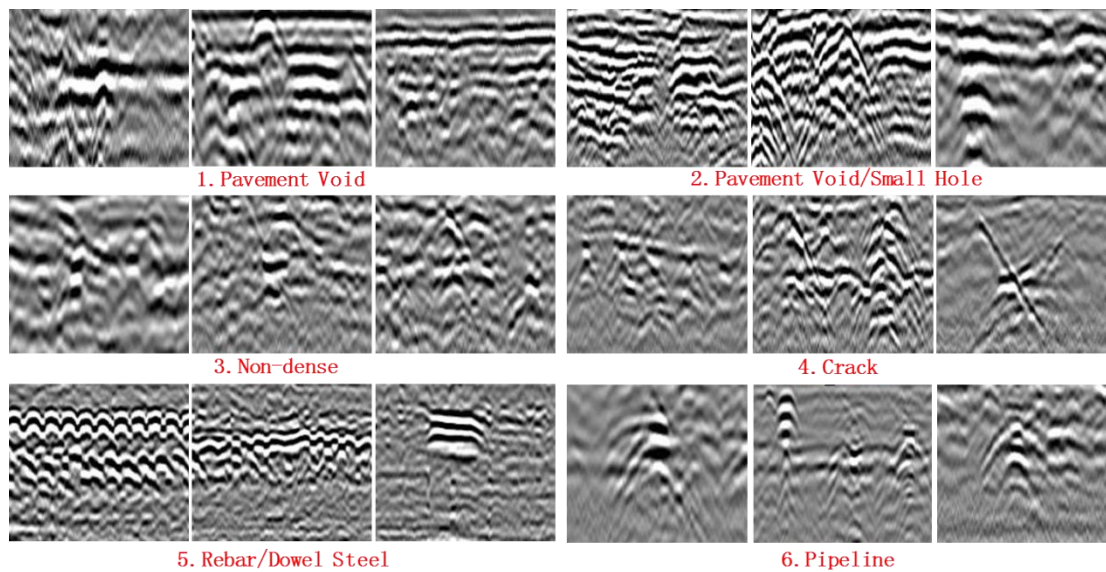


Figure 6. Typical radar images of pavement structural anomalies.

4. Conclusion

This paper makes a comprehensive analysis of the development status of China's civil airports and selects several representative airports to use GPR to conduct a comprehensive inspection of the pavement. GPR is also compared with other detection methods. The following conclusions are obtained:

1. GPR can visually detect pavement structure defects. The detection method is intuitive and reliable.

2. The GPR detection technology has the advantages of high working efficiency and fast construction speed. The GPR equipment is at least 50% more efficient than other non-destructive testing equipment.

3. The detection of GPR cause little damage to the function and structure of the airport and has little impact on the airport's safe operation. It can meet the requirements of the airport's non-stopping construction operations, and has broad application prospects.

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