Research status and development of non-destructive testing technology for deformation and damage caused by tunnel construction on adjacent ancient buildings

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Abstract. This review introduces the impact of tunnel construction on adjacent buildings and analyses the potential hazards to adjacent ancient buildings. List the commonly used non-destructive testing methods for deformation and damage in ancient buildings today, including infrared thermal imaging technology, rebound method, ultrasonic testing technology, X-ray testing technology, and vibration testing technology. Through the analysis of the latest research on non-destructive testing of ancient buildings, it is speculated that tunnel construction will cause deformation and damage to adjacent ancient buildings, and the future development of non-destructive testing technology.

Keywords: Tunnel construction, non-destructive testing, Protection of ancient buildings.

1 Introduction

The impact of tunnel construction on the adjacent environment and buildings has always been an extremely important research topic in the process of infrastructure construction in China. With the rapid development of China's economy and the increasing development of resources and energy, transport, as the lifeblood of the economy, has also developed rapidly. In the contemporary era of the rise of civil engineering, the issue of the impact of tunnel construction on the surrounding environment is becoming more and more prominent, and needs to be gradually advanced and deepened with examples of engineering. Ancient buildings are historical and cultural treasures, and the protection of them always been a hot issue worth exploring. Due to the gradual increase in the number of tunnels, it is inevitable to meet the presence of ancient buildings in the surrounding environment, so it is extremely important to carry out research on the deformation and damage non-destructive testing of tunnel construction on the adjacent ancient buildings. This paper will analyze the impact of today's tunnel construction on the surrounding buildings, list the existing ancient building non-destructive testing techniques and methods and evaluate their advantages and disadvantages, and finally

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analyze the deformation of tunnel construction on the adjacent ancient buildings and damage to the development of non-destructive testing technology.

2 Mechanisms of Tunnel Construction Impacts on Adjacent Ancient Buildings

Tunnel excavation construction produces disturbance to the strata, leading to changes in the original equilibrium state, causing stress redistribution, which in turn triggers deformation and displacement of the strata. For the case of shallow buried tunnel excavation, the excavation disturbance causes the change of the original stress around the cavern, which is transmitted outward with the deformation of the strata, thus affecting the foundation and superstructure of the buildings on the surface. The deformation and displacement of the strata and the self-weight of the soil as well as the consolidation of the soil caused by the action of additional stresses have different characteristics in terms of settlement rate and spatial distribution. Typically, tunnelling induces large displacements in a short period of time, and the effects of such rapid deformations on the stability of buildings are more pronounced. At the same time, when the tunnel passes underneath an existing building, the self-gravitational stresses of the building will have a biasing effect on the tunnel, which in turn will cause surface settlement and in turn affect the ground level building.[1]

Excavation of tunnels will cause surface settlement and deformation, which may damage the structural stability and durability of ancient buildings on the surface, including foundation damage in the form of uniform foundation settlement damage, foundation tilt damage, curvature deformation damage, and foundation horizontal deformation damage. The subsidence of the ground surface will make the ancient buildings occur as a whole uniform subsidence, such deformation will not have too much impact on the ancient buildings; construction excavation may cause uneven settlement of the foundation, which leads to the ancient buildings tilted and subjected to eccentric loads, is the load-bearing structure within the additional stress, foundation pressure redistribution, the ancient buildings of the serious harm; tunnel construction may also make the ancient buildings of the curvature damage to the foundations, is the bottom of the foundation of the ancient buildings may appear instantaneous local overhang phenomenon, at this time may make the bottom of the ancient buildings fracture or wall cracks, and when serious, even cause the collapse of the building; Tunnel construction may also cause horizontal deformation damage to the foundations, foundation horizontal deformation damage, including horizontal tension and compression deformation of two kinds of deformations, tensile deformation may lead to the building of pulling cracks, compression deformation may make the wall to produce horizontal cracks. In the actual construction process, the above four situations are likely to occur, and several situations may occur at the same time, need to be combined with the specific circumstances of the comprehensive analysis.

Due to the long years of the ancient buildings, the aging or weathering of the building components, the bearing capacity and stability will be reduced, and the disturbance caused by the tunnel construction will be more sensitive. On the other hand, the distance

between the ancient buildings and tunnels is different, and the positional relationship is different, and the degree of impact of tunnel construction on the ancient buildings is also different. For example, if the tunnel is deeper or farther away from the location of the ancient buildings, the impact on the ancient buildings will be smaller, if the tunnel axis and the ancient buildings in the tunnel depth out of the vertical projection diagonal intersection, tunnel construction of the ancient buildings may be subjected to distortion and deformation and tilt or fracture.

Tunnel blasting excavation, the vibration generated by blasting will also damage the construction of ancient buildings, especially mortise and tenon structure of ancient buildings, may make the connection structure of the ancient buildings due to vibration loosening, the walls of the ancient buildings may also be due to the vibration of the blasting crack or even fracture.

In summary, due to the ageing of the structure of ancient buildings, they are more vulnerable to the disturbing effects of tunnel construction, which leads to different forms of damage to the foundations, thus posing a hazard to the stability of the ancient buildings. The extent to which the ancient buildings are affected also depends on the distance and location of the tunnels in relation to the buildings. Moreover, blasting excavation may also make the connection structure of ancient buildings loose, wall cracks. The construction process needs to be timely non-destructive testing of ancient buildings, to take appropriate protection measures to reduce the damage to the ancient buildings.

3 Analysis of existing non-destructive testing techniques for ancient buildings

Through non-destructive testing of deformation and damage of ancient buildings, it is possible to understand the stability of ancient buildings and the damage and deformation due to the construction of adjacent tunnels. Existing non-destructive testing methods include infrared thermal imaging technology, ultrasonic detection technology, vibration detection technology, X-ray detection technology, rebound method and so on. The principles of several inspection methods, namely their advantages and disadvantages, are described below.

3.1 Infrared Thermal Imaging Technology

This method is applicable to the detection method used when the outdoor temperature is higher than the indoor temperature. Most of the ancient buildings have a large temperature difference between indoor and outdoor because of the small size of the lighting components, the cool indoor area and the large temperature difference between indoor and outdoor, so it can be used when carrying out non-destructive testing of the ancient buildings in the summer.

This method can generally be used to take infrared images of ancient buildings when the outdoor temperature is high and the temperature difference between indoor and outdoor is large, i.e., 2-3 p.m. in summer, and perform grey scale mapping on the infrared

images and noise reduction and denoising on the images. The method of grey scale mapping is to show the attenuation peak of the image by grey scale or luminance mask, and extract the attenuation peak region to get the attenuation peak image. Noise reduction denoising process is done by attenuating or eliminating the noise in the infrared image by Gaussian blur filter. Finally canny edge detection algorithm is used to obtain the edges of the attenuation region to get the attenuation information of the infrared image. This method can get the damage area of ancient buildings by observing and analyzing the attenuation information.[2]

The advantage of this method is that the damage degree of building components can be detected and evaluated, and infrared thermography can be used to carry out on-site inspection of ancient buildings in a simple and quick way, with good portability. The disadvantage of this method is that the detection time is greatly affected by the temperature, and it needs to be at a specific time to get a good detection effect, and the detection results will also be affected by the temperature.

3.2 Rebound Method

Due to the uniqueness and irreproducibility of ancient buildings, in the deformation and damage detection of ancient buildings, it is necessary to be carried out on the existing structure, and it is necessary to reduce the damage to the components of ancient buildings. The rebound method can be used for the detection of the main structure of ancient buildings, and the rebound method can accurately determine the strength of the main structure under the condition of reducing the damage to the main structure. The principle of this method is that the rebound instrument rebound rod perpendicular to the ancient building components to be detected on the surface, start the instrument after the rebound rod will hit the detection surface, the rebound rod will rebound after hitting the detection surface, at this time can be based on the rebound distance to judge the strength of the components of the ancient building.[3] The rebound method can be mainly applied to the strength of ancient buildings. The rebound method can be mainly applied to the strength test of ancient building walls.

The advantage of this method is that the rebound method has a simple and portable instrumentation, which is easy and quick to operate and inexpensive. The disadvantage of this method is that the soft hammer as the rebound rod may still cause slight damage to the surface of the ancient building [4] The method requires timely repair after the measurement, and factors such as the performance of the equipment and the working environment may have an impact on the test results.[5] The disadvantage of this method is that the soft hammer may still cause slight damage to the surface of ancient buildings.

3.3 Ultrasonic detection technology

Ultrasonic inspection technology makes use of the density and elasticity properties of the material, by detecting the density and elasticity properties of the material you can get the strength and stability of the material.[6] The principle of using ultrasonic waves for non-destructive testing of ancient building components is as follows. The use of ultrasound for non-destructive testing of ancient building components is based on the

following principle, the instrument emits ultrasound, ultrasound to detect the material as a propagation medium, when the ultrasound in the propagation process encounters defects in the detection of the material, the direction of propagation, propagation speed, or the waveform characteristics will change, the original ultrasound changes and then be received by the instrument and will receive the acoustic wave processing, through the processing of the data obtained can be The data obtained through the processing can be analysed to obtain the defects in the material, so as to assess the strength and stability of the material. Ultrasonic testing is usually used for non-destructive testing of masonry defects in ancient buildings.[7]

The advantages of ultrasonic testing include: wide detection range, large detection depth, accurate defect positioning and high precision. The disadvantage of ultrasonic detection is that ultrasonic detection equipment belongs to the precision instruments, need to be properly preserved and transported, otherwise it may affect the test results, and ultrasonic detection of defects is not intuitive, the technical threshold is high.

3.4 X-ray inspection techniques

The use of X-ray inspection instruments on the ancient architecture scanning, can be directly observed in the ancient building components of the existence of cracks and defects. The advantage of this technology is that it can intuitively get the damage image of ancient architectural components and accurately locate the defects, but the disadvantage is that the detection equipment is expensive, and it is not easy to carry out non-destructive testing of ancient architecture on the spot.

3.5 Vibration Detection Technology

Due to ultrasonic detection technology and X-ray detection technology is more expensive, so some researchers through the cheaper mechanical vibration of the components of ancient buildings for deformation and damage detection, the technology can be transmitted through the instrument vibration of the wave to the ancient buildings need to detect the region, when the vibration medium changes, the frequency and amplitude of the wave will also change, through the recording of regional vibration of the frequency, amplitude and waveform changes. It is possible to judge whether there are cracks or defects in the region. This method is quite effective for the detection of tie rod damage in ancient buildings.[8] The method is very effective for the detection of damage of tie rods in ancient buildings.

The advantages of this method are that it is less expensive than traditional ultrasonic and X-ray testing, and through the collection and analysis of empirical data, accurate and comprehensive damage data can be obtained for ancient building components, and even potential microcracks can be detected. The disadvantage is that the method has a large amount of data processing and the technology is still immature.

4 Prospects for the development of non-destructive testing technology research on ancient buildings

Nowadays, in addition to the above five methods for nondestructive testing of ancient buildings, there are many novel methods, such as image recognition method, through a large number of image collection and analysis, and then regression analysis of the results or computer deep learning, can determine the degree of damage to the building materials and strength characteristics, such as Basyigit et al. use image processing technology to assess the compressive strength of different grades of concrete value.[9] Basyigit studied seven different concrete specimens, through image processing and non-destructive testing regression analysis of the test results, assessed the compressive strength of concrete specimens, the same method can be used in the deformation of ancient buildings and non-destructive testing techniques. It is believed that as we continue to develop image recognition technology and combine it with AI, we will be able to predict the extent of damage to an ancient building component and estimate the stability of that component by taking an image of the component and recognising it in the future.

In order to improve the efficiency and accuracy of NDT of ancient buildings, several existing NDT methods can also be combined with each other to complement each other's advantages, such as Wang Rui et al. established a rock strength testing method combining ultrasonic and rebound methods.[10] The method uses binary regression analysis, BP neural network and other methods to establish the ultrasonic rebound strength model, which greatly improves the testing accuracy of specimen strength.

Today's era is the era of the Internet of Things, tunnel construction on the monitoring of the surrounding environment and monitoring also gradually tends to be timely and frequent, the existing monitoring technology can be real-time monitoring of the surrounding environment of the tunnel construction, tunnel construction on the deformation of the adjacent ancient buildings and damage to the non-destructive testing should be done in a timely manner and real-time, in order to protect the existing ancient buildings in order to protect the existing more vigorously. At the same time for the ancient architecture of the non-destructive monitoring technology will be increased, with the development of machine learning, deep learning and AI technology, there will be more efficient and accurate detection technology in the future. In addition, the integration of different technologies will be more frequent in the future, resulting in more efficient, accurate and convenient NDT technologies. It is believed that with the development of non-destructive testing technology, it will be possible in the future to carry out non-destructive testing of ancient buildings efficiently and effectively without damaging them, and to predict the stability of ancient buildings.

5 Conclusion

This review highlights the importance of NDT by describing the damage that tunnel construction may cause to adjacent ancient buildings, and lists several existing NDT methods, including infrared thermography, rebound, ultrasonic, X-ray, and vibration,

and analyses the scope of application and the advantages and disadvantages of each of these techniques. Through the introduction of existing mature technologies, emerging NDT technologies are introduced and the future development of NDT is envisioned. Ancient buildings are the treasures of human culture, and it is the responsibility of human beings to protect ancient buildings from being destroyed and inherit the culture contained in ancient buildings. NDT technology is less damaging to ancient buildings, and combining NDT technology with neural network and machine learning in the future can make NDT technology precise and convenient, which is of great significance to the protection of ancient buildings.

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