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Identification and control of prestress loss of concrete members

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Abstract. Prestressing technology is widely used in buildings, Bridges and other infrastructures, but the problem of prestress loss has been a hinder for the use and maintenance of these facilities. so how to find the existence of prestress loss in time and accurately measure the existing effective prestress is a hot topic. This paper focuses on the development of prestress loss identification methods. They can be classified according to the technical route of direct measurement and indirect calculation. A large number of studies have shown that prestress loss often occurs in the construction stage of the structure. In order to better avoid the problems that may occur during this period, intelligent tensioning and grouting technology has been proposed and is constantly developing, serving various projects. By summarizing the advantages and disadvantages of existing studies, analysis of the means of prestress loss limitation can be formed, looking forward to peek the future development trend of intelligent control methods.

Keywords: prestress loss, effective prestress identification, intelligent control.

1. Introduction

Prestressed concrete members have the advantages of high strength, high stiffness, strong crack resistance, material saving, small weight, economic benefits, etc. In order to solve the contradiction between the material properties of reinforced concrete members and the economy of use, the application of prestressing technology is obviously a superior solution. Prestressed flat structure can meet the requirements of modern buildings, especially high-rise buildings, for interior space and headroom [1]. The use of prestressed concrete beams can improve the bearing capacity of Bridges, reduce self-weight, and enable Bridges to be designed with a larger span, which has been widely used at present [2].

However, the problem of prestress loss has always existed. The phenomenon that the prestress decreases with the passage of tension, anchorage and time is called prestress loss. It is usually generated by the relaxation of steel bars, the expansion and creep of concrete, the fixing of anchorage and other factors, resulting in the reduction of bearing capacity of components, cracks at the bottom, difficult control of upper chamber, and the decline of flatness. For the bridge span structure, prestress loss will lead to the decrease of the bridge deck driving comfort, increase the maintenance cost, affect the safety, durability and applicability, and catastrophic accidents may occur in serious cases [3]. Therefore, how to accurately identify the occurrence of prestress loss and limit it is of great significance for the safety, reliability and economic applicability of building facilities.

The influence of prestress loss is significant, so it is necessary to summarize and analyze the research in various directions. This paper focuses on various development directions of prestress detection technology. Also, efforts are made to summarizes optimization calculation algorithms worldwide, as well as some solutions to limit the occurrence of prestress loss. Finally, some prospects in which the future intelligent development direction will occur are considered.

2. Prestress loss identification method

Objective factors that cause prestress loss include friction between reinforcement and channel wall, temperature difference between reinforcement and bench, elastic shrinkage of concrete, creep of concrete, etc. While subjective factors are negligence and deviation of construction technology in total [4]. These losses are often hidden, slowly generated or occur in the components, and are difficult to be directly observed. With the passage of time, the loss accumulates continuously, and cracks or large plastic deformation occur in the components under the action of load. The direct consequences of the prestress loss can be shown, but it is too late. Therefore, how to find the prestress loss accurately and timely is a big problem. Currently, there are several research directions as follows.

2.1. Direct detection of defects within components

2.1.1. Non-contact testing method

Due to the particularity of concrete components, damaging the integrity of components should be avoided when detecting the defects. At the same time, considering the difficulty of detection personnel, most countries adopt non-contact measurement method for internal flaw detection of components. Ultrasonic method uses low-frequency ultrasonic pulse wave to penetrate concrete, and measures its acoustic parameters such as propagation velocity, first wave amplitude and main frequency in concrete. By analyzing the changes of various ultrasonic parameters, potential defects can be determined [5]. Impact-echo method generates impact-elastic waves in concrete by hammering, and uses sensors to receive wave signals. Parameters such as the wave speed, waveform and frequency of the impact elastic wave and its echo are used to judge the internal defects of concrete structures [6]. Radar method determines the depth and position of the target according to the time of electromagnetic wave propagation to the target and reflection back. By taking advantage of the reflection characteristics of electromagnetic wave in different media, radar images are formed after the received radar signals are processed by computer software [7]. The above methods are mostly suitable for the discovery and positioning of defects such as cracks, voids and compactness in concrete, and have a good effect on the positioning of prestressed channels and the measurement of the compactness of pipeline grouting. However, there are some problems such as low detection accuracy and limited use environment, and they are not suitable for the detection of prestressed reinforcement defects. The main methods of corrosion detection of prestressed reinforcement include ultrasonic method and magnetic leakage method. The working principle of magnetic leakage method is to effectively detect the structure according to the difference of magnetic resistance between different materials and the mutation characteristics of magnetic leakage field at the damage site. Magnetic leakage detection method, natural potential method and resistance method can be used to conduct feasibility study on the corrosion detection of prestressed steel strands. It can also put forward the detection & evaluation methods and standards of the corrosion of prestressed steel bundles. Scholars used these kinds of methods to explore the mechanical properties of the prestressed steel bundles after corrosion, established the corresponding corrosion grade of the prestressed steel bundles, and then realized the quantitative evaluation of the prestressed steel bundles. Although the above method solves the problem of starting from scratch and makes the corrosion detection of prestressed tendons of in-service components more feasible, replacing the traditional embedded sensor method, there is still a great space for development. Its detection resolution needs to be improved, and it is susceptible to interference in the area where the tendons of components are dense, affecting the detection accuracy.

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2.1.2. Direct measurement of effective prestress. Non-contact detection methods are mostly qualitative analysis methods. Although these methods are relatively convenient to operate and can accurately detect the occurrence of defects under certain conditions, they cannot directly measure the actual effective prestress value of components, so other means are still needed to analyze the detection data. Considering the formulation of various specifications and evaluation systems in engineering, as well as the economy of late inspection and maintenance, it is necessary to study the direct measurement method of effective prestress.

The effective prestress under anchors is measured by applying the reverse tension to the prestressed bundles and measuring the displacement of the prestressed bundles. It is called the inverse method, which is mainly applied to the detection of the effective prestress under the anchors of the unpressed prestressed bundles. For the prestressed bundles that have been tensioned without grouting, it can be used as elastic-plastic materials within a certain range of forces, and the effective prestressed stress under anchors can be obtained by measuring the elongation and tension of it in the secondary tensioning process [8].

Based on the deformation coordination theory, the stress release method directly measures the strain of reinforcement. Usually, it can calculate the actual strain variable of concrete according to the strain consistency of reinforcement and surrounding concrete. Finally, the loss of prestress based on the strain value can be calculated [9]. Usually, this method requires opening holes in concrete members, exposing steel bars and attaching strain gauges. The members are cut at a certain distance from the opening holes, and strain gauges are used to measure the strain changes of steel bars.

The effective prestress on prestressed tendons can be measured directly by both the method of back drawing and the method of stress release. Inverse method is usually used after the prestressed tendons are tensioned and before the channels are grouted, which results in this method being used only during construction and not in the operational phase of bridge construction. To some extent, the stress release method will destroy the component and affect the integrity of the component. Its application scenarios are few and its prospect is not clear.

The detection of effective prestress can also use sensors set in the anchoring section of the component to realize long-term monitoring of the prestressed data of the component, which can obtain a large amount of prestressed data information. However, this method increases the maintenance cost of the facility and requires personnel to check regularly. Moreover, the measured data changes greatly under the influence of dynamic load and temperature, without obvious rules, which requires statistical support of software algorithm. Its use economy remains to be studied.

2.2. Prestress loss detection by algorithm calculation

From the point of view of the existing technology, the effective prestress under the anchor of the component can only be directly measured in engineering, but it is difficult to detect the effective prestress within the beam segment. Either the existence of damage can only be detected, which cannot be measured quantitatively, or irreversible damage will be caused to the component. The academic institute expects to find a more convenient and practical method of effective prestress detection in engineering. According to the existing research, it is convenient to measure the parameters of the member, such as mode, strain and deflection, and non-destructive testing can be achieved. How to calculate the actual effective prestress value of the reinforcement from these parameters has become a hot topic. Currently, there are two main research directions: characteristic parameters and load effect.

2.2.1. characteristic parameter. There are many characteristic parameters of prestressed concrete members, and the natural frequency and mode of vibration of the members are often used as the parameters for research. At present, scholars worldwide have made a lot of research on the correlation between characteristic parameters and prestress. This route mainly adopts statistical method to solve the problem. Its basic principle is to use the correlation between the natural frequency of components and the stiffness of components to carry out structural dynamics analysis and establish a reliable model equation between parameters and prestress. The difficulty of this route lies in model selection and construction accuracy. There are various means of statistical analysis. Some scholars directly use neural networks for model fitting, including radial basis (RBF) neural networks and generalized regression neural networks (GRNN), etc. [10,11]. Some scholars also use least square method for dynamic analysis and equation establishment, and then use statistical means for optimization, such as support vector machine, etc. [12,13]. In this way, the anti-interference ability and accuracy of the model are improved. There are many researches using the above methods, and its advantage is that the statistical analysis methods are relatively mature, and abundant researches are carried out in various directions, which brings more new ideas for effective prestress identification. However, its limitations are also obvious. First, the characteristic parameters have little influence on the prestress, so it is difficult to see the change trend and the sensitivity is not high. Secondly, the background of various studies is relatively special, which belongs to the point-to-point, and the application scenarios are relatively limited. At present, most studies are only feasibility studies. Although some scholars are constantly making efforts to improve the accuracy of models, relevant models that can be truly convincing have not yet appeared, and further studies are still needed to support them.

2.2.2. Load effect. The load effect of concrete member is mainly reflected in strain and deflection. It is an effective method to build a mathematical model for systematic analysis. The detection of displacement and deflection of components is relatively simple, and the measurement instrument is convenient to operate and has high precision, which can realize non-destructive testing. Meanwhile, the strain and deflection are more sensitive to the prestress, which is more regular and convenient for analysis. The major difficulty of this route is that deflection is not only the product of the change of prestress, but also the shrinkage and creep of concrete, periodic changes in temperature and load and other factors play an important role. How to eliminate the influence of long-term growth of deflection is a big problem. At present, the inversion theory is the main method to solve the effective prestress by establishing the flexure equation and the influence matrix.

Influence matrix method is to study the mutual influence mechanism of the two by constructing correlation matrix of analysis factors, and then build prediction model. Its earliest use can be traced back to the end of the 20th century, and it is a mature analysis method [14]. However, it always has the disadvantages of too much data and complicated calculation. The computational efficiency of this method has been improved, and it has been used by many scholars for the identification of prestress loss [15].

In the framework of inversion theory, some scholars also study the identification of prestress loss by using probabilistic inversion method. This method uses a relatively mature probabilistic mathematical model to predict the research parameters, and at the same time effectively removes the shrinkage and creep of concrete that affect the deflection. So that a more comprehensive model can be built [16].

At the same time, some scholars pointed out that the above two methods are based on the analysis of long-term monitoring data of deflection, which is still relatively complicated for the actual operation of engineering. The load effect of components under external loads, such as vehicle loads, is also a hot research topic. In contrast, this technical route can realize real-time recognition of prestressed loss and no longer rely on long-term data monitoring. The realization methods are various, and the most reasonable one is the construction of the actual influence line equation of the bridge [17]. This method studies the change mechanism of influence line caused by prestress and establishes the corresponding relationship between prestress and influence line of bridge.

The above method has a relatively simple data measurement method, sufficient available data, and can avoid noise interference. The model construction is more accurate, the correlation is high enough, the reliability is strong, and the practical value is high.

3. Prestress loss limitation method

Prestress loss can occur in various stages of building and bridge construction, which can be mainly divided into design stage, construction stage and operation stage. Negligence in design will lead to the loss of prestressed bridge and floor, which is mainly reflected in the unreasonable layout of steel bars,

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substandard material strength, improper use of anchor models, etc. These problems can be avoided by strengthening supervision and improving the rigor of designers. The loss of prestress in the operation stage is mainly caused by the relaxation of steel bars, shrinkage and creep of concrete, etc. Technically, it can be remedied by reasonable maintenance and late reinforcement measures. The construction phase is the most important for the whole service cycle of components. Prestressed tensioning is the most effective and direct way to solve the prestressed disease of Bridges, which can promote the development of the prestressed technology of Bridges, further extend the service life of Bridges, and reduce the cost of follow-up maintenance [18]. How to implement the tensioning procedure of prestressed steel bar reasonably and precisely control it is a hot research topic at present.

3.1. Traditional tension control measures

(1) Pipeline positioning

The material of the prestress pipe is metal bellows. Workers need to check the bellows one by one before using them. The bellows that are deformed, cracked or defective must not be used. In order to make the installation accuracy of prestressed pipeline meet the design requirements, ensure that the linear section of bellows is straight and smooth, and the linear angle of bending section conforms to the design drawings [19]. Positioning and installation are carried out by using the full-section prestress pipeline positioning clamp as the figure 1.

Figure 1. Prestress pipeline positioning clamp [19].

(2) Anchor plate positioning

Anchor port framework and end die are made of steel plate with small deformation, which can effectively ensure the correct angle of anchor plate and reduce stress loss in the later stage of prestressed tension. The position of anchor cushion plate is lofted in advance according to the drawings, and is bolted with the end die steel plate for overall lifting and positioning to ensure that the mounting surface is perpendicular to the stress pipe [19]. Figure 2 provides a visualization of some kind of anchor port frameworks.

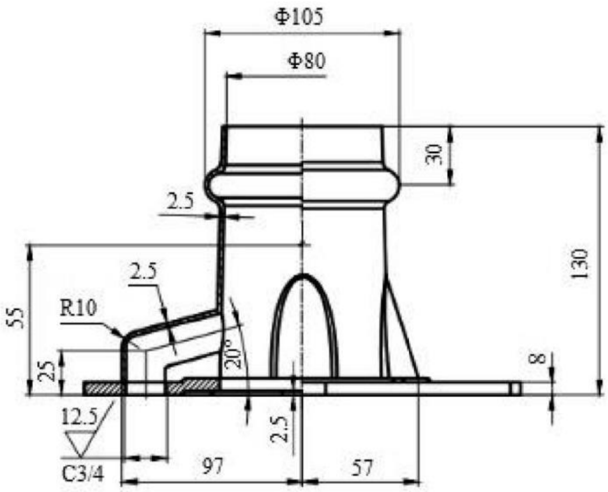

Figure 2. Anchor port framework [20].

3.2. Intelligent tension

The traditional prestressed tensioning construction technology has the problems of inaccurate data and low construction efficiency. The intelligent prestressed tensioning system is developed on the basis of the traditional prestressed tensioning construction technology, which changes the original manual pump station into intelligent pump station, the original manual operation into intelligent control platform, and the traditional manual management mode into information and network management. It is a comprehensive, intelligent and high automation construction technology.

At present, in the prestress tension construction, based on the advanced computer system, the prestress intelligent tension system can carry out accurate tension control on the prestressed concrete member. Prestress intelligent tensioning system has a high level of automation, with numerical control tensioning system playing an important role. It also includes prestress tensioning equipment and rigid auxiliary equipment. During the tensioning construction of the prestress intelligent tension system, the design parameters of tensioning should be input into the computer system first, and then transmitted to the tensioning equipment after the parameters are processed, so that the prestressed concrete members can be precisely tensioned, and the tensioning data can be output by the computer system after the tensioning is completed [21]. Figure 3 provides a visualization of a common type of prestress intelligent tension system.

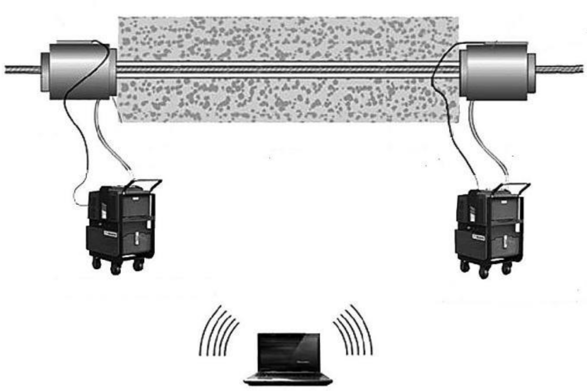

Figure 3. Prestress intelligent tension system [22].

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3.3. Intelligent grouting

The traditional grouting methods generally use air compressor grouting or vacuum auxiliary grouting, but these methods have some defects. Under the condition of poor anchor sealing effect, vacuum-assisted grouting also has insufficient vacuum degree phenomenon, which cannot completely ensure that the air in the pipeline is completely discharged. After solidifying cement grout, there are certain voids and air compartments, and these voids provide storage space for free water in the initial setting process of cement grout, providing a channel for rainwater intrusion. Therefore, the prestressed steel strand can be corroded.

Intelligent circulation grouting system does not rely on manual control of workers, but uses computer intelligent control technology. By automatically operating the instruments, it can complete the whole grouting process with simple operation. As the system has high control precision, it can effectively improve the quality of prestressed construction, and is widely used in automatic control of prestress pipeline grouting of bridges [23]. Figure 4 provides a visualization of a type of intelligent grouting system being widely used.

Figure 4. Intelligent grouting system [24].

3.4. Intelligent strand wire

At present, the prestressing technology mainly determines the tension control force by estimating the loss value of prestressing, so as to obtain the effective prestress. Prestress loss can be divided into instantaneous prestress loss independent of time and long-term prestress loss strongly related to time. According to the analysis, compared with the instantaneous prestress loss, the long-term prestress loss is mainly related to the time and structural materials, which is less affected by the environment, less uncertain, easy to accurately estimate. The instantaneous prestress loss is mainly related to the site conditions of the structural members, which is greatly affected by the construction conditions and easily leads to the abnormal shape of the structure.

If the instantaneous prestress loss value can be obtained through measurement and the tensioning force value can be corrected in real time on site, the accurate effective prestress value can be obtained. Therefore, intelligent steel strand can be used instead of ordinary steel strand of the same type, and the intelligent steel strand can be stretched before large area stretching. The effective prestress value can be obtained by the fiber Bragg grating sensor of the intelligent steel strand, and the tension control force can be determined after several times of deviation correction. Then the tension control force is used to complete the construction process of all steel strands of the same type. At the same time the system can complete the field calibration of tension control force under the premise of not changing the construction tension process. The Construction procedures have not increased.

At present, the monitoring means of effective prestress under anchor is mature, but the monitoring means of effective prestress along the line of force reinforcement is not mature. Fiber Bragg grating integrates sensing and transmission, small size, high test accuracy, strong electromagnetic interference resistance, strong corrosion resistance. By adopting appropriate packaging structure, fiber Bragg grating sensor and steel strand are integrated to make intelligent steel strand, which can survive under harsh construction conditions, so as to conduct quasi-distributed measurement of prestress distribution along the force reinforcement [25].

4. Conclusion

This paper summarizes the methods of identifying prestress loss of concrete members from two aspects of direct measurement and indirect calculation, and analyzes the current research hotspot of prestressed loss control means with the construction stage as the focus. The main conclusions are as follows:

The direct measurement methods for the identification of prestressed loss can be divided into non-contact measurement method using mechanical wave, electromagnetic wave and other means and contact measurement method directly installed on the prestressed reinforcement sensor. The non-contact method has the advantages of simple operation and high detection accuracy, but it can only do qualitative analysis of the existence of damage. The contact measurement method can directly measure the effective prestress value of anchor, increasing the maintenance cost at the same time.

The indirect calculation methods for the identification of prestressed loss can be divided into modal parameter and load effect. The two methods build models by focusing on variables, analyze the data and fit the prestressed data, so as to calculate the prestressed loss. At present, the algorithms for studying modal parameters are not mature, which lies in the convenience of model construction, but the correlation is poor, so more research is needed. Until now, the load effect research algorithm has been fully developed, has formed a set of mature analysis methods, and still has a development prospect, looking forward to more scholars' research.

Limiting prestress loss can be divided into design, construction and operation stages. On the one hand, the negative impact of human factors should be avoided. On the other hand, the construction and maintenance process should be strengthened, or the new technology should be adopted. In the construction stage, the prestressed steel bar tension is the top priority. Usually, intelligent tensile, intelligent grouting and intelligent steel strand can be used to limit the occurrence of prestressed loss.

At present, there is still a large space for the detection of internal defects of concrete components. The monitoring means of various modal parameters can be further developed in the direction of intelligence, and the goodness of fit of various model calculations can be further improved. The research on the immediate load effect of components is the future development direction, and more research is expected.

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