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Study on Settlement Monitoring Quality and Construction Control Technology of Highway Filling Subgrade

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Abstract: With the rapid development of our country's transportation infrastructure construction, the highway construction has become an important support for the economic development. One of the core structural elements of expressway is roadbed, whose quality directly affects the overall quality, durability and safety of highway engineering during construction and operation. In the process of subgrade construction, the speed control of filling operation and the time sequence arrangement of each level of road construction are highly dependent on the monitoring and prediction of subgrade settlement. Both the immediate settlement during highway construction and the long-term settlement after completion have a direct impact on the construction quality and safety performance of the project. Therefore, the scientific monitoring and accurate prediction of subgrade settlement will play an important role in controlling the settlement during the filling period and the settlement after construction. As a key component of highway informatization construction technology system, subgrade settlement prediction is not only a technical challenge, but also a key strategy to ensure project quality. Therefore, strengthening the prediction ability of subgrade filling stage and settlement after completion, especially for sections under special geological or design conditions, and flexibly adjusting construction plan and optimizing operation sequence according to the prediction results, is one of the effective ways to ensure the timely and quality completion of the project and improve the overall safety performance. This methodology not only reflects the refinement and intelligence of construction management, but also is an indispensable part of modern highway construction. Based on the technology of embankment settlement monitoring and construction control, this paper discusses the quality of embankment settlement monitoring and the concrete application of construction control technology through detailed theoretical analysis. Combining grey system theory, settlement observation method and soft soil subgrade settlement control technology, this paper aims to put forward a set of scientific and effective settlement monitoring and construction control system to provide theoretical support and technical guidance for highway construction.

1. Introduction

Highway subgrade is the most important structure of expressway, its stability and settlement control are directly related to project quality and operation safety. In the process of filling construction, the settlement of the roadbed is not only affected by various factors such as geological conditions, filler properties and construction technology, but also by the long-term effects of external factors such as vehicle load and climatic conditions[1]. Therefore, scientific monitoring and accurate prediction of subgrade settlement is one of the important measures to ensure the quality of expressway construction.

2. Overview of highway subgrade settlement

The settlement of highway subgrade specifically refers to the consolidation and compaction process of the soil layer inside the subgrade under the action of self-weight and external load during the construction period and subsequent use of road projects, as well as the comprehensive impact of a series of external environmental factors, which eventually lead to significant subsidence of the surface[2]. This settlement not only affects the smoothness of the road and driving safety, but also may cause long-term damage to the road structure, and then affect its service life.

In-depth analysis of its causes, soil consolidation and compaction is undoubtedly the primary cause of subgrade settlement. In the construction process of roadbed, the soil material is mechanically or artificially compacted, the space between the particles is compressed, the soil volume is reduced, and then the surface subsidence is caused. In addition, improper operations in the construction process, such as improper treatment of the excavated slope, the selection of filling materials and lax control of compaction degree, may lead to uneven settlement of the subgrade soil and the formation of local depressions or cracks.

Natural factors are also one of the reasons that affect the settlement of highway subgrade. Natural disasters such as rainfall and flood not only increase the water content of the roadbed and reduce the soil strength, but also destroy the stability of the roadbed slope through erosion, thus aggravating the settlement phenomenon. When the groundwater level is too high, the continuous soaking and softening effect of water on the subgrade soil will also reduce the bearing capacity of the subgrade and lead to settlement[3]. The complexity of geological conditions, such as soft soil, collapsibility loess and other special soil layer, will directly affect the stability of roadbed. The change of climate conditions, such as the freeze-thaw cycle caused by temperature rise and fall, will also destroy the soil structure and promote the occurrence of settlement. At the same time, with the continuous increase of traffic volume, the repeated action of vehicle load on the roadbed will gradually accumulate and lead to the fatigue settlement of the roadbed.

3. Settlement monitoring method of highway embankment filling

3.1. Leveling method

The basic principle of leveling method is to accurately judge the settlement of the roadbed by measuring the change of the height difference between the settlement observation point and the stable reference point. Before the subgrade is filled, level points are set up on both sides of the subgrade or in the stable zone away from the construction area as a benchmark, and then observation piles are set up at the subgrade position to be observed and the initial elevation is recorded. When measuring, the height difference between the observation point and the reference point is calculated by erecting a level stick and taking a reading with the level adjusted to the horizontal state. With the progress of construction, it is necessary to retest and observe piles regularly. By comparing the height difference changes at different times, the settlement trend and specific settlement amount of the roadbed can be analyzed, which provides an important basis for engineering quality control.

3.2. Inclinometer measurement method

The inclinometer measurement method is based on measuring the slope Angle of the subgrade over time to evaluate its settlement. The method lays observation piles in stable areas on both sides of the roadbed, which are located at key locations such as the edge or center line of the roadbed to fully reflect the settlement (see Figure 1). The number and spacing of observation piles are carefully set according to the size of roadbed and monitoring requirements to ensure data representativeness. Before the subgrade is filled, the initial elevation of each observation pile and the initial reading of the inclinometer are recorded in detail, which lays the basis for the subsequent settlement analysis. Then, according to the actual needs, the appropriate type of inclinometer is selected, such as water pipe type, fixed pendulum type, bubble type or MEMS sensor type, etc., and the installation is carried out according to the steps: the observation pile is firmly driven into the soil layer, the base is installed and levelled, the inclinometer is fixed and its axis is calibrated to the level, and the initial reading is recorded with the reading meter[4]. After installation, it is also necessary to debug and calibrate the inclinometer to ensure that the measurement accuracy is up to standard, so as to accurately reflect the settlement of the roadbed.

Figure 1: Settlement observation pile

3.3. Measurement method of stratified settler

As a professional monitoring tool, the working principle of the layered settler is based on measuring the vertical displacement change of the fixed reference point relative to the soil surface or different depths of the subgrade to accurately capture the occurrence and rate of soil or subgrade settlement. The instrument consists of three core components: one is a reference point firmly installed on the ground at the bottom, which serves as the benchmark of the entire measurement system; The second is the telescopic rod connecting the reference point to the soil surface or the subgrade soil layer, and its deformation degree directly reflects the settlement amount; Third, the sensor installed on the top of the telescopic rod is responsible for detecting the deformation of the telescopic rod and converting it into quantifiable electrical signal output, so as to achieve accurate monitoring of settlement[5]. Before measuring the subgrade, drill holes to install settling pipes at preset positions, and lay settling rings at different depths of the pipes as measurement marks to ensure accurate and stable installation positions. Then, the initial measurement is carried out before the subgrade filling operation, and the initial elevation or depth data of each settlement ring is recorded to provide a baseline for subsequent monitoring. In the process of subgrade filling, it is necessary to regularly use the stratified settler to retest each settlement ring. Through the accurate positioning of the instrument probe and the application of sensing technology, the settlement data can be obtained in real time, and the settlement amount of the subgrade can be compared and analyzed with the previous measurement value, so as to scientifically calculate the settlement amount of the subgrade, which provides an important basis for the stability assessment and construction adjustment of highway engineering.

4. Application of grey system theory in settlement prediction

4.1. Overview of grey system theory

Grey system theory, as a mathematical methodology, focuses on the exploration and analysis of "grey zone" systems where information is neither completely clear nor completely ambiguous. The core value of the theory is that it can make use of the limited and incomplete known information in the system, through a series of advanced mathematical models and algorithms, dig deeply and reveal the inherent laws and trends hidden under these fuzzy boundaries, so as to achieve the understanding of the whole system.

In the complex engineering field of settlement prediction, the diversity of geological structure, the difference of construction technology and the dynamic change of environmental factors together form a complex information network, in which a large number of key data are often difficult to obtain accurately or there are significant uncertainties. Faced with such challenges, grey system theory has shown its irreplaceable advantages. It can not only effectively integrate existing information resources that may be scattered and incomplete, but also scientifically and reasonably predict and evaluate the sedimentation process by constructing appropriate gray prediction models, such as gray GM(1,1) model[6]. This process not only improves the accuracy and reliability of the forecast results, but also provides strong data support for engineering decisions, which helps to identify potential risks in advance, optimize the construction plan, and ensure the safety and stability of the project.

4.2. Application steps of grey system theory in settlement prediction

4.2.1. Data collection and processing stage

Comprehensive collection of subsidence monitoring data, which covers the amount of subsidence, time and other key information that is essential for prediction. The accuracy and completeness of the data are the basis of the subsequent analysis. Strict pre-processing of the collected raw data, including but not limited to denoising, that is, removing random noise caused by measurement errors and environmental factors from the data; The filtering operation is designed to smooth the data curve and reduce the impact of high-frequency fluctuations on the prediction results, thus significantly improving the data quality and providing solid data support for subsequent modeling.

4.2.2. The stage of establishing grey prediction model

After the data preprocessing is completed, the next stage is the construction of the model. The GM (1,1) model is often used in settlement prediction in grey system theory, which is a prediction model based on one-variable first-order differential equation. It is especially suitable for dealing with uncertain and incomplete information systems. The establishment of the model first requires the accumulation generation (AGO) process of the original data. The core of this step is to transform the original data series with random fluctuations and difficult to be directly analyzed into a new series with more regularity through the accumulation operation, so as to facilitate subsequent mathematical modeling and analysis[7]. Based on the new sequence generated after accumulation, the grey differential equation is further constructed, and a series of mathematical methods are used to solve the model parameters, such as the development coefficient and grey action in the time response function, etc., laying the foundation for the subsequent prediction calculation[8].

4.2.3. Model test and accuracy evaluation stage

After the model is established, in order to ensure the accuracy and reliability of its prediction, it must be strictly tested and evaluated. At this stage, methods such as posterior difference test are often used to evaluate the predictive performance of the model through statistical analysis of the error between the predicted value of the model and the actual observed value. At the same time, the prediction effect of the model will be comprehensively evaluated according to the prediction residual, variance and other statistical indicators to ensure that the prediction accuracy of the model can meet the needs of practical applications.

4.2.4. Prediction result output and application stage

According to the verified grey prediction model, the predicted value of future settlement can be calculated. These prediction results not only have high accuracy and reliability, but also can provide important scientific basis for engineering practice. In the engineering field, these predicted values can be widely used in construction control, risk assessment and other aspects. For example, in the prediction of subgrade settlement, the construction scheme can be adjusted in time according to the predicted results, and the construction parameters can be optimized to ensure the quality and safety of the project.

4.3. Advantages of grey system theory in settlement prediction

Grey system theory is suitable for dealing with various complex system prediction problems, especially in the case of incomplete or uncertain information. By elaborately designed model construction and parameter solving strategies, the theory ensures that the grey prediction model can achieve a high prediction accuracy and provide a reliable basis for decision-making. At the same time, the establishment and solving process of the grey prediction model is relatively simplified, and there is no need for complex computing steps or huge computing resources to support it, which further improves its practicality and efficiency.

5. Highway subgrade construction control technology

5.1. Dynamic compaction treatment of subgrade settlement

Dynamic consolidation method, as an efficient foundation consolidation technology, officially known as dynamic consolidation method, its core is the use of tens of tons or even hundreds of tons (common range of 10 to 40 tons) of heavy weights, through large lifting equipment to lift it to the specified height (usually in the range of 10 to 40 meters), and then released to free fall. In this process, the huge impact energy released by the heavy hammer is quickly transferred to the foundation soil layer, causing strong dynamic stress and shock wave, forcing the soil particles to rearrange and contact closely, and thus realizing rapid consolidation of the soil layer in a very short time[9]. This process significantly improves the overall bearing capacity and uniformity of the foundation, and effectively reduces the risk of foundation settlement and deformation in subsequent engineering use. Dynamic compaction method is famous for its wide applicability, especially good at treating a variety of poor foundation types, including gravel soil, low saturation silt and clay, mixed fill with complex composition (such as construction waste, domestic waste and industrial waste) and soft soil[10]. For the large gravel soil and the difficult mixed fill soil which the traditional strengthening method is difficult to work, the dynamic compaction method has shown excellent treatment effect.

In the implementation of dynamic compaction method, the preparation before construction is very important. The precise location and elevation information of infrastructure such as pipelines and structures in the interior of the construction site should be investigated in detail to ensure that dynamic compaction operations will not cause damage to them. Dynamic compaction operations above known pipelines or structures are strictly prohibited. Through the field test tamping, according to the relationship between the number of tamping and the amount of tamping, scientifically determine the number of tamping at each point, usually controlled between 5 and 6 hits, and the settlement caused by two consecutive hits is less than 5 cm as the construction control standard, to ensure that the tamping effect meets the design requirements. Finally, when planning the dynamic compaction treatment range, it should be ensured that the treatment area exceeds a certain width of the embankment foot, and it is generally recommended to exceed at least 3 meters on each side to enhance the overall stability and reinforcement effect of the foundation.

5.2. Geogrid treatment of subgrade settlement

As a kind of reinforced material, geoglass is widely used to control uneven settlement of subgrade. Especially in the complex working conditions such as widening of old road, connecting of new and old roadbed or filling and digging, laying geoglage has become an important means to improve the overall strength and stability of roadbed. The core principle is to make use of the reinforcement effect of the grid, that is, by laying the grid horizontally in the subgrade soil to form an effective reinforcement layer, so as to enhance the integrity of the soil and anti-deformation ability, so as to significantly adjust and control the uneven settlement of the subgrade under load. This reinforcement not only enhances the stability of the roadbed, but also prolongs the service life of the road (see Figure 2).

Figure 2: Geogrid

The geogrid also has multiple functional properties, including but not limited to acting as a filter layer to promote the effective discharge of excess water in the soil and prevent the loss of fine soil materials; As an isolation layer, the soil layers of different properties are separated to prevent mixed effects; At the same time, its tough material can also provide additional protection against external impact and erosion; Under specific conditions, the geoglou can also play an anti-seepage role, prevent the penetration of groundwater or harmful liquids, and protect the safety of the roadbed.

In the construction process, it is very important to ensure the effective application of the geogrids. Before laying, the soil layer should be carefully leveled to ensure that the surface is free of hard protruded objects such as gravel and stone, so as not to damage the grille or affect its performance. Secondly, when the grid is laid, it is necessary to manually tighten, and wrinkles are strictly prohibited to ensure its close fit with the soil and uniform force, and then the anchor is firmly fixed to prevent displacement. The filling operation should be carried out immediately after the completion of the laying to reduce the aging or performance decline that may be caused by the long-term exposure of the grille to the sun, and to ensure that the geogrid plays a lasting and stable role in the roadbed.

5.3. Cement mixing pile method

As a kind of soft soil foundation strengthening technology, the working principle of cement mixing pile method is to use deep mixing machinery to go deep into the foundation, and directly to forcibly mix the soft soil and curing agent (usually cement slurry). In this process, cement slurry, as a curing agent, undergoes complex physical changes and chemical reactions with soft soil, such as cement hydration, ion exchange, hardening reaction, etc., which promotes the soft soil particles to gradually condense into high-quality ground matrix with significant integrity, good water stability and certain bearing strength. This treatment can not only significantly improve the bearing capacity of the foundation, reduce settlement deformation, but also effectively improve the permeability and stability of the foundation, providing a solid foundation for subsequent engineering construction.

In the implementation of cement mixing pile method, strictly following the construction points is the key to ensure the quality of the project. Specifically, the construction of cement soil bi-directional mixing pile adopts the fine process of "two stirring and one spraying", that is, the mixer first downgoes the mixing while spraying to the design depth, then raises the mixing, then mixes the sinking and spraying to the design depth, and finally raises the mixing to the ground. This process ensures the full mixing and uniform distribution of soft soil and cement slurry. Secondly, the preparation process of cement slurry needs to be strictly controlled to ensure that it is fully stirred to achieve a uniform state, and to avoid affecting the reinforcement effect due to the uneven slurry. After the slurry enters the spray tank, it is necessary to keep stirring continuously to prevent the slurry segregation and precipitation, affecting the spray effect. At the end of construction, it is necessary to ensure that all the prepared cement slurry is used up to avoid waste and ensure the integrity of the reinforcement effect. The implementation of cement mixing pile method not only greatly improves the bearing capacity and stability of the roadbed, but also effectively controls the occurrence of settlement phenomenon, provides a scientific and effective solution for the treatment of soft soil foundation, and is an indispensable technical means in highway construction.

5.4. Precompression construction

Precompression construction is an effective settlement control measure taken in the initial stage of roadbed construction. By applying load on roadbed in advance, the roadbed can experience partial or even full settlement process in the construction stage by using the combined action of the weight of roadbed soil and the external pile load. The purpose of this method is to release the compression potential of the subgrade soil in advance, so as to significantly reduce the settlement caused by soil consolidation after the road is opened to traffic, and ensure the long-term stability of the road structure and driving safety.

In the specific implementation process, the key points of preloading construction include accurate calculation and reasonable determination of the amount of preloading earth, which should take into account the physical and mechanical properties of the foundation soil, the design filling height and the expected settlement effect. It is generally recommended that the thickness of the preloading soil layer is between 1 and 2 meters. In order to ensure the pre-compaction effect, the compaction degree of the pre-compaction earthwork should be strictly controlled above 85%, so as to simulate the compaction state of the roadbed under the actual operating state and promote the effective consolidation of the soil mass. Settlement observation is an indispensable part in the process of precompression construction. The settlement data of the roadbed is regularly monitored and recorded through the pre-buried settlement observation board. When the observation results show that the settlement rate is stable below 5mm/ month for two consecutive months, the roadbed can be regarded as having reached the expected stable state. At this time, the pre-loaded earthwork can be discharged and the subsequent roadbed filling and pavement structure layer construction can be carried out. This process not only ensures the construction quality of the roadbed, but also provides a strong guarantee for the overall progress and cost control of the road project.

6. Conclusion

In highway construction, subgrade is an important foundation for bearing pavement structure, and its stability and durability directly affect the overall performance of highway. In this paper, the monitoring quality and construction control technology of highway subgrade settlement are deeply studied, and the research results are of great significance for improving highway engineering quality and prolonging service life. In the future, with the continuous development and application of information construction technology, the settlement monitoring and construction control technology of highway filling subgrade will be more intelligent and refined. Through the introduction of advanced monitoring equipment and data analysis technology, real-time monitoring and dynamic analysis of subgrade settlement can be realized, and more comprehensive and accurate information support can be provided for engineering construction. At the same time, it is also necessary to strengthen the research and application of new materials and new processes to further improve the stability and durability of the roadbed.

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