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Research Article

Shrinkage Compensation Technology of Concrete Filled Steel Tubular Structure of Large Cross-Sea Bridge

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In view of the poor accuracy and unsatisfactory effect of shrinkage compensation for concrete-filled steel tubular structures of large cross-sea bridge (CSTS-LCSB), a new shrinkage compensation technology for CSTS-LCSB is proposed. The shrinkage mechanism of CSTS-LCSB is analyzed, including plastic shrinkage, dry shrinkage, autogenous shrinkage, and carbonation shrinkage. The proportion of dry shrinkage and autogenous shrinkage in ordinary concrete and high-strength concrete is determined. The CSTS-LCSB has different shrinkage forms in different environments, and the shrinkage strain state of CSTS-LCSB in different environments is calculated according to the difference. The shrinkage area of the concrete structure is determined, and the expansion agent is used to compensate for the shrinkage area of CSTS-LCSB. The experimental results show that the proposed compensation technology has a good effect on shrinkage compensation and has certain feasibility.

1. Introduction

As the main building material, concrete is easy to crack in the process of construction and use because of its low tensile strength and small ultimate tensile deformation. Once cracks occur in the concrete structure, it will be difficult for the concrete structure to defend against the erosion of harmful media. The degree of steel corrosion and concrete carbonization will be deepened. Furthermore, the durability of the structure and the functional use of the structure will also be affected. The reinforced concrete-filled steel tube is applied to the large-scalesea-crossing bridge. There are two kinds of cracks in concrete-filled steel tubular structures of large cross-sea bridge (CSTS-LCSB), which are load cracks and nonload cracks. The load cracks caused by the external load can be avoided and controlled by more mature structural design theory, so the load cracks account for about 20% of the total cracks, while the nonload cracks caused by uneven settlement, temperature change, and concrete shrinkage account for about 80%. The direct reason is that the tensile stress (tensile strain) produced by the constraint of the concrete itself or structure deformation exceeds the ultimate tensile strength (ultimate tensile strain) that the concrete material itself can bear at this age [1, 2]. Up to now, the analysis of the temperature field, temperature stress field, and temperature control design method of CSTS-LCSB are relatively mature. Therefore, the cracks caused by shrinkage deformation of concrete account for the vast majority of nonload cracks.

The main factors affecting the shrinkage cracking of CSTS-LCSB are material stiffness, toughness, shrinkage rate, shrinkage, creep relaxation, and restraint degree [3]. In order to meet the requirements of high fluidity and low energy consumption, the concrete used in modern buildings appropriately reduce the proportion of coarse aggregate in the material ratio and increase the proportion of cement and fine aggregate. Therefore, the control of concrete shrinkage cracks is more complicated. In particular, the problem of early shrinkage cracking has become a common problem in contemporary concrete structure engineering. In addition, with the development of social economy and the deepening of urban construction, the forms of buildings have become more complex and diversified, and more super-long structures are designed to meet various functional requirements [4]. However, the causes of concrete shrinkage and cracking are complex and uncertain. At present, there is no mature and complete design theory and calculation method to predict and control. It only depends on experience to take relevant measures from the design and construction to avoid, and it is often due to a variety of human or material, environmental, and other objective reasons. Liu et al. introduce a multifield (hydro-thermo-hygro-constraint) coupling model with the hydration degree of cementitious materials as the basic state parameter to estimate the shrinkage cracking risk of hardening concrete under coupling effects, and a design process based on the theoretical model and key technologies is proposed to control the cracking risk index below the threshold value [5]. It is difficult to effectively prevent shrinkage cracks.

In order to improve the shrinkage compensation effect and accuracy of CSTS-LCSB, a new shrinkage compensation method for CSTS-LCSB is proposed in this paper. The technical route is as follows:

> Step 1: We analyze its shrinkage mechanism, including plastic shrinkage, drying shrinkage, autogenous shrinkage, and carbonation shrinkage, and determine the proportion of drying shrinkage and autogenous shrinkage in ordinary concrete and high-strength concrete.
>
> Step 2: By determining that the shrinkage of it is different in different environments, the shrinkage strain state of concrete-filled steel tubular construction of large-scale sea cross in different environments is calculated.
>
> Step 3: We determine the shrinkage area of the concrete structure and use the expansion agent to complete the compensation for the shrinkage area of the large cross-sea bridge.

2. Literature Review

How to improve the shrinkage compensation of CSTS-LCSB has become a hot issue in this field. Relevant researchers have carried out a lot of research and achieved certain results [6].

Hasholt et al. proposed research, which was to determine the appropriate time at which shrinkage initiates at an early age for various concrete mixtures under field conditions. Besides, a new approach to determine shrinkage initiation at early age depending on the strains of the free and restrained shrinkage was used in this research [7]. The performance research and shrinkage control method of high-strength concrete for super-high bridge towers are proposed to compensate for the shrinkage [8]. In order to study the influence of zeolite gravel, fly ash ceramic sand and superabsorbent resin (SAP) internal curing materials on the performance of C60 high-strength concrete, the influence of single and multiple internal curing materials on the compressive strength, internal relative humidity, and free shrinkage of concrete was analyzed. The results of this study can provide a reference for the application of mass high-strength concrete, but there are some deficiencies in its compensation effect, which need further improvement.

An analysis method for crack resistance of shrinkage compensating concrete impervious panels during construction is proposed by Cai et al. [9]. In order to study the causes of impervious panel cracking during construction, a calculation model was established. In addition, the real-time numerical analysis of the temperature field and stress field of shrinkage compensating concrete impervious panel during construction was carried out. The stress distribution of impervious panels under different thermal insulation measures was obtained, and the causes of cracks were analyzed. During the construction period, the temperature difference between the inside and outside of the panel concrete was large. When the temperature reached 4 d, the temperature stress at the edge of the panel reached the peak value, which was higher than that of the corresponding age concrete. It is easy to produce cracks. When adopting the insulation measures, the temperature gradient caused by the difference in temperature between inside and outside can be greatly reduced [10]. The temperature stress of the 4 d age concrete can be reduced by 29% of the 10 mm polystyrene foam insulation plastic board. It can effectively improve the anticrack performance of the impervious panel, but the degree of crack compensation needs to be further expanded.

In addition, reference [11] took the large-diameterconcrete-filled steel tubular bridge tower structure of a river crossing project as an example and evaluated the risk of structural interface debonding and concrete cracking under different expansion performance curves. The temperature change deformation process and strength of concrete in the pipe under different calcium magnesium compound expansion agent contents were further tested and studied. Although the test provides a high-performance expansion agent that can prepare nonshrinkage high crack-resistant concrete, the shrinkage strain state of concrete-filled steel tubular bridge under different environmental factors was not analyzed and discussed, and the adaptability was unknown.

In reference [12], the effects of the composition system of cementitious materials and the strength of aggregate parent rock on the workability and mechanical properties of concrete were studied. The effects of the amount of the expansion agent on the volume stability of concrete were explored, and the microstructure of a high-strengthconcrete-filled steel tube was analyzed by SEM. High-strength concrete with excellent self-compacting shrinkage compensation can be prepared by mixing silica fume, fly ash beads, and an appropriate amount of expansion agent with basalt macadam. It has been successfully applied to the composite structure pier of the Jinyanghe Bridge in Liangshan, Sichuan. However, it focuses on solving the problem of the high-strengthconcrete-filled steel tubular composite structure with high cast-in-place concrete, large fluidity, and low shrinkage. It does not analyze the shrinkage strain state under different environments, and the shrinkage compensation effect needs to be further improved.

3. Methodology

3.1. Shrinkage Mechanism Analysis of CSTS-LCSB. The concrete-filled steel tube of large-scalecross-sea bridge gradually hardens in the air, and the volume shrinks. The length shrinkage deformation of concrete can reach (300–600) $* 10^6$ after decades and even (800–1000) $* 10^6$ under adverse conditions. However, if the concrete is put into the water, the volume will expand, and the maximum length deformation can reach 150 $* 10^6$. The shrinkage of concrete has the following different reasons and mechanisms, and the shrinkage deformation is the superposition of various shrinkage states [13]. It mainly includes the following aspects.

3.1.1. Plastic Shrinkage. During the period from pouring to the final setting of concrete-filled steel tube (generally about 4–15 hours), the hydration reaction of cement is intense, the molecular chain is gradually formed, and there are phenomena such as bleeding, rapid evaporation of water, and uneven settlement between aggregate and cement slurry [14]. Because these phenomena occur in the plastic stage before the final setting of concrete, it is called plastic shrinkage. Plastic shrinkage can be subdivided into three types: dehydration condensation, chemical shrinkage reduction, and settlement shrinkage [15–18]. The amount of plastic shrinkage can reach about 1%, which will cause irregular surface cracks on the upper surface of the concrete, especially in the parts with poor maintenance, often distributed along the reinforcement [19].

3.1.2. Drying Shrinkage. Shrinkage of concrete for Large Cross Harbour Bridge after the cessation of curing is lost in unsaturated air and the adsorptive water of internal pores and gel holes. The reason is that the internal moisture of concrete-filled steel tube disappears, but the loss of free water at the beginning of drying does not cause concrete shrinkage; the disappearance of internal adsorbed water is the main influence factor [20]. The loss of adsorbed water in the micropore produces capillary negative pressure in the pore and promotes the formation of the gas-liquid meniscus, which causes tensile stress in the pore wall and causes the shrinkage of cement paste.

3.1.3. Self (Body) Shrinkage. Volume change of concrete-filled steel tube of large-scale cross sea bridge has no moisture exchange with surrounding environment. It is the self-drying of concrete in the process of cement hydration due to no external water supply or the speed of external water migrating into the system through pores is less than the speed of hydration water consumption [21]. The cause is that the water in the pores becomes unsaturated, forming a gas-liquid meniscus and making the pores under negative pressure. The volume of cement hydrate is smaller than that of cement and water involved in the hydration reaction, which is an inherent shrinkage caused by the cement hydration reaction. When the water-cement ratio of concrete is small, the self-drying phenomenon generally occurs in the pores, which is manifested as the macro self-shrinkage. When the water-cement ratio is large, the self-drying phenomenon only occurs in the local pores, and the self-shrinkage can be ignored in the macro [22].

3.1.4. Carbonation Shrinkage. The volume shrinkage is caused by the chemical reaction between cement hydrate in concrete and CO_2 in the air under appropriate relative humidity. There are different alkalinity of various hydrates, different amounts of crystal water and water molecules, and different sizes of carbonation shrinkage. The main influencing factors are the dissolution of $Ca(OH)_2$ crystal and the deposition of $CaCO_3$ in cement hydrates [23]. The carbonation rate depends on the water content of concrete, environmental humidity and CO_2 concentration, and the component size.

Both drying shrinkage and self-shrinkage of CSTS-LCSB are caused by capillary stress, splitting tension, and other changes caused by water loss, but the mechanism of water loss is different. The former is caused by internal water being consumed by a hydration reaction, while the latter is caused by water diffusing into the external environment [24]. The drying shrinkage starts from the moment when the concrete is exposed to the atmosphere and continues through the whole life cycle of the concrete structure. The shrinkage starts from the outside to the inside, which accounts for the largest proportion of the total shrinkage. Autogenous shrinkage occurs uniformly in the concrete without water exchange with the outside. It is the result of cement hydration. Although it is earlier than drying shrinkage, its value is less than drying shrinkage [25–27]. Therefore, for ordinary concrete, it is mainly drying shrinkage. For high-strength concrete or high-performance concrete with a low water cement ratio, besides drying shrinkage, autogenous shrinkage cannot be ignored. The proportion relationship between drying shrinkage and autogenous shrinkage in ordinary concrete and high-strength concrete is shown in Figure 1. It can be seen that drying shrinkage is the most important component of concrete shrinkage, which cannot be avoided in any concrete structure shrinkage problem. Correctly distinguishing different types of shrinkage helps take corresponding compensation control measures [28].

3.2. Shrinkage Analysis of CSTS-LCSB. In order to realize the shrinkage compensation technology of CSTS-LCSB, it is necessary to analyze its shrinkage of it. There are some differences in the forms of shrinkage of concrete-filled steel tubular constructions of large-scale sea cross in different environments [29]. The shrinkage strain of that in the natural environment can be expressed as follows:

$$\varepsilon_{\mathrm{t}} = \varepsilon_{\Delta\mathrm{T}} + \varepsilon_{\mathrm{sh}} + \varepsilon_{\mathrm{as}} + \varepsilon_{\mathrm{ds}}. \tag{1}$$

In the formula, $\varepsilon_{\Delta\mathrm{T}}$ represents the contraction strain caused by temperature changes, $\varepsilon_{\mathrm{as}}$ represents the self-shrinkage strain of large sea bridge, $\varepsilon_{\mathrm{ds}}$ represents dry shrinkage strain of large sea bridge, and $\varepsilon_{\mathrm{sh}}$ represents the sum of self-shrinkage and dry shrinkage strain of concrete.

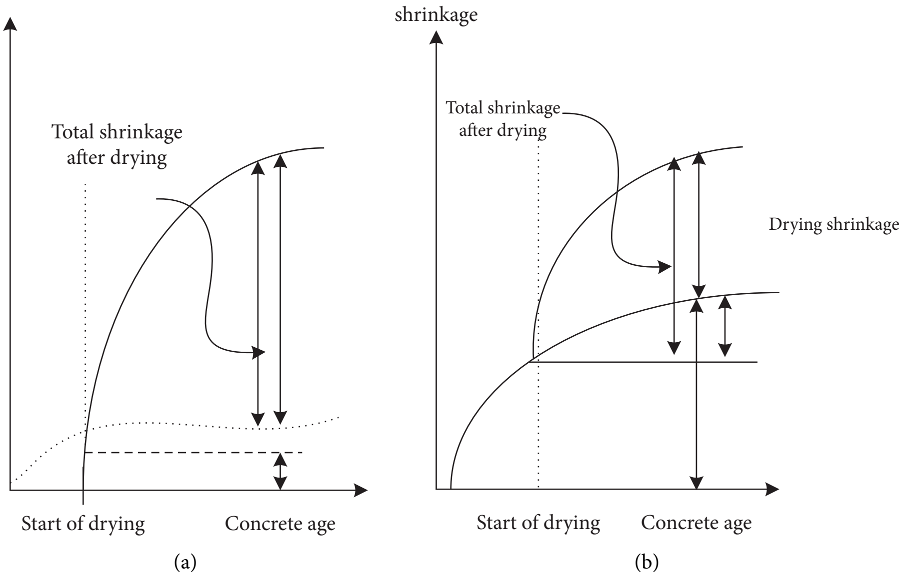

Figure 1: The proportion of dry shrinkage and autogenous shrinkage in ordinary concrete and high-strength concrete.

In the actual application environment, the concrete pipe shrinkage of large sea cross is mainly affected by relative humidity, and the shrinkage caused by temperature is as follows:

$$\varepsilon_{\Delta T} = \mu \times \Delta T = 1 \times 10^{-5} \times \Delta T. \tag{2}$$

In the formula, μ represents the linear expansion coefficient of concrete over large sea bridge and ΔT represents the temperature increment.

When the CSTS-LCSB hardens in the air, the phenomenon of volume reduction is shrinkage. When analyzing the structural stress, not only the temperature change of the structure should be considered, but also the influence of shrinkage on its structure should be analyzed [30]. The composition of concrete-filled steel tube is also the key factor affecting its strain value.

$$\varepsilon_y(t) = \varepsilon_y^0 \times m_1 \times m_2 \times m_n\left(1 - e^{-bt}\right), \tag{3}$$

In the formula, $\varepsilon_y(t)$ represents the strain value of the concrete shrinkage, b represents the construction experience factor, ε_y^0 represents the contraction of the normal limit, and $m_1/m_2/m_n$ represent different correction factors.

3.3. Concrete Creep and Stress Relaxation of Large Sea Bridge.

Creep of CSTS-LCSB refers to the phenomenon that the deformation of the concrete structure increases with time under continuous load. There are two kinds of creep in super-long structure: one is creep deformation, that is, the stress does not change, and the strain increases with the increase of holding time. The other is stress relaxation; that is, the stress decreases with time when the strain is constant. The stress relaxation caused by the concrete creep effect on concrete structures is also an important factor of structural deformation, so the phenomenon of stress relaxation needs more attention [31]. Creep deformation and stress relaxation of structural materials are very important for studying the stress state caused by the deformation of super-long structures. The calculation theory of creep is complex. Linear creep theory is used for super-long concrete and reinforced concrete with low reinforcement ratios. The process of engineering simplified calculation is to calculate the elastic stress first and then multiply it with the relaxation coefficient to get the loose stress.

The relaxation coefficient $H(t, \tau)$ is related to the age and duration of the constraint stress, and the formula is expressed as follows:

$$H(t, \tau) = \frac{\sigma^*(t, \tau)}{\sigma_x(\tau)}. \tag{4}$$

In the formula, $\sigma^*(t, \tau)/\sigma_x(\tau)$ represents the relaxation stress persistence value and $\sigma_x(\tau)$ represents the elastic stress of the instantaneous loading.

On this basis, the binding force around it is also considered. When the CSTS-LCSB contacts along the water surface, the horizontal relative displacement will produce a certain shear stress on the contact surface due to friction and bond resistance [32]. In this case, the point shear stress on the structure can be assumed to be proportional to the horizontal displacement of the point.

$$\tau_x = -C_x \times \delta(x). \tag{5}$$

In the formula, τ_x represents the friction resistance between the peripheral binding force and the concrete, $-C_x$ represents the horizontal resistance coefficient, and $\delta(x)$ represents the distance of the horizontal displacement.

The load transfers of concrete and surrounding constraints of a large sea bridge are shown in Figure 2.

3.4. The Shrinkage Compensation Technology of Concrete Steel Pipe Structure of Large Cross-Sea Bridge.

Based on the shrinkage, creep, and stress relaxation of the large span

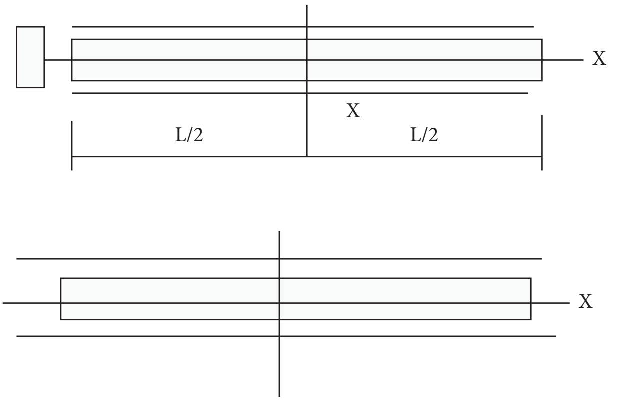

Figure 2: Schematic diagram of load transfer of steel tubular concrete and surrounding constraints of the large cross-sea bridge.

bridge mentioned previously, the shrinkage of the concrete-filled steel tube structure is compensated. Generally, the expansion agent can be used to compensate for the shrinkage structure of the large-scale bridge. Before compensation, the area to be compensated should be determined first. In this paper, the area to be compensated is determined, and its parameters are calculated.

It is assumed that there is an indirect relationship between the compressive strength and the shrinkage area of concrete-filled steel tubular structure as follows:

$$y(t) = r'\frac{t}{b + ct}. \tag{6}$$

In the formula, $y(t)$ represents the mean compressive strength at *t* moment, r' represents the mean value of the compressive strength, and b/c represents common coefficients.

According to the compressive strength of the shrinkage area of the concrete-filled steel tubular structure determined previously, the shrinkage area is directly proportional to its age. Therefore, it is necessary to correct the pressure of the shrinkage area [33].

$$e_c(t) = ke_c. \tag{7}$$

In the formula, $e_c(t)$ represents the compressive strength of the concrete at t day age and k represents the compressive strength coefficient in the contraction area.

On this basis, the areas requiring compensation are determined as follows:

$$R_c = \sum_{c=1}^{n} (p \times f_c). \tag{8}$$

In the formula, R_c represents the weight within a unit volume, p represents the axial core tensile strength, and f_c represents the area to be compensated for.

After determining the compensation area of the shrinkage area, the expansion agent is used to compensate for the shrinkage area of the concrete-filled steel tubular structure. The effect of different expansion agents on shrinkage compensation is different. In this paper, the concrete structure shrinkage compensation needs to consider its application environment, and its amount should also be determined. If the content is too small, it cannot achieve the expected effect of shrinkage compensation. If the content is too large, it may lead to the expansion and cracking of concrete. The sulphoaluminate expansive agent is widely used in China because of its composition and expansion source. The types of sulphoaluminate expansive agents are shown in Table 1.

Aluminite is the most widely used expansive that uses calferitecrystals $C_3A * 3CaSO_4 * 32H_2O$. It expands the volume of the concrete. The mechanism of the type CSA expansion agent is as follows:

$$C_4A_3\overline{S} + 6C_a(OH)_2 + 8CasO_4 + 96H_2O \longrightarrow 3\left(C_3A^{*}3CasO_4^{*}32H_2O\right). \tag{9}$$

Calcite is a kind of only micron crystallization generated in the process of cement hardening, which grows in radiation among the colloidal particles with continuous volume expansion, realizing the concrete shrinkage compensation. The process of stress change of the concrete structure of a large cross-sea bridge is shown in Figure 3.

4. Experimental Result

4.1. Design of Shrinkage Experiment Scheme for CSTS-LCSB. In order to verify the effect of the proposed compensation technology, a simulation experiment is carried out. In the experiment, a section of concrete-filled steel tubular structure in a sea cross is taken as the research object, which is a steel-concrete structure. Due to the deficiency of the bridge foundation conditions, a supporting pile is set in the experiment, whose size is 60 m ∗ 30 m ∗ 0.4 m. Because the structure is long, a section of the pouring belt is set, and the experiment is carried out by continuous pouring of the expansive agent. Firstly, the concrete shrinkage structure of the research object is obtained. The area to be compensated and the change in the overall stress are judged, and the observation is carried out for one month. Among them, the concrete strength grade is C35, and the impermeability grade is p6. The cement used in the experiment is the standard grade cement, which is compensated according to the actual shrinkage structure characteristics. The experimental parameters of the expansion agent are shown in Table 2.

4.2. Shrinkage Test Index of CSTS-LCSB. According to the design of the previous experimental scheme, the comparative experiment is used to analyze and compare the technology. The performance of the shrinkage control method of

Table 1: Types of sulphoaluminate expansive agents.

Expansion and variety	Abbreviation	Expansion source	Standard dosage (%)	Basic composition
Calcium sulphoaluminate expansion agent	CSA	Ettringite	8	Calcium sulphoaluminate clinker and gypsum
Type U expansion agent	UEA	Ettringite	12	Calcium sulfur aluminate clinker, gypsum
Calcium aluminate expansion agent	AEA	Ettringite	10	Calcium sulfur aluminate clinker, gypsum
Alumite expansion agent	EA-L	Ettringite	15	Alumite, gypsum
Type U is a highly efficient expansion agent	UEA-H	Ettringite	8	Calcium sulfur aluminate clinker, gypsum

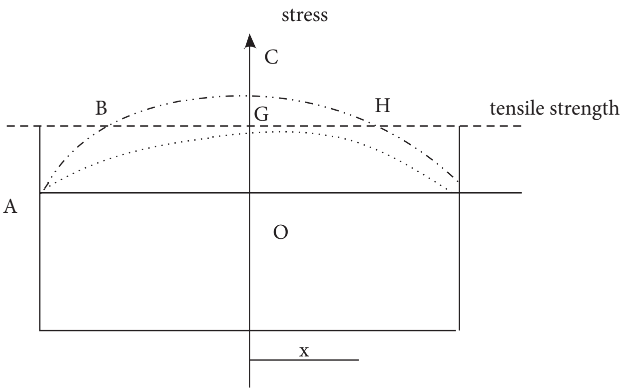

Figure 3: Stress change process of shrinkage compensation for concrete steel pipe structure of the large cross-sea bridge.

Table 2: Mix proportion of the expansion agent for compensation.

Material names	Scaling (%)
Calcium aluminate expansive agent	10%
Water	40%
Cement	5%
Calx	3%
Sand	5%
Other	—
Number of compensations	100

super-high tower high-strength concrete, the anticrack performance analysis of shrinkage compensating concrete impervious panel during the construction period, and the effect of compensation are analyzed. Among them, the compensation effect is reflected by the cracks of the compensated concrete members. The lower the amount of cracks, the better the compensation effect.

4.3. Analysis of Shrinkage Test Results of CSTS-LCSB

4.3.1. Comparison Results of Compensation Accuracy. The accuracy of shrinkage compensation for the structure is an important index to reflect the effectiveness of the method and can reflect the quality of the compensation effect. Therefore, the experimental analysis of the technology in this paper, the performance research and shrinkage control method of high-strength concrete for super-high bridge tower, and the anticrack performance analysis method of the antiseepage panel of shrinkage compensating concrete during the construction period are carried out. The precision of shrinkage compensation for the concrete-filled structure of large sea-cross is shown in Figure 4.

It can be seen from the analysis of Figure 4 that under the same experimental environment, there are some differences in the accuracy of shrinkage compensation for large-scalecross-sea bridge concrete-filled steel tubular construction by using the technology in this paper, the performance research and shrinkage control method of ultra-high tower high-strength concrete, and the anticrack performance analysis method of shrinkage compensating concrete impervious panel during construction. Among them, the accuracy of the proposed method for compensating the sample flood concrete specimen is always high, up to about 97%, and the accuracy of shrinkage compensation by using the performance research and shrinkage control method of super-high bridge tower high-strength concrete is up to about 81%. The crack resistance performance analysis method of shrinkage compensating concrete impervious panels during the construction period has the highest accuracy of 78% for the shrinkage compensation. In contrast, the accuracy of the proposed compensation technology is higher than that of the other two traditional methods. This is because the proposed method fully analyzes the key factors such as concrete creep before compensation, which improves the effectiveness of the compensation technology.

4.3.2. Comparison Results of Crack Amount of Concrete Samples. On the basis of ensuring the previous compensation accuracy, the technology in this paper, the performance research and shrinkage control method of high-strength concrete for super-high bridge towers, and the anticrack performance analysis method of the antiseepage panel of shrinkage compensating concrete during construction are compared in the experiment. The crack generation amount of sample concrete specimens is analyzed, and the results are shown in Figure 5.

By analyzing the data in Figure 5, it is found that with the change of observation time, there are some differences in the production of concrete cracks after compensation among the proposed technology, the performance of high-strength concrete for super-high bridge tower, and the shrinkage control method, as well as the analysis method of anticrack performance of shrinkage compensating concrete impervious panel during the construction period. There are different fluctuations in the three methods. Among them, the fluctuation degree of performance research and shrinkage control method of high-strength concrete for super-high bridge tower is higher than that of the other two methods, and the amount of cracks is also the highest among the three compensation technologies. Its maximum amount of crack generation reaches 12.8%. As for the shrinkage control method, the maximum amount of crack generation reaches 11.7%. In contrast, the amount of cracks in concrete compensated by this compensation technology is lower than that of the other two methods. Therefore, it is proved once again that the method proposed in this paper can achieve better shrinkage compensation effect. This is because the compensation area is confirmed before compensation, and the reasonable proportion of expansion agent is considered to improve the compensation effect.

In order to verify the practical application effect of this experiment, this research method is applied to the practical application research and analysis of a large cross-sea bridge concrete-filled steel tube structure. MgO expansive agent and calcium sulphoaluminate expansive agent are used for hydration, and the effect of compensating the shrinkage of cement materials with a low water-cement ratio is shown in Figure 6.

Figure 6 shows the magnesium oxide composite expansion agent composed of MgO and CaO in different proportions. In the environment of water-saturated curing

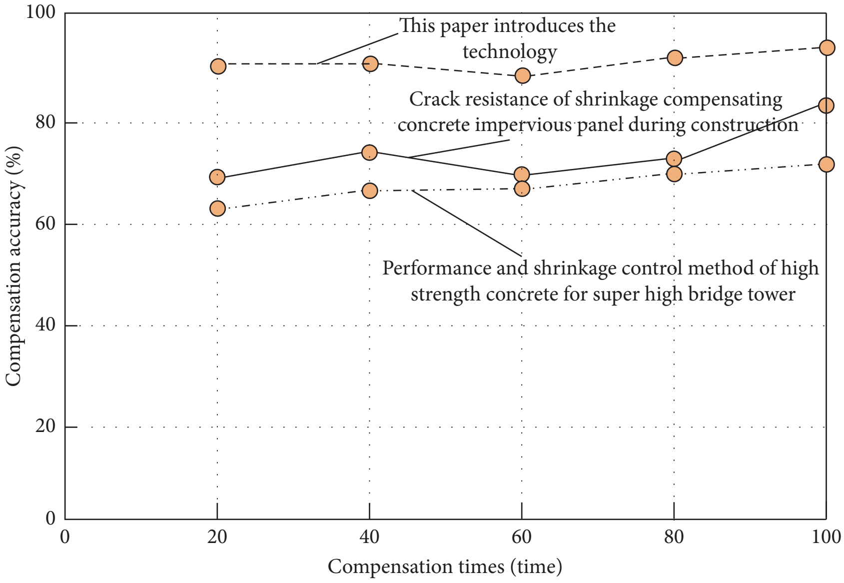

Figure 4: Comparison results of compensation accuracy of different compensation technologies.

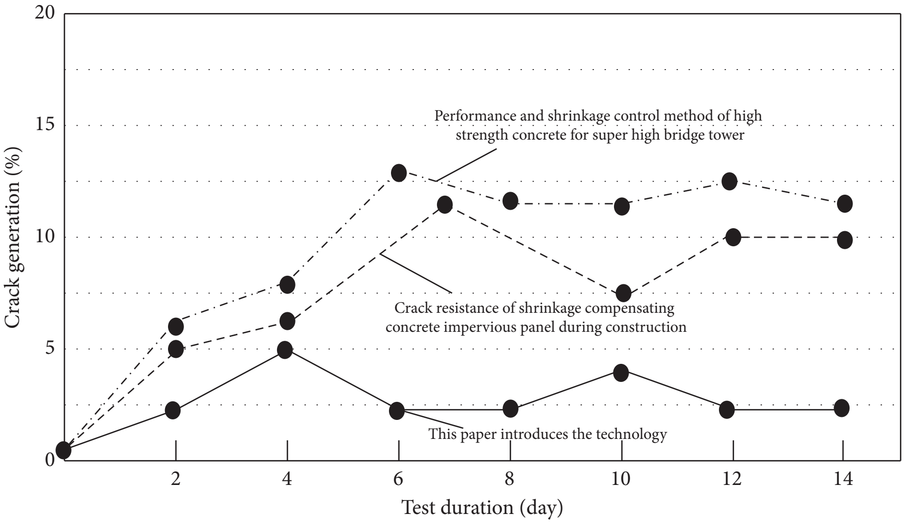

Figure 5: Comparison results of the crack amount of concrete samples with different compensation techniques.

or sealing, the use of a reasonable proportion can effectively eliminate the early autogenous shrinkage or autoexpansion of concrete and has a very obvious effect of inhibiting shrinkage. In practical application, the delayed microexpansion of MgO concrete can be used to compensate for the volume shrinkage of mass concrete in the bad state of cooling. The method proposed in this paper can achieve a better shrinkage compensation effect.

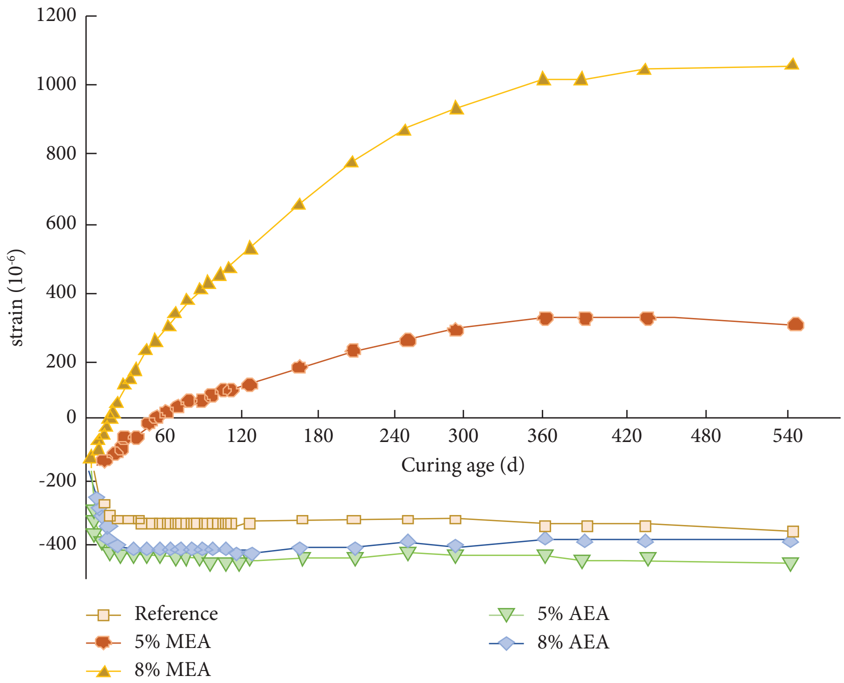

Figure 6: Autogenous deformation of Portland cement pastes containing various contents of MEA under nonwet curing conditions.

5. Conclusion

On the basis of referring to the existing literature on shrinkage compensation of concrete-filled steel tubular structures, a new shrinkage compensation technology is proposed. Firstly, the shrinkage mechanism of CSTS-LCSB is analyzed to improve the shrinkage compensation effect of CSTS-LCSB, analyzing objects including plastic shrinkage, dry shrinkage, autogenous shrinkage, and carbonation shrinkage. The proportion of dry shrinkage and autogenous shrinkage in ordinary concrete and high-strength concrete is determined. The structure has different shrinkage forms in different environments, and the shrinkage strain state in different environments is calculated. The shrinkage area of the concrete structure is determined, and the expansion agent is used to compensate for the shrinkage area of CSTS-LCSB. In order to verify the applicability and the actual shrinkage compensation effect of the method proposed in this paper, a cross-section of CSTS-LCSB is taken as an experimental object for simulation experiments and compared with the performance research and shrinkage control method of super-high-strength concrete for bridge tower and the anticrack performance analysis method of antiseepage panel of shrinkage compensating for concrete during the construction period. The experimental results are as follows:

(1) By comparison, the proposed method has the highest compensation accuracy of 97% for the structural shrinkage of concrete samples and has a certain compensation accuracy.

(2) In contrast, the amount of cracks produced by the proposed method is the least-always less than 5% after shrinkage compensation, which verifies that the effect of the proposed method is effectively alleviated. In practical application, the delayed microexpansion of MgO concrete can be used to compensate for the volume shrinkage of mass concrete in the bad state of cooling and achieve a better shrinkage compensation effect.

Experiments showed that the method proposed in this paper has high precision of shrinkage compensation and the ideal effect of shrinkage compensation. At the same time, this paper analyzes the different causes and mechanisms of concrete shrinkage and analyzes how the shrinkage of CSTS-LCSB is affected by different environmental factors including temperature, humidity, and so on. Although the technology in this paper has achieved some results in the current stage, the environment of concrete is constantly changing. If we want to continuously improve the compensation effect, we need to consider more environmental impact. In future research, we will focus on the improvement of this aspect and contribute to the improvement of concrete performance.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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