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Research Article

Durability Analysis of Small Assembled Buildings in Irrigation Canal System

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With the rapid development of agricultural economy, people are paying more and more attention to how to apply high-efficiency technologies that save resources to improve agricultural production efficiency, so water-saving irrigation technology has gradually developed. China's agricultural irrigation technology is relatively backward. In addition to the inappropriate irrigation methods and irrigation systems, problems such as siltation, seepage, and frost heave damage in irrigation canals have seriously affected the durability and service life of the canals. The backward irrigation technology seriously restricts the development of agricultural water-saving irrigation. Compared with large irrigation channels, the fabricated reinforced concrete small irrigation channels studied in this paper are less prone to frost heave damage and infiltration problems, and have the advantages of standardized production, simple transportation and installation, and convenient maintenance. In order to study the durability issues such as the basic characteristics, frost heave damage, and service life of fabricated irrigation channels, this paper takes the channel concrete and the formed channel as the research objects, and discusses the research on the properties of the channel concrete through theoretical research, numerical analysis, experiments, and other methods. Strength properties, water penetration resistance, cyanide ion penetration resistance and frost resistance; simulate the seasonal frost heave failure process of the channel; finally, on the basis of the test data, the service life aims to explore the safety and applicability of the fabricated reinforced concrete irrigation channel during the design use period.

1. Introduction

With population growth and social development, water shortage has become a prominent problem faced by our country. Coupled with serious water pollution and uneven distribution of water resources, the contradiction between water supply and demand has become prominent and worsened, which has seriously affected people's quality of life and restricted the social progress and economic development. For a large agricultural irrigation country like China, the country's largest water consumption is agricultural water. According to the 2014 China Water Resources Bulletin, China's total water resources are about 2.73 trillion m^3, a decrease of 1.6% compared to previous years. Water consumption accounts for 22.3% of it, of which agricultural water consumption is about 386.9 billion m^3, accounting for 2/3 of the total water consumption, and the water used for the development of irrigation has reached 90%~95% of agricultural water consumption. Therefore, the channel Low water delivery efficiency directly affects the benefits of agricultural production in irrigated areas. According to calculation and analysis, the national average irrigation water utilization coefficient is 0.502, which is far lower than 70% to 80% of the irrigation water utilization rate in developed countries. The waste of water resources will also cause the groundwater depth to rise in some areas, leading to soil salinization, reducing the area of arable land required for agriculture and increasing investment costs. Channels are still the main water delivery facilities in China's irrigation areas. The annual water loss of canal system engineering is about $1730 \times 108\ m^3$. Channel engineering using antiseepage technology can reduce water loss by 70% to 90%. Water agriculture and alleviating the contradiction between supply and demand of water resources, it is necessary to establish a set of safe and reliable transmission and distribution canal system to improve the effective utilization of agricultural irrigation water. With the wide application of channel antiseepage technology in water-saving irrigation, the area of water-saving irrigation projects in China reached 407 million mu by the end of 2013, of which the channel antiseepage irrigation area accounted for about 27% of the total area. According to the plan of the Ministry of Water Resources, before 2020, the area of irrigation projects in the country should be increased to more than 60% of the effective irrigation area, the efficient irrigation area should be increased to more than 30% of the effective irrigation area and, the effective utilization coefficient of agricultural irrigation water should be raised to more than 0.55. It can be seen that the construction of channel lining and antiseepage projects directly affects agricultural production and plays a vital role in improving agricultural water use efficiency and the development of water-saving agriculture [1–7].

Through statistical research, there are relatively serious frost heave damage problems in canal buildings in many irrigation areas across the country. According to the frost heave disaster investigation of canal engineering, water transmission channels without antifreeze heave measures generally have frost damage problems, and frost heave produces many cracks. Under the action of water flow, the canal base stop will gradually get swept away, and then slumps will occur, causing channel damage and affecting the normal use of the channel. Therefore, the prevention of frost heave damage in the irrigation channel is also one of the key research issues of channel antiseepage technology. The small prefabricated buildings of the irrigation canal system have many advantages and are also widely used in farmland water conservancy and land improvement projects. However, there is a lack of systematic theoretical and experimental research on the durability performance of small prefabricated buildings in irrigation canal systems. This paper intends to simulate the durability of small prefabricated buildings in irrigation canal systems through laboratory tests, theoretical analysis, and numerical simulation.

2. Related Work

In the study of the most complex structural buildings in hydraulic engineering, the many advantages of prefabricated buildings have been favored by designers. In 1932, the structure of the powerhouse and the lock equipment of the Swell Hydropower Station used prefabricated concrete structures. The Sydney built in 1985. The Mo Hydropower Station became the largest prefabricated hydropower station in the world at that time. The research and application of prefabricated water conservancy projects was carried out. In 1955, in order to improve the engineering quality of power plants, speed up the construction progress, and reduce the labor force, the Soviet Union proposed the industrialization of construction, the development of prefabricated infrastructure, and the maximum mechanization of manufacturing and installation. In the 1970s, the United States became popular with prefabricated products, and successively issued a series of strict standards of industry behavior, which have been used to this day. Ballar and Harper optimized the installation scheme of prefabricated walls, columns, beams, and slabs using genetic algorithms from the perspectives of efficiency and construction technology. And its research results show that in the case of reasonable design and organizational design, the prefabricated technology is superior to the traditional construction method in terms of technology and efficiency. The connection method of prefabricated buildings is the technical difficulty of prefabricated building technology, and it is also the key point in the development process of prefabricated buildings. A reasonable connection method not only improves the quality of prefabricated buildings, but also facilitates construction and reduces prefabrication time. Piltant expounds the prefabrication principle and method of using bolts to connect statically indeterminate prestressed members. It is also pointed out that due to the statically indeterminate characteristics of concrete structures, their manufacture is standardized, the assembly work is reduced to a minimum, and its standardization can greatly reduce the weight of concrete structures. The craftsmanship of prefabricated buildings is different from that of traditional buildings, and the proportion of concrete materials used will also change accordingly. Optimal design requires continuous development to obtain an ideal mix of precast concrete with high early strength, good workability, and economical utility. Jinglin chooses low alkalinity sulfate cement to mix with ordinary Portland cement and adds polycarboxylate superplasticizer and sodium sulfate. The ideal prefabricated concrete mix ratio with higher early strength was selected through orthogonal tests. The research on prefabricated buildings for water conservancy projects in my country began in the 1950s and 1960s. In 1955, at the National Water Conservancy Construction Conference held by the Ministry of Water Resources, Heilongjiang Province introduced the construction experience of prefabricated aqueducts. Since then, this advanced design and construction method has begun to attract attention from all over the world. In 1956, 80% of the hydraulic structures in Zhanjiang were prefabricated, and more than 40,000 structures were built successively, with more than 20 types of structures. In the initial stage of promotion, it was mainly in the form of "building blocks," and light-weight structures were gradually applied, and then steel mesh cement and prestressed concrete components were used. The prefabricated building mold developed by Gaoyou City has gone through the development process from wood mold to steel-wood combination to mechanized assembly line production. At present, three series of irrigation, drainage, and transportation have been formed, with 10 varieties and 38 models, which can be used for clay and sandy areas in hilly, polder, and plain areas. This achievement has passed the ministerial-level appraisal in November 1992. With the development of information technology, the combination of prefabricated building components and digital technology is the research direction of more and more researchers. The organization and management of information technology can add icing on the cake to the development of prefabricated buildings and promote the development of prefabricated buildings in the direction of modernization. Among them, Mei Yue finds the way of thinking of digital architecture and its corresponding assembly construction and general construction process method and applies it to small design practice activities. With the country's increasing investment in water conservancy project construction year by year, prefabricated slab bridges are also widely used in various water conservancy projects, but as the connection method of prefabricated slab bridges, hinge joints are one of the most prone to disease. [8–14].

3. Durability Parameter Test of Small Prefabricated Buildings in Irrigation Canal System

The object of this test study, the prefabricated concrete U-shaped channel, is mainly used as a water conveyance and diversion channel. In practical engineering applications, the main technical indicators are strength, antiseepage, antifreeze, antichloride ion penetration, and so on. In order to more clearly understand the durability of prefabricated concrete U-channel, it is necessary to test the above indicators of concrete. In this research, by designing different concrete compounding, the concrete test specimens were prepared in the laboratory. The strength characteristics, impermeability, frost resistance, chloride ion permeability resistance of concrete, etc., select the concrete mix ratio suitable for different conditions to meet the working conditions of the corresponding project. The durability can provide the necessary quantitative parameters. In this concrete durability test, the concrete design strength of the fabricated U-shaped channel is C 3 0, and the design slump is 160–180 mm, which is fluid concrete.

3.1. Test Raw Materials. All know, the quality of the raw materials used for mixing concrete may lead to great differences in the performance of concrete. Therefore, the selection of concrete raw materials is crucial to the durability of concrete in the concrete-reduction test. The raw materials required for this experimental study are as follows: cement, coarse and fine aggregates, tap water, mineral powder, fly ash, mineral powder, and water-reducing agent [15].

3.1.1. Cement. In engineering production, cement is an extremely important building material and engineering material, and together with steel and wood, it is called the three major materials of capital construction. This test uses P0.42.5 cement, the chemical composition of cement is shown in Table 1, and its main mechanical properties are shown in Table 2. The properties of various materials are introduced below. Selecting reasonable materials in engineering construction is the key to engineering quality [16].

Table 1: Chemical composition of cement.

Chemical cost of cement (%)					
Sio_2	Al_2O_3	Fe_2O_3	Cao	Mg0	So_3
22.03	8.52	3.76	6 1.37	2.23	2.01

3.1.2. Coarse Aggregates. The aggregate in concrete accounts for about 3/4 of its total volume. Rock particles with a particle size of less than 5.00 mm are called fine aggregates, while those larger than 5.00 mm are called coarse aggregates. Commonly used coarse aggregates include pebbles and gravel. This concrete test uses 5–25 crushed stone on the market. After indoor measurement, the physical index of coarse aggregate is shown in Table 3 and its gradation is shown in Table 4.

3.1.3. Fine Aggregate. Divided into natural sand and artificial sand according to their different production processes and methods. Natural sand can be divided into river sand, sea sand, and mountain sand according to their different sources. Artificial sand can be divided into coarse sand, medium sand, fine sand, and extrafine sand according to the size of the fineness modulus. This test uses medium and fine sand in the building materials market. The fineness modulus of the sand is $Mx = 2.6$, the physical index is shown in Table 5, and the sand particle gradation is shown in Table 6.

3.1.4. Fly Ash. Fly ash is a pozzolanic material with a certain activity. When fly ash is probed into concrete, it can improve the workability of concrete, reduce water consumption, reduce water-cement ratio, and increase the strength of concrete. In this test, the fly ash used is F-class TI grade fly ash with a fineness of 11% and a water demand ratio of 97%.

3.1.5. Mineral Powder. Mineral powder is a concrete admixture obtained by grinding granulated blast furnace slag. It is a powder material that reaches the specified activity index after drying and grinding of granulated blast furnace slag. When grinding slag, a small amount of grinding aid is allowed. The input should be below 144. Mineral powder has potential hydraulic properties, and the main mechanism of action in cement concrete is the cementation effect and the microaggregate effect. The mineral powder that has been separately ground has a surface roughness smaller than that of cement particles, so it also has a certain morphological effect, which can reduce water and increase the fluidity of concrete. In this test, S95 grade granulated blast furnace slag powder was selected, and its surface area was 428 F/kg. The main chemical components are shown in Table 7 [17].

3.1.6. Water Reducer. Adding water reducer to concrete can change the rheological properties of cement paste, thereby changing the internal structure of concrete, thereby

Table 2: The main mechanical properties of cement.

Fineness (80 μm)	Initial setting time (min)	Final setting time (min)	Compressive strength (MPa)			Flexural strength (MPa)		
			3 d	7 d	28 d	3 d	7 d	28 d
4.5%	80	215	28.6	40.3	50.8	5.10	6.45	7.96

Table 3: Physical index of stone.

Specification (mm)	Bulk density (kg/m^3)	Apparent density (kg/m^3)	Mud content (%)	Content of needlelike flakes (%)
5–30	1490	2763	0.8	6.0

Table 4: Grading table of stones.

Specifications (mm)	>25	>20	>16	>10	>5	>2.5
The proportion	8	—	54	—	93	99

Table 5: Physical properties of sand.

Name	Fineness modulus	Apparent density (kg/m^3)	Bulk density (kg/m^3)	Mud content (%)	Mud content (%)
River sand	2.6	2680	1456	2.0	0.6

Table 6: Grain gradation of sand.

Screen size (mm)	>10	>5	>2.5	>1.25	>0.63	>0.315	0.16
Cumulative screening (%)	0	3	10	43	65	91	98

Table 7: Chemical composition of mineral powder (%).

Sio_2	Al_2O_3	Fe_2O_3	Cao	Mg0	So_3	Burn vector
35.23	12.31	3.48	40.38	7.6	—	0.95

improving other properties such as concrete mechanics. In this concrete test, polycarboxylate water-reducing agent was selected as the water-reducing agent.

3.2. Test Mix Ratio. When mixing concrete in engineering construction, the durability of concrete will be completely different when different proportions of materials are adopted. Therefore, in order to obtain concrete that meets the requirements of design quality, it is necessary to calculate the proportion of various materials in the concrete, and through experimental comparison, the concrete mix ratio that meets the durability requirements under the corresponding construction conditions and operating environment is obtained.

In order to study the strength characteristics and durability of the concrete of the prefabricated irrigation canal under different working conditions, three kinds of concrete mix ratios are listed in this experimental study, including the original mix ratio (the mix ratio adopted by the manufacturer) (I), the Add fly ash (II) on the original basis, and then add water-reducing agent (III). The purpose of designing three different concretes is to compare various performance parameters of concrete with different mix ratios, study the applicable environment of concrete with various mix ratios, and meet the safe and applicable durability performance of the channel. See Table 8 for the description of the proportions of three different concretes. [18].

In calculating fly ash in the mixing ratio of (mineral powder) concrete, fly ash (mineral powder) is usually added in two different ways, namely, the method of replacing cement with an equal amount and the method of replacing cement with an excess amount [19].

(1) Equal replacement of cement method, refers to the replacement of cement by the probing fly ash (mineral powder) in equal amount, which can reduce the calorific value of concrete, and can significantly improve the workability and impermeability of concrete, and is often used in mass concrete. The sand replacement method keeps the amount of cement in the concrete unchanged, and hangs fly ash (mineral powder) to reduce the fine aggregate. This kind of concrete has excellent cohesion, water retention

Table 8: Test concrete mix description.

Group	Describe	Water-cement ratio	Sand rate
I	Original mix	0.50	0.41
II	Add fly ash	0.45	0.41
III	Add fly ash, water reducer	0.45	0.41

workability, and impermeability. (2) Oversubstituting cement method, that is, based on the reference concrete mix ratio, according to the principle of equal strength, using the oversubstituting method to adjust the proportion of cement. When calculating the mix ratio in this concrete test study, according to the actual situation of the project, it is planned to use the excess substitution method to design the concrete mix ratio. The use of the excess substitution method to design the mix ratio can determine an economical concrete mix ratio. The design method is completed through testing and trial matching.

3.3. Fabrication and Maintenance of Concrete Specimens. This concrete test plans to complete the concrete strength (tensile, compressive) test, penetration test, freeze-thaw test, and chloride ion resistance penetration test. After statistics, the test pieces to be produced for each group of mix ratios are shown in Table 9. In order to prevent the loss of specimens during the test, there should be excess concrete specimens in each group of mix ratios.

According to the "Standard," the concrete specimens that are formed and demolded should be sent to a standard curing room with a temperature of $20 \pm 2^{\circ}C$ and a relative humidity of more than 95% in time for curing. And the concrete sample should not be washed with water directly. The standard curing age is 28 d, and the test specimens for 7-day compressive strength test shall be taken out for testing at 7 d, and other specimens shall be treated at the corresponding time according to the specifications.

3.4. Experimental Study on the Properties of Concrete Mixtures. The concrete mixture is made by mixing the constituent materials in a certain proportion, and its workability is the most important property of fresh concrete. The workability of the mixture refers to the performance of the mixture that can meet the requirements of the concrete construction process (mixing, transportation, pouring, and vibrating) under the premise of no segregation and bleeding.

The workability of concrete mixture includes fluidity, cohesion, and water retention. Because of its complex connotation, "slump" is used to measure the fluidity, cohesion, and water retention of concrete mixture, so as to evaluate concrete workability of the mixture. During the process of obtaining the mixture in this test, the slump of the mixture was measured, and the statistics are shown in Table 10 [20–22].

4. Durability Analysis and Prediction of Small Prefabricated Buildings in Irrigation Canal System

For any building structure, when designing and constructing, the designer will consider the probability that the building will be used in the expected life time in the future, which is an important basis for judging the "cost-effectiveness" of the building structure. The basic purpose of hydraulic structure design is to make the structure meet various functional requirements predetermined by the design within the predetermined service period, so as to be safe, reliable, economical, and reasonable. The functional requirements of general engineering structures mainly include three aspects.

Safety, serviceability, and durability are commonly referred to as structural reliability. In the design process, in order to obtain the structural reliability that meets the requirements, it is necessary to properly handle the relationship between the two opposites in the structure. On the one hand, the load effect caused by the action (load) applied to the structure, time external force on the structure (such as self-weight, live load, wind load, and water pressure), and other loads (such as humidity deformation, foundation settlement, and earthquake action) cause deformation of the structure. The structural resistance ($R3$) composed of the section size, the number of reinforcements, and the strength of the material is mainly related to the degree of agreement between the structural size of the structural member, the number of reinforcements, the material properties, and the calculation mode of the resistance to the actual situation.

The above load effects and structural resistance R are functions of random variables, so the design of building components is mainly to study the structural resistance 091 used when these two random functions satisfy a certain probability.

4.1. Structural Limit States and Failure Probability. Reinforced concrete structures are widely used in engineering. In the process of design and construction, with the accumulation of experience, the design theory also develops continuously. The process can be divided into three stages: the design method according to the allowable stress, the design method according to the failure stage. The lifetime and prediction in this paper are based on the limit state design concept.

In the engineering field, the limit state of a building structure is generally divided into "bearing capacity limit state" and "normal service limit state" value, mainly considering the applicability and durability of the structural reliability, while the ultimate bearing capacity state refers to the structure or component reaching the maximum bearing capacity or reaching the deformation that is not suitable for continuous bearing. The main consideration is the safety of the structure. The limit state of the structure can be represented by the limit state function Z. In general, many

Table 9: Statistical table of concrete specimens (single group mix ratio).

Type of test	Test specifications	Number of test pieces	Remark
Cube compression	150 mm × 150 mm × 150 mm	6/group	7 days, 28 days old
Split tensile	150 mm × 150 mm × 150 mm	3/group	28 days old
Impermeability test	$D1 = 175$ mm $D2 = 185$ mm $H = 150$ mm	4/group	28 days old
Freeze-thaw test	100 mm × 100 mm × 400 mm	5/group	28 days old
Antichloride test	$R = 100$ mm $H = 50$ mm	3/group	28 days old

Table 10: Measured slump of mixtures.

Group	I		II		III	
	Measurements	Average value	Measurements	Average value	Measurements	Average value
Slump (mm)	175.0 168.0 162.0	1 68.3	165.0 172.0 169.0	168.7	175.0 164.0 168.0	169

factors that affect the limit state are represented by two variables: load effect and structural resistance R, then,

$$Z = g(R, S) = RS. \tag{1}$$

Obvious from the above equation that, when $Z > 0$ (i.e., $R > S$), the structure is safe and reliable; when $Z < 0$ (i.e., $R < S$), the structure fails; and when $Z = 0$ (i.e., $R = S$), it means that the structure is positive In the limit state, so when $Z = 0$ is called the limit state equation of the structure. Since, both R and S are random variables, function B is a random function whose value is not a fixed value and should be described by means of probability theory. In probability theory, failure probability P is generally used to represent the reliability of the structure.

Assuming that $F(Z)$ is the probability density distribution function of the functional function Z, then when $Z < 0$, the formula (2) of the failure probability represents the area of the shaded part of the probability distribution curve in Figure 1.

$$p_f = p(Z < 0) = \int_{-\infty}^{0} f(Z)\mathrm{d}z. \tag{2}$$

If it is assumed that the two random variables, the structural resistance R and the load effect S, obey the normal distribution, and their mean and standard deviation are μ_R, μ_S, σ_R, and σ_s, respectively, it can be known from probability theory that the functional function B obeys a positive distribution, with the mean and standard deviation of Z being μ_z and σ_z, respectively. Then, the probability density function of the Z normal distribution is as follows:

$$f(z) = \frac{1}{\sqrt{2\pi\sigma_z}} \exp\left[-\frac{(z-\mu_z)}{2\sigma_z^2}\right]. \tag{3}$$

Putting equation (3) into equation (2), we can get the following equation:

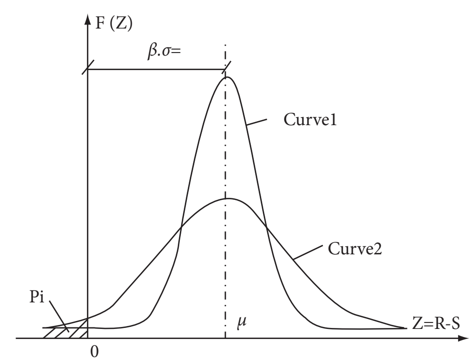

Figure 1: The probability density distribution curve of Z, β, and p_f relationship.

$$p_f = \int_{-\infty}^{0} \frac{1}{\sqrt{2\pi\sigma_z}} \exp\left[-\frac{(z-\mu_z)}{2\sigma_z^2}\right]\mathrm{d}z. \tag{4}$$

In the actual engineering design, it is more complicated to use formula (4) to calculate the failure probability P, so the reliability index is generally used to measure the reliability of the structure.

When the building structure resistance R and load effect S obey the overall distribution, the corresponding relationship between the failure probability p_f and the reliability index β is listed in Table 11. In the design process, when the structural reliability index is determined, the structural failure probability can be obtained, and then the limit state method is adopted to design the structure.

In the design of concrete structures, the probabilistic limit state design concept is mainly used for structural design, so the basic theory adopted in the life prediction of fabricated reinforced concrete irrigation canals is the limit state design theory. The following is the prediction of the service life of the prefabricated irrigation canal under the carbonization condition and the chloride ion environment based on the probability reliability theory, and a certain reference is given for the durability evaluation of the canal concrete.

Table 11: Correspondence between p_f and β.

Beta	p_f
1.0	1.59×10^{-1}
1.5	6.68×10^{-2}
2.0	2.28×10^{-2}
2.5	6.21×10^{-3}
2.7	3.47×10^{-3}
3.0	1.35×10^{-3}
3.2	6.87×10^{-4}
3.5	2.33×10^{-4}
3.7	1.08×10^{-4}
4.0	3.17×10^{-5}
4.2	1.33×10^{-5}
4.5	3.40×10^{-6}

4.2. Life Prediction of Fabricated Irrigation Channels under Carbonation Conditions. The life of the fabricated reinforced concrete irrigation channel under carbonation mainly includes two stages: (1) the time from the concrete surface to penetrate the steel surface; (2) the steel bar begins to corrode until the structural failure occurs. For the corrosion of steel bars, the participation of water and chloride ions is required, so the life prediction part is placed in the later stage of chloride ion steel corrosion. This section only analyzes the time required for the carbonization of the concrete cover.

For the prediction of the concrete carbonation life of the fabricated reinforced concrete irrigation channel, we should first measure the thickness of the steel protective layer, and obtain the average value, mean square error and variation coefficient of the concrete protective layer thickness.

According to the empirical formula, the carbonization rate coefficient of the channel concrete is obtained, the mean square error and variation coefficient of the concrete carbonization coefficient are obtained, and the carbonization life of the concrete is obtained according to formula (4). After measuring the thickness of the protective layer of the irrigation channel in the manufacturing factory, the sample data obtained are shown in Table 12.

According to the knowledge of statistical theory, the average thickness of concrete protective layer can be obtained as μ_c,

$$\mu_c = \frac{1}{N}\sum_{i=1}^{N} x_c = \frac{1}{40}\sum_{i=1}^{40} x_c = 24.9mm . \tag{5}$$

Its mean square error σ_c is,

$$\begin{aligned}\sigma_c &= \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_c - \mu_c\right)^2} \\ &= \sqrt{\frac{1}{40}\sum_{i=1}^{40}\left(x_c - \mu_c\right)^2}. \\ &= 3.12mm\end{aligned} \tag{6}$$

According to the above equation, the carbonization coefficient (in years) is calculated by formula (5), as follows:

$$K = \gamma_1\gamma_2\gamma_3\left(12.1\frac{W}{C} - 3.2\right). \tag{7}$$

In formula 5: the main reference values are γ_1, γ_2, and γ_3.

For the concrete of the prefabricated irrigation channel of the research object, in formula (7), since slag cement is used, the γ_1 value is 1.0; the content of fly ash is 14%, the γ_2 value is 1.1; the channel is mainly used in the northern region, and γ_3 the value is 1.1. Value 1.1: Calculated according to the mix ratio, the water-cement ratio is 0.45, and the above parameter values are taken with AR.

$$K = 1.0 \times 1.1 \times 1.1 \times (12.1 \times 0.45 - 3.2) = 2.72. \tag{8}$$

According to the research, the K value obeys the normal distribution. According to the experience, the mean value μ_k is taken as 2.58 and the standard deviation σ_k is obtained according to the error function. In this study, the value is 0.65.

Substituting $\mu_c = 24.9$ mm, $\sigma c = 3J2$ mm, $\mu_k = 2.58$, and $\sigma_k = 0.65$ into formula (7), and then according to the corresponding values of failure probability P_f and reliability in Table 11, it can obtained carbonation life of fabricated reinforced concrete irrigation channels. According to the calculation, when the failure probability P is 2.28×10^2, its reliability β is 2.0, and the life period $t = 394.4$ years is obtained. The probability of layer carbonization is $P_f = 2.28 \times 10^2$.

After calculation, it is obtained that the service life of the prefabricated reinforced concrete irrigation canal under the carbonation condition is very long. But only under ideal carbonization conditions, there are not many factors considered in the analysis of the carbonization rate coefficient, so this does not represent the service life of the actual channel. The corrosion time of steel bars is solved in the next section.

4.3. Prediction of Channel Life under Chloride Erosion. To analyze the life of concrete in the chloride ion environment, that is to analyze the time T_1, T_2, and T_3 of the three stages of steel corrosion, and finally unify the three times, that is, the concrete is caused by chloride ions. The time of destruction is analyzed from three aspects.

4.3.1. T_1. The time T_1 is the time for chloride ions to reach the steel bar from the concrete surface. It can be considered here that in the original concrete, the nitrogen ions on the steel bar surface are very small, which is not enough to cause the steel bar to corrode. The time T_1 is when the concrete is exposed to the chloride ion environment until the surface of the steel bar begins to accumulate chloride ions.

This time, the approximate probability design method is mainly used to analyze the time T_1. Considering the partial coefficients in the analysis, the endurance limit state equation of the concrete structure corroded by chloride ions can be expressed as follows:

Table 12: The measured value of the thickness of the protective layer of the irrigation channel (mm).

22.8	27.4	22.6	22.3	31.8	21.5	28.1	22.6	20.6	23.1
22.6	26.0	26.0	27.7	26.3	27.8	21.3	25.7	22.5	24.3
22.6	25.6	23.9	21.6	22.5	22.4	23.3	25.1	27.4	22.7
35.8	23.2	27.3	23.2	30.4	25.2	23.1	26.4	28.6	23.7

Table 13: Parameter value table.

Parameter category	k	h_0	θ	λ
Value	12.5 a/mm	0.15 mm	0.01 mm	6.0

$$\begin{aligned} g &= c_{cr}^{d} - c^{d}(x,t) \\ &= c_{cr}^{d} - c_{s,cl}^{d}\left[1 - \operatorname{erf}\left(\frac{x^{d}}{\sqrt[2]{D_{cl}^{d}(t_{SL}).t_{SL}}}\right)\right] \\ &= 0, \end{aligned} \tag{9}$$

where c_{cr}^{d} is the design value of critical chloride ion concentration for steel corrosion, $c_{s,cl}^{d}$ is the set value of chloride ion concentration on the concrete surface, x^{d} is the statistical value of the thickness of concrete protective layer survey, $D_{cl}^{d}(t_{SL})$ is the test value of nitrogen ion diffusion coefficient of concrete, and t_{SL} is the exposure time of concrete elements.

It can be seen from the above formula that the life estimation model that determines the resistance of concrete to chloride ion damage mainly depends on four parameters: the thickness of the concrete protective layer, the chloride ion concentration on the concrete surface, the critical chloride ion concentration, and the nitrogen ion diffusion coefficient. Given these four parameters, the service life and durability design diagram of the channel concrete can be estimated. This paper only needs to predict the service life, and it can be solved directly by the endurance limit state equation. DuraCrete gives the endurance limit state equation for calculating the durable service life of concrete structures.

$$\begin{aligned} g &= c_{cr}^{d} - c^{d}(x,t) \\ &= c_{cr}^{d} - c_{s,cl}^{d}\left[1 - \operatorname{erf}\left(\frac{x^{d}}{\sqrt[2]{t/R_{cl}^{d}(t)}}\right)\right], \\ &= 0 \end{aligned} \tag{10}$$

When predicting the service life of concrete, considering that the repair cost is lower than the cost required to reduce the risk, the time B when the steel bar begins to corrode can be passed. The following expression can be obtained:

$$t_{i}^{d} = \left[\left(\frac{2}{x^{c} - \Delta x}.\mathrm{ref}^{-1}\left(1 - \frac{c_{cr}^{c}}{\gamma_{c_{cl}}}.\frac{1}{A_{C,cl}^{c}}\right)\right)^{-2}.\frac{R_{0,cl}^{c}}{K_{c,cl}^{c}.K_{c,cl}^{c}.t_{0}^{n_{cl}^{c}}.\gamma_{R_{cl}}}\right]^{1/1-n_{cl}^{c}}. \tag{11}$$

Small prefabricated building irrigation canal system, which is the research object of this paper, is similar to the external channel environment, the example in DuraCrete is referred to when determining the parameters and partial coefficients.

The model analyzed in this section is a fabricated concrete irrigation channel. The average thickness of the protective layer is $x^{c} = 24.9\,\mathrm{mm}$, its safety margin is $\Delta x = 5\,\mathrm{mm}$, and its antichloride ion permeability coefficient is $D_{\mathrm{RCM},0} = 9.41 \times 10^{-12}\,\mathrm{m}^2/\mathrm{s}$ (using the value of the third group mix ratio), correspondingly $R_{0,cl}^{0} = 3.3698 \times 10^{-3}$year/$mm^{2}$, the environmental parameter is 0.92, and the curing condition parameter value is 0.79, the test period is 28 days, the attenuation coefficient is 0.37, and the corresponding subitem coefficient is 3.25. Substitute the above values into equation (9) we get the following equation:

$$\begin{aligned} t_{i}^{d} &= \left[\left(\frac{2}{x^{c} - \Delta x}.\mathrm{ref}^{-1}\left(1 - \frac{c_{cr}^{c}}{\gamma_{c_{cl}}}.\frac{1}{A_{C,cl}^{c}}\right)\right)^{-2}\frac{R_{0,cl}^{c}}{K_{c,cl}^{c}.K_{c,cl}^{c}.t_{0}^{n_{cl}^{c}}.\gamma_{R_{cl}}}\right]^{1/1-n_{cl}^{c}} \\ &= \left[\left(\frac{2}{25 - 5}.\mathrm{ref}^{-1}\left(1 - \frac{0.8}{1.2}.\frac{1}{7.76 \times 0.45 \times 1.2}\right)\right)^{-2}\frac{3.3698 \times 10^{-3}}{0.92 \times 0.79 \times 0.0767^{0.37} \times 3.27}\right]^{1/1-0.37}. \end{aligned} \tag{12}$$

Solution: $T_1 = 6.9$ years.

4.3.2. T_2. In actual engineering, the natural environment in which the concrete building structure is located is quite complex. In the process of research and analysis, it is difficult to determine the depassivation time of concrete. Usually, we think this time period is a random variable. Many research results show that when the concrete structure is in an environment with a relatively stable chloride ion source, the depassivation time of the steel bars in the concrete is shorter because the speed of cyanide ions intrusion into the concrete is much faster than the carbonization speed. In the corrosion life, the depassivation time is often considered to be zero, that is, the steel bar is always in an activated state.

4.3.3. T_3. Time B is the development stage of steel bar corrosion, and the steel bar begins to undergo pitting corrosion, which then develops into pit corrosion, and finally produces rust, causing rust expansion and cracking. The corrosion pit at this stage reaches a certain depth, which is usually called the critical depth. In the limit state design method based on probability theory, we regard the depth of the steel corrosion pit reaching a critical depth as the limit state of the durability life of the reinforced concrete. After research, it is considered that the pit corrosion depth on the steel bar obeys the Poisson distribution, and the time length of the steel corrosion development stage based on the failure probability is proposed, and the expression is as follows:

$$T_3 = k\theta \ln\left\{\frac{\ln\left[1 - F_T(t)\right]\left(1 - \exp\ \left(h_0/\theta\right)\right)}{\lambda} + 1\right\}. \tag{13}$$

In the above formula, k is proportionality constant, also known as reinforcement corrosion rate, h_0 is the depth of the pit at the limit state, θ is the average depth of the initial pits, and λ is Poisson flow strength in a Poisson distribution.

For steel bars in fabricated concrete irrigation, by comparing the statistical analysis data of steel bar corrosion in other chloride ion environments, the parameters in formula (13) can be determined as shown in Table 13.

Substitute the parameters in the table into formula (9), and taking the failure probability as 5%, we get the following equation:

$$\begin{aligned} T_3 &= k\theta \ln\left\{\frac{\ln\left[1 - F_T(t)\right]\left(1 - \exp\ \left(h_0/\theta\right)\right)}{\lambda} + 1\right\} \\ &= 12.5 \times 0.01 \times \ln\left\{\frac{\ln\left[1 - 5\%\right]\left(1 - \exp\ \left(0.15/0.01\right)\right)}{6.0} + 1\right\}. \end{aligned} \tag{14}$$

It can be seen by calculation: $T_3 = 12.8$ years, which means that the probability of corrosion damage to the steel bars of the prefabricated irrigation canal concrete after being exposed to the nitrogen ion environment for 12.8 years is 5%.

To sum up, the time required for the corrosion damage of the steel reinforcement of the fabricated concrete irrigation channel in the chloride ion environment is $T_1 + T_2 + T_3 == 6.9 + 0 + 12.8 = 19.7$ years. The service life in the chloride ion environment is 20 years, which meets the life cycle of the general channel.

5. Conclusion

Water-saving irrigation technology refers to the general term for irrigation methods, measures, and systems that significantly save water than traditional irrigation technologies. There is a lack of systematic research on the strength, penetration, freeze-thaw, and other durability of fabricated reinforced concrete irrigation channels. Some durability problems arising from the production and operation of fabricated irrigation channels are analyzed for research.

This study firstly introduced the carbonization mechanism, carbonization rate, and influencing factors of the concrete protective layer, gave the concrete soil carbonization model and life criterion, and predicted the life of concrete under carbonation conditions according to the probability limit state method. Then, the corrosion mechanism of reinforced concrete in nitrogen ion environment and the model and random model of chloride ion intrusion into concrete are introduced, the life criterion of concrete in chloride ion environment is given, and the use of concrete in chloride ion environment according to the probability limit state method is analyzed.

By comparing and analyzing the carbonization life of concrete and the service life in the chloride ion environment, we get that the concrete life in the chloride ion environment is much smaller than the carbonization life. Of course, in the actual engineering structure environment, it is not possible to only carbonize the concrete, but there is often the corrosion of the steel bar by nitrogen ions and the electrochemical reaction. Therefore, in the follow-up research, the service life and durability evaluation of channel concrete should be predicted in the case of concrete carbonation and other coupling conditions.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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