Journal of Geoscience and Environment Protection, 2024, 12, 128-141
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Review on Water and Salt Migration in Saline Soil and Its Effect on Concrete Structure

Jianbing Jiang[1,2,3*], Baocun Yang[1,2], Boyi Li[3], Xiaosong Yang[1,2]

[1]College of Water Resources and Architecture Engineering, Tarim University, Alaer, China
[2]Research Center of Southern Xinjiang Geotechnical Engineering, Tarim University, Alaer, China
[3]214 Geological Team Co., Ltd., Shanxi Bureau of Geological Exploration, Yuncheng, China
Email: *Jiangjianbing163@163.com

How to cite this paper: Jiang, J. B., Yang, B. C., Li, B. Y., & Yang, X. S. (2024). Review on Water and Salt Migration in Saline Soil and Its Effect on Concrete Structure. *Journal of Geoscience and Environment Protection, 12,* 128-141.
https://doi.org/10.4236/gep.2024.1212008

Received: August 1, 2024
Accepted: November 17, 2024
Published: December 20, 2024

Abstract

Under freeze-thaw cycle conditions, salt-affected soil will undergo water and salt migration, which can cause damage to the soil itself and affect the quality of engineering. The present study explores the impact of water and salt migration in saline soil on concrete structures, and the following research findings were obtained: The main factors influencing water and salt migration are water, salt, and temperature, with water and salt being internal factors and temperature being an external factor. Convection of moisture, temperature, and cooling efficiency all directly affect salt migration. At the same time, the understanding of the destructive effects of water and salt migration in salt-affected soil on concrete has been gained. In practical engineering, the erosion of salt-affected soil mainly includes environmental water erosion, sulfate erosion, and chloride salt erosion. Environmental water erosion can be further divided into soft water erosion, carbonate erosion, and general acidic erosion. Sulfate erosion can be categorized into ordinary sulfate erosion and magnesium sulfate erosion. Corresponding to the erosion processes, measures such as the rational selection of concrete materials, the installation of isolation layers, and the increase of concrete density are taken. Additionally, future visions for water and salt migration tests and the impact of water and salt on concrete structures are proposed.

Keywords

Saline Soil, Sulfate Erosion, Chloride Salt Erosion, Concrete Protection

1. Introduction

The book "Saline Soils in China" states that "Saline soils are collectively referred to as those affected by a series of salinization processes. It includes various saline soils, alkali soils, and other soils with varying degrees of salinization and alkalinization (Wang, 1993).” Soil salinization is a major environmental risk caused by natural or human activities. It may not be as striking or destructive as earthquakes and tsunamis, but it has very serious environmental risks and impacts.

Large areas of saline soils distributed at a certain depth below the surface of south Xinjiang present a serious environmental risk. The harmful salts in the soil will migrate vertically and horizontally in the soil body with changes in the water table and underground flow. The accumulation of water and salt migration in saline soils will have a significant impact on the durability of engineering structures.

In recent years, many experts and scholars have conducted many studies on the law of water-salt transport, coupling effect, salt-swelling effect and improvement measures of saline soil in cold and arid regions. Foreign studies on saline soil can be traced back to the 1930s. Richards (1931) analyzed soil water-salt transport from the perspectives of dynamics and mass-energy conservation. Cary & Mayland (1972) proposed that ions have Soret effect during the migration process, and the soil solution will form a concentration gradient. Skopp & Warrick (1974) conducted experimental studies to establish the regular motion equations of water, heat and salt migration. Konrad & Morgenstern (1980) conducted experiments on water migration in frozen soil under different temperature gradients and proposed a prediction model for inflow flux. Corwin & Rhoades (1988) pointed out that water and salt migration is an important link in the formation of saline soil. Nassar & Horton (1992) verified the one-dimensional mathematical model of water-salt migration under water-heat-salt coupling. Tian et al. (2019) described the variation and migration of subgrade soil water in some areas of southern Xinjiang, and found that the salinity in the subgrade of saline soil changed with the migration of water. Zhou et al. (2020) established a mathematical model of water-heat-salt-force coupling of saline soil under the action of temperature. The heat transfer process and deformation characteristics in saline soil are described. All kinds of research results provide scientific guidance for disaster prevention and reduction in saline land area.

By summarizing the law of water and salt transfer in saline soil and the erosion characteristics of concrete structures induced by water and salt, the key problems involved are further discussed, in order to provide guidance for engineering construction in saline soil area.

2. Research on the Water and Salt Migration Law

2.1. Different Test Conditions of Selected Saline Soil

2.1.1. Temperature Difference during the Test

In the indoor test, more self-made temperature control equipment is used, so the temperature control range, cooling curve and temperature control method will be different. The temperature control equipment of water and salt migration test can also be used to study the properties of frost heave of saline soil. Generally, −45˚C

- 80˚C is the temperature that can be adjusted by the equipment. In the experimental process of water-salt migration of saline soil, the test temperature is mostly related to the regional temperature. The temperature range of −8˚C - 32˚C is the temperature range of Xiao & Lai (2018) in the study of Qinghai-Tibet region, and the temperature range of −20˚C - 20˚C is the temperature range of Fang et al. (2016). In the study of Tianjin region, both papers recorded during the experiment that when the top temperature decreased, the temperature of the soil would also decrease correspondingly, and the liquid water of the soil would freeze and the soil would freeze. Water cannot migrate. The experiments of Xiao & Lai (2018) and Fang et al. (2016) explain that there are two kinds of current temperature control schemes: variable temperature and constant temperature. The variable temperature control method uses sine curve to simulate temperature rise and fall. It is relatively consistent with the actual temperature change, but the operation is complicated, and the requirements for personnel and equipment are relatively high. The constant temperature scheme simulates the freeze-thaw cycle by setting the temperature difference between the bottom plate and the top plate.

2.1.2. Water Content Test

There are many ways to test water content. Alcohol burning method, drying method, etc., their principle is 1) The use of heating and other ways to remove water in the soil sample. 2) Measure the quality of the remaining soil. 3) The soil moisture content is obtained by using the formula.

At present, the commonly used measurement methods mainly include time-domain reflectometry and frequency-domain reflectometry, the essence of which is to first measure the dielectric constant of soil by using sensors. The water content is then calculated.

2.1.3. Salt Content Test

Salt ion and drying methods are common indoor methods for salt content testing. The salt ion method dissolves the dried saline soil into distilled water to form turbid liquid according to the ratio of water to soil 1:5. Then the test solution of soluble salt is prepared by the extraction equipment filtration, and the solution is measured by chemical method. Drying method the solution is dried and the residue is weighed.

2.2. Influencing Factors during Water and Salt Migration

After much research, the saline soil is in the process of water and salt migration. The three basic conditions of water, temperature and salt, among which, water and salt are the internal causes. Temperature is the external factor and the direct factor of water and salt migration. Water convection, cooling speed and soil salt are all factors affecting water salt migration.

2.2.1. Soil Moisture Content

Zhou et al. (2020) concluded through laboratory tests that soil water content is the main factor affecting water migration, and the movement becomes intense at the frozen surface. Zhao et al. (2009) quantified the impact of initial water content on water and salt migration by changing initial water content. The results showed a positive correlation between the two. It is found that the main factor affecting salt migration is water movement, and the carrier of salt movement is water. Salt transfer is driven by capillary water in saline soil.

2.2.2. Composition of Soil Salt

Some experts also measured the change of water and salt migration based on salt content. Zhang et al. (2016) concluded that the capillary water rise rate of demineralized soil was higher than that of natural soil through the capillary water rise rate of natural soil and demineralized soil. By using standpipe test, Shao Lei found that soil salt content was negatively correlated with capillary water action, and the migration law of water and salt in soil was as follows: 1) During the freezing process, the saline soil will produce sodium chloride and sodium sulfate crystals, which occupy the channel of water and salt migration and reduce the water migration rate. 2) Sodium chloride and sodium sulfate reduce the freezing point of saline soil, thus weakening the water migration rate; 3) The accumulation of ice salt crystals is due to the increase in salt content. The mechanical properties of saline soil are reduced and the rate of water migration is affected. Zhang Huyuan et al. studied the changes of water migration in different saline soils. Mixed solution of potassium chloride and sodium sulfate > potassium chloride solution > sodium sulfate solution > aqueous solution, and studies have shown that temperature, concentration gradient and combined effects will affect the migration of salt, frozen layer, quasi-frozen layer and non-frozen layer. These three layers are produced by freezing and thawing of saline soil. Water migrates downward, driving salt through the frozen layer. When it melts, the water goes up. Salt builds up to the surface. The salt content of the surface is increased.

2.2.3. Temperature Factors

Bing & He (2011) found that during the freezing process, water and salt in soil mass migrate to the cold end, and the change of temperature has a greater influence on the saline soil, indicating that temperature change will affect the rate of water and salt migration. Zhao et al. (2009) studied the law of water and salt migration by controlling the temperature gradient, and found that the temperature gradient was negatively correlated with the water and salt migration rate, and concluded that water gathered in the warm section.

Xiao Zegan also found this rule, and observed that the soil temperature in the roof decreased. The temperature field changes as the soil water liquefies and freezes. Soil frost heaving water can not migrate. Zhao et al. (2017) conducted a freeze-thaw cycle test on gravel subgrade soil layer, and concluded that the number of freeze-thaw cycles directly affected the water and salt content, and showed a positive correlation trend, showing a small to large distribution. The reason is that in the early stage of freeze-thaw, the soil has no migration channel, the water rate is slow, and the overall salt distribution is wave with the flow of time.

3. The Influence of Environmental Water on the Concrete Structure

3.1. Dissolution Erosion (Soft Water Erosion)

The hydrating substances in cement rock need to be produced stably in a specified amount of lime aqueous solution. If the lime content of the aqueous solution is lower than the limit lime content of the hydrated product, the hydrated product is quickly completely dissolved or decomposed. And the solubility of calcium hydroxide is very large, especially in soft water (slightly soft and less hard water), its solubility is greater. When the cement stone is placed under water, especially in soft water, calcium hydroxide will first be hydrolyzed until the content of calcium hydroxide in the aqueous solution exceeds the limit of lime content (Chen et al., 2016; Cheng, 2018; Wu et al., 2018). However, if the ambient water is turbulent, the hydrolyzed calcium hydroxide will be washed away by the water flow, and the limit lime content will be far from being reached. Calcium hydroxide will continue to be hydrolyzed. Especially when the concrete structure is not tight or there are cracks, a large amount of water enters the concrete under the action of high pressure water. Calcium hydroxide dissolves rapidly and leaches out. Its dissolving effect will become serious. With the continuous development of this process, the lime content of the water in the void is further reduced (Zhang et al., 2012), and has caused the hydrolysis of calcium silicate hydrate and calcium aluminate hydrate. The internal structure of the corresponding cement stone is damaged, and the hardness is further reduced, resulting in the destruction of the entire building. The degree of melting corrosion is directly related to the degree of softness and hardness of water. When the environmental water quality becomes hard, or the water weight carbonate concentration is relatively high, the solubility of calcium hydroxide is negatively correlated, and the erosion degree is weak. On the contrary, the softer the natural environment water, the stronger the degree of corrosion.

3.2. Carbonate Erosion

Rainwater, some springs, and groundwater all contain some free carbonate roots (CO_2), When the concentration is too much, it will play the erosion of cement rock (Karagöl et al., 2018; Zhang et al., 2005). This process is a chemical reaction of calcium hydroxide and carbonate in the cement rock to form calcium carbonate ($CaCO_3$) solution. After the production of calcium carbonate, it reacts with molecular carbonate to form calcium bicarbonate solution, which is soluble in water, as follows:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O \tag{1}$$

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca(HCO_3)_2 \tag{2}$$

Once the cement stone forms calcium bicarbonate under the action of high pressure water with a special treatment process, or is washed away after dissolving in water, these reactions will always be not stable. Calcium hydroxide will continue to start the chemical reaction, and the continuous loss, so that the lime content in the cement rock is gradually reduced, so that the hardened cement rock structure is broken.

Free carbonation in ambient water is positively correlated with erosion; if the temperature is high, the erosion rate will increase.

3.3. General Acid Erosion

Free acidic compounds are found in some groundwater and industrial wastewater. These acids can work with the calcium hydroxide in the cement stone to form a certain amount of calcium carbonate salts (Wang et al., 2024; Mao et al., 2006). The calcium salt is either soluble in water or crystallized in the cement rock gap, expanding in volume and producing corrosive effect. Therefore, the chemical formula between calcium hydroxide and hydrochloric acid and sulfuric acid is as follows:

$$Ca(OH)_2 + 2HCl = CaCl_2 + 2H_2O \tag{3}$$

$$Ca(OH)_2 + H_2SO_4 = CaSO_4 \cdot 2H_2O \tag{4}$$

Calcium chloride obtained after the reaction ($CaCl_2$) Is soluble in water; gypsum ($CaSO_4 \cdot 2H_2O$) will crystallize inside the gap in the cement stone, the volume will rapidly expand, the cement rock is completely broken. Gypsum can also play with the calcium aluminate hydration in cement rock, produce the calcium sulfur aluminate crystal layer, the destructive force becomes stronger. When the content of hydrogen ions in environmental water is larger, or the smaller the pH value, the erosion is more serious.

3.4. Measures to Prevent Water Erosion

To further improve the durability of cement concrete. And prevent the concrete from being damaged by the surrounding water. The construction process should first study and analyze the water quality of the surrounding environment. It is necessary not only to analyze the water quality of the surrounding environment of the river and groundwater, but also to conduct geological research on the reservoir area of the hydropower station, so as to prevent the surrounding environmental water condition from changing due to the flooding of the higher areas after the reservoir is impounded, resulting in corrosion damage. When the analysis results confirm that the water in the surrounding environment has the effect of erosion, the general protection measures are mainly: 1) According to the characteristics of the corrosion of the surrounding environmental water, select the corresponding types of concrete materials. 2) Increase the compactness of concrete materials as much as possible, reduce the infiltration effect of water, reduce the corrosion damage effect of surrounding water, and slow down the rate of corrosion damage. 3) If necessary, a protective film can be provided on the surface of the mortar, such as the construction of asphalt waterproof layer, impervious cement shotcrete layer and plastic waterproof layer.

4. The Effect of Sulfate on the Concrete Structure

Sulfate corrosion is also one of the main reasons leading to durability defects of concrete components and even component damage (Chen et al., 1988). It is also a more complex process, which is very harmful to concrete components. At present, common sulfate corrosion mainly includes sodium salt, calcium salt, magnesium salt and potassium salt, and the corrosion types roughly include external corrosion, internal corrosion (Gao et al., 2010; Zhang et al., 2017; Song et al., 2010), physical corrosion and biochemical corrosion. Sodium sulfate corrosion refers to the secondary hydration reaction of SO_4^{2-} in environmental water and cement hydration product $Ca(OH)_2$ to form AFm, AFt, gypsum, carborundum, etc. A small amount of such products will be filled in the void of concrete components and slowly accumulated and dense, thus promoting the improvement of cement strength. However, due to the continuous occurrence of chemical reactions, the increase of products in the pore pipeline will form an expansion effect and damage the hardened cement structure, resulting in the expansion of structural gaps and volume expansion, and then damage the concrete members.

4.1. Main Factors Affecting Sulfate Erosion

The formation of concrete's resistance to sulfate corrosion is closely related to the type and amount of cement used, the type and amount of mineral admixtures, and the water-to-cement ratio. Research has shown that concrete's resistance to sulfate corrosion is largely dependent on the relative concentration of minerals in the cement clinker (Rajasekaran, 2005), with the relative concentration of C_3A and C_3S in the cement having a direct impact on concrete's resistance to sulfate corrosion. The hydration of C_3A produces calcium aluminate hydrate, which is a prerequisite for the formation of ettringite. Meanwhile, the hydration of C_3S and C_2S in the cement produces larger crystals, which are the main conditions for the formation of ettringite and gypsum. The amount of cement and the water-to-cement ratio directly determine the density of the concrete, thereby determining its resistance to sulfate corrosion. Research has shown that the trial pieces with lower water-to-cement ratios have better resistance to corrosion (Quan, 2023; Zhang et al., 2023; Meng et al., 2023; Liu, 2023). In addition, the addition of mineral fillers (such as slag powder) can enhance the concrete structure's resistance to sulfate corrosion. Generally speaking, the greater the amount of mineral admixtures, the stronger the concrete's resistance to sulfate corrosion. The reasons for this are as follows: 1) Active admixtures can reduce the concentration of C_3A and C_3S; 2) Mineral fillers undergo a secondary hydration reaction in the cement matrix (Shafique et al., 2016; Shi et al., 2016), reducing the possibility of forming expansive substances such as gypsum, etc., but these substances do not crystallize because the concentration of the hydration product is reduced, and the concentration of expansive substances in the concrete material is also reduced, thus improving the concrete material structure's resistance to sulfate corrosion.

Sulfate solution is divided into general sodium sulfate corrosion and $MgSO_4$

Corrosion two categories. The first one is basically the SO_4^{2-} corrode the concrete, while the second is essentially due to Mg^{2+} of the presence of an increased SO_4^{2-}. The corrosion of concrete causes its corrosion damage, which is basically due to $MgSO_4$. The $CaSO_4$ is produced by neutralizing the $Ca(OH)_2$ chemical reaction $CaSO_4$, but $CaSO_4$ would be further associated with $CaO \cdot Al_2O_3 \cdot 12H_2O$ chemical reaction, thus promoting the chemical reaction to the end, further aggravating the corrosion of sulfate to concrete components.

The results show that according to the different content of SO_4^{2-}, Concrete corrosion mechanism, damage degree, corrosion products will also be different (Li, 2020; Fang et al., 2019). When the SO_4^{2-} content is low, AFt crystals form first; when the SO_4^{2-} content is higher, the gypsum is mostly destroyed; When the content is located between the two, it is referred to as SO_4^{2-}, the same formation of calcium alum stone and gypsum. The corrosion resistance of concrete decreases with the decrease of environmental pH; when pH = 12 - 12.5; pH = 11.6 - 12.5; pH = 10.6 - 11.6; pH < 10.6.

4.2. Measures to Prevent Sulfate Erosion

4.2.1. Select the Appropriate Concrete Raw Materials

Taking into account the specificity of the building environment, it is necessary to reasonably select the raw materials for concrete (He et al., 2010). In the process of mixing and constructing concrete, low-C_3A cement clinker should be selected for concrete materials, and the grade of aggregate should be further optimized. In addition, appropriate amounts of mineral admixtures (such as slag powder) and concrete admixtures should be added to reduce the water-to-cement ratio, change the pore structure of concrete materials, and improve their density, so as to enhance the resistance of concrete components to sodium sulfate corrosion.

4.2.2. Improve the Concrete Density

A large number of scientific studies have proved that the sulfate corrosion resistance of concrete is related to the tightness of concrete, and its tightness is also affected by the size of the water-cement ratio. Therefore, the water-cement ratio of building concrete should be strictly restricted, so as to improve the compactness of concrete.

4.2.3. Set Up the Isolation Layer

Coating a protective layer with strong corrosion resistance on the surface of formed concrete, separating the SO_4^{2-} and other erosive ions and moisture in the surrounding environment from the concrete surface layer, can not only reduce the chemical reaction between SO_4^{2-} and its hydration substances, improve the impermeability of concrete, but also effectively avoid corrosion damage to concrete components.

4.2.4. Use of a Preservative

In China, some key construction projects generally use special cement to enhance the sulfate corrosion resistance of concrete components, but because special cement manufacturers are few and expensive, it cannot be applied on a large scale. Therefore, in the process of mixing concrete, antioxidants can be added, or special cement can be replaced by general silicate composite, which can not only save a lot of production costs, but also improve the erosion resistance of concrete structures.

5. The Influence of Chloride Salt on the Concrete Structure

Steel damage and deterioration of concrete components are largely caused by Cl^- corrosion. In saline-alkali areas, steel concrete components are exposed to chloride ion solution for a long time, which is easy to cause corrosion damage and a lot of durability problems. There are roughly several methods for Cl^- to enter the concrete: first, in the process of mixing concrete with the raw materials added to the concrete, and second, in the external corrosion environment of Cl^- through a variety of methods (such as capillary, infiltration, etc.) and expanded into the concrete. With the gradual addition of Cl^- to concrete, when the Cl^- content near the steel bar reaches the highest content that triggers the passivation film reaction on the surface of concrete and steel bars, chloride ions will chemically react with the passivation film on the surface of concrete and steel bars, resulting in damage to the passivation film, resulting in corrosion of concrete and steel bars, and finally damage to the reinforced concrete structure.

5.1. Main Factors Affecting Chloride Salt Erosion

5.1.1. Thickness of Concrete Protective Layer

Scientific research has confirmed that the thickness of the concrete protective layer determines the corrosion degree of chlorine to the diameter of the reinforcement, and the chloride diffusion rate is inversely proportional to the thickness of the concrete protective layer. Therefore, a moderate increase in the thickness of the protective film helps to delay the time of steel corrosion, but the thickness of the protective film can not be infinitely large, when the thickness of the protective film reaches the maximum limit, the reinforced concrete will appear more micro cracks, which creates favorable conditions for chloride ion to enter the concrete. Therefore, the thickness of the protective layer should be strictly controlled according to the environment of the concrete structure.

5.1.2. Cement Variety and Water-Cement Ratio

Cement type and water-cement ratio are the main factors that determine the hydration products of concrete and the compactness of concrete components. The higher the concentration of C_3A in cement clinker, the more complete the hydration reaction of cement and the stronger the corrosion resistance of concrete to chloride ions. In addition, the concrete compactness is negatively correlated with the water-cement ratio and porosity of concrete, and the water-cement ratio directly determines the diffusion rate of chloride ions and the corrosion degree of reinforcement materials.

5.1.3. Content of Chloride Ion on the Surface of the Reinforcement

The concentration of chloride ion on the surface of steel bar directly determines the degree of corrosion of steel bar. The higher the concentration of chloride ion on the surface of steel bar, the easier the steel bar is to corrode.

Therefore, we should not only take corresponding measures to increase the compaction degree of concrete, but also strictly control the concentration of chloride ion in the raw materials of concrete, so as to limit the concentration of chloride ion on the surface of steel bar.

5.1.4. Maintenance Conditions

If the curing process of concrete structure does not meet the standard conditions, it will lead to incomplete cement hydration reaction, which will weaken the corrosion resistance of concrete, and accelerate the chloride ion into the concrete interior. In addition, the curing period can not ignore the impact of environmental temperature of chloride corrosion rate, when the environmental temperature is too low, can reduce the hydration rate and early strengthening of concrete, but the early environmental temperature is too low will lead to early concrete strengthen development slow, hydration product distribution, can make the porosity of concrete components, concrete is not close, increase the diameter of steel corrosion.

5.2. Measures to Prevent Chlorine Salt Erosion

5.2.1. Select the Appropriate Concrete Raw Materials

Cement has the highest chloride ion absorption function of C_3A, and concrete's resistance to chloride ion corrosion is gradually improved with the increase of C_3A concentration in concrete. Therefore, in the process of mixing concrete, it is necessary to use the cement with the highest concentration of C_3A in the cement clinker, and the appropriate mineral filler (such as slag powder), rust inhibitor, etc., which can increase the density of the concrete mix and effectively reduce the diffusion rate of chloride ions, thereby preventing the corrosion of the steel bar material.

5.2.2. Strictly Control the Particle Size of the Aggregate and the Thickness of the Concrete Protective Layer

In the process of mixing concrete, it is necessary to choose appropriate particle size and good graded aggregate to reduce the porosity of concrete, and to appropriately improve the thickness of concrete protective layer to delay Cl^- Infiltration into the surface layer of reinforcement in order to reduce the corrosion degree of reinforcement.

5.2.3. Strictly Control the Content of Chloride Ions in Concrete

The standard specification clearly stipulates that the concentration of ordinary concrete: chloride ion shall not exceed 0.10% (percentage of cement mass); prestressed cement: chloride ion concentration is generally not higher than 0.06% (percentage of cement mass). Since many areas in the north are located in the saline-alkali land zone, corresponding measures must be taken to limit the Cl^- in the concrete. The most effective method is to limit the concentration of Cl^- in the concrete composition.

5.2.4. Set Up the Isolation Layer

Before the combination of concrete and reinforced concrete, on the premise of not reducing the mutual gripping force of steel and concrete, a layer of insulation layer can be coated on the surface of steel, so that the Cl^- in the concrete and steel are separated, to prevent steel corrosion. In addition, when the concrete specimen is cured and formed, the first layer of paint can also be sprayed on the surface of the concrete to form an isolation layer with the concrete surface to reduce infiltration, so as to effectively delay the diffusion of aggressive ions such as Cl^- to the inside of the concrete, thereby preventing the surface corrosion of the steel bar.

6. Research Outlook

6.1. Water and Salt Migration Study

Water-salt migrated under a freeze-thaw cycle. Water salts will accumulate on the surface of the soil. At present, it is generally believed that water and salt migration will produce the most basic water and salt temperature conditions. Water and salt are the internal cause, and temperature is the external cause. Water convection, temperature, and cooling efficiency all directly affect the salt migration. At present, most of the indoor single-factor tests are used. Multi-factor coupling will be the research focus in the future.

6.2. Water and Salt Can Affect the Concrete Structure

Water and salt migration will affect the concrete structure. In practical engineering, there are mainly environmental water erosion, sulfate erosion, chloride erosion, environmental water erosion can be divided into soft water erosion, carbonated acid erosion, general acid erosion, sulfate erosion can be divided into common sulfate erosion and magnesium sulfate erosion. At the same time, for the corresponding erosion process, reasonable selection of concrete materials, set up isolation layer, improve the concrete density and other measures. However, in practical engineering, the erosion of many factors is not considered. In the future, the erosion effect of water and salt should be considered comprehensively.

7. Conclusion

1) At present, there are two main means to study water and salt migration indoors. Water and salt content, salt type and temperature will affect the water and salt migration rate. At the same time, indoor research is too single. For such ideal situations, multi-field coupling can be taken as the research direction in the future.

2) The main impact on the concrete structure is environmental water erosion, sulfate erosion, chloride erosion, environmental water erosion can be divided into soft water erosion, carbonated acid erosion and general acid erosion, and sulfate

erosion can be divided into common sulfate erosion and magnesium sulfate erosion. This paper describes the influencing factors of each erosion process, and also puts forward several preventive measures, such as reasonably selecting the concrete material, setting up the isolation layer, and improving the concrete density. In the actual construction process, we should provide the corresponding preventive measures in each erosion process, so that the concrete components have the characteristics of durable environmental conditions and operating conditions, as far as possible to lengthen the application period, increase benefits.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 51869029).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Bing, H., & He, P. (2011). Experimental Study on the Redistribution Law of Water and Salt in Saline Soil under Different Freezing Methods. *Rock and Soil Mechanics, 32,* 6.

Cary, J. W., & Mayland, H. F. (1972). Salt and Water Movement in Unsaturated Frozen Soil. *Soil Science Society of America Journal, 36,* 549-555. https://doi.org/10.2136/sssaj1972.03615995003600040019x

Chen, D., Yu, X. T., Liao, Y. D. et al. (2016). Research Progress on Sulfate Attack of Concrete. *Journal of Chongqing Jiaotong University: Natural Science Edition, 35,* 7.

Chen, X. B., Qiu, G. Q., Wang, Y. Q. et al. (1988). Physical and Chemical Properties and Mechanical Properties of Heavy Saline Soil under Temperature Changes. *Science in China, No. 4,* 429-438.

Cheng, L. (2018). *Study on the Strength and Volume Change Characteristics of Saline Soil and the Influence of Freeze-Thaw Cycles on Its Structure*. Xi'an University of Technology.

Corwin, D. L., & Rhoades, J. D. (1988). The Use of Computer-Assisted Mapping Techniques to Delineate Potential Areas of Salinity Development in Soils: II. Field Verification of the Threshold Model Approach. *Hilgardia, 56,* 18-32. https://doi.org/10.3733/hilg.v56n02p015

Fang, Q. Y., Chai, S. X., Li, M. et al. (2016). The Influence of Freeze-Thaw Cycles on the Compressive Strength and Deformation of Solidified Saline Soil. *Journal of Rock Mechanics and Engineering, 35,* 7.

Fang, X. W., Lou, Z. K., Gao, Y. L. et al. (2019). Research Progress on Frost Resistance Durability of Concrete under Sulfate Attack. *Concrete, No. 12,* 6.

Gao, Y. J., Wang, Q., Chen, H. E. et al. (2010). Study on the Influence of Temperature on the Moisture Migration of Seasonal Frozen Soil. *Journal of Engineering Geology, 18,* 698-702.

He, K., Wang, E. P., Wang, W. J. et al. (2010). Performance Study of Migratory Anticorrosive and Rust-Inhibiting Agents. *Concrete, No. 8,* 3.

Karagöl, F., Yegin, Y., Polat, R., Benli, A., & Demirboğa, R. (2018). The Influence of Lightweight Aggregate, Freezing-Thawing Procedure and Air Entraining Agent on Freezing-

Thawing Damage. *Structural Concrete, 19,* 1328-1340. https://doi.org/10.1002/suco.201700133

Konrad, J., & Morgenstern, N. R. (1980). A Mechanistic Theory of Ice Lens Formation in Fine-Grained Soils. *Canadian Geotechnical Journal, 17,* 473-486. https://doi.org/10.1139/t80-056

Li, S. W. (2020). Review on Water and Salt Migration in Saline Soil in Cold and Arid Regions under Freeze-Thaw Cycles. *Water Resources and Hydropower Engineering, 51,* 11.

Liu, S. P. (2023). *Study on the Mechanism and Life Prediction of New Anti-Corrosion Measures for Early-Age Concrete in Saline Soil Areas*. Master's Thesis, Lanzhou Jiaotong University.

Mao, X. S., Li, N., Wang, B. G. et al. (2006). Theoretical Model and Numerical Simulation of Water-Thermal-Mechanical Coupling in Permafrost Roadbed. *Journal of Chang'an University: Natural Science Edition, 26,* 5.

Meng, X. H., Feng, Q., Zhang, Y. S., Qiao, H. X., & Xie, X. Y. (2023). Corrosion Deterioration Behavior and Competitive Failure Analysis of Reinforced Concrete in Saline Soil Environment. *Materials Review, No. 14,* 44-53.

Nassar, I. N., & Horton, R. (1992). Simultaneous Transfer of Heat, Water, and Solute in Porous Media: I. Theoretical Development. *Soil Science Society of America Journal, 56,* 1350-1356. https://doi.org/10.2136/sssaj1992.03615995005600050004x

Quan, Z. P. (2023). *Study on the Resistance of Ultra-High Performance Cement-Based Composites to Sulfate Attack in the Western Saline Soil Environment*. Master's Thesis, Xi'an University of Architecture and Technology.

Rajasekaran, G. (2005). Sulphate Attack and Ettringite Formation in the Lime and Cement Stabilized Marine Clays. *Ocean Engineering, 32,* 1133-1159. https://doi.org/10.1016/j.oceaneng.2004.08.012

Richards, L. A. (1931). Capillary Conduction of Liquids through Porous Mediums. *Physics, 1,* 318-333. https://doi.org/10.1063/1.1745010

Shafique, U., Anwar, J., Ali Munawar, M., Zaman, W., Rehman, R., Dar, A. et al. (2016). Chemistry of Ice: Migration of Ions and Gases by Directional Freezing of Water. *Arabian Journal of Chemistry, 9,* S47-S53. https://doi.org/10.1016/j.arabjc.2011.02.019

Shi, Q., Zhang, Y. F., Li, Y. et al. (2016). Study on the Law of Water and Salt Migration under Freeze-Thaw Cycle Conditions in Natural Saline Soil of the Lop Nur. *Engineering Investigation, No. 4,* 5.

Skopp, J., & Warrick, A. W. (1974). A Two-Phase Model for the Miscible Displacement of Reactive Solutes in Soils. *Soil Science Society of America Journal, 38,* 545-550. https://doi.org/10.2136/sssaj1974.03615995003800040012x

Song, H. W., Ann, K. Y., Pack, S. W., & Lee, C. H. (2010). Factors Influencing Chloride Transport and Chloride Threshold Level for the Prediction of Service Life of Concrete Structures. *International Journal of Structural Engineering, 1,* 131-144. https://doi.org/10.1504/ijstructe.2010.031481

Tian, Q. L., Zhu, S. Y., Lu, J., Song, L., & Wang, X. C. (2019). Study on the Water and Salt Migration Law of Saline Soil in the Cold and Arid Region of Northwest China. *Highway, No. 8,* 6.

Wang, Y. P., Wang, Z. J., Wang, L. J., Liu, J. L., Feng, Q., & Zhang, Y. S. (2024). Study on the Accelerated Corrosion Deterioration Behavior of Reinforced Concrete in Saline Soil Environment. *Concrete, No. 6,* 76-83, 92.

Wang, Z. (1993). *Chinese Saline Soil* (pp. 283-290). Science Press.

Wu, Y. P., Wang, N., Pan, G. F. et al. (2018). Study on the Frost Heaving Characteristics of High Salt Fine Sand in Northern Qinghai. *Journal of Glaciology and Geocryology, 40,* 7.

Xiao, Z. A., & Lai, Y. M. (2018). Study on the Water and Salt Migration Law of Saline Soil under Freezing-Thawing and Wet-Dry Cycles. *Journal of Rock Mechanics and Engineering, 37,* 9.

Zhang, D. F., Zheng, Q. H., & Dong, Z. Y. (2005). Discussion on the Mechanism of Water and Salt Transport in Soil under Freeze-Thaw Conditions. *Bulletin of Soil and Water Conservation, 25,* 14-18.

Zhang, G. T., Li, M. Q., & Liu, S. T. (2023). Shear Behavior of Fiber Concrete Columns under Load-Saline Soil Environment Coupling. *Journal of Hunan University (Natural Sciences), No. 11,* 147-158.

Zhang, H. Y., Jiang, X., Wang, J. F. et al. (2016). Study on the Capillary Transport Mechanism of Salt in Mural Ground. *Rock and Soil Mechanics, 37,* 11.

Zhang, J. X., Wang, X., Wang, Y. K. et al. (2017). Study on Rainfall Infiltration and Water Migration Law of Dried Soil in Forest Land in Loess Hilly Region. *Journal of Soil and Water Conservation, 31,* 8.

Zhang, Y., Fang, J. H., Liu, J. K. et al. (2012). Study on the Characteristics of Water and Heat State Changes and the Law of Water and Salt Migration in the Saline Soil of Qarhan Region. *Journal of Geotechnical Engineering, 34,* 5.

Zhao, A. L., Zhu, D. C., & Liu, J. Y. (2017). Experimental Study on the Engineering Characteristics of Gravel Soil Subgrade under Freeze-Thaw Cycles. *Road Subgrade Engineering, No. 1,* 5.

Zhao, G., Tao, X. X., & Liu, B. (2009). Experimental Study on Moisture Migration during the Freeze-Thaw Process of Undisturbed Soil. *Journal of Geotechnical Engineering, No. 12,* 6.

Zhou, F. X., Zhou, L. Z., Wang, L. Y. et al. (2020). Study on the Water and Salt Migration and Deformation Characteristics of Unsaturated Saline Soil under Temperature Gradient. *Journal of Rock Mechanics and Engineering, 39,* 16.