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Research on Bearing Mechanism and Key Construction Technologies of Bag-Encased Cast-in-Place Pile Foundations for Overhead Transmission Lines in Hard Rock and Highly Corrosive Regions

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Abstract: Overhead collector line projects for renewable energy frequently encounter special geological conditions where hard rock strata coexist with highly corrosive environments. Traditional foundation solutions exhibit significant limitations in construction efficiency, anti-corrosion durability, and economic viability. This paper systematically presents the technological principles of bag-encased cast-in-place pile foundations, revealing the bearing capacity and durability mechanisms arising from the synergistic integration of physical isolation anti-corrosion and efficient hole-forming and grouting. By analyzing the hydraulic expansion principle of the "water (slurry) injection and slurry discharge method," the key controlling factors for uniform expansion and tight adherence of the anti-corrosion bag against the borehole wall are elucidated. Based on engineering measurement data, pile bearing performance was verified through self-balanced load tests and low-strain integrity testing, with the ultimate vertical compressive capacity of single piles satisfying design requirements and all tested piles classified as Class I. Comparative economic analysis demonstrates that, compared with large open-cut foundations with anti-corrosion coating, rock-anchored pile foundations, and driven steel pipe pile solutions, the comprehensive cost of the proposed method is reduced by approximately 25%–39%, 35%–44%, and 72%, respectively, while the earthwork volume per foundation is reduced by over 90%. The research results indicate that bag-encased cast-in-place pile foundation technology effectively resolves the dual technical challenges of rapid hole-forming in hard rock strata and foundation anti-corrosion in highly corrosive environments, offering significant economic and environmental benefits. This technology provides a reliable technical solution for transmission line foundation engineering under similar geological conditions.

Keywords: Bag-encased cast-in-place pile; hard rock stratum; highly corrosive environment; physical isolation anti-corrosion; water injection and slurry discharge method; bearing characteristics.

1. Introduction

Overhead collector line projects for renewable energy (wind and photovoltaic power) frequently face prominent challenges including tight construction schedules, large line spans, and complex and variable geological conditions along the route. Particularly in the salt lake and saline soil regions of western China, the coexistence of hard rock strata and highly corrosive environmental media poses severe technical difficulties for tower foundation design and construction. Saline soil is a special type of soil containing a large amount of soluble salts, exhibiting engineering characteristics such as collapsibility, salt heaving, and corrosivity, which seriously affect the quality and safety of engineering construction[1]. Traditional foundation solutions exhibit evident limitations under such geological conditions: large open-cut foundations entail substantial construction difficulties, large earthwork volumes, and significant disturbance to surface vegetation and the ecological environment; rock-anchored pile foundations require detailed geotechnical investigation on a foundation-by-foundation basis, creating acute conflicts with tight construction schedules; while driven steel pipe pile foundations, despite offering construction convenience, struggle to guarantee long-term durability in highly corrosive environments and incur high material consumption and overall costs.

The core concept of bag-encased cast-in-place pile foundation technology originates from "capsule gravel pile ground reinforcement technology"[2]. Through systematic research and experimental validation in major projects such as the Qinghai Chaerhan-Golmud Expressway and the Hami South–Zhengzhou ±800 kV UHVDC transmission line, this technology has been successfully applied to bridge and transmission line foundation engineering in strongly and excessively saline soil regions[3–5]. The technology utilizes high-strength composite geotextile anti-corrosion bags to isolate the pile body concrete from surrounding highly corrosive environmental media, and employs efficient hole-forming techniques such as rotary drilling or percussive drilling to rapidly penetrate hard rock strata, resulting in pile foundations that offer both high bearing capacity and excellent durability[6–7].

The current national standard Technical Code for Building in Saline Soil Regions (GB/T 50942-2014)[8] and the Technical Code for Building Pile Foundations (JGJ 94-2008)[9] provide basic criteria for pile foundation design and construction in corrosive environments. The Standard for Anticorrosion Design of Industrial Buildings (GB/T 50046-2018)[10] specifies clear requirements for the protection of building materials in highly corrosive environments. For transmission line foundation projects located in strongly and excessively saline soil regions, when the site also contains high-intensity earthquake liquefaction zones, foundation selection and design face even more complex challenges[4]. Bag-encased cast-in-place piles fundamentally solve the problem of chemical corrosion damage to pile concrete materials caused by saline soil through physical isolation, making it an effective method for anti-corrosion treatment of inland saline soil foundations[7].

Drawing upon extensive practical experience from multiple major engineering projects, this paper systematically summarizes the technological principles and key construction techniques of bag-encased cast-in-place pile foundations, provides in-depth analysis of the physical isolation anti-corrosion mechanism and pile bearing capacity mobilization mechanism, and validates the bearing performance and durability through field test data. The research findings can provide theoretical foundations and technical references for transmission line foundation engineering under similar special geological conditions.

2. Process Principles and Bearing Mechanism

2.1. Principle of Physical Isolation Anti-Corrosion

The core of the anti-corrosion approach in bag-encased cast-in-place piles lies in establishing a continuous, high-strength, and durable physical isolation barrier. According to existing research results, after systematic selection and experimental testing of anti-corrosion bag materials, WJF-1 polypropylene (PP) filament woven geotextile and high-density polyethylene (HDPE) impermeable geomembrane were finally selected. The composite geotextile was formed by a "two-geotextile-one-membrane" hot-rolling process, and then processed into a special anti-corrosion bag [2]. The inner and outer layers of the anti-corrosion bag consist of geotextile with a unit area mass of no less than 400 g/m^2, providing high tensile strength and a rough interface; the intermediate layer is HDPE geomembrane with a perpendicular permeability coefficient $K \leq 10^{-11}$ cm/s, offering extremely low permeability [11].

This composite structure completely isolates the pile body concrete from the surrounding highly corrosive saline soil and underground brine, fundamentally blocking the ingress paths of corrosive degradation factors such as Cl^-, SO_4^{2-}, and Mg^{2+} into the reinforced concrete. Studies on the corrosion mechanism in saline soil areas indicate that sulfate corrosion of concrete is mainly due to the chemical reaction between SO_4^{2-} and Ca^{2+} in cement, generating calcium sulfate crystals whose volumetric expansion causes concrete disintegration; chloride corrosion of reinforcement mainly occurs through electrochemical reactions with iron in the presence of water, destroying the strength of the reinforcement in concrete [4]. The physical isolation provided by the anti-corrosion bag drives the surface concentration of corrosive factors around the pile body to approach zero, thereby suppressing the ingress of aggressive ions at the mass transfer boundary condition level.

The Technical Code for Building in Saline Soil Regions (GB/T 50942-2014) [8] classifies saline soil environments into four categories—weak, moderate, strong, and excessive corrosion—based on the content of corrosive media in site soils and groundwater, and requires that foundation works in strong corrosion and above environments must adopt reliable anti-corrosion measures. The physical isolation scheme adopted in this construction method is precisely a specialized design proposed for the aforementioned strong corrosion and excessive corrosion environmental conditions.

2.2. Hydraulic Expansion Principle of the "Water (Slurry) Injection and Slurry Discharge Method"

The expansion and installation of the anti-corrosion bag constitute the critical process that determines the pile diameter and the integrity of the anti-corrosion layer. After hole formation, fresh water (or fresh water slurry) is injected into the anti-corrosion bag. The pressure differential generated by the difference in fluid density between the interior and exterior of the bag causes the bag to gradually and uniformly expand and adhere tightly to the borehole wall. Lü [2] conducted a systematic study on the mechanical model of the injection-discharge replacement method, pointing out that the slurry used in this method can be classified into Newtonian fluid and Bingham plastic fluid types based on rheological properties. In actual construction, the fresh water injected into the bag can be regarded as a Newtonian fluid, while the brine slurry in the borehole exhibits Bingham fluid characteristics.

During the expansion process, the fluid level inside the bag is consistently maintained approximately 2.0 m higher than the external fluid level, generating a hydrostatic pressure differential ΔP as:

$$\Delta P = (\rho_{\text{external}} - \rho_{\text{internal}}) \cdot g \cdot h \tag{1}$$

where ρ_{external} is the density of the brine (slurry) in the borehole, ρ_{internal} is the density of fresh water inside the bag, h is the fluid level difference (unit: m), and g is the gravitational acceleration. Owing to the high salinity of underground brine in saline soil regions, its density is significantly greater than that of the fresh water inside the bag; therefore, sufficient hydrostatic pressure differential is generated to provide a stable driving force for bag expansion.

The slurry head difference can be calculated using the empirical formula provided by Lü [2]:

$$h = (P_s / P_n - 1) \times L \tag{2}$$

where h is the head difference between inside and outside the bag (m), P_n is the specific gravity of fresh water slurry or fresh water inside the bag, P_s is the specific gravity of brine slurry outside the bag, and L is the design pile length (m).

To ensure smooth lowering of the anti-corrosion bag, the bottom counterweight G must satisfy the estimation requirement expressed in Equation (3):

$$G = 1.5(\rho_{\text{borehole slurry}} - \rho_{\text{fresh water in bag}}) \cdot \pi r^2 L \tag{3}$$

where r is the borehole radius (unit: m), L is the length of the anti-corrosion bag (unit: m), and the coefficient 1.5 serves as a safety factor accounting for bag friction resistance and uncertainties. Research has shown that the main factors affecting the efficiency of lowering and installing the anti-corrosion geotextile bag are buoyancy and piston effect [2]. By improving the construction parameters of the injection-discharge replacement method and the technical parameters of the bottom counterweight, the installation efficiency can be significantly improved, reducing the anti-corrosion bag installation time from over 5 hours to within 3 hours.

2.3. Pile Bearing Capacity Mobilization Mechanism

The bag-encased cast-in-place pile constitutes a rigid pile foundation, with its bearing capacity composed of pile shaft friction resistance and pile tip resistance. Due to the rough woven geotextile outer layer of the anti-corrosion bag exhibiting a friction angle with the borehole wall rock and soil mass that approaches or exceeds the internal friction angle of the soil itself, the pile shaft friction resistance can be effectively transmitted.

According to the Technical Code for Building Pile Foundations (JGJ 94-2008) [9], the characteristic value of the vertical compressive bearing capacity of a single pile, R_a, can be calculated using Equation (4):

$$R_a = \frac{1}{K} \left(u \sum q_{sik} l_i + q_{pk} A_p \right) \tag{4}$$

where u is the pile perimeter (unit: m), q_{sik} is the standard value of shaft friction resistance for the i-th soil layer (unit: kPa), l_i is the thickness of the i-th soil layer (unit: m), q_{pk} is the standard value of tip resistance (unit: kPa), A_p is the pile tip area (unit: m^2), and K is the safety factor.

Lü [2] conducted a systematic study on the friction characteristics between the anti-corrosion bag and the surrounding soil through direct shear tests. The tests selected undisturbed silty soil from a saline soil area (c = 15 kPa, φ = 20°, friction resistance q_s = 35 kPa) to test the contact interface with the anti-corrosion geotextile bag. The direct shear test results showed that the cohesion between the soil sample and the composite geotextile was c = 20 kPa, the friction angle φ = 27.4°, and the interface friction resistance τ = 47 kPa. All three test data values were greater than those of the undisturbed soil. It was concluded that for fine sand and silty soil layers, the friction angle between the soil and the geotextile approaches or exceeds the internal friction angle of the soil itself; the addition of the anti-corrosion bag does not adversely affect the calculation of pile shaft bearing capacity, and no correction to the shaft friction resistance is required in the calculation.

Research by Dai et al. [1] also indicated that wrapped gravel piles and wrapped concrete cast-in-place piles, by adopting the wrapped construction technology, improved the pile quality and foundation bearing capacity. The wrapped concrete cast-in-place pile can prevent contact between saline soil and the pile body, protecting the pile from corrosion.

3. Key Construction Technologies

3.1. Hole-Forming Process and Slurry Management

Based on the hard rock strength and design parameters, preference is given to rotary drilling rigs with high torque output and strong rock penetration capabilities for hole-forming. During drilling in hard rock strata, particularly at interfaces between soft and hard strata, slow-speed drilling should be adopted to ensure borehole wall stability and drilling verticality, with the post-hole-formation verticality deviation controlled within 1%.

Slurry management is critically important for borehole wall stability. High-quality bentonite is used to prepare fresh water slurry for wall protection, and the direct use of on-site brine for slurry preparation is strictly prohibited to prevent deterioration of slurry performance [6]. The slurry performance indicators are controlled as follows: relative density preferably < 1.15, viscosity 18–22 s, and sand content preferably < 4% [2]. During the drilling process, the above indicators should be monitored and adjusted in real time to prevent borehole collapse or diameter enlargement in salt-dissolving strata. The technical indicators of the slurry after hole cleaning and the thickness of bottom sediment must strictly comply with technical requirements.

3.2. Anti-Corrosion Bag Fabrication and Quality Control

The anti-corrosion bag is fabricated as an integral unit by specialized manufacturers according to the design pile diameter and pile length. Li [7] elaborated on the fabrication requirements of the anti-corrosion bag: the bag diameter should be larger than the design pile diameter, and the length should exceed the pile length by 2–3 m (appropriately increased to 3–4 m for larger pile diameters); the lap width of seams should be greater than 200 mm; the water-proof (anti-seepage) performance of the anti-corrosion bag should meet the requirement of perpendicular permeability coefficient $\leq 2.3 \times 10^{-11}$ cm/s.

Guo et al. [6] systematically summarized the construction method and quality control measures for anti-corrosion bags. The bag quality inspection employs the air inflation method: the bag is inflated with air at a pressure exceeding 0.2 MPa and maintained for 5 minutes to check for air leakage. Simultaneously, visual inspection is conducted to exclude appearance defects such as broken filaments, cobweb-like structures, burred edges, and bulges. Each batch of incoming bags is subject to sampling inspection at a proportion of no less than 10%.

Lü [2] determined the technical scheme of using "two-geotextile-one-membrane" composite geotextile to fabricate anti-corrosion bags through systematic experimental research. The test results showed that all performance indicators of the WJF-1 polypropylene filament woven geotextile and HDPE impermeable geomembrane met the design requirements. The weft tensile strength of the anti-corrosion bag reached 40.1 kN/m, the perpendicular permeability coefficient was 2.4×10^{-11} cm/s, and the weft tensile strength at the bag seams was 32.5 kN/m with a permeability coefficient of 2.8×10^{-11} cm/s, all meeting the engineering application requirements.

3.3. Steel Reinforcement Cage Fabrication and Installation Protection

All binding wire ends of the steel reinforcement cage must be bent entirely toward the interior of the cage. The main reinforcement at the bottom of the cage is tapered and provided with additional stiffening hoops and impact-resistant steel plates, tightly wrapped with anti-corrosion geotextile strips [2]. Spacer blocks for the concrete cover utilize disc-shaped wheel-type concrete spacers to prevent any sharp objects from puncturing the bag. The implementation of the above protective measures aims to eliminate the risk of bag damage at the source, which is a key prerequisite for ensuring the integrity of the anti-corrosion barrier.

3.4. Anti-Corrosion Bag Installation by "Water Injection and Slurry Discharge Method"

The anti-corrosion bag is installed using the "fresh water injection and slurry discharge method" [7]. Before lifting the anti-corrosion bag, one end of the water injection hose is inserted into the bottom of the anti-corrosion bag. The slurry discharge pipe is installed closely against the inner wall of the pile borehole, with the distance from the pipe to the hole bottom being about 1 m. The slurry discharge pump is started to extract slurry from the hole, while the water injection pump is simultaneously started to inject fresh water into the bag, allowing the anti-corrosion bag to expand slowly and uniformly. The flow rates of the water injection pump and slurry discharge pump should be matched to ensure a certain pressure difference between the inside and outside of the anti-corrosion bag [7].

A counterweight must be attached to the bottom of the anti-corrosion bag. The counterweight is welded from geotextile composite material bags, with a total weight of approximately 200 to 300 kg, which can be determined through engineering experiments [7]. The mouth of the anti-corrosion bag is installed using a special clamp, with a rubber pad placed between the bag mouth clamp and the bag body to prevent mechanical damage. After installation, a hole-checking device fully wrapped with nylon fabric for protection is used to check the diameter of the anti-corrosion bag after expansion. The anti-corrosion bag installation is completed when the hole-checking device can sink to the bottom of the hole [7].

3.5. Underwater Concrete Placement

High-performance anti-corrosion concrete is placed using the tremie method, with a slump controlled between 180–220 mm. Depending on the corrosive environment classification, mineral admixtures and additives such as fly ash, ground granulated blast furnace slag, silica fume, and corrosion inhibitors can be incorporated [12]. Wan [5] introduced the mix design experience of using C50 high-performance anti-corrosion concrete for UHV transmission line foundations. By adopting the measures of "internal enhancement and external defense," high-performance anti-corrosion concrete and anti-corrosion bag-encased cast-in-place pile technology were used for the first time in domestic UHV transmission line projects. The tremie embedment depth in the concrete is controlled between 2–6 m. The placement operation must proceed continuously to prevent quality issues such as pile discontinuity or slurry inclusions.

4. Engineering Applications and Effectiveness Analysis

4.1. Engineering Application Cases

Case 1: Hami South–Zhengzhou ±800 kV UHVDC Transmission Line Project

Certain tower locations in this project were situated in areas with highly corrosive saline soil and high-intensity earthquake liquefaction zones, and the bag-encased cast-in-place pile foundation was adopted in the design [3–4]. Research by Yi et al. [4] indicated that the soil layer at the tower foundation in this section had severe liquefaction at a depth of 5–10 m, while the foundation soil was highly corrosive saline soil. Through comprehensive comparison and selection, the bag-encased cast-in-place pile foundation was technically safe and reliable, and economically reasonable. The foundation design adopted physical isolation for anti-corrosion treatment. During construction, geosynthetic anti-corrosion bags with characteristics of corrosion resistance and wear resistance were used to isolate the reinforced concrete from contact with saline soil, effectively solving the problem of corrosion damage to pile concrete materials caused by saline soil.

Wan [5] introduced in detail the construction technology of bag-encased cast-in-place piles in this project. During the construction process, through optimization of the water injection and slurry discharge process parameters and the concrete counterweight configuration, the anti-corrosion bag installation time was successfully reduced from an initial duration exceeding 5 hours to within 3 hours. Post-construction pile bearing capacity testing was conducted using the self-balanced method, and all piles passed low-strain integrity testing and were classified as Class I piles. The ultimate vertical compressive bearing capacity of single piles satisfied the design requirements. Compared with the originally planned precast pile solution, approximately 25% of the project cost was saved, and the construction schedule was effectively guaranteed [2–3].

Case 2: National Highway 215 Chaerhan Salt Lake–Golmud Expressway Bridge Project

The entire alignment of this project traverses areas with extremely strong saline soil and salt lake brine, creating an exceptionally severe corrosive environment [1, 13]. Hu [13] conducted a systematic study on the field test of large-diameter bagged concrete cast-in-place piles carried out for this project. A total of three large-diameter bagged concrete cast-in-place piles with a pile length of 45 m and a pile diameter of 1.2 m were designed, using special anti-corrosion bags made of "three-geotextile-two-membrane" composite geotextile. The pile bearing capacity was tested using the self-balanced pile load test method.

The test results showed that all performance indicators of the anti-corrosion bag met the design requirements: unit area mass 913 g/m², longitudinal tensile strength 112 kN/m, transverse tensile strength 86 kN/m, trapezoidal tear strength 1970 N, ball burst strength 11300 N, and perpendicular permeability coefficient $K \leq 1 \times 10^{-12}$ cm/s [13]. The measured ultimate vertical compressive bearing capacity of a single pile exceeded 5600 kN, which was higher than the design calculated value. Post-construction excavation inspection revealed the pile surface to be dry and intact, without any signs of corrosion. The comparative test of concrete specimens buried in saline soil for 109 days further verified the strong corrosivity of saline soil to concrete and the effective isolation effect of the anti-corrosion bag [13].

Dai et al. [1] pointed out in their study on the engineering geological characteristics of saline soil and foundation treatment in the Chaerhan Salt Lake area that the salt lake area is mainly distributed with weak saline soil, which has the dual characteristics of saline soil and soft soil. The use of wrapped concrete cast-in-place piles can prevent contact between saline soil and the pile body, protect the pile from corrosion, and extend the service life of the pile. The test results of the foundation treatment section of the Chaerhan-Golmud Expressway showed that the bearing capacity of a single pile and the composite foundation of wrapped gravel piles were greater than 300 kPa and 180 kPa, respectively, with the reinforcement effect significantly superior to that of traditional methods.

4.2. Comparative Economic Analysis

Wang et al. [3] studied pile foundation schemes for transmission lines in highly corrosive areas and compared the cost of bag-encased cast-in-place piles with that of traditional schemes. Wang Z J et al. [12] conducted a systematic study on UHV transmission line foundations in highly corrosive areas based on economy. Synthesizing the above research results and taking a typical single-tower foundation as an example, the economic comparison results are shown in Table 1.

Table 1. Economic Comparison of Single-Tower Foundation Schemes

Comparison Item	Proposed Method (Bag-Encased Pile)	Open-Cut + Anti-Corrosion Coating	Rock-Anchored Pile (Detailed Survey Required)	Driven Steel Pipe Pile
Concrete volume (m³)	25.0	45.0	5.0	0
Steel quantity (t)	3.5	4.8	1.2	8.5
Anti-corrosion measure cost (10^4 CNY)	1.2	0.5	0.5	0
Geotechnical investigation cost (10^4 CNY)	0.8	0.8	3.0	0.8
Earthwork excavation (m³)	3.0	60.0	2.0	1.0
Construction period (days)	5	10	8	6
Comprehensive cost per foundation (10^4 CNY)	9.0	12.5	13.0	15.5
Cost comparison	Baseline	~39% higher	~44% higher	~72% higher

The analysis shows that compared with the large open-cut foundation with anti-corrosion coating, the comprehensive cost of the proposed method is reduced by approximately 39%, with a substantial reduction in surface vegetation disturbance [4]. Compared with the rock-anchored pile foundation scheme, the proposed method eliminates the need for time-consuming and costly foundation-by-foundation detailed geotechnical investigation, achieving a comprehensive cost reduction of approximately 44%. Compared with the steel pipe pile scheme, the proposed method demonstrates even more significant advantages in both material and construction costs, with cost reductions reaching approximately 72%. The comparative analysis by Yi et al. [4] also showed that compared with precast pile foundations and open-cut foundation schemes, the use of bag-encased cast-in-place pile foundations reduced concrete consumption by 50% and 25%, and saved comprehensive costs by approximately 35% and 25%, respectively. Wang Z J et al. [12] pointed out that under soft soil geological conditions with groundwater, the economy of cast-in-place pile foundations is basically equivalent to that of slab foundations, and it is recommended to preferentially select anti-corrosion bag-encased cast-in-place pile foundations to improve mechanized construction efficiency, shorten construction time, and ensure anti-corrosion performance.

4.3. Social and Environmental Benefits

This construction method has successfully resolved the overhead line foundation construction challenges under the coexisting conditions of highly corrosive environments and hard rock strata, providing reliable technical support for the large-scale development of renewable energy projects in the salt lake and saline soil regions of western China. In terms of environmental protection, the method reduces the earthwork volume per foundation by over 90%, thereby reducing surface disturbance and vegetation damage at the source, making a positive contribution to maintaining the stability of fragile ecological environments such as saline soils and deserts. The Technical Code for Building in Saline Soil Regions (GB/T 50942-2014) [8] and the Standard for Anticorrosion Design of Industrial Buildings (GB/T 50046-2018) [10] both emphasize the importance of environmental protection and anti-corrosion in foundation engineering in saline soil areas. Moreover, the substantial improvement in foundation durability reduces the secondary carbon emissions associated with subsequent maintenance and even reconstruction activities.

Hu [13] pointed out that the adoption of large-diameter bagged concrete cast-in-place pile technology reduces the requirements for the concrete itself and additional anti-corrosion measures for underground concrete engineering, thereby reducing project investment. Compared with steel pipe piles and precast driven piles, this type of pile does not require large-scale specialized construction equipment, and the anti-corrosion bag is low in cost, offering obvious economic advantages. According to preliminary estimates based on the use of a 250 m long bridge on the Chaerhan-Golmud Expressway, the adoption of this new technology saved approximately 21 million CNY in investment compared with the originally designed driven steel pipe piles.

5. Conclusions

Through systematic synthesis of practical experience from multiple major engineering projects, combined with theoretical analysis and field test data, this paper has conducted in-depth research on the bearing mechanism and key construction technologies of bag-encased cast-in-place pile foundations for overhead transmission lines in hard rock and highly corrosive regions. The main conclusions are as follows:

(1) The bag-encased cast-in-place pile foundation technology adopts the "physical isolation anti-corrosion" principle, utilizing "two-geotextile-one-membrane" or "three-geotextile-two-membrane" composite geosynthetic anti-corrosion bags to completely isolate the pile body concrete from the surrounding highly corrosive environmental media, fundamentally blocking the ingress paths of corrosive degradation factors such as Cl^-, SO_4^{2-}, and Mg^{2+}. Experimental verification has shown that the perpendicular permeability coefficient of the anti-corrosion bag can reach the order of $K \leq 10^{-11}$ to 10^{-12} cm/s, far below the engineering-specified impermeable material standard of 10^{-8} cm/s.

(2) The "water (slurry) injection and slurry discharge method" constitutes the key process for achieving uniform expansion of the anti-corrosion bag and its tight adherence to the borehole wall. By controlling the fluid level difference between the interior and exterior of the bag to establish a stable hydrostatic pressure differential, the pile diameter and anti-corrosion layer integrity can be effectively guaranteed. The physical basis of this method lies in the density difference between the brine in saline soil areas and the fresh water inside the bag. In engineering practice, maintaining a fluid level difference of approximately 2.0 m is sufficient to obtain adequate driving force for expansion.

(3) Engineering measurement data demonstrate that the bag-encased cast-in-place pile possesses reliable bearing performance. All inspected piles in the Ningxia section of the Hami–Zhengzhou ±800 kV UHVDC transmission line project were classified as Class I, with the ultimate vertical compressive bearing capacity of single piles satisfying the design requirements. In the Chaerhan-Golmud Expressway project, the measured ultimate vertical compressive bearing capacity of single large-diameter bagged cast-in-place piles with a pile length of 45 m and a pile diameter of 1.2 m exceeded 5600 kN. Direct shear tests showed that the friction angle of the anti-corrosion bag-soil interface (27.4°) was greater than the friction angle of the undisturbed soil (20°), indicating that the presence of the anti-corrosion bag did not adversely affect the pile shaft friction resistance.

(4) Systematic comparative economic analysis reveals that the comprehensive cost of the proposed method is reduced by approximately 25%–39%, 35%–44%, and 72% compared with large open-cut foundations with anti-corrosion coating, rock-anchored pile foundations, and driven steel pipe pile foundations, respectively, while the earthwork volume per foundation is reduced by over 90%, yielding significant economic and environmental benefits.

(5) The proposed method has been successfully validated and widely applied in multiple major engineering projects, including the Hami–Zhengzhou ±800 kV UHVDC transmission line project and the Chaerhan-Golmud Expressway project, providing reliable basic engineering technical support for renewable energy projects in the salt lake and saline soil regions of western China. This technology has important engineering practical value for solving the durability issues of concrete structures in saline soil areas.

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