Comprehensive Detection Method and Leakage Prevention Measure for Classical Garden Pond

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Abstract. The issue of leakage in classical garden ponds after prolonged use is highly pronounced. The exerting effects are not only detrimental to the overall landscape of the garden but also lead to the wastage of valuable water resources. This paper takes the detection and remediation project of leakage in a classical garden landscape pond in Shanghai as a case study. Focusing on the formidable challenges encountered in investigating leakage in classical garden ponds, demanding on-site implementation conditions, and the elevated requirements for surrounding environmental conservation, a comprehensive approach encompassing terrain measurement geological exploration, and high-density electrical resistivity non-destructive testing is employed to conduct leakage detection in the ponds. This approach enables the accurate identification of leakage locations and the targeted establishment of flexible vertical impermeable barriers. Through comparative analysis utilizing water level monitoring, it is demonstrated that this leakage prevention remediation initiative effectively resolves the issue of pond leakage. It also could provide valuable insights and guidance for leakage detection and impermeable measures in other classical garden ponds.

Keywords: Classical garden; Landscape pond; Electrical resistivity tomography (ERT); Flexible cutoff wall.

1 Introduction

Existing research on pool leakage mainly focuses on artificially constructed pools made of concrete, including detection and waterproofing treatments for concrete cracks [1, 2]. However, there is limited research on the detection and management of leakage in garden pools, and no mature experience to follow. In 2005, the "waterproofing project" of the Old Summer Palace (The summer palace) sparked a significant controversy [3]. There is still a scarcity of targeted, feasible, and effective methods for detecting and addressing leakage in classical garden landscape pools. Therefore, conducting research on the detection of leakage locations and waterproofing disposal solutions for classical garden landscape pools holds significant importance.

Taking the leaking engineering project in a classical garden pond in Shanghai as an example, this garden represents one of the finest examples of classical garden art in

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southern China. Within the garden, there is a scenic water pond located adjacent to the river on the northern side, with stone revetments lining both sides of the river. Between the pond and the revetments, a concrete retaining wall of unspecified dimensions has been constructed, as depicted in Fig. 1. Since 2021, the water level in the Qiuxiapu pond has been steadily decreasing, accompanied by evident signs of water leakage. Automated water level monitoring data reveals an average daily decline of approximately 3.5 cm, with a daily leakage volume of approximately 65.6 m3.

The continuous leakage of the water pool has significantly affected the overall landscape aesthetics of the garden, necessitating prompt resolution of the water leakage issue.

Fig. 1. Laylayout of pond and river

The present project differs from conventional impermeability engineering in terms of the following challenges it entails:

(1)The investigation of leakage poses significant challenges due to various factors. Firstly, the irregular shape of the reservoir and the meandering course of the embankment present difficulties in locating potential leakage areas, with a perimeter spanning 650 meters. Moreover, the surrounding terrain exhibits significant undulations, resulting in variations in ground surface depths at potential leakage points. Lastly, the complex geological conditions at the site, particularly the substantial differences in properties between the shallow soil layers and the backfilled soil, further contribute to the complexity of identifying and determining the leakage points.

(2)The implementation conditions are stringent: The vicinity of the water pool is densely populated with buildings, rocks, and trees that require protection. The site for leak detection is limited, and the operational space is restricted, thereby limiting the application of conventional detection methods. The implementation of leakage prevention measures is constrained by spatial limitations, as the construction space is narrow, rendering conventional machinery unusable and significantly increasing the construction difficulty.

(3)The surrounding environment requires a high level of protection, necessitating the implementation of detection and impermeability measures that should not cause damage to the surrounding landscape and protective structures. The environmental protection standards are stringent. The implementation process should not disrupt the normal activities of park visitors, and on-site construction should adhere to high standards of civility. The detection and impermeability measures must not cause contamination to the water and soil, thus necessitating the selection of environmentally friendly and non-polluting impermeable materials.

2 Comprehensive detection and analysis

2.1 Comprehensive detection methodology

Considering the large surface area, intersecting perimeters, and complex topography of the pond under investigation, multiple techniques such as topographic surveying, geological exploration, and non-destructive testing were employed in this leakage investigation. Initially, an on-site reconnaissance and topographic survey were conducted on the landscape water pond. Through an investigation into the distribution of the pond and its surrounding environment, the suspected leakage area was identified as the northern side of the pond. Taking into account the position of the leakage point and the characteristics of the site's topography, a perturbation exploration method was adopted to carry out comprehensive probing work, eliminating potential leakage points and progressively narrowing down the scope. In order to understand the distribution and characteristics of the shallow soil layers along the edge of the pond, drilling holes were arranged within a certain range on the northern bank of the pond, with a cumulative depth of soil penetration reaching 3.5 meters. The drilling process employs small threaded drilling tools, with manual labor providing the driving force for shallow stratum penetration. The advancement per cycle does not exceed 0.5 meters, reaching a certain depth to complete the drilling process into the undisturbed soil.

Taking into account the observed locations of water leakage, site topography, and results of geological surveys during on-site reconnaissance, a further investigation was conducted using electrical resistivity tomography (ERT) [4] to detect the specific areas of leakage in the northern soil layers adjacent to the pond. Due to the presence of rocks and artificial hills near the pond, which do not meet the requirements for the continuous linear layout of Electrical resistivity tomography (ERT), the profiles were primarily arranged on the relatively open areas on both sides of the road to the north of the pond. Among them, two profiles (L1 and L2) were positioned on the west side of the discharge outlet, and one profile (L3) was positioned on the east side, as shown in Fig. 2 and Fig.3. The GMD-9 electrical resistivity meter was used in this investigation, and the Werner apparatus was employed to perform measurements on the three profiles separately. In addition, three water level monitoring points were arranged in Fig.3.

Fig. 2. Electrical resistivity tomography (ERT) testing

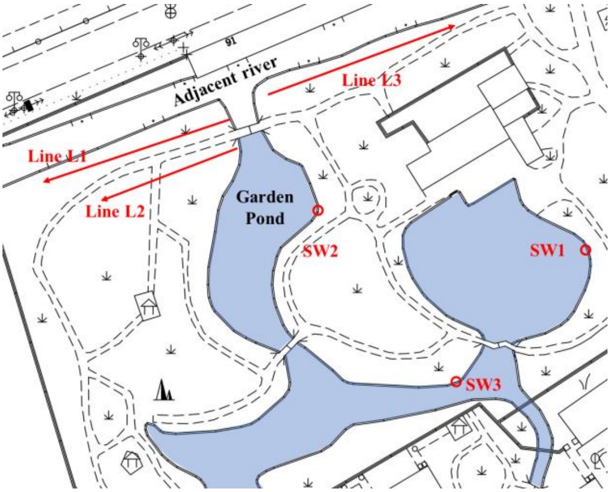
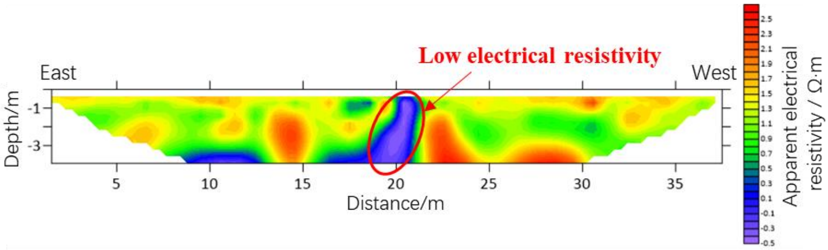


Fig. 3. Location of ERT lines and water level monitoring points

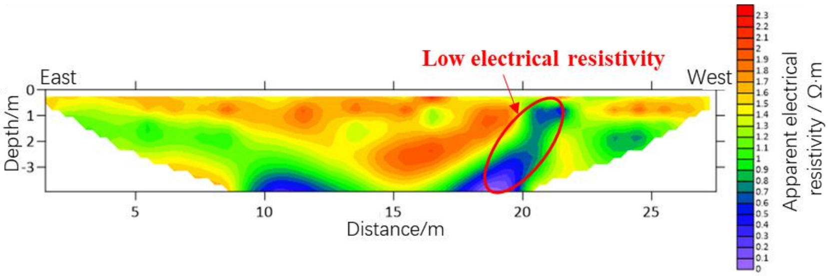
2.2 Electrical resistivity tomography (ERT) analysis

Based on the results of the topographic survey, it is evident that the surrounding ground elevation of the pond is generally higher than the water surface elevation by more than 1.0 m, except for the riverbed on the northern side. There is a high likelihood of groundwater flow from the surrounding strata into the pond, while the possibility of pond water infiltrating the surrounding soil layers is relatively low. The water surface elevation of the pond is approximately 0.55 m higher than that of the river channel on the northern side, creating a significant hydraulic head. This will result in the pond water seeping northward along the soil mass and also flowing into the river channel through leakage pathways. Geological investigation reveals that the second layer of the pond's edge consists of silty clay, which exhibits weak permeability and stable distribution, with the pond bottom located within this layer. The first layer, exposed through drilling, consists mainly of clayey fill soil with loose and heterogeneous characteristics.

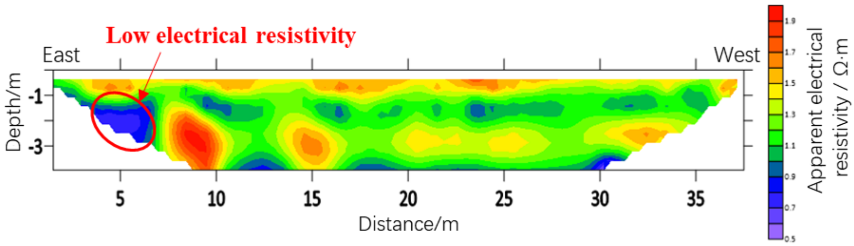
The data obtained from non-destructive testing is subjected to inversion processing to obtain the resistivity-depth profiles of each survey line position, as illustrated in Fig. 4. The detection profiles indicate that the overall impedance within the survey range is homogeneous, with only a localized relative low-resistivity anomaly enclosed within the red contour. Through comprehensive analysis considering the field conditions, it is evident that significant low-resistivity anomalies exist in the resistivity profiles of positions 18.5 m to 21.5 m along survey lines L1 and L2, while the resistivity profiles at other positions of these survey lines exhibit good layering characteristics. Furthermore, the low-resistivity anomaly observed at positions 0.0 m to 6.0 m along survey line L3, in close proximity to the river channel, is attributed to the presence of high water content in the soil layers adjacent to the river. The resistivity profiles at the remaining positions of survey line L3 demonstrate overall good layering characteristics without any significant anomalies. Based on comprehensive analysis considering geological survey results, the suspected locations of leakage channels are circumscribed as shown in the following figure. The notable thickness of backfilled soil at this location, coupled with a relatively high moisture content below the initial water level, constitutes the primary cause for the occurrence of anomalies.



(1) Measurement line L1



(2) Measure line L2



(3) Measure line L3

Fig. 4. High-density electrical resistivity testing achievement profile

3 The measures and implementation outcomes of leakage prevention.

3.1 Leakage prevention measures

Various measures are implemented to prevent leakage, and the technical feasibility, minimal negative environmental impact, and economic rationality must be considered. For artificial lakes and landscape lakes, the preferred leakage prevention method generally involves the use of HDPE. This approach exhibits minimal leakage, with the primary consequence being the interruption of water circulation, which may have some impact on groundwater recharge. An example is the artificial lake in the Beijing Botanical Garden, where a leakage prevention membrane was installed in 2002. After the completion of the project, the water level in the garden has been maintained at an appropriate level throughout the year. Since the lake is artificially excavated and functions as a water reservoir, the leakage prevention measures have not adversely affected the surrounding ecological cycles.

Taking into account the leakage location, causes, and on-site construction conditions, the proposed leakage prevention measure entails the implementation of a flexible leakage prevention barrier between the north side of the pond and the river channel, thereby interrupting their hydraulic connection while preserving the hydraulic circulation within the pond and its surrounding environment. To ensure an effective leakage prevention outcome for the landscape pond and enhance its practicality and longevity, an innovative composite leakage prevention system using HDPE and bentonite (Fig.5) has been employed.

Fig. 5. HDPE-bentonite composite leakage prevention system

The impermeability of the HDPE membrane flexible vertical impermeable wall is more than 100 times that of the traditional rigid vertical impermeable wall, with an extremely low permeability coefficient ($k < 10^{-12}$ cm/s). It possesses high extensibility, strong formability, and applicability to various terrains. At room temperature, the material exhibits excellent corrosion resistance and durability [5]. To prevent the interstitial space between the impermeable membrane and the foundation trench from becoming a leakage channel, self-healing mineral soil such as bentonite[6-8] is used as backfill material. By introducing high-purity natural cohesive soil to the conventional cementitious matrix, the self-compactness and impermeability of the material are improved, and it can bond with the surrounding soil to form a unified whole. This approach is environmentally friendly and non-polluting because it significantly reduces cement consumption. By innovatively combining these two materials, a dual impermeable system is formed, effectively compensating for the shortcomings of a single impermeable material as an isolation barrier.

Fig. 6. Flexible cutoff wall construction

The specific implementation process is as follows: (1) A cofferdam is constructed outside the original retaining wall position on the north side of the pond and at the narrowest part in the middle. The pond water is then drained to provide construction conditions. (2) The original brick retaining wall is preserved, and a trench is excavated along the inner side. The length of the trench is approximately 40 m with a width of 0.8 m. The actual excavation depth is based on reaching a depth of 0.5m into the second layer of silty clay. Excavation is carried out in sections, and timber supports are placed on both sides of the trench to prevent collapse. (3) The bottom of the trench is cleaned, leveled, and compacted. Along the centerline of the excavated trench, a 3-meter-long galvanized double-hole steel square tube is buried every 3 meters. The verticality must be ensured during the insertion process. (4) HDPE impermeable membrane is inserted into the double-hole square tube, with the impermeable membrane passing through fine slits on both sides of the square tube. The square tube is then filled with a specially formulated impermeable liquid. (5) Grout is injected on both sides of the impermeable membrane, and after the grout is filled, the timber supports are removed. The flexible impermeable wall is then cured for a period of time to form a complete structure, as shown in Fig. 6. (6) After the construction is completed, the ground is restored by back-filling soil and landscaping. The cofferdam is removed, and the pond is filled with water to restore its original appearance. Subsequent water level monitoring is conducted. The construction adopts small-scale construction equipment and low-carbon construction techniques, which not only ensures the landscape of the pond during the construction process but also minimizes noise generation, thereby reducing environmental impact.

During the process of governance, it was discovered that large amounts of tiles and construction waste, approximately 30cm thick, were present below the 1.5m depth of the west-side backfill, forming multiple direct leakage channels. Additionally, evident leakage channels were observed at the junction between the two sides under the bridge and the middle of the original concrete dam on the north side, as shown in Fig. 7, which is consistent with the results of the previous leakage detection.

Fig. 7. Leakage location and situation

3.2 Implementation results

In early March 2023, the on-site implementation of a flexible leakage prevention barrier was completed. After a period of maintenance, the ponds were filled with water, and the automated water level monitoring platform continuously monitored the water level changes. Currently, over a month has passed, and by comparing the water level data of the ponds before and after the remediation (Fig. 8), it can be observed that the water level at the SW2 monitoring point on the north side of the pond, as well as the water levels at SW1 and SW3 on the south side of the second-phase pond, have remained relatively stable. The rate of water level decrease has significantly reduced from 3.44 cm/day before the remediation to 0.45 cm/day, indicating that the leakage pathways in the former ponds have been largely blocked, demonstrating a significant improvement in the effectiveness of the remediation measures.

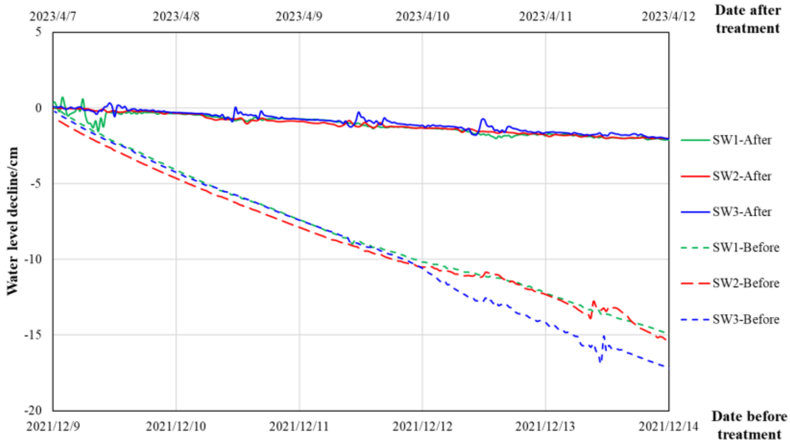


Fig. 8. Comparison of the pond water level before and after leakage control treatment

4 Conclusion

Based on anti-leakage engineering practice of a classical garden pond, this study summarizes the technical system for leakage investigation and control. It involves comprehensive leakage investigation methods, environmentally friendly and effective composite leakage prevention materials, as well as low-carbon and minimally invasive construction techniques. The materials of HDPE-bentonite composite leakage prevention prevention are non-toxic and not adversely affected the surrounding ecological cycles. Through comparison of water level monitoring before and after treatment, this leakage prevention measures effectively solve the leakage problem of landscape ponds. It not only revitalizes classical garden landscapes, but also conserves water resources. It exhibits significant social, environmental, and economic benefits. The findings of this study can serve as a valuable reference for the management and treatment of pond leakage in numerous Chinese classical gardens.

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