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Original Paper

Analysis and Remedial Measures for Basement Leakage in a Residential Building

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Abstract

In the realm of residential construction, the issue of leakage remains a significant quality challenge for construction enterprises. An analysis of maintenance data from our company since 2010 reveals that 75% of user-reported repair issues involve basement leakage. This article examines the waterproofing project of a residential basement, delving into the quality issues encountered during actual construction. Through in-depth analysis, it proposes targeted solutions. Additionally, the article compiles relevant data to assess the specific impact of these solutions on improving the effectiveness of residential waterproofing projects. Integrating the principles of total quality management, the article proposes a scientific governance strategy aimed at enhancing the overall quality of waterproofing projects. Furthermore, the article emphasizes the importance of continuous monitoring and feedback mechanisms to ensure the long-term effectiveness of these strategies.

Keywords

Residential Construction, Basement leakage, Cause analysis, waterproofing

1. Introduction

The importance of waterproofing in residential projects is paramount in the construction industry. The concept of "home" has been deeply rooted in Chinese culture since ancient times, and the quality of waterproofing in residences directly impacts the living environment, comfort, and even the safety of property for users. Therefore, the quality of waterproofing holds a critical position in the management of construction project quality. In China, the construction sector is a significant pillar of the national economy, with a vast number of residential projects being completed and put into use annually. However, leakage issues in residential projects remain a major quality challenge for construction companies (Geng, 2018; Wang, 2012; Han, 2012). According to maintenance data from our company

since 2000, 75% of user repair issues are related to leaks. Despite the implementation of comprehensive quality management in China, many companies often carry out these practices superficially. With societal advancement and the improvement of people's living standards, construction companies generally adhere to the principle of "people-oriented, customer first," making it imperative to enhance the quality of waterproofing in residential projects.

Residential projects are complex systems where each part is interconnected, and waterproofing, as a crucial component, must be strictly controlled to ensure quality and prevent subsequent issues (Zhu, 2024; Zuo et al., 2024; Sun, 2023; Liu, 2023). The Chinese construction industry suffers from severe formalism, with a long-standing lack of emphasis on residential waterproofing. Some construction companies focus excessively on the completeness of waterproofing documentation rather than the effectiveness and quality of the waterproofing itself. All parties involved often prioritize maximizing their profits, severely neglecting the management of waterproofing quality, which is a primary cause of frequent leakage problems in residential projects. This article aims to study residential waterproofing projects, integrate the concept of comprehensive quality management, analyze various factors affecting residential waterproofing, identify key management points, and propose a scientific and reasonable management approach to enhance and ensure the quality of residential waterproofing projects.

2. Overview of a Residential Waterproofing Project

2.1 Project Overview and Waterproofing Project Overview

This study focuses on a large-scale residential development project in Chengdu, Sichuan Province, China. The project, with a total construction area of approximately 10 million square meters, is developed by a central enterprise real estate group. The design philosophy of the project is deeply rooted in the group's corporate culture, aiming to leverage its abundant corporate resource advantages to create a modern cultural community that coexists harmoniously with nature, integrating commercial, educational, office, and residential functions. Currently, the construction of high-rise residential buildings and underground garages in E and F districts has been successfully completed.

The project is located in the southern part of Chengdu, situated in the subtropical monsoon climate zone. The climate characteristics of this region are mild winters, hot summers, significant seasonal changes, ample sunshine, abundant rainfall, and no persistent frost period. Under such climatic conditions, the waterproofing standards for the residences have been correspondingly elevated to ensure the durability of the buildings and the comfort of the living spaces. Additionally, the project's design has fully considered the local climate characteristics, employing advanced construction techniques and materials to adapt to the variable climatic conditions, thereby ensuring the quality of life for the residents.

2.2 Design Concept and Application of Waterproofing in Residential Engineering

2.2.1 Design Concept

Proper waterproofing design is crucial for ensuring the success of residential projects in terms of

waterproofing. The waterproofing design philosophy for this residential project strictly adheres to the principles of "combining prevention and drainage, with prevention as the primary focus; integrating rigidity and flexibility, with flexibility to adapt to changes; using composite materials, setting up multiple layers of protection, enhancing sealing at critical points, and implementing comprehensive management." As a systematic project, waterproofing involves the synergy of various factors, making the design of waterproofing projects particularly critical. Within the waterproofing system, the inherent waterproofing capability of the structure plays a vital role. Depending on the different environments in which the engineering entity is situated, the design requirements and specifications for the structure's self-waterproofing capabilities also vary.

2.2.2 Application

In the construction of the underground garage for this project, the quality of the waterproofing system is of paramount importance due to the extensive construction area and the long-term underground nature of the facility. Given that the garage is deeply embedded underground and covered with green vegetation, inadequate waterproofing design can easily lead to extensive leakage issues. To effectively prevent groundwater infiltration, this project employs a composite waterproofing technology that combines coating and sheet waterproofing methods.

The exterior walls of the underground structure, once constructed, are concealed beneath the ground, making them a hidden project with irreversible consequences. If leakage occurs, it can only be patched from the inside, which, while temporarily managing surface leaks, does not address the root cause of groundwater permeating into the structural core, thus failing to effectively protect the structure from water damage.

The waterproofing of the underground facility must achieve complete seal. Given the pervasive nature of groundwater and the prolonged submersion of the basement in it, the construction process must ensure a complete seal to prevent any form of leakage.

The waterproofing materials used in the underground facility should possess certain corrosion resistance. The corrosive nature of groundwater varies across different regions, and the materials, being constantly submerged, must withstand corrosive damage to maintain the effectiveness of the waterproofing.

Additionally, the waterproofing materials for the underground facility need to exhibit a degree of flexibility. Due to potential ground deformation or uneven settlement, the materials must have good flexibility to prevent breakage during deformation, thereby avoiding leakage in the basement (Sui et al., 2010).

3. Case Analysis

In residential waterproofing projects, the basement waterproofing sub-item not only accounts for the largest proportion but also presents the most complex challenges due to its intricate environment and concealment. The leakage issues in basements, due to their intractable nature, often result in significant

financial losses and reputational damage. This article, based on actual engineering cases, provides a thorough analysis of residential basement waterproofing projects, aiming to effectively address the practical issues in basement waterproofing through scientifically sound and reasonable management methods and approaches.

3.1 Basement Waterproof Project Case Description and Waterproof Effect

3.1.1 Briefing

The total area of the basement in this project is 15,174.44 square meters, with a waterproofing grade designated as Class I. The basement structure is constructed using C35 concrete, which offers a P6 level of impermeability. The base slab's cushion layer is made of 100mm thick C15 concrete. The post-cast concrete in the construction joints is of grade C40, also providing P6 level impermeability. The basement is equipped with multiple connecting openings that link the bicycle ramps and underground parking areas, where prefabricated rubber water stop technology is employed. The waterproofing protection for the exterior walls of the basement is achieved through the application of Polymer Cement Type II waterproof coating.

3.1.2 Waterproof Effect

Upon completion of the backfill soil work in the residential construction project, the construction team conducted an inspection of the waterproofing effectiveness in the basement. The inspection revealed multiple leakage issues within the basement. After analysis by the project department, these issues can be primarily categorized into the following points:

(1) Leakage through the basement exterior walls. Inspection identified several cracks in the basement exterior walls, which allowed groundwater to seep through in the form of droplets, damaging the interior wall coatings.

(2) Water seepage around penetrations through basement walls. Traces of water were observed around the wall penetrations, forming watermarks and accompanied by mold growth on the interior walls, affecting both the structural integrity and aesthetics of the walls.

(3) Leakage at the basement connection points. Groundwater continuously flowed out from the gaps at the connection points, leading to standing water within the basement and severely hindering subsequent construction activities.

(4) Leakage through the basement floor slab. Although the area affected was small, continuous seepage of groundwater created localized puddles, impeding further construction.

(5) Leakage at the joint of the post-cast strip on the basement ceiling. The leakage resulted in droplet formation, causing mold growth on the ceiling's decorative surface and affecting the functionality of the basement.

3.2 Cause Analysis of Basement Leakage Problem

In response to the leakage issues identified during the project inspection, a special quality rectification team was established by the project department to analyze the basement leakage problems one by one. The team investigated the possible causes of such issues to formulate a reasonable rectification plan

and prevent their recurrence in subsequent projects. The specific reasons identified by the project department are as follows:

3.2.1 Leakage in the Basement Exterior Walls

(1) During the formwork erection process, the seams between the forms were not tightly sealed, causing concrete slurry to leak from the seams during the pouring of the exterior wall concrete, resulting in local areas of the concrete being insufficiently dense.

(2) The embedded pull rods for basement formwork support were not processed according to strict waterproof measures; some waterproof plates were inadequately welded or missing, and the sealing of the exterior wall rod holes was not tight, leading to inadequate waterproofing.

(3) During the pouring of the basement exterior wall concrete, improper operator actions led to insufficient vibration of the concrete, causing local areas of the concrete to be insufficiently dense.

3.2.2 Leakage around Basement Wall Penetrations

When pipes and bridges pass through the basement exterior walls, penetration sleeves are typically installed with waterproof rings on them. Improper handling of detailed construction methods resulted in gaps between the sleeves and the pipe equipment, causing water leakage.

3.2.3 Leakage at Basement Connection Points

(1) Uneven settlement of the building caused deformation at the connection points, leading to the deformation and failure of the rubber waterproof strips.

(2) The design scheme was unsuitable for the actual site conditions, causing the waterproof materials to easily fail and result in leakage.

3.2.4 Leakage in the Basement Floor

(1) Due to design issues, the waterproof layer of the basement floor did not closely adhere to the basement floor structure, leading to separation and local failure of the waterproof layer.

(2) The basement floor pouring involved large-volume concrete, and excessive hydration heat during the pouring process caused significant temperature differences within the concrete. Inadequate subsequent concrete maintenance resulted in temperature cracks in the local floor concrete, providing a pathway for groundwater leakage.

3.2.5 Leakage at the Post-cast Joint on the Basement Roof

(1) The post-cast concrete was the last to be poured, with a long interval from the other roof concrete pouring. The embedded waterproof steel plates were inadequately protected and damaged, leading to leakage.

(2) During the post-cast concrete construction, inadequate supervision of the construction process resulted in insufficient concrete compaction, causing poor bonding between the new and old concrete at the post-cast joint.

4. Analysis and Treatment of Basement Leakage Problem

Through a thorough analysis of the basement leakage causes by the construction unit, project quality managers and supervising engineers have jointly identified the critical points for quality control in basement waterproofing works. Based on this, specific rectification measures and corresponding quality management strategies for basement waterproofing have been proposed.

4.1 Control Measures for Basement Waterproofing Projects

In basement waterproofing projects, clearly defining quality responsibilities is crucial for ensuring project success. The construction unit is not only responsible for procuring high-quality waterproofing materials but also for meticulous construction of the basement waterproofing system and conducting rigorous water testing upon completion. Subsequently, the construction unit and supervisory engineers will conduct acceptance inspections to ensure the continuity and quality of the entire process.

To further enhance project quality, pre-construction briefings are essential. For instance, prior to concrete pouring, detailed technical briefings must be provided to the carpentry and concrete teams, emphasizing the quality of template joints and concrete vibration, and establishing clear rewards and penalties to improve the quality of concrete pouring for basement exterior walls.

Controlling material quality is also a critical aspect. All waterproofing materials entering the site must undergo witness sampling and only be used after passing the tests. Additionally, due to the unique nature of waterproofing materials, special attention must be paid to the protection of raw materials during storage.

Thorough quality inspection is another vital step in ensuring project quality. Each construction step must undergo rigorous quality checks, with notification to supervisory engineers for joint acceptance, ensuring that every step of the basement waterproofing process meets standard qualifications.

Lastly, enhancing the skill level of construction operators is essential for maintaining project quality. For critical areas of basement waterproofing, such as exterior basement walls, the construction unit should deploy experienced operators or adopt a "veteran-led-newcomer" construction strategy to ensure the quality of the waterproofing sub-items and reduce leakage issues due to improper construction practices.

4.2 Analysis and Treatment of Leakage Issues in Basement Exterior Walls

In a serious tone, the primary cause of leakage issues in basement exterior walls stems from inherent defects in concrete, primarily cracks and pores. Cracks typically form due to the shrinkage deformation of concrete exceeding its maximum extensibility or internal shrinkage stress surpassing the ultimate tensile strength limit. Pores are mainly generated due to inadequate sealing of formwork joints leading to concrete leakage and insufficient compaction due to human factors. To address these leakage problems arising from concrete defects, the method of grouting for sealing is commonly employed.

Initially, known leakage points or areas with concrete defects are marked. Subsequently, water-soluble polyurethane sealing material is utilized for treatment. This material, composed of toluene diisocyanate and water-soluble polyether, is a polymer. Upon contact with water, it disperses and gels autonomously,

undergoing polymerization with water to form a solid. This solid exhibits excellent properties such as extensibility, elasticity, low-temperature resistance, and superior anti-permeability. Upon contact with water, it also foams and expands, effectively blocking the pathways for groundwater leakage. This method effectively addresses the inherent defects of concrete by automatically repairing imperceptible pores or cracks with the flow of waterproof grout, thereby achieving the desired waterproofing effect.

Additionally, adhering to standardized practices for tie rods in basement exterior walls is crucial. The waterproof plates on both sides of the middle of the bolt must be securely connected to the bolt, with wooden wedges or spacers placed on both sides. After concrete pouring, the exposed bolts should be removed using gas cutting, the wooden blocks excavated, and waterproof mortar used to seal the original wooden block positions, followed by the application of waterproof materials externally to ensure the durability of the waterproofing effect.

4.3 Analysis and Resolution of Leakage Issues in Basement Penetration Pipes

In addressing issues of seepage through wall pipes, it is imperative to precisely excavate the affected area to accurately locate the joint between the embedded casing and the pipe. Subsequently, a mixture of waterproof fine aggregate concrete or waterproof mortar, incorporating an expansive agent, is used for filling and compacting. Additionally, a layer of polyurethane waterproof coating is applied on the surface to enhance waterproofing capabilities.

To prevent recurrence of such issues, it is crucial for construction units to rigorously adhere to technical briefing procedures prior to construction. Technical officers should thoroughly explain the techniques of embedding and sealing wall casings to the construction personnel, while on-site supervisors must rigorously oversee each critical construction step to ensure the quality of waterproofing work.

Before the construction of wall pipes in basements, it is customary to pre-embed casings within the wall structure and install water stop rings. These rings must be tightly welded to the casings, with weld heights exceeding 5mm and no voids permitted. The gap between the wall pipe and the casing is typically filled with bituminous hemp or oil-soaked asbestos rope; metal embedded parts require two coats of anti-rust paint before installation, followed by filling the gaps with hot bitumen. Furthermore, the outer edge of the wall pipe fittings should maintain a distance of more than 250 millimeters from corners, recesses, and protrusions, and no pipe interfaces should be present within the casing.

4.4 Analysis and Treatment of Water Infiltration Issues at Basement Connection Points

In the basement design of this project, multiple access points were included, connecting areas such as bicycle ramps and underground garages. These access points were situated between the structures of two buildings and were equipped with flexible waterproof materials to prevent groundwater infiltration. However, post-completion of the basement, leakage issues were identified at these access points, with groundwater continuously seeping through the gaps, leading to accumulation of water in the basement and severely impacting subsequent construction progress.

To swiftly address this leakage issue, the construction unit convened a meeting with the design, supervision, and construction teams to develop a corrective action plan. After deliberation, a strategy

combining blocking and drainage was adopted. Professional technicians inspected the leaking areas one by one, identified the leak points, and manually excavated drainage channels to divert the water into a basement sump. Wooden studs were used for stabilization, surrounded by waterproof silicone, and finished with stainless steel plates.

To prevent future recurrence of similar issues, after consultation with the design unit, it was decided to modify the subsequent project designs to incorporate removable waterproof steel frames. This measure offers several advantages:

1. It resolves the issue of traditional rubber waterstops failing due to settlement or aging, as the removable design allows for timely replacement of the waterstop in case of leakage, preventing the problem from escalating.
2. By creating drainage channels, it cleverly avoids extensive structural damage to the leaking areas for sealing, effectively addressing the leakage issue and long-term mitigation of the adverse effects of groundwater infiltration.
3. It reduces maintenance costs in the later stages, with a simple and quick inspection process.

5. Analysis of Waterproofing Effectiveness Following Remediation of Basement Leakage Issues

Following the implementation of the aforementioned rectification plan, the construction unit conducted a thorough re-inspection of the waterproofing effectiveness at all rectified areas, meticulously documenting the results. Drawing lessons from this experience, the construction unit adopted the summarized quality control points for basement waterproofing in subsequent project practices. Additionally, comparative analyses were performed on the waterproofing effectiveness of corresponding sections to ensure the consistency and effectiveness of the construction quality.

5.1 Analysis of Waterproofing Effectiveness Following Rectification of Basement Wall Leakage Issues

Upon completion of the rectification, the construction team conducted a field inspection of the waterproofing effectiveness, confirming that all leakage points had been repaired, with the walls now appearing dry and smooth, free of any leakage phenomena. In subsequent construction phases, the construction team identified the primary issue as stemming from inadequate skilled labor in the preparatory stages, particularly in the carpentry and concrete teams, which led to defects in the concrete and subsequent leakage. To address this, the construction team increased the deployment of skilled workers during the construction of the basement of Buildings 3#, 4#, and 5# in the second phase of this project (excluding the previously completed Buildings 1# and 2#). Post-construction, an inspection of the waterproofing effectiveness was conducted and the results were compared with those of the earlier constructed Buildings 1# and 2#. Detailed comparison data can be found in Table 1.

Table 1. Comparison of Waterproof Rectification Effects on Basement Exterior Walls

	Number of Skilled Workers per Team	Number of Apprentice Workers per Team	Compliance Rate of Water Prevention Measures for Exterior Wall Bolts	Number of Leak Points
Building 1	1	4	75%	7
Building 2	1	4	90%	4
Building 3	2	3	100%	1
Building 4	3	2	100%	0
Building 5	3	2	100%	0

It is evident that each main building concrete team and carpentry team should be equipped with 3 skilled workers for the waterproofing construction of the basement exterior walls. After strengthening the inspection of the water stop measures for the exterior wall tie rods, the leakage points have significantly reduced. Additionally, with the increase in skilled workers and the adoption of new finishing practices, no further water leakage has been observed in the basement exterior walls, demonstrating significant effectiveness.

From the analysis of this waterproofing case, it is clear that construction and management issues are particularly prominent in this instance. Waterproofing projects rely on professional personnel, and only through the skilled technical operations of these professionals can excellent waterproofing results be achieved. Selecting subcontracting units with sufficient professional technical capabilities and personnel for construction, and ensuring thorough technical briefings, strict quality control during the construction process, and seeking more reasonable construction techniques, will enhance the quality of the basement exterior wall waterproofing projects and prevent local issues from affecting the overall waterproofing effect.

5.2 Analysis of Waterproofing Effectiveness After Rectification of Basement Penetration Pipe Leakage Issues

In a serious tone, with minor modifications to the content and without expanding it, the English rephrasing is as follows:

After implementing corrective measures for the leakage issues around wall-penetrating pipes, the construction team conducted on-site inspections to verify the effectiveness of the waterproofing. The results indicated that all previously leaking areas had been successfully repaired, with the surrounding walls now appearing dry and clean, showing no signs of leakage. Additionally, the construction team analyzed the waterproofing effectiveness at the wall-penetrating pipe locations in the basements of five main buildings in the second phase of the project. The basements of Buildings 1# and 2# were completed concurrently with those of the first phase, thus employing identical management strategies and construction techniques. In contrast, the basements of Buildings 3#, 4#, and 5# were constructed

later, during which the construction team incorporated lessons learned from the first phase, particularly enhancing the quality control, requirements, and technical briefings for the waterproofing details around the wall-penetrating pipes. Following the completion of the basements in Buildings 3#, 4#, and 5#, the construction team compared their waterproofing performance with that of Buildings 1# and 2#. The comparative results, as detailed in Table 2, provide concrete data support.

Table 2. Comparison of Waterproofing Remediation Effects for Basement Penetration Pipes

	Measures Implemented: Yes/No	Number of Leak Points	Total Number of Penetrating Pipes	Non-Leakage Rate
Building 1	No	4	10	60%
Building 2	No	3	10	70%
Building 3	Yes	0	10	100%
Building 4	Yes	0	6	100%
Building 5	Yes	0	10	100%

Following the enhancement of quality control by the construction unit on the waterproofing details of basement wall penetrations, the issue of leakage at these points has been significantly managed, with no recurrence of such leakage incidents. This measure has notably improved the waterproofing efficiency, effectively addressing the leakage problems at the source for basement wall pipes.

5.3 Analysis of Waterproofing Effectiveness after Rectification of Leakage Issues at Basement Connection Points

In a serious tone, the construction unit addressed the leakage issues at basement connection points by implementing the established rectification plan. Post-repair, on-site inspections confirmed that all leakage points had been effectively remedied, with no signs of groundwater seepage in the connection areas and surrounding floors remaining dry, free of standing water. During the second phase of the project, the construction unit employed an improved design scheme at all basement connection points. Following construction, a thorough inspection of the waterproofing effectiveness was conducted and compared with the corresponding areas in the first phase. Detailed comparative results are presented in Table 3.

Table 3. Comparison of the Effect of Improved Waterproofing Scheme of Basement Connecting Opening

	Number of Leaks	Number of Non-Leaks	Total Inspected	Pass Rate
Original Design	4	20	24	83.3%
Revised Design	0	24	24	100%

Given the factors at the design level, the initial design scheme was flawed, failing to fully reflect the actual conditions on-site and lacking in detailed structural design, which led to leakage issues. After adjustments to the design scheme, significant improvements were achieved, effectively ensuring the quality of the basement waterproofing project.

5.4 Analysis of Waterproofing Effectiveness Following Rectification of Basement Slab Leakage Issues

In a serious tone, the construction company addressed the leakage issues in the basement floor by implementing the established rectification plan. Post-repair, on-site inspections confirmed that all leakage points were effectively remedied. A comprehensive grid-like inspection of the basement floor revealed a dry surface with no standing water, affirming the absence of leakage points. Drawing from the lessons learned in the first phase, the construction team enhanced the quality management of large-volume concrete pouring for the basement floors during the construction of buildings 3#, 4#, and 5# in the second phase. They appointed dedicated personnel for the maintenance of temperature gauges and optimized the basement floor design by adopting internal waterproofing technology. Upon completion of the project, the waterproofing performance of the basement floors in buildings 3#, 4#, and 5# was meticulously compared with that of buildings 1# and 2#, with detailed comparative results presented in Table 4.

Table 4 Enhanced Basement Floor Waterproofing Measures and Post-Modification Effect Comparison

	Has the quality control plan for large-volume concrete pouring been strengthened?	Has the improved design scheme been implemented?	Number of leakage points.
Building 1	No	No	8
Building 2	Yes	No	4
Building 3	Yes	Yes	1
Building 4	Yes	Yes	0
Building 5	Yes	Yes	0

It is evident that by intensifying quality monitoring during the concrete pouring process for the foundation slab and enhancing post-construction maintenance, the temperature cracks in the basement have been effectively managed. Following the implementation of these measures, the number of leakage points has been reduced by 50%. Additionally, to ensure the overall waterproofing effectiveness of the basement, the construction team has improved the waterproofing methods for the foundation slab, addressing the fundamental issues of separation between the waterproof layer and the slab, as well as the difficulties in repair. After the modification of the design scheme, the leakage issues in the basement slab have been substantially resolved, and the effectiveness of waterproofing quality control has been significantly demonstrated.

6. Conclusion

In this article, through specific residential construction examples, we have identified various types of leakage issues in residential basement projects. Drawing on these examples, we analyze the causes of leakage in different parts of the basement and propose corresponding solutions. Additionally, we have collected follow-up data on the implemented solutions and compared it with pre-intervention data, thereby presenting a concrete illustration of the improved waterproofing effectiveness through specific metrics.

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