

Suggestions for Anti-Floating Design of Basement Structures in Weakly Permeable Layers

Zhenlan Zhao^a, Bowang Chen^b, Wanqiong Xie^c, and Chao Tan^d

College of Civil Engineering, Central South University of Forestry and Technology, Changsha 410004, China

^azhaozhenlan123@outlook.com, ^bw462824624522@163.com, ^c20221200583@csuft.edu.cn, ^d2067976608@qq.com

Abstract

This study focuses on common anti-floating issues associated with underground structures in weakly permeable geological conditions. Based on a real engineering case, the research systematically analyzes the primary causes of buoyancy failure by examining the disconnect between design and construction phases. The findings indicate that insufficient consideration is often given to the configuration of anchor rods, waterproofing measures, backfill compaction, and surface drainage systems in current anti-floating designs. These oversights can lead to abnormal rises in groundwater levels during extreme rainfall events or in later stages of construction, ultimately resulting in structural uplift. The study further investigates the disturbance effects of underground structures on groundwater seepage fields, highlighting the necessity of accounting for the coupled influence of structural dimensions, embedment depth, and soil permeability in anti-floating design. This is essential to ensure long-term stability and safety under service conditions. In addition, common construction defects related to prestressed anchors are summarized, and practical recommendations are proposed to enhance the integrity and durability of anti-floating systems. The outcomes of this research provide both theoretical reference and practical guidance for anti-floating engineering of underground structures in similar geological settings.

Keywords

Weakly Permeable Layer; Underground Structure; Anti-floating Design.

1. Introduction

In current engineering design and construction practice, insufficient attention is often given to buoyancy resistance in underground structures, and certain misconceptions persist. Some engineers consider the presence of anti-floating anchor rods sufficient to ensure buoyancy control, assuming that the anchorage alone prevents uplift. However, effective buoyancy resistance depends not only on the pullout capacity of anchor rods but also on the combined effect of structural self-weight, overburden pressure, and other counteracting factors. If the total weight of the structure is insufficient, or the anti-floating design water level is underestimated, there remains a considerable risk of buoyancy failure.

In addressing common construction challenges such as poor compaction of the over-excavation backfill, it is sometimes believed that sealing the backfill surface is enough to prevent buoyancy issues. However, Luo Zhaohua [1] demonstrated through long-term field hydrological monitoring that although surface sealing can temporarily block surface runoff infiltration, once the seal is damaged, rainwater still penetrates the subsoil. The impermeable surface layer also hinders moisture

release, causing water accumulation and rising groundwater levels, ultimately triggering uplift failure of the structure.

In cases of buoyancy failure, remedial action often involves installing additional anchor rods due to previously underestimated design water levels. However, this process differs significantly from initial construction. After backfill, the soil around the basement has been restored, making it difficult to drain water efficiently as in open-pit conditions. Dewatering can only be done via relief wells, which proves inadequate in loose backfill conditions due to high permeability. Each rainfall episode leads to continuous groundwater seepage through the anchor rod holes, as illustrated in Fig.1 Relying solely on limited relief wells cannot control the overall water level effectively, particularly near exterior walls, where water accumulates faster and infiltrates more intensely, imposing greater construction risks.



Fig.1 Reinforcement Construction Photograph

To mitigate this issue, grouting in the backfill zone is commonly adopted to block seepage paths and limit rapid rainwater infiltration. While effective, this method incurs significantly higher costs than standard drainage solutions. It highlights that failure to properly evaluate design water levels, ensure backfill compaction, or assess the dynamic hydrological conditions during the design stage may result in higher post-construction costs and remediation complexity. Therefore, anti-floating design must go beyond local structural measures and take an integrated approach-considering geological conditions, structural configuration, construction processes, and long-term groundwater fluctuations-to ensure overall project safety and stability.

2. Surface Drainage Design

Construction activities typically alter the natural topography and terrain, which in turn affects runoff patterns and catchment areas. Without systematic drainage planning, rainwater may collect in low-lying or backfilled areas, resulting in surface ponding and infiltration, which increases uplift forces and the risk of buoyancy failure.

Drainage system design must be informed by site investigation results and account for post-construction topographical changes. An effective system should guide runoff toward designated channels, minimizing the infiltration into subsoil and adhering to the principle of “drain first, prevent second” [2]. Additionally, for projects discharging into municipal drainage systems, the capacity of the local network must be verified. If insufficient to handle peak rainfall during construction or operation phases, early upgrades or alternative drainage strategies should be proposed to maintain system reliability.

Drainage planning should also prevent overflow or off-site runoff that may affect surrounding areas. Only by integrating site-specific hydrology, topography, and municipal infrastructure can the drainage and anti-floating strategies be unified to ensure long-term safety and functional integrity of the structure.

3. Hydraulic Barrier Effects of Underground Structures

Underground structures not only alter surface runoff but also disrupt groundwater flow within the soil. Studies show that due to their impermeability, underground structures act as hydraulic barriers, impeding natural seepage and causing localized rises in groundwater levels. Zheng Pin [3] found through laboratory experiments that such barriers significantly affect upstream and downstream water levels and delay equilibrium. When a structure extends beyond 70% of the aquifer thickness, its influence on the seepage field increases sharply. Similarly, numerical simulations by Lin Mulong[4] revealed that differential pore water pressure across the structure leads to lateral buoyancy imbalances, and a correction model was proposed to simulate structural loads in seepage fields.

Research by Xu Yeshang [5], Wang Junhui [6], and others further confirms that structural dimensions and embedment depth have a significant impact on groundwater distribution-particularly in weakly permeable or multilayered soils. Dense, continuous underground structures can cumulatively alter the regional seepage field, cause upstream water level rise, and potentially lead to localized foundation seepage failures.

Thus, anti-floating design must consider the disturbance of natural seepage caused by underground structures, especially the additional pore water pressure from hydraulic obstruction at the sides and bottom. Designers should avoid oversimplified hydrostatic assumptions and instead adjust the pore pressure distribution based on factors such as soil permeability, embedment depth, and structural dimensions to ensure safety and long-term stability.

4. Selection of Anti-Floating Anchors

Current research and inspection practices often focus solely on the pullout capacity of anchor rods, without sufficiently addressing their bond to the slab or waterproofing performance-factors critical to buoyancy resistance. Pressure-type prestressed anchors are commonly used to enhance anti-floating capacity. Despite their high tensile strength, these systems are vulnerable to leakage at the connection between the anchor and the waterproof slab. Common issues observed in practice include:

- 1) In high groundwater conditions, water accumulates in the drilled hole and dilutes the cement grout. After sedimentation, the grout body may not reach the top of the cushion layer, leaving part of the tendon unbonded and reducing structural integrity.
- 2) The transition steel sleeve is often not well integrated with the cushion, allowing concrete to leak into the sleeve during slab casting, hindering prestress tensioning and re-grouting.
- 3) The flexible PVC corrugated sheath lacks rigidity, and the exposed portion (1.5–2.5 m) tends to deflect laterally under self-weight, causing it to adhere to the hole wall, compromising the protective layer and durability [7].
- 4) Absence of pre-installed re-grouting ports in the steel sleeve means that after tendon tensioning, the anchor head and bearing plate block access to the sleeve, resulting in poor grout compaction and groundwater infiltration along the sleeve wall, as shown in Fig.2.

Therefore, designers and contractors should establish clear specifications for anchor type selection, waterproofing details at anchor-slab connections, grout sequence planning, and re-grouting provisions to ensure durable and watertight anchorage systems.



Fig.2 On-site Photograph of Anchor Rod Leakage

5. Conclusion

This section analyzes discrepancies between design assumptions and construction realities in anti-floating design and proposes the following targeted optimizations:

- 1) Surface drainage systems should be based on topographic changes and municipal discharge capacity, ensuring that runoff is properly diverted and buoyancy risks minimized.
- 2) Design should consider how underground structures disrupt natural seepage paths and cause local water level rise, avoiding underestimation of buoyant forces from hydrostatic assumptions.
- 3) Weak points in anchorage systems-such as grout bonding and connection waterproofing-must be addressed to enhance buoyancy resistance, water tightness, and anchor durability.

Acknowledgments

This work was supported by the Hunan Province Graduate Research Innovation Project(Grant No. CX20240691); the Central South University of Forestry and Technology Graduate Research Innovation Fund(Grant No. 2024CX02098).

References

- [1] Luo Zhaohua, Luo Han. Dynamic Characteristics of Groundwater Levels and Determination of Anti-Floating Design Water Levels in Landfill Areas [J]. *Geology and Prospecting*, 2023, 59(2): 387–397. (In Chinese).
- [2] Liu Hao. Investigation and Design Requirements for Anti-Floating Measures in Construction Engineering [J]. *New Urban Construction Technology*, 2024, 33(3): 110–112. (In Chinese).
- [3] Zheng Pin, Xu Yeshang, Shen Shuilong. Experimental Study on the Barrier Effect of Underground Structures on Aquifers [J]. *Chinese Journal of Underground Space and Engineering*, 2011, 7(2): 253–256, 268. (In Chinese).
- [4] Mu Linlong, Wang Le, Li Jie, et al. Numerical Analysis of Changes in Groundwater Levels Induced by Underground Structures in Seepage Fields [J]. *China Civil Engineering Journal*, 2019, 52(S1): 78–84. (In Chinese).
- [5] Xu Yeshang, Shen Shuilong, Ma Lei. Blocking Effect of Underground Structures on Groundwater Seepage [J]. *Journal of Zhejiang University (Engineering Science)*, 2010, 44(10): 1902–1906. (In Chinese).
- [6] Wang Junhui, Han Xuan, Zhou Honglei, et al. Analytical and Semi-Analytical Methods for the Barrier Effects of Underground Structures on Seepage Fields [J]. *Hydrogeology and Engineering Geology*, 2009, 36(2): 13–18, 24. (In Chinese).
- [7] Wang Huifang. Practical Issues of Prestressed Anti-Floating Anchors in Basement Engineering [J]. *Building Technology Development*, 2021, 48(1): 90–91. (In Chinese).