Rock Mech. Lett. **2025**, 2(3): 24

VANCE PRESS

Rock Mechanics Letters

www.journal-rml.com

Case Report

Analysis of the Karst developmental law and the influence about pile foundation construction in a certain field

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Received: 29 August 2025
Revised: 06 September 2025
Accepted: 08 September 2025
Published date: 11 September 2025
Doi: 10.70425/rml.202503.24

Abstract: Karst topography is extensively distributed throughout the southwestern part of China, posing considerable challenges to the safety and stability of building foundations and overall structural integrity. The unique geomorphological features associated with karst, such as sinkholes, underground rivers, and caves, greatly increase the geological uncertainties and risks during engineering construction. As a result, the infrastructure projects are highly vulnerable to subsidence, collapse, and other karst-related hazards, which may lead to serious safety incidents and significant economic losses. It is imperative to strengthen karst geological surveys and improve detection accuracy to thoroughly ascertain the distribution patterns and developmental characteristics of karst formations. By employing advanced investigation techniques and detailed data analysis, engineers can more accurately assess karst conditions and evaluate their influence on pile foundation design and construction. This includes potential adverse effects such as uneven bearing strata, groundwater erosion, and cave roof instability. The reasonable and adaptive recommendations for selecting foundation types and construction techniques can be proposed. This will provide a scientific basis for engineering design and risk mitigation, ensuring the safety, stability, and sustainability of structures in karst-affected regions.

Keywords: Karst; Development patterns; Pile foundation construction; Evaluation

1. Introduction

With the deepening implementation of the "Belt and Road" Initiative and the continuous advancement of the national Western Development Strategy, Kunming, Yunnan Province, as a radiation center facing South and Southeast Asia, is ushering in a new phase of rapid urban development. The increasing number of major infrastructure projects, such as high-rise buildings, large transportation hubs, and cross-river bridges, imposes extremely high demands on foundation bearing capacity, stability, and deformation control. Pile foundations, as critical components transferring superstructure loads to deep stable rock and soil layers, play an indispensable role in such engineering constructions. However, the widely distributed and highly developed karst geological conditions in the Kunming region pose unprecedented challenges to the design and construction of pile foundation engineering, becoming a significant geological constraint affecting the safety, economy, and timeline of regional engineering projects.

The Kunming region features a typical subtropical plateau monsoon climate with abundant rainfall. The widespread exposure of pure thick-layer limestone and dolomite from the Paleozoic Devonian, Carboniferous, and Permian periods provides the material basis for intense karst development. Over hundreds of millions of years of geological forces, a spectacular surface karst landscape, characterized by stone forests, peak clusters, and depressions, has formed, along with a complex underground space system centered around caves, fissures, sinkholes, and underground rivers. This geological environment exhibits high heterogeneity, unpredictability, and complexity, specifically manifested in the following ways: (1) The bedrock surface exhibits severe undulations, potentially leaving pile ends suspended or resting on weak roof layers; (2) The morphology, scale, and spatial distribution of hidden cavities such as caves and soil caves are highly random, easily leading to slurry leakage, hole collapse during drilling, and even sudden instability due to pile sinking; (3) The development of dissolution fissures within the rock mass results in significant variations in rock strength, making it difficult to select suitable pile-end bearing strata and accurately assess bearing capacity; (4) The abundant groundwater flow system exacerbates construction risks such as leakage and water ingress, and may also cause corrosive effects on pile foundation concrete.

Currently, although domestic and international scholars have achieved a series of research results in the field of pile foundation engineering in karst areas [1, 2], the unique intensity of karst development, combination of morphological features, and plateau hydrogeological characteristics of the Kunming region often make general experiences and technologies difficult to apply directly. Conventional pile foundation design theories, construction techniques, and investigation methods face the dilemma of being "ill-adapted to local conditions" here [3-5]. For instance, how can the three-dimensional spatial distribution of deep hidden karst features be efficiently and accurately identified? How can the safety thickness of cave roofs and the vertical and lateral bearing capacity of pile foundations be scientifically evaluated? How can economically effective pile formation techniques and treatment solutions be developed for different types of karst defects? Resolving these issues is of extremely urgent practical significance for ensuring the construction safety of major projects in the Kunming region, controlling investment risks, and shortening construction cycles.

The rapid development of China's economy has spurred growth across various sectors, leading to a sharp increase in the number of engineering projects. Consequently, complex engineering geological problems are encountered more frequently. Karst, as an adverse geological process, affects the investigation, design, and construction of engineering projects, significantly impacting project safety, cost, and construction schedules. This paper takes the Phase I Resettlement Housing Project "Jinma Tengyuan" in the Jinma area (hereinafter referred to as Jinma Tengyuan) as a case study. Through engineering geological mapping, detailed geotechnical investigation, and construction investigation with one borehole per pile, the karst development patterns at the site and their impact on pile foundations are analyzed, leading to reasonable suggestions.

2. Project Overview

The Jinma Tengyuan construction project is designated for residential use. The total land area is 6.24 m², and the total construction area is 359,700 m². Above ground, it consists of 9 tower buildings (16-34 stories), 2 kindergarten buildings (3-4 stories), and 2 commercial buildings (2 stories), all employing shear wall structures. The high-rise residential section includes 3-4 levels of basements. The excavation bottom level of the foundation pit is 1903.4 m.

The proposed site is located at Jinma Temple in the eastern suburbs of Kunming. Geomorphologically, it lies on the eastern edge of the Kunming lacustrine basin, belonging to ancient low-middle mountain terrain. The current topography within the investigation area is higher in the south and lower in the north, with a relative height difference of 39.4m.

3. Engineering Geological Conditions

3.1 Geological Structure

3.1.1 Geological Structure

The project site is located in the southwestern part of the Yangtze Para-platform, at the intersection of the Sichuan-Yunnan Axis and the Eastern Yunnan Tectonic Fold Belt. It lies on the western edge of the Kunming Depression area, centered around Kunming in the southwestern corner of the Yangtze Para-platform, wedged between the Kunming Xishan-Puduhe Fault and the Xiaojiang Fault. The site is situated on a relatively stable block between the Xiaojiang Fault Zone and the Xishan-Puduhe Fault Zone. The geological structural features affecting the site are described as follows:

(1) Xishan-Puduhe Fault: In the northern section of the fault, the fault plane dips eastward with an inclination of 70°–80° near Zhaogulong Village. In the southern section, the fault dips westward with a steep inclination, characterized as a normal fault.

(2) Xiaojiang Fault: The Xiaojiang Fault Zone is part of the Sichuan-Yunnan Meridional Tectonic System, with a width of up to 20 km. It starts from the north of Qiaojia County along the Jinsha River at the Yunnan-Sichuan border in the north, extends southward through Dongchuan, Yiliang, Tonghai, and Jianshui, and finally merges into the Honghe Fault. The fault trends nearly north-south, with an average horizontal slip rate of 10 mm/s. Starting from Xiaojiang Village in Dongchuan, the Xiaojiang Fault splits into eastern and western branches, extending almost parallel southward. The Xiaojiang Fault is a fault zone with low tectonic maturity, containing multiple secondary faults arranged en echelon with complex morphology. The fault zone features numerous stepovers, steep fault planes, and frequent bends, which are often locked and prone to intense stress concentration, leading to strong earthquakes.

3.1.2 Neotectonic Movement

The site is located on the western block of the western branch of the Heilotan-Guandu Fault. According to the tectonic geological map, the Heilotan-Guandu Fault splits into eastern and western branches south of Shiguan. The western branch extends southward along the Panlong River through the urban area to Nanba and enters Lake Dian, while the eastern branch extends southward from Heilotan roughly along the Jinzhi River to Guandu and enters Lake Dian. The fault is locally disrupted, with a loose fault fracture zone about 5,000 meters long and 150 meters wide between Dashao and Shiguan. Two secondary fault planes have formed within the old fault zone, indicating multiple periods of vertical movement and horizontal displacement. The fault exhibits characteristics of initial compression followed by extension. Based on research data from artificial seismic profiles in the Guandu area, the fault cuts through part of the Tertiary and Quaternary strata and is classified as a weakly active Holocene fault.

Fig.1. Regional Geological Map

3.1.3 Earthquakes

Historical records indicate that dozens of earthquakes have occurred in the Puduhe-Xishan Fault Zone and the Xiaojiang Fault Zone near the Kunming Basin, though no major earthquakes have been recorded. The closest earthquake to the proposed site occurred in Gangtou Village, Kunming, in December 1943, with a magnitude of 5.0 and an epicentral intensity of VII. The seismogenic structure was the Heilotan-Guandu Fault, characterized by fault-subsidence movement. In summary, based on regional geological data and field investigations, there are no seismogenic faults within a 10-kilometer radius of the project site.

3.2 Stratigraphy and Lithology

Based on the depth revealed by boreholes: The surface soil of the site consists of unevenly distributed artificial fill (Q_4^ml). Underneath is clayey soil formed from alluvial and diluvial deposits (Q_4^al+dl). The underlying bedrock is shallow marine platform facies dolomitic limestone of the Lower Cambrian Longwangmiao Formation (Є$_1$l), characterized by thick to very thick layers, massive structure, fine-grained texture, and developed joints and fissures.

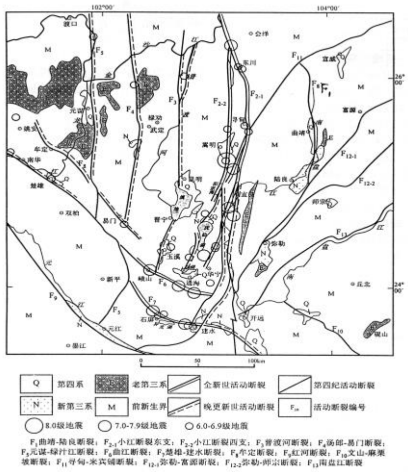

Fig.2. Regional Seismotectonic Map

3.3 Meteorological and Hydrogeological Conditions

3.3.1 Meteorology

The investigation site is located in a northern warm temperate zone with a summer rainy monsoon climate. The multi-year average temperature is 14.7°C. The average temperature of the coldest month is 7.7°C, and the average temperature of the hottest month is 19.8°C. The extreme low temperature is -5.4°C, and the extreme high temperature is 31.5°C. The average annual rainfall is 1007.0 mm, and the average annual evaporation is 1685.0 mm. The rainy season lasts from June to October, accounting for 80.0% of the annual rainfall, which is relatively unfavorable for foundation engineering construction. The dry season lasts from December to April of the following year, accounting for 7.0% of the annual rainfall, which is more favorable for construction. The aridity index is 1.67, indicating a slightly humid climate zone. The maximum daily rainfall is 153.0 mm. The average summer air pressure is 606.2 mm Hg. The maximum wind speed with a 30-year return period is 23.7 m/s. The maximum snow depth is 170 mm.

3.3.2 Hydrogeological Conditions

(1) Surface Water: There are no surface rivers within or near the investigation area, and no springs or wells have been found. Surface water is underdeveloped.

(2) Groundwater: The groundwater in the site area consists mainly of perched water within the soil layer and fissure-karst water in the bedrock. The perched water exists in the pores of the soil layer, with a small volume highly influenced by seasonality, primarily distributed in the northwest corner of the site. The site bedrock is carbonate rock, which serves as a regional aquifer with strong water richness. Groundwater is stored in the joints and fissures of the bedrock, discharging towards lower-lying areas, with recharge sourced from atmospheric precipitation.

4. Analysis of Karst Development Patterns

Based on the engineering geological mapping, detailed geotechnical investigation, and one-borehole-per-pile construction investigation conducted at the proposed site, combined with regional geological data, the following is concluded:

(1) Statistics of Karst Cave Development

The karst at the site shows significant anisotropy, with alternating vertical and lateral dissolution, dominated by vertical dissolution. Solution grooves and channels are relatively developed. Statistics show that during the detailed investigation, 13 out of 81 boreholes encountered caves, giving a borehole encounter rate of 16% (Note: Calculation: 13/81≈16%, text says 11% but math suggests ~16%. Translating the given figure 11%). The maximum vertical height was 4.7m. During construction investigation: For Building 1, 28 out of 83 boreholes encountered caves (34% rate); Building 2, 31 out of 110 boreholes (28% rate); Building 4, 49 out of 110 boreholes (45% rate). Additionally, the rock surface levels between adjacent boreholes fluctuate significantly. Therefore, the assessment indicates that the karst development degree at the site is: highly developed.

The clear heights of the cavities range from 0.5 to 7.5 m. Most cavities are filled with clayey soil of varying consistency, mostly plastic, but also including soft plastic and hard plastic states. The clay contains blocks and gravel of dolomitic limestone in a highly weathered state. The distribution of cavities is irregular. The thickness of the cavity roofs varies from 0.3m to 10.8m.

Fig.3. Karst conditions exposed after foundation pit excavation to formation level

(2) Analysis of Karst Development Patterns

The abscissa (X-axis) of the above figure represents boreholes where karst caves were encountered, and the ordinate (Y-axis) represents elevation (m). From top to bottom, the lines indicate ground elevation, cave roof elevation, and cave floor elevation. It can be observed that the revealed depth of the caves is between 10-30m. The development of karst caves shows some correlative similarity with the topography and geomorphology.

Under different geomorphological conditions, the karst development process varies. Karst development is largely influenced by surface water and infiltration conditions, which in turn are often affected by geomorphological factors such as ground slope, incision depth, and water system distribution. Therefore, the karst development process often exhibits a certain correlative similarity with the geomorphological development process.

The size of the ground slope directly affects the amount of infiltration. In relatively flat areas, surface runoff velocity is slow, infiltration is greater, and karst is more developed. Conversely, the steeper the slope, the faster the runoff velocity, the smaller the infiltration, and the less developed the karst.

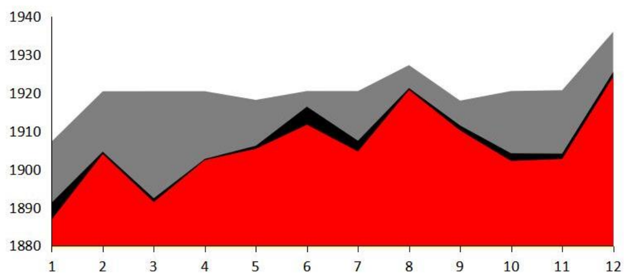

Fig.4. Distribution map of karst caves at the site

5. Analysis of the Impact of Karst on Pile Foundation Construction

Based on a comprehensive analysis of the proposed structure's ±0.00 level, variations in site geological conditions, building loads, project cost, difficulty of foundation construction, and environmental impact, it was determined that rotary drilling cast-in-place piles would be used for Buildings 1, 2, and 4.

Due to the randomness of karst development, complex engineering geological conditions, and improper construction practices, projects may fail to meet standards. Issues include drill sticking when penetrating cave roofs, borehole wall collapse burying drills, slurry loss in areas with developed empty caves and fissures, significant over-pouring of concrete, and failure to meet code requirements for sediment at the borehole bottom.

To prevent the aforementioned problems, the following engineering measures are recommended:

(1) Conduct construction investigation with one borehole per pile or multiple boreholes before construction to clarify the burial depth of cave roofs and floors, guide pile foundation construction, ensure full understanding, and try to select tools with smaller stroke to treat the cave roof.

(2) To avoid drill burial accidents, use steel casing during construction, which can also save a significant amount of concrete.

(3) To address slurry loss, first rationally select the mud concentration, then ensure the mud pit capacity is sufficient for rapid mud and water replenishment during loss. Additionally, the process of backfilling with rock fragments and concrete can be used.

(4) For smaller cavities, fill the empty caves with filling material. Use rock blocks or low-grade concrete to fill the caves before drilling again to ensure pile quality. For high caves (greater than 4m), the above fillers are difficult to complete the filling of the empty cave completely, and backfilling efficiency is low, making construction cumbersome. Cement mortar or low-grade concrete can be backfilled, and drilling can only proceed after initial setting.

(5) For sediment treatment, use a clean-bottom drill bit to remove sediment before placing the rebar cage. Ensure pouring immediately after cage placement to minimize borehole stagnation time. When conventional methods cannot clean sediment thoroughly, use the air-lift reverse circulation process for hole cleaning.

6. The Impact of Karst on Pile Foundation Bearing Capacity and Settlement

(1) Pile foundations in karst areas are mostly rock-socketed end-bearing piles. The vertical load borne by the pile top is primarily supported by the bearing capacity of the rock layer at the pile tip. The size of the cave, roof thickness, span, and the karst development status of the roof rock mass directly affect the bearing capacity and settlement of the pile foundation, endangering building safety. The depth of construction investigation boreholes should reach 3 times the pile diameter below the pile tip elevation and not less than 5m. The depth should be appropriately increased when the bedrock surface levels at adjacent pile tips fluctuate significantly.

(2) Bored cast-in-place piles are commonly used in karst areas. Due to the developed caves, grooves, and channels, incidents like drill sticking and borehole wall collapse are prone to occur. After hole cleaning and before concrete pouring, a certain thickness of sediment may form at the bottom. The sediment layer is often flow-plastic, with low strength and high compressibility, preventing the full mobilization of end bearing capacity and resulting in pile capacity values far less than the design values. The specialized mud for wall protection or full steel casing hole-forming techniques should be used to prevent hole collapse. Simultaneously, reliable processes and cleaning measures must be employed for hole cleaning. The thickness of the sediment at the borehole bottom should be strictly controlled within the limits specified by codes and design requirements to prevent secondary settlement caused by excessive sediment thickness.

7. Conclusion

The patterns of karst development in karst areas are very complex. In practical work, it is essential to consider the specific project conditions comprehensively, integrate site engineering geological conditions, adopt comprehensive and reasonably effective investigation methods, thoroughly understand the development patterns and trends of site karst, make correct evaluations of the work area, propose reasonable suggestions, and achieve economical rationality and safety reliability.

Acknowledgments

The authors express their sincere gratitude to China Energy Engineering Group Shanxi Electric Power Survey & Design Institute Co., Ltd. for their assistance.

Conflicts of Interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

References

1. Detailed Geotechnical Investigation Report for the Phase I Resettlement Housing Project "Jinma Tengyuan" in the Jinma Area[R], Yunnan Provincial Construction Engineering Design Institute Co., Ltd., October 2014.
2. National Standard of the People's Republic of China, Code for Investigation of Geotechnical Engineering (GB50021-2001, 2009 Edition)[S], Beijing, China Architecture & Building Press, 2009.
3. National Standard of the People's Republic of China, Technical Standard for Building Foundation in Karst Region (GB/T 51238-2018)[S], Beijing, China Planning Press, 2018.
4. Industry Standard of the People's Republic of China, Technical Code for Building Pile Foundations (JGJ94-2008)[S], Beijing, China Architecture & Building Press, 2008.
5. Shi Xiaonan, Discussion on the Influence of Karst Geology on Pile Foundation Construction and Countermeasures[J], Engineering Construction Technology, 2018.03.