STUDY ON STRENGTHENING SOLUTIONS FOR PILE FOUNDATIONS IN INDUSTRIAL BUILDING RENOVATION

NGHIÊN CỨU GIẢI PHÁP GIA CƯỜNG MÓNG CỌC TRONG CẢI TẠO, SỬA CHỮA NHÀ CÔNG NGHIỆP

Nguyen Tien Thanh[1]*, Nguyen Xuan Loc [1]

Abstract: In the context of increasingly limited industrial land resources, the renovation and upgrading of production facilities within existing factory premises have become an inevitable trend to optimize investment costs. However, the reuse of existing structures presents significant engineering challenges, particularly regarding the structural inadequacy of pile foundations when subjected to increased loads and eccentric moments caused by column misalignment during construction. This study analyzes current conditions, evaluates factors affecting structural integrity, and proposes effective strengthening solutions for pile foundations in industrial building renovation projects.

Tóm tắt: Trong bối cảnh quỹ đất công nghiệp ngày càng hạn hẹp, giải pháp cải tạo và nâng cấp không gian sản xuất trên nền nhà xưởng hiện hữu đang trở thành xu hướng tất yếu nhằm tối ưu hóa chi phí đầu tư. Tuy nhiên, việc tái sử dụng hệ kết cấu cũ đặt ra những thách thức kỹ thuật phức tạp, đặc biệt là sự thiếu hụt khả năng chịu tải của móng cọc dưới tác động của tải trọng kết cấu mới phát sinh và các nội lực phụ sinh ra do sai số định vị trục (lệch tâm) trong quá trình thi công. Bài báo phân tích hiện trạng, đánh giá các nguyên nhân gây suy giảm an toàn kết cấu móng và đề xuất một số phương án gia cường móng trong các dự án cải tạo nhà công nghiệp.

Keywords: Foundation strengthening, industrial building renovation; eccentricity; structural upgrading.

Từ khóa: Gia cường móng, cải tạo nhà công nghiệp, lệch tâm, nâng cấp kết cấu.

Received: February 10, 2026; Revised: February 20, 2026; Accepted: May 11, 2026.

I. INTRODUCTION

1.1 Urgency

Currently, Vietnam's rapid industrialization has led to a shortage of available land in key industrial zones. Consequently, investment strategies are shifting from acquiring new land to maximizing the use of existing infrastructure. Renovating and upgrading existing factory buildings has therefore become an optimal solution for many enterprises.

From an economic perspective, this solution offers significant advantages over investing in entirely new construction. It helps investors save considerably on initial investment costs, shortens the time to bring the production line into operation, and allows them to utilize existing supporting facilities (technical infrastructure, electricity, water).

However, changing the intended use or adding floors to a factory building with an existing structure presents complex construction engineering challenges, especially for the pile foundation – the most important but also the most difficult to control load-bearing component. The main risks include:

- Increased loads: Additional equipment and structural modifications may exceed the original design capacity.
- Dynamic effects: Machinery-induced vibrations can lead to material fatigue and uneven settlement.
- Material degradation: Long-term use may reduce the strength of concrete and reinforcement due to environmental exposure.

Without proper assessment and timely intervention, these factors may result in structural failure, excessive settlement, operational disruption, and safety hazards. Therefore, effective strengthening solutions for pile foundations are essential in renovation projects.

Figure 1. Large-span industrial factory building

1.2 Research Objectives

Based on the above reality, this article focuses on addressing the following specific objectives:

(1) **Analysis of causes and mechanisms of failure:** Systematizing the causes of reduced load-bearing capacity of pile foundations during renovation, including both objective factors (increased load, corrosive environment) and subjective factors (axis positioning errors, foundation eccentricity during new column construction).

(2) Proposing appropriate reinforcement solutions: Research and propose specific technical solutions (such as expanding the foundation cross-section, using additional piles) to restore and enhance the load-bearing capacity of the foundation system.

[1]. Faculty of Civil Engineering, Vietnam Maritime University
*Email: thanhnt.ctt@vimaru.edu.vn

(3) Optimizing construction methods: Proposed solutions must satisfy the specific constraints of the renovation project: construction in confined spaces, low ceiling height, and minimizing vibration impacts on nearby operating production lines.

II. RESEARCH MATERIALS

Hai Phong contains many industrial zones built on reclaimed land, with embankments constructed on previously muddy areas along rivers and the coast; the geological conditions are complex; low shear strength, high porosity, and low permeability coefficient are fundamental characteristics of weak soil, leading to problems of instability during construction and prolonged residual settlement during operation, including uneven settlement.

Figure 2. Two-bay factory building

2.1. Current status of existing pile foundation quality

In industrial factory renovation projects, reusing old foundations often faces three main problems: material degradation over time, adverse changes in the load-bearing scheme due to construction errors, and stringent construction conditions.

(1) Material degradation: Concrete foundation slabs can carbonize, reducing pH and compromising the protective capacity of the reinforcing steel. In chemical or textile factories, groundwater containing Cl^- or SO_4^- ions penetrates and corrodes the reinforcing steel, reducing the actual load-bearing cross-section of the slab.

(2) Inaccurate as-built documentation: A common problem in older factories (built 10-15 years ago) is discrepancies between archived as-built documentation and the actual site conditions. This leads to significant risks during calculations and inspections if engineers rely solely on drawings without conducting on-site surveys.

Figure 3. Industrial building foundation

2.2 Analysis of eccentricity problems and changes in the load diagram

This is the most complex technical issue in factory renovation. When constructing a new column and frame system (especially prefabricated steel columns) on the old foundation, ensuring that the center of gravity of the new columns coincides perfectly with the center of gravity of the old pile caps is very difficult due to:

- Errors in surveying and centerline positioning.
- New architectural or technological requirements necessitate relocating the columns.

This deviation creates an eccentricity e between the point of force application and the center of stiffness of the pile group, leading to the following structural consequences:

(1) Additional bending moment generated: In addition to the axial force N, the foundation footing must withstand an additional bending moment M = N.e. The old footing system, originally designed primarily to withstand concentric (or slightly eccentric) compression, now has to withstand a large bending moment, causing tensile stress exceeding the load-bearing capacity of the concrete, leading to fracture of the footing.

(2) Redistributing internal forces within the pile group: Eccentric moments will alter the pile head reactions. Piles on the compression side will be overloaded (exceeding the soil bearing capacity), while piles on the opposite side may experience pull-out (tension), posing a risk of failure to the pile-cap connection.

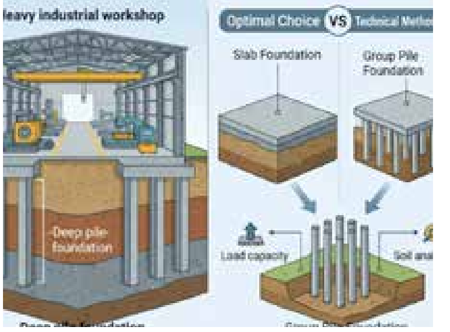


Figure 4. Industrial building foundation solutions

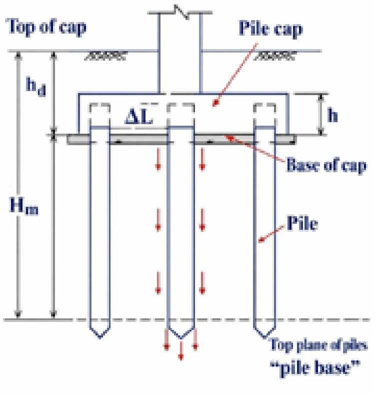


Figure 5. Pile foundation option

2.3. Specific constraints when constructing in a factory building

Unlike new construction, foundation reinforcement work in existing (or partially renovated) factory buildings is subject to strict constraints:

(1) Limited working height: Existing metal roof or mezzanine floor structures often limit working height to under 6m, or even under 3m. This renders it impossible to use conventional pile driving/pressing equipment or large-scale pile drilling machines.

(2) Limited construction space: The area surrounding the foundation site is often enclosed by machinery, underground pipelines, or adjacent foundation structures, making it difficult to excavate and expand the foundation slab.

(3) Vibration and noise control: Construction work must not generate significant vibrations (such as pile driving) as this will affect the accuracy of nearby production machinery or cause cracks in existing structures.

III. EXCHANGE AND DISCUSSION

To provide an accurate reinforcement solution, the research process needs to follow a strict sequence from experimental survey to theoretical simulation, based on current design standards [1], [2], [3].

3.1. Calculation basis - Structural condition assessment process

Before calculations , it is necessary to accurately determine the input parameters of the existing foundation system through non-destructive and local destructive testing methods:

(1) Determining the actual concrete strength (Rb): Using a combination of rebound hammer testing and core drilling at representative foundation locations. The test results help determine the existing concrete strength grade after a long period of operation.

(2) Checking for steel reinforcement corrosion: Use a steel reinforcement detector to determine the location, diameter, and thickness of the concrete cover. Combine this with measurements of carbonation depth and Cl- ion content to assess the degree of steel cross-sectional degradation.

(3) Determine the actual eccentricity (e): Use an electronic total station to measure the actual grid of the new column anchor bolts relative to the centerline of the old foundation footing. The eccentricity values ex , ey are the most important input parameters for the verification problem.

3.2. Theoretical basis for calculating internal force distribution

When eccentricity occurs, the foundation footing is no longer subjected to concentric compression. The problem shifts to eccentric compression (bending compression). The load acting on the i-th pile in the pile group is determined by the structural mechanics formula:

$$P_i = \frac{N}{n} + \frac{M_x.y_i}{\sum y_i^2} + \frac{M_y.x_i}{\sum x_i^2} \quad (1)$$

In there:

P_i : Pile head reaction force at position i.

N: Total vertical load.

n: Total number of piles in the foundation.

M_x, M_y: Bending moments due to eccentricity and lateral load (M = N.e).

xi , yi : Coordinates of the i -th pile relative to the centroid of the pile group.

Safety inspection standards:

A foundation system is only considered safe if it meets two conditions ***simultaneously:***

(1) Land conditions: P_{max} < [P] (Allowable bearing capacity of pile foundation) and P_{min} > 0 (No excessive uplift force occurs that would damage the pile-cap connection).

(2) Conditions for pile cap strength: The shear, punching shear, and bending strength of the pile cap (after accounting for material degradation) must be greater than the internal forces generated by Pi .

3.3. Soil-Pile-Structure Interaction Model

Due to the complexity of the reinforcement process (combining old and new materials), manual calculations are often insufficiently accurate. This study uses the finite element method to simulate the simultaneous operation:

(1) Modeling the old-new connection: Using connection elements to simulate the ability to transmit shear force across the interface between the old concrete foundation and the reinforced concrete layer. The force transmission mechanism is based on sliding friction and the shear resistance of the drilled steel.

(2) Analysis tools: Use specialized software (such as ETABS or SAFE) to assess differential settlement and stress redistribution when adding new piles to an existing pile cap system.

3.4. Propose reinforcement solutions

Based on the assessment of the current situation and verification calculations, the selection of a reinforcement solution must ensure a balance between three factors: load-bearing capacity, feasibility of construction in confined spaces, and economic efficiency. Below are three groups of proposed technical solutions commonly applied to industrial workshops.

3.4.1. Solutions for expanding the cross-section of the foundation slab

a. Principle:

This is a traditional reinforcement method, performed by pouring an additional layer of reinforced concrete around or over the existing foundation.

b. Scope of application:

(1) When calculations show that the existing pile system is still strong enough to bear the load, but the foundation slab is not strong enough to withstand bending or shear due to the increased load.

(2) Addressing eccentricity: Extending the foundation towards the compression side increases the lever arm, rebalancing the bending moment caused by axial misalignment.

c. Construction techniques:

The key to success is the ability of the old and new concrete to work simultaneously (as a whole). The required process includes:

Surface treatment: Roughen the surface of the old concrete to expose the aggregate, and remove rust from any reinforcing steel (if present).

(1) Steel rebar anchoring: Using specialized chemical anchoring agents (Epoxy resin) to anchor the reinforcing steel bars to the existing foundation, ensuring shear force transmission at the interface.

(2) Bonding additive: Apply a layer of bonding slurry or latex additive before pouring new concrete to prevent delamination.

3.4.2. Supplementary solution: Small-diameter bored piles (Micropile piles)

a. Principle:

Using small-diameter piles (D = 150 - 300 mm), constructed by drilling holes, placing steel cages (or load-bearing steel pipes), and pumping high-pressure cement/concrete grout, micropile piles act as new "supports," bearing the increased load that the old piles could not withstand.

b. Outstanding advantages in renovation:

(1) Adaptable to confined spaces: Compact drilling equipment, suitable for use in workshops with low ceiling heights (< 3m) and cramped areas.

(2) Vibration control: The drilling technology generates minimal vibration, minimizing disruption to precision machinery operating in the vicinity.

(3) Penetration capability: It is possible to drill through old foundation slabs or thick concrete layers to penetrate deep into good soil.

c. Structure of the bond:

Micropile pile heads are fixed into the existing foundation footing by expanding the footing or by inserting reinforcing steel through boreholes in the existing footing, forming a unified system.

3.4.3. Segmented pile driving solution

a. Principle:

Hydraulic jacks are used to drive short pile sections (usually precast steel or reinforced concrete piles, 1-1.5m long) into the ground. The unique aspect of this method is that it utilizes the weight of the factory building itself (via the beam/foundation system) as a counterweight to drive the piles.

b. Scope of application:

(1) Suitable for addressing local settlement issues or reinforcing foundations when subjected to very large increases in load.

(2) This method is best applied in locations where the supporting structural frame is rigid enough to serve as a support point for the hydraulic jack.

c. Advantages:

Know the bearing capacity immediately: The pressure reading on the jack gauge is the actual bearing capacity of the pile, eliminating vague calculation assumptions.

Unlike bored piles, it does not generate noise or sludge.

3.5. Calculation examples

To illustrate the effectiveness of the proposed solution, the paper presents the results of calculations, verification, and reinforcement design for a textile factory in an industrial park, which was upgraded from 2 stories to 3 stories and had a new production line installed.

3.5.1. Input Parameters

Current status: Reinforced concrete (RC) pile foundation with a cross-section of 300x300mm. Foundation cap with 4 piles (2x2). Allowable bearing capacity of the piles according to soil conditions: [P] = 45 tons.

(1) Load capacity:

- Initial design load: N_O = 160 tons.

- Load after renovation (recalculated): N_1 = 230 tons.

(2) Construction error: On-site survey revealed that the new steel column is misaligned from the center of the old foundation by a distance ex = 15cm in the horizontal direction of the building.

3.5.2. Assessing the load-bearing capacity before reinforcement

Using the formula for calculating the internal force distribution (Section 3.2), we have the bending moment generated due to eccentricity:

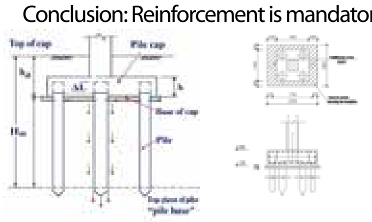
$M_y = N_{new}.ex = 230x0.15 = 34.5\ Tm$

The reaction force on the pile head subjected to the greatest compression (Pmax) in the pile group:

$$P_{max} = \frac{230}{4} + \frac{34.5}{2x0.6} = 57.5 + 28.75 = 86.25\ tấn$$

Comment: P_{max} = 86.25 tons > [P] = 45 tons; The pile is severely overloaded (exceeding 91%), the foundation is at risk of failure due to local compression and large bending moment.

Conclusion: Reinforcement is mandatory.



a. Existing pile foundation *b. Reinforced pile foundation*

Figure 6. Existing foundation and foundation after reinforcement.

3.5.3. Proposed reinforcement options

Combine the two solutions (as analyzed in Section 4):

(1) Additional piles: Construct two additional micropile piles with a diameter of D200 (P_{micro} = 40 tons/pillar) on either side of the foundation to reduce the vertical load.

(2) Expanding the foundation: Pouring concrete to expand the foundation from 1.4x1.4m to 2.2x1.8m to enclose the two new piles and increase the bending stiffness of the foundation.

3.5.4. Results after reinforcement

After running the interactive model on ETABS/SAFE software with the new foundation system (4 old piles + 2 Micropile piles), the results of the internal force redistribution are as follows:

Parameter	Before reinforcement (Old system subjected to new load)	After reinforcement (Mixed system)	Conclude
P_{max} (Old pile)	**86.25 tons**	**41.5 tons** (< 45	**Obtain**
P_{max}	N/A	**32.0 tons** (< 40	**Obtain**
Stress in the tower	A wide crack has appeared.	Within the elastic limit	**Obtain**

IV. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Based on theoretical analyses and practical computational examples, the paper draws the following main conclusions:

a) The importance of eccentricity: In industrial building renovation, axis positioning errors are a leading risk factor. Ignoring the bending moment due to eccentricity (M = N.e) can lead to serious misjudgments of structural safety, even when the total vertical load appears satisfactory.

b) The effectiveness of the hybrid solution: Combining micropile piles (withstanding vertical loads) and extended foundation slabs (increasing stiffness and moment resistance) is the most optimal solution for limited construction space. This solution thoroughly addresses both issues: insufficient load-bearing capacity and instability due to eccentricity.

c) Construction feasibility: The proposed solutions are suitable for the "low height" conditions and do not disrupt the factory's production line.

4.2. Recommendations

To improve the quality of renovation work, the authors recommend:

a) Mandatory survey process: Strict adherence to regulations on site surveys as stipulated in circulars, decrees, and certain provisions of the construction law (exploratory excavation, actual grid-based measurement, NDT testing: Non-Destructive Testing) is required before preparing renovation design documents. Under no circumstances should designs be based solely on old as-built documentation.

b) Safety factor: It is necessary to study the application of a higher safety factor (FS > 2.5) for old piles during verification calculations, due to the uncertain nature of the material after a long period of operation.

c) Monitoring: It is mandatory to install a settlement monitoring and stress measurement system during the reinforcement construction process and the initial phase of operation with new loads to allow for timely corrective action.

Acknowledgements:

This research is funded by Vietnam Maritime University under grant number: DT25-26.93.

Reference:

[1] TCVN 10304:2025. (2025). *Pile foundations – Design standard* (In Vietnamese).

[2] TCVN 5574:2018. (2018). *Design of concrete and reinforced concrete structures – Design standard* (In Vietnamese).

[3] Phan, V., & Thao, H. T. (2013). *Analysis and calculation of pile foundations.* Ho Chi Minh City National University Press (In Vietnamese).

[4] Kiem, L. V. (2009). *Damage, repair and reinforcement of foundations.* Construction Publishing House, Hanoi (In Vietnamese).

[5] Kiem, L. V. (2004). *Damage, repair and reinforcement of structures.* Ho Chi Minh City National University Publishing House (In Vietnamese).

[6] Bich, N. X. (2002). *Repair and reinforcement of construction works.* Science and Technology Publishing House, Hanoi (In Vietnamese).

[7] Ransom, W. H. (2005). *Building failures: Diagnosis and avoidance.* Taylor & Francis e-Library.