USE OF PILE PLATE TO SUPPORT BANKS – MEASURES TO PREVENT LABOR ACCIDENTS ON CONSTRUCTION SITES

First A. Drd. Adrian MOISE, *National University of Science and Technology POLITEHNICA Bucharest***,**
Second B. Alina TRIFU, *National Research and Development Institute for Occupational Safety INCDPM Bucharest*
Third C. Drd. Nicoleta MERLOI, *National University of Science and Technology POLITEHNICA Bucharest*
Fourth D. Sl. dr. ing. Cornelia LUCHIAN, *National University of Science and Technology POLITEHNICA Bucharest*
Fiveth E. Conf. dr. ing. Claudia BORDA, *National University of Science and Technology POLITEHNICA Bucharest*
Sixth F. Conf. dr. ing. Marinela Nicoleta MARINESCU, *National University of Science and Technology POLITEHNICA Bucharest*

ABSTRACT. In a world where construction is in full swing, worker safety is of crucial importance. Construction work, which often involves deep excavations and work in areas with unstable ground, poses significant risks to workers. The appropriate use of bank supports is an essential measure to protect workers and prevent accidents. The purpose of this article is to analyze the role of sheet piles in bank support, with a focus on their contribution to the prevention of work-related accidents. Their operating principle, installation methods, technical advantages and the relevant legislative framework are analyzed. The risks associated with working without adequate support systems are also highlighted and practical recommendations are formulated for designers, contractors and decision-makers in the construction field.

KEY WORDS : sheet piles, shore support, risks, prevention of work accidents.

1. INTRODUCTION

In the field of civil and industrial construction, excavation works are essential stages for the construction of foundations, municipal infrastructures or other structures below ground level. However, excavations in the ground, especially those of great depth or carried out in unstable soils, pose significant risks to workers, equipment and the environment [1-4]. One of the most frequent and dangerous incidents associated with these works is the collapse of banks.

Workplace accidents caused by the collapse of vertical walls or side banks are often serious, leading to serious injuries or even deaths. In addition, such events can cause major property damage, delays in execution and legal sanctions, especially in the context of strict occupational health and safety regulations.

To prevent these risks, it is essential to implement effective bank support systems. Among the available solutions, sheet piles have proven to be one of the most effective technical methods for stabilizing land during excavation works[5,6]. These elements, made of steel, concrete or composite materials, are inserted into the soil to create a vertical wall that prevents the landslide of earth masses.

2. SHEET PILE. DESCRIPTION

Sheet piles are linear elements used to create temporary or permanent support systems, with the aim of stabilizing banks and preventing landslides in excavation works [13,15]. They function by forming a continuous vertical wall, which takes on the lateral pressure exerted by the soil and/or water, ensuring the stability of the excavated area and thus protecting workers and equipment in the vicinity.

2.1 Types of sheet piles

Depending on the material they are made of and the technical conditions of the project, sheet piles can be classified as follows:

- Metal sheet piles (made of rolled steel) – the most commonly used due to their high mechanical strength, durability and ease of reuse [17, 18]. They can have various profiles (Z, U, straight) (Fig.1).
- Reinforced concrete sheet piles (precast) – used especially in permanent constructions, where high corrosion resistance is required [20].
- PVC or composite sheet piles – used in small-scale works or in chemically aggressive environments, where steel could undergo rapid degradation (fig. 2.).

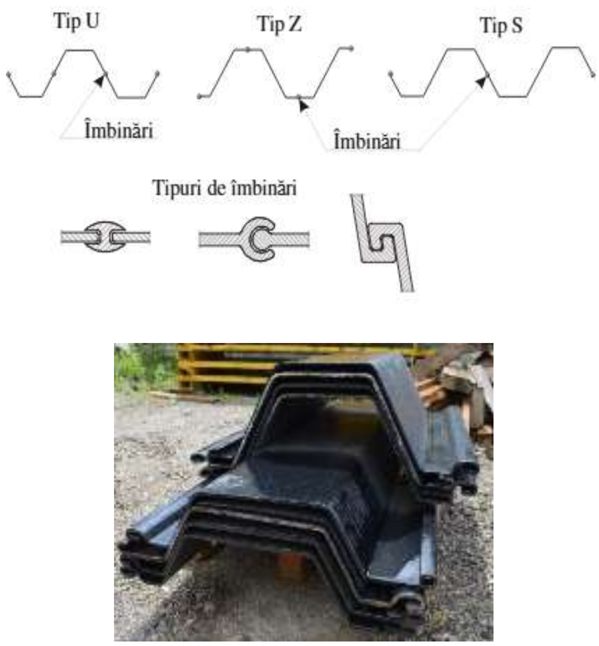

Figure 1. Examples of metal sheet piles and types of joints

Figure 2. PVC sheet piles

Sheet piles are inserted into the ground, by hammering, vibrating or pressing, forming a continuous, watertight or semi-watertight wall. Each sheet pile has a joint system on the sides (most often "wedge and slot" type) that allows for perfect connection with adjacent elements, thus increasing the rigidity and load-bearing capacity of the assembly [21, 23]. They function as a mechanical barrier, transferring the lateral forces of the soil to a deeper and more stable base. In cases where work is carried out near water or in aquiferous lands, sheet piles can also have a sealing role, preventing water infiltration into the excavated area.
PVC sheet piles are manufactured by co-extrusion, two layers of PVC, one recycled and one new on the outside, treated with additives to increase resistance to weathering, UV, fading. Pultrusion is a continuous process of manufacturing composite material with constant section, in which a bundle of fibers or nets is pulled through a bath of resins, sometimes followed by a pre-forming system. These are passed through a heated calibration die where the resin undergoes a polymerization process. The resins used are: polyester, polyurethane, vinylester, epoxy, etc.

2.2 Technical advantages

The use of sheet piles offers a number of important benefits in the context of construction works:

- Reducing the risk of bank collapse – directly protects workers and equipment.
- Speed of execution – installation is done with specialized equipment and in a relatively short time.
- Adaptability – can be used in various soil types, including in congested urban areas.
- Reuse – in the case of metal ones, sheet piles can be recovered after the work is completed and reused in other projects.
- Compatibility with complex solutions – can be part of wider support systems (e.g. with anchors, crown beams, bracing, etc.).

3. APPLICATIONS IN SUPPORTING SHORES

The use of sheet piles in bank support works is one of the safest and most effective methods of preventing collapses in deep excavations [23 -25]. The correct choice of installation technology, correlated with the type of soil, the groundwater level and the depth of the excavation, is essential for the efficiency of the support system.

3.1 Installation techniques

The method of inserting sheet piles into the ground is chosen depending on the nature of the terrain and the context of the work. The most commonly used methods are:

- Mechanical driving – using hydraulic or pneumatic hammers to drive sheet piles into the ground. It is effective, but can produce significant vibration and noise.
- Vibration – using vibrating hammers mounted on cranes or excavators. This method is faster and less environmentally aggressive than classic hammering.
- Static pressing – used mainly in urban areas where vibrations need to be reduced. The sheet piles are slowly pushed into the ground with hydraulic equipment.
- Drilling and injection – in hard soils, it is sometimes necessary to pre-drill the route or inject suspensions to reduce friction and increase stability.

3.2 Calculation elements – system stability

When designing a sheet pile system, the following elements must be considered:

- Active and passive soil pressure;
- Required embedment depth;
- Free length exposed to bending stresses;
- Additional loads (traffic, machinery, neighboring buildings);
- Groundwater level and hydrostatic pressure.

A simplified calculation is based on the moment balance between the active and passive zones of the soil. In general, a safety factor of at least 1.5 against failure is ensured.

The use of sheet piles is influenced by the properties of the material from which they are manufactured, compared to the conditions at the installation site.

The stability of a sheet pile system is determined by its ability to resist the forces exerted by the soil and, in some cases, water. The calculation is based on the theory of active and passive soil pressures, according to classical geotechnical methods [26, 28]. The system can be: cantilevered – the sheet pile is embedded in the soil without additional supports; supported – the sheet pile is additionally supported with anchors, braces or beams.

The static calculation scheme for sheet piles embedded in the ground and free at the top, operated above ground level with a concentrated force P, for example the resultant of the pressure exerted by a water column, is presented in Figure 3.

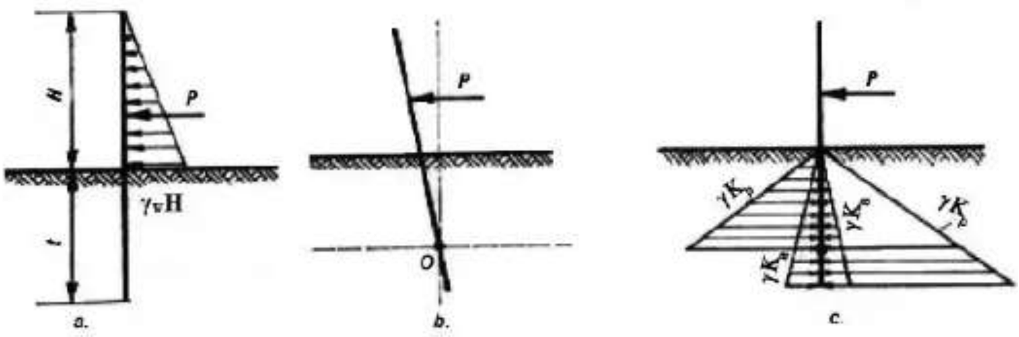

Figure3. Sheet pile embedded in the ground and acted upon by a concentrated force

Under the action of the force P, the sheet pile bends and rotates. If bending

deformations are neglected, the sheet pile can be viewed as a rigid one that rotates around point *O (* fig.3,b).
On the front face, above point O, the sheet pile presses on the ground, it is compressed, creating conditions for the development *of passive resistance* , while below point O the sheet pile moves away from the ground, it is stretched, developing *active thrust.* On the back face the situation is the opposite .
If the friction between the wall and the ground is neglected, the pressure diagrams (fig. 3,c) have, according to Rankine's theory, the slopes γKp and γKa, where the coefficients of passive resistance and active thrust are:

$$K_p = tg^2\left(45^o + \frac{\emptyset}{2}\right); \quad K_a = tg^2\left(45^o - \frac{\emptyset}{2}\right) \quad (1)$$

The wall has assured stability if the embedment moment given by the resultants of the passive resistances that develop on the two sides of the diagram balances the overturning moment given by the force P.

3.3. Case study - support bank for 4 m deep ditch, in an urban area

In order to correctly and safely execute a sewer pipe in a crowded residential neighborhood, to avoid the high risk of bank collapse and damage to the foundations of neighboring buildings, Rankine theory was applied to determine the stability of a sheet pile system to support the banks of the excavation.
The calculations performed, based on the theory of active and passive soil pressures, according to classical geotechnical methods, led to the following solution applied on the construction site:

- The use of U-type metal sheet piles, length 6 m;
- Installation method: vibration with excavator-mounted equipment;
- Embedment depth: 2 m below the bottom of the excavation;
- Additional anchoring with horizontal stiffening beams (at the top);
- Total installation time: 2 days.

The result of the correct design and installation of the sheet pile system was that the trench excavation works were carried out without incidents, without deformation of the banks and without interruptions to traffic in the area.

4. RISKS ASSOCIATED WITH WORKING WITHOUT PROPER SUPPORT

Without adequate bank support measures, excavation work becomes extremely dangerous, both for workers and for nearby structures. Bank collapse is one of the most common accidents on construction sites involving deep excavations, and the effects can be devastating [4].
The main types of major risks are:

1. Bank collapse and workers buried
   - The most serious and common risk is the collapse of the excavation walls, leading to the partial or complete burial of workers in the trench.
   - Water-saturated sandy or clay soils are particularly unstable.
2. Landslides in adjacent areas
   - Without support, the soil mass can slide, affecting roads, sidewalks, or the foundations of nearby buildings.
3. Impact on municipal networks
   - Water, gas or cable pipes can be broken by subsidence or ground movements.
4. Instability of equipment and machinery

- The edge of the unsupported excavation may collapse under the weight of heavy equipment (excavators, cranes), leading to their overturning.

5. Accidents due to falling into voids
   - Workers can fall into unmarked or improperly secured excavations.

According to data from the Territorial Labor Inspectorate and reports in the field of construction safety:

- Over 20% of fatal accidents on construction sites are associated with excavation work;
- In Romania, between 2015 and 2022, dozens of serious accidents caused by bank collapses were recorded annually, many of them caused by lack of support or incorrect design;
- In a high-profile case in 2021, a worker was buried alive in a 3-meter-deep trench dug without support in an urban area. An investigation concluded that minimum safety precautions were not followed.

Ignoring these risks, especially in an urban environment or on a construction site with heavy traffic, can have consequences not only for worker safety, but also from a legal and financial point of view, through fines, work stoppages or even criminal cases in the event of a serious accident.

5. The role of sheet piles in preventing work accidents

Sheet piling plays a key role in ensuring the safety of excavation works, preventing the most serious incidents that can occur in the absence of adequate support measures. The correct application of this technology not only meets the technical requirements of the work, but also significantly reduces the risks to the health and life of workers on the site.

Sheet piling contributes to creating a safe working environment in the following ways:

- Ensures bank stability: the continuous wall formed by sheet piles prevents lateral soil movements, preventing it from collapsing on workers or equipment.
- Eliminates hydrostatic pressure: in areas with high groundwater, sheet piles act as a screen that reduces water penetration into the excavation, thus avoiding erosion and bank instability.
- Allows work in prolonged safe conditions: in the case of complex works or long execution times, supporting with sheet piles maintains safety throughout the entire duration of the intervention.

The use of support systems, including sheet piles, is expressly provided for in Romanian and European legislation on occupational safety:

- Law No. 319/2006 on occupational safety and health provides that the employer is obliged to take all necessary measures to protect the life and health of workers.
- Government Decision No. 300/2006, on minimum safety requirements for temporary or mobile construction sites, requires supporting the banks in the case of deep excavations.
- The NP 120-2022 regulation on the design of geotechnical works provides for technical calculation and execution measures to support excavations.

In addition to preventing direct accidents, the use of sheet piles:

- Improves site organization by creating clear boundaries of the work area;
- Allows work in proximity to existing utility networks, reducing the risk of damage;

- Facilitates access and pedestrian traffic control in the case of urban works.

In conclusion, sheet piles are not just a technical support element, but an active measure to protect the life and health of workers. Their choice, correct design and efficient implementation must be part of an integrated occupational safety plan, adapted to the specifics of each construction site.

6. Intelligent Integrated Sheet Pile Monitoring System (IIPMS)

Recent research has highlighted the need to integrate digital technologies and real-time risk analysis into the shoreline support process. An **Intelligent Integrated Sheet Pile Monitoring System (IIPS) is proposed** , which combines geotechnical analysis with automated occupational risk assessment.

SIIMP system structure

1. Displacement and vibration sensors on sheet piles;
2. Data acquisition and analysis platform ;
3. Dynamic mathematical model for risk assessment;
4. Automatic alerts sent to OHS managers.

Original benefits and contributions

- Introducing sensor-based predictive analytics into sheet pile monitoring;
- Correlating technical risk with professional risk , in real time;
- Transforming static inspection into a dynamic, digitally assisted process ;
- 80% reduction in overall accident risk through proactive measures.

Through this system, sheet piles are no longer just passive support elements, but active components of a digitalized security infrastructure, compatible with the principles of *Safety 4.0* and *Industry 4.0* .

The Intelligent Integrated Pile Monitoring System (IIMPS) is designed as a complete operational chain, "sensors → data → analysis → decision" , operating in near real time and transforming raw geotechnical measurements into quantifiable indicators of stability and SSM risk . In the field, the system starts with a modular network of sensors mounted on the sheet pile wall and in the soil mass: tiltmeters, linear displacement transducers, piezometers and geophones. Their placement follows critical stress paths (section ends, stratification change zones, corners), and the sampling varies from 10–50 Hz in the dynamic phases (vibro-hammering, pumping) to 0.1–1 Hz in the background monitoring. Each sensor transmits measurements to an industrial "edge gateway", which ensures synchronization, noise filtering and quality validation (QA/QC), then uploads the data encrypted to the analytical platform.

In the platform, the data are processed and contextualized : active and hydrostatic pressures are recalibrated with the current water table, and the displacements/rotations are correlated with the technological phase (excavation, anchoring, concreting). A dynamic risk model calculates the $R_{d\ \text{indicator}}$, which integrates the total lateral pressure, the system stiffness (material + embedment/anchors) and kinematic penalties for relative exceeding of the permitted displacement and angle. In parallel, a conversion map translates Rd into a semi-quantitative occupational risk index R_r (probability × severity), allowing reporting in the language of SSM. For management, SIIMP also provides an integrated coefficient $K_{si} = (1-R_d)/(1+R_r)$, a single score between 0 and 1, useful for comparisons between fronts, shifts or projects.

Decision component is carried out through a configurable "playbook", aligned with the regulatory framework

(Law 319/2006, GD 300/2006, NP 120-2022). For yellow level (moderate risk) the system automatically increases the monitoring frequency, requests visual inspection and verification of the crown beam. At orange level (high risk) it restricts access to heavy machinery, recommends adjusting the drainage and preparing the bracing. At red level , it triggers the stoppage of works , sends alerts to the HSE manager, the site supervisor and the geotechnical designer and generates a list of immediate actions. All events are automatically logged (time, measure applied, result), providing full traceability for audit.

In operation, operators use two complementary interfaces. The SSM interface (fig.4) is focused on alerts, colored levels and intervention buttons ("Stop work", "Check stiffening", "Control drainage"), for quick reactions and operational training. The engineering interface (fig.5) ("industrial dashboard") presents pressure, vibration and displacement graphs, excavation map, numerical values for Rd, Rr, Ksi and contextualized automated messages. Together, they provide both strategic visibility and tactical control on the construction site.

The robustness of the system is ensured by IP65–IP67 enclosures, UPS power supply, redundant communications (mesh/LTE/Wi-Fi), as well as cybersecurity policies (TLS, role-based control, periodic backup). From a performance perspective, SIIMP tracks KPIs such as: time in "green"/"yellow"/"red", rate of increase of displacements (dδ/dt), average alarm response time, hours worked without incident and delays avoided. In essence, SIIMP transforms sheet piles from a purely structural element into an active prevention infrastructure , connecting geotechnical engineering with occupational health and safety management.

Figure 4. Occupational health and safety interface (with emphasis on alerts, colored risk levels, intervention buttons and preventive recommendations) of Intelligent Integrated Pile Monitoring System (IIPMS)

Figure 5. The technical interface of the "industrial dashboard" type (with graphs, risk bars, excavation map, numerical indicators and automatic messages) of Intelligent Integrated Pile Monitoring System (IIPMS)

6. CONCLUSIONS

The safety of excavation works is one of the most important challenges of modern construction, especially in urban areas, where the density of infrastructures and the proximity of buildings impose strict control over the stability of the ground. The use of sheet piles is no longer just a technical support measure, but a true protective barrier for the life and health of workers. They ensure a dynamic balance between the pressures exerted by soil and water and the stability of the temporary or permanent structure, directly contributing to reducing the risk of bank collapse and maintaining the integrity of the work area.

Sheet piles significantly contribute to reducing the risk of bank collapse, protecting both workers and nearby infrastructure. Their use is justified both technically and legally, being regulated by national legislation and European occupational safety and health standards. Modern installation methods allow their application in almost any soil conditions, including sensitive urban environments. The initial costs of implementing sheet pile systems are justified by the benefits in terms of accident prevention, material damage avoidance and legal risk reduction. Supporting excavation with sheet piles is a reliable and efficient solution in modern construction. This innovative method protects excavation works against the risks of collapse, providing a solid and secure foundation for construction projects. Due to its advantages, such as safety, efficiency, durability and low costs, sheet piles are increasingly used in various types of excavation works, contributing to the success of construction projects. By using sheet piles responsibly, engineers and builders can not only improve the quality of execution, but also actively contribute to reducing the number of work accidents in the construction field.

In the context of technological evolution, the integration of digital monitoring systems , such as the Intelligent Integrated Sheet Pile Monitoring System (SIIMP), marks a transformational stage in occupational safety management. This system brings a predictive approach: sensors distributed on sheet piles collect real-time data on displacements, pressures and vibrations, and the digital platform analyzes this information and transforms it into easy-to-interpret risk indicators. Thus, safety decisions are no longer based exclusively on experience or periodic inspections, but on objective, continuously updated data , which allow intervention before a dangerous situation materializes.

By correlating technical risk (wall stability) with occupational risk (worker exposure), the SIIMP system creates a direct link between engineering and safety. This means that a variation in soil pressure or a displacement beyond the permissible limit triggers not only a technical alarm, but also an organizational reaction: automatic alerts, work stoppages, visual checks or adjustments to the execution technology. At the same time, the platform becomes an educational tool – workers can observe how their actions influence the level of risk, developing an active safety awareness .

Therefore, sheet piles become part of an intelligent infrastructure , which combines geotechnical engineering, data analysis and occupational safety legislation into a coherent prevention system. Implementing such a solution in urban construction sites contributes to reducing incidents, saving time and costs.

In conclusion, the responsible application of sheet piling, associated with intelligent monitoring, reinforces a modern culture of prevention and sustainability in construction. Their use saves lives, reduces material losses, and makes construction sites safer and more efficient.

REFERENCES

[1]. Boţu N., Muşat V., Colţ OE, Aniculăesi M., "Foundations", vol.I. Matei-Teiu Botez Academic Society Publishing House, 2015

[2]. Rădulescu N., Popa H., Munteanu A., "Foundations - Design Guide", MatrixRom Publishing House, Bucharest, 2012

[3]. Stanciu, A., Lungu I., *Foundations – Physics and Mechanics of the Earth,* Ed. Tehnica, Bucharest, 2006

[4]. Dianu, V., D., Gheorghiu, V., V. - *Deep foundations in difficult terrain conditions. (vol. II),* Technical Publishing House, Bucharest, 2000 .

[5]. A.Moise, OR Chivu, M.Gheorghe, C Borda, A.Iacob, *Study regarding the use of banks support systems in the field of construction,* Annals of the „Constantin Brancusi" University of Targu Jiu, Engineering Series , No. 4/2024.

[6]. A. Moise, A. Iacob, A. Cană, S. Țepure, M. G. Bobocea, M. Gheorghe ,*The current stage regarding the risks of accidents through surprising the shores,* Fiabilitate si Durabilitate - Fiability **&** Durability No 1/ 2024 Editura "Academica Brâncuşi" , Târgu Jiu,

[7]. *** - Indicative C 169-88 – "Regulations regarding the execution of earthworks for the construction of foundations for civil and industrial constructions"

[8]. *** - Indicative NP 122/2010 - "Regulation on the determination of characteristic and calculation values of geotechnical parameters"

[9]. *** - Normative NP 120/2014 – "Normative regarding the requirements for the design, execution and monitoring of deep excavations in urban areas"

[10]. *** - Normative NP 124:2010 – "Normative on the geotechnical design of supporting works"

[11]. *** - Standard SR EN 12063:2003 - "Execution of special geotechnical works. Sheet pile walls"

[12]. *** - Standard SR EN 13331-1:2004 - "Trench support systems. Part 1: Product specifications"

[13]. Gotman A L. Pile Foundations as an e ff ciently developing direction of foundation engineering[J]. Soil mechanics and foundation engineering, 2020

[14]. Wang XF, Li J L. Effect of pile arrangement on lateral response of group-pile foundation for offshore wind turbines in sand. Applied

ocean research, 2022(104): 103194.3.
[15]. Zhang Q. UWB indoor location method based on moving node auxiliary positioning, Journal of Chinese Inertial Technology, 2023, 31(02): 141-147.19.
[16]. Zhang Y, Chun F, et al. UWB positioning analysis and algorithm research. Procediacomputer science, 2022(198):466-471.
[17]. Maria I, Raffaele D, Luca D. Serviceability analysis of piled foundations supporting tall structures. Acta geotechnica, 2021, 16 (12): 3963-3973.4.
[18]. Wei YB, Cao Z. Research and application of over-filling monitoring technology for underwater cast-in-place piles, IOP conference series: earth and environmental science, 2019, 1371(1): 022066
[19]. de Sanctis L, Mandolini A (2006) Bearing capacity of piled raftson soft clay soils. J Geotech Geoenvir Eng 132(12):1600–16105.
[20]. de Sanctis L, Russo G (2008) Analysis and performance of piledrafts designed using innovative criteria. J Geotech GeoenvironEng 134(8):1118–11286.
[21]. de Sanctis L, Di Laora R, Garala TK, Madabhushi SPG, ViggianiGMB, Fargnoli P (2021) Centrifuge modeling of the behavior of pile groups under vertical eccentric load. Soils Found61(2):465–4797.
[22]. Di Laora R, de Sanctis L, Aversa S (2019) Bearing capacity of pile groups under vertical eccentric load. Acta Geotech14(1):193–2058.
[23]. Dobry R, Gazetas G (1988) Simple method for dynamic stiffness and damping of floating pile groups. Geotechnique38(4):557–57
[24]. Iovino M, de Sanctis L, Maiorano RMS, Aversa S (2021) Failure envelopes of pile groups under inclined eccentric load. GeotechLett 11(3):1–7. https://doi.org/10.1680/jgele.21.0 005910 .
[25]. Mandolini A, Russo G, Viggiani C (2005) Pile foundations: experimental investigations, analysis and design. State of the Art Report. Proceedings of 16th international conference on soilmechanics and geotechnical engineering, Vol 1. Osaka, Japan, Balkema, Rotterdam, The Netherlands, pp 177–21311.
[26]. Mylonakis G, Gazetas G (1999) Lateral vibration and internal forces of grouped piles in layered soil. J Geotech Geoenviron Eng125(1):16–2514.
[27]. Poulos HG (1994) Effect of pile driving on adjacent piles in clay. Can Geotech J 31(6):856–86716.
[28]. Russo G, Viggiani C (1998) Factors controlling soil-structure interaction for piled rafts. In: International conference on soil-structure interaction in urban civil engineering, DarmstadtGeotechnics, No 4, pp 297–32
[29]. Russo G, Viggiani C, de Sanctis L (2004) Piles as settlement reducers: a case history. Advances in geotechnical engineering: the Skempton Conference: proceedings of a three-day conference on advances in geotechnical engineering, organized by the Institution of Civil Engineers and held at the Royal Geographical Society, London, UK, pp 1143–1154.