Special Contribution

Potential role of Press-in Piling to increase the resilience of critical infrastructure in Europe

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Introduction

Extreme weather events can have catastrophic consequences on critical infrastructure such as flood defences (dykes) and transport networks. The decade from 2011 to 2020 was the warmest on record. A significant impact of rising temperature is frequent and intense precipitation events. Governments and infrastructure owners need to make informed decisions on investments that evaluate the risk of climate change and the benefits that accrue from making investments in mitigation and adaptation measures. However, these decisions are inherently uncertain and solutions should be implemented that minimize the whole life-cycle costs considering financial and environmental costs. To limit their exposure, infrastructure owners have been trying to move towards more proactive asset maintenance approaches. These allow them to invest money in a prudent, sensible fashion, which maximizes utility and subsequently gives the best return on their investment. European industry and academia have successfully used the European Framework research programs such as FP7, Horizon Europe, etc. to foster collaboration at a European level and deliver research excellence. The programs value impact in societal problems. A number of individual projects, e.g. SMART RAIL - Smart Maintenance and Analysis of Transport Infrastructure (https://cordis.europa.eu/project/id/285683) developed of state of the art methods to analyze and monitor existing transport infrastructure (such as bridges, tunnels and earthworks) and make realistic scientific assessments of safety. These engineering assessments of the current state were used to design remediation strategies to prolong the life of existing infrastructure in a cost-effective manner with minimal environmental impact. Later projects including Destination Rail -Decision Support Tool for Rail Infrastructure Managers (https://cordis.europa.eu/project/id/636285) developed decision support tools to allow infrastructure managers to increase network safety and reduce the cost of investment by using the information management systems, IMS to manage the network. These IMS used data from monitoring and real-time analyses to prevent unnecessary line restrictions and closures, achieved lower maintenance costs by optimizing interventions in the life cycle of the asset and optimized traffic flow in the network. The potential of artificial intelligence algorithms to assist in real-time object detection and predict asset degradation was developed in GoSAFE RAIL - Global Safety Management Framework for RAIL Operations (https://cordis.europa.eu/project/id/730817). Many of the early projects focused on Rail Networks. This was because a large proportion of the European rail infrastructure, bridges, tunnels and earthworks was developed from the 1850s. Given their age and form of construction, many of these assets are particularly vulnerable to climate impacts. The techniques developed were applied to critical infrastructure across the road, rail and inland waterway modes in the SAFE-10 - Safety of Transport Infrastructure on the TEN-T Network (https://cordis.europa.eu/project/id/723254).

As geotechnical engineers, we know that quantifying the interaction of soil and water is crucial for understanding the response of the ground. Geotechnical engineers can be at the forefront of tackling the challenge of changing climate primarily through mitigation (increasing the resilience of existing infrastructure) and through adaptation, (developing ways to harness low emission technologies to reduce Co2 emissions). The Press-in method of installation significantly reduces environmental impacts by minimizing noise and vibrations. The very advanced, largely automated systems increase worker safety. From an engineering perspective, the piles are installed in such a way that they maximize the available soil resistance and thus are immediately available to resist external loads resulting in a foundation system that is proven reliability against external loads and natural disasters. In this article, we consider a few critical applications where Press-in piles can provide excellent solutions to problems faced by infrastructure owners.

Transport Infrastructure

Europe needs a safe and cost-effective transport network to encourage movement of goods and people within the EU and towards major markets in the East. This is central to European transport, economic and environmental policy. Historic levels of low investment, poor maintenance strategies and the deleterious effects of climate change (for example scour of bridge foundations due to flooding and rainfall induced landslides) has resulted in critical elements of the rail network such as bridges, tunnels and earthworks being at significant risk of failure. The consequence of failures of major infrastructure elements is severe and can include loss of life, significant replacement costs (typically measured in millions of Euro's) and line closures which can often last for months.

Bridge Scour

Scour refers to the erosion of foundations soils during flood events is a leading cause of bridge collapse worldwide, Forde et al. (1999). A study by Wardhana & Hadipriono (2003). found that over 50% of the 500 bridge failures that occurred in the United States in an 11-year period were the result of flooding and scour problems. This issue presents a significant cost burden on bridge owners and managers worldwide between inspections, scour protection installation and repairing damage caused by the occurrence of scour. Scour failures typically occur quite suddenly and generally, without warning, potentially leading to loss of life. An example is the failure of Malahide Viaduct Rail Bridge on the TEN-T network between Dublin and Belfast in Ireland, See Fig. 1(a).

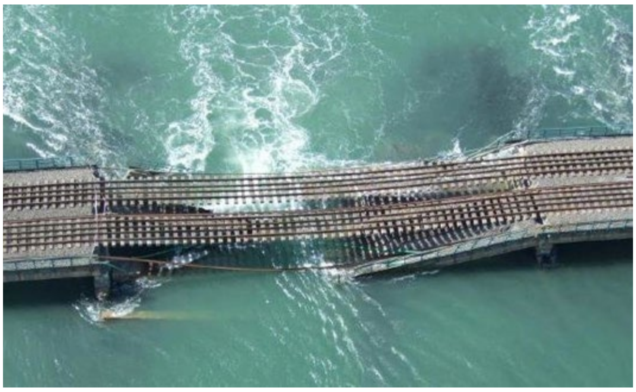

Fig. 1. (a) Bridge failure due to scour

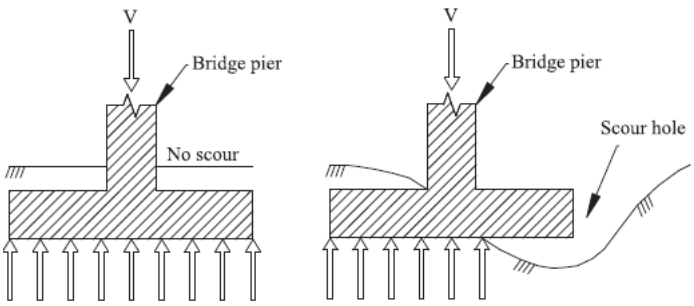

Fig. 1. (b) Mechanism of scour beneath a shallow foundation

The mechanism causing scour failure of a shallow foundation occurs as soil is removed from beneath a part of a shallow foundation, the soil beneath the part of the foundation still in contact becomes over-stressed and rotation will occur. Engineering solutions include; (i) allowing scour to occur and providing discrete structural piles that through the existing foundation (e.g. using the Gyropress system) in order to transfer the structural loads to deeper, more competent soils unaffected by scour or (ii) providing an enclosing structure that prevents scour under the structure, See Fig. 2. The unique clamping mechanism of the Giken piling system allows for remedial works to be undertaken even where scour is already in progress as described by Takuma et al. (2019)

Fig. 2. (a) Press-in piling solution for scour

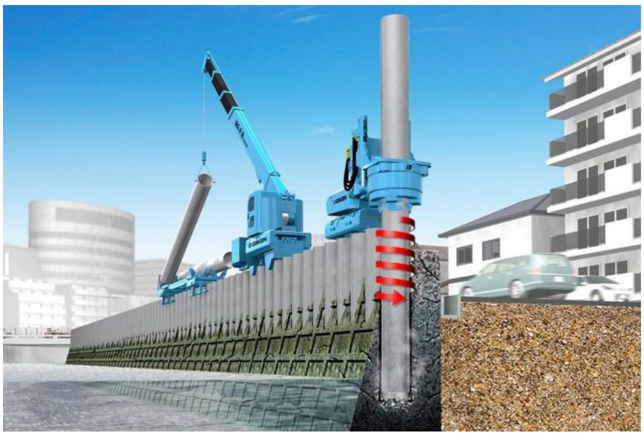

Fig. 2. (b) Gyropress system

Slope Stability

Whilst modern transport infrastructure benefits from engineered slopes, many slopes along railway networks were built more than 100 years ago, before modern design standards existed. As a result, the average angle of these slopes is usually much higher than would typically be permitted for modern transport infrastructure. Common problems affecting slopes are shallow (typically less than 2m deep) translational landslides caused by high rainfall; See Fig. 3a and deep-seated rotational failures caused by weak subsoils which are triggered by increased loading and/or changes in location of the water table level.

Fig. 3. (a) Example of shallow translational slip causing train derailment

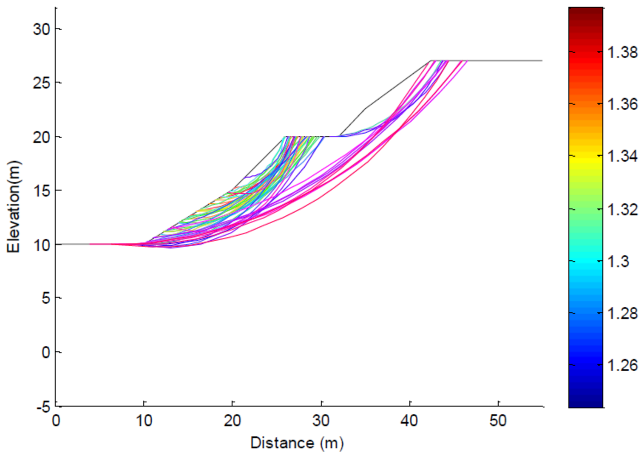

Fig. 3. (b) Analyses showing a range of shallow and deep failure mechanisms with similar Factors of Safety, ranging from 1.26 to 1.38.

Engineering solutions can be determined for the most likely failure mechanism, see Stipanovic et al. (2021). Reale et al. (2015) show that for a given slope, the two potential failure mechanisms might exist with very similar probabilities of failure, See Fig. 3b. Press-in piling methods The solution shown in Fig. 4 provides a solution for both failure mechanisms and can be implemented without interference to the rail traffic.

Fig. 4. (a) Implementation of an embedded retaining wall

Fig. 4. (b) Maintenance of traffic flow during construction works

Port Infrastructure

European Ports play a key role in vital supply-chains. They also act as hubs for interconnecting different transport modes. Challenges facing challenges including (i) increasing vessel size requiring deeper ports, (ii) coping with rising sea-levels and riverine flooding and (iii) providing adequate facilities to support the energy transition. The Port of Rotterdam situated close to Delft is one of the largest ports in the world. The Port of Rotterdam Authority invests in sustainable and future proof design solutions with the aim to reduce the port's CO_2 emissions by 50% in 2030 and achieve a zero-carbon footprint by 2050. One of the key steps in this process is optimizing the design of all the components of port infrastructure such as quay walls. The Port is currently constructing deep-sea quays in an area of land reclaimed from the North Sea known as Massvlakte II. A typical cross-section is shown in Fig. 5a. The primary soil retaining combi-wall is comprised of closely spaced open-ended tubular piles. The concrete relieving platform is supported by axially loaded piles, whilst additional horizontal resistance is provided by tension anchors. For the very deep seawall anchor capacities > 10 MN are provided by Muller Verpress (MV) tension piles. These consist of a steel I-beam impact driven into the soil whilst injecting grout under pressure through two grout pipes mounted at the pile toe. The Port Authority has invested significant resources in proof-load testing of the axial load piles in recent years through a research project, Improved Axial Capacity of Piles in Sand project, funded through Het Topconsortium voor Kennis en Innovatie (TKI) Deltatechnologie and seven industry partners: Delft University of Technology, Deltares, Dutch Association of Piling Contractors (NVAF), Dutch Ministry of Infrastructure and Water Management, Fugro, Port of Rotterdam Authority and the Municipality of Rotterdam. As part of this project axial load tests were performed on the most commonly adopted pile types in the Port of Rotterdam, See Fig. 5. Namely, precast concrete driven piles, driven cast-in place piles and screw-injection piles. Loads of to 25 MN were applied to cause geotechnical failure of the fully instrumented piles.

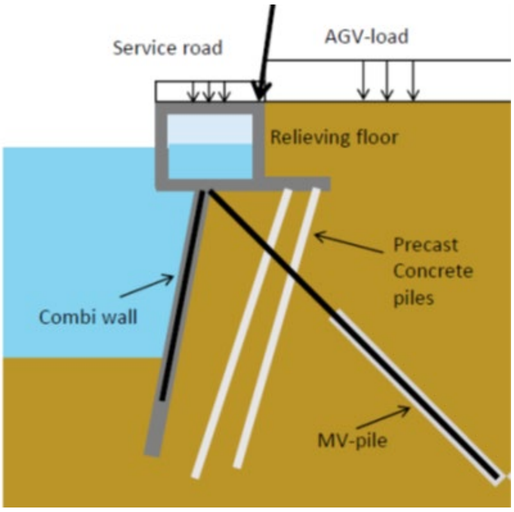

Fig. 5. (a) A typical deep sea quay wall

Fig. 5. (b) Axial load test set-up

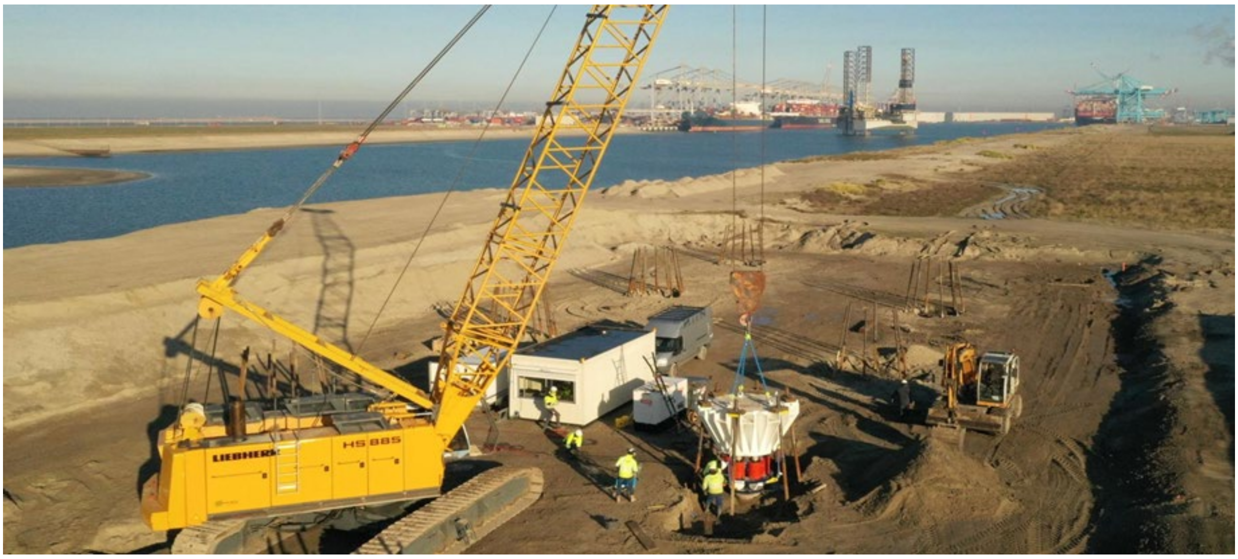

Fig. 5. (c) Overview of test site

One of the primary objectives of this field test program was to investigate whether limiting values of pile shaft and base resistance, prescribed in design codes were too conservative in the dense sand deposits encountered in port. Whilst CPT values are typically higher than 30 MPa in the sand later where piles are founded, a limit of 15 MPa is set for the base resistance and in the case of the shaft resistance, the q_c profile is limited to 12 MPa for layers less than one meter in thickness, and 15 MPa for layers greater than one meter in thickness. The load test results indicated that limiting resistance was not required. The impact of removing the limiting values is shown in Fig. 6a with respect to pile volume and 6b regarding the financial and environmental costs (considering only material volume).

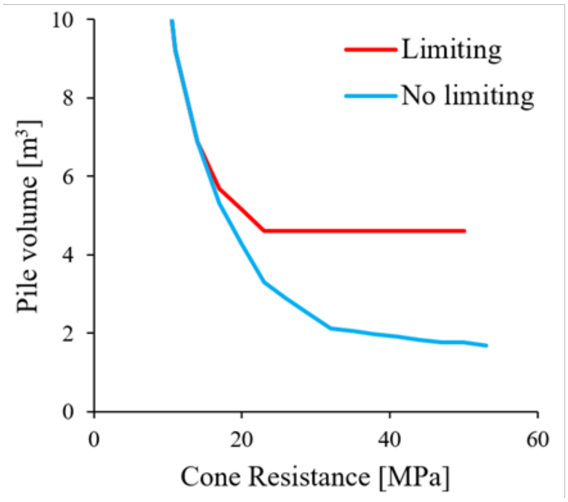

Fig. 6. (a) Impact of cones resistance on pile volume obtained for each realization using the NEN 9997-1 design method with and without limiting resistances

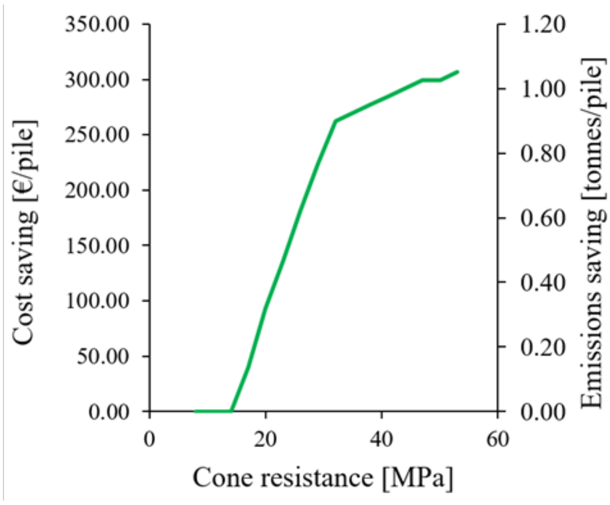

Fig. 6. (b) Resulting savings from utilizing the design method without limiting resistances compared to the design method with limiting resistances

The load tests also revealed that installation method, quality control of pile construction and time were significant factors for the Port authority in choosing a pile system. The research program encourages other pile types to be tested in the geotechnical conditions prevalent at the Port and a Push-in systems could have many benefits that could prove to be commercially attractive over the life cycles considered in Port infrastructure projects.

Urban Quay Walls

Historic quay walls provide the unique character of many Dutch cities. However, their age and various deterioration mechanisms have led to huge challenges in preserving these cultural heritage items. Many local authorities in the Netherlands are engaged in research and market consultation on how to prolong the life of these structures. Given the constraints of space, the need to minimize noise and vibration in the historic city center locations, where heritage buildings are founded on deep, soft clay deposits, Press-in piling has many advantages over conventional construction systems. From their European headquarters in the Netherlands, Giken piling work closely with local partner organizations to provide solutions. A recent project, Lijnbaan in the Hague involved reconstruction of 44m of quay wall using an F301-G1000 machine, See Fig. 7a. A key constraint at the site was that existing trees were to be preserved and construction works were very tightly scheduled as the canal has very high traffic volumes and work had to be completed before the tourist season. G-Kracht B.V., a joint venture company established predominantly by GIKEN Europe B.V. recently completed the pilot phase of a quay wall renovation project in Amsterdam, See Fig. 7b.

Fig. 7. (a) Reconstruction of a section of quay wall at Lijnbaan, Den Haag

Fig. 7. (b) The renovation project in Amsterdam

The municipality of Amsterdam is particularly concerned about quay wall stability in the city following a recent quay wall collapse. As a result, it is investing heavily in a research program, led by the Dutch research agency, NWO to investigate about 200 kilometers of quay walls, and where necessary, to restore these. societal partners to search for solutions within this challenging area. TU Delft are heavily involved in the entire program, including the UrbiQuay project led by the University of Twente which will develop an integrated life-cycle assessment tool to allow owners to decide on lifetime extension measures for their quay walls. Building on their work at the Port of Rotterdam, the geotechnical engineering group at TU Delft will develop an assessment method to quantify the actual safety level of the existing quay walls and thus quantify any structural upgrade solutions.

Summary

There are a wide range of markets for which Press-in piling systems can provide solutions for both private and public sector clients in the EU. At the moment one of the most exciting markets for both companies and researchers is the offshore renewables market. Many EU governments have proposed ambitious targets for the development of offshore wind in particular in the coming years. The supply charge is still being constructed for most of these projects. Offshore floating wind is one of these new markets. Foundation systems will have to provide long-term resistance to cyclic loading. Research on traditional piling systems has shown that installation actually significantly damages the soil resistance required to withstand the loading experienced. Press-in piling could significantly mitigate this damage whilst providing an environmentally friendly solution for many developments. The method also addressed many of the objectives expressed the European Commission in policy documents on the future of Europe. The automation processes were developed to provide benefits in worker safety and quality of life. The systems provide data during installation that is vital for the new wave of digital twins that are being created. Giken Ltd. is already engaged in collaborative projects through the International Press-In Association, IPA and directly through collaboration in EU Horizons research projects e.g BEEYONDERS' – Breakthrough European technologies Yielding construction sovereignty, Diversity & Efficiency of Resources (https://beeyonders.eu/project/). This project led by Acciona Construction aims to make extensive use of AI, automation, and digitization and demonstrate these techniques in real-world applications, including quay wall constructions.

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