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How long does a sheet pile wall actually last?

Hydrography as a tool for civil engineers to analyse remaining service life with precision

An article by KARSTEN HOLSTE

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The aging of waterway infrastructure in Europe presents a critical challenge for engineers, infrastructure operators and policymakers. A large proportion of structures such as quay walls, locks and coastal protection systems – many of which were constructed after World War II – are now reaching or exceeding their intended service life. As a result, there is an urgent need for reliable assessment methods to determine whether these structures require repair, strengthening or complete replacement. In this context, digitalisation – particularly through the implementation of digital twins – offers transformative potential for lifecycle management in civil engineering (Fig. 1).

Digital twins enable the comprehensive digital representation of infrastructure assets, integrating geometric, structural and condition-related data into a unified model. This allows stakeholders to access, share and analyse inspection results without loss of information, thereby improving decision-making processes. The research projects »3D HydroMapper«, »port_AI« and »port_Evolution« are carried out in Germany between 2018 and 2027, aim to develop and implement such digital solutions by focusing on advanced data acquisition, processing and visualisation techniques.

1 Challenges in data acquisition for maritime infrastructure

While geospatial data acquisition on land – using vehicles, drones or mobile mapping systems – has become standard practice, the systematic recording of maritime infrastructure remains underdeveloped. Traditional inspection methods rely heavily on divers, who perform localised and periodic inspections. However, these inspections typically cover only about 5 to 10 % of underwater surfaces. Given that approximately 50 to 60 % of many hydraulic structures are located below the waterline, a significant portion of the structure remains unassessed.

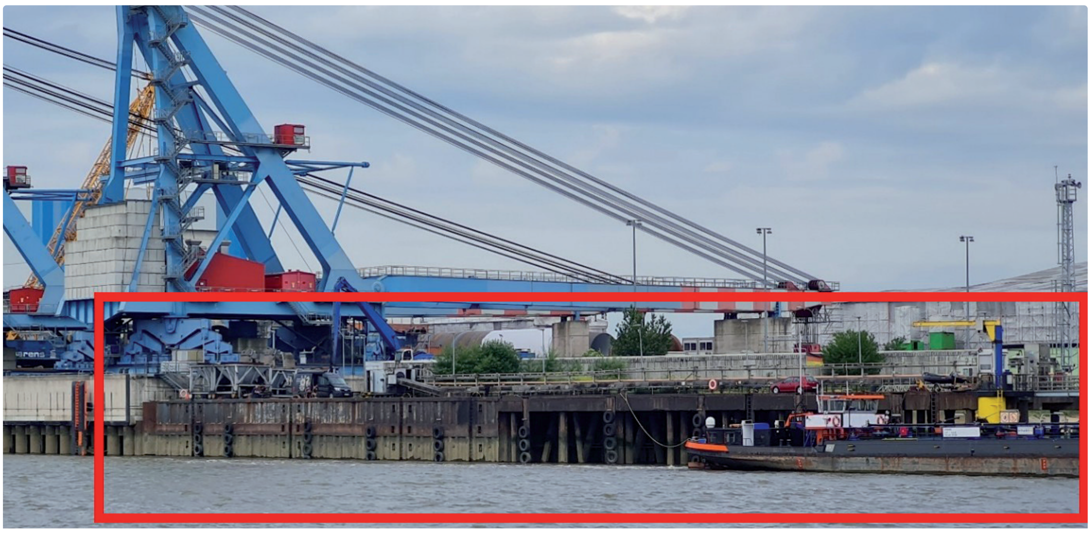

Fig. 1: Typical view of a quay wall in Bremerhaven, Germany, the structure is not recognisable under water for the inspector. Therefore, an exemplary dive by the structure diver at intervals of 150 to 300 ft is required

This lack of comprehensive data introduces considerable uncertainty in evaluating structural conditions. Infrastructure operators increasingly require complete datasets, such as high-resolution 3D »as-built« models, to support maintenance planning, lifecycle analysis and investment decisions. However, data acquisition in maritime environments is inherently challenging. External factors such as waves, wind, currents, sedimentation and ship traffic complicate measurements and affect data quality. Additionally, both above-water and underwater components must be captured with high accuracy to provide a holistic understanding of structural integrity (Fig. 2).

To address these challenges, modern measurement approaches combine multiple sensing technologies. Sonar systems, particularly multibeam echo sounders, are used for underwater mapping, while laser scanning and photogrammetry are applied above water. When integrated with inertial measurement units (IMUs) and global navigation satellite systems (GNSS), these technologies enable the generation of highly accurate, georeferenced 3D point clouds. These datasets allow engineers to detect structural damage, deformation and material loss with unprecedented detail.

2 Multibeam scanning for underwater infrastructure

A central component of the 3D HydroMapper system is the development of a specialised multibeam scanning system for underwater infrastructure assessment. This system is mounted on a floating measurement platform, where sensors can be dynamically aligned with the structure being surveyed. Such adaptive alignment is essential for achieving high-resolution data and minimising measurement errors.

Under optimal conditions, the system can survey approximately one mile (around 1.6 km) of quay wall per day. Compared to traditional diver-based inspections, the resulting datasets are significantly more complete – up to 16 times more comprehensive. This increased data density allows for detailed analyses of structural components, including complex geometries such as closely spaced pile foundations or multi-layered timber structures.

The creation of accurate 3D models requires two key steps: precise positioning of the measurement platform and optimal acquisition of the structural surface. Positioning is achieved through a combination of IMU and GNSS technologies, using multiple satellite systems (GPS, GLONASS, Galileo and BeiDou) to ensure high accuracy. Additional corrections can be applied using base stations or reference data from surveying authorities. The quality of the scanning process depends heavily on sensor orientation. Adaptive alignment helps overcome common issues such as object shadowing, unfavourable incidence angles and platform drift caused by environmental conditions. By maintaining optimal sensor positioning, the system ensures consistent data quality and minimises noise and systematic errors.

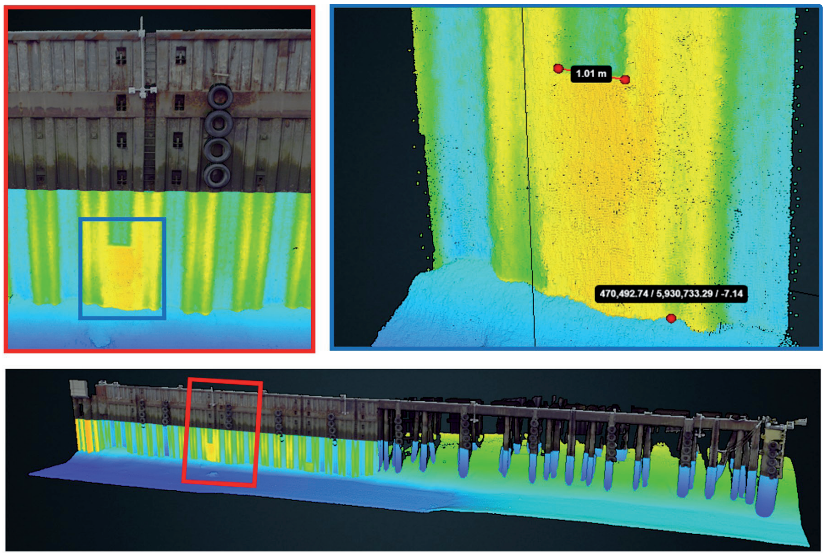

Fig. 2: Quay wall shown above after the 3D as-built survey. Perfect support for inspection to detect deformations of the combined sheet pile wall

To achieve the required level of detail for structural inspection, specific acquisition parameters must be maintained. These include low vessel speeds (approximately 0.5 to 1 knot), short distances between sensor and object (up to 5 metres) and multiple overlapping measurement passes (typically triple coverage). The resulting point clouds can achieve densities of up to 10,000 points per square metre and accuracies of approximately ±2 cm. Such high-resolution datasets are essential for identifying structural anomalies, including deformations and cross-sectional losses in sheet pile walls. They also support compliance with evolving standards, such as the updated DIN 1076, which increasingly recognises imaging techniques as viable alternatives to traditional inspection methods, particularly in environments with poor visibility or strong currents.

3 InfraCloud and digital lifecycle management

A key component of the digital transformation of maritime infrastructure management is the development of integrated data platforms that enable efficient access, analysis and use of large and heterogeneous datasets. Within the research project port_AI (2021 to 2025), the cloud-based data portal »InfraCloud« was developed to support infrastructure operators, engineers and construction companies throughout the entire lifecycle of port structures. The primary objective of this data portal is to provide low-threshold, user-friendly access to complex datasets derived from multi-sensor measurements. These datasets include georeferenced point clouds, photogrammetric models, meshes and additional metadata such as inspection results or material measurements. By integrating these diverse data types into a unified platform, the system enables a holistic understanding of the structural condition and facilitates collaboration among stakeholders.

A central innovation of the InfraCloud framework lies in the fusion of measurement data with automated evaluation methods. The platform incorporates Internet of Things (IoT)-based sensor technologies and artificial intelligence (AI) algorithms to process and analyse large volumes of data efficiently. For example, pattern recognition and machine learning techniques can be applied to identify and classify structural damage within 3D datasets. This significantly reduces the need for manual inspection and accelerates the overall assessment process. Another important feature of the data portal is its modular architecture. This allows the system to be expanded with additional data sources, including stationary monitoring sensors or manual input from inspection personnel. As a result, both automated and human-generated data can be combined within a single digital environment. This integration is particularly valuable for lifecycle management, as it enables continuous updating of the structural condition based on real-time or near-real-time information.

The availability of comprehensive and up-to-date data also enables more accurate service life predictions. Traditionally, structural assessments rely on conservative assumptions and generalised models, often leading to overly cautious decisions. In contrast, the InfraCloud platform allows engineers to base their analyses on actual measured conditions, thereby improving the reliability of recalculations and reducing uncertainties.

From an operational perspective, the implementation of such a data portal offers significant efficiency gains. The update frequency of structural condition data can be reduced from multi-year inspection intervals (e.g., six years) to near-continuous monitoring cycles. This leads to faster detection of damage, enabling timely and targeted maintenance measures. As a result, planning times can be reduced by approximately 25 to 50 %, while inspection efforts may decrease by up to 50 % (Fig. 3). In addition to time savings, the system contributes to cost reduction. By optimising the use of sensor technologies and minimising redundant data acquisition, hardware and installation costs for monitoring can be reduced by up to 60 %. Furthermore, improved coordination and data availability help avoid duplicated work and inefficiencies in multi-stakeholder projects. Finally, the integration of monitoring data and analytical models enables advanced concepts such as stress-level management and predictive maintenance. By combining measured data with structural models, it becomes possible to better estimate the actual load-bearing capacity and remaining service life of infrastructure. This can lead to a service life extension of up to 10 %, corresponding to approximately ten additional years for typical port structures.

In summary, the InfraCloud data portal represents a crucial step toward fully digitalised infrastructure management. By integrating data acquisition, analysis and decision-making processes into a single platform, it enables more efficient, ac-

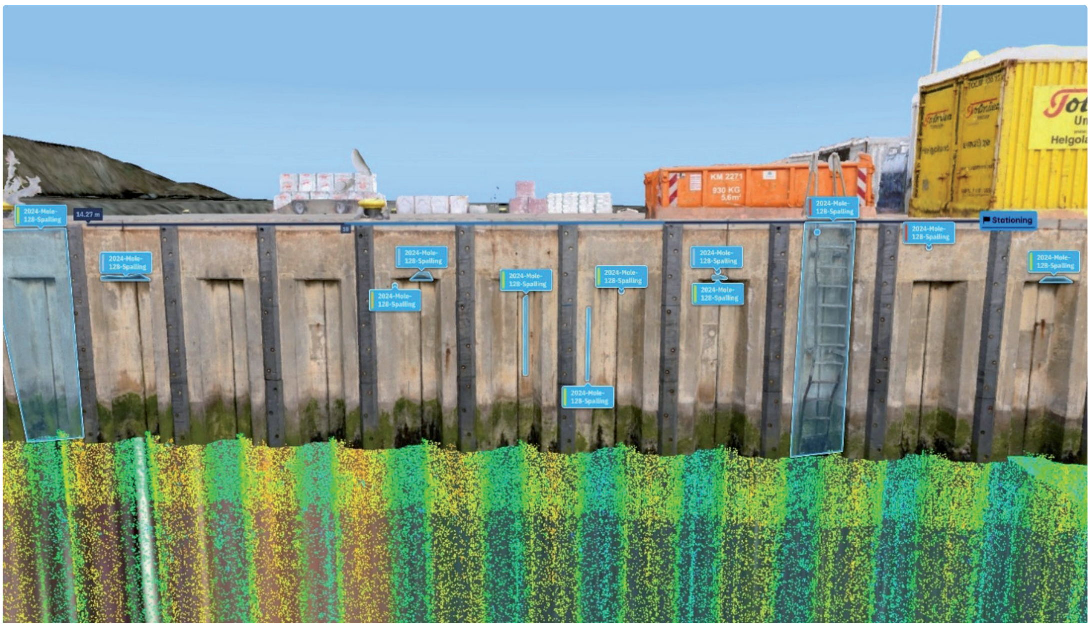

Fig. 3: 3D scene: Photogrammetry and laserscan converted to a mesh (blue: damage labels), merged with the underwater point cloud

curate and sustainable management of maritime infrastructure systems.

4 Extending the service life of quay walls

One of the most significant applications of 3D scanning technologies is the extension of the service life of quay walls. These structures, often constructed from steel sheet piles, are subject to continuous corrosion, especially in the splash zone and low-water areas. Traditionally, their condition is assessed through periodic measurements of residual wall thickness, typically conducted every six years. Based on these measurements, engineers estimate the remaining load-bearing capacity using extrapolated corrosion rates and conservative design assumptions.

However, this approach has limitations. Many older quay walls, particularly those built in the mid-20th century, were designed with minimal material usage and simplified load assumptions due to post-war resource constraints. As a result, recalculations often indicate reduced structural stability, sometimes suggesting that immediate replacement is necessary. In practice, this can lead to costly and potentially premature interventions (Fig. 4).

The integration of 3D scanning data offers a more accurate alternative. By capturing the complete geometry of the structure, including deformations and material losses, engineers can perform more realistic structural analyses. In the presented use case, a spline-based approximation method was developed to analyse the point cloud data. This method involves filtering outliers, smoothing the dataset and deriving a bending curve that reflects the actual structural behaviour.

From this bending curve, the internal stresses within the quay wall can be calculated and compared with design assumptions. In the case study of an approximately 820-metre-long quay wall, conventional analysis indicated an overload of 150 %, implying that the structure was no longer safe for operation. However, the analysis based on 3D scanning data revealed a utilisation level of only 60 %. This discrepancy highlights the limitations of traditional assessment methods and demonstrates the value of high-resolution measurement data. Based on the improved analysis, the quay wall was deemed safe for continued operation for an additional 10 to 15 years. This not only avoided unnecessary reconstruction but also resulted in substantial cost savings and more efficient resource allocation.

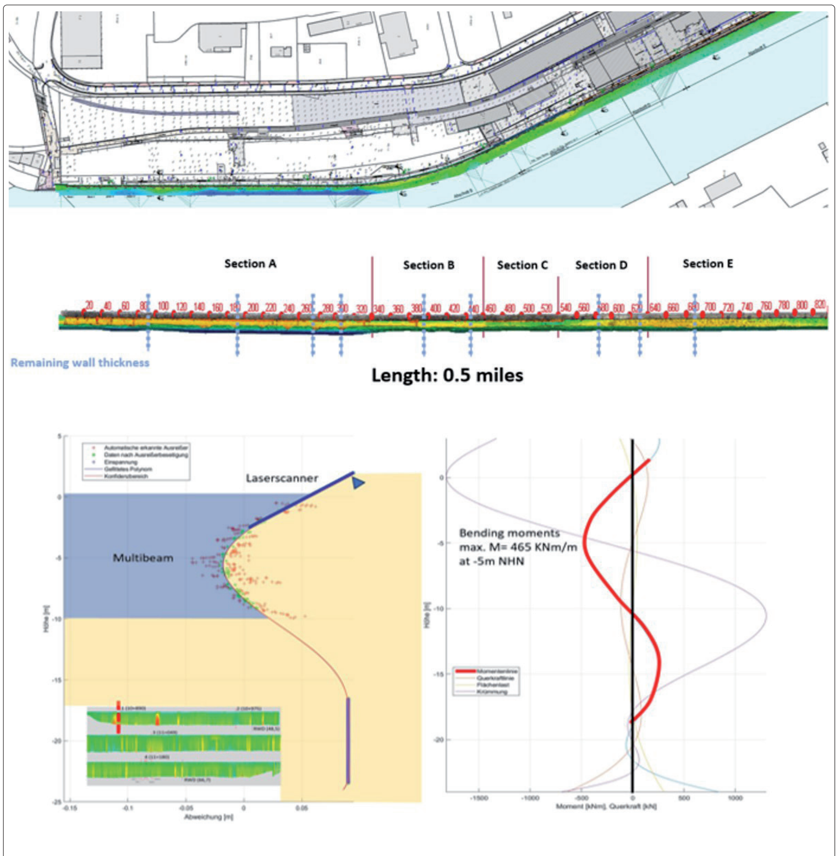

Fig. 4: Site plan and sections of the quay wall

Conclusion (integrated perspective)

The integration of multibeam scanning, laser scanning, and photogrammetry represents a significant advancement in the assessment and management of maritime infrastructure. These technologies enable the creation of detailed and accurate digital representations of structures, supporting more reliable condition assessments and informed decision-making.

For students and future engineers, this development illustrates a broader shift in civil engineering toward data-driven methodologies. The use of digital twins and advanced sensing technologies not only improves technical accuracy but also enhances sustainability by extending the service life of existing infrastructure and reducing unnecessary construction activities.

Ultimately, the research presented in this paper demonstrates that modern 3D scanning technologies can bridge the gap between theoretical models and real-world conditions. By providing comprehensive, high-quality data, these methods enable a more precise understanding of structural behaviour and open new possibilities for efficient and sustainable infrastructure management. //