

SmartSheetPile

Structural Health Monitoring solution for innovative infrastructures



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1. Introduction

In modern infrastructure management, ensuring safety, sustainability and peak functionality for critical facilities like ports, dykes and other steel sheet pile-based structures remains a persistent priority.

As the demand for more efficient and resilient infrastructure solutions rises, SmartSheetPile emerges as a cutting-edge **Structural Health Monitoring** solution.

Its core objectives are to secure infrastructure integrity, enhance digital awareness and foster environmental responsibility.

SmartSheetPile integrates advanced technologies – embedded sensors, big data analysis, digital twin technology and Artificial Intelligence – to deliver a comprehensive real-time monitoring system combined with preventive and predictive alert capabilities.

AI-powered algorithms process and analyse data collected for the sheet piles, providing actionable insights and predictions to identify potential operational issues or environmental risks before they escalate.



2. Key benefits of SmartSheetPile

Real-Time Monitoring

Advanced sensors feed real-time dashboards, enabling precise tracking of critical parameters like deformation, corrosion, impacts and other structural indicators.

Timely Alerts

Personalized notifications ensure swift response to operational damages or environmental threats, such as flooding, reducing risks to assets and personnel.

Digital Twin Technology

A multidimensional virtual replica of the asset's design and performance provides a deeper understanding of current conditions and supports predictive modelling for future scenarios.

Data-Driven Decision-Making

Robust data integration consolidates critical information into a single, unified model, empowering stakeholders to make informed, strategic decisions.

Sustainability and Efficiency

By optimizing infrastructure design, minimizing material consumption, and lowering CO₂e emissions, SmartSheetPile contributes to global environmental goals while enhancing operational excellence.

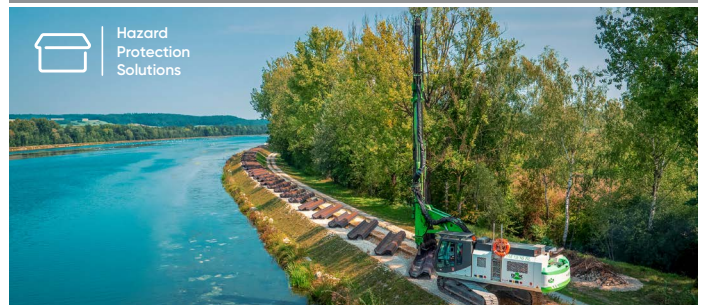
SmartSheetPile redefines the standards for infrastructure resilience, safety and sustainability, offering a holistic approach to asset monitoring and management. It stands as a testament to innovation, aligning advanced technology with the need for reliable and eco-conscious infrastructure solutions.



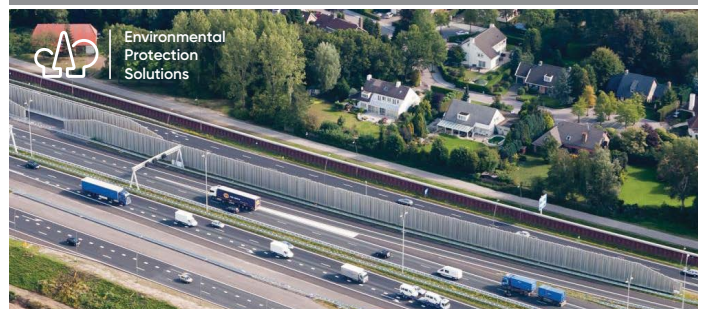
Monitor the health, loads and deformation of bridge abutments in real time. Reduce downtime and traffic disruption with more efficient preventive maintenance.



Uncover hidden quay wall capacities to improve productivity on asset operations. Monitor corrosion in real time with precise remaining thickness measurement.



Raise the alarm on water levels and water pressure. Detect early signs of potential catastrophic failure.



Verify the integrity of the sheet pile wall against declutching. Ensure the imperviousness of the sheet pile wall.

3. Process flow

Each project is uniquely different, which means a specific approach is necessary to reach the optimal solution. The process involves four key steps, as shown below:



3.1. Select the combination of phenomena relevant for the project

The first step involves selecting the combination of phenomena relevant to the specific project. This selection is based on the list of parameters and aligns with the project’s specifications and the needs of the project owners and end-users.

Depending on these factors, either one of the provided standard solutions can be chosen, or, if required, a customized solution can be proposed to meet the precise specifications.

The parameters to consider cover a range of factors related to the core behaviour of sheet piles and their interaction with environmental and surrounding conditions. The table outlines key parameters, categorized for clarity. Additional parameters can be added upon request, provided the necessary data is available.

This table is not exhaustive and additional factors can also be incorporated as needed to address unique project challenges.

Environmental/Surrounding conditions
Earth pressure
Soil movement
Water levels in front and behind the wall (groundwater, tides and flood levels)
Temperature
Pore pressure
Core behavior of Sheet Pile
Corrosion / Material loss
Shock / Impact
Force / Load applied
Inclination / Tilt
Deformation
Anchor tension
Settlement

3.2. Detailed propositions (quantities & positions of sensors)

Once the primary list of parameters is identified based on the project specifications and client preferences, a detailed plan for sensor allocation is defined. This involves determining the specific number and distribution of sensors according to engineering requirements and identifying sensitive areas for each parameter.

Specialists determine the number and optimal placement of instrumented piles within the structure. These decisions are based on the project's technical requirements to ensure accurate data collection and effective monitoring.

Several factors influence these choices, including:

Length of the wall: Longer walls may require more sensors to ensure uniform monitoring along their length.

Length of the pile: Longer piles may demand additional sensors to capture variations along their depth.

Sensitive areas: Critical zones, such as locations experiencing high loads, splash zone, deformation or environmental hazard, may need extra attention.

Soil conditions: Variability in soil types and properties may require adjustments in sensor distribution.

Hydraulic conditions: Groundwater flow, tidal influence and water levels could necessitate specific sensor placement.

Load distribution: Uneven or concentrated loads in specific areas may dictate additional monitoring.

Structural complexity: Complex designs or irregular shapes may require more customized sensor arrangements.

Environmental factors: Exposure to extreme temperatures, ice loads or corrosive environments can impact sensor placement.

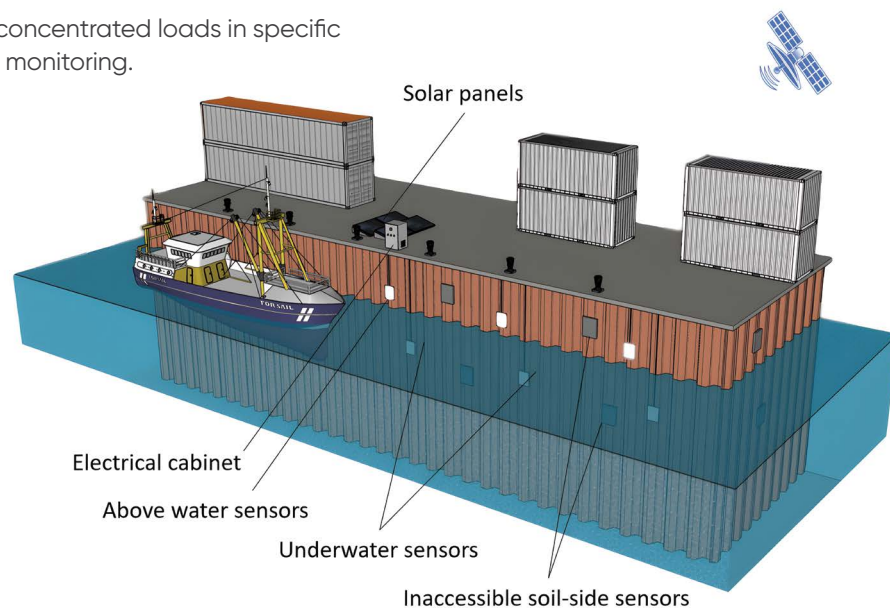
Dynamic loads: Areas subject to vibrations, shocks or other dynamic forces may need focused instrumentation.

Where feasible, sensors can be grouped in the same location and housed within a single box. The specific placement of sensors depends on the characteristics of each parameter being monitored. Sensors may be positioned on the front, back, soil side or water side of the structure and may be covered or exposed.

Additionally, sensor accessibility can vary:

- Accessible sensors: placed in locations where regular maintenance or replacement is feasible.
- Inaccessible sensors: positioned in areas where physical access is limited or impractical, often relying on robust and long-lasting designs to minimize maintenance needs.

By carefully considering these factors, the sensor setup ensures both optimal functionality and practical maintenance strategies for long-term monitoring efficiency.



Schematic representation of a monitoring system of an asset

3.3. Installation and deployment

The installation and deployment phase ensures that all monitoring components are prepared for seamless integration on-site. Sensors, protective housings, and cabling are fully installed and secured prior to the delivery of sheet piles to the job site.



Instrumented SmartSheetPile

3.4. Driving test

Many preliminary driving tests were conducted to evaluate the robustness of the cables, sensors and protective housings under real driving conditions.

The first test was carried out in two phases: the first phase utilized a vibratory hammer, while the second phase employed an impact hammer at varying speeds.

To achieve the test, two pairs of sheet piles AZ 26-700 with a length of 18 m were used. Only one of the piles is instrumented and monitored during the test.

The second pile is used to detect possible sensor damage due to side impact and heating due to interlock friction.

To ensure durability and protection during transportation and installation:

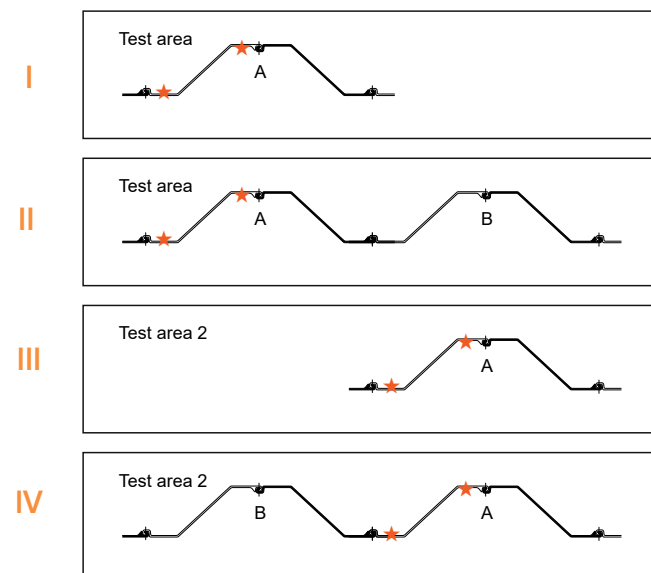
- **Sensor protection:**

Special care has to be taken when handling these piles, especially when there are cables hanging around. All sensors are enclosed in welded, robust steel housing boxes to safeguard against physical damage, environmental exposure and external forces.

- **Cable protection:**

Where required, cables are routed through steel tubes to provide additional shielding from mechanical stress, moisture and corrosion.

Upon arrival at the job site, a pre-installation verification process is conducted to confirm sensor integrity and connectivity. This pre-installation process minimizes on-site labour, reduces the risk of damage during handling, and ensures the sheet piles arrive at the site ready for immediate deployment, contributing to the efficiency and reliability of the overall project.



Driving test sequences

Phase 1

A PVE 2350 vibratory hammer was used to drive and extract two interlocked piles –instrumented pile A and standard pile B– while recording sensor data.

Initially, with the piles resting on the ground, sensors were logged to establish baseline readings. Pile A was then driven into the left test area (Diagram I) with interrupted data capture. Pile B was subsequently interlocked to the right of pile A and driven in (Diagram II), the sensors were logged after the driving was complete.

Following this, pile B was removed and re-driven at a location with similar soil conditions to assess test repeatability.

Pile A was then re-driven after having been removed, interlocked to the right of pile B (Diagram IV), with sensor data captured after the process. It was later removed and partially re-driven (6 m) at a new site in preparation for the hammer test.

Phase 2

In this phase, a diesel hammer with an AZD 17/28 driving cap replaced the vibratory setup. Pile A was driven at the designated site (Diagram III). The sensors were logged after the driving was complete.

The vibratory hammer was then used to extract pile A. The series concluded with the final removal of pile B.

The dynamics were recorded throughout the driving test.



Driving the sheet piles A and B using a vibratory hammer (Phase 1)

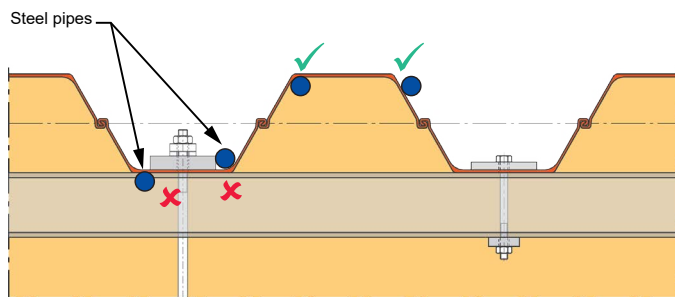


Driving the instrumented sheet pile A using a diesel Impact hammer (Phase 2)

Design considerations

For sheet pile structures using waling beams and anchor plates, special care must be taken in the routing of steel pipes used for housing sensor cables.

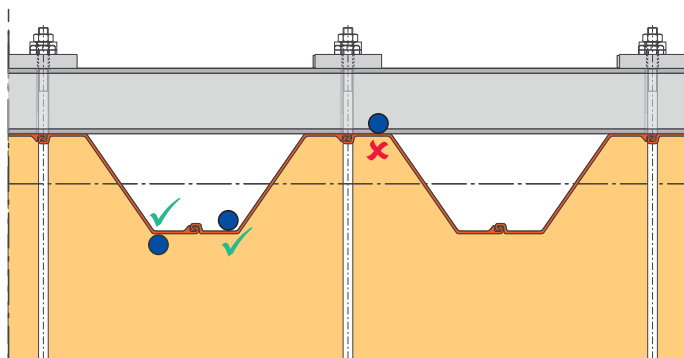
Special considerations must be taken in the application of smart sensors to avoid construction and structural clash with electric components of the sensors. For example, in case of an anchored wall with waling the steel pipe for cable housing shall be placed to avoid the contact point between waling, anchor plate and the sheet piles.



U-Sections: Recommended layout to avoid clashes with waling and anchors

Additionally, prior to the installation, it is essential to have a complete understanding of all the design features, such as anchors, waling systems, capping beams and overall configuration. Additionally, it is important to consider installation and driving constraints such as a guiding frame to guide the sheet piles during driving, or any other driving assistance as water-jetting.

Finally, it is also important to know beforehand any additional surface treatment (i.e. coating, galvanisation) or protection of the steel that might be done after delivery by another company.



Z-Sections: Recommended layout to avoid clashes with waling and anchors

This information is crucial to properly plan the routing of pipes and placement of sensors, and to avoid any potential structural clashes.

Outcome

The results of the driving test indicate successful execution for both vibratory and impact driving tests. The data collected by the sensors during the driving tests period are displayed in the graphs below.

Sensor readings across temperature, vibration, inclination, and strain channels show consistent and expected responses to the applied forces.

Throughout the test duration, there were no interruptions in data transmission, no anomalies in sensor output and no signs of damage or degradation in the sensors, cables or sheet pile components. This confirms that the entire system remained fully operational and structurally intact, validating the robustness and reliability of the setup during driving activities.

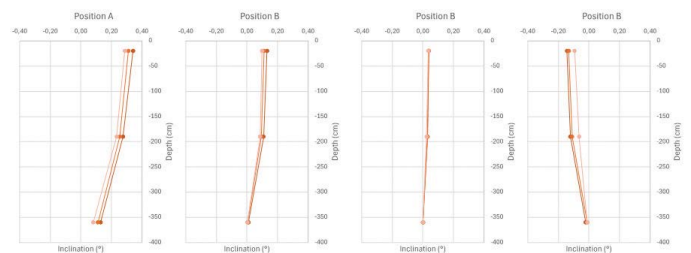


Data recorded during driving tests

3.5. Long-term online monitoring and alert triggering

Once installation and deployment are complete on-site, including the installation of acquisition units and connection of the system via 4G network or other communication protocols, the long-term monitoring system is fully operational. The system provides online and continuous monitoring of all specified parameters. Additionally, it includes advanced features such as data filtering and detailed analysis for each aspect, ensuring comprehensive oversight and enabling proactive management.

Position	Material loss vs. expected
A	22 %
B	67 %
C	39 %
D	7 %



The long-term monitoring system offers a reliable solution for maintaining consistent oversight over critical operations. With its ability to filter data, the system reduces noise and enhances the accuracy of collected information.

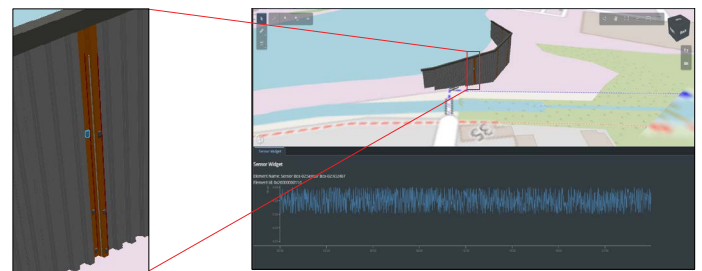
Detailed analysis tools enable users to interpret trends, detect anomalies and make informed decisions. This proactive approach not only helps in mitigating risks but also improves the efficiency and effectiveness of management strategies.

Furthermore, the adaptability of the system to different communication protocols ensures seamless integration across various platforms, making it an ideal choice for diverse operational environments.

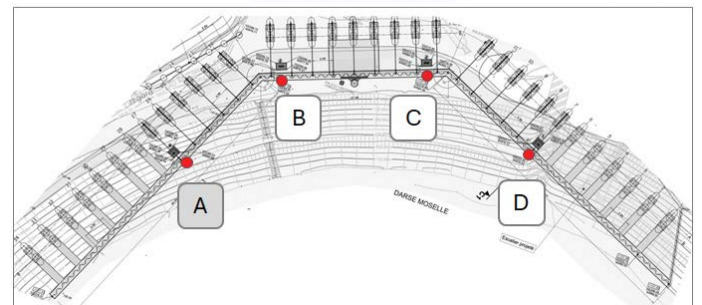
One of the standout features of the solution is its customizable alerting. Alerts can be programmed for any monitored parameters based on the preferences of the asset owner, enabling quick responses to unusual trends or anomalies in real time.

Users can set specific limit values for different measurements such as temperature, vibration, water levels, load pressure, structural impacts, deformation or corrosion.

If any of these limits are passed, the system immediately sends notifications to the appropriate people through selected communication channels. This proactive alert system helps teams take quick action, reduce risks, avoid damage and maintain smooth operations.



Port Mertret: Water level



4. SmartSheetPile standard packages solution: Basic/Advanced/Expert

Each project has its own complexity and budget limitations, which is why this solution is offered in three standard packages for each application:

- **Basic:** covers core monitoring of essential parameters.
- **Advanced:** includes a broader range of sensors and enhanced analytics capabilities.
- **Expert:** offers an extensive suite of high-precision sensors, fully customizable analytics, and complete system integration.

Each solution is mapped to the core application domains of steel sheet piling, including water transport, hazard protection, mobility infrastructure, environmental projects and temporary structures. If additional sensors or custom configurations beyond the standard packages are needed, a tailored solution can be provided upon request.

The table below outlines the parameters included in each solution package.

4.1. Water transport

SmartSheetPile is an essential tool for the water transport sector. It reveals hidden quay wall capacities, such as extended lifetime and how the structure is responding to corrosion over time, by providing precise, real-time monitoring of structural conditions. In port infrastructures, it measures the actual loading capacities of quay walls and detects corrosion through accurate remaining thickness measurements. This continuous monitoring helps improve

productivity and makes sure maintenance is done at the right time, which helps quay walls last longer and supports sustainable maritime operations.

The table below presents the available solution packages along with the most important parameters recommended for monitoring in this application.

Parameter	Basic	Advanced	Expert
Material loss detection (corrosion coupon)	✓		
Material loss evolution (corrosion ER)		✓	
Thickness of the wall (Corrosion US)			✓
Temperature	✓	✓	✓
Structural movement	✓	✓	✓
Structural deformation (strain)		✓	✓
Impact/Shocks		✓	✓
Earth pressure			✓
Water level in front of the wall			✓
Water level behind the wall			✓

4.2. Hazard protection

SmartSheetPile acts as an early warning system for potential structural failures. By continuously measuring water levels, earth pressure and deformation, the system can detect early signs of stress or degradation that may precede a catastrophic event. This proactive monitoring is vital for flood defence projects and other scenarios where rapid changes in environmental conditions can endanger both households and crucial infrastructure. The real-time data helps asset managers to initiate preventive measures well before a hazard escalates into an emergency.

The table on the right presents the available solution packages along with the most important parameters recommended for monitoring in this application.

Parameter	Basic	Expert
Temperature	✓	✓
Structural movement	✓	✓
Water level soil	✓	✓
Earth pressure		✓

4.3. Mobility infrastructure

Mobility infrastructures such as bridge abutments face significant challenges, including wear and tear from heavy traffic, vibrations from moving vehicles and maintaining structural stability under varying loads and weather conditions.

In that context, SmartSheetPile offers critical insights into structural health. The system continuously monitors loads, vibration, deformation and other stress indicators, ensuring that any potential issues are identified early. This real-time data not only improves the safety of these structures by enabling predictive maintenance but also minimizes downtime and traffic disruptions by facilitating planned repairs. By ensuring that the structural integrity of mobility infrastructures is maintained, SmartSheetPile contributes to smoother and safer transportation networks.

The table on the right presents the available solution packages along with the most important parameters recommended for monitoring in this application.

Parameter	Basic	Expert
Material loss evolution (corrosion ER)	✓	✓
Temperature	✓	✓
Structural movement	✓	✓
Structural deformation (strain)		✓

4.4. Environmental protection

SmartSheetPile provides innovative solutions for environmental protection challenges, including monitoring soil erosion, water contamination and temperature changes. It guarantees the integrity of the sheet pile wall against declutching, as well as the watertightness of the sheet pile wall. An ideal solution for environmental projects, SmartSheetPile will alert you in the event of a serious malfunction that could endanger the environment on a decontamination site.

The table on the right presents the available solution packages along with the most important parameters recommended for monitoring in this application.

Parameter	Basic	Expert
Temperature	✓	✓
Structural movement	✓	✓
Water level soil	✓	✓
Earth pressure		✓



5. Power supply, maintenance and lifespan

Sensors are powered via a robust cabling infrastructure that links each sensor cluster to an instrumentation cabinet housing the data acquisition unit. Power can be supplied continuously from a 230 V or 110 V AC grid, or via a solar panel and battery package when on site mains power is unavailable.

Maintenance requirements also depend on the power source; grid-powered installations require no routine upkeep, while solar-powered systems need battery replacements every 4 to 10 years to maintain continuous operation.



	Power supply	Maintenance
Option 1	Continuous 230V or 110V AC grid power	No on-site maintenance is required
Option 2	Solar panel with battery package	Solar panels replacement every 10 years

The Mean Time to Failure (MTTF) provides a valuable estimate of the operational lifespan of each sensor used in monitoring systems. As shown in the table, the sensors selected for this solution are built for long-term performance in demanding environments.

The anchor load cell has an exceptional MTTF of over 300 years, while temperature sensors are rated for more than 200 years. ER corrosion sensors, inclinometers, and water level sensors each have an MTTF exceeding 100 years, indicating their robustness and long-lasting reliability.

The accelerometer offers an MTTF of over 60 years, and the strain sensor, though lower in comparison, still delivers a strong performance with a lifespan of over 20 years.

These figures demonstrate the system’s durability and the minimal need for sensor replacement, which is especially beneficial in long-term infrastructure and environmental monitoring applications.

Sensor	Anchor load cell	Inclinometer	Accelerometer	ER corrosion	Temperature	Strain	Water level
MTTF	> 300 y	> 100 y	> 60 y	> 100 y	> 200 y	> 20 y	> 100 y

It is important to note that these MTTF values may evolve over time, depending on advancements in sensor technology and the adoption of new materials or designs. The available solution packages will be regularly reviewed

and updated to reflect these improvements, ensuring continued performance, reliability, and alignment with industry best practices.

F.A.Q. (Frequently Asked Questions)

Who owns the data?

The ownership of the data typically belongs to the asset owner or the client commissioning the monitoring system. All collected data, including measurements, alerts, and analysis results, are the property of the client, unless otherwise agreed upon in a contractual arrangement. Data privacy and access rights are protected in accordance with applicable regulations and are clearly defined in the service agreement.

Will the sensors withstand the installation process?

All sensors and cables are securely protected in housings (cluster) on the sheet piles, preventing damage and resin leakage during driving. Their placement is optimized for both performance and durability.

Is the sensor suitable for use with buried sheet piles?

The system is designed in a way that all sensors can be used and installed underground or in the water.

What is the cost of each solution?

The cost of each solution depends on the selected package – Basic, Advanced, or Expert – and the specific requirements of the project, such as the number of sensors, installation complexity, and integration needs. Because each project varies in scope and budget, pricing is provided upon request and tailored to ensure the most cost-effective approach for the intended application. Instrumentation is typically recommended for one sheet pile every 15 meters up to every 50 meters, depending on the monitoring objectives and structural design.

What is the lifetime of the monitoring?

- The sensors are expected to have an average operational life of 50 years.

- Electronics (readout): expected operational life of 15 years, but can be replaced when a component fails (so will not impact the lifetime of the overall operational life of the monitoring setup as a whole).

Is there any impact on the installation?

- Additional care to be taken with the instrumented sheet piles during transportation and site preparation.
- After piling: a separate intervention is required to install the readout nodes, the acquisition cabinets and get the monitoring going. This is prepared and taken care of by ArcelorMittal or a trained and certified subcontractor.

Could those sensors last and function properly for 100 years?

While most sensors are not expected to function for a full 100 years without any maintenance, many of the sensors used in this solution have a Mean Time to Failure (MTTF) exceeding several decades



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