DEPARTMENT OF
COMPUTER SCIENCE

JOÃO MANUEL SILVEIRA SIMÕES PALMA

BSc in Computer Science and Engineering

DEVELOPMENT OF A WEB INTERFACE FOR AN INCLINOMETER MONITORING SYSTEM

MASTER IN COMPUTER SCIENCE AND ENGINEERING

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Adviser: Nuno Miguel Nuno Cavalheiro Marques
Assistant Professor, NOVA University Lisbon

Co-adviser: Ricardo Correia dos Santos
Assistant Researcher, Laboratório Nacional de Engenharia Civil

Examination Committee

Chair: Fernanda Maria Barquinha Tavares Vieira Barbosa
Assistant Professor, NOVA University Lisbon

Rapporteur: João Miguel Gomes Pires Manso
Assistant Researcher, Laboratório Nacional de Engenharia Civil

Adviser: Nuno Miguel Nuno Cavalheiro Marques
Assistant Professor, NOVA University Lisbon

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Abstract

Inclinometric monitoring is an important tool for the assessment of the behaviour of geotechnical structures. The current challenge in inclinometer monitoring in geotechnical engineering lies in the high cost associated with in-place inclinometer (IPI) solutions, leading to its infrequent usage. This financial barrier restricts the widespread adoption of inclinometer systems and, when implemented, often results in irregular sensor placement due to budget constraints.

The available and costly commercial solutions have outdated interfaces and the latency in data analysis, caused by its non-real-time availability of data, adds a compelling aspect to the problem, given its direct impact on the robustness and reliability of the monitoring processes. To address this, a low-cost inclinometer monitoring system was developed at LNEC, and this dissertation aims to enhance it by proposing a comprehensive and easy-to-use web interface solution.

The proposed approach of a prototype for a web interface is designed to be intuitive, interactive and adaptable to the constantly evolving needs of geotechnical engineers. The solution aims to be a technological upgrade that standout from the unrefined alternatives that lack a sophisticated and user-friendly interface, as well as, an efficient data visualization and analysis. The development of the web application should enable to interactively analyze the data collected by the inclinometers, with appropriate tools, in real-time as the readings from sensors are gathered. To ensure the successful integration of the web interface with the existing inclinometer system, different validation processes were carried out, including the evaluation of graphical interactions, laboratory testing, analysis of performance metrics and user surveys.

Beyond immediate outcomes, this solution addresses the fundamental issues of usability and data analysis in existing inclinometric monitoring systems, fostering a more efficient and user-centric approach.

Keywords: Web interface, Inclinometer monitoring, Low-cost fixed-in-place inclinometer, Interactive graph analysis, Real-time monitoring, Database

Resumo

A monitorização inclinométrica é uma ferramenta importante para a avaliação do comportamento das estruturas geotécnicas. O desafio atual na monitorização inclinométrica em engenharia geotécnica reside no elevado custo associado às soluções de inclinómetros fixos (IPI), o que leva à sua utilização pouco frequente. Esta barreira financeira restringe a adoção generalizada de sistemas de inclinómetros e, quando implementada, muitas vezes resulta numa colocação irregular de sensores devido a restrições orçamentais.

As soluções comerciais disponíveis e dispendiosas têm interfaces obsoletas e a latência na análise de dados, que é causada por estes não estarem disponíveis em tempo real, acrescenta um aspecto relevante ao problema, dado o impacto direto na robustez e confiabilidade dos processos de monitorização. Para resolver este problema, foi desenvolvido um sistema de monitorização inclinométrica de baixo custo pelo LNEC e esta dissertação tem como objetivo aprimorá-lo, propondo uma solução de uma interface web abrangente e fácil de utilizar.

A abordagem proposta de um protótipo de uma interface web foi concebida para ser intuitiva, interativa e ajustada às necessidades em constante evolução dos engenheiros geotécnicos. A solução pretende ser uma melhoria tecnológica em relação às alternativas, que carecem de uma interface sofisticada e fácil de utilizar, assim como, de uma visualização e análise eficiente de dados. O desenvolvimento da aplicação web permitirá analisar interativamente os dados recolhidos pelos inclinómetros, com as ferramentas apropriadas, em tempo real, à medida que as leituras dos sensores são obtidas. Para garantir o sucesso da integração da interface web com o sistema de monitorização existente, foram efetuados diferentes processos de validação, incluindo a avaliação das interações gráficas, testes de laboratório, análise de métricas de desempenho e questionários a utilizadores.

Para além dos resultados imediatos, esta solução aborda os problemas fundamentais de usabilidade e análise de dados nos sistemas de monitorização inclinométrica existentes, promovendo uma abordagem mais eficiente e centrada no utilizador.

Palavras-chave: Interface web, Monitorização inclinométrica, Inclinómetro fixo de baixo custo, Análise gráfica interativa, Monitorização em tempo real, Base de dados

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Acronyms

API Application Programming Interface *(pp. ix, 3, 4, 36, 37, 64, 65, 69, 80, 102)*

BPMN Business Process Model and Notation *(pp. ix, 72–74)*

DOM Document Object Model *(pp. 25, 30, 31)*

ERD Entity-Relationship Diagram *(pp. viii, 4, 40–46)*

IoT Internet of Things *(pp. 3, 19–21)*
IPI Fixed In-Place Inclinometer *(pp. iii, iv, viii, 3, 5, 8, 10–13, 15, 16)*

JWT JSON Web Token *(pp. 55–57)*

LINCS Low-cost Inclinometer monitoring system prototype *(pp. 1, 2, 13)*

MEMS Micro-Electro-Mechanical Systems *(pp. 11, 12)*
MQTT Message Queuing Telemetry Transport *(p. 18)*

REST Representational State Transfer *(p. 80)*

UI User Interface *(pp. ix, 55, 95, 96, 98)*

1

Introduction

This introductory chapter presents the motivation, the context in which this dissertation fits and the objectives outlined to develop and it is divided in three sections.

The subsequent section 1.1 elucidates the context and motivation of the dissertation, placing it within the framework of the encompassing project.

On section 1.2, the objectives of this dissertation are established and relevant design and development methods are discussed.

The following section 1.3 serves as a guideline for the structure of the document.

1.1 Context and Motivation

This dissertation is included in a comprehensive project, within the scope of a research protocol with Laboratório Nacional de Engenharia Civil (LNEC).

The fulfilment of this project is based on an existing data collection system from sensors embedded in a low-cost inclinometer monitoring system prototype, known as LINCS, which will serve as the starting point for the development of the dissertation. The processing of data gathered by the sensors is essential and its analysis provides a structured method for evaluating and overseeing subsurface characteristics and structural safety.

This dissertation culminates in the development of a web application designed to manage, store and visualize data collected by sensors in inclinometers in a concise and intuitive manner. This application aims to address the lacking features from existing solutions, enhancing the produced visualizations, by offering an interactive, simple, and intuitive interface that addresses the specific needs of inclinometer monitoring. To execute this project, various aspects need to be considered, such as, the underlying system supporting the application, the storage of essential data and the web application itself, which is the focal point of this project.

The web application aspires to stand out from existing solutions, providing key features that include the management of monitoring groups and profiles, interactive graph visualization, data filtering options and the capability to view and rectify profiles based on images. By focusing on usability and functionality on a set of continuous data sources, this project intends to facilitate more accurate and timely decision-making, ultimately contributing to improved safety and performance in inclinometer monitoring analysis.

1.2 Objectives and Contributions

Based on the context of the dissertation, the main objectives for the thesis are:

- Study and extension of the LINCS architecture.
- Definition of the architecture that supports the web interface for the existing system.
- Development of a prototype for a web interface to enable interactive graphical analysis.
- Validation of the prototype through various approaches, testing different aspects of the integration.

This thesis focuses on the development of a prototype for a web interface for LINCS, validating the integration with the existing system, assess the results obtained, and evaluate the overall impact of this innovative development on the field of inclinometer monitoring. This required an exploration of the intended purpose guiding the development, addressing the complexities of design to ensure an user-friendly experience, and achieving seamless integration with existing systems and components.

The successful completion of development and integration, involved an evaluation of the results, including an assessment of the obtained visualizations and their interactions, a study using scale model laboratory tests, performance metrics and overall user experience surveys.

Looking beyond immediate results, the long-term enhancements aim to improve the further analysis of inclinometer monitoring systems, not only helping the crucial work of technicians and engineers, while also contributing to the well-being of those affected, even unknowingly. The prototype's long-term impact on the field of geotechnical engineering can be assessed through factors, such as, scalability, flexibility and usability. By addressing existing limitations and proposing analysis improvements, this thesis can contribute to a more effective decision-making process and provides a structure for further refinements.

1.3 Document Outline

This document is structured by the following chapters:

- Chapter 1 - Introduction: The introductory chapter presents the motivation, the context in which this dissertation fits and the objectives outlined that were developed.

- Chapter 2 - Background: This chapter serves as contextualization of the dissertation, emphasizing the importance of inclinometer monitoring in geotechnical engineering.

- Chapter 3 - State Of The Art: This chapter provides an overview of the general architecture of the prototype of the low cost IPI system developed at LNEC. The impact that IoT systems have in geotechnical engineering is discussed and is carried out a comparative analysis that highlight the need of these technologies. The success of the proposed web interface hinges on its seamless integration with a newly developed cost-effective IPI. It also provides a detailed description of the technologies, programming languages, frameworks, and databases used.

- Chapter 4 - System Architecture: Provides a detailed description of the approaches taken and the decisions made throughout the development process. It includes a thorough explanation of the database schema, the design of the web interface, and the description of other relevant system components.

- Chapter 5 - Inclinometer Data Processing: In this chapter, the methods and processes involved in handling and processing inclinometer data are discussed. It covers the importance of the study of inclinometer data for the implementation process, the approaches used to process the data, and how historical data is visualized in the system. This chapter is crucial in understanding the operations that allow for the effective analysis of inclinometer monitoring data through the web interface.

- Chapter 6 - Implementation: The implementation chapter presents an explanation of how the system was built. It discusses the integration of different components, the challenges encountered during development, and the solutions implemented to overcome them. Additionally, it outlines the various APIs implemented to ensure efficient data handling and user interaction.

- Chapter 7 - Evaluation: Within this chapter an evaluation of the developed system is conducted and different approaches are explored, beginning with an analysis of the graphical interactions. Additionally, a laboratory testing was conducted and the handling of produced inclinometer monitoring data from that scale model is described. The chapter also discusses the performance metrics results and the findings from user surveys, analyzing user feedback and identifying areas for improvement.

- Chapter 8 - Conclusions and Future Work: The final chapter summarizes the primary insights and contributions of the dissertation. It reflects on the objectives set out in the introduction and evaluates how well they were achieved. The chapter also discusses the limitations of the current work and proposes directions for future research and development.

This document also includes the following annexes:

- Annex I - Entity Relationship Diagram (ERD): Complete view of the ERD, discussed in detail in Chapter 4.2.
- Annex II - Data Dictionary: Detailed descriptions of the data tables dictionary, offering a clearer understanding of the ERD.
- Annex III - User Surveys: Contains the complete document used for the user survey, including the introduction, initial profiling, set of tasks, set of questions, and answer sheet.
- Annex IV - User Surveys Suggestions: Contains the summary of suggestions made by users during the user surveys, detailing those implemented in the final version as well as suggestions for future work.
- Annex V - Web Interface Mock-Ups: Set of mock-ups representing the final version of the developed web interface..
- Annex VI - API Documentation: API document, generated using OpenAPI, containing the complete list of available endpoints.

2

Background

This chapter unfolds the background knowledge essential for a comprehensive understanding of the subject and it's composed by three sections.

Section 2.1 emphasizes the crucial role that geotechnical engineering has on establishing the foundation of infrastructures, guiding construction practices and ensuring the stability and safety of structures. It focus, more specifically, on inclinometer monitoring and how this technique offers relevant insights to guarantee an adequate geotechnical risk assessment.

Section 2.2 describes and compares the different types of inclinometer systems, highlighting the principles and processes behind each approach.

On section 2.3 are analyzed the main solutions available for IPI systems and what each brings to the improvement of inclinometer monitoring.

2.1 Importance of Inclinometer Monitoring in Geotechnical Engineering

Geotechnical engineering is a branch of civil engineering that deals with the behaviour of soil, rock and groundwater, and also their interaction with structures like buildings, bridges, dams, and tunnels. It involves the assessment of the ground conditions and provides recommendations to ensure the stability, safety, and durability of those structures. Geotechnical engineering is thus paramount to the success and safety of various civil engineering projects [2, 3].

At the essence of geotechnical engineering lies the crucial contribution of geotechnical engineers in site investigations, soil testing, foundation design, slope stability analysis, and overall geotechnical risk assessment. By understanding the geotechnical properties of the underlying geological materials, engineers can make informed decisions to mitigate potential hazards and optimize the design and construction processes.

Geotechnical monitoring is an important aspect of geotechnical engineering, providing a structured method for evaluating and overseeing subsurface characteristics and structural safety. It involves the systematic observation and measurement of soil and structural conditions over time. By continuously monitoring the evolution of the behaviour of the soil and structures, it is possible to detect changes or anomalies that may indicate issues such as settlement, deformation, or other factors affecting stability. This information allows for proactive decision-making, helping to prevent or mitigate potential problems before they escalate [4].

In numerous instances, the implementation of geotechnical monitoring is mandatory to meet regulations and benchmarks, guaranteeing alignment with recognized safety and quality criteria [5]. Many of geotechnical structures heavily rely on systematic monitoring for ongoing evaluation and maintenance. Whether it be retaining walls, slopes, embankments, tunnels, or other geotechnical structures, regular monitoring is an indispensable practice. Using an observational approach allows for the prompt detection and management of potential accidents or incidents, emphasizing the crucial role that monitoring plays throughout the life cycle of geotechnical projects.

For instance, monitoring is an important component in embankment dams to ensure their safety, stability, and long-term performance. Embankment dams, vulnerable to diverse environmental forces, necessitate consistent monitoring for the timely identification of potential issues like seepage, deformations, or structural weaknesses. These concerns can lead to undesirable structural and hydraulic behaviour in both the embankment body and its foundation, ultimately posing a risk of dam failure. Such an event can have far-reaching repercussions, strongly impacting lives, the environment, and the economy [6, 7].

Transportation infrastructures also face potential geotechnical failure modes, including slope instability, presenting substantial risks to both drivers and surrounding structures. The implementation of a robust monitoring system within embankment/excavation slopes enables the tracking of changes in slope movements over time, the early detection of warning signs indicating potential instabilities, and the timely implementation of corrective measures. This monitoring approach is essential for thereby enhancing the resilience of transportation networks and minimizing the risk of accidents and disruptions [8–10].

One key tool in geotechnical engineering is inclinometer monitoring, a technique that offers valuable insights into ground movement, structural stability, and risk management [11]. The core principle of inclinometer monitoring is to measure the inclination (or tilt) at discrete depths in the ground in relation to the vertical axis [12, 13].

With the assistance that inclinometers provide, it is possible to do an early detection of ground instabilities, thereby prioritizing safety as an essential concern [14, 15]. Inclinometers are engineered to enhance readings with exceptional precision. It comes with certain challenges, such as the cost of equipment, installation and data management, all of which necessitate thorough planning to ensure a successful and efficient inclinometer monitoring process.

Inclinometer monitoring typically involves the use of a metal or plastic pipe (casing) with inner grooves in two orthogonal directions (A and B) that is installed in a borehole drilled within the ground being monitored or embedded in a structure [10, 15]. The gap between the casing and the borehole is typically filled with a grout mixture with mechanical characteristics similar to the surrounding soil. This process minimizes differential movements and ensures better load transfer between the soil and the casing. It provides stability to the borehole and enhances the overall performance of the soil-casing interface. Figure 2.1 shows an example of the installation of an inclinometer casing in a geotechnical work.

Figure 2.1: Installation of an inclinometer casing in the ground of a work site [16]

Casing connections are designed to prevent soil and grout ingress, maintaining clean grooves. By regularly measuring the inclinations of that casing at specific depths, engineers and geotechnical experts can determine the lateral deformations in two orthogonal directions and assess the stability of slopes, tunnels, excavations, dams, and other geotechnical structures [9, 12, 14].

Figure 2.2 shows the basic principle of the inclinometer measurement procedure. The angle θ represents the tilt measured at a given depth in the ground and for a given vertical plane. The variable L represents the measurement distance interval. The horizontal displacement relative to the measured position is calculated using $L \sin(\theta)$. To obtain the total displacement at the top of the inclinometer, the procedure requires the sum of all relative horizontal displacements obtained from measurements at various depths.

Throughout these calculations, it is assumed that the base of the inclinometer remains fixed in a bedrock layer. Verification and quality control are essential aspects of this process. This involves ensuring that all measurements are consistent and within expected ranges, as well as confirming the assumption of a fixed base in the bedrock layer. Finally, comprehensive documentation is crucial. All measured values, calculations, and assumptions should be recorded systematically for future reference. This inclusive approach contributes to the reliability and traceability of the inclinometer measurements [9].

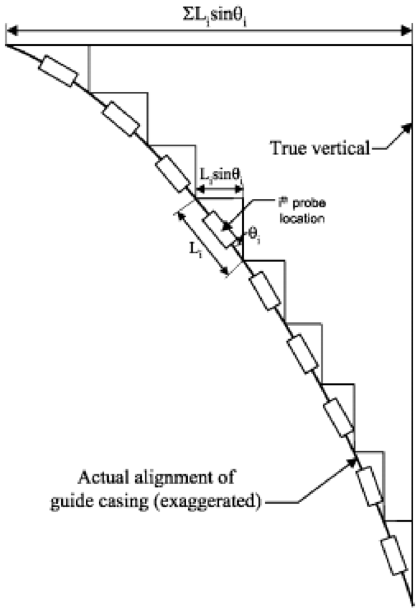


Figure 2.2: Illustration of the principle of inclinometer monitoring [9].

2.2 Types of Inclinometer Systems

There are essentially two types of inclinometer systems currently available: (i) the inclinometer probe and (ii) the fixed in-place inclinometer (IPI). It is essential to explore and emphasize the distinctions between these two types, offering insights into their respective applications, advantages, and disadvantages.

This comparative analysis will provide a comprehensive perspective, aiding in informed decision-making when selecting the most suitable inclinometer for a particular geotechnical application. In order to choose the ideal inclinometer type, it is necessary to conduct an initial assessment taking into account various parameters such as sensitivity, durability, and costs, aligning the equipment with the intended purpose.

The most used instrument type, the inclinometer probe (also referred to as gravity-sensing sensor) was introduced to the industry in the late 1960s [13]. Figure 2.3 shows an image of a traditional inclinometer probe and the respective readout system unit. It is a monitoring device known for its durability, reliability, and waterproof capabilities.

The inclinometer probe is equipped with force-balanced accelerometers in a stainless steel carriage and features spring-pressured wheels for precise guidance and orientation. Figure 2.4 shows the layout of the inclinometer probe when it is inserted inside the casing.

With the inclinometer probe, the casing's shape is established through consecutive manual measurements, usually placing the probe at 50 cm intervals (typical distance between the guiding wheels). The inclinometer probe incorporates a cable that allows control fixture at the casing's top aids probe/cable movement and offers a repeatable depth reference, often incorporating a pulley wheel to reduce cable bending and a clamp for stability at each measurement depth. This cable includes visible markings (e.g. every

0.5 m) for accurate depth positioning [8], and also enables transmission of the sensor data to the readout unit.

Figure 2.3: Typical inclinometer probe, cable and readout unit [8].

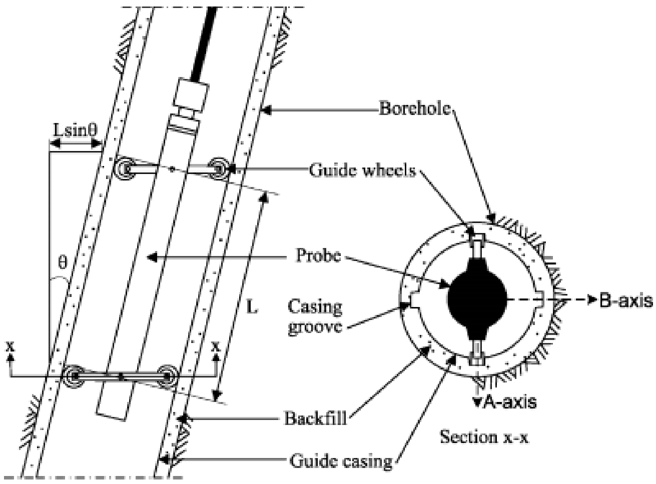


Figure 2.4: Illustration of the inclinometer probe inserted into the casing [9].

The multiple measurements made with the inclinometer probe yield a profile of the casing in two orthogonal directions (A and B). Measurements are conducted with the probe wheels aligned first along the A axis and then along the B axis. At each measuring position, the probe provides the tilt angles in both A and B directions, allowing the computation of the horizontal displacements with the use of mathematical (trigonometric) expressions.

The inclinometer probe itself is equipped with a minimum of one or two force-balanced servo-accelerometers designed to measure the inclination of the casing concerning the vertical axis. When a single accelerometer is utilized, the probe is referred to as an uniaxial probe. For uniaxial probe it is required four distinct passes (A+, A-, B+ and B-) to assess the casing's tilt accurately. The prevailing probe commonly used is the biaxial probe. This configuration incorporates two perpendicular accelerometers, which results in a reduced requirement of only two passes for measuring movement in all four directions. One accelerometer measures the tilt within the plane of the inclinometer wheels that follows the longitudinal groove of the casing. Concurrently, the other accelerometer measures the tilt within the plane perpendicular to the wheels. The inclinometer probe system is widely used in various geotechnical works [9].

For horizontally installed casing, the inclinometer probe is configured differently. In this case, readings are typically obtained by utilizing sensors specifically calibrated to allow calculation of vertical displacements. These sensors are integrated into the inclinometer probe, and as the probe moves within the casing, the sensors detect changes in vertical inclination. The information collected is then processed to provide precise readings of the vertical displacement along the length of the horizontally installed casing. Additionally, fixed bottom-tracking wheels contribute to the accuracy of these readings by ensuring stable and controlled movement within the casing, enhancing the reliability of the data gathered.

The main advantage of the inclinometer probe is its high reliability. It can also be considered cost-effective in terms of equipment required, because one single probe can be used to measure tilts in multiple inclinometer casings. Other advantage is the simplicity of is usage in a wide variety of projects and locations.

Nonetheless, it does come with certain limitations, notably in the data acquisition process. In addition, this process is both labor intensive and time consuming, demanding the presence of an expert team to conduct measurements manually. In certain instances, it may also necessitate the involvement of appropriate authorities to manage traffic around the measurement site, thereby leading to potential delays and high costs in the overall process.

To mitigate the existing limitations with the inclinometer probe, an alternative type of inclinometer, the IPI, is available, offering a solution to overcome some of those challenges. The IPI involves the installation of multiple sensors at discrete depths along the tube casing and are useful when frequent monitoring of ground movement is essential or when site accessibility is limited [12] (Figure 2.5).

Due to the cost associated with equipment and its installation, as well as the data management structure required, the use of IPI's has not been as common as the usage of the transversing probe. With advances in technology in recent times, there has been a growing use of these systems and significant improvements have been made in sensor accuracy, a reduction in production costs (due to mass production of necessary components), and a more compact and energy-efficient design.

The IPI system has gained prominence in recent decades due to the development of the Micro-Electro-Mechanical Systems, also simply called MEMS. These are micro integrated systems that combine electrical and mechanical components, such as, sensors and actuators, and they usually have a central processing [17].

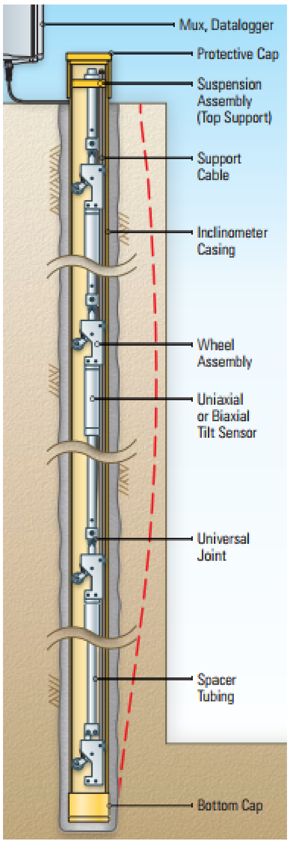


Figure 2.5: Typical application of IPI to monitor the stability of a flexible retaining wall [18].

The main advantages of these kinds of systems are the compact size, the low cost of production and the efficient performance they present, which resulted in a widespread distribution in different areas. They are commonly found in smartphones, tablets, cars and even medical devices, because they can detect motion, orientation and pressure [19].

The principle of MEMS accelerometers relies on detecting changes, for example, in capacitance, piezoelectricity, or thermal conductivity caused by accelerative forces [20]. When the accelerometer undergoes acceleration, these microstructures move, leading to a change in capacitance or other quantifiable properties. This change is then converted into an electrical signal, which can be analysed and used to ascertain the acceleration applied to the sensor.

In the IPI system, accelerometers are distributed along the inclinometer casing, placed at regular intervals or are positioned in locations that have been previously assessed as points of interest. By being strategically positioned, they eliminate the need for physical site visits, thus addressing a limitation of traditional inclinometer probe.

One of the significant advantages of IPI is their continuous data acquisition capabilities. As ground movement occurs, the sensors detect even subtle changes in slope and provide real-time data, offering a comprehensive view of how the monitored area is behaving over time.

However, they do come with certain drawbacks, such as the cost of the inclinometer itself and its installation, which can sometimes make them less accessible, especially for smaller-sized companies. Additionally, effective data management is essential, demanding the establishment of a capable system to handle the data requirements.

2.3 Need for the Developed Inclinometer System

In today's market, there are several companies that produce and sell IPI systems. Among the prominent ones, it is essential to highlight the work of some such as SisGeo (sisgeo.com), GeoSense (geosense.co.uk), SignalQuest (signalquest.com), Measurand (measurand.com), and Soil Instruments (soilinstruments.com). Each of these companies has various strengths and weaknesses regarding their respective inclinometers and how the management structure is implemented.

For instance, GeoSense system not only provides IPI solutions (Figure 2.6) while also offering an inclinometer probe that uses MEMS instead of traditional accelerometers. Moreover, they provide an Android smart device with an Android application that communicates with the inclinometer via Bluetooth. It's worth highlighting the detailed documentation included for their equipment, installation processes and mobile application usage. On the downside, despite the addition of a mobile application alongside the existing software, both have a very outdated and unintuitive design.

Figure 2.6: Deployment of an IPI system into an inclinometer casing [21]

Another example to highlight is Measurand, which is the most recognizable name among its competitors, offering various market solutions depending on the specific inclinometer application, whether installed vertically, horizontally. Measurand also provide a wide range of services for automated data management and collection through wireless communications. On the other hand, the software used for readings and data processing is not intuitive, providing sometimes insufficient details and featuring a very outdated interface.

Through this analysis, it is possible to verify that the various solutions available in the market present numerous advantages, including reliability, ease of data acquisition, sometimes in real time and remotely, without the need for manual readings and the involvement of appropriate authorities. This makes IPI's a significantly improved alternative than the traditional method.

Nevertheless, the solutions presented by these companies share a common significant drawback: the very high cost. This challenge prevents many small companies cannot afford the associated costs of the device and installation.

To meet the need for an inclinometer system that is both accurate and low-cost, the LINCS was developed at LNEC, with a focus on cost-effectiveness in terms of the required equipment while still delivering precise results. In the next chapter, a more in-depth overview of the prototype and its development will be presented, exploring its key features and innovations.

3

State Of The Art

This chapter provides a comprehensive overview of the state of the art, presenting the details of the existing physical IPI prototype, and comparative analyses relevant to the field, providing a thorough understanding of the existing market leading solutions in inclinometer monitoring, outlining the foundation for the subsequent development and evaluation phases of this dissertation.

The first section explores the prototype of a new low-cost inclinometer prototype, detailing its architecture and communication elements. This section is further divided into subsections, with subsection 3.1.1 describing the general system architecture and subsection 3.1.2 focusing on how system elements communicate.

The next section examines the impact of Internet of Things technologies on inclinometer monitoring systems, discussing how IoT integration has transformed data collection and analysis.

Following this, section 3.3 delves into real-time monitoring and data analysis, highlighting current capabilities and methodologies for processing and interpreting data as it is collected.

Section 3.4 presents a comparative analysis with market-leading solutions, evaluating the different features offered and highlighting areas of improvement.

In section 3.5, the focus shifts to graph analysis. This includes the objectives of graph analysis in inclinometer monitoring 3.5.1, the visualization of graphs within web interfaces 3.5.2, and the types of charts used for geotechnical insights 3.5.3.

The following section discusses image-based position correction in monitoring profiles, exploring the techniques that can be used to improve the accuracy of data analysis using profile images.

The last section delves into the technologies employed, covering programming languages, frameworks and libraries, databases, APIs and services, and development and testing tools. This section aims to detail the technical foundation upon which the web application is built.

3.1 Prototype of a New Low-cost IPI

Based on the information presented, it is possible to highlight the absence of a system that fulfills all the main requirements of geotechnical engineers, such as robustness, precision, and reliability, while also being cost-effective. The development of this low-cost IPI system addresses several needs in the field of geotechnical monitoring and structural stability assessments.

In the figure 3.1, it is possible to observe the different components of the system that were used to create the prototype of the low-cost IPI system. This IPI prototype contains four sensor nodes, presented in figure 3.1 (b). Each node (Figure 3.1 (a)) includes an accelerometer sensor that wirelessly transmits its data to a master node. This master node then forwards the received sensor data to a web-based timeseries database at a given time interval.

Figure 3.1: (a) Sensor node components; (b) Inclinometer prototype setup; (c) Calibration rigid casing used in tests [22].

Sensor nodes consist of an accelerometer board (HW-86C) and a microcontroller (ESP8266 D1 mini R2), both easily obtainable at cost-effective prices (less than 3 euros per unit). A specially designed PCB board handles power distribution and guarantees smooth communication between the microcontroller and the accelerometer, eliminating the need for wiring [22].

The wireless transmission uses the ESP-NOW protocol, which is a connectionless Wi-Fi communication protocol, where the data is condensed and sent efficiently and directly from one microcontroller to another.

The system is based on some important points:

- Affordability: Many small companies may not have the budget for the existing IPI solutions. A low-cost IPI system provides an affordable alternative, enabling a broader range of projects to benefit from inclinometer monitoring.

- Scalability: This low-cost IPI system offers a scalable solution that allows companies to use the application only for one inclinometer or scale to a huge set of IPI's if necessary. This adaptability enhances the versatility of the system for various geotechnical works.

- Innovation and Market Growth: The development and adoption of low-cost IPI systems stimulate innovation in the geotechnical monitoring industry. It creates possibilities for emerging market competition, ultimately propelling technological advancements and decreasing overall expenses.

- Research and Education: Educational institutions and researchers often face budget limitations. A low-cost IPI system provides an opportunity for students, researchers, and educational institutions to engage in practical geotechnical monitoring projects without compromising on data quality.

3.1.1 General Existing System Architecture

The system represented in the figure 3.2 illustrates the global scope of the system, where three essential points of communication need to be highlighted: the inclinometer set and its respective master, the broker and databases, and the web application. All components have been previously developed with exception of the web interface, which is the focus of this thesis.

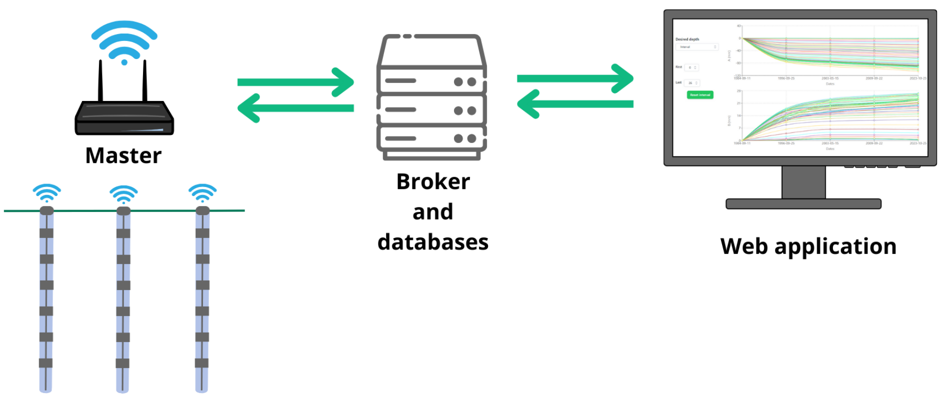


Figure 3.2: General system architecture.

The seamless communication among the various components in this sequence of actions is vital for the efficient operation of the system, facilitating the acquisition of readings and real-time data visualization.

The implemented system centers on a sophisticated architecture leveraging a combination of hardware and software technologies to achieve precise inclinometer monitoring. This flow of operations enables the system to provide accurate inclinometer monitoring capabilities. The hardware components, such as, sensors and microcontrollers, were chosen to obtain the best possible solution and a strong viable alternative to the existing options.

Furthermore, the interaction of these components is meticulously designed to handle the data flow effectively, enabling fast communication and data transfer between the inclinometers and the web application. The system's architecture emphasizes reliability and responsiveness by delivering real-time insights and enhancing the overall geotechnical monitoring measurement.

The system has also been based on some non-functional requirements that were essential to consider during development. These requirements can be identified as: security, where secure authentication of all users is fundamental; usability, which needs to be prioritized to ensure a user-friendly experience and interaction with the system, ensuring that it is easy, intuitive, clear, and accessible throughout the use of the platform; responsiveness, ensuring that response and execution times are within expected parameters, allowing operations to be carried out in the minimum possible time; reliability, as it is necessary to have accurate results displayed so that the analysis can be made effectively.

3.1.2 System Elements Communication

While ESP8266 board can technically use both ESPNow and Wi-Fi simultaneously, there are some practical limitations. The switching between ESPNow and Wi-Fi may cause interruptions, leading to unstable performance. That is why the master node, serving as an acquisition system and internet gateway, comprises two ESP8266 microcontrollers, represented in the figure 3.3. The first microcontroller receives wireless data (via ESP-NOW protocol) from sensor nodes, storing each read in an array, at regular intervals, and aggregates the sensor data into JSON format, sending this information over Serial communication to the second microcontroller. A vital feature of the code is a timeout mechanism, ensuring data transmission even if not all sensors provide readings within a specified time frame [22].

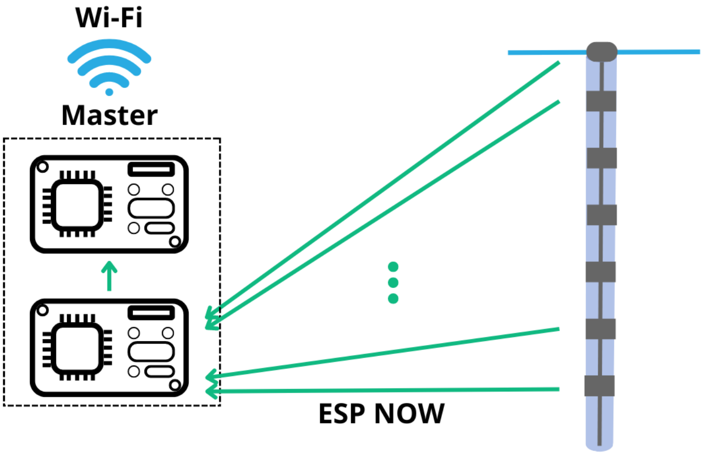


Figure 3.3: Communication between a set of sensors of an inclinometer and the respective master.

The second microcontroller establishes a secure Wi-Fi connection, receives incoming JSON data from the Serial port that contains measurements from all sensors and uses the MQTT (Message Queuing Telemetry Transport) protocol for data forwarding. This protocol is publish-subscribe communication protocol, which is widely used due to the reliability and efficiency that it provides, allied with a small power consumption as a consequence of the data packets size with a low overhead minimum [23]. In order to establish this type of protocol it is mandatory to have a central communicating infrastructure, the broker, which is responsible for receiving published messages and forwarding them to the subscribers that have subscribed to relevant topics. A clear advantage of the publish-subscribe communication is that the publisher and the client do not need to know each other in order to communicate[23]. This allows to have flexible and scalable communication between the different components of the system.

The master operates as an MQTT client that publishes data to a specific topic defined by an inclinometer code. To facilitate this communication, a free MQTT broker, established using HiveMQ's cloud service, controls and aggregates all published messages [22]. The Broker represents the centerpiece of the whole communication, because of its role as a middleman between the master, that contains the data from the set of inclinometers, the databases and even the web application.

The data gathered from the master is stored in a time series database, which logs the data transmissions from the sensors in different time frames, using an open-source platform, InfluxDB. It offers an efficient way to manage high volumes of time-stamped data, with fast querying and retrieving options.

Figure 3.4 illustrates a summary of the communication process, beginning with the master receiving data from the sensors and continuing through to its transmission and eventual storage in the time-series database.

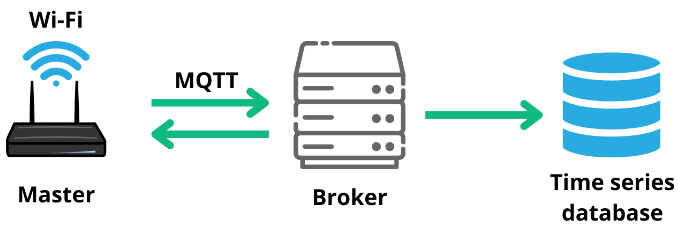


Figure 3.4: Communication between the master, the broker and the databases.

3.2 The Impact of IoT in Inclinometer Monitoring Systems

The Internet of Things, commonly known as, IoT, has recently experienced rapid growth and has become one of the most emerging and powerful technologies, with the main goal of improving the quality of life [24].

The introduction of IoT technologies in the geotechnical field of work enables to have a different approach to many processes and procedures than the traditional way.

The advancement of these technologies revolutionizing numerous fields enable a continuous and real-time stream of data. Traditionally, obtaining data from the sites where the inclinometers are located required scheduling physical visits to manually collect the data, followed by subsequent data processing on a computer by the engineers or technicians. This method can be highly time-consuming, resulting in significant delays between data acquisition and analysis. IoT technology transforms this process by facilitating real-time data collection and remote monitoring, providing substantial advantages over traditional methods.

The real-time monitoring offers a unique advantage by allowing immediate access to data, which is especially important when dealing with infrastructure stability and safety. The emphasis is on maintaining a sampling frequency that accurately reflects the process's dynamics, rather than on constantly measuring every moment [25].

The prompt decision-making process that the system enables, such as detecting early signs of potentially dangerous ground movement or other structural instabilities, facilitates prompt responses to emerging issues, potentially preventing more severe problems from developing.

3.3 Real-time Monitoring and Data Analysis

The dynamic interaction between the Earth's subsurface and human structures necessitates vigilant monitoring. Its vital role in ensuring the stability and longevity of infrastructural projects, demands continuous improvement and a focus on achieving the most accurate results.

Traditional monitoring practices have evolved into refined and sophisticated data analysis methods, that allows a real-time data gathering and proactive and preventive methodology when facing a risk assessment situation. This has not only enhanced the precision of data collected by sensors but has also provided geotechnical engineers with a comprehensive understanding of subsurface dynamics. The integration with Internet of Things (IoT) systems has empowered technicians to detect even minimal changes, prevent potential risks and implement preventive measures.

Real-time monitoring is one of the most important advantages of the use of IoT systems in the context of inclinometer monitoring. It allows to have an actual precise value without having to go where the inclinometer is located and without having to plan ahead a visit to the site. This approach relies on a huge amount of wireless sensor networks that produce a continuously streamline of data [24] and provides real-time intel of potential stability problems and can be configured to detect and warn automatically if the system detects abrupt ground movement. The integration with IoT systems have a proactive risk management, which is an obvious distinction from the traditional way of monitoring.

Another significant benefit of real-time monitoring is the increased frequency of data collection, leading to a more detailed and accurate analysis. Traditional methods often limit data collection to specific intervals due to the logistical challenges of site visits. In contrast, IoT-enabled systems can gather data continuously, providing a richer dataset over the same period.

The data analysis is also improved from this remote monitoring, that allows to make strategic decision-making insights about the data received in a shorter time. This combined with a powerful analysis tool, can provide valuable results analyzing the historical data and creating patterns to prevent potential problems with a prompt response time.

To assist with the decision-making process, visualization tools can be used to provide strong data analytics that help interpreting big data acquired from the various IoT devices [24].

The interfaces created for this purpose can take advantage of the large amount of data and provide a simple and, at the same time, complete representation of this data collection to create an analytic visualization that illustrates situations that have an efficient decision-making process. A fast and precise approach is crucial when it comes to these kinds of systems that have the responsibility to ensure the safety of infrastructure and consequently human lives.

The integration of user interfaces with advanced monitoring techniques can have a key role in bridging the gap between complex data and useful insights, ensuring a simple and straightforward interaction with the smart environment [26].

Effective visualization tools and user-friendly dashboards are vital for converting complex datasets into clear and practical insights for decision-makers. As the volume and complexity of data grow, ensuring that these interfaces are both user-friendly and capable of delivering real-time analytics becomes indispensable. This not only improves the overall assessment, but also enhances the ability to make informed decisions, especially when dealing with environments where timely intervention can prevent significant risks and ensure safety.

Although the integration of IoT into inclinometer monitoring systems can face some challenges during the development and installation, it has the potential to revolutionize the way that the flow of work occurs and add a new perspective to retrieve information, analyse it and acting sooner.

3.4 Comparative Analysis with Market Leading Solutions

The prototype of the presented application aims to be a robust alternative to the options available in the market provided by competing companies. To conduct a market study and assess prospective solutions, fundamental aspects need to be considered in order to evaluate the user interactions, the interface presentation and the available functionalities. The following aspects related to the presented interfaces were analyzed:

- Usability: Ease of use and interaction of the available tools. It includes having a user-friendly interface, a straightforward and intuitive design and how accessible is for users to navigate around the interface with the objective of perfoming a specific task;

- Appearance: Defines the overall look of the interface, focusing on details such as color, size and positioning of each interface component. As this criterion may involve subjective opinions, given that it can depend on personal preferences, the evaluation will focus only on inconsistencies in design choices and situations that make it difficult to read or use the interface;

- Functionalities: Features and tools offered by the application. This will evaluate the requirements and needs that these solutions provide and highlight the best and worst aspects that each one has.

These considerations are essential for the design and development of an application and were the key ones to be taken into account, despite other equally important aspects being left out, for which significant results were not obtained, such as performance, which evaluates the response time and fluidity of the performed operations.

Existing alternatives, despite being functional, exhibit a somewhat unrefined and unintuitive design with several inconsistencies and generally limited functionalities. In figure 3.5, it is possible to observe the alternative presented by the company Measurand, one of the market leaders mentioned in section 2.3 of chapter 2.

A careful analysis of the interface easily highlights inconsistencies in the color palette used and the inappropriate choices that it brings, at times causing difficulty in reading interface elements, something that should be avoided and considered to be a quite serious mistake. The menus are also very rudimentary, offering few solutions for detailed interactive viewing of the data being studied.

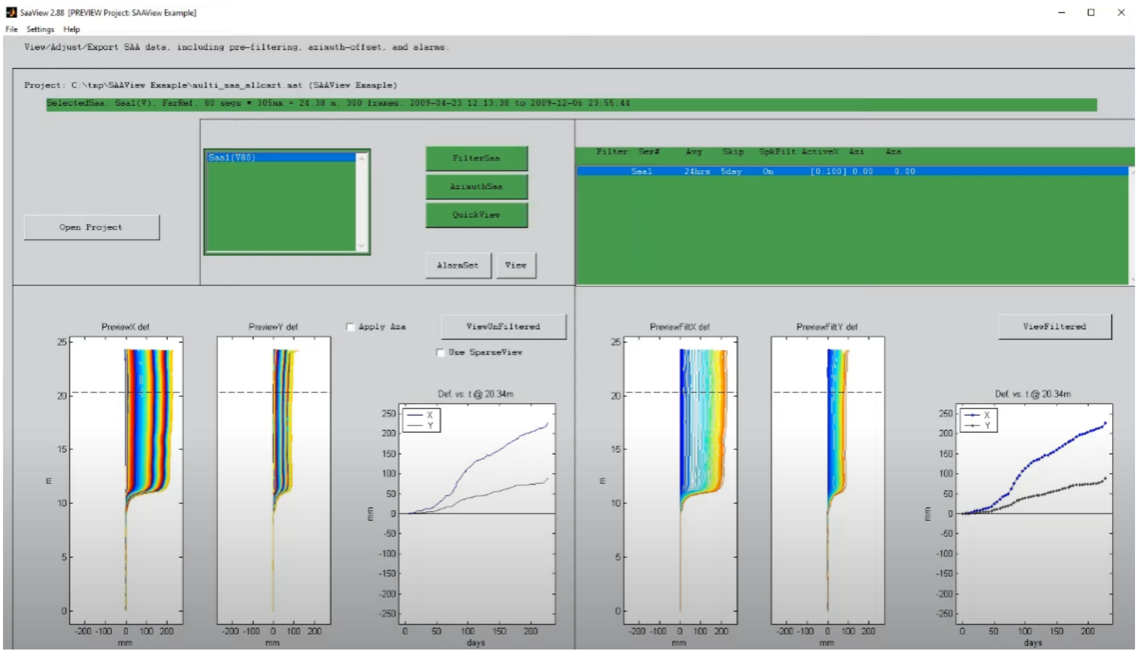


Figure 3.5: Example project preview using the Measurand software [27].

Another example of an existing solution in the market is presented by the company Geokon, which uses the SiteMaster application, whose interface is shown in figure 3.6. Compared to the previously analyzed application, this one shows a substantial visual improvement, although the design remains outdated.

Regarding the interface design, it seems to provide more information and in a more personalized manner. However, some design choices, such as the use of pop-up windows for information that could be placed directly in the interface, add unnecessary complexity that could be simplified and made more intuitive.

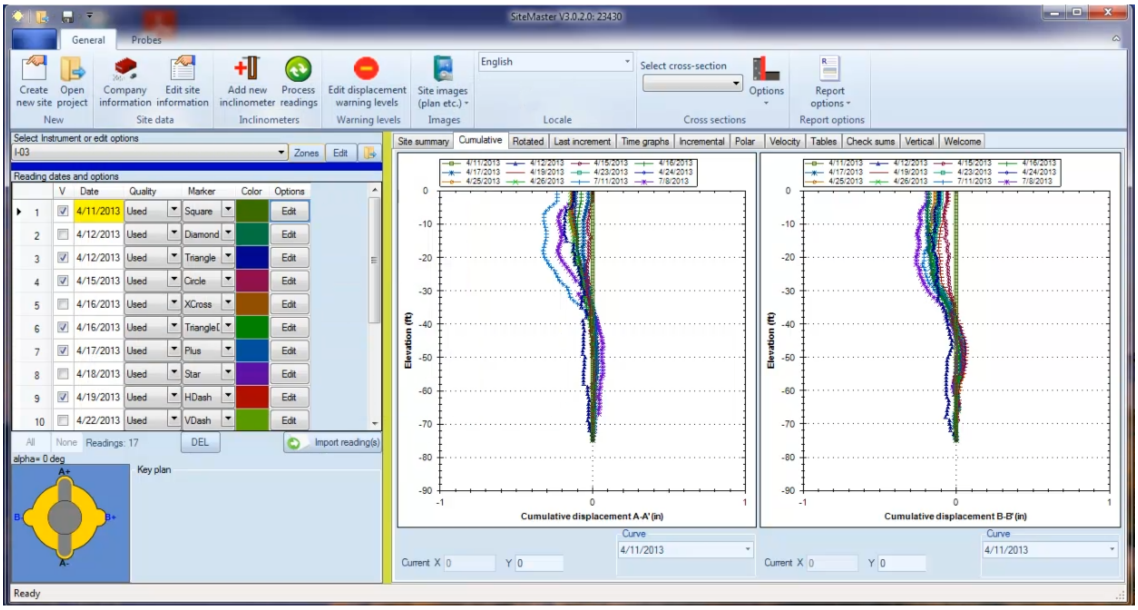


Figure 3.6: Example project using the SiteMaster software [28].

In terms of functionalities, SiteMaster allows for an interesting management of inclinometer data with various details that can be analyzed. However, this is not facilitated by the interface, which overlays various parameters and filters, thus complicating the interpretation of the data. Despite the presence of various representative charts, the lack of interaction is an important point to highlight since it is a fundamental element for the analysis and understanding of data, facilitating interpretation.

Through the analysis of the most competent market solutions, it is possible to highlight the most important and necessary points that an application to be developed must have, and also to deduce areas where these solutions are not very competent or lack various functionalities that would be very helpful in the analysis of data obtained by inclinometers.

The web application needs to have the possibility to not only present the graphical visualization in an improved and interactive manner, using various relevant data filters and real-time data without the need to import data files but will also allow for the interactive management of monitoring profiles with an actual picture representation of the environment around the working site. This includes the ability to correct the positions of inclinometers interactively, delineate the surrounding terrain, to view and change the data related to each inclinometer. This functionality could offer a new approach that adapts to the specific needs of real-time monitoring, providing relevant and updated data for analysis and decision-making processes.

3.5 Graph Analysis

3.5.1 Objective of Graph Analysis in Inclinometer Monitoring

Graph analysis, in geotechnical works, is a fundamental tool, because it allows to understand and study the behavior of the ground in an efficient and concise way. This data provides valuable insights regarding structural stability, ground movement and potential risks around the area of assessment, which is crucial, as it is related to the safety of the technicians who access the site.

This analysis, in addition to, identifying patterns and irregularities in the ground or structures, also allows the comparison between multiple readings of the behaviour over time and in different locations of measuring. The visual intel that the graphs provide could also help to calibrate and validate the data collected to ensure its reliability and overall accuracy of the sensors.

Due to unpredictability and external factors that are challenging to control, there are instances when it is necessary to access and analyse the data efficiently within a short period of time. Therefore, gathering the data in real-time is an advantage that this project has and could let up to a more efficient and safe monitoring.

3.5.2 Visualization of Graphs in The Web Interface

Considering the importance of obtaining a visual representation of data, graphical visualization becomes a crucial aspect in data analysis. Given the dynamics of the data and the possible representations they offer, a study of the potential visualization and chart creation package to be used was conducted, where the standout candidates were *Chart.js* and *D3.js*.

For the definition of the criteria of selection, the following aspects were taken into account: ease of use, flexibility, types of charts available, learning curve, documentation and integration with the web application. As represented in the table 3.1, both are strong contenders that meet various analyzed criteria. However, *D3.js* stands out due to its advanced capabilities, particularly in the user interaction field and the diverse range of chart options, despite its higher learning curve and complexity.

D3.js was developed as response to an emerge need for robust and flexible data visualization that is also web-accessible [29] and using it could bring some extra benefits. The integration of frameworks built on top of *D3.js* and *React* can provide a compelling approach in the domain of data visualization. Among the numerous existing options, *Nivo*[30] and *Recharts*[31], emerge as the alternatives that present greater robustness and efficiency.

The framework *Recharts* provides a set of composable components, that offer an easier way to develop and build web applications and the framework *Nivo* brings a more customizable approach when it comes to pre-built components for different chart types.

Factors \ Solutions	Chart.js	D3.js
Ease of Use	User-friendly alternative. Requires less code to use it, so the setup and configuration is simpler and faster.	Requires advanced programming knowledge about Document Object Model (DOM).
Flexibility	Simpler, with limited options for customization.	Highly customizable data graphs, with greater details.
Types of Charts	Focused on common chart types.	Greater variety of charts compared to Chart.js and with more and better interactions with the charts itself.
Learning Curve	Easier to understand and learn.	Requires an extensive knowledge, due to the immense customization options.
Documentation	Easier for beginners to find documentation and support.	Comprehensive and extensive documentation.
Integration	Well-suited for an efficient integration in web applications.	Seamless integration with other libraries and frameworks.

Table 3.1: Chart packages comparison.

One of the key benefits of using these specialized charting frameworks is the ease of integration with a React component-based structure, allowing to scale the application, while not forgetting the user experience. The dynamic and interactive way the user connects with the interface is one primary goal that should not be set aside.

Therefore, the optimal approach for data visualization involves using *D3.js* with a framework that can enhance its capabilities to have a final product that share the advanced features of this chart creation package and the user experience provided by the React-based application.

3.5.3 Chart Type for Geotechnical Insights

As mentioned earlier, the portrayal and visualization of charts are fundamental elements in the analysis of data from inclinometers. Therefore, a comprehensive exploration of types of charts were studied to obtain the graphical representation that best suits a more comprehensive and effective analysis.

To achieve this, it is necessary to consider the distinct datasets to be analyzed, with the primary focus on depth displacement. The measurement of the displacement is performed at each reference point, allowing the creation of a line that represents the displacement along the casing depth. The date of the reading is also an important element to consider, as comparative analysis between readings is a valuable tool for determining displacement over time, providing various insights into the infrastructure underlying this analysis.

As depicted in figure 3.7, a representation of cumulative displacement through a line chart allows for a better temporal comparative visualization than any other type of chart. Each sensor present in an inclinometer captures the values at the exact point it is installed, facilitating a relative displacements view. However it is more useful to analyze the cumulative displacements from the point embedded in the bedrock than the relative displacements of each portion of the inclinometer. This representation highlights various reference points in depth while simultaneously emphasizing displacement through the line in each reading.

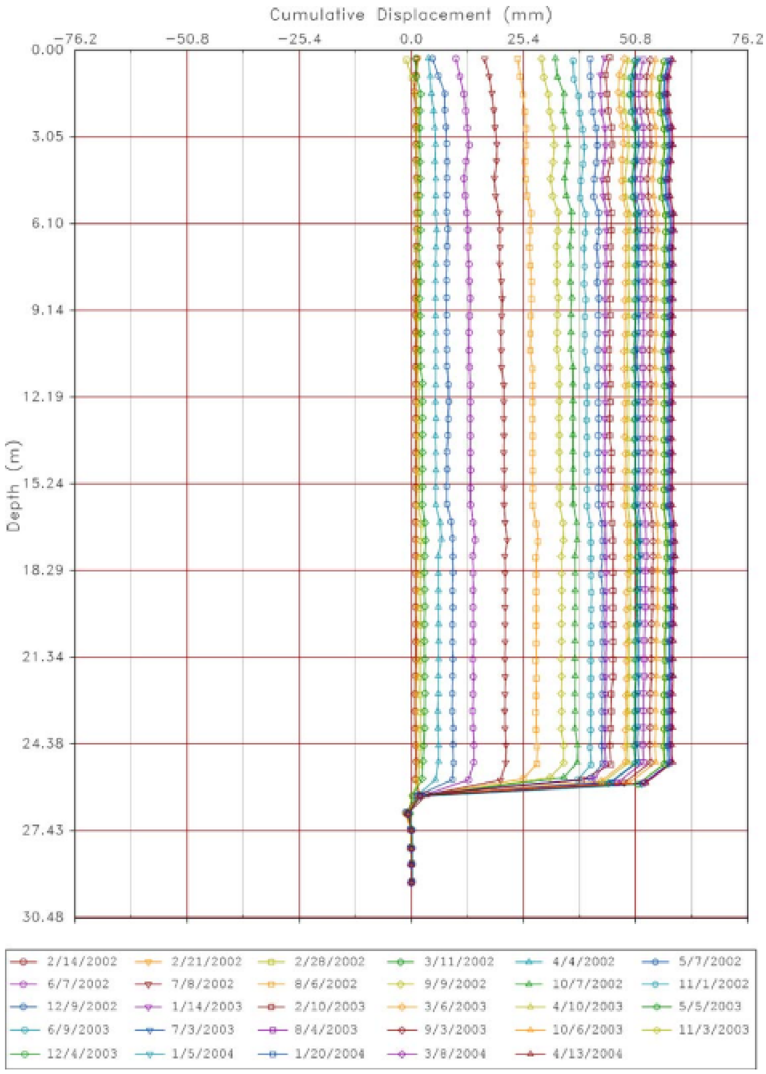


Figure 3.7: Graph with the cumulative displacement gathered from a slope inclinometer [9].

The interaction with each of these reference readings was also a crucial point to consider during the development of the web interface. In case it is necessary to analyze a specific point in depth, direct interaction with the chart enables a rapid and more dynamic analysis, bringing an innovative perspective to this topic and facilitating the interpretation of results.

3.6 Image-Based Position Correction in Monitoring Profiles

The monitoring profiles are set of inclinometers that the user can define in order to view their results simultaneously. This is highly relevant and an innovative aspect in the context of the proposed web interface design. Through the interface, it will be possible to define various monitoring profiles and manage them in an accessible manner. Each monitoring profile includes two kinds of representations: Plan and Cross-section.

In the case of it being a plan, the system allows for a correction and adjustment of the associated positions of the various inclinometers. The associated table of inclinometers generated by each specific monitoring profile enables the definition of points that need to be altered and are also indicated on the image in the corresponding location.

For this purpose, the system needs to have two options: the user can upload an image of the location, or if not available, this interaction will be performed through the view of the map visualization tool, OpenStreetMaps, using the inputs of latitude and longitude of the inclinometer. If the user chooses the first option, the system is capable of interacting with the user uploaded photos, where points need to be placed, saved, and, when data is queried, easily accessed and represented on the image.

For the cross-section, the system needs to have the ability to draw a line on the image at each position for any inclinometer present on the profile, representing its length. This feature provides a visual depiction of the inclinometers in relation to the structure depth, making it easier to understand their placement and orientation.

With this in mind, two tools that allow the intended interaction with images were analyzed and studied: Fabric.js and Konva.js.

Both contenders were strong choices for the envisioned system. Each has numerous features and standout aspects that make them robust alternatives, deserving a more detailed exploration. To achieve this, an initial proof of concept was conducted to verify essential characteristics that were needed, such as, the ease of use, performance and user interaction. The trial involved both interfaces in a simplified and illustrative environment, mirroring the intended application.

Comprehensive documentation with specific use-case examples enhances the accessibility and testability of both frameworks. Additionally, they offer diverse options for shape drawing, demonstrating comparable performance levels.

Despite the similarity in usage, the Konva.js framework stands out for its simplicity, both in terms of user experience and task execution during development. Figure 3.8 showcases the use of Konva.js with a real image of a profile used as an example to test this tool. In this example, points were strategically placed on the image to specify the relative position of each inclinometer present in the image. These points have two coordinates relative to the canvas, which can be saved and repositioned when required.

Upon an in-depth analysis of these frameworks, Konva.js emerges as a more effective and suitable solution for its intended purpose. While both frameworks possess standout features, Konva.js takes a unique approach, setting it apart in delivering the desired solution.

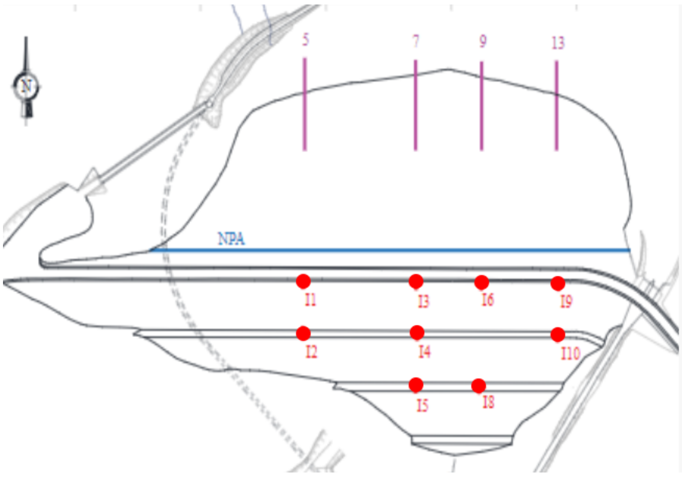


Figure 3.8: Testing of Konva.js using an image of a profile on an earthfill dam.

3.7 Technologies

3.7.1 Programming Languages

Kotlin: In order to develop the application, a base language for the backend part for the project needed to be chosen. With this, the question of what is the language that best suits the project arise. The top choices that check all the boxes were Java and Kotlin, each offering unique advantages and features.

Java is a consolidated and stable programming language, with a widespread adoption, powering a vast array of applications from enterprise systems to mobile application. Using this language, it is remarkable how easy it is to find suitable resources and libraries with a vast community-supported documentation. However, Java lacks built-in null safety and null pointer exceptions are common errors, which represent a significant drawback. It also may have more boilerplate code compared to Kotlin.

On the other hand, Kotlin is a programming language that recently emerges with a different approach. Designed to be fully interoperable with Java, which means it can be seamlessly integrated with Java projects, it has a more concise syntax design [32]. The way Kotlin is structured enhances readability and maintainability of the code produced, reducing the need for boilerplate code [33]. This language is easy to learn, especially with previous Java knowledge, and can be used to build large systems, even though it is mostly known for building mobile applications. In contrast with Java, Kotlin has built-in null safety features, reducing the risk of null pointer exceptions [32], and has some more useful tools, such as, the extension of functionalities of classes without having to inherit them from a class.

After comparing these two programming languages and measuring the pros and cons, Kotlin stands out as the suitable choice for this project. The decision to choose Kotlin over Java was driven by the enhanced productivity, quality of the produced code and the interoperability that it brought.

TypeScript: Used alongside the React framework, TypeScript improved the development process in multiple aspects. The initial setup was done using JavaScript, however after some testing and a comparative analysis between JavaScript and TypeScript, TypeScript was ultimately chosen.

One of the key benefits of this programming language is its ability to catch errors during the development phase, reducing runtime errors and ensuring a more robust maintainable code. Compared to JavaScript, TypeScript offers a more structured approach to writing code itself, with the use of type definitions, interfaces, and classes. Its compatibility with existing JavaScript code allows for interoperability with JavaScript frameworks and libraries. TypeScript's integration with React provides a more efficient development process, higher code quality, and a more maintainable web interface.

3.7.2 Frameworks and Libraries

Spring: Before diving into the application development, it was necessary to consider the various aspects involved in the process, including not only choosing the programming languages that best fit the project but also selecting frameworks that can be used in conjunction with the languages to optimize and enhance the development and the final outcome of the application. In this context, the Spring framework emerged as a fundamental foundation for structuring the application. Known for its modularity and extensibility, Spring is an open-source framework for the programming language Java, capable of developing complex and easily scalable applications with high performance, with its primary focus being the infrastructural support at the application level [34]. Spring simplifies composing applications by taking care of creating application objects and injecting their dependencies [35].

The primary advantages of using Spring, which were evident throughout the development process, include:

- Integrated features: Spring offers a comprehensive toolkit with core features in various areas such as security, data access and management, and testing. For example, in terms of security, Spring includes Spring Security, a customizable authentication and access-control framework, equips developers with various authentication providers and a range of pre-built security filters to mitigate common security attacks.

- Integration with JVM languages: Spring not only supports the Java language but also seamlessly integrates with other languages running on the Java Virtual Machine (JVM). In recent years, Spring has embraced the rise of the Kotlin language, providing extensive capabilities that enhance the development environment and ecosystem.

- Production of concise and maintainable code: The framework promotes best practices in software development, emphasizing component modularity and code readability. This approach reduces development time and enhances error detection and correction.

- Test-driven development: Spring supports a variety of testing options, including JUnit and Mockito, facilitating the creation of mock objects for accurate testing of functionalities in a real scenario.

Despite the steep learning curve, the benefits offered by this platform proved advantageous, ultimately contributing to a more robust and efficient final solution. The implementation of Spring in the development process ensured that the application is well-structured, secure, and easily maintainable, highlighting the value of selecting the right framework for the system.

React: Before selecting the platforms to be used, it was crucial to assess the goals intended for the application, define the essential functionalities, and pinpoint the key elements that required greater attention when initiating the interface construction. Following this initial evaluation, some areas were identified that needed proper emphasis and represented the main challenges to develop: monitoring groups and monitoring profiles management; and, more specifically, the graphical representation of data.

To meet all these objectives, the React framework was chosen for the development of this project. React, an open-source JavaScript library for building user interfaces, proved to be an excellent choice despite its relatively recent emergence. React's component-based library uses structured components that can be efficiently reused compared to other frameworks. The component-based structure also allowed seamless integration with various services and functionalities, which can sometimes be a challenge.

The modular structure of React components facilitated not only reusability but also maintainability and scalability. Each component encapsulated its own logic and state, making it easier to manage and update specific parts of the application without affecting the entire system. This modularity is particularly beneficial when dealing with complex applications [36].

Furthermore, React's virtual Document Object Model (DOM) provides optimal rendering performance by updating only the parts of the DOM that have changed, minimizing unnecessary re-rendering, which results in faster and more responsive actions and feedback. This is extremely important due to intended use for the web interface is non static, which means that each part of the DOM has a state represented by the user interface that a web browser needs to render, and that state can be changed when an event occurs [37].

The comprehensive documentation available for React provides a useful way to understand and leverage the library's features. Moreover, the continuous improvement and the availability of numerous third-party libraries and tools that enhance development capabilities, made React the right fit for creating the web interface.

Recharts: For creating the specific chart representations that the web interface needs, Recharts was the framework selected. This framework is able to generate a detailed visualization of complex data in an intuitive and accessible manner, ensuring that users could interpret and analyze data effectively. It facilitated the creation of diverse chart styles, each representing specific types of data crucial for inclinometer monitoring.

The system required various chart styles for each specific purpose, such as, the representation of the displacement in different orthogonal directions, the total displacement, and temperature over depth, providing multiple viewing possibilities for better understanding the scenario being analyzed. Another chart style developed focused on illustrating the displacement in depth over time, where the featured lines represent each depth. The distinct visualizations allowed users to track changes and identify patterns over depth and time, offering valuable insights into the stability of structures.

Furthermore, Recharts was used to produce charts that offered a relative representation of orthogonal directions over elevation. These charts were particularly useful because they allowed for scaling each chart to the relative size of each inclinometer and aligning them to a set elevation. This customization enhanced the comparison of different inclinometer data present on the same profile.

Recharts was chosen for several reasons:

- Response Times: One of the most important aspects to consider was the response times between an user action that changed the data displayed on the charts. Its rapid response times when loading data, even with large amounts, were essential due to the need to frequently update the number of dates selected during data analysis.

- Interactive Features: The dynamic interaction with the charts was a standout feature compared to other alternatives. The interaction is enabled by hovering across the different data points represented on the charts, making it easy to gather specific information about each precise data representation. Also, the framework's animation capabilities enhanced the user experience by providing smooth and engaging visual transitions.

- Customization: Recharts offers extensive customization options, ranging from the chart itself to the tooltips, supporting the replacement of the default themes for each component into a customizable version. For instance, the tooltips were completely replaced to display the desired information when interacting with the charts and a reference line with the reference data displayed at the bottom were added to show a more comprehensive visualization.

- Integration: The ability to implement various chart types and styles with React that met the data analysis needs allowed for an easy integration with the rest of the system.

After careful consideration and analysis of other chart generation frameworks, Recharts emerged as the top choice, filling out all the requirements for the implementation to ensure both efficient data handling and a user-friendly experience.

Konva: As mentioned on section 3.6, Konva was the framework selected to enable the interaction of the user with uploaded photos of monitoring profiles, creating an unique feature that separates the developed system from the existing ones. This framework was used with two distinct approaches in mind for interacting with the images, depending on the particular type of monitoring profile.

The first approach involved identifying the relative position of each inclinometer on photos of plans by selecting each point directly on top of the corresponding photo. This method allowed users to mark and adjust the positions of inclinometers on the image, facilitating a clear and relative mapping of a specific set of inclinometers.

The second approach allowed the user to place the relative position of each inclinometer present alongside a cross section, creating a line by selecting two points, that could be adjusted as needed. The ability to dynamically adjust these points ensured that the visual representation remained flexible and could be tailored to the specific needs of the analysis. Once the positions are properly added on each of these approaches, the system store them automatically in the database, allowing for an efficient retrieval and analysis later on.

In contrast to the precise geopositioning of exact coordinates, the ability to adjust the individual inclinometer positions provides a relative, rather than perfectly accurate, location. This approach significantly simplifies the process and makes it more user-friendly, as it does not require precise measurements. It serves as a helpful guide for more in-depth analysis without the need for exact positioning. This relative positioning emerges as a different way to visualize and understand the data being shown when a closer and precise analysis is being made.

By using Konva, the need for traditional paper-based drawings or photo-editing software can be replaced with a seamless interaction directly within the application. This integration not only streamlines the workflow but also enhanced accessibility of monitoring profile data, ensuring that users can efficiently interpret the information.

Tailwind CSS: One of the most versatile CSS frameworks available is Tailwind CSS, which greatly enhances the development process by providing an extensive set of predefined classes for styling elements.

A primary advantage of using this framework is its straightforward naming convention for hexadecimal colors, which allows for easy and consistent application of standard colors throughout the interface. This feature ensures that the color scheme remains uniform, promoting a cohesive and visually appealing user interface without the need for custom CSS for every element.

Tailwind also provides many useful layout features, offering a wide array of utilities that enable a consistent yet complex responsive layout design without requiring extensive custom CSS [38]. By applying these features directly to HTML elements, the process of creating adaptive and well-structured layouts becomes significantly more efficient and intuitive.

Material-UI: To create a unique style of design, another framework that worked alongside Tailwind CSS is Material UI. This React component library offered a comprehensive set of pre-built components that served as base components for various elements such as tables, sliders, selects, and switches. These components provided a solid foundation, enabling an efficient integration of essential functionalities without starting from scratch. This approach allows to focus more on the unique aspects of each user interaction with the element, rather than spending excessive time on basic UI elements.

One of the standout features that this library has is its high level of customization. Each component comes with extensive customization options, allowing for an easily modifiable element to match the desired look and feel. The ability to override default styles and apply custom themes ensures that the application maintains a consistent and cohesive design structure throughout, making this library a powerful tool for building modern and responsive user interfaces [39].

Material UI's extensive documentation is another significant advantage. The well-organized documentation provides detailed information about each component, along with practical examples and code snippets. This resource is valuable for developers, as it accelerates the learning curve and simplifies the process of integrating the library into projects.

Additionally, Material UI includes a large collection of icon packs, that can be customized to enhance its utility and integration. This set of icons can add visual appeal to the interface and can help the user take specific actions based on commonly known symbols.

Node.js: Node.js was selected for its capability to facilitate simple and efficient application development, due to the extensive array of frameworks available through the Node Package Manager (npm).

Additionally, npm was utilized to host the frontend React server, which facilitated a seamless and integrated development process. The ecosystem of npm packages and libraries allowed for the efficient setup and management of the React development environment, ensuring that the frontend could be rapidly developed and deployed alongside the backend services.

3.7.3 Databases

InfluxDB: In order to store the data transmissions from the inclinometer sensors in real-time, InfluxDB is utilized as a time-series database. The primary advantage of using a time-series database is its ability to efficiently manage and analyze high volumes of time-stamped data.

The open-source platform InfluxDB offers a solution that enables high-performance data querying and retrieving options, which is crucial for applications that require real-time monitoring and frequent updates of data.

The Flux language, an advanced data scripting and query language developed by InfluxData, significantly extends the functionality and versatility of InfluxDB. Flux provides a more flexible approach to querying and processing data compared to a database traditional SQL query language [40].

The system can accommodate multiple connections for different structures, providing a scalable solution for each specific monitoring needs. To store each connection, a simple form can be filled in by the user, and a connection test can be made to ensure that the available measurements will be accessible.

PostgreSQL: In the context of creating a relational database to store all the necessary data, PostgreSQL was chosen. This open-source database system is used to store a wide range of data types, from inclinometer data and monitoring profiles data to map markers coordinates. Its advanced functionalities and support for complex queries make it an ideal choice for the system, ensuring the efficiency and reliability needed.

The integration of PostgreSQL with Spring and Kotlin is seamless, largely due to the use of Spring Data JPA repositories. Repositories simplify the implementation of data access layers, allowing developers to focus on logic rather than boilerplate code [41]. This integration is further enhanced by Kotlin's concise syntax and powerful features, as mentioned on 3.7.2, making database interactions more straightforward.

Moreover, PostgreSQL's ecosystem includes pgAdmin, a comprehensive management tool that provides a complete interface for database administration. PgAdmin facilitates a prompt and intuitive view of the data, offering functionalities such as query execution, database design, and performance monitoring. The combination of PostgreSQL's robust capabilities and pgAdmin's user-friendly interface significantly enhances the overall efficiency of database management and operations.

Google Cloud Firestore: In order to store the user-uploaded photos of monitoring profiles, various solutions were considered, including Azure Blob Storage. However, Google Cloud Firestore was ultimately chosen due to its scalable and flexible NoSQL cloud database capabilities, which provide real-time data synchronization and powerful querying. Its document-oriented data model allows for the storage of data in documents organized into collections, offering a straightforward and intuitive approach to database management. Files introduced by the user can only be in typical image formats, such as jpg, jpeg, png and svg, but if necessary, the storage use can be extended to use documents of other types.

One of the primary advantages of using Firestore storage is its low latency of responses, which is critical for applications that require real-time updates and fast data retrieval. This low latency ensures that users experience minimal delays when accessing or modifying data, resulting in a smoother and more responsive application. Firestore efficiently handles large data sets and scales automatically based on demand, allowing it to accommodate a growing number of users and an increasing volume of images without compromising performance [42].

Another useful feature is the folder managing structure on which the storage is built. It allows to separate the data into specific nest folders, easily organized and categorized, in a way that facilitates the creation of regular expressions to retrieve and upload the desired files.

Overall, Google Cloud Firestore's powerful features and seamless integration with the rest of the system make it an excellent choice for managing and storing images, with the possibility of extending to other file types.

3.7.4 APIs and Services

OpenStreetMap: Prior to selecting the OpenStreetMap platform, a comprehensive evaluation of another alternative, Google Maps, was conducted for viewing the coordinates of inclinometers. Despite Google Maps' advanced features, OpenStreetMap was ultimately chosen due to its open-source nature, which affords greater flexibility and customization opportunities. This open-source platform proved to be more suitable for the specific requirements, enabling extensive modification and seamless integration with the system.

This flexibility allowed for the development of custom markers, labels, and popups to achieve a cohesive integration with the overall system workflow. These custom elements are crucial for accurately depicting the inclinometers on the map, ensuring that the information presented is both clear and relevant to the users. The implementation of custom popups, in particular, offered a seamless integration of inclinometer data with the map interface, enhancing user interaction and a comparative analysis of each inclinometer present on a monitoring profile.

This interactive feature significantly enhances the user experience by providing a more intuitive and easy method for visualizing and analyzing the data, thereby contributing to the overall efficacy of the system.

3.7.5 Development and Testing Tools

Postman: The application Postman proved to be extremely useful during the development and testing phases of the project by providing a platform for API testing. It facilitated the testing of various endpoints, facilitating the assessment of their functionality and performance. By enabling detailed examination of API responses and the ability to simulate different request scenarios, Postman ensured that the API endpoints performed as expected under various conditions [43]. This testing capability was essential for identifying and addressing issues before deployment, thereby improving the reliability and robustness of the system.

Postman's interface, while complex, proved to be highly efficient for managing and testing APIs. Its comprehensive set of features includes the ability to create and send requests in multiple formats, with custom headers and a wide range of data formats including JSON and XML.

Additionally, Postman offers a user-friendly approach to viewing and analyzing responses. The application provides intuitive visualization of response data, including formatting and syntax highlighting, which aids in efficiently interpreting the results of API calls. Postman's features for storing and arranging requests into collections streamline the testing process, allowing developers to efficiently manage and reuse test scenarios, ranging from authentication, data querying or data insertion.

OpenAPI: OpenAPI is a framework designed to generate extensive and interactive documentation for API endpoints. By defining API endpoints, request parameters, and response formats using a standardized specification, OpenAPI ensures that comprehensive documentation is automatically generated and kept up-to-date. This documentation provides developers with essential insights into API usage, including available endpoints, data formats, and response structures, ensuring clarity and accessibility for effective interaction with the API.

One of the key benefits of OpenAPI is its ability to simplify future development and integration tasks. The document generated provides a well-defined specification between the frontend and backend, making it easier for new developers to understand the API's functionality. This framework can also be used to automatically generate client libraries and test cases, which speeds up development and reduces encountered errors [44].

OpenAPI integrates seamlessly with Spring through its use of annotations within the code. By applying OpenAPI specific annotations to Kotlin classes and API interfaces, developers can directly embed API documentation into the code. This approach not only keeps the documentation synchronized, but also simplifies the process of maintaining and updating the documentation as the API evolves. The integration with Spring enhances the developer experience by leveraging the framework's capabilities to produce comprehensive and accurate API documentation with minimal additional overhead.

4

System Architecture

This chapter explores the system architecture, providing a detailed examination of the various components and technologies involved, focusing on how they contribute to the overall functionality and performance of the system.

In first section, 4.1, the components of the system and how they interact are described, ensuring seamless data flow and integration.

Next, the database schema design is examined in section 4.2, including the entity-relationship diagram and the design considerations for managing inclinometer data, monitoring groups, and profiles.

The web interface design is addressed on section 4.3, discussing the user interface elements and choices that were made to create an intuitive and interactive experience for users.

Finally, section 4.4 explores other components of the system aside from the chart visualization and profile tools, including authentication mechanisms, notifications and alerts, soil layers management, and settings and connections.

4.1 System interactions and communication

The web application serves as the central hub for interaction within the system architecture, connecting three distinct databases to provide real-time data visualization and management, as illustrated in figure 4.1. The primary focus of the project, the web application, facilitates communication with a relational database, a time-series database, and a cloud database, each serving a unique purpose in the system's overall functionality.

The relational database, implemented using PostgreSQL, is responsible for storing distinct types of data, such as, inclinometer data (excluding the readings), user information, and database connections parameters. This database ensures that all the needed information is well-organized and accessible, allowing for efficient data access and retrieval.

The time-series database, which uses InfluxDB, plays an important role in handling the real-time sensor data gathered by the system. InfluxDB acts as the connection point between the raw data collected from the sensors and the rest of the visualization part of the system. The real-time access to sensor readings is an innovative aspect for monitoring and analyzing inclinometer data, offering a significant advantage over other existing applications.

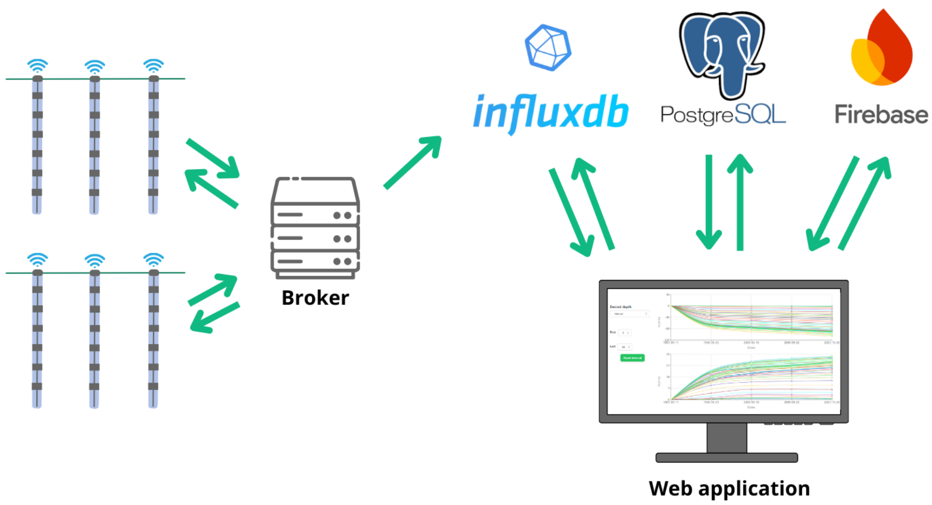


Figure 4.1: Communication between the different components of the system.

Additionally, the system incorporates a cloud database using Firestore. This database is used for storing and accessing images of profiles and plans uploaded by users, serving as a proof of concept for potential future cloud based system. The integration of Firestore demonstrates the system capabilities to handle cloud data, providing a starting point for a broader cloud implementation in the future. A more detailed discussion on this integration is available in section 6.3.

The communication between the web application and these databases is designed to be efficient and reliable, ensuring that users can interact with the data in a straightforward way. The system architecture supports the visualization of real-time data, enabling engineers to make informed decisions with all the resources needed. The application's design prioritizes usability, security, and performance, ensuring that it meets the needs of its users.

In summary, the web application not only provides a user-friendly interface for data interaction but also effectively combines sensor data, user management, and real-time visualization, making it a powerful tool for engineers and technicians.

4.2 Database Schema Design

The system requires three databases with different types, each serving a specific purpose:

- Time-series database: Used to store the data transmissions from the sensors, which are organized by time frames. For this purpose, an open-source platform, InfluxDB, is utilized, ensuring easy access and efficient storage of data, as mentioned on section 3.1.2.
- NoSQL cloud database: Firestore is integrated to store the photos of profiles and plans uploaded by users, providing an alternative cloud solution to manage this specific kind of data.
- Relational database: The choice of this database type was driven by several considerations, including the ultimate purpose, implementation requirements, and seamless integration with the other components of the system. For this purpose, PostgreSQL was selected.

The data storage needs to have two distinct kinds of data: user-related information and specific inclinometer data, excluding readings, such as location, sensor spacing, soil layers, coordinates, and database connection parameters.

Opting for a relational database for the user data was a straightforward decision, because it is the suitable choice for the required parameters. Regarding the specific data for each inclinometer, it was necessary to study the various available alternatives and a thorough exploration revealed two contenders: a relational database and a spatial database.

Spatial databases offer distinct advantages in storing and retrieving geolocation-based data, being especially known for efficiently storing, indexing, and querying of this type of data [45], a critical aspect worth highlighting. On the other hand, there was also a need to store diverse data beyond geographical coordinates, leading to the question of whether another database could be used solely for geographic coordinates, while the remaining data could be stored in a relational database. After thoughtful deliberation and recognizing the unnecessary complexity it would entail, the decision was made to solely utilize a relational database for storing the specific data associated with each inclinometer. The data in these databases is handled carefully, and sensitive information, such as passwords, is encrypted.

4.2.1 Entity-Relationship Diagram

In order to facilitate the design and development of the application, an entity-relationship diagram (ERD) of the complete schema was developed, which is a visual representation that illustrates the relationships among entities within a database. ERD's purpose is to facilitate database design by allowing specification of a schema that represents the overall logical structure of a database [45]. This is an essential component when designing a database schema and provides a compact and clear overview of the data structure, highlighting the objects that are present in the system and the different associations between them.

The entities[1], represented in a rectangular shape, are the main objects that need to be stored in the database. These entities have attributes associated to each one, represented in an oval shape, which correspond to certain properties or particular values that defines the need to have that entity. Among these attributes, there is a primary key, which is a unique identifier for each record inside an entity, represented by underlining that attribute. Last but not least, the relationships, represented in a diamond shape, illustrates the interactions and associations that an entity has with another entity. There are three types of relationships: one-to-one, one-to-many, or many-to-many. These types define the associations between records from both entities and if they are linked to only one or multiple records at the same time. The aggregation, represented with a rectangular shape surrounding a group of entities, is a relationship between entities, where it defines a unique set with each other.

To better understand the diagram, the main entities represented on the ERD are:

- Monitoring Group: Set of inclinometers belonging to a given structure being monitored.
- Inclinometer: Set of many sensors installed in the same borehole.
- Sensor: Sensor of an inclinometer, which is the actual point where the data is being collected.
- InfluxDB: Connection parameters to the InfluxDB time-series database, which is essential for establish a connection to retrieving data.
- Structure: Structure or work site associated with a set of inclinometers.
- Monitoring Profile Group: Set of monitoring profiles gathered into a group to assist with the assessment of different views of the same structure.
- Monitoring Profile: Set of inclinometers that the user defines in order to view their results simultaneously.
- Profile Position Adjustment: Position being corrected in a monitoring profile, which can be represented as a point, marker, or line, each offering a different interaction.
- Soil and Water Layers Set: Set of layers of an inclinometer.
- Layer: Single layer present along the length of an inclinometer.

[1] The full guidelines for the notation used can be found in the book *Database System Concepts*, 2019 [46]

Due to its size, the ERD is available in annex I and only relevant sections that require appropriate emphasis will be demonstrated. Each section is just a partial representation and does not include all the attributes that each entity has, in order to make the interpretation easier.

To complement the ERD and provide a more detailed understanding of the structure, a data dictionary was created. This dictionary offers a comprehensive view of the various entities, outlining their attributes along with examples of expected values. It also specifies the data types for each attribute and highlights any relevant restrictions, such as being a primary key, foreign key, or a non-null value. With the guidance provided by the data dictionary, the ERD analysis can be enhanced, offering a more structured approach to understanding the relationships and entities presented. The full data dictionary can be found in annex II.

4.2.2 Inclinometers

Figure 4.2 shows a simplified partial version of the ERD that highlights inclinometer particular details. Each inclinometer has a set of sensors that are spaced at a specific distance from one another, as depicted on section 2.2. In order to represent that peculiarity, the entity "Sensor" has a relationship with itself that has an attribute with the distance between each sensor. The decision behind this choice lies on the need to have the distance between each sensor on the casing and it allows to calculate the distance between any two sensors, even if they are not adjacent to each other, being only necessary to store the distance to the nearest sensor. With this design, for instance, it is possible to calculate that a sensor A, placed at 50 centimeters from a sensor B, is at 90 centimeters from a sensor C, that is placed at 40 centimeters from sensor B, assuming that A is adjacent to B and B is adjacent to C. The entity "Sensor" has a direct many-to-one relationship with the entity "Inclinometer".

The "Inclinometer" is also directly associated with the entity "Soil and Water Layers Set", which stores the different soil layers present at the inclinometer's site location, enabling the creation of the bar chart displayed alongside the displacement charts. This entity has a global scope for each particular layer defined by the user, which is represented by the entity "Layer".

In addition to the relationships described, tables 4.1 and 4.2 provide detailed views of the entities and their attributes using partial representations of the data dictionary.

Table 4.1 shows the data dictionary for the "Inclinometer" entity, offering a comprehensive breakdown of each attribute, containing the respective data type, restrictions, and a provided example of common values given. When an inclinometer is created on the database, only the "id" and "name" are provided, because they are detected as part of the readings available in the time-series database. The lack of non-null restrictions on other attributes can be explained by the fact that they are not mandatory for the chart analysis and can be later configured.

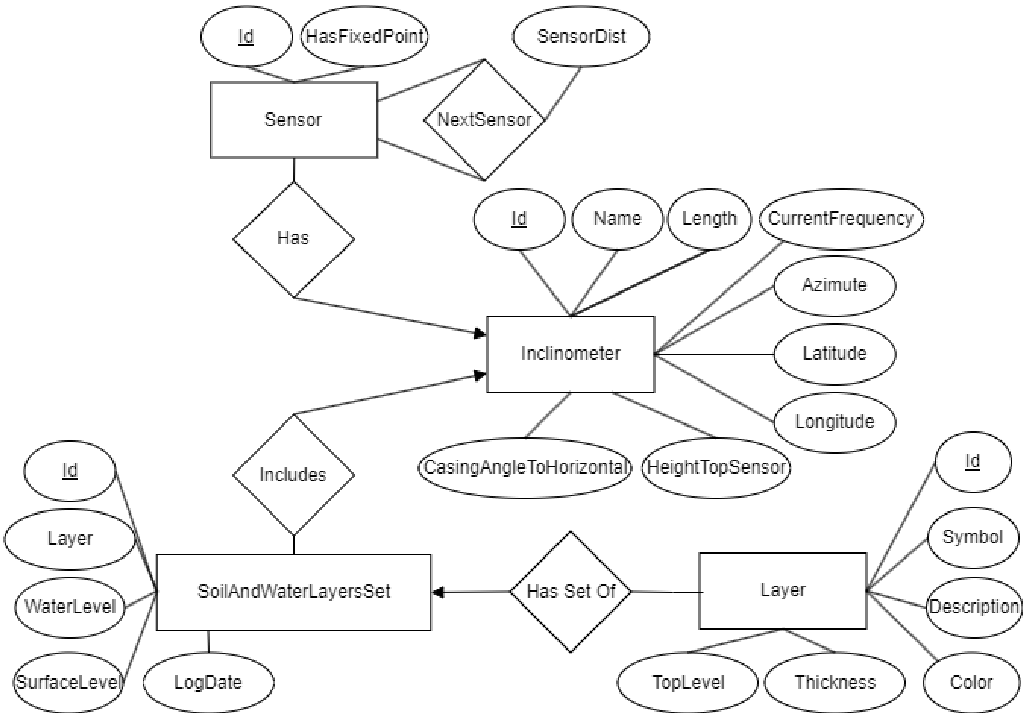


Figure 4.2: View of the inclinometer section of the ERD.

Inclinometer			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	I1
Latitude	FLOAT		41.55680
Longitude	FLOAT		-6.89017
Azimuth	INT		90
Length	FLOAT		51
CurrentFrequency	INT		231552000
HeightTopSensor	FLOAT		606
CasingAngleToHorizontal	INT		0

Table 4.1: Inclinometer data dictionary.

The "Sensor" entity and the table generated by the relationship that the entity has with itself is illustrated in the table 4.2. The "Sensor Distance" table, as explained earlier, captures the distances between sensors, allowing for accurate calculations of the distance of each unique sensors. By storing the distance only between adjacent sensors, this design minimizes redundancy and supports more efficient data processing and analysis.

Sensor			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
SensorId	VARCHAR	NOT NULL	4
HasFixedPoint	BOOLEAN	NOT NULL	TRUE
InclinometerId	INT	FK, NOT NULL	1

NextSensor			
Name	Data Type	Restrictions	Example
SensorId1	INT	PK, FK	1
SensorId2	BOOLEAN	PK, FK	2
SensorDistance	FLOAT	NOT NULL	50

Table 4.2: Sensor data dictionary.

4.2.3 Monitoring Groups

The aggregation, represented in figure 4.3, is the result of the relationship between monitoring groups and inclinometers, and is an important piece of the design. The unique relationship that these two entities have, led to the implementation of an aggregation to efficiently represent each set of inclinometers within a monitoring group. This approach simplifies the data handling and ensures that the data is accessible to the particular needs of the analysis process.

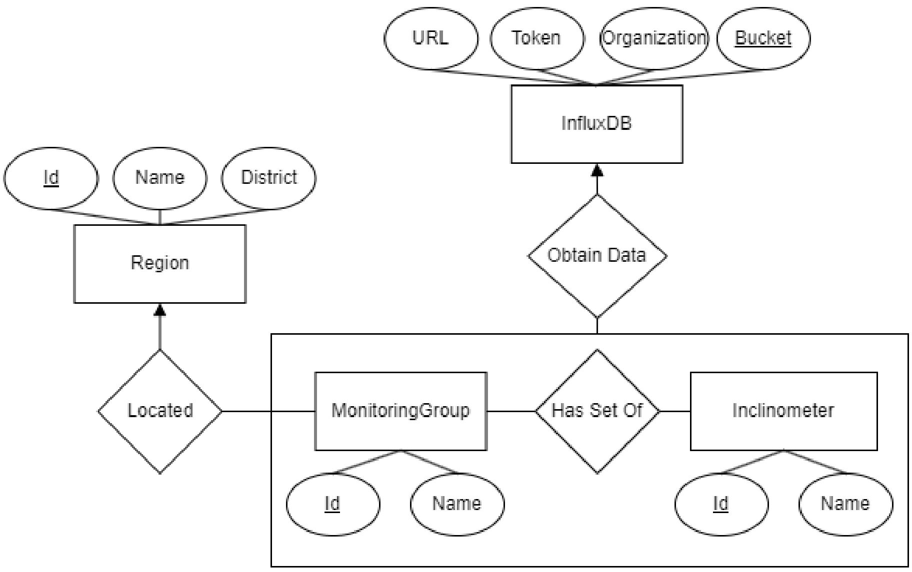


Figure 4.3: View of the monitoring group and inclinometer aggregation of the ERD.

A monitoring group essentially represents a set of inclinometers associated with a specific structure or site being monitored. The entity "Region", associated with any monitoring group, allows for the clear definition of the location associated with the site, allowing for easy categorization of the structures.

To better illustrate the aggregation, consider a scenario where a site has ten inclinometers placed at different locations and depths, all belonging to a certain structure. When creating a monitoring group, the available structures are selected, and the respective inclinometers are displayed. From the ten inclinometers present in the site, the user making the analysis only wants to visualize three inclinometers that belong to a foundation of the structure. That monitoring group will have a unique association with the three inclinometers. If another monitoring group is created, it could also include the same inclinometers from the chosen set, but it would be considered a different monitoring group, meaning that each relationship is unique.

Furthermore, table 4.3 provides the data dictionary for the "Monitoring Group" entity and the associated aggregation, detailing each attribute within the system. It is worth meaning that the aggregation represented by the "MonitoringGroup_Inclinometer" table has a joint between the "id" of each inclinometer and the respective monitoring group to function as a primary key, emphasizing the unique aspect that the aggregation provides.

MonitoringGroup			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	Azibo's dam
Description	VARCHAR		Azibo's dam monitoring
RegionId	VARCHAR	FK	Macedo de Cavaleiros

MonitoringGroup_Inclinometer			
Name	Data Type	Restrictions	Example
MonitoringGroupId	INT	PK, FK	1
InclinometerId	INT	PK, FK	1
Bucket	VARCHAR	FK, NOT NULL	Inputs

Table 4.3: Monitoring group data dictionary.

The attribute "bucket", which is a direct result of the integration with InfluxDB, helps identify the specific database bucket where the monitoring data is collected and stored. The InfluxDB entity allows for the storage of the connection parameters needed to establish the link to the associated bucket. The datasets provided by InfluxDB are only stored in the time-series database, avoiding the duplication of large quantities of data.

4.2.4 Monitoring Profiles

The "Monitoring Profile" entity, represented in figure 4.4, is also an important piece of this ERD and the associated data dictionary can be found in figure 4.4. Usually, inclinometers are grouped together in profiles, which facilitate the systematic monitoring of subsurface conditions across different locations. Each profile is included in a set managed by the entity "Monitoring Profile Group", which organizes profiles into groups to facilitate the assessment of different views of the same structure. This entity has a many-to-one relationship with entity "Monitoring Groups" and a many-to-many relationship with the

"Structure" entity. The entity "Structure" represents the structures available for evaluation, containing the essential data needed to define a set of inclinometers within a particular measurement.

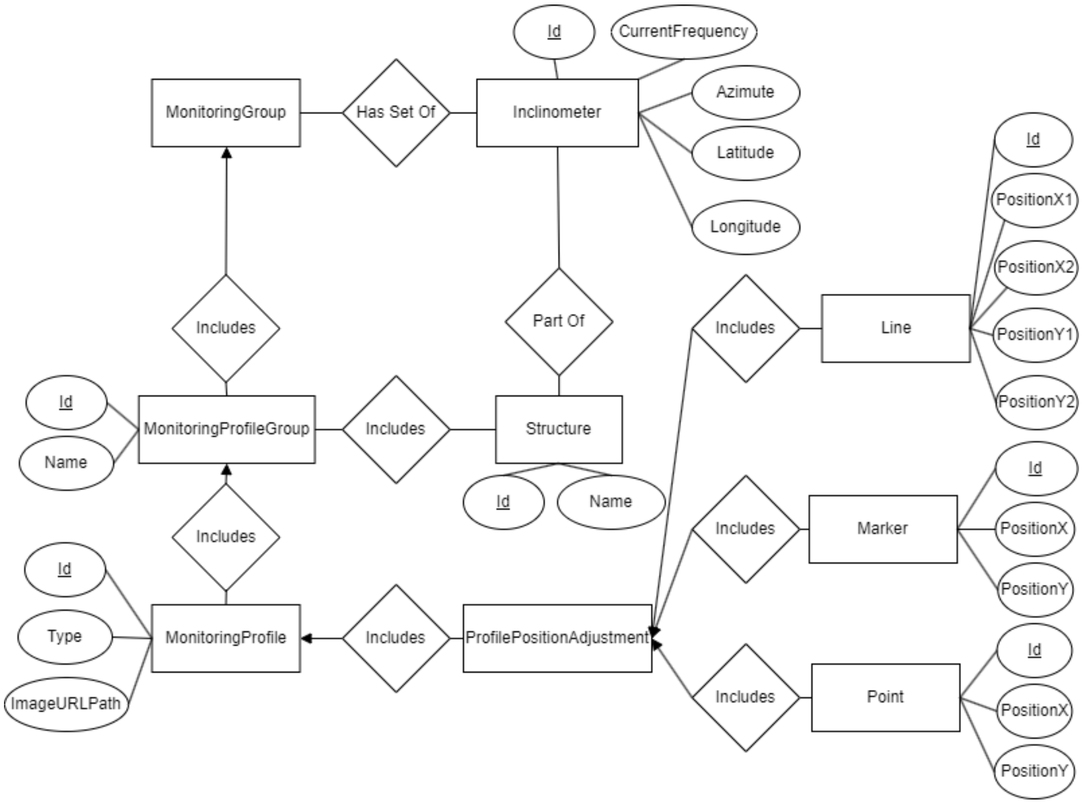


Figure 4.4: View of the monitoring profiles section of the ERD.

MonitoringProfile			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	Azibo's dam profiles
Code	VARCHAR	NOT NULL	P1
Description	VARCHAR	NOT NULL	Inc 1 and 2
Type	VARCHAR	NOT NULL	PLAN
ImageURLPath	VARCHAR		https://firebaseURL.com
MonitoringProfileGroupId	INT	FK, NOT NULL	1

Table 4.4: Monitoring profile data dictionary.

This arrangement of associations may seem complex at first, but its practical use in the web interface makes it more intuitive. Each monitoring profile group belongs to a monitoring group and contains a set of inclinometers within a structure. The web interface ensures that every inclinometer is correctly associated with its respective structure. For example, when adding a new monitoring profile, a multiple selection component allows users to choose the associated inclinometers.

As shown in figure 4.5, this component displays the available inclinometers within the selected structure and monitoring profile group, with checks in place to ensure only valid inclinometers are selected.

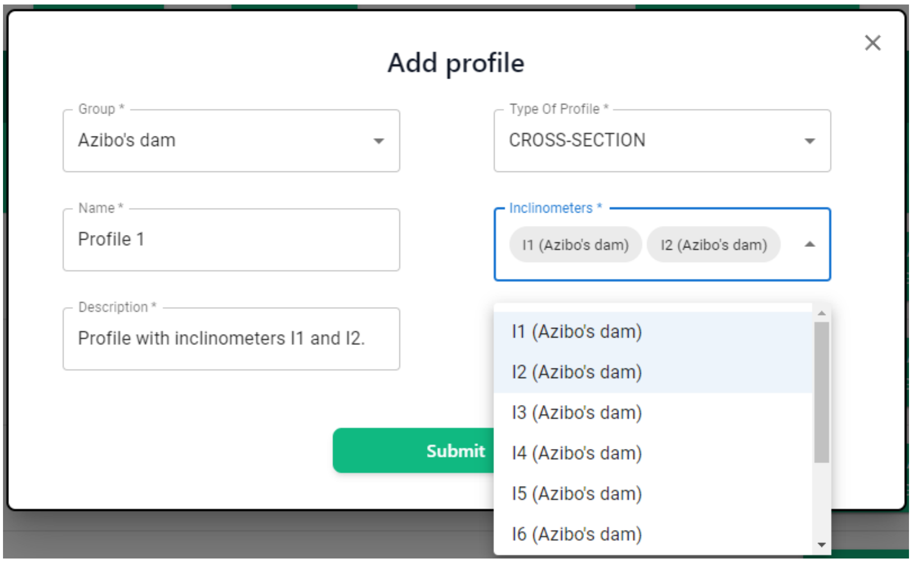


Figure 4.5: Creation of a new monitoring profile within a monitoring profile group on the web interface.

The entity "Monitoring Profile Adjustment" has an interesting set of relationships, because of the different applications that it entails. For each inclinometer, there are three distinct types of positional data. First, the geopositioning data, managed by the "Marker" entity, which stores the precise coordinates of the inclinometer's location. Second, the point positioning, defined by the "Point" entity, which records the inclinometer's relative position on a plan. Lastly, the line positioning, managed by the "Line" entity, captures the relative position of the inclinometer within a cross-section, including its depth. For a more detailed understanding of these different types of data, table 4.5 highlights the various data dictionary tables for each and the necessary data for their respective representations. This part of the diagram exhibit the functionality described in section 3.6.

Due to the fact that each monitoring group has a defined set of inclinometers and that can have shared inclinometers between more monitoring groups, the position adjustment is specific to a particular inclinometer that belongs to a particular monitoring profile. Adjusting the position of that particular inclinometer only affects the data related to that monitoring group and if the inclinometer is present on another monitoring group, it remains the same. However, regarding the possibility of having duplicate information, the peculiar use of the same inclinometer by several monitoring groups requires the existence of the aggregation between the two entities, in order to portray each specific case.

Point			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
PositionX	FLOAT		294.01108323444424
PositionY	FLOAT		139.10776712689537
MonitoringProfileId	INT	FK, NOT NULL	1

Marker			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Latitude	FLOAT		41.55680
Longitude	FLOAT		-6.89017
MonitoringProfileId	INT	FK, NOT NULL	1

Line			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
PositionX1	FLOAT		294.01108323444424
PositionY1	FLOAT		139.10776712689537
PositionX2	FLOAT		397.35154340739814
PositionY2	FLOAT		153.8640976749052
MonitoringProfileId	INT	FK, NOT NULL	1

Table 4.5: Point, marker and line data dictionary.

To illustrate this scenario, for example, a monitoring group, MG-A, is created and it has the inclinometers IX, IY and IZ associated. This monitoring group also has a monitoring profile group, MPG-1, which includes a profile, P-1, classified as a plan. This plan has an uploaded image of an aerial view of the whole site where the inclinometers from MG-A are located. Using the position adjustment tool, the position of inclinometer IX needed to be corrected, as it slightly deviates from the actual location. To change this kind of data, the specific profile and the joint between MG-A and the respective inclinometers data needs to be accessed and changed so it only affects that specific common data. If there was a monitoring group, MG-B with the inclinometer IX, at the same time, the data related to that inclinometer would not change when correcting the position of the same inclinometer, but in a different monitoring group.

4.3 Web Interface Design

The web interface was meticulously designed to ensure a seamless user experience while delivering the essential functionalities for structural analysis. This section outlines the base elements of the interface, including the color scheme, logo, structure, and navigation. By establishing a consistent and intuitive design, the interface aims to facilitate efficient data visualization and interaction, fulfilling the user's needs. The thoughtful integration of these design elements supports the usability and aesthetic appeal of the application, ensuring that it meets the standards required.

The initial design and prototypes of the web interface were developed with a user-centered approach, focusing on ease of use, clarity, and desired workflow. Early sketches were created to map out the layout and flow of the interface, ensuring that all essential features were accessible and intuitive. These prototypes underwent several iterations based on the different functionalities being implemented, refining the design to address any usability issues and enhance the overall experience. The goal was to create a visually appealing and user-friendly interface that allowed seamless interaction with the data analysis, enabling users to promptly navigate through different areas and perform actions that have the expected outcome for a swift analysis.

Color Scheme: The color scheme of the web interface plays a central role in enhancing the visual appeal of the application. The chosen palette, represented on figure 4.6, includes a range of greens and greys, carefully selected to ensure a balance between aesthetic appeal and functional clarity.

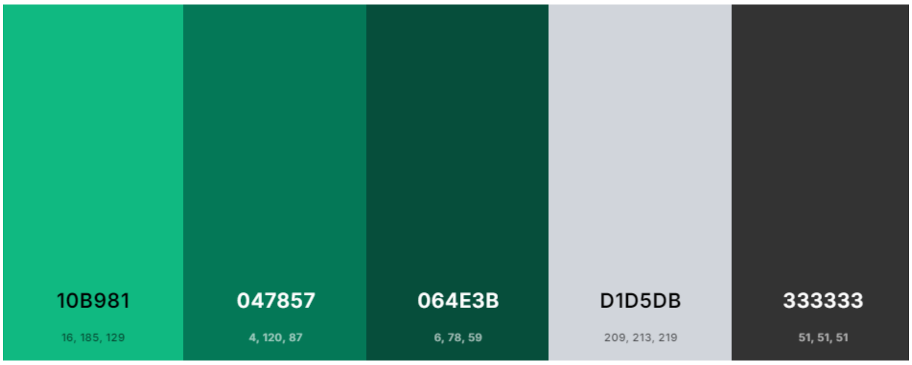


Figure 4.6: Web Interface Color Palette.

The three shades of green are used to highlight key elements and actions within the interface. The lighter green serves as the primary action color and it is used for buttons and interactive elements that require user engagement. This helps users recognize which elements can be interacted with. The medium green is used for highlighting the elements that have been selected and for and hover effects, creating a differentiation between elements by colors. The darkest green is applied to the header and to the borders of elements, providing some finishing touches to the web interface.

The two shades of grey are employed to contrast with the green colors, primarily used for some element borders, specific hover effects and the footer. The contrast ensures readability against opposite styled backgrounds. In addition to the main palette of colors, there are three situations that other color schemes are used: the notification system, the lines representing each date or depth selected on the charts, and the displacement arrows feature.

The notification system uses three colors to distinguish the level of each notification, so the user has the perception of the content of the notification by simply looking at the color. A green color (#81C784) is associated with a correct or successfully completed action, a yellow color (#FFB74D) with warning actions and a red color (#E57373) with wrong actions, missing values or denied access.

The effectiveness of a page design lies in ensuring that visual cues accurately depict the relationships between elements, making it easier to understand which items are related and how they are structured, ultimately creating a clear visual hierarchy [47].

Each chart on the interface has the possibility to have different lines represented at the same time. On some charts each lines represents a specific date when the measurement was made or in other cases, the lines serve as a depth line, indicating each depth present on the chart. When a large number of dates are selected, the representation of the lines creates visual clutter, which could interfere with the analysis. In order to solve this problem and easily create contrast between each line, fifty colors, ranging from lighter to darker, were selected to associate with each line, making them stand out from each other. It is not common to evaluate more than a reduced set of dates or depths at the same time, but the system allows the user to analyse as many readings as necessary. Therefore, if the readings surpass the fifty default colors, the system will start again from the beginning of the color set, ensuring all lines have a distinct color between the closest ones.

The displacement arrows feature allows the user to visualize a colored arrow on top of any inclinometer present on a plan that had the position adjusted. The arrows are pointed to each individual displacement direction and have some factors, such as the depth or the displacement taken into consideration. To produce a simple visual cue of the relative range of values for the displacements, a set of five colors was chosen: lighter green (#4ade80), darker green (#65a30d), yellow (#eab308), orange (#ea580c), red (#991b1b). This range allows for the classification of five different categories of displacements for all inclinometers by selecting the maximum displacement and dividing them based on that maximum value. The lighter green acts as the lowest displacement category, while the red servers as the maximum displacement category.

The graphical structure on a web page can effectively guide users by utilizing basic shape elements along with variations in density, size, and color to create a sense of space and movement, directing the user's focus and enhancing navigation [48].

Layout: Depicted in figure 4.7, the layout of the web interface is structured into several areas that guide the user through their interaction with the application:

- Header: The header is positioned at the top portion of the interface. It contains the logo of the application at the center and a navigation side bar icon on the left part. The presence of a header creates a visual consistent design that is easily recognizable and accessible, ensuring users know where to interact to navigate to other pages.

- Footer: The bottom part of the interface is occupied by the footer, which contains some brand information and contacts.

- Side Floating Scroll Buttons: The dimension of the pages can extend beyond a typical page size, requiring users to scroll up or down to access more important information not visible at first glance. Based on user survey feedback, this feature was added to enhance the workflow, appearing only when needed. The buttons adapt dynamically to the user's position on the page, guaranteeing that the desired options are always accessible.

- Content Area: The central piece of the web interface is the content area, where, depending on the page's content, users can visualize and interact with the elements being displayed, such as charts, images, buttons, and so on. It is designed to be adaptive and flexible to different types of functionalities and purposes.

Figure 4.7: Layout of the web interface.

Navigation: To facilitate smooth navigation across the application, the interface includes a comprehensive navigation sidebar, represented in figure 4.8. This sidebar, accessible via the icon on the header, holds the main path to every route available on the interface. It can be accessed through the icon on the header and allows to switch between the different pages. Each page was designed to be self-evident, allowing the average user to immediately understand its purpose and how to navigate it at a glance [47].

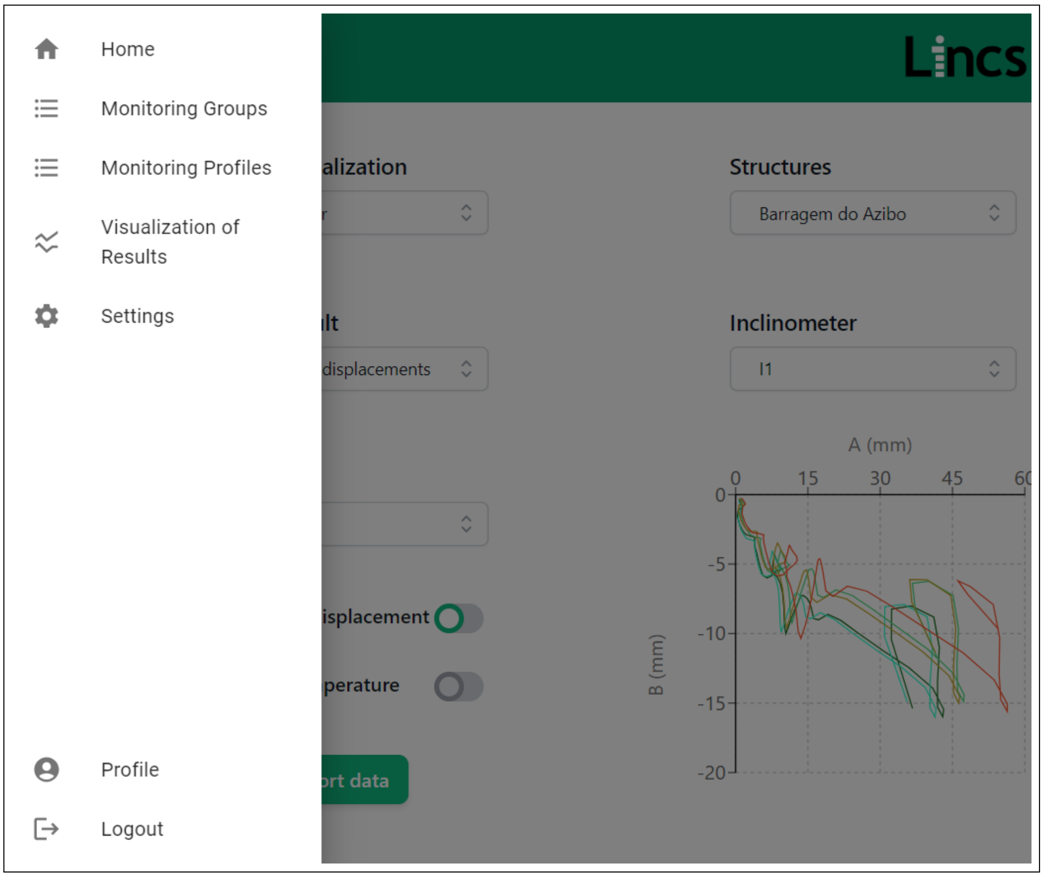


Figure 4.8: Navigation sidebar.

The pages layout is composed by:

- Home: The home page serves as a landing page, mainly used for displaying information about the project.
- Monitoring Groups: The monitoring groups page provides an easy and straightforward way to create and manage different groups based on the available structures. Each group contains a set of inclinometers organized according to the specific structure they monitor. Users can define the inclinometers to be analyzed within each group and manage various details related to the inclinometers. This includes updating information, such as the spacing between sensors, geographic coordinates, and the soil layers in which the inclinometer is placed.
- Monitoring Profiles: This page supports tools for creating and managing monitoring profiles, as well as associated plans. These profiles encompass the various inclinometers present within a structure and allow users to dynamically interact with images they have uploaded. These images, which may represent cross-sections or plans, can be linked to specific inclinometers for later viewing on the "Visualization of Results" page. This feature enhances the ability to correlate real-world structures with the data collected, providing a more comprehensive analysis environment.

- Visualization of Results: This section offers two interaction modes: one for viewing interactive graphs of individual inclinometers and another for analyzing profiles and plans, integrating graphical data with geographic and relative image positioning information, allowing users to examine data from multiple inclinometers simultaneously. An example of this particular page is illustrated in figure 4.9.

- Settings: Inside this page, users can manage connections to time-series databases associated with, with currently support provided for InfluxDB. The connection definitions can be added, and tests performed to ensure the system functions work correctly.

- User Profile: This page allows users to view information about their account, including personal details and their role within the company.

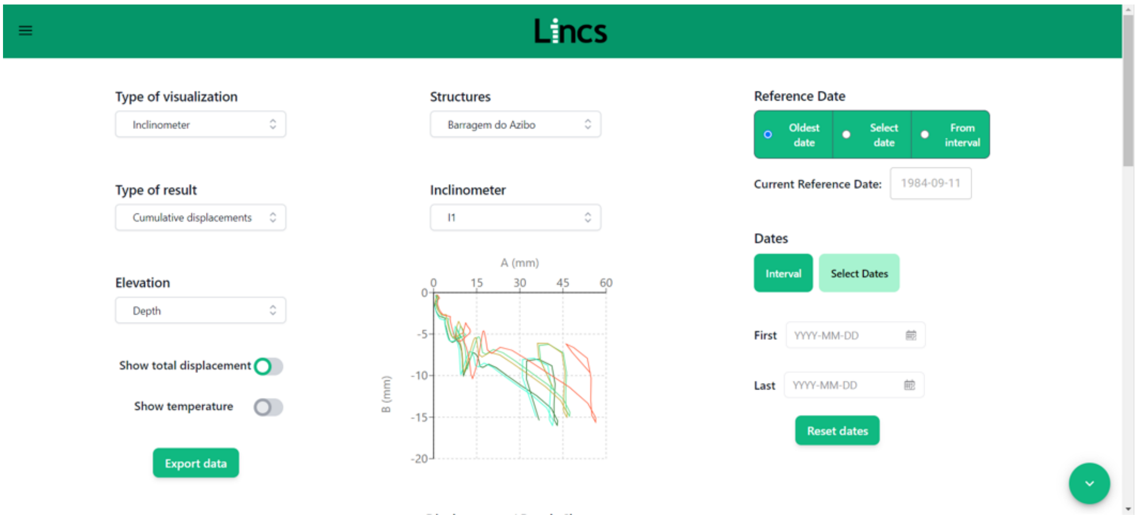


Figure 4.9: Visualization of Results page.

The web interface also includes a notifications system designed to provide users with feedback during various interactions. This feature enhances user experience by ensuring that relevant information is communicated effectively while performing specific tasks. Notifications are triggered for actions such as inserting and updating parameters for monitoring profile groups and monitoring profiles, and uploading photos to a profile, providing knowledge of successful operations.

Each notification is designed with color-coding for easy recognition and includes smooth entering and exiting transitions. The notification system categorizes feedback into three distinct types: success, warning and error and are displayed on the top right corner of the screen for five seconds, providing users with sufficient time to review the feedback before it disappears.

This implementation serves as a proof of concept for the notification system. It is designed to be scalable, with the potential to accommodate additional notifications for future enhancements and more complex interactions.

Soil Layers: The charts suitable to an inclinometer monitoring analysis display displacements over depth or elevation and provide additional information for understanding the behaviour of a site could enhance the overall assessment.

The "Soil Layers" entity defines the distinct geological formations that the inclinometer casing passes through at various depths. These layers help identify the types of soil or rock strata encountered, providing crucial information for understanding subsurface conditions and how they may affect ground stability and inclinometer readings. The soil layers are visualized in a bar chart composition adjacent to the displacement on orthogonal direction over depth charts, adapting dynamically to the specific layers present in each inclinometer, as represented in figure 4.10.

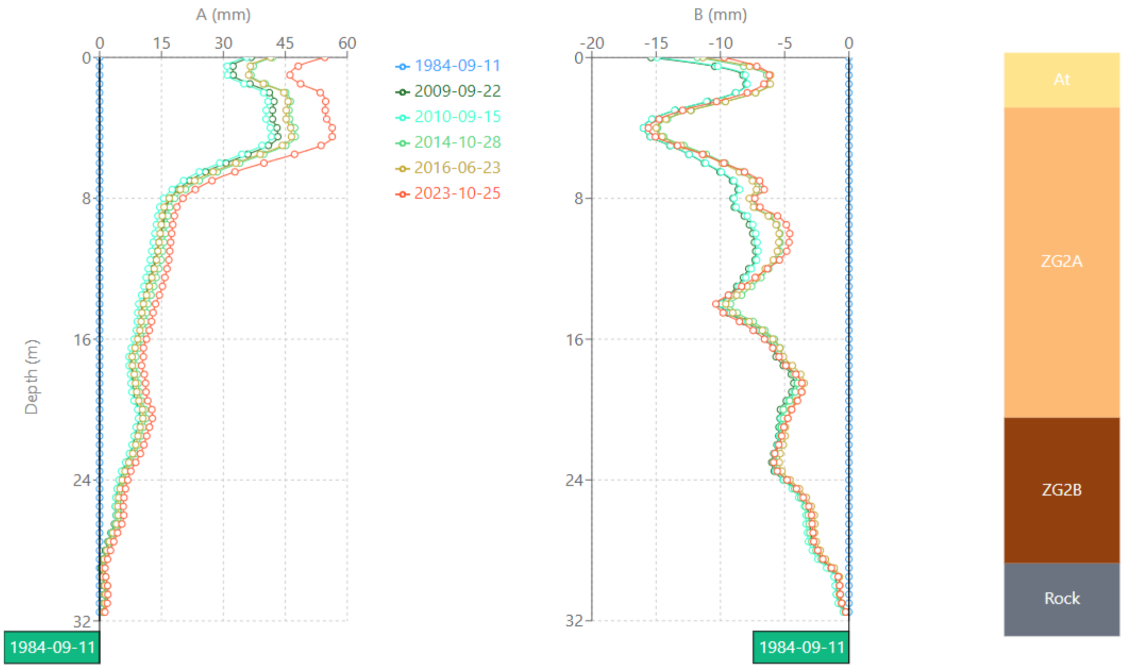


Figure 4.10: Soil layers over depth bar chart alongside the orthogonal directions displacement over depth charts.

To facilitate the creation and management of these layers, a user-friendly interface, as depicted in figure 4.11, was developed. Each soil layer can be defined by several parameters, including a symbol, description, thickness, top level, as well as a color that can be selected using a color picking tool. After defining each layer, users can easily arrange them by dragging the elements to their desired positions or removing them entirely if needed. This intuitive interface ensures that the soil layers are accurately represented, providing valuable context for interpreting inclinometer data.

This feature was designed to be interactive, enabling users to easily customize and adjust the soil layers to reflect the actual conditions of a structure. By providing this additional detailed and easy to interpret representation, it ensures that the analysis is both comprehensive and accurate, ultimately helping to achieve a better decision-making process.

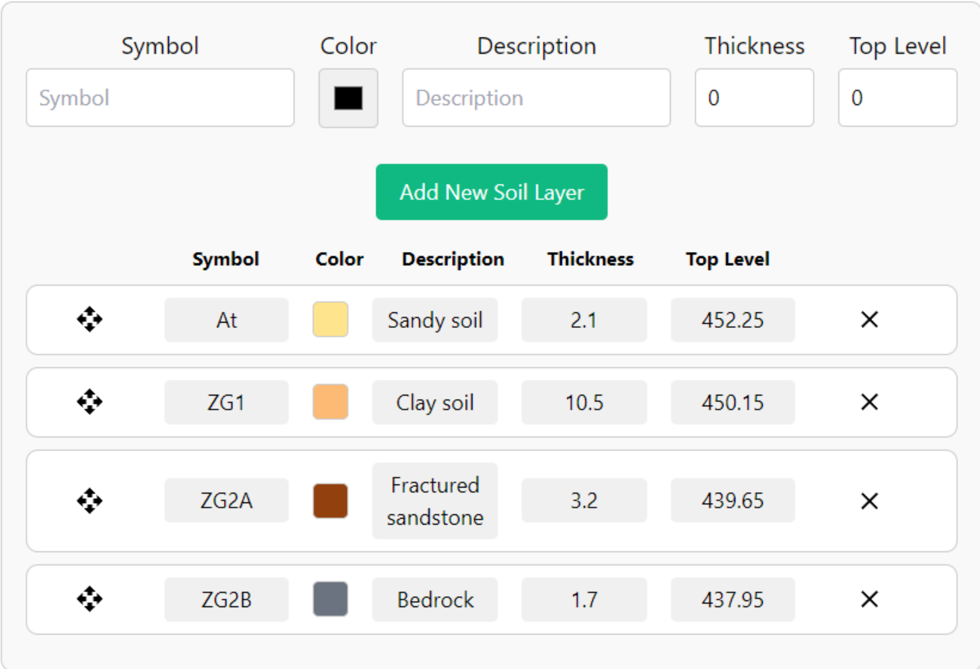


Figure 4.11: Soil layers management UI element.

4.4 Other components

4.4.1 Authentication

During the development of the backend, several security techniques were implemented in order to secure user sensitive data and communication between the frontend and backend. Authentication processes fundamentally involves safeguarding systems that depend on electronic systems, addressing not only direct threats but also broader concerns related to the reliance on digital technologies [49]. A request authentication mechanism was implemented with the use of JSON Web Tokens (JWT) to verify the legitimacy of requests and ensure that only authorized users can access system resources.

JWT is a token used to securely transmit information between two endpoints as a JSON object. Commonly used in authentication methods where a request needs to be authorized in order to access the requested resource. This token, represented on the schema in figure 4.12, can be divided into three parts: a header, a payload, and a signature.

The first one, the header has two subdivisions: the type of token, which is JWT, and the signing algorithm being used, HS512 (HMAC with SHA-512). The payload contains the claims, which are statements about an entity being authenticated. The claims used include the user email to which the token belongs, the date of creation, and the expiration date, both represented as Unix timestamps, providing a numerical representation of each date. The signature validates the integrity of the token by combining and signing the encoded header, the encoded payload, a secret key (established by the system), and the HS512 algorithm, ensuring that the token has not been altered. Signatures are a key advantage of JWT, providing a secure and efficient way to share data between clients and intermediaries through a straightforward data format and established signature algorithms [50].

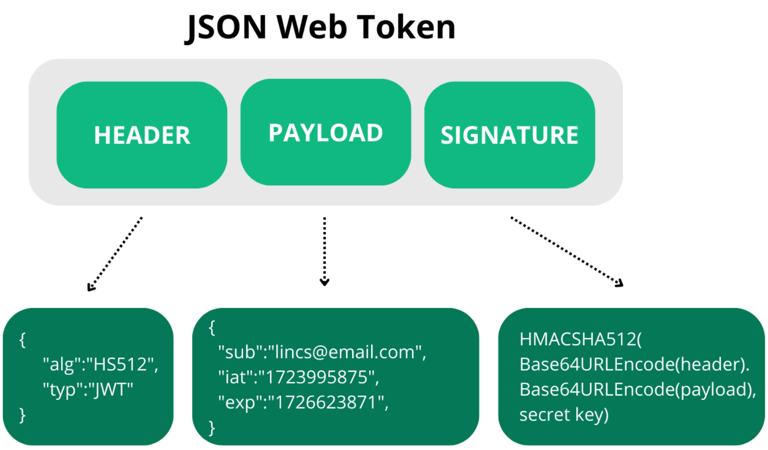


Figure 4.12: JSON Web Token structure.

After a user is authenticated by the system during login, a JWT access token is generated, alongside a JWT refresh token. When the access token expires, the user must obtain a new one to continue interacting with the system. To facilitate seamless user experience, a method to refresh tokens was implemented, allowing the token to be renewed easily.

Every request sent to the backend or relational database must include the JWT token. The system checks this token to validate the request and ensures that only authenticated requests are processed. If the token is invalid or expired, the request is denied.

Another security measure implemented in the system is the use of Spring Security, which was studied before development began. With Spring Security, some security policies are enforced to prevent unwanted requests from non-authorized endpoints. The system only allows requests from a predefined list of origins, headers, and methods. This means that only trusted sources can communicate with the backend, preventing unauthorized access or potential security breaches.

In addition to request validation, the system also ensures that sensitive data, such as user passwords, is securely stored. As discussed in section 4.2, all passwords are encoded before being stored in the relational database. This is done using Spring Security password encoder, a hashing algorithm designed for password hashing, adding an extra layer of security.

By combining JWT authentication, rigorous request validation, and a secure password management, the system ensures an essential security layer that aligns with modern practices.

4.4.2 Settings and Connections

This aspect of the system is designed to support the integration with various time series databases, enabling users to connect to and manage data sources for different structures. It is particularly helpful for configuring and testing connections to ensure that the system can retrieve and process data accurately. With the ability to manage multiple connections, the system offers a scalable solution that can be adapted to the unique monitoring needs of each structure. Users can easily establish these connections by filling out a simple form that includes the necessary details for InfluxDB, such as the URL, port, token, and organization.

Once the connection details are entered, the system grant users the ability to perform a connection test to verify that the database is accessible and that the measurements can be retrieved. This testing feature ensures that any potential issues with data accessibility are identified and resolved early in the setup process.

While the system currently supports the specific needs of InfluxDB, future development plans could include expanding compatibility to other time series databases. This expansion would further increase the system's scalability, serving as a hub for managing these connections.

Throughout this chapter, the structural foundation, key components, and design processes of the overall system were outlined, emphasizing the integration with the existing system, the development of the web interface, and database management. The architectural and design choices served as the starting point to create a system that allowed for efficient data collection, storage, and retrieval, ensuring that the system operates reliably and meets the demands of real-time inclinometer monitoring. The next chapter will focus on the data collected by the sensors, detailing the different datasets utilized during the testing and development phases, methodologies, and processes employed to transform the collected raw data into meaningful insights.

5 Inclinometer Data Processing

Before starting the implementation process, it was necessary to study the specific needs and characteristics of inclinometer data. Understanding the structure of this data sets up a path to ensure that the implementation of the system is organized and efficiently structured. This chapter addresses the data processing methods and techniques used in the developed inclinometer monitoring system. It describes how data is collected, processed, and visualized to support effective decision-making.

The first step of this process is to analyze how the data is gathered and stored in the time-series database. Section 5.1 exhibits the study of the different types of data and the specific aspects of the datasets used during the development and evaluation stages, highlighting the distinctive approaches that each dataset needed.

With the gathered information, identifying the particular needs of each filter and the techniques used to achieve the appropriate interactions with the application proved to be essential during the development process and facilitated a continuous improvement perspective. The main filters used in the chart visualization and within the profile visualization are described in section 5.2, outlining the purpose of each and the features they enable.

The subsequent section 5.3 explores data processing, discussing the raw data captured from sensors and the transformations applied to create meaningful visualizations.

Section 5.4 covers the visualization of historical data and the methods to identify patterns over time.

On chapter 6, a more detailed view of the implementation process is provided, discussing both the technical challenges and the solutions applied to ensure a smooth integration with the web interface.

5.1 Datasets Overview

The datasets used during both the development and validation stages offered diverse perspectives on typical inclinometer monitoring data. By working with two distinct datasets, it was possible to test the system under different scenarios, which varied in terms of data frequency and volume.

The first dataset, Azibo's Dam, represents a real-world earth-fill dam. This dataset contains inclinometer data collected quarterly over several years, resulting in a total of 44920 entries. The second dataset, Scale Model, was created during a laboratory experiment designed to simulate deformations in a controlled environment. The data was collected at much shorter intervals of ten seconds, leading to a total of 4947 entries. The primary objective of the higher frequency of readings in the scale model experiment was to provide a valuable testing dataset for assessing the system's ability to handle volumes of data that require second-level accuracy in data processing and analysis.

The chart depicted in figure 5.1, shows the difference in the volume of data between the two datasets. Despite the significantly larger volume of entries, the Azibo's Dam dataset represents a longer period but with fewer frequent readings. On the other hand, the Scale Model's smaller dataset captures a shorter time period, giving insights into rapid deformations in controlled settings.

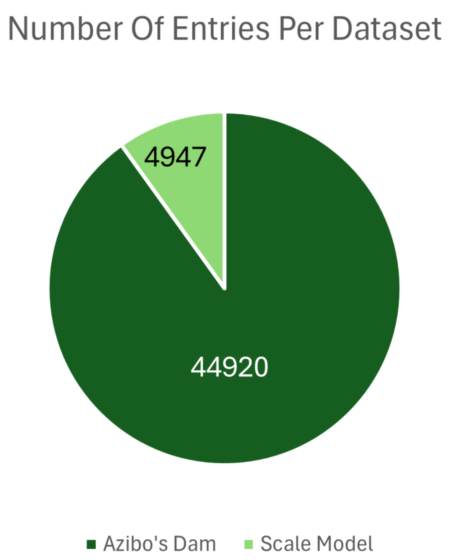


Figure 5.1: Number of entries per dataset.

Figure 5.2 illustrates the number of individual dates available on which a reading was recorded. Azibo's Dam data spans across 22 dates, while the Scale Model has data from 51 dates due to its higher frequency of readings. This chart highlights the difference in time intervals used between the two datasets and the system's flexibility in handling datasets with different recording frequencies.

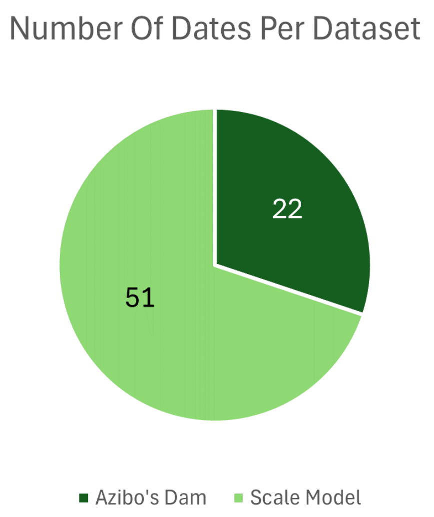


Figure 5.2: Number of dates per dataset.

The datasets also differ in the number of inclinometers and their respective depths, as detailed in Figure 5.3. Azibo's Dam data employs nine inclinometers, with depths ranging from 14.5 meters to 51 meters, providing a detailed view of the dam's structural behaviour over time across different locations. The depth and the number of sensors in Azibo's Dam dataset naturally result in longer processing times, especially when working with cumulative results. On the other hand, the Scale Model dataset contains only one inclinometer with a depth of 2 meters, and four sensors spaced 0.5 meters apart. This simplified setup, less comprehensive in terms of depth, was crucial for testing the system's ability to process data in a high frequency environment.

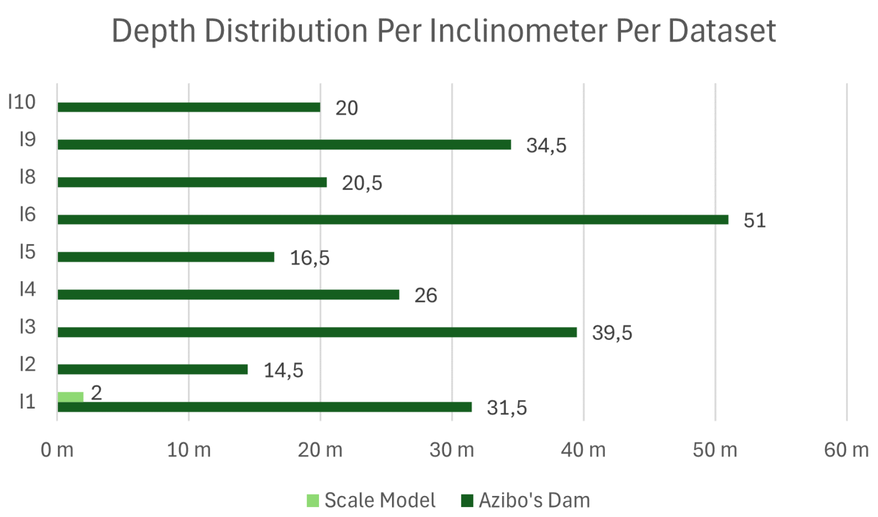


Figure 5.3: Depth distribution per inclinometer per dataset.

The datasets from Azibo's Dam and the Scale Model provide different perspectives: one offering insights into long-term structural behaviour with real-world data, and the other providing high-frequency laboratory data for testing the system's capacity to handle shorter periods of time.

5.2 Data Filtering

The data used in the filters is carefully managed to ensure efficient and relevant visualizations. The web interface displays multiple visualizations simultaneously, meaning that the data needs to be adjusted to affect all displayed charts.

To optimize performance, the system only uses the data relevant to the selected filter for calculating displacement values. This means that any unnecessary data is excluded from the dataset during analysis. For instance, temperature values are only needed when the temperature view filter is active, so they do not need to be filtered at all times. Similarly, angle values that correspond to non-useful orthogonal directions, such as angles parallel to the inclinometer casing, are discarded since they do not contribute to the displacement analysis.

All filters can affect the filtered dataset to reduce duplicate information compared to a multiple filtered dataset approach, while retaining an original dataset to restore data as needed without requiring additional requests to the database. This improves the web interface responsiveness from the user's perspective.

This selective approach allows the system to process and display data more efficiently, reducing the data processing load while ensuring that the visualizations present accurate information for the analysis process.

Before starting an in-depth analysis, an initial selection must be made to define which filters and specific data should be illustrated. For that purpose, a filter called "Type of Visualization" was created to let users choose between an individual inclinometer analysis or a monitoring profile analysis. By selecting one of the options, the interface adapts to the needs of the analysis in terms of filters, presenting the appropriate selection of parameters for a more effective assessment.

Individual Inclinometer Visualization In the individual inclinometer visualization, users have several filters at their disposal to guide the assessment process and refine the data presented in the charts to suit their needs. The available filters are:

- Structure selection: Allows users to choose between different available structures within the monitoring group, enabling the analysis of inclinometers from different locations.

- Inclinometer selection: This filter grants users the possibility to select a specific inclinometer for a detailed analysis, focusing on the individual aspects provided for more targeted insights.

- Type of result: Determines how the data is calculated and displayed based on the type of analysis being performed. With this filter the results are adjusted according to the selected method, providing different alternatives for a more comprehensive evaluation.

- Elevation reference: Enables users to select the elevation reference displayed on the charts, either depth or elevation. It ensures that the displayed results are consistent with the elevation perspective chosen for analysis.

- Reference date: The reference date filter is used for calculating displacement values by setting the reference date for an analysis over time. This filter allows users to choose between the oldest available date, a specific date, or the first date in a selected interval.

- Dates Filtering: This feature enables the readings displayed on the charts to be selected by dates. Users can either select a range of dates using a calendar tool or choose from a list of available dates.

- Total displacement view: This filter allows to change the chart viewing area to display the total displacement instead of the orthogonal directions. This change affects both the over depth charts and the over dates charts.

- Temperature view: If the total displacement view filter is active, users can add to the chart viewing area an additional chart that displays the temperature over depth.

- Depth range selection: With this filter selection, users can adjust the depth range of the data to be displayed on the displacement over dates charts. The range can be defined using an interactive slider or input specific depth values. This filter helps focus on certain depth, especially when dealing with large datasets.

When selection an individual inclinometer visualization, a typical interaction with the interface begins with the selection of the structure being monitored, allowing users to focus on a specific structure within the monitoring system. After selecting the structure, the next step is to choose a particular inclinometer, which narrows down the data to that specific sensor's readings. Once the inclinometer is chosen, users then select the type of result they wish to analyze, adjusting the calculations and values displayed. The remaining filters complement the usual workflow, providing additional control over the data displayed in the charts and allowing users to refine the visualizations to suit their analytical needs.

Monitoring Profile Visualization The individual inclinometer visualization and the monitoring profile visualization share a set of common filters that streamline the data analysis process. These filters include the type of result, the elevation reference, the reference date and the dates filtering.

These shared filters provide flexibility and adaptability across both visualization types, ensuring that users can adapt the displayed data to their specific requirements.

In the monitoring profile visualization, the focus shifts towards analyzing a broader data set across multiple inclinometers within a structure, gathered on a profile. Users can apply filters to narrow down the analysis and concentrate on particular points of interest. The following specific filters are available:

- Profile selection: By using this filter, users can select a specific profile for detailed analysis, retrieving all related information of each individual profile.

- Orthogonal direction selection: If the selected profile is a cross-section, an additional filter will become available, allowing users to adjust the data displayed in both the charts and the table to focus on one of the available orthogonal directions.

- Displacement arrows view: This filter becomes available when a user-uploaded image is selected for a profile. It overlays arrows on the locations of each inclinometer, showing the a scaled representation of the displacement for each, which facilitates an easier interpretation of the data.

- Location reference: Enables users to choose the targeted location reference for both the table data and displacement arrows, either to the surface or to the sensor where the displacement is at its maximum. This ensures that the displayed information is consistent with the selected reference point for analysis.

A usual interaction with the web interface starts with the selection of the profile to be analyzed. If necessary, users can also choose the appropriate orthogonal direction to refine the analysis further. When available, images attached to the profile can be displayed, providing additional context and offering a more comprehensive understanding of the area's structure or even the plan. The complementary filters add to the workflow by changing the data displayed to better suit the users needs or to give additional features that help gather relevant information to support their analysis.

5.3 Data Processing

The ability to generate accurate and meaningful visualizations is crucial for understanding and interpreting the data collected from sensors.

The preprocessing of data allows for the identification of patterns and the creation of desired visual representations. The developed system is designed to handle a variety of data types and results. Each of these requires specific preprocessing steps and calculations to ensure accurate and insightful visualizations.

Inclinometer Data: The raw data supported by the time series database is structured in an optimal format, providing all the necessary information to analyze inclinometer displacements over time. Table 5.1 displays the important fields of a query response from the time series database using InfluxDB. Each field has an associated example of what a typical value might look like. Some specific parameters, such as the one called "Field", determine how other fields are presented. The "Field" value defines the property being analyzed, such as angle ("aX", "aY" or "aZ") or temperature ("temp"), with each value being associated with a particular "Value" property.

"Host" and "Measurements" fields are used to identify the structure from which the data is collected, while the remaining fields categorize each sensor value of an inclinometer at a specific point in time.

The response also includes parameters related to the request configuration and the database data location, which are discarded as they do not provide relevant information for the analysis.

Name	Value Data Type	Value Example
Host	string	de41c92c9186
Inclinometer	string	I1
Sensor ID	string	11
Field	string	aY
Measurement	string	Barragem do Azibo
Time	string	1988-03-14T00:00:00Z
Value	number	-1.599906071

Table 5.1: Key fields in time series database query responses

In order to send a query to InfluxDB, an API must be configured, using the URL for the database, a token generated to grant user access to that database, and an organization token. This API configuration, along with an example of a Flux query, is illustrated in figure 5.4. As mentioned in section 3.7.3, the Flux query provides a different approach to querying data from the database compared to traditional SQL queries. The example in the figure returns data associated with a bucket containing all the data for a set of structures, filtered by a measurement (representing the structure being analyzed) and by a timestamp range (representing the initial and final timestamps being analyzed).

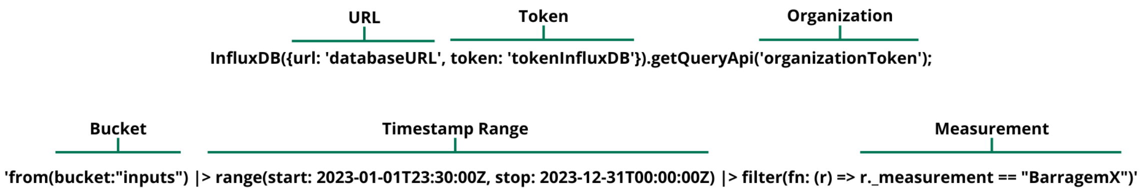


Figure 5.4: InfluxDB API configuration and an example of a Flux query using a timestamp range and measurement selection.

Data Organization and Categorization: The preprocessing of sensor data begins with the organization and categorization of raw data according to various factors, including the specific inclinometer under observation, the date of each reading, individual sensor identifiers, reading types, and corresponding values. This categorization enables the identification of specific patterns within the data and facilitates grouping to create desired visual representations. The data is initially arranged by date, inclinometer, and sensor, which facilitates the calculation of the displacements and the respective chart visualization.

Depending on the type of result being analyzed, the graphs may require cumulative, relative, or both types of values. This influences the calculations for displaying information in each graph, with minimal latency observed when switching between result types.

The system supports several types of results, each requiring specific preprocessing and calculation methods:

- Cumulative Displacements: This type involves calculating the displacement for each sensor based on the cumulative value up to that point in time, which is determined by the angle registered during each reading. The formula used for this calculation is as follows:

$$\text{Displacement (mm)} = \sin\left(\frac{\text{Angle} \times \pi}{180}\right) \times \text{Sensor Spacing}$$

- Relative Cumulative Displacements: Similar to cumulative displacements, this type focuses on the cumulative values but without calculating the differences between consecutive readings.

- Relative Displacements: Using this type, the displacement is calculated for each point individually, independent of other sensor readings. This method is useful for analyzing the incremental changes between readings.

- Sensor Angles: This type of result provides a straightforward visualization of the angles recorded by each sensor, allowing for an easy assessment of the different readings at various points within the inclinometer.

- Casing Distortions: The calculation for casing distortions is based on the angle acquired by the sensor, with the values being converted into a percentage using the formula:

$$\text{Casing Distortion (\%)} = \sin\left(\frac{\text{Angle} \times \pi}{180}\right) \times 100$$

Each of these result types can be visualized for two orthogonal directions, A and B. Additionally, the total displacement can be calculated using the following formula:

$$\text{Total Displacement (mm)} = \sqrt{A^2 + B^2}$$

This calculation provides a comprehensive view of the overall displacement by combining the contributions from both directions.

Additional Visualizations Beyond the previously described charts (Displacements in orthogonal directions over depth charts), the system also supports additional visualizations, such as a temperature over depth chart, a displacement chart of the orthogonal directions over dates (represented in figure 5.5, which allows for a more detailed view of each displacement at all available depths) and an orthogonal direction A over the orthogonal direction B chart, that mainly shows the direction of the movement of the inclinometer on the ground. The temperature over depth chart only requires the data to be arranged by date, inclinometer, and sensor, while the other displacement chart necessitates filtering the data to display readings by date rather than depth. The visualization of the chart A over B merges the data from individual displacements calculated for both directions. Alongside these line charts, a bar chart displaying the composition of different soil layers by depth is included to provide insights into specific patterns related to the areas where the casing is placed.

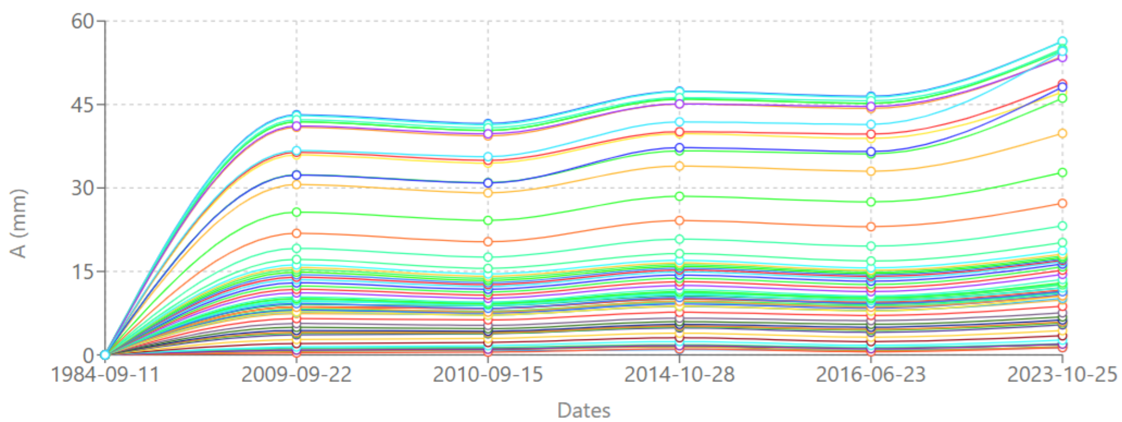


Figure 5.5: Example of a displacements in orthogonal direction A over dates chart produced by the web application.

In addition to graphical visualizations, the system provides a table representation of displacements for orthogonal directions A, B, and the total displacement. This is particularly useful on the profiles tab, where it displays detailed information about the inclinometers present in the profiles for selected dates. The table consolidates many of the calculations used for chart visualizations, but presents them in a format that is easier to analyze, only showing one reading per date selected for each inclinometer.

The default sensor shown in the table is the one at the surface, but users can choose to display the maximum displacement sensor instead. The system automatically identifies the maximum displacement for each date and displays the corresponding data. When the orthogonal direction is set to A or B, the system focuses on the selected directions values. However, when the total displacement is selected, particularly in the context of plans, the system searches for the maximum displacement across all directions and compares them to determine the absolute maximum.

Following testing, it was decided that the web interface would default to displaying a predefined number of readings, including the reference reading and the five most recent readings, to maintain visual clarity and prevent clutter. Direct interaction with the charts enables a brief and more dynamic analysis of specific points, offering an innovative perspective and facilitating result interpretation. To minimize latency and ensure a smooth user experience, calculations for the various data points of each inclinometer on each available date for the desired type of result are performed in the background. This approach guarantees that even if the data are not currently displayed in the interface, the preprocessing allows for responsive and easy transitions between different filters.

Preprocessing sensor data is an essential step in generating accurate representations for the desired purposes. By organizing and categorizing raw data, and applying specific calculations adjusted to different types of results, the system ensures that users can easily interpret the data and make informed decisions about the stability and safety of structures being studied.

5.4 Visualization of Historical Data

The sensors within each inclinometer transmit data periodically, based on the definition a reading frequency that suits the needs of result analysis. These datasets include timestamps, which are crucial for cataloging the exact moment at which each reading was recorded. This temporal information is essential for facilitating comparative analysis of the results over time, allowing for a comprehensive understanding of the displacement trends.

Analyzing displacements over multiple readings during a certain period enables the identification of potential risks associated with the location where the inclinometer is installed. By examining these patterns, engineers and technicians can assess whether the current reading frequency is sufficient or if it needs adjustment to gather data more frequently. This ensures that potential issues are detected early, allowing for timely interventions at the site if necessary.

This analysis should be performed concerning a reference point, usually the initial reading taken after the inclinometer's casing installation, serving as a control for the original position. The reference point can also be changed for a detailed view for another specific date, requiring a new reprocessing of the dataset to accommodate such changes.

To achieve a visualization that accurately reflects reality, a composition can be created combining an image of the profile being studied with its scaled displacements, as shown in figure 5.6. In this figure, the initial position of the inclinometers in the profile is marked in red, and the cumulative displacement lines at depth for the specified date in the image legend are shown in blue. This compositing technique allows for a realistic view of the displacement, enabling users to compare the effects of different soil layers on the inclinometer's casing position. It also allows for a realistic view of the displacement, enabling the comparison of the effects of different soil layers on the inclinometer's casing position and the changes undergone by inclinometers in the same profile, making it a highly valuable and effective visualization.

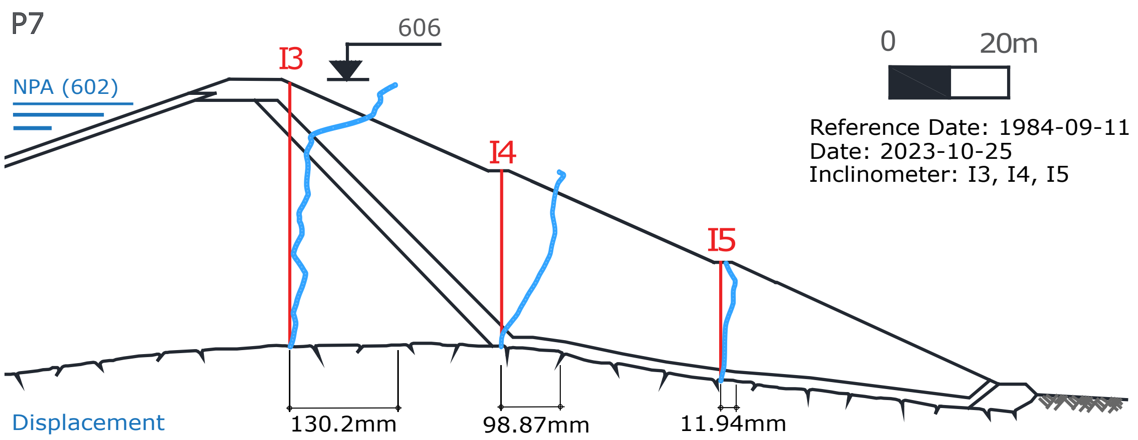


Figure 5.6: Compositing of displacement measurements taken on 2023-10-25 of inclinometers I3, I4 and I5 on top of a profile on an earthfill dam (Azibo dam).

In the proposed system the human decision-maker needs to be able to easily compare the behaviour of the system in related places and dates. Effective decision-making relies on thorough data analysis, encompassing analyzing profiles of the surrounding terrain affected by diverse factors, such as soil composition in which the inclinometer casing is inserted, water level (pertinent, for example, for inclinometers in earthfill dams), and sometimes unpredictable factors such as weather phenomena.

The system is designed to offer a set of tools for historical data visualization, which enhances the decision-making process. Users can select specific dates to analyze, enabling them to trace the evolution of displacements over time. For instance, by comparing displacement patterns over several months or years, gradual shifts that may indicate emerging risks can be identified.

Additionally, the system offers a view of multiple datasets within the same profile, enabling a comparative analysis of different time periods and inclinometer locations within the same structure.

The present chapter highlights the methods and processes that transform raw sensor readings into meaningful insights. The effective processing and representation of data not only facilitates displacement pattern analysis and anomaly detection but also provides engineers and technicians with a deeper understanding of structural behavior over time.

With this basis established, the next chapter delves into the practical realization of these concepts. It explores the architectural views through various diagrams representing different aspects of the system, alongside a detailed exploration of the filters and visualizations available on the web interface. Additionally, the chapter outlines the web interface functionality for correcting inclinometer positions in monitoring profiles and presents the specification of application APIs is presented, detailing the structures and endpoints designed to streamline the flow of data.

6 Implementation

The Implementation chapter details the practical aspects of developing the system. It outlines the process of translating some design aspects into a functionality, focusing on various key components and their integration.

The initial section provides an extensive look at the system's structure and design. Diagrams included in this section illustrate the overall architecture, highlighting the relationships between different components and how they work together to achieve the system's objectives.

Following this, section 6.2 details the methodologies employed on different filters to the displayed visualizations.

The next section discusses the methods implemented to ensure the relative positioning of data within monitoring profiles.

Section 6.4 specifies the APIs developed for the application, detailing their endpoints and describing the use for each part of the system.

6.1 Architecture Views

After exploring initial concepts and sketches of the different system components and optimal interactions between them for the purposed system, the overall structure was established. The architecture of the system can be depicted through a series of diagrams that illustrate the design, interactions and features at different levels of abstraction.

The selected diagrams serve as essential tools for understanding the development process, the flow of interactions between various components, and an implementation guide of the thought process behind the optimization of each presented feature.

The feature diagram, represented in figure 6.1, depicts the available features and functionalities in the individual inclinometer analysis. This type of diagram has a ramification layout, where each branch is a part of the higher block.

To better understand the figure, there are some concepts to consider[1].

[1]The full guidelines for the notation used can be found in the *Common Metamodel of Component Diagram and Feature Diagram in Generative Programming*, 2016 [51]

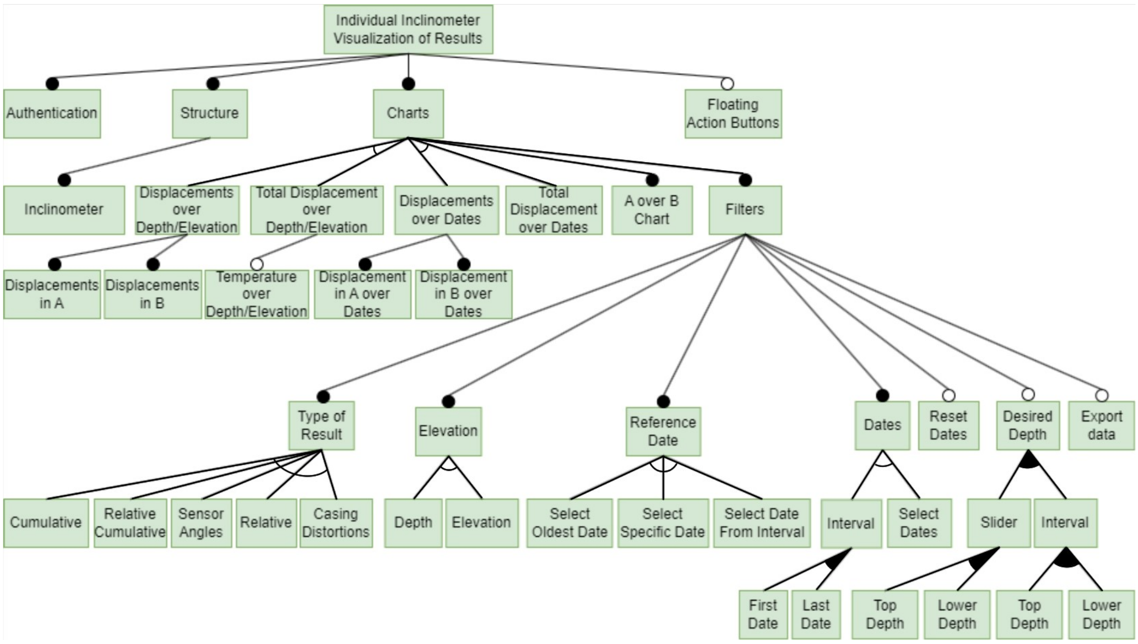


Figure 6.1: Feature diagram of the individual inclinometer visualization of results.

The “mandatory features”, represented by a fully colored circle on one of the edges, indicates that these features are present in all interactions with the system. For example, the selection of the "structure" field is a mandatory feature, because it is necessary for visualizing the associated data.

Optional features, depicted by a circle with a colored border, show features non-essential to the core functionalities of the system. An example of this is the “floating action buttons”, which, although available in the system, are not essential to the main goals of the interface, only enhancing the workflow.

The "or" distribution is represented by an arch with a clear interior between al least two connections and is used when one or more of the connected sub-features must be selected. For instance, the selection of the “desired depth”, users can choose between a slider or an interval feature, or use both simultaneously.

The “alternative” distribution, illustrated with an arch that has a fully colored interior between al least two connections, indicates that only one of the connected sub-features can be chosen at a time. For example, the “type of result” displays only one selected type at the same time.

These elements of the feature diagram are designed to provide a clear understanding of the features and their connections, describing how each individual feature has different levels of abstraction.

The feature diagram provides a view of a set of functionalities and relationships within the system. However, it does not offer a detailed sequence or flow of actions performed for common scenarios.

In order to fill that gap, three Business Process Model and Notation (BPMN) diagrams were created to describe a typical flow of action of some particular interactions with some components. A BPMN diagram illustrates a specific workflow with step-by-step action detailing, allowing to perceive how a system should behave during the execution of a task.

The notation[2] used in these types of diagrams can be more complex compared to the previously analyzed diagram. Beginning with the simpler elements: actions, represented by blue blocks, indicate various tasks carried out by an entity, whether it be a user or the system itself.

The process starts with the green circle, known as the "start event," and concludes with the red circle, referred to as the "end event." There are situations where the task could be ended earlier than expected due to another type of event, an "intermediate event". This can also represent a particular event or process ending and the subsequent continue of the flow of actions.

Gateways, depicted as yellow diamonds, introduce flexibility in the sequence of activities, allowing the process to branch into different directions. Although there are more than the represented ones, the gateways utilized in the BPMN include: exclusive gateway, which indicates that only one action can be chosen from the available paths; the inclusive gateway, which allows to take either path individually or both at the same time; and the parallel gateway, which requires that both paths must be chosen.

The first BPMN, portrayed in figure 6.2, illustrates the filtering by dates feature available for chart visualization and was selected for it being one of the main filters that impact the displayed readings across all charts. For clarity, some actions and verifications were simplified in this representation, such as, the data processing steps, describing the most important processes when performing this set of actions.

The sequence relies on the access to the time series database in order to get the proper data to display and the combination of different kinds of gateways to work simultaneously ensuring that the results are shown with the lowest latency possible.

[2]The full guidelines for the notation used can be found in the book *Business Process Model and Notation: Third International Workshop, BPMN* 2011 [52]

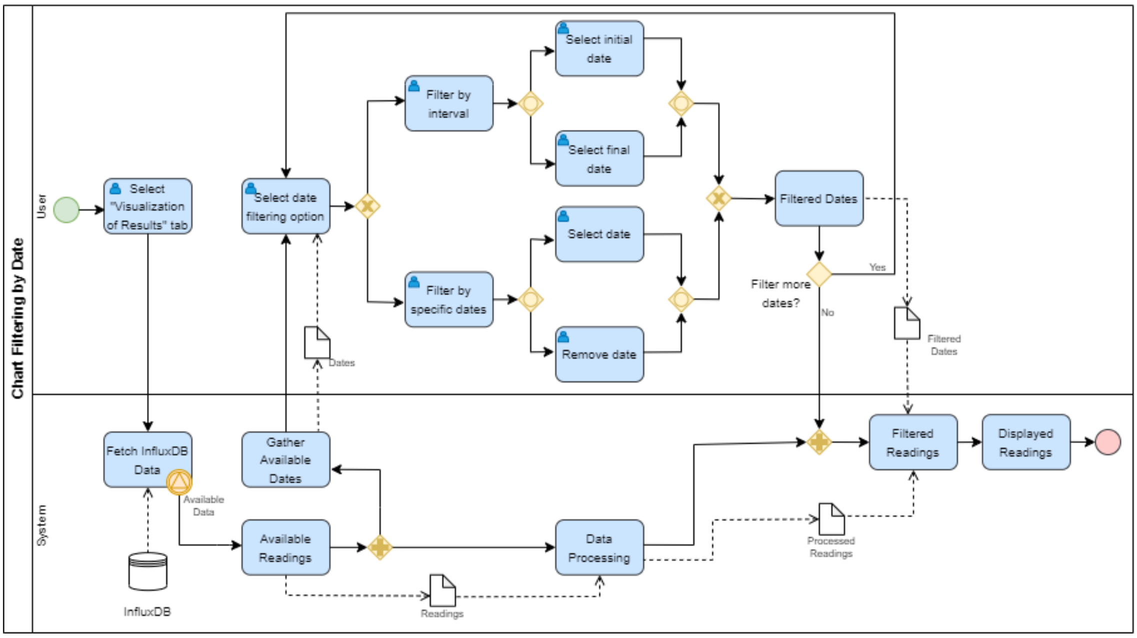


Figure 6.2: BPMN diagram of the chart filtering by date.

Moreover, the BPMN featured in figure 6.3, exhibits the correction of positions in a cross-section profile. This diagram displays the interaction of a user placing an inclinometer across their length on top of an uploaded image, which is represented by a line. This particular sequence has a cyclic pattern that allows the user to adjust the line after being drawn, guaranteeing that the final look will have the desired outcome. As the previous BPMN diagram, some steps and action options were hidden for their irrelevance to this specific use case or for clarity reasons.

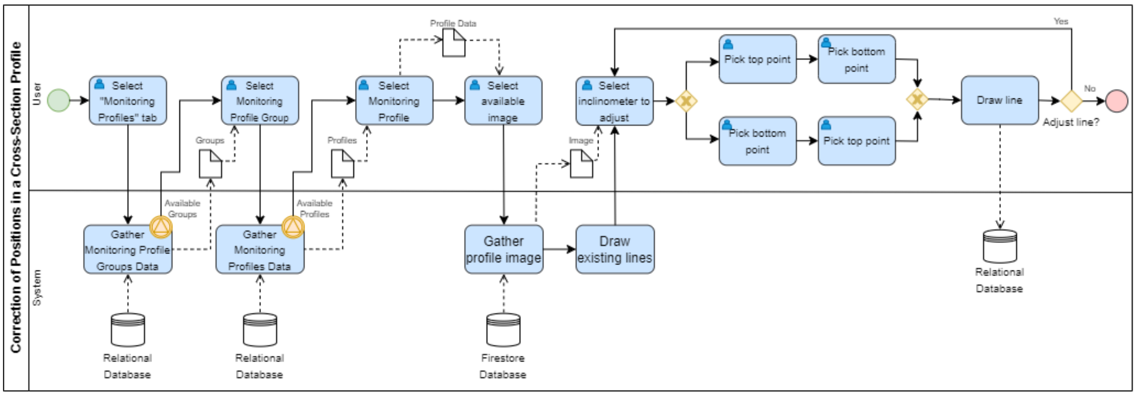


Figure 6.3: BPMN diagram of the correction of positions in a cross-section profile.

In figure 6.4, a BPMN diagram of the time series connection testing is depicted. This diagram shows the process of defining a connection to a time series database, testing the connection itself and storing the parameters to later access the structures available. This sequence, different from the other two, has the notification system, referenced in section

4.3, integrated with the workflow, ensuring that the user receives the feedback that this specific situation requires.

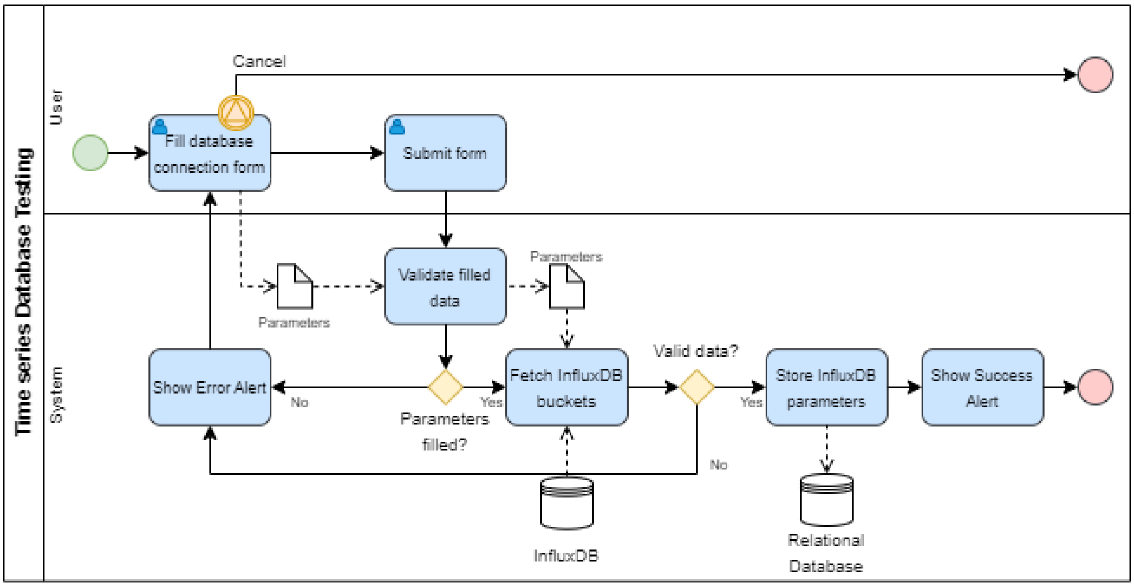


Figure 6.4: BPMN diagram of the time series connection testing.

Last but not least, in figure 6.5, a deployment diagram[3] is presented to outline the physical arrangement of the system components, including the frontend, backend, and the three types of databases (relational, time series, and cloud-based). This diagram is essential for understanding the infrastructure behind the web interface, detailing how different components are deployed and how they interact with each other. This specification could help in future developments of the application, enabling a simple and intuitive understanding of the connection between the different parts of the system.

By incorporating these diagrams, the structure and functionalities of the application are highlighted, providing a visualization of the scope of some of the most relevant features, and demonstrating how the system meets its primary objectives for the intended purpose.

[3]The full guidelines for the notation used can be found in the book *The Elements of UML2.0 Style*, 2005 [53]

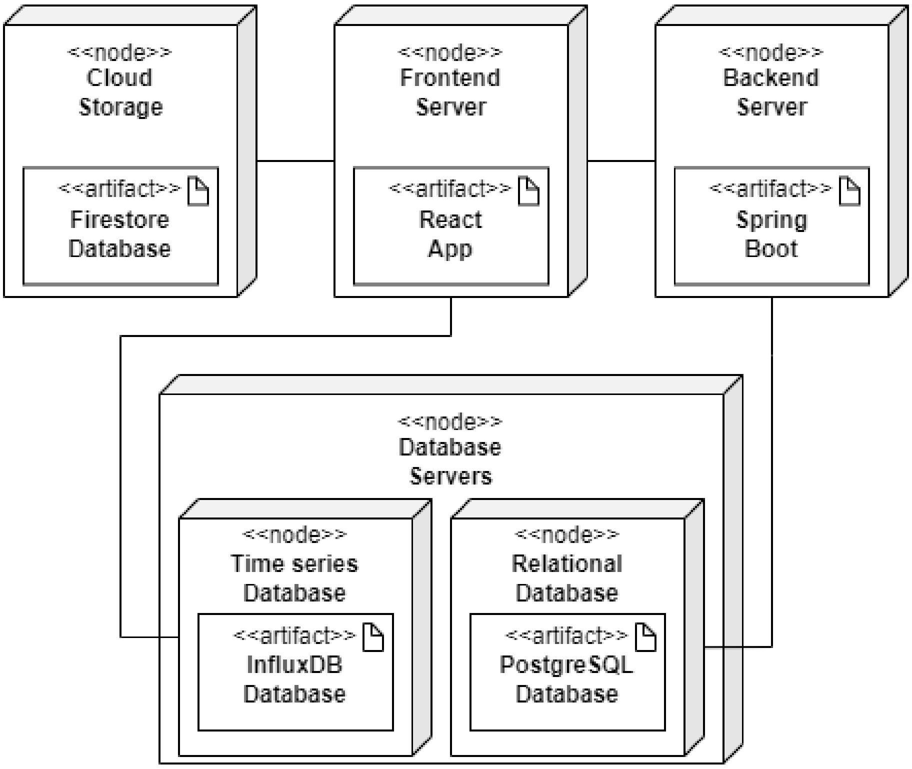


Figure 6.5: Deployment diagram of the system.

6.2 Data Filtering and Visualization

The "Visualization of Results" page is the central of the detailed analysis process. Within this tab, users have the option to choose between two distinct views: individual inclinometer analysis and profile analysis. These views share common filtering options, such as, the selection of the structure, type of result, elevation reference, displayed dates, reference date and depth reference, but also include unique filters adapted to their specific needs.

For instance, the individual inclinometer analysis requires selecting a specific inclinometer, while the profile analysis includes a location filter that focuses the data on a particular point, including the surface and the node with maximum displacement in order to reduce the extended size of the data and enhance the readability.

The structure filter allows users to switch between different structures within a monitoring group, making it easier to evaluate different areas with a simple change in a selection box option.

The type of result filter, discussed in section 5.3, adjusts the calculations and displayed values according to the type of analysis being conducted, offering a complete approach to data interpretation.

Date selection is an important aspect of the system, offering two distinct options: interval and date selection. The interval option, depicted in figure 6.6, allows users to select a range of dates using a calendar tool for both the first and last date. After picking a specific day, the system automatically identifies the nearest available data reading within that range.

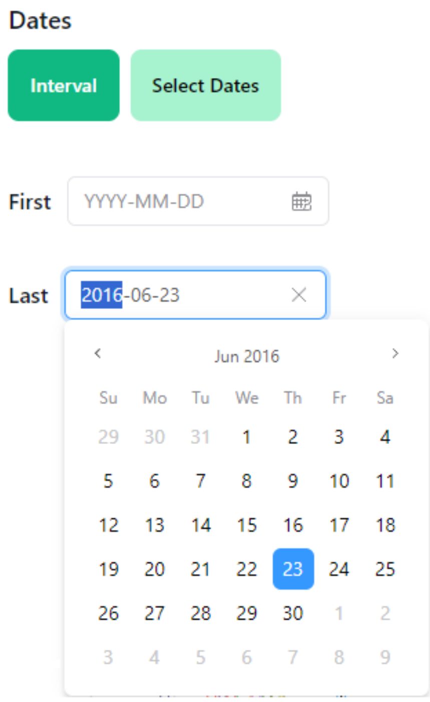


Figure 6.6: Date selection filter by interval.

Illustrated in figure 6.7, the date selection tool displays a grid of detected dates, simplifying the selection process. If the dates are evenly spaced over longer periods, only the year, month, and day are displayed, where if dates are closer together in time are shown with greater precision, including seconds, minutes, and hours. Users can select dates by just clicking on them and are followed by checkboxes to mark the selected ones. By default, the system selects the reference date and the five most recent dates. There is also an option to select all available dates, though this is subject to limitations to ensure proper tooltip and legend functionality within the charts.

Charts that display displacement over depth have specific constraints on the number of readings shown in tooltips and legends. For instance, the tooltip is limited to twenty-five readings, and the legend is limited to twenty-two or twelve readings, depending on the level of precision required by the size of the dates.

In contrast, the displacement over dates chart accommodates more readings - sixty-six - due to the nature of the data, where each line represents a depth rather than a date. Depths usually create a larger scale of individual lines, as the sensors typically have a 0.5m spacing between each other and can extend for tens of meters.

To manage large datasets, users can filter data using a depth slider, interactively dragging each side to select the desired limits or selection boxes to manually set upper and lower depth limits, providing a more focused view of the data.

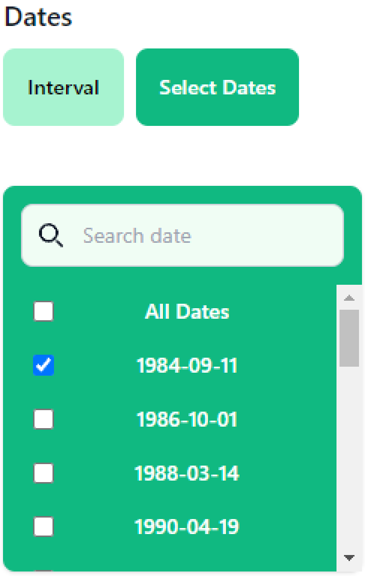


Figure 6.7: Date selection filter by specific date selection.

The reference date selection feature offers a radio selection group for easy switching between reference options: the oldest date, a specific date, or the first date in a selected interval. The reference date is crucial for calculating the displacement values, with the "from interval" option being particularly useful as it uses the closest available date to the selected interval start date as a reference. The current selected reference date is also displayed on screen below this selection group.

To accommodate the constant changes in data, the system creates two datasets when retrieving from the time-series database: one with the original data and another with the filtered data. The dates also follow a similar approach. After the system automatically detects the dates, it stores an original dataset that remains unchanged throughout all processes. This strategy allows for efficient data management, enabling users to add or remove data segments as needed without affecting the integrity of the original dataset and avoiding unnecessary requests to the database.

For the type of result selection, the system updates only the necessary values displayed, generating the appropriate mathematical calculations for each filtered reading in the background while maintaining all the structured data interfaces.

During development, several challenges were encountered, particularly with data synchronization and the impact that filters have on data. The date selection tool, for example, required careful synchronization between the data and the web interface, which initially affected the user experience. To address these issues, extensive validations were implemented to ensure that all filters function correctly together, reducing latency and creating a smooth user-friendly experience.

6.3 Correction of Inclinometer Positions in Monitoring Profiles

In geotechnical monitoring, engineers and technicians often track the position of inclinometers to create an analysis environment that suits the needs of each structure. The "correction of inclinometer positions in monitoring profiles" feature was implemented to enhance the flexibility of positioning these instruments within the monitoring profiles, replacing the need to have a paper version or one made using external editing software, thus maintaining all the analysis on the same place, the web interface. This feature allows users to place the relative positions of inclinometers on images, ensuring that the data visualization is both meaningful and easy to interpret.

The position correction feature was developed using the framework Konva, which had seamless integration with React and allowed for a dynamic and interactive experience where users can adjust the positions of inclinometers directly on the image of the profile.

The development process encountered various challenges. One of the primary issues encountered was ensuring smooth and responsive feedback during user interactions. Initially, there was a noticeable visual delay when users adjusted the position of an inclinometer. This delay was caused by the need to constantly update the positions on the canvas layer overlaying the image, coupled with performance bottlenecks when switching between the uploaded image and an alternative view. To address these issues, the rendering process was optimized, resulting in near-instantaneous feedback during position adjustments.

One of the key advantages of using Konva is its ability to deliver precise positioning. The positions are stored and rendered with up to 14 decimal places of accuracy, which is particularly important when dealing with images of different sizes that are divided into pixels. This level of precision ensures that the inclinometer positions are as accurate as possible to the place chosen by the user, contributing to the overall reliability of the system.

The system supports two distinct types of position corrections depending on the profile type: plan and cross-section.

- Plan: This type of correction allows users to place a dot on the plan representing the relative position of each inclinometer. Once the positions are adjusted, the plan can be viewed with the dots, providing a clear visual representation of where each inclinometer is located. Additionally, this type of position correction serves as a base for the displacement arrows feature (referenced in section 4.3), which visualizes the direction and magnitude of displacements for each inclinometer. These arrows are color-coded and take into account the calculated displacement.

- Cross-Section: Given the nature of cross-sections, the position correction in this view involves placing a line to represent each inclinometer along its length. Users can select the top and bottom points of the inclinometer, and the interface automatically draws and adjusts the line to match these points. This approach ensures that the inclinometer position is accurately represented in relation to its depth.

The positions in both types are automatically saved to the relational database and can be adjusted at any time, although this process is typically set up before data analysis and rarely needs to be changed.

The position correction views are accompanied by a table that displays basic information about each inclinometer in the profile. This table includes features such as a button to select each point on the image and a checkbox to validate the position once it has been adjusted. Figure 6.8 shows the layout of the web interface page with a plan selected.

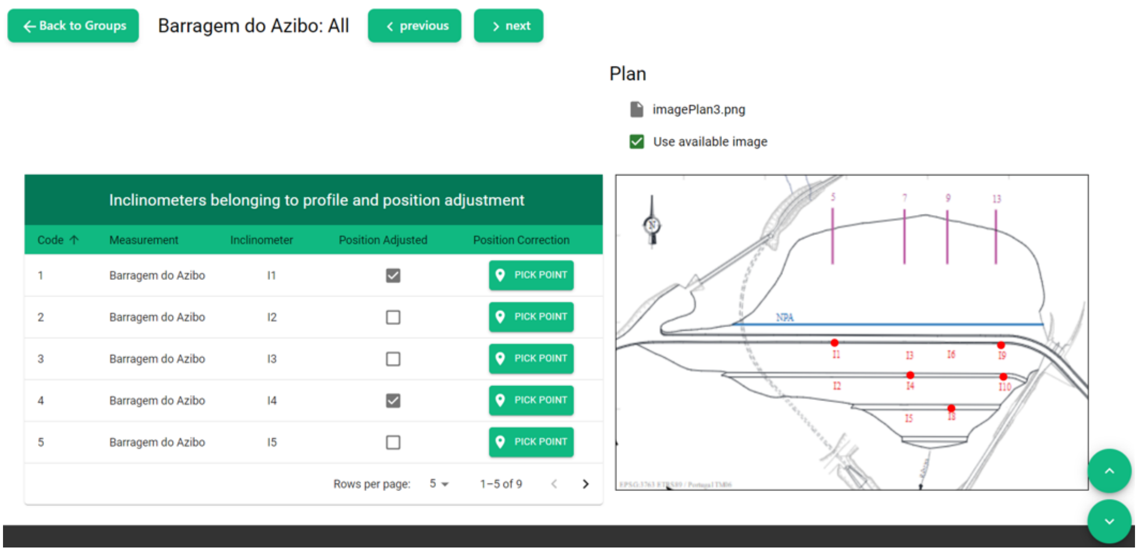


Figure 6.8: Correction of inclinometer relative positions using Konva.

On the interface, there is the option to switch the view to an aerial map of the site using OpenStreetMap, with interactive markers indicating the position of each inclinometer, as shown on figure 6.9.

In the case of cross-sections, a view of the associated plan for that monitoring profile can be visualized to ensure maximum accuracy when placing relative positions.

This combination of visual and interactive tools provides a comprehensive and intuitive way to manage inclinometer positions within monitoring profiles, ultimately enhancing the accuracy and reliability of the assessment process. As a result, this feature not only improves the quality of data analysis but also simplifies the overall process, supporting users in making more informed decisions.

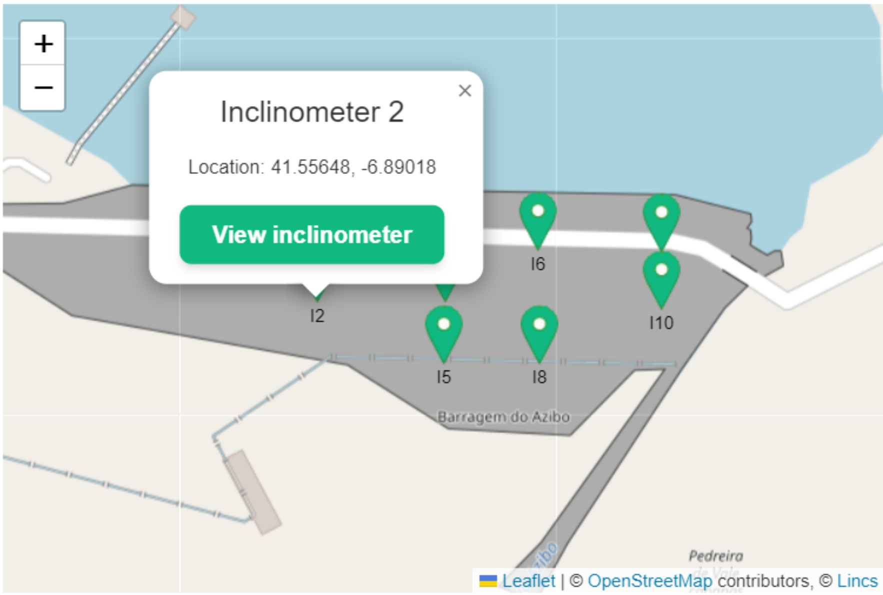


Figure 6.9: Inclinometer map interaction.

6.4 Application APIs Specification

The REST API serves as the core component of the system, facilitating the communication between the web application and the backend. It provides a structured and standardized way to interact with different components and databases. The API is organized into six key areas, each addressing specific aspects of the system: authentication, monitoring groups, monitoring profiles, inclinometers, users, and settings.

Authentication endpoints manage user access and security, while monitoring groups and monitoring profiles endpoints enable the organization and configuration of the distinct inclinometer monitoring tasks. The inclinometers endpoints handle data related to individual inclinometers, storing and managing all related information except for the readings. User management is handled through dedicated endpoints, meanwhile the settings endpoints are responsible for managing the configurations of the time-series databases.

Detailed information about each endpoint, including methods, enpoints and description, is presented in Tables 6.1 through 6.6. For a comprehensive overview, the full API documentation generated using OpenAPI is available in Annex VI. This documentation provides a complete description of the available RESTful web services, which can support future enhancements and developments more effectively.

Method	Endpoint	Description
POST	/api/auth	Create access and refresh tokens
POST	/api/auth/refresh	Refresh access and refresh tokens

Table 6.1: Authentication API endpoints

Method	Endpoint	Description
POST	/api/monitprofiles/	Create monitoring profile
POST	/api/monitprofiles/group	Create monitoring profile group
POST	/api/monitprofiles/point	Create inclinometer point
POST	/api/monitprofiles/line	Create inclinometer line
POST	/api/monitprofiles/marker	Create inclinometer marker
PUT	/api/monitprofiles/	Update monitoring profile
PUT	/api/monitprofiles/group	Update monitoring profile group
GET	/api/monitprofiles/	Retrieve all monitoring profiles
GET	/api/monitprofiles/group	Retrieve all monitoring profile groups
GET	/api/monitprofiles/posAdjust	Retrieve all adjustment positions
GET	/api/monitprofiles/posAdjust/mpId	Retrieve adjustment positions of a profile
GET	/api/monitprofiles/point/mpId	Retrieve inclinometer point of a profile
GET	/api/monitprofiles/line/mpId	Retrieve inclinometer line of a profile
GET	/api/monitprofiles/marker/mpId	Retrieve inclinometer marker of a profile
DELETE	/api/monitprofiles/	Delete monitoring profile
DELETE	/api/monitprofiles/group	Delete monitoring profile group

Table 6.2: Monitoring Profiles API endpoints

Method	Endpoint	Description
POST	/api/monitgroup	Create monitoring group
POST	/api/monitgroup/measurement	Add measurement to monitoring group
PUT	/api/monitgroup	Update monitoring group
GET	/api/monitgroup	Retrieve all monitoring groups
DELETE	/api/monitgroup	Delete monitoring group
DELETE	/api/monitgroup/measurement	Remove measurement from monitoring group

Table 6.3: Monitoring Groups API endpoints

Method	Endpoint	Description
POST	/api/inclinometer/	Create inclinometer
POST	/api/inclinometer/additionalInfo	Add additional information to an inclinometer
POST	/api/inclinometer/sensor	Add sensor spacing between two sensors
POST	/api/inclinometer/soilLayers	Add soil layers to an inclinometer
PUT	/api/inclinometer/	Update inclinometer
PUT	/api/inclinometer/additionalInfo	Updates additional information of an inclinometer
PUT	/api/inclinometer/sensor	Updates sensor spacing between two sensors
PUT	/api/inclinometer/soilLayers	Add soil layers to an inclinometer
DELETE	/api/inclinometer/	Delete inclinometer

Table 6.4: Inclinometers API endpoints

Method	Endpoint	Description
POST	/api/user/	Register user
PUT	/api/user/	Update user information
PUT	/api/user/password	Update user password
GET	/api/user/email	Retrieve user information
DELETE	/api/user/email	Delete user

Table 6.5: Users API endpoints

Method	Endpoint	Description
POST	/api/settings/connection	Create connection
PUT	/api/settings/connection	Update connection
GET	/api/settings/connectionMP/mg	Retrieve all monitoring group connections
GET	/api/settings/connection/user	Retrieve all connections
DELETE	/api/settings/connection	Delete connection

Table 6.6: Settings API endpoints

The current chapter has outlined the practical steps taken to bring the design to life, detailing the layout of the system components and functionalities, while also presenting the data filtering and visualization capabilities, as well as the documentation created to facilitate future enhancements to the application.

After the implementation phase, the next chapter examines its evaluation. It begins with the examination of the obtained graphical interactions, followed by the processing of inclinometer monitoring data gathered from laboratory testing. The "Evaluation" chapter also includes various performance metrics utilized to test different parts of the system and the user surveys conducted to ensure the application meets the needs of expert users. These evaluation methods offer valuable insights into the usability, effectiveness, and areas for potential improvement of the system, providing a assessment of its real-world applicability.

7 Evaluation

The web application developed serves as the primary interface, offering users a platform that facilitates real-time data visualization and the possibility to plot and analyze historical data in an intuitive and user-friendly manner. This application is specifically designed to support engineers and technicians in the field of inclinometer monitoring by delivering accurate and detailed insights, significantly enhancing the capabilities beyond traditional methods. The proposed application was designed to enhance the functionalities offered by existing applications, incorporating additional features to create an assessment environment that meets the desired needs.

This chapter is dedicated to evaluating the functionality and effectiveness of the proposed system. It involves four distinct validation approaches: graphical interactions discussed in section 7.1, data from a scale model experiment presented in section 7.2, performance metrics in section 7.3, and user surveys results detailed in section 7.4. The evaluations provided offer valuable insights into various data processing and visualization techniques, enabling a complete and extensive analysis and supporting comprehensive human analysis and informed decision-making.

7.1 Graphical Interactions

One of the unique features of this system is the level of interactivity offered by the graphical representations, which, according to the studies carried out, represents an innovation when compared to other applications that lack dynamic interactive capabilities. The ability to directly interact with the charts, whether through adjusting depth levels, switching between types of results, or changing the selected dates, allows for a more thorough analysis. This interactivity was a primary focus during the project development, ensuring that users can perform rapid and straightforward analyses without needing to manually test different scenarios at a time or even do it in a spreadsheet. By providing these interactive tools, the system helps users gain useful insights more efficiently, which not only improves the evaluation process but also simplifies the reasoning of significant amounts of data.

The cumulative displacements representations shown in Figure 7.1, measured in millimeters, are depicted for two orthogonal directions (A and B) in an inclinometer installed at the Azibo dam in Portugal. These plots show the displacements as a function of depth across various dates, requiring precise data processing to ensure accurate representation. Four dates were selected for representation in the figure, with the reference date highlighted by an indicator displaying the corresponding date. By interacting with the graph, detailed information about the displacement value at each date and at a specific depth can be obtained, allowing for a more interactive analysis. This type of graph can also be adjusted to display information based on levels instead of depth, providing real values for the different levels where sensors are located.

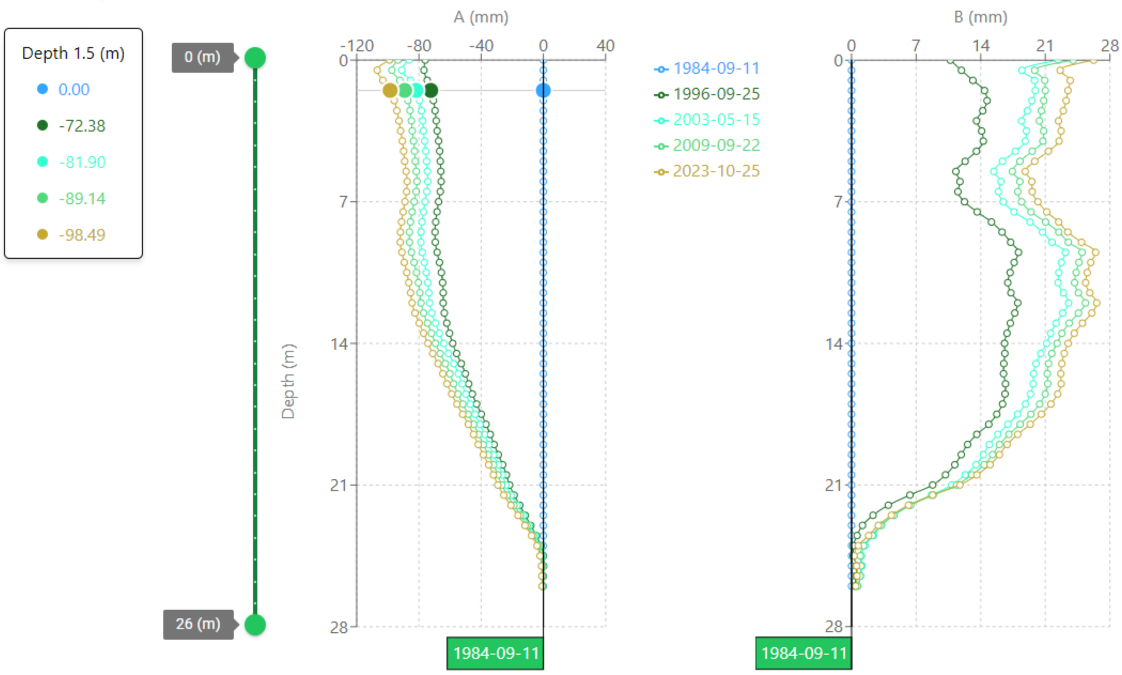


Figure 7.1: Graphical interaction with charts A/Depth and B/Depth from inclinometer I4

Additionally, it is possible to switch the view of angles A and B to show total values and temperature values at different depths. A slider has been added alongside these graphs, allowing for depth variation and enabling users to limit the display of graphs representing angles A and B across different dates, as illustrated in Figure 7.2.

Another chart visualization was developed with the focus of enabling multiple chart comparisons. This view, designed specifically for the integration of monitoring profiles, allows for the simultaneous display of different inclinometers within a profile. Each depiction of an inclinometer is scaled to match the others available, resulting in a more accurate comparison and easier interpretation. The inclinometer representations are not only scaled by elevation and displacement values but also by the depth at which each inclinometer is placed, allowing for a relative visualization of their lengths and positions alongside the monitoring profile. Similar to the individual inclinometer visualization, the implemented filters are also designed to work effectively in this comparative view, facilitating a more detailed analysis between at least two inclinometers. Figure 7.3 illustrates a monitoring profile containing the inclinometers 6 and 9, which are located 30 meters apart from a surface point perspective and have depths of 51m and 20.5m, respectively.

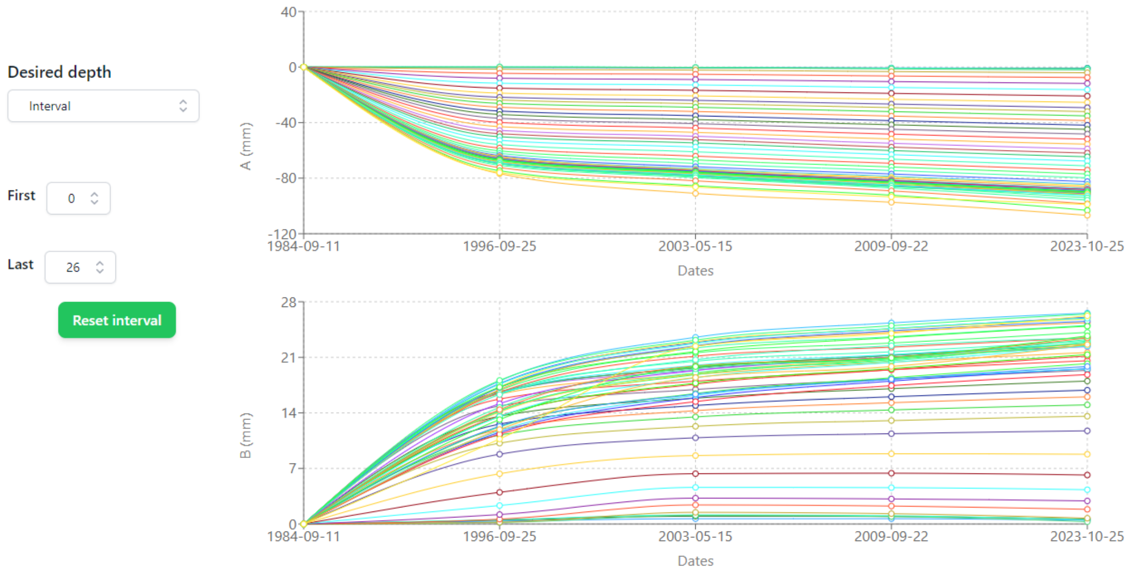


Figure 7.2: Charts A/Dates and B/Dates from inclinometer I4

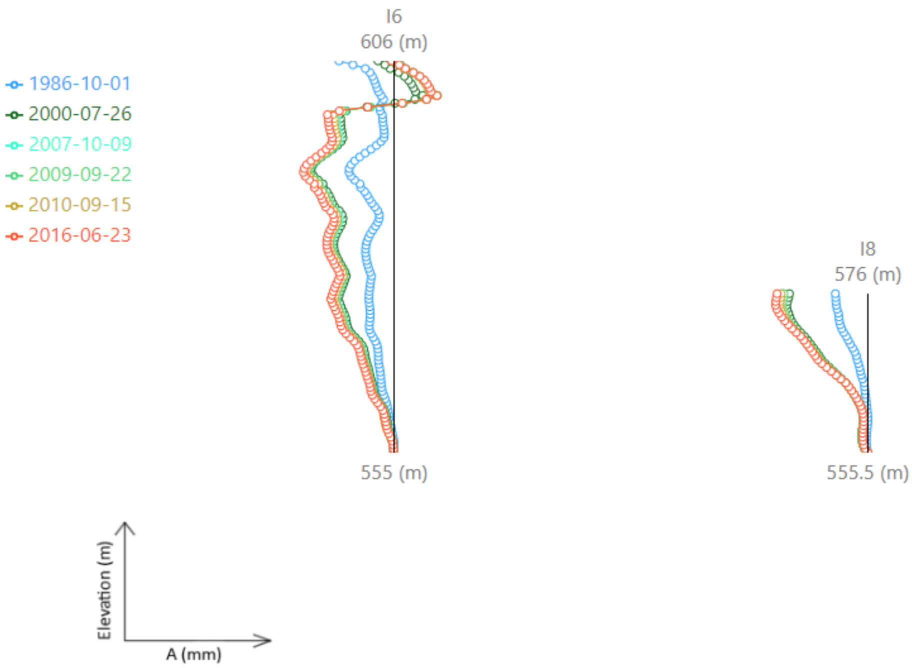


Figure 7.3: Orthogonal direction A over elevation charts from a monitoring profile with inclinometers I6 and I9.

7.2 Inclinometer Monitoring Data from a Scale Model

In addition to utilizing real-world data for web interface visualization testing, an experiment involving a scaled model was also performed to simulate various field conditions in a controlled environment. This experiment involved placing a vertical inclinometer equipped with four accelerometer sensors in a laboratory setting and applying gradual forces to induce position deformation. The primary aim was to replicate potential deformation scenarios that could occur in real-world structures and to obtain a dataset with a closer frequency between readings to test the accuracy of the system when analysing data by the second.

Two distinct tests were conducted to assess the inclinometer's response to different force applications. The first test involved applying force at the inclinometer's upper portion, which simulated a ground movement near the surface. The second test applied force at an intermediate point along the inclinometer, simulating deformation within a deeper intermediate soil layer. These scenarios provided a comprehensive dataset that reflected varying deformation conditions, with data readings recorded at ten-second intervals and force increments applied every minute.

The datasets obtained from these experiments were crucial not only for conducting system validation tests and ensuring effective communication between the various constituent parts, but also for generating a real-time dataset with a shorter periodicity. Similar to the actual data, the scale model data required preprocessing and adjustment for visualization purposes.

During preprocessing, the data reading frequency was adjusted to thirty-second intervals. This adjustment proved optimal for identifying significant changes while filtering out irrelevant data that could obscure meaningful patterns during visualization and subsequent analysis.

Figures 7.4 and 7.5 represent the cumulative displacements in orthogonal directions A and B in relation to depth and the selected reading dates, respectively. These figures show some changes that can be observed in the chart legend, reference date, and, for Figure 7, the values presented on the Dates axis. These changes are directly attributable to the system ability to detect and present data at an optimized frequency, showcasing its adaptability to different monitoring scenarios.

For the earth-fill dam data gathered from the Azibo's dam dataset, the readings were recorded with lower frequency (quarterly), making it unnecessary to show information beyond the specific day. The scale model data allowed for testing and validating this system functionality, enabling the web interface to be used with different types of data.

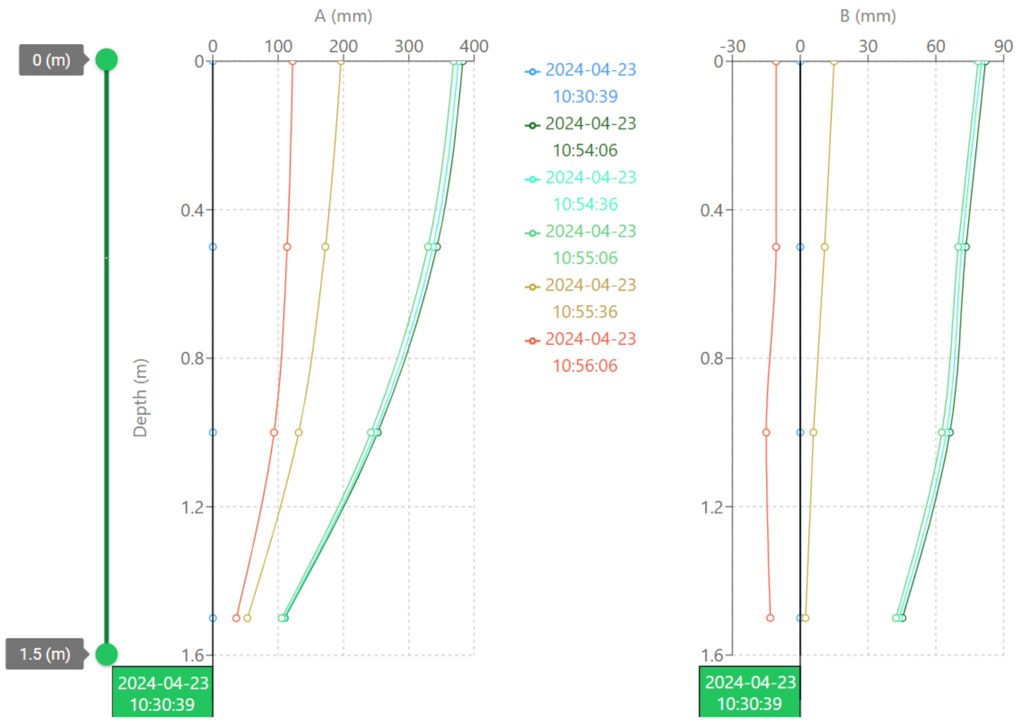


Figure 7.4: Charts A/Depth and B/Depth from IPI prototype inclinometer

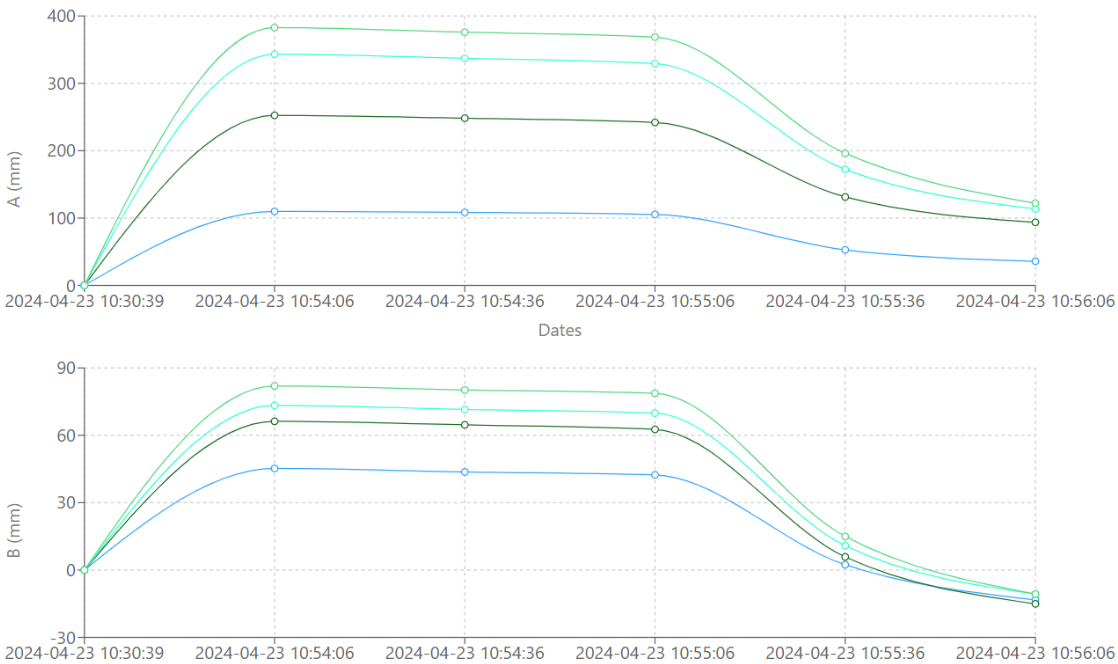


Figure 7.5: Charts A/Dates and B/Dates from IPI prototype inclinometer

7.3 Performance Metrics

Performance testing is an important evaluation technique employed to assess the availability and reliability of various features and connections within the web interface. This evaluation process ensures that the system meets performance expectations and can handle the anticipated load efficiently.

The tests were performed on a Windows machine, with the backend, frontend, PostgreSQL, and InfluxDB running locally. A total of 20 tests were conducted for each request and operation, producing the average, minimum, and maximum values, which represent the expected performance benchmarks range.

To achieve the expected outcomes, two kinds of tests were made: requests to the evaluate the database connections and assessment of the processing time of some data processing operations.

Table 7.1 presents data from performance tests involving five different requests to the different databases:

- 1: InfluxDB request for Azibo's dam data
- 2: InfluxDB request for scale model data
- 3: PostgreSQL database request for monitoring profiles data
- 4: PostgreSQL database request for geopositions of inclinometers in a profile
- 5: Firestore database request for a profile image

Request Nº	Average TTFB (ms)	Min TTFB (ms)	Max TTFB (ms)	Average Content Download (ms)	Min Content Download (ms)	Max Content Download (ms)	Average Total Response Time (ms)
1	69.7	62.17	82.02	610.05	542.87	729.88	679.75
2	9.54	8.7	10.77	12.6	11.19	13.93	22.1
3	6.06	3.5	9.67	2.15	0.62	13.93	8.21
4	7.49	5.66	12.24	0.91	0.23	2.17	8.39
5	249.4	221.55	259.44	5.15	0.42	24.77	254.55

Table 7.1: Performance metrics of requests to the databases

The performance metrics[1] for these requests include Time to First Byte (TTFB), Content Download, and Total Response Time. TTFB measures the time elapsed from the initiation of a request to the receipt of the first byte of the response, testing the responsiveness of the server. The Content Download parameter assesses the time taken to download the content after the first byte is received, providing insights into the efficiency of data transfer. The Total Response Time represents the total time taken to process a request, including both TTFB and Content Download times, and is crucial for understanding the overall performance of the request.

From the first and second requests described in table 7.1, both involving the time-series database, it is evident that processing the Azibo's dam dataset takes longer than processing the scale model dataset. This difference is attributable to the larger size of the Azibo's dam dataset, which contains 44920 data entries compared to the 4947 data entries in the scale model dataset.

The third and fourth requests, concerning the PostgreSQL database, show typical processing times for relational data, aligning within the expected values due to the fact that the database is deployed locally. In contrast, the fifth request, which accesses a cloud database, shows a significantly higher response time, especially when compared to the other local database requests.

Table 7.2 presents the InfluxDB requests total response times using Flux queries to limit the dates for the dataset collected from Azibo's dam. The average total response time was assessed by progressively increasing the number of dates queried and comparing the results with queries that had all available dates (22 in total).

The dataset sizes increase significantly, as shown in table 7.3. As expected, the results show a direct correlation between the size of the dataset being retrieved and the total response time, which increases as more entries are included. This is due to the Content Download phase, where larger datasets naturally result in longer download times.

An interesting observation from the gathered data reveals a significant jump in total response time between queries with 5 dates and queries with 10 dates. The increase in the total response time is larger compared to other intervals, suggesting that once the dataset reaches a certain size, the performance of the requests could begin to degrade more significantly. However, from this point onward, the data stabilizes, particularly noticeable when the number of dates doubles from 10 to 20 dates.

[1]A complete description of the metrics used is available in *Web Performance in Action: Building Faster Web Pages*, 2017 [54]

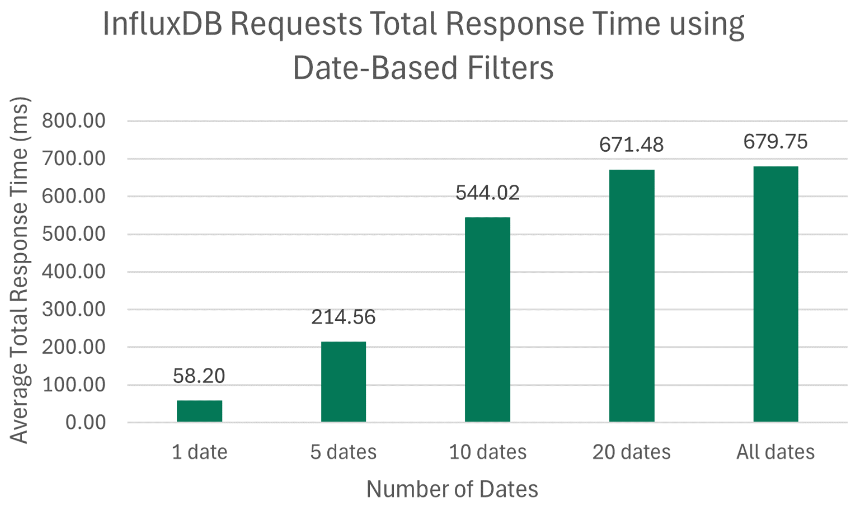


Table 7.2: InfluxDB Requests Total Response Time using Date-Based Filters

Number of Dates	Number of Entries
1	1492
5	11832
10	22172
20	42852
22 (All Dates)	44920

Table 7.3: Number of entries per number of dates analyzed on the InfluxDB requests testing.

The core challenge in optimizing the performance of these requests reveals a duality between making more frequent requests with smaller amounts of data or fewer requests containing larger amounts of data. In this case, the second perspective was chosen. This approach was driven by the needs of the web interface, which supports multiple filters being applied simultaneously. If more requests were made with smaller datasets, it could lead to an increased latency between user inputs and the resulting visualizations.

Choosing fewer requests allows for more streamlined handling of the data, ensuring that the interface can simultaneously manage multiple filters without introducing significant delays. This is also important to generate some key values from the gathered data, that require working with the full dataset to extract, such as, the available dates or the depth. However, this choice means the user could experience some slight delays when retrieving the data for the first time, but have a faster interaction with the system afterwards.

For future work, a combination of the two approaches could be explored to further optimize the performance, balancing the number of requests with the latency associated with the size of the datasets.

Table 7.4 details nine operations related to data processing for visualizations and tables:

- 1: Azibo's dam data processing for displacements in orthogonal direction A over depth chart with default dates
- 2: Azibo's dam data processing for displacements in orthogonal direction A over depth chart with all available dates
- 3: Azibo's dam data processing for displacements in orthogonal direction A over dates chart with default dates
- 4: Azibo's dam data processing for displacements in orthogonal direction A over dates chart with all available dates
- 5: Scale model data processing for displacements in orthogonal direction A over depth chart with default dates
- 6: Scale model data processing for displacements in orthogonal direction A over depth chart with all available dates
- 7: Scale model data processing for displacements in orthogonal direction A over dates chart with default dates
- 8: Scale model data processing for displacements in orthogonal direction A over dates chart with all available dates
- 9: Azibo's dam data processing for summary of results table in a profile

The main parameter measured during these tests is the Total Processing Time, displaying the time required by the system to complete the operations involving the process of data.

The data processing tests for chart visualization were conducted on two analyzed structures: Azibo's dam and the scale model. The tests were performed for two different sets of dates: the default date selection, which includes the reference date and the five most recent dates, and the all dates selection, which includes twenty-two dates for Azibo's dam and fifty-one dates for the scale model.

The results indicate that processing time increases with the selection of additional dates, as expected, especially when dealing with a larger sums of data that not only have more data entries but also include larger additional parameters, such as depth. The processing times for displacements in orthogonal direction A over depth and over dates show only a small difference, reflecting the additional filtering required for date-based data but a relatively similar processing workload.

Operation Nº	Average total processing time (ms)	Min total processing time (ms)	Max total processing time (ms)
1	5.77	3.30	10.89
2	25.68	18.39	39.09
3	6.80	4.24	12.72
4	26.18	18.89	39.98
5	0.22	0.09	0.5
6	0.24	0.18	0.5
7	0.29	0.1	0.9
8	0.31	0.25	0.39
9	6.50	4.3	9.79

Table 7.4: Performance metrics of some data processing operations

Figures 7.6 and 7.7, as well as Table 7.5 depict some examples of the practical visualization of some operations, displaying the final results after data processing, either in the form of a chart or a table.

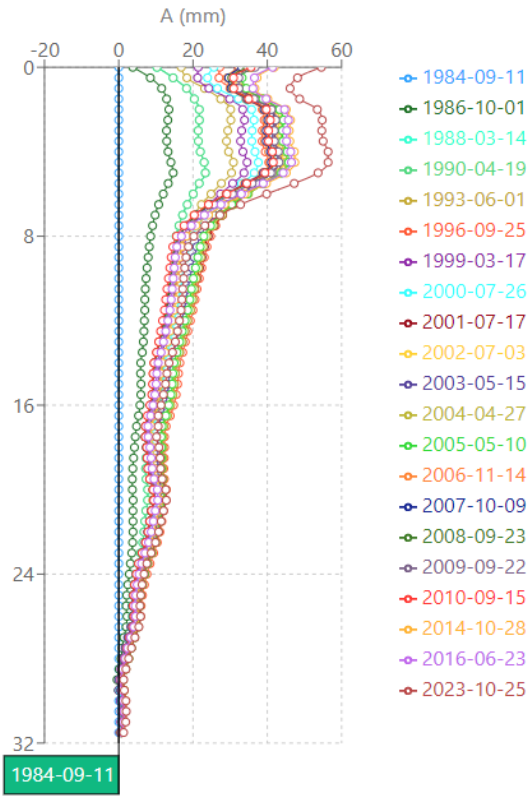


Figure 7.6: Visualization of the chart produced by operation 2

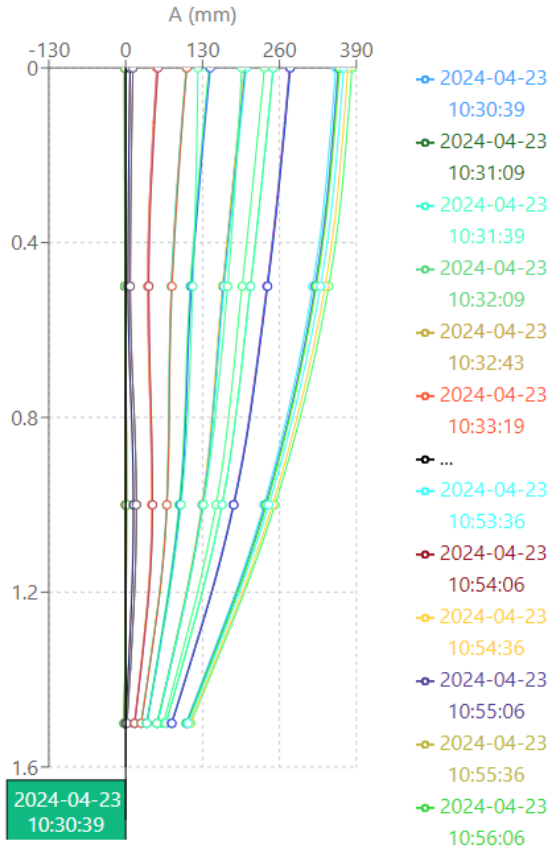


Figure 7.7: Visualization of the chart produced by operation 6

Summary of Results

Incl ↑	A (mm)	B (mm)	Total (mm)	Direction (°)	Node	Level (m)	Date
1	36.71	-15.39	39.81	90	Surface	606	2009-09-22
1	35.62	-14.93	38.62	90	Surface	606	2010-09-15
1	41.88	-11.79	43.51	90	Surface	606	2014-10-28
1	41.43	-11.36	42.96	90	Surface	606	2016-06-23
1	54.56	-9.7	55.42	90	Surface	606	2023-10-25

Rows per page: 5 ▾ 1–5 of 43 ‹ ›

Table 7.5: Visualization of the table produced by operation 9

The overall performance tests can demonstrate that the system efficiently handles various types of database requests and data processing operations. These metrics provide valuable insights into different database interactions and data processing tasks. The increase in the time to retrieve data from a request and the extended processing time with additional date selections are examples of expected outcomes and highlight the system's ability to manage varying data loads effectively. The overall performance results support the system's capability to deliver real-time data visualization and analysis, crucial for the intended goal for the web interface.

7.4 User Surveys

The primary goal of the user surveys was to evaluate how users interacted with and navigated through the interface while performing different tasks. Following the completion of these surveys, valuable insights were collected after each task, highlighting elements for improvement and identifying any issues that needed to be addressed. This feedback was crucial for ensuring that the final web interface met the desired functionalities, while maintaining the appropriate look and feel.

The approach with a real-world testing environment is essential for validating the application. It allowed for an in-depth analysis of the navigation and interactions of the different tasks offered. Users offer unique and genuine feedback, as they can identify their needs and preferences by interacting with the site directly [55].

The complete document containing the user surveys is available in annex III.

7.4.1 Tasks

The survey was structured to ensure a comprehensive understanding of user experience and knowledge. It began with an introductory section that provided context and motivation for the survey, setting an initial scope of the global system for respondents. This was followed by two initial questions aimed at assessing the respondent's familiarity with inclinometer monitoring techniques and their previous experience with applications used for visualizing and analyzing inclinometer data. These preliminary questions helped in creating a basic profiling of each user, offering insight into their level of expertise and identifying if they required additional context or explanations for specific tasks.

Following this initial profiling, respondents proceeded to complete a series of five tasks, with guidance provided throughout each task. This structured approach ensured that users could perform the tasks effectively while receiving appropriate support and providing suggestions during the completion of each step. The tasks were designed to test various aspects of the web UI, including its usability and functionality, as well as how well it met the users needs. After completing the tasks, respondents answered three sections of questions, plus an additional comments and suggestions box, on a provided paper form. Each section was divided in a way that ensured the collected results were well-organized and easily compiled at the end of the survey.

The survey itself was divided in four sections:

- Web UI Testing Specific Feedback: The first section of the survey was dedicated on evaluating the user experience related to the specific performed tasks and navigation within the web interface. The questions were designed to assess how successfully users could complete assigned tasks, the ease with which they could find and perform these tasks, and their overall navigation experience. Each question was rated on a scale from 1 to 5, with 1 representing the lowest rating and 5 representing the highest, covering aspects such as task completion success, the intuitiveness of task execution, ease of navigation, and the responsiveness of the interface to user common actions like clicks and hovering. This feedback was essential for analyzing the practical effectiveness and efficiency of the web UI, providing valuable insights that guided improvements to enhance user interaction and task performance;

- General Feedback: The general feedback section allowed to gather insights into the overall usability and design of the website. This assessment consisted of questions rated on a scale from 1 to 5 that were aimed to evaluate the general ease of use, intuitiveness, visual appeal, readability of text, and the organization of the web application. The feedback from this section of the survey helped to better understand how well the web application functioned as a whole, how user-friendly it was, and how its aesthetic and structural elements contributed to the overall user experience;

- Inclinometer Monitoring Knowledge Feedback: In this segment, the survey targeted users with experience using inclinometer monitoring applications, seeking to compare the specific features of the web interface with other solutions they had used. The questions, rated on a scale from 1 to 5, focused on the interactions with charts and the profile monitoring features, specifically comparing them to those available in other similar applications. This feedback was crucial for evaluating the suitability and efficiency of the inclinometer monitoring functionalities, as well as identifying areas where the interface could better align with common workflows;

- Comments and Suggestions: The final part of the survey provided an open section for users to report any technical issues they encountered and to offer general suggestions for improvement. This section was essential for gathering important insights and addressing any specific issues that might not have been covered by the previous questions.

7.4.2 Results and Data Analysis

The data analysis of the user surveys provides insightful and comprehensive feedback on the performance and usability of the system, with the results visualized through various charts for easier interpretation.

A pie chart, shown in figure 7.8, was created to represent the overall user scores across all sections of the survey. The chart revealed that most of the ratings were highly positive, with the highest ratings occupying the largest portion of the pie chart. Scores of 4 have nearly a quarter of the chart, while scores of 3 were present but having a very small percentage of the total ratings. This distribution indicates that users were generally satisfied with the tasks performed.

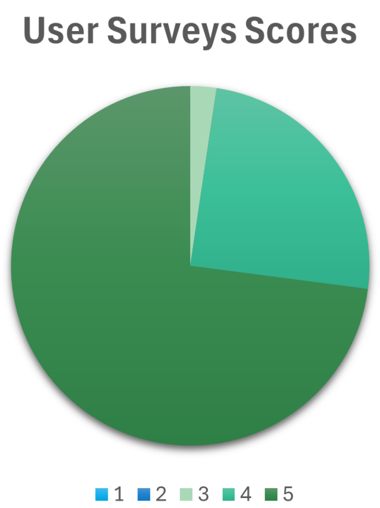


Figure 7.8: Overall user surveys scores.

Additionally, three bar charts were generated, one for each section of the survey: web UI testing specific feedback (Figure 7.9), general feedback (Figure 7.10), and inclinometer monitoring knowledge (Figure 7.11). Each bar chart represents a question on that particular section and displays the number of responses for each rating (1 through 5).

In the complete version of the user surveys, in annex III, a detailed description of the questions is available on the feedback section of the document. To streamline the discussion, only the question numbers will be mentioned.

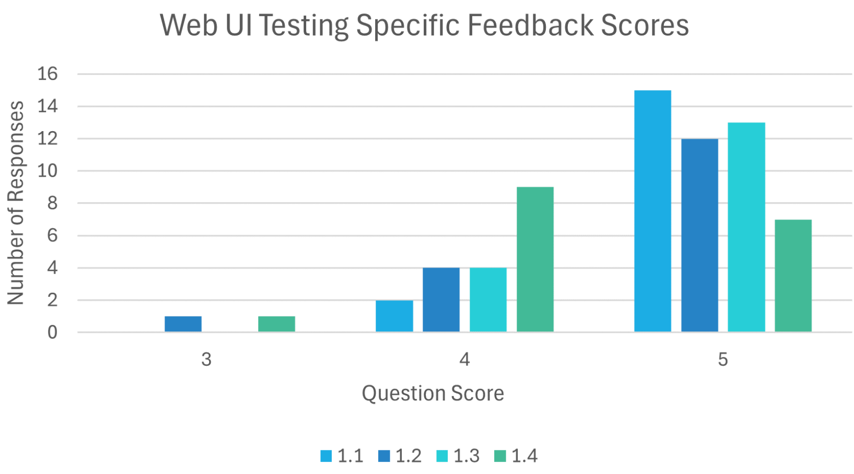


Figure 7.9: Web UI testing specific questions scores.

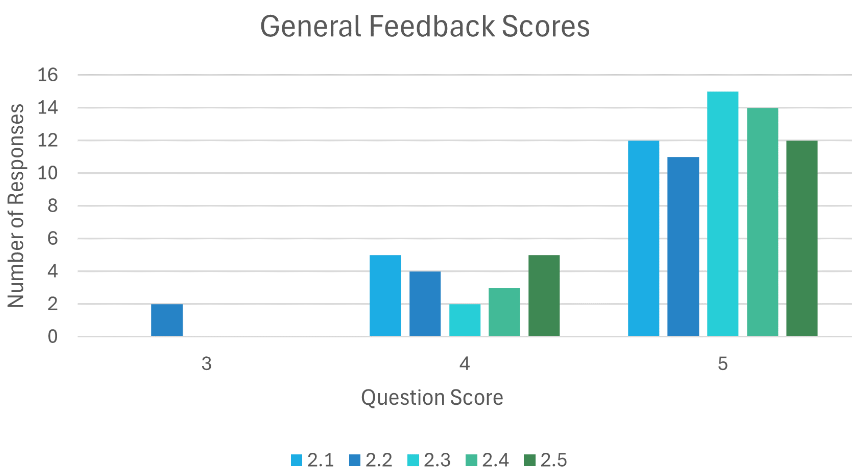


Figure 7.10: General questions scores.

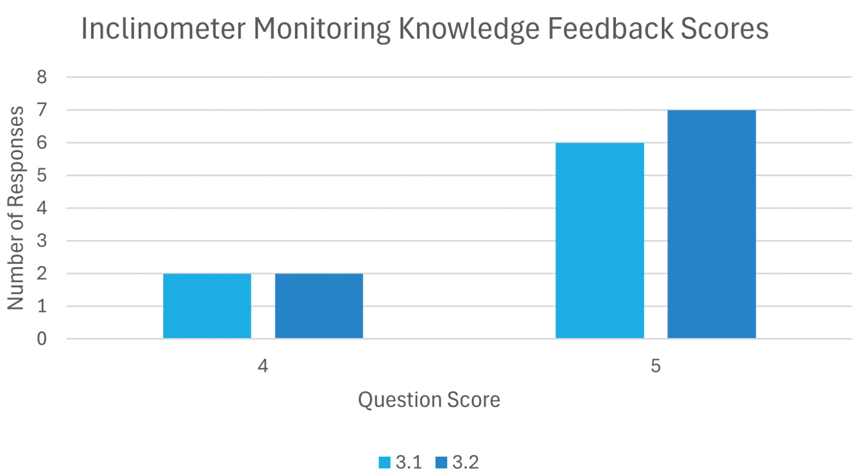


Figure 7.11: Inclinometer Monitoring knowledge questions scores.

The web UI testing section had ratings between 3 and 5, with the highest concentration of ratings being 4 and 5, as shown in figure 7.9. Questions 1.1 and 1.3 had slightly lower scores compared to the others, indicating specific areas, such as, the ease of navigation through the interface could be enhanced.

In the general feedback section, represented in figure 7.10, the ratings also ranged from 3 to 5, with very few responses at the 3 level and a predominant number of ratings at 5. Question 2.2 appeared to have generated more difficulties for the users, as reflected by a relatively lower score compared to the other questions in this section.

The bar chart for this section showed a significant lean towards the 5 rating, reinforcing the overall positive structure of the web interface. Finally, the inclinometer monitoring knowledge section, illustrated in figure 7.11, received exclusively 4 and 5 ratings. This indicates that users found the chart interactions and profile monitoring features highly effective and outstanding compared to other similar applications.

These chart visualizations provided a clear and concise overview of the user feedback. The scores and positive responses across various sections highlight the effectiveness of the application design and functionality. Meanwhile, the areas with relatively lower scores offer valuable insights for improvements.

The ratings from the survey can be considered overwhelmingly positive, as described in Table 7.6, with an average score of 4.71 out of 5. The best-performing questions received a score of 4.88, shared by questions 1.1 and 2.3, reflecting users correct completion of the tasks and the visual appeal of the solution compared to the existing solutions.

On the other hand, the question with the lowest score still achieved a 4.35, on the question 1.4, which indicate some specific actions were not performing as the user expected, but with the information gathered on the problems, they were corrected shortly after.

When examining the average scores per section, the web UI testing section had the lowest average, suggesting room for improvement on some particular elements and the inclinometer monitoring knowledge section had the highest average, which suggests a strong approval of the inclinometer functionalities.

Average Question Score	Best Question Score	Worst Question Score	Average Feedback Score		
			Web UI Testing	General	Inclinometer Monitoring Knowledge
4.71	4.88	4.35	4.66	4.73	4.76

Table 7.6: Score surveys metrics

The survey was completed by a total of 17 respondents, consisting of 14 expert users and 3 non-expert users, as shown in Table 7.7.

User	Number of respondents
Expert Users	14
Non-expert users	3
Total	17

Table 7.7: Number of respondents by user type

The effectiveness of usability evaluations relies on selecting respondents who accurately represent the user population, as testing with non-representative participants undermines the utility of the results [56]. This distribution ensured that the feedback was predominantly informed by users with some level of experience and knowledge in the field, providing valuable insights the application functionalities. The inclusion of non-expert users also added a layer of general usability feedback, making the overall results more comprehensive and well-rounded.

The surveys revealed how target users interacted with the interface in practical scenarios, leading to useful suggestions on how to improve the structure of the application to better align with an experienced users workflow. Some examples of these changes include repositioning the UI element for filtering dates on the charts.

After the surveys, this element was moved closer to the reference date selection element for better accessibility. Another example is the addition of floating helper arrows that remain on the screen at all times within the chart analysis tab, allowing users to scroll up and down the page more easily. This suggestion was implemented to help users efficiently navigate through all the available charts and options.

A complete document with all the suggestions gathered during the surveys in available in annex IV. The suggestions that could significantly enhance the user experience and workflow without requiring substantial changes to the application structure have been implemented. The remaining suggestions could serve as a baseline for future work improvements.

The insights gained from the user surveys, especially from expert users, confirmed the application strengths and pinpointed specific areas where enhancements were necessary. The feedback also provided a detailed understanding of user interaction patterns and ensured that the final application is user-friendly and has the needed tools expected by expert users.

8

Conclusion and Future Work

This chapter will outline the primary conclusions and achievements, in section 8.1, and explore the directions for future work, in section 8.2, addressing how the work could progress beyond the completion of this thesis.

8.1 Conclusion and Achievements

This thesis aimed to develop a prototype for a web interface tailored for an existing in-place inclinometer monitoring system. The primary objectives were to study, design, integrate, and evaluate the system, as well as to explore the future impact of the developed prototype on the field of geotechnical engineering. The work focused on enhancing inclinometer monitoring capabilities through an intuitive and interactive interface, designed to streamline the data processing and visualization processes essential for informed decision-making.

Two main components emerged as central pieces to the development: the chart visualization and the monitoring profiles management. The chart visualization features were developed to present complex inclinometer data in an accessible and interactive format, allowing users to easily interpret and analyze patterns emerging from the readings.

Meanwhile, the profile management system was designed to ensure an efficient integration with additional useful information, that enables users to manage and visualize monitoring profiles alongside the inclinometer data. These components were crucial in fulfilling the project's goals, ensuring the system met the practical needs of its expert users.

The final developed prototype successfully met the initially outlined objectives. The system proved to be a valuable tool in the field of inclinometer monitoring, offering enhanced visualization, user-friendly interactions, and various options when it comes to data management capabilities. It addressed the gaps in the existing inclinometer monitoring systems by providing a clear and intuitive interface that simplifies the process of data interpretation and decision-making.

The positive feedback from the evaluation phase further validates the system's usability, demonstrating its potential to make significant contributions to geotechnical engineering.

During the development phase of the prototype, several challenges were encountered. Learning to use new tools and frameworks sometimes presented a demanding learning curve, while typical development issues, such as debugging and optimization, required considerable effort to resolve. These challenges were overcome through continuous iteration and adaptation, trying to apply strategies that bridged the gap between the initial objectives and the final product. The experience of navigating these challenges contributed to a deeper understanding of both the development process and the technologies employed.

The system was subjected to a thorough evaluation process involving four distinct approaches: graphical interactions, data from a scale model experiment, performance metrics, and user surveys. Each approach served a specific purpose, from testing the interactive elements and performance under simulated conditions to gathering feedback directly from expert users. The graphical interactions validated the usability and intuitiveness of the interface, while the scale model experiment provided additional testing insights into the system's accuracy and reliability in different scenarios. Performance metrics were used to assess the efficiency and responsiveness of the system, and user surveys offered direct feedback on the overall user experience and provided suggestions for enhancing the workflow. These evaluation methods confirmed the system's effectiveness and highlighted areas for future enhancement.

An additional outcome of this thesis was the opportunity to contribute to the EPIA 2024 conference in the Knowledge Discovery and Business Intelligence category. The research conducted for this thesis provided a strong basis for an article[1] that was well-received at the conference, showcasing the innovative aspects of the developed system and its significance on the field.

The full source code developed during this project is available on GitHub[2], providing open access for review and future improvements. The repository contains the code for the web interface, backend, databases integration, and the experimental data. The API specification is also included in the repository to facilitate further research and development.

This thesis has successfully achieved its goals of developing and validating a web interface prototype for an inclinometer monitoring system. The challenges faced during development were vital in refining the system, ensuring it is both robust and user-friendly. The validation processes have demonstrated the system's value and potential impact, highlighting its contribution to the field. This work aims to establish a foundation for further research and development.

[1] The article, published by Springer, is available at: https://link.springer.com/chapter/10.1007/978-3-031-73503-5_15

[2] The source code is available at: https://github.com/JoaoPalmaFCT/WebInterfaceIPISystem.

8.2 Future Work

The development and implementation of the system have established a solid base for continued innovation and improvements. Future work could further enhance the system's capabilities, extend its functionalities, and maintain its ongoing relevance in the field.

One of the key areas for future enhancement is the integration of artificial intelligence to optimize data collection. The next phase of development could focus on AI-driven frequency adaptation, where machine learning algorithms will dynamically adjust the reading frequency based on previously collected data. This approach will involve forecasting displacement patterns, allowing the system to determine the optimal frequency for data collection. By doing so, the system will not only ensure data accuracy but also minimize resource consumption, thereby maintaining efficient monitoring and providing more relevant and timely data insights without compromising performance.

Another valuable improvement could involve integrating the system with additional mapping platforms, such as QGIS (an open-source geographic information system), to display various types of maps. This integration would enable the system to present topographic, geological and meteorological data, and even 3D mappings of the areas surrounding a monitoring location. By offering a more comprehensive view of the monitored area, this feature would provide deeper insights into the environmental factors influencing geotechnical stability, thus improving decision-making processes.

To build upon the usability and functionality of the system, the development of a dashboard for managing users and permissions is proposed. This dashboard would also feature statistical data to help administrators monitor system usage and performance. By adding user management and providing key statistics, the system would become more efficient in supporting the needs of a diverse range of operations involved in monitoring activities.

Furthermore, a potential full cloud integration for the system could be developed in the future. An initial study on different cloud solutions has already been explored with the successful integration of a cloud database, Google Cloud Firestore, for managing monitoring profile images. Expanding cloud integration to other areas of the system will enhance the system's capabilities, improving data accessibility, scalability, and reliability, without sacrificing performance. This upgrade would guarantee that the system can adapt to evolving technological demands.

These future enhancements will ensure the system remains at the cutting edge of inclinometer monitoring technology, continuing to meet the evolving needs of engineers and technicians in the field.

Bibliography

[1] J. M. Lourenço. *The NOVAthesis LaTeX Template User's Manual*. NOVA University Lisbon. 2021. URL: https://github.com/joaomlourenco/novathesis/raw/main/template.pdf (cit. on p. i).

[2] D. Basu, A. Misra, and A. J. Puppala. "Sustainability and geotechnical engineering: perspectives and review". In: *Canadian Geotechnical Journal* 52 (1 2015). ISSN: 0008-3674. DOI: 10.1139/cgj-2013-0120 (cit. on p. 5).

[3] K. L. S. Bernhardt, J. E. Loehr, and D. Huaco. "Asset Management Framework for Geotechnical Infrastructure". In: *Journal of Infrastructure Systems* 9 (2003). ISSN: 1076-0342. DOI: 10.1061/(ASCE)1076-0342(2003)9:3(107) (cit. on p. 5).

[4] W. A. Marr and J. Standing. "Principles of geotechnical monitoring". In: 2nd ed. Vol. 2. Emerald Publishing Limited, 2023. DOI: 10.1680/icemge.66830.1495 (cit. on p. 6).

[5] A. Segalini, A. Carri, and R. Savi. "Role of Geotechnical Monitoring: State of the art and new perspectives". In: (2017). ISSN: 2303-8403 (cit. on p. 6).

[6] B. Li, J. Yang, and D. Hu. "Dam monitoring data analysis methods: A literature review". In: *Structural Control and Health Monitoring* 27 (2020). ISSN: 1545-2255. DOI: 10.1002/stc.2501 (cit. on p. 6).

[7] R. N. C. dos Santos, L. M. M. S. Caldeira, and J. P. B. Serra. "FMEA of a tailings dam". In: *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 6 (2012). DOI: 10.1080/17499518.2011.615751 (cit. on p. 6).

[8] G. Machan and V. G. Bennett. *Use of Inclinometers for Geotechnical Instrumentation on Transportation Projects*. 2008 (cit. on pp. 6, 9).

[9] T. D. Stark and H. Choi. "Slope inclinometers for landslides". In: *Landslides* (2008) (cit. on pp. 6–10, 26).

[10] J. Dunnicliff. *Geotechnical Instrumentation for Monitoring Field Performance. National Cooperative Highway Research Program. Synthesis of Highway practice, n. 89*. 1982 (cit. on p. 6).

[11] P. E. Mikkelsen. "Advances in Inclinometer Data Analysis". In: A.A. Balkema, 2003 (cit. on p. 6).

[12] S. Uhlemann et al. "Assessment of ground-based monitoring techniques applied to landslide investigations". In: *Geomorphology* 253 (2016), pp. 438–451. ISSN: 0169555X. DOI: 10.1016/j.geomorph.2015.10.027 (cit. on pp. 6, 7, 10).

[13] G. E. Green and P. E. Mikkelsen. *Deformation Measurements with Inclinometers. Transportation Research Record, n. 1169*. 2008 (cit. on pp. 6, 8).

[14] X. Ding et al. "Automatic Monitoring of Slope Deformations Using Geotechnical Instruments". In: *Journal of Surveying Engineering* 126 (2000). ISSN: 0733-9453. DOI: 10.1061/(ASCE)0733-9453(2000)126:2(57) (cit. on pp. 6, 7).

[15] W. R. Stevens and B. E. Zehrbach. "Inclinometer Data Analysis for Remediated Landslides". In: American Society of Civil Engineers, 2000. ISBN: 9780784405185. DOI: 10.1061/40518(294)10 (cit. on p. 6).

[16] *Geo Observations*. URL: https://geo-observations.com/ (visited on 2024-01-03) (cit. on p. 7).

[17] F. Freddi et al. "Laboratory Assessment of an In-Place Inclinometer Chain for Structural and Geotechnical Monitoring". In: *Sensors* 23 (2023). ISSN: 1424-8220. DOI: 10.3390/s23208379 (cit. on p. 11).

[18] *Geotechnical Instrumentation Model 6150 datasheet*. URL: www.geokon.com (cit. on p. 11).

[19] C. Li et al. "Use of MEMS accelerometers/inclinometers as a geotechnical monitoring method for ground subsidence". In: *Acta Geodynamica et Geomaterialia* (2014). ISSN: 12149705. DOI: 10.13168/AGG.2014.0015 (cit. on p. 11).

[20] W. Niu et al. "Summary of Research Status and Application of MEMS Accelerometers". In: *Journal of Computer and Communications* 06 (12 2018), pp. 215–221. ISSN: 2327-5219. DOI: 10.4236/jcc.2018.612021 (cit. on p. 11).

[21] *Geo Instruments*. URL: https://www.geo-instruments.com/ (visited on 2024-01-03) (cit. on p. 12).

[22] R. Correia dos Santos and J. Marcelino. "Development and laboratory testing of a low-cost wireless in-place inclinometer prototype". In: *Proceedings of the XVIII ECSMGE 2024. Geotechnical Engineering Challengers to Meet Current Emerging Needs of Society*. Ed. by SPG. ISSMGE, 2024. ISBN: 9781032548166 (cit. on pp. 15, 17, 18).

[23] R. A. Atmoko and R. Riantini. "IoT real time data acquisition using MQTT protocol". In: *Journal of Physics Conference Series* 853 (2017). DOI: 10.1088/1742-6596/853/1/012003 (cit. on p. 18).

[24] A. Protopsaltis et al. "Data visualization in internet of things: Tools, methodologies, and challenges". In: Association for Computing Machinery, 2020. ISBN: 9781450388337. DOI: 10.1145/3407023.3409228 (cit. on pp. 19, 20).

[25] M. F. Acevedo. *Real-Time Environmental Monitoring: Sensors and Systems*. CRC Press, 2015. ISBN: 9781482240207 (cit. on p. 19).

[26] K. Michalakis, J. Aliprantis, and G. Caridakis. "Visualizing the Internet of Things: Naturalizing Human-Computer Interaction by Incorporating AR Features". In: *IEEE Consumer Electronics Magazine* 7 (2018). ISSN: 21622256. DOI: 10.1109/MCE.2018.2797638 (cit. on p. 21).

[27] *Measurand Software*. URL: https://measurand.com/ (visited on 2024-01-03) (cit. on p. 22).

[28] *Geokon Software*. URL: https://www.geokon.com/SiteMaster (visited on 2024-01-04) (cit. on p. 23).

[29] S. Benbba. *Comparison of D3.js and Chart.js as visualization tools*. 2021 (cit. on p. 24).

[30] *Nivo*. URL: https://nivo.rocks/ (visited on 2023-12-26) (cit. on p. 24).

[31] *Recharts*. URL: https://recharts.org/ (visited on 2024-07-29) (cit. on p. 24).

[32] A. Soshin. *Kotlin Design Patterns and Best Practices: Build scalable applications using traditional, reactive, and concurrent design patterns in Kotlin*. 2nd ed. Packt Publishing, 2022. ISBN: 1801815720 (cit. on p. 28).

[33] *Kotlin*. URL: https://kotlinlang.org/ (visited on 2024-01-19) (cit. on p. 28).

[34] *Spring*. URL: https://spring.io/ (visited on 2024-01-18) (cit. on p. 29).

[35] A. Sarin and J. Sharma. *Getting started with Spring Framework: a hands-on guide to begin developing applications using Spring Framework*. 2nd ed. CreateSpace Independent Publishing Platform, 2014. ISBN: 1491011912 (cit. on p. 29).

[36] *React*. URL: https://react.dev/ (visited on 2023-12-17) (cit. on p. 30).

[37] A. Fedosejev. *React.js Essentials: A fast-paced guide to designing and building scalable and maintainable web apps with React.js*. Packt Publishing, 2015. ISBN: 9781783551620 (cit. on p. 31).

[38] *Tailwind CSS*. URL: https://tailwindcss.com/ (visited on 2024-07-26) (cit. on p. 33).

[39] *Material-UI*. URL: https://mui.com/ (visited on 2024-07-26) (cit. on p. 33).

[40] *InfluxDB*. URL: https://www.influxdata.com/ (visited on 2024-07-27) (cit. on p. 34).

[41] *PostGreSQL*. URL: https://www.postgresql.org/ (visited on 2024-07-28) (cit. on p. 34).

[42] *Google Cloud Firestore*. URL: https://cloud.google.com/firestore (visited on 2024-07-28) (cit. on p. 35).

[43] *Postman*. URL: https://www.postman.com/ (visited on 2024-07-29) (cit. on p. 36).

[44] *OpenAPI*. URL: https://swagger.io/specification/ (visited on 2024-07-26) (cit. on p. 37).

[45] A. Silberschatz, H. F. Korth, and S. Sudarshan. *Database system concepts*. McGraw-Hill, 2011, p. 1349. ISBN: 9780073523323 (cit. on pp. 40, 41).

[46] A. Silberschatz, H. Korth, and S. Sudarshan. *Database System Concepts*. 7th ed. McGraw-Hill Education, 2019. ISBN: 9781260084504 (cit. on p. 41).

[47] S. Krug. *Don't Make Me Think! A Common Sense Approach to Web Usability*. 1st ed. 2000. ISBN: 0321344758 (cit. on pp. 50, 51).

[48] F. Y. Liu, S. S. Bai, and Y. X. Gao. "Study on Information Graphics in Web Interface Design". In: *Advanced Materials Research* (2014). DOI: 10.4028/www.scientific.net/AMR.998-999.1257 (cit. on p. 50).

[49] R. Meeuwisse. *Cybersecurity for Beginners*. ISBN: 9781911452034 (cit. on p. 55).

[50] S. Peyrott. *JWT Handbook*. Auth0 Inc., 2018 (cit. on p. 56).

[51] M. Novak, I. Magdalenic, and D. Radosevic. "Common Metamodel of Component Diagram and Feature Diagram in Generative Programming". In: *Journal of Computer Science* 12 (2016). DOI: 10.3844/jcssp.2016.517.526 (cit. on p. 70).

[52] C. Natschläger, R. Dijkman, and J. Hofstetter. *Business Process Model and Notation: Third International Workshop*. 1st ed. Lecture Notes in Business Information Processing №95. Springer, 2011. ISBN: 3642251609 (cit. on p. 72).

[53] S. W. Ambler. *The Elements of UML 2.0 Style*. Cambridge University Press, 2005. ISBN: 0521616786 (cit. on p. 74).

[54] J. Wagner. *Web Performance in Action: Building Faster Web Pages*. 1st ed. Manning Publications, 2017. ISBN: 1617293776 (cit. on p. 90).

[55] M. B. Kinzie. "A User-centered Model for Web Site Design: Needs Assessment, User Interface Design, and Rapid Prototyping". In: *Journal of the American Medical Informatics Association* 9 (2002). DOI: 10.1197/jamia.M0822 (cit. on p. 95).

[56] D. Nugraheni, I. Alicy, and B. Noranita. "Usability evaluation to approve an information system design - case study: Immunization monitoring interface design". In: *E3S Web of Conferences* 125 (2019). DOI: 10.1051/e3sconf/201912523014 (cit. on p. 100).

I

Entity Relationship Diagram

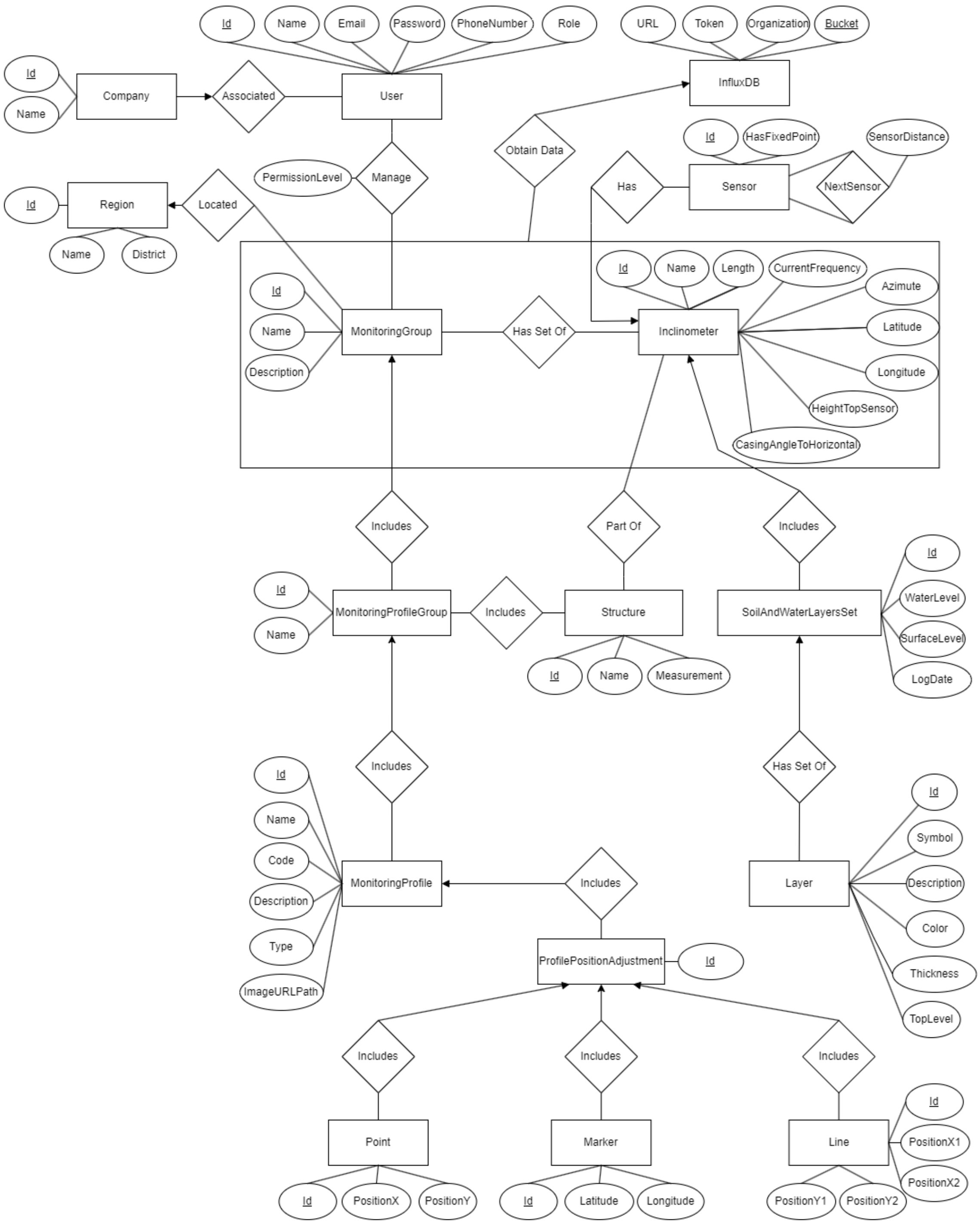


Figure I.1: Entity Relationship Diagram.

II

Data Dictionary

Inclinometer			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	I1
Latitude	FLOAT		41.55680
Longitude	FLOAT		-6.89017
Azimuth	INT		90
Length	FLOAT		51
CurrentFrequency	INT		231552000
HeightTopSensor	FLOAT		606
CasingAngleToHorizontal	INT		0

MonitoringGroup			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	Azibo's dam
Description	VARCHAR		Azibo's dam monitoring
RegionId	VARCHAR	FK	Macedo de Cavaleiros

MonitoringGroup_Inclinometer			
Name	Data Type	Restrictions	Example
MonitoringGroupId	INT	PK, FK	1
InclinometerId	INT	PK, FK	1
Bucket	VARCHAR	FK, NOT NULL	Inputs

Region			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	Macedo de Cavaleiros
District	VARCHAR	NOT NULL	Bragança

Sensor			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
SensorId	VARCHAR	NOT NULL	4
HasFixedPoint	BOOLEAN	NOT NULL	TRUE
InclinometerId	INT	FK, NOT NULL	1

NextSensor			
Name	Data Type	Restrictions	Example
SensorId1	INT	PK, FK	1
SensorId2	BOOLEAN	PK, FK	2
SensorDistance	FLOAT	NOT NULL	50

InfluxDB			
Name	Data Type	Restrictions	Example
Bucket	VARCHAR	PK	Inputs
URL	VARCHAR	NOT NULL	https://influxdb.com
Token	VARCHAR	NOT NULL	5q-pfsRjWHQvyFZqhkER
Organization	VARCHAR	NOT NULL	6632b480819

MonitoringProfileGroup			
Name	Data Type	Restrictions	Example
Id	VARCHAR	PK	1
Name	VARCHAR	NOT NULL	Azibo's dam profiles
MonitoringGroupId	INT	FK, NOT NULL	1

Structures			
Name	Data Type	Restrictions	Example
Id	VARCHAR	PK	PK250_300
Name	VARCHAR	NOT NULL	Azibo's dam
Measurement	VARCHAR	NOT NULL	DamX

Structure_Inclinometer			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
StructureId	VARCHAR	FK, NOT NULL	PK250_300
InclinometerId	INT	FK, NOT NULL	1

Structure_MonitoringProfileGroup			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
StructureId	VARCHAR	FK, NOT NULL	PK250_300
MonitoringProfileGroupId	INT	FK, NOT NULL	1

MonitoringProfile			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	Azibo's dam profiles
Code	VARCHAR	NOT NULL	P1
Description	VARCHAR	NOT NULL	Inc 1 and 2
Type	VARCHAR	NOT NULL	PLAN
ImageURLPath	VARCHAR		https://firebaseURL.com
MonitoringProfileGroupId	INT	FK, NOT NULL	1

ProfilePositionAdjustment			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
MonitoringProfileId	INT	FK, NOT NULL	1

Point			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
PositionX	FLOAT		294.01108323444424
PositionY	FLOAT		139.10776712689537
MonitoringProfileId	INT	FK, NOT NULL	1

Marker			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Latitude	FLOAT		41.55680
Longitude	FLOAT		-6.89017
MonitoringProfileId	INT	FK, NOT NULL	1

Line			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
PositionX1	FLOAT		294.01108323444424
PositionY1	FLOAT		139.10776712689537
PositionX2	FLOAT		397.35154340739814
PositionY2	FLOAT		153.8640976749052
MonitoringProfileId	INT	FK, NOT NULL	1

SoilAndWaterLayersSet			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
WaterLevel	FLOAT		600
SurfaceLevel	FLOAT		606
LogDate	VARCHAR	NOT NULL	2024-04-26 00:00:00
InclinometerId	INT	FK, NOT NULL	1

Layer			
Name	Data Type	Restrictions	
Id	INT	PK	1
Symbol	VARCHAR	NOT NULL	ZG2B
Description	VARCHAR	NOT NULL	BedRock
Color	VARCHAR	NOT NULL	#10b981
Thickness	FLOAT	NOT NULL	2.1
TopLevel	FLOAT	NOT NULL	452.25
SoilAndWaterLayersId	INT	FK, NOT NULL	1

User_MonitoringGroup			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
MonitoringGroupId	INT	FK, NOT NULL	1
UserId	INT	FK, NOT NULL	1
PermissionLevel	VARCHAR	NOT NULL	ADMIN

User			
Name	Data Type	Restrictions	Example
Id	INT	PK	1
Name	VARCHAR	NOT NULL	João
Email	VARCHAR	NOT NULL	joao@email.com
Password	VARCHAR	NOT NULL	$2a$10$v6YZMUwl
PhoneNumber	INT		123456789
Role	VARCHAR	NOT NULL	ADMIN
CompanyId	INT	FK,NOT NULL	1

Company			
Name	Data Type	Restrictions	Example
Id	VARCHAR	PK	1
Name	VARCHAR	NOT NULL	LNEC

III

User Surveys

User Surveys

"Development of a Web Interface for an Inclinometer Monitoring System"

Introduction

This survey is going to be conducted as part of a master's dissertation, involving a comprehensive project developed within a research protocol between the *Laboratório Nacional de Engenharia Civil (LNEC)* and *Ascendi*. The development of this project is based on a data collection system from sensors embedded in a low-cost inclinometer prototype, which served as the starting point for the dissertation.

Processing the data collected by the sensors is essential, and its analysis provides a structured method to evaluate subsurface characteristics and the safety of surrounding structures.

This dissertation culminates in the development of a web application designed to manage, store, and visualize the data collected by the sensors in a concise and intuitive manner.

The web application aims to stand out from existing solutions by offering an interactive, simple, and intuitive system, enabling faster and more effective graphical visualization and analysis. The system also allows for monitoring group management and the visualization and correction of profiles based on images.

Initial Profiling

- On a scale from 0 to 5, evaluate your knowledge of inclinometer monitoring techniques, where 0 means no knowledge and 5 means total knowledge.

- Have you ever used any application for visualization and analysis of data from inclinometers? (Yes / No):

  If your answer is yes, could you specify which application?

User Surveys

“Development of a Web Interface for an Inclinometer Monitoring System”

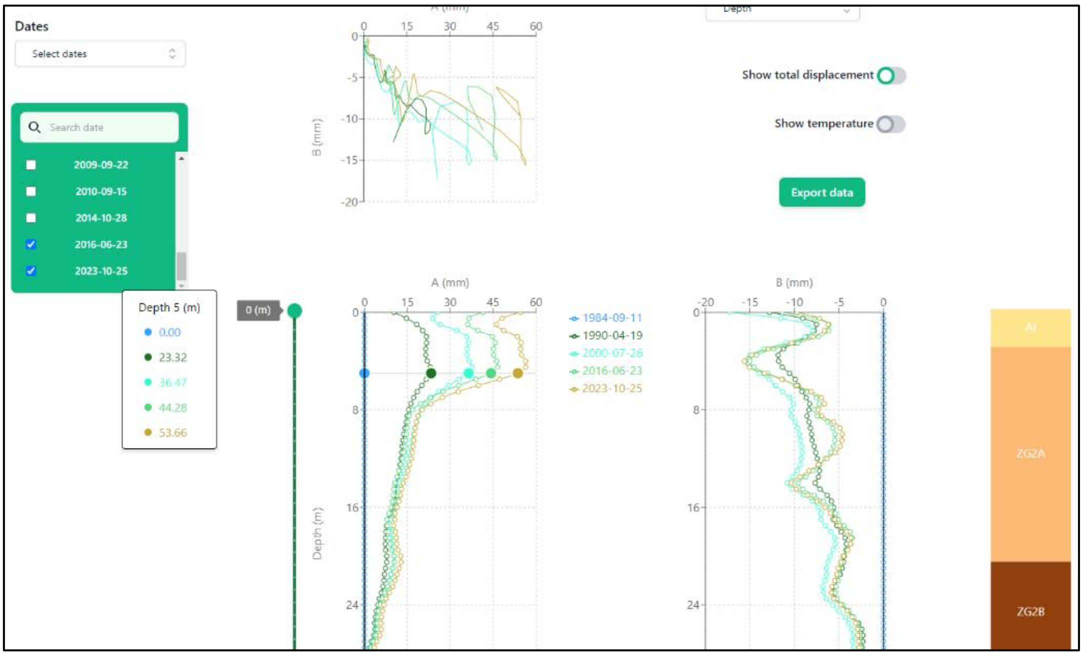
Test 1 – Visualization of an individual inclinometer

Description:

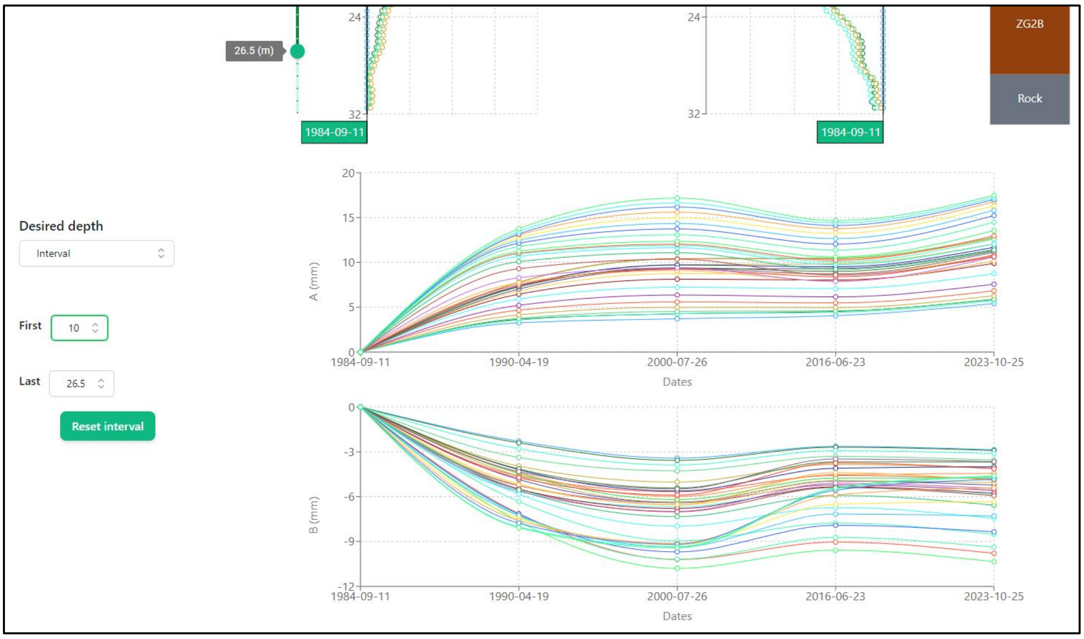
Dynamic interaction with the graphs allows for a quick and simple analysis. Integration with various filters enables more efficient analysis compared to traditional methods. These filters include multiple parameters that allow filtering by result type, date (either through time intervals or by selecting specific dates), structure to be analyzed, inclinometer, and depth.

How to perform:

1. Select the "Visualization of Results" tab on the side menu;
2. Ensure the following information is selected:
    a. Inclinometer – 1
    b. Structure – “Barragem do Azibo”
    c. Type of result– Cumulative displacements
3. By default, the five most recent dates and the reference date are selected. Select the "Select dates" option in the "Dates" filter, remove the dates for the years 2009, 2010, and 2014, and add the dates for the years 1990 and 2000;
4. Compare the displacement values obtained at 5 meters depth in the graph for orthogonal direction A by depth ("A/Depth" graph) with the values obtained at 24 meters depth in the same graph. What conclusions can you draw from this comparison?
5. Try to find the displacement at 10.5 meters and 15.5 meters depth in the year 2000 in the graph corresponding to the orthogonal direction A for the selected dates (“A/Dates” graph). Adjust the depth limits to facilitate the reading, either by choosing the depth range or using the slider next to the “A/Depth” graph.



Dates
Select dates
Search date
2009-09-22
2010-09-15
2014-10-28
2016-06-23
2023-10-25
Depth 5 (m)
0.00
23.32
36.47
44.28
53.66
0 (m)
Show total displacement
Show temperature
Export data
A (mm)
B (mm)
Depth (m)
1984-09-11
1990-04-19
2000-07-26
2016-06-23
2023-10-25
Al
ZG2A
ZG2B



26.5 (m)
1984-09-11
1984-09-11
ZG2B
Rock
Desired depth
Interval
First
10
Last
26.5
Reset interval
A (mm)
B (mm)
Dates
1984-09-11
1990-04-19
2000-07-26
2016-06-23
2023-10-25

2

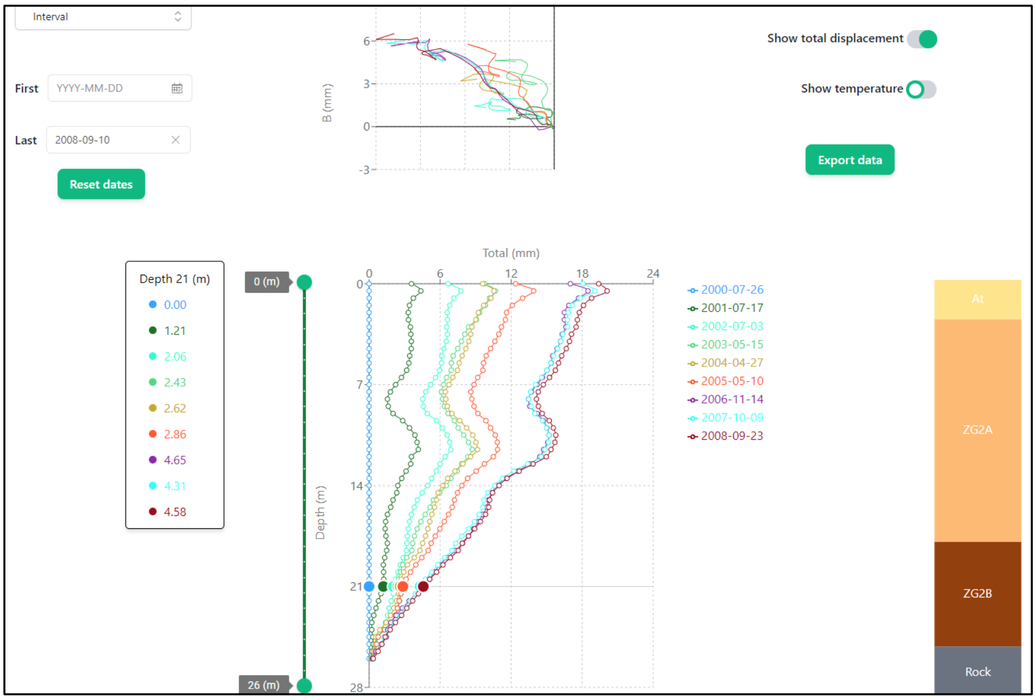
Test 2 – Visualization of an individual inclinometer

Description:

The reference date allows for a visualization of the data from the moment the first measurement was taken, after the inclinometer was installed. If necessary, it is possible to change it to a desired specific date or to the date chosen through the date range. Besides the graphs related to displacements in orthogonal directions A and B, the user can choose to view the graphs for total displacement and the recorded temperature.

How to perform:

1. Start by selecting inclinometer 4;
2. Using the specific dates selection you used previously (“Select dates” on filter “Dates”), activate all available dates;
3. After verifying the changes, switch the reference date option to “From interval,” allowing you to set the reference date based on the start date of the interval;
4. Choose the desired day and month of the year 1998 for the start date and the desired day and month of the year 2015 for the end date from the calendar;
5. Can you determine the value obtained in 2014 at a depth of 4 meters?
6. Finally, switch the view to the graphs related to total displacement using the "Show total displacement" option and compare the readings obtained at the surface and at 21 meters depth on the selected dates.



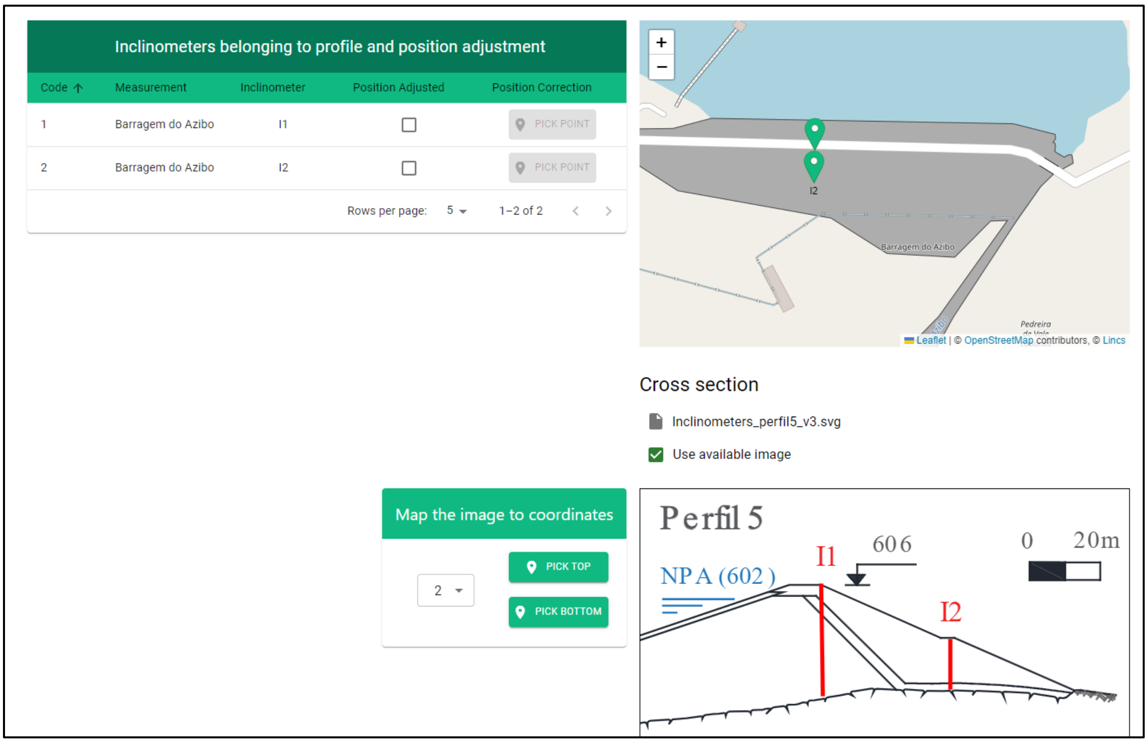
Test 3 - Adding and defining a monitoring profile and plan

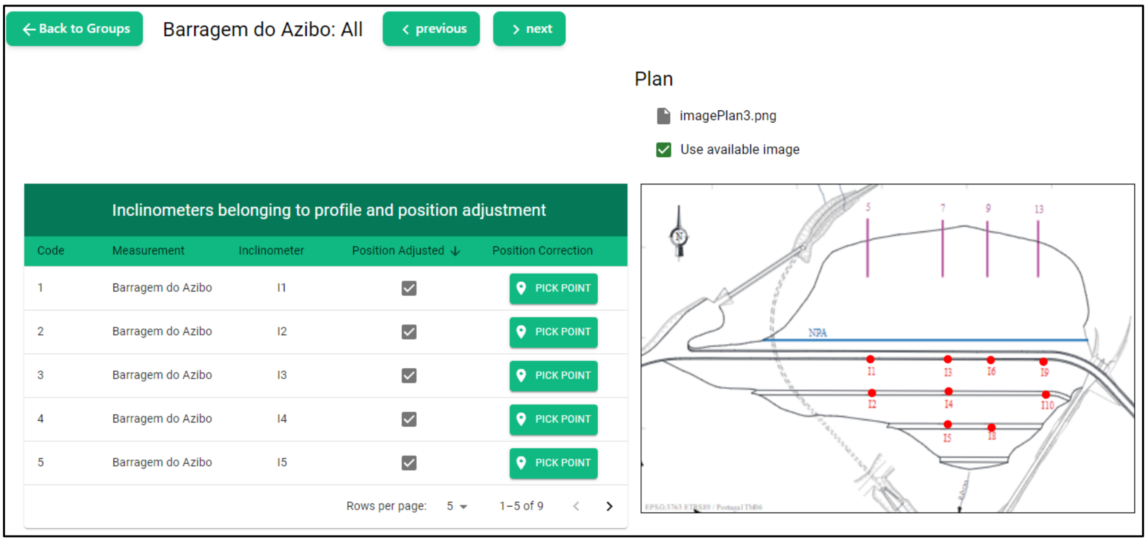
Description:

The application allows grouping inclinometers by profile, which represents a vertical cut of terrain. Each set of inclinometers can be represented in plans or cross sections. The user's choice determines how interaction with the application is possible. In the case of a cross section, the user can add lines corresponding to the position of each inclinometer in the profile. If it's a plan, it allows for an interactive aerial view of the location where the inclinometers are situated.

How to perform:

1. Open the side menu and click on the option corresponding to the "Monitoring profiles" tab.
2. Within this page, select the group corresponding to readings taken at "Barragem do Azibo";
3. Next, locate profile "P5" and add the corresponding image found in the indicated folder;
4. After adding the image, click on the profile and in the section corresponding to the cross section, select the option indicating that you want to use the available image ("Use available image");
5. In this case, there are 2 inclinometers associated with this profile and it will be necessary to define the relative position of each inclinometer. Choose a reference point above and below by clicking directly on the image for each inclinometer present in the profile. If it is not in a position you find suitable, you can change it following the same steps;
6. Return to the monitoring groups using the "Back to Groups" button at the top of the page and select the available plan ("Plan");
7. Select the option that allows you to view the available image ("Use available image") ;
8. On the plan, there are 9 associated inclinometers and some are already represented in the figure. Try to complete the remaining ones so that all are assigned a position. To add and adjust the position of each inclinometer, you will need to use the "Pick Point" button present in each row of the table.


Inclinometers belonging to profile and position adjustment
Code
Measurement
Inclinometer
Position Adjusted
Position Correction
1
Barragem do Azibo
I1
PICK POINT
2
Barragem do Azibo
I2
PICK POINT
Rows per page: 5
1–2 of 2
Leaflet | © OpenStreetMap contributors, © Lincs
Barragem do Azibo
Cross section
Inclinometers_perfil5_v3.svg
Use available image
Map the image to coordinates
2
PICK TOP
PICK BOTTOM
Perfil 5
NPA (602)
606
I1
I2
0
20m


Back to Groups
Barragem do Azibo: All
previous
next
Plan
imagePlan3.png
Use available image
Inclinometers belonging to profile and position adjustment
Code
Measurement
Inclinometer
Position Adjusted
Position Correction
1
Barragem do Azibo
I1
PICK POINT
2
Barragem do Azibo
I2
PICK POINT
3
Barragem do Azibo
I3
PICK POINT
4
Barragem do Azibo
I4
PICK POINT
5
Barragem do Azibo
I5
PICK POINT
Rows per page: 5
1–5 of 9
NPA

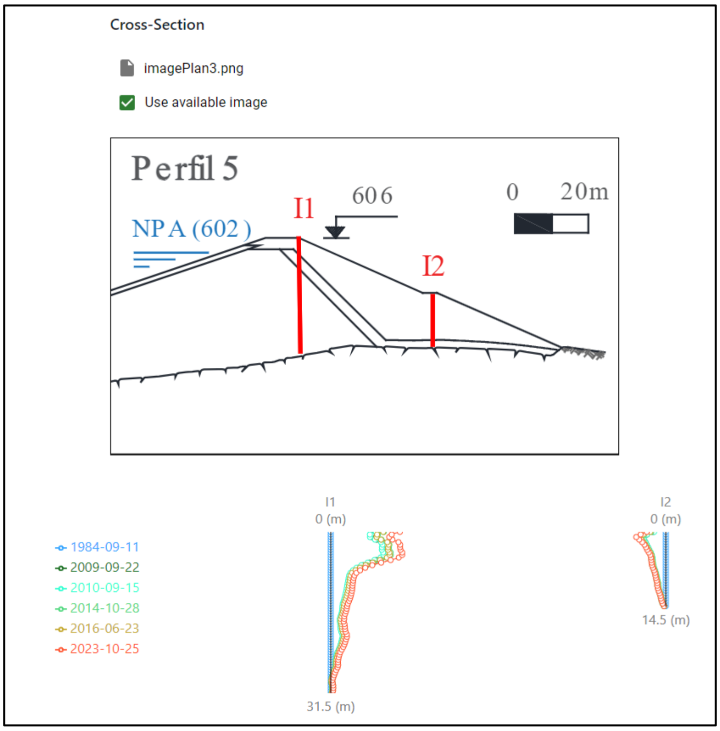
Test 4 - Visualization of a monitoring profile

Description:

The data previously entered on the profiles tab can be viewed under the "Profile" visualization option. This tab displays various profiles and their respective data. If it is a cross-section, the user can analyze the corrected positions of the profiles and the data related to the inclinometers, both in graphical visualization and in a table format. If the user wishes, they can also change the displayed displacement value to correspond to the value relative to the surface, for the sensor that recorded the maximum displacement.

How to perform:

1. Return to the menu tab that corresponds to the visualization of results;
2. Change the visualization type to "Profile";
3. Select the profile "P5";
4. Select the option that allows you to view the available image ("Use available image") in the cross-section part of the profile and verify if the changes made earlier in the third test are correctly positioned;
5. Next, look in the table for the data regarding the displacement value in orthogonal direction A on inclinometer 2 on the date "2010-09-15".
6. Change to "Max" displacement in the "Displacements at" filter. Search the table again for the data regarding the displacement value in orthogonal direction A on inclinometer 2 on the date "2010-09-15". What conclusions can you draw from this comparison?


Cross-Section
imagePlan3.png
Use available image
Perfil 5
NPA (602)
I1
606
I2
0
20m
I1
0 (m)
31.5 (m)
I2
0 (m)
14.5 (m)
1984-09-11
2009-09-22
2010-09-15
2014-10-28
2016-06-23
2023-10-25

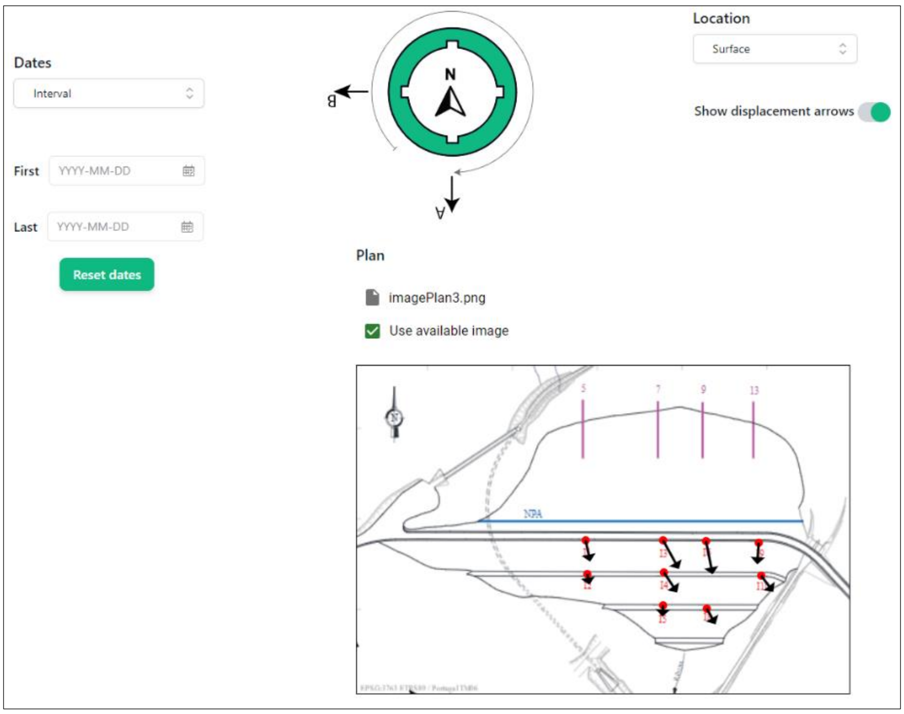
Test 5 - Visualization of a plan

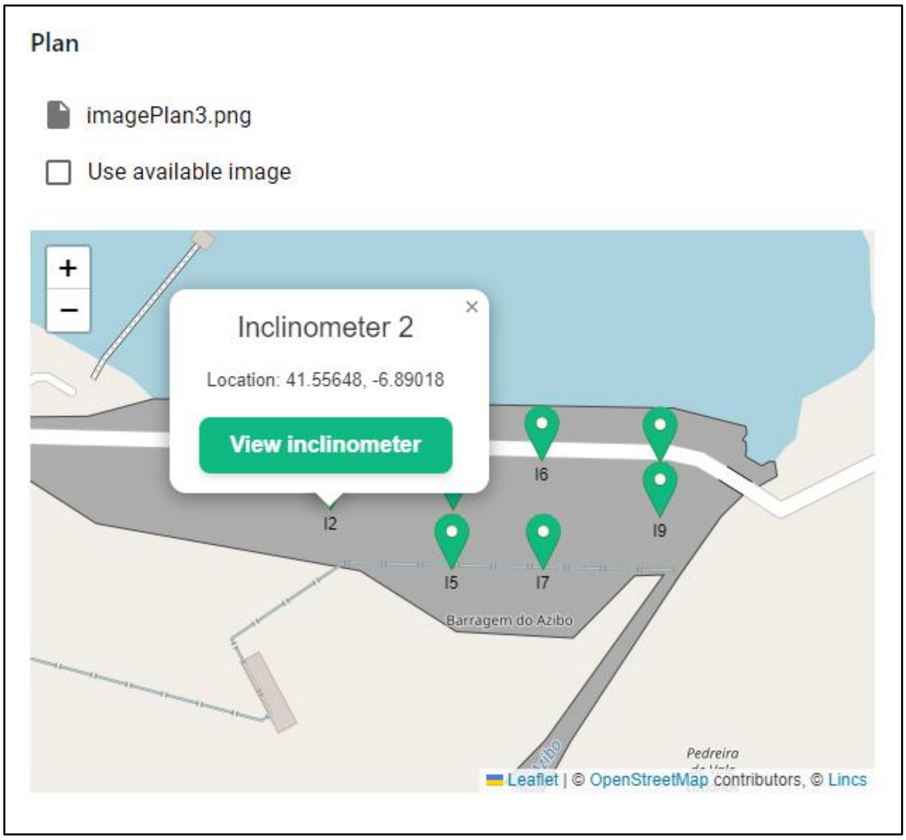
Description:

If the user wishes to analyze a site plan, the displayed data includes all inclinometers present, enabling analysis in both orthogonal directions and the total displacement. It also allows visualization of relative displacement on the most recent date directly on the figure, enabling a more effective analysis of the direction of displacement.

How to perform:

1. Select the profile "All";
2. Using the available image ("Use available image"), view the points added in test 2;
3. Activate the button that allows visualization of displacement for the most recent date using arrows on the figure ("Show displacement arrows");
4. Can you conclude what is the predominant direction of displacement?
5. Return to the aerial view with representation on the map, deactivate the associated image, and click on an inclinometer on the map of your choice;
6. Click on the marked button at the chosen point to view the data related to that inclinometer.




Plan
imagePlan3.png
Use available image
Inclinometer 2
Location: 41.55648, -6.89018
View inclinometer
I6
I9
I2
I5
I7
Barragem do Azibo
Pedreira
Leaflet | © OpenStreetMap contributors, © Lincs

Feedback – Specific to Web Ui Testing

Questions - 1 to 5 rating

1. How successful were you in completing the tasks assigned during the web UI testing?
2. How easy was it to find ways to perform the assigned tasks within the web interface?
3. How easy was it to navigate around the web interface?
4. How responsive was the interface to your actions (clicks, hovering, etc.)?

Feedback – General

Questions - 1 to 5 rating

1. How easy was it to use the website overall?
2. How intuitive was the website to use?
3. How appealing did the website's visual design appear?
4. How easy was it to read the text on the website due to the color and font choices?
5. How well-organized was the website's structure?

Feedback – Inclinometer monitoring knowledge

Questions - 1 to 5 rating (If previous used another inclinometer monitoring application)

1. How did the chart interactions on this website compare to other applications?
2. How did the profile monitoring features on this website compare to other applications?

Comment / suggestions / bug report

- Did you encounter any technical problems while using the website? If so, please describe them.
- Do you have any suggestions for improvement or bug reports? Please share them.

Feedback – Specific to Web Ui Testing

Pergunta	1	2	3	4	5
1					
2					
3					
4					

Feedback – General

Pergunta	1	2	3	4	5
1					
2					
3					
4					
5					

Feedback – Inclinometer monitoring knowledge

(If you previous used another inclinometer monitoring application)

Pergunta	1	2	3	4	5
1					
2					

Comment / suggestions

IV

User Surveys Suggestions

Suggestions	Implementation Status
The "Select dates" option, currently using a dropdown element, could be replaced with radio buttons for improved clarity between the two available options	This suggestion was implemented
Addition of labels to each chart's area to enhance the user's understanding of different sections of the interface.	This suggestion was implemented
Addition of another "Current Reference Date" label closer to the reference date selection element	This suggestion was implemented
The placement "Select dates" option element could be closer to the reference date, grouping all the date related options	This suggestion was implemented
Addition of scroll buttons for easier navigation up and down the page	This suggestion was implemented
Possibility to enable the automatic selection of the "Bottom" or "Top" option after one is chosen in the monitoring profile adjustment of the cross-section, eliminating the need to manually click the remaining option	Future work could focus on implementing improvements from this suggestion
Possibility to keep the "All dates" option in the "Select Specific Dates" element always visible when scrolling	Future work could focus on implementing improvements from this suggestion
Possibility of having a reference line in the displacements in an orthogonal direction over dates chart	Future work could focus on implementing improvements from this suggestion
Addition of a feature that allows for the selection of a specific depth directly on the displacements charts in the orthogonal direction over dates	Future work could focus on implementing improvements from this suggestion
Addition of displacement rates to certain part of the displacements chart to enhance the visualization	Future work could focus on implementing improvements from this suggestion
Possibility to allow different azimuths to be displayed alongside the inclinometer in a monitoring profile when required	Future work could focus on implementing improvements from this suggestion

Addition of water level lines in the displacement charts	Future work could focus on implementing improvements from this suggestion
Possibility of adjusting the orientation of charts for inclinometers that are not placed in a vertical orientation	Future work could focus on implementing improvements from this suggestion

V

Web Interface Mock-Ups

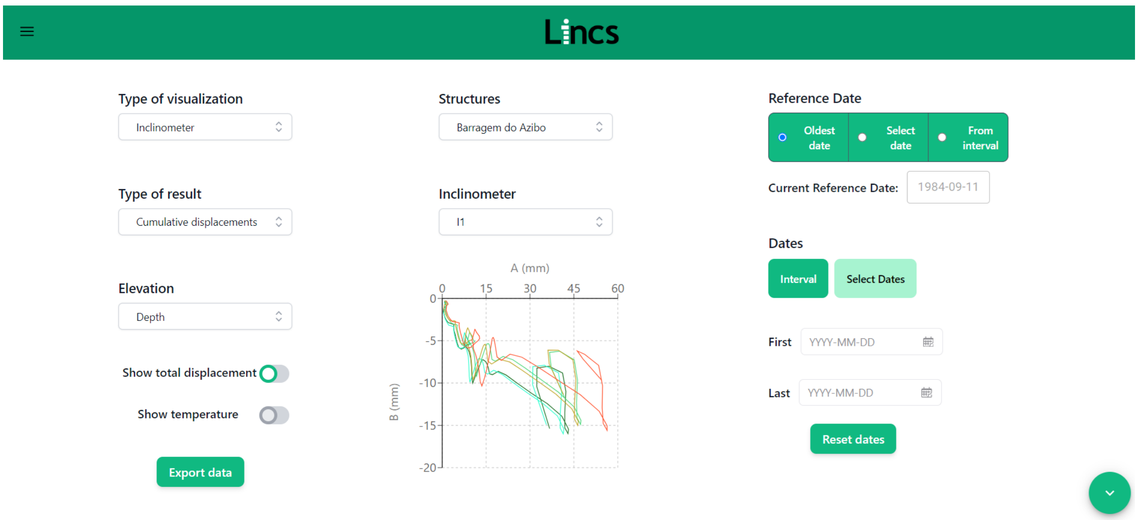


Figure V.1: Filters in the visualization of individual inclinometers page.

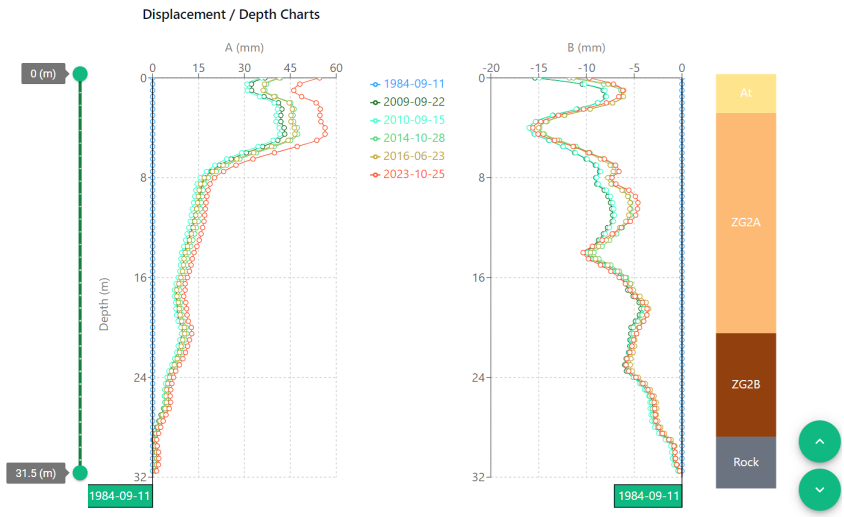


Figure V.2: Displacement/Depth charts and soil layer chart in the visualization of individual inclinometers page.

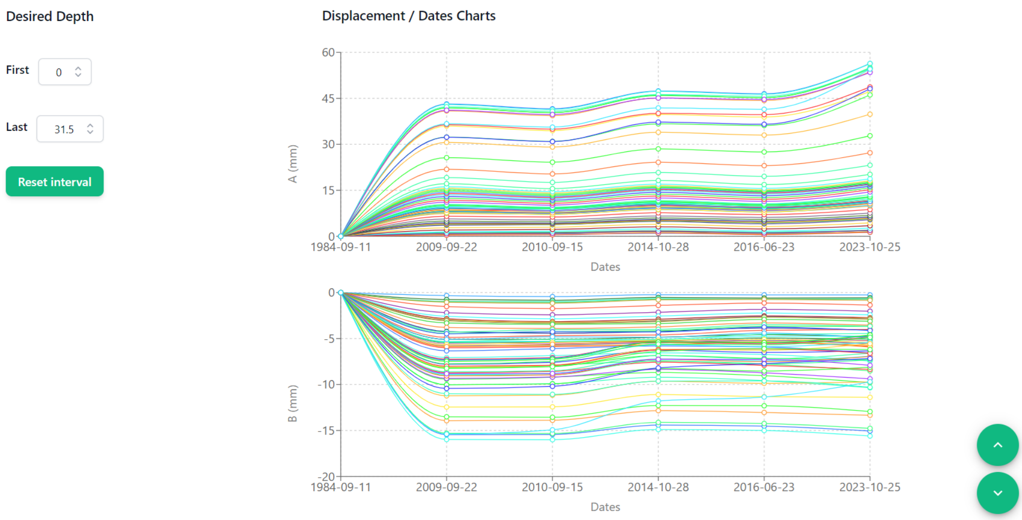


Figure V.3: Displacement/Dates charts in the visualization of individual inclinometers page.

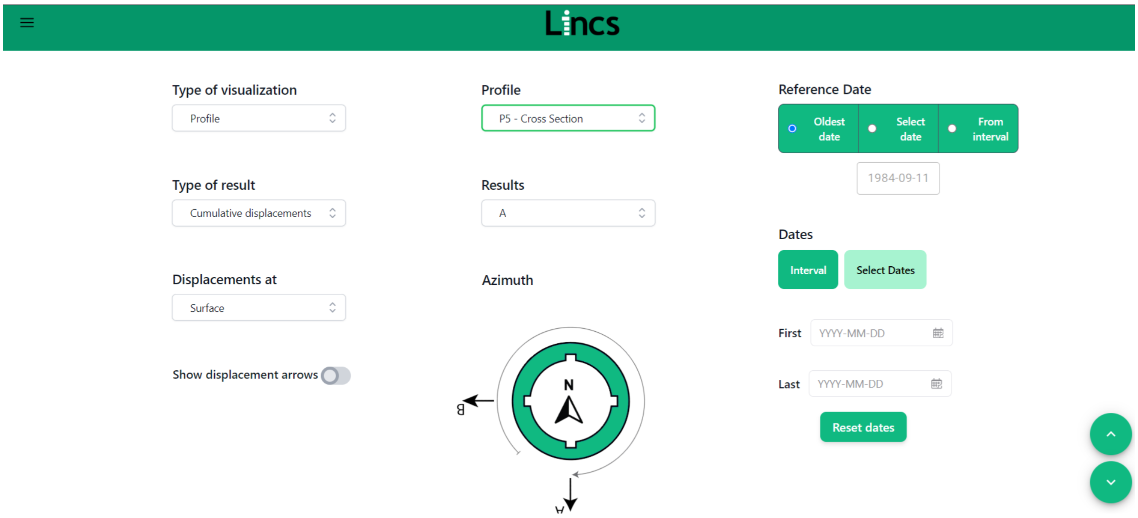


Figure V.4: Profile filters in the visualization of profiles page.

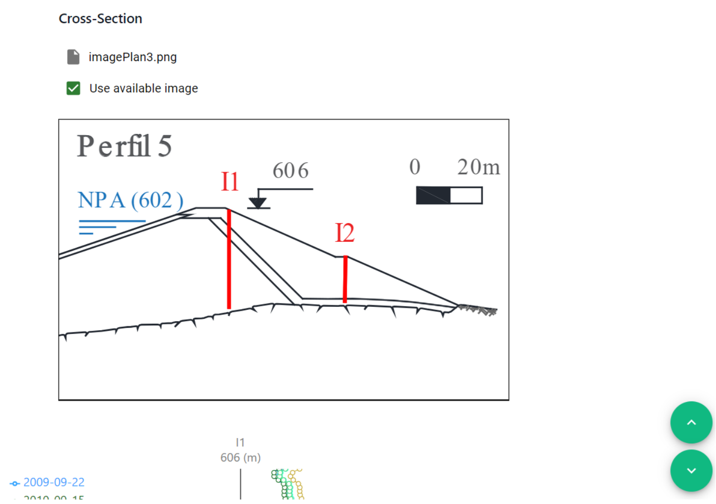


Figure V.5: Cross-section profile relative displacement viewing in the visualization of profiles page.

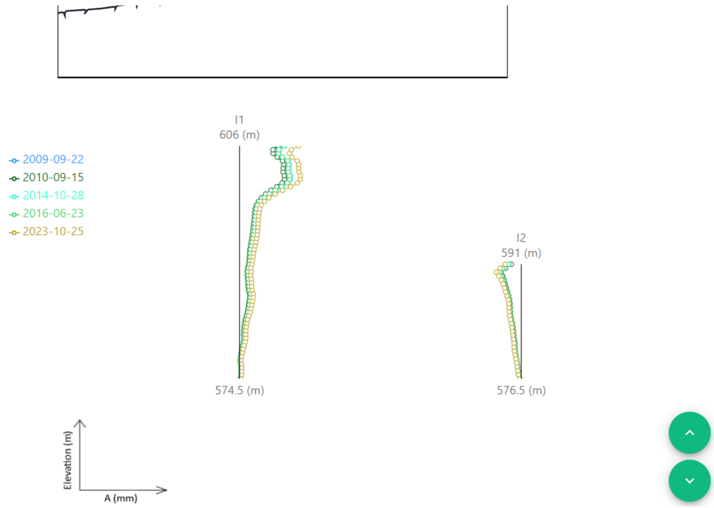


Figure V.6: Cross-section profile scaled charts in the visualization of profiles page.

Summary of Results

Incl	A (mm)	B (mm)	Total (mm)	Direction (°)	Node	Level (m)	Date
1	36.71	-15.39	39.81	90	Surface	606	2009-09-22
1	35.62	-14.93	38.62	90	Surface	606	2010-09-15
1	41.88	-11.79	43.51	90	Surface	606	2014-10-28
1	41.43	-11.36	42.96	90	Surface	606	2016-06-23
1	54.56	-9.7	55.42	90	Surface	606	2023-10-25

Rows per page: 5 1–5 of 10

Figure V.7: Data table in the visualization of profiles page.

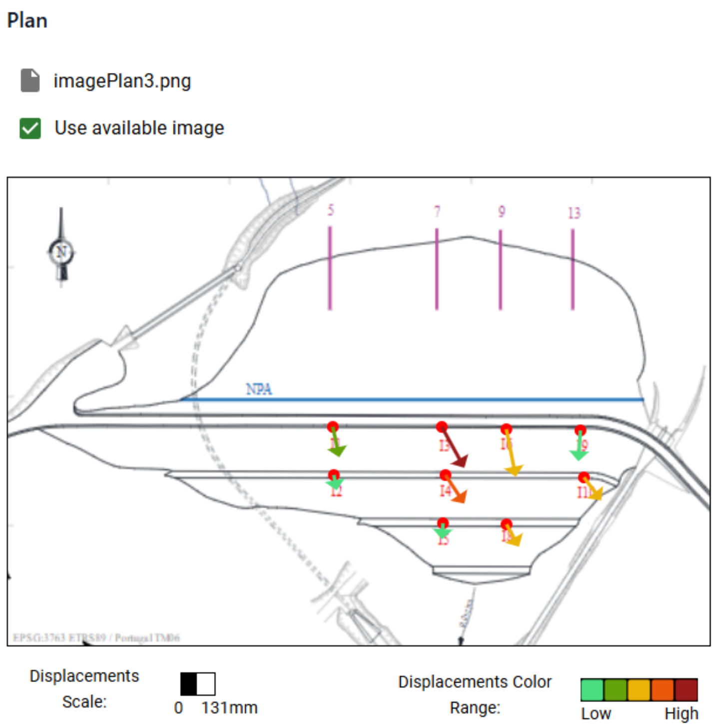


Figure V.8: Displacement arrows feature on top of a plan in the visualization of profiles page.

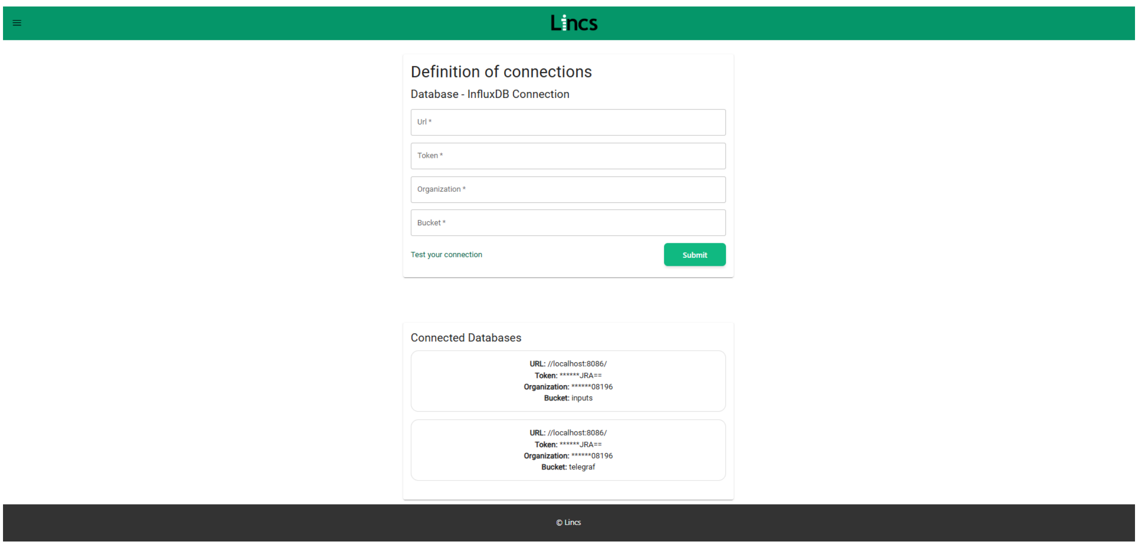


Figure V.9: Definition of connection in the settings page.

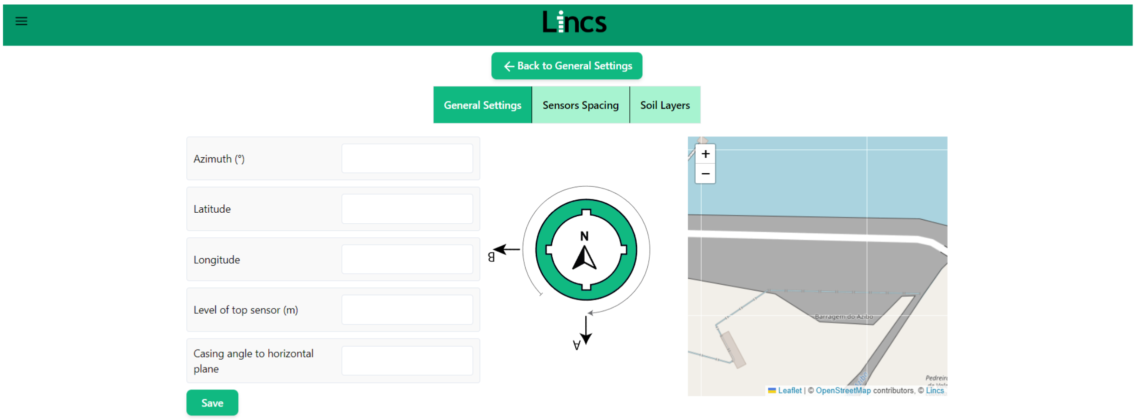


Figure V.10: General settings in the monitoring groups page.

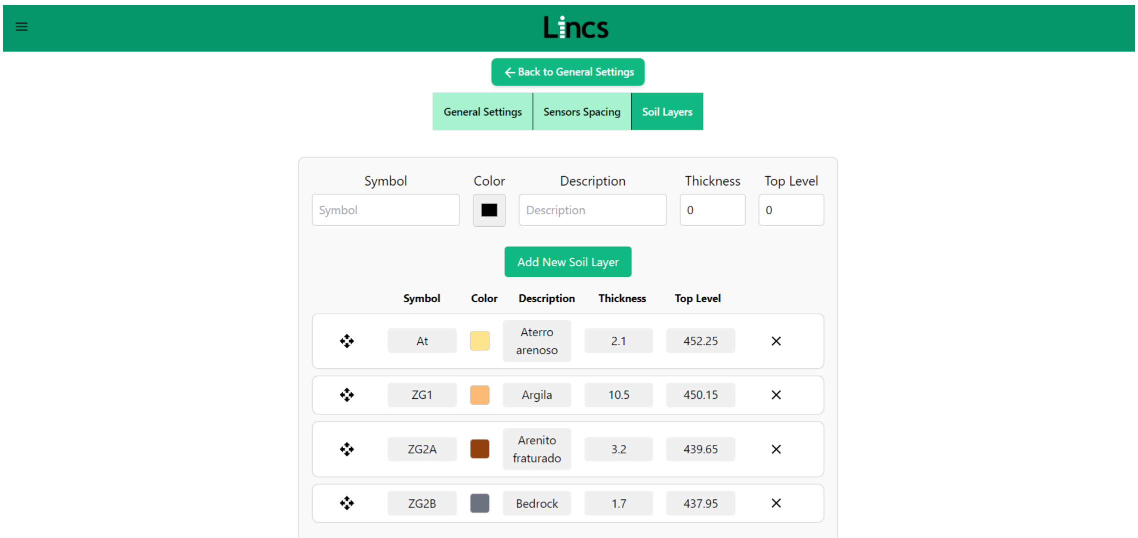


Figure V.11: Soil layers management in the monitoring groups page.

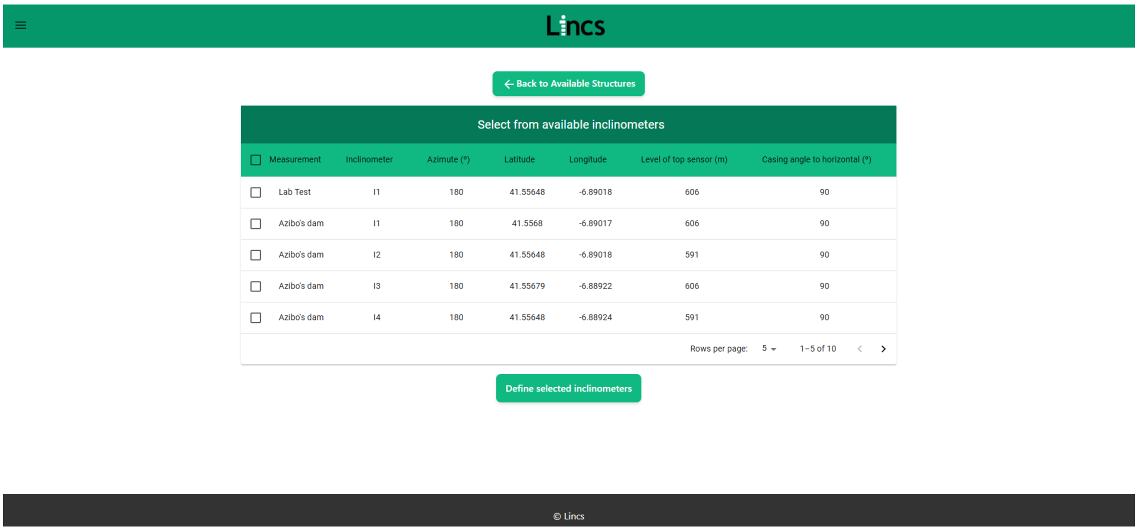


Figure V.12: Available inclinometers management in the monitoring groups page.

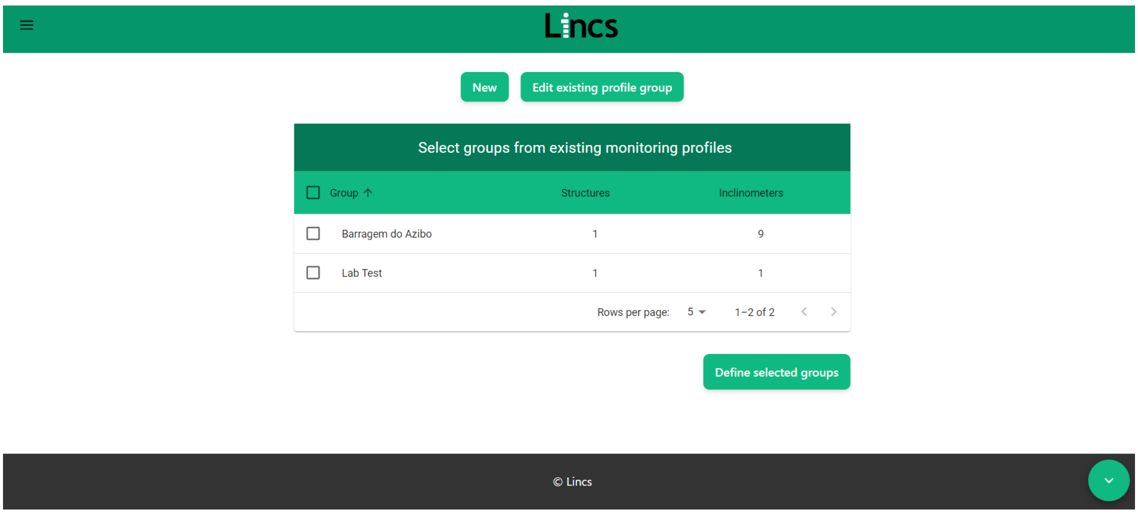


Figure V.13: Monitoring profiles groups management in the monitoring profiles page.

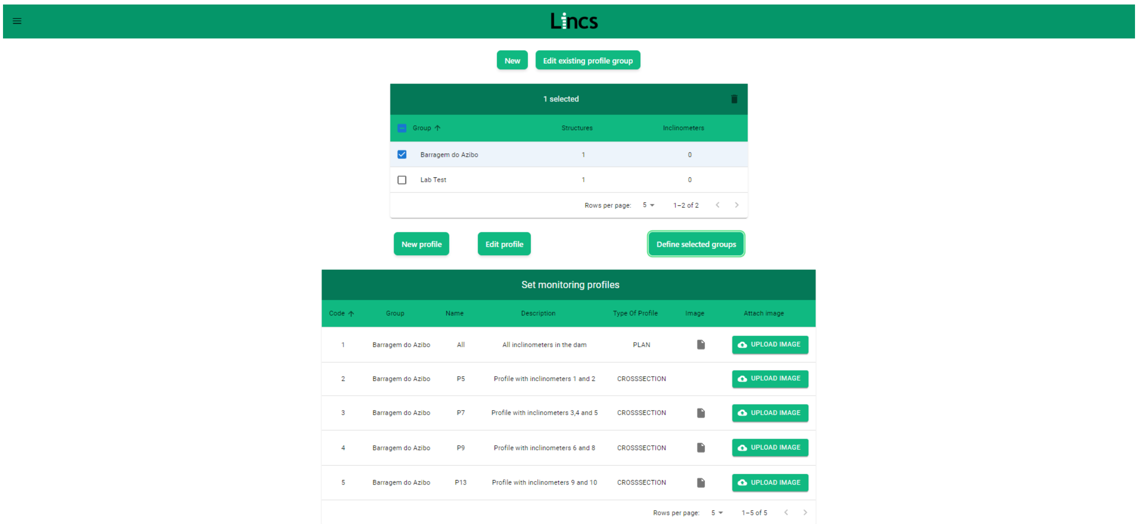


Figure V.14: Monitoring profiles management in the monitoring profiles page.

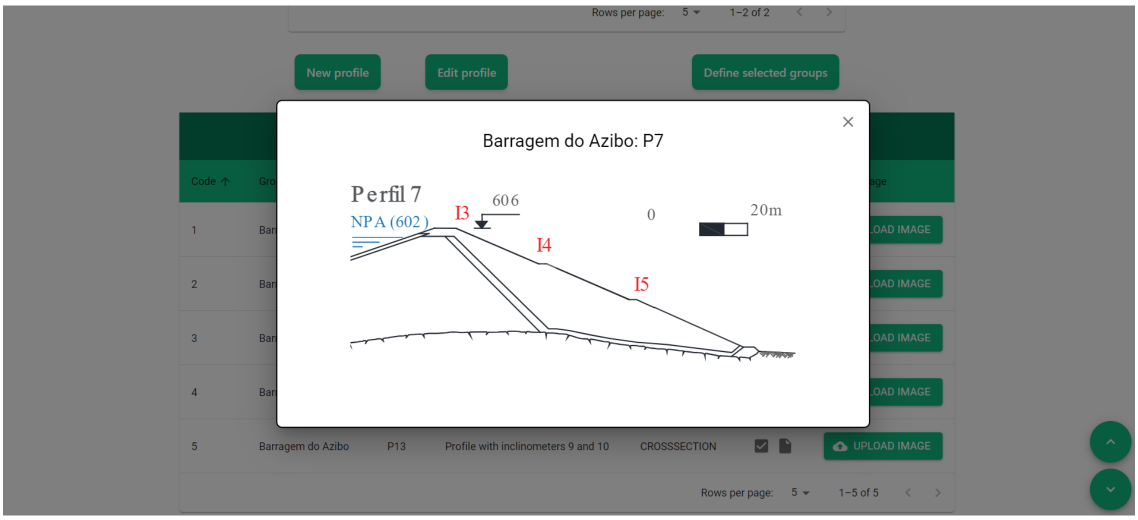


Figure V.15: Uploaded image view in the monitoring profiles page.

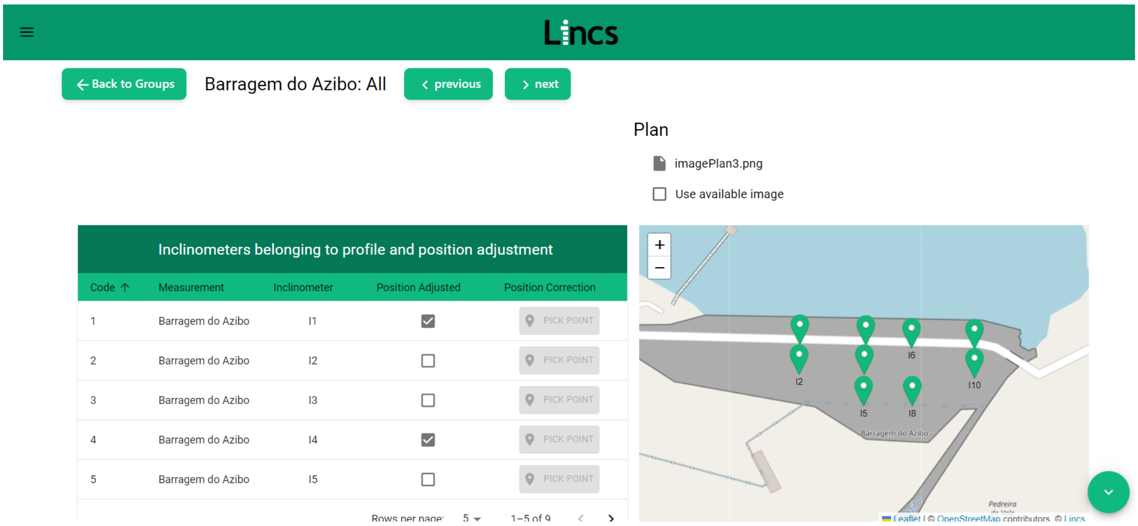


Figure V.16: Plan aerial map view in the monitoring profiles page.

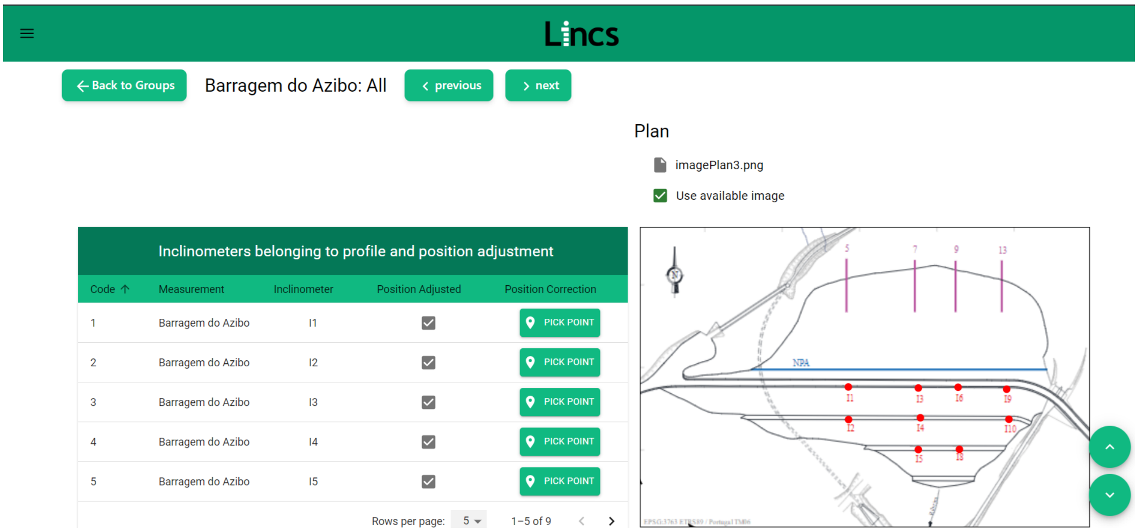


Figure V.17: Correction of positions of the inclinometers in a plan in the monitoring profiles page.

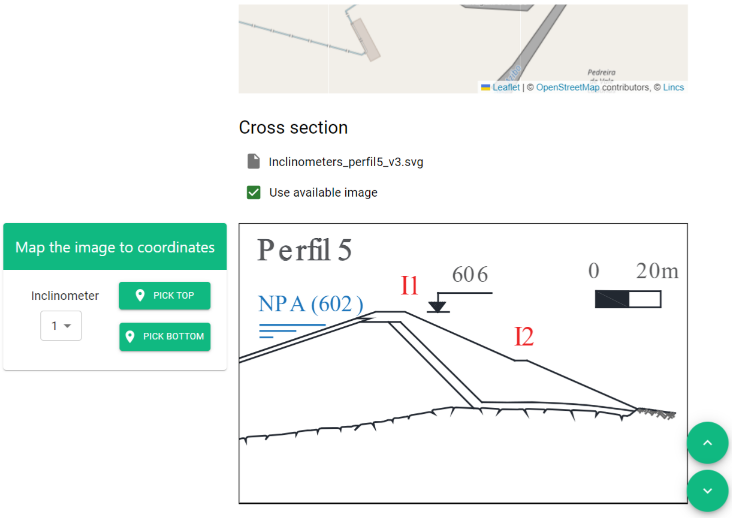


Figure V.18: Correction of positions of the inclinometers in a cross-section in the monitoring profiles page.

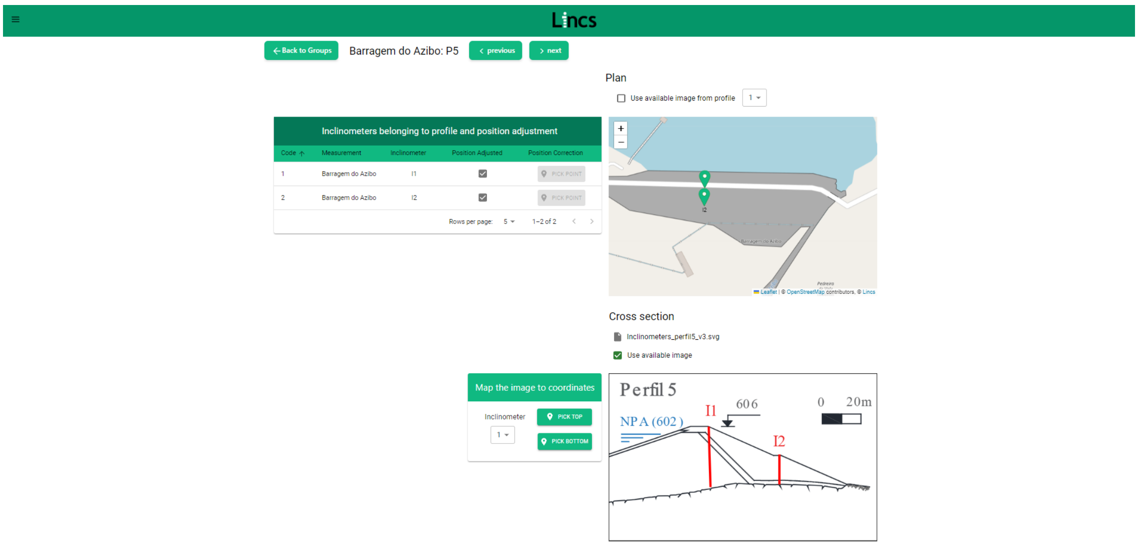


Figure V.19: Complete view of the correction of positions in a cross-section in the monitoring profiles page.

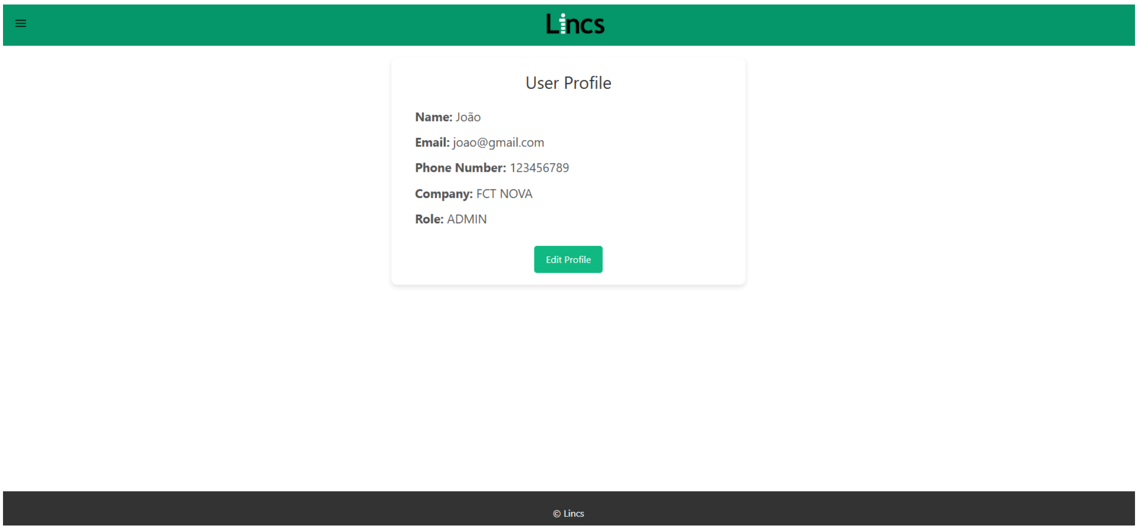


Figure V.20: User related data in the user profile page.

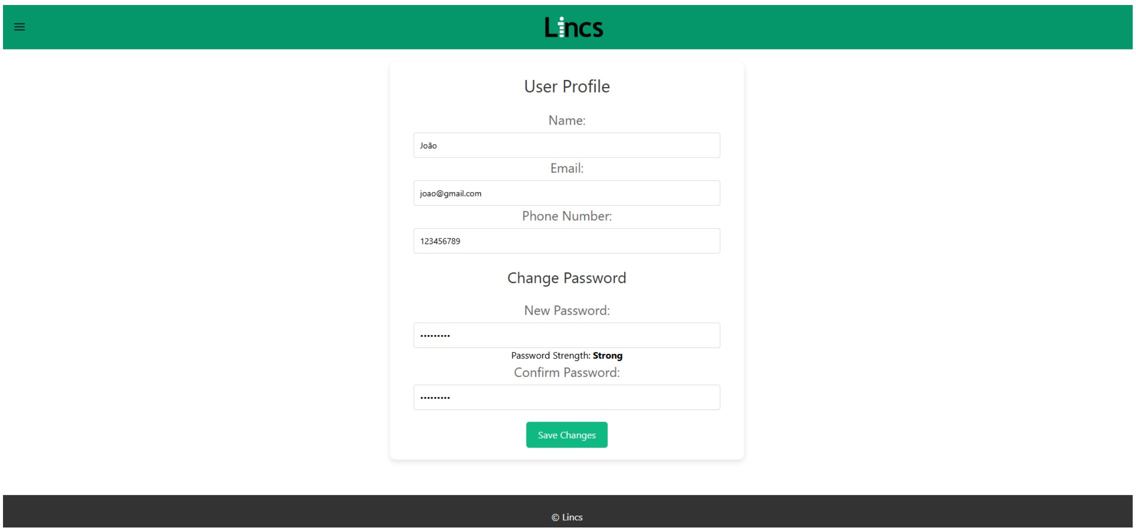


Figure V.21: User related data editing page.

VI

API Documentation

Web Interface For An Inclinometer Monitoring System API

Overview

API of a web interface for an IPI system. Project made by: João Palma

Tags

Monitoring Groups
Monitoring Groups API

Authentication
Authentication API

Monitoring Profiles
Monitoring Profiles API

Inclinometer
Inclinometers API

Settings
Settings API

Users
Users API

Paths

PUT `/api/user/password` Update user password

Updated password of an existing user in the system. The user data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	User updated successfully	No Links
400	Invalid user data	No Links
404	User not found	No Links

PUT `/api/user/` Update user data

Updates an existing user in the system. The user data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	User updated successfully	No Links
400	Invalid user data	No Links
404	User not found	No Links

POST `/api/user/` Register user

Adds a user to the system. The user data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	User registered successfully	No Links
400	Invalid user data	No Links

PUT `/api/settings/connection` Update a new connection

Updates an existing connection to the system. The connection data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid connection data	No Links
204	Connection updated successfully	No Links

POST `/api/settings/connection` Create a new connection

Adds an connection to the system. The connection data must be valid and complete.

Responses

Code	Description	Links
204	Connection created successfully	No Links
500	Internal Server Error	No Links
400	Invalid connection data	No Links

DELETE `/api/settings/connection` Delete a connection

Deletes an existing connection to the system. The connection data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Connection deleted successfully	No Links
400	Invalid connection data	No Links

GET `/api/monitprofiles/group` Get all monitoring profile groups

Retrieves all monitoring profile groups from the system. The monitoring profile groups data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Monitoring profile groups successfully listed *Content* /	No Links
400	Invalid monitoring profile groups data *Content* /	No Links

PUT `/api/monitprofiles/group` Update a monitoring profile group

Updates a monitoring profile group in the system. The monitoring profile group data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Monitoring profile group updated successfully	No Links

Code	Description	Links
400	Invalid monitoring profile group data	No Links

POST `/api/monitprofiles/group` Create a monitoring profile group

Adds a monitoring profile group to the system. The monitoring profile group data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Monitoring profile group created successfully	No Links
400	Invalid monitoring profile group data	No Links

DELETE `/api/monitprofiles/group` Delete a monitoring group

Removes a monitoring profile group from the system. The monitoring profile group data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Monitoring profile group deleted successfully	No Links
400	Invalid monitoring profile group data	No Links

GET `/api/monitprofiles/` Get all monitoring profiles

Retrieves all monitoring profiles from the system. The monitoring profile data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links

Code	Description	Links
400	Invalid monitoring profile data *Content* /	No Links
200	Monitoring profiles successfully listed *Content* /	No Links

PUT `/api/monitprofiles/` Update a monitoring profile

Updates an existing monitoring profile in the system. The monitoring profile data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid monitoring profile data	No Links
204	Monitoring profile updated successfully	No Links

POST `/api/monitprofiles/` Create a monitoring profile

Adds a monitoring profile to the system. The monitoring profile data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid monitoring profile data	No Links
204	Monitoring profile created successfully	No Links

DELETE `/api/monitprofiles/` Delete a monitoring profile

Deletes an existing monitoring profile from the system. The monitoring profile data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid monitoring profile data	No Links

Code	Description	Links
204	Monitoring profile deleted successfully	No Links

GET `/api/monitgroup/` Get all monitoring groups

Retrieves all existing monitoring groups from the system.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid monitoring group data	No Links
200	Monitoring groups successfully listed	No Links

PUT `/api/monitgroup/` Update a monitoring group

Updates an existing monitoring group in the system. The monitoring group data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid monitoring group data	No Links
204	Monitoring group updated successfully	No Links

POST `/api/monitgroup/` Create a monitoring group

Adds a monitoring group to the system. The monitoring group data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid monitoring group data	No Links
204	Monitoring Group created successfully	No Links

DELETE `/api/monitgroup/` Delete a monitoring group

Removes an existing monitoring group from the system. The monitoring group data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Monitoring group deleted successfully	No Links
400	Invalid monitoring group data	No Links

PUT `/api/inclinometer/soilLayers` Update soil layers to an inclinometer

Updates soil layers to an existing inclinometer from the system. The inclinometer and soil layers data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid soil layers data	No Links
204	Soil Layers updated successfully	No Links

POST `/api/inclinometer/soilLayers` Add soil layers to an inclinometer

Adds soil layers to an existing inclinometer from the system. The inclinometer and soil layers data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Soil Layers added successfully	No Links
400	Invalid soil layers data	No Links

PUT `/api/inclinometer/sensor` Update sensor spacing between two sensors

Updates the sensor spacing between two sensors of an inclinometer in the system. The inclinometer and sensors data must be valid and complete.

Parameters

Type	Name	Description	Schema
query	**sensorID1** *required*		integer (int32)

Type	Name	Description	Schema
query	**sensorID2** *required*		integer (int32)
query	**inc** *required*		integer (int32)

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Sensor spacing updated successfully	No Links
400	Invalid sensor data	No Links

POST `/api/inclinometer/sensor` Add sensor spacing between two sensors

Adds the sensor spacing between two sensors of an inclinometer in the system. The inclinometer and sensors data must be valid and complete.

Parameters

Type	Name	Description	Schema
query	**sensorID1** *required*		integer (int32)
query	**sensorID2** *required*		integer (int32)
query	**inc** *required*		integer (int32)

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid sensor data	No Links
204	Sensor spacing added successfully	No Links

PUT `/api/inclinometer/additionalInfo` Update additional information to an inclinometer

Updates additional information to an existing inclinometer from the system. The inclinometer data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid information data	No Links
204	Additional information updated successfully	No Links

POST `/api/inclinometer/additionalInfo` Add additional information to an inclinometer

Adds additional information to an existing inclinometer from the system. The inclinometer data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Additional information added successfully	No Links
400	Invalid information data	No Links

PUT `/api/inclinometer/` Update an inclinometer

Updates an existing inclinometer in the system. The inclinometer data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid inclinometer data	No Links
204	Inclinometer updated successfully	No Links

POST `/api/inclinometer/` Add an inclinometer

Adds a new inclinometer to the system. The inclinometer data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid inclinometer data	No Links
204	Inclinometer added successfully	No Links

DELETE `/api/inclinometer/` Delete an inclinometer

Deletes an existing inclinometer from the system. The inclinometer data must be valid.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Inclinometer deleted successfully	No Links
400	Invalid inclinometer data	No Links

POST `/api/monitprofiles/point` Create a point

Adds an inclinometer position point to the system. The inclinometer position point data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Point created successfully	No Links
400	Invalid point data	No Links

POST `/api/monitprofiles/marker` Create a marker

Adds an inclinometer position marker to the system. The inclinometer position marker data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Marker created successfully	No Links
400	Invalid marker data	No Links

POST `/api/monitprofiles/line` Create a Line

Adds an inclinometer position line to the system. The inclinometer position line data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	Line created successfully	No Links

Code	Description	Links
400	Invalid line data	No Links

POST `/api/monitgroup/measurement` Add a new measurement to a monitoring group

Adds a measurement to a monitoring group in the system. The measurement data must be valid and complete.

Parameters

Type	Name	Description	Schema
query	**mg** *required*		MonitoringGroupDTO

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid measurement data	No Links
204	Measurement added successfully	No Links

DELETE `/api/monitgroup/measurement` Remove measurement from monitoring group

Removes an existing measurement from a monitoring group in the system. The measurement data must be valid and complete.

Parameters

Type	Name	Description	Schema
query	**mg** *required*		MonitoringGroupDTO

Responses

Code	Description	Links
500	Internal Server Error	No Links
400	Invalid measurement data	No Links
204	Measurement removed successfully	No Links

POST `/api/auth`

Responses

Code	Description	Links
200	OK *Content* /	No Links

POST `/api/auth/refresh`

Responses

Code	Description	Links
200	OK *Content* /	No Links

GET `/api/user/{email}` Find a user by its email

Retrieves a user from the system. The user data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**email** *required*		string

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	User found *Content* /	No Links
404	User not found *Content* /	No Links

DELETE `/api/user/{email}` Delete a user

Deletes a user from the system. The user data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**email** *required*		string

Responses

Code	Description	Links
500	Internal Server Error	No Links
204	User deleted successfully	No Links
404	User not found	No Links

GET `/api/settings/connectionMP/{mg}` Get all Monitoring Group connections

Retrieves all connections of a monitoring group from the system. The connection data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**mg** *required*		string

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Monitoring group connections successfully listed *Content* /	No Links
400	Invalid connection data *Content* /	No Links

GET `/api/settings/connection/{user}` Get all connections

Retrieves all connections of a user from the system. The connection data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**user** *required*		string

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Connections successfully listed *Content* /	No Links
400	Invalid connection data *Content* /	No Links

GET `/api/monitprofiles/posAdjust` Get all positions

Retrieves all inclinometer positions from the system. The inclinometer positions data must be valid and complete.

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Positions successfully listed *Content* /	No Links

Code	Description	Links
400	Invalid position adjustment data *Content* /	No Links

GET `/api/monitprofiles/posAdjust/{mpId}` Get all positions of a profile

Retrieves all inclinometer positions of a profile from the system. The inclinometer positions of a profile data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**mpId** *required*		integer (int32)

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Positions successfully listed *Content* /	No Links
400	Invalid position adjustment data *Content* /	No Links

GET `/api/monitprofiles/point/{mpId}` Get points

Retrieves all inclinometer position points of a profile from the system. The inclinometer position points of a profile data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**mpId** *required*		integer (int32)

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Points successfully listed *Content* /	No Links
400	Invalid points data *Content* /	No Links

GET `/api/monitprofiles/marker/{mpId}` Get markers

Retrieves all inclinometer position markers of a profile from the system. The inclinometer position markers of a profile data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**mpId** *required*		integer (int32)

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Markers successfully listed *Content* /	No Links
400	Invalid markers data *Content* /	No Links

GET `/api/monitprofiles/line/{mpId}` Get lines

Retrieves all inclinometer position lines of a profile from the system. The inclinometer position lines of a profile data must be valid and complete.

Parameters

Type	Name	Description	Schema
path	**mpId** *required*		integer (int32)

Responses

Code	Description	Links
500	Internal Server Error *Content* /	No Links
200	Markers successfully listed *Content* /	No Links
400	Invalid markers data *Content* /	No Links

Components

Schemas

UpdatedUserPasswordDTO

Properties

Name	Description	Schema
email *required*		string
password *required*		string

UpdatedUserDTO

Properties

Name	Description	Schema
email *required*		string
name *required*		string
phoneNumber *required*		string
role *required*		string

ConnectionDTO

Properties

Name	Description	Schema
url *required*		string
token *required*		string
org *required*		string
user *required*		string

MonitoringProfileGroupDTO

Properties

Name	Description	Schema
group *required*		string
measurements *required*		string
monitoringGroupId *required*		integer (int32)

MonitoringProfileDTO

Properties

Name	Description	Schema
code *required*		string
group *required*		string
name *required*		string
description *required*		string
type *required*		string
attachedImage *required*		string
inclinometers *required*		string
monitoringGroupId *required*		integer (int32)

MonitoringGroupDTO

Properties

Name	Description	Schema
name *required*		string
description *required*		string
inclinometers *required*		string

SoilLayersDTO

Properties

Name	Description	Schema
position *required*		integer (int32)
symbol *required*		string
color *required*		string
description *required*		string
thickness *required*		integer (int32)
topLevel *required*		integer (int32)

InclinometerDTO

Properties

Name	Description	Schema
name *required*		string
length *required*		integer (int64)
currentFrequency *required*		string
azimuth *required*		integer (int64)
latitude *required*		integer (int64)
longitude *required*		integer (int64)
heightTopSensor *required*		integer (int64)

Name	Description	Schema
casingAngleTo Horizontal *required*		integer (int64)

UserDTO

Properties

Name	Description	Schema
email *required*		string
name *required*		string
password *required*		string
phoneNumber *required*		string
company *required*		integer (int32)
role *required*		string

PointDTO

Properties

Name	Description	Schema
positionX *required*		number (double)
positionY *required*		number (double)
profilePosition AdjustmentId *required*		integer (int32)

MarkerDTO

Properties

Name	Description	Schema
lat *required*		number (double)
lng *required*		number (double)

Name	Description	Schema
profilePosition AdjustmentId *required*		integer (int32)

LineCrossSectionDTO

Properties

Name	Description	Schema
topX *required*		number (double)
topY *required*		number (double)
bottomX *required*		number (double)
bottomY *required*		number (double)
profilePosition AdjustmentId *required*		integer (int32)

MeasurementsDTO

Properties

Name	Description	Schema
measurement *required*		string
host *required*		string
inclinometers *required*		string

AuthenticationRequest

Properties

Name	Description	Schema
email *required*		string
password *required*		string

AuthenticationResponse

Properties

Name	Description	Schema
accessToken *required*		string
refreshToken *required*		string

RefreshTokenRequest

Properties

Name	Description	Schema
token *required*		string

TokenResponse

Properties

Name	Description	Schema
token *required*		string

ProfilePositionAdjustmentDTO

Properties

Name	Description	Schema
uniqueId *required*		integer (int32)
code *required*		string
measurement *required*		string
inc *required*		string
type *required*		enum (PLAN,CROSSSECTION)
positionAdjusted *required*		boolean
monitoringProfileId *required*		integer (int32)

2024 Development of a Web Interface for an Inclinometer Monitoring System João Palma

NOVA SCHOOL OF SCIENCE & TECHNOLOGY