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Guidelines for selecting and monitoring soil containment in buildings in urbanized areas

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ABSTRACT
There is a need to establish criteria for the choice and monitoring of soil containment in urban areas to ensure safety on the construction site and prevent accidents. This paper aims to establish criteria for the choice and monitoring of soil containment in urbanized regions; no containment of open slopes or dams is discussed since the main focus is the contribution to managing urban areas. The research sought to identify characteristics and define concepts in choosing and monitoring soil containments in urbanized areas. Once the criteria were established, two case studies were performed, monitoring the containment structure's horizontal and vertical displacements. The quantitative results of the research were the flowcharts of stages and criteria of choice and monitoring of soil containments in urbanized regions. It was also possible to observe the low magnitude of the displacements, which varied between 0.01 mm and 0.20 mm. It was impossible to measure the total displacement of accommodation of the structure, the safety of workers, and neighboring buildings during the excavation stage. It is concluded that the study serves as the basis for applying the criteria in different regions, contributing to the management of including from the variability of soil parameters and local practices of soil containment structures to the choice of appropriate solutions in monitoring and data collection.

KEY-WORDS: soil containment, geotechnical monitoring, criteria of choice, safety, monitoring criteria.

1 INTRODUCTION

Civilization has an inevitable tendency to urbanization, reflecting society's industrialization level (LIU et al., 2019). Over the years and with the diffusion of new technologies, the buildings' constructive limits and maximum sizes were gradually surpassed, which increased the density of occupation in urban areas and the vertical growth of buildings (YU et al., 2010). The growth of urban verticalization is a point of global debate: it explores the idea that population growth brings with it the demand for better land use about efficiency and density, becoming a matter of academic and professional interest worldwide. Regardless, markedly vertical constructions are considered viable from the economic point of view and allow the best use of the location (PALME; RAMÍREZ, 2013). However, not all cities are prepared for the vertical expansion arising from this new system, especially if they do not consider the possible environmental and functional impact products of the indiscriminate proliferation of high-rise buildings (AL-KODMANY, 2020). In this context, during the risk analysis and planning in urban infrastructure constructions, there is an insufficiency in the adequate approach to possible risks, compromising decision-making and the prevention of urban accidents (WOLFF; SANTOS FILHO, 2016). Related to excavation works, planning becomes fundamental in construction and development in urbanized regions (AL-JAWADI; AL-DABBAGH; DAWLAT, 2021).

The works of soil containment are covered by several technical standards, such as NBR 9061 (ABNT, 1985), NBR 11682 (ABNT, 2009), NBR 8044 (ABNT, 2018), and NBR 6122 (ABNT, 2019), which address objectively criteria concerning procedures used in excavation, but without the specific function of determining guidelines in the choice and monitoring of containments, which leads the professionals involved to a search guided by variability and risk. Regardless of whether a geological-geotechnical investigation is carried out before the beginning of design conceptions, the uncertainty caused by variability is something inevitable in projects with soils

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and rocks, causing the professional to define some pre-design characteristics conditions of the land (DUNNICLIF; MARR; STANDING, 2012).

Regarding the choice of containments, there are some methods and criteria already evaluated in the scientific literature in several countries: United Kingdom (GARCÍA ADROGUER et al., 2015), Malaysia (BALASBANEH; MARSONO, 2020) and Spain (MUÑOZ-MEDINA, 2021), for example. The methods evaluate indicators of environmental impact, cost cycle, social and population impact, which are sometimes measures relevant only to the context of the research in which they are applied and evaluated only after the completion of the construction, but do not consider factors included in premises adopted in the design phase of the geotechnical project. It is crucial to establish that the choice of containments must take into account, during its conception, multiple critical factors in addition to those cited, including excavation geometry, soil conditions, presence of water, structures already allocated from the neighborhood, construction site and available equipment, durability, presence of contaminants and aggressiveness of the environment, construction speed and services required for deployment, among others (MILITITSKY, 2016).

It is important to stress that geotechnical work, both in design and in construction itself, must be a final solution that meets the appropriate safety requirements against failures, has acceptable displacements along the range of loads applied, be durable during permanent established service life (CORKE; SUCKLING, 2012). These points are expected in soil containments in the basement of a building, although not all containment has the function of being permanent. In this case, the monitoring emerges as an essential item in the safety of the excavation, the structure, and the neighborhood, besides confirming the conditions of the elaborated project and allowing the monitoring of the behavior of the solution over time (MILITITSKY, 2016; MILITITSKY et al., 2019). These data can contribute to the verification of design forecasts and structure behavior (DRUSA, 2016), a fact that reinforces the importance of monitoring containment structures, ensuring not only the quality of the solution but also the safety of the workers involved and the preventive maintenance of the structure (LIENHART et al., 2018). However, well-defined criteria that relate the range of monitoring solutions to the available structures still need to be made available in the scientific literature.

Geotechnical monitoring plays a critical role in assessing slope safety and performance. In addition to soil investigation, it is essential to monitor horizontal and vertical movements and the piezometric level (GERSCOVICH, 2016). Lack of information and process knowledge can result in delays, increased costs, neighborhood impact, and prolonged litigation. The monitoring provides quantitative data on the soil and adjacent structures, allowing comparison with expected performance and prediction of future problems (GHORBANI et al., 2012). Among the technical benefits of monitoring, it highlights minimizing damages, implementing the observational method, identifying unknown conditions, and guaranteeing constructive methods (DUNNICLIFF; MARR; STANDING, 2012).

The mentioned factors reinforce the need for an objective approach of fundamental criteria regarding selecting and monitoring soil containments in urbanized regions. Such criteria can confirm project parameters and ensure construction site safety, avoiding accidents - such as breaking the retaining wall in Morro do Gavazza in Salvador (CODESAL, 2023). In addition, regulatory standards, which present employers' duties in the fulfillment of workers' safety

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assurance, have a direct role in the stage of building excavations; the NR-Regulatory Standard18 - Safety and health conditions at work in industry and construction - addresses in item 18.7.2.9: "the excavations of the construction site near buildings should be monitored and the documented result" (BRAZIL, 2020, p. 8).

Thus, the objective is to establish criteria for choosing and monitoring soil containment in urbanized regions in Brazil, with application in a case study. It is essential to point out that, even discussing the category "containments," the paper does not focus on the containment of open slopes or dams since, in these cases, scientific materials and technical procedures are more present and justified, considering that these are papers of significant impact.

2 RESEARCH METHOD

To establish the workflow, the research method was subdivided into two major stages. The first stage involved developing frameworks, a process informed by a comprehensive literature review, work experience, and valuable insights from professionals in the field. The second stage, the practical application and validation of these frameworks in a real-world case study, was a testament to the method's effectiveness and relevance.

2.1 Proposal of criteria for choice and monitoring of soil containments in urbanized regions

2.1.1 Selection criteria for containment

The criteria for choosing soil containment were based, first, on bibliographic research to identify the most used containment solutions in densely urbanized regions where soil containment is needed, such as subsoils and sharp cuts of neighboring land. In this sense, only containments were considered permanent solutions without aesthetic needs (Chart 1).

Chart 1 – Review of international and national scientific literature on shoring and types of containments

Containment	Shoring	Source
Reinforced concrete curtain	Cable-satayed	BARREIRA *et al.* (2019)
Diaphragm wall	Truncate	CHENG *et al.* (2021)
		MAŠÍN; BOHÁČ; TŮMA (2011)
	Cable-satayed	CASTELLI; LENTINI (2016); ZHUSSUPBEKOV; OMAROV; TANYRBERGENOVA (2019)
	Cable-satayed	KARATAG; AKBAS; GEL (2013)
Pile walls	Free	ALTUNTAS; PERSAUD; POEPPEL (2009); MOHAMAD *et al.* (2011)
	Truncate	MALAJ (2019)
Spaced Pile walls	Cable-satayed	CARVALHO; PINTO (2018)
Soil-cement	Cable-satayed	KIM; CHO (2010)

Source: prepared by the authors.

In addition to the base material (Table 1), the research for documented solutions allowed the visualization of commonly observed factors, which were listed in a sequence, to

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establish a flow of activities and parameters that should be considered, as Clayton et al. (2014), Milititsky (2016), Milititsky et al. (2019).

Another factor in the elaboration of the criteria was the authors' work experience in Geotechnics, especially foundations and soil containments, and their contact with more experienced professionals in the area. This accelerated the learning process related to the subject and facilitated the resolution of some practical and theoretical differences. As a result, the criteria are presented in a framework.

2.1.2 Criteria for monitoring containment

Containment monitoring criteria were developed based on references and local experiences, given the lack of dissemination of this issue in Brazil, especially in companies that perform this type of solution. Knowledge was acquired through research and daily practice during the process, resulting in a proposal that unites theory and practical application.

Authors such as Dunnicliff et al. (2012), Eberhardt and Stead (2011), and Mazzanti (2017) served as the basis for the selection of essential parameters in geotechnical monitoring. In addition, Eurocode, Parts 1 (BSI, 2004) and 2 (BSI, 2007), was instrumental in understanding the importance of monitoring in land construction. Suppliers of systems and sensors such as HBM (2022), Megatron (2022), and Slope Indicator (2004) contributed to the improvement of construction practices. The result of this process is a set of monitoring criteria presented in a framework.

2.2 Characterization of the case study

The study was conducted in partnership with a company in a city located in the southern region of Brazil. The company has more than 20 years of experience in executing foundations, retainers, and earthworks. The region is urban and has borders with nearby buildings.

The construction of the case study totals 16 floors, and the first three floors require containment of the soil of neighboring land associated with nearby buildings. Due to the sharp unevenness of the location, the containment also has different levels according to the length of the terrain.

The recognition of the site's soil was performed according to the methods of probing and testing SPT, based on the procedures of NBR 6484 (ABNT, 2020), Soil—Simple Survey with SPT—Test Method.

In the case study project, 120 continuous propeller excavated stakes were present at the back and sides of the terrain, while the staples are mostly located at the bottom since a neighboring building needs to be contained, and on the right side, where there is an amount of land today used as a construction site. The stem variation of the piles is due to the unevenness of the terrain, both north-south and east-west.

The objective behavior of the monitoring was the accommodation of the containment structures during the stages of extensive excavations. For this, the data on horizontal and vertical displacements of the connecting beams of the piles were collected. The monitoring was

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performed on the ground floor, and the data were collected from displacements of the same connecting beam of the piles at two different points. Two stations were set up: the first had channels 1 and 2, located 1.60 meters horizontal distance from the site already excavated; the second, with channels 5 and 6, located 3.50 meters from the excavated tip - the channels will be detailed later in the results.

In the instrumentation, the WI displacement transducer and the QuantumX MX840B data acquirer from HBM (Hottinger Baldwin Messtechnik) GmbH were used. As installing reference fixed points was difficult, the horizontal sensors were supported in the steel waiting of the beam in the two measurements, and the vertical sensors in a steel plate were installed in the upper part of the respective connecting beam.

Data were collected manually, without an internet connection, with the local connection between the sensor, data acquisition, and software via notebook. The collection and processing of data in real-time were carried out with the help of the Catman software, also produced by HBM GmbH. It was observed that an amount of data was difficult to manipulate with the help of Excel, so scripts were made in Python to clean and visualize displacement data. A relationship based on the Pearson Coefficient (LY; MARSMAN; WAGENMAKERS, 2009) was also constructed to measure the statistical relationship between the displacement results, considering -1 (inversely correlated variables), 0 (not related), and +1 (variables directly correlated).

3 PROPOSAL OF CRITERIA FOR CHOICE AND MONITORING OF SOIL CONTAINMENTS IN URBANIZED REGIONS

3.1 Selection criteria for containment

The proposed framework of containment choice criteria (Figure 1) was subdivided into five main items, indicating a flow of activities for the final structure selection. Each item acquires the data relevant to the work and is divided as follows.

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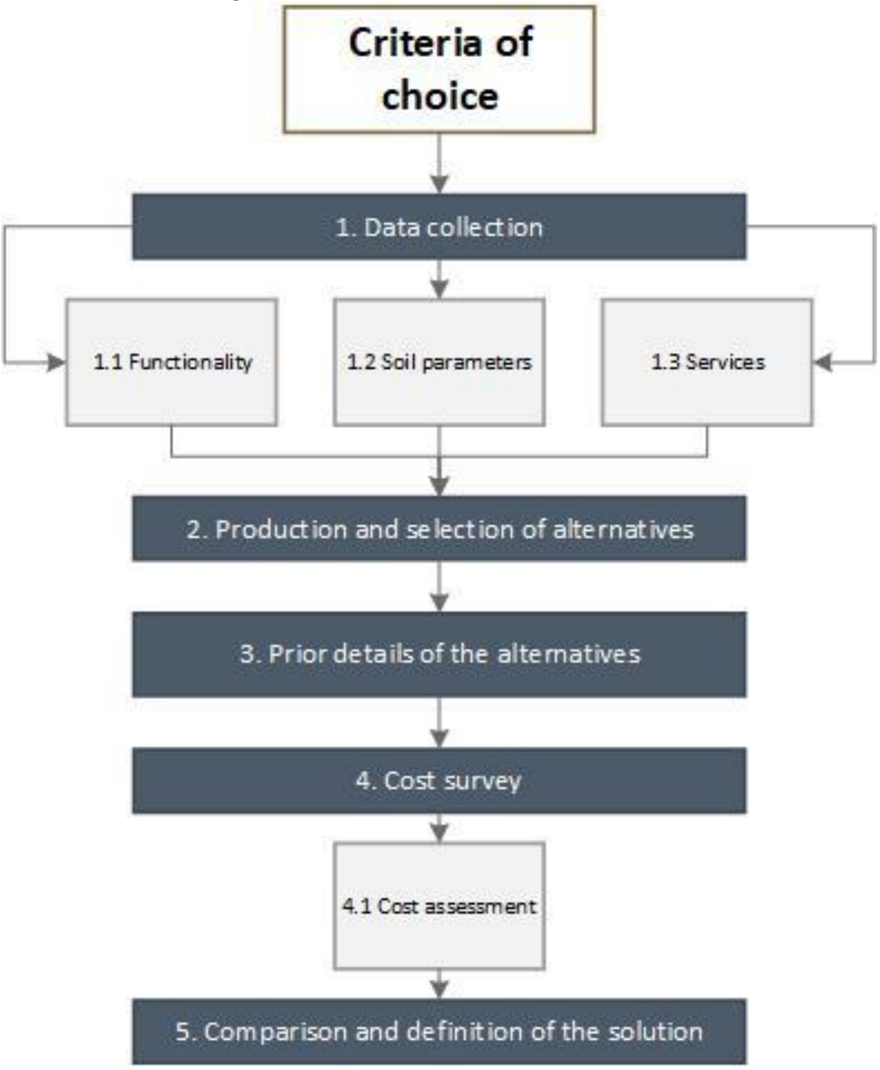
Figure 1 – Soil containment criteria framework



Source: prepared by the authors.

1. Data collection

The first step is acquiring fundamental data aimed at security, technical performance, and the possibility of executing the containment solution. The data are subdivided into functionality, soil parameters, and services and are equally important in the proposition of a containment alternative.

1.1 Functionality data: geometry and depth of excavation, clearance between deployment boundaries, available site, public infrastructure, and adjacent buildings, applicable standards and codes.

1.2 Soil parameters: soil conditions, presence of water and contaminants (aggressiveness of the medium), type of retained soil and foundation, groundwater parameters, and topography.

1.3 Services: equipment, services, and techniques available, access to the construction site, speed of execution (deadlines), volume of execution (size of the work), experience, and local practice.

2. Production and selection of alternatives

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After the initial acquisition of the data, the first phase of analysis must be elaborated through the tabulation of the advantages and disadvantages of the initial alternatives. The main activity of this stage is the qualitative comparison of ideas and the exclusion of some.

3. Prior details of the alternatives

The minimum detail of the previously defined solutions should be carried out to allow a decision; only for extreme cases should a basic project be elaborated. The proposal is to evaluate possible facilities and difficulties of each of the remaining solutions.

4. Costs survey

This stage consists of a survey of the most significant items; no entire budgets are required. It is also essential to analyze factors such as the amount of steel and concrete for each type of solution, drilling expenses, assembly, and cost per square meter of containment.

5. Comparison and definition of the solution

From the data acquired throughout the stages and the gradual elimination of solutions, the final selection depends on evaluating some imponderable items: delays, deadlines, executive limits, impacts on the neighborhood, etc.

The selection of the best alternative considers that it should ensure the performance, safety, and economy of soil containment.

3.2 Criteria for monitoring containment

The development of the framework addresses specific items aimed at selecting instrumentation and data collection for the application, subdivided into the following five stages (Figure 2).

1. Monitored factors

Each soil containment demand is unique and aims to solve a specific problem; the critical factors were selected after the investigation of the characteristics of the soil and the site of the work, as well as possible constructive limitations of the type of containment chosen and designed.

Among the factors present in the monitoring are deformations of both soil and structure, water poropressure, and loads and stresses in the soil-structure interaction.

2. Sensor location

Once the factors are defined and the containment structure is known, the location of the sensor aims to collect important data on the structure's behavior. The measurement point can vary according to the critical factor to be observed: continuous monitoring of loads, monitoring of the structure's settlement on critical days of large soil withdrawals, etc.

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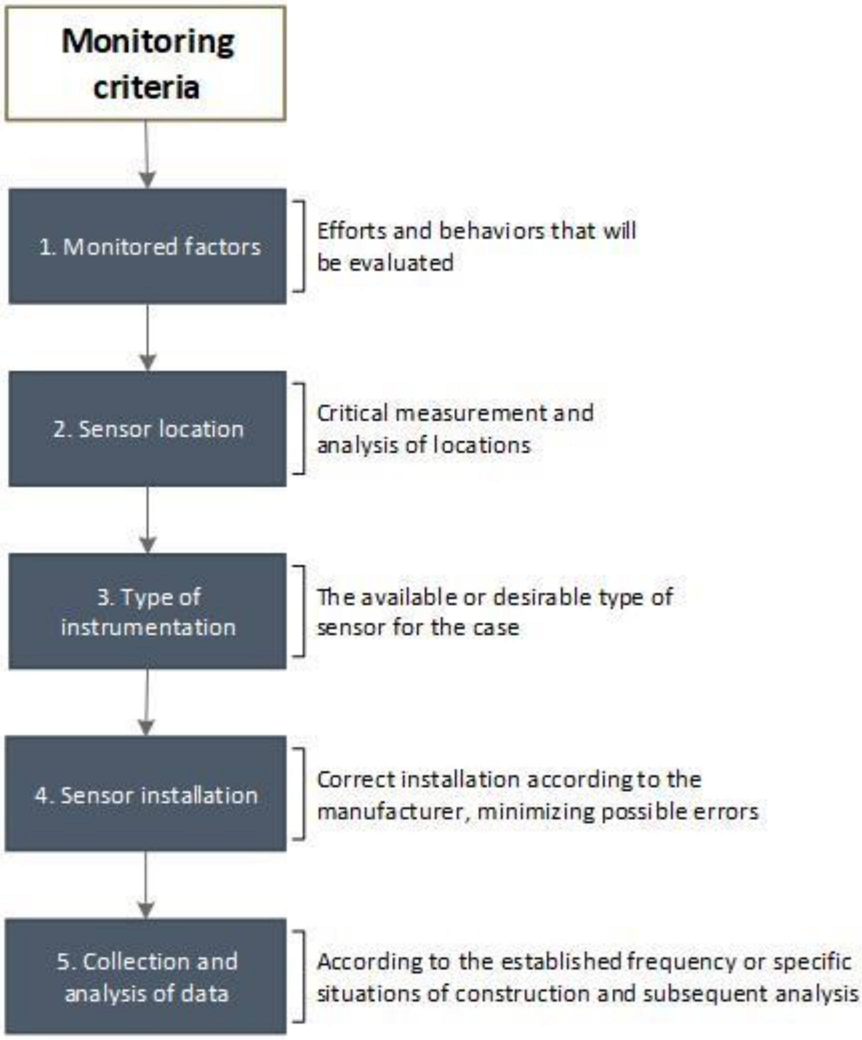
Figure 2 – Soil containment monitoring criteria framework



Source: prepared by the authors.

3. Type of instrumentation

The selection of the type of instrumentation depends on the ability to answer the geotechnical questions required for each case. Sometimes, it also depends on the availability of sensors and monitoring systems. However, the monitored factors must be a priority when selecting materials.

The material includes the sensor responsible for acquiring and physically transforming the data into signals captured by the data acquisition and further processed in the monitoring system software.

4. Sensor Installation

The selection of the monitoring material and the definition of the observed parameters dictate that the installation at the desired site must follow the manuals of the sensors' suppliers, minimizing possible failures in data collection.

5. Collection and analysis of data

The collection can be defined continuously, with determined intervals, observing the behavior over time or on critical construction steps in more punctual measurements.

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This activity is usually done from the data acquisition defined in the previous moment, with the data being captured by the software and transformed into spreadsheets. For better data visualization, comparative graphs are constructed according to the desired analysis, whether comparative between two or more measuring points, behavior over time, or evaluation of stresses and displacements at specific times.

4 CASE STUDY RESULTS

4.1 Application of the criteria of choice in the case study

1. Data collection

The work foresees excavations of up to 3 meters underground and 4.40 meters in the elevator duct, focusing on soil containment on the sides and rear due to the uneven terrain. Survey reports indicate variations in soil type but no water. The company mainly uses drills for foundations and soil containment.

2. Production and selection of alternatives

Considering the applicability of each solution, the machinery, and the available local experience, Chart 2 presents the production and selection of case study alternatives.

Chart 2 – Seleção preliminar de contenções

Previous choice	Advantages	Disadvantages
Reinforced concrete curtain	Good structural performance and efficiency in large excavations	Needs operational practice and does not have such agile execution
Spaced Pile walls	Low cost and ease of execution	Does not perform well in flooded areas and needs good access to the excavation site
Pile walls	Low cost and efficiency in the protection against surrounding water	It needs operational practice for execution; in the execution itself, it can compromise the primary stakes
Diaphragm wall	Agility of execution and protection against surrounding water	Availability of specific machinery and executive techniques
Precast concrete wall	Agility of execution and low cost	Usually has its use in temporary containments

Source: prepared by the authors.

The responsible company did not have the necessary equipment to execute diaphragm walls, so this alternative was discarded.

The precast concrete walls were discarded because they are permanent underground containments in buildings with nearby neighboring buildings. The pile wall solution was discarded due to the company's and the operator's lack of operational practice in this type of soil containment.

As alternatives, the reinforced concrete curtain and the curtain of juxtaposed piles remained two usual solutions in Brazil in urbanized regions.

3. Prior details of the alternatives

The reinforced concrete curtain is executed by excavating the terrain in stages, from top to bottom. It needs concreting with shapes and armor placement, block by block until it reaches the final level. It is commonly found as a solution of tethers anchored to the wall.

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The curtain of juxtaposed piles has an execution and design very similar to the excavation of piles for the foundation. In general, the drill still operates with the ground at a higher level at the end, performing the holes followed by armor placement and concreting. The diameter for this solution is usually 40 cm, and the maximum spacing between piles is 5 cm. Sometimes, the solution uses connecting beams between piles for greater stability.

4. Costs survey

As the costs vary between different companies and execution sites, according to the company's practice and culture, the reference values used for the survey were those of the SINAPI table for the month of execution and site of the work (CAIXA ECONÔMICA FEDERAL, 2022).

The curtain solution of juxtaposed piles features a composition integrating all execution stages, including material supply. The containment in the reinforced concrete curtain was defined by its composition, following the Technical Notebooks of Compositions made available by Caixa Econômica Federal (2019).

The total costs associated with constructing the reinforced concrete curtain and the juxtaposed piles, as specified in the SINAPI Code, are R$ 178.64 per square meter for the reinforced concrete curtain and R$ 139.08 per square meter for the juxtaposed piles. These values represent the overall cost of performing these types of containment

5. Comparison and definition of the solution

Overall, the two solutions present costs of similar magnitudes, considering that the stacks need a greater depth than the curtains, which also consume much more steel. The execution time of the juxtaposed piles is shorter, because this solution requires fewer employees.

As technically the two options are applicable for the slope of the project, the company and the owner opted for the curtain solution of juxtaposed piles.

4.2 Application of monitoring criteria in the case study

1. *Monitored factors*

Due to the extensive excavations after the completion of the pile curtains and nearby buildings, the vertical and horizontal displacements of the containment were monitored to evaluate the structure's settlement.

2. *Sensor location*

Due to accessibility and rigidity, the sensors were placed on the top beam of the piles and the reinforcement seams. The choice considered ease of access, the ability to adjust, and the use of existing structures on the site.

3. *Type of instrumentation*

Four LVDT sensors and one Quantum data acquisition were selected to monitor displacements in the case study. The sensors were evaluated before installation and monitored continuously, verifying possible irregularities in the graphics generated by the Catman software.

4. *Sensor Installation*

Once again, access to the site was critical when installing the sensor. The sensors were installed in the structures present in the work, beams for measurement of vertical

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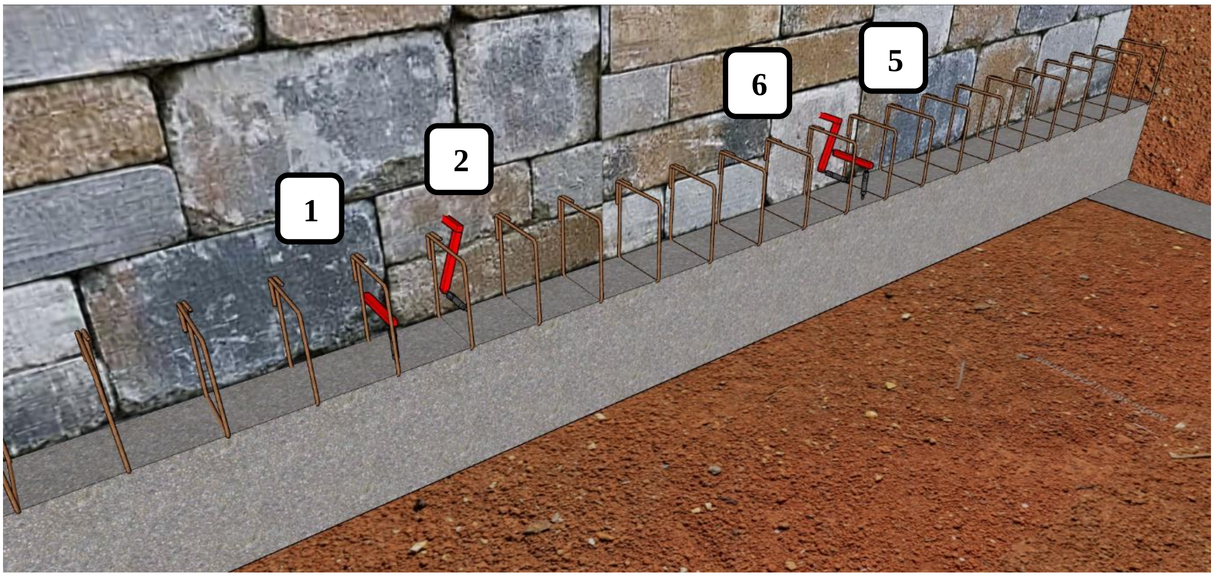
displacements, and reinforcements for horizontal displacements in both stages. As the sensors have no fastening structure, metal sheets were glued to the beams and fixed with magnetic bases, avoiding as much as possible shaking during the excavations and that the LVDT left the location point.

In the case study, during the measurement, the sensors were installed on the same beam at the bottom of the site (Figure 3).

Figure 3 – Installation of case study measurement sensors



Source: prepared by the authors.

5. *Collection and analysis of data*

After data collection and analysis using specific scripts, the displacements were represented in comparative graphs for vertical and horizontal sensors. The monitoring lasted 45 minutes. The analysis of channels 1 and 5 indicated a uniform displacement behavior during the structure's laying period, recording 0.20 mm in channel 1 and 0.14 mm in channel 5 (Figure 4).

A nonlinear behavior was observed when comparing the horizontal sensors. Channel 2 had a larger initial displacement, reaching a maximum of 0.18 mm during excavation, possibly due to the excavation's proximity to the sensor's location. In contrast, channel 6 had a more constant displacement, reaching a maximum value of 0.10 mm.

Applying the Pearson correlation in the sensors, it was also possible to observe a very strong correlation between the vertical sensors, reaching 0.99. The horizontal channels show a strong correlation (0.79), mainly due to the initial displacement of the channel 2 sensor.

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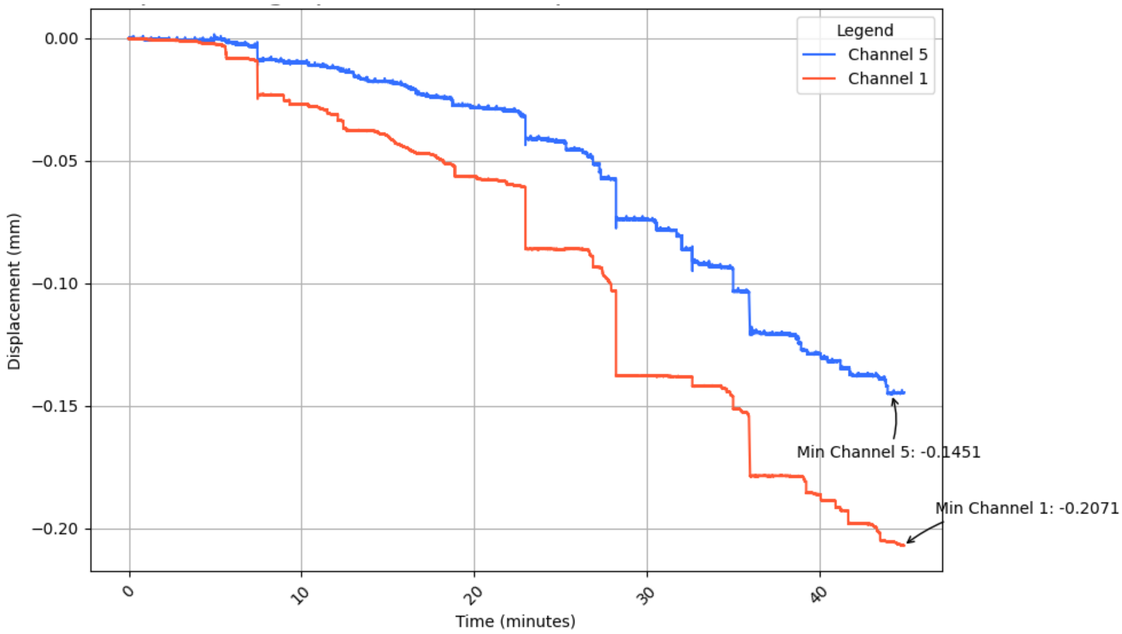
Figure 4 – Comparison of vertical displacement of channels 1 and 5



Source: prepared by the authors.

5 CONCLUSION

The research proposed the definition of criteria for selecting and monitoring containments in urbanized regions. These criteria could be used in similar applications, considering the criteria of soil parameters, geometry and depth of excavation, and variability of material costs and time in each stage of the frameworks elaborated in items 3.1 and 3.2.

Using specialized frameworks for choosing and monitoring soil containment in urbanized regions is crucial in improving urban planning. Amid the accelerated growth of urban areas, adopting innovative approaches to address geotechnical challenges associated with soil stability is imperative. The proposed frameworks allow the systematic analysis of soil characteristics, identifying characteristics and providing valuable information for properly selecting containment strategies. In addition, monitoring these containments enables a proactive response to possible changes in soil conditions. Integrating this data into the urban planning process makes it possible to mitigate risks associated with soil instability, promoting the sustainable development of urban areas and ensuring the long-term security of infrastructures and communities.

Soil containment plays a crucial role in urbanized regions, preventing accidents and ensuring the integrity of employees and structures. However, monitoring is crucial in ensuring stability and measuring design parameters. If done continuously, it can help refine the project and identify the structure's commitment. The monitoring data should be documented and used continuously during the steps' execution, in addition to considering the bibliographic importance of capturing data from different structures and soil parameters.

Also, the monitoring criteria were applied in the case study restraints, and the results showed a low magnitude of horizontal and vertical displacements, with the most critical values reaching 0.18 mm and 0.20 mm, respectively. The values should also be considered based on

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the magnitude of the monitoring time, with a maximum of 56 minutes. The analysis of displacement and design of the containment structure converges to a robust structure concerning the size of the excavation, with excess stiffness and safety factors.

The criteria for choice depend on local factors: soil type, regional practices, company experience, government regulations, and budget constraints. The nature of the soil and groundwater affects design decisions, local experience, availability of materials, and labor. Financial considerations, along with the purpose of the project and the loads to be borne, also play a significant role. In summary, the choice of containment structure requires an approach that considers all these variables, as presented in the frameworks.

Structural monitoring is imperative to ensure the safety and integrity of structures over time. However, it is crucial to recognize the limitations related to landmarks, which are often fixed and not adaptable to change. Although the ideal location of these points may be off-site, this solution is only sometimes feasible, depending on the context and materials involved.

The study was the basis for applying the criteria in different regions, with the variability of soil parameters and local practices of soil containment structures, both in the choice of appropriate solutions and in monitoring and data collection. In addition, a monitoring system that includes real-time monitoring and specificities for soil containment is possible, aiming to refine ongoing projects.

Also, it is suggested that future research focus on the development of accurate sensors formulated from accessible materials, capable of providing real-time data on the integrity and stability of the structure, the application of artificial intelligence techniques and machine learning, aiming at predictive analysis of allowing the early identification of possible problems and the application of the criteria of choice and monitoring of containments in works of different dimensions and locations.

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