GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 85, 2024

Iot device for monitoring the tilt of containment in basket gabions

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ISSN 2318-8472, v. 12, n. 85, 2024

ABSTRACT
In the present work, an IoT (Internet of Things) electronic device was developed, used, and evaluated to monitor and measure the inclination of a containment structure executed in box gabions. This device collected information from an accelerometer, sending it over the internet to a cloud server, where this data was stored, allowing access to the history of the slope variation. The readings collected by the equipment made it possible to correlate its variations to the executive phases of the containment and to conduct statistical analyses to verify whether the variations captured by the sensor consisted of a possible lack of containment.

KEYWORDS: Structural Health Integrity Monitoring. Cloud. IoT.

1 INTRODUCTION

Retaining walls are used to maintain the stability of landfills. After being built, these structures must be inspected to verify that they present the expected design development.

However, most of the time, the sites to be inspected are challenging and dangerous, increasing the cost of the retaining walls' periodic maintenance. Even if technical staff using proper equipment can get to a retaining wall to analyze it, the period between the inspections can be long enough not to detect a structural pathology on the wall's concrete facing (ARAÚJO, 2017).

The strategy used for continuous monitoring of the concrete structural integrity of construction works (bridges, tunnels, and retaining walls) is known as Structural Health Monitoring (SHM). The SHM makes it possible to follow the structural conditions over time and, in many cases, predict the pathology's evolution and behavior over time once it can perform continuous measurements (FARRAR; WORDEN; DULIEU-BARTON, 2009).

Industry 4.0 has contributed to many technological solutions that industries can use, decreasing costs and increasing the production rhythm without negatively impacting the manufactured products' final quality. Civil engineering professionals can benefit from the technological tools made available by Industry 4.0 to plan and develop activities in the civil construction industry (SOUZA, 2019).

Civil construction has gradually used tools and resources to automate and control processes and use customer metadata to form a more complex production network (MIYASAKA; FABRICIO; PAOLETTI, 2018).

There is an expectation that in the future, it will be possible to automate the entire construction site; however, without the Internet of Things (IoT), the fully automated construction site is a general idea, as it is the IoT that allows communication and information management between objects in the physical world and the virtual world

Having knowledge and the intention of adapting to the technological advance, it was decided in this research to develop and use an IoT system, which conducted the monitoring of the inclination of a containment structure of a stretch of the bank of the Córrego dos Machados "Machados Stream", located in the East Zone of São Paulo, continuously recording all readings referring to the behavior of the work on a server in the cloud, providing dashboards and graphic reports in real-time that can be accessed from any device that has a web browser and that can be exported for carrying out statistical analyses.

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2 LITERATURE REVIEW

2.1 Earthfill movements: General aspects

Mass movement refers to the displacement of a given soil or rock mass volume, guided using a characteristic rupture surface, classified as falling, rolling, overturning, or sliding (ABNT, 2009). The leading cause of the movement of a massif is the reduction of the capacity to resist stresses requested in the soil. The decrease in the resistance of a massif can happen due to weathering processes or anthropic intervention (PINTO; DORTAS, 2020). Table 1 demonstrates the terminology established by NBR 11.682 (ABNT, 2009) concerning the different types of mass movement:

Table 1 - Appropriate terminologies for types of mass movement

Terminology of types of mass movement	Definition
Free Fall/Roll	Detachment of fragments from the terrain, regardless of size, which precipitate in free fall or any trajectory.
Tipping	Mass movement in the form of a bascule with an axis at the base.
landslide	Mass movement by displacement over one or more surfaces.
Flow	Mass movement with fluid properties with slow or fast flow.

Source: adapted from the NBR 11.682 standard (ABNT, 2009).

The Brazilian Institute of Geography and Statistics (IBGE) published a study on the susceptibility of landslides in Brazil, indicating that 5.7% of the national territorial extension has a high susceptibility to landslides and that most of this risk is concentrated in the states of Southeast region with 23.2% of areas characterized as very high risk.

The definition of the safety factor to be used in a slope stability analysis is directly related to the impact of an eventual instability in the contained massif, considering the impacts resulting from such an accident, such as the verification of possible loss of human lives and the possibility of material and environmental damage. Table 2 displays the criteria established by ABNT NBR 11.682 (ABNT, 2009) for determining the minimum safety factor to be obtained in stability analyses:

Table 2 - Minimum safety factors for landslides

Level of security against damage to human lives / Level of security against material and environmental damage	HIGH	AVERAGE	LOW
HIGH	1,5	1,5	1,4
AVERAGE	1,5	1,4	1,3
LOW	1,4	1,3	1,2

- In case of significant variability in the results of the geotechnical tests, the safety factors in the table above must be increased by 10%. Alternatively, the semi-probabilistic approach indicated in Annex D can be used.
- In the case of rock chips/blocks stability, partial safety factors may be used, focusing on the parameters γ, ϕ, and c, depending on the uncertainties about these parameters.

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-The calculation method must also consider a minimum safety factor of 1.1. The geotechnical, civil engineer must justify this case. - This table does not apply to crawling, gullies, ravines, and falling or rolling blocks.

Source: adapted from the NBR 11.682 standard (ABNT, 2009).

2.2 Retaining walls

The retaining structures (or retaining walls) are elements used to stabilize a soil massif. They must withstand all efforts from the contained massif, as well as an accidental load of 20kPa, uniformly distributed over the surface of the massif. Embankment so that instabilities do not occur in the contained soil (ABNT, 2009). The main types of retaining structures are:
Gravity walls: This type of structure ensures containment of the soil mass through its weight; gravity walls oppose horizontal thrusts through their weight and are used to contain differences in the levels below 5m; they can be constructed of concrete, stone, gabions, and even used tires (GERSCOVICH; SARAMAGO; DANZINGER, 2019).

- **Bending walls**: These types of retaining walls are resistant to bending forces; this type of wall uses part of the own weight of the supported massif and has an "L"-shaped cross-section, which it rests on to keep it in balance (ABNT, 2009)
- **Anchored structures**: These are structures that guarantee the stability of the massif through anchored rods and may have a continuous structure, in a grid, in plates, or buttresses (ABNT, 2009).
- **Reinforced soil structures**: These are structures built by introducing elements resistant to traction in the soil, such as metallic tapes, geotextile blankets, steel mesh, etc. Its main components are the landfill soil, the reinforcement elements, and the face elements. However, the face elements do not have a structural function (BENJAMIN, 2006).

2.2.1 Retaining walls built with gabions

Gabions are cages made using double-twisted hexagonal mesh metal screens, filled with rocks, and joined using lashing, forming a monolithic structure to contain earth masses (SANTA et al., 2022). Figure 1 demonstrates an example of an retaining wall built with basket gabions.

Figure 1- Containment structure made with basket gabion

Source: Barros et al. (2017)

Retaining walls executed with gabions are classified as gravity walls, and, in the same

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way as other types of retaining structures, stability analyses must be conducted. The analyses to be carried out are global stability and local and internal stability (SANTOS JUNIOR, 2018). In addition to basket gabions, there are two other types: bag and mattress. Bag-type gabions are cylindrical and generally used to support containment structures in water or soils with low support capacity (SANTA et al., 2022). The Reno® mattress-type gabions also have a parallelepiped shape. However, they have a small thickness when compared to box-type gabions. This gabion is mainly used to cover the banks and bottoms of watercourses. However, it has complementary applications such as a drainage channel, slope coating, and deformation platform that protect the bases of walls (BARROS et al., 2017).

2.2 Structural Health Monitoring — SHM

The continuous monitoring strategy, using a detection system that can provide information that allows the location, evaluation, and monitoring of the evolution of possible damage to a structure, is called Structural Health Monitoring (SHM) and denominated damages or anomalies the alterations in the elements, material and geometric properties of a structure that can affect its current or future performance, preventing its partial or complete use (FARRAR; WORDEN; DULIEU-BARTON, 2009).

The geotechnical engineer responsible for the design of a containment structure must consider in the executive project the possibility of monitoring the structure, defining which instruments should be installed in a containment work, and indicating the frequency of inspections to be carried out (ABNT, 2009).

In short, the purpose of SHM is damage detection and condition assessment. It is possible to find in its implementation the use of various types of sensors, data acquisition devices, data transmission methods, databases for management, analysis, and data modeling, and user interfaces for visualization (SUN et al., 2020). According to Milititsky (2016), there are adequate instruments for monitoring variables related to the behavior of slopes and retaining structures, and current techniques allow not only local monitoring but also allow this information to be recorded and transmitted remotely to the responsible for evaluating the structure. In the research developed by Wong and Ni (2009), there is a reference to the SHM composed of 283 instruments, divided into eight groups of sensors, associated with 3 data acquisition stations, which have been operating on the Tsing Ma bridge in Hong Kong since its inauguration in 1997, allow the monitoring of the behavior of the structure throughout its useful life.

According to Mello (2020), geotechnical monitoring and evaluation of excavation and containment work approximately 30m deep was carried out, using four inclinometers and surface marks to support topographic sights and tell tales on the contained slopes. In the article by Oliveira and Guimarães (2019), an earth dam was monitored in the state of Minas Gerais. The horizontal and vertical displacements of the massif were measured using topographical instruments, and four piezometers were used to monitor the evolution of the pressures acting on the embankment and the dam foundations.

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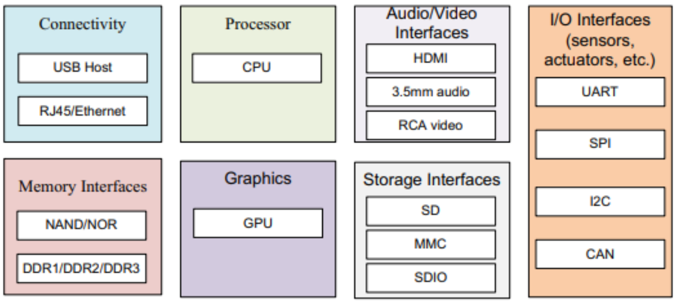
2.4 Internet of Things (IoT) and Cloud Computing

The Internet of Things is not a new technology but a division of Information Technology, a result of the continuous development of technology, especially in the miniaturization of electronic devices and new communication protocols. The term Internet of Things was first mentioned in 1999 by Kevin Ashton in a presentation for Procter & Gamble (MOUHA, 2021). IoT devices must have the computational capacity and the possibility of connecting to the internet (PEDOTTI, 2019). An IoT arrangement must have interfaces that allow external data collection, processing capacity, and connectivity for data transmission over the Internet (RAY, 2018). Figure 2 shows the components of an IoT device, as stated by Ray (2018).

Figure 2- Components of an IoT device



Source: Ray (2018)

The use of adequate sensing IoT devices and the functionalities found in cloud platforms for data storage and modeling allows the creation of SHM strategies for monitoring the integrity conditions for practically all types of civil construction structures.

Miao et al. (2019) present the development of a low-power wireless acceleration sensor that connects to the cloud through a gateway in their scientific article. The developed system was validated in a field test on the Chijing Bridge in Shanghai and considered by the authors as a promising, complete, practical, readily available, and low-cost IoT system for monitoring the integrity of bridges.

Cloud Computing or Cloud Computing is the term used to designate virtual servers distributed around the planet being accessed through the internet. These servers can store specific information and systems, run programs, and deliver content.

The possibility of contracting a specific configuration of hardware and software packages for handling or storing information, paying in many cases only for the volume of data transferred or stored, highlights one of the main benefits of cloud computing, which is cost reduction (SRIVASTAVA;KHAN, 2018).

Access to cloud computing technology enables the implementation of faster and more economical solutions when compared to the investment of time and resources that would be destined for the creation of an infrastructure for the operation of software and platforms since

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cloud solution providers currently provide such infrastructure at affordable prices (AHAD et al., 2020).

3 METHODOLOGY

3.1 Methodology Characterization

As for its approach, this research is characterized as quantitative of an applied nature, as it presents the survey and recording of characteristics of the behavior of a phenomenon; in the case of this work, the slope of the monitored retaining wall and correlates it with the activity's execution during the monitoring period.

Concerning the procedures taken, this work has practical research characteristics compatible with the methodological procedure of the action-research type. Action research proposes that the researcher adopt a collaborative and interactive posture so that the participants can understand situations and transform practices to promote change processes in a given environment (THIOLLENT, 2022).

This item will describe the hardware and software components, as well as details of the programming done, both on the device and on the cloud platform, in addition to detailing the method of transmission and storage of data used to create the IoT device responsible for monitoring the inclination of the box gabion retaining wall built in the east zone of São Paulo.

3.2 MPU6050 Sensor and TTGO T-Call ESP32 Development Board

The MPU6050 uses MEMS (Micro-Electro-Mechanical Systems) technology, with an acceleration sensor (accelerometer) and a rotation sensor (gyroscope) in its chip housing, both triaxial, allowing the monitoring of acceleration (m/ s²) and angular velocity (rad/s) in the x, y, and z axes.

The TTGO T-Call ESP32 is a development board composed of two main modules: a 32-bit dual-core ESP32 microcontroller, clocked at 240MHz, 4MB of Flash memory, and 8MB of PSRAM memory. This microcontroller has digital and analog inputs and outputs, communication interfaces such as I2C, SPI, UART, SDIO, I2S, and CAN, and connectivity options through Wi-Fi and Bluetooth. The second module of the TTGO T-Call ESP32 development board is the GSM/GPRS modem, model SIM800L, with a SIM Card slot, which allows data to be sent and received using the internet plan of market cell phone operators.

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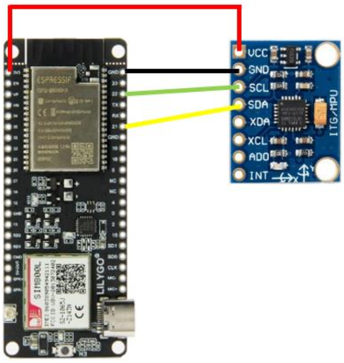
Figure 3- The connection between TTGO T-Call and MPU6050

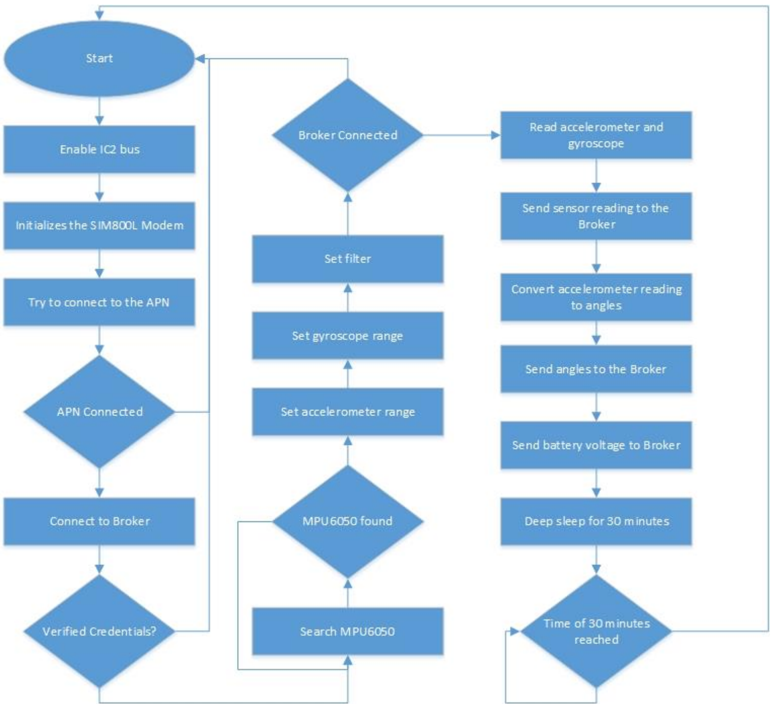


Source: The researchers

3.2.1 TTGO T-Call ESP32 source code development

The programming of the development board was carried out according to the flowchart shown in Figure 4.

Figure 4- Logic flowchart developed for TTGO T-Call



Source: The researchers

3.2.2 Web interface and database development

Node-RED is a low-code platform created by IBM for developing applications that use technologies such as hardware, services, protocols, and APIs compatible with IoT (Internet of Things). Application programming is done on pages called “Flows", function libraries can be imported to increase data manipulation possibilities. Data manipulation in Node-RED is done by functions called nodes.

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The screens for viewing the data collected by the TTGO T-Call ESP 32 through the MPU6050 sensor were developed using the nodes available in the dashboard library. The user must use a web browser (Google et al.), and access a web address, to view the data in real time and access the history of the variables, which are stored in the database. Figures 5 and 6 present the interface between user and the device.

Figure 5 - Angles view screen received in Node-RED

Source: The researchers

The system user was not allowed to access the SQL database directly; however, a query tab was created so that the person who had access to the system using a web browser could select an interval between dates and obtain access to the history of the desired variable.

Figure 6- Database query performed through the web interface

Source: The researchers

3.4 Characterization of the monitored construction work and installation of the device

During a period of heavy rains, which caused an increase in the flow of the Machados stream, located in the east zone of São Paulo, there was a collapse of the containment of the right bank of the watercourse. The stream bank containment is composed of box gabions.

According to residents, the same stream stretch had already ruptured. This one was recovered; however, it collapsed again. Opposite the accident site is a stormwater gallery with

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a sizeable quadrangular section. The stream bed was also silted up, and a large volume of garbage and debris was trapped in the containments. Among the possible causes of the collapse is the hypothesis of erosion of the foundations of the ruptured bank containment by the enormous flow from the gallery, which discharges the rain flow practically directly into the ruptured containment. Figure 7 shows the location where the containment rupture occurred in studies:

Figure 7- General view of the site and temporary containment.

Source: The researchers

The containment used on the banks of the Machados stream was already composed of box gabions. So that elements with different mechanical behavior concerning the existing containment were not introduced, it was decided to continue using the same containment solution to recover the collapsed bank. The lining of the bottom of the stream's watercourse, in the recovered section, was carried out with gabion mattresses.

3.4.1 IoT device installation

During the execution of the work, a 50 cm x 1.5 cm x 50 cm MDF board (L × W × H) was placed in one of the containment cages, located on the last row of the latter, so that this board was positioned between the stones and the mesh on the face of the containment, serving as a base for the installation of the IoT device. The developed device was positioned in the center of the IP65 hermetic box, which was fixed in the center of the MDF board so that if there were movements in the MDF board, it would be transmitted to the box containing equipment, as shown in Figure 8.

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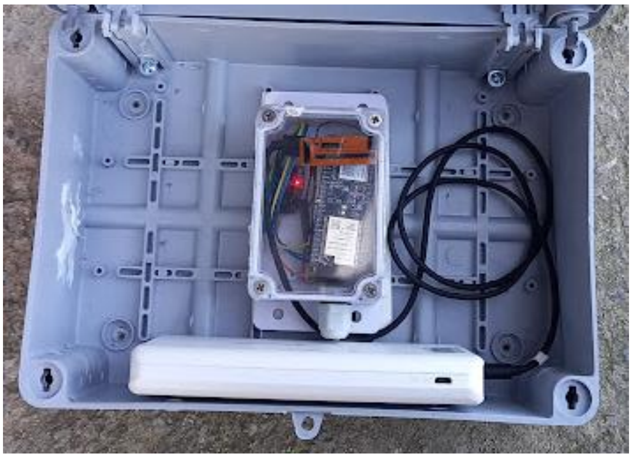
Figure 8- IoT device components in enclosure.



Source: The researchers

The installation location of the box containing the IoT was chosen since possible instabilities, such as global failure, foundation failure, landslide, overturning, and internal rupture, would be felt more intensely at that point; all these instabilities will directly influence the inclination of the face of the external face of the structure (Figure 9).

Figure 9- IoT device installed on gabion retaining wall face.

Source: The researchers

4 RESULTS AND DISCUSSIONS

Remote monitoring of the inclination of the gabion box containment was carried out during the execution phase of the work for 89 consecutive days, starting on June 13 and ending on September 9, 2022. The device was configured to carry out the reading of the gyroscopes and accelerometers of the MPU6050 sensor, calculating the angles of inclination and transmitting these variables at intervals of 30 minutes to the cloud server, resulting in a total of more than two thousand readings, during the monitoring period of the structure.

For analysis and discussions on the results collected by the IoT device, it was decided to export the readings of the ANG_Y variable (since this variable represents the slope measured

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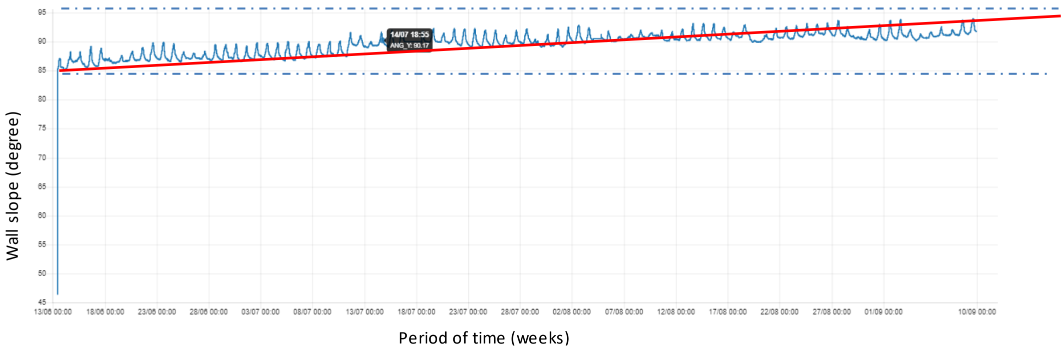
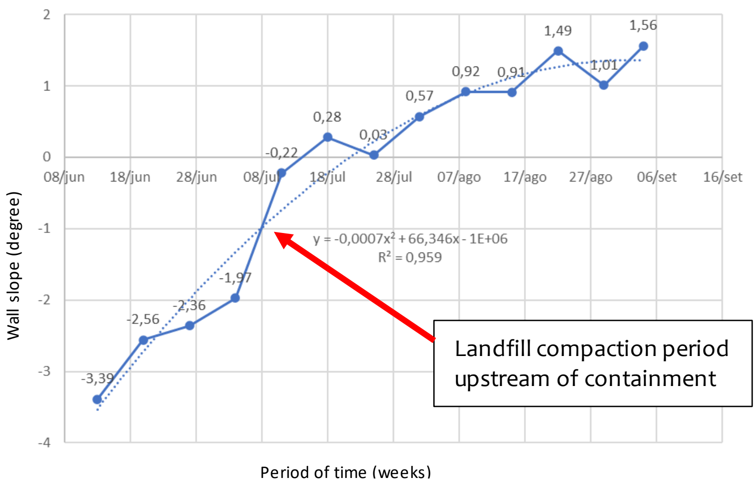
parallel to the face of the structure), stored in the SQL database, to a spreadsheet (Microsoft Excel), similar to creating graphical representations for better visualization and understanding of the variation in inclination, which is also influenced by the vibrations captured by the acceleration sensor of the MPU6050 board. Hence, the values presented in the graphs show the average variation in inclination as a function of the monitoring period of the structure. Figure 10 shows the graph of the slope variation during the entire collection period performed by the IoT device, seen from the web interface. Figure 11 shows the graph treated from Excel to display the average slope with the same scale as the graph in the web interface.

Figure 10- History of slope variation viewed through the web interface.



Source: The researchers

Figure 11- Slope history visualized in an electronic spreadsheet.



Source: The researchers

Figure 11 shows that during the containment execution, the sensor indicated variations in its plumb line, indicated by a well-adjusted binomial correlation, an R^2 value of 0.95. Such a coefficient also indicates the low variation concerning the irregular readings by the sensor, proving its good functioning during the follow-up period. Variations in readings can be correlated to specific periods of the work. The most significant variations in inclination occurred between June 11 and July 18, during which the compaction works on the landfill upstream of the containment were carried out. In this time interval, there was an angular variation of 4%.

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From the end of compaction until the end of the readings, the angular variation was 1.4%. The statistical analysis of the measured slopes is presented below:

Table 3 - Statistical analysis of the readings obtained

Average	**89.71º**
The lower limit of the mean (95% confidence)	88.69º
The upper limit of the mean	90.73º
(95% confidence)	90.28º
median	1.67º
Standard deviation	91.56º
Maximum	86.61º
Minimum	1.8%

Source: The researchers

For the interpretation of the average of the readings obtained, to verify if this is significant about the desired contention (90º), which would indicate its plumb line (inclination=0), a T-test was performed on the averages of the readings presented in Figure 19. For this, the following hypotheses were considered:

- Ho= mean reading equal to 90º ($p>0.05$);
- Ho= mean reading different from 90º ($p<0.05$).

The following table presents the analysis carried out:

Table 4 - Statistical analysis of the mean readings obtained using the T-test.

Average	**89.71º**
Reference value	90º
normal distribution	ok
p-value	0.55

Source: The researchers

Thus, based on Table 2 presented, it can be seen that the p-value is more significant than 0.05, indicating the validity of the Ho hypothesis; that is, the mean does not differ statistically from the reference value of 90º. Thus, it appears that, even though during its constructive stage, the containment presented variations in inclination (indicated by the sensor), these are not statistically significant to the point of being out of plumb in relation to the containment.

5 CONCLUSIONS

The IoT device could calculate the slope of the gabion box retaining wall using the values measured by the MPU6050 accelerometer as references. The slope values were transferred through the GSM/GPRS modem of the TTGO-TCall ESP32 development board, using the MQTT communication protocol that sent the data over the internet to Node-RED installed on a virtual server, hosted on Uol Cloud Server. Through the programming resources available

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in Node-RED, it was possible to establish communication with the SQL database installed on the virtual server and store the history of the slope variation during the entire collection period. The developed dashboards allowed users to access the application link, the value of the last reading of the slope, and also search the history of the stored variable using a web browser.

Regarding the variation of the inclination of the retaining wall, based on the analysis of the variable's behavior history, it was verified that the average, minimum, and maximum values of the inclination have an increase in function of the time, existing a difference of 4.95º of the average inclination, between the first and the last week of collection. The increase in the inclination value during the collection period is attributed to the grounding, compaction, and paving activities carried out in the contained massif and which had the use of heavy tools and machinery, which influenced the change in the values of the acceleration measured by the MPU6050 sensor because when activities were concentrated in other areas of the work, such as when the gabion mattress was installed in the stream, the variation in inclination was practically zero (0.25°). However, after paving, the last intervention in the contained massif, there was an increase of 0.89°. After reopening the road, the maximum inclination value was 91.56º, a variation of 0.64º concerning the inclination measured during the execution of the paving.

Statistical analyses of the y-axis inclination angle values indicated that the equipment was working correctly since the calculated binomial correlation was 0.95, indicating a low variation in the readings. The angular variations indicated that the variations of the inclination measured by the device were more significant in the execution of embankment and compaction of the retaining post. By carrying out the T-test, it was verified that despite the variations in inclinations, they were not significant enough to consider a containment failure.

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