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ARTICLE

APPLICATION OF CALIBRATION CERTIFICATE OF DIGITAL LEVELING SYSTEMS IN THE MONITORING OF STRUCTURES: A CASE STUDY AT THE GOVERNADOR JOSÉ RICHA HYDROELECTRIC POWER PLANT - PR

Aplicação do certificado de calibração de sistemas de nivelamento digitais no monitoramento de estruturas: estudo de caso na Usina Hidrelétrica Governador José Richa - PR

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Abstract:

The monitoring of the vertical behavior of benchmarks installed in the dam crest of the Governador José Richa hydroelectric power plant (UHGJR) has been performed by the first-order differential leveling method with the use of digital leveling systems which are composed of a digital level and a invar barcode rod. By default, the scales of these instruments are the same, but over time both can change, degrading the observations. In the past, the simultaneous calibration of these systems was not considered in the determination of UHGJR settlements, however, after the development of the first calibration system of digital leveling systems in Brazil, it was possible to investigate the equipment performance as well as to determine a scale factor to be applied to correct the level readings. The results achieved are the systems calibration used in the monitoring of the UHGJR and the calibration certificate application in leveled sections in November 2016. The maximum correction applied to the elevation differences was of the order of nine tenths of millimeters, result attributed to the region observed in the rod, since the deviations obtained in the calibration vary according to the reading position at the rod.

Keywords: First-order differential leveling; Calibration; Monitoring of structures.

Resumo:

O monitoramento do comportamento vertical de referências de nível instaladas na crista da barragem da Usina Hidrelétrica Governador José Richa (UHGJR) tem sido realizado através do método de nivelamento geométrico de primeira ordem, onde são utilizados sistemas de nivelamento digitais, compostos por um nível digital e uma mira de ínvar gravada em código de

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barras. Por construção, as escalas destes equipamentos são iguais, porém com o passar do tempo ambos podem mudar, degradando as observações. Até o momento, a calibração simultânea destes equipamentos não era considerada na determinação dos recalques observados na UHGJR, contudo, após o desenvolvimento do primeiro sistema de calibração de sistemas de nivelamento digitais do Brasil, foi possível investigar o desempenho dos equipamentos, bem como determinar o fator de escala a ser aplicado para corrigir as leituras do nível. Como resultados, apresentam-se a calibração dos sistemas utilizados no monitoramento da UHGJR e a aplicação do certificado de calibração nas seções niveladas em novembro de 2016. A máxima correção aplicada nos desníveis foi da ordem de nove décimos de milímetros, resultado atribuído a região observada na mira, pois os desvios obtidos na calibração variam de acordo com a posição de leitura na mira.

***Palavras-chave**:* Nivelamento geométrico de primeira ordem; calibração; monitoramento de estruturas.

1. Introduction

Currently there are 219 Hydroelectric Plants (UHE) in operation in Brazil and these enterprises correspond to 61.18% of the country's electricity generation capacity (Brazil 2017). The hydroelectric power plants are mainly composed of the dam and this structure is one of the most important engineering constructions used for water supply, flood control, agricultural uses and electricity generation (Kalkan 2012).

The safety of dams is a permanent concern for governmental entities, either because of their economic importance or because of the potential risk represented by the possibility of a rupture or other serious accident, in terms of human lives, environmental impact, material damages and economic and financial repercussions (Eletrobrás 2003). Recently a serious accident occurred in the city of Mariana-MG, in which Fundão dam collapsed, a fact related to negligence in the monitoring or operation of the enterprise (Gonçalves, Fusco and Vespa 2015).

Thus, dam monitoring is an essential component after construction and during its operation and should allow the early detection of any behavior that could damage the structure, resulting in its shutdown or failure (Kalkan, Alkan and Bilgi 2010). Han, Guo and Jiang (2013) also argue that monitoring structural deformation is a major concern when it comes to structures such as dams, bridges or tunnels.

According to Mukupa et al. (2017), several studies have been conducted for monitoring structures and different geodetic techniques have been applied. Among the geodetic techniques used, it can be mentioned first-order differential leveling or precise leveling, gravimetric survey, positioning by satellites, traverse, and laser scanning. In dams, the parameters that should be monitored are the movements of control points, uplift pressures on the dam, settlement, seepage and leakage from the abutments and foundation, and the presence of cracks (Pytharouli et al. 2007). Therefore, different horizontal and vertical control survey techniques can be applied. The settlement is one of the main causes of pathologies in structures and in some cases of total collapse (Corrêa 2012), then this study will emphasize vertical monitoring that can be used to quantify and determine vertical deformations.

In recent years, several structures have been monitored from the geodetic techniques mentioned, for example, Kalkan, Potts and Bilgi (2016) monitored the Atatürk dam in Turkey, where points located on the surface and at the dam crest were observed. In this study, the first-order differential leveling, trigonometric leveling and satellite positioning were applied to evaluate the possible vertical deformations of the structure and provide information about the safety of the dam. The authors verified that the results obtained with the first-order differential leveling provided the highest precision among the three methods after quantifying and evaluating the observed deformations and, therefore, it was used as a reference to compare the precision of the other applied techniques.

Pytharouli et al. (2007) also used precise leveling to measure vertical displacements of benchmarks located on the crests of the Ladon and Kremasta dams in Greece. The vertical deformation monitoring was also applied by Lacy et al. (2017) in the Arenoso dam in southern Spain, where the precision of the observations made by geodetic leveling techniques was better than 1 millimeter.

Zogg and Ingensand (2008) studied the possible deformations of a viaduct, comparing the vertical displacements measured with a precision leveling system (digital level and barcode invar rods) with the results obtained by Terrestrial Laser Scanner (TLS). Dardanelli et al. (2014) conducted an experiment at Castello, Italy, where they compared the results obtained by GNSS with the leveling technique. And Scaioni et al. (2014) also used the results obtained by leveling to compare the deformation of a tunnel by photogrammetric techniques. In all three studies are examples of how the differential leveling is used as reference in comparison of other techniques.

Therefore, precise leveling is the most widely used geodetic method for the measurement of vertical deformations in artificial structures such as bridges, historic buildings, dams and the like (Scaioni et al. 2014). Thus, it is essential that the equipment used during the surveys is checked, rectified and calibrated to ensure precision during observations.

The first calibration system for digital leveling systems in Brazil was developed at the Laboratory of Geodetic Instrumentation (LAIG) of Federal University of Paraná (UFPR) (Gemin, Matos and Faggion 2016).

A digital leveling system consists basically of a digital level and a invar barcode rod, where by construction the scale of the instrument, which is a function of the constant CCD (Charge-Coupled Device) derived from the level, is equal to that of the rod, but over time both can change (Takalo and Rouhiainen 2004). For this reason, a calibration procedure must be carried out to simultaneously verify the behavior of the level and the barcode rod, in order to allow the assessment of the influence of the system components on the measurements to ensure that the precision required in the surveys is achieved (Woschitz and Brunner 2003).

Currently, the calibration of digital leveling systems is performed in horizontal or vertical calibration structures. The procedure consists in comparing the readings carried out on a barcode rod, which is moved horizontally or vertically depending on the structure, with reference readings obtained by a laser interferometer. However, depending on the calibration system used, oscillations may occur due to the displacement of the bar code rod, as verified by Takalo and Rouhiainen (2004).

Therefore, to minimize the influence of errors due to the displacement of the rod it has been proposed to maintain the leveling rod in a single position during the calibration. To make this unprecedented proposal viable, it was necessary to develop and manufacture a piece to fix a flat mirror at 45° over a transport system that moves up the rod, enabling readings in the full extent of the rod. This is a new approach to vertical and horizontal calibration systems adopted in other countries such as the United States, Austria, Czech Republic, Finland, among others (Gemin, Matos and Faggion 2016).

Until now, no research was found that addresses the proposed methodology, making necessary the investigation of unique characteristics inherent to the development of the system. Due to the horizontal displacement of the transport system it were studied factors that can influence the result of the calibration, including: the design of the proposed system; construction and positioning of the mirror at 45°, because this is one of the conditions for a vertical image of the barcode rod to be visualized by the level; the deduction of the mirror dimension at the maximum observation distance, because the mirror dimension influences the roughness and flatness effects (Gonçalves 2009); and the determination of the vertical irregularities of the rails through which the transport system moves, because as verified can cause deviations in the ideal position of the mirror. These and other characteristics of the calibration system can be analyzed in Gemin, Matos and Faggion (2016) and are related only to the adequacy performed in the proposed calibration system.

Thus, in order to investigate and analyze the proposed new calibration methodology, this present paper presents the result of the calibration of two digital leveling systems to evaluate the performance and consistency of the results in a first-order differential leveling.

The research group of Geodesy Applied to Engineering of UFPR develops activities in the area of monitoring of large structures, especially for dams, for a long period. Among the geodetic monitoring carried out is the study of possible vertical movements on the dam crest of the Governador José Richa Hydroelectric Power Plant, also known as Salto Caxias Hydroelectric Power Plant, located in the state of Paraná, where survey campaigns are carried out using the first-order differential leveling technique using a digital leveling system (Faggion et al. 2016).

Finally, this work aims to use the calibration system of the LAIG to verify the performance of the digital leveling systems used in the monitoring of the dam of the UHGJR, as well as generate a certificate of calibration to correct the level readings. Thus, it will be possible to compare the elevation difference obtained before and after the application of the calibration certificate, guaranteeing greater precision and reliability in the results obtained during the monitoring of the structure.

2. Methodology

2.1 Study Area

The UHGJR is located on the boundary of the municipalities of Capitão Leônidas Marques and Nova Prata do Iguaçu, in the southwest of the state of Paraná (Figure 1), and is part of the hydroelectric projects built on the Iguaçu River. The dam has more than a kilometer in length and in volume is the largest structure in roller compacted concrete (RCC) of the country. In addition, the dam crest was transformed into highway (PR-592) which shortened the distances between the municipalities of the west and southwest of Paraná (Copel 2017).

Figure 1: Governador José Richa Hydroelectric Power Plant.

Source: Copel 2017.

2.2 Differential leveling

The monitoring of structures by first-order differential leveling is a well-established technique and is frequently used in surveys conducted at UHGJR dam (Faggion et al. 2016). In order to monitor the possible vertical displacements at the dam crest, surveys were carried out using a leveling system composed of a Leica DNA03 digital level (n° 333660) (Figure 2A) and a pair of 2 m invar barcode rod (rods n° 30207 and n° 30211) (Figure 2B). The digital level has precision specification of 0.3 mm per kilometer for the double run leveling for height measurements (Leica Geosystems 2006).

Figure 2: Survey by first-order differential leveling at the crest of UHGRJ dam. (A) Leica DNA03 digital level and (B) Leica 2 m invar barcode rod.

The monitoring and determination of elevation differences are performed by the survey of nine reference level (RRNN) implanted near the UHGJR dam and along the PR592 highway. The RRNN are identified as RN 50A, RN 50B, RN 50D, RN 50E, RN 50F, RN 50G, RN 50H, RN 51 and RN 52 (Figure 3).

Figure 3: Approximate positions of the RRNN located on UHGJR dam.

Source: Adapted from Google Earth 2017.

Regarding the position, the RRNN 50B, 50G and 50H are superficially located below the road level (Figure 4A), since they were implanted before the end of PR592 construction. However, the RRNN 50A, 50D, 50E and 50F are on the road, because they were implanted after its construction (Figure 4B). The distances between the RRNN are related by dam region which has the aim of monitoring. From RN 50A to RN 50B, the larger distance, there are the spillway constructed in conventional concrete and the other ones are in RCC, focus of this research.

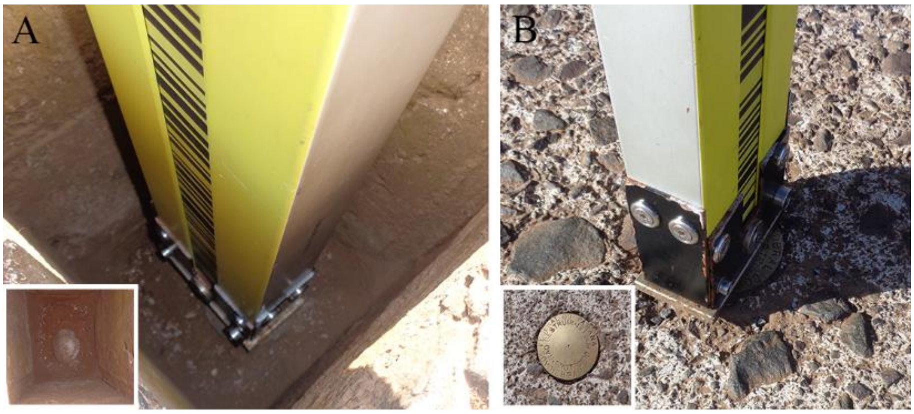

Figure 4: RRNN located on the dam crest of the UHGJR. (A) RN below the road level. (B) RN on the road.

To minimize the occurrence and propagation of systematic errors during the surveys, some precautions were taken:

• In order to determine the collimation and vertical axis error, the instrument was checked before commencing leveling in accordance with the manufacturer's handbook (ISO 17123-2 2001). The collimation error exists if when after leveling the instrument, its line of sight is not horizontal (Ghilani and Wolf 2012). There is the error of verticality of the main axis when the main axis does not coincide with the vertical of the place due to a problem in the leveling of the instrument (Silva and Segantine 2015).

• In differential leveling, horizontal lengths for the backsight and foresight should be made about equal (Ghilani and Wolf 2012). Then, a maximum variation between the backsight and foresight lengths adopted was less than 10% (ISO 17123-2 2001). Balancing backsight and foresight lengths will minimize errors due to instrument (like the collimation error) and to the combined effects of the Earth's curvature and refraction (Ghilani and Wolf 2012).

• In each observation made on the rod, the reading of the horizontal plane observed was obtained from the average of three readings performed with the digital level;

• The readings were made from 20 cm above the ground to minimize the effects of reverberation (IBGE 1983). Wind can cause instrument vibration and make the rod difficult to hold in a steady position, so to reduce disturbances the leveling keep the rod to its shortest length and use a wind break to shelter the instrument (Schofield and Breach 2007);

• To minimize the index error a pair of rods was used, so that the rod that started the leveling section is the same one that ended the survey (IBGE 1983);

• Use of leveling plates along the turning points (IBGE 1983);

• It is important to realize the amount of misclosure in leveling, so it was adopted a permissible criteria based on the distance levelled. The criterion used to assess the misclosure (E) is (Schofield and Breach 2007):

$$E = m\sqrt{k} \tag{1}$$

Where k is the total length leveled in kilometers, m is constant with units of millimetres, and E is the allowable misclosure in millimetres. Since the digital level used is classified as of higher precision, the allowable misclosure adopted for all the sections should be 1mm√k (Torge 2001); and

• To correct the elevation difference by applying the calibration certificate of digital leveling system (item 3.2), were measured through a portable weather station the temperature at the time of survey. The temperature was measured every one minute, where the mean temperature of the leveling section was used as a reference.

The last leveling survey occurred in November 2016, where the elevation differences were measured starting from RN 50A to RN 52. Therefore, the data obtained on this date were used in the investigation of the application of the calibration certificate of the digital leveling systems used, as explained below.

2.3 Calibration system of LAIG

Some installations have already been built for the calibration of digital leveling systems in several countries, for example: United States, Czech Republic, Austria, Malaysia, Germany, Japan and Finland, and are commonly referred to as comparator systems. However, in Brazil the first efforts to develop this system began only in 2016 and the first was developed at the Laboratory of Geodetic Instrumentation of UFPR (Figure 5A) (Gemin, Matos and Faggion 2016).

In a digital leveling system, the observed horizontal plane height is calculated electronically through a correlation process where the barcode image of the rod is captured and compared with a standard image stored in the equipment (Ghilani and Wolf 2012). Thus, it is possible to affirm that the digital leveling systems are related to the barcode rod scale, as well as the CCD devices present at the levels (Takalo and Rouhiainen 2004). However, over time, both the scale of the level and the rod may change, degrading the results of the observations (Takalo and Rouhiainen 2004). Therefore, to achieve and guarantee precision it is essential that the instruments are checked, rectified and calibrated.

The basic principle of calibration is to compare the readings performed on the rod by a digital level, with reference readings obtained by a laser interferometer. In LAIG, the calibration system has the characteristic of keeping the rod fixed in the horizontal position, so it is necessary to move a mirror for indirect observation of the bar code rod image (Figure 5B). This calibration methodology (keeping the rod fixed in the horizontal position) is innovative in relation to current methodologies and aims to minimize oscillations due to the displacement of the rod, as verified by Takalo and Rouhiainen (2004).

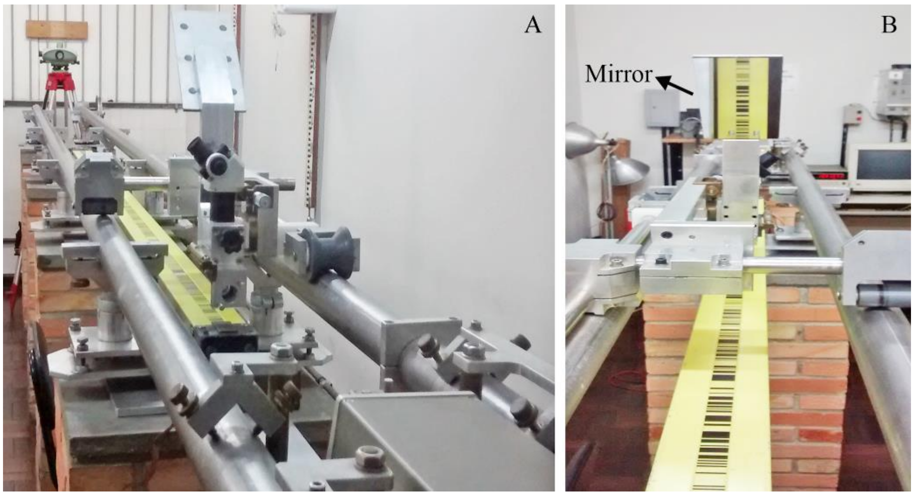

Figure 5: (A) Calibration system for digital leveling systems of the LAIG and (B) reflection of the barcode rod image in a plane mirror positioned at 45°.

A horizontal movement system on a pair of rails is used to fix and move the laser reflective laser reflector together with the mirror positioned at 45°, such that it is possible to make readings in the rod by digital level and by interferometric system simultaneously. The mirror must be plane and be positioned at 45° to the line of sight of the level and the normal line of rod, as it is one of the conditions for a vertical image of the barcode rod to be visualized and captured by the level. In addition, other cautions are performed during calibration procedures and can be verified in Gemin, Matos and Faggion (2016).

In order to investigate the performance and scale of the digital leveling systems used in monitoring the UHGJR dam, the calibration of the equipment was executed by calibration system of LAIG. Two systems were calibrated, the first formed by level n° 333660 and rod n° 30207 (system 1) and the second formed by level n° 333660 and rod n° 30211 (system 2). The mean temperature, humidity and relative air pressure during the calibration procedures were 22.4°C, 50.0% and 689.8mmHg respectively for system 1 and 23.1°C, 51.5% and 689.3 mmHg respectively for system 2.

Six series of observations were performed during the calibration whose readings were measured every 20 mm, length is adopted as ideal (Chumanová 2014). With each new series, the readings of the calibration system for reading were alternated, that is, first readings were taken from the base towards the top of the rod and then from the top to the base, minimizing possible influences of the calibration system.

The results obtained consist of information related to the performance and scale of digital leveling systems. According to Suárez (2014), this information compiles the data needed to generate a document called a calibration certificate, which presents information about the metrological performance of the measurement system and provides the errors from the instrument at the time of calibration, allowing the user to perform more precise and reliable measurements. Finally, the calibration results and the application of the calibration certificate, that is, the application of corrections to the level readings in the survey using the precise leveling of November 2016 can be analyzed in the item 3.

3. Results

3.1 Calibration result for digital leveling systems

The performance of the leveling systems used in the monitoring of UHGJR dam were derived from the difference between the mean level readings (N_i) with the mean reference values (I_i) of each position, so, to calculate the deviations from the readings (ΔH_i) was applied Equation 2.

$$\Delta H_i = N_i - I_i \qquad (2)$$

The first set, level n° 333660 and rod n° 30207 (system 1), was identified during the surveys and was used in the foresight readings, while the second set, level n° 333660 and rod n° 30211 (system 2) were used in the backsight readings. The results of the performances of systems 1 and 2 can be analyzed in Figure 6A and 6B, respectively.

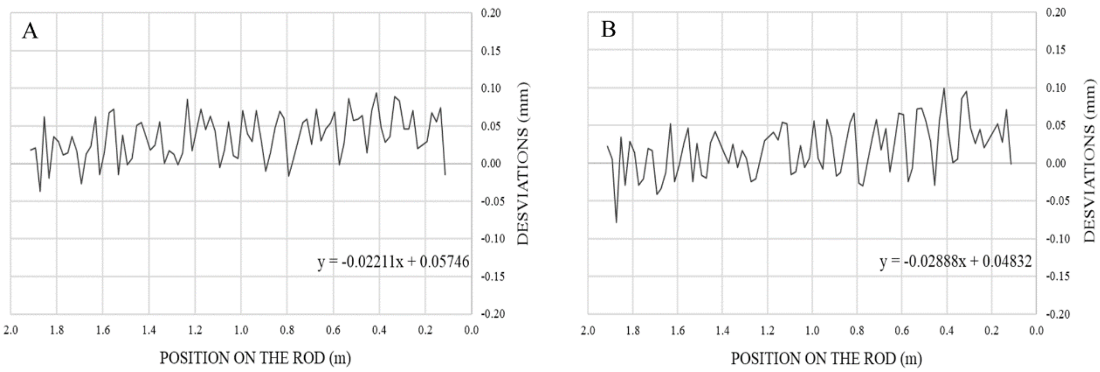

Figure 6: Performance of the digital leveling systems used in UHGJR dam. (A) Deviations from readings obtained by system 1 (B) Deviations from readings obtained by system 2.

In Figure 6A it is possible to evaluate the result of the calibration of system 1, where the maximum deviation was in the order of hundredth of a millimeter (0.094 mm) at the position 0.41305 m from the rod, with the mean of the readings equal to 0.039 mm. In Figure 6B is shown the performance of the second calibrated leveling system where the maximum deviation was 0.099 mm at the 0.41303 m position of the rod, the mean of the deviations was equal to 0.032 mm. Such deviations may be related to the process of recording barcodes of the rods, abrasions, and scratches or even related to the level CCD sensor, optical system and other components that form the digital level.

The calibration result also enables the scales of digital leveling systems to be obtained. These are represented by the linear regression equations estimated from the observed data and represent the scale of system 1 (Equation 3) and system 2 (Equation 4), respectively. The numerical terms of the equation represent the angular and linear coefficients of the line and x must be replaced by the level reading.

$$y_i^{system1} = -0.02211\mathrm{x} + 0.05746 \quad (3)$$

$$y_i^{system2} = -0.02888\mathrm{x} + 0.04832 \quad (4)$$

The readings measured in the field with calibrated digital leveling systems can be corrected considering the scale factor (linear and angular coefficients of equations 3 and 4) and the temperature at the time of measurement. So, based on the equation provided by Woschitz and Brunner (2003), the corrected reading (h^{corr}) of the observed horizontal plane can be calculated (Equation 5):

$$h^{corr} = h^{med} \cdot \left[1 - b + \alpha^{inv} \cdot \left(t^{inv} - t^{ref}\right)\right] - a \quad (5)$$

Where h^{med} is the measure reading, b b is the angular coefficient of the linear regression equation in ppm, a a is the linear coefficient of the linear regression equation in ppm, α^{inv} is the coefficient of thermal expansion of invar (12-13 ppm/°C), t^{inv} is the temperature of the invar band of the rod whilst measuring, and t^{ref} is the reference temperature used during calibration of the digital leveling systems. Residues (r_i) were calculated (Equation 6) to verify the precision of the leveling systems. These have a variation around ±0.015 mm (Figure 7A and Figure 7B).

$$r_i = \Delta H_i - y_i^{system} \quad (6)$$

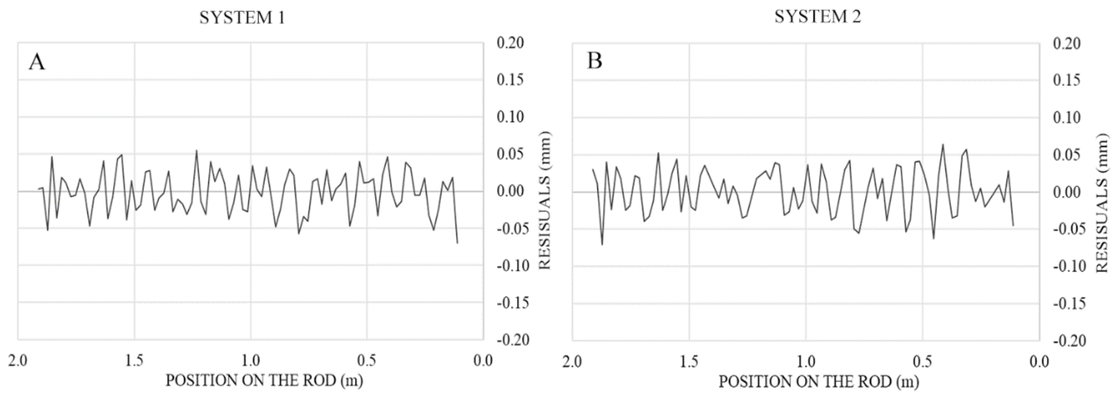

Figure 7: Residuals from digital leveling systems used in UHGJR dam. (A) Residuals from readings obtained by system 1 and (B) residuals from readings obtained by system 2.

Finally, from the information presented, it was possible to correct the level readings by applying the calibration certificate that will be discussed in item 3.2.

3.2 Application of the calibration certificate

After the calibration of the digital leveling systems, the information generated was used to correct the precise leveling data performed at UHGJR dam in November 2016. In Tables 1 and 2 it is possible to visualize the mean temperature at the time of leveling of each section, total lengths of each level section, the elevation differences obtained in double run leveling, that is, for example, the leveled sections RN 50A for RN 50B (leveling) and RN 50B for RN 50A (leveling back), the allowable misclosure (1mm√k), the committed error in the section, as well as the elevation differences calculated before and after the application of the calibration certificate.

Table 1: Results of surveys of the leveled sections at UHGJR dam.

ORIGINAL DATA							
Section	Temp. °C	Total length of double run (Km)	Elevation difference by double run leveling		Allowable misclosure (mm)	Committed error in the section (mm)	Elevation difference (m)
			Leveling (m)	Leveling back (m)			
RN 50A to RN 50B	22.0	0.54177	-0.36521	0.36551	± 0.74	-0.30	-0.36536
RN 50B to RN 50D	22.1	0.20229	0.32385	-0.32356	± 0.45	0.29	0.32371
RN 50D to RN 50E	22.4	0.12489	0.02332	-0.02358	± 0.35	-0.26	0.02345
RN 50E to RN 50F	22.6	0.08358	-0.01001	0.01023	± 0.29	-0.22	-0.01012
RN 50F to RN 50G	23.0	0.09760	-0.27756	0.27731	± 0.31	0.25	-0.27744
RN 50G to RN 50H	23.0	0.15059	0.01048	-0.01026	± 0.39	0.22	0.01037
RN 50H to RN 51	23.2	0.11594	0.27622	-0.27629	± 0.34	-0.07	0.27626
RN 51 to RN 52	27.1	0.306045	-14.22486	14.22531	± 0.55	-0.46	-14.22508

Table 2: Results of surveys of the leveled sections at UHGJR dam after the application of the calibration certificate of digital leveling systems.

DATA CORRECTED WITH CALIBRATION CERTIFICATE							
Section	Temp. °C	Total length of double run (Km)	Elevation difference by double run leveling		Allowable misclosure (mm)	Committed error in the section (mm)	Elevation difference (m)
			Leveling (m)	Leveling back (m)			
RN 50A to RN 50B	22.0	0.54177	-0.36523	0.36553	± 0.74	-0.30	-0.36538
RN 50B to RN 50D	22.1	0.20229	0.32387	-0.32358	± 0.45	0.29	0.32372
RN 50D to RN 50E	22.4	0.12489	0.02332	-0.02358	± 0.35	-0.26	0.02345
RN 50E to RN 50F	22.6	0.08358	-0.01001	0.01023	± 0.29	-0.22	-0.01012
RN 50F to RN 50G	23.0	0.09760	-0.27758	0.27733	± 0.31	0.25	-0.27745
RN 50G to RN 50H	23.0	0.15059	0.01048	-0.01026	± 0.39	0.22	0.01037
RN 50H to RN 51	23.2	0.11594	0.27624	-0.27631	± 0.34	-0.07	0.27627
RN 51 to RN 52	27.1	0.306045	-14.22387	14.22432	± 0.55	-0.44	-14.2241

In Table 1 it was possible to verify the temperature difference between the leveling performed between the RRNN 50A to 52. A significant increase in temperature occurred in the survey between the RN 51 to RN 52, since it was performed in the afternoon, while the other RRNN were leveled in the morning. The temperature difference at the time of the survey in relation to the reference temperature, that is, the temperature of the laboratory when the leveling systems were calibrated, influence in the correction of the readings performed with digital level and consequently in the elevation differences between the RRNN, so it is important to measure and correct observations in high-precision leveling.

The tolerance for the allowed misclosure is calculated as a function of the total length of the leveling and leveling back distances, therefore varies according to each section. Comparing the allowed misclosure with the committed error in the section (tables 1 and 2), verified that in all the leveled sections the errors were smaller than the tolerance of 1mm/km, achieving the requirements for first-order leveling.

In both tables, it is possible to compare the elevation differences between the leveling (tables 1 and 2) and leveling back (tables 1 and 2) sections before and after the application of the calibration certificate in the digital level readings. Comparing the elevation difference in the leveling, occurred corrections between the RN 50A and RN 50B (0.02mm), RN 50B to RN 50D (0.02mm), RN 50F to RN 50G (0.02mm), RN 50H to RN 51 (0.02mm) and RN 51 to RN 52 (0.99 mm). The elevation difference in the leveling back after application of the calibration certificate is of the same magnitude. Corrections of the order of the hundredth of a millimeter are related to the flat topography of the leveling region, where the same area of the rod was observed. The most expressive result occurred between the RRNN 51 and 52, where the elevation difference is about 14 m, which allowed different areas of the rods to be observed (base, middle and top of the rod).

In addition, there was a significant difference between the temperature during the leveling and the reference temperature, resulting in a correction of nine tenths of a millimeter. Sections RN 50D to RN 50E, RN 50E to RN 50F and RN 50G to RN 50H were not corrected.

After applying the calibration certificate, it was possible to note that between the RRNN 51 to 52 there was a decrease in the committed error of two hundredths of a millimeter. Finally, when comparing the elevation difference after the application of the calibration certificate (table 1 and 2), corrections occurred of the following magnitudes: 0.02 mm (RN 50A to 50B), 0.01 mm (RN 50B to 50D), 0.01 mm (RN 50F to 50G), 0.01 mm (RN 50H to 51) and 0.98 mm (RN 51 to 52).

The RN 50A is considered as a reference and has a height equal to 100.00000 m. In order to calculate the height of the RN 52 from the RN 50A, the elevation differences obtained along the RRNN located at the dam crest were used. Next, the law of error propagation was applied, obtaining as height the value of 85.75579 ± 0.00079 m. After applying the calibration certificate the new calculated height was equal to 85.75676 ± 0.00077 m, indicating an addition in the elevation difference between the RRNN of 0.97 mm, as well as an increase in the precision the height of the RN 52. Even though the surveys at the UHGJR were performed according to the criteria presented in item 2.2, a correction of almost 1 mm was applied in the height of RN 52, change that may be significant in monitoring studies.

4. Conclusion

The calibration system of digital leveling systems developed by UFPR enabled the performance and scale factors of the systems used in the monitoring of UHGJR dam to be investigated and estimated. By analyzing the performance of the two calibrated digital leveling systems, it was possible to verify that different deviations occurs by maintaining the digital level and changing the leveling rod, that is, the physical conditions of the rod, such as scratches, stains and factors of the construction process, cause differences in readings. In addition, it is not possible to identify the portion of possible errors related to the level, which may be caused, for example, by the optical system or by the CCD device. Therefore, it is important to consider the simultaneous calibration of leveling systems in first-order surveys.

When applying the calibration certificate in a region with a large elevation difference, it was possible to verify a significant change in the value of the correction of the readings performed with the digital level, correcting the final elevation difference about 0.9 mm. This can be related as several measurements made at the base, middle and top of the rod. In addition, more variation of the temperature at the time of the surveying in relation to the reference temperature, causes more influence in the corrections in the measured reading.

When the differences between the sections were less than 0.5 m, corrections occurred after the application of the calibration certificate in order of 0.02 mm, a result related to the observation of the same area on the rod and the low variation of the temperature in relation to the reference temperature.

Finally, with the case study in the UHGJR, whose scope is the monitoring of structures, it was possible to verify the importance of the application of the calibration certificate in digital leveling systems, where corrections of about 1 mm were determined.

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