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Structural behavior of Pracana dam 30 years after rehabilitation due to severe ISR-ASR damage

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Abstract

The Pracana dam is a buttress structure, 60 m high, completed in 1951, built with a concrete mix including quartzite and granite aggregates. An abnormal behavior was observed since the first filling of its reservoir, characterized by progressive vertical and horizontal displacements and intense cracking. These important deteriorations and the assessment of the insufficient capacity of the spillway, led to empty the reservoir in 1980. Physical and chemical tests performed over time, on samples taken from the dam´s body, confirmed the existence of ISR-ASR of great magnitude. At the end of the eighties of the last century the reservoir remained empty, to allow large scale rehabilitation works that have been implemented from 1988 to 1992, by the dam's owner EDP - Energias de Portugal. The rehabilitation included the waterproofing of the upstream face by a geomembrane, the foundation and concrete treatments, the construction of two alignments of concrete struts at the foundation level connecting the buttress webs, one of them connecting the buttresses downstream toes, as well as the update of the monitoring system. Additionally, a new spillway was built and a new generator unit was installed in the powerhouse.

Since the refill of the reservoir in December 1992, the swelling rate (computed from the vertical displacements measured by precise levelling) generally declined, although not in an uniform way throughout the structure. In the central buttresses the average vertical accumulated strains were 680×10^{-6} in the period 1952-1980 (average annual rate of 24×10^{-6}/year) and 105×10^{-6} in the period 1992-2020 (average annual rate of 4×10^{-6}/year), which indicates a significant swelling rate reduction of about six times due to the rehabilitation works. However, in the blocks located on the right bank, the swelling effects were similar in both periods of dam's operation (average annual swelling rates of 18×10^{-6}/year and of 22×10^{-6}/year during the first and the second periods, respectively). Regarding the left bank, the average annual rates were 72×10^{-6}/year and of 28×10^{-6}/year during the first and the second periods, respectively; however, the vertical accumulated strain of the abutment block B15, only monitored during the second period, has a huge value of 2670×10^{-6} (annual rate of 100×10^{-6}/year), which is about 25 times higher than the expansion rate in the central zone of the dam, issue which is under investigation. Due to these results, a medium-term structural intervention in the lateral blocks could be needed.

In global terms, the rehabilitation of Pracana dam, associated with the previous 12 dewatering years, can be considered a successful case, enabling the reservoir operation without limitations for the next years.

***Keywords**: Pracana dam; ISR-ASR damage; rehabilitation; monitoring; structural condition*

1. INTRODUCTION

Pracana dam is a worldwide well-known case of a successful rehabilitation related with damage due to concrete swelling [1-4]. In fact, an abnormal behavior of the dam was observed since the first filling of its reservoir in 1951, characterized by progressive vertical and axial horizontal displacements (upstream-downstream direction) and extensive cracking, due to an intense ISR-ASR process, which led to empty the reservoir in 1980. The reservoir remained empty for 12 years. During this period several studies were developed, which culminated with the execution of large rehabilitation works of the dam, which take place from 1988 to 1992. This rehabilitation included the waterproofing of the

upstream face by a geomembrane, the foundation and concrete dam body treatments by the grouting of cement and epoxy resins, the construction of two alignments of concrete struts to link the buttresses webs at the foundation level, one of them at the downstream toe, and the construction of a new spillway. An update of the monitoring system, including additional devices, was also implemented.

Since the refill of the reservoir in December 1992, the swelling rate declined, although not in an uniform way throughout the structure. It is therefore important to evaluate regularly the swelling evolution, as well as its possible recovery signs in different sections of the structure, and to reassess the structural safety conditions of the dam. In this context, the paper presents the most recent and relevant monitoring results and its statistical treatment, in order to assess the condition of the dam structural elements.

2. PRACANA DAM HISTORY

2.1 Dam's characteristics and history

The Pracana dam is a buttress structure, 60 m high (Figure 2.1), founded on a rock mass of phyllite and greywacke alternations. It was completed in 1951. Quartzite and granite aggregates were used in the concrete mix. An abnormal behavior was observed since the entry into service of the dam, characterized by progressive vertical and horizontal U-D displacements, and intense cracking. Physical and chemical tests were performed, on samples taken from the dam´s body, which confirmed the existence of ISR-ASR of moderate magnitude. At the end of the eighties of the last century the reservoir remained empty for a long period, to allow large scale rehabilitation works.

Figure 2.1: Downstream view of Pracana dam in 1992, after the rehabilitation works

The main events related to the dam are the followings:

    1948/1951 - Construction of the scheme

    Since1952 - Several anomalies in the dam were detected, which have continuously increased

    1971 -   Restrictions to operation (limiting the reservoir level)

    1972/1973 - Unsuccessful repair works

    1977 -   The scheme was owned by EDP

    1978 -   The reservoir was emptied due to insufficient capacity of the spillway and progressive deterioration of the dam's structure (fast decrease of the structural safety factor)

    1985 -   Conclusion of the rehabilitation studies

    1988 -   Beginning of the site works

    1992 -   Conclusion of the civil engineering works and refilling of the reservoir

The reservoir has been empty for 12 years (1980-1992).

2.2 Brief description of the dam's rehabilitation

The rehabilitation investigation and design was concluded in 1985. The site works started in 1988 and have consisted of dam structural rehabilitation and the execution of complementary works, namely the construction of an auxiliary frontal spillway and the updating of the powerhouse, including the construction, in the dam body, of the intake for the new generation unit.

The structural rehabilitation of the dam included the following works: i) general treatment of concrete, to its regeneration; ii) placement of an impermeable membrane on the upstream surface, including the construction of an upstream foundation plinth; ii) construction of two sets of concrete struts for locking the buttress webs at the foundation level, one next to the downstream toe and the other in an intermediate position; and iii) consolidation of the foundation and execution of new waterproofing and drainage curtains, being the last ones executed form the top of a plinth built along the dam upstream toe. The improvement of the monitoring system was also done.

The buttress concrete regeneration was made by: i) the treatment of cracks with an opening greater than 5 mm by injection of cement stabilized grout; and ii) the mass treatment by injection of epoxy resin. The execution and control of these treatments have been supported by direct ultrasonic tests.

The waterproofing system of the upstream surface consists of a non-adherent synthetic membrane in order to prevent the contact of the reservoir water with the concrete and, thus, stop the water supply to the ASR and simultaneously prevent the uplift developing in existent cracks of the buttresses heads (Figure 2.2). The system selected by EDP is a Carpi patented system consisting of an impervious flexible PVC geomembrane 2.5 mm thick, heat-coupled during extrusion to a non-woven, needle-punched 500 g/m² geotextile. The PVC geomembrane, which was applied over a HDPE geonet with drainage purpose, fulfil many requirements, namely: i) low permeability ($k \approx 10^{-12}$ cm/s); ii) high flexibility, that enables installation also on not smooth faces; iii) resistance to punching, tearing and impact; iv) resistance to high temperature gradients and to freeze-thaw cycles; v) resistance to stresses induced by large relative movements, such as movements induced by earthquakes; and vi) expected long durability.

During the dam rehabilitation the monitoring system was revised to conform with the Portuguese regulations for dam safety, which had been approved in the meantime [5], and also enhanced to better monitor the structural behavior and the swelling process evolution. So, the following instruments have been introduced (Figures 2.3 and 2.4): i) multiple rod extensometers installed along the heads of five buttresses (P1, P4, P6, P9 and P12); ii) two rod extensometers on each buttress foundation, one near the head and other at the downstream toe; iii) inverted plumb lines in fife buttresses (P1, P4, P6, P9 and P12), with suspension near the dam crest and anchored into the foundation rock; iv) thermometers located inside two buttresses (P5 and P7); and v) new jointmeters to measure the relative movements of joints. The geodetic monitoring system was also revised and improved.
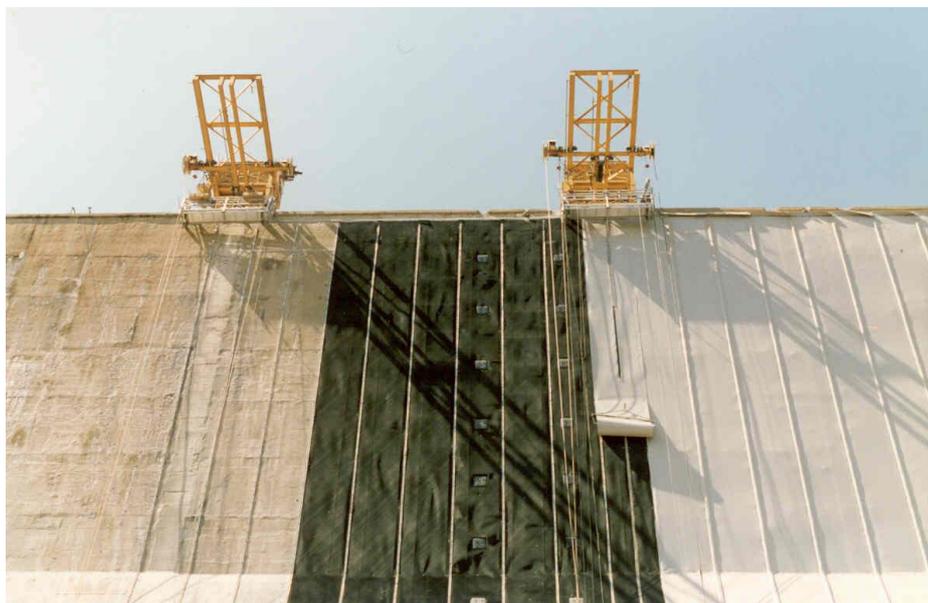

Figure 2.2: Stage of installation of the upstream impervious membrane

1 – Inverted plumb-line

2 – Multiple rod extensometer
     (dam's body)

3 – Rod extensometer
     (foundation)

4 – Levelling marks

5 – Geodetic targets

6 – Angles and distances
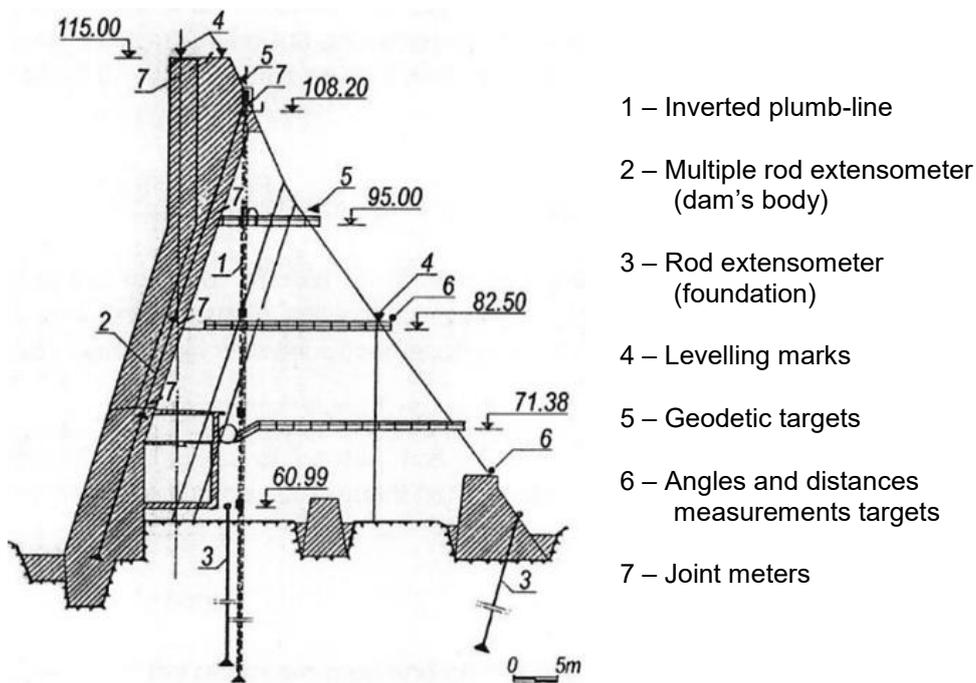   measurements targets

7 – Joint meters

Figure 2.3: General scheme of the new monitoring instruments installed in 1992 to measure displacements of the dam and its foundation

When the dam rehabilitation works were carried out, 63 thermometers were installed inside P5 buttress, at five different elevations, and another 63 thermometers were installed inside P7 buttress with equal distribution. These instruments, installed with the purpose of characterizing the structure's response to thermal action, began to be read in May 1986, about six and a half years before the beginning of the refilling of the reservoir and although many are no longer operational, mainly in the P5 buttress, so it is only possible to extract relevant information in the P7 buttress. Thus, the average temperature of the concrete in the P7 buttress, in the period in which the reservoir was empty, was 18.6 ºC, considering the 63 thermometers, and was 17.2 ºC since the refilling (December 1992) until March 2020, considering only the 47 thermometers that continuous operational. In the upper part of the buttresses' head, the differences reach more than 6ºC.
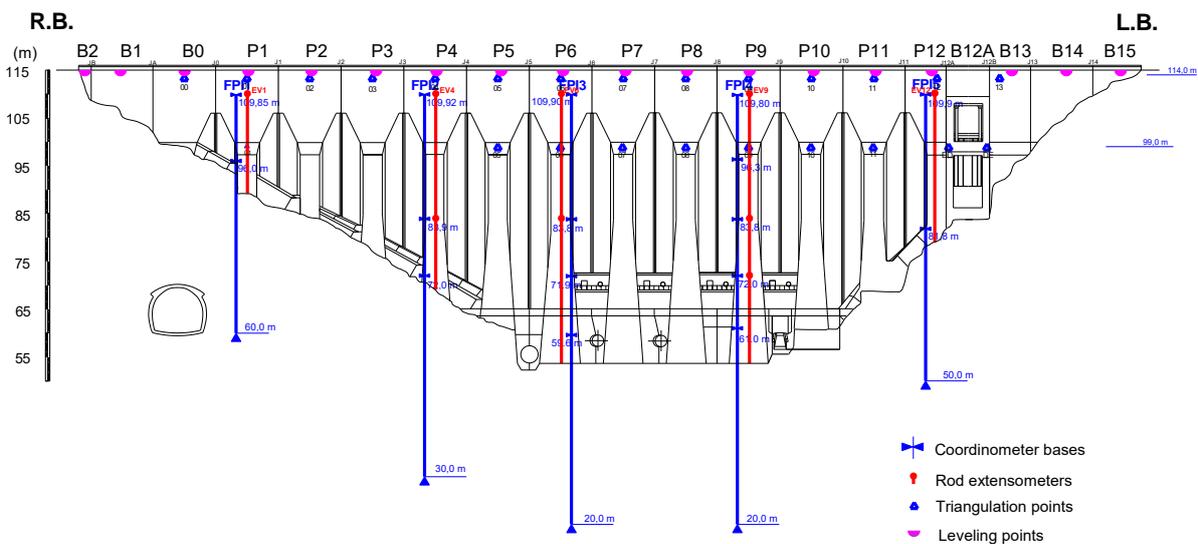

Figure 2.4: Monitoring instruments to measure horizontal and vertical displacements of the dam's buttresses

3. ANALYSYS AND INTERPRETATION OF THE OBSERVED BEHAVIOR

3.1 Statistical model adopted

The analysis and interpretation of the observed dam's behaviour was carried out using a statistical model of quantitative interpretation of the displacements measured over time by geodetic methods, rod extensometers and plumb lines. Quantitative interpretation consists of the analysis of a behavior mathematical model by which a functional relationship is established between the quantities or effects observed and the actions that originate them. The principle of superposition is assumed, considering that the actions corresponding to hydrostatic pressures and seasonal variations in temperature cause reversible effects and that the irreversible effects, due to non-elastic phenomena, depend only on time [6]. In the statistical model, a function of the type was adopted,

$$\text{E}_{calc}(h, t', t) = \sum_{i=1}^{N} a_i\, h^i + \text{b}_1 \cos \frac{2\pi\, t'}{365} + b_2 \sin \frac{2\pi\, t'}{365} + \sum_{j=1}^{M} c_j\, t^j + d \left(1 - e^{-\frac{t^n}{\beta}}\right) + k \qquad (1)$$

where E_{calc} represents the calculated response, h is the hydrostatic action usually represented by the upstream water level (when important the downstream level must also be considered), t' is the number of days since the beginning of the year and t is the number of days counted from the initial observation date. . The parameters a_i, b_1, b_2, c_j, d and k are calculated by linear regression, performed by the least-squares method. N and M represent the degree of the polynomials used to represent the hydrostatic pressure and time effects, respectively, the terms in sine and cosine are intended to represent the effect of the annual thermal wave, it is considered a polynomial expression to reproduce the time effects and an exponential term is used to represent the effects of expansive action.

The differences between the values observed in the prototype and the values calculated by the statistical model are the residuals r, defined by the expression,

$$r = E_{obs}(h, t', t) - E_{cal}(h,\ t', t) \qquad (2)$$

The coefficient of determination R^2 of a quantitative interpretation, which assesses the significance of the regression, is expressed by the equation,

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(E_{cal}(h, t',\ t) - E_{obs}(h, t', t)\right)^2}{\sum_{i=1}^{n}\left(E_{obs}(h, t',\ t) - \bar{E}_{obs}(h, t', t)\right)^2} \qquad (3)$$

where n is the number of observations and $\bar{E}_{obs}(h, t', t)$ is the average of the observed values. Closer the value of R^2 is to 1, more the model adjusts to the observed values.

3.2 Structural behavior interpretation during the first period of operation (1952-1980)

The first period of the dam's operation started in October 1951 (first filling of the reservoir) and finished in May 1980. In Figure 3.1 are represented the water level in the reservoir (a) and the air temperature (b) during this period. It can be seen that after the first filling the reservoir has been emptied three times (October 1954, September 1958 and October 1973). The values of the average daily air temperature, observed between February 1953 and December 1978, allowed the computation of an annual period harmonic function. The thermal air wave is characterized by the average value of 17.7 ºC, the half-amplitude of 7.6 ºC and by a lag of 214.1 days in relation to the maximum annual value. In this period, the highest maximum and minimum lowest temperatures recorded were 39.0 C and 0.0 C, respectively.

(a) Water level in the reservior
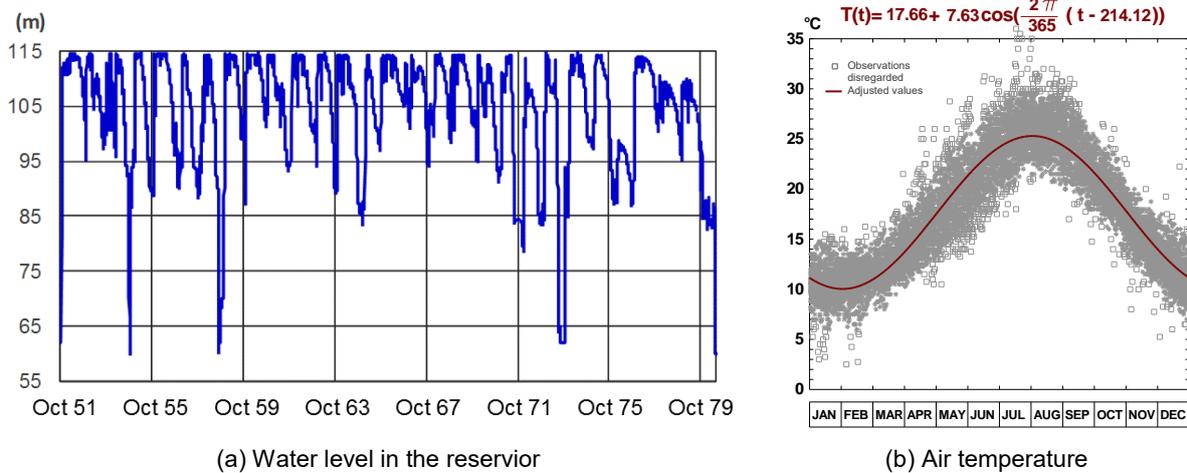
(b) Air temperature

Figure 3.1: Main actions in the period 1952-1980: (a) water level in the reservoir and (b) average daily air temperature observed and harmonic function adjusted

During this period the monitoring system was based mainly on geodetic methods. The results of the monitoring campaigns allowed the detection of irreversible upward displacements and, also, downstream horizontal displacements, on the blocks B0 and B14 and on buttresses P2, P4, P6, P8, P10, P11 and P12. Just before the decision of stopping the operation and emptying the reservoir was taken, the quantitative interpretation results showed that the crest irreversible components of vertical and horizontal displacements, related to the time effect, were, very high, with average rates of 1.0 mm/year and 1.2 mm/year, respectively. Figure 3.2 shows the results of the statistical model application for vertical displacements measured on P8 buttress, since 1952 to 1980. A value of about 32 mm was computed to the irreversible vertical displacement due to the swelling process.
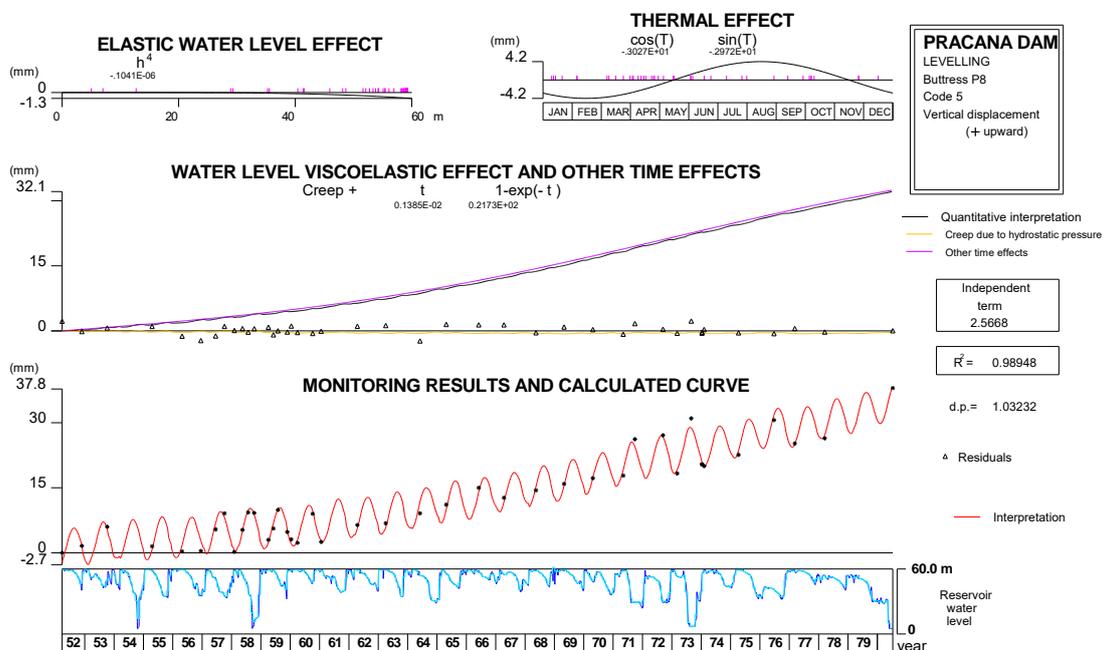

Figure 3.2: Results of statistical model application for vertical displacements measured on the top of P8 buttress since 1952 to 1980

In Figure 3.3 the results of statistical model application for horizontal upstream-downstream (U-D) displacements measured on the top of P9 buttress, since 1952 to 1980, are presented. Large irreversible displacements were computed in the downstream direction due to creep and swelling.

The magnitude of the computed vertical and horizontal displacements due to the swelling effects are compatible with the cracking patterns observed at that time.
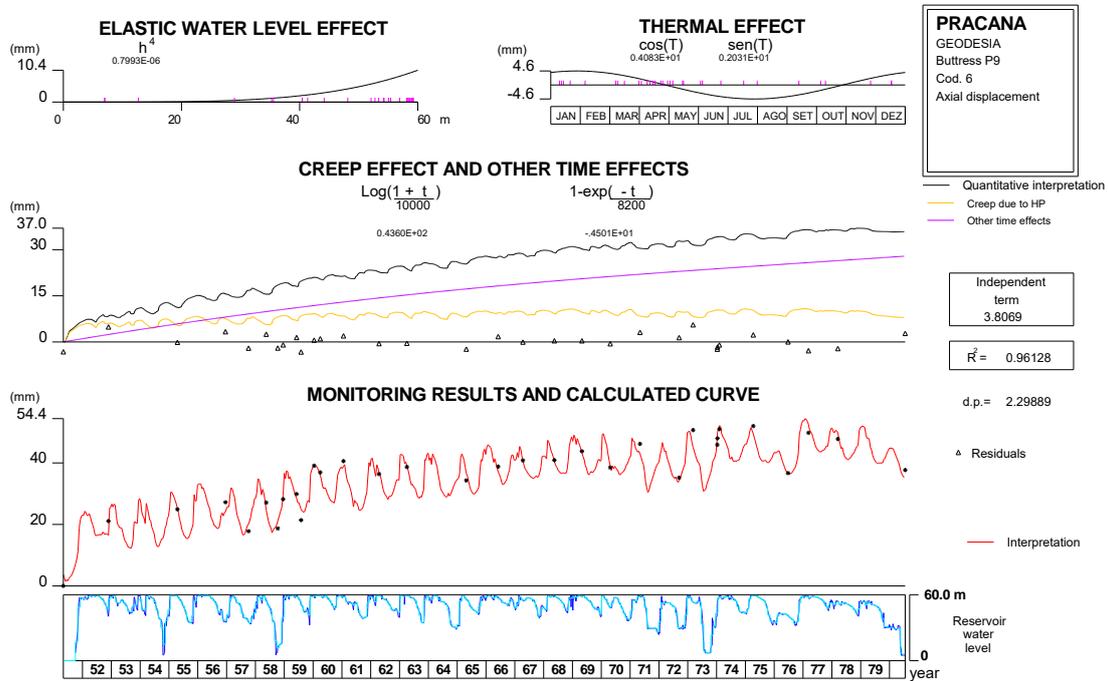

Figure 3.3: Results of statistical model application for horizontal (U-D) displacements measured on the top of P9 buttress since 1952 to 1980

3.3 Structural behavior interpretation during the operation period after the rehabilitation works (1992-2020)

The second period of dam's operation began in December 1992, after 12 years in which the reservoir has been empty. During these 12 years several studies were carried out, the dam rehabilitation project was developed, and all the rehabilitation works were executed.

In Figure 3.4 (a) the water reservoir level over time is presented. After the initial refilling, which occurred in December 1992, the reservoir was emptied in July 1994 and again refilled in September 1994. Since then the water level in the reservoir has varied, almost always, between elevation 95 m and the normal water level 114.0 m. Figure 3.4 (b) represents the values of the average daily air temperature, observed between December 1992 and January 2020, and the annual period harmonic function adjusted to the monitored data. The thermal air wave is characterized by the average value of 16.2 ºC, the half-amplitude of 7.6 ºC and by a lag of 207.1 days in relation to the maximum annual value. In this period, the highest maximum and the minimum lowest temperatures recorded were 45.0 C and -5.0 C, respectively.

The application of the statistical model to the horizontal displacements measured on the upper coordinometer basis of the plumb lines, considering 970 records, shows that the axial components (upstream-downstream direction) due to water level variations and temperature changes are compatible with these actions, and reveals the occurrence of irreversible displacements towards upstream, reaching, at the end of this 28 years' period, the maximum of 4.6 mm at the top of buttress P9. Regarding the transversal displacements, measured in the same coordinometer basis, the quantitative interpretation model shows a very small component due to water level variations, a component due to temperature changes compatible with the thermal action, and reveals, in the plumb lines closer to the abutments, the occurrence of irreversible displacements, 2.3 mm towards the right bank at buttress P1 and 1.8 mm towards the left bank at buttress P12. In Table 3.1 the results of the quantitative interpretation model applied to horizontal displacements are presented.

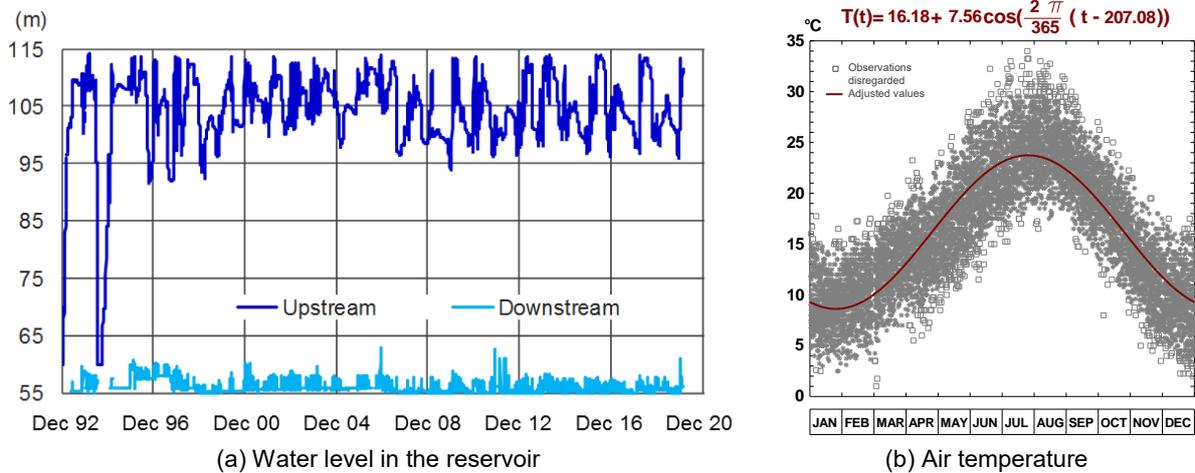(a) Water level in the reservoir

(b) Air temperature

Figure 3.4: Main actions in the period 1992-2020: (a) water level in the reservoir and (b) average daily air temperature observed and harmonic function adjusted

Table 3.1: Main results of the quantitative interpretation model applied to horizontal displacements measured on plumb lines

Buttress	Axial displacements (mm)			Transversal displacements (mm)		
	Water effects	Temperature effects	Effects over time	Water effects	Temperature effects	Effects over time
P1	2,2	1,0	-4,3	0,6	1,5	-2,3
P4	4,9	3,3	-4,1	0,3	0,8	-0,9
P6	5,2	4,5	-3,8	0,0	0,1	-0,6
P9	5,0	4,8	-4,6	-0,1	0,8	1,1
P12	2,3	2,4	-3,0	-0,5	1,5	1,8

Axial displacements toward downstream are positive
Transversal displacements toward left bank are positive

The statistical analysis of vertical displacements for all points of the upstream and downstream precise levelling lines located at crest, which data was acquired in the 33 campaigns performed between December 1992 and January 2019, shows components due to water level variations and temperature changes compatible with these actions and reveals irreversible displacements upwards. These irreversible displacements are higher on the downstream line, with values, in the central zone of the dam, between buttresses P2 and P11, ranging from 4 mm and 8 mm and on the upstream line displacements ranging from 2 mm and 5 mm. It can also be seen that in the side blocks B1 and B0 on the right bank and B14 and B15 on the left bank the displacements are very significant. The corresponding calculated irreversible displacements correspond to vertical strain, accumulated during 27 years, that are small in the central zone of the dam, with average values below 100×10^{-6} and high deformations in the side blocks, mainly on the two blocks close to the left bank, as can be seen in Figure 3.5.
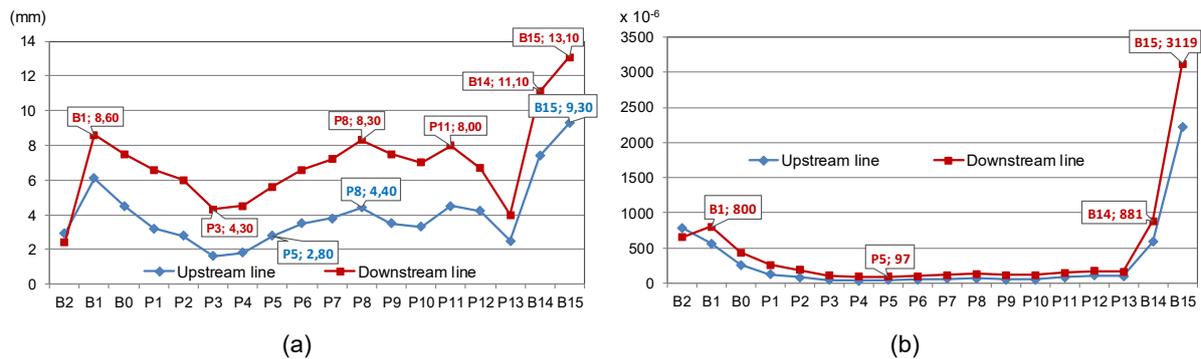
Figure 3.5: (a) Irreversible vertical displacements on levelling marks at crest and (b) accumulated vertical strains on the buttresses and side blocks.

The application of the statistical model to the displacements measured by the simple and multiple rod extensometers installed in the heads of buttresses P1, P4, P6, P9 and P12, parallel to the upstream face and about 4 m from that surface, with the heads of the instruments on the downstream surface of the buttresses at 110 m elevation and anchors near the foundation, show results compatible with those obtained by levelling. During this period 957 campaigns were carried out. Table 3.2 shows results related to the irreversible components of the displacements and respective strains, where the last column shows results obtained from levelling analysis.

Table 3.2: Main results of the quantitative interpretation model applied to displacements measured on rod extensometers

Buttress	Rod extensometers				Levelling accumulated strains ($\times 10^{-6}$)
	Anchor elevation (m)	Rod length (m)	Accumulated displacements (mm)	Accumulated strains ($\times 10^{-6}$)	
P1	84	27,4	5,6	204	127-263
P4	84	27,4	3,8	139	-
P4	64	48,5	4,5	93	38-95
P6	84	27,4	5,5	201	-
P6	54	59,0	5,3	90	56-105
P9	84	27,4	5,8	212	-
P9	72	39,5	4,9	124	-
P9	54	59,0	7,0	119	56-120
P12	79	32,6	6,2	190	109-174

The shading cells corresponds to rod extensometer showing malfunction.

The quantitative interpretation model has revealed progressive displacements for all the observed rods, showing that the swelling process has continued with upwards crest movements, registering however a small attenuation. For longer rod extensometers the time effect results are compatible to those obtained by levelling. It can also be observed that the shorter rod extensometers have higher accumulated strains.

3.4 Swelling developed before and after the dam rehabilitation

In Table 3.3, the results of quantitative interpretation of vertical displacements, obtained from the crest levelling before and after the dam rehabilitation, are compared. These two periods have similar duration and the results clearly show that the accumulated swelling and the expansion average annual rates are significantly lower in the second period, with exception if block B1. In all buttresses with monitored results in both periods there were reductions between 5 and 8 times and in block B14, on the left bank, there was a reduction of 2.5 times. However, in block B1, on the right bank, there was an increase of about 40% in the annual swelling rate.

Table 3.3: Average swelling accumulated and average annual rates, during the first and second periods, obtained through the analysis of the crest vertical displacements (levelling)

Buttress	Height (m)	First period (October 1952 to May 1980)			Second period (December 1992 to January 2019)		
		Accumulated vertical displacements (mm)	Accumulated vertical strain (x10^{-6})	Annual swelling rate (x10^{-6})	Accumulated vertical displacements (mm)	Accumulated vertical strain (x10^{-6})	Annual swelling rate (x10^{-6})
B2	3.7	-	-	-	2.7	716	27.4
B1	10.8	5.6	521	18.4	7.4	684	26.2
B0	17.2	-	-	-	6,0	349	13.4
P1	25.1	-	-	-	4.9	195	7.5
P2	32.1	33.1	1050	37.1	4.4	137	5.3
P3	38.6	-	-	-	3.0	76	2.9
P4	47.3	29.0	607	21.5	3.2	67	2.6
P5	57.8	-	-	-	4.2	73	2.8
P6	63,0	31.8	550	19.4	5.1	80	3.1
P7	62.3	-	-	-	5.5	88	3.4
P8	62.3	32.1	535	18.9	6.4	102	3.9
P9	62.3	-	-	-	5.5	88	3.4
P10	60.9	26.8	466	16.5	5.2	85	3.2
P11	53.4	33.1	685	24.2	6.3	117	4.5
P12	38.4	30.6	836	29.5	5.5	142	5.4
B13	24.2	-	-	-	3.3	134	5.1
B14	12.6	25.5	2024	71.5	9.3	734	28.1
B15	4.2	-	-	-	11.2	2667	102.2

Block B15, on the left bank, is the one with the greatest irreversible deformations (it was not monitored in the first period of the dam's life).

3.5 Waterproofing geomembrane behavior

The drainage system, installed between the waterproofing system and the upstream concrete face of the dam, is divided into eight main independent compartments, as shown in Figure 3.6. The water collected in each compartment is conducted to drains located at the upstream face, immediately above the plinth surface, which are equipped with downstream outlets to enable the measurement of the respective discharges.
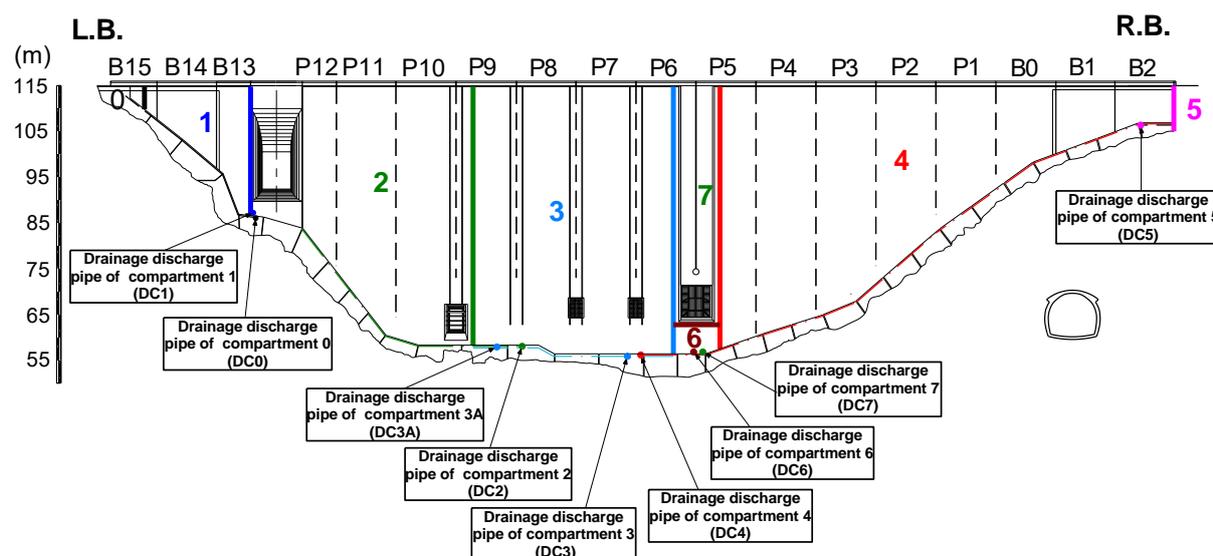

Figure 3.6: Drainage system of geomembrane from the eight independent compartments, with location of the drainage discharge pipes of each compartment.

Figure 3.7 shows the discharges evolution in the different geomembrane drainage compartments. As can be seen, in the compartments 1 and 4, where several membrane ruptures have occurred, the discharges were higher. In compartment 1, where the most significant ruptures occurred in 2011, 2018

and very recently (December 2019), the discharges have reached maximum values of about 75 l/min. The discharges from compartment 4 had a first increase between 2000 and 2003, with maximum values of about 65 l/min, but since 2011 to 2016 the increase was higher, reaching a maximum value of 209 l/min in April 2016. In November 2016 there was a geomembrane repair intervention that drastically reduced those discharges. However, in 2019 new rips appear to have occurred.
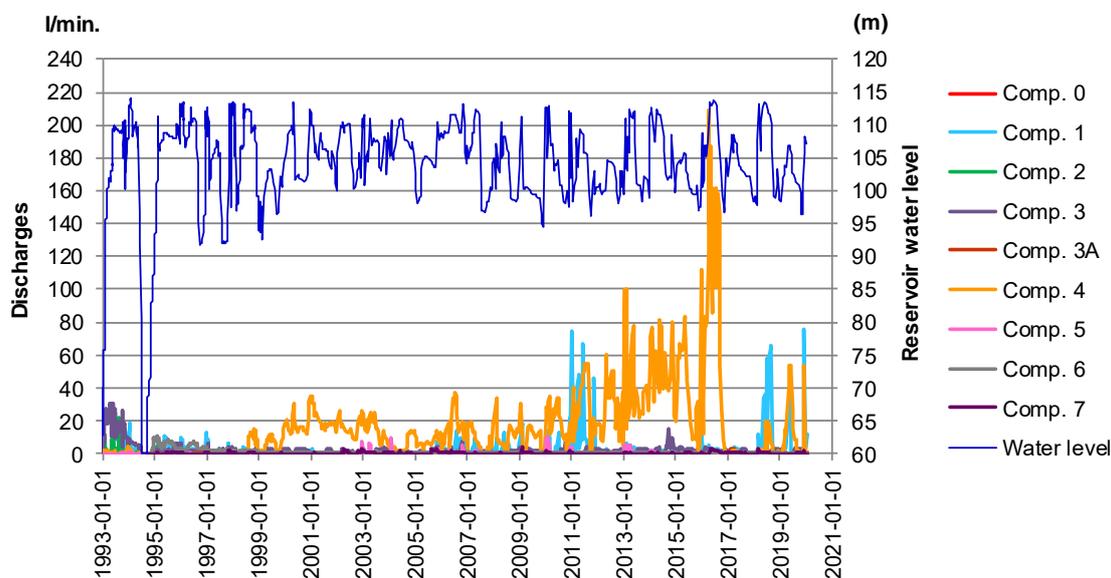

Figure 3.7: Discharges evolution in the different geomembrane compartments

It should be noted that the measured values of the water level in the compartments have been systematically zero, which indicates there is no accumulated water between the geomembrane and the upstream surface of the dam, and that the compartment drains have an appropriate discharge capacity. Nevertheless, preventive actions must be taken to remove the solid material that floats in the reservoir, particularly in flooding periods, to avoid its impact on the geomembrane, which has been the cause of the rips that have occurred.

4. CONCLUSION

The monitoring system installed in Pracana dam indicates progressive upstream horizontal displacements and vertical upwards crest displacements. Interpretation of levelling, plumb lines and rod extensometers displacements by statistical models has shown that the swelling process, although still present, has a significant lower rate in relation to the first period of dam's operation, before the execution of the rehabilitation works.

In the first period of operation, the average vertical accumulated strain in the central seven monitored buttresses was 680×10^{-6}, corresponding to an annual swelling rate of 24×10^{-6}/year. In the second period of dam's operation the average vertical accumulated strain in the central twelve monitored buttresses was 105×10^{-6}, with an annual swelling rate of 4×10^{-6}/year. A swelling rate significant reduction of about six times was achieved with the rehabilitation works.

The results for the side blocks B2, B1 and B0, located on the right bank, are similar in the two periods of dam's operation. In the first period the vertical accumulated strain of block B1 was 520×10^{-6}, with an annual swelling rate of 18×10^{-6}/year, and in the second period the corresponding values for the three blocks were 580×10^{-6} and 22×10^{-6}/year, respectively. However, this last value is five times higher than the correspondent value computed for the central zone.

Regarding the left bank, the comparison is made considering only the block B14 because it is the only one that was monitored in both periods and also because the results obtained in the three blocks B13, B14 and B15 are very different. Thus, in the first period vertical accumulated strain of block B14 was 2020×10^{-6}, with an annual swelling rate of 72×10^{-6}/year, and in the second period the average vertical accumulated strain in the same block was 730×10^{-6}, with an annual swelling rate of 28×10^{-6}/year.

However, vertical accumulated strain of block B15 during the second period was 2670×10^{-6}, with an annual swelling rate of 100×10^{-6}/year. This value is about 25 times higher than the expansions in the central zone, which require further investigation and, if necessary, a medium-term intervention.

Mitigation of the swelling process proportionate by the rehabilitation works is undoubtedly a positive result to which the geomembrane installation on the upstream surface has given an important contribution. However, the long period with the reservoir emptied and the dam weather conditions, relatively warm and dry, may have also contributed to reduce the speed of the swelling process. In view of the results obtained, it is considered that the geomembrane continues to exhibit a good performance and functionality, preventing the upstream water access to the dam body. After 28 years of natural exposure, the evaluation of its physical condition must be checked frequently, which is done by carrying out visual inspections, in order to detect rips usually caused by floating woody material, especially after the occurrence of important floods. These rips are usually repaired in the following dry season.

Finally, it must be recognized that the rehabilitation of the Pracana dam is a successful case, because since that time it has been operating without limitations. However, in addition to the implemented observation plan, which includes the analysis of the monitoring data and of the visual inspections, it is advisable to perform laboratorial tests for assessing the current situation of the swelling process and to predict its evolution, in order to ensure the safety of the dam.

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