Abstract
In one of the inspections carried out on Infiernillo 0 Bridge at the kilometric point 251 + 500, Cuota Federal Road "Patzcuaro-Lazaro Cardenas" in the State of Michoacan, Mexico, a remarkable inclination of the center pile was detected. Such tilting occurred, according to the responsible of the conservation of the structure, after a discharge of the Infiernillo reservoir, located upstream of the bridge, which caused an important rotation in the pile. Among the decisions taken to reverse the damage in the bridge, monitoring of the pile was adopted, while the necessary measures to restore the bridge to its original condition were adopted.
In this case, statistical control methods were used in order to see if the rotation was stabilized (continuous under control) or if they continued to evolve. These methods are suitable in view of the limited influence of temperature variation on the pile due to the reduced height and the presence of water in foundations as a thermal regulator as explained as follow.

Keywords: Bridge, Civil Engineering, Statistical Control Methods, Experimental validation

1. INTRODUCTION
The Infiernillo 0 Bridge combines spans made out of several concrete beams and two upper arches. The total length is 359.02 m (25.42+25.84+26.60+2x101.65+26.60+25.84+25.42). APIA XXI-Louis Berger IDC was responsible for the monitoring to control the movements in order to know if the rotation varied, stabilized or tended to decrease, providing, if necessary, a rehabilitation project.
Displacement transducers (TH), accelerometers (AV), inclinometers (CC) and temperature sensors (TP) were placed at the end bridge deck-pile and bridge deck-abutment.

Figure 1 View of the leaning pile from the abutment 1
Behavior of pile No.5 was analyzed during several months, being able to distinguish the following milestones:

- 07/10/2013: standard day in which the level of the dam was minimal.
- 09/20/2013: stormy day under the influence of Manuel and Ingrid hurricanes and the dam draining.
- 09/22/2013: Manuel and Ingrid hurricanes return to land (the stormy weather is reactivated) and the dam reservoir reaches maximum levels, continues discharging.
- 09/26/2013: hurricanes weaken but the dam continues discharging. The stability of the water flow is not achieved.
- 11/1/2013: the stability of the water flow is achieved. The beginning of hurricane season is not expected until mid-May.

2. TENDENCIES STUDY

Typically, statistical control techniques are applied to data obtained from an iterative procedure, so, unless erroneous, all the results are similar. When these results are not as similar as expected and are outside the control limits, it is said that the process is not controlled.

The basis of Statistical Control were used in the case of Infiernillo 0 Bridge in order to
see if the rotation was stabilized (continuous under control) or if they continued to evolve. In this case, this method is suitable in view of the limited influence of temperature variation on the pile due to the reduced height and the presence of water in foundations as a thermal regulator.

2.1. CC31. Longitudinal downstream

The following graph shows the maximum, minimum and mean values of rotation CC31. A remarkable trend has not been found in the average or the maximum and minimum values.

What we see is a variation of the maximum and minimum values in the days corresponding to the storm and a subsequent recovery towards pre-storm values. In the following charts the evolution of these maximum and minimum values is analysed.

![R Diagram CC31_max](image1)

**Figure 4. R Diagram CC31_max.**

![X Diagram CC31_max](image2)

**Figure 5. X Diagram CC31_max.**
Each sample shown in the chart represents a single day. Until early September, up to almost the 60th sample, the maximum values were controlled by varying around a mean value. On 17, 18, 19 and 20 September (red dots in green circle) have maximum values exceeding the expected range. Afterwards, the values seem to stabilize and a controlled situation is recovered.

![Diagram CC31_min. X]

**Figure 6. X Diagram CC31_min.**

![Diagram CC31_min. R]

**Figure 7. R Diagram CC31_min.**

The same was observed after analyzing the minimum values.

**2.2. CC34. Transversal upstream**

The following graph shows the maximum, minimum and mean values of rotation CC34. A remarkable trend has not been found in the average or the maximum and minimum values.
What we see is a variation of the maximum and minimum values in the days corresponding to the storm and a subsequent recovery towards pre-storm values. In the following charts the evolution of these maximum and minimum values is analyzed.

![Diagram CC34_max. X](image)

**Figure 8.** Diagram CC34_max.

![Diagram CC34_max. R](image)

**Figure 9.** R Diagram CC34_max.

Each sample shown in the graph represents a single day. Until early September, up to almost the 60th sample, the maximum values were controlled, varying around a mean value. On 17th, 18th, 19th and 20th September (red dots in green circle) have maximum values exceeding the expected range. Afterwards, the values seem to stabilize and a controlled situation is recovered.
The same was observed after analyzing the minimum values.
3. RESULTS AND DISCUSSION

3.1. CC34. Transversal upstream

The existence of a trend in the increase of the transverse rotation of the pile upstream is observed. Thus, during the days of the dam discharge, the pile tended to reduce its inclination due to the action of the water pressure as the thrust opposed its growing inclination. Once the water level and pressures on the shaft are lower, it returns to head upstream.

![Figure 12. R Diagram CC34_mean.](image)

![Figure 13. \( \bar{X} \) Diagram CC34_mean.](image)
4. CONCLUSIONS

- Until the arrival of Ingrid and Manuel, rotations in pile were controlled both in terms of average, maximum and minimum values.

- Between 15th and 21st September the expected behaviour of the pile was affected by the arrival of the hurricane and the opening of the floodgates of the dam. Rotations suffer unexpected variations so far but not significant.

- Day after day 21st, until September 26th, it seems that once again that the behaviour of the rotations goes back to the one before the arrival of storms. It seems that the pile tends to recover the initial degree of inclination which is good from the point of view of stability of the pile and the bridge.

- When analysing all the data of the registered rotations until the end of November (26.11.2013), the existence of a trend in the increase of the transverse turn of the pile upstream was observed. Thus, during the days of the dam discharge the pile tended to reduce their inclination effect of the thrust of the water because the thrust opposed his growing inclination. Once reduced water level and pushes on the pile, it returns to head upstream. It has achieved an average speed increase of transverse spin that, although small, should continue to be examined. This speed is 0.005 mrad / day.

- The actions to which the pile is subject are critical (right under the reservoir) and far from a recovery in the rotations of the pile, it continues with its initial trend, rotation towards upstream.
• It appears that streams on the foundation of the pile 5 have led to the formation of cavities and/or decompression phenomena of the terrain in the vicinity of the support. Therefore, it is clear that there is a problem of local undermining. The existence of the pile in the middle of the stream produces contraction of the water film and the concentration of flow in this area leads to the formation of vortices that develop corkscrew around the shaft. The bed materials are stripped from the upstream edge of the vertical component of the flow, and driven by high current. A hollow conical shape is formed in the case of non-cohesive soils whose deepest point is at the upstream edge of the pile. Ideally, the materials are again deposited downstream.

• It should be further noted that the existence of cavities results in increased bending moments in the piles, as the free length is increased and the lateral ground resistance is decreased as there is a smaller length on embedment.

As a result of the data obtained with the monitoring, APIA XXI-Louis Berger IDC performed the project corresponding to the underpinning of the pile using micropiles and reinforcement using a rock riprap at the base of it.

5. ACKNOWLEDGMENTS
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