# Discussion on "Thermal displacements of concrete dams: Accounting for water temperature in statistical models"

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**Abstract**

A discussion on the paper by Tatin et al. (2015) is presented. The paper described an innovative statistical model to interpret dam behaviour, which was validated with artificial data and then applied to seven dams in operation. This discussion provides several comments about the model performance evaluation, as well as suggestions for further analysis of the monitoring data.

*Keywords:* Concrete dams, Structural health monitoring, Thermal effects, Statistical analysis, Finite element method, Pendulum displacements

## 1. Discussion

Tatin et al. (hereinafter "the authors") presented an innovative statistical method to interpret dam behaviour. It is based on the traditional HST (Hydrostatic, Season, Time) [1]. Likewise the more recent Thermal HST (HSTT) [2], the new method considers the actual temperature measurements, but also the water temperature and the reservoir level variation in a simplified manner [3]. The result is the method called HST-Grad.

We agree with the authors in that the thermal effect is important in concrete dams, and particularly that caused by the presence of water. In this sense, the new tool constitutes an advance over HST and HSTT, largely maintaining the simplicity of both methods. Nonetheless, it is noteworthy that recent studies have revealed that other phenomena such as solar radiation, shading [4], [5] and night and evaporative cooling [6], are also relevant to the

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| Simulation | Boundary conditions | | |
| --- | --- | --- | --- |
| | Air temperature | Water temperature | Reservoir level |
| 1 | Variable | - | Empty (constant) |
| 2 | Variable | Variable | Full (constant) |
| 3 | Variable | Variable | Variable |

Table 1: Simulations performed by the authors for the heuristic case [3].

temperature field in the dam body and thus affect the displacement field.

The authors admit the inaccuracy of assuming that the thermal load is homogeneous in the upstream face. In our opinion, the situation in the downstream face may be similar in the general case, due to solar radiation and shading [6].

The new method was validated by means of its application to an artificially-generated time series of dam displacements. These data were obtained from a bi-dimensional finite element (FE) model of the Izourt Dam, a 44-m height gravity dam. Then the performance of the new method was assessed by considering actual monitoring data from seven dams in operation. In both cases ("heuristic" and "real" cases from here on, following the authors' terminology in [3]), the HST-Grad model was compared to HST and HSTT.

The HST-Grad model resulted in smaller residuals in most cases, and thus offered a more accurate identification of dam behaviour. The main advantage of these tools is their ease of interpretation, as opposed to others based on machine learning, which nonetheless proved to be highly accurate in recent studies [7], [8], [9].

For the heuristic case, three simulations were performed in [3], whose features are summarised in Table 1.

The result of this analysis showed a better fit of the HST-Grad model, in particular for the Simulation 3. This is coherent with the construction of the three models, and with the boundary conditions applied in each simulation.

The results for the heuristic case could be considered as an estimate of the lower boundary of the residuals that can be expected with each model in practice (Simulation 3). In other words, the error resulting from the application of HST-Grad model to a real case should increase with respect to that shown in Fig. 5 in [3] due to the simplifications introduced in the FE model: the actual water temperature and its spatial and temporal variation, the actual air temperature, the unconsidered thermal effects, and the thermal inertia of the water mass (in the case presented, the time delay to account for heat transfer between air and water was chosen arbitrarily). Furthermore, the measurement error should be added.

The authors presented the results for the real cases as the standard deviation of the residuals (mm), unlike in the heuristic case, where they were shown "as the ratio (in %) between the standard deviation of the residuals and the amplitude of the displacement analysed". In our opinion, it is more convenient to present the results in relative terms, for three reasons:

- In practice, the relevance of the residual depends on its relationship with the displacement amplitude. The same applies to model comparison.
- A dimensionless residual allows comparison between different dams, whose behaviour depend on several factors, including the dam typology and height.
- The use of the same goodness-of-fit index would ease comparison between the results for the heuristic and the real cases correspondent to Izourt Dam.

We found particularly relevant the similarity of the results for the calibration and forecast periods (Fig. 12 in [3]). This indicates that the residual for the training period is a good indicator of the general model accuracy. For the same reason, a deeper analysis would be needed for the Izourt Dam, which was the only exception: the standard deviation of the residuals increased between the calibration (0.5 mm) and the forecast period (0.8 mm; Fig. 12 in [3]). The description provided for Izourt Dam does not suggest a potential explanation, given that it is the lowest (44 m) and simplest (rectilinear gravity dam) of the seven dams considered.

We analysed the results published by the authors by extracting comparable values from Fig. 5 and Fig. 12 in [3]. They are showed in Table 2.

It should be noted that the results largely differ between the heuristic and the real cases in terms of relative residual reduction (75 to 10%). However, the difference in absolute value is much less relevant (0.1 mm).

In our opinion, though the heuristic case is highly valuable for validation purposes, the HST-Grad model assessment should be mostly based on the results for the real cases. For

| Case | Residuals standard deviation (mm) | | HST-Grad residual reduction | |
|---|---|---|---|---|
| | HSTT | HST-Grad | Absolute (mm) | Relative (%) |
| Heuristic (Simulation 3) | 0.2 | 0.05 | 0.15 | 75 |
| Real | 0.5 | 0.45 | 0.05 | 10 |

Table 2: Results of HST-Grad for Izourt Dam. Approximated values extracted from [3]. The displacements amplitude was supposed to be 5.0 mm (Fig. 8 in [3])

the seven dams considered, the residual standard deviation obtained with HST-Grad was around 10-15% lower than that of HSTT (Fig. 12 in [3]).

A more detailed analysis of the contribution of each source of error for the real cases would be highly interesting, as well as the influence of other specific dam features: typology, height, location, orientation, and reservoir operation. Regarding the latter, it would be helpful to know the reservoir level variation for the analysed dams, both in the calibration and forecast periods, as well as the reading frequency (the amount of data available). This could help the interpretation of the results of the comparative study, once the heuristic case confirmed that the relative performance of HSTT and HST-Grad was strongly influenced by the reservoir level variation.

We also consider that a four-way comparison between the FE model, the monitoring data, and the HSTT and HST-Grad estimates for Izourt Dam would be highly valuable. It might allow evaluation of the advantages and disadvantages of either model. FE models can be useful, especially for gravity dams that can be modelled in 2D. They have been previously applied for interpreting dam behaviour even for buttress dams, which are more complex and must be modelled in 3D [10].

## 2. Conclusion

The HST-Grad method presented by the authors constitutes an improvement over other currently used statistical methods to interpret dam behaviour. However, it is our belief that the reduction in the residuals deviation with respect to HSTT will generally be much closer to that obtained for the real cases (10-15%), than for the heuristic one (75%).

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