LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

# LONG-TERM GEODETIC DISPLACEMENTS. EVALUATING THE QUALITY OF MEASURED DISPLACEMENTS

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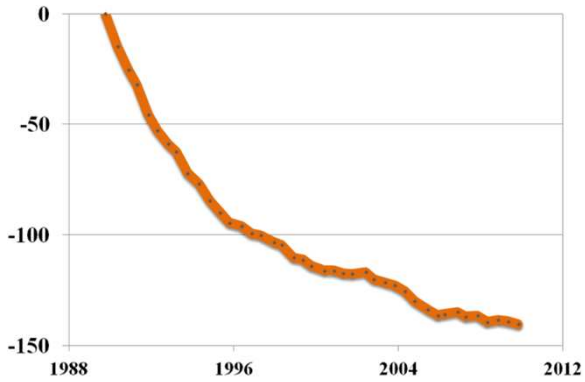
## Embankement dam

## Vertical displacements measured by surveying methods

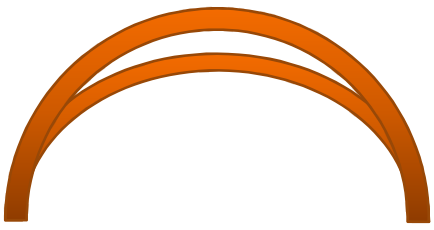
Embankement dam






## Glulam (glued laminated timber) arch

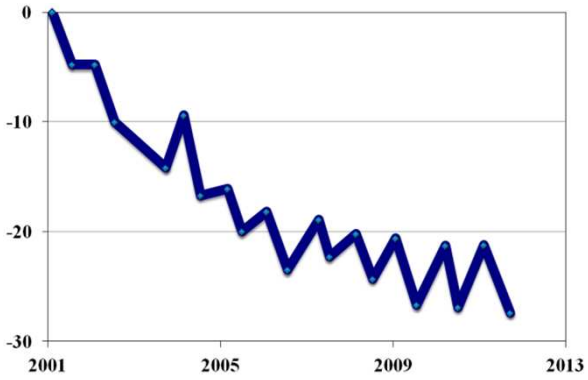
Pavilion



Effect of the humidity

## Vertical displacements measured by surveying methods

Pavilion






?

When the structure has a normal behaviour why not use this information to analyse the displacements of a structure and to predict values of displacements

# Paper summary

- 1. INTRODUCTION
- 2. LONG-TERM GEODETIC DISPLACEMENTS
- 3. REGRESSION MODEL
- 4. EVALUATING DISPLACEMENTS
- 5. LOADS ON THE STRUCTURE
- 6. REGRESSION MODELS APPLIED TO CIVIL ENGINEERING STRUCTURES
- 7. CONCLUSIONS



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# Regression model

is used to establish the relation between the variables measured and loads on the structure:

$$y = a_0 + a_1 f(x_1) + a_2 f(x_2) + \ldots + a_k f(x_k)$$

$$Y = A\,B$$

y: variable measured (displacement component, inclination, etc.).

x: loads on the structure (temperature, reservoir water level, age, etc)

a0, …, ak : the coefficients (the unknowns)



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# Loads on the structure

1. **Anual Periodic Changes**

$$a_k \sin\frac{2\pi\, t'}{365.25} + a_j \cos\frac{2\pi\, t'}{365.25}$$

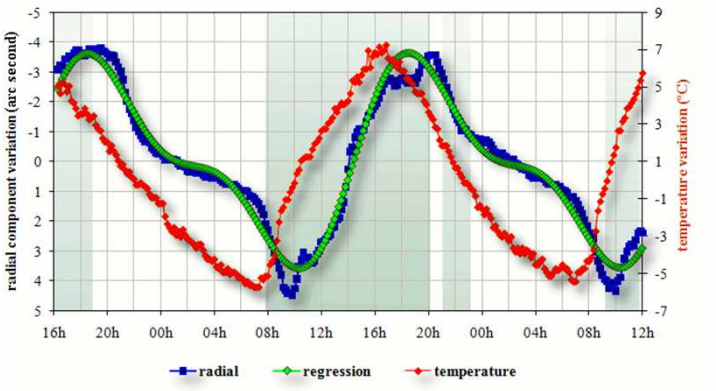
2. **Daily Periodic Changes**

$$a_k \sin\frac{2\pi\, t'}{24} + a_j \cos\frac{2\pi\, t'}{24}$$

$$y = a_0 + a_1 f(x_1) + a_2 f(x_2) + \ldots + a_k f(x_k)$$



Example of a daily change of inclination in radial direction




$$i(h,t) = a\,h + b_1 \cos\frac{2\pi t}{24} + b_2 \sin\frac{2\pi t}{24} + b_3 \cos\frac{2\pi t}{12} + b_4 \sin\frac{2\pi t}{12} + c$$

# Loads on the structure

3. **Water Level in Reservoirs**

$$a_k h^n$$

4. **Time effects**

$$a_k \frac{1}{(t-t_0)^n} \quad \text{or} \quad a_k \ln\left(1 + \frac{t-t_0}{\alpha}\right)$$

$$y = a_0 + a_1 f(x_1) + a_2 f(x_2) + \ldots + a_k f(x_k)$$



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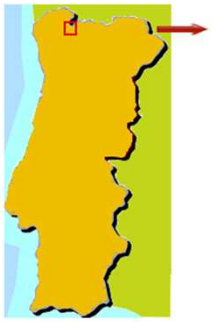
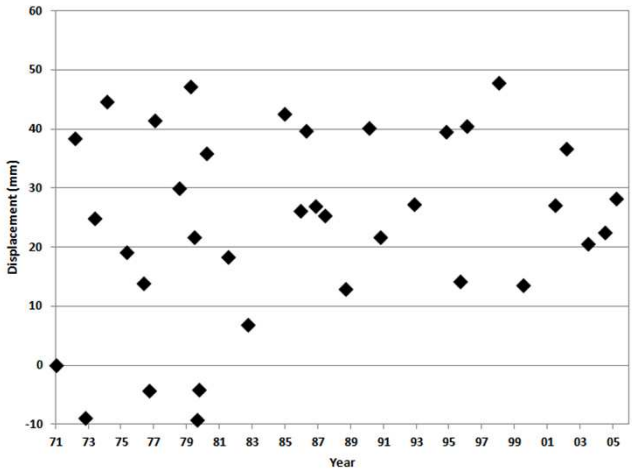
# Concrete dam



Vilarinho das Furnas

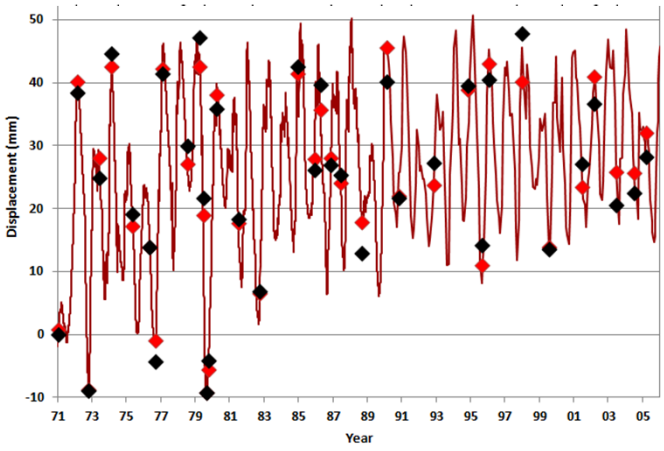


# Radial displacements



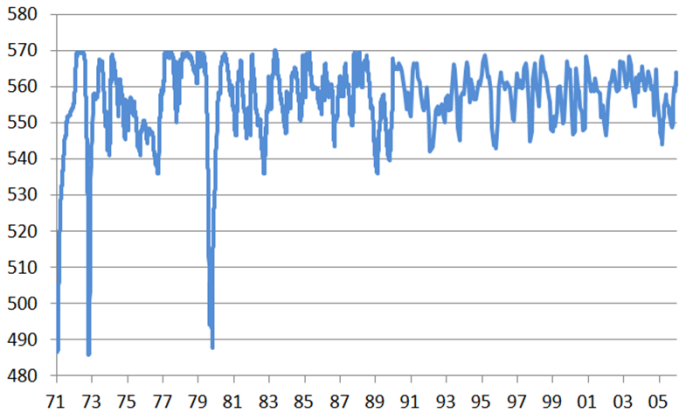
# Radial Displacements Modeled

$$y = a_0 + a_1 \cos\left(2\pi \frac{t'}{365.25}\right) + a_2 \sin\left(2\pi \frac{t'}{365.25}\right) + a_3 h + a_4 h^n + a_5 \ln\left(1 + \frac{t - t_0}{\alpha}\right)$$






# Water level in the reservoir



# Using Excel

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | date | water level | AB568 | DE568 | IJ568 | MN568 | PQ568 |
| 2 | 1971-01-27 | 488.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 1972-03-08 | 569.49 | 1.4 | 3.5 | 19.4 | 36.7 | 38.5 |
| 4 | 1972-10-24 | 486.70 | 2.1 | 0.7 | -2.4 | -4.6 | -9.0 |

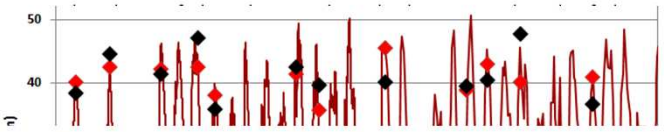
| | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | construction finishing | | const | f1 | f2 | f3 | f4 | f5 | | | AB568 | DE568 | IJ5 |
| 2 | 1970-06-15 | | 1 | 0.89 | 0.45 | 9 | 642.7 | 0.56 | | a0 | 1.93 | 1.59 | -0. |
| 3 | minimum water level | | 1 | 0.39 | 0.92 | 90 | 728757.0 | 1.13 | | a1 | 0.94 | 1.61 | 4.( |
| 4 | 479.5 | | 1 | 0.40 | -0.92 | 7 | 373.2 | 1.35 | | a2 | 0.09 | 1.16 | 4.3 |
| 5 | n | | 1 | -0.86 | 0.52 | 88 | 682169.2 | 1.53 | | a3 | 7.81E-02 | 3.03E-02 | -1.22 |
| 6 | 3 | | 1 | 0.64 | 0.77 | 89 | 709016.4 | 1.70 | | a4 | -7.20E-06 | 6.77E-07 | 3.54E |
| 7 | α | | 1 | -0.70 | 0.72 | 73 | 381393.6 | 1.94 | | a5 | -1.59 | -1.66 | 0.2 |
| 8 | 300 | | 1 | -0.73 | 0.68 | 68 | 311665.8 | 2.11 | | | | | |

$$y = a_0 + a_1 \cos\left(2\pi \frac{t'}{365.25}\right) + a_2 \sin\left(2\pi \frac{t'}{365.25}\right) + a_3 h + a_4 h^n + a_5 \ln\left(1 + \frac{t - t_0}{\alpha}\right)$$

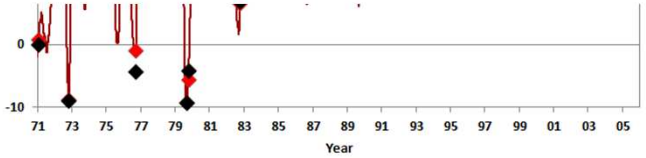


# Radial Displacements Modeled

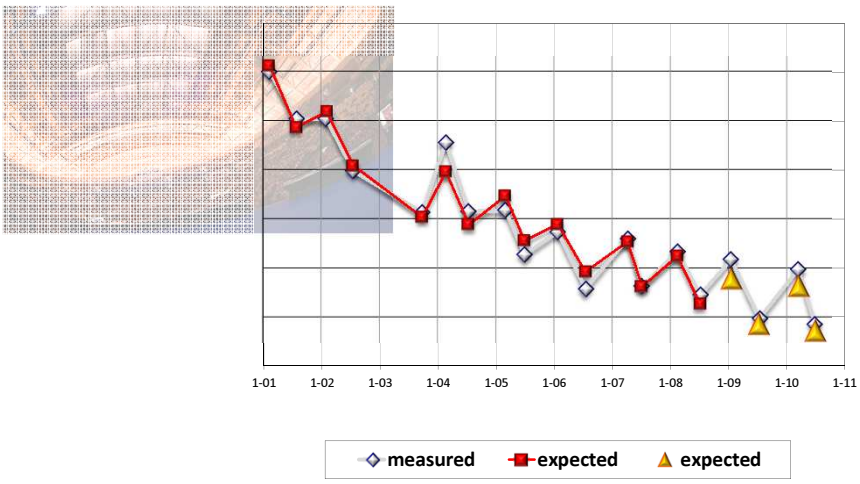
$$y = a_0 + a_1 \cos\left(2\pi \frac{t'}{365.25}\right) + a_2 \sin\left(2\pi \frac{t'}{365.25}\right) + a_3 h + a_4 h^n + a_5 \ln\left(1 + \frac{t - t_0}{\alpha}\right)$$




| BA | BB | BC | BD | BE | BF | BG | BH | BI | BJ |
|---|---|---|---|---|---|---|---|---|---|
| date | water level | const | f1 | f2 | f3 | f4 | f5 | AB568 | DE56 |
| 1981-06-13 | 564.97 | 1 | -0.95 | 0.31 | 85 | 624368.0 | 2.67 | -1.0 | -1.0 |
| 1989-12-30 | 567.40 | 1 | 1.00 | -0.02 | 88 | 679151.4 | 3.21 | -0.3 | 1.0 |

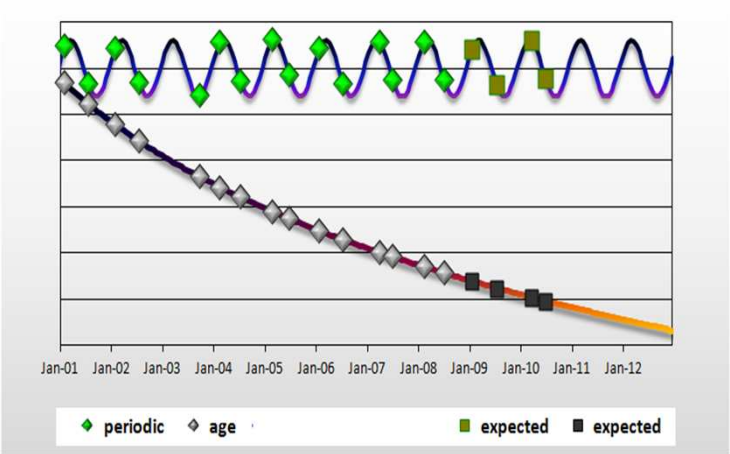


# Pavillion: Vertical displacements






# Periodic and aging effect



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# Conclusion

It was presented a simple method to build statistical/empirical models using functions of a well known spreadsheet application (Excel). The regression model used, that can be applied to analyse displacements, establishes linear relations between loads, time effects and structural response.

Excel macros developed to compute the statistical model coefficients are available