Trends and Challenges of Metrology Applied to Civil Engineering Research

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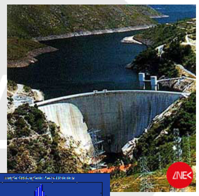
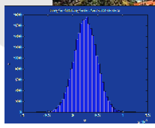
Agenda

- > Introduction;
- > Measurement and Traceability;
- > Research related to Scientific Metrology applied to Civil Engineering;
- > Research related to laboratorial Metrology applied to Civil Engineering;
- > Research related to Field Testing Metrology applied to Civil Engineering;
- > Conclusions and Future Trends.





1. Introduction

Introduction

The Civil Engineering research field covers a wide and diversified range of domains, each one dealing with specific issues requiring rigorous study but all share one thing in common: the need of measurement to perform experimental modelling.

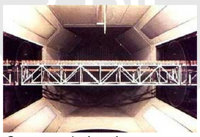
Risk Assessment and Quality are major aims of Civil Engineering research.

Introduction

Concrete Dams

Hydraulics and Environment

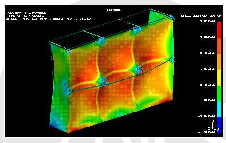
Transportation (roads, tunnels, …)



Structures (seismology, structures performance and monitoring, …)- …

Introduction

Buildings (technology, physics, quality, …)



Materials (properties, applications).

Geotechnique (foundation, buildings, bridges, towers, …)

Introduction

Research activities are related to experimental work in laboratories and in open field.

In both cases, is essential to accomplish this task being responsible for providing traceable measurements that support the obtained conclusions.

Metrology research applied to Civil Engineering can be organized in three subsystems:

- Scientific metrology,
- Laboratorial metrology;
- Field testing metrology.

2. Measurement and Traceability basis

Measurement and Traceability basis

The Quality of Experimental Activity

Considering the correctness of the functional relations applied, the critical steps to Measurement Quality are strongly related with the following tasks:

identification of the measurands – this task relevance is due to the fact that it ensures the interface between mathematical modelling and physical modelling; in some cases, due to the complex nature of some quantities, multi-stage indirect measurements must be provided;

calibration of instrumentation – in some cases, calibration could be a problem because of the difficulty to define reference conditions or standards in order to provide the connection to the SI traceability framework;

calculation of correction curves – the development of mathematical algorithms in order to correct calibration deviations can be complex when dealing with multivariable systems;

evaluation of measurement uncertainty - the measurement process can occur in different frameworks, being obtained under static or dynamic conditions, being described on complex scalar or matrix basis, having non-linear functional relations, among others, which may be not compatible with the requirements of conventional methods used to evaluate measurement uncertainty .

3. Research related to Scientific Metrology applied to Civil Engineering

Research related to Scientific Metrology

Flow rate calibration or measurement in closed conduits using electromagnetic flowmeters

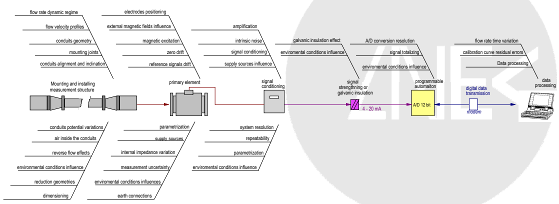


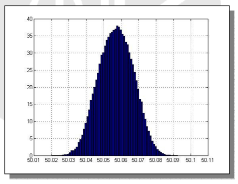
Figure 1 – Uncertainty sources diagram related with the use of electromagnetic flowmeters for the measurement of flow rate in closed conduits

Research related to Scientific Metrology

Flow rate calibration or measurement in closed conduits using electromagnetic flowmeters

In the mentioned case, despite the shape of the probability density function (PDF) seemed Gaussian (Fig. 2), the evaluation of measurement uncertainty and specially **the evaluation of excess kurtosis statistical parameters allowed to conclude that their was a departure from Gaussian distribution that was responsible for the differences obtained.**

The comparison between ISO-GUM and MCM showed an increase of the measurement uncertainty in the case of MCM, being related with the values of excess kurtosis of -0,38 and -0,41 obtained for experimental mass flow rates tested of 10 kg/s and 50 kg/s [Ribeiro *et al.*, 2010].



Research related to Scientific Metrology

Calibration of 25 Ω standard platinum resistance thermometers (SPRT) used to establish the traceability of laboratorial testing thermometers

Main concern:
Evaluation of calibration curves and correlation between ITS90 coefficients. Again, MCM was used considering the interpolation in the ranges of
0 ºC to 419,527 ºC and
–38,834 4 ºC to 29,764 6 ºC.

Research related to Scientific Metrology

Calibration of 25 Ω standard platinum resistance thermometers (SPRT) used to establish the traceability of laboratorial testing thermometers

I_2: From the Triple Point of Mercury (-38,834 4 ºC) to the Melting Point of Gallium (29,764 6 ºC)

Deviation function common both parts of the temperature interval:

$$W(t_{90}) - W_r(t_{90}) = a[W(t_{90}) - 1] + b[W(t_{90}) - 1]^2$$

Reference function and inverse function

for positive temperatures:

$$W_r(t_{90}) = C_0 + \sum_{i=1}^{9} C_i \left[\frac{(t_{90}/°\mathrm{C} - 481)}{481}\right]^i, \qquad t_{90}/°\mathrm{C} = D_0 + \sum_{i=1}^{9} D_i \left[\frac{W_r(t_{90}) - 2{,}64}{1{,}64}\right]^i,$$

for negative temperatures:

$$\ln[W_r(T)] = A_0 + \sum_{i=1}^{12} A_i \left[\frac{\ln(T/273{,}16\ \mathrm{K}) + 1{,}5}{1{,}5}\right]^i \qquad \frac{T}{273{,}16} = B_0 + \sum_{i=1}^{15} B_i \left[\frac{W_r(T)^{1/6} - 0{,}65}{0{,}35}\right]^i$$

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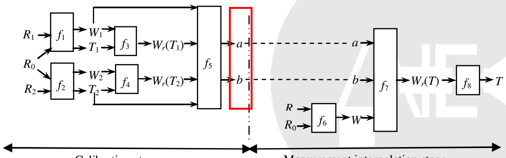

Fig. 1. Chain of functions. The f_i denote mathematical models relating to the steps in the sequence of operations. For instance f_6 is the determination of W from R and R_0

Research related to Scientific Metrology

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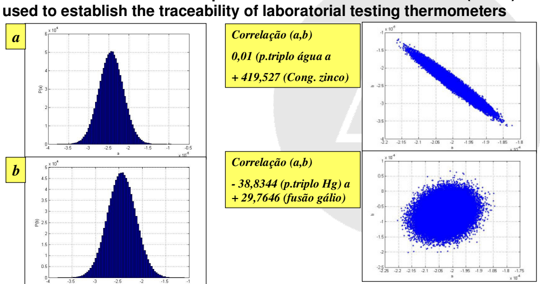


4. Research related to Laboratorial Metrology applied to Civil Engineering

Research related to Laboratorial Metrology

Uncertainty related to the use of a two-pressure humidity generator

The iterative nature of the mathematical model used in the indirect determination of **dew-point temperature** is a challenge in terms of meas. uncertainty evaluation since conventional approaches are not suitable to provide a solution for this problem.

$$rh = \frac{p_{\mathrm{ws}}(t_{\mathrm{s}}) \cdot f_{\mathrm{ws}}(p_{\mathrm{s}}, t_{\mathrm{s}}) \cdot p_{\mathrm{c}}}{p_{\mathrm{ws}}(t_{\mathrm{c}}) \cdot f_{\mathrm{ws}}(p_{\mathrm{c}}, t_{\mathrm{c}}) \cdot p_{\mathrm{s}}} \eta$$

The evaluation of the dew-point temperature using a two-pressure humidity generator requires a solution for this expression through an iterative method. A typical approach is based on Newton-Raphson numerical method.

$$t_{\mathrm{d}_{n+1}} = t_{\mathrm{d}_n} - \frac{g(t_{\mathrm{d}_n})}{g'(t_{\mathrm{d}_n})} \qquad g(t_{\mathrm{d}_n}) = \frac{p_{\mathrm{ws}}(t_{\mathrm{s}}) \cdot f_{\mathrm{ws}}(p_{\mathrm{s}}, t_{\mathrm{s}}) \cdot p_{\mathrm{c}}}{p_{\mathrm{ws}}(t_{\mathrm{d}_n}) \cdot f_{\mathrm{ws}}(p_{\mathrm{c}}, t_{\mathrm{d}_n}) \cdot p_{\mathrm{s}}} \eta - 1$$

Research related to Laboratorial Metrology

Uncertainty related to the use of a two-pressure humidity generator

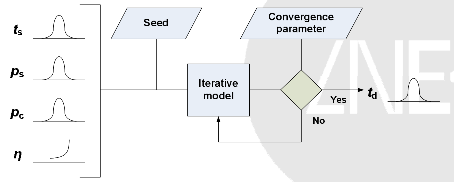


Figure 5 – Forward measurement uncertainty propagation by the MCM.

Research related to Laboratorial Metrology

Uncertainty related to the use of a two-pressure humidity generator

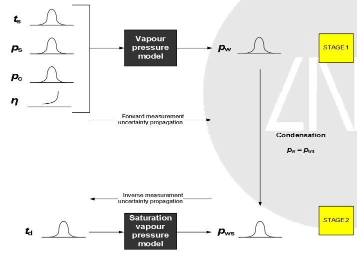


Figure 6 – Inverse measurement uncertainty propagation by BI.

Research related to Laboratorial Metrology

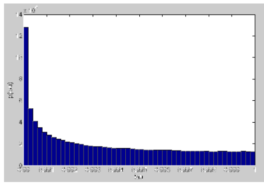
Evaluation of measurement uncertainties in SBI Test – Reaction to Fire

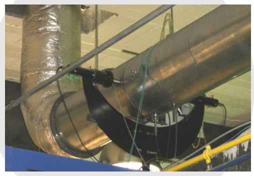
The use of the Monte Carlo Method (MCM) was applied to perform the **evaluation of measurement uncertainties in fire reaction testing of construction materials** (see [Martins *et al.*, 2009]) allowing to overcome the main difficulties found in this context, namely, the **high number of measured input quantities**, the **non-linear nature of some applied mathematical models** and existing **physical limits** that should be accounted for.

Research related to Laboratorial Metrology

Evaluation of measurement uncertainties in SBI Test – Reaction to Fire

MCM allows a correct physical representation of the dispersion of transmittance values (max. value upto 100%) when performing the 100 % calibration point.





Smoke measuring system (SBI Test - reaction to fire)

5. Research related to Field Testing Metrology applied to Civil Engineering

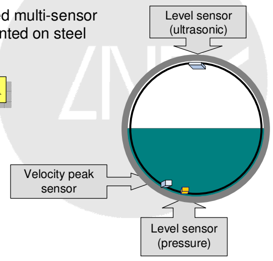
Research related to Field Testing Metrology

Evaluation of flow rate measurement uncertainties in open conduits

Area-Velocity method uses a combined multi-sensor system (level and velocity sensors mounted on steel ring fixed to conduits.

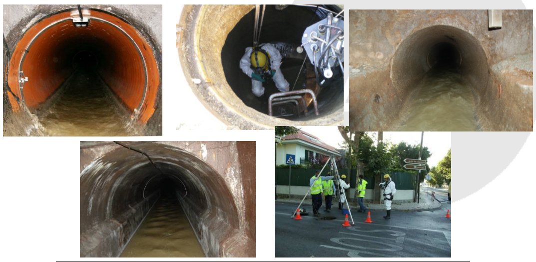
Continuity equation applies: $Q = U \cdot A$

Volumetric flow rate: Q
Average velocity: U
Flow "wet" area: A



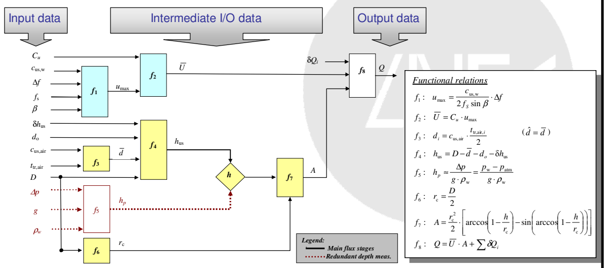
Research related to Field Testing Metrology

Evaluation of flow rate measurement uncertainties in open conduits



Research related to Field Testing Metrology

Evaluation of flow rate measurement uncertainties in open conduits



Research related to Field Testing Metrology

Evaluation of flow rate measurement uncertainties in open conduits

In the measurement process, the influence due to the "cross-sectional wet area" is given by the following expression

$$A = \frac{r_c^2}{2} \cdot \left[\operatorname{acos}\left(1 - \frac{h}{r_c}\right) - \sin\left[\operatorname{acos}\left(1 - \frac{h}{r_c}\right) \right] \right]$$

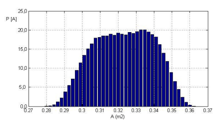


Figure 10 – Input cross-section wet area PDF

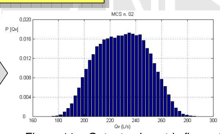


Figure 11 – Output volumetric flow rate PDF.

Research related to Field Testing Metrology

Consolidated triaxial compression tests on water saturated soil

A representative example of field testing, in the geotechnical area, is the consolidated triaxial compression tests on water saturated soil.

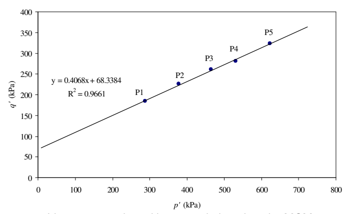
The purpose of this test is to characterize the soil in terms of two parameters, the friction angle ϕ' and the cohesion c'.

The test consists in applying a constant cell pressure on the consolidated soil specimen which is loaded to failure (sheared) by moving the piston into the triaxial cell with a constant rate on the loading frame [*ISO/TS 17892-9: 2004].*

Research related to Field Testing Metrology

Consolidated triaxial compression tests on water saturated soil

The method used to for the regression analysis is the so-called 'Generalised distance regression', GDR [ISO TC 69/SC 6 N, 2007].



Linear regression with uncertainties given by MCM

6. Conclusions and Future Trends

Conclusions & Future trends

- Increasing contribution from Metrology research to Civil Engineering Research;
- Better knowledge of solutions increase technical and economical performance;
- Metrology is becoming relevant for the process of risk assessment.

Future trends

- Study and development of new methods;
- Field testing has plenty of issues to work;
- New technologies (wireless, fiber optics, multi-variate systems, …) are new challenges;
- New issues are proposed (new standards and reference materials, modeling strategies, computational metrology, …);
- Establish strong bonds between Metrology and mathematical and physical modeling in Civil Engineering.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