Quality Control Guidelines in Small Scale Concrete Masonry Facilities Using Nondestructive Testing and Statistical Process Control

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Introduction

- Masonry is a prime building material in construction industry
- Baked clay and concrete masonry units (CMU)
- CMU is rapidly replacing the baked clay bricks
- CMU manufacturing operations
  - Large scale automated production plants
  - Small scale production facilities

Introduction

- The small scale CMU production facilities are primarily artisanal
- Lack effective procedures for:
  - Quality assurance testing and control guidelines
- The use of substandard CMU was the one of the primary causes of widespread destruction in:
  - Kashmir 2005, Pakistan Earthquake
  - Haiti 2010 earthquake

Introduction

- Quality assurance and control
  - Destructive testing (DT) using Universal testing machine
  - Nondestructive Testing (NDT) using surface hardness and stress wave techniques
- Destructive testing is reliable, however,
  - Expensive and extent of testing is limited

Introduction

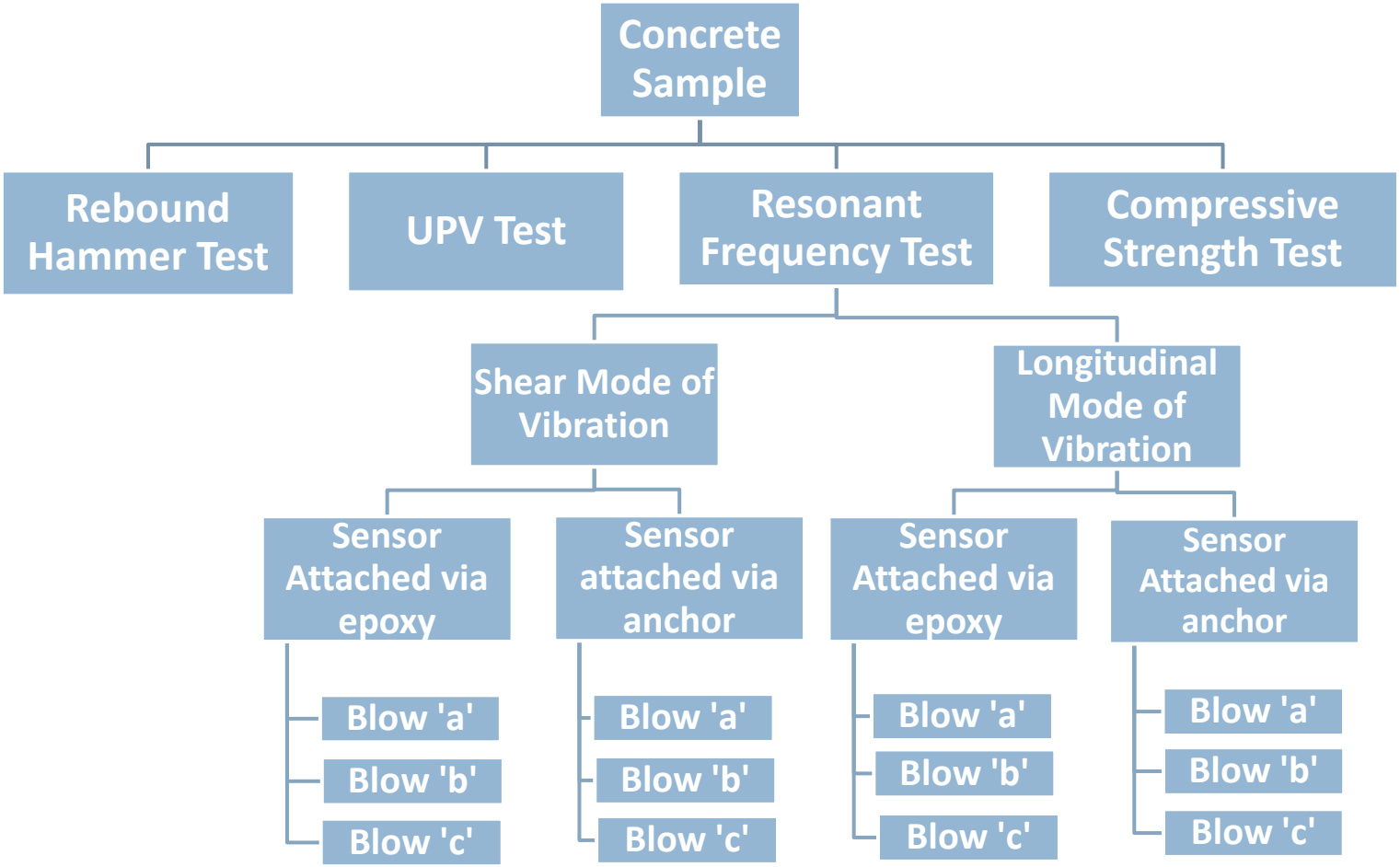
- Need for an alternative to conventional destructive test using UTM
  - Cost effective
  - Practicable and acceptable reliability of test results
- NDT is an efficient and cost effective technique, however
  - Indirect testing
  - Reliability of the test results may not be as high as DT

Introduction

Introduction

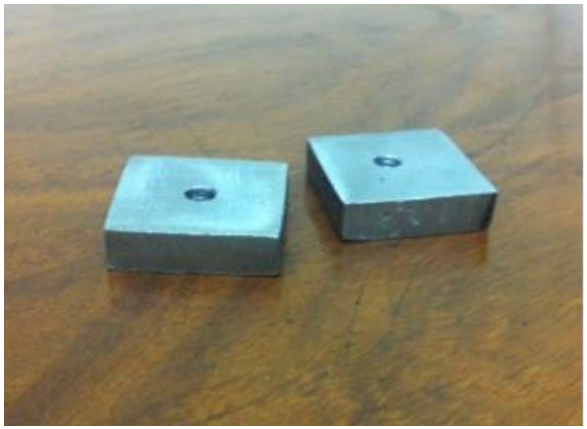
- This work attempts to:
  - Explore various available NDT methods for strength estimation of CMU
  - Reliability of test results
  - Quality assurance and control using NDT
  - Reliability of the proposed method

Experimental Program



Experimental Program

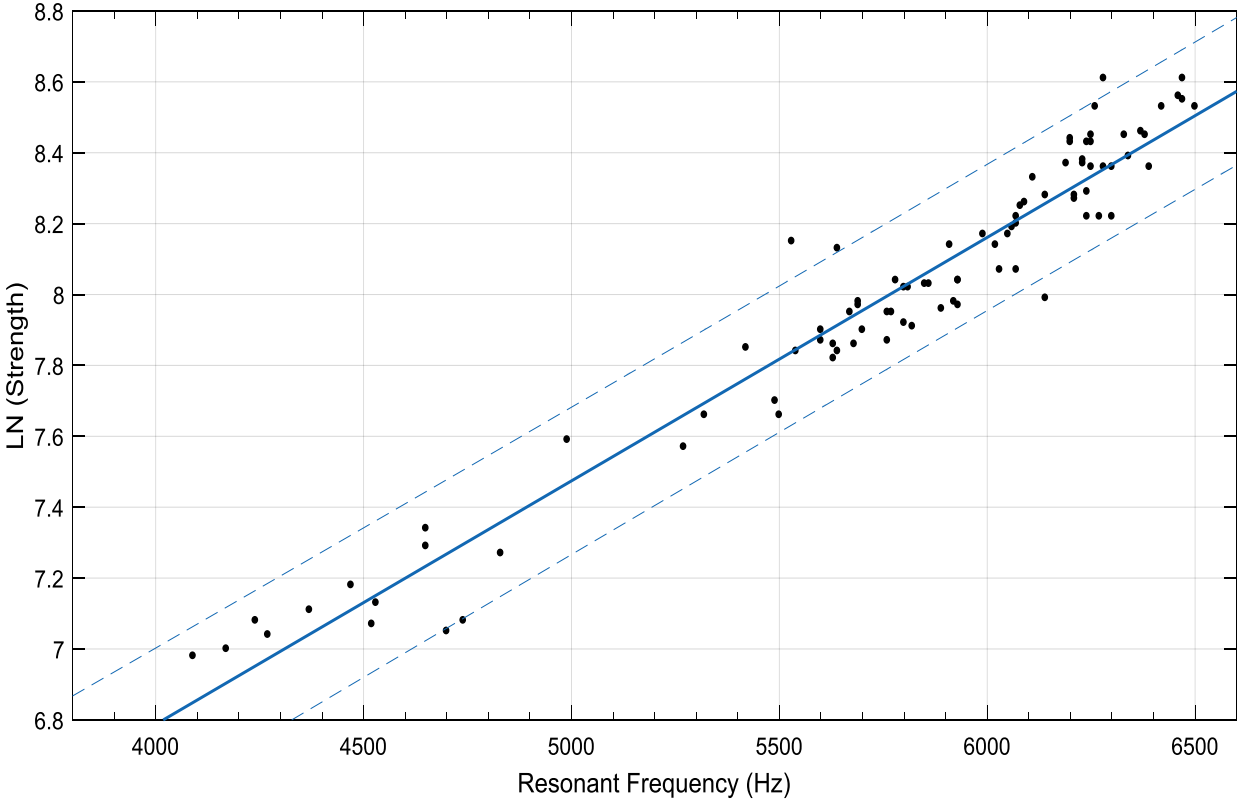
- Number of tests
- Parameters investigated
- Repeatability of measurements
- Results and sources of variability



Resonant Frequency Test Results

- The focus of this work is the resonant frequency test (RFT) as NDT
- Resonant frequency test conducted as per ASTM C215
- The results of the concrete vibration under the stress wave are recorded in the longitudinal mode
- The correlation using regression for the RFT with DT

Resonant Frequency Test Results



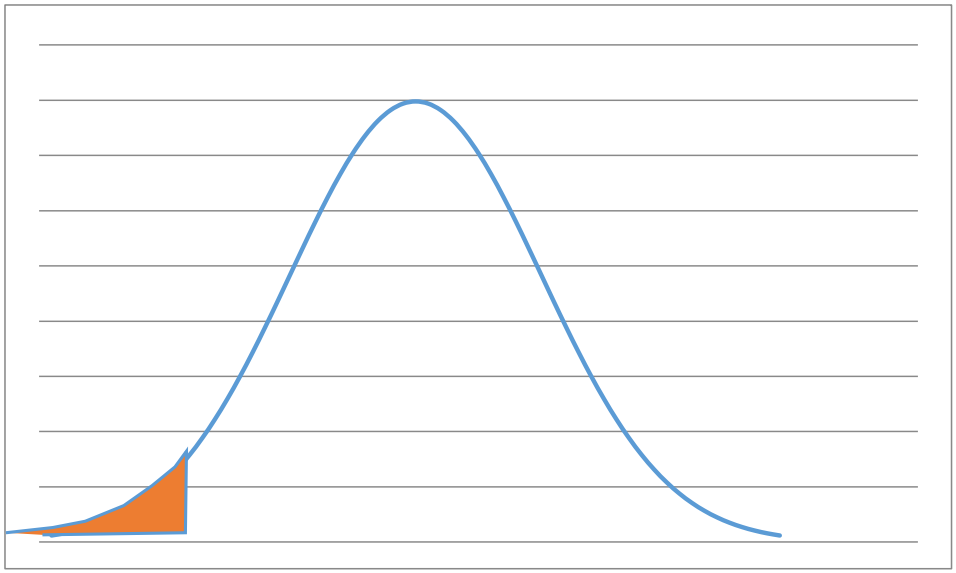
Regression Analysis		Goodness of fit:	
$\ln(fc) = a_1 * RFT + a_2$		SSE	0.9362
Coefficients (with 95% confidence bounds):		R^2	0.9444
a_1 =	0.0006869 (0.00065, 0.00072)	Adjusted R^2	0.9438
a_2 =	4.04 (3.835, 4.244)	RMSE	0.1031

Quality Control Procedures

- Limit state design (CSA S304, Design of Masonry Structures) accounts for uncertainties in
  - Strength of the materials
  - Loads on the structure
- Nominal Compressive strength
  - 5% exclusion limit with 75% confidence level

    (CSA S408-11 Guidelines for the development of limit states design standards)

Quality Control Procedures



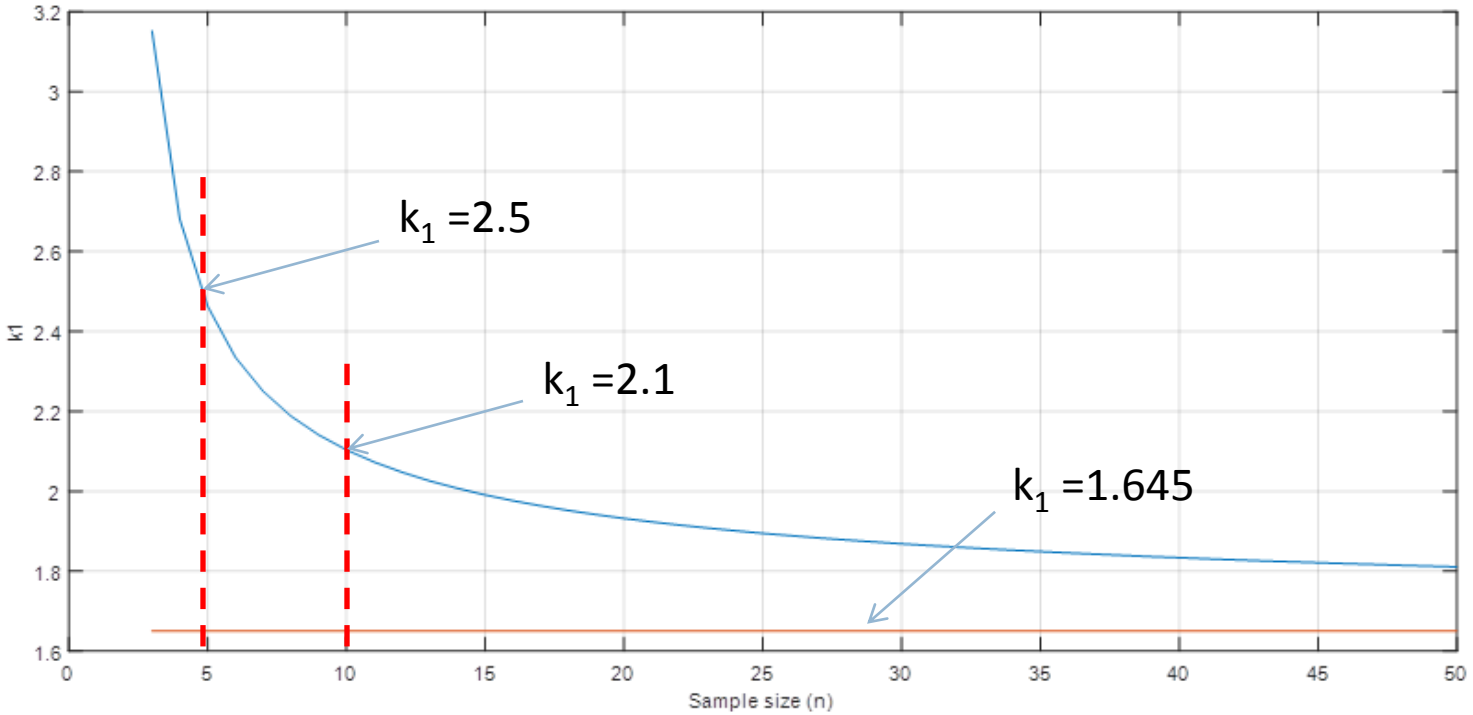
Definition of the 5% exclusion limit

- 5% exclusion limit
- Assumption: Normal distribution on f_c' (CSA 165.1-14)
  - (n =5+ if CoV <15%, and n = 10+ > 15%)

$$f_{cn} = \bar{X} - 1.645s$$

Quality Control Procedures

- 5% exclusion limit with 75% confidence level
- Defined as $f_{cn} = \bar{X} - k_1 s$, where k_1 is a function of the confidence level and sample size.



Uncertainties in DT and RFT

- The uncertainties are quantified using variance
- Considering a target nominal strength value of 20 MPa,
- The uncertainties in DT is 2.4 MPa by assuming a coefficient of variation of 10% (mean is 24 MPa)
- The uncertainty in NDT test results is (for lognormal):

$$\sigma_{\varepsilon}^2 = e^{2\theta+\omega^2}\left(e^{\omega^2}-1\right)$$

$$\sigma_{\varepsilon}^2 = (2.4\,MPa)^2$$

- Where θ = 8.15 and ω^2 = 0.10 from the regression

Uncertainties in DT and RFT

- NDT is indirect testing
- The uncertainties in strength estimation using RFT is:

$$\sigma^2_{Total} = \sigma^2_{indirect\ observations} + \sigma^2_{fc}$$

- The additional uncertainties due to NDT can be reduced by increasing the number of observations above those required for DT.

Statistical Process Control

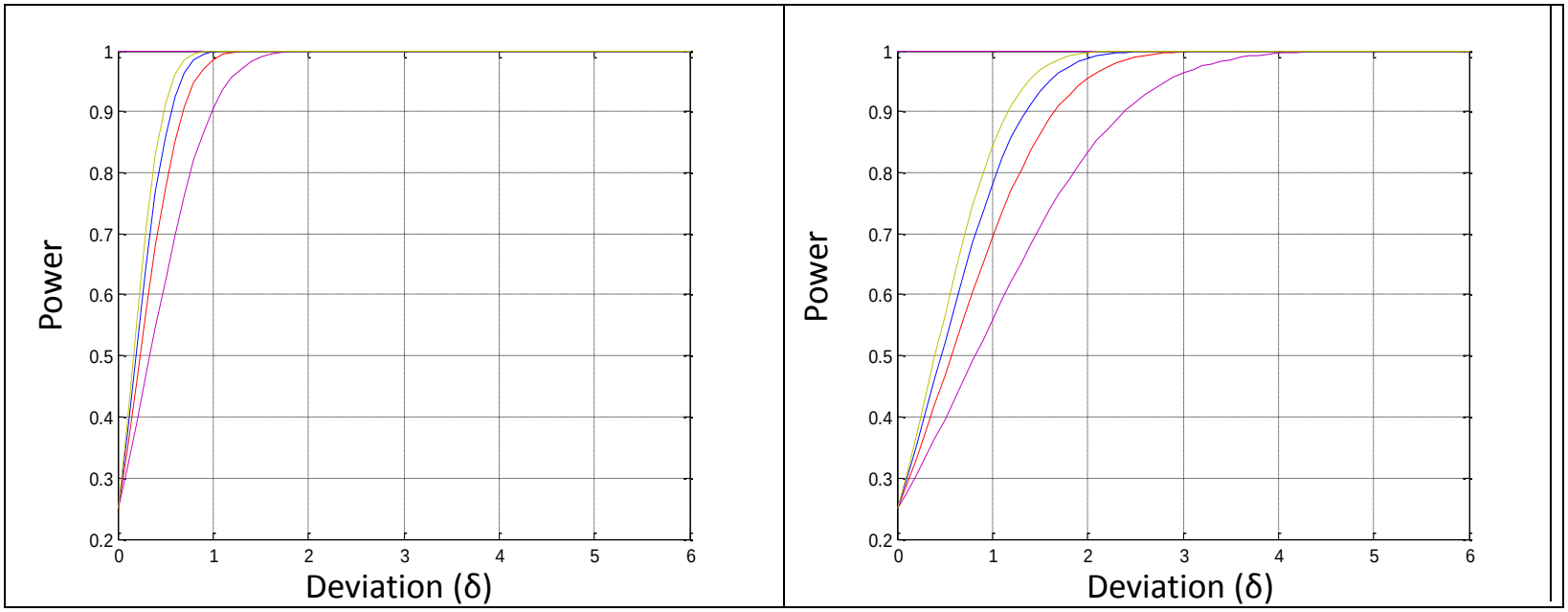
- Statistical hypothesis test
  - Type I error (α): Reject process that meets specs (e.g. 20 MPa)
  - Type II error (β): Accept process that does not meet specs (< 20 MPa)
- α = 25% (i.e. 75% confidence level of CSA S408-11)
- Power of the test (1- β):
  - Probability of detecting process that deviates from specs (by δ)
  - Operating Characteristic curve (β as a function of δ and n)

Statistical Process Control

- Reliability of quality control using operating characteristic curves
- Function of:
  - Sample size n
  - Coefficient of variation (5%, **10%**, 15%)
  - Significance level (25%)

Results

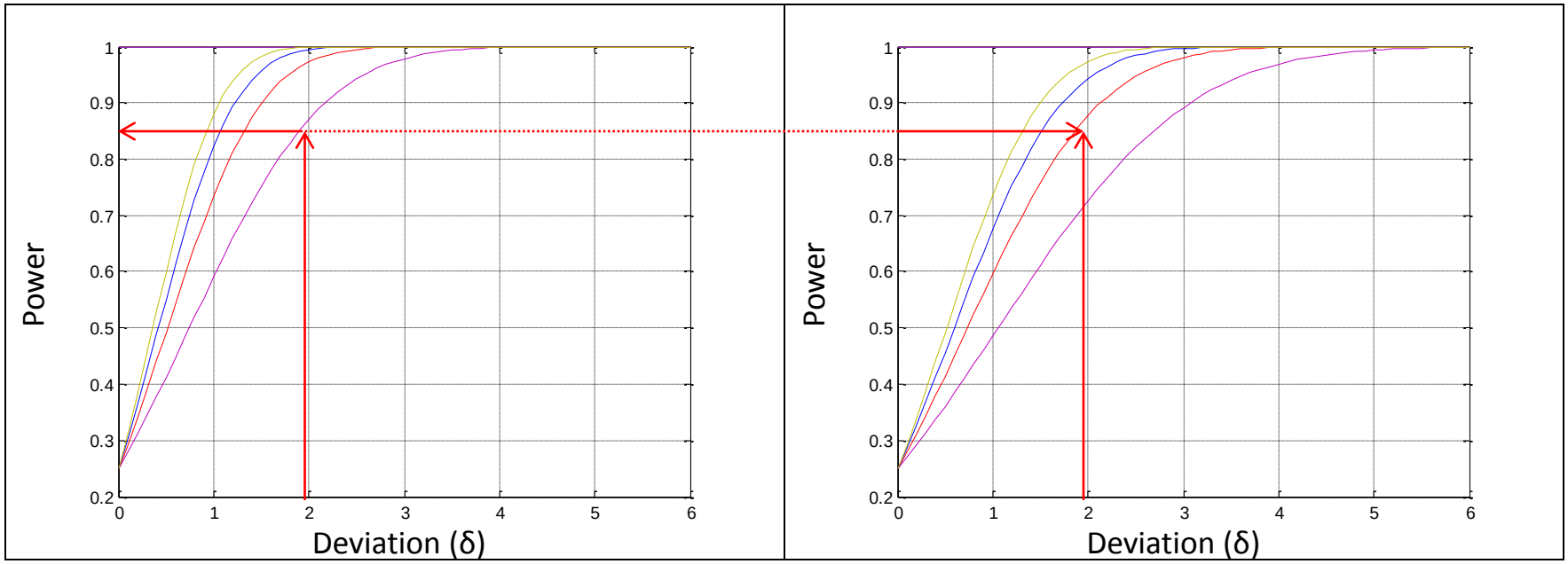
- Quantification of Uncertainty
  - Coefficient of Variation = 5% (n > 5+)



Results

- Quantification of Uncertainty
  - Coefficient of Variation = 10% (n > 5+)

f_{cn} minimum = 18 MPa with 85% POD



n = 5 for DT

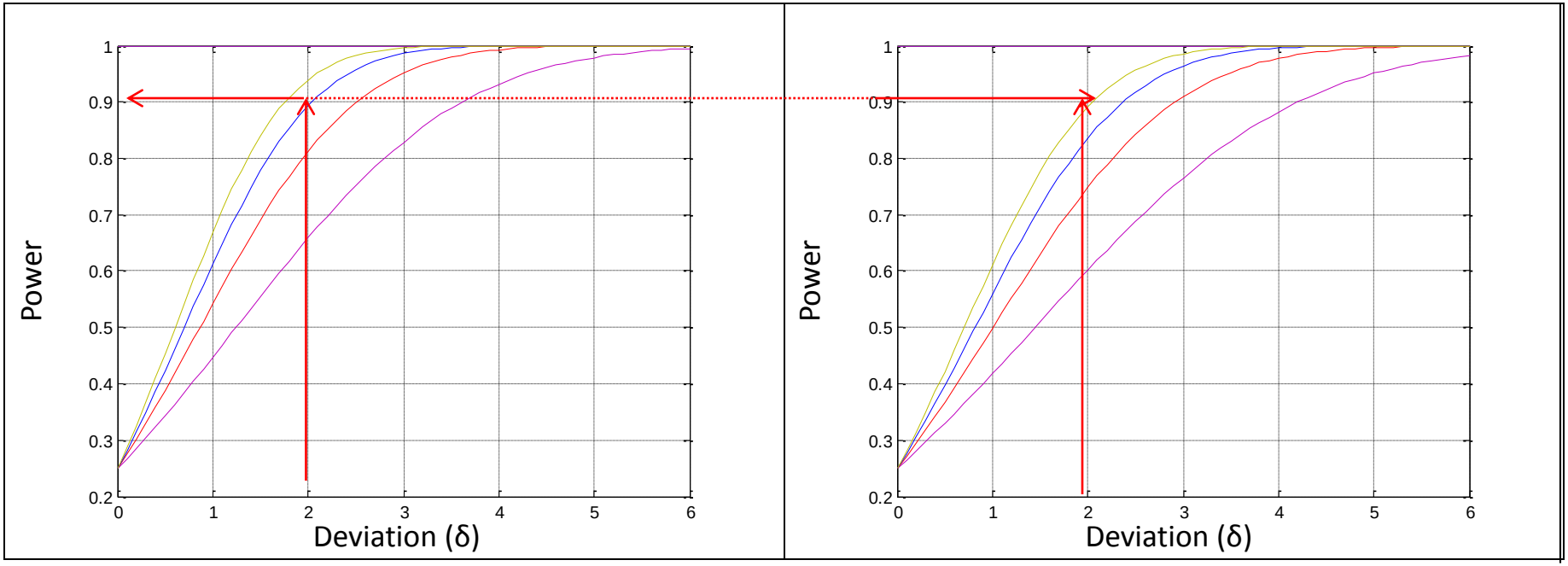
n = 10 for NDT

Results

- Quantification of Uncertainty

f_{cn} minimum = 18 MPa with 85% POD

  - Coefficient of Variation = 15% (n > 10+)



Conclusions

- NDT can be employed in quality control in small scale facilities given a calibration equation is already developed
- The number of samples needed for NDT to achieve the same power as the DT is determined objectively to satisfy the standards
- The effect of the coefficient of variation affects the required number of samples
- A high coefficient of variation may be expected for small artisanal CMU facilities

Future work

- Determine tolerable deviations from specifications and probability of detection using reliability and risk analysis for shear walls
- Review of existing standards
  - Wide range of quality control procedures
  - Some inconsistencies in procedures

Thanks