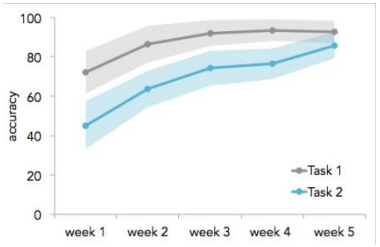
Roping in uncertainty – measuring the tensile strength of steel wire ropes

Riaan Bergh

27 September 2016

our future through science

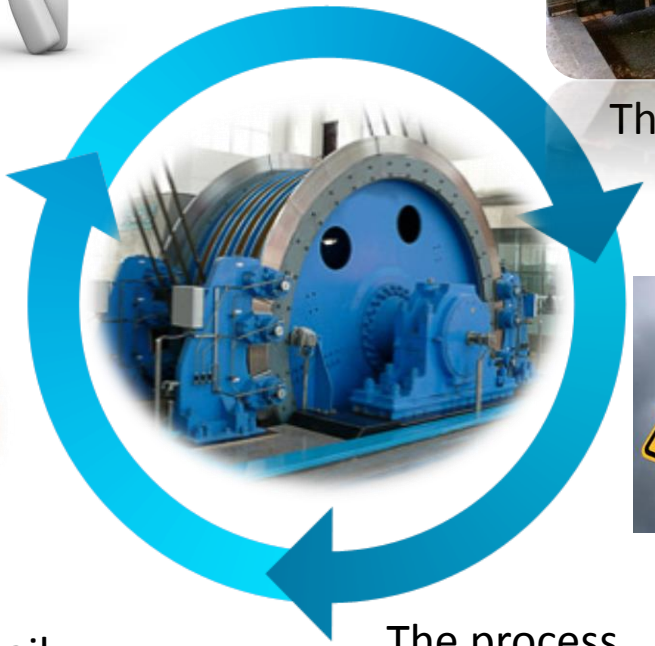
Presentation outline



The outcome

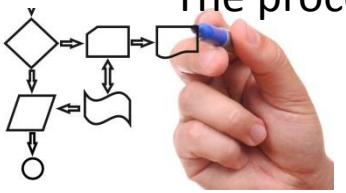
Why test?

The test environment



$$v_{\text{eff}} = \frac{u_c^4(y)}{\sum_{i=1}^{N} \frac{u_i^4(y)}{v_i}}$$

The detail



The process

CSIR
our future through science

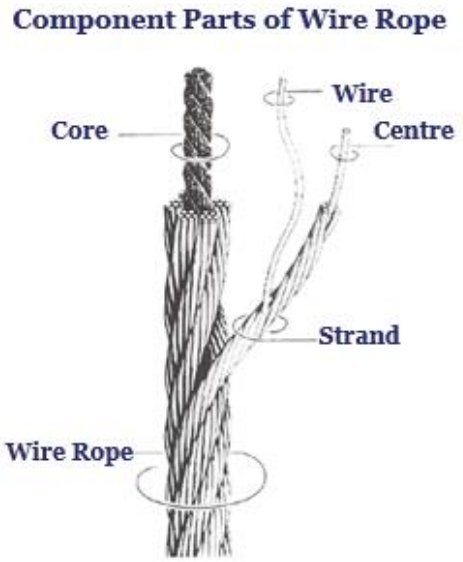
Why do we test new ropes?

Theory vs. Practice

$$UTS_{rope} \neq \sum UTS_{t\_wires}$$

Rope strength depends on:

- Material properties of wires
- Wire uniformity
- Rope construction

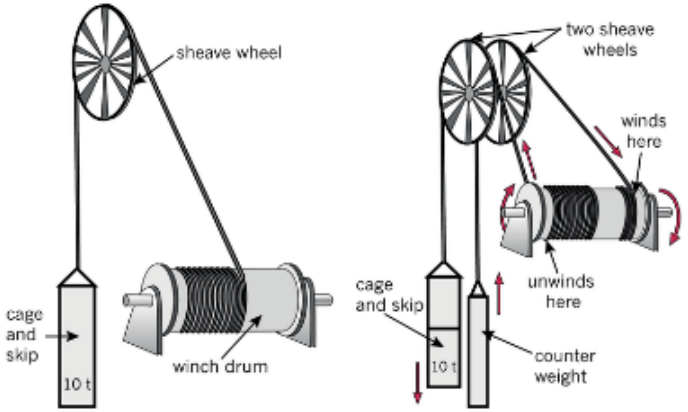


our future through science

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

Why do we test ropes in service?

- Rope condition will deteriorate with use
- Rate of deterioration cannot be predicted
- Conveyance is held by one rope only
- MHSA Reg 16.41 – mandatory tensile test and
- SANS 10293 CoP – discard criteria ($UTS_{used} \geq 0.9UTS_{new}$)



our future through science

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

High force, high stakes environment

- MFL Tensile tester
  - 15 000 kN capacity testing from 750 kN (5% of FS)
  - 2 m stroke length, 8 m daylight
- Laboratory space 1200m^2, not climate controlled
- Calibration duration, cost
- No CRM, no PT schemes
- No re-test of the same UUT

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

Enter uncertainty…

? Instrumentation

? Environment e.g. temperature and humidity

? Variability

? Resolution of force measurement

? Electromagnetic noise

? Test method

? Personnel

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

The estimation process

The GUM method

- Model the measurement
- Identify and quantify all sources of error
- Evaluate all sources of error to obtain the uncertainty contribution
- Combine uncertainty contributions
- Calculate the degrees of freedom for the combined uncertainty
- Choose level of confidence
- Calculate the expanded uncertainty, U
- Report the result

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

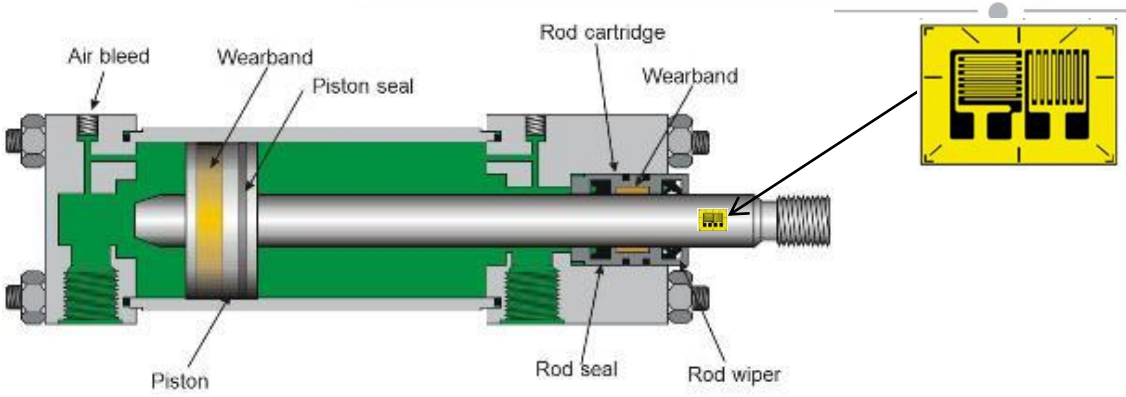
The detail – Mathematical model

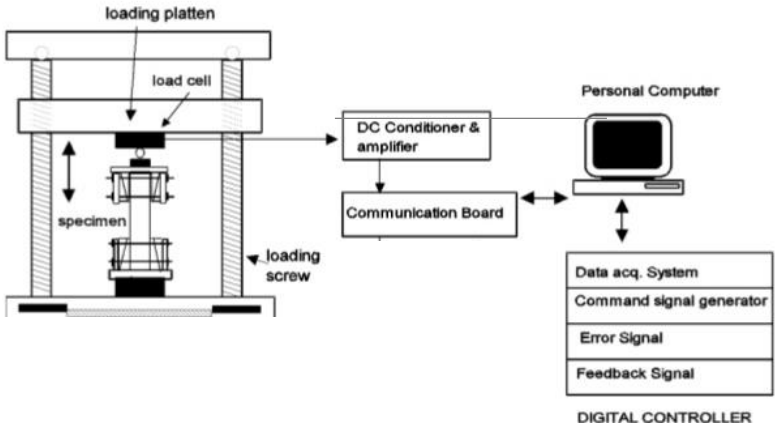
- $\sigma = E\varepsilon$
- $\varepsilon = \frac{1}{GF}\Delta R/_R$
- $\varepsilon = \frac{-2V_r}{GF[(v+1)-V_r(v-1)]}$

Where $V_r = \frac{V_{ch\_strained} - V_{ch\_unstrained}}{V_{ex}}$

or

$F_{apply} = F_{record}$





Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

Sources of error

- Accuracy of machine force measurement system
- Accuracy of reference load cell – uncertainty quoted by calibration lab
- Resolution of force measurement
- Repeatability
- Reproducibility
- Effect of temperature

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

Uncertainty budget

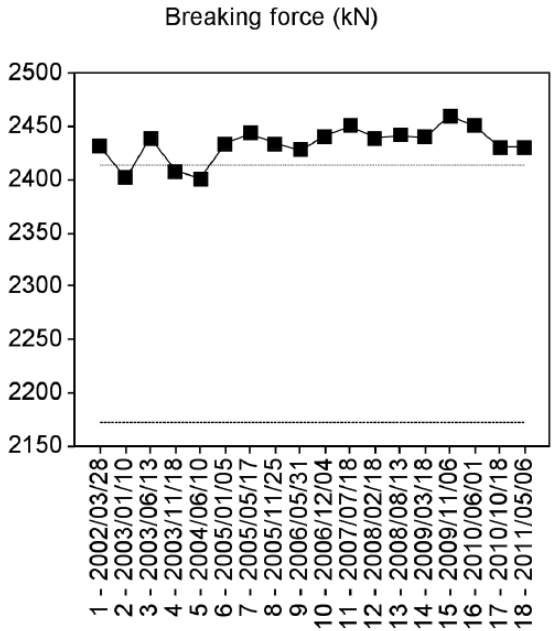
Symbol	Description	Type	Exp Val	Distr	Uncert. Est.	units	Divisor	Standard uncertainty $u(x_i)$	units	Sens. Coeff. c_i	units	Uncertainty contributor $u(y_i)$	Reliability	Deg of Freedom v_i	Significance
F_{accLC}	Accuracy of LC + amp	B	300	R	1.14	kN	1.73205	6.5886E-01	kN	1	kN/kN	6.5886E-01	100%	infinite	12.54%
F_{acc_refLC}	Accuracy of reference LC	B	0	R	2.77	kN	1.73205	1.5987E+00	kN	1	kN/kN	1.5987E+00	100%	infinite	73.83%
F_{res}	Resolution of force meas.	B	0	R	0.10	kN	1.73205	5.7735E-02	kN	1	kN/kN	5.7735E-02	100%	infinite	0.10%
F_{repr}	Reproducibility	A	300	N	0.67	kN	1	6.7171E-01	kN	1	kN/kN	6.7171E-01	100%	5	13.03%
F_{var}	Repeatability	A	300	N	0.13	kN	1	1.2849E-01	kN	1	kN/kN	1.2849E-01	100%	3	0.48%
F_{temp}	Effect of temperature	B	0	R	0.05	kN	1.73205	2.5981E-02	kN	1	kN/kN	2.5981E-02	100%	infinite	0.02%
										$u_c(y)$		1.86054E+00			
			Notes							v_{eff}		293.65			
Working point in force range:			1	***300***	kN					Level of Confidence		95.45%			
Mean indication error at the calibration point			2	-0.38%						Coverage factor		2.009			
Ref LC uncertainty			3	0.92%						***U***		**3.7378153**	kN		
Repeatability			4	Lookup table							or	1.246%			
Reproducibility			5	Lookup table											
Temp effect on force measurement			6	0.02%											

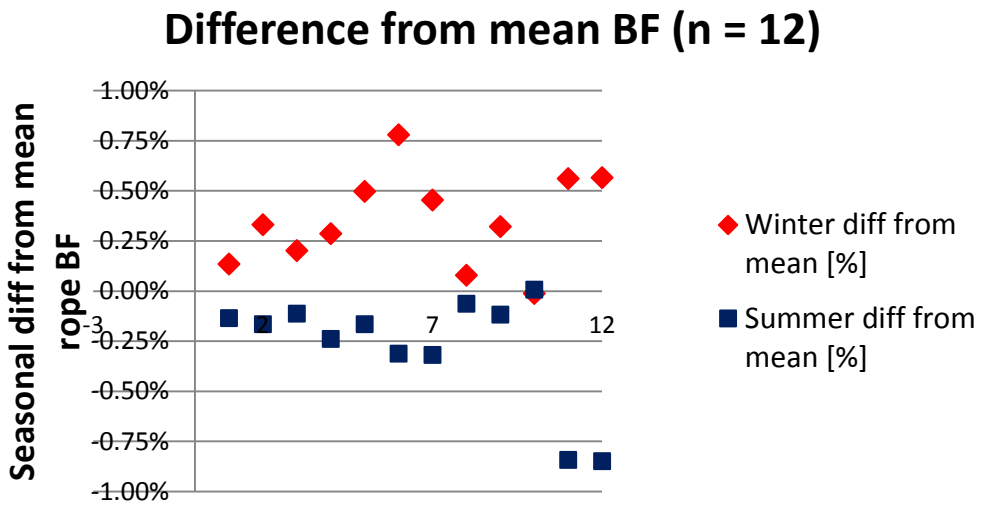
Table 1 - Summary of estimated uncertainty

The result of the measurement was found to be (300.0 ± 3.8) kN with a coverage factor of 2.009 at a level of confidence of 95.45%

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

Temperature effect





Summer: +0.3%
Winter: -0.3%

ΔT = 20°C (12 months to date)

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

The outcome – Example 1 at 852 kN working point

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**Symbol**	**Description**	**Type**	**Expected Value**	**Distribution**	**Uncertainty Estimate**	**units**	**Divisor**	**Standard uncertainty**	**units**	**Sensitivity coefficient**	**units**	**Uncertainty contributor**	**Reliability**	**Degrees of Freedom**	**Significance**
2									$u(x_i)$		c_i		$u(y_i)$		v_i	
3																
4	F_{accLC}	Accuracy of LC + amp	B	0	R	2.6	kN	1.7321	1.4757E+00	kN	1	kN/kN	1.4757E+00	100%	infinite	30.28%
5	F_{acc_refLC}	Accuracy of reference LC	B	0	R	2.0	kN	1.7321	1.1806E+00	kN	1	kN/kN	1.1806E+00	100%	infinite	19.38%
6	F_{res}	Resolution of force meas.	B	0	R	0.1	kN	1.7321	5.7735E-02	kN	1	kN/kN	5.7735E-02	100%	infinite	0.05%
7	F_{var}	Variability in force meas.	A	852	N	1.2	kN	1	1.2000E+00	kN	1	kN/kN	1.2000E+00		5	20.02%
8	F_{temp}	Effect of temperature	B	0	R	2.6	kN	1.7321	1.4757E+00	kN	1	kN/kN	1.4757E+00	100%	infinite	30.28%
9																
10											$u_c(y)$		2.68188E+00			
11											v_{eff}		124.73			
12											Level of Confidence		95.45%			
13											Coverage factor		2.020			
14											**U**		**5.4174024**	kN	or	0.636%
15																
16									The result of the measurement was found to be (852.0 ± 5.5) kN with a coverage factor of 2.02 at a level of confidence of 95.45%							

The outcome – Example 2 at 1965 kN working point

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**Symbol**	**Description**	**Type**	**Expected Value**	**Distribution**	**Uncertainty Estimate**	**units**	**Divisor**	**Standard uncertainty**	**units**	**Sensitivity coefficient**	**units**	**Uncertainty contributor**	**Reliability**	**Degrees of Freedom**	**Significance**
2									$u(x_i)$		c_i		$u(y_i)$		v_i	
3																
4	F_{accLC}	Accuracy of LC + amp	B	0	R	3.9	kN	1.7321	2.2690E+00	kN	1	kN/kN	2.2690E+00	100%	infinite	18.08%
5	F_{acc_refLC}	Accuracy of reference LC	B	0	R	4.7	kN	1.7321	2.7228E+00	kN	1	kN/kN	2.7228E+00	100%	infinite	26.03%
6	F_{res}	Resolution of force meas.	B	0	R	1.0	kN	1.7321	5.7735E-01	kN	1	kN/kN	5.7735E-01	100%	infinite	1.17%
7	F_{var}	Variability in force meas.	A	1965	N	2.0	kN	1	2.0000E+00	kN	1	kN/kN	2.0000E+00		5	14.05%
8	F_{temp}	Effect of temperature	B	0	R	5.9	kN	1.7321	3.4035E+00	kN	1	kN/kN	3.4035E+00	100%	infinite	40.67%
9																
10											$u_c(y)$		5.33656E+00			
11											v_{eff}		253.45			
12											Level of Confidence		95.45%			
13											Coverage factor		2.010			
14											***U***		**10.7264833**	kN	or	0.546%
15																
16									The result of the measurement was found to be (1 965 ± 11) kN with a coverage factor of 2.01 at a level of confidence of 95.45%							

Room for improvement

- Temperature effect
  - Control lab temperature
  - Condition specimens prior to testing
  - Apply a temperature correction to test result
- Accuracy of machine force measurement
  - Apply correction
  - Adjust machine force calculation polynomial coefficients
- Uncertainty of reference load cell
  - Load cell?
  - Calibration laboratory

Riaan Bergh - September 2016 - rbergh@csir.co.za - 011-482 1300

Thank you.