Novatech
Loadcell Design & Manufacture

Loadcell Calibration - Evaluation of Uncertainties

This document is a revision of the evaluation issued in June 2015.

Novatech´s calibration laboratory is not UKAS accredited due to the high number of loadcell models, their complexities and variations, and the simple fact that UKAS accreditation and procedures would not be in keeping with our competitive product and recalibration prices. We do not have an equivalent to UKAS accreditation but do offer complete calibration traceability via our fully traceable calibration laboratory. This uncertainty evaluation document was created to back up our traceability statement that is found upon our sensor and sensor/instrument system calibration certificates. Our loadcell product performance specification are based upon simple straight-line mathematics. (See the Engineering section on our main website for engineering sheets that explain these simple concepts).

This evaluation uses information from equipment calibration certificates and manufacturers specifications. Where an item of equipment has been given a class or type specification this has been used in the calculations even though the actual item can be shown to be better than its specification. This allows the replacement of an item with one of the same type without affecting the evaluation. The calculations given in appendix A to G will remain valid.

The equipment evaluated here is all subject to a planned programme of re-calibration. This is carried out at external calibration laboratories or by using in-house standards that are calibrated at external calibration laboratories. The calibration programme means that all our loadcell calibrations are traceable to national standards by a clearly defined route.

In line with most uncertainty evaluations the components that make up a total uncertainty are combined by calculating the square root of the sum of the squares of the individual components.

Turn to section 4 “Summary Of Uncertainties” for a brief summary of the overall uncertainties for our loadcell calibration laboratory.

This document does not have a controlled circulation outside of Novatech Measurements Ltd so if you need the latest issue please check with our engineering department or download a copy from our website.

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1. Weights

The evaluations in this section support the claim of an uncertainty of ±0.02% of applied load for all dead-weight calibrations at 2g and above. This is based on a 0, 50% and 100% sequence of calibration points.

The estimates are based upon the class tolerance for the weights or the tolerance used by the external calibration laboratory if a standard class is not applicable. The calibration information shows that most of the weights have errors that are significantly less than their target tolerances.

Where the calculations have been carried out to more decimal places than are shown the results have been rounded following normal mathematical standards.

The weight classes used in this evaluation are to OIML standards. Where a nominal weight is not available in the OIML standard sequence the next highest weight tolerance has been used. This results in a pessimistic uncertainty value.

1.1 Weight Set W5025

This is a set of 28 disc weights in a 1, 2.5, 5, 7.5, 10, 12.5 and 37.5g sequence. There are 4 weights of each value, identified as A, B, C or D. The 1g and 2.5g weights are made of aluminium, all the other weights are made of brass. An external laboratory calibrates the weights to fall within ±0.01% tolerance of the nominal value.

Table 1

Nominal Weight (g)	Calibration Tolerance (g)
1.0	±0.00010
2.5	±0.00025
5.0	±0.00050
7.5	±0.00075
10.0	±0.00100
12.5	±0.00125
37.5	±0.00375

The weights are calibrated against F_1 standards by the calibration laboratory and their F_1 standards are calibrated against E_2 standards by a second calibration laboratory. The $\mathbf{F_1}$ tolerances are listed in Table 2 below.

Table 2

Nominal Weight (g)	F_1 Tolerance (g)
1.0	±0.00010
2.5	±0.00016
5.0	±0.00016
7.5	±0.00020
10.0	±0.00020
12.5	±0.00025
37.5	±0.00030

The certificates for the set of weights does not give a value for the estimated uncertainty for the calibration so an uncertainty that is equal to twice the F_1 tolerance has been used. This value has been combined with the calibration tolerance using the formula below.

$$\text{Total uncertainty} = \pm\sqrt{(\text{calibration tolerance})^2 + (F_1 \text{ tolerance} \times 2)^2}$$

The calculated uncertainties for each weight value are listed in Table 3 below.

Table 3

Nominal Weight (g)	Total Uncertainty (g)	Total Uncertainty (% of nominal)
1.0	±0.00010004	±0.0100040
2.5	±0.00025010	±0.0100041
5.0	±0.00050010	±0.0100020
7.5	±0.00075016	±0.0100021
10.0	±0.00100016	±0.0100016
12.5	±0.00125025	±0.0100020
37.5	±0.00375036	±0.0100010

1.2 Weight Set W767

This is a set of five brass weights in a 10, 25 and 50g sequence. An external laboratory calibrates the weights to fall within the class M_1 tolerances.

Table 4

Nominal Weight (g)	M_1 Tolerance (g)
10	±0.002
25	±0.003
50	±0.003

The weights are calibrated against F_1 standards by the calibration laboratory and their F_1 standards are calibrated against E_2 standards by a second calibration laboratory. The **F_1** tolerances are listed in the table below, where a nominal weight is not available in the OIML standard sequence the next highest weight tolerance has been used. This results in a pessimistic uncertainty value.

Table 5

Nominal Weight (g)	F_1 Tolerance (g)
10	±0.0002
25	±0.0003
50	±0.0003

The certificates for the set of weights does not give a value for the estimated uncertainty for the calibration so an uncertainty that is equal to twice the F_1 tolerance has been used. This value has been combined with with the M_1 tolerance using the formula below.

$$\text{Total uncertainty} = \pm\sqrt{(M_1 \text{ tolerance})^2 + (F_1 \text{ tolerance} \times 2)^2}$$

The calculated uncertainties for each weight value are listed in Table 6 below.

Table 6

Nominal Weight (g)	Total Uncertainty (g)	Total Uncertainty (% of nominal)
10	±0.00201	±0.02010
25	±0.00306	±0.01224
50	±0.00306	±0.00612

The calculated value of uncertainty for 10g is just over the target of ±0.02% but is acceptable because the existing 10g weights are within the M_1 tolerance by twice the F_1 tolerance. The 10g weights are normally a relatively small percentage of the applied load when this weight set is used, often with set W115-01. This reduces the effect of this uncertainty as a percentage of the total load.

1.3 Weight Set W2654

This is a set of three brass weights in a 50, 100 and 200g sequence. The 50g weight is a hanger. An external laboratory calibrates the weights to fall within the class M_1 tolerances.

Table7

Nominal Weight (g)	M_1 Tolerance (g)
50	±0.003
100	±0.005
200	±0.010

The weights are calibrated against F_1 standards by the calibration laboratory and their F_1 standards are calibrated against E_2 standards by a second calibration laboratory.

Table 8

Nominal Weight (g)	F_1 Tolerance (g)
50	±0.0003
100	±0.0005
200	±0.001

The certificate for the set of weights does not give a value for the estimated uncertainty for the calibration so an uncertainty that is equal to twice the F_1 tolerance has been used. This value has been combined with with the M_1 tolerance using the formula below.

$$\text{Total uncertainty} = \pm\sqrt{(M_1\,\text{tolerance})^2 + (F_1\,\text{tolerance} \times 2)^2}$$

The calculated uncertainties for each weight value are listed in Table 9 below.

Table 9

Nominal Weight (g)	Total Uncertainty (g)	Total Uncertainty (% of nominal)
50	±0.00306	±0.00612
100	±0.00510	±0.00510
200	±0.01020	±0.00510

1.4 Weight Set W115-01

This is a set of five brass weights in a 50, 150 and 200g sequence. One 50g weight is a hanger. An external laboratory calibrates the weights to fall within the class M1 tolerances.

Table 10

Nominal Weight (g)	M_1 Tolerance (g)
50	±0.003
150	±0.01
200	±0.01

The weights are calibrated against F_1 standards by the calibration laboratory and their F_1 standards are calibrated against E_2 standards by a second calibration laboratory.

Table 11

Nominal Weight (g)	F_1 Tolerance (g)
50	±0.0003
150	±0.001
200	±0.001

The certificate for the set of weights does not give a value for the estimated uncertainty for the calibration so an uncertainty that is equal to twice the F_1 tolerance has been used. This value has been combined with with the M_1 tolerance using the formula below.

$$\text{Total uncertainty} = \pm\sqrt{(M_1\ \text{tolerance})^2 + (F_1\ \text{tolerance} \times 2)^2}$$

The calculated uncertainties for each weight value are listed in Table 12 below.

Table 12

Nominal Weight (g)	Total Uncertainty (g)	Total Uncertainty (% of nominal)
50	±0.00306	±0.00612
150	±0.01020	±0.00680
200	±0.01020	±0.00510

1.5 Weight Set W104-01 to 21

This is a set of twenty one 500g cast iron slotted weights. One weight is a calibrated hanger. These production test weights are calibrated against a 500g F_2 reference weight using a comparison technique with an electronic balance.

F_2 tolerance (500g) = ±0.008g

Uncertainty of reference weight calibration = ±0.0015g

Resolution of the electronic balance = ±0.01g

Maximum error allowed on the production test weights = ±0.09g

$$\text{Total uncertainty} = \pm\sqrt{(0.008^2 + 0.005^2 + 0.01^2 + 0.09^2)}$$
$$= \pm 0.09104\,\text{g}$$

This is ±0.01845% of 500g

1.6 Weight Set W114-01 to 04

This is a set of four 500g stainless steel disc weights. These production test weights are calibrated against a 500g F_2 reference weight using a comparison technique with an electronic balance.

F_2 tolerance (500g)	= ±0.008g
Uncertainty of reference weight calibration	= ±0.0015g
Resolution of the electronic balance	= ±0.01g
Maximum error allowed on the production test weights	= ±0.09g

$$\text{Total uncertainty} = \pm\sqrt{(0.008^2 + 0.005^2 + 0.01^2 + 0.09^2)}$$
$$= \pm 0.09104\,\text{g}$$

This is ±0.01845% of 500g

1.7 Weight Set WNT A to J

This is a set of ten 1kg cast iron slotted weights. An external laboratory calibrates the weights to fall within 0.01% of 1kg.

The weights are calibrated against F_1 standards by the calibration laboratory and their F_1 standards are calibrated against E_2 standards by a second calibration laboratory.

±0.01% tolerance (1kg)	= ±0.1g
F_1 tolerance (1kg)	= ±0.005g

The certificate for the set of weights does not give a value for the estimated uncertainty for the calibration so an uncertainty that is equal to twice the F_1 tolerance has been used. This value has been combined with with the 0.01% tolerance.

±0.01% tolerance (1kg)	= ±0.1g
F_1 tolerance (1kg)	= ±0.005g

$$\text{Total uncertainty} = \pm\sqrt{(0.1)^2 + (0.005 \times 2)^2}$$
$$= \pm 0.10050\,\text{g}$$

This is ±0.01005% of 1kg

1.8 Weight Set W105-01 to 23

This is a set of twenty three 5kg cast iron slotted weights. One weight is a calibrated hanger. These production test weights are calibrated against a 5kg F_1 reference weight using a comparison technique with an electronic balance.

F_1 tolerance (5kg)	= ±0.025g
Uncertainty of reference weight calibration	= ±0.005g
Resolution of the electronic balance	= ±0.01g
Maximum error allowed on the production test weights	= ±0.9g

$$\text{Total uncertainty} = \pm\sqrt{(0.025^2 + 0.005^2 + 0.01^2 + 0.9^2)}$$
$$= \pm 0.9004\,\text{g}$$

This is ±0.018% of 5kg

1.9 Weight Set W113-01 to 04

This is a set of four 5kg stainless steel disc weights. These production test weights are calibrated against a 5kg F_1 reference weight using a comparison technique with an electronic balance.

F_1 tolerance (5kg)	= ±0.025g
Uncertainty of reference weight calibration	= ±0.005g
Resolution of the electronic balance	= ±0.01g
Maximum error allowed on the production test weights	= ±0.9g

$$\text{Total uncertainty} = \pm\sqrt{(0.025^2+0.005^2+0.01^2+0.9^2)}$$
$$= \pm 0.9004\,\text{g}$$

This is ±0.018% of 5kg

1.10 W111-01 to 02 10kg Small Dead-weight Rig Platforms

These platforms are calibrated against a 5kg F_1 reference weight and a W105-XX 5kg weight using a comparison technique with an electronic balance. The best W105-XX 5kg weight is selected for this calibration.

Uncertainty of W105-XX weight calibration from 1.9 assuming a maximum measured error of 0.2g:

$$\text{W105-XX uncertainty} = \pm\sqrt{(0.025^2+0.005^2+0.01^2+0.2^2)}$$
$$= \pm 0.0202\,\text{g}$$

F_1 tolerance (5kg)	= ±0.025g
Uncertainty of reference weight calibration	= ±0.005g
Resolution of the electronic balance	= ±0.5g
Worst measured error on the platforms	= ±1.8g

The above are combined to give a total uncertainty:

$$\text{Total uncertainty} = \pm\sqrt{(0.202^2+0.025^2+0.005^2+0.5^2+1.8^2)}$$
$$= \pm 1.879\,\text{g}$$

This is ±0.01879% of 10kg

1.11 Weight Set W106-01 to 48

This is a set of forty eight 20kg cast iron bar weights. These production test weights are calibrated against a 20kg F_2 reference weight using a comparison technique with an electronic balance.

F_2 tolerance (20kg)	= ±0.3g
Uncertainty of reference weight calibration	= ±0.06g
Resolution of the electronic balance	= ±0.5g
Maximum error allowed on the production test weights	= ±3.5g

$$\text{Total uncertainty} = \pm\sqrt{(0.3^2+0.06^2+0.5^2+3.5^2)}$$
$$= \pm 3.5487$$

This is ±0.0177% of 20kg

1.12 W108-01 to 04 Large Dead-weight Rig Platforms

These platforms are calibrated against a 5kg F_1 reference weight, a 20kg F_2 reference weight and a W105-XX 5kg weight using a comparison technique with an electronic balance. The best W105-XX 5kg weight is selected for this calibration.

Uncertainty of W105-XX weight calibration from 1.5 assuming a maximum measured error of 0.2g:

$$\text{W105-XX uncertainty} = \pm\sqrt{(0.025^2+0.005^2+0.01^2+0.2^2)}$$
$$= \pm 0.0202\,\text{g}$$

F_1 tolerance (5kg)	= ±0.025g
Uncertainty of 5kg reference weight calibration	= ±0.005g
F_2 tolerance (20kg)	= ±0.3g
Uncertainty of 20kg reference weight calibration	= ±0.06g
Resolution of the electronic balance	= ±0.5g
Worst measured error on the platforms	= ±5.5g

The above are combined to give a total uncertainty for the 30kg platforms:

$$\text{Total uncertainty 30kg platform} = \pm\sqrt{(0.202^2+0.025^2+0.005^2+0.3^2+0.06^2+0.5^2+5.5^2)}$$
$$= \pm 5.53489\,\text{g}$$

This is ±0.01845% of 30kg

One platform is fitted with chains that weigh 10kg. These have to be calibrated separately because of the limited range of the electronic balance. The calibration is carried out using the two 5kg weights as above.

Measured error on the chains = ±2.0g

$$\text{Total uncertainty 10kg chains} = \pm\sqrt{(0.202^2+0.025^2+0.005^2+0.5^2+2.0^2)}$$
$$= \pm 2.07158\,\text{g}$$

The chain and platform uncertainties are combined to give a total uncertainty for the 40kg platform:

$$\text{Total uncertainty 40kg platform} = \pm\sqrt{(5.53489^2+2.07158^2)}$$
$$= \pm 5.90986\,\text{g}$$

This is ±0.014775% of 40kg

1.13 Buoyancy And Deadweight Calibration Of Loadcells

The air surrounding a suspended weight exerts an upward buoyancy force that reduces its weight. The magnitude of possible uncertainties in the calibration of loadcells in deadweight rigs needs to be evaluated to see if they are significant.

The weights used for calibration are really standard masses that are calibrated against standard masses of greater precision using comparison techniques in air. The reference density for the standards is 8000kg per cubic metre and the air density is 1.2kg per cubic metre. The reference density is typical for stainless steels.

At the level of precision we are working to the comparison method removes errors due to variation in acceleration due to gravity, g, as the value is the same for both weights.

If two weights have the same density and identical masses the buoyancy effects would cancel, as they would displace equal volumes of air. The effect on weights of different densities can be assessed using a density range that covers stainless steel, iron and brass weights.

Reference mass density	= 8000 kg per cubic metre
Reference air density	= 1.2 kg per cubic metre
Variation in density of metals used for weights	= 7200 to 8800 kg per cubic metre
The buoyancy effect on a standard 8000kg mass	= 1.2kg
Range of weight densities as % of reference density	= ±(800/8000) x100%
	= ±10%
Variation in buoyancy for this range of densities	= 1.2kg ±10%
	= ±0.12kg
Buoyancy error as a % of 8000kg weight	= ±(0.12/8000) x100% change in
	= ±0.0015% change in weight

As this change is a factor of 13 smaller than the target uncertainty of ±0.02% for forces applied by weights it can be ignored in the standard uncertainty evaluation for the weights.

If the air density varies from the standard value when the standard mass is used for calibrating a loadcell this will result in an error in the applied force. This can assessed using typical values.

Typical variation in air density (NPL)	= 1.1 to 1.3 kg per cubic metre
Standard mass	= 8000kg
Volume of standard mass	= 1 cubic metre
Variation in weight of the standard mass due to air density change	= ±0.1kg
Change as a percentage of 8000kg weight	= ±0.00125% change in

As this change is a factor of 16 smaller than the target uncertainty of ±0.02% for forces applied by weights it can be ignored in the standard uncertainty evaluation for the weights.

1.14 Acceleration Due To Gravity And Deadweight Calibration Of Loadcells

Deadweight calibrations are carried out by applying a force to the loadcell using a weight and measuring the loadcell output. The loadcell is always measuring a force even when the units applied to the calibration are kilograms so strictly the units should be kilograms force (kgf). This distinction is important because the weights used are really standard masses and the force applied by suspending a standard mass of 1kg will only produce a force of 1kgf if the local value of the acceleration due to gravity, g, is the standard value of 9.80665 m/s^2. This means that the output obtained from the loadcell is affected by the local acceleration due to gravity. This varies over the Earth's surface by ±0.26% relative to the standard value of 9.80665 m/s^2 so correction needs to be made to achieve the best accuracy in the calibration.

The National Physical Laboratory have published a method for estimating the local value of g. See appendix H.

The value of g for Novatech's location calculated using this formula is 9.811165736 m/s^2. This means that a standard mass of 1kg will exert a force of 9.811165736N or 1.00046kgf. The loadcell output will be 0.046% higher than the output for 9.80665N or 1kgf.

To correct this error all measured loadcell outputs are reduced by 0.046% after zero correction. The loadcell calibration is then correct for true force measurement. The deadweight computer program carries this out. The correction is applied manually using a calculator for deadweight calibrations that are not carried out under computer control.

If loadcells are used in weighing systems the errors can be large if the variation in g is not taken into account. At the poles or the equator the error is approximately 0.26%. The simplest way to correct this error is to calibrate the system with standard masses in its final location. This is always the best method for other reasons particularly if multiple loadcells are used to support a weighing vessel.

1.15 Notes

a. The uncertainties of the applied forces is ±0.02% of applied load for all dead-weight calibrations at 2g and above. This is based on a 0, 50% and 100% sequence of calibration points. Currently our smallest calibration range is 2g as the smallest weights we have are 1g.

b. The uncertainties do not include the effect of any test fittings used for calibration.

2. Meters Used For Loadcell Calibrations

2.1 E132-01 to 04

These meters are dc ratio meters with a measuring range of ±3.3mV/V. A nominal 10V excitation supply powers the loadcell under test. The ratiometric operation of the meter corrects for any drift in the excitation supply. The six-digit display has a resolution of 0.00001mV/V.

The meters are calibrated by National Physical Laboratory at 13 points between 0.02 to 3.30 mV/V and at 13 points between -0.02 to -3.30mV/V. They calculate the expanded uncertainty at each measured point, this includes the resolution of the dc ratio meter.

The expanded uncertainty figure given below are the worst values for both positive and negative readings taken from four sets of calibration results.

Nominal calibration temperature = 20°C

Expanded uncertainty at 0.02 mV/V = ±0.061% of reading

Expanded uncertainty at 0.1 mV/V = ±0.014% of reading

Worst expanded uncertainty 0.15 to 3.30mV/V = ±0.011% of reading

Span drift over 10 to 30°C = ±0.0015% of reading (from meter specification)

$$\text{Total expanded uncertainty } 0.02\text{mV/V} = \pm\sqrt{(0.061^2 + 0.0015^2)} = \pm 0.0610\,\%\text{ of reading}$$

$$\text{Total expanded uncertainty } 0.10\text{mV/V} = \pm\sqrt{(0.014^2 + 0.0015^2)} = \pm 0.0141\,\%\text{ of reading}$$

$$\text{Total expanded uncertainty } 0.15\text{ to } 3.30\text{mV/V} = \pm\sqrt{(0.011^2 + 0.0015^2)} = \pm 0.0111\,\%\text{ of reading}$$

2.2 Notes

a. The estimated uncertainties for measuring loadcell outputs is ±0.0111% for outputs between 1.5mV and 33mV over an ambient temperature range of 10 to 30°C.

b. The best resolution is 0.1µV.

c. The meters are compared every 3 months using a stable resistive loadcell simulator to check for any problems that might arise between the external calibrations carried out at NPL.

3. Reference Loadcells

The outputs of the reference loadcells are measured using ratio meters E132-01, -02 and -03. The uncertainty in measuring calibration forces is a combination of the output measurement uncertainty and reference loadcell calibration uncertainty. These are collated for each reference loadcell assuming a temperature range of 18 to 28°C and using the specification data given by the manufacturer. The tables showing the individual components that make up the uncertainty are included at the end of this report.

All the reference loadcells are calibrated by the National Physical Laboratory at Teddington.

3.1 Reference Loadcell L100 - Range 35kN

This loadcell is normally only used up to 25kN. Loadcell accuracy classification is C6, OIML R60.

Force kN	Uncertainty ±% of force
2.5	0.157
5	0.086
10	0.054
15	0.047
20	0.043
25	0.042

See Appendix A.

3.2 Reference Loadcell L101 - Range 45kN

Loadcell accuracy classification is C3 OIML R60.

Force kN	Uncertainty ±% of force
4.5	0.227
10	0.108
20	0.064
30	0.052
40	0.047
45	0.045

See appendix B.

3.3 Reference Loadcell L103 - Range 300kN

Loadcell accuracy classification is C3, OIML R60.

Force kN	Uncertainty ±% of force
30	0.227
90	0.084
150	0.060
210	0.051
270	0.047
300	0.045

See appendix C.

3.4 Reference Loadcell L105 - Range 100kN

Loadcell accuracy classification is C3, OIML R60.

Force kN	Uncertainty ±% of force
10	0.227
20	0.119
40	0.068
60	0.054
80	0.048
100	0.045

See appendix D.

3.5 Reference Loadcell L106 - Range 1000kN

Loadcell accuracy classification is C2, OIML R60.

Force kN	Uncertainty ±% of force
100	0.254
200	0.132
400	0.074
600	0.058
800	0.051
1000	0.047

See appendix E.

3.6 Reference Loadcell L107 - Range 10kN

Loadcell accuracy classification is C6, OIML R60.

Force kN	Uncertainty ±% of force
1	0.157
2	0.086
4	0.054
6	0.047
8	0.043
10	0.042

See appendix F.

3.7 Reference Loadcell L108 - Range 2000kN

Loadcell accuracy classification is 0.05 HBM.

See appendix G.

Force kN	Uncertainty ±% of force
200	0.516
400	0.267
800	0.151
1200	0.117
1600	0.103
2000	0.095

3.8 Notes

a. The uncertainties of the applied forces up to 1000kN are between ±0.042 and ±0.254% of the applied force over an ambient temperature range of 18 to 28°C, subject to notes b and c.

   The uncertainties of the applied compression forces up to 2000kN are between ±0.095 and ±0.516% of the applied force over an ambient temperature range of 18 to 28°C, subject to notes b and c.

b. Reference loadcells are not used to measure forces less than 10% of their full range. This gives a measurement range between 1.0 and 1000kN in compression and tension. Compression only calibrations extend to 2000kN.

c. The uncertainties do not include the effect of any test fittings used for calibration.

d. Monthly rig checks are made to check for any reference loadcell problems that may arise between the external reference calibrations.

4. Summary Of Uncertainties

4.1 Forces Applied By Weights

a. The uncertainties of the applied forces is ±0.02% of applied load for all dead-weight calibrations at 2g and above. This is based on a 0, 50% and 100% sequence of calibration points. Currently our smallest calibration range is 2g as the smallest weights we have are 1g.

b. The uncertainties do not include the effect of any test fittings used for calibration.

4.2 Loadcell Output Measurement For Dead-weight Calibrations

a. The estimated uncertainties for measuring loadcell outputs is ±0.0111% for outputs between 1.5mV and 33mV over an ambient temperature range of 10 to 30°C.

b. The best resolution is 0.1μV.

c. The meters are compared every 3 months using a stable resistive loadcell simulator to check for any problems that might arise between the external calibrations carried out at NPL.

4.3 Loadcell Output Measurement For Transfer Calibrations

a. The estimated uncertainties for measuring loadcell outputs is ±0.0111% for outputs between 1.5mV and 33mV over an ambient temperature range of 10 to 30°C.

b. The best resolution is 0.1μV.

c. The meters are compared every 3 months using a stable resistive loadcell simulator to check for any problems that might arise between the external calibrations carried out at NPL.

4.4 Forces Applied By Transfer Standard Rigs

a. The uncertainties of the applied forces up to 1000kN are between ±0.042 and ±0.254% of the applied force over an ambient temperature range of 18 to 28°C, subject to notes b and c.

   The uncertainties of the applied compression forces up to 2000kN are between ±0.095 and ±0.516% of the applied force over an ambient temperature range of 18 to 28°C, subject to notes b and c.

b. Reference loadcells are not used to measure forces less than 10% of their full range. This gives a measurement range between 1.0 and 1000kN in compression and tension. Compression only calibrations extend to 2000kN.

c. The uncertainties do not include the effect of any test fittings used for calibration.

d. Monthly rig checks are made to check for any reference loadcell problems that may arise between the external reference calibrations.

5. Appendix A: L100 35kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
2.5	0.0111	0.1150	0.037	0.005	0.1000	0.1573
5	0.0111	0.0575	0.037	0.005	0.0500	0.0856
10	0.0111	0.0288	0.037	0.005	0.0250	0.0545
15	0.0111	0.0192	0.037	0.005	0.0167	0.0465
20	0.0111	0.0144	0.037	0.005	0.0125	0.0434
25	0.0111	0.0115	0.037	0.005	0.0100	0.0418

Force kN	Uncertainty ±% of force
2.5	0.157
5	0.086
10	0.054
15	0.047
20	0.043
25	0.042

File AppendixA2014.ods

6. Appendix B: L101 45kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
4.5	0.0111	0.2000	0.037	0.008	0.1000	0.2271
10	0.0111	0.0900	0.037	0.008	0.0450	0.1081
20	0.0111	0.0450	0.037	0.008	0.0225	0.0639
30	0.0111	0.0300	0.037	0.008	0.0150	0.0518
40	0.0111	0.0225	0.037	0.008	0.0113	0.0468
45	0.0111	0.0200	0.037	0.008	0.0100	0.0453

Force kN	Uncertainty ±% of force
4.5	0.227
10	0.108
20	0.064
30	0.052
40	0.047
45	0.045

File AppendixB2016.ods

7. Appendix C: L103 300kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
30	0.0111	0.2000	0.037	0.008	0.1000	0.2271
90	0.0111	0.0667	0.037	0.008	0.0333	0.0843
150	0.0111	0.0400	0.037	0.008	0.0200	0.0596
210	0.0111	0.0286	0.037	0.008	0.0143	0.0508
270	0.0111	0.0222	0.037	0.008	0.0111	0.0466
300	0.0111	0.0200	0.037	0.008	0.0100	0.0453

Force kN	Uncertainty ±% of force
30	0.227
90	0.084
150	0.060
210	0.051
270	0.047
300	0.045

File AppendixC2016.ods

8. Appendix D: L105 100kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
10	0.0111	0.2000	0.037	0.008	0.1000	0.2271
20	0.0111	0.1000	0.037	0.008	0.0500	0.1186
40	0.0111	0.0500	0.037	0.008	0.0250	0.0684
60	0.0111	0.0333	0.037	0.008	0.0167	0.0543
80	0.0111	0.0250	0.037	0.008	0.0125	0.0483
100	0.0111	0.0200	0.037	0.008	0.0100	0.0453

Force kN	Uncertainty ±% of force
10	0.227
20	0.119
40	0.068
60	0.054
80	0.048
100	0.045

File AppendixD2016.ods

9. Appendix E: L106 1000kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
100	0.0111	0.2300	0.037	0.009	0.1000	0.2539
200	0.0111	0.1150	0.037	0.009	0.0500	0.1315
400	0.0111	0.0575	0.037	0.009	0.0250	0.0742
600	0.0111	0.0383	0.037	0.009	0.0167	0.0576
800	0.0111	0.0288	0.037	0.009	0.0125	0.0506
1000	0.0111	0.0230	0.037	0.009	0.0100	0.0469

Force kN	Uncertainty ±% of force
100	0.254
200	0.132
400	0.074
600	0.058
800	0.051
1000	0.047

File AppendixE2016.ods

10. Appendix F: L107 10kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
1	0.0111	0.1150	0.037	0.005	0.1000	0.1573
2	0.0111	0.0575	0.037	0.005	0.0500	0.0856
4	0.0111	0.0288	0.037	0.005	0.0250	0.0545
6	0.0111	0.0192	0.037	0.005	0.0167	0.0465
8	0.0111	0.0144	0.037	0.005	0.0125	0.0434
10	0.0111	0.0115	0.037	0.005	0.0100	0.0418

Force kN	Uncertainty ±% of force
1	0.157
2	0.086
4	0.054
6	0.047
8	0.043
10	0.042

File AppendixF2016.ods

11. Appendix G: L108 2000kN Reference Loadcell Uncertainty Calculations

Force kN	Meter	Loadcell	Calibration Laboratory	Output drift 10°C	Repeatability	Total
200	0.0111	0.5000	0.062	0.05	0.1000	0.5162
400	0.0111	0.2500	0.062	0.05	0.0500	0.2673
800	0.0111	0.1250	0.062	0.05	0.0250	0.1507
1200	0.0111	0.0833	0.062	0.05	0.0167	0.1170
1600	0.0111	0.0625	0.062	0.05	0.0125	0.1026
2000	0.0111	0.0500	0.062	0.05	0.0100	0.0952

Force kN	Uncertainty ±% of force
200	0.516
400	0.267
800	0.151
1200	0.117
1600	0.103
2000	0.095

File AppendixG2016.ods

12. Appendix H: Calculation Of Acceleration Due To Gravity

An approximate value for g, at a given latitude and height above sea level, may be calculated from the formula:

$g = 9.780\,318\,4\,(1 + A\sin^2 L - B\sin^2 2L) - 3.086\times10^{-6}\,H$

Where A = 0.0053024

B = 0.0000059

L = Latitude in degrees

H = height in metres above sea level

The uncertainty in the value of g so obtained is generally less than ±5 parts in 10^5.

Values for Novatech's location.

L	50.88345°	Measured by GPS
H	102m	Estimated from OS map Explorer sheet 124

g from NPL formula	9.811165736m/s^2
Force exerted by a 1kg mass	9.811165736N
Standard value of g	9.80665m/s^2
Force exerted by 1kg mass	9.80665N
Difference between the forces	0.046048% of force at standard g value

