Morehouse®
THE FORCE IN CALIBRATION SINCE 1925

UNDERSTANDING LOAD CELL SPECIFICATIONS

HENRY ZUMBRUN AND MARK JONES

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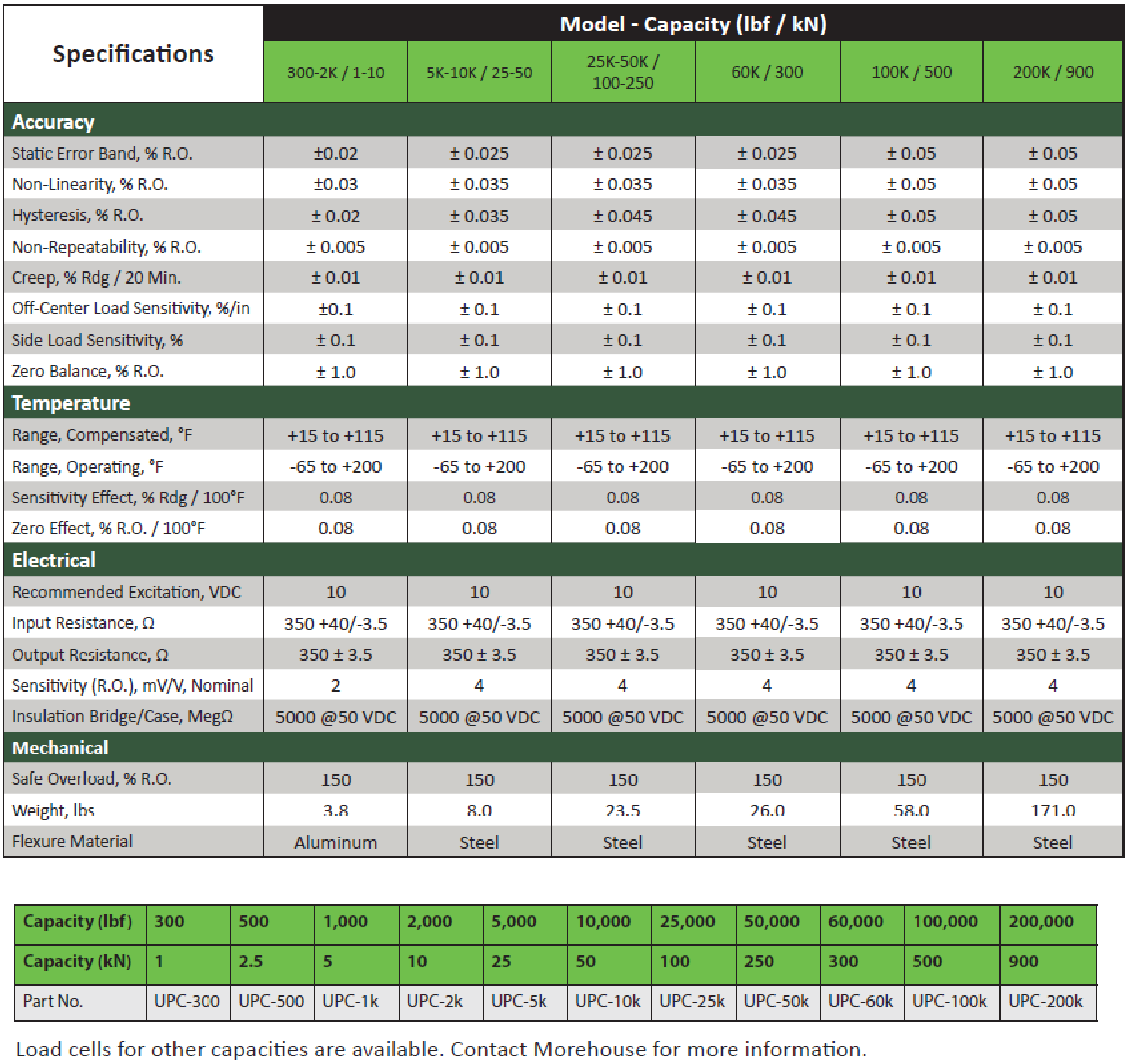
Load Cell Specifications Explained



Specifications	Model - Capacity (lbf / kN)					
	300-2K / 1-10	5K-10K / 25-50	25K-50K / 100-250	60K / 300	100K / 500	200K / 900
Accuracy						
Static Error Band, % R.O.	±0.02	± 0.025	± 0.025	± 0.025	± 0.05	± 0.05
Non-Linearity, % R.O.	±0.03	± 0.035	± 0.035	± 0.035	± 0.05	± 0.05
Hysteresis, % R.O.	± 0.02	± 0.035	± 0.045	± 0.045	± 0.05	± 0.05
Non-Repeatability, % R.O.	± 0.005	± 0.005	± 0.005	± 0.005	± 0.005	± 0.005
Creep, % Rdg / 20 Min.	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01
Off-Center Load Sensitivity, %/in	±0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1
Side Load Sensitivity, %	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1
Zero Balance, % R.O.	± 1.0	± 1.0	± 1.0	± 1.0	± 1.0	± 1.0
Temperature						
Range, Compensated, °F	+15 to +115	+15 to +115	+15 to +115	+15 to +115	+15 to +115	+15 to +115
Range, Operating, °F	-65 to +200	-65 to +200	-65 to +200	-65 to +200	-65 to +200	-65 to +200
Sensitivity Effect, % Rdg / 100°F	0.08	0.08	0.08	0.08	0.08	0.08
Zero Effect, % R.O. / 100°F	0.08	0.08	0.08	0.08	0.08	0.08
Electrical						
Recommended Excitation, VDC	10	10	10	10	10	10
Input Resistance, Ω	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5
Output Resistance, Ω	350 ± 3.5	350 ± 3.5	350 ± 3.5	350 ± 3.5	350 ± 3.5	350 ± 3.5
Sensitivity (R.O.), mV/V, Nominal	2	4	4	4	4	4
Insulation Bridge/Case, MegΩ	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC
Mechanical						
Safe Overload, % R.O.	150	150	150	150	150	150
Weight, lbs	3.8	8.0	23.5	26.0	58.0	171.0
Flexure Material	Aluminum	Steel	Steel	Steel	Steel	Steel

Capacity (lbf)	**300**	**500**	**1,000**	**2,000**	**5,000**	**10,000**	**25,000**	**50,000**	**60,000**	**100,000**	**200,000**
Capacity (kN)	**1**	**2.5**	**5**	**10**	**25**	**50**	**100**	**250**	**300**	**500**	**900**
Part No.	UPC-300	UPC-500	UPC-1k	UPC-2k	UPC-5k	UPC-10k	UPC-25k	UPC-50k	UPC-60k	UPC-100k	UPC-200k

Load cells for other capacities are available. Contact Morehouse for more information.

Figure 1 Example of a Typical Morehouse Load Cell Specifications Sheet

Load cells are precision devices used to measure force or weight, and their performance is defined by various specifications.

The purpose of this guidance document is to explain the typical load cell specifications sheet.

Let's break down the key parameters from a typical Morehouse Load Cell Specifications Sheet and explain what each of them means:

1. Accuracy Parameters:

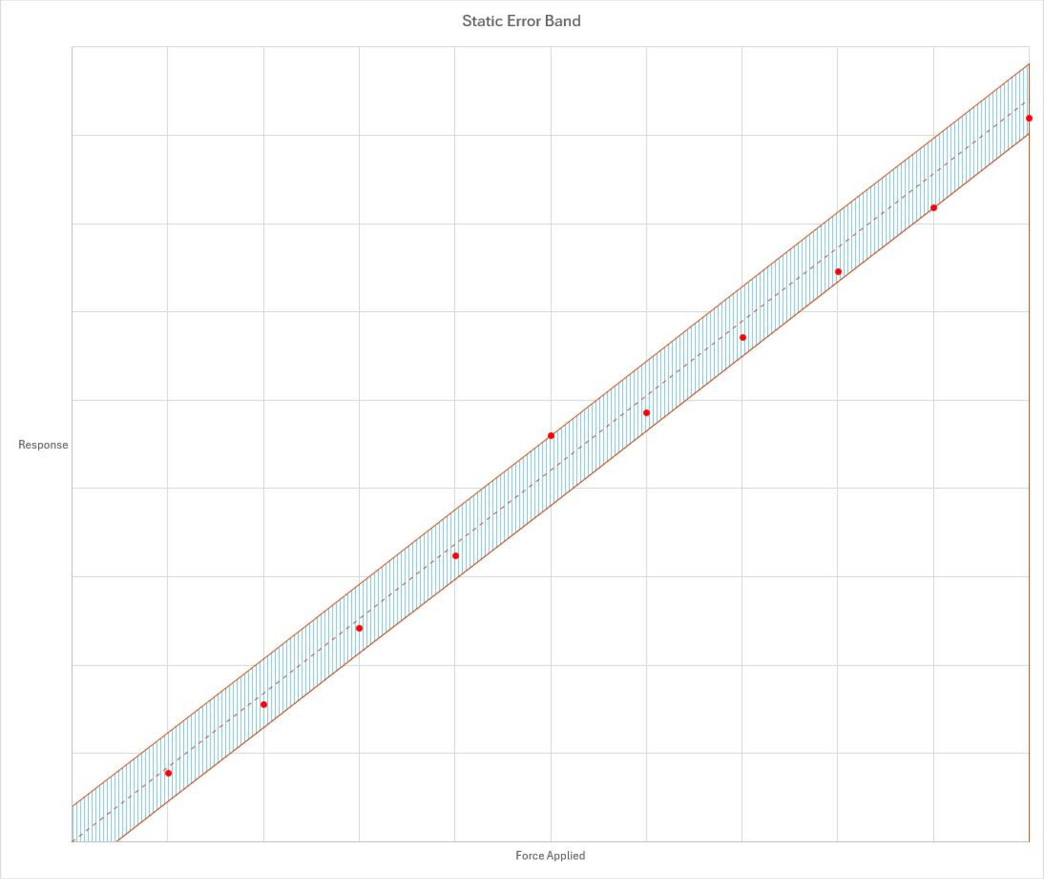


Figure 2 Load Cell Specifications SEB Example

- Static Error Band (SEB), % R.O.: This represents a subset of errors in the load cell's output, including sources such as non-linearity, hysteresis, and return to zero after loading. A lower SEB means higher accuracy. For example, the static error band for smaller capacities is ±0.02 % R.O., meaning the error is within 0.02 % of the rated output (R.O.).

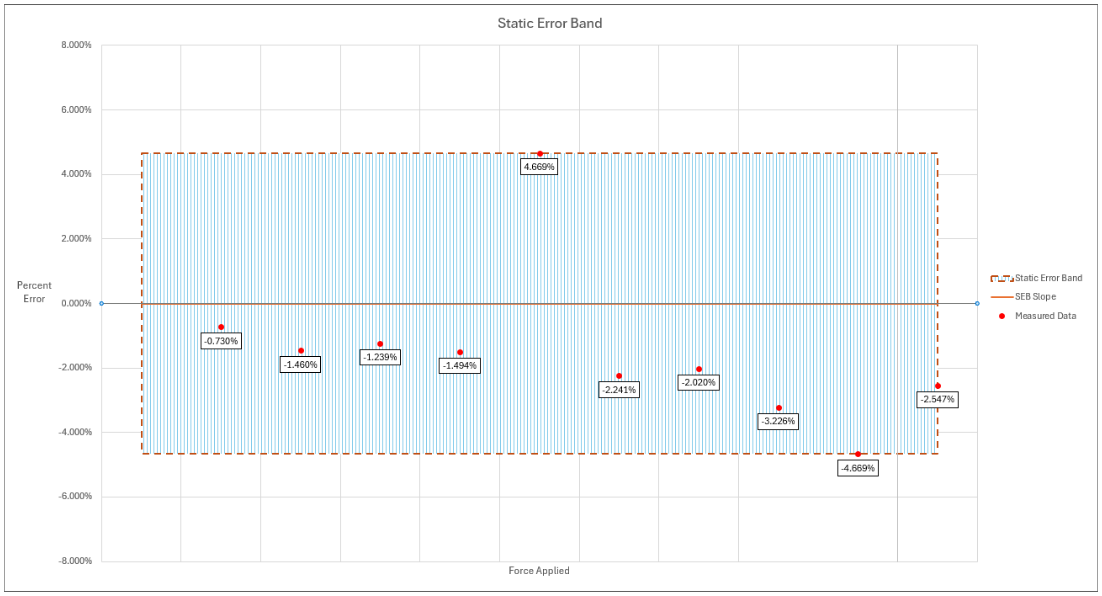


Figure 3 SEB Shown in an alternate way using the % error from the SEB slope.

Note: The rated output is typically equivalent to full scale output or the full-scale capacity of the load cell.

Our goal is to find a line that results in the smallest, maximum error. This line also needs to fit through the origin (0, 0), so only the slope needs to be calculated via $(y_1+y_2) / (x_1+x_2)$. The best approach to this is to iterate across every pair of percent force applied of full scale (**% FS**) and the zero adjusted responses.

For each pair, calculate the slope, use the slope to calculate the percent error for all % FS, and take the largest error as that slope's "absolute error" value. Repeat this for all possibilities, taking the slope that has the smallest absolute error value.

Note: If the load cell is used for ascending measurements and, on occasion, descending measurements are needed, the user may want to evaluate Non-Linearity and Hysteresis separately, as those two definitions may provide a more accurate depiction of the load cell's performance.

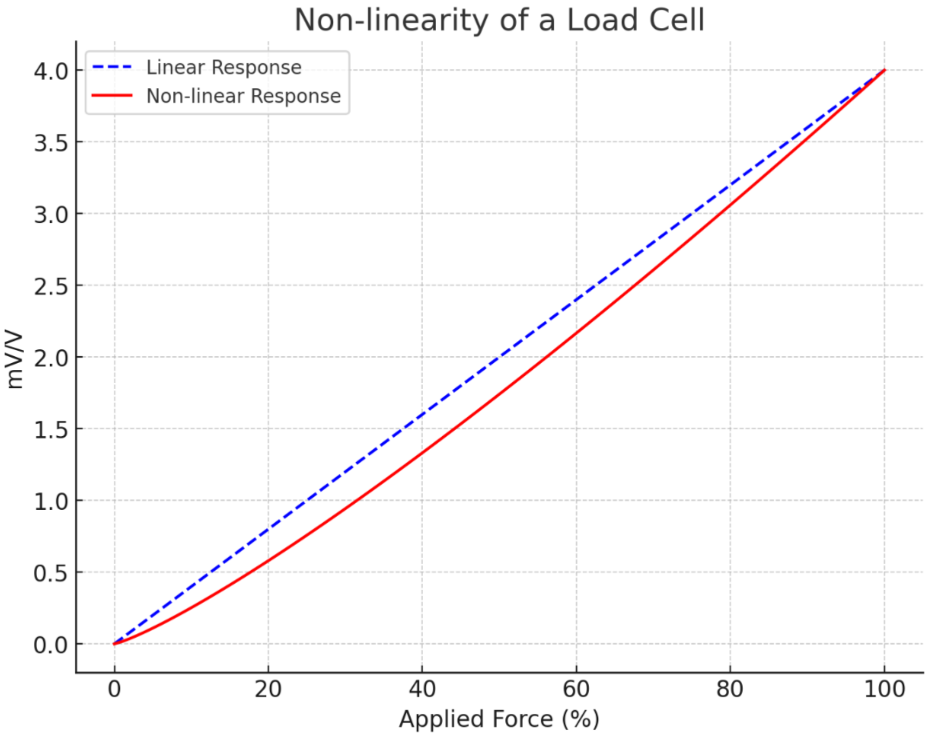


Figure 4 Load Cell Specifications Non-Linearity Example

- Non-Linearity, % R.O.(Rated Output): This specifies the deviation from a straight line when force is applied. A lower value indicates that the load cell response is more linear, which is ideal for precise measurements. Reported Non-linearity can vary for the same cell depending on how this straight line is defined. Typical definitions are endpoint, best fit straight line and best fit straight line thru zero. The SEB example above, uses the best fit straight line thru zero to calculate the linearity.

  An ideal measurement device has a perfectly linear response to force applied ratio. However, this is rarely true; most devices have a non-linear ratio. The purpose of the non-linearity calculation is to show how the recorded responses deviate from the ideal ratio. Non-linearity is typically expressed in the percent of full-scale (% FS).

  A line between the initial zero and full-scale points should be drawn to calculate Non-Linearity. This line represents the ideal response ratio that is compared against each of the ascending points. Calculate the slope using the equations below to draw a line between the two points. With the slope, the intercept can be calculated using either of the two points used to calculate the slope with the equation below. With the line properties calculated, use each of the recorded responses in the final calculation below to calculate the % FS of non-linearity.

  Note: Some manufacturers use higher-order equations to improve their Non-Linearity specification. Therefore, it is important to ask them how they calculate non-linearity.

At Morehouse, we use the more conservative straight-line approach method.

Calculate Slope

$Slope = (0_{start(force)} – FullScale_{(force)}) / (0_{start(response)} – FullScale_{(response)})$

Calculate Intercept

$Intercept = FullScale_{(force)} – Slope \times FullScale_{(response)}$

Calculate Non-Linearity per Response

$Non\text{-}Linearity = (Point_{(force)} – (Slope \times Point_{(response)} + Intercept)) / FullScale_{(force)}$

Example: A load cell reads 0 at 0 lbf, 1.20003 at 600 lbf, and 2.00010 mV/V at 1000 lbf.
To calculate the slope, the formula would be (0-1000)/(0-2.00010) = 499.975001249937
To calculate the Intercept 1000 – (499.975001249937 * 2.00010) = 0.0
Non-Linearity = (600 – (499.975001249937*1.20003+0))/1000 = 0.0000150
This value is 0.0015 % using the 600 lbf (60 %) point.

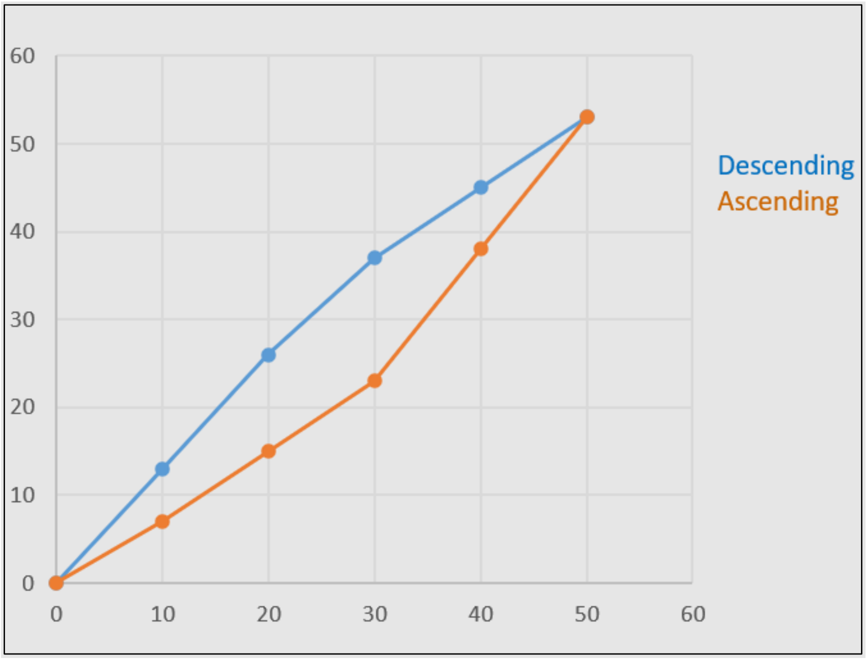


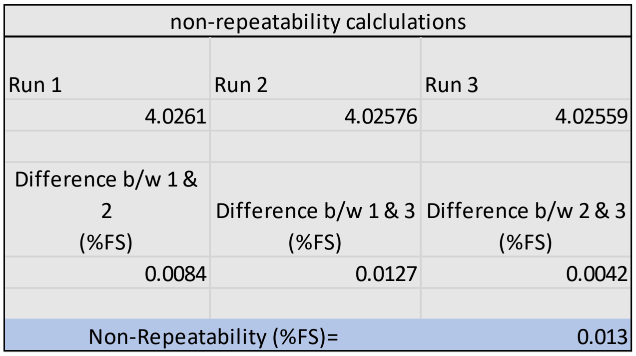
Figure 5 Load Cell Specifications Hysteresis Example

- Hysteresis, % R.O.: Hysteresis measures the difference in output between ascending and descending values. It reflects the load cell's ability to return to its initial state. Lower hysteresis values (as low as ±0.02 %) indicate less error and better accuracy.

For force measurements, **Hysteresis** is defined as the difference between two responses of a single given load, one ascending from the lowest non-zero load applied, the other descending from the full-scale load. Hysteresis is typically calculated near 50 % load.

To calculate Hysteresis, two responses must be recorded for the same load applied. Following the below equation, the full-scale response should be subtracted from the ascending load's response. The difference should be divided by the descending load's response. To ensure Hysteresis is a positive value, the absolute value of the quotient is used.

Calculate Hysteresis
Hysteresis = | (Ascending(response) - Descending(response)) / FullScale (response) |



non-repeatability calclulations		
Run 1	Run 2	Run 3
4.0261	4.02576	4.02559
Difference b/w 1 & 2 (%FS)	Difference b/w 1 & 3 (%FS)	Difference b/w 2 & 3 (%FS)
0.0084	0.0127	0.0042
Non-Repeatability (%FS)=		0.013

Figure 6 Load Cell Specifications Non-Repeatability Example

- Non-Repeatability, % R.O.**:** This is the maximum difference between repeated measurements under the same conditions. Non-repeatability values as low as ±0.005 % show that the load cells produce very consistent results.

Non-repeatability = ABS(Run1-Run2)/AVERAGE (Run1, Run2, Run3) *100

Non-repeatability tells the user a lot about the performance of the load cell. It is important to note that non-repeatability does not tell the user about the load cell's reproducibility or how it will perform under different loading conditions (randomizing the loading conditions). At Morehouse, we have observed numerous load cells with good non-repeatability specifications that do not perform well when the loading conditions are randomized, or the load cell is rotated 120 degrees as required by ISO 376 and ASTM E74.

The calculation of non-repeatability is straightforward. First, compare each observed force point's output and run a difference between those points. The formula would look like this: *Non-repeatability = ABS(Run1-Run2)/AVERAGE (Run1, Run2, Run3) *100.* Do this for each combination or runs, and then take the maximum of the three calculations.

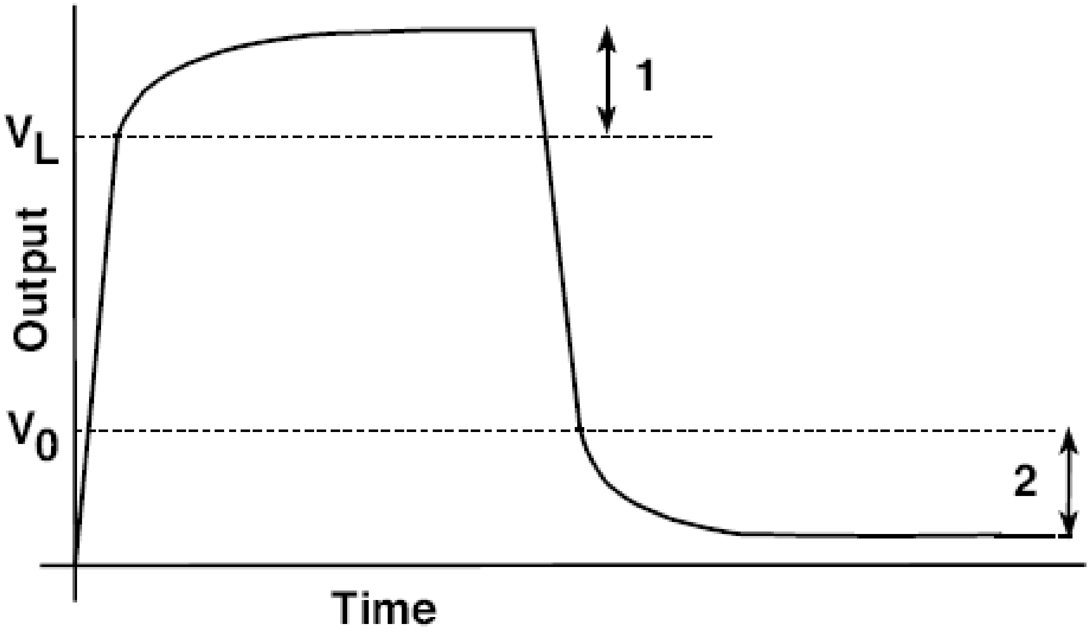


Figure 7 Load Cell Specifications Creep Example

- Creep, % Rdg(Reading)/20 Min: Creep measures how much the load cell's output drifts when a constant load is applied over time with all environmental conditions remaining constant. Low creep values (±0.01 %) indicate that the output remains stable, even during long measurements.

Creep Recovery.: The change in LOAD CELL SIGNAL occurring with time immediately after removal of a load which had been applied for a specified time interval, environmental conditions and other variables remaining constant during the loaded and unloaded intervals.

Creep recovery is expressed as the percentage difference between the output change at zero force after a creep test and the initial zero force output at the start of the test, divided by the output during the test. The zero force measurement is taken once mechanical and electrical stability are reached, at a time equal to the duration of the creep test.

Creep Recovery Error, % of Output at Maximum Applied Force = 100 × (Output 30 seconds after zero force is achieved – Initial zero reading) /Output at Maximum Applied Force.

- Off-Center Load Sensitivity (%/in): This specification refers to how much the load cell's output changes when a load is applied off-center, i.e., not directly along the central axis of the load cell.

  If a load is not perfectly centered on the load cell, it can create bending or uneven force distribution. The off-center load sensitivity quantifies how sensitive the load cell is to this type of misalignment.

  Example from the Load Cell Specification: In the datasheet, off-center load sensitivity is specified as ±0.1 %/in. This means that if the load is applied 1 inch away from the center of the load cell, the output could deviate by up to 0.1 % of the rated output.

- Side Load Sensitivity (%): Side load sensitivity measures how much the load cell's output changes when a force is applied perpendicularly or laterally, rather than along the intended load axis.

  Side loads can introduce measurement errors by causing strain on parts of the load cell that are not designed to measure force in those directions. High side load sensitivity would make the load cell less accurate under such conditions.

  Example from the Load Cell Specification: The side load sensitivity in the datasheet is also listed as ±0.1 %. This means that if a side load of the output could deviate by 0.1 % of the rated output at maximum rated side load. This specification indicates the load cell's ability to minimize errors when forces are applied in directions other than the primary loading axis. The exact amount of side load a load cell can withstand is typically not listed on most specification sheets. And although the load cell will survive the maximum rated sideload, it is not recommended in high accuracy applications. If a large side load is applied to loadcell used as reference standard, recalibration may be required.

  Many of the Morehouse cells use eight gages, as opposed to four which can help minimize alignment errors. Typically, the max side force is around 40 % of the rated range for the Morehouse UPC, PC, and C models. If other extraneous load is applied, torque or bending, then this maximum force would need to be lowered.

Zero Balance (% R.O.): Zero balance refers to the output signal of the load cell when no load is applied. Ideally, the output should be zero when no force is acting on the load cell. However, due to manufacturing tolerances, material properties, and slight imbalances in the strain gauges, there is usually a small non-zero output even when the load is at zero. This small output is referred to as the **zero balance**.

Zero balance is typically expressed as a percentage of the Rated Output (R.O.). In the specification sheet for the Ultra Precision Shear Web Load Cells, the zero balance is listed as **±1.0% R.O.** This means that when there is no load on the load cell, the output could be up to 1% of the rated output in either direction (positive or negative).

Thus a 4.0 mV/V load cell would be in spec at ± 0.04 mV/V.

Figure 8 A Morehouse Load Cell Tester

Note: [A Morehouse load cell tester] is a great tool to test zero balance, and many other specifications including insulation resistance, and input/output resistance.

2. Temperature Specifications:

- Temperature Range, Compensated (°F): The compensated temperature range (+15°F to +115°F) is the range within which the load cell compensates for temperature effects to maintain accuracy. Outside of this range, temperature fluctuations might affect the accuracy of measurements.

  To Convert to Celsius the formula is $°C = \frac{(°F-32)}{1.8}$, thus our compensated range is -9.44 °C to 46.11°C.

- Temperature Range, Operating (°F): The operating range (-65°F to +200°F) is broader than the compensated range. The load cell can function within this range but may experience more temperature-related errors outside the compensated range.

- Sensitivity Effect, % Rdg / 100°F: This represents how much the load cell's sensitivity changes with temperature. The specification indicates that the sensitivity may change by 0.08 % of the reading for every 100° F temperature change.

  Note: Many labs and standards work in °C. To convert the % Rdg / 100°F we use Δ°F= 1×1.8 = 1.8°F. If we divide 0.08 % / 100 = 0.0008 % we get a change of 0.0008 % per °F. To convert to Celsius we multiply by 1.8, we get ***0.00144 % sensitivity effect per °C****.*

- Zero Effect, % R.O. / 100°F: This parameter measures the change in zero balance (the output when no load is applied) due to temperature variations. Like the sensitivity effect, the zero effect is minimal, with a change of 0.08 % R.O. per 100° F.

  Example: Rated output is 2 mV/V and the temperature variation is 1 °C, thus the possible effect would be 2 x 0.0015 %, or 0.00003 mV/V.

  Note: *The observed return-to-zero error during each run includes contributions from both creep recovery error and thermal zero shift uncertainty components.*

3. Electrical Specifications:

- Input/Output Resistance (Ω): These parameters describe the electrical characteristics of the load cell. These values ensure the electrical compatibility of the load cell with measurement systems.

  Load cell resistance refers to the electrical resistance of the strain gauge bridge inside the load cell. A load cell generally consists of a Wheatstone bridge circuit formed by four strain gauges.

  When a load is applied to the cell, these strain gauges change resistance, producing a small voltage corresponding to the applied load.

  Input Resistance: This is the resistance measured between the two excitation terminals (often labeled as +EX and –EX). It represents the total resistance of the circuit that the excitation voltage is applied to and can be used to calculate nominal power consumption of the loadcell.

  Output Resistance: This is the resistance measured between the two signal terminals (often labeled as +SIG and –SIG). It represents the resistance through which the measurement signal (proportional to load) is obtained. This value normally has no effect on power consumption.

  Calculating Power Consumption: Lower resistance load cells require more power to operate. This means they draw more current from the excitation voltage provided by the load cell amplifier or signal conditioning equipment.

  A 350-ohm bridge balances these extremes and typically delivers an output in the 2-4 mV/V range, which is sufficient for most signal amplification and processing circuits.

  If we look at the formula for the current $I = \frac{V}{\mathbf{R}}$ where *I* is the current, V is the Voltage, and R is the resistance. We find that a 350 Ω load cell draws approximately 0.029 Amps.

$$I = \frac{10\ V}{350\ \boldsymbol{\Omega}} = 0.029\ A$$

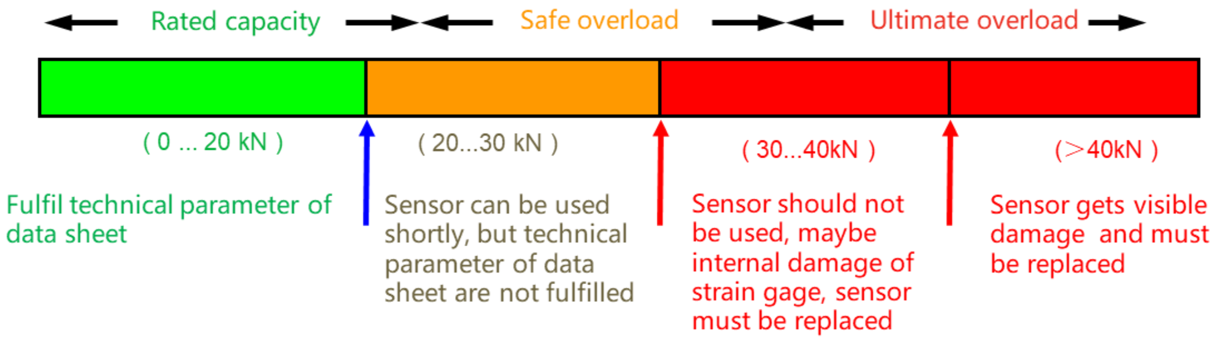
- Sensitivity: Sensitivity is also referred to as Rated Output (R.O.) or Full-Scale Output (F.S.O or F.S.). Sensitivity defines the nominal output signal produced by the load cell for each volt of excitation voltage applied or. For example, for a 10,000 lbf capacity load cell, the sensitivity is 4 mV/V, meaning the output voltage would be 4 millivolts per volt of excitation.
- Insulation Resistance (MegΩ @ 50 VDC): This parameter indicates how well the load cell's electrical circuits are isolated from its body, reducing the chances of electrical interference. With an insulation resistance of 5000 Megohms, the load cell is well-protected against electrical noise.

4. Mechanical Specifications:

- Safe Overload, % R.O.: This is the amount of overload a load cell can withstand without being damaged.

  Note: Most Morehouse load cell can handle overloads up to 150 % of its rated output without permanent damage.

  Example: Example : sensor rated capacity 20kN, safe overload 150%, ultimate overload 200%



- Weight and Material: The load cells are available in various capacities, ranging from grams to millions of lbf. Depending on the capacity, the load cells are made from aluminum or steel, affecting their weight and suitability for different applications. In our example, a 300 lbf load cell weighs around 3.8 lb., while a 200,000 lbf load cell weighs 171 lb.

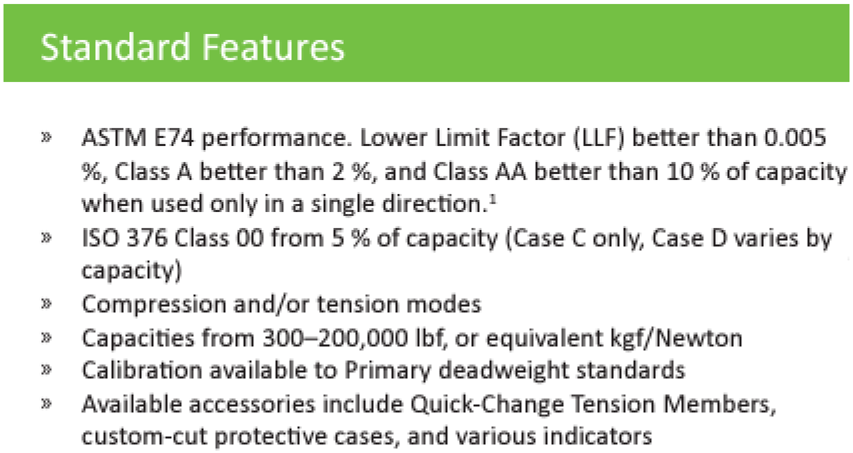
Figure 9 Multiple Morehouse Load Cells

Note: Morehouse has several load cells, many with slightly different load cell specifications.

All Morehouse load cells are designed with temperature compensation to minimize errors caused by temperature fluctuations.

This compensation ensures accurate measurements even in varying temperature environments.

Temperature compensation helps correct the sensitivity and zero-balance shifts mentioned earlier, ensuring that performance remains consistent across the compensated temperature range.



Standard Features

- ASTM E74 performance. Lower Limit Factor (LLF) better than 0.005 %, Class A better than 2 %, and Class AA better than 10 % of capacity when used only in a single direction.[1]
- ISO 376 Class 00 from 5 % of capacity (Case C only, Case D varies by capacity)
- Compression and/or tension modes
- Capacities from 300–200,000 lbf, or equivalent kgf/Newton
- Calibration available to Primary deadweight standards
- Available accessories include Quick-Change Tension Members, custom-cut protective cases, and various indicators

Figure 10 Morehouse Datasheet Example Showing ASTM E74 and ISO 376 Performance.

Load Cell Specifications Explained Conclusion:

Each load cell specification on the load cell datasheet is crucial for understanding the performance, accuracy, and environmental limits of the device.

The electrical, mechanical, and thermal characteristics work together to provide highly accurate and reliable force measurements across a wide range of conditions.

One key detail Morehouse will provide is how well the load cell will perform regarding ASTM E74 requirements as well as ISO 376 on our datasheet.

These numbers often tell one about the expected performance of the load cell when used under similar conditions at which it was calibrated.

For further details on calculations related to these load cell specifications, you can refer to Morehouse's calculation guidance (Morehouse-Calculation-Guidance), which covers advanced topics such as non-linearity, hysteresis, and other force measurement-related factors, and the calculations used to determine many specifications.

Morehouse is happy to help you with any of your load cell challenges. We offer both commercial load cells and highly customized solutions tailored to your unique requirements.

Our team is ready to assist you in selecting the perfect load cell for your application and provide ongoing support to ensure your continued success.