Load Cells and Weigh Modules | Technical Note VPGT-03

Legal Metrology

Scope

This application note is meant to provide the user with a reasonably quick reference to a fairly complex subject; the load cell requirements for legal-for-trade non automatic weighing instruments, according to section 4.12 of OIML Recommendation R76 (EN45501).

Every effort has been made to include most of the important topics and to enable the user to select load cells for a particular approved non automatic weighing instrument. The type of weighing instruments covered are: single range instruments, multiple range instruments and multi-interval instruments.

The first pages cover the metrological terms used to describe load cell features according to OIML Recommendation R60. These terms are implemented in section 4.12, and should therefore be explained.

Standardized Metrology — OIML

The establishment of a worldwide standardized metrology or measurement system has two main functions. One related to scientific activities assuring world-wide consistency and repeatability of critical scientific units, while the other is concerned with legal metrology which is the name given to all applied metrology or measurement subjected to regulations by law or governmental degree. In most countries, legal metrology covers measurements in protection of individuals from a financial, health and environmental point of view.

In order to harmonize and standardize on an international basis, a convention was held in Paris on October 12, 1955, and the participating States (countries) agreed to set up an international organization of legal metrology — the OIML was born. Because the official language of the OIML was French, the name of the organization is Organisation Internationale de Metrologie Legale.

The OIML is a worldwide inter-governmental organization whose main task is that of harmonizing the regulations and metrological controls applied by the Weights and Measures of its Member States. Because it is a Treaty Organization, membership of a country is subject to the signature of a convention through diplomatic channels. Once a member, a country has moral and ethical obligations to harmonize with the beliefs and output of the OIML.

The aim of such harmonization is to facilitate free trade and commerce between countries not only for measuring instruments, but for all commodities and services whose value is determined by measurements.

OIML Recommendations and Documents relate to specific measuring instruments and technology. International Recommendations (OIML R) are model regulations generally establishing the metrological characteristics required of the measuring instruments concerned and specifying methods and equipment for checking their conformity. OIML member states are expected to implement these Recommendations as far as possible.

Metrological Terms For Load Cells

The metrological terms most frequently used in the load cell field can be divided into two main categories; load related terms or accuracy related terms.

1. Load Related Terms

Minimum dead load (E_{min}):

The smallest value of a quantity (mass) which may be applied to a load cell without exceeding the maximum permissible error.

Maximum capacity (E_{max}):

The largest value of a quantity (mass) which may be applied to a load cell without exceeding the maximum permissible error.

Load cell measuring range:

The range of values of the measured quantity (mass) for which the result of measurement should not be affected by an error exceeding the maximum permissible error.

Safe load limit:

The maximum load that can be applied without producing a permanent shift in the performance characteristics beyond those specified.

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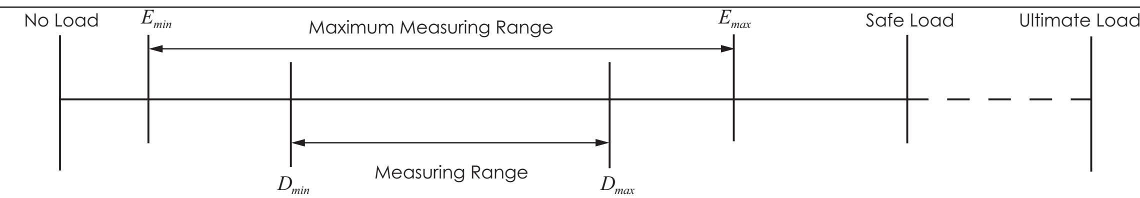
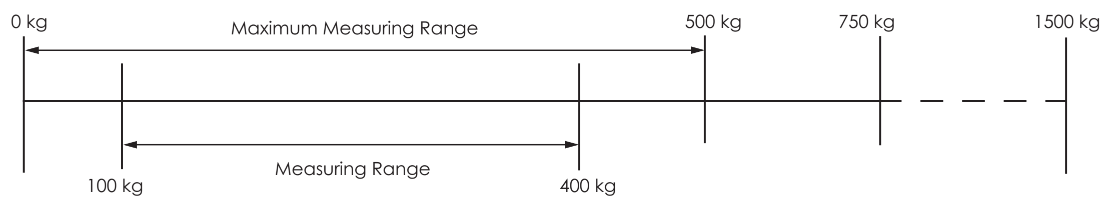


The terms that appear above the central horizontal line are parameters that are fixed by the design of the load cell. The terms that appear below that line are parameters that are variable, depending on the conditions of use and the quality of the load cell as measured during tests.



As a specific example, an "S" type load cell with a capacity of 500 kg is used to weigh a hopper with a dead load of 100 kg (D_{min}) and a live load of 300 kg (D_{max} = D_{min} + 300 = 400 kg). E_{min} = 0 % of E_{max}, the safe load limit is 150% of E_{max} and the ultimate load limit is 300% of E_{max}.

Ultimate load limit:

The maximum load that can be applied without physical destruction of the load cell.

2. Accuracy Related Terms

Load cell interval:

Part of the load cell measuring range into which that range is divided.

Load cell verification interval (v):

The load cell interval, expressed in units of mass, used in the test of the load cell for accuracy classification

Number of verification intervals (n):

The number of verification intervals, used in the test of the load cell for accuracy classification.

Accuracy class:

A class of load cells which are subjected to the same conditions of accuracy.

Load cells are ranked, according to their overall performance capabilities, into four classes whose designations are "Class A", "Class B", "Class C" and "Class D". A load cell is classified by the alphabetical classification and the maximum number of load cell intervals stated in units of 1000; for example C3 represents class C, 3000v.

The number of verification intervals (n) into which the measuring range of a class C load cell can be divided is fixed between 500 and 10000. VPG Transducers offers a wide range of class C industrial load cells from 1000v to 6000v. Class C load cells are suited for class C3 and C4 weighing systems.

Minimum verification interval (v_{min}):

The smallest value of a quantity (mass) which may be applied to a load cell without exceeding the maximum permissible error. Specified as E_{max}/γ or as a percentage of the measuring range.

The minimum verification interval is inextricably linked to the utilization of the load cell. The utilization can be defined as the minimum measuring range (MMR) for a particular load cell over which full specification will be maintained. The following formulas can be applied:

$$MMR(kg) = v_{min} * n_{max}$$

or

$$MMR(\%) = n_{max} * 100 / \gamma$$

For example a 1 t load cell, with $v_{min} = E_{max} / 10000$ has a minimum measuring range of

$$1000 * 4000 / 10000 = 400 \text{ kg}$$

or

$$4000 * 100 / 10000 = 40\%$$

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The minimum measuring range can apply over any part of the measuring range between E_{min} and E_{max}. In practice, certain accuracy parameters (linearity, hysteresis) will improve when a smaller part of the load cell rated capacity is utilized. However, temperature effect on zero load output is a fixed error percentage of the rated output, and must be tightly controlled to achieve lower V_{min} values for a particular grade of load cells.

The effect of the utilization factor on creep will depend on which part of the load cell range is being used for the scale. For example, creep will be more significant in a scale where its working range is at the top end of the load cell's rated capacity than when it is at the bottom.

Load cells having a small value for v_{min} are most suitable for applications with a relatively high dead load. The above calculation applies to a single load cell when used on its own. The requirements for multiple load cell weighing instruments are specified further on.

Non-linearity:

The deviation of the increasing load cell calibration curve from a straight line which passes through minimum load output and the load cell output at 75% of the measuring range, at 20°C.

Hysteresis error:

The difference between load cell output readings for the same applied load, one reading obtained by increasing the load from minimum load and the other by decreasing the load from maximum load.

Creep:

The change in load cell output occurring with time while under constant load (>90% of the load cell capacity) and with all environmental conditions and other variables also remaining constant.

Minimum dead load output return:

The difference in load cell output at minimum dead load, measured before and after load application.

Temperature effect on minimum dead load output:

The change in minimum dead load output due to a change in ambient temperature.

Temperature effect on sensitivity:

The change in sensitivity due to a change in ambient temperature.

Combined error:

The approach taken by R60 recognizes that several load cell errors must be considered together when fitting load cell performance characteristics to the error envelope permitted. It is possible to have low non-linearity and hysteresis and moderate temperature errors or, conversely, to have moderate non-linearity and hysteresis errors and low temperature errors.

Thus, it is not considered appropriate to specify individual error limits for given characteristics (non-linearity, hysteresis and temperature effect on sensitivity), but rather to consider the total error envelope allowed for a load cell as the limiting factor. The use of an error envelope concept allows balancing individual contributions to the total error of measurement while still achieving the intended result.

Maximum permissible load cell errors

The maximum permissible load cell errors for each accuracy class, the indicated load cell output having been adjusted to zero at minimum dead load, are related to the maximum number of verification intervals. The table below shows the error limits as represented on the VPG Transducers datasheets. "Temperature effect on Sensitivity" and" Combined error" are combined in such a way that the load cells

Accuracy Designation		C1	C2	C3	C4	C5
Combined Error	%S	0.0300	0.0230	0.0200	0.0150	0.0100
Non-Repeatability	%S	0.0200	0.0100	0.0100	0.0090	0.0070
Minimum Dead Load Output Return	%S	0.0500	0.0250	0.0167	0.0125	0.0100
Creep Error (30 minutes)	%S	0.0490	0.0245	0.0245	0.0184	0.0147
Creep Error (20-30 minutes)	%S	0.0105	0.0053	0.0053	0.0039	0.0032
Temperature Effect on Sensitivity	%S/5°C	0.0085	0.0060	0.0055	0.0045	0.0035

Note: OIML recommendation R60 specifies the maximum permissible errors in terms of verification intervals or minimum verification intervals. The maximum permissible errors for combined error are similar to those of non automatic weighing instruments, when a factor of 0.7 (pi-factor) is used. A copy of the recommendation is available on request.

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meet the OIML R60 tolerance envelope. S equals Rated Output and corresponds directly with E_{max}.

EN 45501, Requirements For Load Cells

Section 4.12 of EN 45501 (OIML R76) requires that load cells have been tested in conformity with International Recommendation OIML R60. These load cells can be applied in three groups of weighing instruments:

1. **Single interval instruments:** Instrument having one weighing range.
2. **Multiple range instruments:** Instrument having two or more weighing ranges with different maximum capacities and different scale intervals for the same load receptor, each range extending from zero to its maximum capacity.
3. **Multi-interval instruments:** Instrument having one weighing range which is divided into partial weighing ranges, each with different scale intervals, with the weighing range determined automatically according to the load applied, both on increasing and decreasing loads.

The most important metrological terms for weighing instruments are:

Reduction ratio:

The reduction ratio of a load transmitting device is given by:

$$R = FM / FL$$

Where:

FM = The load acting on the load measuring device (total number of load cells).

FL = The load acting on the load receptor (scale).

Maximum capacity (*Max*):

Maximum weighing capacity, not taking into account the additive tare capacity.

Minimum capacity (*Min*):

Value of the load below which the weighing results may be subject to an excessive relative error.

Actual scale interval (*d*):

Value expressed in units of mass of:

- The difference between the values corresponding to two consecutive scale marks, for analogue indication, or
- The difference between two consecutive indicated values, for digital indication.

Verification scale interval (*e*):

Value, expressed in units of mass, used for the classification and verification of an instrument.*

Number of verification scale intervals (n):

Quotient of the maximum capacity and the verification scale interval, for a single-interval instrument:

$$n = Max / e$$

1. Requirements For Single Interval Instruments

1.1 The maximum capacity of the load cell shall satisfy the condition:

$$E_{max} \geq Q * Max * R / N$$

Where:

E_{max} = Maximum capacity of the load cell

N = Number of load cells

R = Reduction ratio

Q = Correction factor

The correction factor $Q > 1$ considers the possible effects of eccentric loading, dead load of the load receptor (scale), initial zero setting range and non uniform distribution of the load.

To be precise: the total capacity of all load cells should be larger or equal to the maximum capacity of the scale, the dead weight of the construction and the overall effect on zero-setting and zero-tracking devices. The overall effect of zero-setting and zero-tracking devices shall be not more than 4% and of the initial zero-setting device not more than 20%, of the maximum capacity. Further to this, the following eccentric loading conditions should be considered:

- On an instrument with a load receptor having n points of support, with n4, the fraction **$1/(n - 1)$** of the sum of the maximum capacity and the maximum additive tare effect shall be applied to each point of support.
- On an instrument with a load receptor subject to minimal off-center loading (e.g., tank, hopper) a test load corresponding to one-tenth of the sum of the maximum capacity and the maximum additive tare effect shall be applied to each point of support.

* Note: "e" equals "d" in the majority of digital weighing instruments. A scale interval should be numbered in the form 1 * 10k, 2 * 10k or 5 * 10k, k being a positive or negative whole number or equal to zero.

If the above considerations are applied on a platform scale with a capacity of 1500 kg and a dead load of 100 kg, the individual load cell capacity if four load cells are used can be calculated by:

Eccentricity behavior tested with

$1/(n-1) * Max = 1/3 * 1500 = 500$ kg

Dead load weight distribution equals

$100/n = 100/4 = 25$ kg

Zero-setting/tracking:

$(24\%$ of $1500)/n = 360/4 = 90$ kg

Hence, the load cell capacity (E_{max}) should at least be

$500 + 25 + 90 = 615$ kg

1.2 The maximum number of load cell intervals shall satisfy the condition:

$n_{lc} \geq n$

For each load cell, the maximum number of load cell intervals n_{lc} shall not be less than the number of verification scale intervals n of the instrument, e.g., a 3000d class weighing instrument should have at least class C3 load cells.

1.3 The minimum load cell verification interval shall satisfy the condition:

$v_{min} \leq e * R / \sqrt{N}$

The minimum load cell verification interval v_{min} shall not be greater than the verification scale interval e multiplied by the reduction ratio R of the load transmitting device and divided by the square root of the number N of load cells. This formula can be rewritten as:

$e \geq v_{min} * \sqrt{N}/R$

For example, a platform scale with a capacity of 1500 kg is built with four load cells, type SSB-C3-1t, with $v_{min} = E_{max}/8333$.

1) The load cell capacity is in agreement with point 1.1 (see calculation example).
2) The maximum number of scale intervals should be smaller or equal to the maximum number of load cell verification intervals. Hence, the maximum number of scale intervals is 3000.
3) By applying the formula given at point 1.3, the minimum value for e can be calculated:

$e \geq v_{min} * \sqrt{N}/R$, e ³ 1000 * 2/8333 * 1
e ³ 0.240 = > $e = 0.5$ kg

It is important to verify the output per scale division with the required minimum signal level for the measuring device to ensure compatibility. The output per scale division (in µV) can be calculated by:

$UE * S * Max * 1000 / (N * E_{max} * n)$

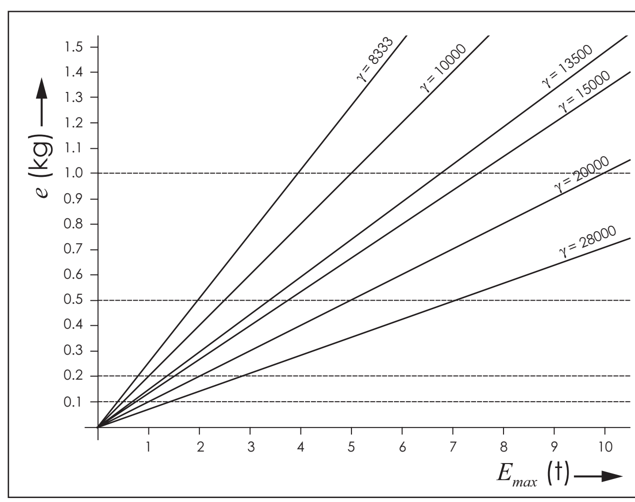
Where:

- UE = Excitation voltage
- S = Rated output load cell
- N = Number of load cells
- n = Number of scale divisions

The SSB load cell has a rated output of 2 mV/V. The output per verification scale interval at an excitation voltage of 10 V for the example above will be:

$10 * 2 * 1500 * 1000/(4 * 1000 * 3000) = 2.5\ \mu V$

The graph below represents the minimum value for e, in relation to the load cell capacity (E_{max}) when the instrument is constructed with **four** load cells (Reduction ratio $R = 1$).



2. Requirements for Multiple Range Instruments

On multiple range instruments, each range is treated basically as an instrument with one range. Switching while the instrument is loaded, from one weighing range to another is only allowed if the verification scale interval increases. Furthermore, it is not allowed to enter a lower range after a tare setting, or by using a preset tare value. An example of a multiple range instrument with three ranges is given in the following diagram:

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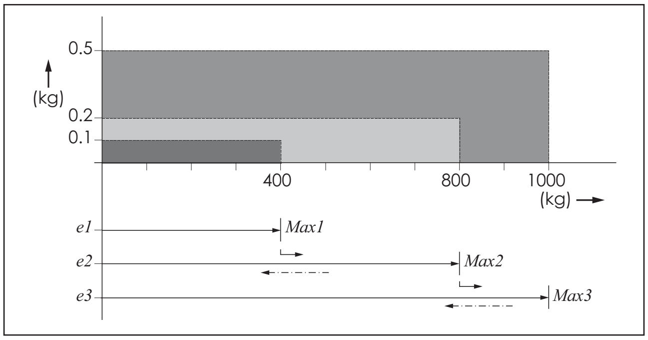

The requirements for load cells are:

2.1 The maximum capacity shall satisfy the condition:

$E_{max} \geq Q * Max_r * R/N$

2.2 The maximum number of load cell intervals shall satisfy the condition:

$n_{lc} \geq n$

2.3 The minimum load cell verification interval shall satisfy the condition:

$v_{min} \leq e_1 * R / \sqrt{N}$

2.4 The minimum dead load output return of the load cell shall satisfy the condition:

$DR \leq e_1 * R/N$

Or, where DR is not known (specifically specified on the R60-certificate) the following acceptable solution should be satisfied:

$n_{lc} \geq 0.4 * Max_r / e_1$

Where:

- n_i = the number of verification scale intervals for range i (i = 1, 2, etc.)
- Max_r = the maximum capacity of the highest weighing range
- e_1 = the verification scale interval of the smallest weighing range

For example, a platform scale with a capacity of 1000 kg is built with four load cells, 0.5 t, with $v_{min} = E_{max} / 13500$.

1) The eccentricity behavior will be tested with:

   $Max_r/(n-1) = (1/3) * 1000 \approx 325$ kg

   This is well below the capacity of the load cell, hence, acceptable.

2) The number of scale verification intervals should be smaller than or equal to 4000.

3) The minimum scale verification interval can be calculated by:

   $e_1 \geq v_{min} * \sqrt{N/R}$, $e_1 \geq 500 * 2 / 13500$

   $e_1 \geq 0.074$ kg

   Hence, e_1 will be 0.1 kg

4) As there is no value specified for the DR in the certificate, the use of the following formula is acceptable:

   $n_{lc} \geq 0.4 * Max_r / e_1$, $n_{lc} \geq 0.4 * 1000 / 0.1$

   $n_{lc} \geq 4000$

Hence, the following ranges are allowed to use:

0–400 kg with e = 0.1 kg (4000 divisions)

0–800 kg with e = 0.2 kg (4000 divisions)

0–1000 kg with e = 0.5 kg (2000 divisions)

These values are used in the diagram on the previous page.

Multiple range instruments shall satisfy the following conditions:

On a multiple range instrument the deviation on returning to zero from Max_1 shall not exceed 0.5 e_1. Furthermore, after returning to zero from any load greater than Max_1 and immediately after switching to the lowest weighing range, the indication near zero shall not vary by more than e_1 during the following 5 minutes.

Zero setting in any weighing range shall be effective also in the greater weighing ranges, if switching to a greater weighing range is possible while the instrument is loaded.

The tare operation shall be effective also in the greater weighing ranges, if switching to a greater weighing range is possible while the instrument is loaded.

A preset tare value may only be transferred from one weighing range to another one with a larger verification scale interval but shall then be rounded to the latter.

MR-load cells

Load cells suitable for multiple range instruments should preferably have a high γ value (E_{max} / v_{min}). VPG Transducers has distinguished special MR versions in the latest certificates.

3. Requirements for Multi-Interval Instruments

A multi-interval weighing instrument has one weighing range, which is divided into partial weighing ranges, each with different scale intervals. The weighing range is determined automatically according to the load applied, both on increasing and decreasing loads.

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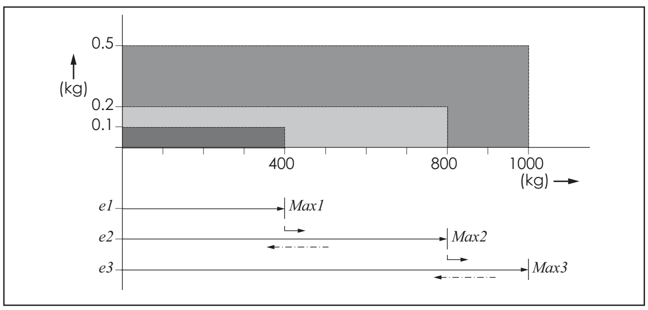
A multi-interval instrument offers the end-user more flexibility with its partial weighing ranges in comparison to multiple range instruments. It is possible to enter a lower partial range after a tare setting or by using a preset tare-value. An example of a multi-interval weighing instrument with two partial ranges is given in the following diagram:



The requirements for load cells are:

3.1 The maximum capacity shall satisfy the condition:

$E_{max} \geq Q * Max_r * R / N$

3.2 The maximum number of load cell intervals shall satisfy the condition:

$n_{lc} \geq n$

3.3 The minimum load cell verification interval shall satisfy the condition:

$v_{min} \leq e_1 * R / \sqrt{N}$

3.4 The minimum dead load output return of the load cell shall satisfy the condition:

$DR \leq 0.5 * e_1 * R / N$

Or, where DR is not know (specifically specified on the R60-certificate) the following acceptable solution should be satisfied:

$n_{lc} \geq Max_r / e_1$

Where:

n_i = The number of verification scale intervals for partial range i (i = 1, 2, etc.)

Max_r = The maximum capacity of the highest partial weighing range

e_1 = The verification scale interval of the smallest partial weighing range

MI-load cells

VPG Transducers model RLC has two versions, specially certified for multi-interval instruments. These versions are coded RLC-C3MI6 or RLC-C3MI7.5.

Specifications:

C3MI6: DR = $1/2E_{max}$ / 6000 $v_{min} = E_{max}$ / 7000
C3MI7.5: DR = $1/2E_{max}$ / 7500 $v_{min} = E_{max}$ / 7000

For example, a platform scale with a capacity of 10 t is built with four load cells type RLC-C3MI7.5-3.5t, with $v_{min} = E_{max}$ / 7000 and $DR = ½E_{max}$ / 7500.

1) The eccentricity behavior will be tested with:
   $Max_r / (n - 1) = 10000 / 3 \approx 3250$ kg
   This is well below the capacity of the load cell, hence, acceptable.
2) The number of scale verification intervals for each partial range should be smaller or equal to 3000.
3) The minimum scale verification interval can be calculated by:
   $e_1 \geq v_{min} * \sqrt{N / R} \Rightarrow e_1 \geq 3500 * 2 / 7000$
   $\Rightarrow e_1 \geq 1$ kg

Hence, e_1 should be greater or equal to 1.0 kg

4) DR is specified as $1/2E_{max}$ / 7500, hence the following formula should be applied:
   $DR \leq 0.5 * e_1 * R / N \Rightarrow 1750 / 7500 \leq 0.5 * e_1 * 1 / 4$
   $\Rightarrow e_1 \geq 1.87, \Rightarrow e_1 = 2$ kg

Hence, the following partial ranges are allowed to be used:

0–6000 kg with e_1 = 2 kg (3000 divisions)
6000–10000 kg with e_2 = 5 kg (2000 divisions)

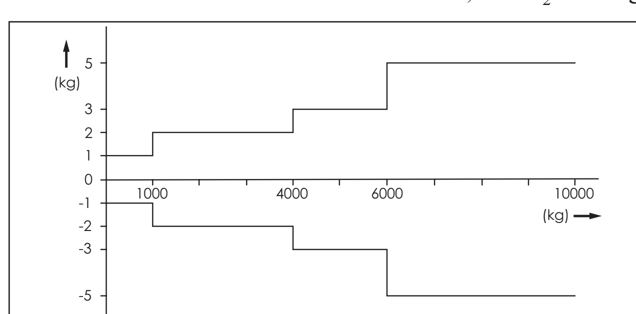
These values are used in the diagram on the previous page. The error envelope for the above mentioned scale will be:

$0\ e_1 \rightarrow 500\ e_1 \approx$ $0 \rightarrow 1000$ kg
max. error, $\pm 0.5\ e_1 \approx \pm 1$ kg

$500\ e_1 \rightarrow 2000\ e_1 \approx 1000 \rightarrow 4000$ kg
max. error, $\pm 1.0\ e_1 \approx \pm 2$ kg

$2000\ e_1 \rightarrow 3000\ e_1 \approx 4000 \rightarrow 6000$ kg
max. error, $\pm 1.5\ e_1 \approx \pm 3$ kg

$1200\ e_2 \rightarrow 2000\ e_2 \approx 6000 \rightarrow 10000$ kg
max. error, $\pm 1.0\ e_2 \approx \pm 5$ kg



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By applying formula 3.3 and 3.4, the following values for e_1 can be obtained:

Load cell capacity E_{max} (kg)	type C3MI6; $1/2E_{max}/6000$		type C3MI7.5; $1/2E_{max}/7500$		Recommended capacity Max_r (kg)	
	e_1 (kg) 3LC	e_1 (kg) 4LC	e_1 (kg) 3LC	e_1 (kg) 4LC	3LC-hopper	4LC-platform
500	0.5	0.5	0.2	0.5	1000	1000
1000	0.5	1	0.5	1	2500	2500
2000	1	2	1	2	5000	5000
3500	2	5	2	2	8000	10000
5000	5	5	2	5	12000	12500

As a second example, a hopper with a capacity of 5000 kg is built with three load cells type RLC-C3MI6-2t, with $v_{min} = E_{max} / 7000$.

The smallest verification scale interval (e_1) can be obtained from the table above and equals 1 kg. Hence, the following ranges are allowed to be used:

0–3000 kg with e = 1 kg (3000 divisions)
3000–5000 kg with e = 2 kg (1000 divisions)

Multi-interval instruments shall satisfy the following conditions:

On a multi-interval instrument, the deviation on returning to zero as soon as the indication has stabilized, after the removal of any load which has remained on the instrument for one half hour, shall not exceed 0.5 e_1.

The maximum preset tare value shall not be greater than Max_1 and the indicated or printed calculated net value shall be rounded to the scale interval of the instrument for the same net weight value.

It should be realized that the field of application for multi-interval weighing instruments has become smaller by the introduction of more accurate load cells and more sensitive measuring devices (indicators).

The hopper-application on the previous page could for example also be served with three load cells type RLC-C5-2t.

However the advantage of multi-interval instruments are a stronger signal per division (μV/d) and larger error limits at the high end of the measuring range (of particular interest at applications with the presents of force-shunts, i.e., hoppers).