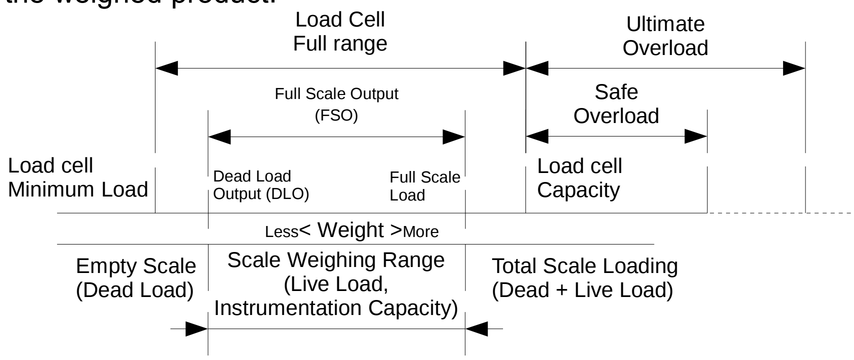
A guide to selecting the correct load cell capacity and instrument compatibility.

Two of the most important aspects of assembling a weighing system are the load cells to detect the load and the instrumentation that converts the load cell signal into a meaningful weight, force or pressure.

Load cells and indicators have different characteristics and compatibility with the desired outcome needs to be checked.
The terminology can be confusing, and it is best to first become familiar with the important parameters and what they mean. To start simply the non-approved industrial weighing situation will first be considered.

Scale: In this discussion the term "scale" means a weighing system comprising load cells to convert a force into an electrical signal + some structure (platform, hopper, etc.) to carry the substance or product to be weighed and transmit that force to the load cells + instrumentation to process the load cell signal and present the weight of the weighed product.



The diagram above shows some terminology used in describing the loads on the load cells (top) and the loads on the scale (bottom) and how they may correspond.

The load cell capacity needs to be selected to best carry the load over the range of weights to be measured and the indicator needs to be selected to work well with the load cells, some alignment of parameters is required which is also affected by how the scale will be used.

Scale

The basic scale has the following loading parameters.

Dead Load: When the scale is built there is almost always some load on the load cell(s) from the mechanism used to carry the load to be measured, this could be as small as a wire to hang a load on a tension load cell, the weight of the load cell itself or a large steel structure like a weigh bridge to carry trucks. When measuring horizontal forces, there is often no gravitational weight component, and therefore there may not be dead load.

Live Load: This is the range of variable loading that is to be measured. The instrumentation will usually be calibrated to display from zero to maximum live load which will be set as the Capacity in the instrument. Above this capacity the instrument may blank or show overload. Sometimes the instrument capacity may be rounded up above the live load to a round value or to capture small loading excesses.

Total Scale Load: This is the total load on the load cells (scale structure + load to be weighed), as will be explained below the maximum load on any load cell may not be the total scale load divided by the number of load cells or support points.

Load Cell

The load cell has parameters which relate to calculation of capacity and additional parameters that relate to performance and compatibility with the instrumentation.

Load Cell Minimum Load: Some load cells will not operate properly all the way down to zero load and therefore will have a minimum load specified. If not specified in PT specifications it can be assumed to be zero. This is an absolute load, and for a load cell that operates in tension and compression it is not the capacity in negative loading.

Load Cell Capacity: The capacity of the load cell is generally the load at which the sensitivity (mV/V) is specified and should be the maximum load under generally occurring operating conditions. Some errors in the specifications are referenced to load cell capacity.

Safe Overload: Although the load cell should be operating day to day below the capacity, there is a margin above the capacity where the load cell can briefly operate without electrical or mechanical damage. The reason I state briefly is because the load cell may be "safe" but specifications may not be valid in this range and continuous use in overload may permanently affect performance or invalidate warranty.

Ultimate Overload: At (or above) the point of ultimate overload the integrity of the load cell cannot be assured, it may suddenly break or permanently bend. In the region between safe and ultimate overload the electrical characteristics of the load cell may start to be affected and permanent deformation may occur and the load cell will progressively become unusable. Note that the load cell may be stronger than the mountings, so check all mountings for limiting strength.

Full Scale Load: This is the load on the load cell when the scale is full. This should be kept below load cell capacity during normal operation. Each load cell in a multi-cell installation needs to be evaluated for effects such as unbalanced or off centre loading, wind, vibration, seismic activity, etc.

Dead Load Output (DLO): When the scale is empty (has nothing to be weighed on it) there is usually some dead load and therefore signal from the load cell. This signal can change with temperature, up to the value according to the load cell specifications. In a scale that is normally empty, where you put something on the scale to weigh and then take it off, this variation can be negated by tracking in the instrumentation. In a scale where it remains loaded for longer periods, a hopper or silo, these temperature effects can't be tracked and need to be considered.

Full Scale Output (FSO): Some errors relate to parameters affected by dead load output while other errors relate to the change in load. This change in load is referred to in PT specifications as FSO and prameters related to this are easily identified in the specifications and must be considered.

Now that there is a general explanation of scale and load cell terminology, we will take a look at selection of load cell capacity.
Some things to consider;

1. a silo or tank may have heavy equipment (pumps, motors) to one side putting more load on that side load cells,
2. silos, hoppers and tanks installed outdoors will have regular wind forces, pushing on the structure more weight will be transferred to the down-wind load cells,
3. dry contents in a hopper may not sit centrally and mound up to one side, placing more load on the load cells on that side,
4. the installation may be subject to vibration from heavy equipment, transport or seismic activity with vertical and/or horizontal additional force affecting loading on the load cells or there could be shock loading from large rocks or scrap iron on a conveyor or dropped into a hopper, cattle bucking around on a scale (where shock loads 5x the weight of the cattle have been recorded),
5. as a very general rule, highly stressed parts do not last as long as less stressed parts. A strain gauge load cell may typically last 1 to 10 million cycles at full load, vibration and in motion weighing applications for instance can quickly eat into this, shock loads will shorten life, a load cell acting in tension and compression has twice the load variation shortening life. As a general rule don't push the boundaries and consider generously specifying capacity,
6. load cells generally have very small deflections, 0.1mm or less in cases. If the scale (hopper, silo) structure is very rigid, it will not deflect much but a foundation or footing on soil or elastic steel or concrete structure can deflect substantially in comparison. A silo on 4 legs can easily end up with most of the load on only 2 load cells if the other 2 supports relax mere millimetres,
7. performance specifications related to FSO are not greatly affected by load cell capacity but specifications related to load cell capacity need to be considered more carefully when the FSO becomes a smaller proportion of the load cell full range,
8. there may be limitations with the instrumentation that need consideration for load cell capacity selection. Modern instrumentation is very good today and there is a lot of latitude for calibration but some instrumentation may have limited resolution, scaling and offset capabilities to consider,
9. instrument zero tracking or zero setting (zero at power on, zero button) can mask the actual load on the load cells,

Acceptable outcomes. Discuss what is considered acceptable or not where there may be adverse loading.

- You want the load cells to survive moderate winds, you don't want them to break in a cyclone but are willing to replace them after a cyclone.
- You want the load cells to be in working condition after gale force winds.

- You want the load cells to survive vibration from trucks and dropping heavy rocks into a hopper, you don't want them to break in an earthquake but are willing to replace them after an earthquake.

If in any doubt consult your design engineer and he/she can calculate the maximum load on any load cell. If this is not possible, take the conservative approach.

Following are some basic guidelines, for best results calculation of the maximum load at each load cell is advised.

Example 1.

For a very calm environment, no wind, no vibration, where the load is added and removed smoothly and the load is perfectly distributed (a vessel with 1 load cell or a symmetrical vessel containing liquid with 3 legs) you will see that the total load cell capacity in the example below is about 1.5 times the total load to be measured. Every case will be different, but you can see that selecting the correct load cell is not as simple as dividing the scale weighing range or total scale load by the number of load cells;

$$LC_{rcap} = ((DL + (LL * Ku))/N_{LC} + LL*ZS(\%)/100/ N_{LC})*SF$$

where;
LC_{rcap} = Load Cell Rated Capacity
DL = Dead Load
LL = Live Load (contents)
Ku = usage factor (in this example Ku may be 1.1 to 1.2)
N_{LC} = Number of load cells
ZS = the zero setting range of the instrument combining zero tracking, zero button and automatic zero on power on, in %. Typically this could be 2-50%, check instrument settings.
SF = Stiffness factor (6 above, in this example stiffness doesn't affect load distribution greatly, use SF = 1.1).

Consider a tank on 3 legs (3 load cells), dead load = 250kg, live load = 1000kg, zero on power on = 2%, zero tracking and zero button combined limited to 2%.
The formula below (in red) can be pasted into a spread sheet for future use.

$$LC_{rcap} =((250+(1000*1.1))/3+1000*4/100/3)*1.1 = 509.7kg$$

the calculated LC_{rcap} is 2% above 500kg, the controlled parameters of this installation would allow rounding down up to 5% and the recommended load cell capacity would be 500kg. In other applications the next higher up load cell capacity should be used.

Example 2.

Consider a 4 leg, 4 load cell silo (DL = 6250kg, LL = 30000kg, no zero at power on, no zero tracking, 2% zero setting range, even weight distribution) that is very stiff on individual pad footings with some truck or railway vibrations;

$$LC_{rcap} = ((DL + (LL * Ku))/N_{LC} + LL*ZS(\%)/100/ N_{LC})*SF$$

where;
LC_{rcap} = Load Cell Rated Capacity
DL = Dead Load
LL = Live Load (contents)
Ku = usage factor (in this example Ku may be 1.2 to 1.4)
N_{LC} = Number of load cells
ZS = the zero setting range of the instrument combining zero tracking, zero button and automatic zero on power on, in %. Typically this could be 2-50%, check instrument settings.
SF = Stiffness factor (6 above, in this example stiffness may significantly affect load distribution greatly, use SF = 1.4).

The formula below (in red) can be pasted into a spread sheet for future use.

$$LC_{rcap} =((6250+(30000*1.3))/4+30000*2/100/4)*1.4 = 16047.5kg$$

The calculated LC_{rcap} is rounded up to the next load cell capacity which may be 20000kg or 25000kg (20t or 25t)

Where distribution of load on the load cells is not even due to uneven live load, uneven dead load, wind, vibration, earthquake and other loads, calculate the load at each load cell separately for the various combinations.

$$LC_{rcapn} = (DL_n + (LL_n * Ku)+WL_n+EL_n+AL_n+LL_n*ZS(\%)/100)*SF$$

where;
LC_{rcapn} = Load Cell n Rated Capacity
DL_n = Dead Load on load cell n
LL_n = Live Load (contents) on load cell n
WL_n = Wind Load acting on load cell n
EL_n = Earthquake Load acting on load cell n
AL_n = Additional Load acting on load cell n (such as snow, or water)
Ku = usage factor (this takes into account vibration and risk of spurious loads and can be 1.1 – 5.0)
ZS = the zero setting range of the instrument combining zero tracking, zero button and automatic zero on power on, in %. Typically this could be 2-50%, check instrument settings.
SF = Stiffness factor (6 above). This is in the range 1.1 to 2.0. The choice can be affected if the load analysis takes into account support/foundation stiffness.

Instrumentation considerations

The load cell capacity selection may need to be re-visited after considering parameters of the instrumentation. Instrumentation today is almost exclusively digital, where the load cell signal is broken up into small increments or divisions. There is also a finite maximum number of these divisions that the instrument can process. As the size of the division decreases and the number of divisions the signal is resolved into increases the cost also increases.
Weighing equipment of the type PT sells can offset the zero point, so the dead load doesn't eat into the resolution. PT instruments also scale the signal so that the weighing range can be resolved into the maximum number of divisions. Other instruments will be covered seperately.

Note that high accuracy is not implied because the instrument division is very small, the error is generally determined from the load cell characteristics, the indicator may just be resolving that error in fine detail with a small division.

Most load cells have an operating accuracy between 1000 and 10000 divisions, so an excessively high number of divisions may have limited practical application. Weighing indicators must step up in increments and to facilitate easy viewing of a digital reading weighing indicators step up in increments that are a multiple of 1, 2 or 5.
An indicator has a maximum sensitivity specification, the smallest amount of load cell signal that can be resolved. To be confusing this is called by various terms, minimum input sensitivity (because it is the minimum signal that can be resolved), maximum input sensitivity (because it is the maximum sensitivity of the input circuitry) and is expressed in terms of microvolts per division (μV/D).

$$(\mu V/D) = IV_{ex} * LC_{mV/V} * I_{cap} / LC_{rcap} / N_{LC} / n * 10^3$$

where;
LC_{rcap} = Load Cell Rated Capacity
IV_{ex} = Instrument excitation voltage
I_{cap} = Instrument capacity setting
LL = Live Load (contents)
$LC_{mV/V}$ = usage factor (in this example Ku may be 1.2 to 1.4)
N_{LC} = Number of load cells
n = Number of indicator divisions
10^3 = 1000 or 1E3 to convert from mV to μV

Example 3.

Consider example 2 above, assume you want to display up to (30t) 30000kg. A good load cell accuracy in good conditions may be 5000 divisions. 30000/5000= a division of 6kg. As previously stated the division must be a multiple of 1,2 or 5. with a division of 5kg, the scale would have a range of 6000 divisions. With a division of 10kg it would have a range of 3000 divisions.

We can check if the instrument can achieve the finer resolution of 6000 divisions, and if so this implies the coarser resolution of 3000 divisions would also be possible. Assume the instrument has an excitation voltage of 5V and the load cells chosen are 4 pieces 25000kg and have a signal output of 2mV/V at capacity.
The formula below (in red) can be pasted into a spread sheet for future use.

(µV/D) =5*2*30000/25000/4/6000*1E3 =0.5 µV/D

Almost all PT instruments would achieve this. A PT210 instrument could achieve better than 0.2 µV/D and therefore an increased number of divisions n.
If it had resulted in a µV/D that was too small for the instrument, the options are any combination of; reduce the number of instrument divisions (n), use a more sensitive instrument, use a lower capacity load cell (consider very carefully here) or use a load cell with a higher signal ($LC_{mV/V}$)

Note that a corner matching box (summing box) may reduce the load cell output affecting the above calculation. Note also the instruments also have a specified minimum number of divisions and a specified maximum µV/D.

Accuracy considerations

Just because we have worked out that the instrument will show the resolution calculated above does not mean that this is the accuracy. The instrument and the load cell have inaccuracies. The instrument and load cell parameters will need to be checked to determine the accuracy.
As previously mentioned some load cell errors relate to the weighing range and others to the load cell capacity. It can arise that the you can discharge a small amount from a silo with greater accuracy than the total contents can be determined. If there is a need to discharge or load smaller amounts from/into a large silo or hopper with increased accuracy then there can be an argument for a larger number of divisions than would be normal with the understanding that the resolution may be greater than the accuracy.

The best way to understand this might be to work through an example. Looking at examples 2 and 3, lets assume the silo has 4 pieces of PT model CSC-C3 25t load cells and these are connected to a PT210 instrument.

- The PT210 has a non-linearity of <0.0015% FSO, this is <0.45kg in 30000kg.
- The PT210 has a temperature coefficient <2PPM (0.0002%) /C. For a 20 degree temperature change this is <1.2kg in 30000kg.

As can be seen indicator errors are very small. Load cell errors are explored below.

- Linearity error is < 0.02% FSO, this is 0.02% of 30000 or 6kg. Many instruments have linearity correction to reduce linearity error. This value of 6kg also assumes correct calibration and applies to the total contents of the silo.
  - If you are discharging from the silo, for example 3000kg, the error in the amount discharged due to linearity is around 0.02% of 3000 or 0.6kg.
- Non-repeatability < 0.02% FSO and may be another 6kg.
  - This could be the same value 6kg for discharge of a smaller amount.
- Creep < 0.016% FSO is an error amounting over time and is related to a change in weight, in 30000kg it may contribute 5kg over 30minutes or 10-15kg over a much longer time. When you fill the silo with 30000kg, creep could see that value change 15kg over a day or so.
  - If you discharged 3000kg from the silo in a short time, the error in the 3000kg due to creep may be less than 0.5kg. Creep is more significant when the load stays on the scale a long time.
- Temperature effect on span <0.011% /10C. This is a change in the load cell mV/V due to temperature. For an empty scale at zero, the instrument can track and cancel the effect on the dead load. For a scale that is loaded while the temperature changes, the effect is upon the combined dead load and load on the scale. In the case of our silo example, with 27000kg in it, if the temperature changed 20 degrees from 10C to 30C the indicated weight could change as follows 0.011/100*20/10*(27000+6250)=7.3kg.
  - For 3000kg discharged from the silo, this effect could be only 0.7kg

- Temperature effect on zero <0.015%/10C. For an empty scale at zero, the instrument can track and cancel the effect on the dead load. For a scale that is loaded while the temperature changes this effect is seen as a change in weight or error. This effect is related to the capacity of the load cells. For our example the load cell capacity is 4x25000=100000kg, if the temperature changed 20 degrees from 10C to 30C the indicated weight could change as follows 0.015/100*20/10*4*25000=30kg. For a different model load cell with a high temperature effect on zero this error can be significant.
    - Note that if the consideration is for the amount of material discharged (or added to) a scale in a short time where the temperature changes little during discharge the temperature effect on zero will have little effect on the discharge accuracy.

The above is related to load cell characteristics, inaccuracy can be introduce from other (mechanical, etc.) aspects of the installation.
It is important to check the expected accuracy and review the load cell choice if the outcome is not as desired.