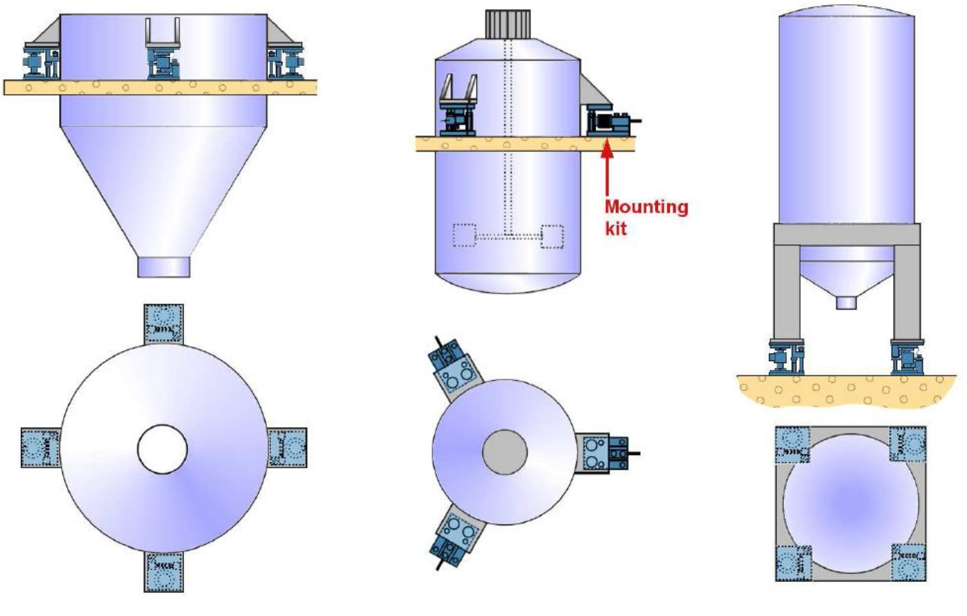
Tank weighing

Load cells may be used to weigh tanks, hoppers or vessels in various installation configurations. The installation of load cells into a practical field application requires following several basic rules as well as careful design attention if the system has to be accurate and provide a long, maintenance free span of operation.

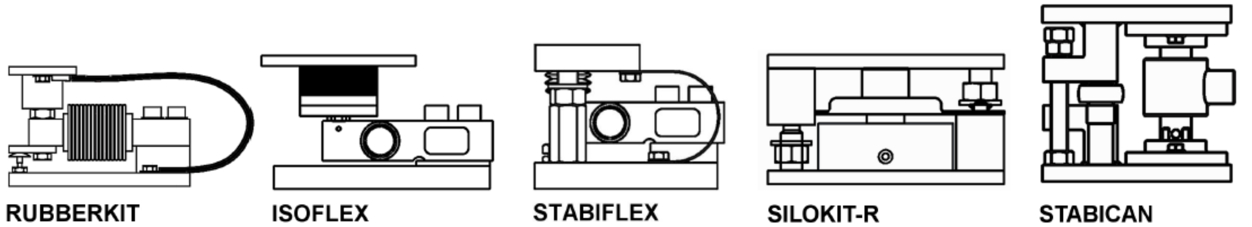
Compression versus tension
Load cells measure force in one of two directions; tension or compression. The use of a tension or compression system depends upon the mechanical structure around the vessel and the ease of creating the system.

Compressive mode
In the compressive mode a vessel is supported by load cells. If a vessel must be placed on an open concrete pad, compression will be a logical way to operate, because a tension system would require an expensive additional overhead supporting structure.



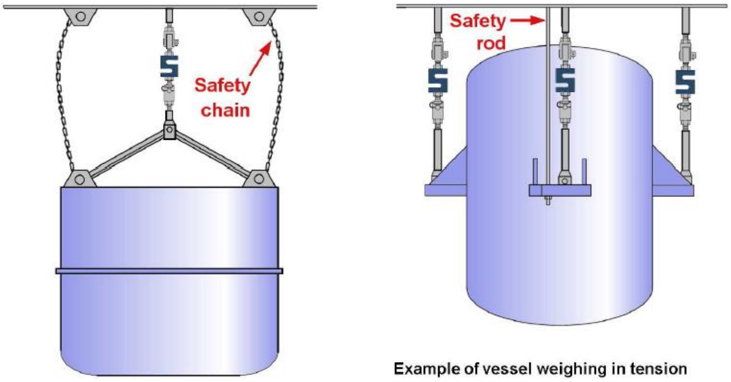
Tanks weighing with compression mounting kits

To help load cell mounting, SCAIME offers compression mounting kits especially designed for tank weighing.
A typical compression mounting kit includes a top plate (which receives the load), and base plate (which is bolted to the floor or other support surface). Some kits provide also additional devices (see data sheet) as :
· A hold-down bolt used to prevent the vessel from tipping.
· Stay rod or limiting stops for eliminating unwanted side forces
· Elastomer dumper for shock or vibration absorption



Tensile mode

In the tensile mode the vessel is suspended from one or more load cells. if a suitable structure for a tension application is available, it is usually easier, and less costly to suspend the vessel up to a vessel capacity of 10 tons. When the vessel capacity exceeds this value there is more cost involved in making the required hardware than providing an adequate base for compression assemblies.



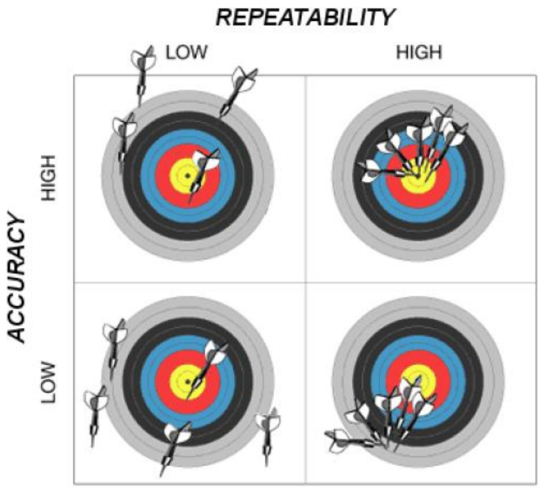
Example of vessel weighing in tension

In theory, suspension of a vessel by a single load cell may be the ideal solution, but such tension installations are not usually feasible.

Three of four point supports are the most commonly used configurations.

Weighing system performance

Accuracy, resolution, and repeatability are basic concepts used to measure a weighing system's performance. ***Resolution*** *is the smallest weight change that a digital scale can detect. Resolution is measured in increment size, which is determined by the capabilities of the load cells and digital indicator. A digital weight indicator may be able to display a very small increment size, such as 0.01 kg (resolution); however, that does not mean the system is accurate to 0.01 kg.*



Accuracy *is how close the reading on a scale's indicator is to the actual weight placed on the scale. A scale's accuracy is usually measured against a recognized standard, such as certified test weights.*

Repeatability *is a scale's ability to display a consistent weight reading each time the same weight is placed on the scale. It is especially important for batching and filling applications, which require that the same amount of a material be used for each batch.*

Repeatability and accuracy go hand in hand. You can have a repeatable system that is not accurate, but you cannot have an accurate system unless it is repeatable.

The following factors can influence the accuracy and repeatability of a weighing system. They are discussed in detail later in this guide :

· ***Load cells factors*** *: Type, Number, capacity, specification (see chapter 4)*
· ***Mechanical factors*** *: Tank design, Support Structures, Piping Design*
· ***Environmental Factors****: Wind, Temperature, Vibration*
· ***Calibration***

How many load cells ?

The number of load cells to support a vessel is usually fixed by the design of the tank. The most ideal situation is to support a vessel by 3 load cells. If a weighing tank is supported by 4 or more load cells, 3 or in the worse case only 2 load cells will bear the total weight. In this case, an overload situation on these cells might occur. By measuring the output of every individual load cell, such a situation can be recognized and corrected by placing shim plates underneath the cells with minor output

The load cells should be positioned in such a way that each load cell will bear the same amount of weight

Applied load calculation

Load cells must resist to the total applied load in normal and exceptional conditions.

The minimum load cell capacity, CLC must satisfy:

$$C_{LC} \geq \frac{Q \times (Tare + C_{live})}{N}$$

where **Tare** *: Tare or dead load (kg)*

C_{live} *: Live load, maximum weight applied (kg)*
Q *: safety factor*
N *: number of load cells*

Safety factor Q

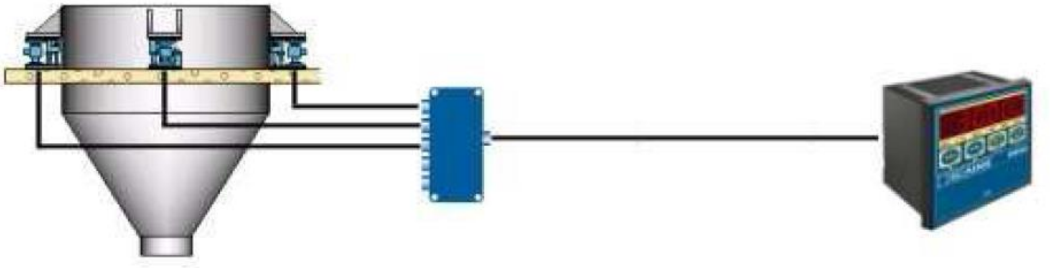
It doesn't exist rules to define factor Q which usually depend from the following environmental conditions :
- *Eccentric loading conditions*
- *Shocks and dynamic load*
- *Wind forces*
- *Load receptor design*

Some examples for information :

	Q
4 load cells platform scale	**1,8**
Indoor vessel	**1,3**
Vessel with agitator	**1,7**
Weighbridge	**2**
1 load cell platform scale	**1,4**

Weighing system capabilities

The ability of a combination of load cells and indicator to give the desired system resolution or increment size must be determined.



System resolution

the desired system resolution or increment size can be determined by the following formula:

$$\text{Signal by increment } (\mu V) = \frac{\text{Desired Increment Size} \times \text{Load Cell Sensitivity (mV/V)} \times \text{Excitation Voltage (V)} \times 1\,000}{\text{Individual Load Cell Capacity} \times \text{Number of Load Cells}}$$

Enter the desired increment size into the formula, along with the load cell and indicator parameters. If the signal by increment (µV) exceeds the minimum allowed for the indicator, the system should be able to deliver the desired resolution.

Example

Suppose a tank scale has four 5 000 kg load cells (2 mV/V) attached to an IPE50 indicator. You want to be able to weigh up to 15 000 kg at 2 kg increments (7,500 displayed increments).

Use the formula to determine the required signal by increment : $\frac{2\ kg \times 2\ mV/V \times 5\ VDC \times 1000}{5000\ kg \times 4} = 1\ \mu V$

The minimum allowable signal by increment for an IPE50 is 0.3µV microvolt per increment. Since the 1 µV signal derived from the formula is above this 0.3 µV, you should be able to display 2 kg increments.

Excitation voltage

In a measuring chain, the excitation voltage provided by the transmitter must be adequate to supply load cells in current.

Weighing system resistance $Z = \frac{R_{LC}}{N}\ \Omega$ *where* R_{LC} *: load cell input resistance*

N *: number of load cells*

The indicator must provide a current (A) $I_{exc} = \frac{U_{exc}}{Z}$ *where* U_{exc} *: load cells excitation voltage*

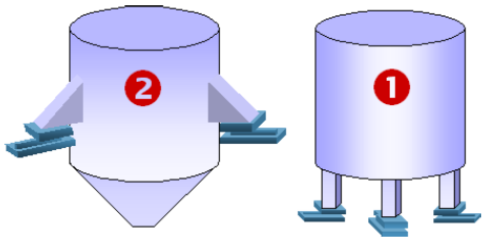
it must be checked $Z > R_{min}$ ***or*** $I_{exc} < I_{max}$ ***with***

R_{min} ***: minimum resistance of transmitter***

I_{max} ***: maximum current of transmitter***

Load cells location

The 2 most common places that load cell assemblies are mounted, are:



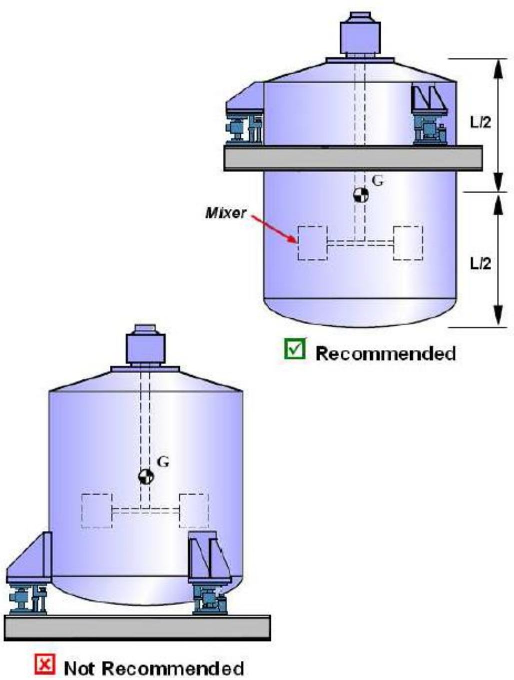
1 Under the vessel's legs.

2 Between a gusseted bracket and a mezzanine floor.

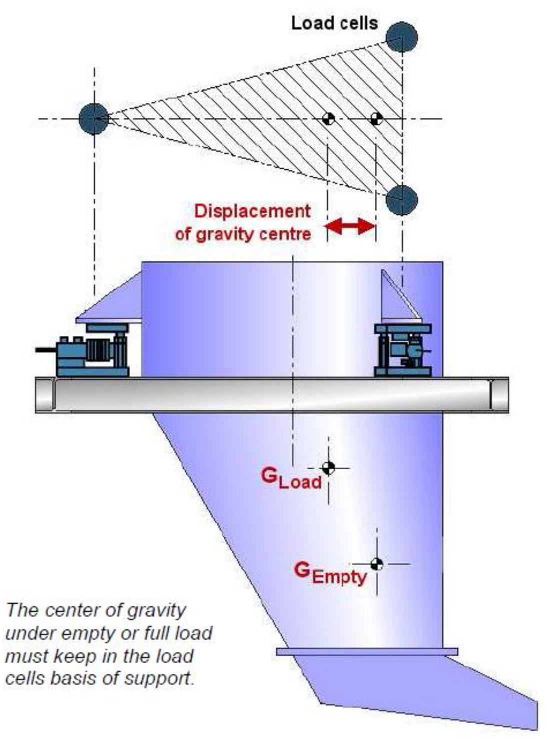
Mounting the assemblies under the legs is perfectly acceptable. However, the second case is the best one, due to the natural stability offered by a low centre of gravity.

Some example of load cells location

Vessel with mixer

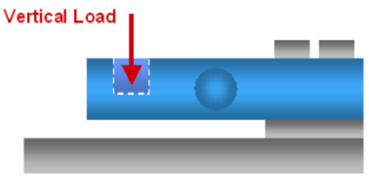


Eccentric vessel with gravity center variation



Load introduction

Load cells that use strain gauges are sensitive enough to detect very small changes in weight. The trick is to make sure that they react only to the weight you want to measure, not to other forces. To get accurate weight readings, you must carefully control how and where weight is applied.

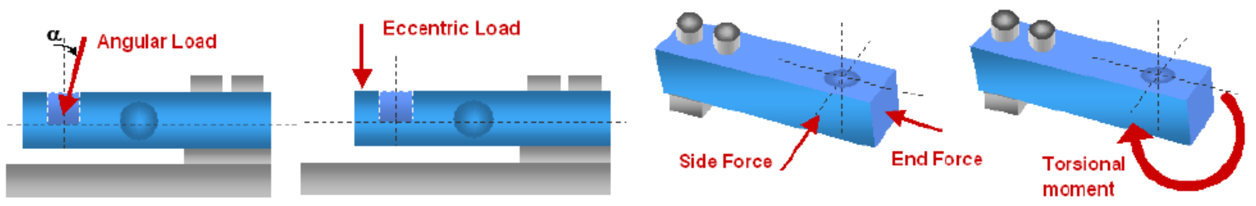


a load cell should be installed so that the load is applied vertically throughout the entire weight range.

To attain that ideal, the load cell support would need to be level, parallel, and rigid.

Loading force problems

When the load cell is not installed properly, there are several types of forces that can affect its accuracy.

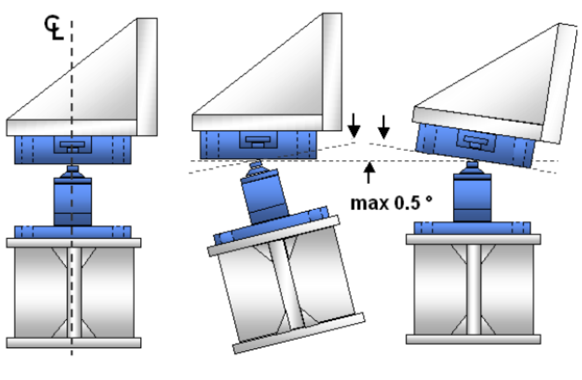


***Angular loading** occurs when a force that is not perfectly vertical is applied to a load cell.*

***Eccentric loading** occurs when a vertical force is applied to a load cell at a point other than its centre line. This problem can be caused by thermal expansion.*

***Side and end loading** occur when horizontal forces are applied to the side or end of a load cell. They can be caused by thermal expansion, by misalignment, or by movement due to dynamic loading.*

***Torsional loading** occurs when a side force twists a load cell. It can be caused by structural deflection, system dynamics, thermal movement, or misalignment.*



- ***Top support and base support should be aligned and levelled***
- ***Top support and base support should not deflect more than 0.5°***
- ***The centre line (CL) of the load on the cell should align to the centre line of the support to prevent structure deflection.***

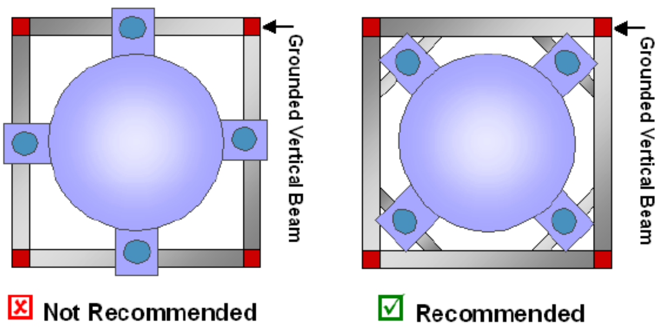
The weight error will increase with the angle at which the support is leaning: $Error = 1 - \frac{1}{\cos(angle)} \times weight$

Structural integrity

It is a common misconception that a load cell can be considered as a solid piece of metal on which vessels, silos or hoppers can be supported. The performance of a load cell depends primarily on its ability to deflect under highly repeatable conditions when load is applied or removed.

Support structure design

Metal support structures tend to bend or deflect as the amount of weight placed on them increases. Too much deflection can affect the accuracy of a tank scale



Mounting load cells at mid-span of the support beams will cause the most deflection on the beams at high loads.

A better way to reduce deflection is to mount weigh modules near grounded vertical columns. Be sure to support all cells with the same size structural beams to prevent differential deflection.

Reinforcement to the support beams is recommended to minimizing deflection

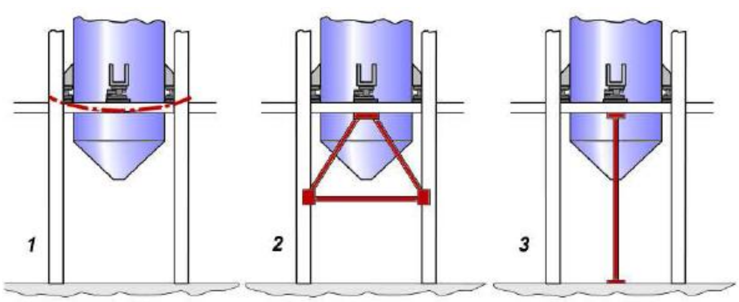
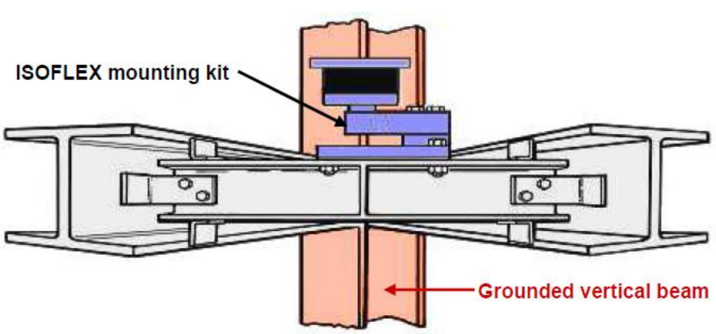


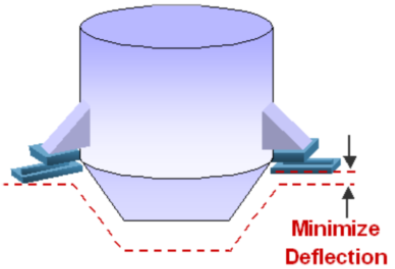
Figure 1 shows how a support beam can deflect when a weigh module is mounted at mid-span. If this type of arrangement cannot be avoided, you should reinforce the support beams to minimize deflection.

Figure 2 and 3 show typical reinforcement methods.

Methods used to mount load cells near grounded vertical beams



Structure deflexion

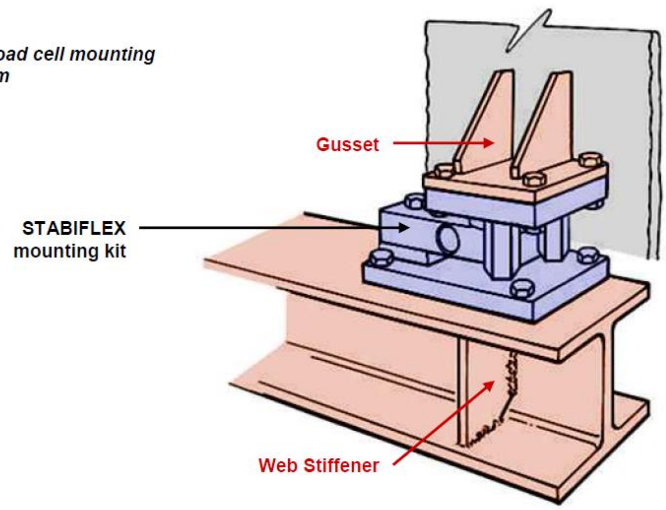


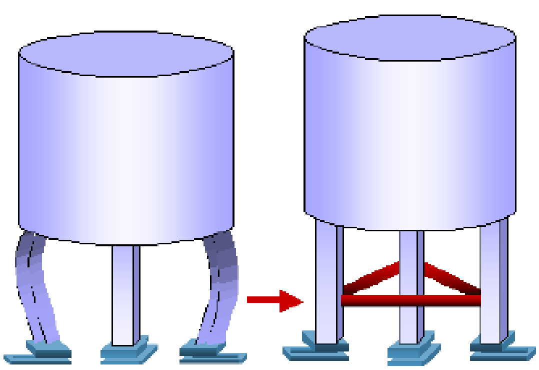
A tank scale's structure should deflect as little as possible, and any deflection should be uniform at all support points.

Support structures and foundation base should be level (+/-0.5 degree) and in the same plane.

Add web stiffeners or gussets if necessary to prevent the beam from twisting under load.

- ***Reinforced load cell mounting support beam***

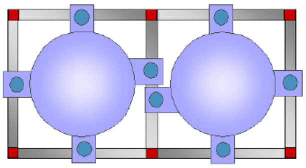




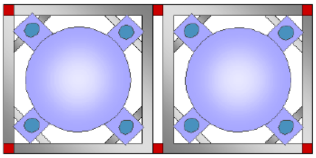
In some cases, a tank's legs will deflect under the weight of the tank. If the deflection is great enough to affect weight readings, you should brace the legs to keep them rigid.

Use the same support beam sizes to avoid non-uniform deflection

Tank interaction
Tanks sharing the same support structure will have an affect on each other's weighing performance. Any movement and disturbances from one tank is easily transferred to the next tank sharing the same support structure.



☒ Not Recommended



☑ Recommended

The worst choice is to mount the cells at the mid-span of a horizontal beam, with the two tanks sharing a common support structure. This allows both deflection and vessel interaction.

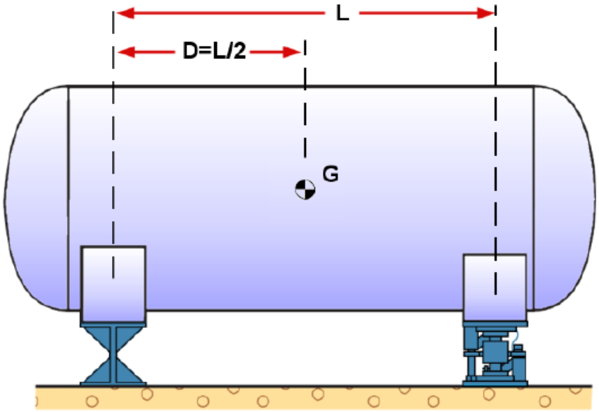
best choice is to mount the cells near vertical beams, with a separate support structure for each tank.

Pivoted Weighing Systems

In certain applications it is possible to weigh only half the vessel, the other half is supported on dummy load cells or flexure beams acting as pivots.

Pivoted weighing systems can provide an economic method of low accuracy (±1%) level detection system. There are quite severe restrictions associated with these systems:
· ***The vessel is symmetrical around a vertical line through the content's centre of gravity.***
· ***The vessel is level and the ends are identical in shape.***
· ***The vessel is inside and not subject to wind forces.***

These restrictions ensure that as the vessel fills, the center of gravity of the contents rises along a vertical line. They also practically limit this sort of application to liquid contents.



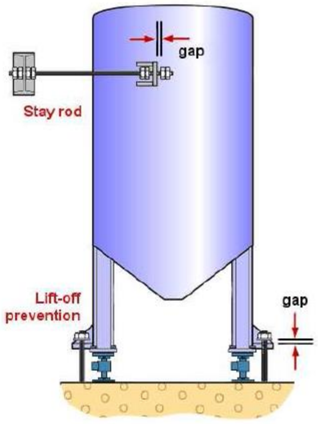
In fact not the weight, but the force is measured by the load cell. The force on the load cell(s) can be calculated by :

$$F_{LC} = \frac{D \times F_{total}}{L}$$

The distance between the live and dummy cells (L) should be as long as possible.

Additional restraint methods

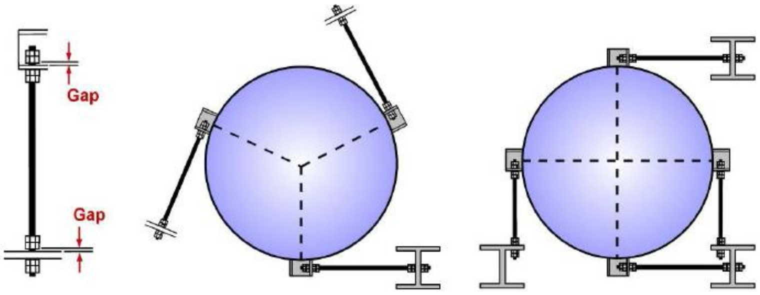
Even if most mounting kits provide in-built protection against side forces or lift-off, additional restraint devices must be used in applications with a potential for excessive wind or seismic load forces or when a vibrator or mixer. These assemblies are designed to allow ample vertical freedom for weight sensing, while simultaneously eliminating side forces



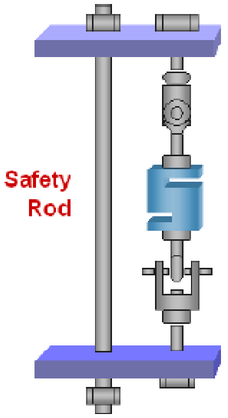
Stay rods are used to limit a tank's horizontal movement so that it will not tip or rotate. They should be positioned at or above the centre of gravity of the full tank.

Lift-off prevention rod must also be used if mounting kits do not provide in-built device.

Note that the rods are tangential to the tank, with a gap between the nuts on the end of the rods and the brackets on the tank. This enables the rods to restrain the tank while allowing for minor thermal expansion.



Safety rods in tension



Any tank that is suspended by tension weigh modules should have a secondary safety restraint system.

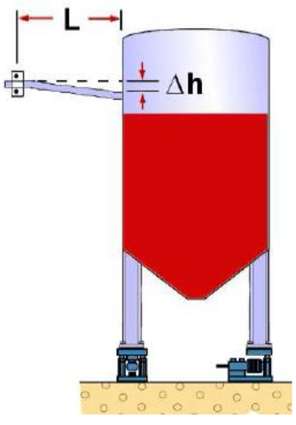
Fit each safety rod through an oversized hole in the bracket so that the rod does not influence the weight readings.

Safety rods must be strong enough to support the filled tank in case the primary suspension system fails.

Horizontal check rods or bumpers can be used around the perimeter of the tank to keep it from swaying.

Piping connections

Any time that piping is connected to a tank scale, there is a potential for mechanical binding. If piping is not installed properly, it can cause weighing errors by pushing or pulling on the tank.



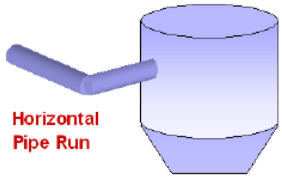
Force exerted by pipe

When the tank is full, it moves downward because of the deflection (Dh) of the load cell and the structure. The pipe exerts a force on the tank, affecting weight measurements. The more flexible the piping is, the less force it will exert on the tank.

the force exerted by pipe is:

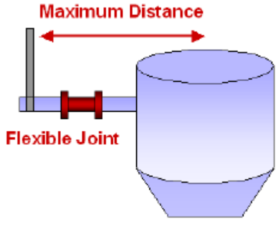
$$F_p = \frac{0{,}6 \times (D^4 - d^4) \times \Delta h \times E}{L^3}$$

where: *D = Outside diameter of pipe (mm)*
d = Inside diameter of pipe (mm)
E = Young's modulus (for steel: 210.000 N/mm2, for copper: E= 110.000 N/mm2)

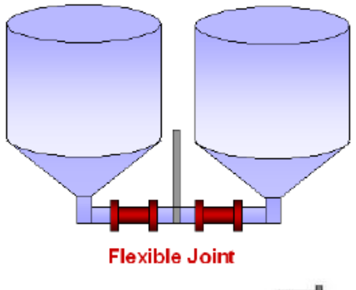


Run all pipes horizontally from the tank. A 90-degree bend in A horizontal run of pipe will make the piping more flexible.

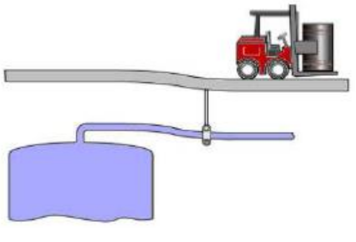
Use pipe with the smallest diameter and lightest gauge possible. That will make the piping more flexible.



Use flexible piping or connections whenever possible.
Locate the first rigid support for the piping as far away from the tank as possible. That will make the piping more flexible.



When a single discharge pipe is used by adjacent tanks, design the system so that the discharge piping from each tank is supported independently and does not interact with the other tank.



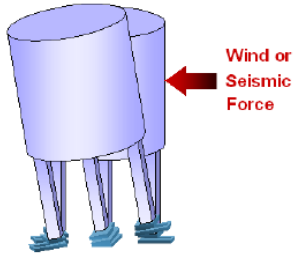
Do not attach piping to supports for a structure that deflects separately from the tank.
Instead, attach piping to the tank's support structure so that the piping moves along with the tank.

Environmental factors

Because environmental factors can affect the accuracy and safety of a weigh system, they must be considered during the design stage.

Wind or seismic loading

Wind and seismic forces can have a great affect on outdoor weighing system. Upward, downward, and shear forces are exerted on load cells.



- ***Use larger capacity load cells to accommodate for the added loads.***
- ***Mechanical restraints can be applied to maintain the scale's position.***

Wind effect

The effect of wind on a weighing system makes it important to select the right load cell capacity and determine the best mount to use in outdoor application. These effects are complex and depend on factors such as the degree of exposure, local topography and maximum wind speed.

Beaufort scale specifying wind speed

	Beaufort	Km/h	m/s
Strong normal wind	5	30-40	8-11
Strong wind	6	40-50	11-14
Very strong wind	7	50-60	14-17
Stormy	8	60-72	17-20
Storm	9	72-85	20-24
Heavy storm	10	85-100	24-28
Very heavy storm	11	100-115	28-32
Hurricane	12	115-180	32-50

Wind striking an exposed tank or silo will generate a side force which causes an overturning moment and a smaller vertical force.
When the silo is empty: *The wind force may be sufficiently strong to overturn the structure.*
When the silo is full: *The combination of the overturning force reaction, and the total weight of the silo, may generate load cells overloading.*

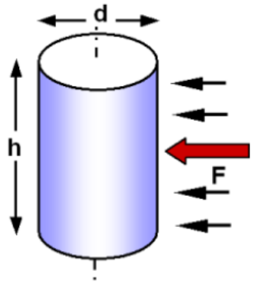
Wind force

The installation is affected by horizontal forces, acting in the direction of the wind.

These forces can be calculated, in N by: $F = \frac{1}{2} \times \delta \times C \times A \times V^2$

δ : *Air voluminal density (1,293 kg/m^3),*
C : *Drag coefficient (0,8 for a upright circle cylinder)*
A : *Exposed cross section (m^2)*
V : *Air velocity of wind (m/s)*

Example



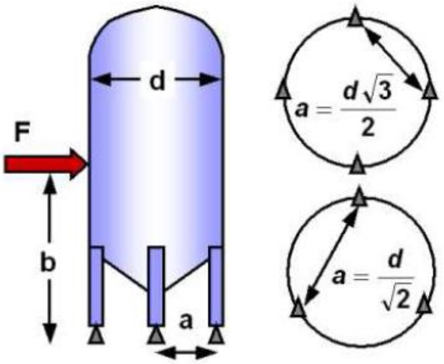
Specifications

- $V = 30m/s$
- $h = 10m$
- $d = 3m$
- $A = hxd$

$$F = 0{,}5 \times 1{,}293 \times 0{,}8 \times h \times d \times V^2$$

$$F = 13960\ N$$

Overturning force
The wind force generates a overturning moment, which will be counteracted by a reactive moment of the load cells.



$$F_{ov} = \frac{F \times b}{a}$$

- F_{ov} : Overturning force caused by wind force
- **a** : Distance between load cells
- **b** : height at which the wind force acts

*Using the previous calculated wind force of **13960 N** and a value for **b** which is half the height of the silo:*

$$F_{ov} = \frac{13960 \times 5}{3} = 23300N$$

The overturning force and overloading reaction in **kg** is: $$F_{ov} = \frac{23300(Newton)}{9{,}8} = 2380kg$$

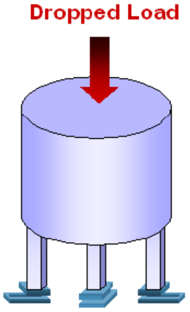
Conclusion

I***n case of an empty silo:***
*Uplift protection should be considered if the dead weight of the tank on each load cell is smaller **2380 kg.***

In case of fully loaded silo:
***2380 kg** must be added to the calculated load cell capacity.*

Shock loading

A load dropped on the scale from above can exert strong forces that can damage the load cells. Use larger capacity load cells to accommodate for large shock loads and use shock absorbing materials to damp the loading.



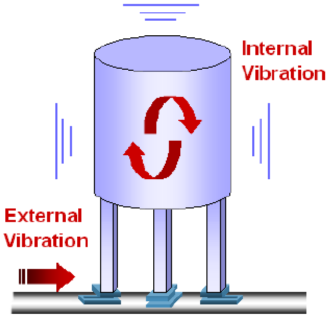
- *Shock forces caused by dropped weights :*

$$W_1 \times \left(1 + \sqrt{\frac{(1+2H)\times K)}{W_1 + W_2}}\right) + W_2$$

Where: W_1 = *Weight being Dropped (kg)*
W_2 = *Dead Weight (kg)*
K = *Load cell spring rate: rated capacity divided by load cell deflection at rated capacity (kg/m).*
H = *Height from which Object is Dropped*

Vibration

Caused by the surrounding environment or mixer's agitation, vibration Induces electrical noise on the load cell's signal.



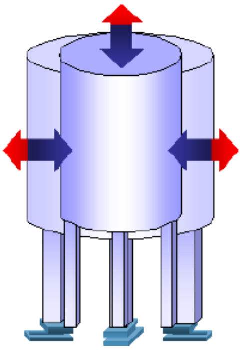
Separate the surrounding structure from the load cell supports.

Use interior baffles.

Use isolation pads between the load cells and structure.

Temperature effects

Temperature can affect a load cell by causing structural supports to expand and contract or by exceeding the operating limits of the load cell. As a tank expands and contracts, it pushes or pulls on attached piping.
If the piping connections are rigid, this can cause weighing errors.



Insulation and low thermal conductive material can be used in between the cells and the tank.

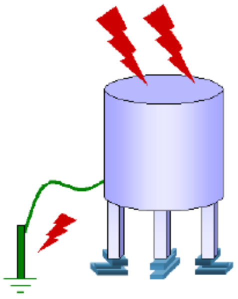
Moisture, corrosion and debris

Moisture and corrosive substances can damage the cells physically and by shorting out its electronics. Debris collected on the load cells will cause weighing errors by mechanically binding the scale.

· Provide adequate drainage away from the cells.
· Regularly clean accumulated debris. Keep cables clean and in good condition.
· Protect cells and cables from corrosive materials.

Lightning and surge protection

Electrical surges can cause permanent damage to the load cells. Electrical surges may be caused by lightning, large electrical machines or welding.



Verify the integrity of any existing grounding systems.

Use a single-point grounding system and surge protection devices.

Don't carry out electric welding near load cells.

Every load cell should be shunted by a stranded copper cable to prevent welding currents from flowing through the load cell.

Calibration

Calibration preparation

Before calibration, each load cell's signal output is measured to ensure an even load distribution.

Hang a test weight near one load cell mount and take a reading. Move the test weight to a second load cell, take a reading and repeat for each load cell mount.

The load cells mounts should be shimmed until the signal output from each individual load cell varies less than 25% of each.

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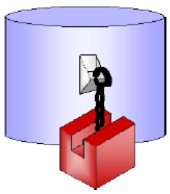
This applies mainly to vessels with 4 or more load cells. Vessels with 3 load cells that have been levelled, should provide automatic weight distribution. The aim is to get each load cell mount bearing the same amount of weight.

Common sense must prevail however. If the vessel has a large offset load, then the load cell nearest to this will have a higher output. As long as the load cell is not overloaded when the vessel is full, this situation is acceptable.



Build brackets, evenly spaced around the tank to hang test weights.

When a weighing system is installed, it must be calibrated so that the readings on the indicator accurately reflect the amount of weight placed on the scale. There are 4 main methods used to calibrate weighing system:

Calibration with test weights

The most accurate, reliable way to calibrate a scale is with test weights. This method is usually limited to small capacity weigh vessels due to the difficulty of handling large amounts of test weights, and finding a place on the vessel to hang or place them :

- *Empty the vessel, ensure there is no interference with the vessel.*
- *Zero the weighing instrument.*
- *Hang the test weights on the vessel.*
- *Calibrate the weighing instrument, so that it reads the same as the weight applied.*
- *Remove the calibration weights and check for return to zero.*
- *If you have sufficient weight, add the weights to the vessel one by one and check the linearity of the system. If the system is badly non-linear, check for mechanical interference.*

Calibration with material substitution

For large tank scales, it is often physically impossible to hang test weights equal to the tank's full capacity. In those cases, you can use a combination of test weights and a material (such as water) to calibrate the scale.

- *For example, after taking a zero reading you might hang 1000 kg of test weights and take a reading.*
- *Then remove the test weights and add water to the tank until the weight reading is the same as that obtained with the test weights.*
- *With the water still in the tank, hang the same test weights and take a second reading.*
- *Continue substituting water for the weights and taking readings until you reach the full capacity.*

Calibration with material Transfer

This method uses another measuring instrument to measure the weight of a set amount of material, and then uses this material as the test weight. The most common methods are using a volumetric flow meter to measure water flowing into the vessel, or using another scale.

- *This method often presents a simple way to calibrate a weigh vessel, but the accuracy of the weigh vessel will only ever be as good as the accuracy of the measuring instrument.*

Load cell simulation

When using the electronic calibration method, replace the load cell cables with leads from a load cell simulator. The simulator sends out a signal equal to the signal the load cells should produce.

The main disadvantage of the load cell simulator is that it does not simulate the effect of variations caused by misalignments or mechanical connections to the weighing system.

- *With the simulator adjusted to zero output, set the indicator to zero.*
- *Adjust the simulator to full output (a signal equal to that which all the load cells should produce at their rated capacity).*
- *Adjust the indicator to show the total capacity of all load cells in the system.*
- *Attach the load cell input to the indicator.*
- *Set the indicator to read zero for the empty weight of the tank.*

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Weeg- en testtechniek

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