Presented By

An ISO 17025
Accredited Company

Dallas Ft Worth Austin Houston

NicolScales.com

800.225.8181

Contact Us

Nicol Scales & Measurement is an ISO Accredited Calibration Company that has provided calibration, repair and sales of all types of weighing and measurement products since 1931.

Tank Weighing Woes:

Why Load Cells have a Bad Reputation and what needs to be done to fix it

Written by Ryan Titmas, Product Manager, Sartorius North America

I cannot tell you how many manufacturing facilities currently have load cells installed in tank systems that are no longer operational. Most of the times the load cells are left in place and the electrical cables connecting to the controls are simply cut. Production Managers, QC Managers, and maintenance personnel alike have surely encountered "that tank" or "vessel" which never weighed correctly. Why? Why have so many switched from a supposedly higher accuracy load cell solution to old fashioned level probes or site glasses to determine tank contents? There are several major causes, all of which will be highlighted within this brief paper. Don't worry your not alone and be assured that some simple knowledge and consultation will help you better understand the root cause of your vessel weighing dilemmas.

The Beginning

Ok, I am an engineer and I must admit before I specialized in load cell solutions I could care less what type of load cell was specified under a tank during project design phases. Pick a load cell from the local catalog; mount one under each leg, and bingo, a perfect weighing system. The only science involved is finding the vessel "dead-weight", specific gravity of the product, and then estimate the total weight. Easy design, simple drawing integration, no need to worry about load cells, time to move on.

Improper specification of load cell systems is not due to incompetence by the engineer, rather lack of education on load cell weighing systems and what real life factors effect these installations. Some simple mechanics, installation tips, and real life lessons found in this paper will help give design engineers some tips on correctly integrating load cells in the future. QC Managers, Production Managers, and other production personnel will also learn some tips on correcting their existing tank or hopper installations.

Mechanical Properties of the Problem: Shear Beam Load Cell

Shear beam load cells are general force sensors and cannot discriminate against true vertical load and side/torque loading. The idea of a load cell system is to capture the true vertical load or the weight within the tank, however real world conditions or improper installation will cause the load cells to see much more than vertical loading. These "other" factors are what causes un-repeatability in weighing and ultimately leads to load systems being dismantled. Before learning about the factors that cause inaccurate tank weighing it is important to learn how a shear beam actually works.

> A shear beam load cell is basically a precision milled piece of stainless steel that has electronic sensors called strain gages adhered to it. The strain gage is positioned at a 45 degree angle to measure the steel shear strain. **Illustration A** shows the positioning of the strain gages on the shear beam load cell.

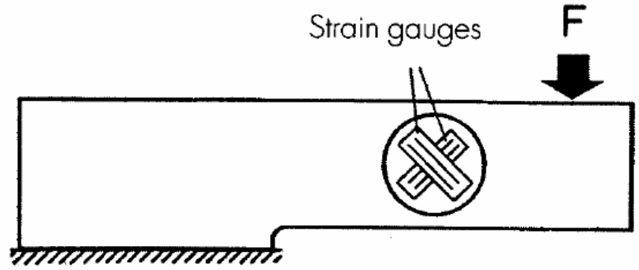


Illustration A: Shear Beam Cell strain gauge positioning, F indicating load introduction

Strain gages are zigzag-shaped strip conductors, etched from thin metal film. They use the effect of the change that the electrical resistance of a conductor will undergo when it is subjected to mechanical stress (the change in resistance is caused by a change in length, cross section and specific resistance). The letter "F" in the above picture shows the required force introduction point on the load cell.

The body of the load cell is typically constructed of a mild steel, stainless steel alloy or aluminum. A typical load cell will undergo thousands of weighing cycles, so the composition of the metal is very critical in producing accurate weighing results. A "Shear" beam load cell is actually measuring the shear strain of steel which occurs, so if the steel itself is not monolithic throughout, errors in weighing and load cell failures will occur. In general it is critical that load cell manufacturers obtain steel and aluminum that is high grade to produce the best weighing results.

Why Beams don't typically work in industrial vessel weighing

Bending beam and shear beam load cells are the industry standard for bench and floor scales. Next time you have a free moment, lift up the pan and look underneath a scale, more than likely you will find some type of bending beam load cell. (See **Figure A**) If these types of load cells are used in bench scales then why can't they be used in vessel weighing tasks?

Scales and balances are self contained units that rarely encounter the extraneous side forces and environmental influences vessels do. Yes, it is true that scales are subject to environmental factors, however not to the extent of process vessels. The fact is that bending beam load cells are perfect for environments where typical static weighing will take place; they are not intended for process vessel applications. Vessel weighing applications require a load cell and mechanical support system that will eliminate non-vertical loading and produce reproducible weighing results.

Figure A
Hygienic Bench Scale with Bending Beam Cell Installed

Fixing the Problem:

First thing first, a vessel or tank weighing application will never be successful if the actual tank construction is not adequate. What do I mean by adequate? Well, when vessels are designed they are designed to adequately and safely hold product, withstand environmental issues such as wind, earthquakes and other forces of nature. The idea that the vessel needs to weigh accurately is generally an afterthought in the design process of a tank.

The most important thing to remember with tanks is the construction of the "weighing frame" or frame where the load cells will be mounted. This frame mechanically connects all load cells under the vessel and ensures that they cannot move in different directions independently of each other. Since the load cells only transfer vertical compression forces (compression load cells will be discussed later in the paper) the design has to ensure that in case of external forces the load cells cannot tilt. **Figure B** shows the best type of installation. Notice how the load cells are placed in the middle of the beams and that the load cells are situated between (2) two frames. This frame network ensures the load cells will move together, creating a more repeatable weighing environment.

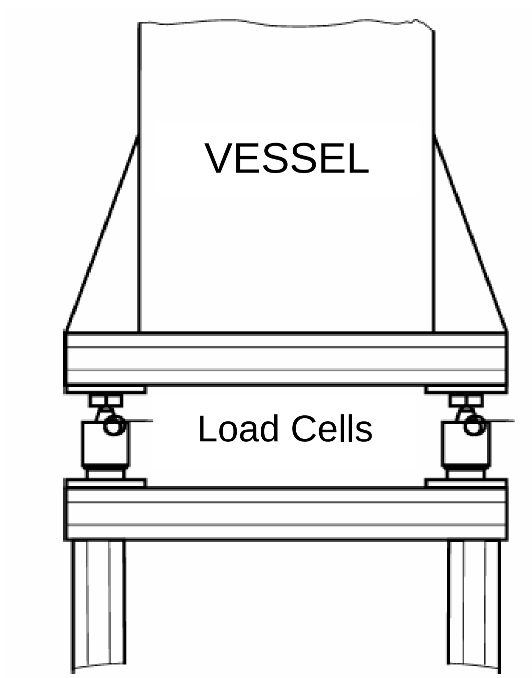


Figure B
Compression Load Cells Installed
properly in a double frame design

In **Figure B** the load cells are mounted on top of a bottom frame assembly which provides a good rigid and stiff foundation. Remember that the weight of the vessel is being transferred to the load cells and then to the bottom frame. With this in mind it is critical that this transfer of force is carried out with minimal deflection. Please also note that the load cells can be mounted directly to the floor without the bottom frame, however the construction of the floor must allow little deflection and settling. The load cells are measuring deflection down to thousands of a millimeter, so if your foundation deflects, you are not going to achieve acceptable accuracy.

Figure C illustrates another design problem typically found in tank weighing applications. It shows load cells installed on the end of very long tank legs. This type of installation will typically cause weighing errors due to the separate legs moving in different directions. Repeatability problems due to the variability in movement and drift concerns caused by the extraneous deflection. **Figure D** illustrates a good load cells installation because the legs from the tank are shorter, minimizing separate leg movement, and the load cell has a top and bottom frame to help induce a more uniform loading pattern. Please note that these illustrations show only examples and each weighing applications is different)

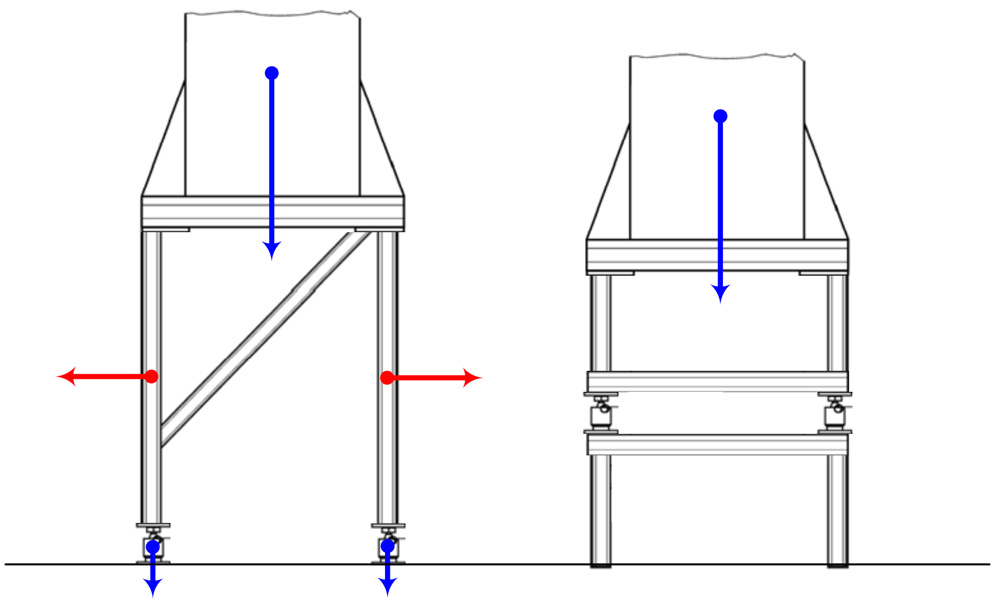


Figure C
Vessel illustrated with long legs and poor cross-bracing will generally produce poor weighing repeatability

Figure D
Vessel illustrated with shorter legs and a top/bottom frame construction. Good rigidity and cross bracing will produce excellent weighing accuracy.

Rigid tank construction with a solid foundation, got it, but what other tank design factors must be considered? One of the most overlooked factors is the vessels peripheral connections and accessories, such as pipes, mixers, ladders, walkways, etc. Each of these external fixtures carries a specific influence on the weighing system that must be addressed.

Pipes entering and exiting a vessel are always exerting forces on a vessel and create no real problem under stable ambient conditions, e.g. constant temperature. We all know that industrial applications are far from "ambient" thus pipe expansion, and movement will adversely affect weighing results. To better visualize this effect simply stand on your bathroom scale and take your weight reading (don't worry I don't like what it reads either!) Next weigh yourself by gently pushing on the wall, and then once more by pulling on a nearby towel rack. The results are different aren't they? This type of action/reaction force is similar on vessel weighing applications where pipes are present.

A simple way to dampen the effects of pipes on weighing measurements is to have all pipe connections enter from the side. (If possible) Pipe hangers should be placed as far away from the tank as possible to allow for flexing as the tank moves up and down during loading. Flexible pipe connections and bellow can also be used to connect hard pipe to the vessel, however ensure the flexible connections are truly flexible. (A 1" flex joint on a 4 inch pipe probably isn't effective)

Figure E illustrates the possible forces and displacements of piping: a rigid pipe can lift some weight off the vessel and cause a displacement (δ_P) A force Fp along the pipe can push the vessel to the side and exert forces downward or vise versa.

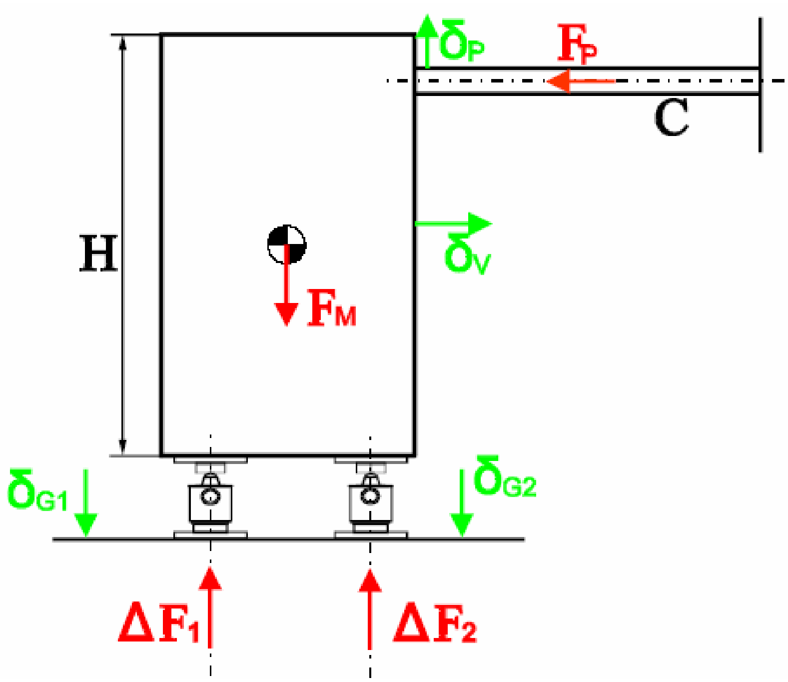


Figure E: Illustrates the various forces reacting between hard-piping and a vessel.

Compression Load Cells and Mounting:

Once you ensure that your tank is constructed properly and all pipe connections are flexible, the next step is to utilize compression type load cells. Compression load cells, unlike shear-beam or bending beam, don't allow non-vertical load introductions simply by mechanical design. Properly constructed compression load cells simply cannot accept non vertical loading by utilizing a spherical top and bottom design. The rounded top and bottom allow the cells to "right" themselves during side loading by a principle of restoring forces. Compression cells, like pictured in **Figure F**, are designed to shift during vessel expansion and are constrained by mechanical design to eliminate other non-vertical force influences.

Figure F: 20,000 kilogram compression load cell and mounting hardware with installed heat shield.

Compression load cell are not bolted to the floor or to sub-framing like typical shear beam load cells. All external forces, including mixers and heat expansion cannot be avoided when using beam type load cells. These nasty forces can be eliminated with proper compression cell mounting solutions due to both the load cell design and mechanical restraining.

Mechanical restraints are simple devices; however take care of most complex side loading influences when used properly. Constraining devices are generally installed on the sides of the load cell mounting kits and are similar in many ways to classic turn-buckle assemblies. The mounting of the turnbuckle assemblies absorb non-vertical forces from direct side loading (wind influence, etc) and torque forces created from vertically mounted mixers. **Figure G** is a typical compression cell mounting kit with an integrated turn-buckle as described previously.

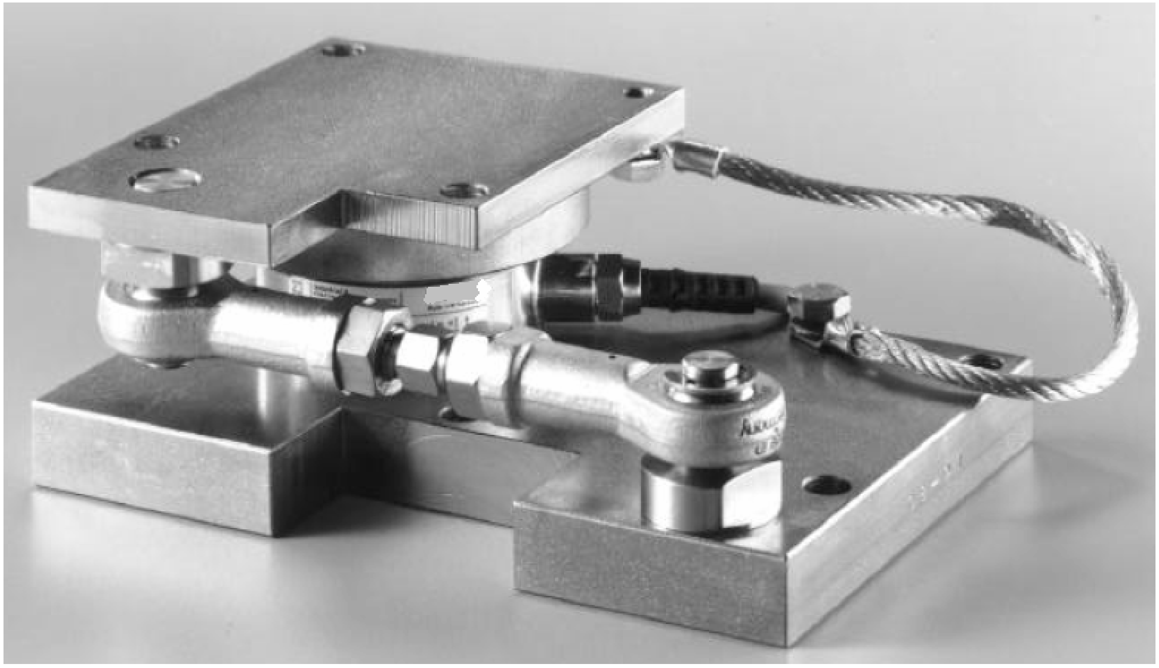


Figure G: A compression load cell mounting kit with side force protection. Top plate pictured above would mount to a tank leg and bottom plate to foundation or bottom supporting frame

Mounting kits only perform properly if they are installed in rigid vessels as described previously, but they also must be aligned properly to absorb side forces. **Figure H** illustrates how to properly install mounting kits in both 3-legged and 4-legged vessels. As you can see the turnbuckle assemblies are tangential to the tank in 3-leg applications. This type of arrangement is used to absorb torque forces from mixers and equally distribute side forces amongst the constrainers. The 4-leg tanks have the mounts installed so that no one turnbuckle points toward another. This arrangement is necessary to avoid unnecessary axial binding and ensure each turnbuckle is absorbing equal load across the entire base of the vessel.

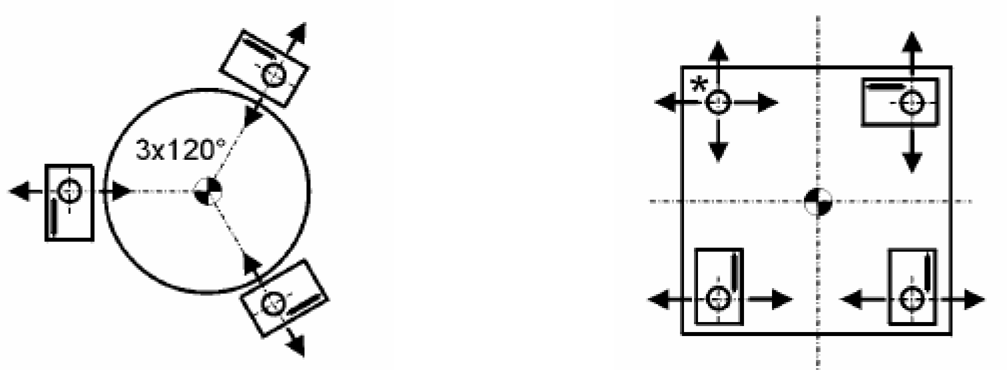
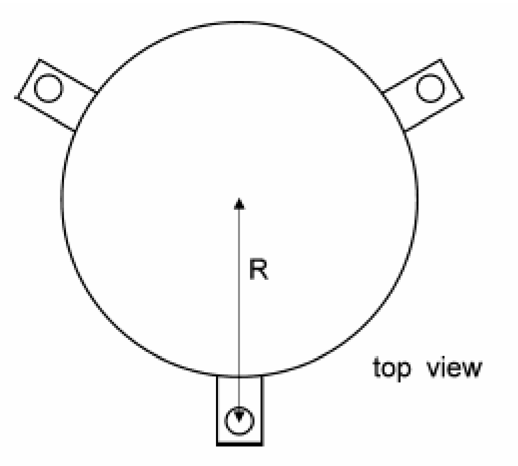


Figure H: Illustrations above show proper installation of compression cell mounting kits. Load cell should be directly under tank leg for direct load introduction and turnbuckles as noted by thick black lines

One final issue to address in tank weighing is the thermal expansion of the tank. Thermal expansion and contraction occurs for a variety of different reasons, the most common being; jacketed heating or cooling, environmental temperature changes, and hot/cool liquids being added to the vessel. In these applications where shear or bending beams are used there is no physical way to stop the expansion of the vessel from inducing a load on the cells. The vessel wall will now be pressing outward on the load cells, creating a force vector in the downward direction, which will show as a weight change on the weighing system. This expansion will cause drastic weight changes from a few pounds or kilograms up to hundreds of kilograms.

Consider the drawing below. A stainless steel vessel (AISI304/1.4301) is calibrated under ambient conditions (20 deg. C) and operated at a temperature of 250 deg C when the jacket heating system is running.



Radius of the tank (R) =	**1.25 meters**
Expansion coefficient (k) =	**1.6 mm/m/100K (different depending on material!)**
Temperature Difference =	**250C – 20C = 230 deg C**
Strain (Σ_T) =	**1.6mm/m x 230C/100K = 3.68mm/m**
Expansion of the radius =	**1.25 meters x 3.68mm/m = 4.6 mm**

The expansion of the tank 4.6mm in a shear beam weighing applications will produce severe weighing errors. Compression load cells are not physically bolted to the floor, but rather are floating and allowed to shift slightly when the tank expands. This allows for more accurate weighing during tank radius fluctuation caused by tank wall expansion.

Blowing cool air on load cells, wrapping insulation around load cells, or dowsing water on cells is not an adequate solution for stopping the effects of tank expansion on load cells. Installing load cells that can mechanically expand with the vessel and eliminate external side forces mechanically is the best solution.

Summary:

The key to an accurate and dependable tank weighing system is more than just picking out load cells. The system needs to possess the mechanical characteristics which support accurate weighing. Remember the following points when designing or troubleshooting a tank weighing system:

#1 **Rigid support structure**: Construct vessel weighing applications with adequate cross bracing, a stiff foundation and rigid legs.

#2 **Isolate the tank**: All pipes entering/exiting the tank should have flexible connections and support structures such as ladders & walkways cannot be "hard" connected to external structures. Mixers should be part of the weighing system.

#3 **Use compression type load cells:** Shear beam type load cells are not typically designed for industrial applications due to their inflexibility in dealing with external forces found in tank weighing applications. Compression cells are proven to produce better results in these applications.

#4 **Install proper mounting kits**: Adequate mounting kits will provide protection against unwanted side forces, thermal tank expansion, and tank lift off.

#5 **Consult, consult, consult**: Ask an expert in the field of weighing about your tank application and make sure they are familiar with industrial tank systems. A simple call could save you many headaches in the future.

Money Talks:

No matter the industry, weighing accuracy equals money, and in most cases it equals lots of money. Operating a plant with tanks and/or vessels that do not weigh properly can cost time and plant efficiency which equates to a cost. Inaccurate tank weighing can literally cost thousands of dollars in lost product and wasted time. It is critical to consult with an experienced tank weighing company, familiar with not just load cell specifications, but rather the engineering behind the system.