Structural Design of Tank Weighing Systems

1. Initial observations

Some essential rules must be followed when installing load cells in tanks. For example, tanks are frequently subject to weather conditions or effects related to production. When new upright tanks are erected outside (silos, coal hoppers, etc.), applicable building regulations must be observed for the relevant structures. Note that subsequently installed weighing devices may also be considered as *"significant changes"* in terms of building regulations. The advice of a structural engineer is recommended in these cases. Building regulations generally cite the "state of the art" in terms of safety considerations. For example, wind loads are covered by DIN 1055 Part 4 “Load assumptions for structural components”.

The project engineer for a tank layout should also be informed about any special company-internal rules. Tanks must frequently be secured so they cannot be picked up, even in areas covered by a roof if the contents are hazardous and forklift trucks are in operation around the storage area.

2. Load distribution

An optimum arrangement of load cells for determining the weight of tanks is achieved when the tank rests on three bearing points and a load cell is positioned on each support. This state is referred to as statically determinate. The overall load should also be distributed as evenly as possible over the three load cells. In the case of upright or suspended cylindrical tanks the best way to meet this requirement is if the three load cells are arranged at equal distances from the vertical axis of the tank and are offset from each other by 120° on the same plane. Figure 1 defines the arrangement of bearing points for horizontal tanks.

If not all the supports in a system are equipped with load cells, an uneven distribution of the support load is recommended. The supports with load cells should have greater loads than the supports without load cells. This measure can improve the overall accuracy of the weighing device. When designing the system and selecting the load cells, it is preferable for all the load cells to be subject to a load of the same magnitude.

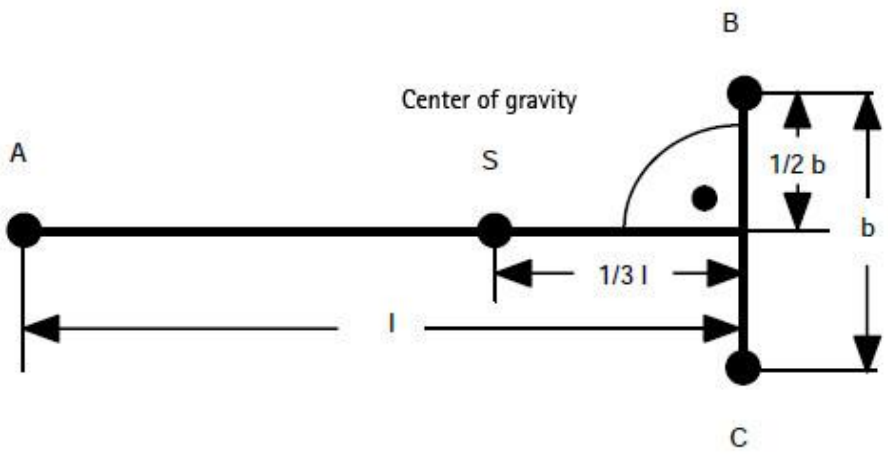

Figure 1: Arrangement of bearing points A, B and C for a horizontal tank

If a tank is supported on four or more points, the bearing of the tank is statically redundant. Load cells must be installed at all the bearing points in these cases. An even distribution of the load on the individual transducers can only be achieved during assembly. The transducer loads must be measured individually for this purpose. Then if there are impermissible differences the height of the relevant load cells must be changed (with compensating shims, etc.). Load cells with loads that are too low are generally positioned diagonally opposite from each other.

3. Center of gravity of a tank

Ideally the center of gravity of a filled tank should not be any higher than the bearing points of the tank – a feature that is frequently not implemented.

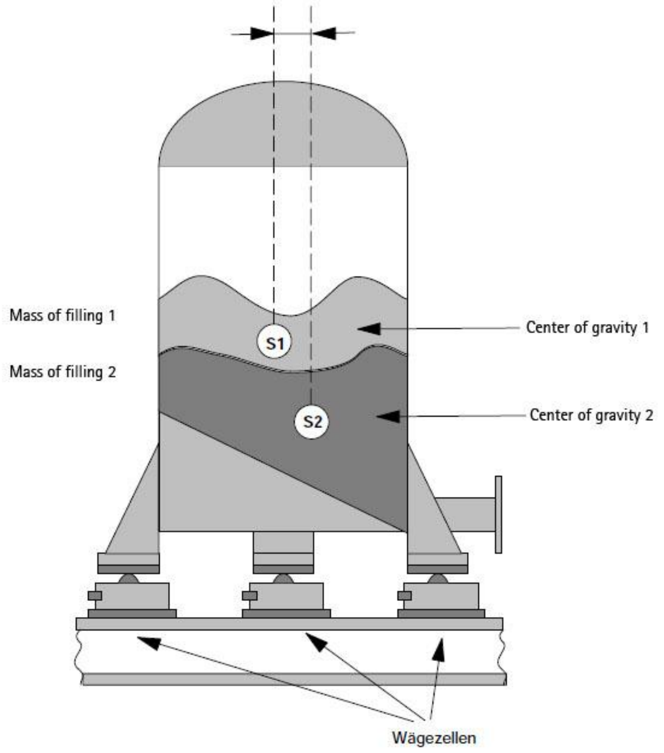

Figure 2: Distribution of the center of gravity of a tank with an inclined discharge base depending on the mass of filling

For reasons of stability it is advantageous for the center of gravity to be lower than the bearing points. The position of the center of gravity as a function of the filling level has a considerable effect on the number of load cells that are used. If the filling is arranged symmetrically to the load cells, it may be possible to set up a weighing device with one load cell, since the position of the center of gravity moves along a vertical line (see also 6.3). If the center of gravity also moves to the side as the mass of filling changes, all the supports must be equipped with load cells. Rocker and fixed bearings should never be considered for applications of this type!

Figure 2 illustrates the necessity of using load cells on all bearing points if the position of the center of gravity changes.

4. Supply connections on tanks

Tanks frequently require supply connections, for example to supply and discharge contents and for the electrical, hydraulic or pneumatic supply of additional units mounted on the tank.

These supply connections can lead to force shunts, which manifest themselves as errors that affect the measuring accuracy of the weighing device. Supply connections must be flexible in the vertical direction. Figures 3 to 7 show some examples of suitable designs for supply connections. In any case, these aspects should always be taken into consideration for financial reasons in the design and planning phase. If rigid pipes without a flexible link are used, the tank should preferably be connected with the longest possible horizontal pipe section. The pipe section should also have expansion compensation in the longitudinal direction (figure 3).

The horizontal section of pipe has a spring effect in the vertical direction which becomes more yielding as the length increases. The mechanical force exerted by the pipe in the form of a pseudo load (tensile or compressive) on the load cells becomes correspondingly small and is no longer relevant for measuring accuracy.

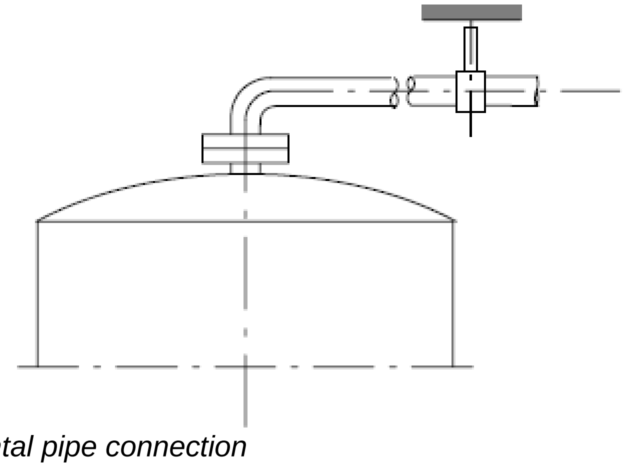

Figure 3: Long horizontal pipe connection

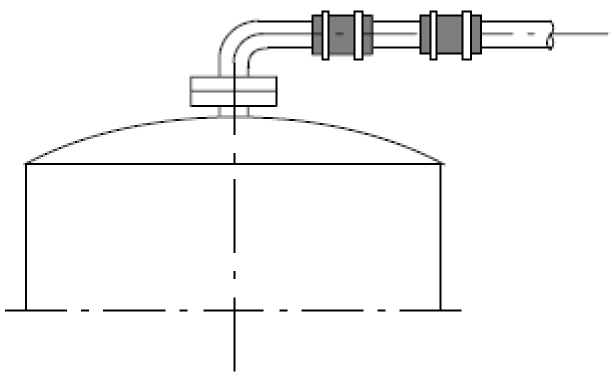

Figure 4: Elastic pipe coupling

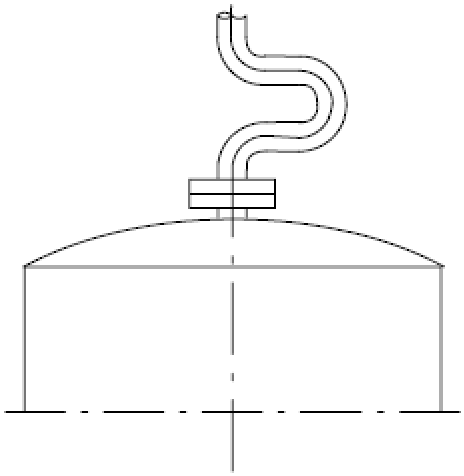

Figure 5: Pipe elbow

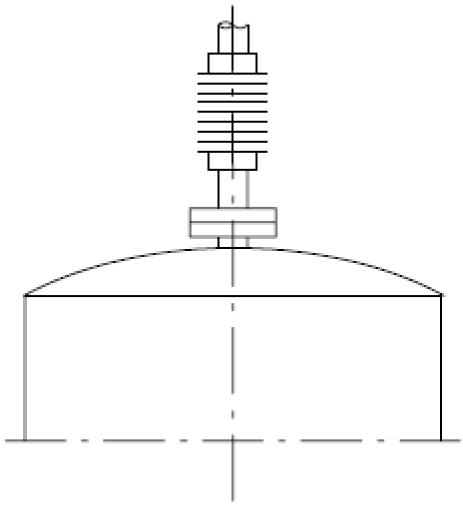

Figure 6: Mechanical compensator

Several pliable couplings can also be used instead of a layout with one long pipe (figure 4). Good results in terms of preventing force shunts are obtained with hose connections made of readily malleable elastic materials. In this case the compatibility of the elastic materials with the filling and/or cleaning materials must be checked (in the food industry or pharmaceutical technology, for example). Another possibility for reducing undesirable force shunts caused by connecting pipes is using a layout with a pipe elbow (figure 5).

In cases where a vertical pipe supply is required (i.e. in the direction of the gravitational force to be measured) or hose connections cannot be used, pipe connections with compensators (such as metal bellows) have proven effective (figure 6). Strict installation tolerances must be observed when installing these compensators. If a second set of metal bellows is used and connected with the first by a section of pipe, it is possible to compensate for greater tolerances. Metal bellows are not permitted in some cleaning-intensive areas of the food industry.

The connecting branch shown in figure 7 represents the best solution in terms of reducing force shunts. An open connecting branch prevents contact between the pipe and the tank. This form cannot be used in closed systems, for example in pressure tanks.

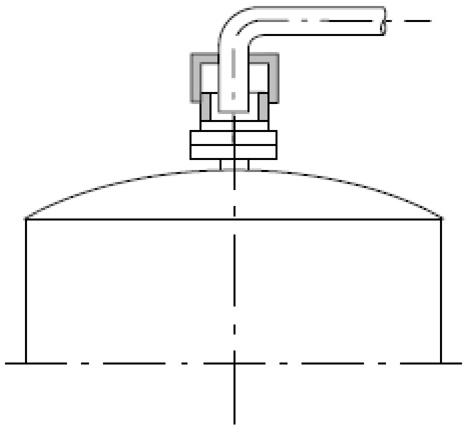

Figure 7: Open filling stud

It should always be noted that the material in the connecting lines is included as part of the weight. The filling level of the supply and discharge lines that are directly connected with the tank should therefore be reproducible when the weight is measured. This means the lines should be either always empty or always full when measurements are taken.

5. Pressurized tanks

In closed plants the pressure in the system can affect the weighing results. Especially in the chemical industry, high positive pressures are required for some processes. On the other hand, extraction plants for weighing powdered material generate negative pressures of 100 ... 300 mbar. If the piping is connected to the tank vertically, as shown in figures 5 and 6, a force is exerted that directly affects the measurement results. The effect is equivalent to the product of the force times the cross-sectional area of the piping. If pressure conditions during the weighing process are constant, this amount can be taken into consideration (calculated) in the measurement. A horizontal pipe layout is more suitable and preferable to a vertical pipe connection in every case. In this case the parasitic forces that arise are absorbed by the installation supports.

6. Examples of designs for arranging and installing load cells

Typical tank designs are represented in a stylized manner by way of example. Design details and references to problems are presented in greater detail in the relevant sections.

6.1 Upright tanks

Arrangements with two fixed supports and one load cell are possible for liquids and bulk goods with central filling. The tank must have a symmetrical layout to do this so that the line representing the center of gravity of contents over the entire range of filling level forms approximately a vertical line appropriate for the required accuracy. In all other cases, especially if greater accuracy is required, the arrangement with preferably three, and in some circumstances more load cells is necessary.

6.1.1 Rigid installation of a load cell

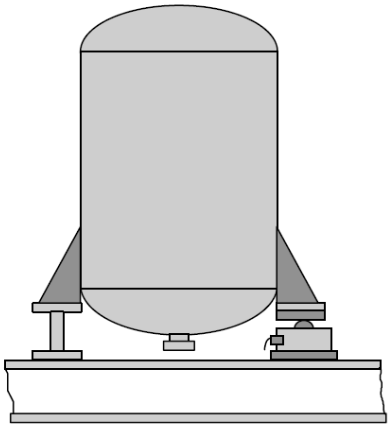

Figure 8: Upright tank in rigid installation with one load cell

This simple design on a carrier and rigidly installed load cell is not recommended. The design alone results in problematic effects on the load cell. Due to deformations as the filling level changes as well as vibrations and changes in temperature, effects on the load cells generally cannot be ruled out. A few cases of this design may nevertheless be found.

6.1.2 Upright tank with two fixed bearings and one load cell with compensation

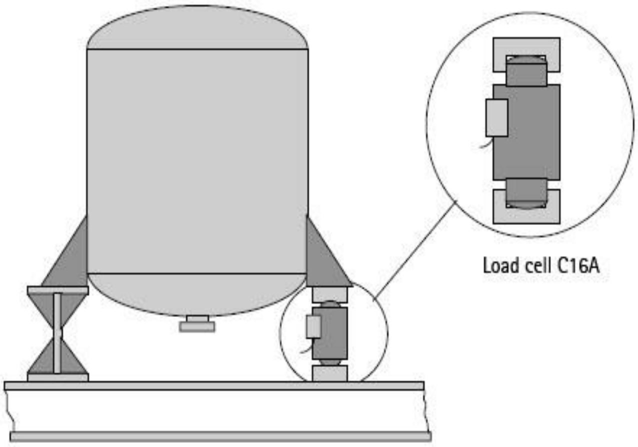

Figure 9: Upright tank with two fixed bearings and one load cell with compensation

This filling level measurement uses a load cell arranged in a cradle with two fixed bearings, which also serve to restrain horizontal movement of the tank. This cost-effective design keeps the load cell free of unacceptable effects.

6.1.3 High round silo on three or four load cells

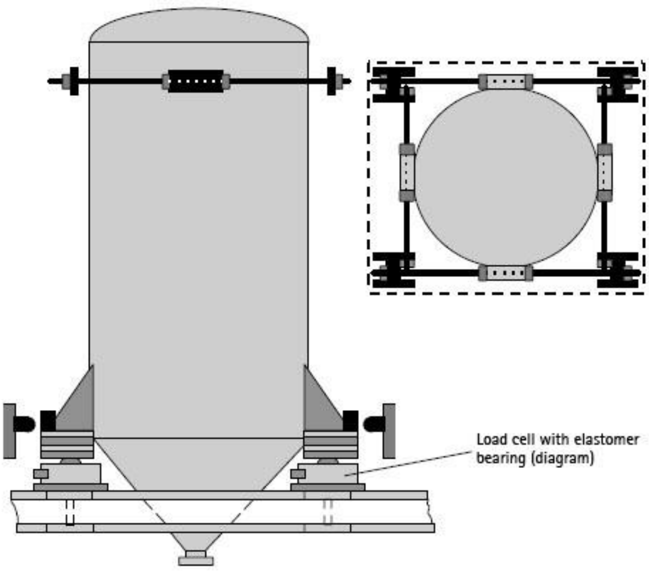

Figure 10: High round silo

Exact levels are usually measured on three load cells. Although arrangements with four load cells are sometimes found in rectangularly symmetrical designs, this arrangement is generally unfavorable due to the statically redundancy and higher price. On the other hand, they are easier to install in the structure. Self-centering elastomer bearings do not require any stay rods. They are usually combined with fixed stops instead. Additional stay rods guides are needed in the upper area for very high tanks. In the example they are designed as stay rods with loose initial stress and locking. Fixed stops would continuously come in contact with the tank at this point whenever it unavoidably moved slightly out of its ideal position and the contact friction would lead to force shunts. Roller stops or cable guides are less frequently used alternatives.

6.1.4 Round silo on three weighing modules

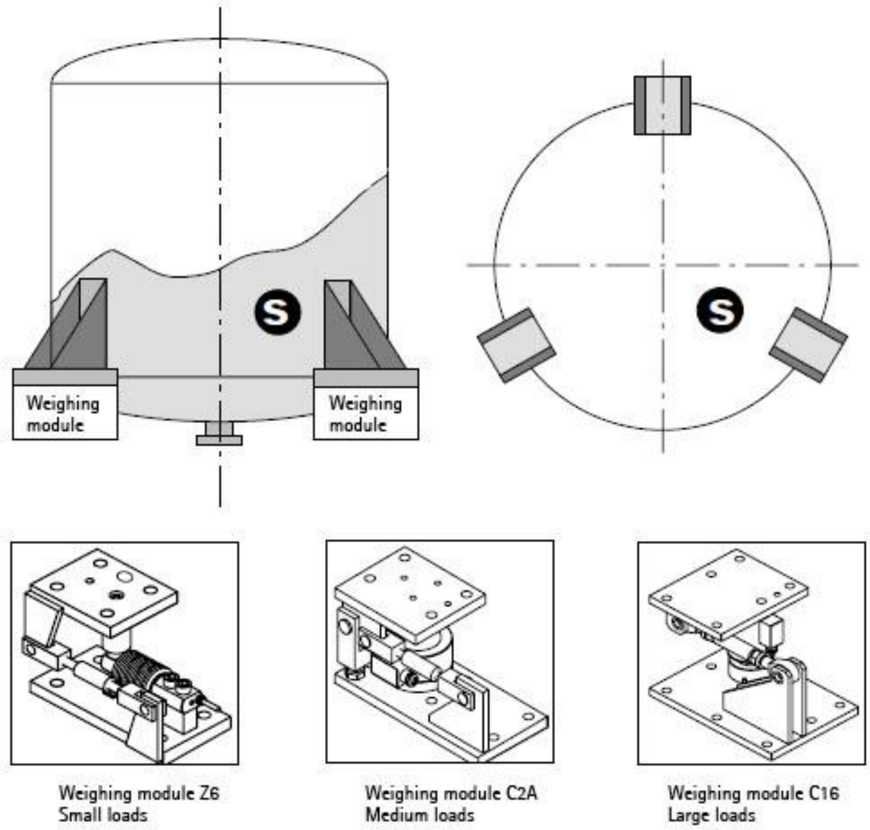

Figure 11: Round silo on weighing modules

Three weighing modules with integrated stay rods that contact the circumference of the structure tangentially will hold the tank horizontally stable with no need for any additional measures. The anti-liftoff device, also located in the weighing module, prevents the tank from tipping over. This eliminates several structural details in the outer construction. Typical weighing modules for lower, medium and higher loads are also illustrated here by way of example. These standardized elements simplify design and save considerable constructive expenses. On the other hand the design requires considerable care and overhead to ensure that contact surfaces are parallel, heights are aligned, etc.

6.1.5 Flanged tanks on weighing modules

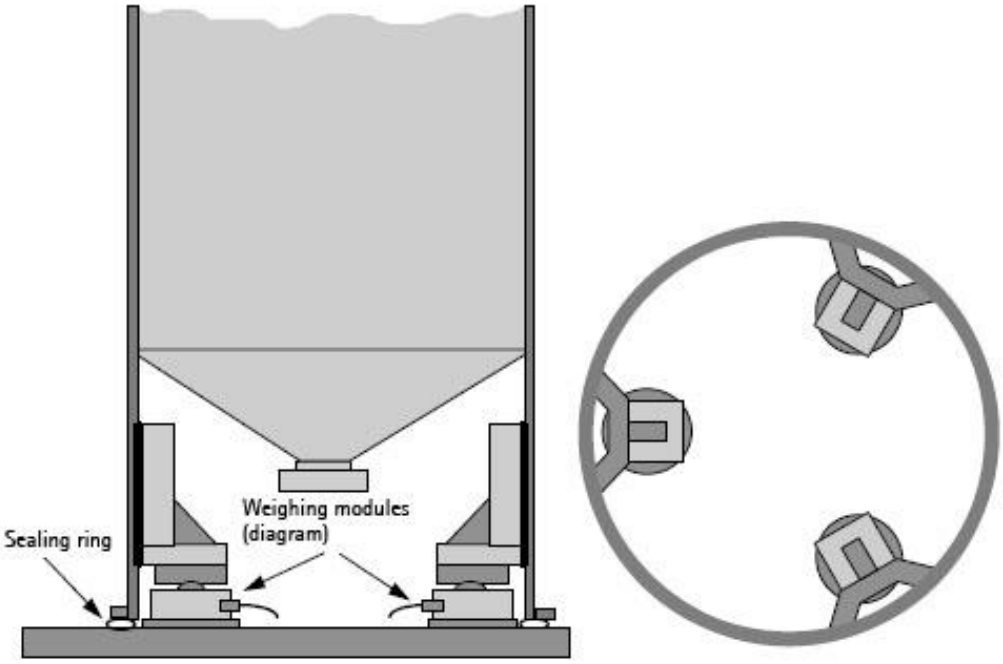

Figure 12: Arrangement of weighing modules for a flanged tank

Flanged tanks, which are used quite frequently in practical applications, have an outer casing which extends to the base and serves to ensure the overall stability of the arrangement. Installation on load cells is not a simple matter. Figure 12 shows a design variant for weighing these tanks with load cells. This suggestion is also relatively easy to implement in already existing systems. Braces are mounted or welded into the inside wall of the tank. The load is inserted rigidly into the load cell. Load cell weighing modules should preferably be used in this case as well, since they contain an anti-liftoff device, etc. (not shown in figure 12 to enhance clarity). Raising the structure even slightly is enough to direct the entire weight force into the load cells. The system must be sealed frequently. This is achieved through a circular sealing ring that does not cause any force shunts due to its flexibility.

6.1.6 Rectangular hopper in a filling station on four load cells

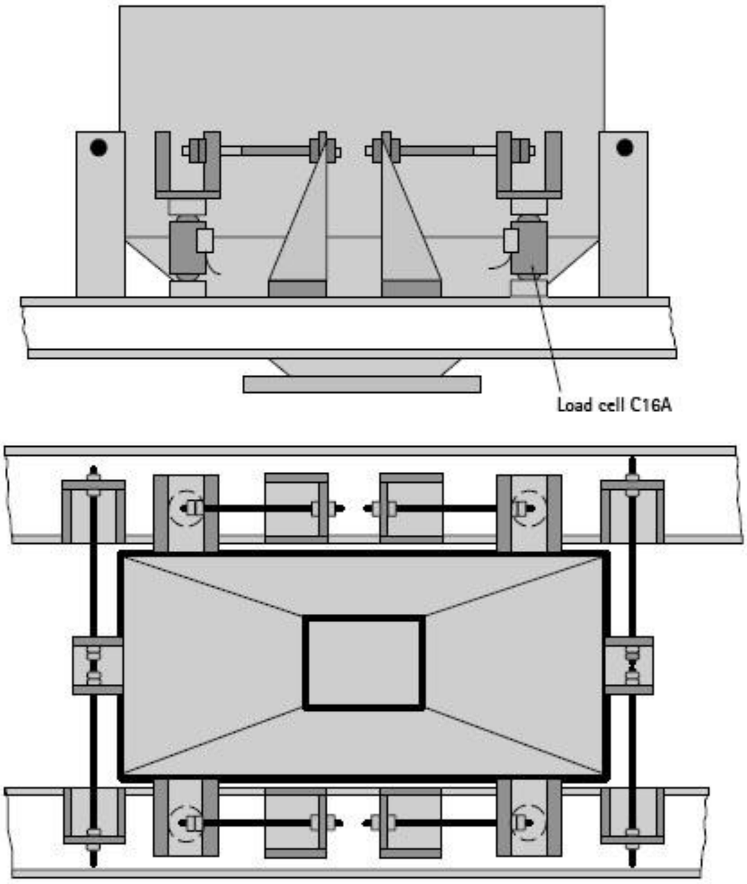

Figure 13: Rectangular hopper on four load cells

Conditions are very harsh at filling stations due to vibrations from transport systems, oscillations from connected supply and removal equipment and, if the weighing hopper is part of a movable system, due to the acceleration of moving processes. Coarse bulk goods may strike inclined side surfaces when they are poured into the tank with sufficient force to cause considerable shear loads. An especially stable stay rod restraint must be provided in these cases with tight initial stress. Occasionally the weighing tank is held by an additional fastening from which it is only released for the weighing process. The rectangular symmetry is advantageous in this case for reasons of stability and is therefore usually incorporated into the load cell arrangement. Load cells with elastomer bearings and like those in the example of pendulum load cells are used.

6.2 Suspended tanks

Centering problems can often be eliminated or simplified on suspended tanks with simple pliable round tie rods. In addition to tipping protection, which is always necessary, stay rods are also needed to prevent oscillating and turning.

6.2.1 Suspension on two or three load cells

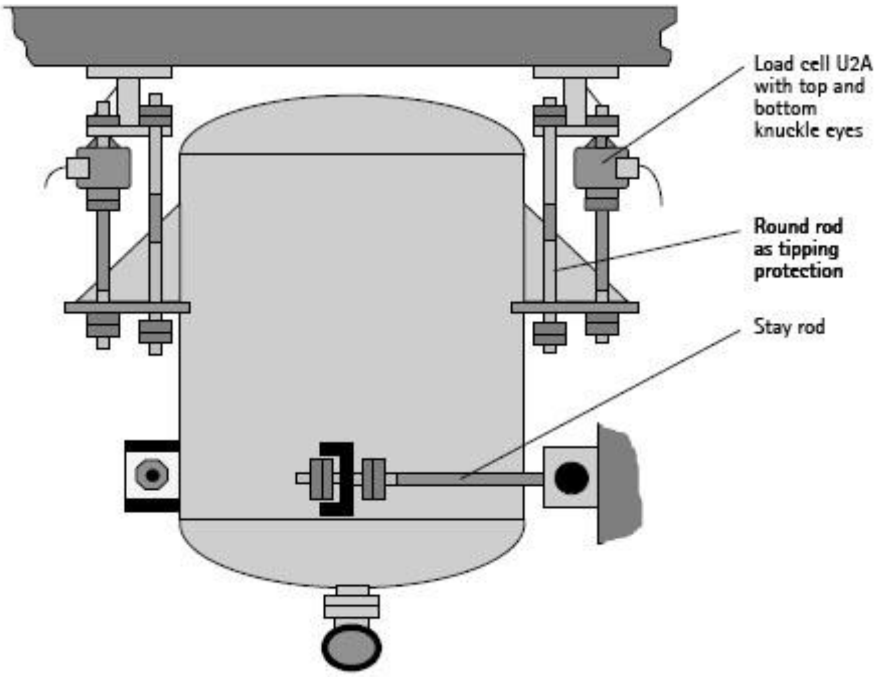

Figure 14: Suspended tank on three load cells

The overall simple design requires several tangentially arranged stay rods. In cases with reduced stress their functions can be taken over by a lower side pipe outlet.

6.2.2 Centric suspension on one load cell

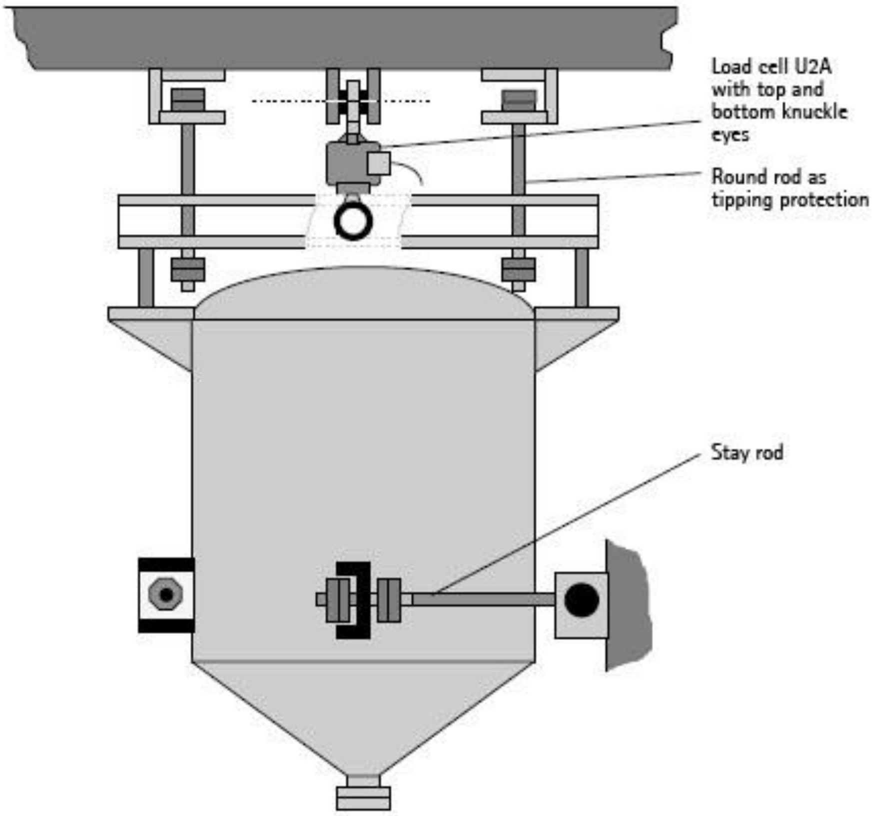

Figure 15: Suspended tank on one load cell

A special restraint is indispensable in this arrangement to prevent oscillating and turning.

6.3 Horizontal tanks for liquids

Horizontal tanks for liquids usually fulfill the condition that the center of gravity of the content must move approximately along a vertical line as the mass of filling changes. The arrangement of one load cell under one tank bracket and two fixed bearings under the other tank bracket is therefore sufficient for relatively simple level measurements. The idealized tank rests with half its weight on one self-centering pendulum load cell and on two fixed bearings. No further restraint is required under normal circumstances. In the case of very long tanks, however, as additional protection against tipping over due to lateral impact against the tank, fixed stops can be provided to limit lateral movements at both ends of the tank cradle which is resting on the load cell.

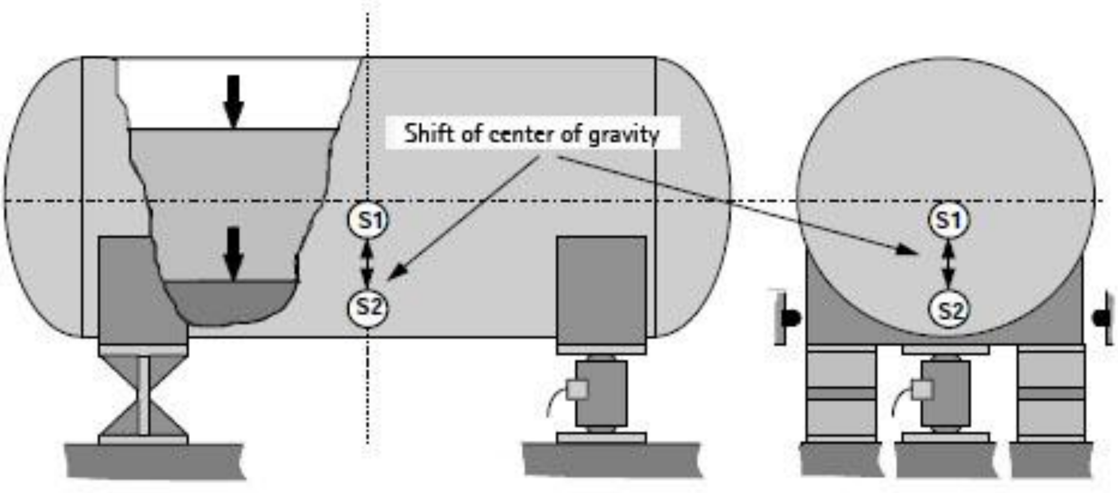

Figure 16: Horizontal tank for liquids with a C16 load cell (diagram)

In practical applications, however, the distribution symmetry of the content is often disturbed by a slight, deliberate inclination of the base line to one side and the outlet which is located there. A self-centering arrangement of three load cells is the optimum solution for more exact weighing, with fixed stops as the best way to implement horizontal restraint.

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