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Typical damage in steel storage tanks in operation

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Abstract

The safe and long service life of structures could be assured only when adequate design and construction are combined with a proper and regular maintenance. The principal objective of this paper is to identify the most common failures that may occur in above ground cylindrical steel storage tanks in operation, to suggest better design decisions, possible solutions for repair and provide guidelines for appropriate care and maintenance of this type of structures.

A group of specialists was assigned the task to conduct a site inspection and provide a statement for the operational condition of 7 new and 13 steel storage tanks in service, owned by State agency “State reserve and war-time stocks”. The facilities contain different oil products – petrol, diesel and mixed fuel stored at ambient temperature and atmospheric pressure. The anchorage conditions vary. Some of the examined storage tanks were built in the 1970s, others – in the period 2009 - 2014. The audit was carried out in accordance with the Agency’s internal directive and standards API 650, API 653, EN 1993-4-2, EN 14015.

Based on this representative study and the practical design experience of the authors, this paper classifies the most frequently reported damage in different elements of tanks in operation – foundations, anchorage (if present), annular plates, tank bottom, shell, roof (fixed or floating), attached accessories and systems. Illustrative examples are presented, along with explanations for the critical aspects of adequate maintenance. Finally, some conclusions are drawn in the form of guidelines for failure prevention and if the damage already exists - possible ways for restoration of the facility to its proper operational state.

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1. Introduction

One of the eminent Bulgarian engineers – Prof. Peter Staykov says in an interview with Ekaterina Toteva from BTA (2014): “Most bridges are like centenarians, without proper care their life could have ended at 50”. The essence of this quotation applies just as well to vertical cylindrical steel storage tanks. These facilities, though not as beautiful and popular as bridges, are no less responsible engineering works. They often contain dangerous and/or environmentally hazardous substances. Moreover, during nearly all of their operational life storage tanks are filled to their maximum allowable level, respectively design stresses are constantly at the limit of the load-bearing capacity. Besides for various reasons (in Bulgaria and probably in other countries as well) the belief that once built, a facility can be exploited for many years with almost no maintenance still exists. Evidence for the latter is provided by Chang and Lin (2006). They review 242 accidents of storage tanks that occurred in industrial facilities in the period 1960-2004. Almost half of the reported cases (46%) were caused by human errors including poor operation and maintenance, equipment failure, crack, leak and rupture, etc., i.e. could have been avoided.


The usage of those documents has its practical implementation. In 2018 a group of specialists was assigned the task to conduct a site inspection, analysis and provide a statement for the operational condition of 7 new and 13 steel storage tanks in service, owned by the Bulgarian State agency “State reserve and war-time stocks”. The inspection, analysis and conclusions had to comply with the requirements of the Agency’s internal directive (2015). Nevertheless, the provisions of some of the leading design codes for steel tanks: API 650, API 653, EN 1993-4-2, EN 14015, were taken into consideration as well. The facilities contain different oil products – petrol, diesel and mixed fuel stored at ambient temperature and atmospheric pressure. The anchorage conditions vary. Some of the examined steel tanks were built in the 1970s, others – in the period 2009 - 2014. Unfortunately, the 13 storage containers in operation were full of fuel at the time of the audit, so access to their internal surfaces was impossible. The visual external inspection showed some damage typical for this type of facilities.

2. Typical damage

2.1. Typical damage of the foundations

According to Bulgarian design practice, the foundations under the investigated steel tanks constitute of a combination of an unrestrained sand cushion and a circumferential reinforced concrete (RC) ringwall, shifted radially in the outward direction, see Fig. 1(a). This solution has an advantage over the classical earth foundations without a ringwall, in a matter of reduction of the area occupied by the foundation, see Fig. 1(b).

![Figure 1. Foundations under steel storage tanks (a) radially shifted reinforced concrete ringwall; (b) earth foundation](image-url)
Some typical damage observed during the site inspection includes:
- cracking and spalling of the circumferential reinforced concrete ringwall, see Fig. 2(a) and (b);
- deterioration of the concrete in the ringwall, loss of the concrete cover and complete exposure of the reinforcement, see Fig. 2(c);

Fig. 2. Damage in RC ringwall (a), (b) severe cracking and splitting; (c) concrete destruction and reinforcement exposure

- cracking between the asphalt cover and the reinforced concrete ringwall, which is particularly characteristic for this type of foundation. Very often vegetation grows in this area, see Fig. 3(a);
- growth of plants between the reinforced concrete ringwall and the catching basin around it. If not removed promptly, they can reach human height, see Fig. 3(b);
- vegetation in the area of the annular bottom plate, see Fig. 3(c), (d). It can also grow very tall;
- cracking of the pavement and vegetation in the anchorage zone, see Fig. 3(e).

Fig. 3. Vegetation on the foundation and the tank base area

With continuous operation settlement develops in the earth layer beneath the tank, but not in the reinforced concrete ringwall, which remains at the same level. As a result, around the tank’s bottom forms an area from which
the rainwater cannot be drained out. This leads to the retention of water on the annular bottom plate and its fast and untimely corrosion, Zdravkov (2005). For some of the inspected tanks, different repairment decisions had been taken to address this problem. The first one is to build a new pavement with a slope steep enough so that it would allow unobstructed drainage of atmospheric water. Because of the settlement, the annular bottom plate is relocated to a level lower than the reinforced concrete ringwall, thus the new pavement covers the joint connection between the tank bottom and the tank shell, see Fig. 4(a). The new joint that forms in the area between the tank shell and the pavement, see Fig. 4(b), is a certain precondition for rainwater retention and accelerated corrosion of the joint shell-bottom. In other words, this approach is quite controversial.

Another solution presented in Fig. 4(c) is cutting channels for water drainage in the peripheral ringwall.

Fig. 4. Repair attempts (a), (b) new pavement laid over the annular bottom plate; (c) new slots in the peripheral ringwall

2.2. Typical damage of the tank bottom

Access to the internal surfaces of the tanks in operation during the inspection was impossible. For this reason, only external damage has been noted. Some examples are:

- sinking of the tank bottom into the surrounding pavement. Sometimes this process is also associated with bending of the annular bottom plate, see Fig. 5(a);
- lifting of the annular bottom plate over the pavement, see Fig. 5(b);

Fig. 5. Damage in the annular bottom plate area (a) sinking and bending; (b) cavity under the annular bottom plate
2.3. Typical damage of the tank shell

Typical damage of the tank shell includes:

- paint coating deterioration and initiation of intensive corrosion processes, see Fig. 6. Occasionally, large areas appear where the paint cover is completely detached and has fallen off. The rather uncommon occurrence in these examples is the fact that the inspected tanks have been repaired and painted over the period 2008-2010, which is relatively soon. When using quality paint coatings, designed to protect steel tanks in the petrochemical industry, and applying them in accordance with dyeing technology, no damage of this type should be present;

![Fig. 6. Damage of the tank shell (a),(b) on the paint coating; (c),(d) corrosion on elements](image)

- local deformation of the tank shell, see Fig. 7.

![Fig. 7. Local deformation of the tank shell (a) outward deformation; (b) inward deformation](image)

2.4. Typical damage of the tank roof

Typical damage on fixed tank’s roof is:

- paint degradation and intense corrosion on the roof plates and attached nozzles for equipment, see Fig. 8(a),(b). The above mentioned in 2.3. regarding paint detachment is fully applicable here, as well;
- poorly implemented attempts to repair the roof plates, see Fig. 8(c).
The damage, observed on the floating roofs includes:

- product leakage and retention on the floating roof. The cause of this problem is a rupture in the roof membrane. Unfortunately, the tank in Fig. 9(a) has been in service with this damage for over a year and a half;
- deformation of the foam dam, see Fig. 9(b). This malfunction is due to the fact that the metal sheet of the foam dam is not properly stiffened at the top;
- opening of a gap between the roof seal and the tank shell, see Fig. 9(c). This poses a twofold problem – on one hand, stored fuel evaporates through the gap and on the other - rainwater enters in the reservoir;
- presence of rainwater and moist inside the pontoons of floating roofs leading to intense corrosion, see Fig. 10(a);
- product leakage and evaporation into the pontoon, see Fig. 10(b);
- radial displacement of the floating roof and excessive deformation of the seal around the roof guide pole, see Fig. 10(c).

2.5. Geometric deviation.

Geometric deviations from the design positions and shape of the tank elements could also lead to structural or operational failure. Even if they do not pose a significant structural problem, they may begin to interfere with the free movement of the floating roof in case one is present.
2.6. Typical damage on attached appurtenances such as stairways, ladders, handrails, support framework, manholes, nozzles, stiffeners, water drain and venting systems, monitoring and protection systems, etc.

Some of the most common damage on attached appurtenances and systems is:

- protective paint degradation and corrosion;
- poor quality welding, crossing of vertical and horizontal welds, distance between welds and adjacent elements is less than the allowable minimum;
- missing connection bolt assemblies on roof manholes and flanges;
- elements such as plates, pipes, etc. are not in their design positions;
- deformation in elements for example hatches, flanges, etc.;
- closed/open rim vent covers (opposite of the design condition);
- damaged seals;
- compromised integrity of the bunding (the tank or tank group shall be surrounded by a ditch or an embankment).

3. Conclusions

Vertical cylindrical steel storage tanks are responsible facilities that are filled at their maximum capacity during almost all of their operational life. They often contain toxic, flammable and/or expensive products and therefore should be treated with caution and responsibility. Unfortunately, some tank owners still believe that once built a facility can be exploited for a long time without proper maintenance.

Based on the inspection of the thirteen tanks with a long-time operation and the practical experience of the authors, it is possible to summarize some measures that would increase the safety of all vertical steel tanks:

3.1. Design stage measures

- The foundation design solution presented in Fig. 1(a) - with a ringwall, radially shifted from the base, should not be applied to new tanks;
- A high degree of soil compaction should be prescribed for the soil and/or crushed stone below the bottom of the tank;
- Quick and easy drainage of rainwater from the roof and the tank shell should be ensured. The connection joints of steel elements should be designed in a manner that does not allow water retention;
- The paints, prescribed in the “Anticorrosion Protection” project should be selected to provide long-lasting protection for the steel elements of the tank.
3.2. Fabrication and construction stage measures

- Fabricated elements of the structure shall be checked for complete compliance with the design;
- Construction and assembly shall be monitored and implemented by authorized personnel so that it fully complies with the legislative documents and technical requirements for the products and processes.

3.3. Measures during operation

- Steel tanks should be inspected regularly, as prescribed by a relevant legislative document. Regular maintenance is highly recommended;
- Along with the tank structure, all the attached accessories and supporting systems shall be evaluated for necessary repairs or replacements;
- All observed faults or damage should be described in a log and repaired as soon as possible;
- Grown vegetation should be removed promptly.

3.4. During repair works

- When applying the corrosion-resistant coating, the technological requirements for maximum humidity, minimum temperature and the degree of cleaning of the surfaces have to be met;
- All repairs should not deteriorate the condition of the tank;
- All materials used and processes implemented must comply with the guidelines and requirements provided by the manufacturer and the relevant legislative documents.

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