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Application of Statistical Analysis for the Identification of Critical Bottom Areas Due to Corrosion in Atmospheric Storage Tanks

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Equipment ageing containing hazardous substances is a criticality for the safe as leakages can give rise to serious accidental scenarios such as fires, explosions, and dispersions of chemicals into the environment. The attention towards this issue grows over the time and becomes significant when the equipment is reaching the end of its lifetime. Ageing management usually includes targeted and in-depth integrity controls performed at regular intervals. Atmospheric storage tanks of hydrocarbons are particularly critical as the control of the bottom integrity requires not only the service interruption, but also the need for the inspectors to stay long time in hazardous environments during the time required for the thickness measurements. One of the main causes of perforation is corrosion. The whole bottom is in any case subjected to significant stress, therefore, the thickness of the bottom plates must not be below a threshold value to avoid leakages. The aim of this work is to investigate the entire bottom of an atmospheric storage tank to identify the most susceptible locations with respect to the deterioration due to localised corrosion. The assessment of the probability of perforation of the bottom indicated the annular ring as the most critical. To achieve this objective, the latest inspection data have been used that allowed identifying the probabilities of leakage for the various homogeneous areas identified in the bottom. An estimate of the time to reach the critical thickness has also been given based on a recent approach that combines the extreme value theory of with the Bayes theorem.

1. Introduction

Atmospheric storage tanks of hydrocarbons are particularly critical because the control of the bottom integrity requires that they must be taken out of service. Internal inspections are very costly and time consuming, in addition there is also the need for the inspectors to stay long time in hazardous environments for the execution of thickness measurements. The localised corrosion is one of the main causes of the bottom perforation. The outer edge at the base of the tank, so-called annular ring, is particularly critical to corrosion because it includes the shell welding. Numerous standards (EEMUA, 2014; API, 2016) points that it is essential to monitor the thinning of the bottom plates of storage tanks as well as the annular ring to avoid leakages and catastrophic floor ruptures. The assessment of the integrity of annular ring can be made from the interior or the exterior of the tank. The inspection from the exterior with ultrasounds (UT) requires thoroughly removing all corrosion products, this is not a safe operation, thus it is preferred to inspect them during planned bottom inspections. Other in-service inspection methods are acoustic emissions, but these provide only indications of the potential evolution of damages.

Several documents evidenced the relevance of equipment ageing in contributing to major accidents (Wood et al., 2013; Semmler, 2016; Gyenes and Wood, 2016; OECD, 2017; Pasman and Fabiano, 2021). In particular, the Seveso Directive explicitly requires the operators of major hazard accident establishments to demonstrate the adoption of proper management plans to control deterioration processes. To this scope, it would be useful for the operators to be able to make predictions about the future equipment condition, to calculate the probability of release due to ageing and to understand how long it is possible to safely extend the residual

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useful lifetime (RUL). The knowledge of the probability of leakage from the bottom plates and the annular ring of atmospheric storage tanks allows integrating these accidental scenarios into the safety report of major accident hazard establishments.

The aim of this work is to investigate the entire bottom of an atmospheric storage tanks to identify the most susceptible areas to the deterioration due to localised corrosion. This is possible the elaborating data from the latest inspection in order to identify the probabilities of leakage for the various critical areas. An estimate of the time to reach the critical floor thickness (bottom plates including its annular ring of the tank) has also been made based on a recent approach that combines the extreme value theory of with the Bayes theorem (Milazzo et al., 2022). Thickness measurements are obtained by means of field inspections with different measurement techniques such as ultrasounds and magnetic flux leakage. This study has been developed within the MAC4PRO project, which supported by the Italian Workers' Compensation Authority (INAIL), and focuses on a wider investigation context, including civil infrastructures and industrial structures. The paper is structured in the following sections: Section 2 discusses the methodology for the assessment of the probability of leakage from the bottom and the residual useful lifetime; Sections 3 presents the case-study investigated in this study; Section 3 shows the results of the application and the discussion; finally, Section 4 provides some conclusions and future remarks.

2. Methodology

The proposed approach for the assessment of the perforation probability of the bottom of atmospheric storage tanks and the residual lifetime uses the extreme value theory and the Bayesian inference (Milazzo et al. 2022;). The input data to the model is the thickness measurements obtained through field inspections. The studied area is divided firstly in homogeneous areas and then into smaller parts. For each part, the minimum thickness is identified. After, the sets of the maximum corrosion values are obtained for each homogeneous area, the Gumbel distribution (Gumbel, 1958) is used to estimate the probability of the critical depth for each area:

$$F(x) = \exp\left(-\exp\left(-\frac{x-\beta}{\alpha}\right)\right) \tag{1}$$

where $F(x)$ is the cumulative probability function; α and β are respectively the scale and the location parameters of the distribution.

To determine α and β, a reduced variate (y) is introduced to make the linearization of the Gumbel function (Gumbel plot). The parameters α and β are obtained from the slope and the intercept of the line representing the Gumbel plot:

$$y = \frac{x-\beta}{\alpha} \tag{2}$$

$$y = -\ln\left(\ln {}^{1}\!\!/_{F(y)}\right) \tag{3}$$

where $F(y)$ is the cumulative probability.

The Bayesian inference allows estimating a posterior probability of the scale and position parameters $\chi''(\alpha|x_{\max})$, and $\lambda''(\beta|x_{\max})$ at a given time. This is possible by means of inspection data, i.e. the likelihood functions $f(x_{\max}|\alpha)$ and $f(x_{\max}|\beta)$, and the a priori probabilities $\chi'(\alpha)$, and $\lambda'(\beta)$ which includes the knowledge deriving from inspections made for tanks with similar characteristics. The following correlations represent the Bayesian inference:

$$\chi''(\alpha \mid x_{\max}) = \frac{\chi'(\alpha)\cdot f(x_{\max}\mid\alpha)}{\int \chi'(\alpha)\cdot f(x_{\max}\mid\alpha)\cdot d\alpha} \tag{4}$$

$$\lambda''(\beta \mid x_{\max}) = \frac{\lambda'(\beta)\cdot f(x_{\max}\mid\beta)}{\int \lambda'(\beta)\cdot f(x_{\max}\mid\beta)\cdot d\beta} \tag{5}$$

Once the prediction of the parameters of the Gumbel distributions have been obtained, a new plot position is constructed that represents the expected trend after a given time. By using the past and expected plot positions, the probability (y axis) that corrosion is less or equal to a given value (x axis) can be read. If several inspections are available, it possible for a certain probability to draw the graph corrosion vs. time. The corrosion rate is the slope of the curve and is not constant. Finally, the curve allows also estimating the residual useful life (RUL), associated to the same probability, which is obtained by intersecting the curve corrosion vs. time with the threshold limit for the thickness of the bottom and annular ring.

3. Case-study

The methodology has been applied to an atmospheric storage tank containing diesel fuel (Figure 1a), located in a storage depot of an Italian Seveso site. The measures of thickness have been taken for the 135 carbon steel plates of the tank bottom and in three locations points of the annular ring (external side, central and internal side for the main cardinal directions and some intermediate directions) (Figure 1b). The nominal thickness of bottom plates is 8 mm, whereas it is 8.5 mm for the annular ring. The circular covered area of the tank is about 1855 m^2 with a radius of 24.3 m. The tank is in-service since the 1965. Two non-destructive inspections, carried out for the bottom and the annual ring, have been analysed for this study. Between the first and second bottom inspections, no plate changes have been carried out. A summary of the statistics of the inspection data is shown in Table 1.

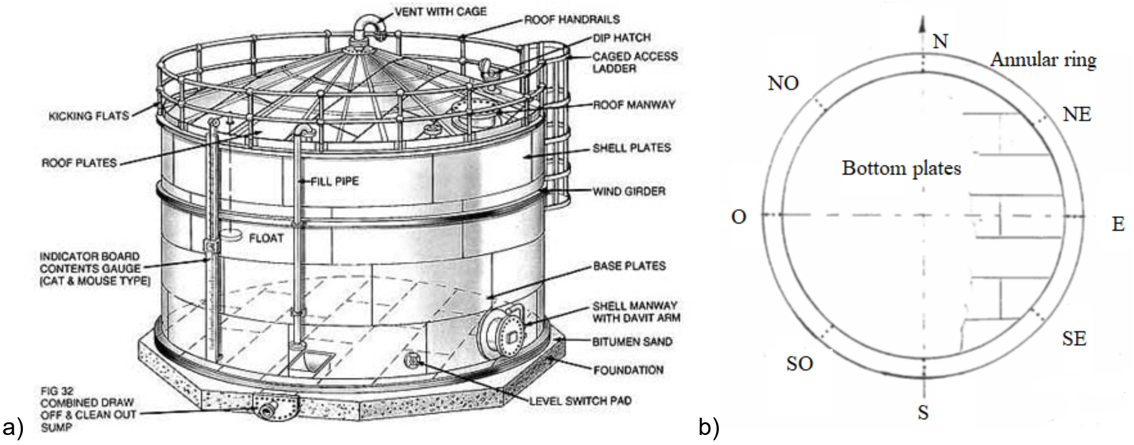


Figure 1: a) Scheme of a typical atmospheric storage tank with fixed roof [API 650] and b) location map of the measured points during the annular ring inspections.

Table 1: Statistics for the inspection data for annular ring and bottom plates.

Component	ID inspection	Year	Technique	Average thickness [mm]	Minimum thickness [mm]	Standard deviation
Bottom plates	1	1990	UTM	6.84	6.1	0.21
	2	2019	MFL	5.1	0.4	1.82
Annular ring	1	2002	UTM	7.27	5.8	0.67
	2	2008	UTM	6.37	4.2	1.05

4. Results and discussion

The sets of maximum corrosion depths deriving from the inspection of the bottom and the annular ring have been used for the estimation of the parameters of the Gumbel distributions and the subsequent analysis gave the corrosion rate and RUL by applying the methodology described in Section 2.

4.1 Application of the extreme value theory

Figure 2a) and 2b) gives the plot positions constructed by using the inspections 1 and 2 respectively for the bottom plates and the annular ring. The parameters of the Gumbel distributions have been obtained (Table 2). The values of scale and location parameters of the bottom plates and the annular ring refer to different years, therefore, an annual increase has been calculated for them (Δ).

It can be observed that the scale parameter (α), which represents the dispersion of pits over the surface, grows in similar way for both the bottom and the annual ring; whereas the location parameter (β), which is the most frequent pit depth, significatively increases for the annular plates (~50% for the annular ring and ~19% of the bottom plates). This investigation confirms that the annular ring is the most critical area of an atmospheric storage tank containing hydrocarbons.

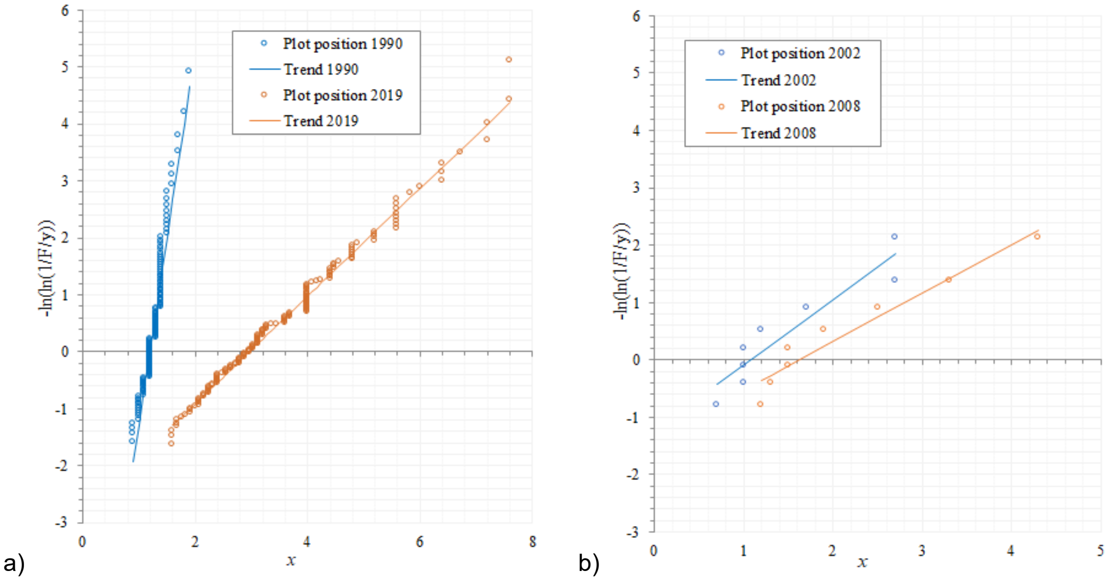


Figure 2: Plot positions for inspection 1 and 2 respectively for: a) bottom plates and b) annular ring.

Table 2: Gumbel parameters.

Year	Bottom plates		Annular plates	
	Scale parameter (α)	Position parameter (β)	Scale parameter (α)	Position parameter (β)
2002	0.527	1.926	0.876	1.076
2008	0.715	2.292	1.186	1.613
Δ	0.188	0.366	0.309	0.538
Δ(%)	35.6%	19.0%	35.3%	50.0%

4.2 Model validation

The approach has already been validated for the bottom plates in a previous work (Milazzo, et al., 2022). In this study the validation has been made for the annular ring area by using the data collected during the first inspection (2002). The prediction of the distribution parameters has been done at the time of the second inspection in order to compare the result with the actual parameters. Figure 3 shows the a priori and posteriori distributions of the distribution parameters. Table 3 shows the results of the Bayesian inference and compare them with those obtained from the application of the approach presented in Section 2.

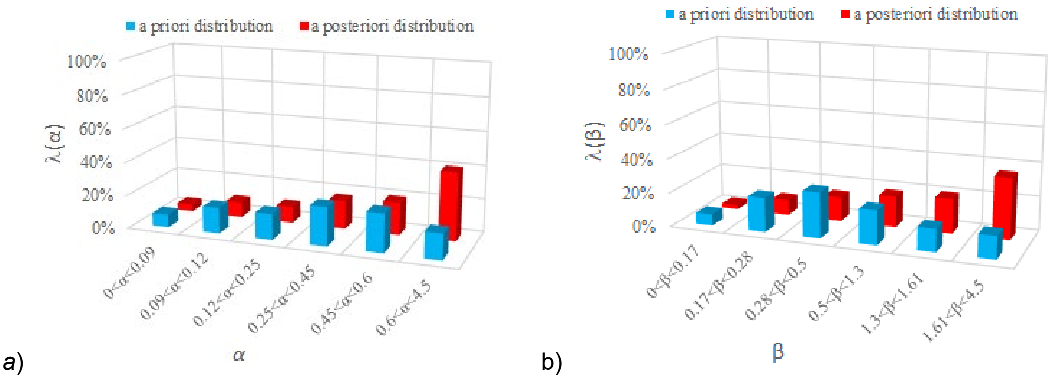


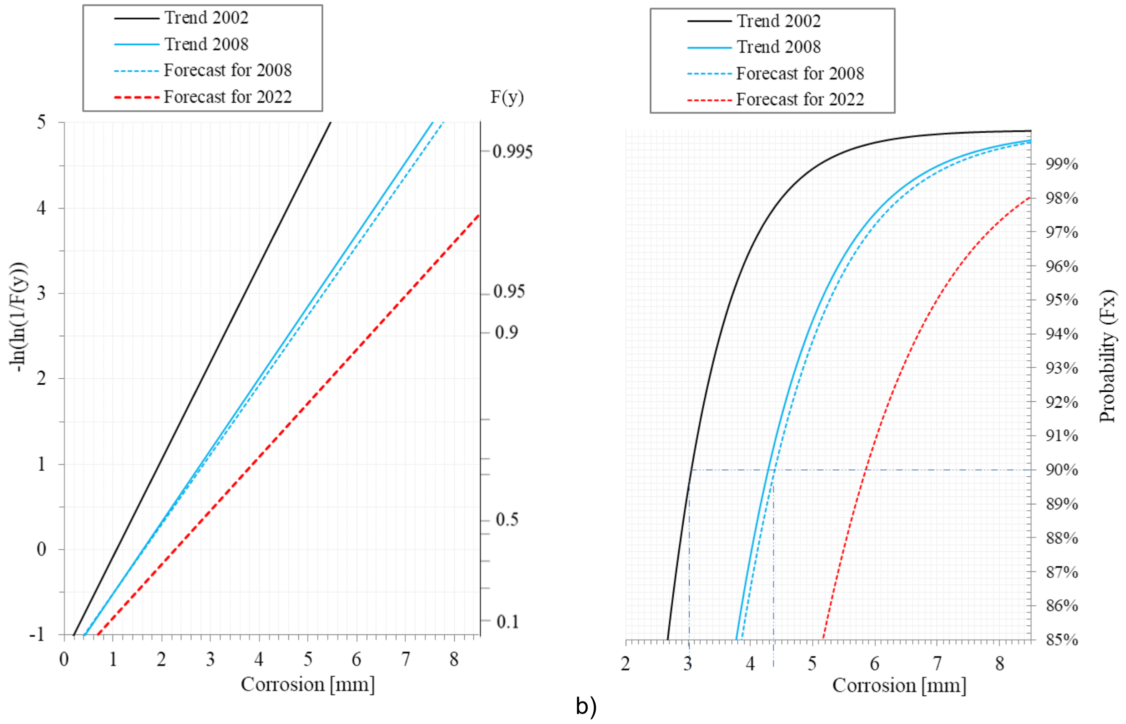
Figure 3: A priori and posteriori distributions for: a) the scale parameter, b) the location parameter.

Table 3: Actual and expected Gumbel parameters for the inspection of 2008.

	Scale parameter (α)	Position parameter (β)
Actual values	1.186	1.613
Values from Bayesian inference	1.225	1.630

4.3 Estimate of the RUL

Once the most critical part of the bottom of the atmospheric tank has been identified the RUL has been estimated. By means of the Bayesian inference the distribution parameters and the corrosion rate in 2022 have been predicted by assuming that no replacement has been made since the last inspection and that the surrounding conditions have not been modified (repairs, partial or total replacements of plates, change of the type of substance stored inside, etc.). Since the nominal thickness of the plates is 8.5 mm, a critical threshold of 6 mm has been used to define the residual useful lifetime of the equipment as suggested in EEMUA (2014). In Figure 4a) the actual and expected plot positions are reported, whereas in Figure 4b) a detail of the Gumbel cumulative probability curves is shown. Finally, Figure 5 shows the corrosion rate and the RUL associated with a probability of 90%. The corrosion rate has been estimated to be 0.22 mm/year. The RUL for the equipment after the second inspection of the annular plates (i.e. in 2008) is about 7 years.



a) b)

Figure 4: a) Actual and expected plot positions for the annual ring, b) Actual and expected Gumbel cumulative probability distributions for the annual ring (detail).

5. Conclusions

The approach allows identifying the most critical area based on the analysis of inspection data and thus on the conditions detected. At the same time the establishment operator can make forecast about the evolution of the degradation of the whole bottom tank based on the estimation of the probability of the residual thickness. The approach supports in planning the next inspection by reducing the out-service time and the exposure of operators (maintenance workers and inspectors) to a dangerous environment if the degradation of the tank has been well-controlled.

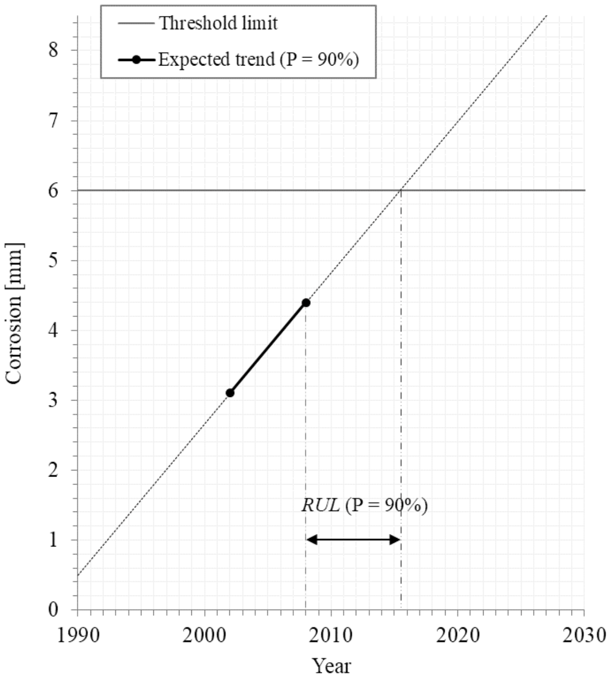


Figure 5: Residual Useful Lifetime (probability 90%).

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