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Pressure Vessel Fitness-for-Service Evaluation Based on API579 and API581 Standards

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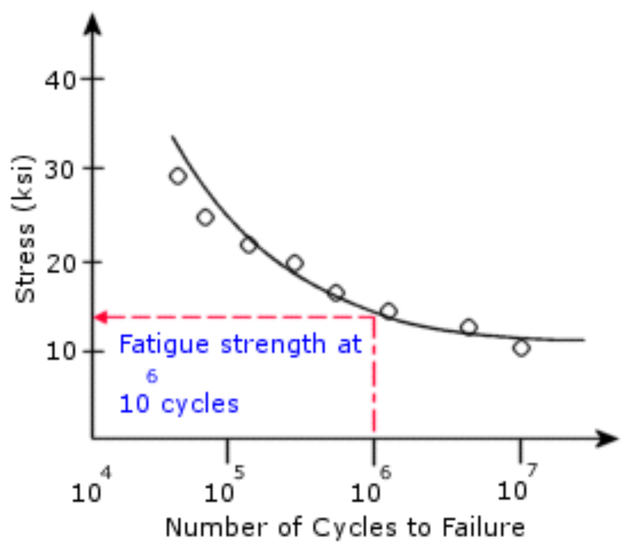
Summary

- 1. Introduction
- 2. Method of Analysis
- 3. Application
- 4. Conclusion

Introduction

- Structures that may present fatigue failure are usually designed using SN curve model.
- This model encompasses in a single curve the nucleation and propagation phase of the crack furnishing a estimate of the structural detail operational life. For pressure vessel design the SN curve is used considering it free from cracks.



Introduction

- On the other hand, for vessels in service, cracks may be identified during periodic inspections.
- During structure operation non-destructive inspection methods are used to evaluate structural integrity based on crack size evaluation, according to API 579 standard requirements.
- A method based on crack growth estimate and crack size effects on structural integrity must be used to evaluate failure probability during structure operational life.
- The present paper uses The Failure Assessment Diagram (FAD) for the analysis of elastoplastic fracture of structural components which was originally proposed in 1975.

Method of Analysis

System architecture

Stress and strength

Mission profile

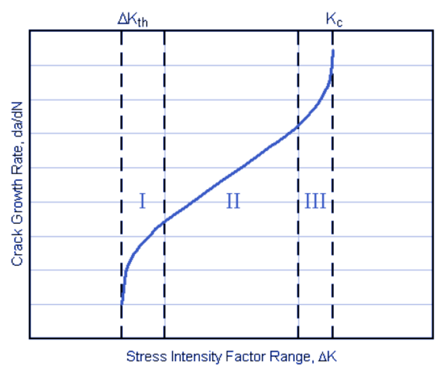
Random variables

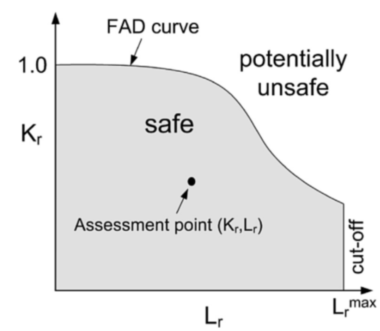
Statistical distributions

Crack growth law

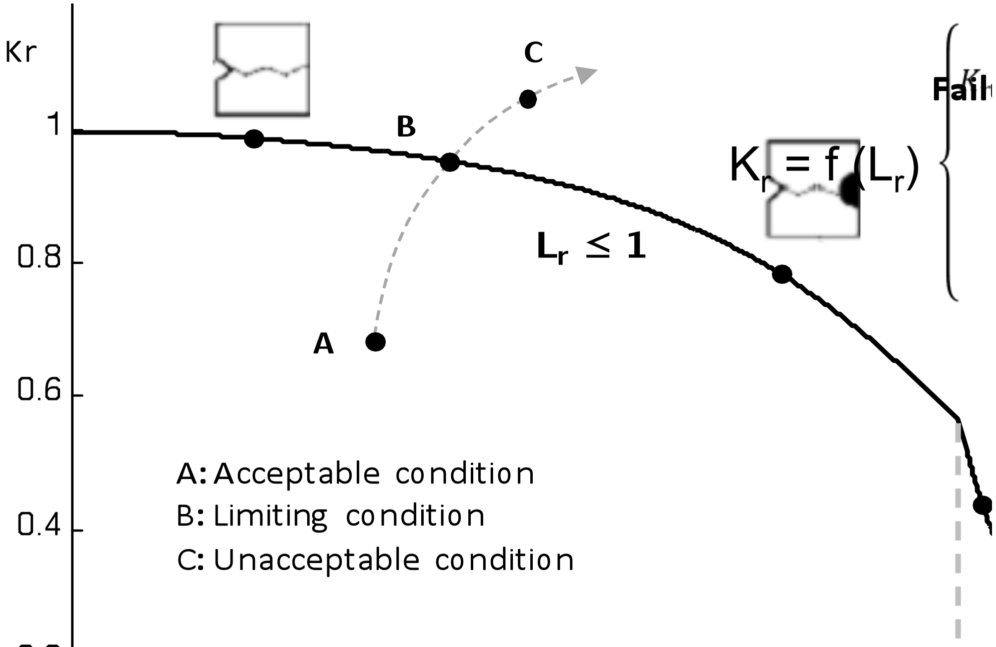
Probability densi

Fail





Method of Analysis



$$\begin{cases} K_r = f(L_r) = \left(1 + \frac{1}{2} L_r^2\right)^{-\frac{1}{2}} . \left[0{,}3 + 0{,}7 . e^{(-\mu . L_r^6)}\right], & for\ L_r \\ K_r = f(L_r) = f(1) . L_r^{\frac{N-1}{2N}} & for\ 1 < L_r < L_{max} \\ K_r = f(L_r) = 0 & for\ L_r \geq L_{max} \end{cases}$$

$$N = 0{,}3 . \left(1 - \frac{\sigma_Y}{\sigma_U}\right)$$

$$\mu = min\left(0{,}001 . \frac{E}{\sigma_Y}, 0{,}6\right)$$

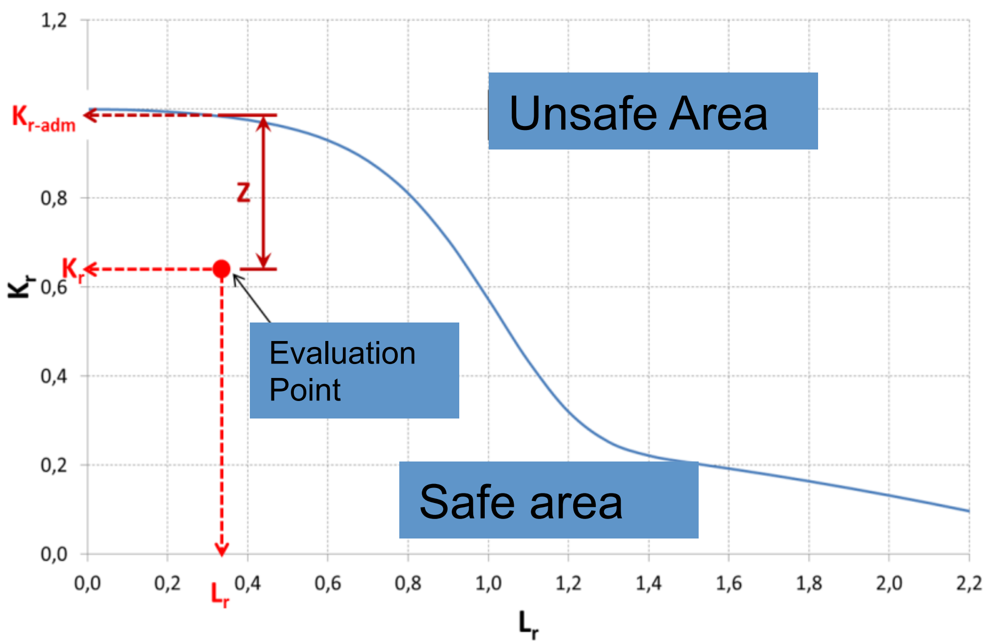
$$L_{max} = \frac{\sigma_Y + \sigma_U}{2 . \sigma_Y}$$

$$L_r = \frac{\sigma_{stress}}{\sigma_{strength}} ; \quad K_r = \frac{K_{stress}}{K_{strength}}$$

↑ the ratio between the stress and the ductile strength of the material

↑ the ratio between the stress and the fracture strength of the material

Method of Analysis



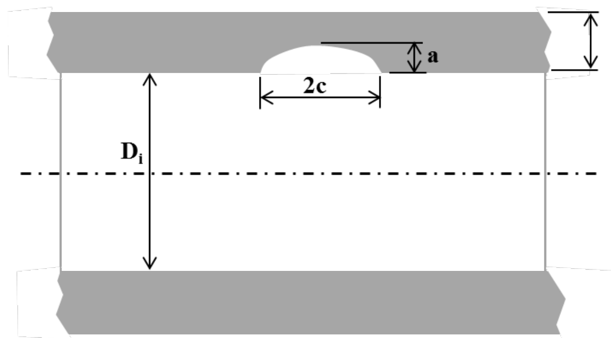
$$L_r = \frac{\sigma_{ref}}{\sigma_Y}; \qquad K_r = \frac{K_I}{K_{mat}}$$

Models for σ_{ref} and K_I depend on the geometry of the structure and flaw.

Performance Function as for Reliability Analysis

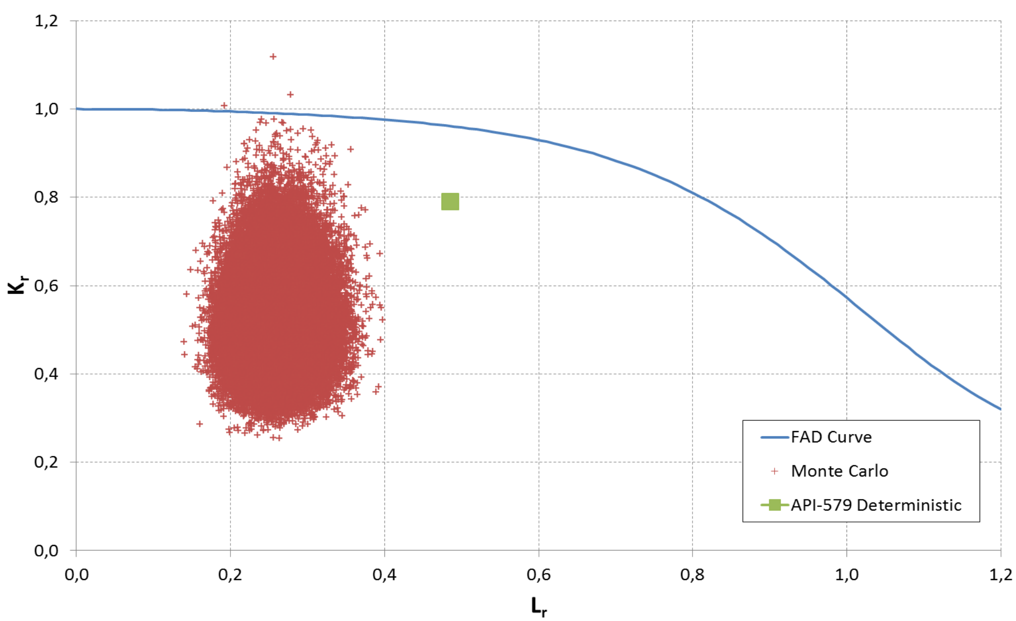
$$Z = K_{r-adm} - K_r$$

Application



Variable
Internal pressure (P
Internal diameter (I
Wall thickness (t) [

Application



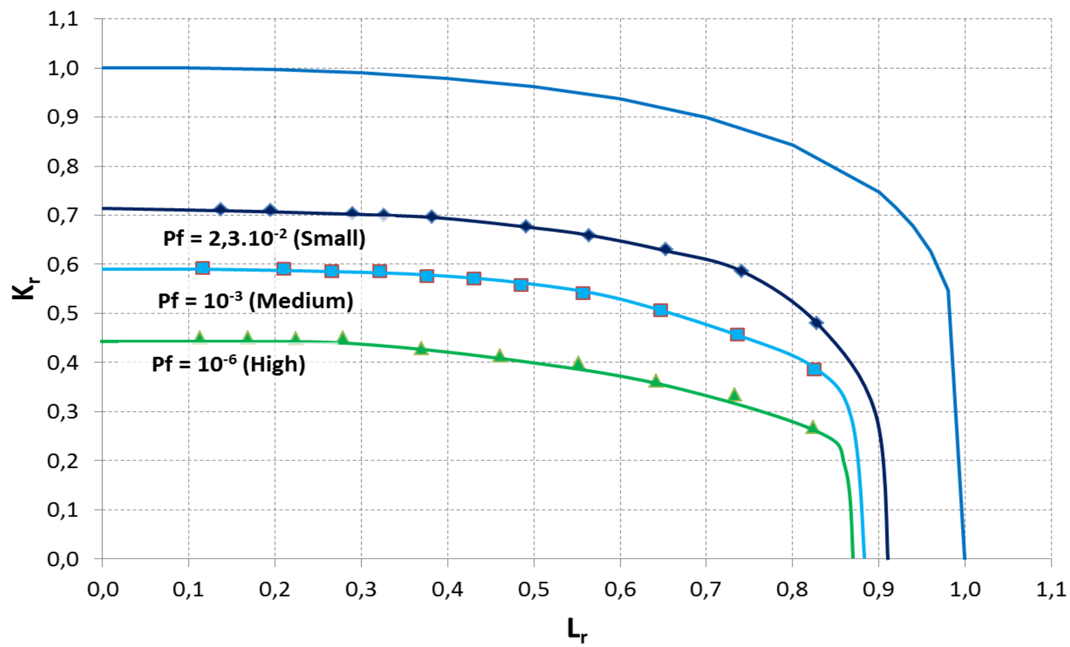
$$K_I = \frac{p.R_o^{\,2}}{R_o^{\,2} - R_i^{\,2}}.\sqrt{\frac{\pi.a}{Q}}.F\left(\frac{a}{c},\frac{a}{t},\frac{R_i}{t},\theta\right)$$

$$\sigma_{ref} = \frac{g.P_b + \left[(g.P_b)^2 + 9\left(M_s.P_m.(1-\alpha)^2\right)^2\right]^{0,5}}{3(1-\alpha)^2}$$

Results from 10^5 Monte Carlo simulations of the cracked pressure vessel. The isolated point in the graph is the result from a deterministic assessment for this vessel

Application

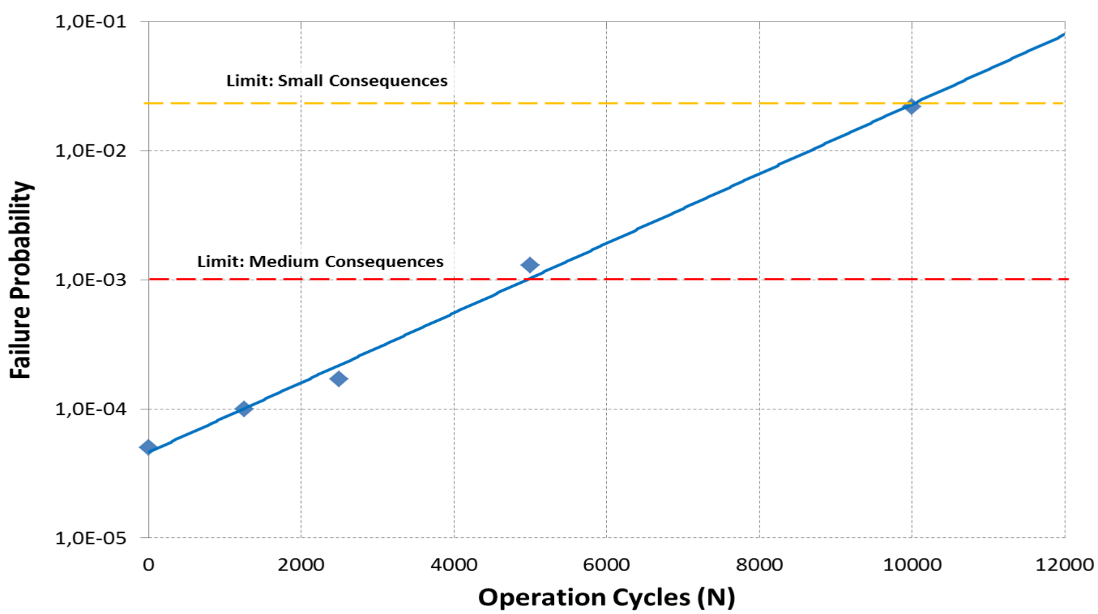
FOSM based Probability of Failure Evaluation



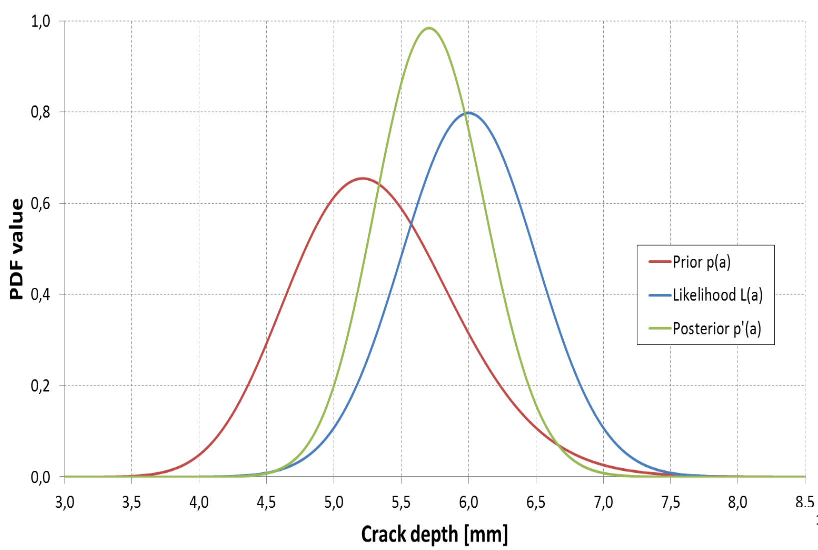
Application

Crack Growth estimative based on da/dNxΔK
Results fitted to Lognormal distribution

N [cycles]	a [mm] Mean	COV [%]	2c [mm] Mean	COV [%]
1250	5.18	10.5	81.30	0.6
2500	5.32	11.7	81.30	0.6
5000	5.62	17.2	81.32	0.6
10000	6.17	29.8	81.43	0.8



Application



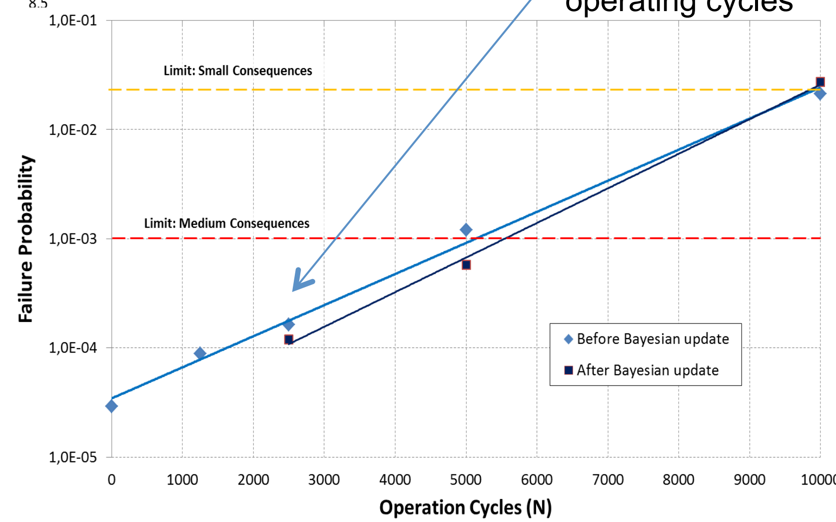
$$p'(a) = C.N[6.0;0.5].LN[5.32;0.62]$$

Posterior crack depth distribution

Crack depth distribution - Inspetion

Crack depth distribution - estimated

Inspection after 2500 operating cycles



Conclusion

- FAD is a generic failure criteria that considers the contribution of brittle and ductile failure modes. The FOSM based reliability analysis can be automated and generalized for different systems under different operational contexts.
- The probabilistic method presented lower failure probability than that indicated by the deterministic methodology from API-579.

Conclusion

- Despite its complexity due to information required on the PDFs for the input data, the application of the probabilistic method brings relevant information to the plant operator to maximize equipment availability.
- The use of the probabilistic re-evaluation of the remaining life of the evaluated pressure vessel