Updating the failure probability of miter gates based on observation of water levels

Thuong Van DANG, Quang Anh MAI
Pablo G. MORATO, Philippe RIGO

Department of ArGEnCo, University of Liège, Belgium

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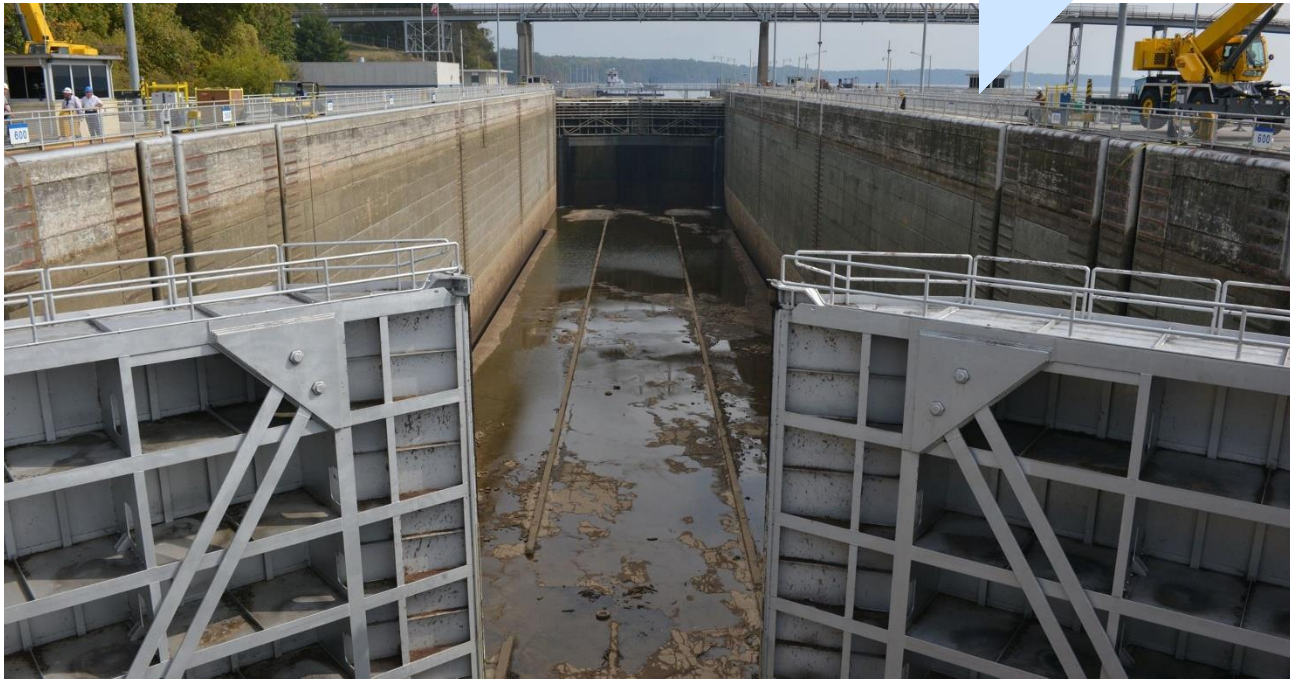
Motivation

Deterioration of welded joint

Water observation levels

Update probability of failure



Message Objective

- The aim of this research is to predict the inspection time of a welded joint using the observed water levels from the operational history.
- The updating of the failure probability is done for three inspection techniques, considering annual probability and repair decisions.

Outline

- ❖ Introduction
- ❖ Equivalent stress range
- ❖ Calibrating Fracture mechanic model
- ❖ Updating Probability of failure
- ❖ Conclusion

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Introduction

- Basically, miter gates are inspected at approximately 5-10 years intervals.
- The results of the inspection provide data to update failure probability every 5–10 years.
- This study introduces another technique that updates failure probability based on critical annual probability, considering the probability of detection and repair decisions.

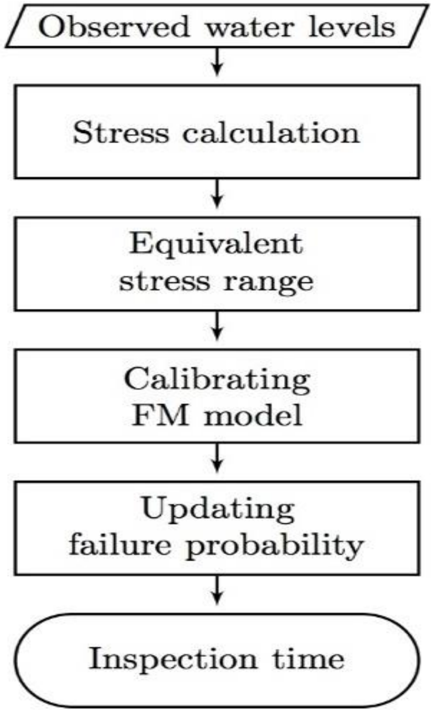

Figure 1. Updating procedure

Equivalent stress range

- The different stress-ranges occurs during the year are represented by an equivalent stress-range value, as follows Eq. (1).

$$\Delta\sigma = \sqrt[m]{\frac{D_{tot}C}{nT}} \qquad (1)$$

- Where D_{tot} is total accumulated damage, C is material parameter, n = 7048 is the number of levelling per year and T = 50 years is the time of observations.

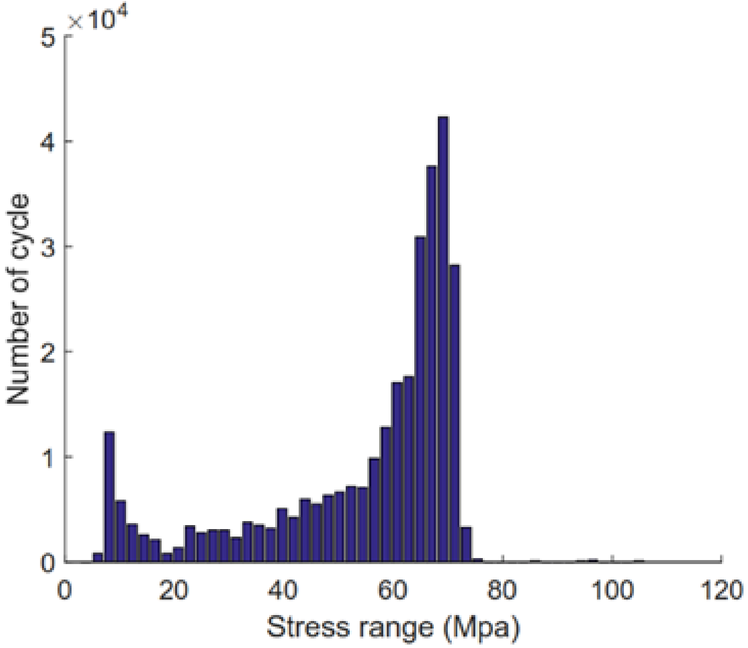

Figure 2. Stress range histogram

Calibrating Fracture mechanics model

Failure probability of the welded joint is first calculated using a limit state function based on Miner's rule (S-N model), Eq. (2).

$$g = \Delta - n\,\frac{B_S^m \Delta\sigma^m}{C} \qquad (2)$$

where Δ and Bs are the damage criteria and uncertainty load factor, respectively. First order reliability method (FORM) and second order reliability method (SORM) are used to calculate reliability index and the cumulative probability of failure for S-N curve model.

Calibrating Fracture mechanics model

Table 1. Input data for S-N model

Parameters	Description	Distribution	Mean	Cov
n	No. of cycle/year	Deterministic	7048	
Δ	Uncertainty Fatigue damage	Lognormal	1.0	0.3
m	Material parameter	Deterministic	3	
Δσ (MPa)	Stress range	Deterministic	57	
T (Years)	Time service	Deterministic	100	
Bs	Uncertainty load	Lognormal	1	0.25
C	Material parameter	Lognormal	3.5239e11	0.486

Calibrating Fracture mechanics model

To incorporate the crack inspection results into assessing failure probability, a fracture mechanic (FM) model is used for crack propagation. The most widely used model is the Paris-Erdogan law:

$$\frac{da}{dN} = C(Y\Delta\sigma\sqrt{\pi a})^m \quad (2)$$

where da/dN is the rate of crack growth, C and m are material parameters, Y is geometry function, Δσ is the equivalent stress-range.

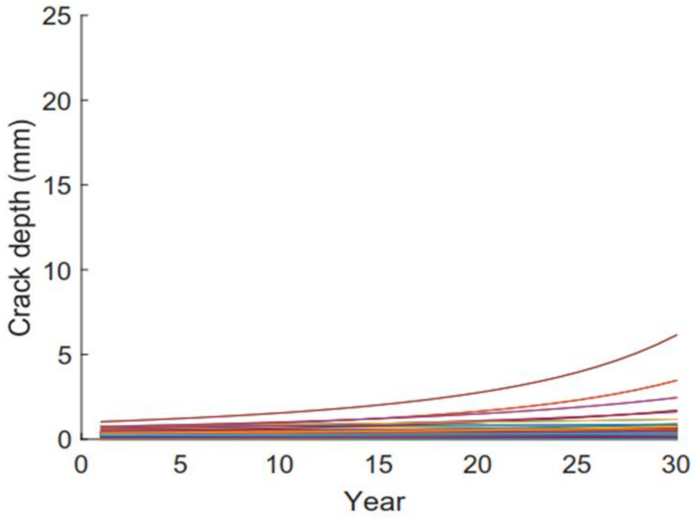

Figure 3. Crack propagation

Calibrating Fracture mechanics model

The calibration algorithm is carried out by a least-squares fitting in cumulative failure probability space (P_f), as shown in Eq. (3).

$$min \sum_{t=1}^{T} (P_{fSN}(t) - P_{fFM}(t; x_1 \dots x_N))^2 \qquad (3)$$

where $P_{fSN}(t)$ is the cumulative failure probability at time t, evaluated using the S-N model; $P_{fFM}(t; x_1 \dots x_N)$ is the cumulative failure probability at time t, evaluated using FM model with a set of parameters $(x_1 \dots x_N)$ representing initial crack size, C, uncertainty of geometry function. T is the service life of the considered structures.

Calibrating Fracture mechanics model

Table 2. Input data for FM model

Parameters	Description	Distribution	Mean	Cov
n	No. of cycle/year	Deterministic	7048	
m	Material parameter	Deterministic	3	
Y	Geometry function	Deterministic	1.12	
B_y	Uncertainty geometry	Normal	1.0	0.649
$\Delta\sigma$ (MPa)	Stress range	Deterministic	57	
T (Year)	Service life	Deterministic	100	
a_0 (mm)	Initial crack size	Exponential	0.16	
a_c (mm)	Thickness	Deterministic	25	
B_S	Uncertainty load	Lognormal	1	0.25
C	Material parameter	Lognormal	2.483e-12	0.664

Calibrating Fracture mechanics model

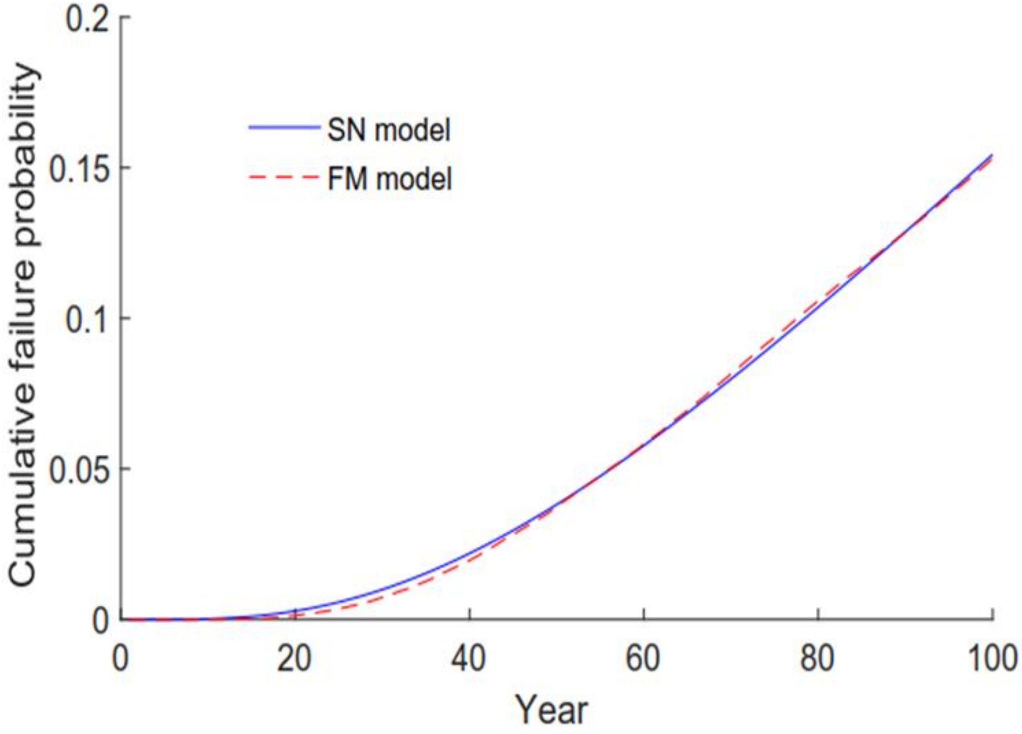

Figure 4. Calibrated result

Updating Probability of failure

The simulation method is used to update the failure probability (P_f), considering POD and repair policies. It is assumed that all detected cracks are repaired.

The maximum allowable annual probability of failure P_f =1.4×10^{-3} (equivalent to a target reliability index after 50 years is 1.5 in EN1990) and 90% POD in three inspection techniques A, B, C are used. The POD curves are represented by the Log-Odds-Log scale model:

$$\mathrm{POD(a)} = \frac{\alpha a^{\gamma}}{1+\alpha a^{\gamma}} \qquad (4)$$

where a (mm) is the detectable crack and α, γ are regression parameters of A, B, C.

Updating Probability of failure

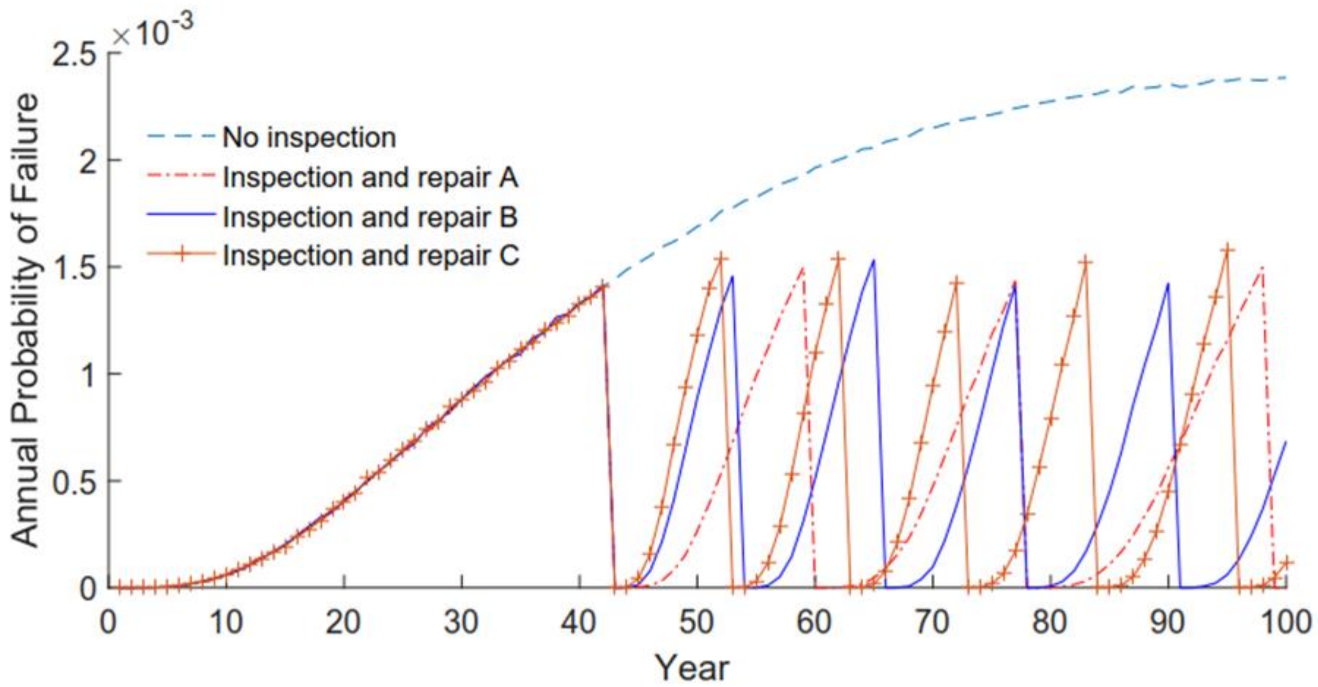

Figure 5. Updating annual failure probability

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Updating Probability of failure

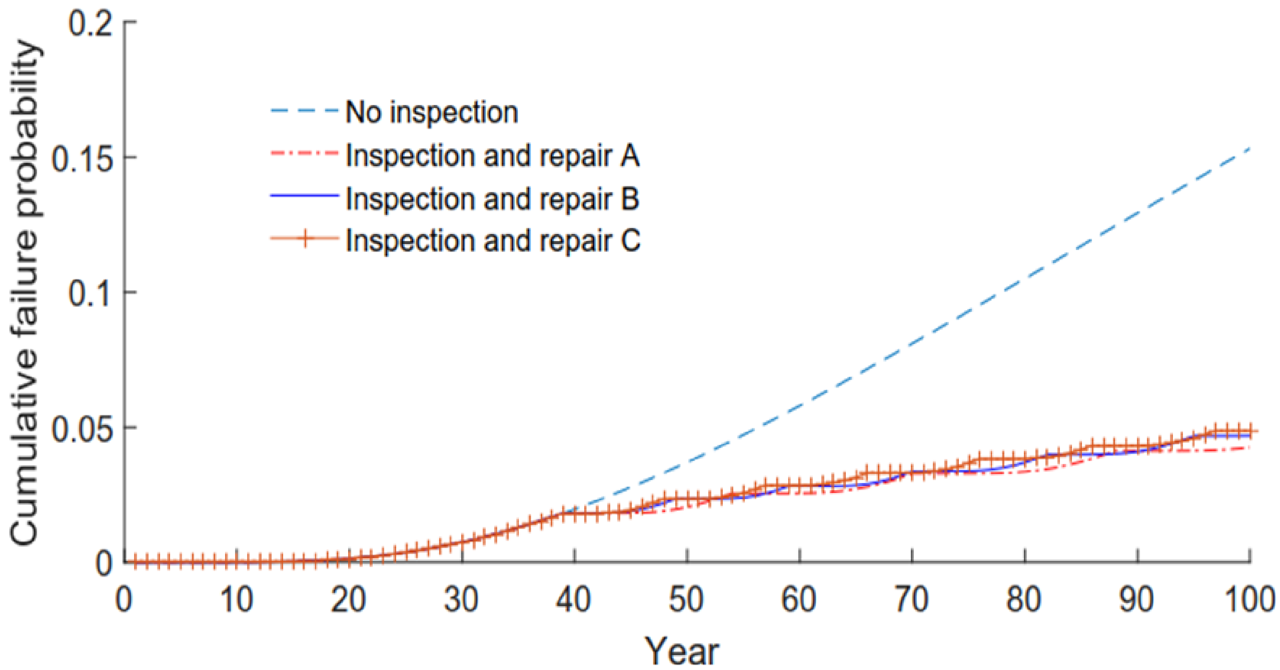

Figure 6. Updating cumulative failure probability

Conclusions

- Different stress-ranges occurring during the year are represented by an equivalent stress-range value.
- The calibration algorithm is carried out by a least-squares fitting in cumulative probability space.
- This study presented efforts to update probability of failure for a miter gate based on critical annual probability and inspection techniques.
- By considering the cost of welded joint repair and the cost of periodic inspections of the gate, the updated failure probability will be useful for optimizing maintenance plan of lock gates.