The Effect of Failure Criteria on Risk-based Inspection Planning of Offshore Wind Support Structures

MS-2 Life-Cycle Performance Assessment of Civil Engineering Systems

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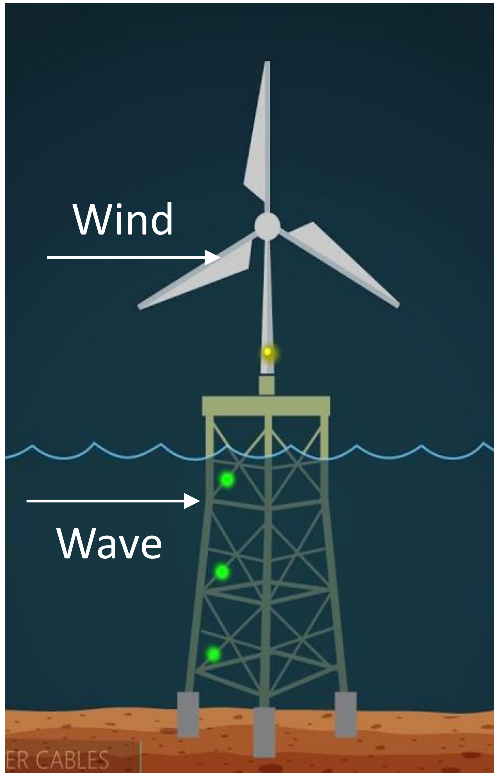
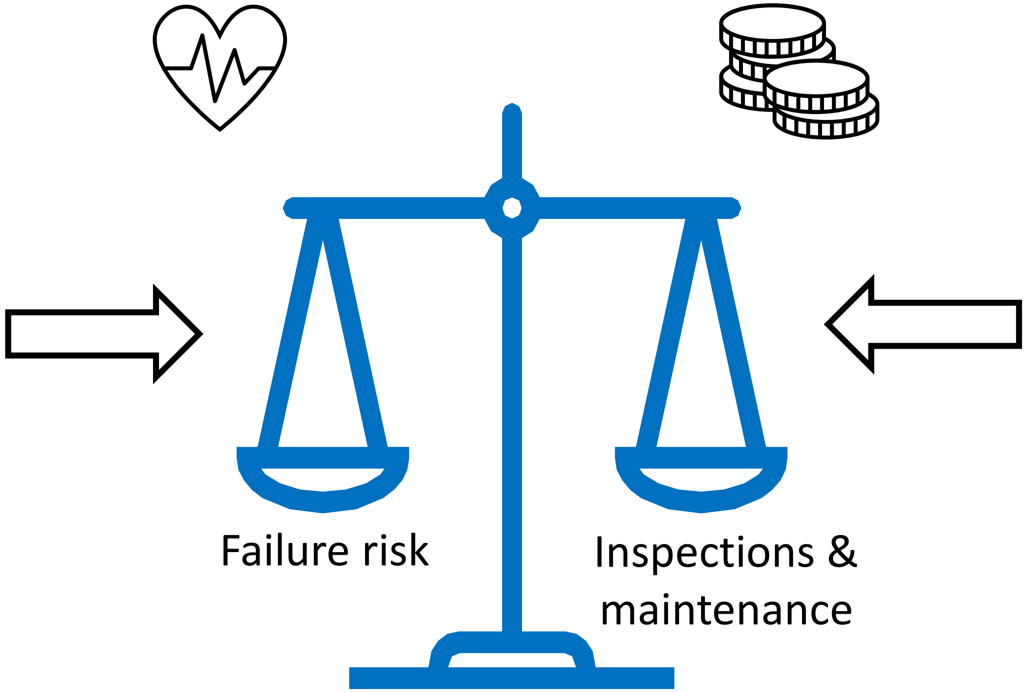
Fatigue deterioration



Source: https://i.ytimg.com/vi/ixQQiGvBK6U/maxresdefault.jpg

Predictive maintenance

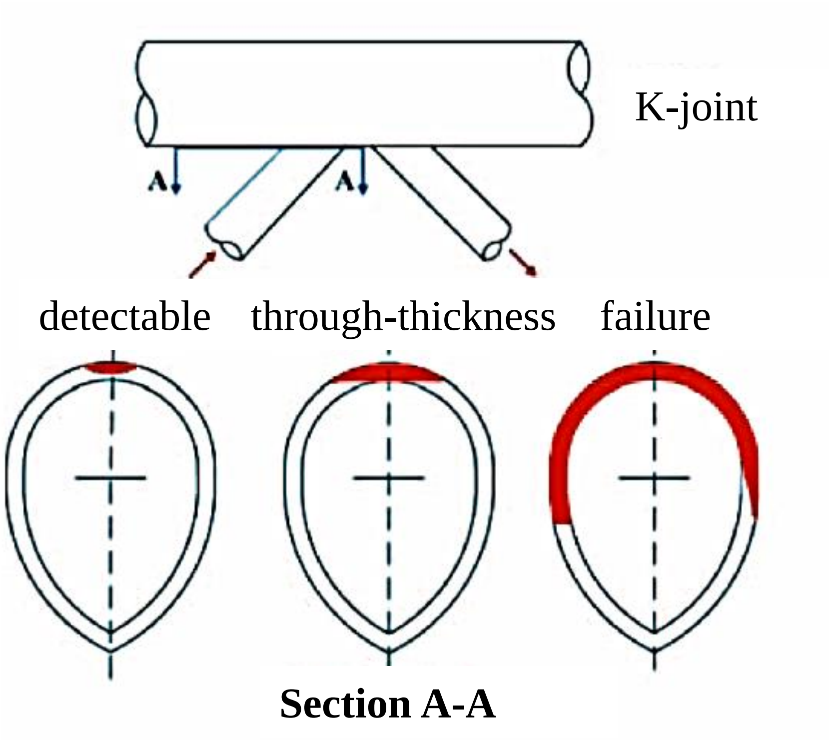


Information available through inspections

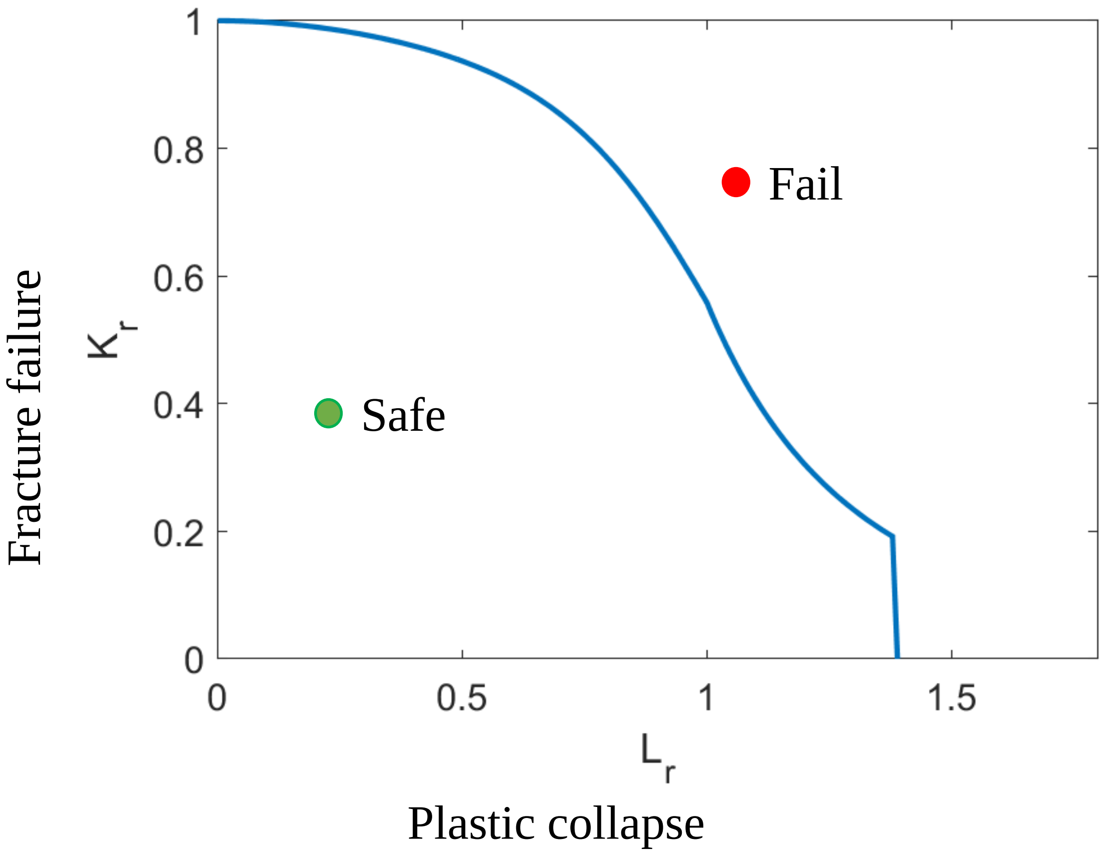
Source: https://cdn.offshorewind.biz/wp-content/uploads/sites/2/2020/06/19144758/offshore_inspection_SkySpecs.png

Failure Criteria

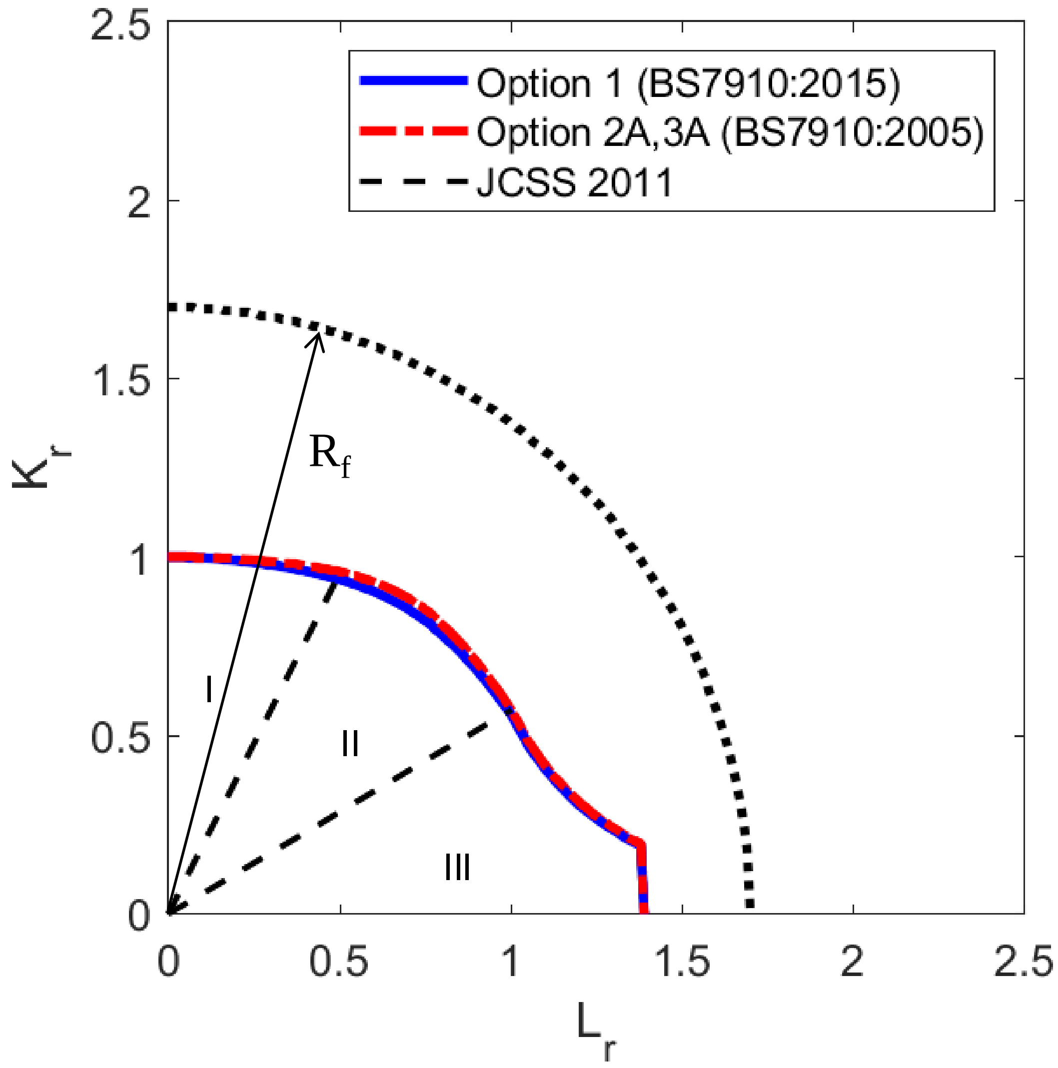
Conventional through-thickness criteria → Failure Assessment Diagram (for redundant structures)



Source: https://www.sciencedirect.com/science/article/pii/S0951832012001160?via%3Dihub



Failure Assessment Diagram Options



Simplified Failure Assessment Diagram criterion (JCSS 2011)

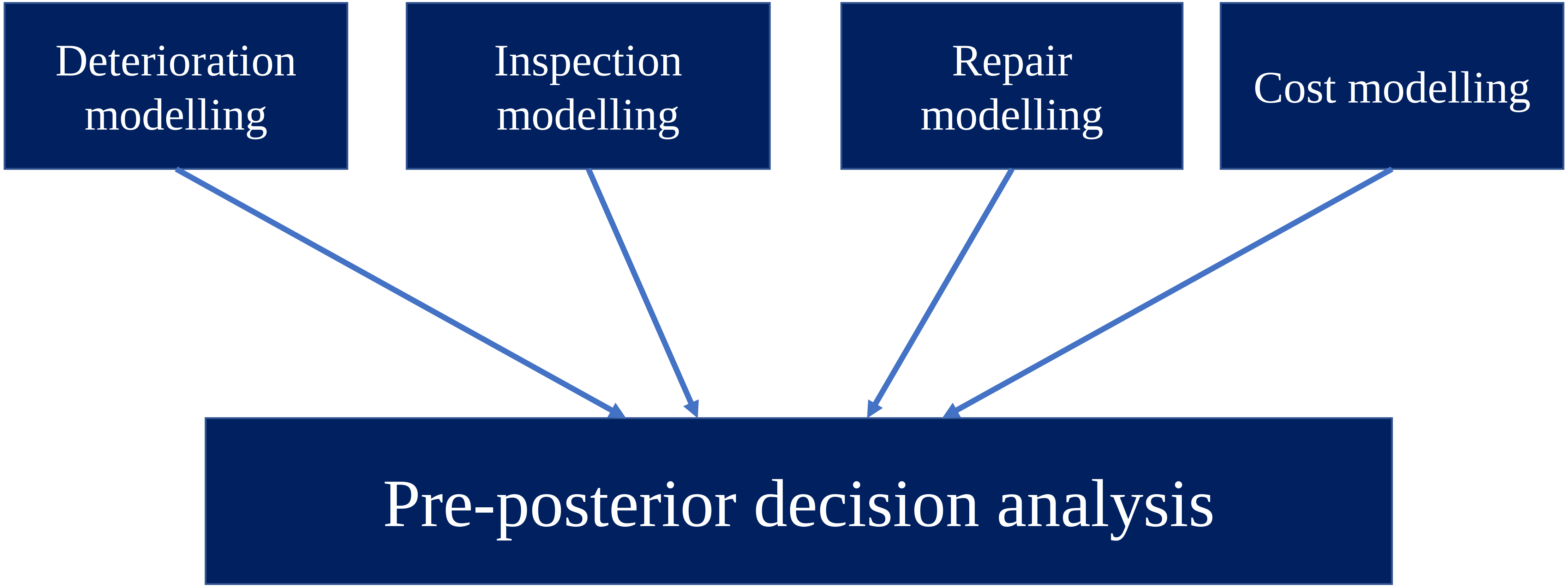
Limit state:

$$g(t) = R_f - \sqrt{K_r^2(t) + L_r^2(t)}$$

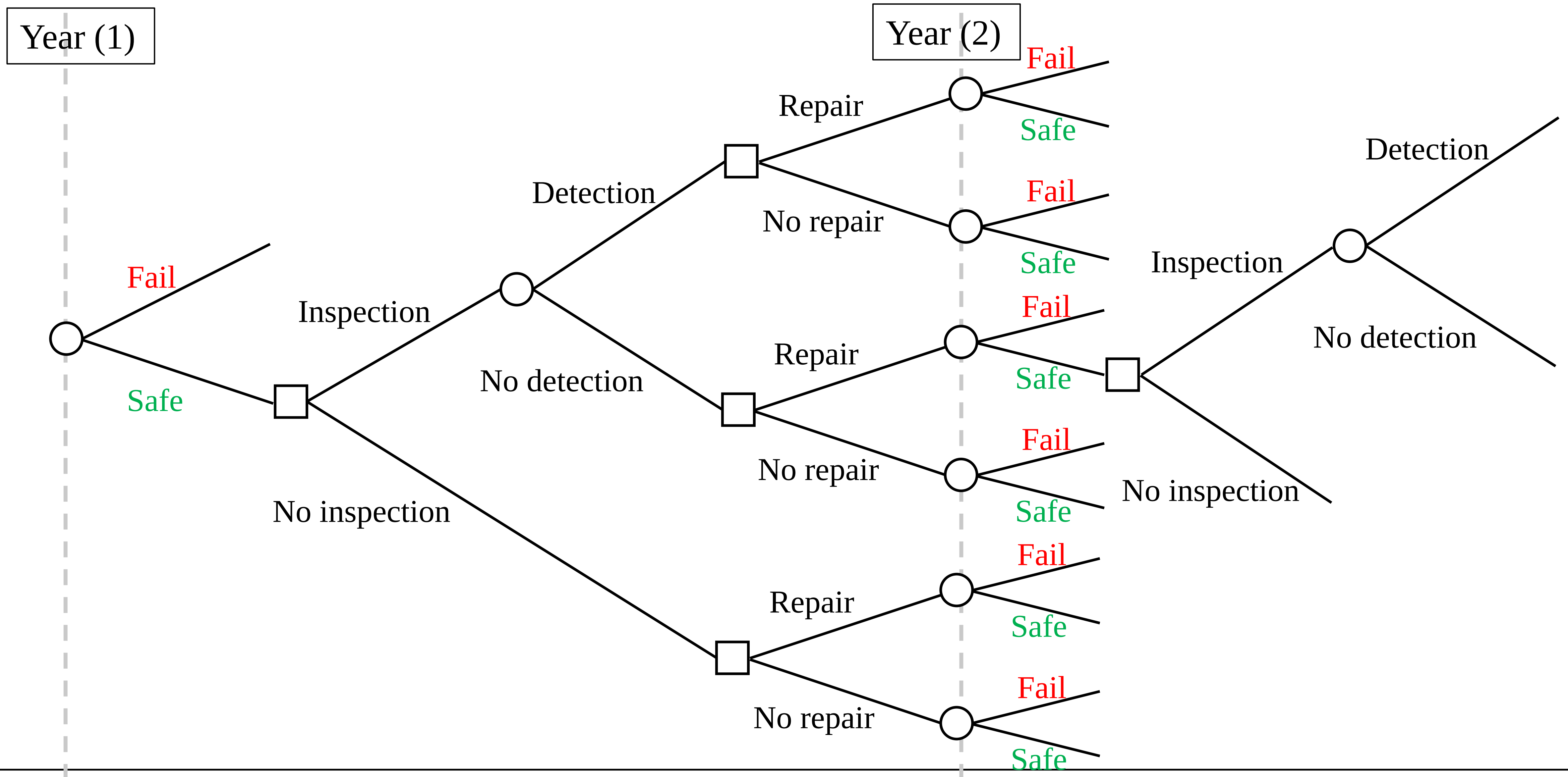
Assessment point:

$$K_r = \frac{K_I}{K_{mat}} + \rho \; ; \quad L_r = \frac{\sigma_{ref}}{\sigma_Y}$$

Risk-based Inspection Framework



Pre-posterior Decision Analysis



Pre-posterior Decision Analysis

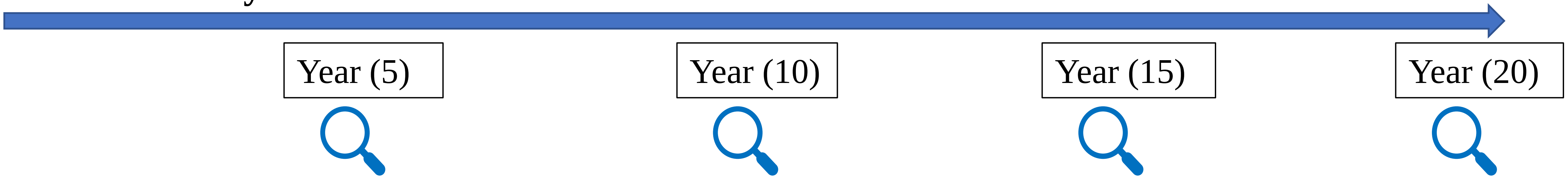
- Decision Rule: Heuristic rules
  - Equidistant inspections
  - Constant failure probability threshold

To identify optimal interval and optimal failure probability threshold.

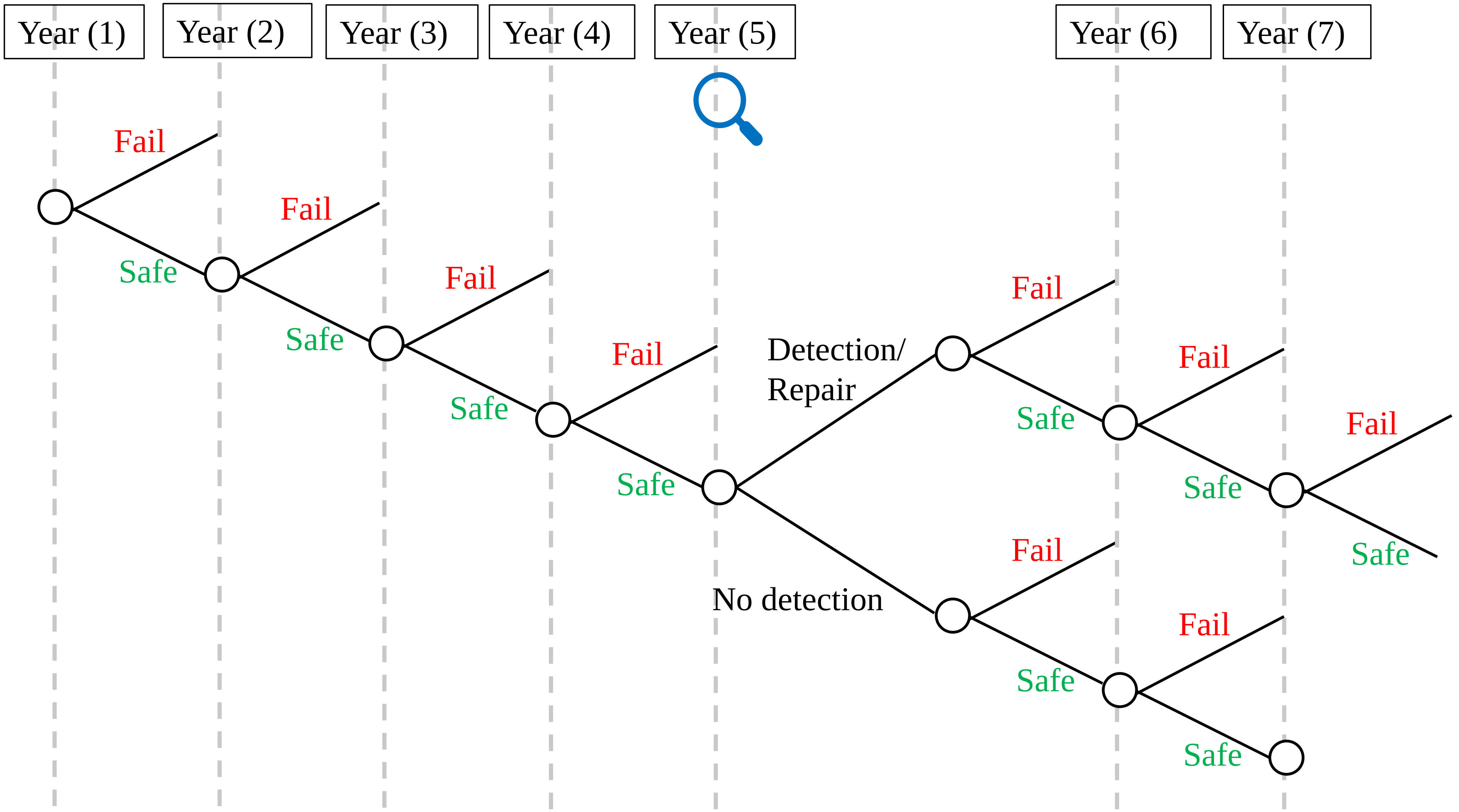
- Decision Rule: Repair if the inspection outcome is “Detection”

- **Example:** Inspection at every 5 years, Repair if the inspection outcome is “Detection”

Lifetime = 20 years



Pre-posterior Decision Analysis



Application – Deterioration Modelling

- Design (Fatigue model – SN curves)
- Miner's Rule:

$$\boldsymbol{D} = nT_d\left[\frac{\boldsymbol{q}^{m_1}}{\boldsymbol{a_1}}\Gamma\left(1+\frac{m_1}{h};\left(\frac{S_1}{\boldsymbol{q}}\right)^h\right)+\frac{\boldsymbol{q}^{m_2}}{\boldsymbol{a_2}}\Upsilon\left(1+\frac{m_2}{h};\left(\frac{S_1}{\boldsymbol{q}}\right)^h\right)\right]$$

- Inspection (Fracture mechanics model – crack growth)
- Paris Law:

$$\frac{d\boldsymbol{a}}{dn} = \boldsymbol{C_a}(\boldsymbol{\Delta\sigma}\,\boldsymbol{Y_a}\sqrt{\pi\boldsymbol{a}})^m \;; \quad \frac{d\boldsymbol{c}}{dn} = \boldsymbol{C_c}(\boldsymbol{\Delta\sigma}\,\boldsymbol{Y_c}\sqrt{\pi\boldsymbol{a}})^m$$

- Calibrated SN – FM

Application – Deterioration Modelling

One-dimensional FM Model

Variable	Distribution	Parameters
$\boldsymbol{a_0}$	Exponential	$\mu = 0.1235$
$\boldsymbol{log(Ca)}$	Normal	$\mu = -27.7903\,;\sigma = 0.3473$
q (calibrated)	Normal	$\mu = 6.4839\,;\sigma = 0.2$
n	Deterministic	$3.5 \cdot 10^7$
Y_a	Lognormal	$\mu = 1\,;CoV = 0.1$
m	Deterministic	3
a_{crit}	Deterministic	16

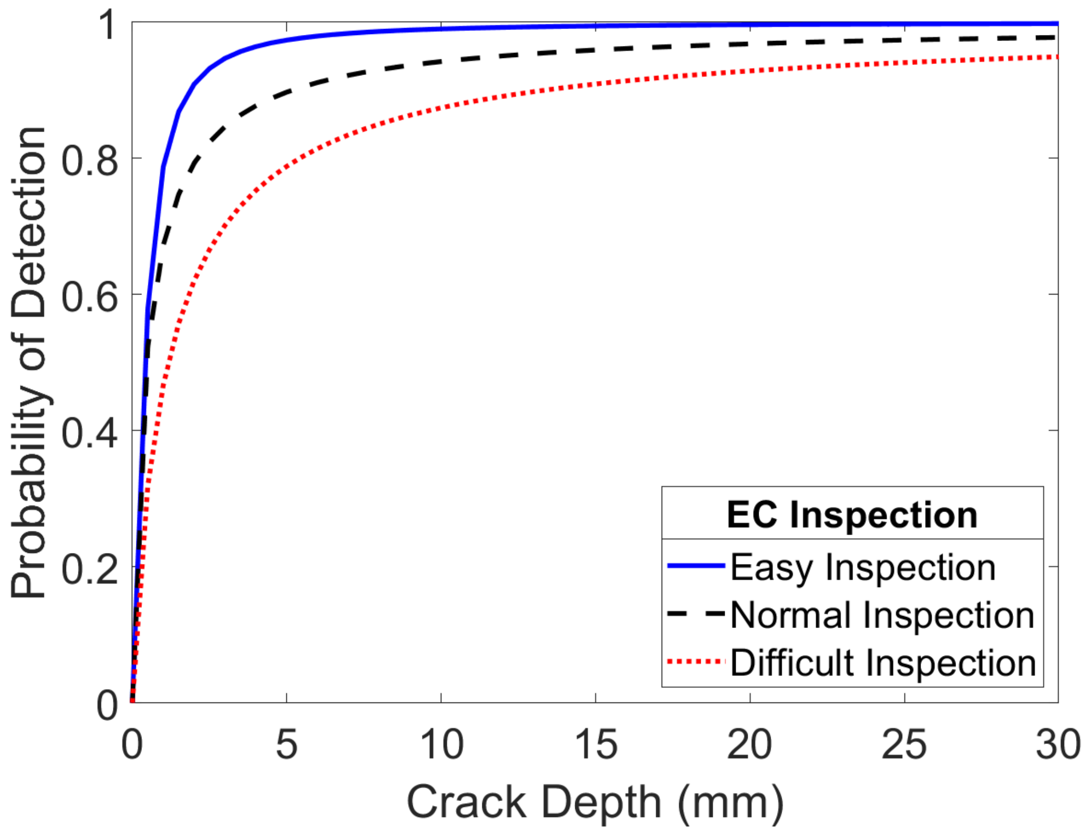
Two-dimensional FM Model

Variable	Distribution	Parameters
$\boldsymbol{a_0}$	Exponential	$\mu = 0.1603$
$\boldsymbol{log(Ca)}$	Normal	$\mu = -27.6302\,;\sigma = 0.4599$
a_0/c_0	Deterministic	0.2
DOB	Deterministic	0.81
C_a/C_c	Deterministic	1
m	Deterministic	3
a_{crit}	Deterministic	16

SN Model

Variable	Distribution	Parameters
m_1	Deterministic	3
m_2	Deterministic	5
$\log_{10}(a_1)$	Normal	$\mu = 12.48\,;\sigma = 0.2$
$log_{10}(a_2)$	Normal(Fully correlated)	$\mu = 16.13\,;\sigma = 0.2$
Δ	Lognormal	$\mu = 1\,;CoV = 0.3$
$q(*)$	Normal	$\mu = 6.4839\,;\sigma = 0.2$
h	Deterministic	0.8

Probability of detection (POD) of eddy current (EC) inspection



Cost modelling

Failure cost (10^6 monetary units)

Inspection cost (10^3 monetary units)

Repair cost (10^4 monetary units)
*assumed to be perfect repair

Discount rate (6 %)

Application – Risk-based Inspection Analyses

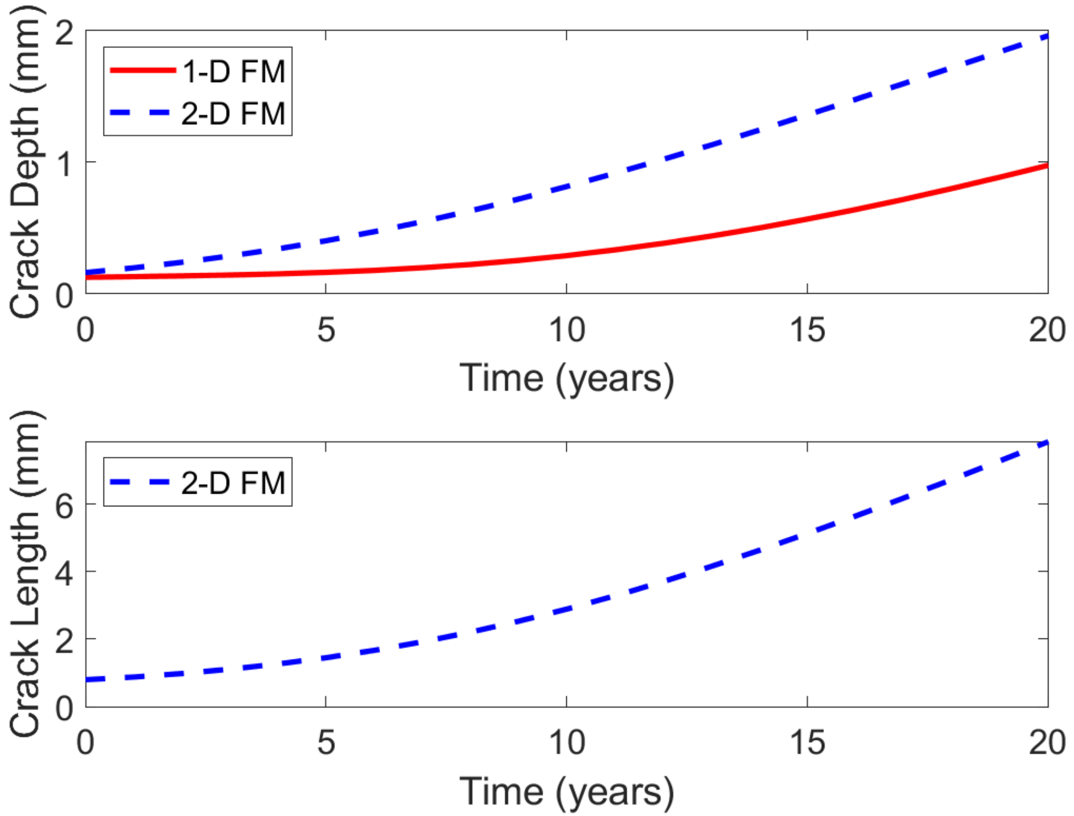
- **Option 1**
  - One-dimensional crack growth + Through-thickness failure criteria

- **Option 2**
  - Two-dimensional crack growth + Through-thickness failure criteria

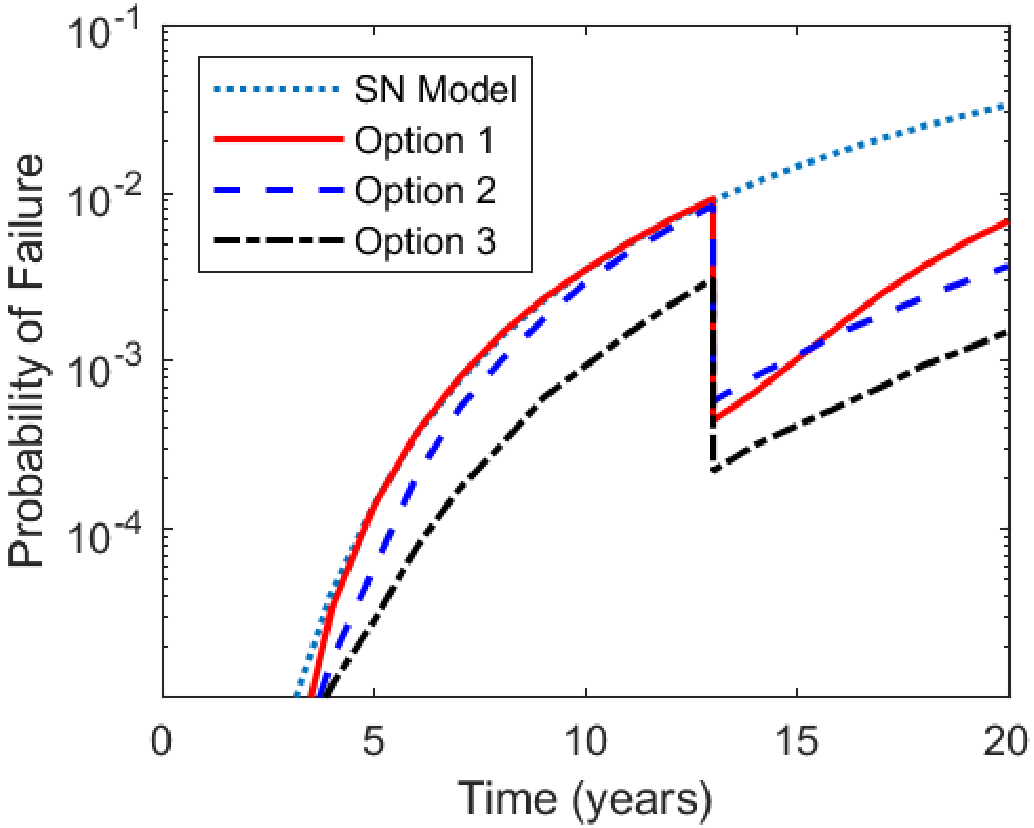
- **Option 3**
  - Two-dimensional crack growth + Simplified FAD criteria

Application – Results

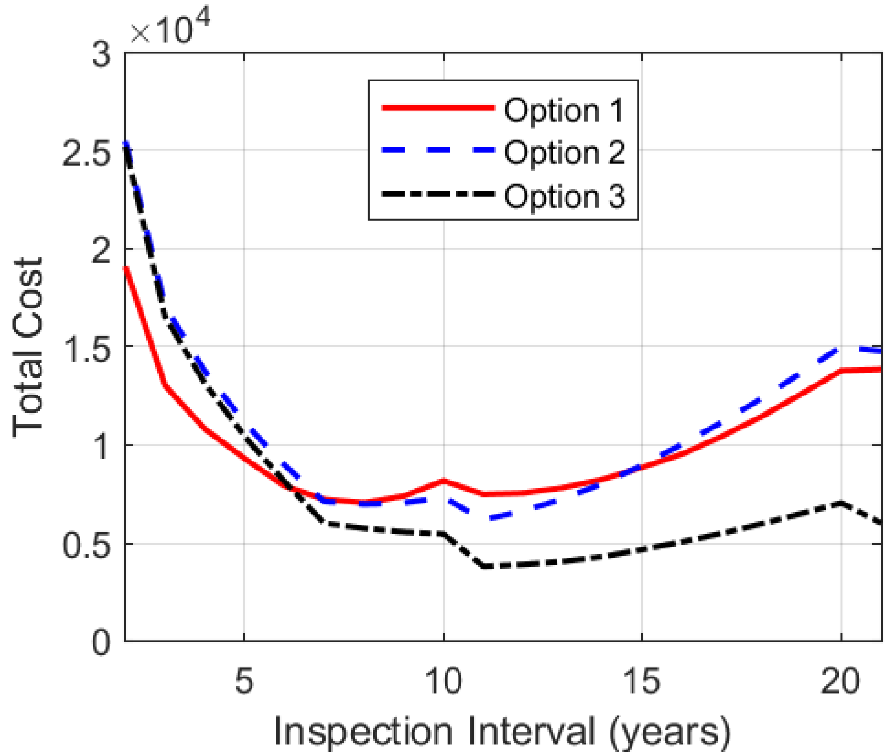
Crack Growth



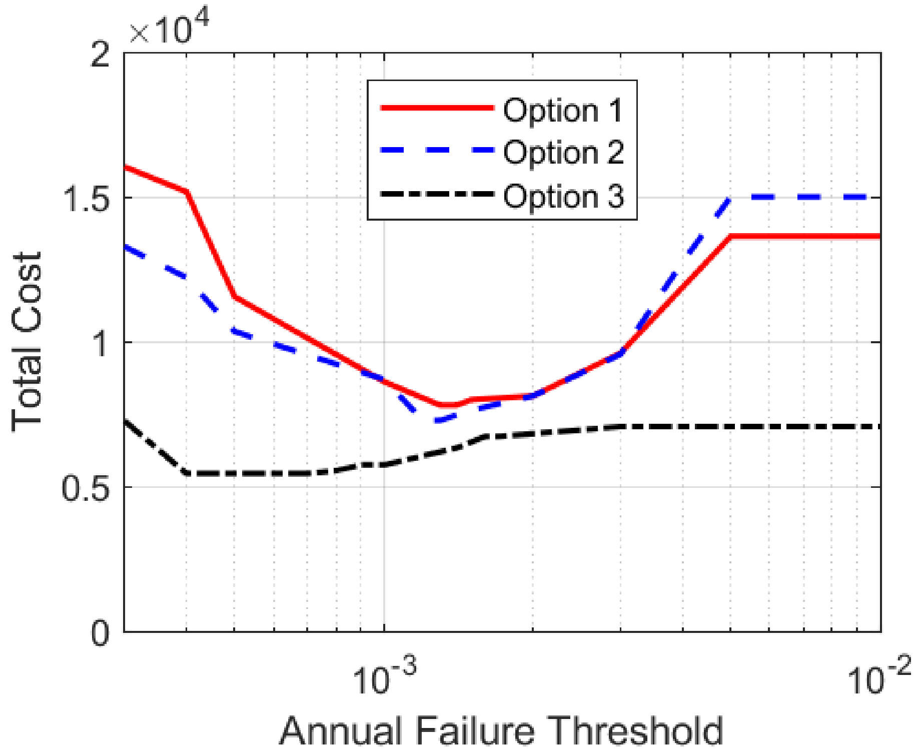
Reliability Updating



Equidistant inspections



Constant failure probability threshold



In both cases, option 3 ⟹ less number of inspections and lower expected cost.

Conclusion – Discussion and Future Work

- Both failure criteria and fracture mechanics model can affect the optimal inspection decision.
- Significant reduction of failure cost (>50%) by using the failure assessment diagram criterion.
- Limitation: only for reductant structures with high fracture toughness.
- **Future research interest:**
  - Inspection method which gives discrete crack size
  - POMDP/DRL which can provide dynamic policies

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