Innovation and Networking for Fatigue and Reliability Analysis of Structures – Training for Assessment of Risk

Damage Detection and Deteriorating Structural Systems

Lijia Long[1,2], Sebastian Thöns[1,2], Michael Döhler[1,3]

1. Dept. 7.0: Safety of Structures, Federal Institute for Materials Research and Testing (BAM), 12205 Berlin, Germany, lijia.long@bam.de

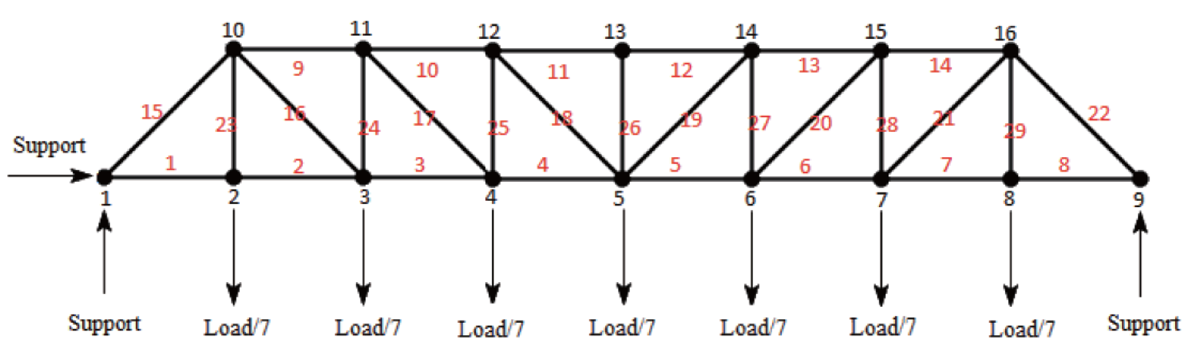
2. Dept. of Civil Engineering, Technical University of Denmark, 2800 Lyngby, Denmark, sebt@byg.dtu.dk

3. Inria, I4S, 35042 Rennes, France, and IFSTTAR, COSYS, SII, Bouguenais, France, Michael.doehler@inria.fr

1. Introduction

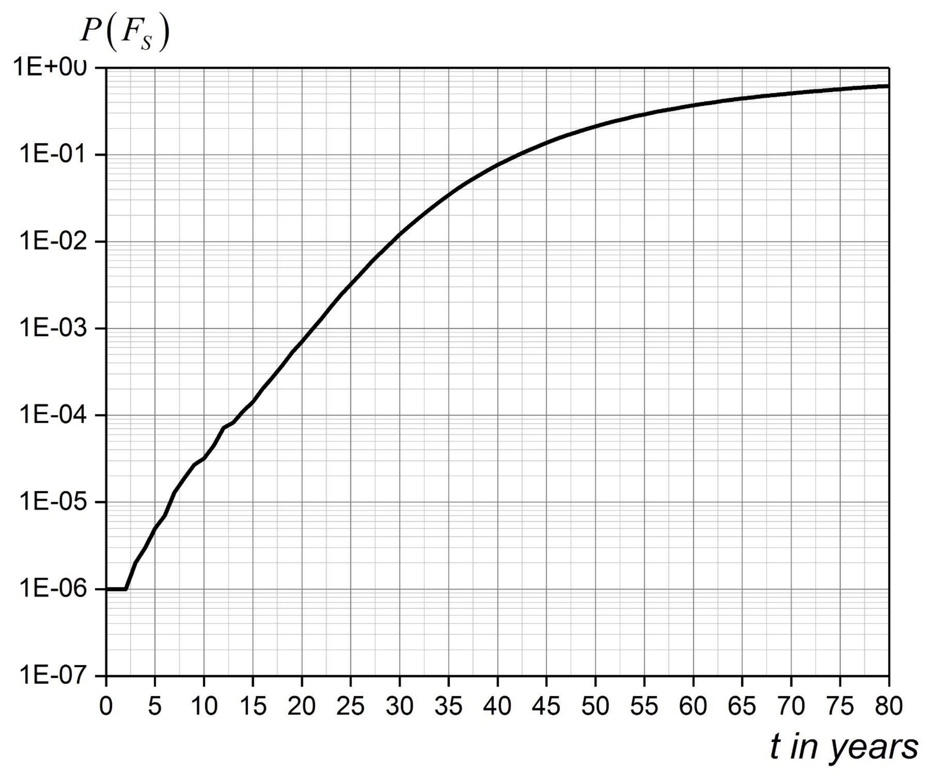
A truss bridge is under certain system state after 10 years in practical life. The bridge manager wants to carry out inspection plan but he is not sure whether or when to implement damage detection system (DDS). Quantification the value of DDS is of great interest for decision-making.

2. Structural system modeling



When it is under extreme loading, we set that the truss will collapse if the stresses in any member exceed the material strength. Due to this absence of determinate redundancy, series system formulation is chosen. The probability of component/system failure is calculated by Monte Carlo Simulation .

$$P(F_S) = P\left(\bigcup_{i=1}^{n_i}\left(M_{R,i}R_{i,0}\left(1-\sum_{i=1}^{t}\Delta_{D,i}\right)-M_sS\right)\leq 0\right)$$



The probability of truss failure will increase with time due to deterioration damage.

TABLE I. DESCRIPTION OF THE BRIDGE.

Descriptions	Values	Description	Distribution	Expected value	Standard deviation
Number of components	29	Loading of component S_i	Weibull	3.5	0.1
Number of nodes	16	Resistance model uncertainties M_R	Lognormal	1.0	0.1
Length of non-diagonal element	$10m$	Loading model uncertainties M_s	Lognormal	1.0	0.1
Length of diagonal element	$10\sqrt{2}m$	Component resistance $R_{(i,0)}$	Lognormal	Calibrated	0.1
Youngs modules E	14400 N/m^2	Deterioration damage $\Delta_{(D,i)}$	Normal	0.007	0.003
Cross section A	10/144 m^2	Coefficient of correlation for resistances ρ_R	Deterministic	0.1/0.5/0.9	
Mass per component	0.02	Coefficient of correlation for damages ρ_D	Deterministic	0.1/0.5/0.9	
Damping ratio	2%				

TABLE II. PARAMETERS IN THE COST AND BENEFIT ANALYSIS.

Variable	Discount rate r	Repair cost C_R	Failure cost C_F	Inspection cost C_{Insp}	DDS cost C_{DDS}	Annual benefit B
Value	0.02	10	100	1	2	0.7

3. Updating the structural system reliability with DDS information

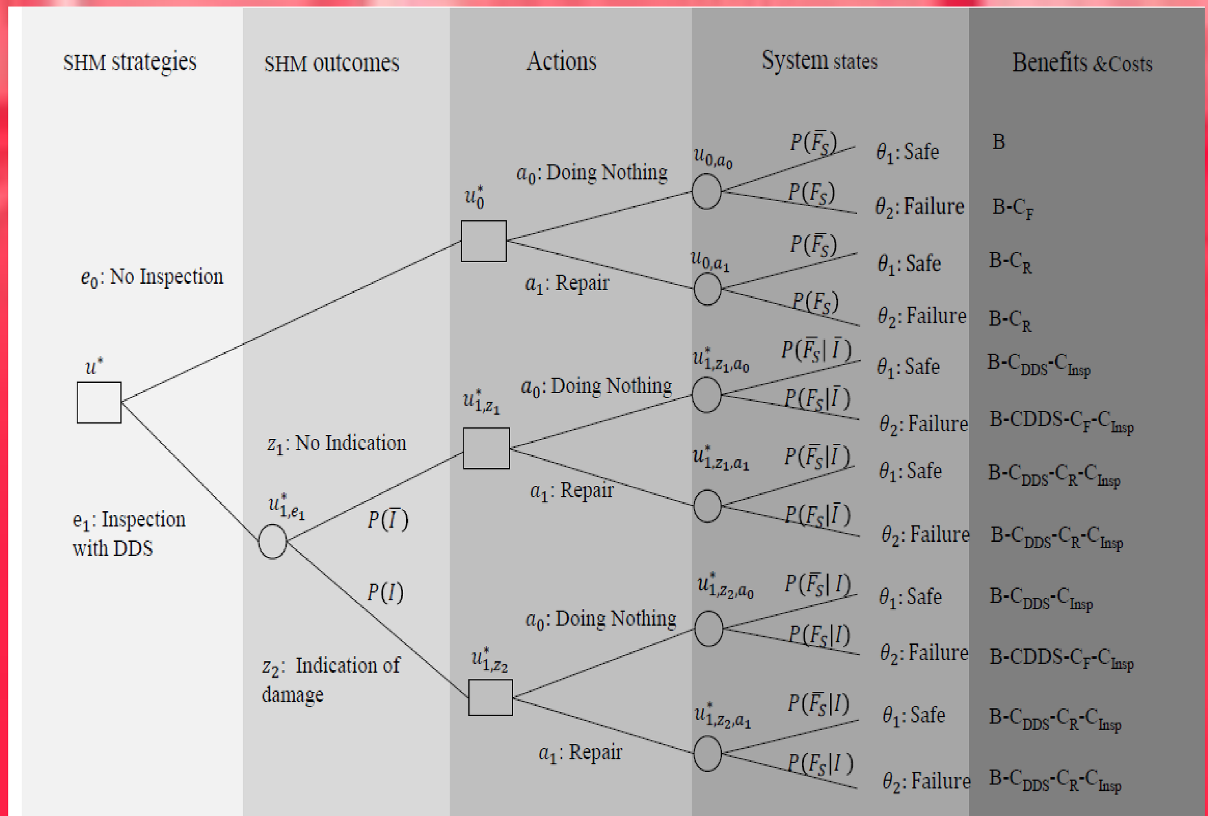
The updated probability of failure if there is no indication of damage can be calculated following Bayes' rule. The probability of no indication of detecting damage can be calculated by integrating in the region which is defined with the limit state function $g_u < 0$.

$$P(F\,|\,\mathrm{D},\bar{I}) = \frac{P(\bar{I}\,|\,F,\mathrm{D})\,P(F,\mathrm{D})}{P(\bar{I})} = \frac{P(F|\mathrm{D}\cap\bar{I})}{P(\bar{I})} = \frac{P(g\leq 0\cap g_u\leq 0)}{P(g_u\leq 0)}$$

$$P(\bar{I}) = 1-P(I) = \int_{\Omega_\mathrm{D}}(1-\rho(I\,|\,\mathrm{D}))\,f_\mathrm{D}(\mathrm{D})\mathrm{dD}$$

$$g_U = P(I\,|\,\mathrm{D})-u$$

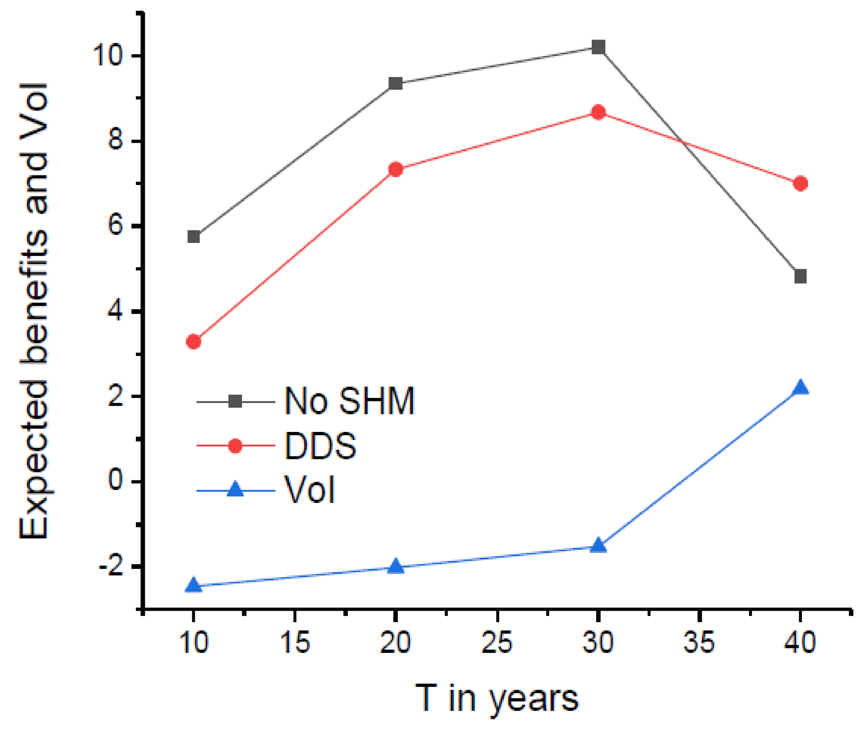
4. Quantification the value of information



The expected Value of Information (VoI) can be found as difference between expected utilities of the optimum decisions with and without that information.

$$VoI = u_1^* - u_0^*$$

5. Results



The expected value of service life benefits first increase and slightly decrease at the late stage of service life, which can be explained with the increasing probability failure of system and decreasing accumulated benefit and costs due to discounting. The value of DDS will increase with time, which indicates that the risks of system failure are significantly higher than the accumulated structural integrity management benefit and costs.

6. Conclusion

It is beneficial to implement a DDS system at a later stage of service life when damages have progressed.

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MARIE CURIE ACTIONS

ITN Innovative Training Networks

BAM Bundesanstalt für Materialforschung und -prüfung