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Estimating the time-dependent reliability of aging structures in the presence of incomplete deterioration information

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Background

- The safety evaluation and service-life prediction of deteriorating structures should be based on reliability concepts and methods, aiming at preventing the use of these structures beyond an acceptable safety level.
- The probabilistic distribution of degraded resistance often remains unaddressed due to the limits of available data.

- The error of reliability induced if one chooses empirically the deterioration probabilistic model ?
- How to estimate the structural reliability under incomplete deterioration information?

Structural reliability analysis

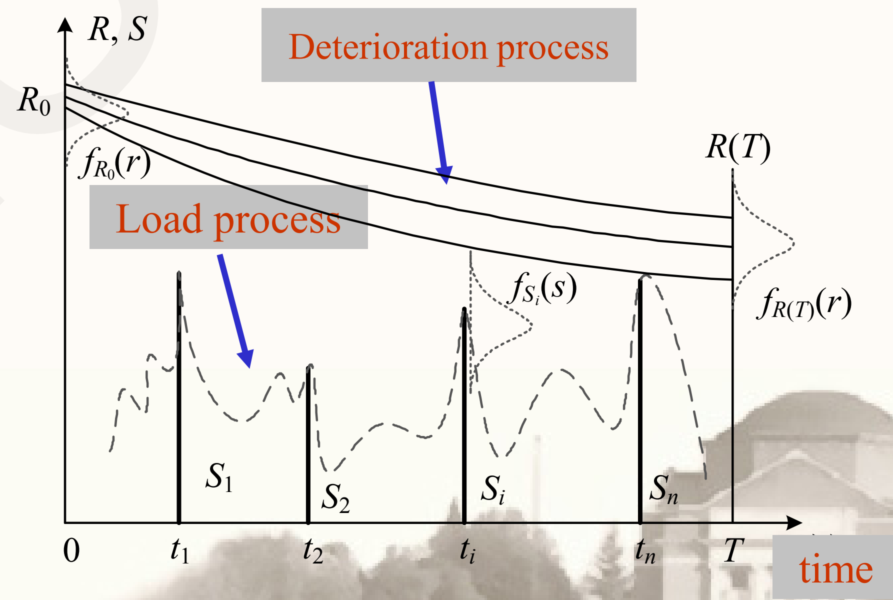
Consider the time-dependent reliability of a structure over time interval $(0,T]$, $L(T)$.

$$L(T) = \Pr[R(t_1) > S(t_1) \cap \ldots \cap R(t_n) > S(t_n)]$$

where Pr[ ] denotes the probability of the event in the bracket, $R(t_1)$, $R(t_2)$,...$R(t_n)$ are the resistances corresponding to times t_1, t_2... t_n, $S(t_1)$, $S(t_2)$,...$S(t_n)$ are the load effects occurring at times t_1, t_2... t_n, respectively.

For a non-stationary load process with a time-variant occurrence rate of $\lambda(t)$ and a time-variant cumulative density function of $F_S(s, t)$ for each load effect (Li et al, 2015),

$$L(T) = \exp\left\{-\int_0^T \lambda(t)\{1 - F_S[r(t),t]\}\mathrm{d}t\right\}$$



Probabilistic model of resistance deterioration

The resistance deterioration is assumed to be a fully correlated process, as it provides a reasonable estimate for structural time-dependent reliability (Li et al, 2015).

$$R(t) = R_0 \cdot [1 - G(t)]$$

where $R(t)$ is the resistance at time t, R_0 is the initial resistance, and G(t) is the deterioration function.

Taking into account the uncertainty associated with $G(T)$,

$$L(T) = \int_{-\infty}^{+\infty} \exp\left[- \int_0^T \lambda(t)(1 - F_S[r(t|g), t])\mathrm{d}t \right] \cdot f_G(g)\mathrm{d}g,$$

While the mean value and standard deviation of $G(T)$ can be estimated according to limited observed data, the probability distribution of $G(T)$ is often unknown.

Candidate distributions for $G(T)$:

Uniform, Normal, Beta, Gamma and inversed-lognormal.

Reliability under incomplete deterioration information

c.f. Eq.(18) and appendix B

$$L(T)=\frac{a_0}{2}+\sum_{m=1}^{\infty}\left[a_m\sum_{j=0}^{\infty}c_{2j}\cdot(m\pi)^{2j}(-1)^j\right]=\frac{a_0}{2}+\sum_{m=1}^{\infty}\left[a_m f(m\pi)\right]$$

where the coefficients a_i can be obtained according to Eq. (14a), and the function f can be solved numerically by

$$f''(x)=-f(x)+Af(\gamma_4 x)+Bf(\gamma_4^2 x)$$

The proposed reliability analysis method:

(1) is independent of the probability distribution of $G(T)$;

(2) provides an “averaged” reliability considering all possible distributions of $G(T)$.

Illustrative examples

Configuration

Load combination (ACI Committee 318-14, 2014)

$$0.9R_n = 1.2D_n + 1.6L_n$$

where R_n, D_n and L_n are the nominal resistance, dead load and live load, respectively.

Time-variant mean value of live load

$$\mu_L(t) = (0.4 + 0.005t) \cdot L_n$$

Initial resistance

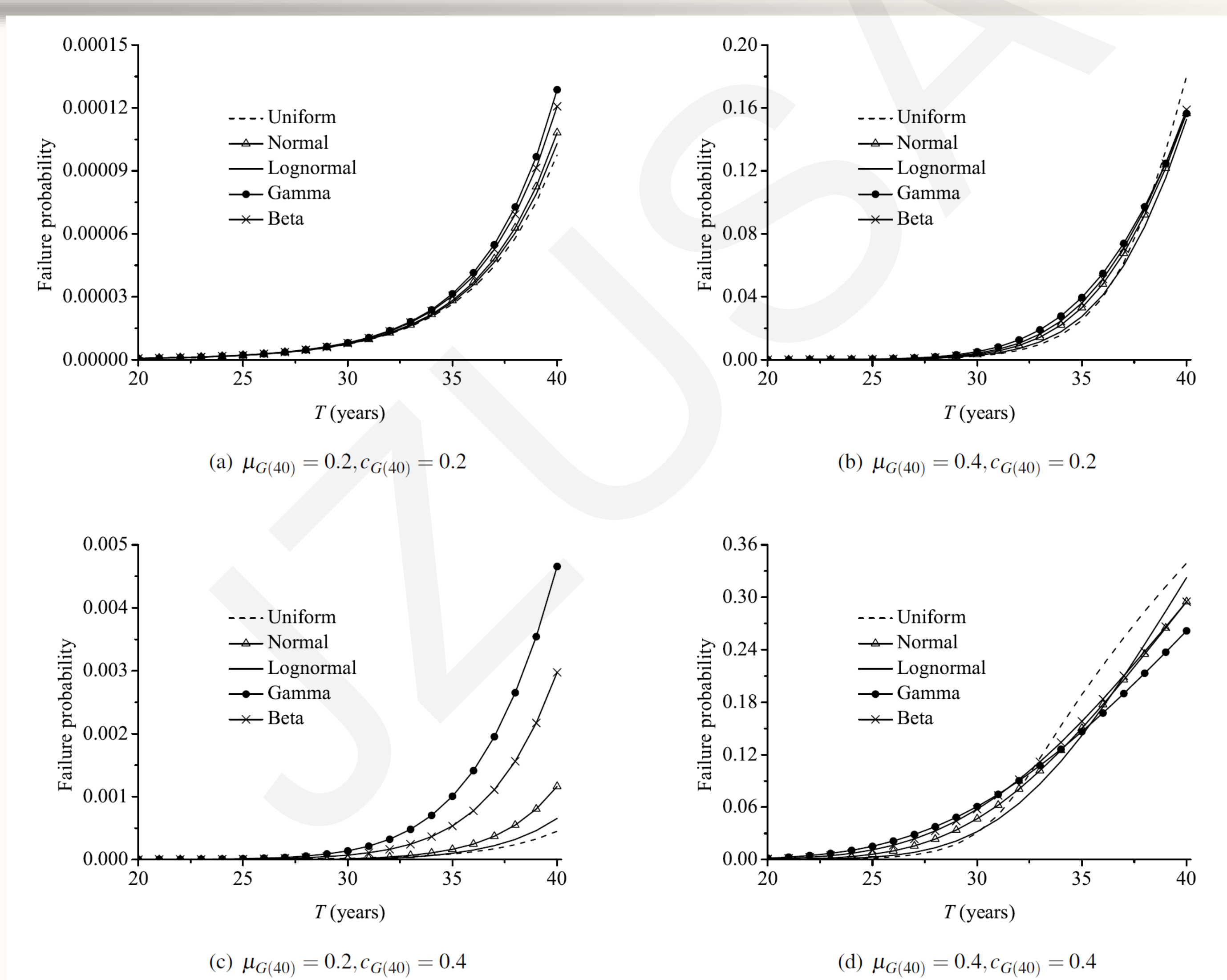
R_0 is assumed to be deterministic, and equal to $1.05R_n$;

Dead load

The dead load, D, equals its nominal value (Dn), and is assumed to be deterministic.

The mean load occurrence rate of the live load is 1/year, and a reference period of 40 years is considered.

Dependence of failure probability on resistance deterioration



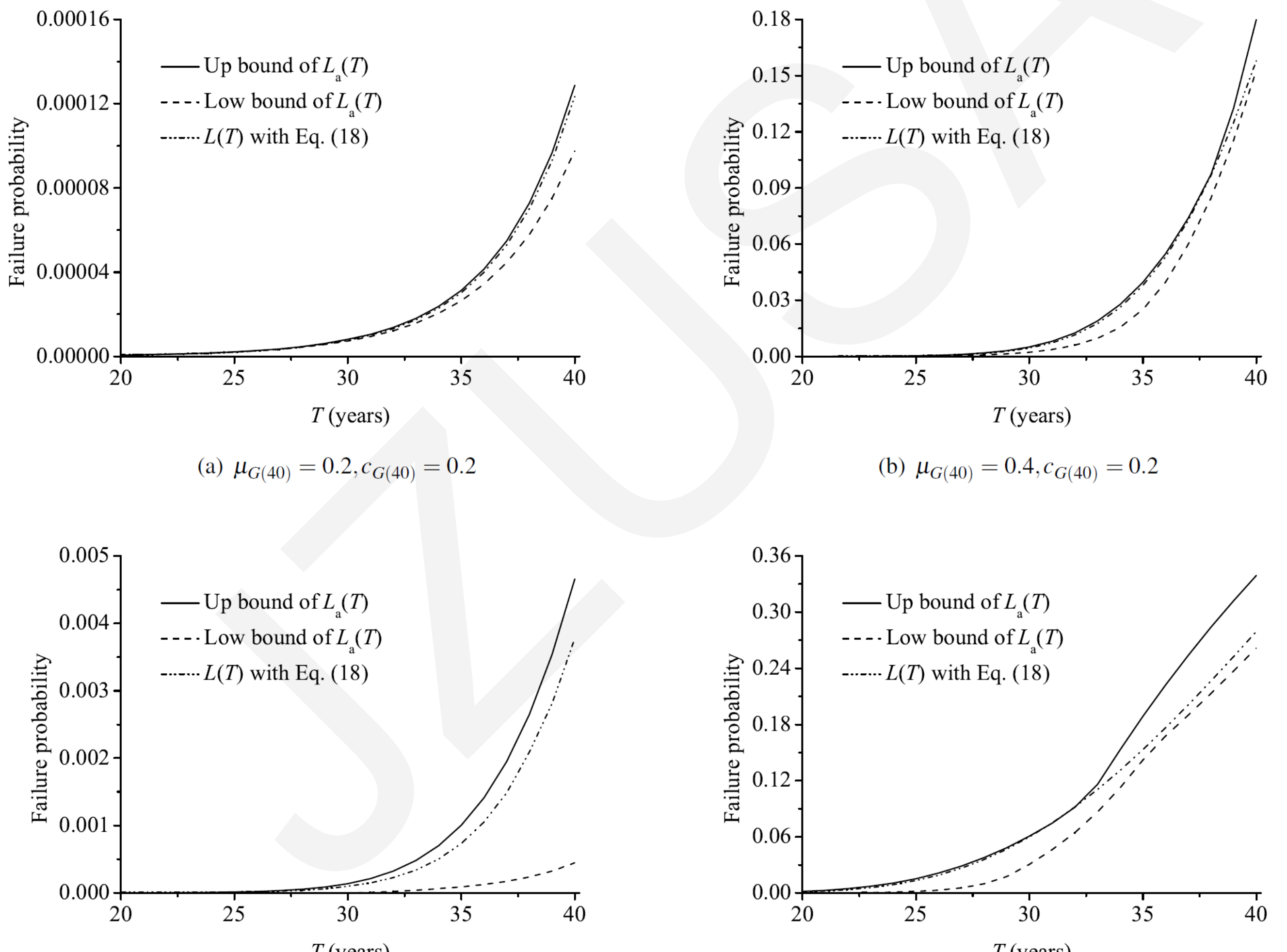
(a) $\mu_{G(40)} = 0.2, c_{G(40)} = 0.2$

(b) $\mu_{G(40)} = 0.4, c_{G(40)} = 0.2$

(c) $\mu_{G(40)} = 0.2, c_{G(40)} = 0.4$

(d) $\mu_{G(40)} = 0.4, c_{G(40)} = 0.4$

Impact of resistance deterioration on structural averaged failure probability



(a) $\mu_{G(40)} = 0.2, c_{G(40)} = 0.2$

(b) $\mu_{G(40)} = 0.4, c_{G(40)} = 0.2$

(c) $\mu_{G(40)} = 0.2, c_{G(40)} = 0.4$

(d) $\mu_{G(40)} = 0.4, c_{G(40)} = 0.4$

Conclusions

(1) With the increase of the variation associated with resistance deterioration, the reliabilities associated with different deterioration models differ significantly.

(2) No such a deterioration model exists that results in the greatest or smallest failure probability for all deterioration conditions.

(3) A new method is developed to estimate the averaged time-dependent reliability of aging structures. It is independent of the probabilistic mass scenario of the candidate deterioration models.

Thank you.