Closed-form solution for seismic structural performance assessment for systems with two failure mechanisms

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INTRODUCTION

The objective of this research is to provide a simple means of quantifying the likelihood of structural failure. This work proposes improved simplified expressions based on the results of nonlinear time history analyses. Furthermore, an analytical expression is suggested for seismic performance assessment of systems with two different mechanisms contributing to the systems annual probability of failure.

Assumptions?

The 'b' value is assumed equal to 1 as per the equal displacement rule

The hazard curve is estimated using power law function in log-log space

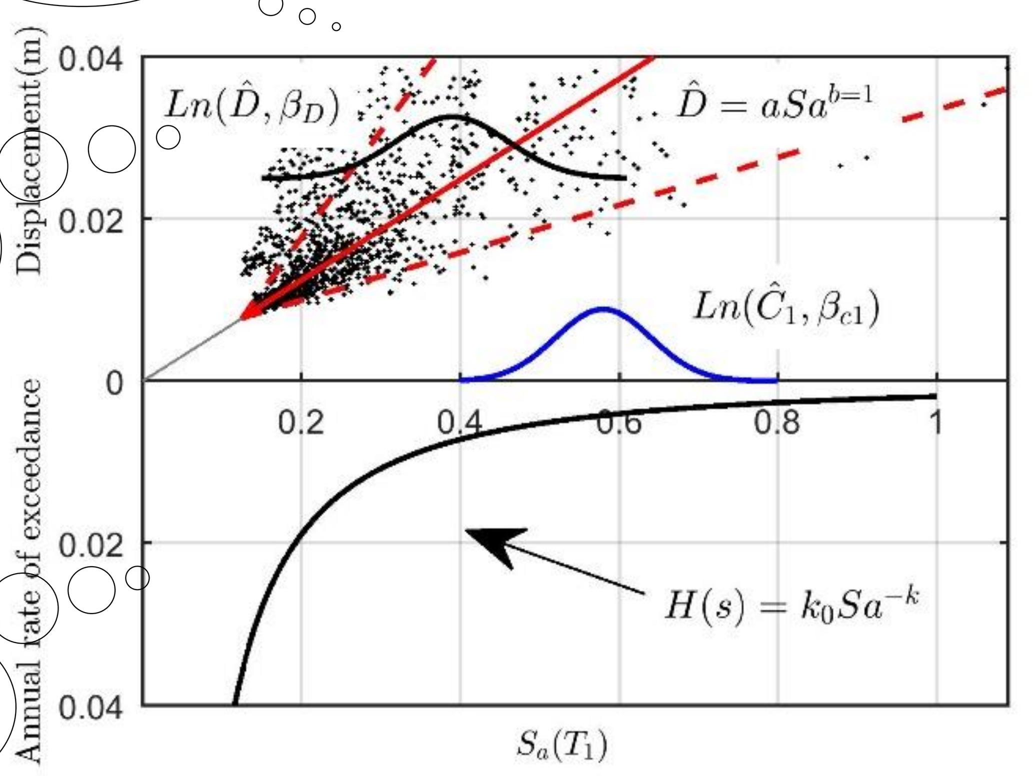


Figure 1. FEMA/SAC (Cornell et al., 2002)

Improvements: 'b' value

Nonlinear time history analysis (NTHA) for a set of single degree of freedom (SDOF) systems with different hysteresis rules, periods and yield strength were carried out by Stafford et al., (2016). Accordingly, nonlinear regression analyses were conducted adopting two different model functions for each SDOF. Consequently, the error distribution plot and QQ plot were employed to evaluate the precision of the regression analysis results for each case.

m, k, F_y

$$C_y = \frac{F_y}{mg}$$

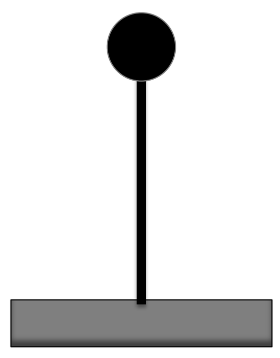


Table 1. Hysteresis models

Hysteresis Model	Parameters
Bi-Linear	r = 0.05
Takeda (Thin)	r = 0.05, α = 0.5, β = 0.0
SINA	r = 0.05, Fcc = 0.3Fy
Flag-shaped	r = 0.05, β = 0.3

T_1(s):

0.1, 0.2, 0.3, 0.4, 0.5 — Short periods

0.6, 0.8, 1.0, 1.5, 2.0 — Medium periods

2.5, 3.0, 3.5, 4.0 — Long periods

Cy: 0.025, 0.05, 0.075, 0.1, 0.125, 0.15, 0.2, 0.3, 0.4, 0.5. — Yield strength

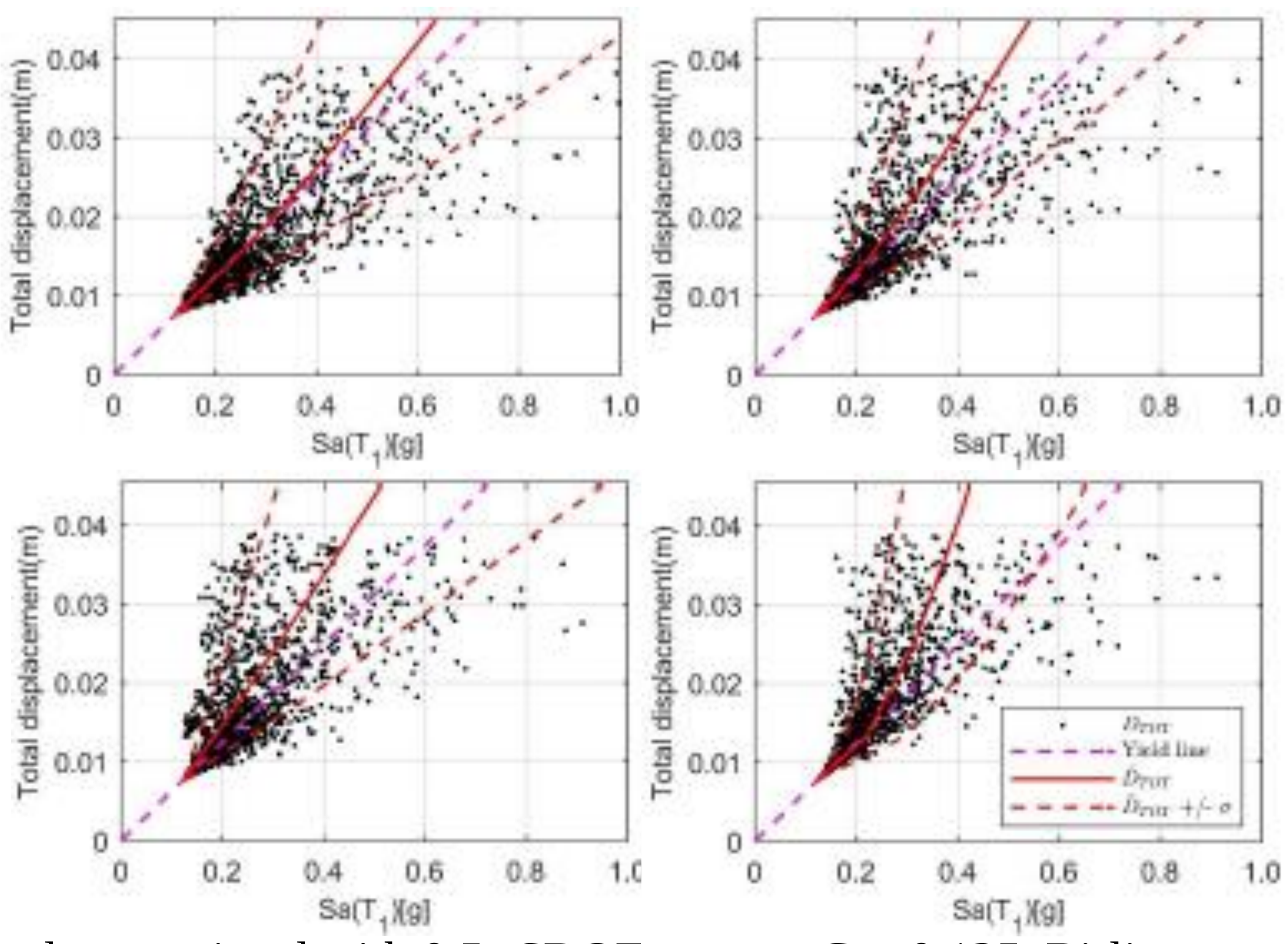


Figure 2. The NTHA results associated with 0.5s SDOF system, C_y =0.125, Bi-linear (top-left), Takeda (top- right), SINA (bottom - left), Flag-Shape (bottom - right)

Updated 'b' values

Table 2. The 'b' values obtained for different periods and hysteresis models based on NTHA

Period	Bilinear		Takeda		Flag		SINA	
T(s)	$\hat{b}$	β	$\hat{b}$	β	$\hat{b}$	β	$\hat{b}$	β
0.1	1.25	0.05	1.32	0.06	1.43	0.06	1.33	0.07
0.2	1.14	0.02	1.19	0.03	1.21	0.02	1.27	0.04
0.3	1.11	0.02	1.15	0.02	1.17	0.02	1.23	0.02
0.4	1.10	0.03	1.14	0.03	1.16	0.03	1.27	0.03
0.5	1.08	0.01	1.12	0.01	1.14	0.01	1.21	0.03
0.6	1.06	0.01	1.09	0.02	1.11	0.02	1.17	0.03
0.8	1.05	0.01	1.07	0.02	1.10	0.01	1.16	0.03
1.0	1.04	0.02	1.06	0.02	1.09	0.02	1.12	0.03
1.5	1.03	0.01	1.05	0.01	1.07	0.01	1.07	0.02
2.0	1.03	0.01	1.05	0.02	1.08	0.02	1.06	0.02
2.5	1.03	0.01	1.05	0.02	1.08	0.01	1.05	0.02
3.0	1.04	0.02	1.05	0.02	1.09	0.02	1.06	0.02
3.5	1.05	0.03	1.06	0.04	1.10	0.03	1.07	0.03
4.0	1.03	0.02	1.05	0.03	1.09	0.03	1.05	0.03

$\hat{b}$ indicates the median associated with lognormal distribution;
β represents the associated dispersion

Updated 'b' values

Table 3. Generalization of the proposed 'b' values to short, medium and long period ranges

Period	Bilinear		Takeda		Flag		SINA	
T(s)	$\hat{b}$	β	$\hat{b}$	β	$\hat{b}$	β	$\hat{b}$	β
0.2 ≤ T < 0.6	1.10	0.03	1.14	0.03	1.16	0.03	1.25	0.03
0.6 ≤ T < 4.0	1.04	0.02	1.06	0.02	1.09	0.02	1.08	0.05

Monte Carlo simulation combining two mechanisms

In order to evaluate the combination of two different limit state exceedance mechanisms, Monte Carlo numerical simulations are adopted. Figure 3 demonstrates that the annual probability of system limit state exceedance can be computed using the second mechanism prior to the intersection point (IP) of the fragility curves, with the first mechanism used after the IP. Accordingly, an analytical expression is suggested.

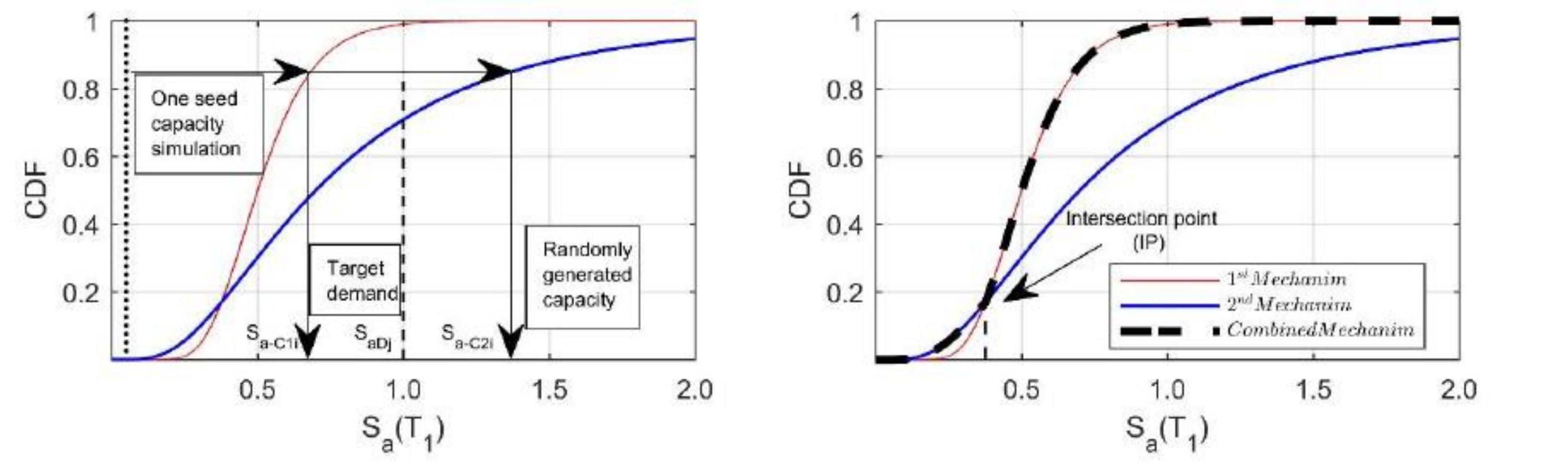
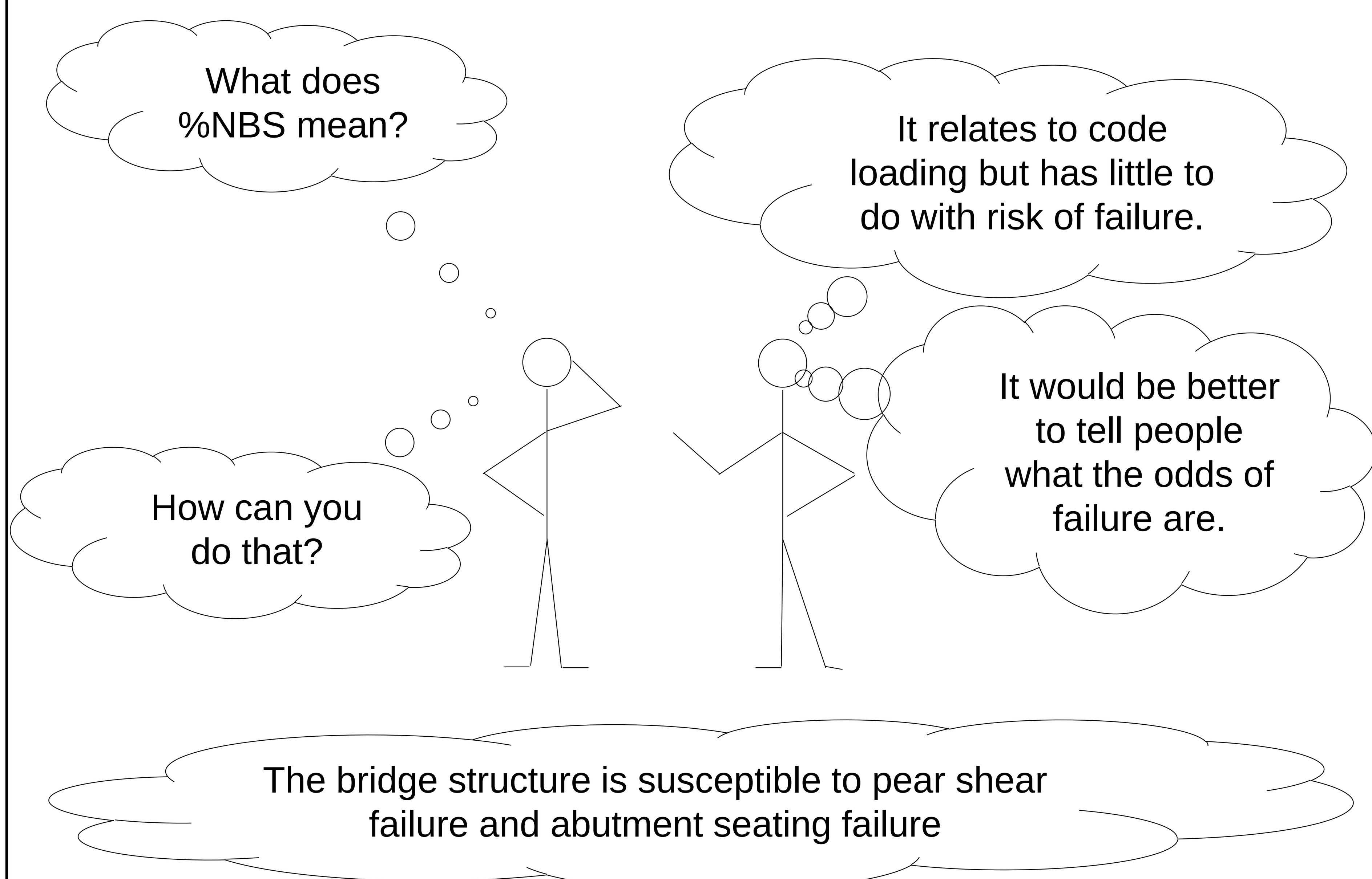
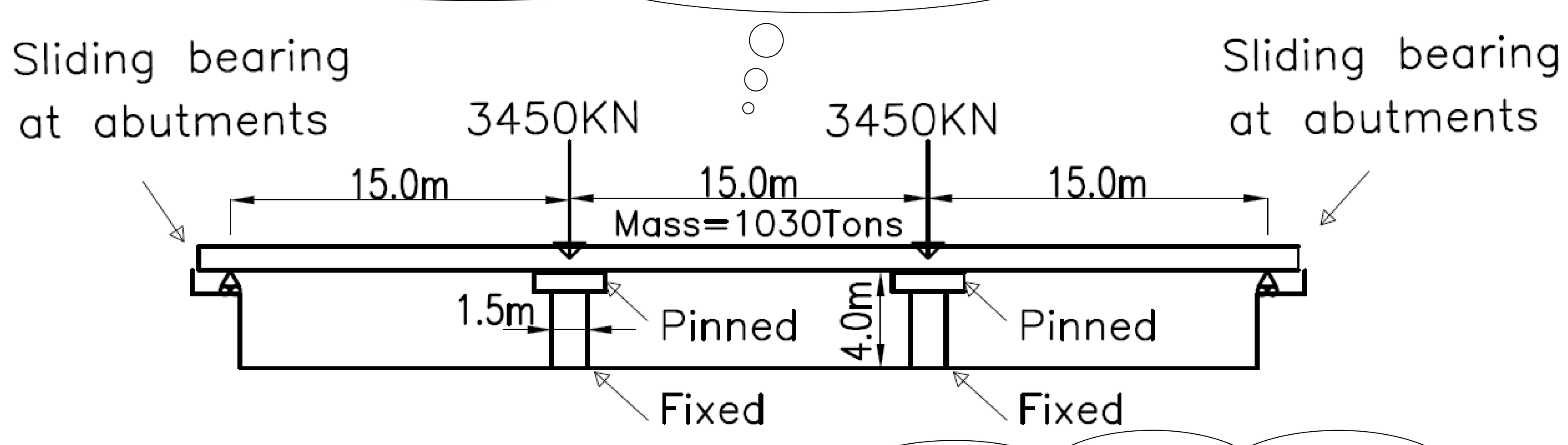
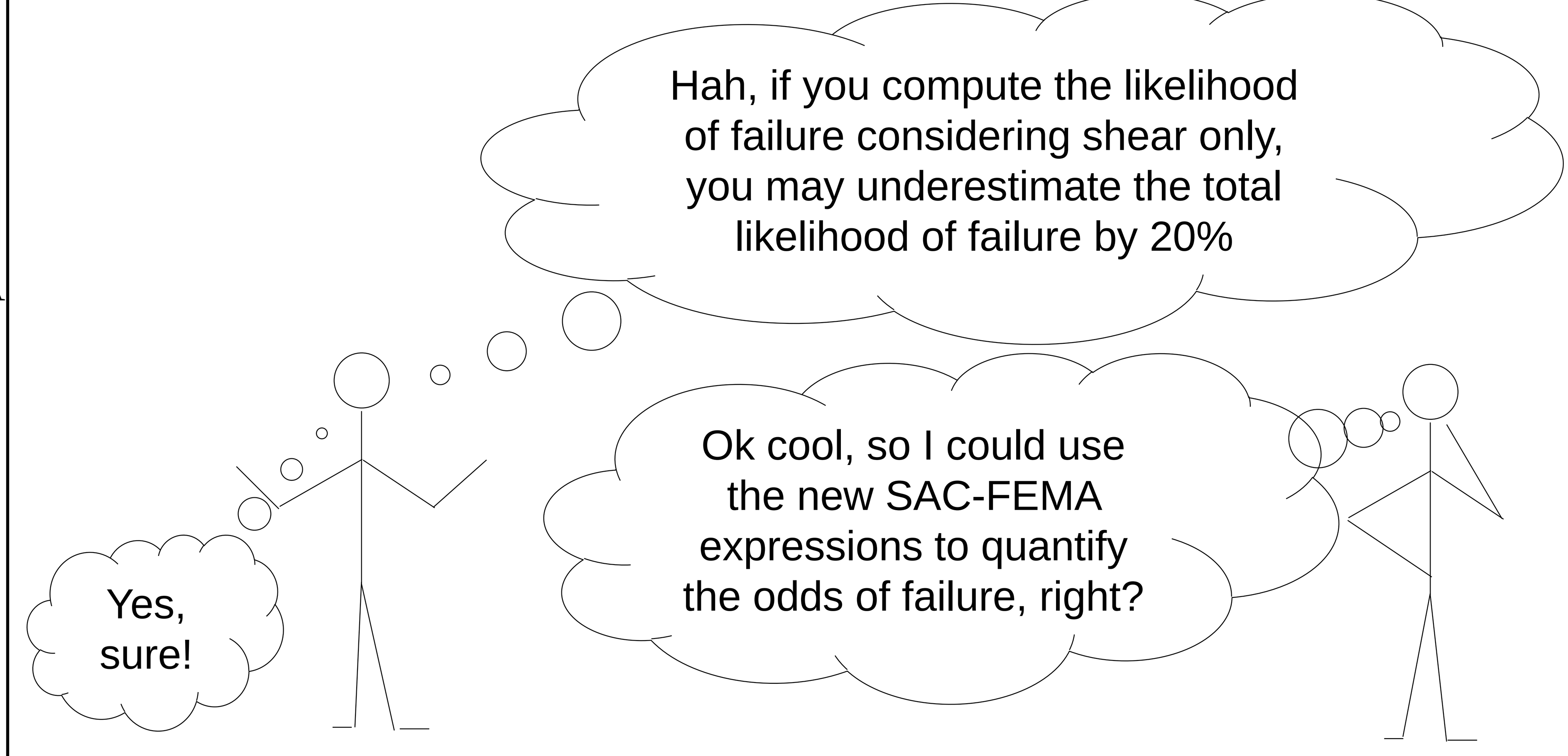


Figure 3 The Monte Carlo simulation (left) and achieved union fragility curve (right)

Developing expressions for the likelihood of failure applicable to systems with two failure mechanisms







CONCLUSIONS

These research findings make the SAC/FEMA approach more accurate. Furthermore, applying the proposed expressions, the SAC/FEMA method can be used to assess the impact of various mechanisms on failure likelihood. More research is required to focus on partially correlated failure mechanisms.

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