# Practical development and application of fragility functions

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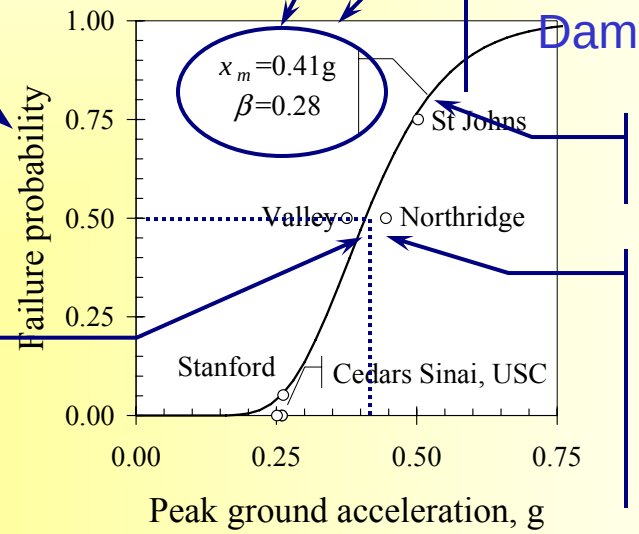
# What's a fragility function?

Here, probability that a component exceeds a damage state as function of demand parameter DP




Parameters of lognormal

Component: *hydraulic elevator*
Damage state: *nonfunctional*

Probability that elevator rendered nonfunctional

Lognormal CDF fit to data

50% probability of loss of functionality at PGA = 0.41g

Data: 91 elevators shaken in Loma Prieta and Northridge earthquakes

DP: base acceleration (=PGA)

# Challenge

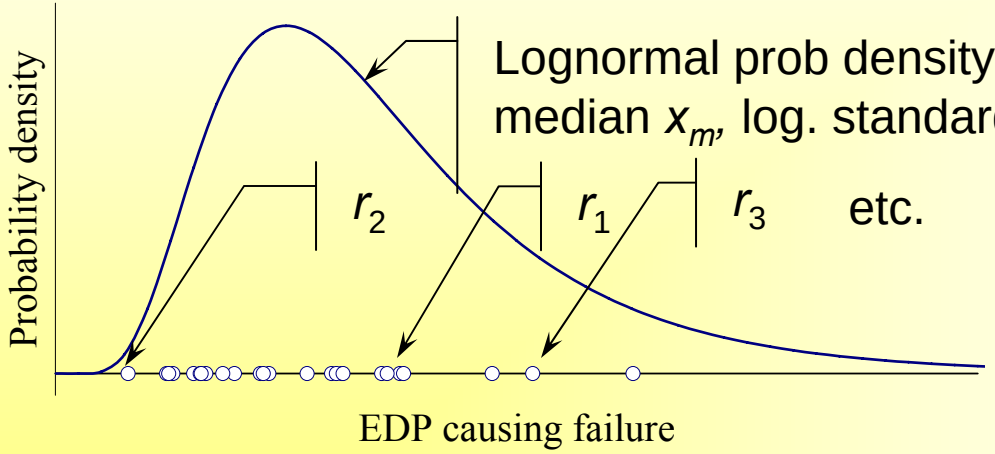
- Creating fragility functions has been an art with no art school
- Want comprehensive, consistent, vetted methods
  - Data come in numerous forms; many ways and levels of effort to analyze them
- Assign quality levels to fragility functions, e.g.
  - From lots of data & peer-reviewed analysis to expert opinion of 1 or 2 experts
- Should not require PhD to create fragility functions
  - But should require a beard and ~5'-6" height

# Six kinds of data

A. **Actual demand data**: specimens tested with slowly increasing DP to failure, DP at failure is known.
B. **Bounding demand data**: specimens observed in lab or field, some failed, some not. Max DPs are known.
C. **Capable demand data**: specimens tested in lab, none failed, max DP for each is known.
D. **Derivation**: estimate capacity with structural analysis.
E. **Expert opinion**: capacity from engineering judgment.
U. **Updating**: Bayesian updating of existing fragility function with new type-A, B, or C observations.

# Method A
## Known failure DP, each specimen

- Tabulate failure DP observed for each specimen *i*




| *i* | $r_i$ |
|---|---|
| 1 | 1.42 |
| 2 | 0.39 |
| 3 | 0.59 |
| 4 | 0.32 |
| 5 | 0.53 |
| … | |

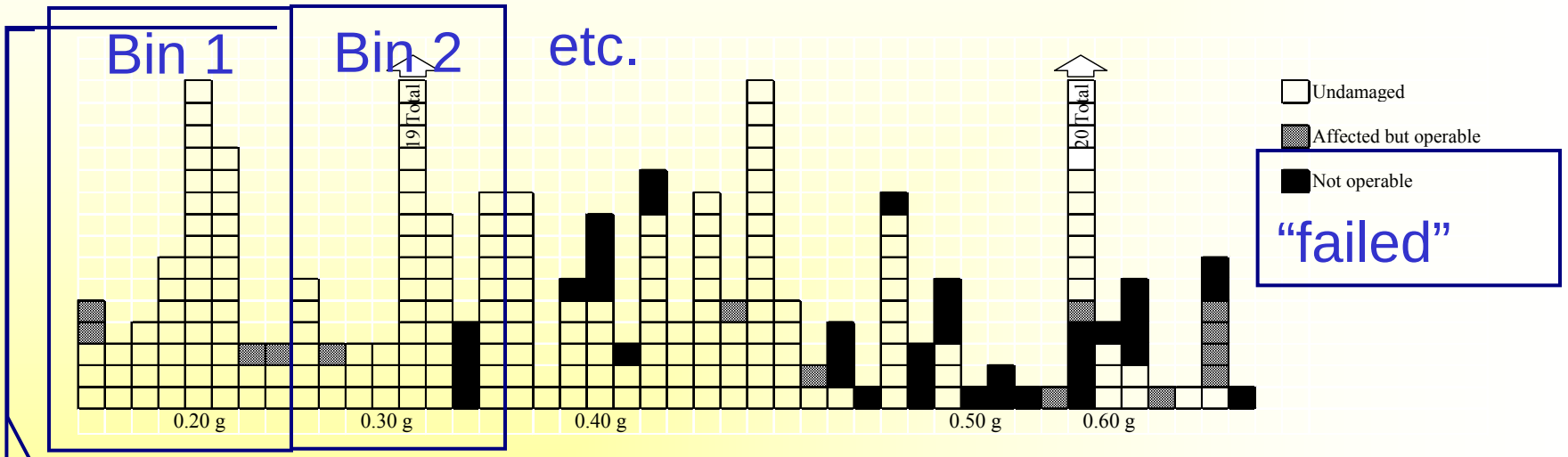
- Calculate parameters of probability

$$x_m = \exp\left(\frac{1}{M}\sum_{i=1}^{M}\ln r_i\right)$$

$$\beta = \sqrt{\frac{1}{M-1}\sum_{i=1}^{M}\left(\ln\left(r_i/x_m\right)\right)^2}$$

# Method B

## Known max-DP, some failed, some not




~0.2g: 0/52 failed = 0% failure rate (0 black-filled boxes, 52 boxes)

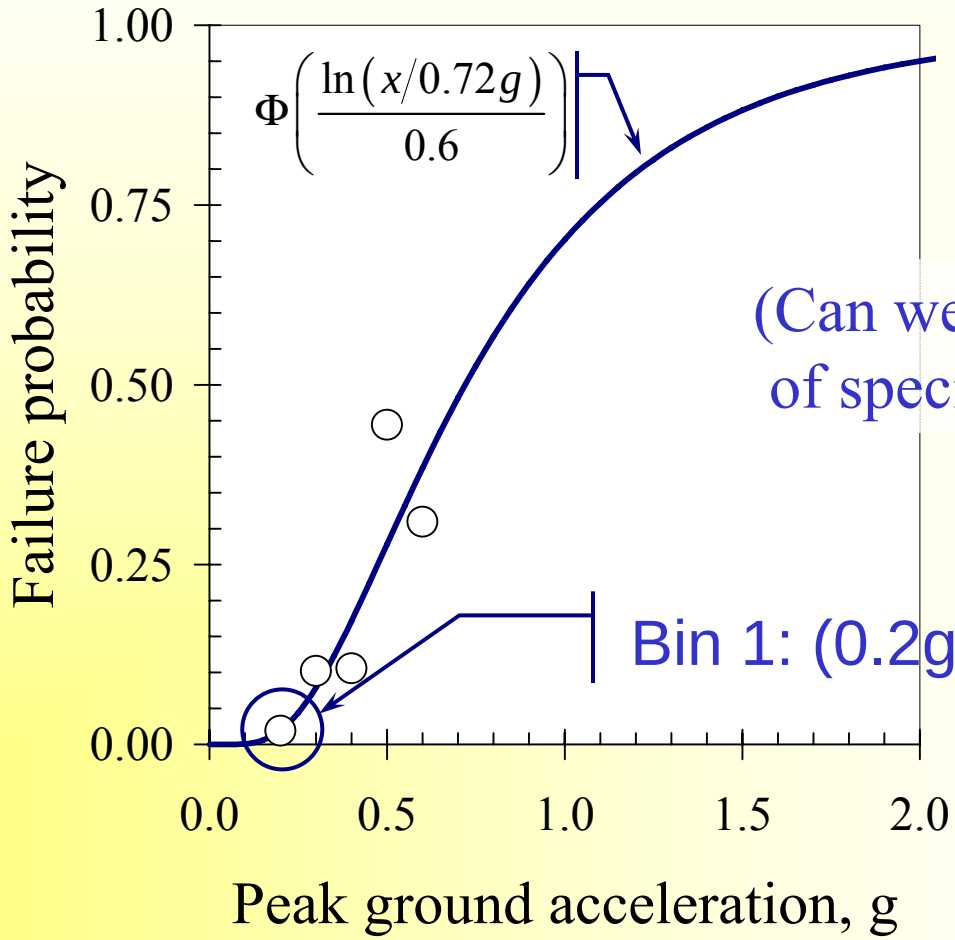
~0.3g: 4/48 failed = 8.3% failure rate

~0.4g: 8/84 failed = 9.5%

~0.5g: 15/35 failed = 43%

# Method B

## Known max-DP, some failed, some not



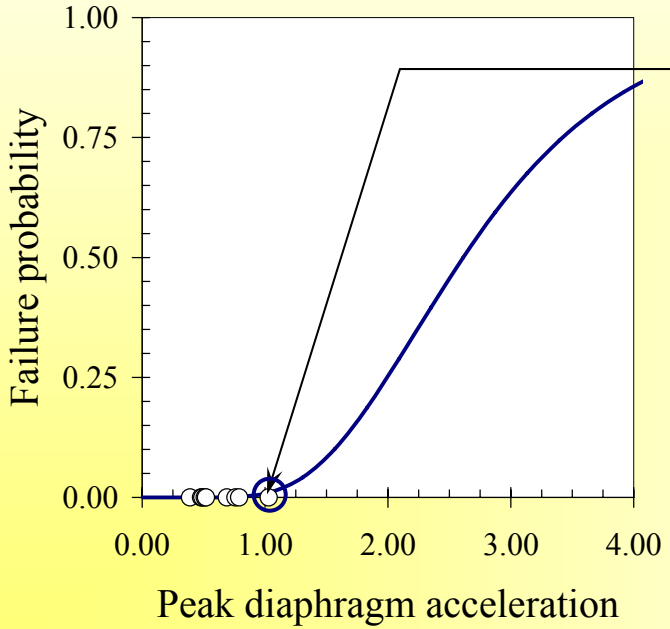

(Can weight points by # of specimens in each bin)

Bin 1: (0.2g, 0/52 failed)

# Method C

## No specimens failed, DP known

Case 1: No specimens with distress, several tested near max DP*



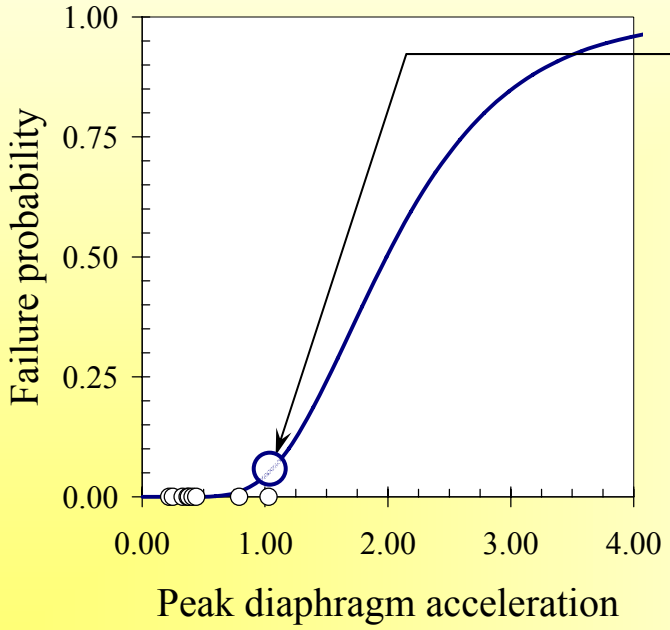

Assume 1% failure prob. at max DP and $\beta = 0.4$, so $x_m = 2.54 \cdot (\text{max DP})$

* 3+ specimens with DP $\geq 0.7$(max DP)

# Method C

## No specimens failed, DP known

Case 2: No specimens with distress, few tested near max DP*



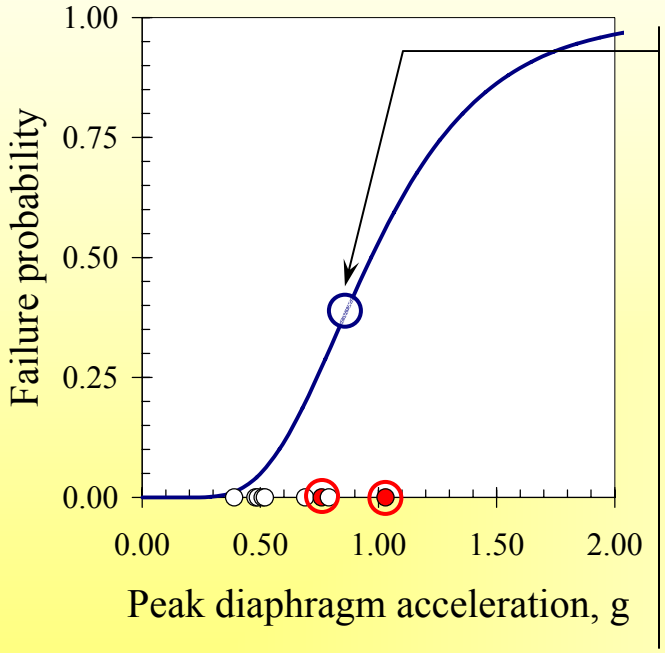

Assume **5%** failure prob. at max DP and $\beta = 0.4$, so $x_m = 1.93 \cdot (\text{max DP})$

* 1 or 2 with DP $\geq 0.7$(max DP)

# Method C

## No specimens failed, DP known

Case 3: Some specimens with distress



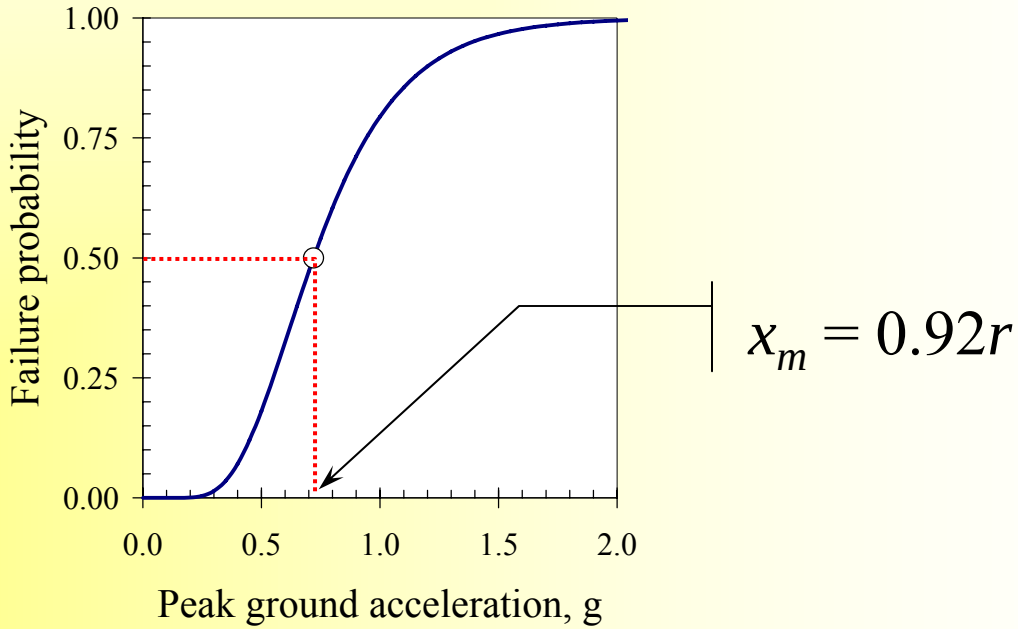

| Treat specimens with | As if $P_f$ = |
|---|---|
| severe distress | 0.5 |
| some distress | 0.1 |
| no distress | 0.0 |

Calculate average *DP* and $P_f$ of top-DP specimens, take $\beta = 0.4$, & fit curve through this point

Distress

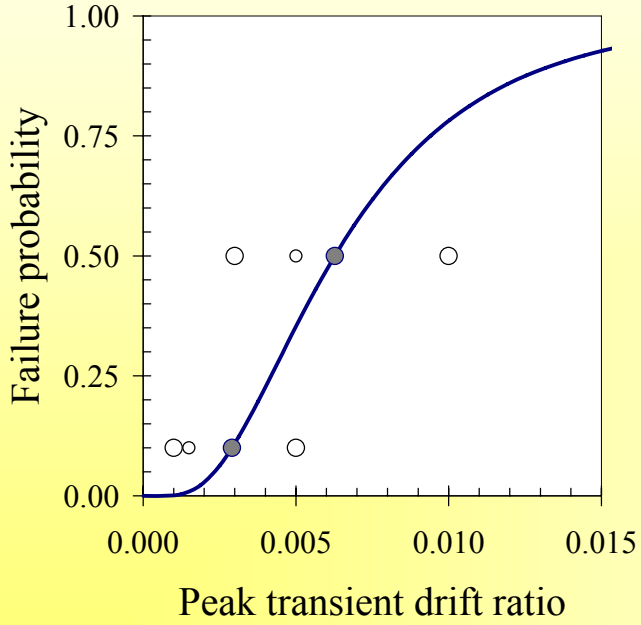
# Method D
## Derived (analytical) capacity

- No empirical failure data available
- Get deterministic capacity *r* from structural analysis
- Treat *r* as mean capacity, take $\beta = 0.4$, so $x_m = 0.92r$



# Method E
## Expert opinion

No data, too complex to analyze well

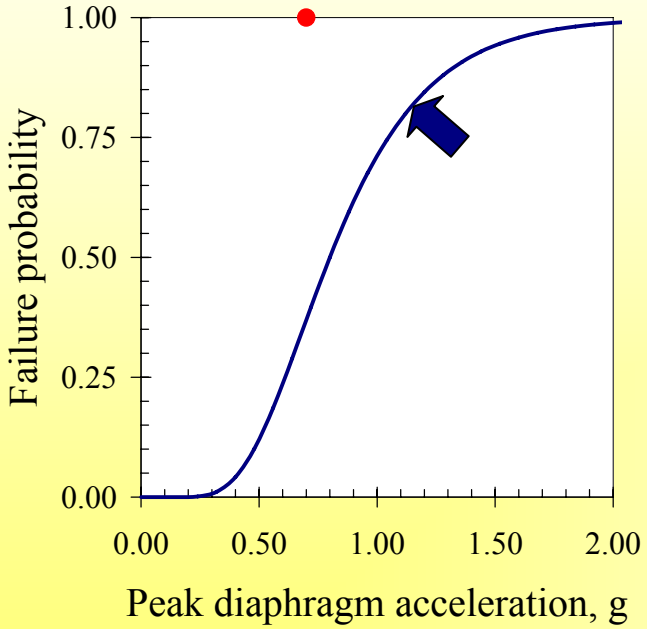



- Using a form, poll experts for
  - Median failure DP, $x_m$
  - 10th percentile DP, $x_l$
  - Level of expertise, $w$
- Calculate weighted average $x_l$, $x_m$
- Fit curve through these

# Method U

## Fragility function exists, update with new data

Bayesian statistics provide a theoretical, consistent basis for updating a distribution based on new observations




- A prior fragility function exists
  - Its $x_m$ and $\beta$ are treated as uncertain
  - Fragility function uses their mean vals
- New data arrive
- Calculate new distr. of $x_m$ and $\beta$
  - New fragility function uses mean $x_m$, $\beta$
- Function moves toward new data

# Other issues

- Why lognormal CDF? Other distributions?
- Goodness of fit and outliers
- Other methods, e.g., U with type-A data
- 2+ damage states, fragility functions that cross
- Assigning quality to a fragility function
- Fragility testing and reporting
- Software to do all these calcs automatically

# Questions?

**Paper and extended report at**
**www.sparisk.com/publications.htm**

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