

# Improved HAZUS Vulnerabilities for PAGER

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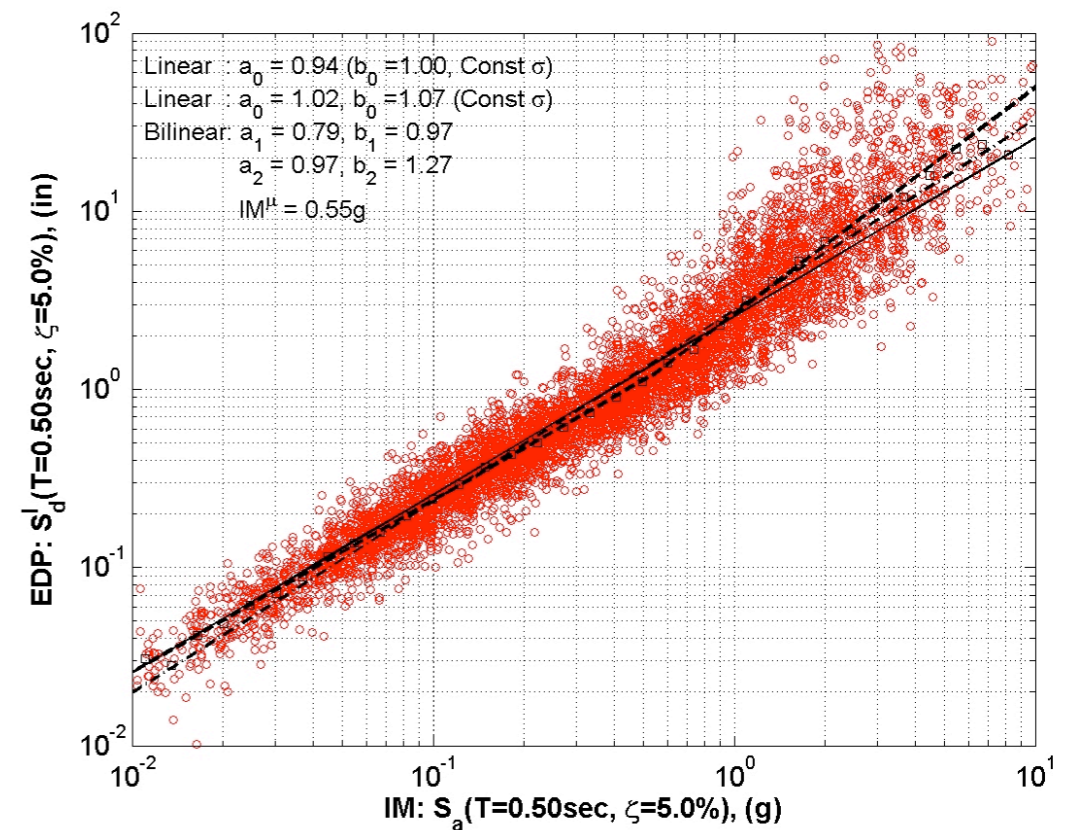
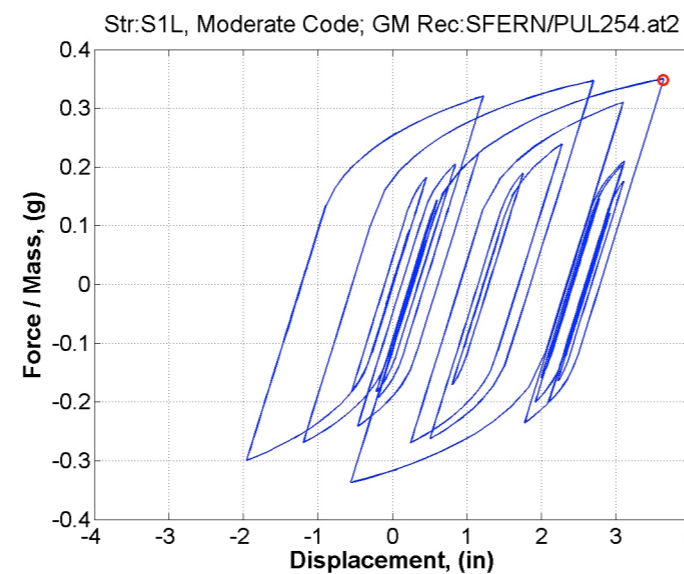
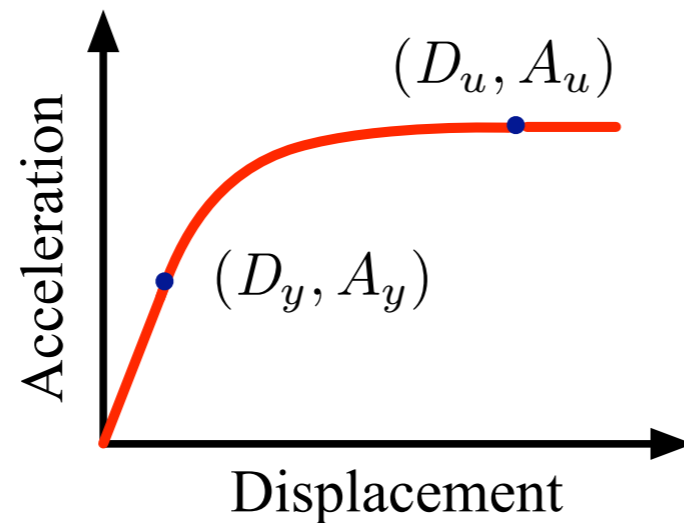
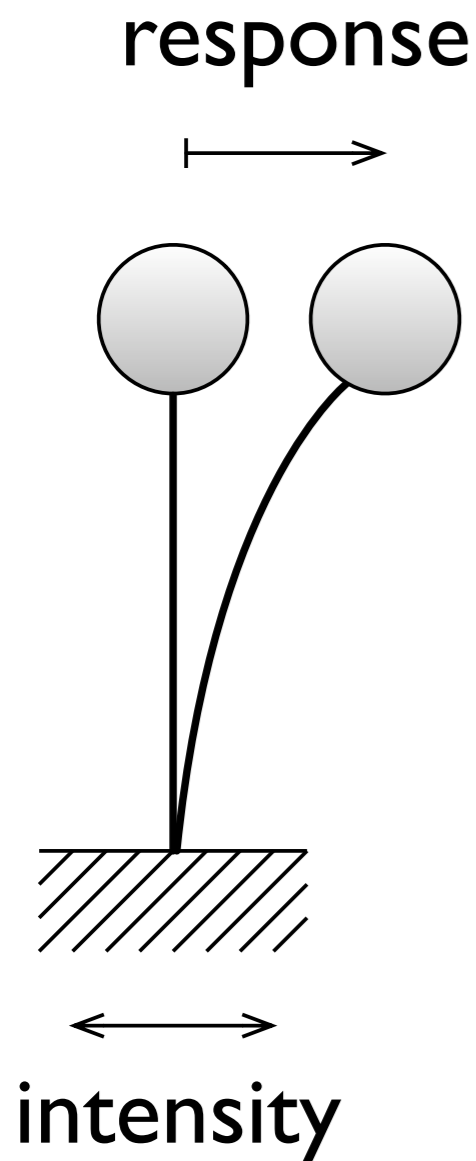
# Outline

- HAZUS Fragility/Vulnerability Models
- Improved Fragility Models
  - Multilinear Capacity Curves
  - Capacity-Consistent Damage State Thresholds
  - Collapse Fragility Models
- Link to PAGER
  - Example for Taiwan Buildings

# HAZUS Fragility Models

- Conditioned on spectral displacement
- Not compatible with USGS hazard curves/maps
- Coupled capacity spectrum method
- Not able to accurately consider record-to-record randomness
- Vulnerability models provide only mean value of loss ratio

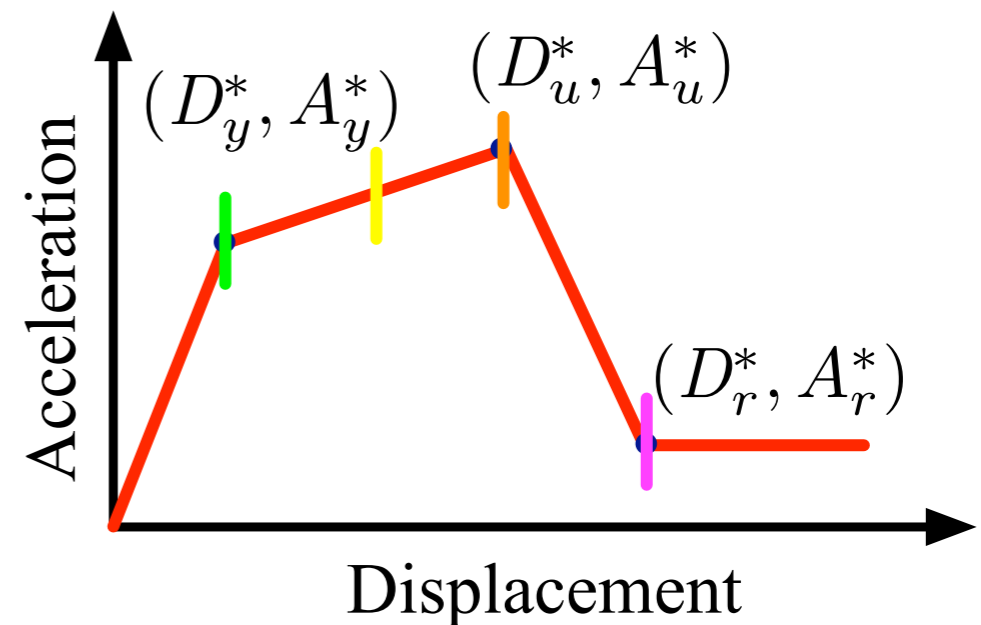
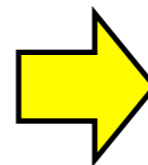
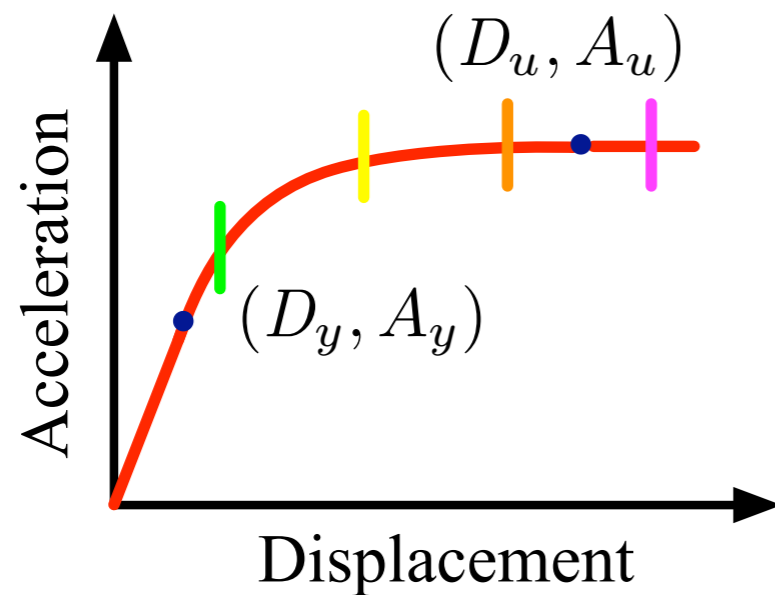
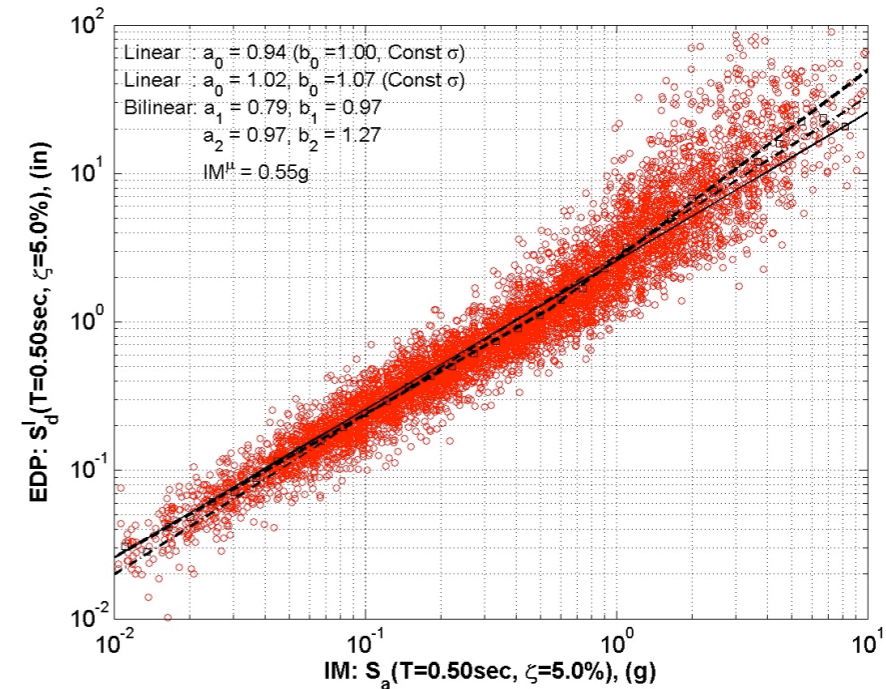
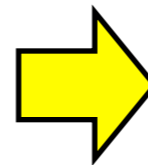
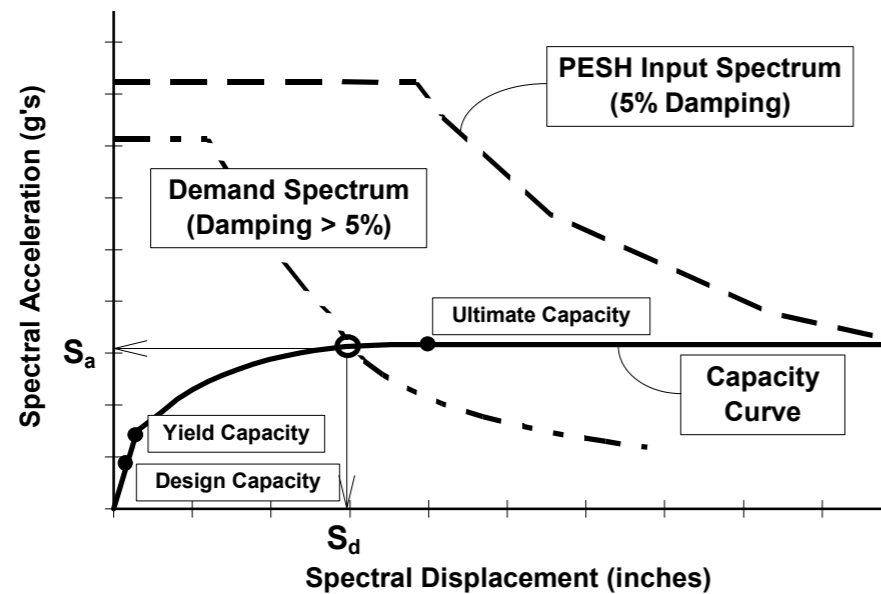
# Hazard-compatible Fragility Models



$$P(DS \geq ds | IM = im) = \int_{edp} P(DS \geq ds | EDP = edp) \cdot f_{EDP|IM}(edp|im) dedp$$

(Karaca and Luco, 2008)

# Improved HAZUS Fragility/ Vulnerability Models



# Multilinear Capacity Curve

$$D_y^*$$

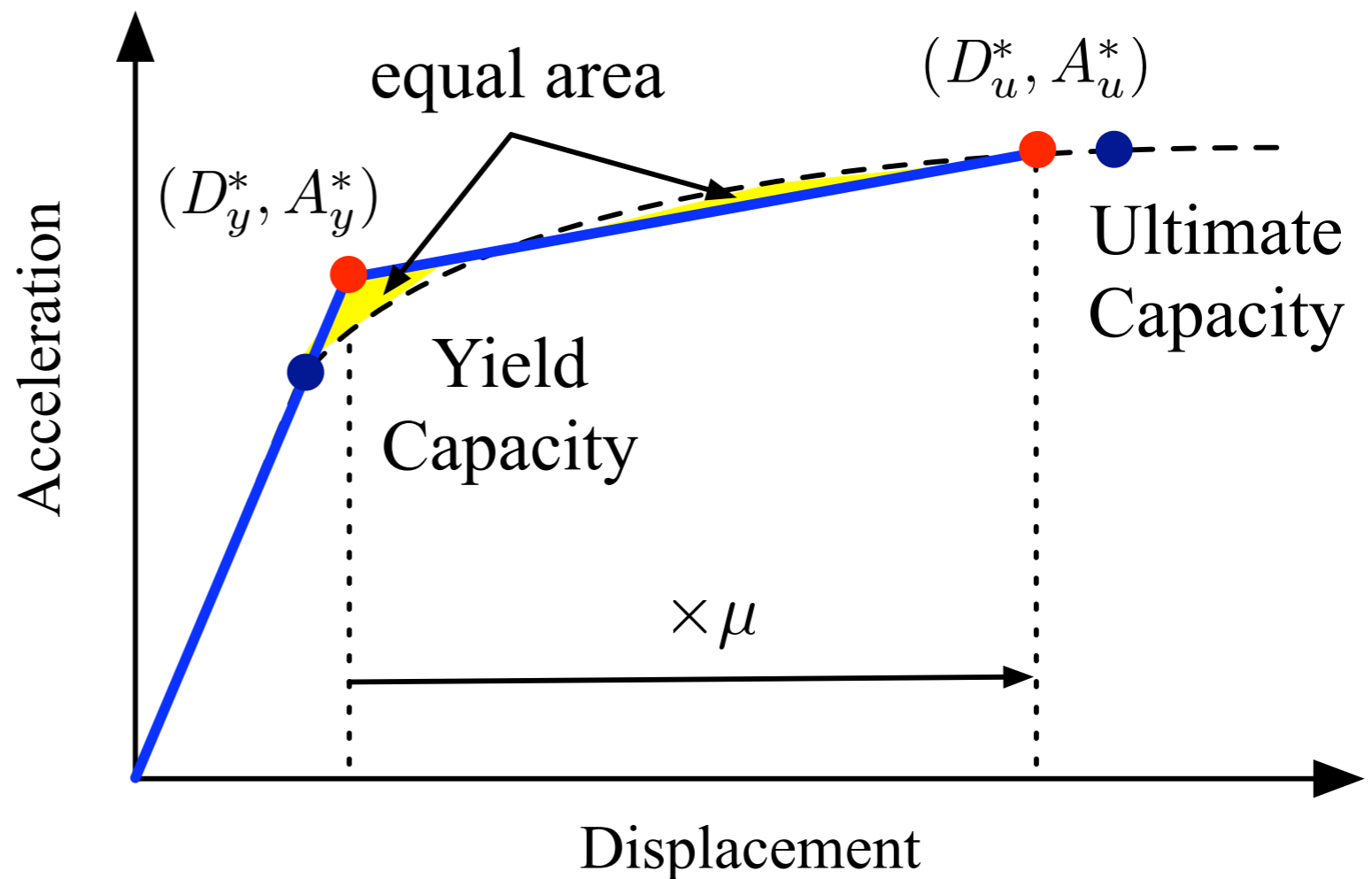
$$A_y^* = D_y^* / (9.8T_e^2)$$

$$D_u^* = \mu \times D_y^*$$

$$A_u^* = A_u$$

$$D_r^* = \frac{S_{d,complete}}{S_{d,extensive}} \times D_u^*$$

$$A_r^* = \lambda_r \times A_y^*$$



\*: proposed values  
 else: provided in HAZUS

(Ryu et al., 2008)

# Capacity-Consistent DSTs

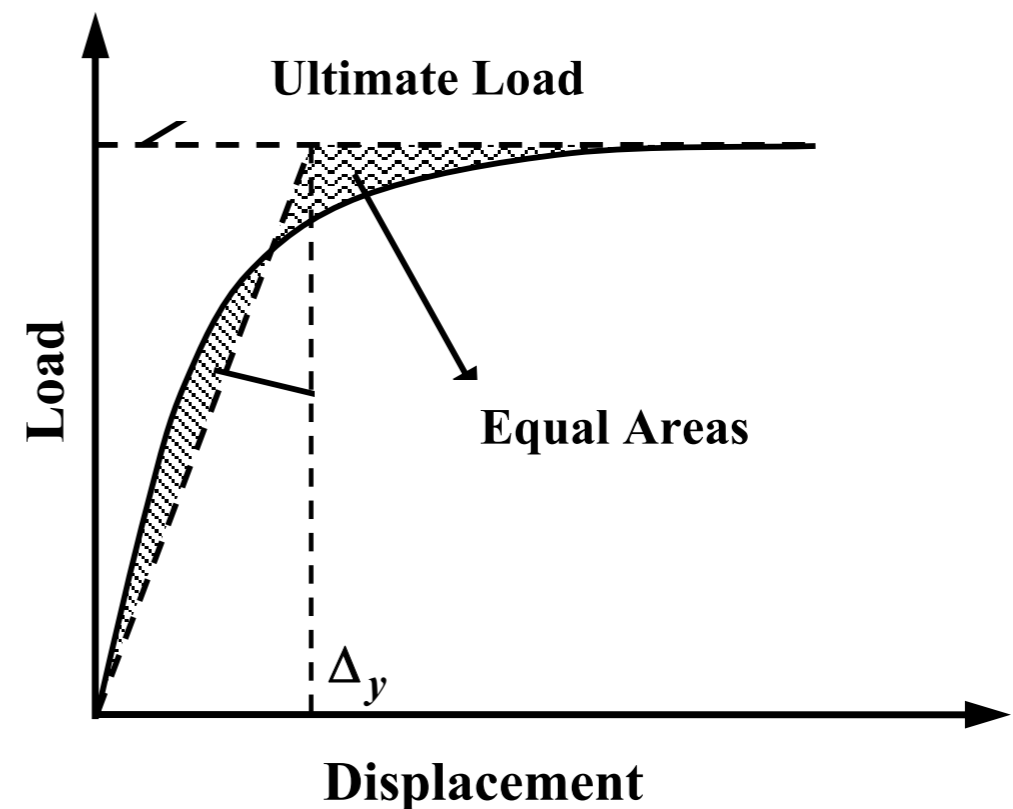
$$S_{d,slight}^* = \alpha_h D_y^*$$

$$S_{d,moderate}^* = \alpha_h \Delta_y$$

$$S_{d,extensive}^* = \alpha_h D_u^*$$

$$S_{d,complete}^* = \alpha_h D_r^*$$

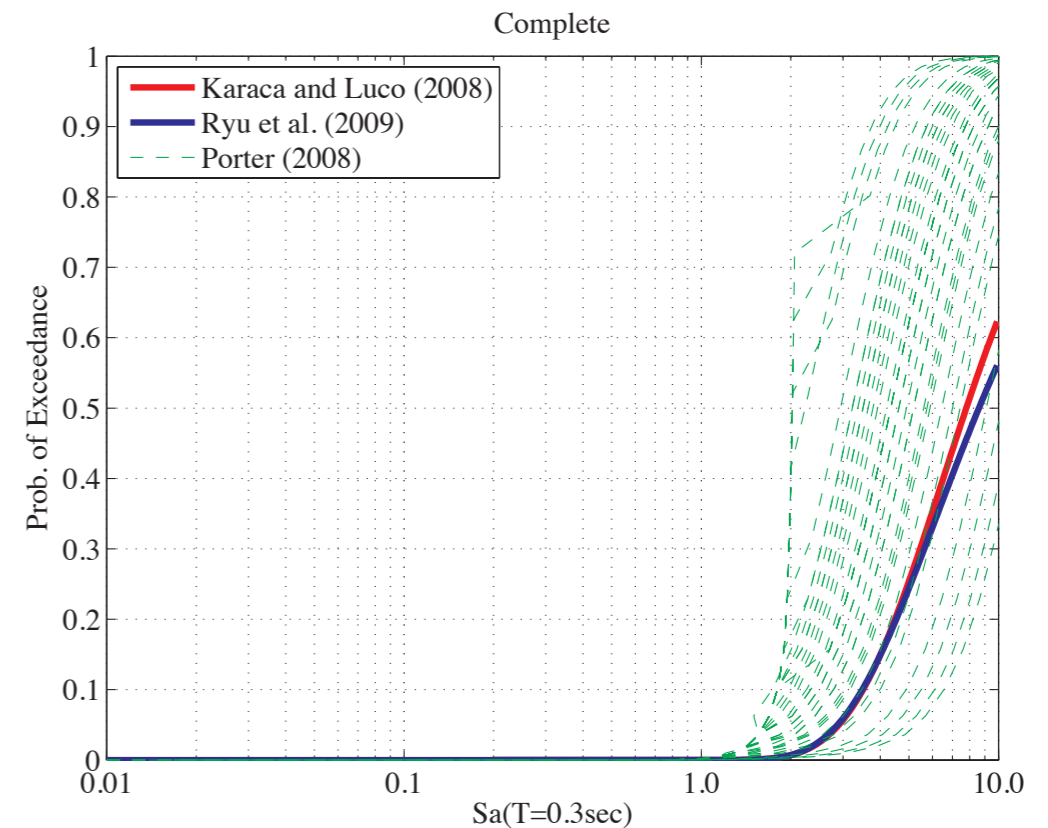
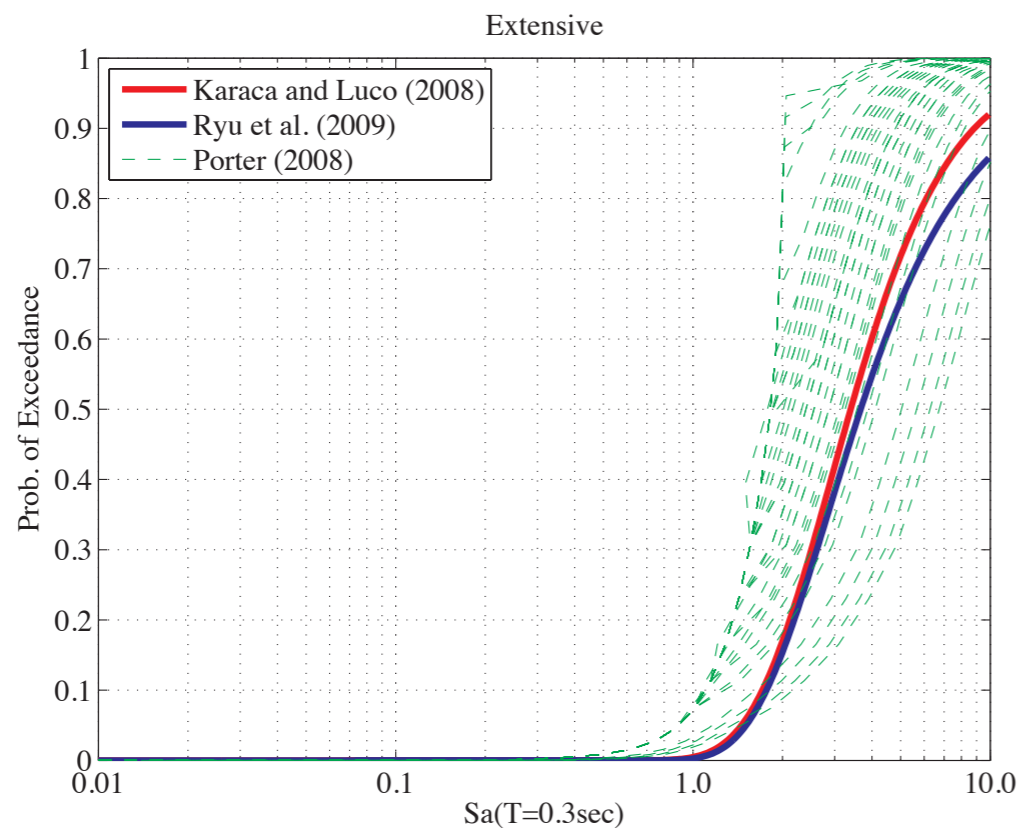
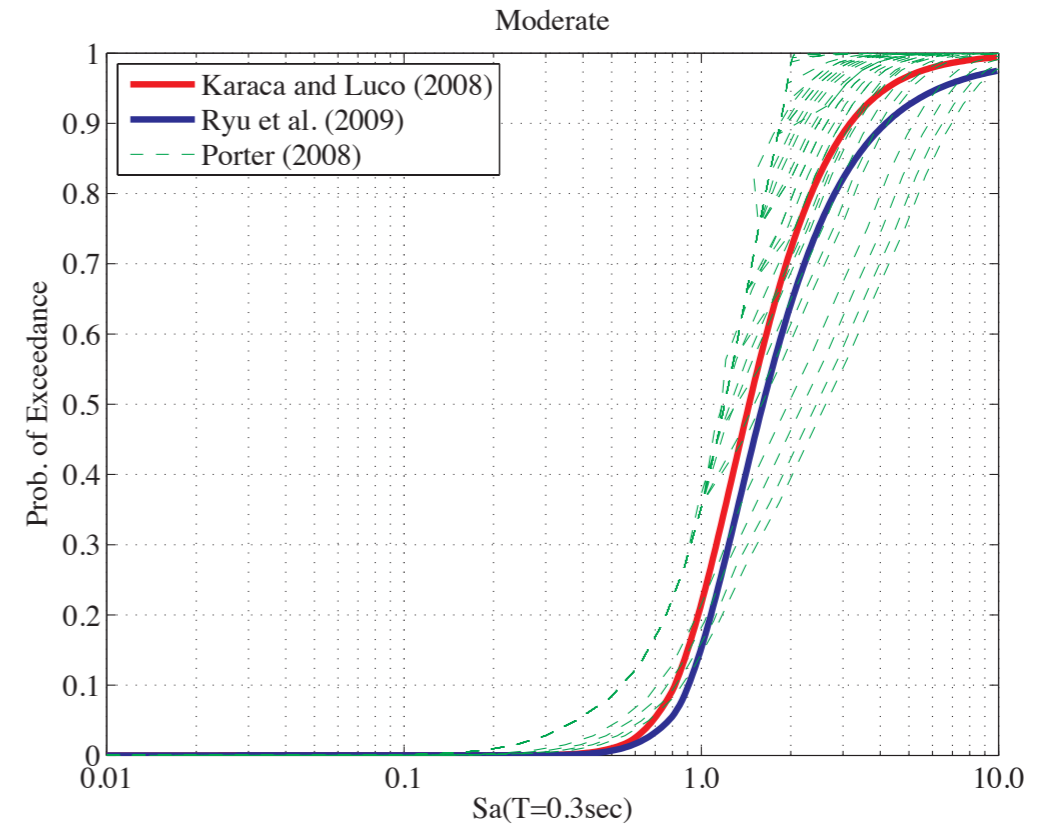
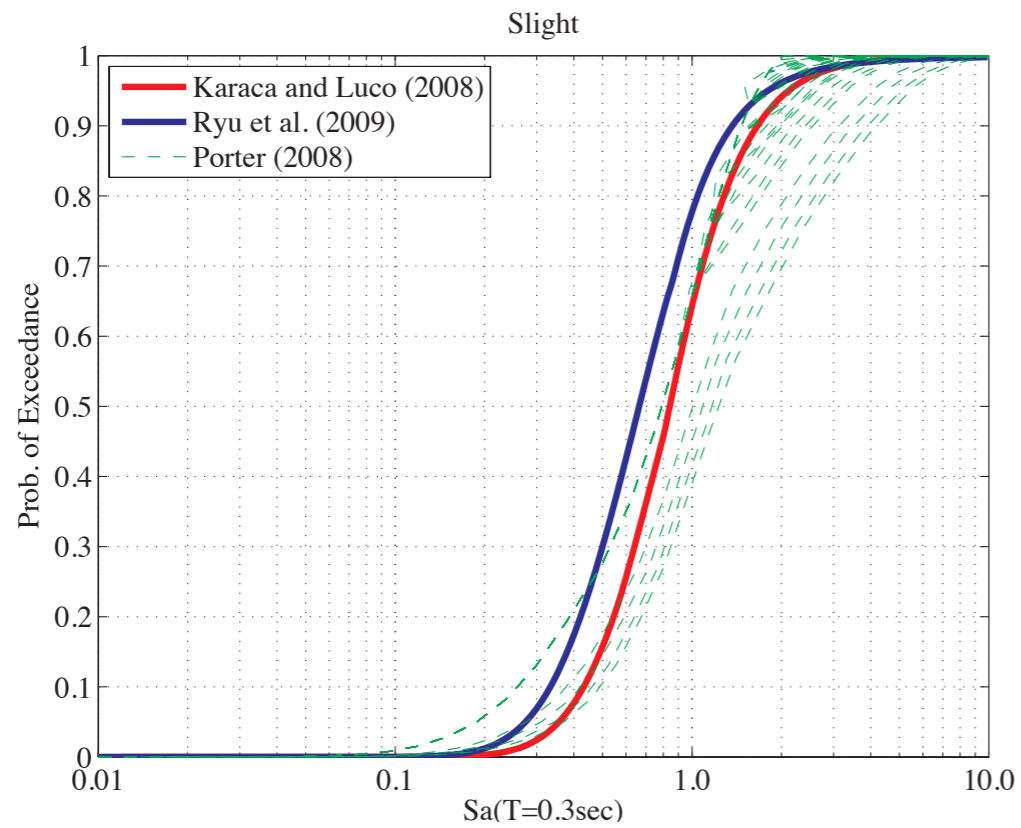
$\Delta_y$  (Park, 1988)



where  $\alpha_h = \begin{cases} 1.0 & \text{for low-rise} \\ 0.67 & \text{for mid-rise} \\ 0.5 & \text{for high-rise bldgs.} \end{cases}$

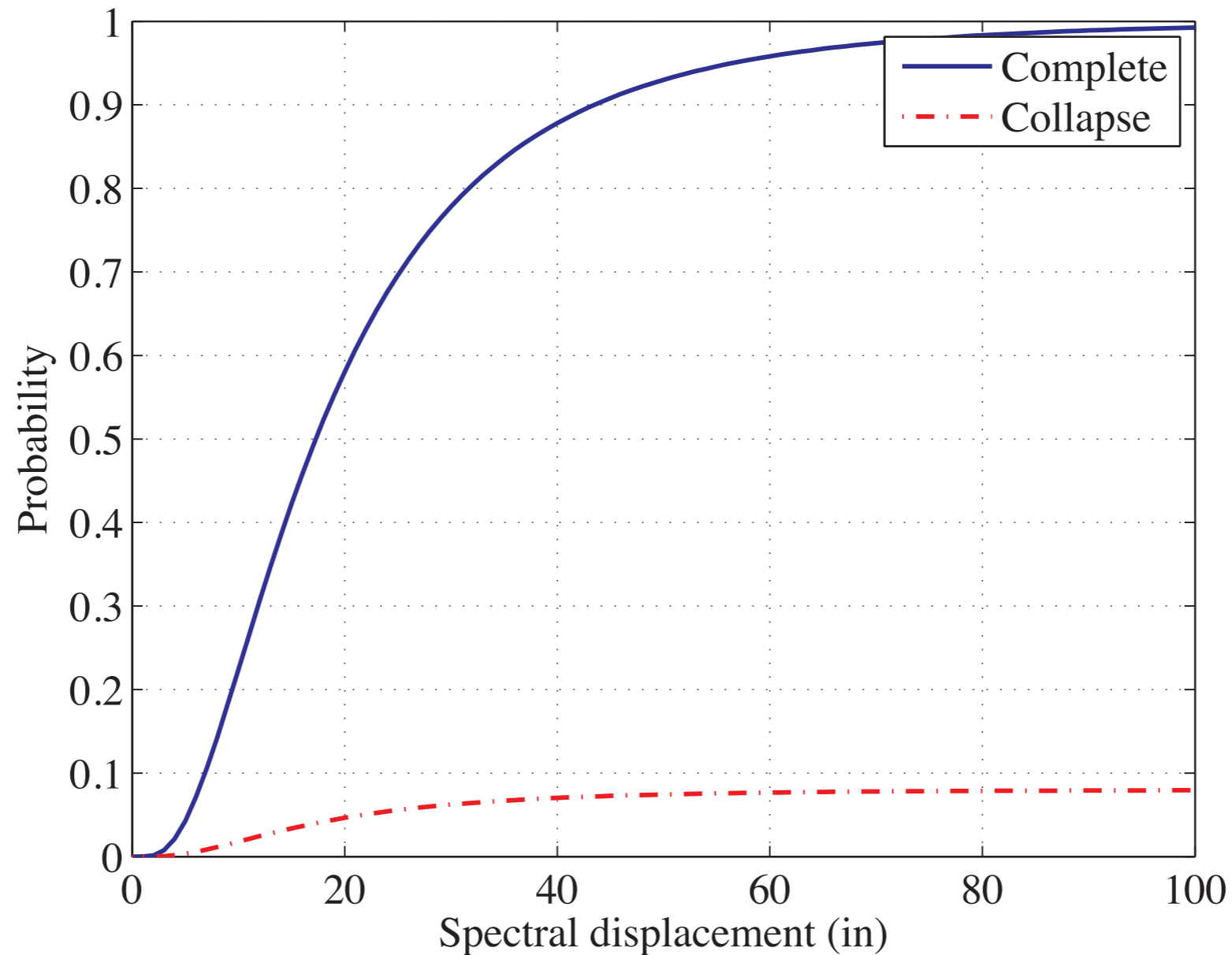
# Comparison

## S4Lh: Steel Frame with concrete shear walls





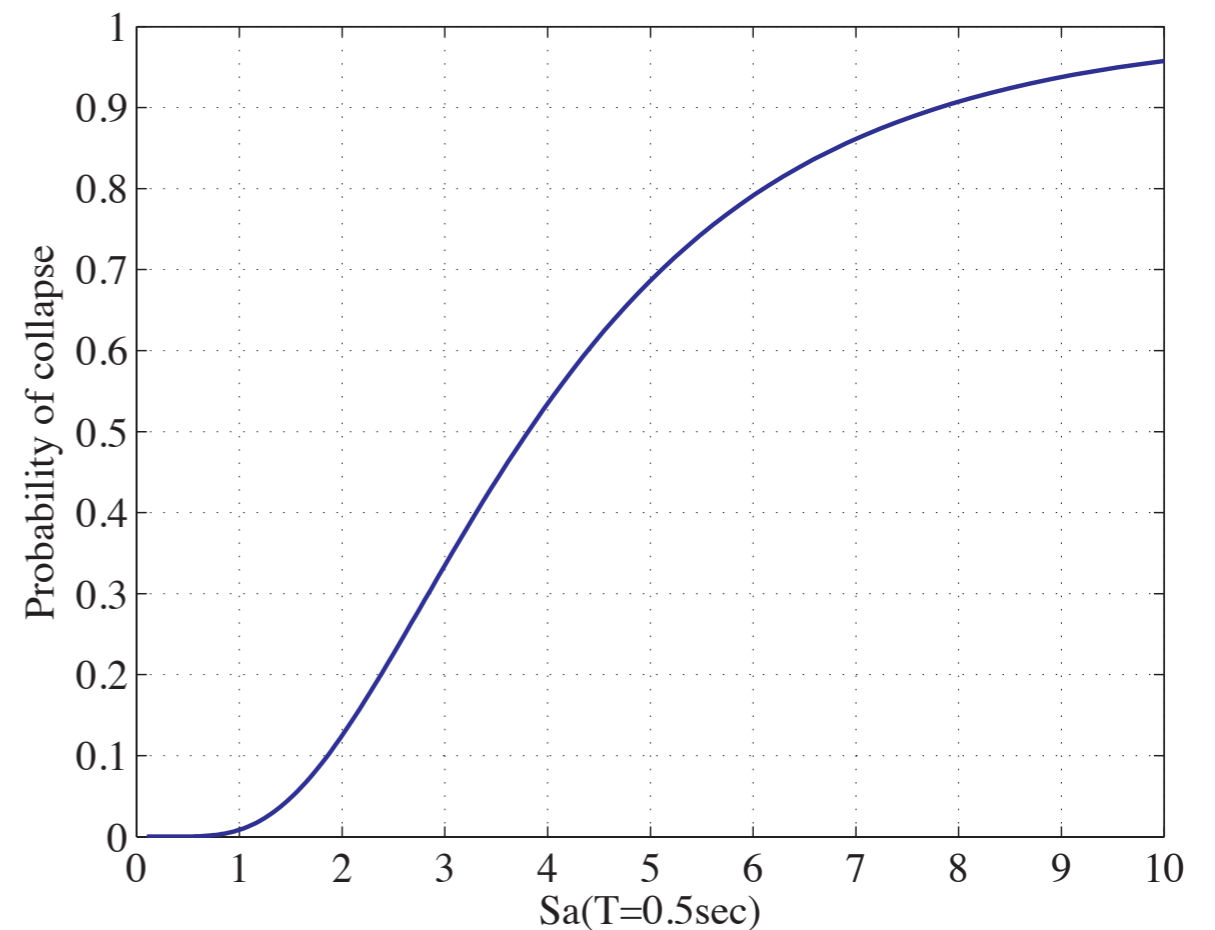
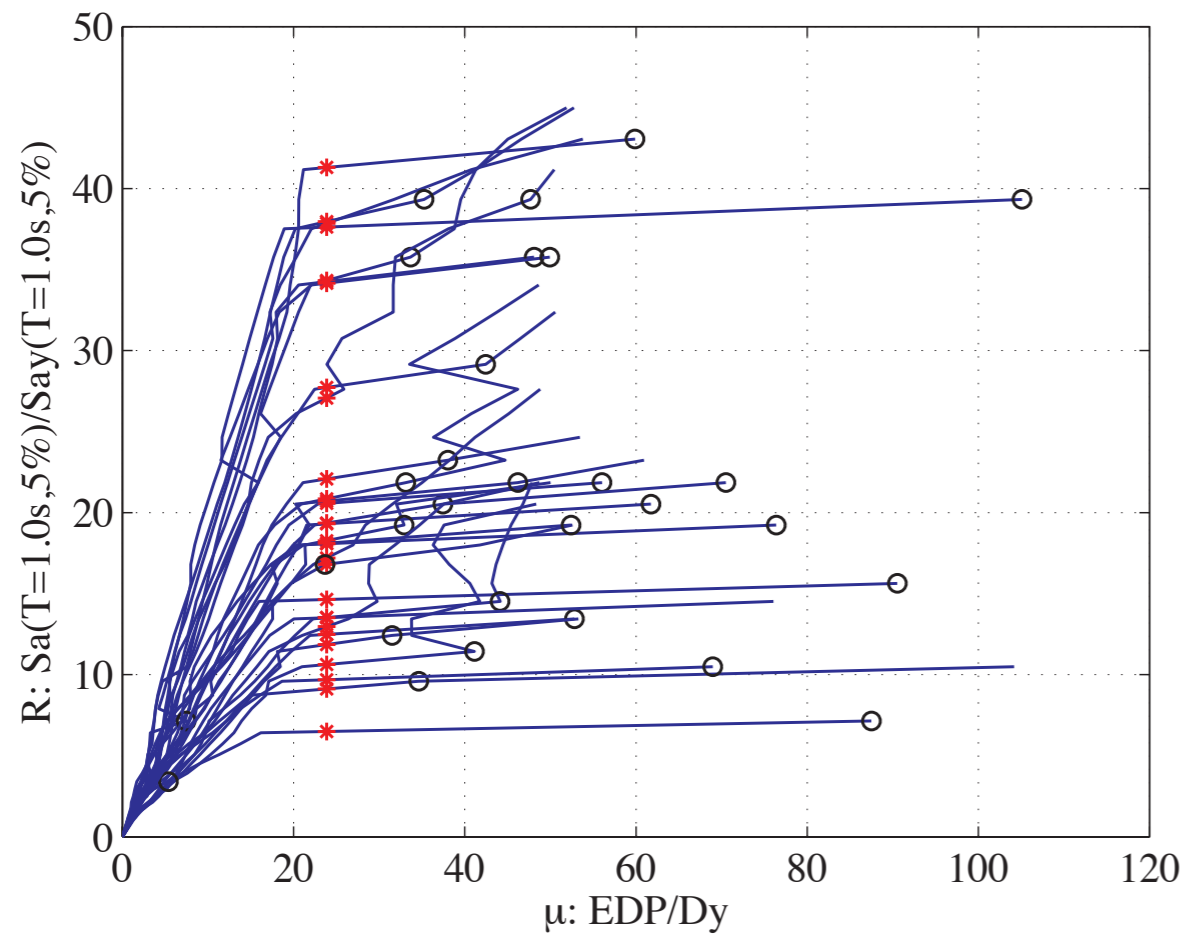
# HAZUS Collapse Fragility



$$P[DS = \text{collapse} | S_d = x] = P_c \times P[DS = \text{complete} | S_d = x]$$

# Improved Collapse Fragility

## Incremental Dynamic Analyses

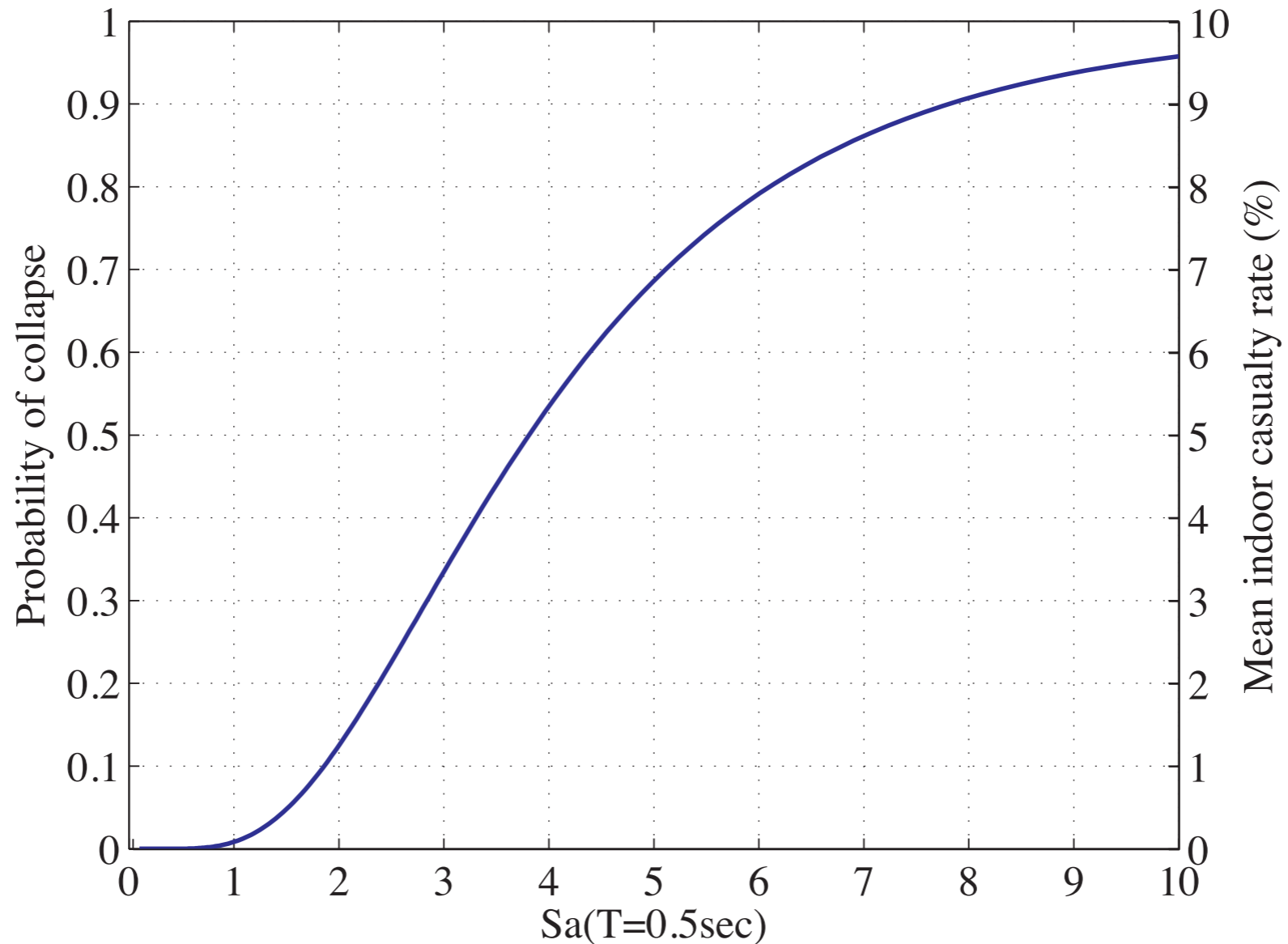


$$P(\text{collapse} | S_a(T) = x) = P(S_{a,c} \leq x) = \Phi\left(\frac{\ln(x / \hat{m})}{\hat{\xi}}\right)$$

# Link to PAGER

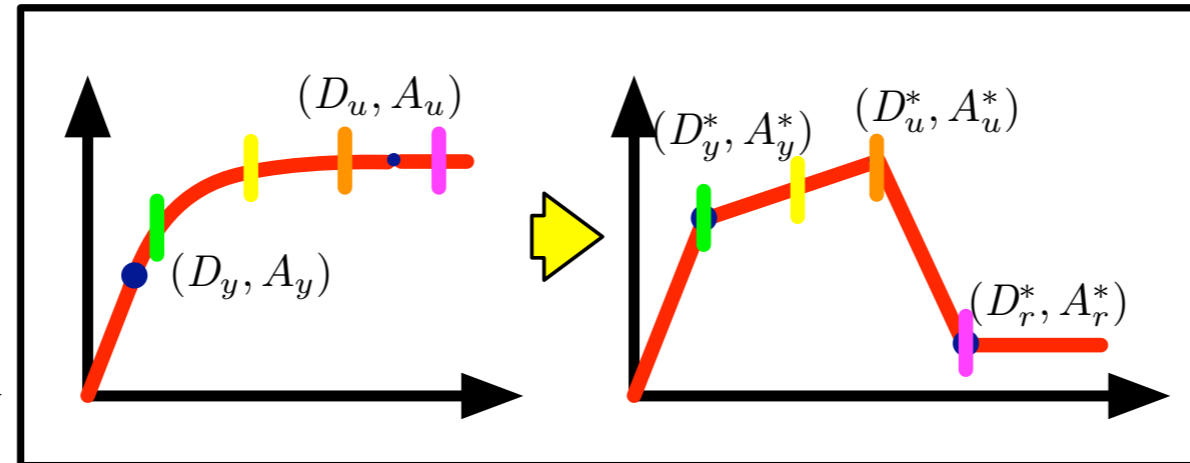
## Fatality Assessment

$$L(S_a = x) \cong P[DS = \text{collapse} | S_a = x] \times L_{ds}(DS = \text{collapse})$$



# Link to PAGER

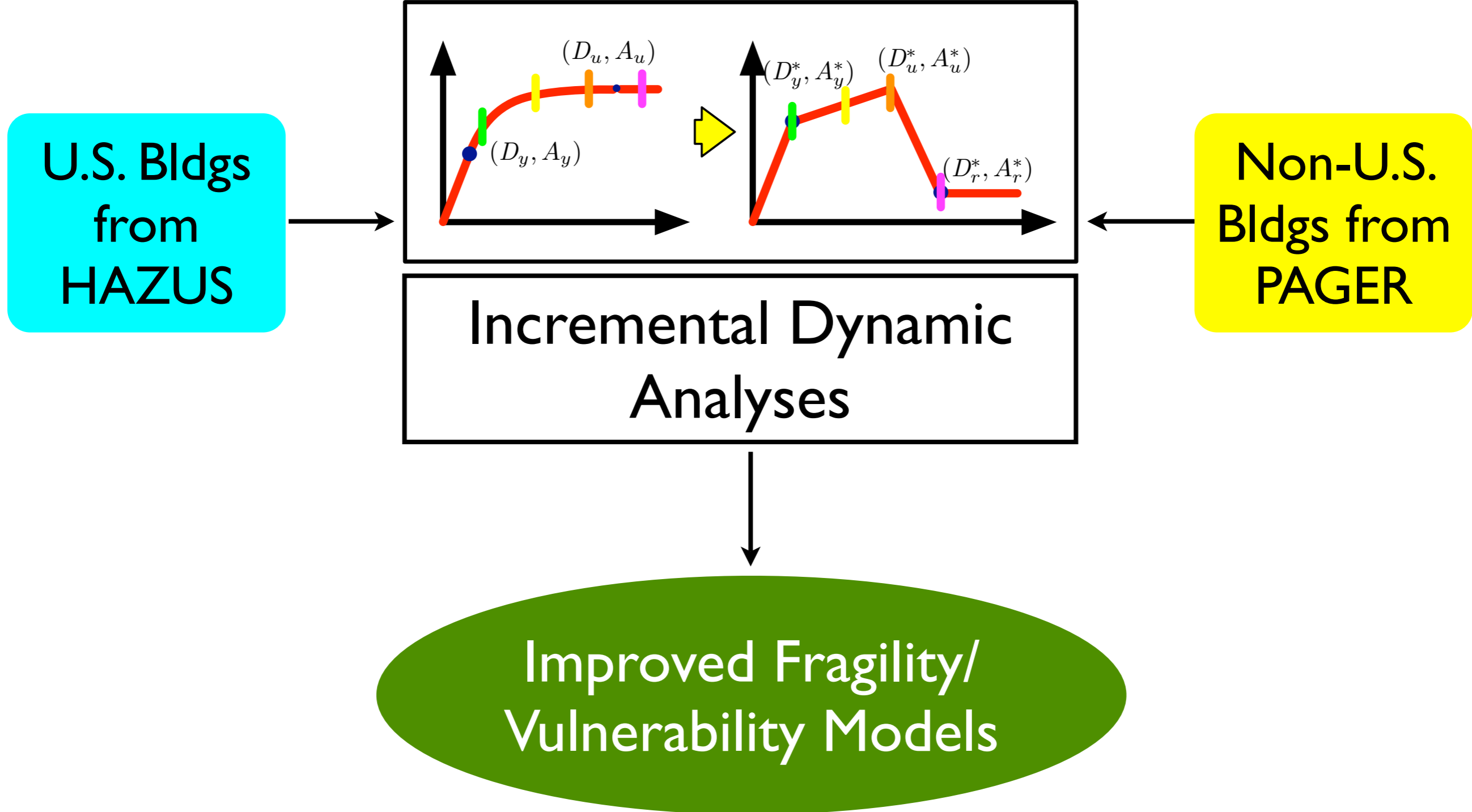
U.S. Bldgs  
from  
HAZUS



Incremental Dynamic  
Analyses

Improved Fragility/  
Vulnerability Models

# Link to PAGER

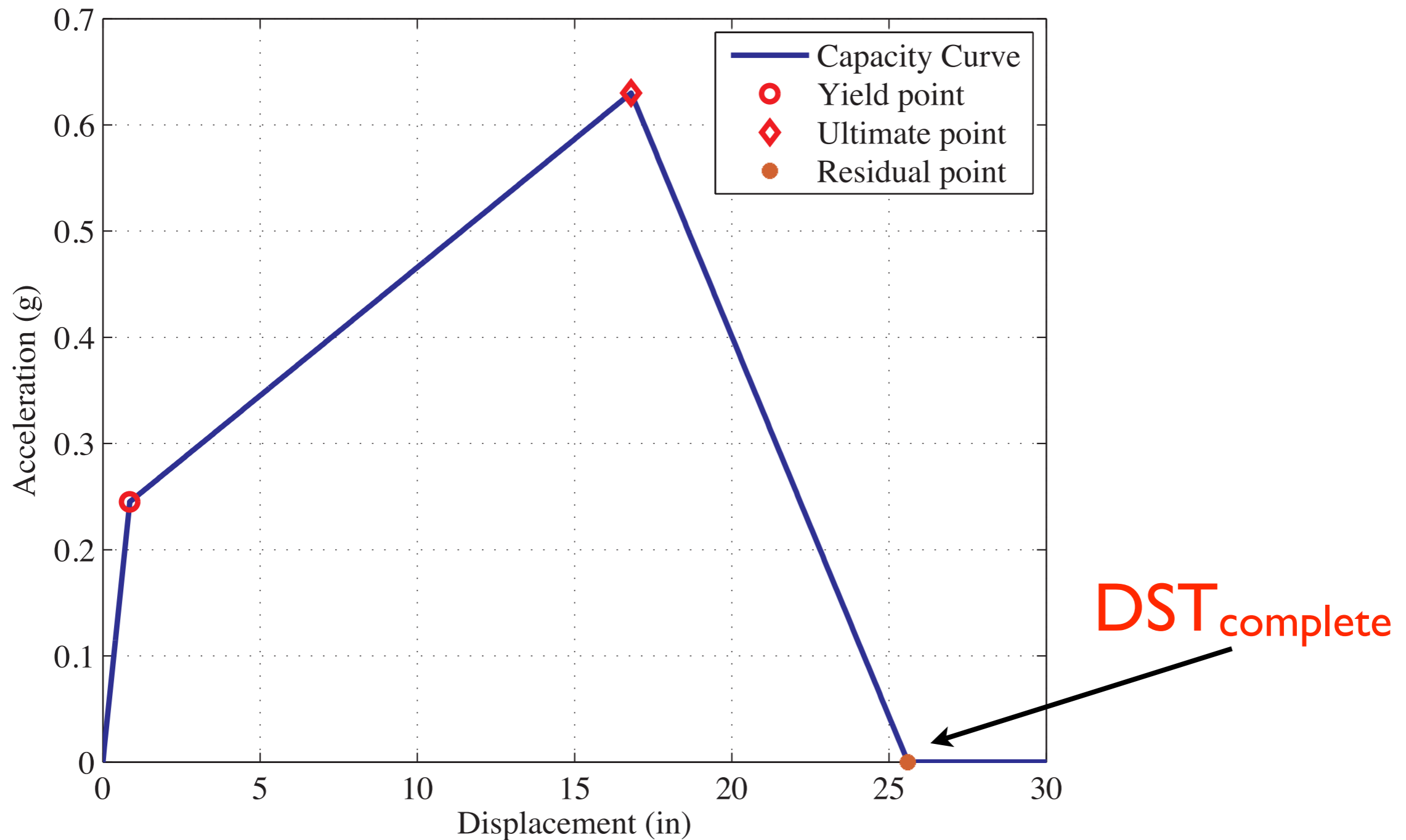


# IDA vs. SPO2IDA

	IDA	SPO2IDA
IM	User-specified	$S_a(T_1, 5\%)$
GMs	User-specified	$6.5 \leq M \leq 6.9$ $15 \text{ km} < R < 33 \text{ km}$
Hysteresis model	User-specified	Moderately pinching model, no cyclic deterioration

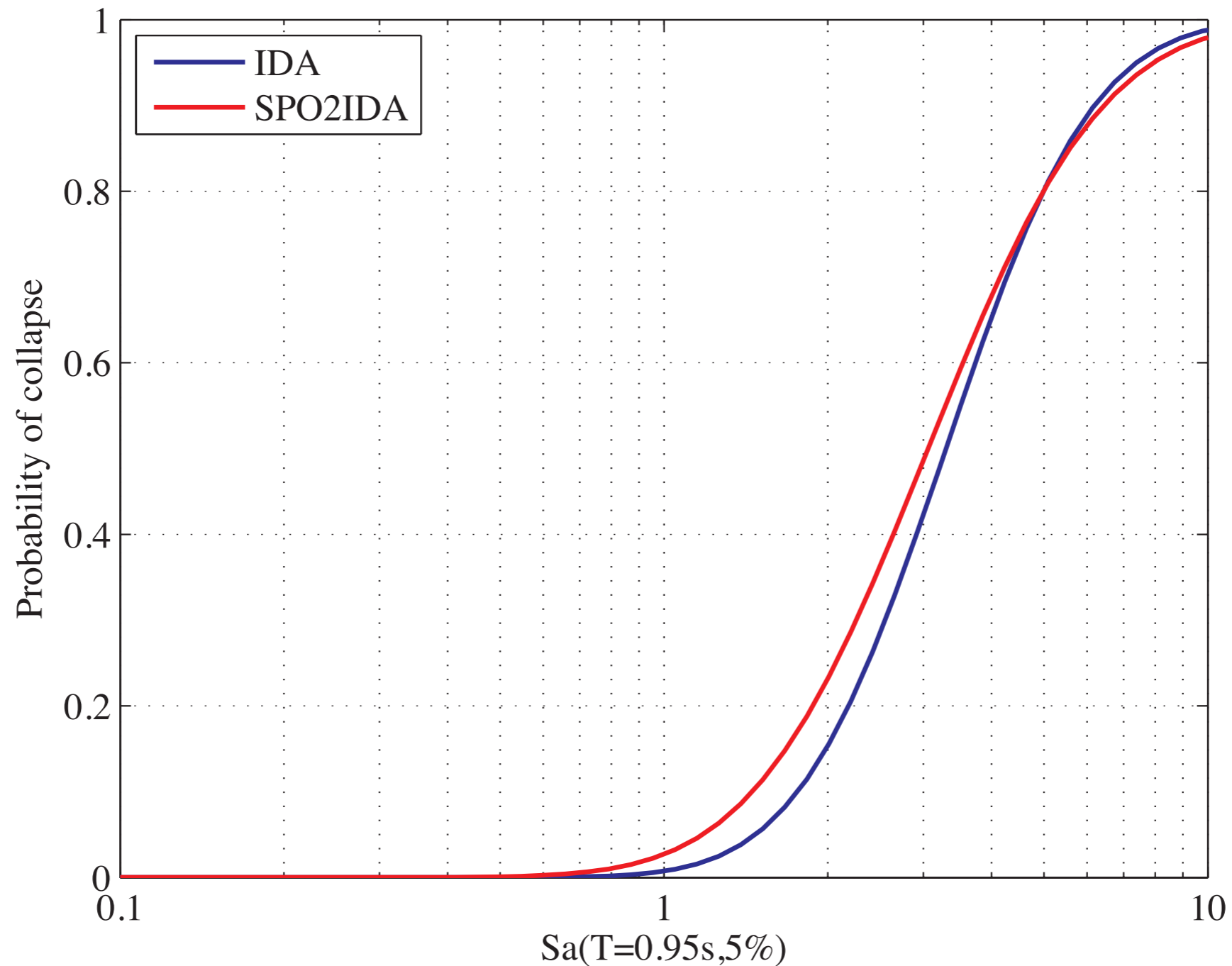
# Example for Taiwan Bldgs

## Low-Rise Unreinforced Masonry



# Collapse Fragility Models

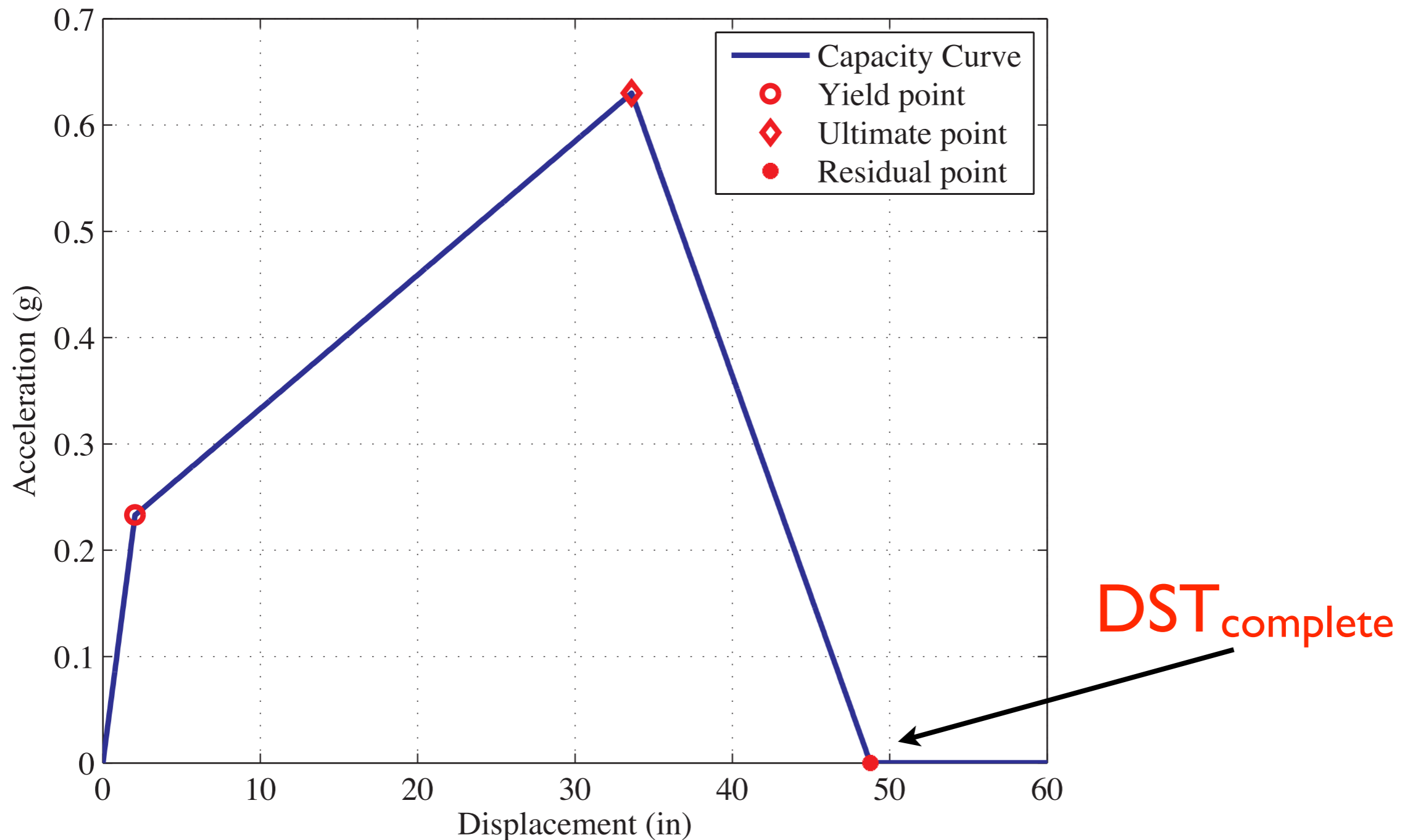
## Low-Rise Unreinforced Masonry





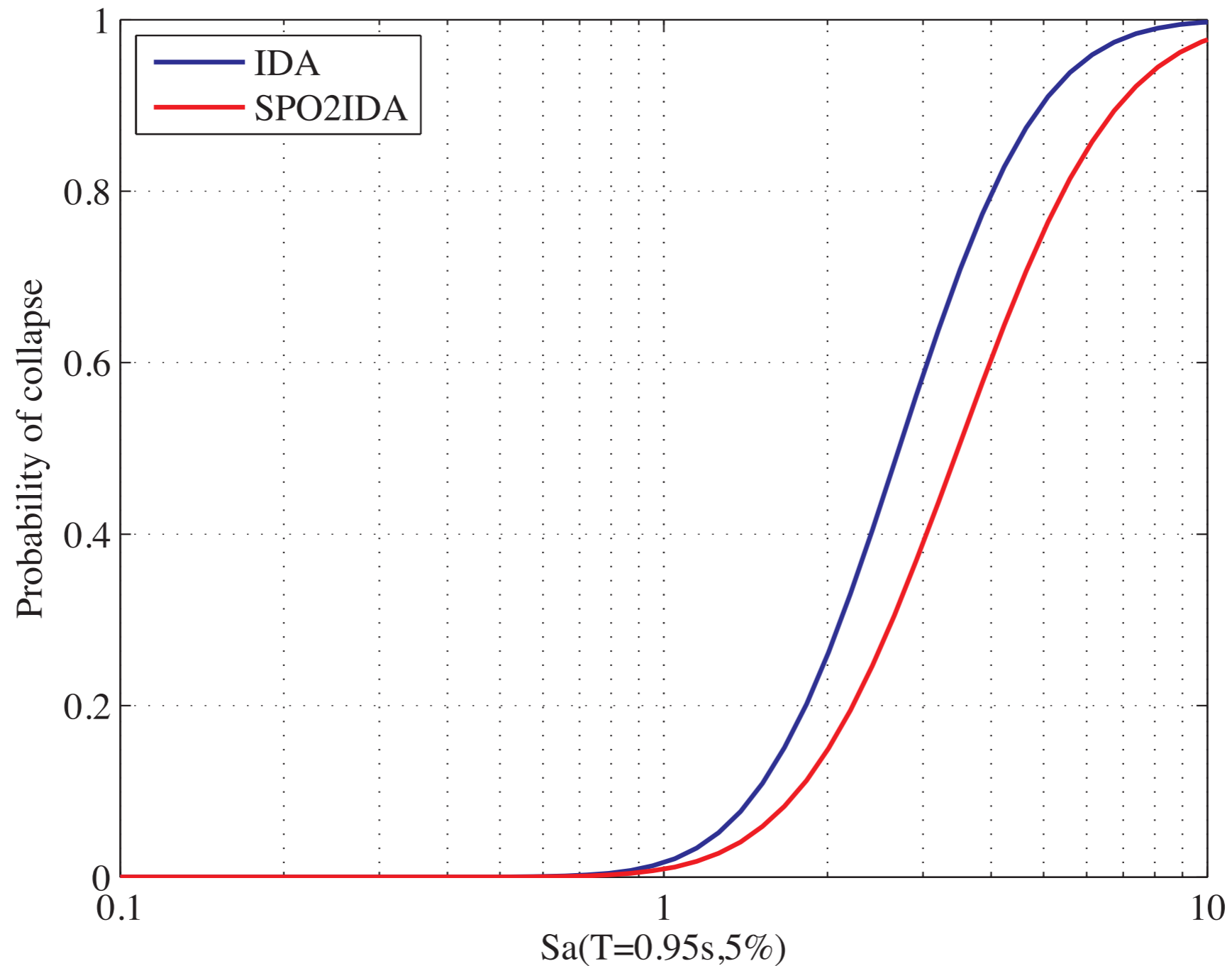
# Example for Taiwan Bldgs

## Mid-Rise Concrete Moment Resisting Frame



# Collapse Fragility Models

## Mid-Rise Concrete Moment Resisting Frame



# Summary

- Improved fragility/vulnerability models already being developed for U.S. building types from HAZUS.
- Development methodology applicable to non-U.S. building types from PAGER.