Post-earthquake Risk-based Decision Making Methodology for Turkish School Buildings

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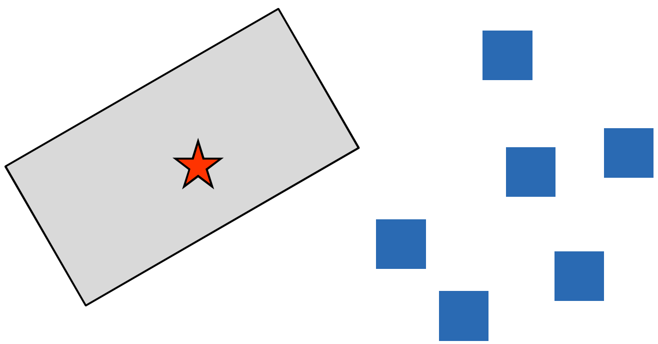
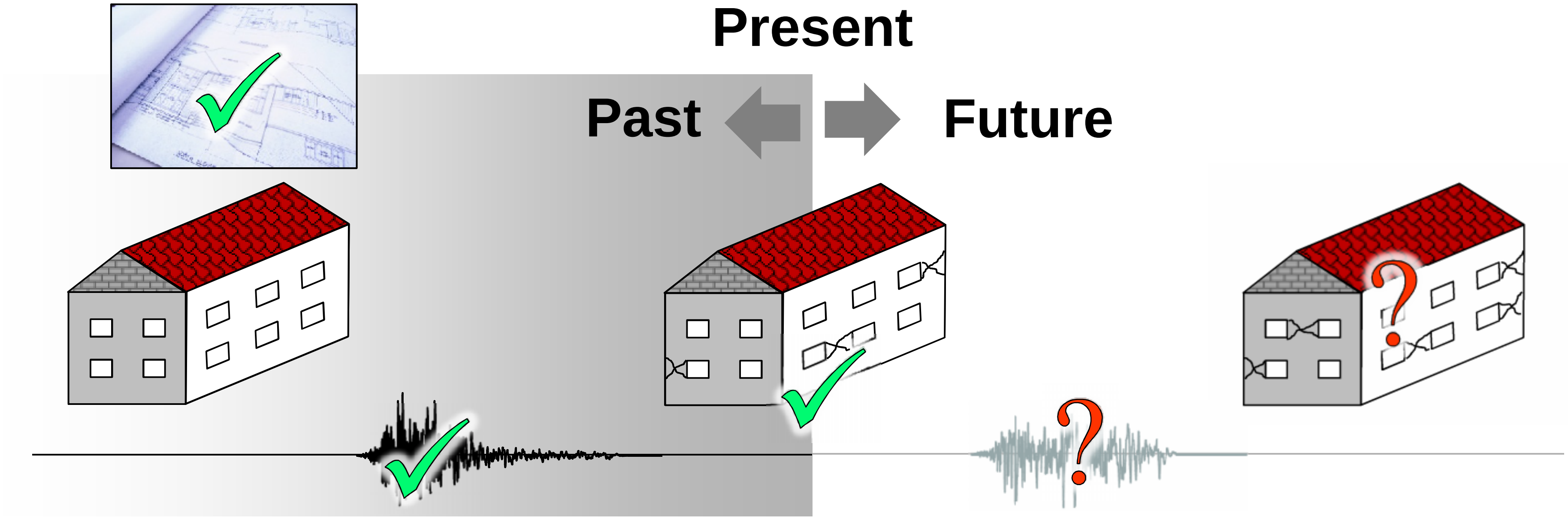
Objective

- **Develop a method for the safety evaluation of school buildings.**



Introduction: Post-Earthquake Assessment



<u>Question:</u>

- ***Is the building safe enough to be occupied?***

Characteristics of School Buildings

- They are often constructed based on prototype designs
- Schools usually have regular structural systems
- They have no wallpapers, suspended ceilings or decorative claddings
- They can be found in almost every settlement (e.g. remote villages, urban districts).
- Design loads are are higher for schools compared to residential buildings (50% higher in TEC(1975), 40% higher in TEC(1998,2007)).

Safety Assessment: Conventional Approach

- Evaluate the earthquake resistance of the structure
- Estimate the seismic hazard at the site
- Compare the capacity of the structure with a conservative estimate of the peak demand
- Verifty that the probability of structural failure is below an acceptable threshold level

Safety Assessment: Proposed Approach

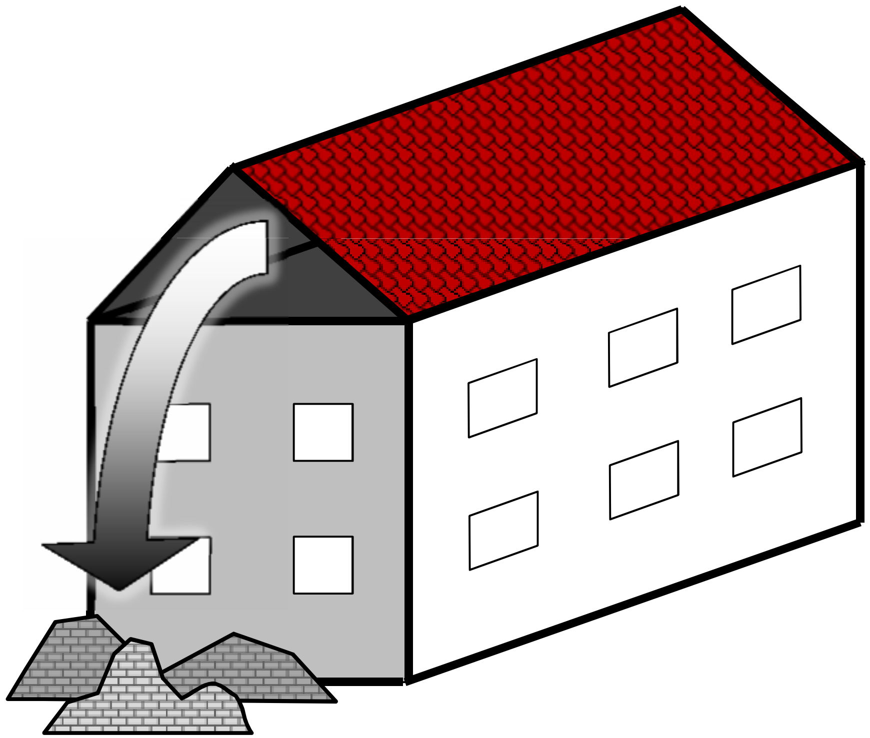
- Evaluate the safety based not on the probability of failure but on the **risk** associated with the school.

RISK =f(HAZARD, VULNERABILITY, CONSEQUENCE)

- Directly take into account the consequences of the failures of both the structural and non-structural components

Importance of Consequences

Example case: Gable wall failure.

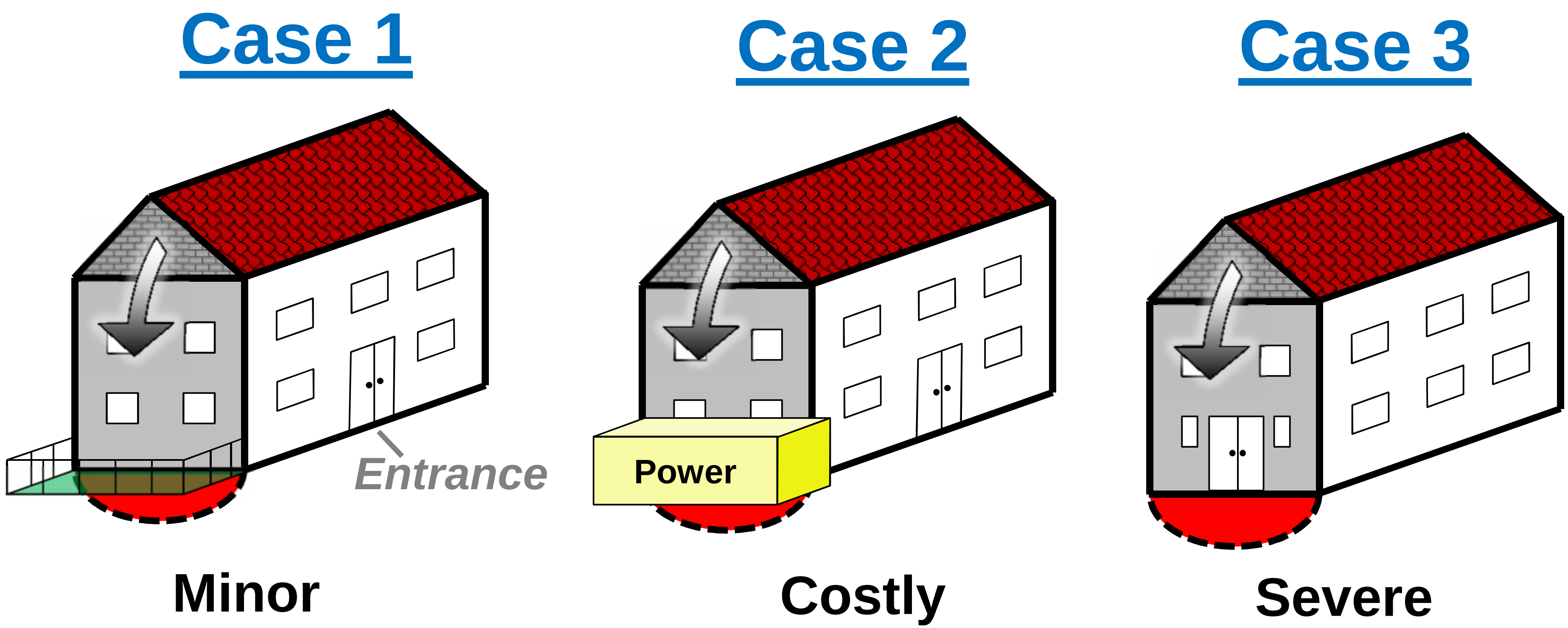


Example Case: Gable wall failure

- **Abdurrahman Gazi School for the Hearing Impared, Van**
- **Gable wall failed during the Van EQ**

Example Case: Gable wall failure

<u>Consequences</u> of the failure at a school depends on the circumstances for that school.



Estimating Pr(C_i): continuous case

- Estimating the likelihood of consequence(*i*), C_i:

$$\Pr(C_i) = \int_F \int_{EDP} \int_{IM} f_{C_i|F}(w|x) f_{F|EDP}(x|y) f_{EDP|IM}(y|z) f_{IM}(z) \mathrm{d}z$$

Probability density of the failure (F) taking place given an engineering demand parameter (EDP) level period

Estimating Pr(*C*): discrete case

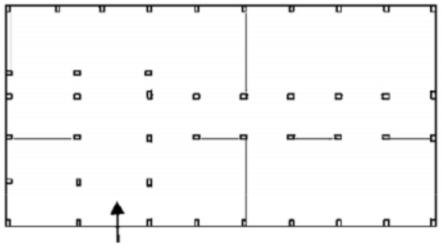
- Estimating the likelihood of *i*th consequence, C_i:

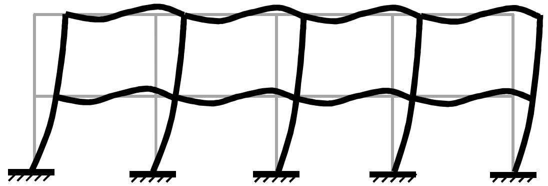
$$\Pr(C_i) \cong \sum_j \sum_k \sum_l \Pr(C_i | F_j) \Pr(F_j | EDP_k) \underbrace{\Pr(EDP_k | IM_l)}_{} \Pr(IM_l)$$

*Estimated before the damage is inspected (**Prior**)*

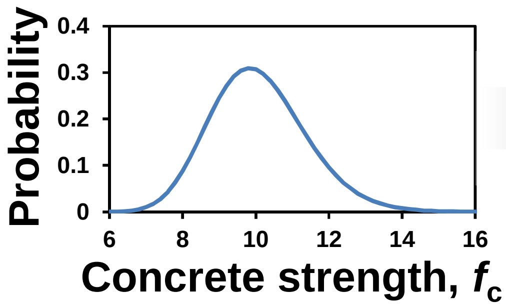
Estimating Pr(*EDP*|*IM*): Conventional meth.

1. Establish an idealized model





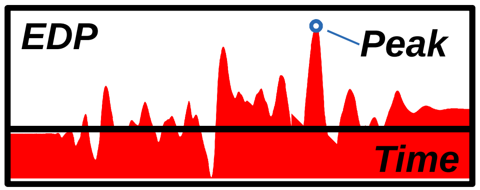
2. Generate random realizations of the uncertain input parameters



#	f_c [MPa]	f_y [MPa]	ζ [%]	…
1	8.1	216	4.2	…
2	10.4	237	3.6	…
…	…	…	…	…
N	9.2	242	4.8	…

Estimating Pr(*EDP*|*IM*): Conventional meth.

3. Simulate the response for each realization and obtain the EDP for that simulation



$$\Pr\left(EDP_k \middle| IM_l, S_m\right)$$

4. Identify the probabilistic character of the *EDP* based on entire set of simulations.

$$\Pr\left(EDP_k \middle| IM_l\right) = \sum_m \Pr\left(EDP_k \middle| IM_l, S_m\right)\Pr\left(S_m\right)$$

Proposed appr.: update with evidence

- Updating the likelihood of *i*th consequence, C_i:

$$\Pr\left(C_i \middle| E\right) \cong \sum_j \sum_k \sum_l \Pr\left(C_i \middle| F_j\right) \Pr\left(F_j \middle| EDP_k\right) \Pr\left(EDP_k \middle| IM_l, E\right) \Pr\left(IM_l\right)$$

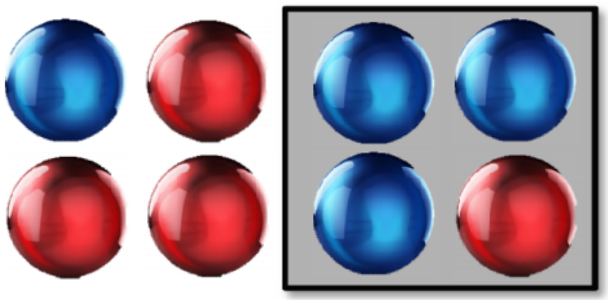
Updated after the evidence indicators (E_l) are inspected (Posterior)

Estimating Pr(*EDP*|*IM*,*E*): Basis

- Bayes' Theorem: basis of updating the likelihoods:

$$\Pr(B|A) = \frac{\Pr(A|B)\Pr(B)}{\Pr(A)}$$

Example:



What is the probability of a ball being in the gray area given that it is blue (i.e. Pr(G|B))?

B: Ball is blue, G: Ball is in the gray area
Pr(B) = 50%
Pr(G) = 50%
Pr(B|G) = 75%
Pr(G|B) = Pr(B|G) * Pr(G) / Pr(B) = (75%)*(50%) / (50%)
= 75%

Estimating Pr(*EDP*|*IM*,*E*): Formulation

- Conditioning the likelihoods on *E*:

$$\Pr(EDP_k|IM,E)=\sum_m \Pr(EDP|IM,S_m)\Pr(S_m|E)$$

Bayes' Theorem

$$=\sum_m \Pr(EDP|IM,S_m)\cdot\left[\frac{\Pr(E|S_m)\Pr(S_m)}{\Pr(E)}\right]$$

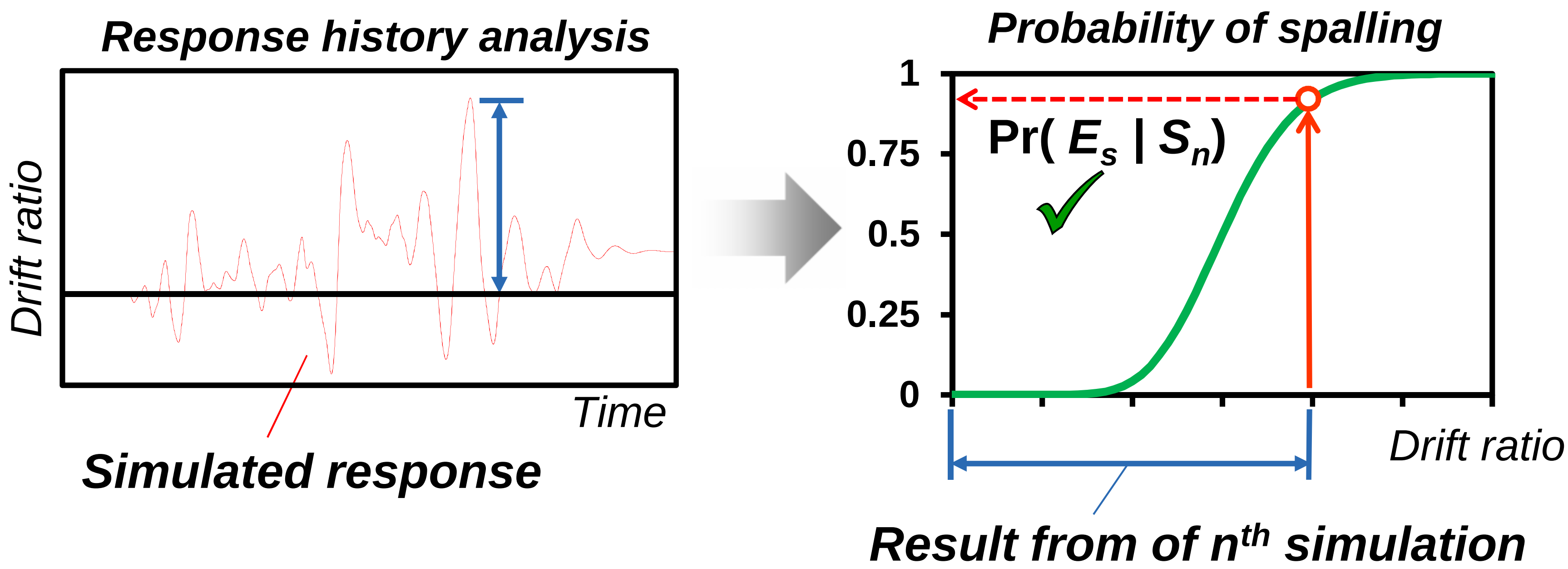
Total Probability Theorem

$$=\sum_m \Pr(EDP|IM,S_m)\cdot\left[\frac{\Pr(E|S_m)\Pr(S_m)}{\sum_n \Pr(E|S_n)\Pr(S_n)}\right]$$

Estimating Pr(E |S_n)

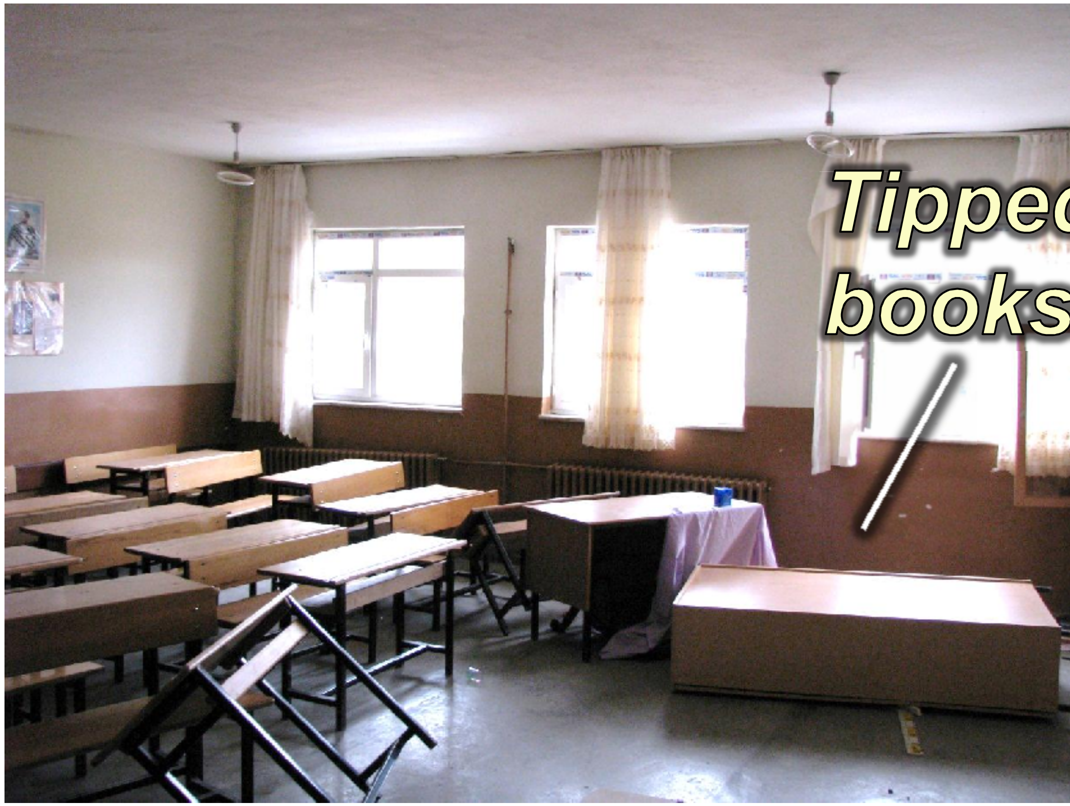
- Likelihood of 'E' conditioned on n^{th} simulation S_n

1st Example: **Consider the evidence spalled cover concrete**



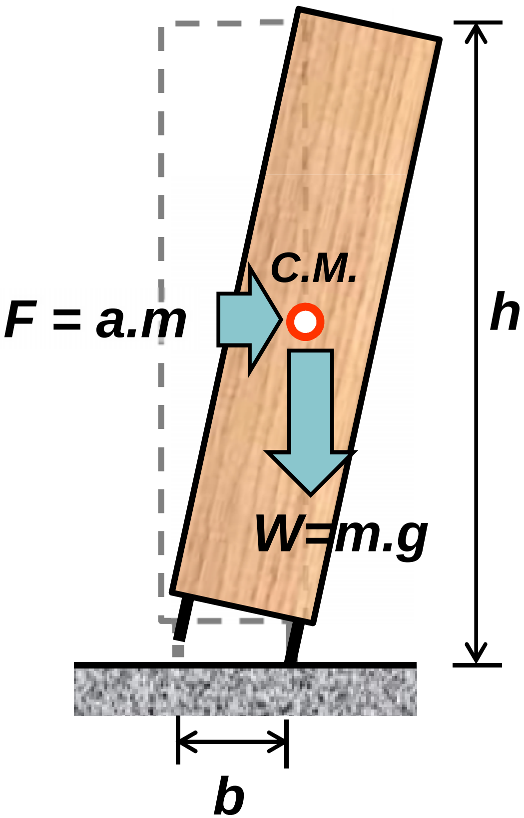
Estimating Pr(E |S_n)

- ***2nd Example:*** Tipped-over bookshelves



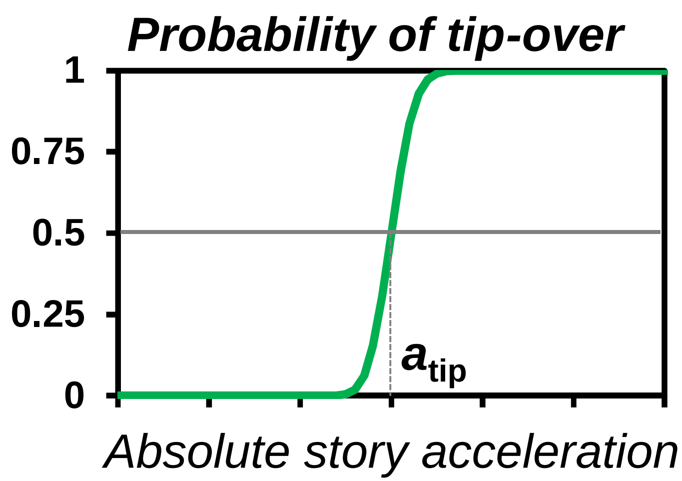
Estimating Pr(E |S_n)

- Example 2: Tipped-over bookshelves



$$m \cdot a_{tip} \cdot \frac{h}{2} = m \cdot g \cdot \frac{b}{2}$$

$$a_{tip} = \frac{b}{h} \cdot g$$



Uncertainty due to sliding, vertical acceleration, etc.

Proposed approach: estimating Pr(C$_i$ | *E*)

- Putting the pieces together ...

$$\Pr\left(C_i \middle| E\right) \cong \sum_j \sum_k \sum_l \Pr\left(C_i \middle| F_j\right) \Pr\left(F_j \middle| EDP_k\right) \Pr\left(EDP_k \middle| IM_l, E\right) \Pr\left(IM_l\right)$$

where $$\Pr\left(EDP \middle| IM, E\right) = \sum_m \Pr\left(EDP \middle| IM, S_m\right) \cdot \left[\frac{\Pr\left(E \middle| S_m\right) \Pr\left(S_m\right)}{\sum_n \Pr\left(E \middle| S_n\right) \Pr\left(S_n\right)} \right]$$

✓ ***Likelihood is estimated by taking the observed damage into account.***

Overall evaluation and ranking

- Total likelihood of one or more unacceptable consequence occuring for the school:

$$\Pr\left(C^*\right) = 1 - \prod_i \left[1 - \Pr\left(C_i\right)\right]$$

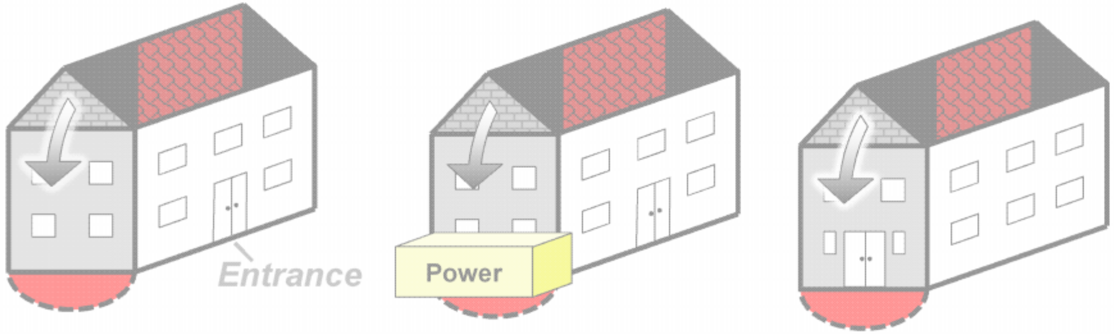
- Schools having the highest Pr(C*) can be identified as the ones with the highest risk

Conclusions

- Estimation of consequences is critical for effective evaluation of the safety
- The framework is based on objectively estimating the likelihoods of the potential consequences.
- Various damage evidences can be objectively taken into account when estimating the likelihoods of consequences.

Acknowledgements

- **Ministry of National Education**
- **Istanbul Technical University**
- **SERIES Workshop Organizers**



Thank you

$$\Pr(C_i|E) \cong \sum_j \sum_k \sum_l \Pr(C_i|F_j)\Pr(F_j|EDP_k)\Pr(EDP_k|IM_l,E)\Pr(IM_l)$$

where $\Pr(EDP|IM,E) = \sum_m \Pr(EDP|IM,S_m) \cdot \left[\frac{\Pr(E|S_m)\Pr(S_m)}{\sum_n \Pr(E|S_n)\Pr(S_n)} \right]$

Cover spalling drift limit

Performance Models for Flexural Damage in Reinforced Concrete Columns

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and

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University of Washington

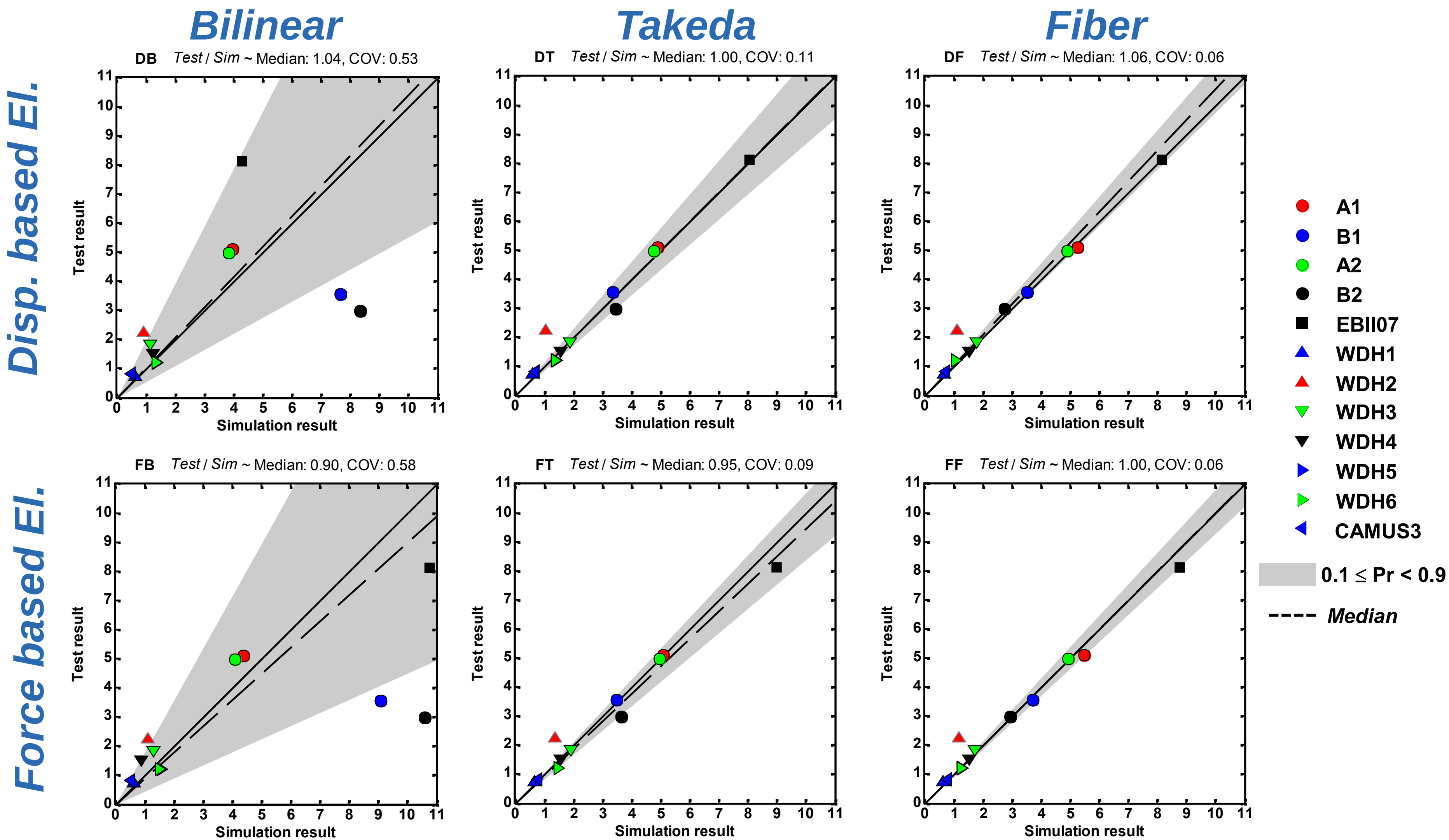
PEER 2003/18
AUGUST 2003

drift ratio at the onset of cover spalling ($\frac{\Delta_{spall}}{L}$)

$$\frac{\Delta_{sp}^{calc}}{L}(\%) \cong 1.6\left(1-\frac{P}{A_g f_c'}\right)\left(1+\frac{L}{10D}\right)$$

D is the column depth,
P is the axial load,
A_g is the gross area of the cross section,
L is the distance from the column base to the point of contraflexure.

Evaluation: Maximum Average Drift [%]

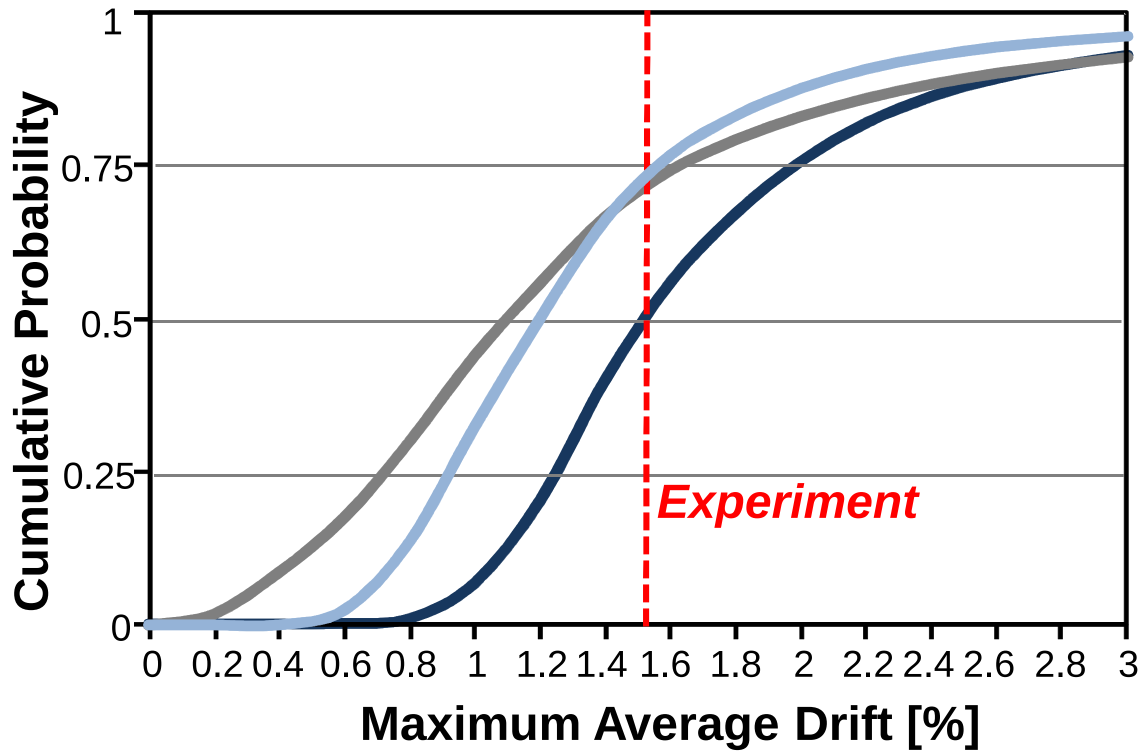


Results:

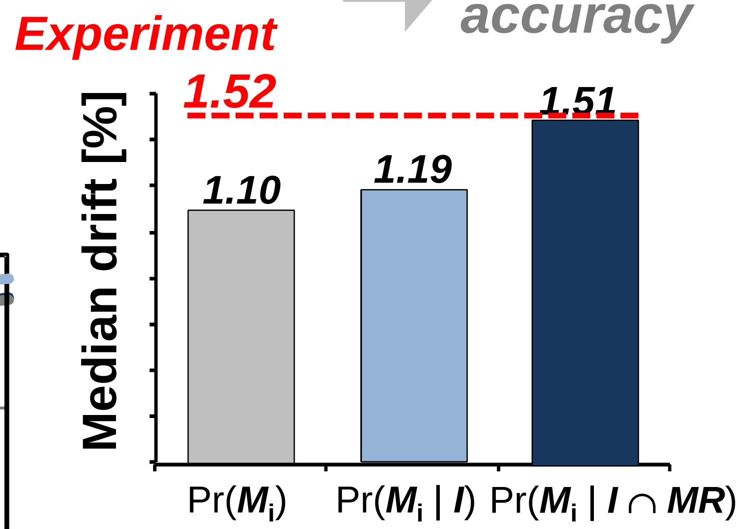
Pr(M_i) — ***Prior***

Pr(M_i | I) — ***Damage inspection***

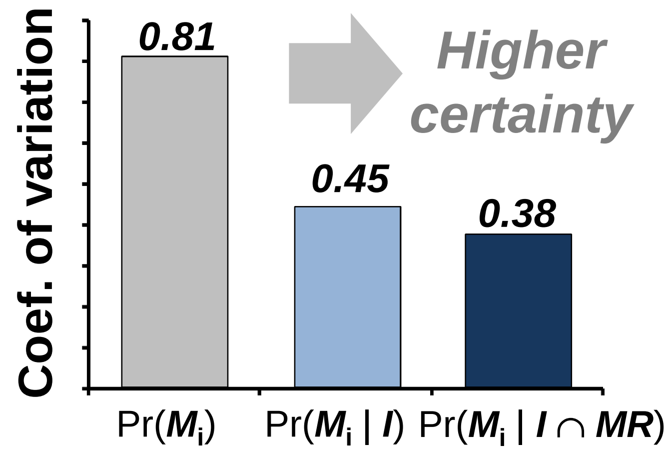
Pr(M_i | $I \cap MR$) — ***Damage inspection & residual displacements***



Better accuracy



Higher certainty



Residual structural properties for WDH4