DOĞAL AFET SİGORTALARI KURUMU

Earthquake Physical Risk / Loss Assessment Models and Example Applications

Sinan Akkar

Earthquake Engineering Department, Boğaziçi University

BOĞAZİÇİ ÜNİVERSİTESİ KANDİLLİ RASATHANESİ VE DEPREM ARAŞTIRMA ENSTİTÜSÜ

Some definitions

Earthquake Risk Model

A tool to measure the rate (or probability) of the undesirable outcome (structural/nonstructural damage, collapse or loss -e.g., repair costs-)

Components

- **Seismic hazard** — *Measures the rate (or probability) of ground-motion intensity level*

*

- **Fragility functions** — *Measures the probability of a damage state conditioned on ground-motion intensity*

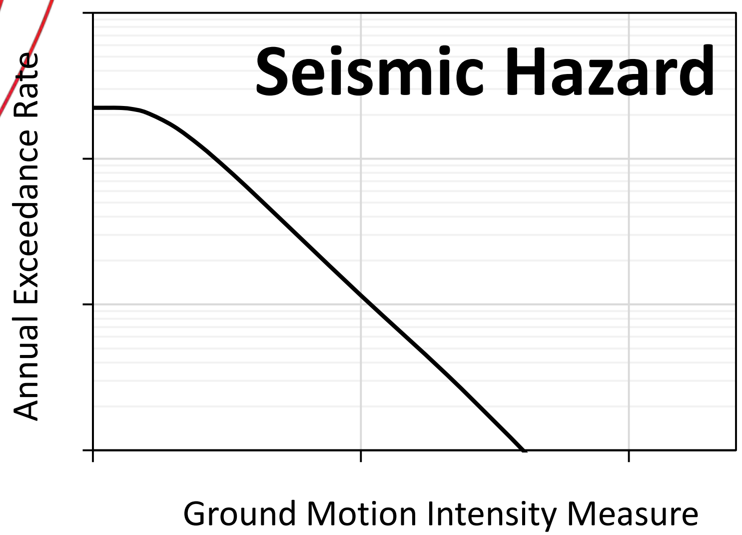
*

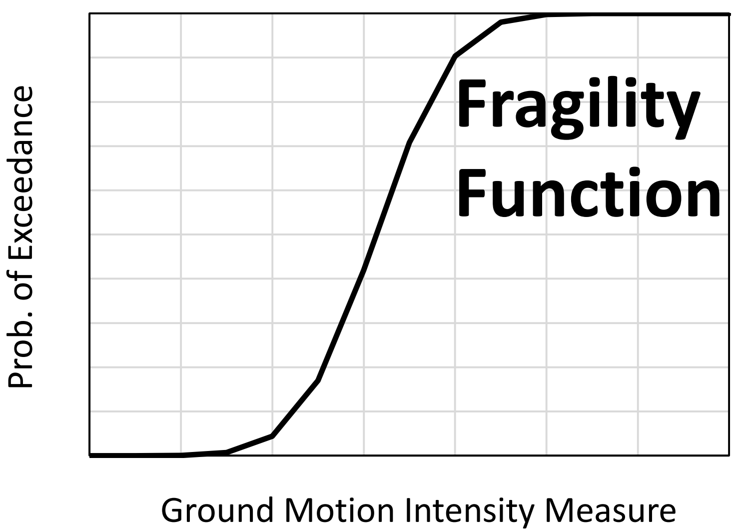
- **Consequence functions** — *Relates the damage state with a consequence of interest (e.g., repair costs)*

Vulnerability model

Measure of loss conditioned on ground-motion intensity

Probabilistic Earthquake Risk Model



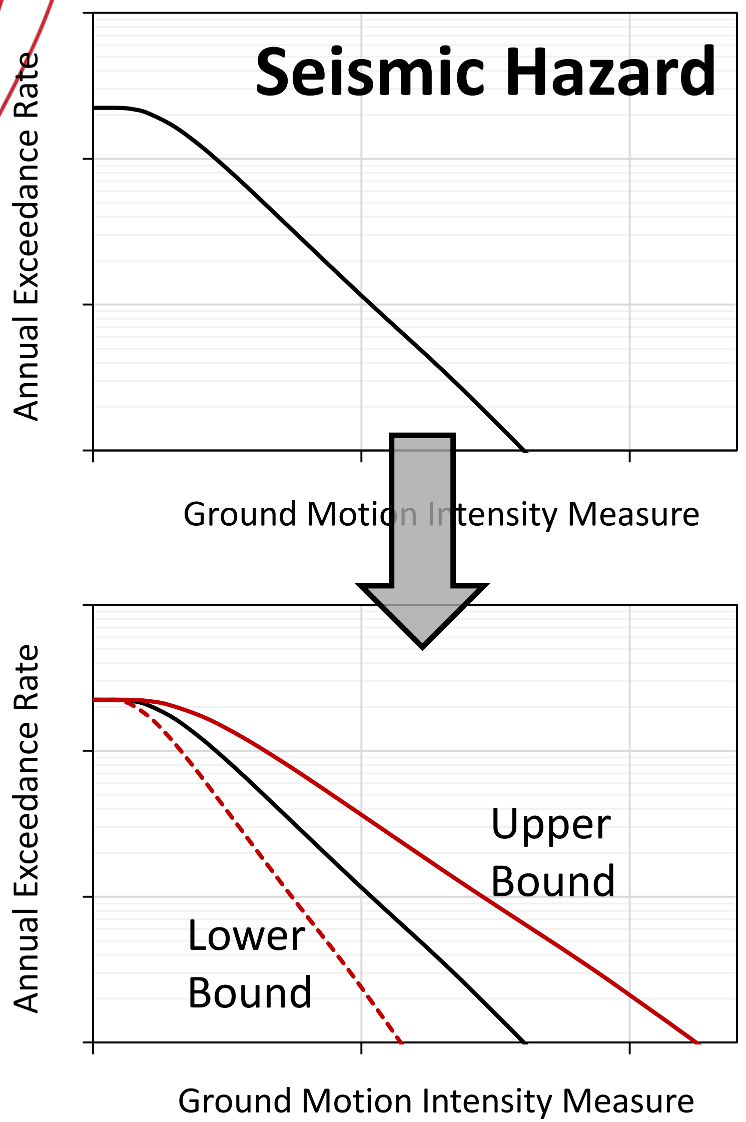


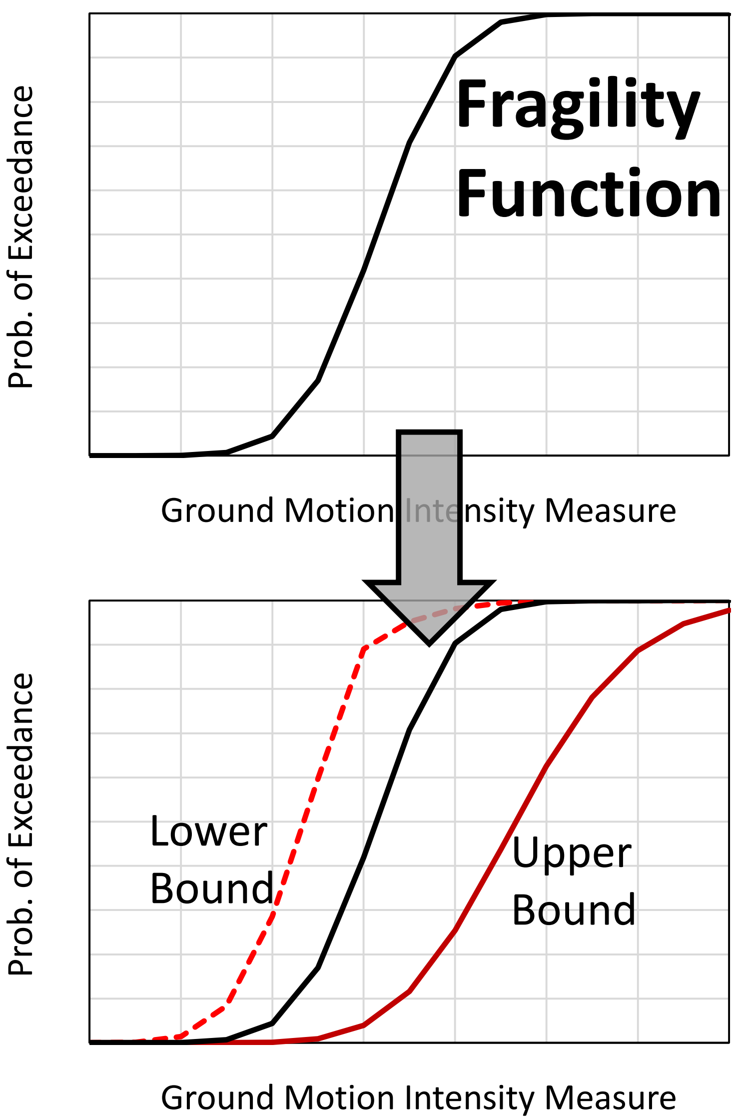
Consequence Function

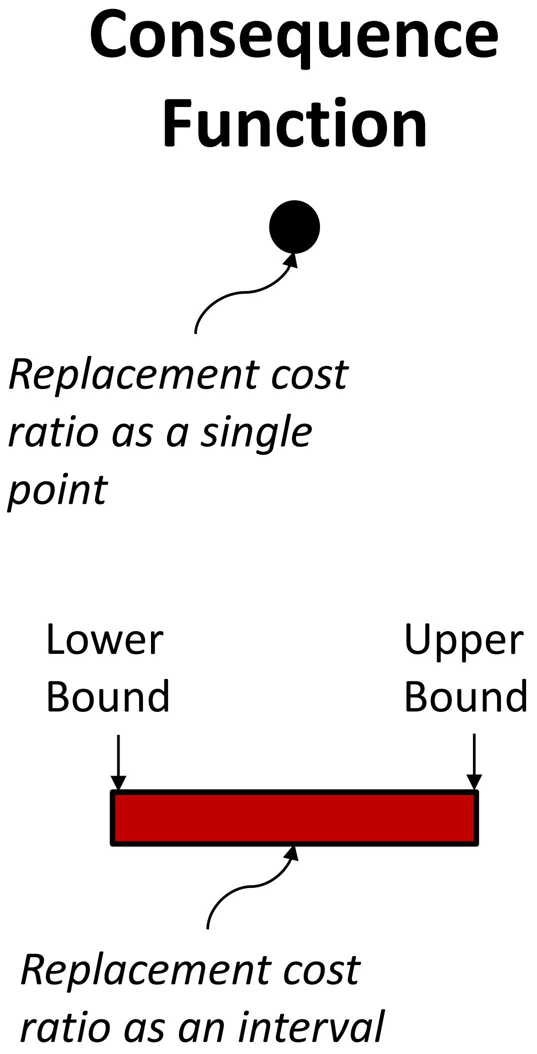
Replacement cost ratio as a single point

Easier

Probabilistic Earthquake Risk Model







Easier

Complicated

Sinan Akkar

Objective

A loss estimation model for residential building content for large building inventories that can be used in earthquake premium calculations

- *Emphasis on model uncertainty in fragility and consequence functions through Monte Carlo sims*
- *Development of content fragility functions for different building types by considering Total Probability Theorem*
- *Progressive influence of fragility and consequence modelling uncertainty on loss*

Acknowledgements

Turkish Earthquake Foundation, Turkish Catastrophe Insurance Pool and Turkish Insurance Association (Project grants)

Prof. Mustafa Erdik (Project coordination, risk modeling)

Dr. Cüneyt Tüzün and Dr. Can Zulfikar (Content database compilation, content fragility literature)

Dr. Ozer Ay and Prof. Altug Erberik (Building fragility compilation and fragility models)

Dr. Mine B. Tumsa (Seismic Hazard, GIS Work)

Prof. Ufuk Yazgan (Risk modeling)

Dr. Merve Çağlar (Risk modeling and software development)

Main modeling strategy

Establish building sensitive content fragilities

Use Total Probability Theorem and Monte Carlo Simulation technique to account for model uncertainty in building damage and content damage conditioned on building damage

Establish consequence functions

Use expert judgement and Monte Carlo Simulation technique to account for model uncertainty in replacement cost ratios conditioned on content damage

Seismic hazard

Use national seismic hazard study

Establish content loss for building types in the inventory conditioned on ground motion intensity

Average Annual Loss Ratio for a given content housed in a specific building type and its risk conditioned on ground motion intensity

Ground motion intensity measure

Macroseismic intensity scale (MMI)

PROs

availability of a well compiled MMI based building damage fragility library for the residential building stock in Turkey that considers model uncertainties

(speculatively) suitable for large building inventory loss assessment since it is independent of building period

CONs

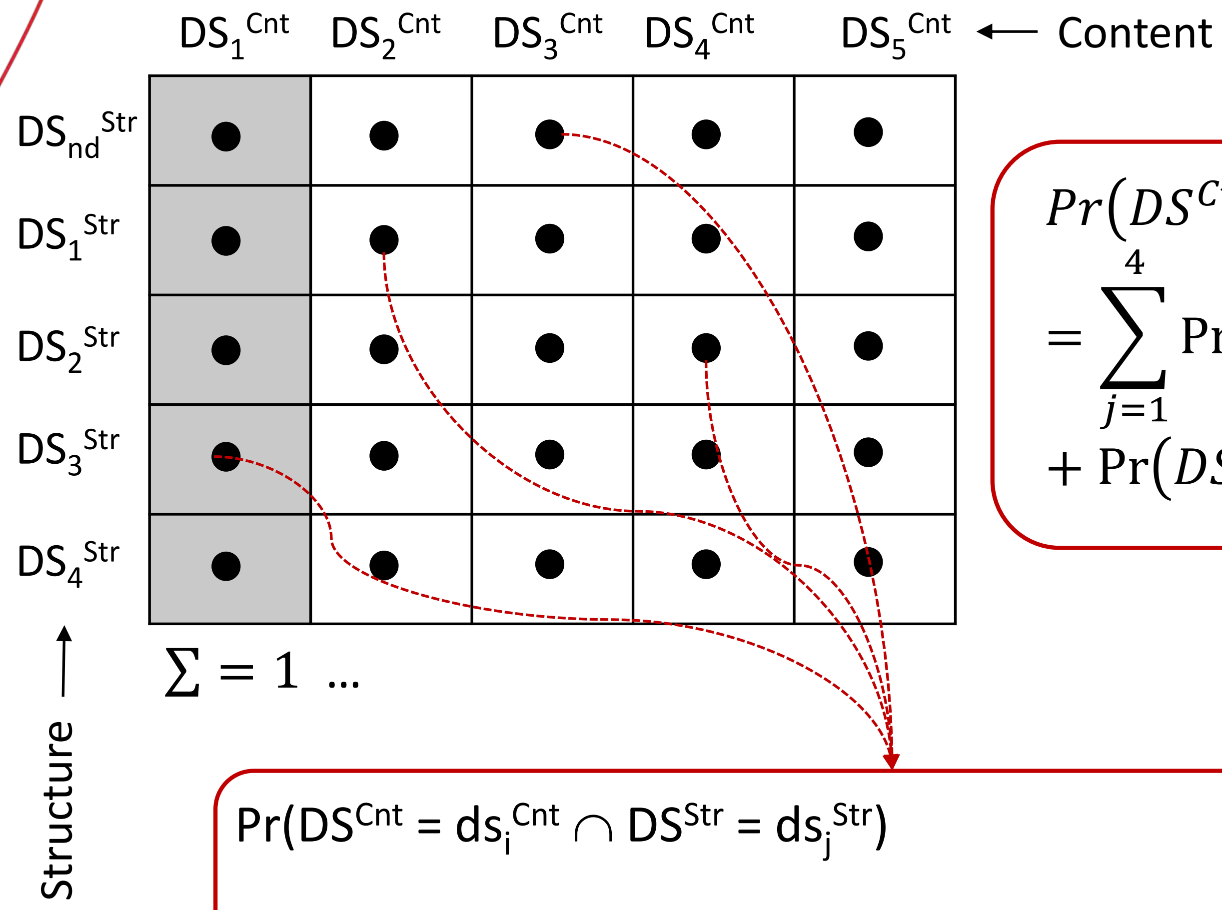
May not directly reflect important ground motion features such as directivity or directionality

May not fully reflect content damage (acceleration and drift sensitive equipment damage)

Building-sensitive content fragilities (Theory)

Decompose content damage probability into its components that consider probabilities of building damage states at all levels

Building-sensitive content fragilities (Theory)

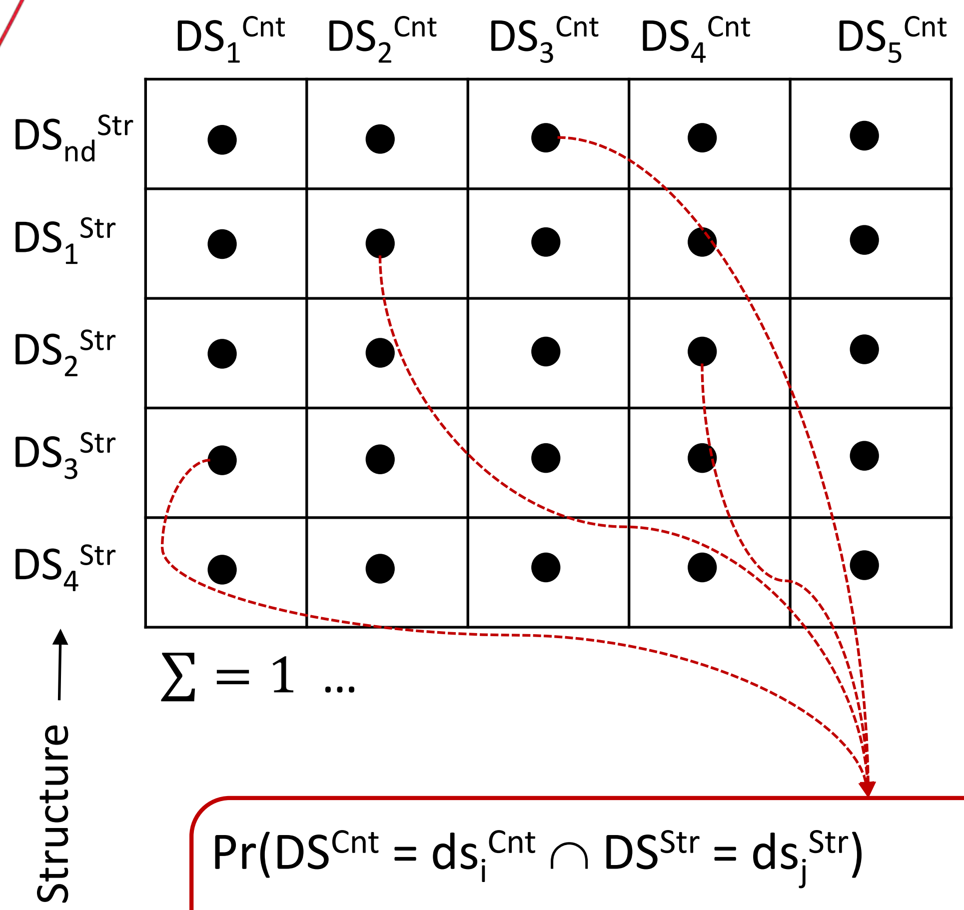


$\sum = 1$ ...

$$Pr\left(DS^{Cnt} = ds_i^{Cnt}\right)$$
$$= \sum_{j=1}^{4} \Pr\left(DS^{Cnt} = ds_i^{Cnt} \middle| DS^{Str} = ds_j^{Str}\right) \cdot Pr\left(DS^{Str} = ds_j^{Str}\right)$$
$$+ \Pr\left(DS^{Cnt} = ds_i^{Cnt} \middle| DS^{Str} = ds_{nd}^{Str}\right) \cdot Pr\left(DS^{Str} = ds_{nd}^{Str}\right)$$

$$\Pr(DS^{Cnt} = ds_i^{Cnt} \cap DS^{Str} = ds_j^{Str})$$
$$= \Pr(DS^{Cnt} = ds_i^{Cnt} \mid DS^{Str} = ds_j^{Str}) \cdot \Pr(DS^{Str} = ds_j^{Str})$$

Building-sensitive content fragilities (Theory)



$$Pr\left(DS^{Cnt} = ds_i^{Cnt}\right)$$
$$= \sum_{j=1}^{4} Pr\left(DS^{Cnt} = ds_i^{Cnt} \middle| DS^{Str} = ds_j^{Str}\right) Pr\left(DS^{Str} = ds_j^{Str}\right)$$
$$+ Pr\left(DS^{Cnt} = ds_i^{Cnt} \middle| DS^{Str} = ds_{nd}^{Str}\right) Pr\left(DS^{Str} = ds_{nd}^{Str}\right)$$

Known - Building fragilities (with some level of uncertainty); ***Monte Carlo sims***

Unknown; ***Monte Carlo sims***

$Pr(DS^{Cnt} = ds_i^{Cnt} \cap DS^{Str} = ds_j^{Str})$

$= Pr(DS^{Cnt} = ds_i^{Cnt} \mid DS^{Str} = ds_j^{Str}) \cdot Pr(DS^{Str} = ds_j^{Str})$

Why?

ATC-13

EARTHQUAKE DAMAGE EVALUATION DATA FOR CALIFORNIA

Funded by

FEDERAL EMERGENCY MANAGEMENT AGENCY
Contract No. EMW-C-0912

ROBERT R. WILSON
Project Officer

Prepared by

APPLIED TECHNOLOGY COUNCIL
3 Twin Dolphin Drive, Suite 275
Redwood City, California 94065

CHRISTOPHER ROJAHN
Principal Investigator

ROLAND L. SHARPE
Co-Principal Investigator

- ATC-13 provides building independent earthquake induced content fragilities as a function of MMI for different equipment considering a common building construction quality for California (from systematic expert evaluation)

In responding to the questionnaire, please note that your answers should be based on the following general assumptions:

- The structure is founded on firm soil, i.e., the foundation does not aggravate damage
- Fault rupture does not aggravate damage
- Inundation does not aggravate damage
- Fire does not aggravate damage
- Design and construction quality is regular

(Damage due to collateral causes—ground failure, fault rupture, inundation, and fire—are considered separately.)

Please also note that equipment is assumed to be (1) at ground level and (2) unanchored.

The structure is founded on firm soil, i.e., foundation does not aggravate damage

Please note that equipment is assumed to be (1) at ground level and (2) unanchored

- More recent guidelines (HAZUS, FEMA P58) provide acceleration and drift sensitive content fragilities that are suitable **for single asset assessment** (may require more rigorous assumptions for their implementation to a large building stock)

- Buildings are constructed in Turkey!

Damage state definitions

Building

- DS_1^{Str}: **Light** structural damage
- DS_2^{Str}: **Moderate** structural damage
- DS_3^{Str}: **Severe** structural damage
- DS_4^{Str}: **Very severe** (almost collapse) structural damage

Content

- DS_1^{Cnt}: **Slight** (limited localized) content damage not requiring repair
- DS_2^{Cnt}: **Light** (significant localized) content damage generally not requiring repair
- DS_3^{Cnt}: **Moderate** (significant localized) content damage warranting repair
- DS_4^{Cnt}: **Heavy** (extensive) content damage requiring major repairs
- DS_5^{Cnt}: **Very heavy** (widespread) content damage either demolished or repaired

Pr(Content damage|building damage)

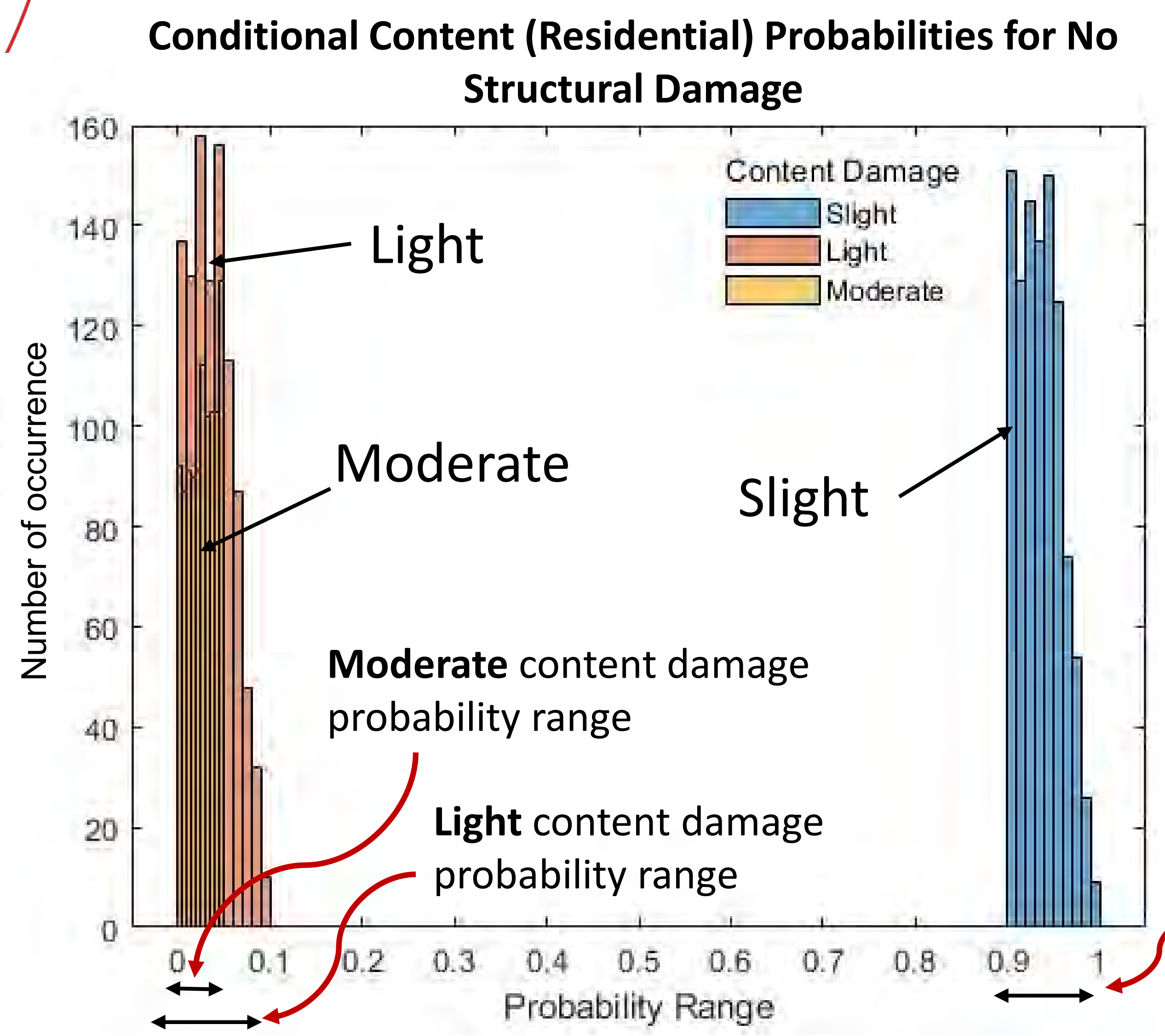
Conditional content damage probabilities are generated via Monte Carlo simulations by following the below concept

Structure	**No Damage**	**Light**	**Moderate**	**Severe**	**Very Severe**
Content	**Slight**	**Slight to Light**	**Moderate (Heavy)**	**Moderate to Heavy**	**Very Heavy**
	Content damage is more likely to be **slight**	Content damage is more likely to be **slight and light**	Content damage is more likely to be **moderate** (with some considerable possibility to **heavy damage**)	Content damage is more likely to be **moderate** and **heavy**	Content damage is more likely to be **very heavy**

Sinan Akkar

Pr(Content damage|building damage)

No structural damage



Slight content damage probability range

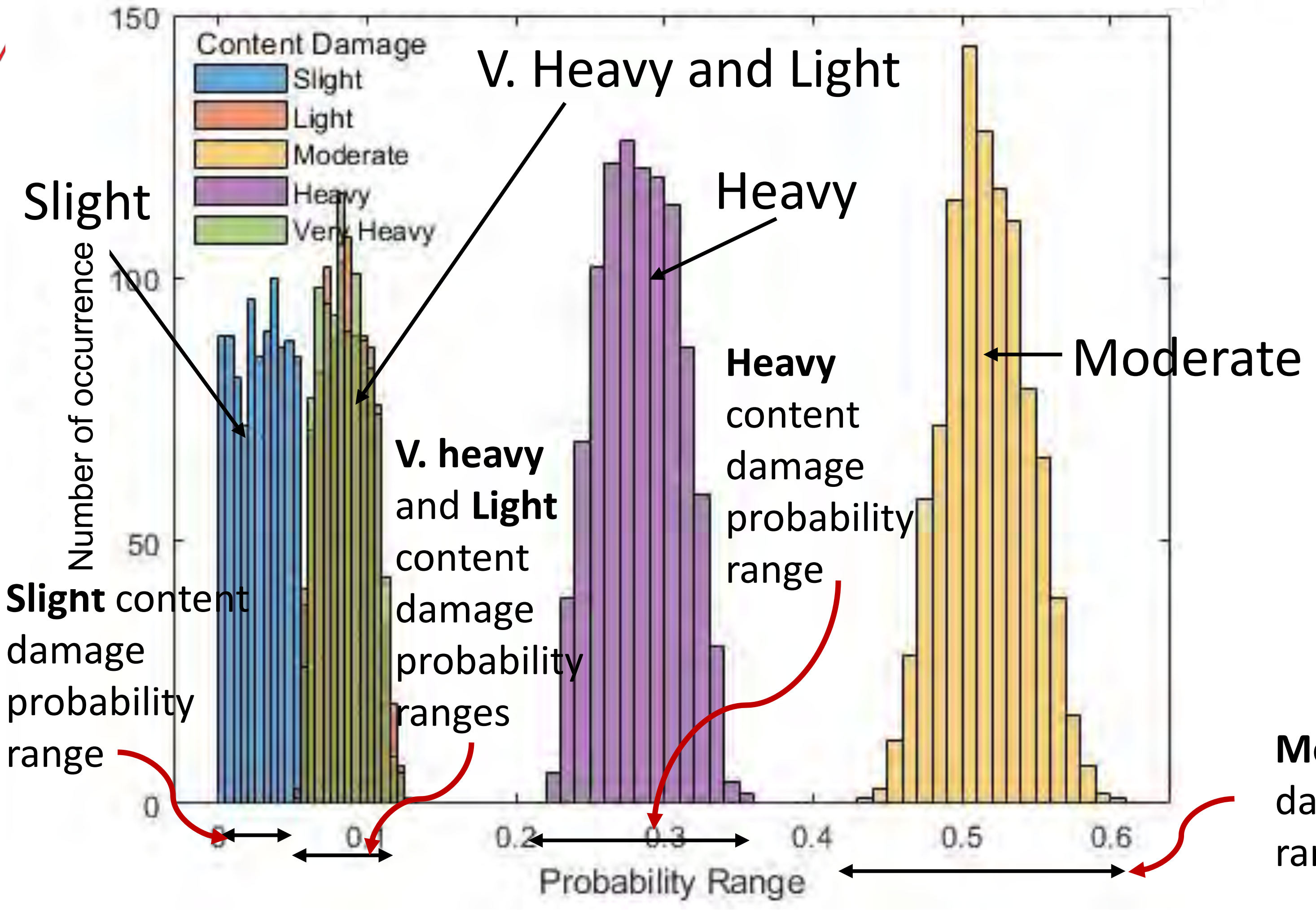
When no structural damage, content is most probably slightly damaged (other damage states are negligible)

Sinan Akkar

Pr(Content damage|building damage)

Moderate structural damage

Conditional Content (Residential) Probabilities for Moderate Structural Damage



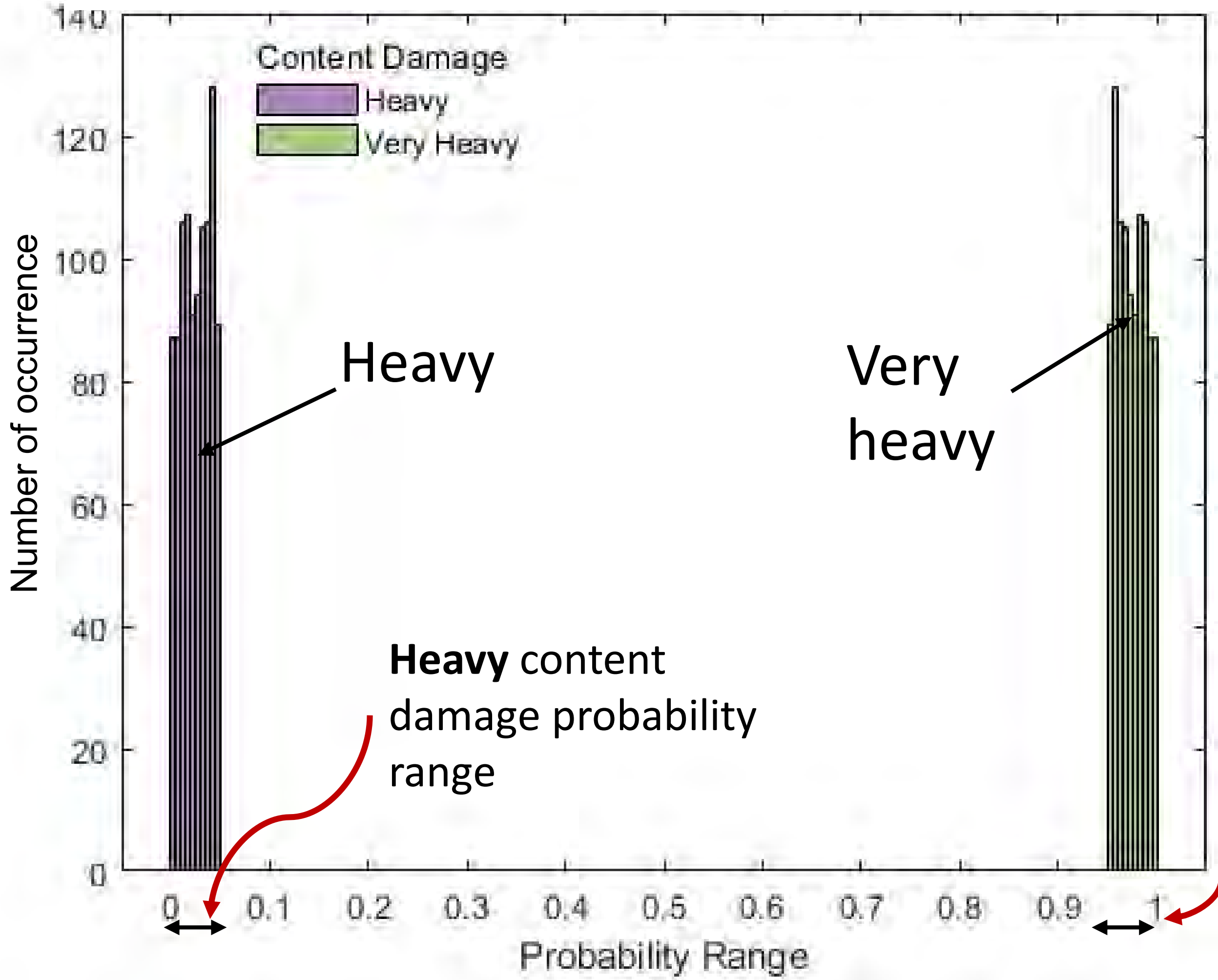
Moderate content damage probability range

When <u>moderate structural damage</u>, content is most probably <u>moderately damaged</u> followed by <u>heavy damage</u> probability

Pr(Content damage|building damage)

Very severe structural damage

Conditional Content (Residential) Probabilities for Very Severe Structural Damage

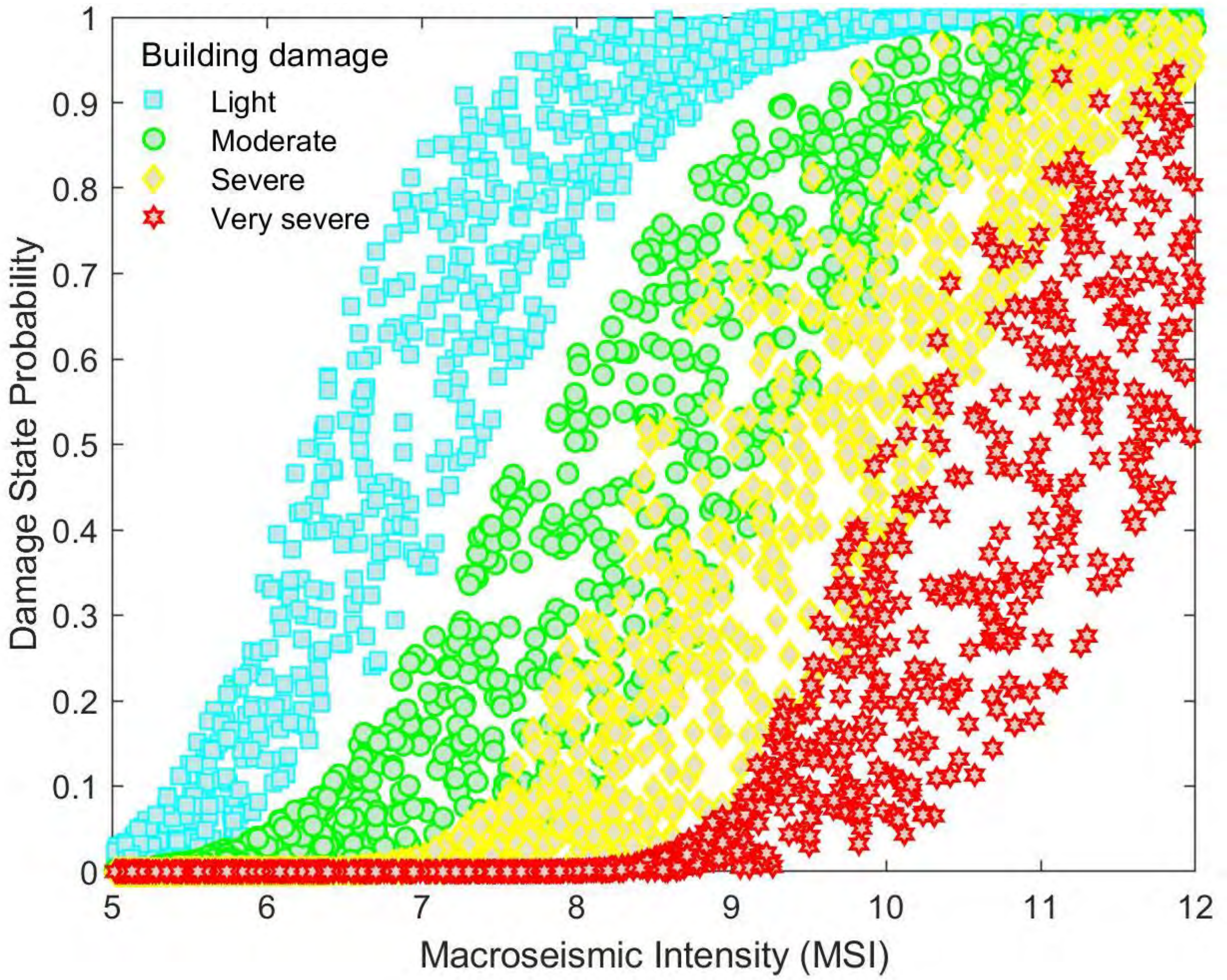


When <u>very severe structural damage</u>, content is most probably <u>very heavily damaged</u> (other damage states are either negligible or with some limited likelihood)

Very heavy content damage probability range

Building fragilities
(including model uncertainty)

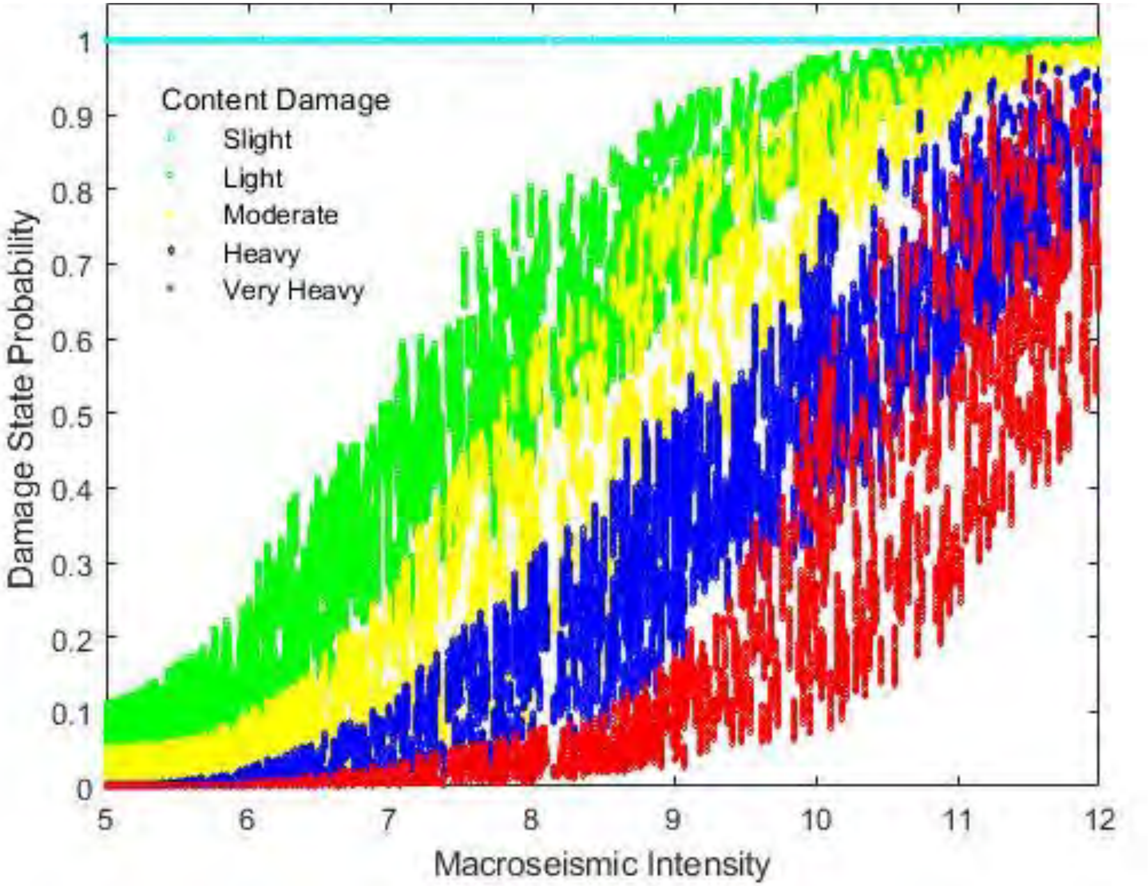
Mid-Rise RC Building Constructed After 2000



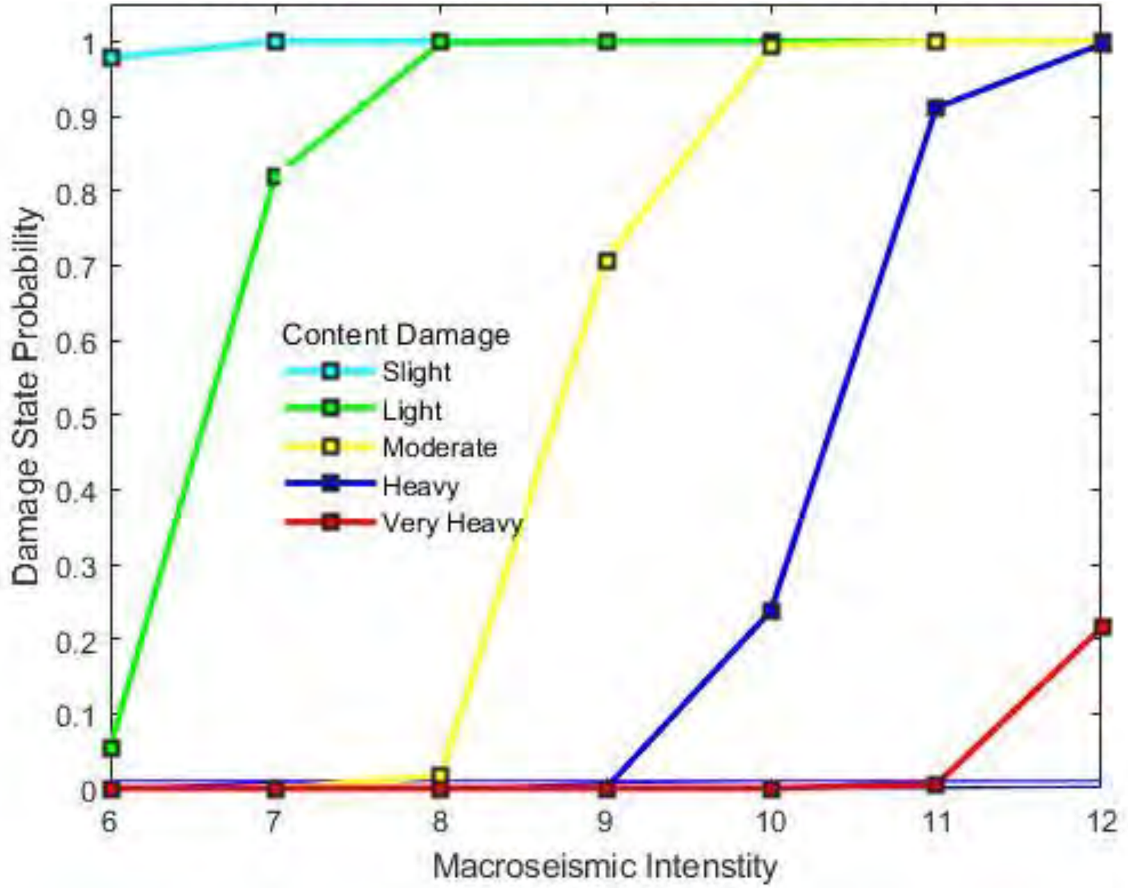
- The model uncertainty in building fragilities are taken into account by running Monte Carlo simulations
- Moderate, severe and very severe building fragilities overlap at some MMI levels due to model uncertainties. Such overlaps are reflected in the simulations

Building Sensitive Content Fragilities
(including model uncertainty)

Content (Residential) Fragilities for Mid-Rise RC Building Constructed After 2000



ATC-13 Content (Residential) Fragilities for Buildings in California Having Regular Design and Construction Quality

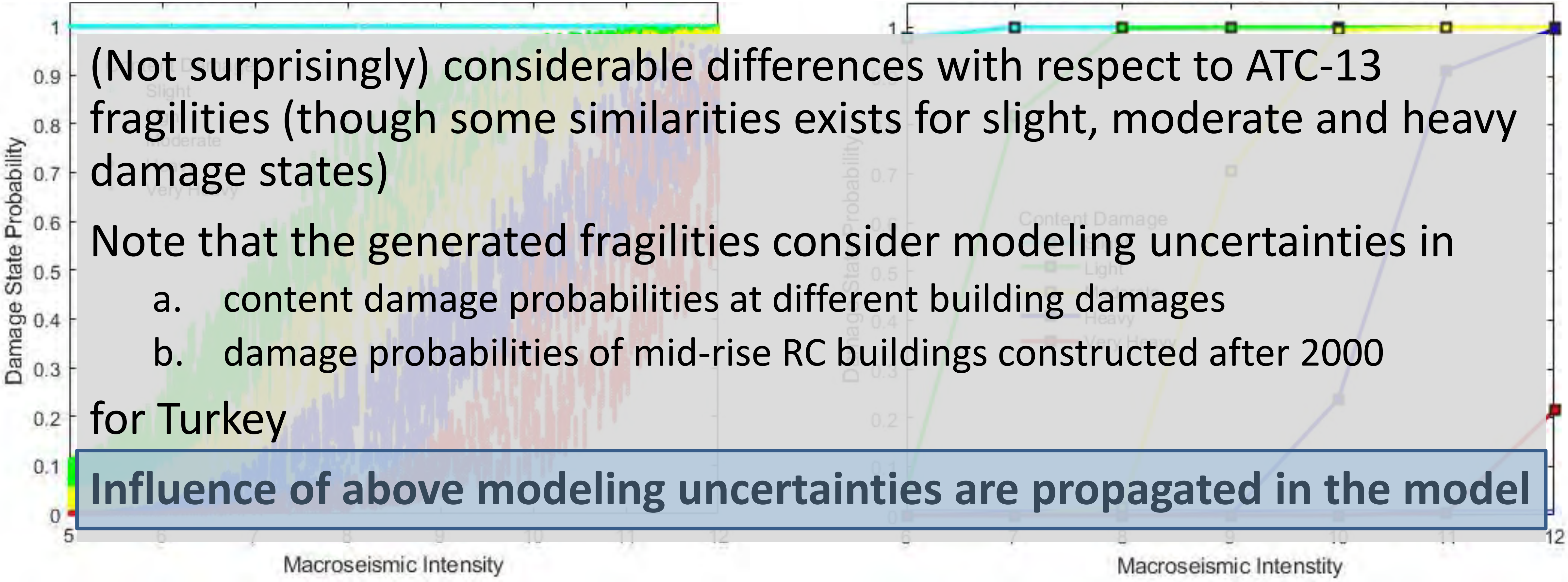


Sinan Akkar

Building Sensitive Content Fragilities
(including model uncertainty)

Content (Residential) Fragilities for Mid-Rise RC Building Constructed After 2000

ATC-13 Content (Residential) Fragilities for Buildings in California Having Regular Design and Construction Quality



(Not surprisingly) considerable differences with respect to ATC-13 fragilities (though some similarities exists for slight, moderate and heavy damage states)

Note that the generated fragilities consider modeling uncertainties in

a. content damage probabilities at different building damages

b. damage probabilities of mid-rise RC buildings constructed after 2000

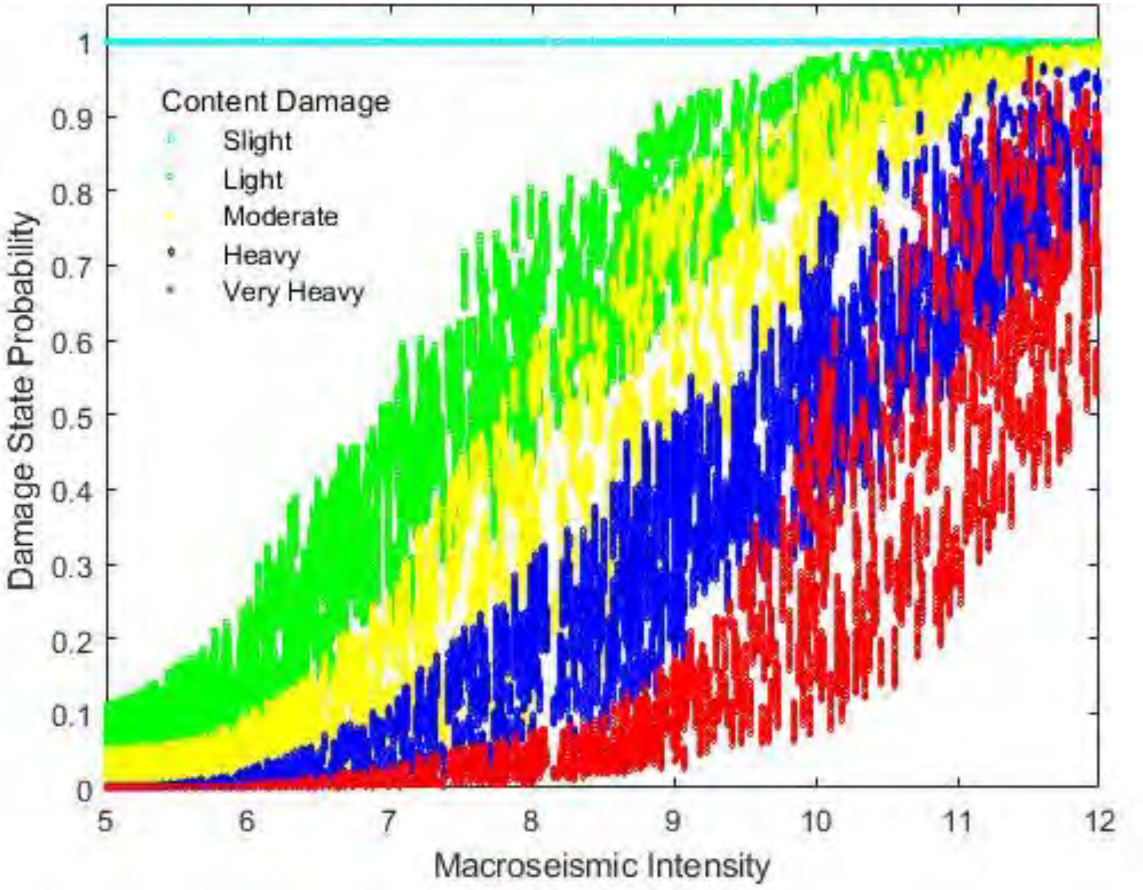
for Turkey

Influence of above modeling uncertainties are propagated in the model

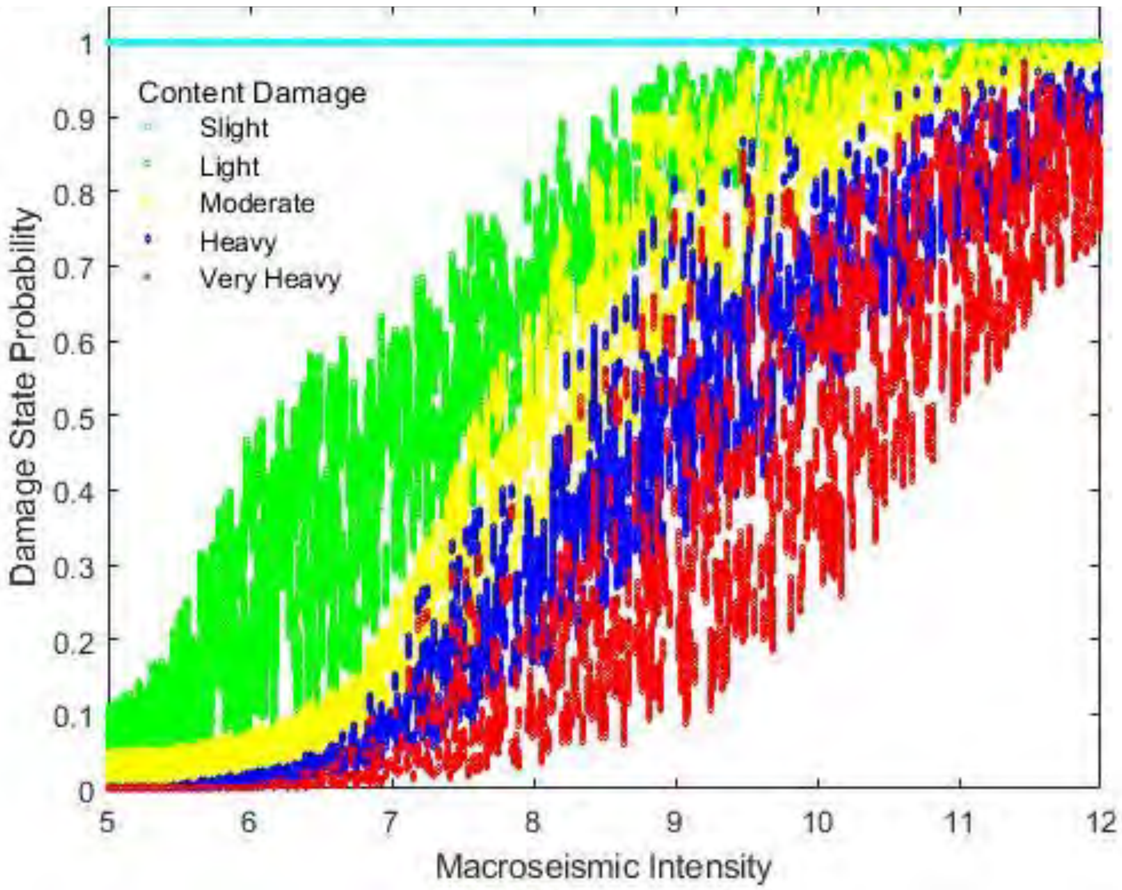
Sinan Akkar

Building Sensitive Content Fragilities
(Hi-code vs. low-code)

Content (Residential) Fragilities for Mid-Rise RC Building Constructed After 2000

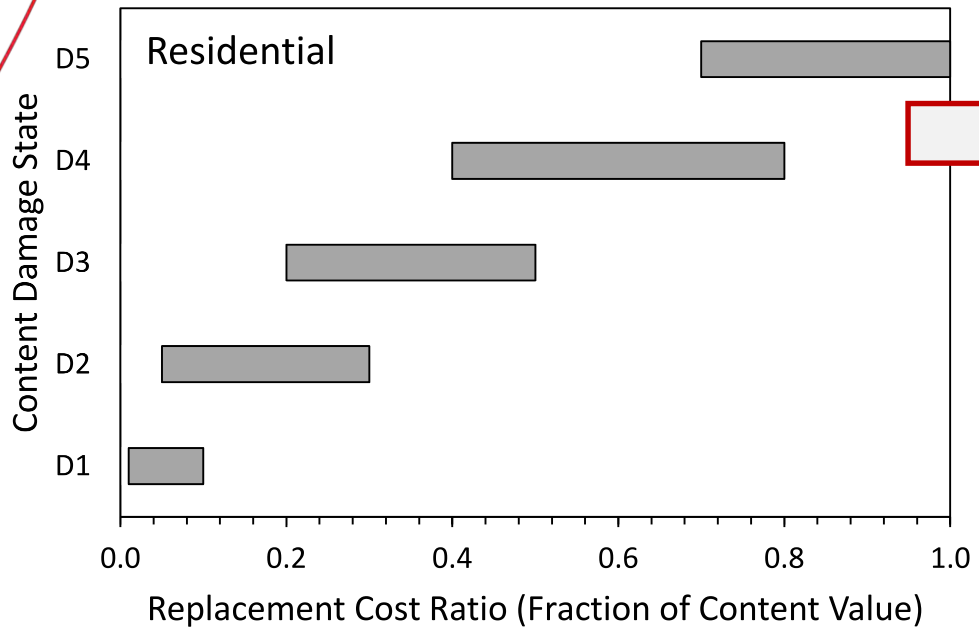


Content (Residential) Fragilities for Mid-Rise RC Building Constructed Before 1979



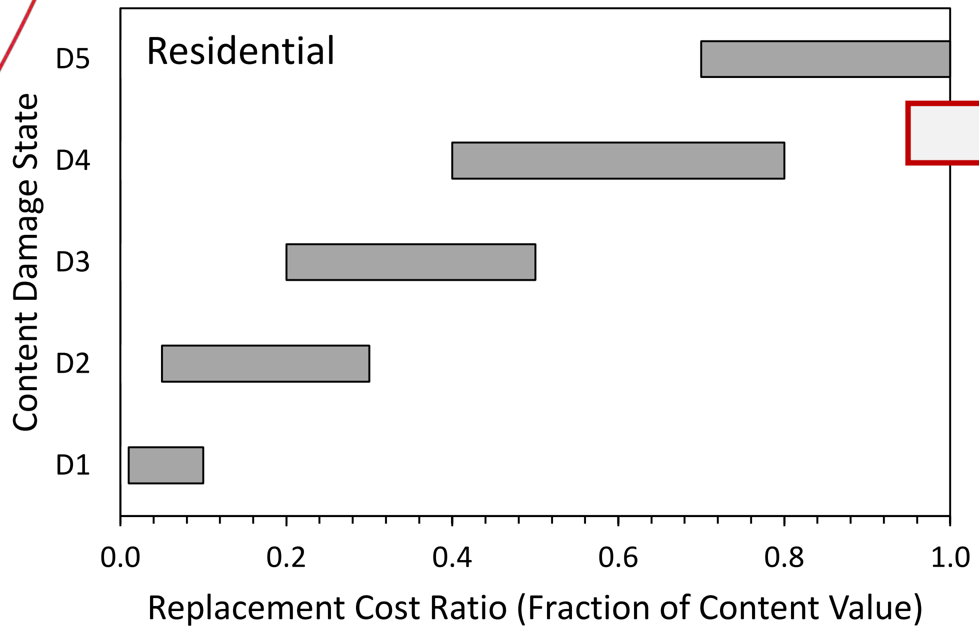
Sinan Akkar

Consequence model
(including model uncertainty)

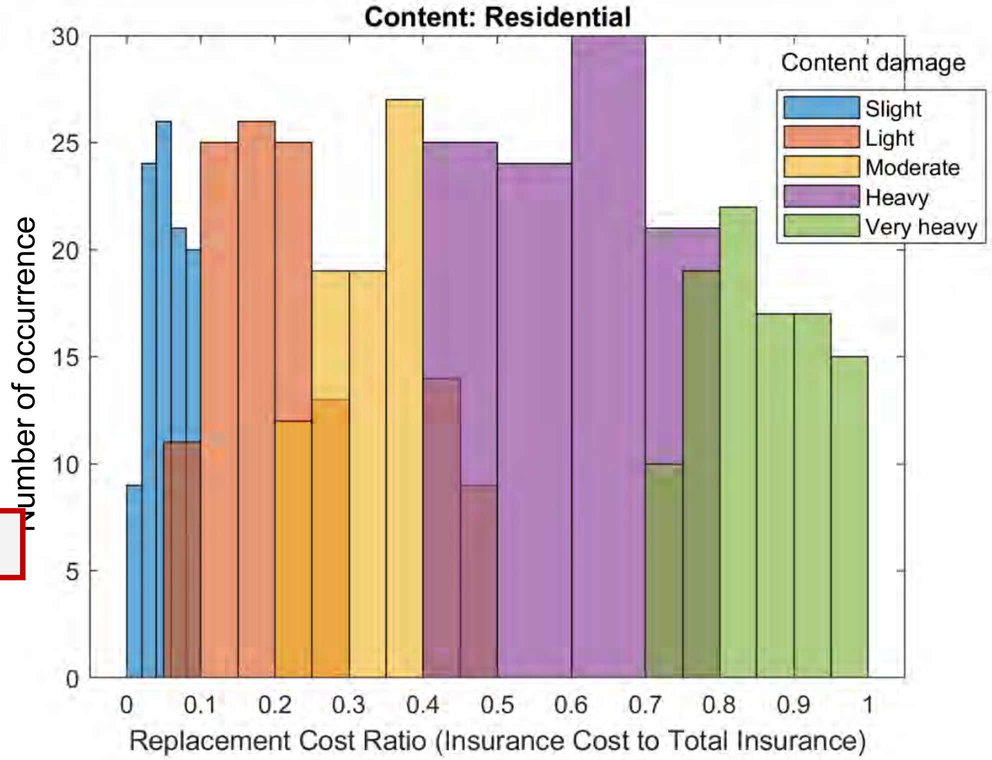


Consequence model (Replacement cost as a fraction of content value) is compiled from a group of experts and are evaluated as “replacement cost bands”

Consequence model
(including model uncertainty)



Consequence model (Replacement cost as a fraction of content value) is compiled from a group of experts and are evaluated as “replacement cost bands”

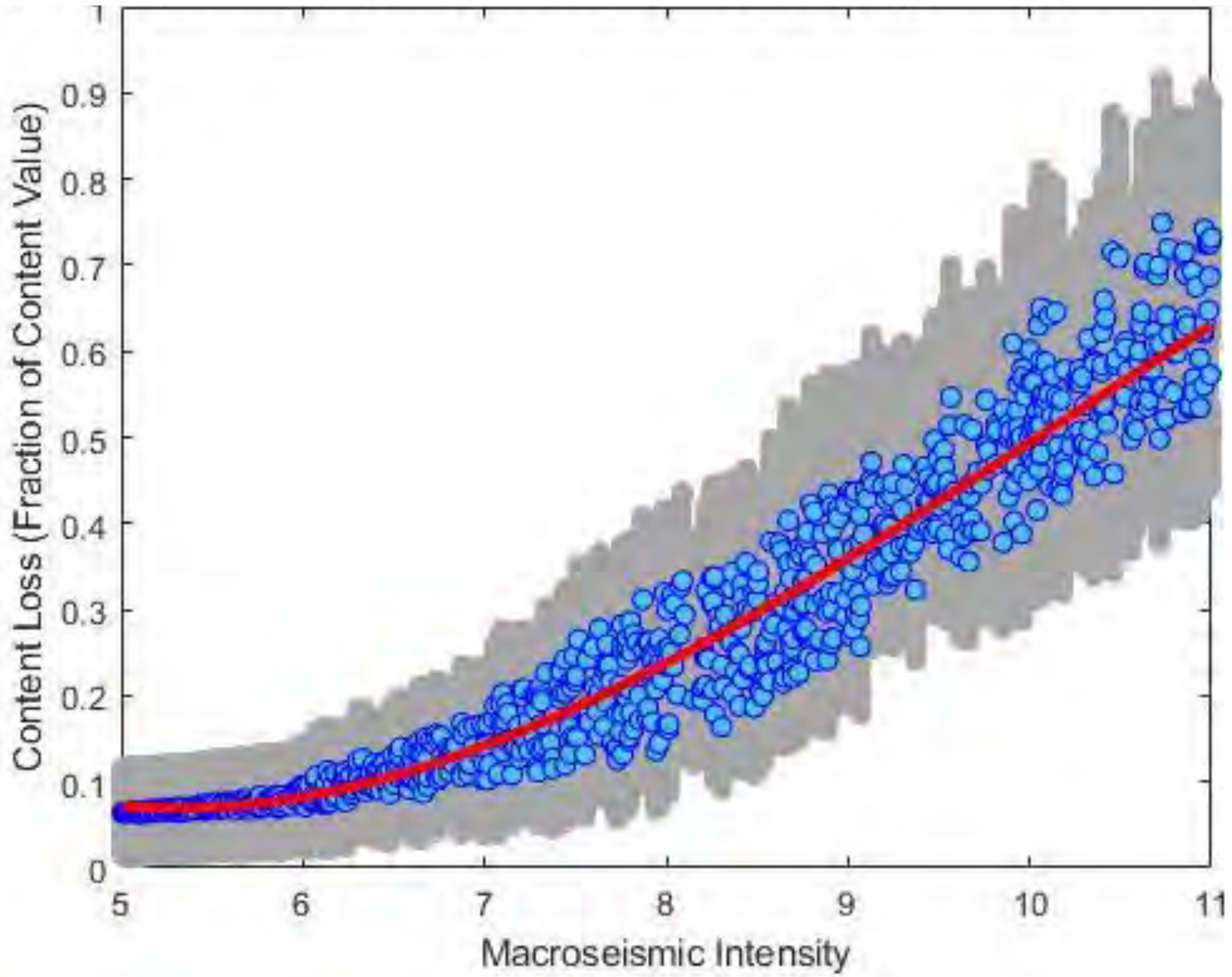


They are reflected on the computations via Monte Carlo simulations

Sinan Akkar

Content Loss
(progression in model uncertainty)

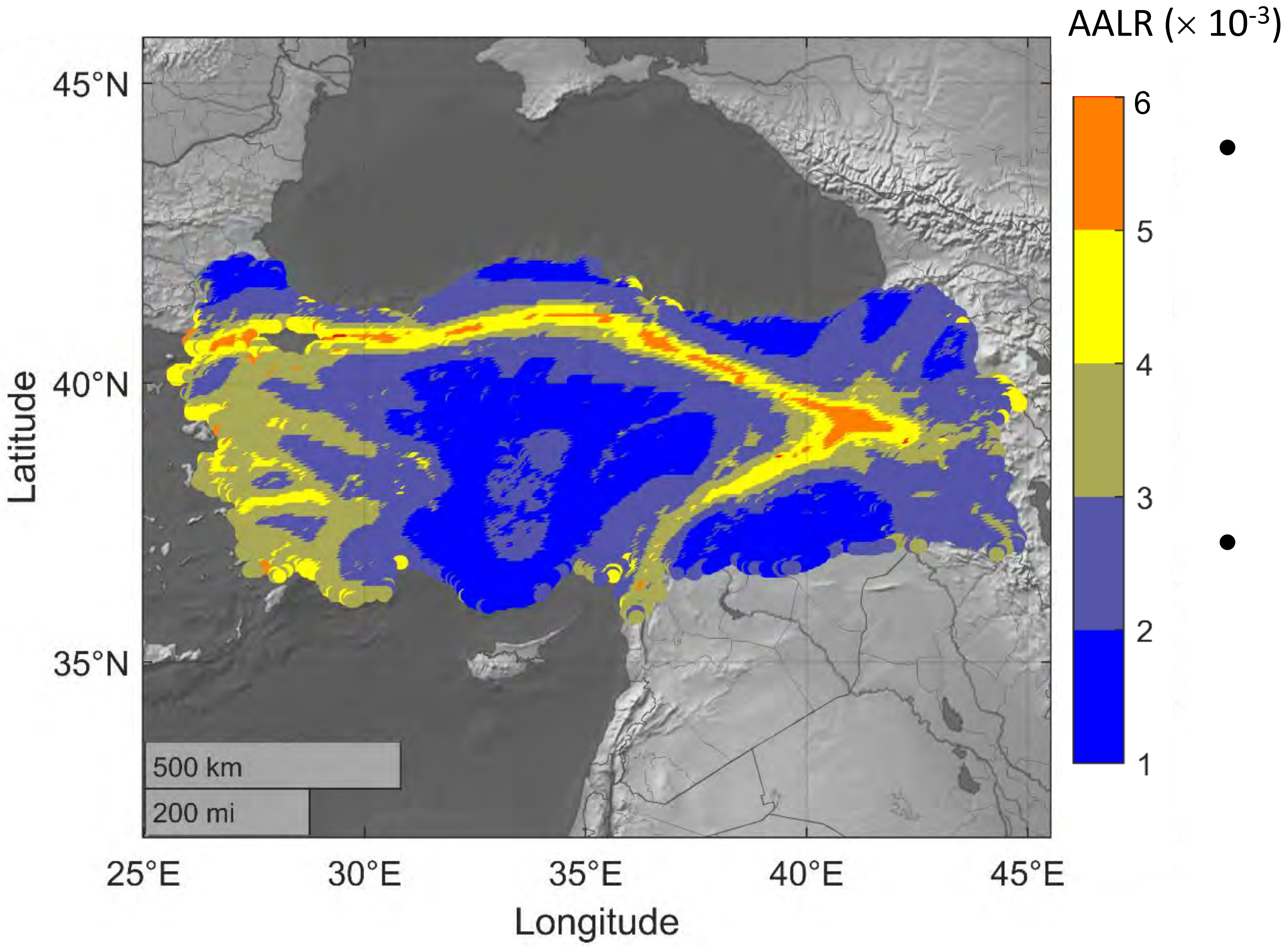
Content (Residential) Loss for Mid-Rise RC Building Constructed After 2000



- The grey cloud (after 10 million simulations) shows the progressive influence of uncertainties originating from
  - content damage probabilities conditioned on building damage
  - building damage probabilities
  - replacement cost (as a fraction of content value)
- The **red** curve is the mean loss and the **blue** points resemble the confidence interval about the mean loss

Average Annual Loss Ratio

Content (Residential) – Mid-Rise RC Building after 2000



- Average annual loss ratio distribution for entire Turkey using mean loss curve and soil class sensitive hazard
- More complicated computation would consider the entire scatter of loss distribution

Conclusions

- Recent advances in computer technology allow us to develop sophisticated probabilistic risk models for earthquake insurance. (In fact seismic hazard experts have started to develop such models much before than the experts in risk field).
- The level of sophistication and assumptions made in the risk models should be calibrated by systematically compiled building databases, building and content fragilities as well as consequence models. (These efforts should be country specific since conditions in each country differ).
- Well developed and calibrated risk models can be simplified for their efficient use at different levels of loss estimations. (Either for a single asset or for large building inventories).

Thank you