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RAPID EARTHQUAKE LOSS ASSESSMENT BASED ON MACHINE LEARNING AND REPRESENTATIVE SAMPLING

Z. Stojadinović, M. Kovačević, D. Marinković, B. Stojadinović

Department of construction project management, Faculty of Civil Engineering, University of Belgrade

MORE IN THE ARTICLE BY THE SAME TITLE AND AUTHORS, PUBLISHED IN: **EARTHQUAKE SPECTRA, 2022, 38, 1, 152-177**

The goal of the proposed RELA framework:
to improve the low accuracy
of traditional loss assessment systems

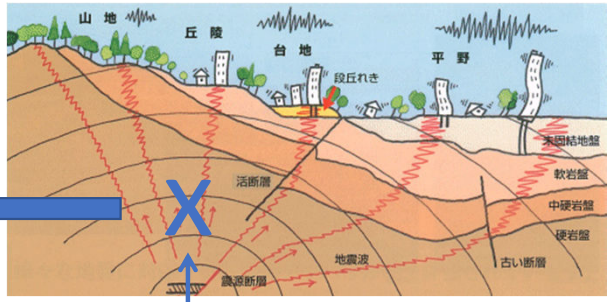
Traditional rapid earthquake loss assessment

1. Pre-earthquake phase

- Creating the building portfolio – building types (BT)
- Defining damage states (DS)

- Establishing a Ground Motion Model

$=f(x)



- Damage prediction - relationship between ground motion and damage states
- Loss quantification in relation to replacement value (from 0% do 100% RV)

2. Co-earthquake phase - activating the system to perform predetermined calculations, based on earthquake characteristics

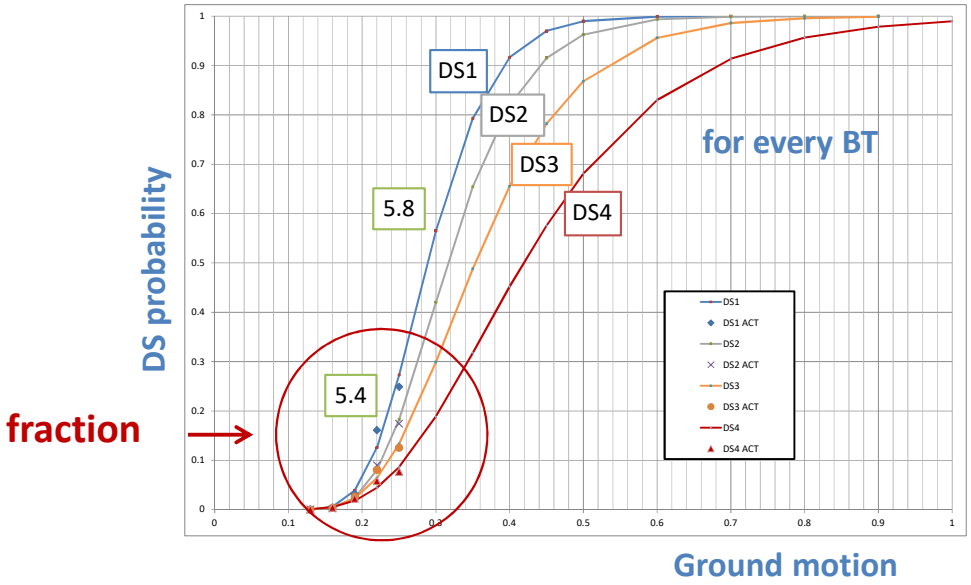
X

Uncertainties in traditional systems

- in generating shake maps
  in algorithms and
  in measurements of ground motion,
- in fragility/vulnerability relations
  in approximating actual buildings to theoretical building types and
  in using limited empirical data or data gathered elsewhere,
- in loss assessment (converting DS to $)
  in replacement ratios and
  in replacement values.

“BEFORE”-induced problems in the traditional approach

- Analytical:
  - ✓ Pre-determined formulas before an earthquake - **multiplying uncertainties**
- Empirical:
  - ✓ If gathered locally – **incomplete data** (fraction of the whole GM-BT-DS spectrum)
  - ✓ If gathered globally - **transferable theoretically, but not really**



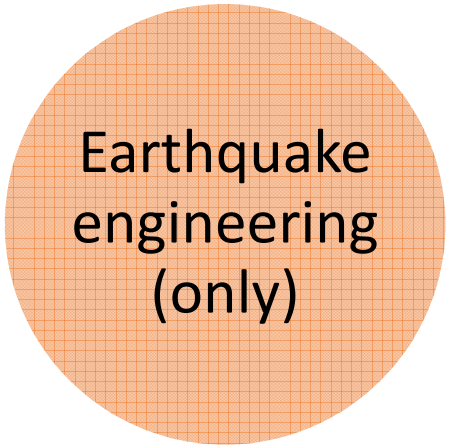
REALITY CHECK

According to HAZUS, the total uncertainty is "possibly at best a factor of two or more"?!?

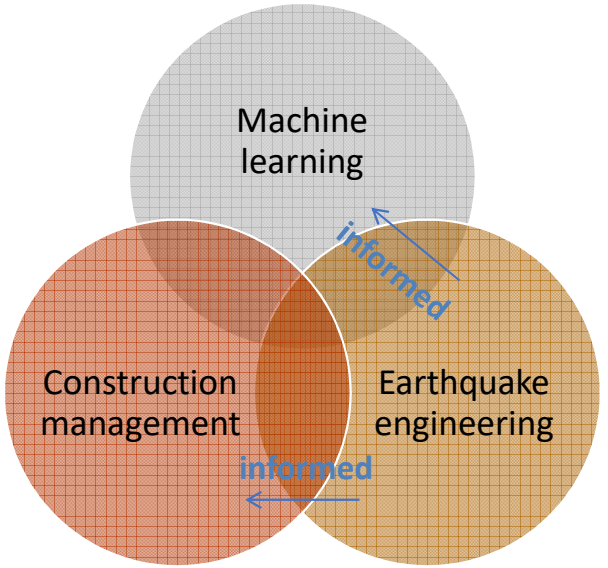
Traditional loss assessment is rapid but not accurate

(even though scientifically justified)

Traditional vs our approach



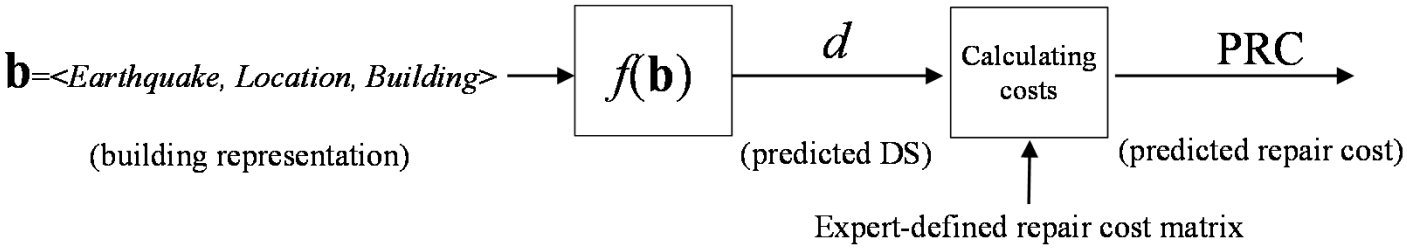
MODEL CREATED BEFORE
assumptions, uncertainty



MODEL CREATED AFTER
real buildings, real damage

This research & case study
refers to buildings and direct loss (repair or replace buildings)

Proposed damage and loss prediction model



- **Learn the mapping** between a building characteristics vector and the associated DS **after observing DS on a representative set** of buildings.

- Improve monetizing loss and logistics:
  - ✓ **Cost matrix** for all BT/DS combinations
  - ✓ **Soft rule formula** for predicting PRC

$$PRC_{soft} = \sum_{\mathbf{b}\in B} \sum_{d\in DS} p_d(\mathbf{b}) a(\mathbf{b}) c_{dt}$$

- **p** probability of building *b* belonging to state *d*,
- **a** footprint area,
- **c** cost per footprint area

(2017)	BT1	BT2	BT3	BT4	BT5	BT6
DS1	3,43	12,04	8,36	10,43	9,14	9,14
DS2	13,40	16,04	15,14	18,86	17,54	18,64
DS3	55,69	46,30	44,15	38,87	29,72	32,75
DS4	350,00	350,00	350,00	350,00	350,00	350,00

Earthquake engineering-informed – cost/footprint area depending on the nature of damage and building type

CASE STUDY: 5.4 Kraljevo 2010 earthquake

Predicted / Actual	DS0	DS1	DS2	DS3	DS4	Total number of buildings:	**Recall**
DS0	1314	11	0	1	1	1327	0.99
DS1	27	234	38	18	11	328	0.71
DS2	6	64	37	13	7	127	0.29
DS3	7	31	17	69	9	133	0.52
DS4	3	18	14	10	19	64	0.30
total:	1357	358	106	111	47	**Accuracy** 1673/1979=0.85	
Precision	0.97	0.65	0.35	0.62	0.40		

Good, but not good enough – small sample, not enough entries for all damage states

Promising validation results: soft rule relative error
|PRC – ARC|/ARC = only 5%!

PRC - Predicted Repair Cost, ARC - Actual Repair Cost

Do we need earthquake data to predict earthquake damage?

	Earthquake + Location + Building	*Earthquake + Building*	*Location + Building*	*XY + Building*
Accuracy (%)	85.4	83.6	85.4	85.4
Kappa	0.69	0.68	0.71	0.71

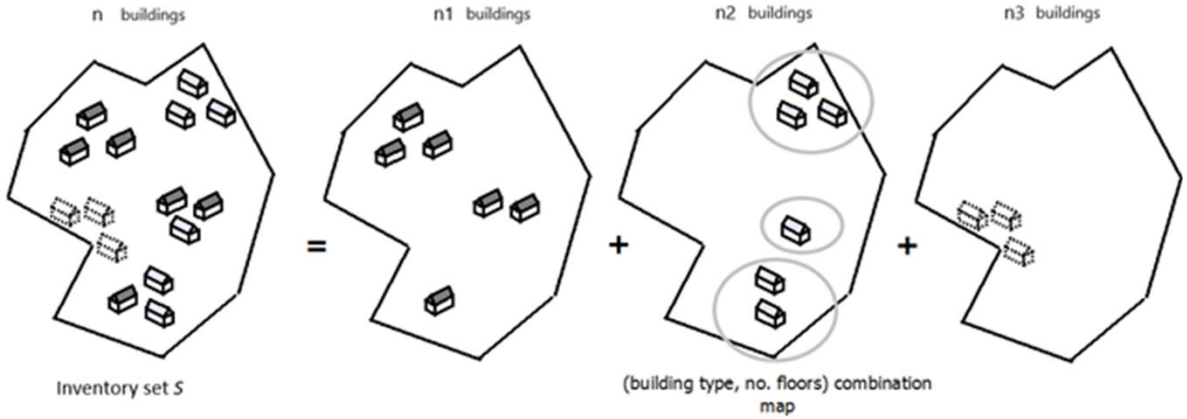
- Breakthrough! No need for earthquake data.
- Proposed representation: geo-coordinates, building type, year of construction, number of floors, and footprint area – easy to obtain.
- This is now an ML problem – buildings are rudimentary seismometers for the DS distribution across a territory.

Representative sampling

- Earthquake engineering-informed* way to choose buildings that represent the entire portfolio well: <BT, no. of floors> combination

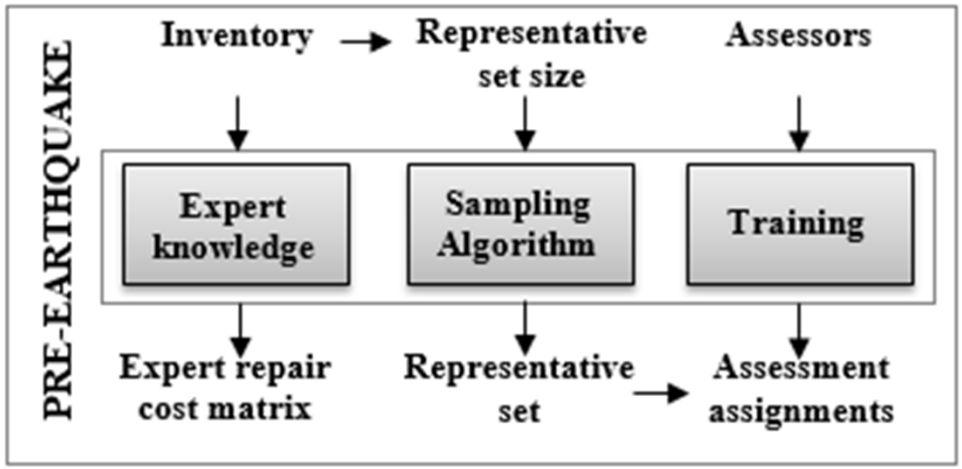
  * BT captures seismic behavior, the number of floors and footprint area capture the dynamics of the building

- Method: K-means clustering algorithm in each <BT, no. of floors> combination



- **Crucial framework element** – enables a **small data set** to be sufficient for machine learning and enables **speed**

RELA Framework: Pre-earthquake phase

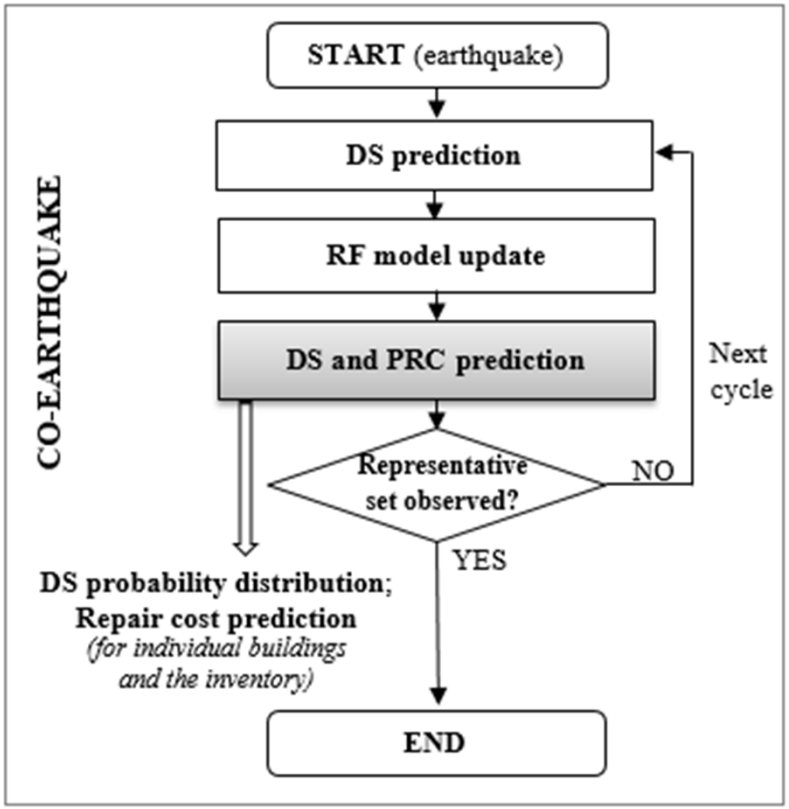


- Form a database of buildings with the proposed representation.
- Form a sample that represents the portfolio well – a representative set.
- Train a group of assessors to detect the damage states of buildings.
- Prepare a repair cost matrix

RELA Framework: Co-earthquake phase

1. Detecting damage states on a representative set by trained assessors
2. Training the Random Forest model to predict damage states for the rest of the portfolio
3. Predicting repair cost using the cost matrix

Every day

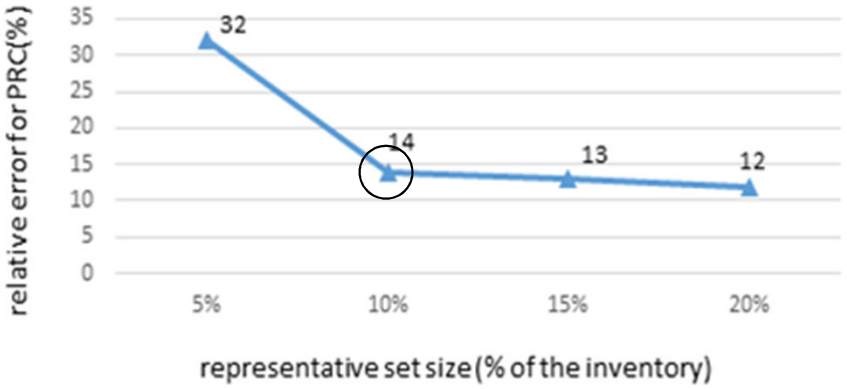


- Accuracy improves with each daily observation cycle
- Since observing the representative set takes a couple of days, the prediction process can be categorized as rapid.

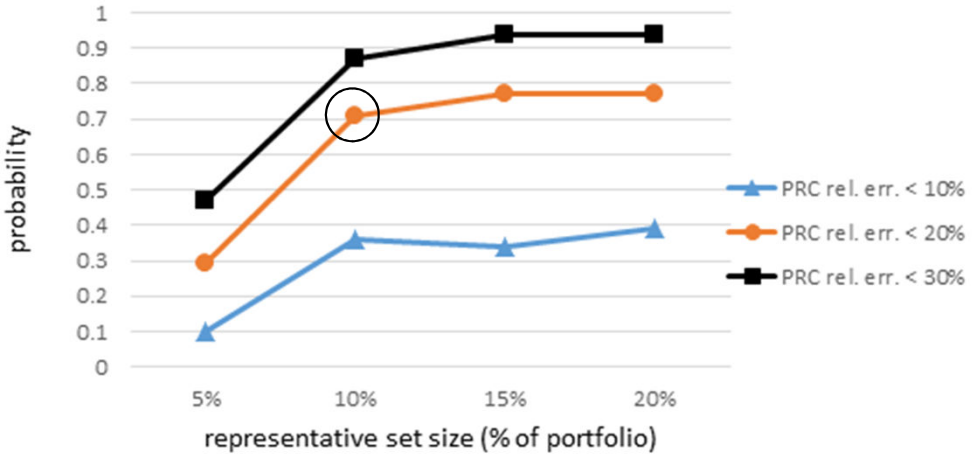
5.4 Kraljevo 2010 earthquake – 40.000 buildings, 6.000 damaged.

For 10% RS (4.000), 57 assessors, 35 buildings/day = 2 DAYS = RAPID

The proposed RELA Framework - accuracy



Evaluating the performance of the RELA framework
in relation to the representative set size
(median values for relative error for predicted repair cost - PRC).



The probability that a model built on the representative set
containing 5%, 10%, 15%, and 20% of the building portfolio
produces the relative PRC error smaller than 10%, 20%, and 30%.

RELA framework is accurate, rapid, inexpensive, and easy to implement anywhere

THANK YOU

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