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Improving Decentralized On-site Earthquake Early Warning by rapid estimation of interstorey drift

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The goal of an earthquake early warning (EEW) system is to send a rapid alert in order to mitigate the risks associated with earthquakes.

There are two types of approaches:

- **Regional** (network-based), these systems estimate source parameters (location and magnitude) and predict peak ground motion at distant sites

- **On-site** (single station), starting from the early p-waves ground shaking these systems predict the ground shaking associated with s-waves

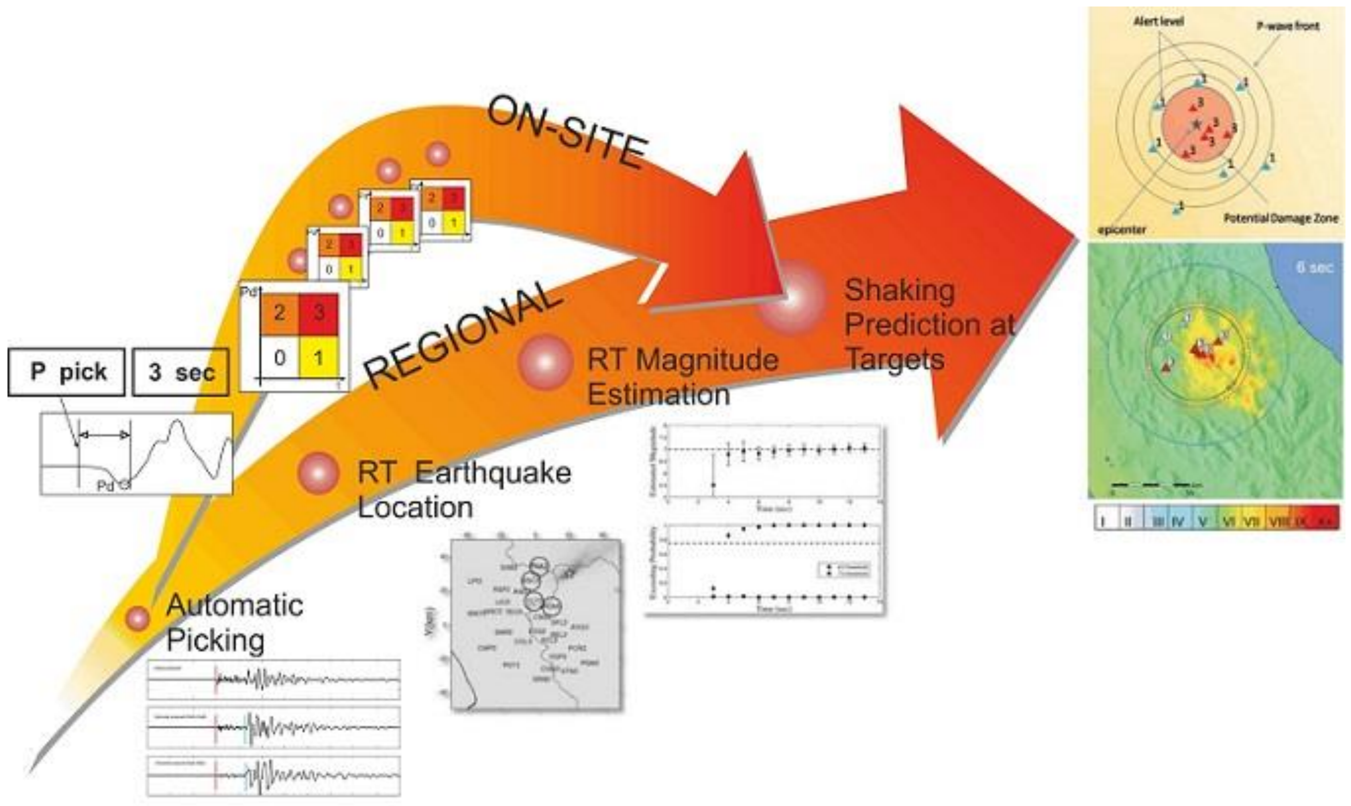

Fig.1: Difference between regional and on-site approaches (Zollo et al., 2010 mod.)

Why focus on on-site approach?

- It is useful for target areas, where dense strong-motion networks are not avaible

- Provide local alert

A modern early warning rapid response system should provide an estimation of the damage that can affect a structure, either before the strong motion phase has arrived

Estimate probability of exceedance of limits associated with damage state

The goal could be achieved as follows:

- Analyzing peak ground displacement (pgd) in a few seconds after p-wave arrival time
- Estimating a relationship that could lead us to calculate the expected engineering parameter connected with building's health
- Estimating the probability of exceeding damage limits

An on-site early warning software has been developed (Parolai et al., 2015) in which the alarm detection system is characterized by matrices each one filled depending on the value assumed by the estimated peak ground parameter when considering the mean plus the standard deviation (σ) value and the employed threshold

The idea is to improve the EEW system by estimating the probability of exceeding thresholds as an alternative to the use of matrices

1. Relationship between maximum of total drift or interstory drift and peak ground displacement was estimated

The method is applied to seismic recordings of Italian earthquakes of magnitude > 4.5 obtained from Seismic Observatory of Structures (OSS) managed by DPC

- Estimation of peak ground displacement recorded at the bottom of the buildings in a time window of 3 s after p-waves arrival time
- Estimation of the maximum of total drift
- Estimation of interstory drift

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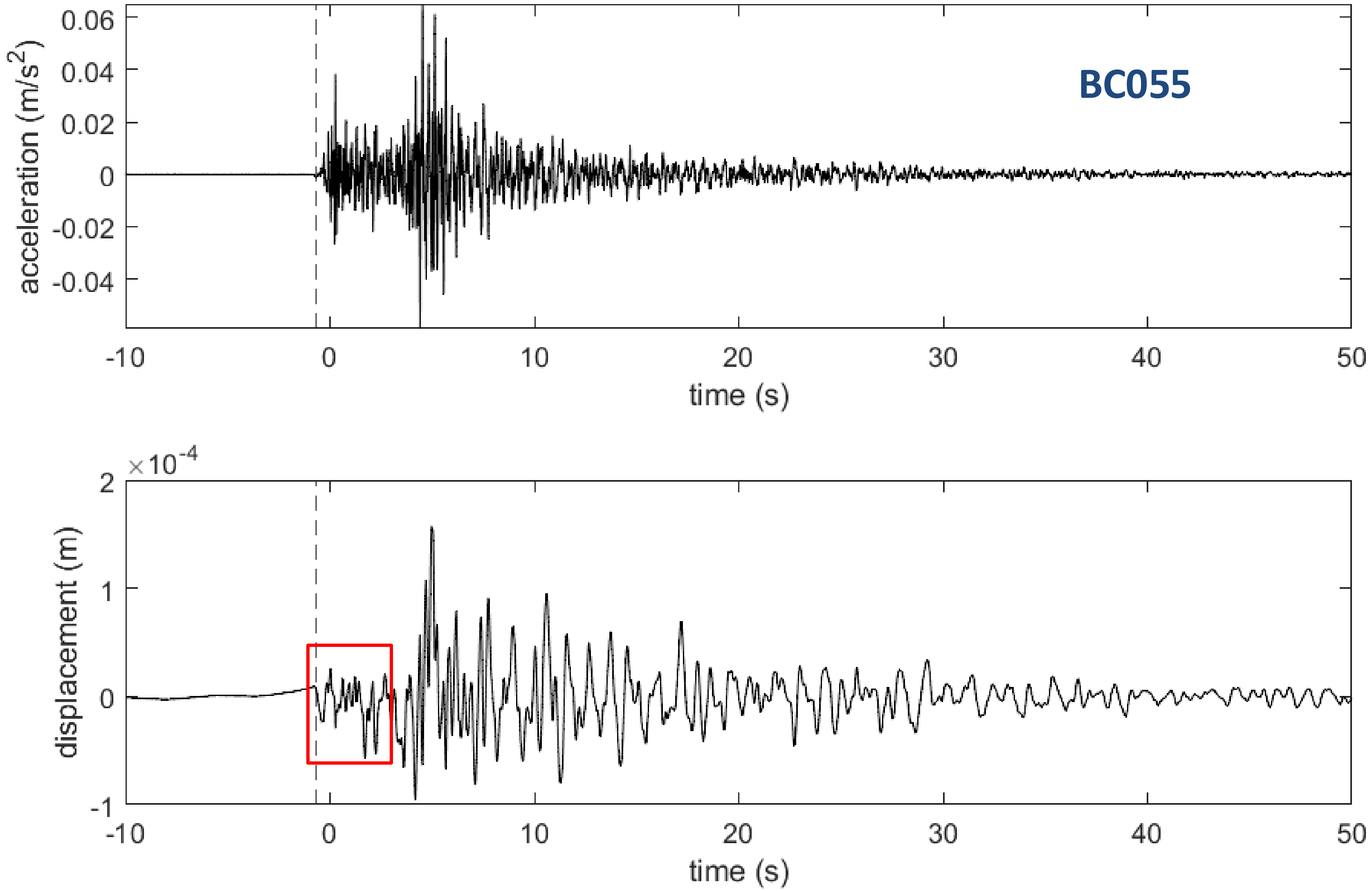
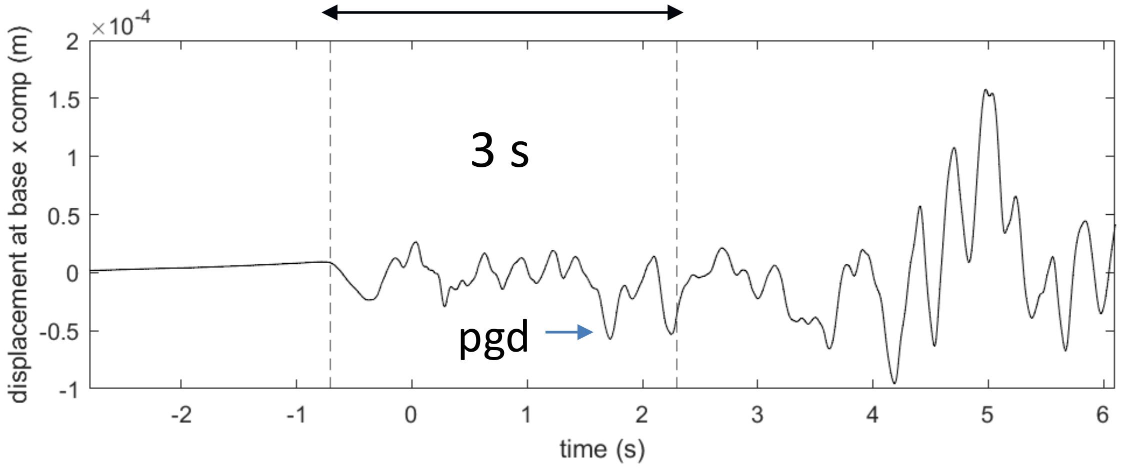




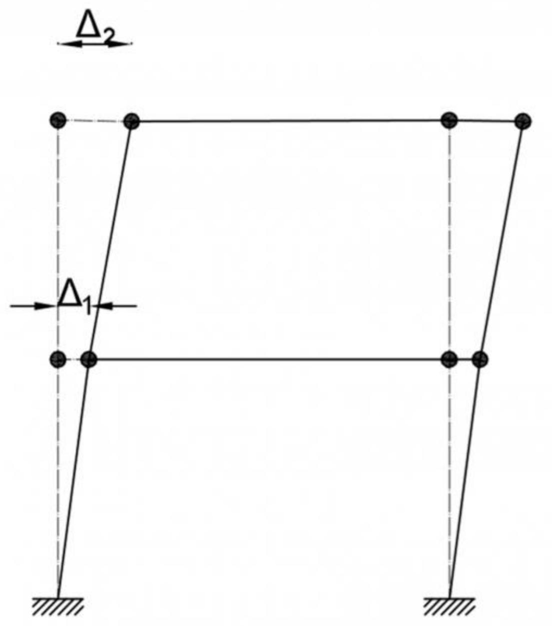
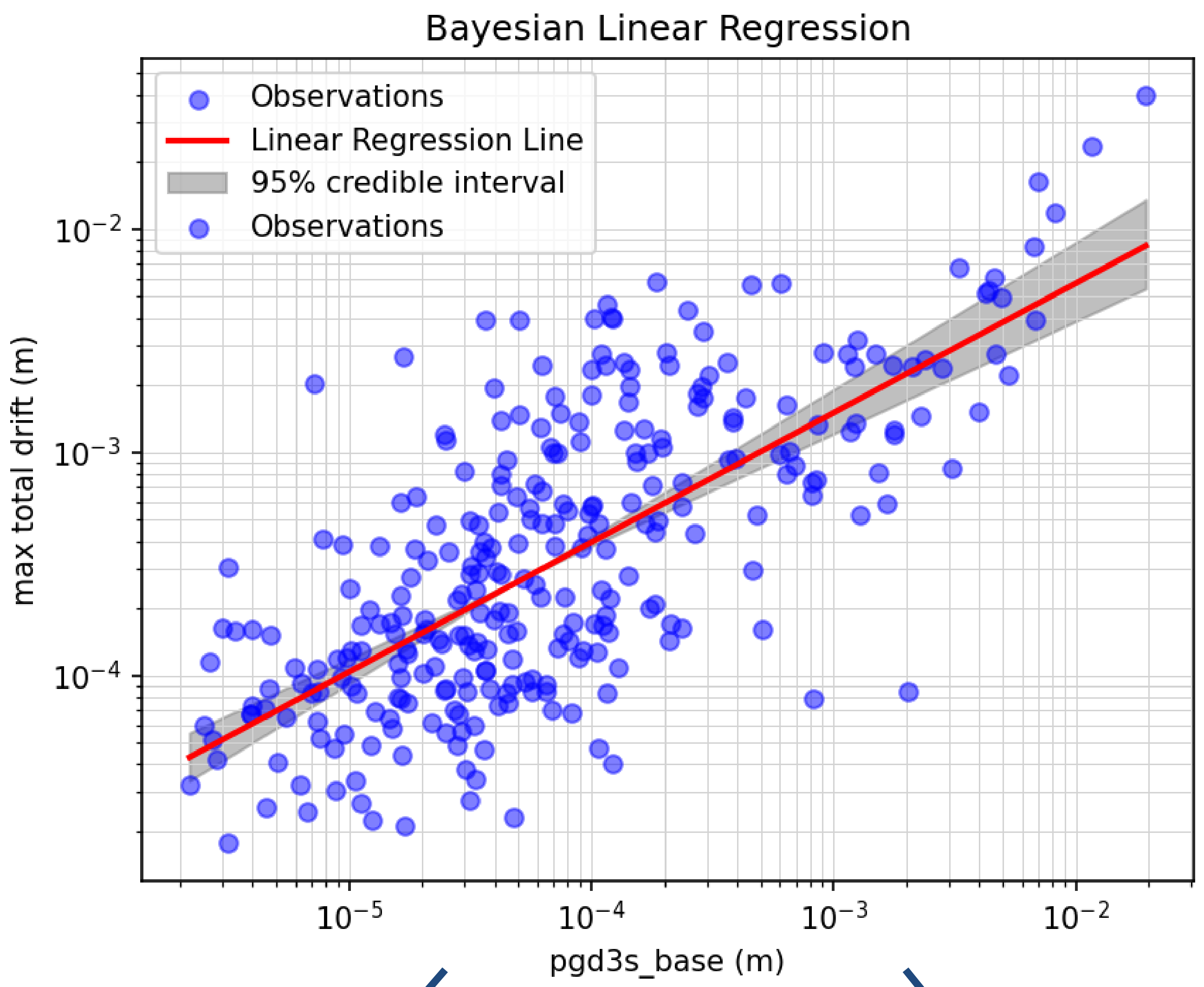


Fig.2: Definition of drift/interstory drift (mdpi.com)

Total drift (relative displacement between the top and the bottom of the structures) was calculated as the difference between displacement recorded at the top of the buildings and displacement recorded at the bottom of the buildings

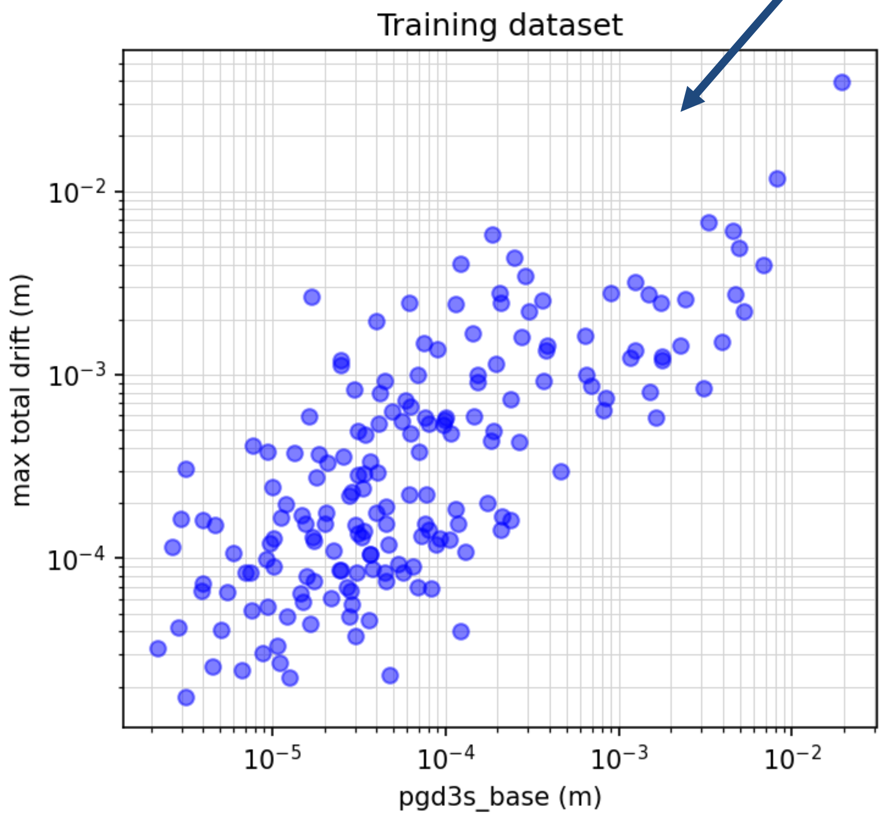


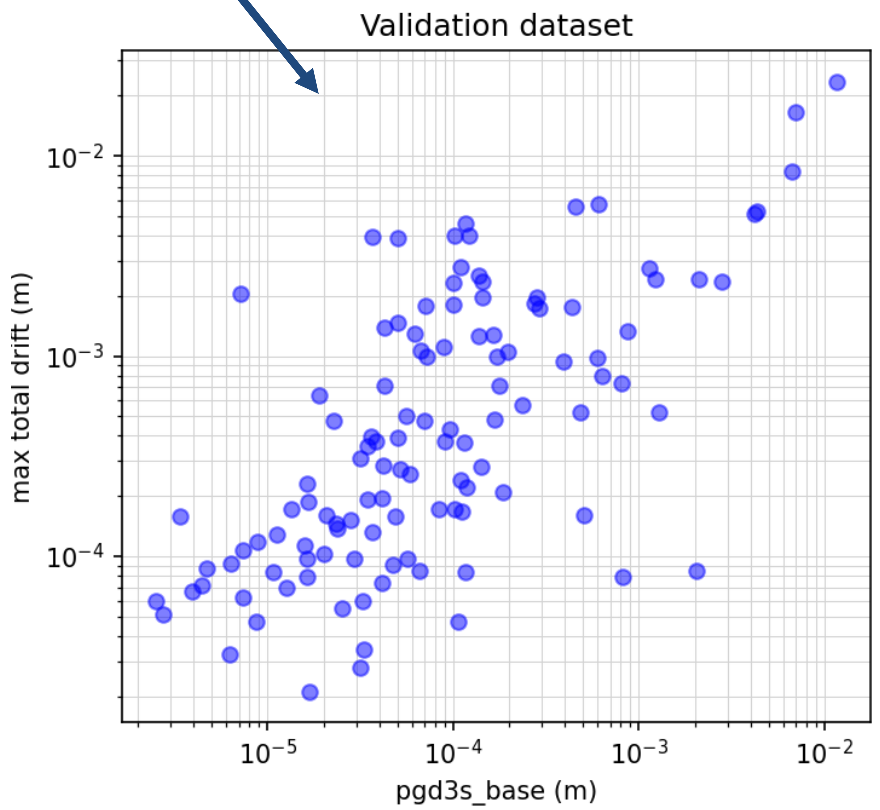
The predicted model was estimated through Bayesian linear regression that gives the probability distribution of the model parameters:

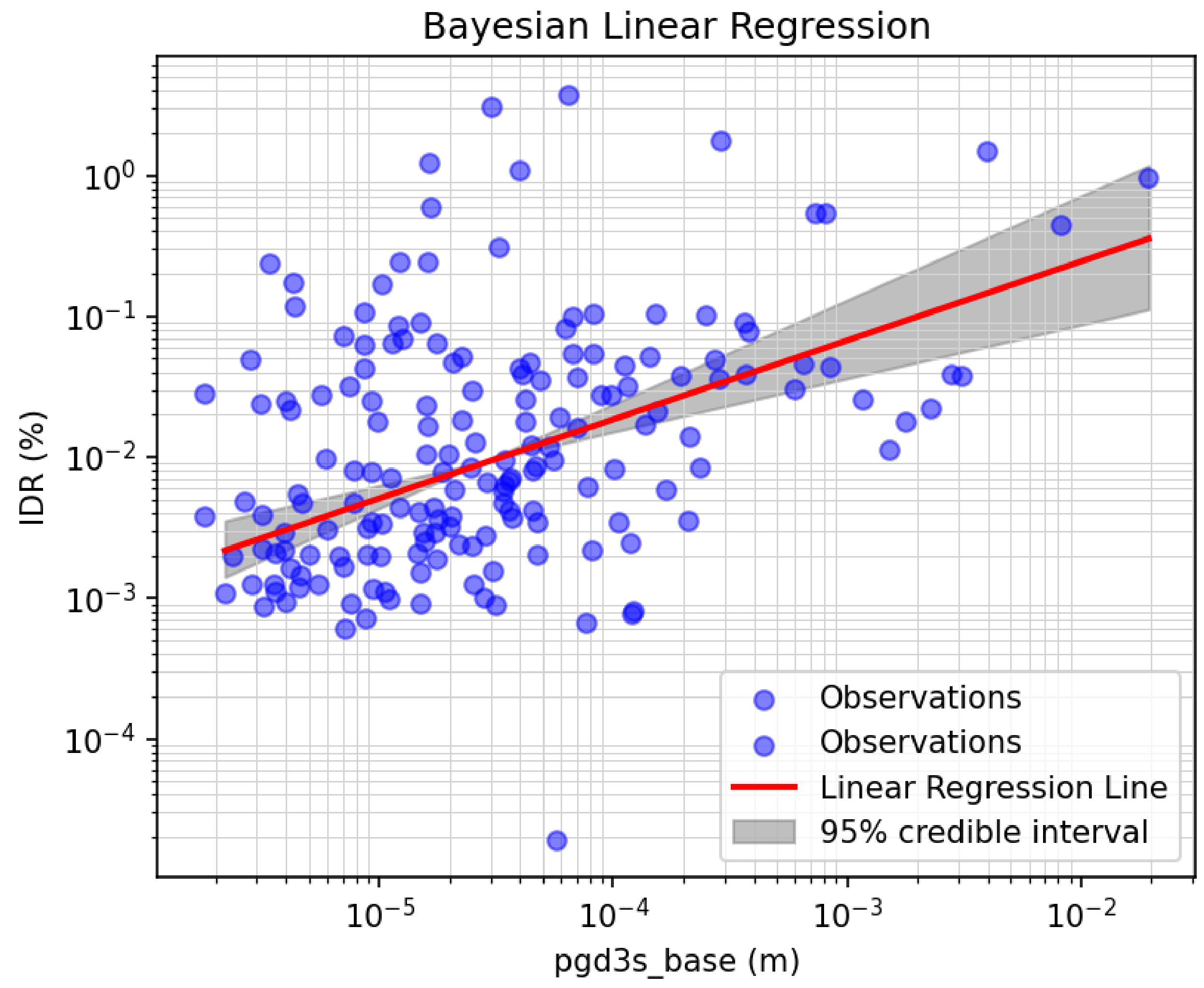
- Posterior mean of the parameters
- Standard deviation of the parameters
- Variance (uncertainty associated with the estimation of the parameters)

The dataset was divided into two sub-datasets :

- A training dataset that was used to estimate the model
- A validation dataset







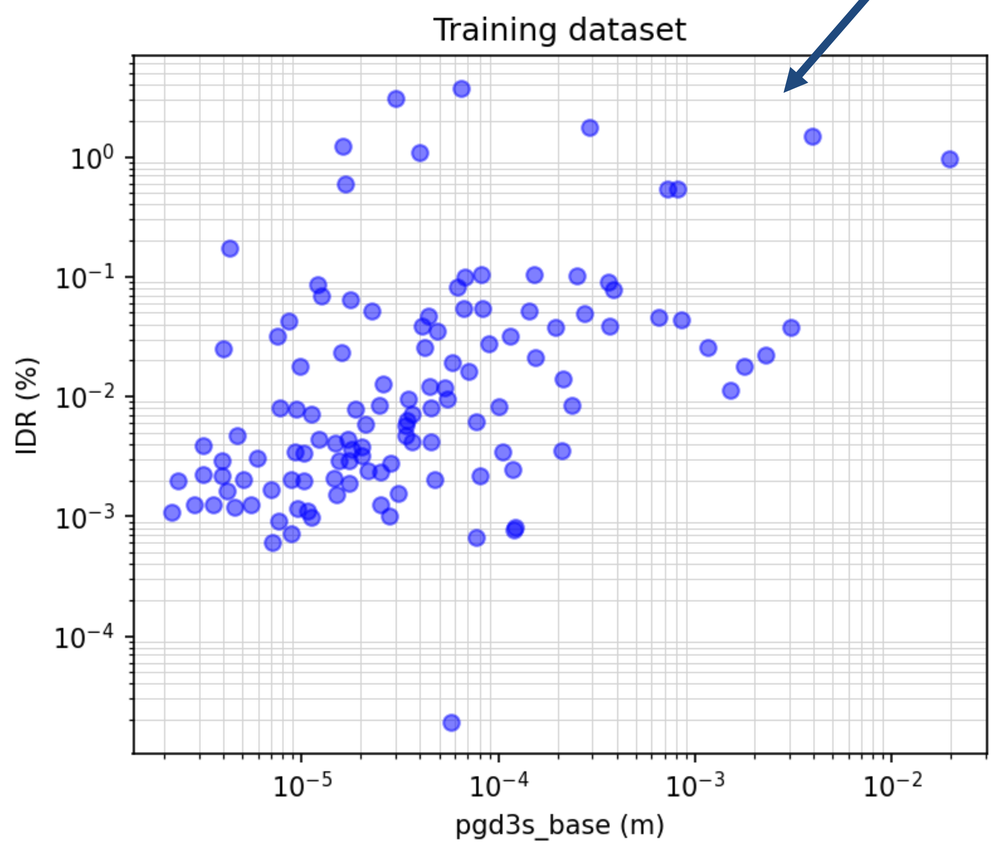
Interstory drift was calculated as interstory drift ratio (IDR)

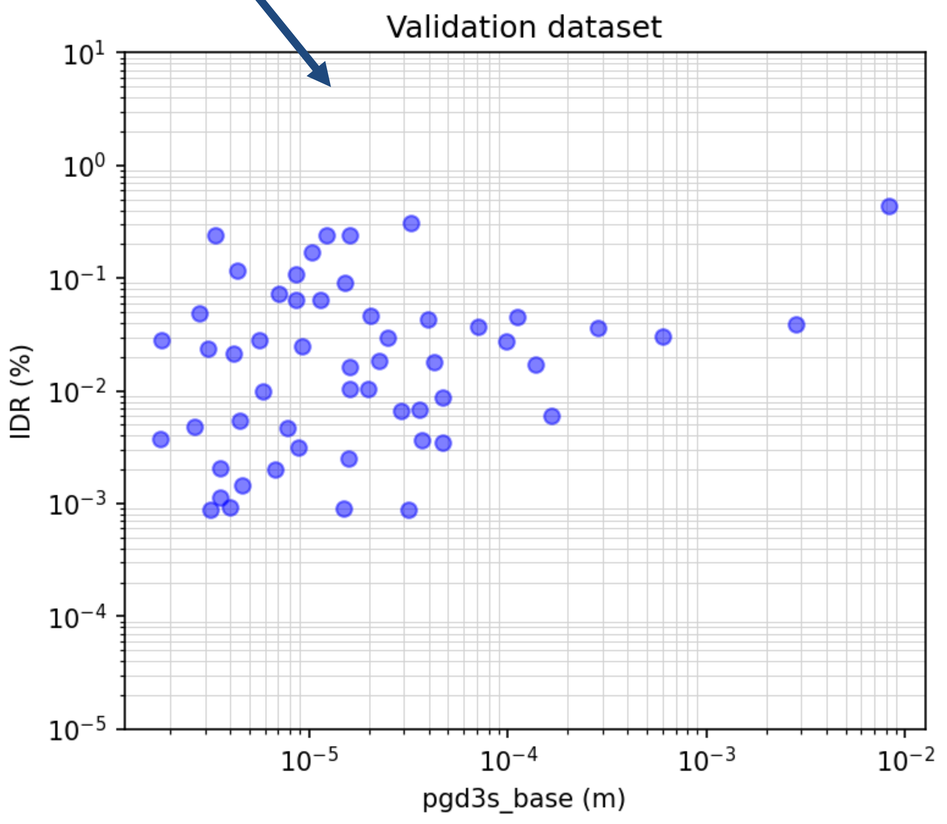
$$IDR = \frac{relative\ translational\ displacement\ between\ two\ consecutive\ floors}{storey\ height}$$

We decided to calculate IDR also through approximations, assuming:

- Linear distribution of the drift
- Shear beam model (non-linear distribution of the drift)

Analysis of residuals





2. Estimation of the probability of exceeding drift and interstory drift thresholds

$$p_n(> \log(drift)) = \int_{\text{thr\_}log(drift)}^{4\sigma_n} \frac{1}{\log(\sigma_n)\sqrt{2\pi}} e^{\frac{-(\log(\,drift)-\log(g_n(pgd)))^2}{2\log(\sigma_n)**2}} dlog(drift)$$

or

$$p_n(> \log(IDR)) = \int_{\text{thr\_}log(IDR)}^{4\sigma_n} \frac{1}{\log(\sigma_n)\sqrt{2\pi}} e^{\frac{-(\log(IDR)-\log(g_n(pgd)))^2}{2\log(\sigma_n)**2}} dlog(IDR)$$

We considered thresholds available in literature:

- **Lagomarsino and Giovinazzi (2006)** for drift
- **Borzi et al. (2008), Mouroux and Brun (2006)** for IDR

We calculated the probability of exceeding thresholds for each value of peak ground displacement considered

This means that we obtained for each type of building and for each damage state a table that associates to each value of pgd the corresponding value of probability

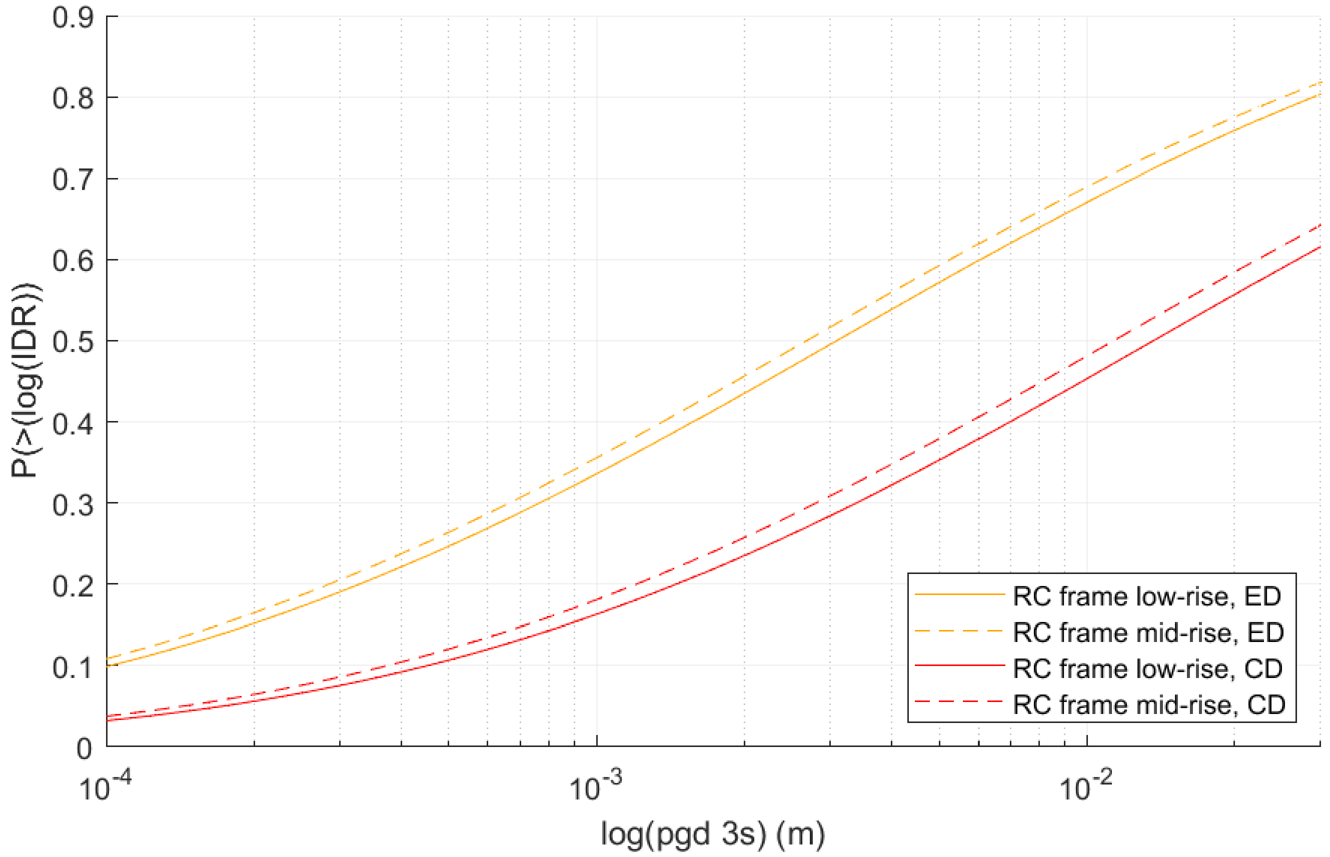


Fig.3: Example of estimated probability of exceeding IDR as function of pgd for reinforced concrete buildings (extensive damage state ED and complete damage state CD) low-rise (1-2 stories) and mid-rise (3-5 stories) (Morga et al., 2024, in prog.)

How this method could be useful to improve a Decentralized On-site Early Warning system?

The validation dataset could be used to validate the method and set probability thresholds which will characterize the alarm system

⇩

- Calculate the probability of exceeding literature thresholds corresponding to the observed peak ground displacement (using validation dataset)
- Based on the drift and IDR measured, check if buildings have been exceeded the damage state limits
- Check how many times the EEW system gives:
    - **Missed alarms**
    - **False alarms**

Thank you for your attention

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