**EX**perimental & **C**omputational **H**ybrid **A**ssessment of **N**atural **G**as Pipelines **E**xposed to Seismic **Risk**

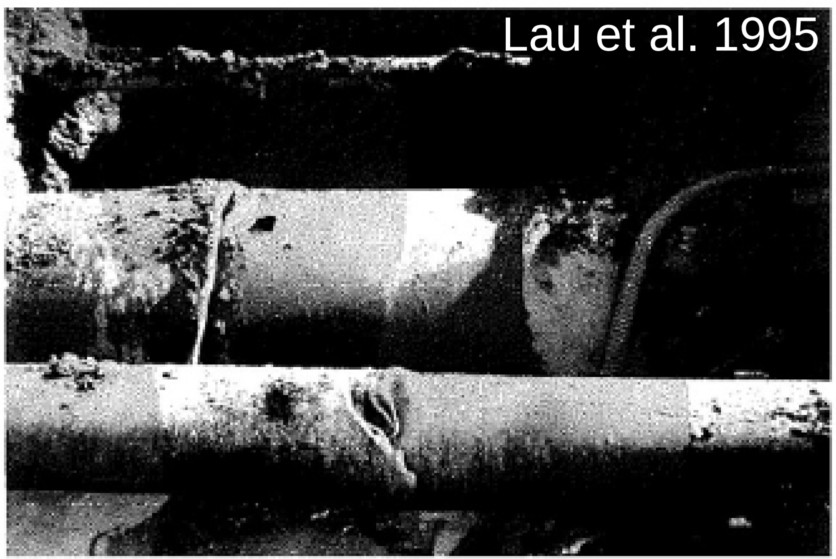
# Post-event risk assessment for gas pipelines at regional scale:

## The Friuli case – vulnerability model and data on the network

*Flavia De Luca*

# Introduction and Motivation

"*Natural events, such as earthquakes and floods, can trigger accidents in oil and gas pipelines with potentially sever consequence to the population and to the environment. These conjoint technological and natural disasters are termed* ***NaTech accidents*** […]. *Most of NaTech studies on pipelines focus on seismic risk analysis and on structural damage without considering the* ***potential loss of containment****.*" [Piccinelli and Krausmann, 2013]



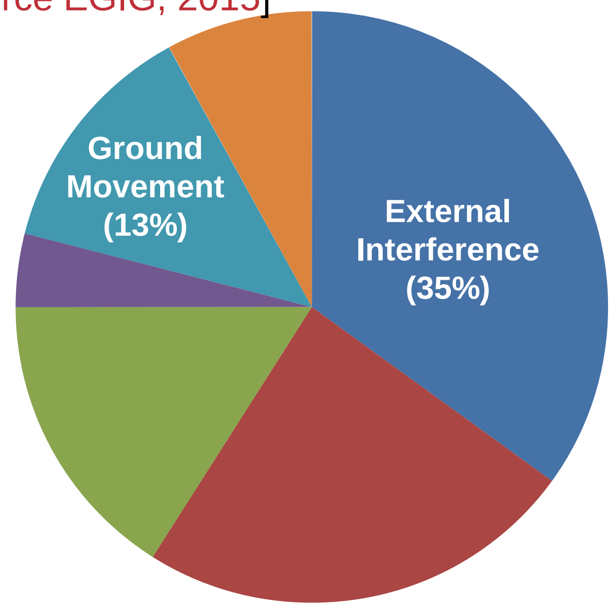
Lau et al. 1995

# Introduction and Motivation

In the 9th report of the *European Gas Pipeline Incident Data Group* related to the period 1970-2013 is emphasized how incident caused by external interference (35% in 2004-2013) and ground movement (13% in 2004-2013) are characterized by potential severe consequences (24% corrosion, 16% construction defects/material failures, 4% hot tap, 8% other/unknown) [EGIG, February 2015]

**Incidents (2004-2013)**

[Source EGIG, 2015]

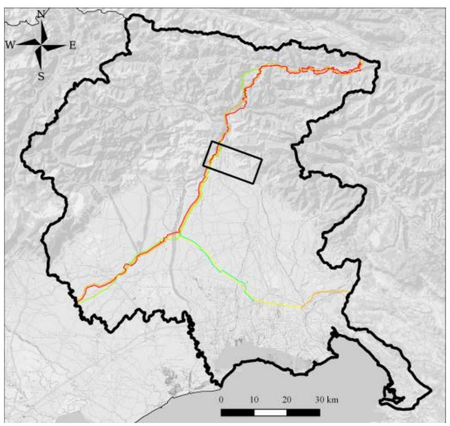



Landslides are by far the most common type causing a ground movement incidents (i.e., 85% in 2004-2013). Failure frequency decreases with the diameter class. No incidents are recorded in the whole database 1970-2013 as caused by earthquakes.

# Scope of the study

In recent years, many studies have focused on the seismic performances of gas lifelines. Seismic reliability studies for short-term and long-term post-event characterization of risk and losses have proposed.

*We started from the simulation-based risk assessment framework proposed by Weatherill et al. (2014) and Esposito et al. (2015) as benchmark for the state-of-the-art practice on risk of gas pipelines in Europe.*




## *What we did?*

Post-event framework for damage and loss assessment at regional scale, applied to the Italian National Grid (high-pressure transport network) and to the Friuli 1976 earthquake case.

## *What's new?*

- Ground failure from both landslide and liquefaction in a single three-step framework
- A new machine learning classification approach for vulnerability

## Literature empirical models

Fragility models can be divided in two categories, those considering damage caused by Strong Ground Shaking (SGS) and those caused by Ground Failure (GF), including fault displacements, liquefaction and landslides. For both causes we have the "classical approach" and the "industrial risk approach"

| SGS | | GF | |
|---|---|---|---|
| 1)RR=a·IM$^b$ | 2) P(DS≥DSi or RS≥RSi ) | 1)RR=a·IM$^b$ | 2)P(DS≥DSi or RS≥RSi ) |

1) The "classical approach" – optimized to provide consequence assessment results mainly in terms of repair expenditures

2) The "industrial risk approach" – optimized to provide consequence assessment not only in terms of structural damage but also including industrial risk consequences (e.g., release of flammable or pollutant liquid).

# Vulnerability

## *Literature empirical models*

1) The "classical approach" – optimized to provide consequence assessment results mainly in terms of repair expenditures

   The example of ALA (2001) vulnerability functions is considered. They are based on 18 earthquake events and employed in Esposito et al. (2013) and (2015). For steel welded joint, large D (>400mm) pipelines $K_1$ and $K_2$ are equal to 0.15.

**SGS**

- IM = PGV
- $RR\ (in\ 1/km) = K_1 \cdot 0.002416 \cdot PGV\ (in\ cm/s)$

**GF**

- IM = PGD
- $RR\ (in\ 1/km) = K_2 \cdot 11.223 \cdot PGD^{0.319}\ (in\ m)$

## *Literature empirical models*

1) The "classical approach" – the example of ALA (2001)

**SGS**

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According to HAZUS the type of repair or damage depends on the type of hazard (i.e., SGS = 0.8 leaks + 0.2 breaks; GF = 0.2 leaks + 0.8 breaks)

| HAZUS (NIBS, 2004) | Damage State | Damage description | Serviceability |
|---|---|---|---|
| DS1 | No damage | No break/leak | operational |
| DS2 | Leakage | At least on leak along the pipe length | Reduction of the flow |
| DS3 | Failure | At least one break along the pipe length | Disruption of the flow |

# Vulnerability

## *Literature empirical models*

2) The “industrial risk approach” – optimized to provide consequence assessment not only in terms of structural damage but also including industrial risk consequences (e.g., release of flammable or pollutant liquid).

The example of Lanzano et al. (2014) is considered. They are based on 20 earthquake events for continuous pipelines (CP) and segmented pipelines (SG)

SGS (for CP and SP)

- IM = PGV
- RS≥RS1 and RS=RS2

GF (for CP and SP)

- IM = PGA
- RS≥RS1 and RS=RS2

## Literature empirical models

2) The "industrial risk approach" – example of Lanzano et al. (2014)

**SGS (for CP and SP)**

- IM = PGV
- RS≥RS1 and RS=RS2 (or DS)

**GF (for CP and SP)**

- IM = PGA
- RS≥RS1 and RS=RS2 (or DS)

| States | Hazard | Patterns (structural damage) |
|---|---|---|
| DS0 | Slight | Investigated sections with negligible damage; pipe buckling |
| DS1 | Significant | Longitudinal and circumferential cracks; compression joint break |
| DS2 | Severe | Tension cracks for continuous pipelines; joint loosening in the segmented pipelines |

# Vulnerability

## *Literature empirical models*

2) The “industrial risk approach” – example of Lanzano et al. (2014)

**SGS (for CP and SP)**

- IM = PGV
- RS≥RS1 and RS=RS2 (or DS)

**GF (for CP and SP)**

- IM = PGA
- RS≥RS1 and RS=RS2 (or DS)

| States | Hazard | Patterns (loss of containment) | |
|---|---|---|---|
| | | Gas/Vapor/Liquefied gas | Liquid |
| RS0 | No losees | Investigated sections with negligible damage; pipe buckling | |
| RS1 | Very limited losses:toxic ($\phi$<1mm/m); flammable ($\phi$<10mm/m) | Limited, time-distributed loss of hazardous substance: multiple losses ($\phi$<10mm/m) | |
| RS2 | Non-negligible losses | Large loss (e.g., entire tube surface) or multiple losses ($\phi$>10mm/m) | |

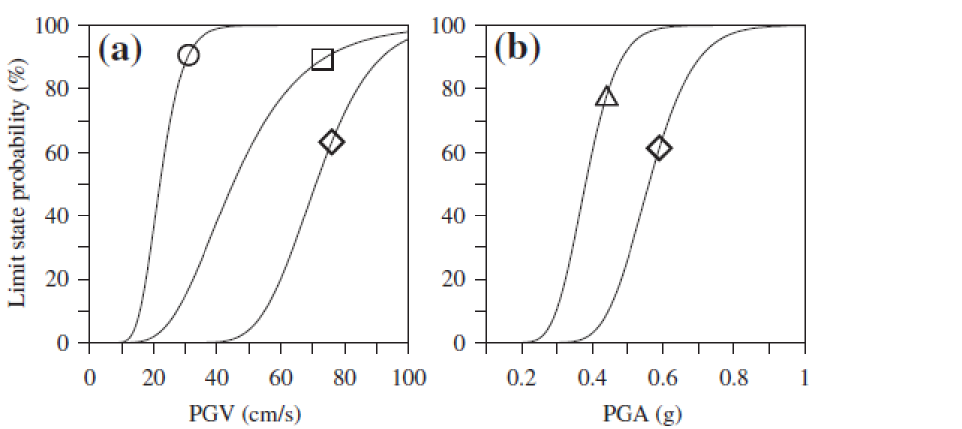
# Vulnerability

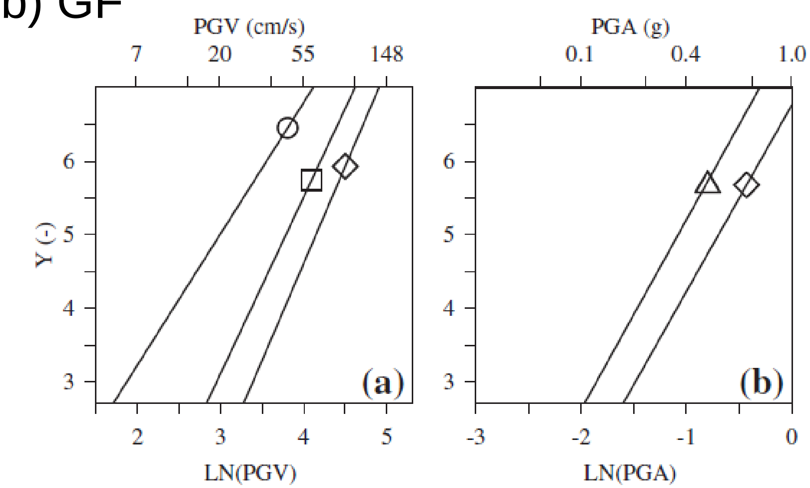
## *Literature empirical models*

2) The “industrial risk approach” – example of Lanzano et al. (2014)

| | |
|---|---|
| SGS (for CP and SP) | • IM = PGV<br>• RS≥RS1 and RS=RS2 |
| GF (for CP and SP) | • IM = PGA<br>• RS≥RS1 and RS=RS2 |

Lognormal and Probit models for a) SGS and b) GF



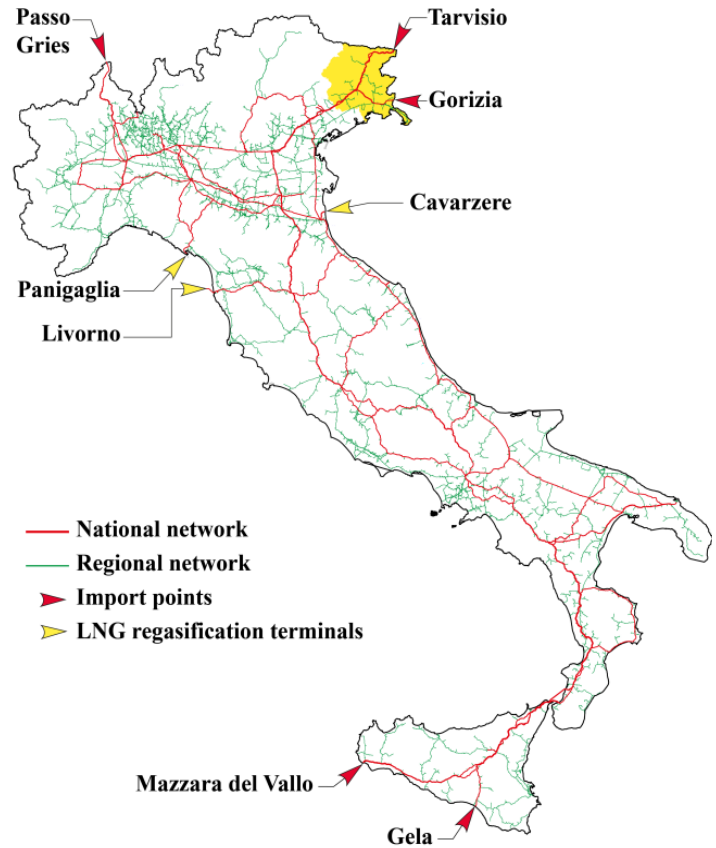

. □: CP RS ≥ RS1; ◇: CP RS = RS2; ○: SP RS ≥ RS1; △: SP RS = RS2.

# Case Study Network

## *Data collection*

The transport of natural gas in Italy is an integrated service which involves the transport of the gas delivered to **Snam Rete Gas S.p.A.** at the entry points of the National Network up to the redelivery points of the Regional Network (in Italy this classification was made by DL164 23/05/2000).

| Pipeline System | Pressure (bar) | | Diameter (cm) |
|---|---|---|---|
| | Nominal | Operating | |
| National Network | 70 | 50 | 90-140 |
| Regional Network | 25 | 20 | 25-50 |
| Local Distribution | 5 | 4 | 8-15 |



# Case Study Network

## *Data collection*

Open-source data on the Italian network were considered:

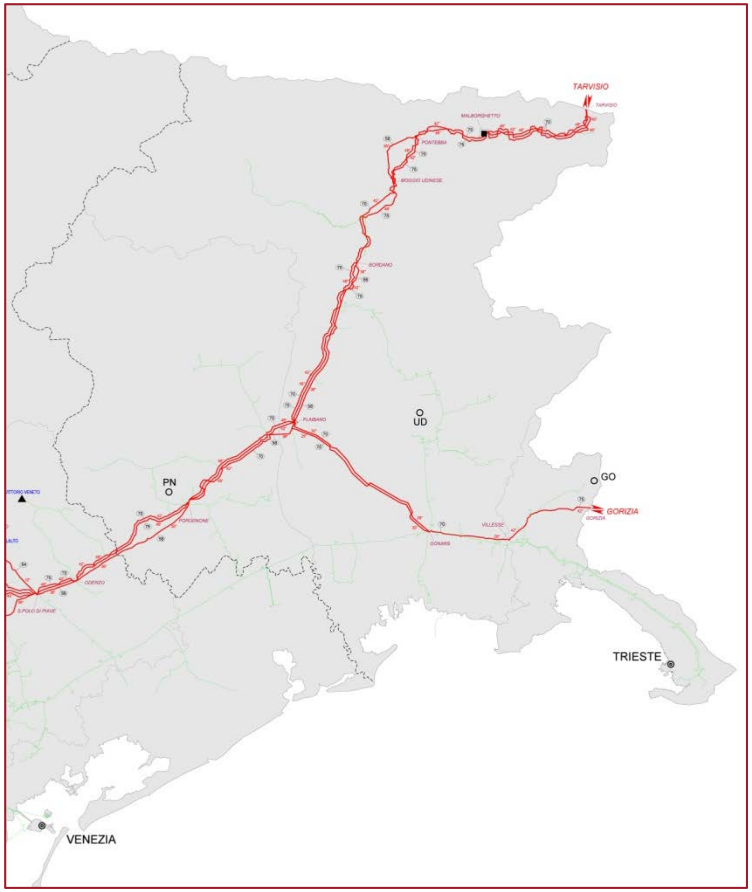
o Localization of the network (for geo-referencing)

o Diameter

o Max Operating Pressure [www.snamretegs

o Average Buried depth 1.5m, higher than 0.90m

[Vianello and Maschio, 2014; DM 17/04/2008]



# Case Study Network

*Data collection*

Why Friuli Region?

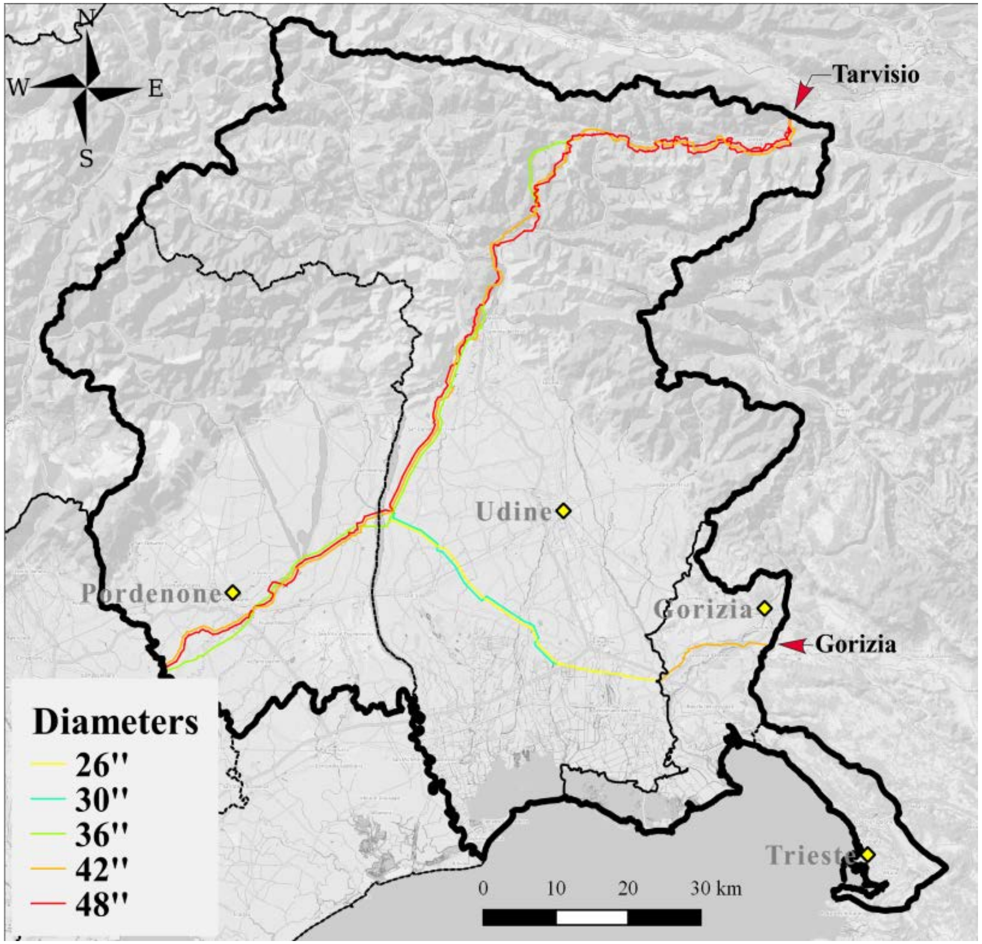
o Strategic (i.e., two entry points)

o High Seismicity area

o High Liquefaction Susceptibility

Total length of network considered is ~510km divided in 40m segments on average with maximum of 60m.

The scenario is purely for academic purposes since the network data are referred to 2013, and the event dates back to 1976.



# Vulnerability

## *Machine learning classification*

- The classical approach does not fit properly for potential applications in the industrial risk field.

- The industrial risk approach provides a damage from SGS and one form GF, the envelope of the two can be too conservative and not straightforward to implement.

- What about a model providing not only the damage but also its “cause”?

- What about a model that carries out one damage level?

# Vulnerability

## *Machine learning classification*

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- What about a model that carries out one damage level?

***Let’s approach vulnerability with a machine learning classification!***

## *Machine learning classification*

### *Parallel Coordinates Plot*

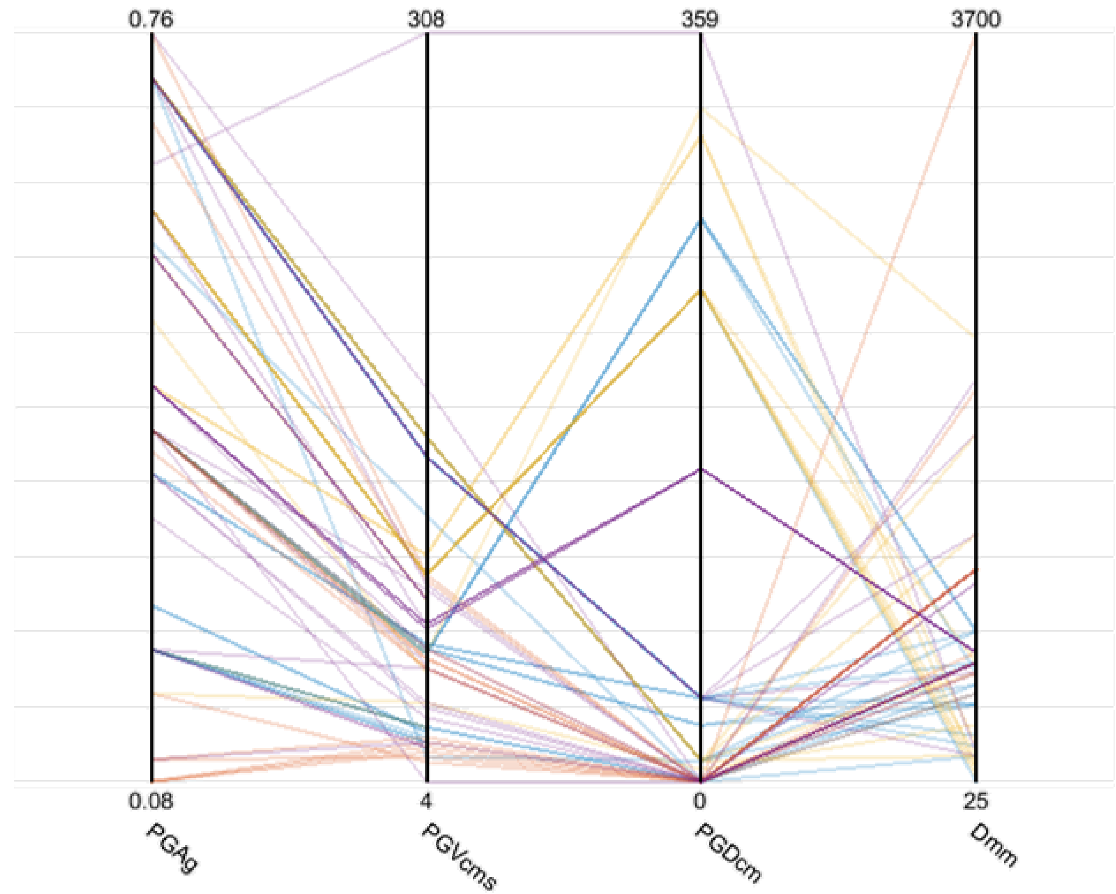
o 82 samples of continuous, welded joint, steel pipelines from the database by Lanzano et al. (2015)

o 4 predictors
(PGA, PGV, PGD, D)

o 3 predictors
(PGA, PGV, D)

o 4 responses classes

**DS0** **DS1-SGS** **DS1-GF** **DS2**



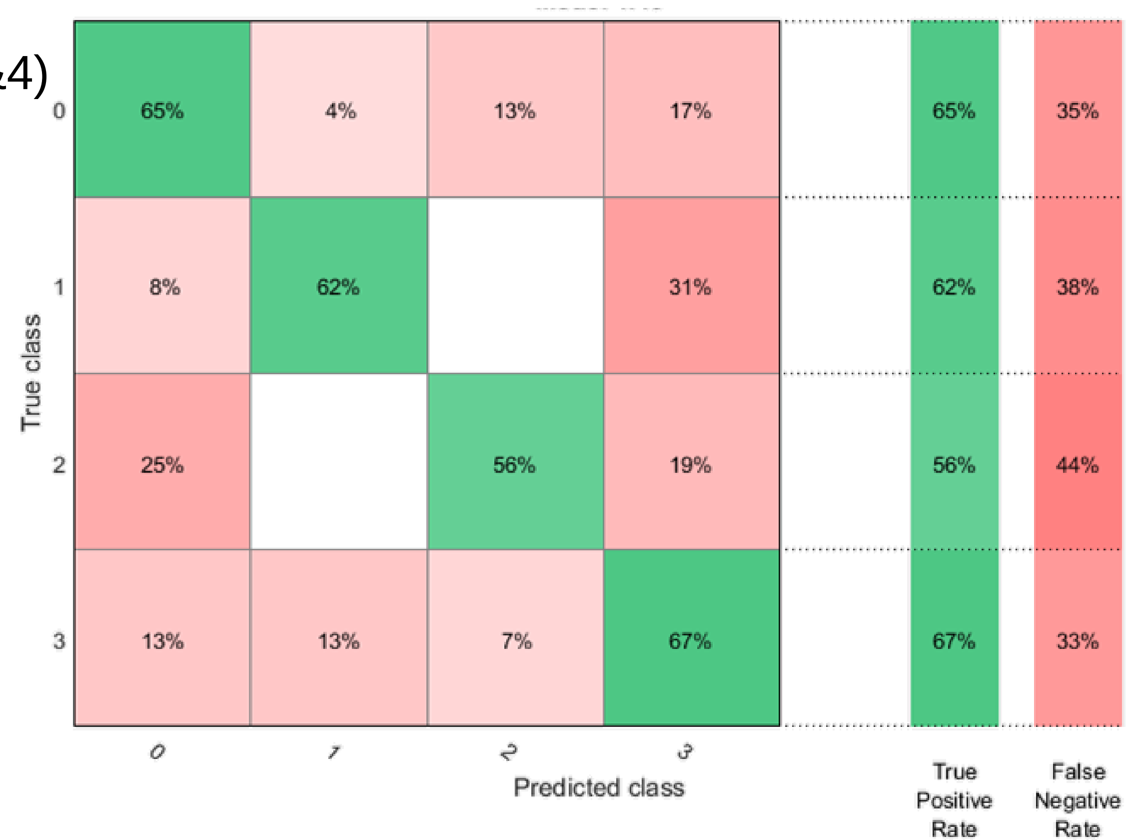
# Vulnerability

## *Machine learning classification*

### *Confusion Matrix*

- o accuracy 63.4%  and 62.2% (3&4) (ensemble bagged/boosted tree, 10-fold cross validation)
- o 3 or 4 predictors (PGA, PGV, ~~PGD~~, D)
- o 4 responses

DS0    DS1-SGS    DS1-GF    DS2



# Vulnerability

## Machine learning classification

### Confusion Matrix

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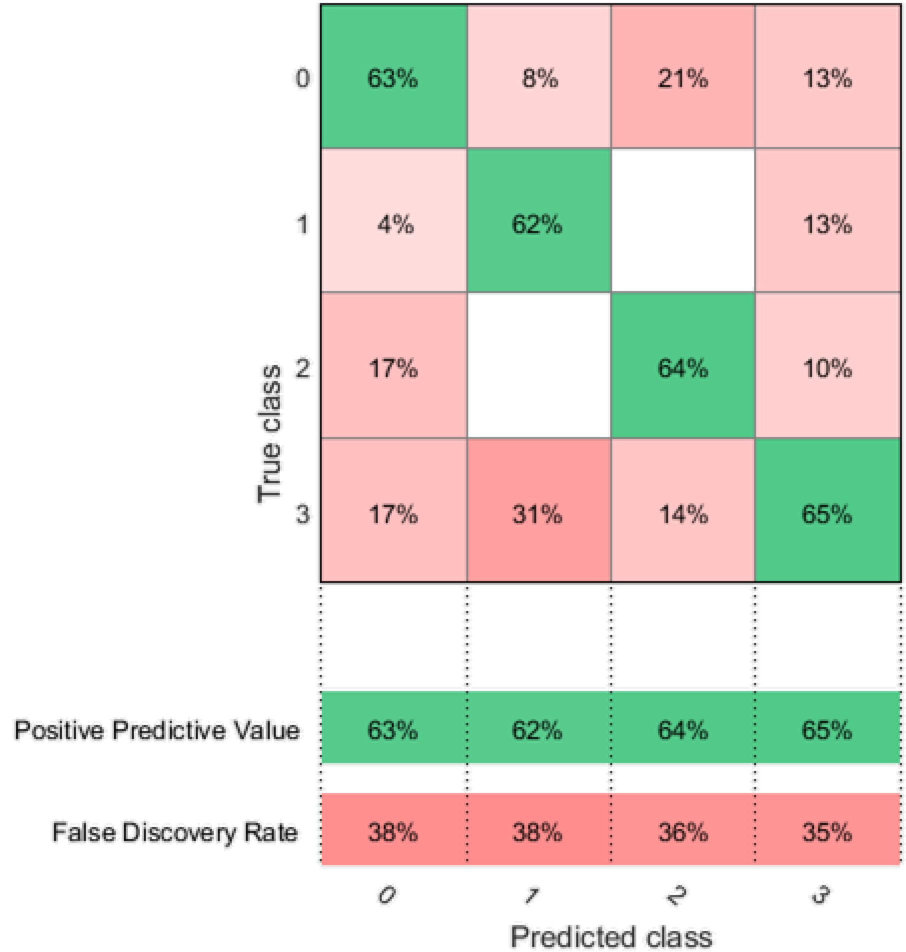
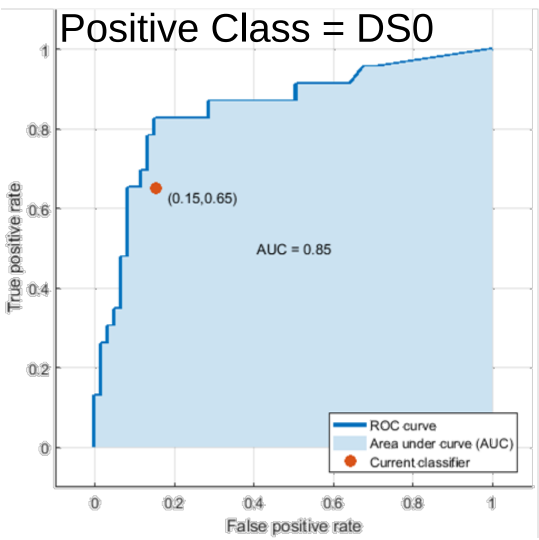
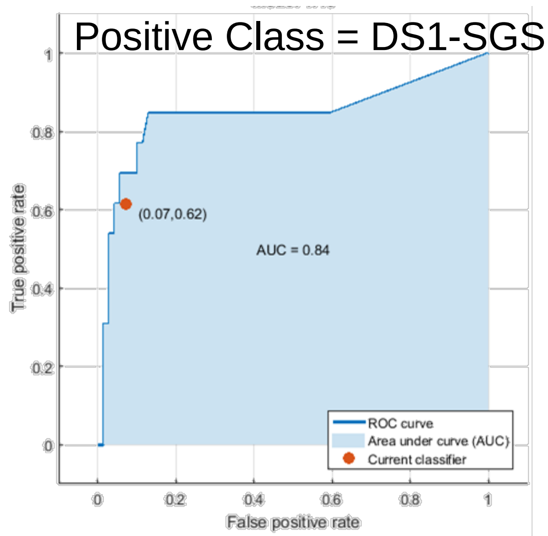


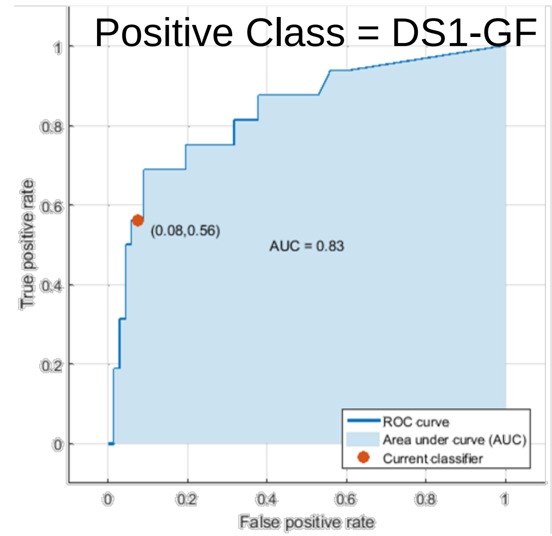
# Vulnerability

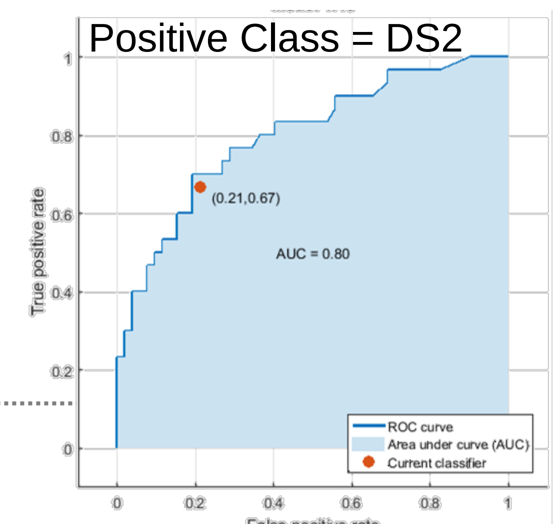
## *Machine learning classification*

### *ROC Curves 3-predictors case (63.4%)*




The Receiver Operating Characteristic (ROC) curve shows true positive rate versus false positive rate for the currently selected trained classifier. The marker shows the values of the false positive rate (FPR) and the true positive rate (TPR) for the currently selected classifier. AUC is a measure of the overall quality of the classifier.

# Vulnerability

## *Machine learning classification*

o accuracy 63.4% (ensemble bagged tree, 10-fold cross validation)
4 predictors (PGA, PGV, D)

o accuracy 62.2% (ensemble boosted trees, 10-fold cross validation)
3 predictors (PGA, PGV, PGD, D)

o accuracy 61.0% (ensemble boosted trees, 10-fold cross validation)
3 predictors (PGA, PGV, $D_{HAZUS}$)

o accuracy 59.8% (ensemble bagged tree, 10-fold cross validation)
4 predictors (PGA, PGV, PGD, $D_{HAZUS}$)

RESPONSE:

**DS0 DS1-SGS DS1-GF DS2**

# Vulnerability

## Machine learning classification

### *Results for SGS only*

o 26 samples of continuous, welded joint, steel pipelines from the database by Lanzano et al. (2015) for SGS

o 3 predictors
(PGA, PGV, D)

o 3 responses classes
**DS0 DS1-SGS DS2-SGS**

o accuracy 69.2%
(Support Vector Machine Fine Gaussian, 10-fold cross validation)

## Machine learning classification

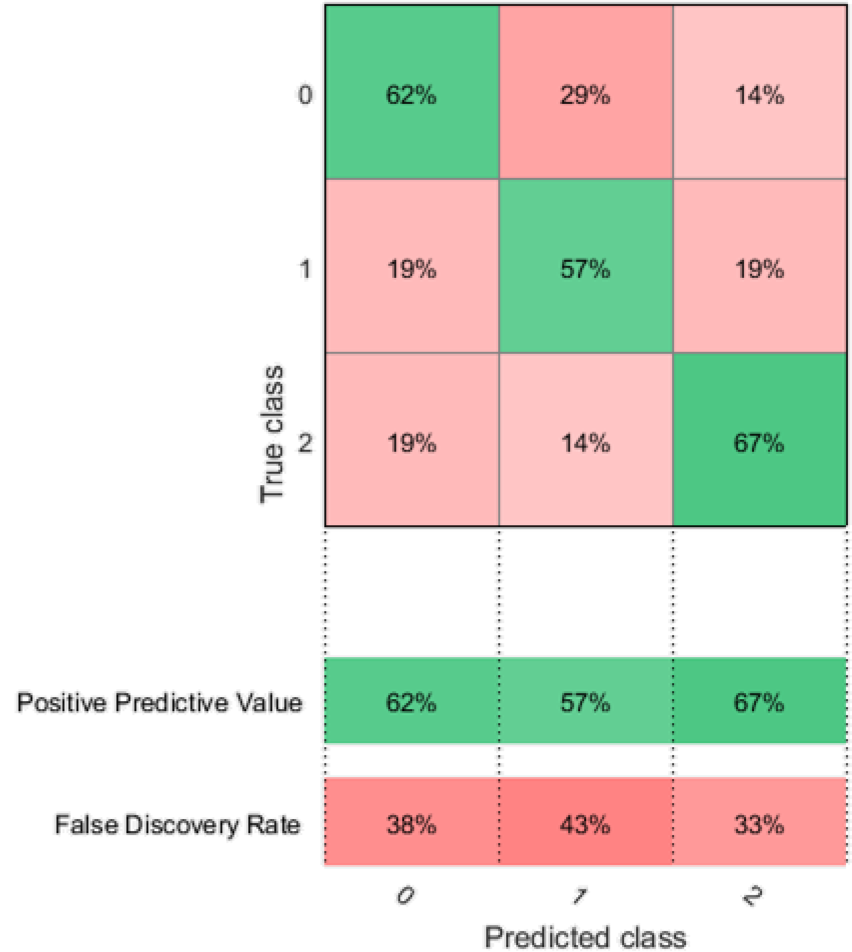
### *Results for GF only*

o 56 samples of continuous, welded joint, steel pipelines from the database by Lanzano et al. (2015) for GF

o 4 predictors
(PGA, PGV, PGD, D)

o 3 responses classes
**DS0 DS1-GF DS2-GF**

o accuracy 64.3%
(Ensemble bagged Tree, 10-fold cross validation)



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# Final Remarks

- The classification identifies the cause of a leak differentiating between DS1-SGS and DS1-GF in a single vulnerability model.
- PGD does not add much information and accuracy to the model for data considered.
- Diameter if considered as continuous variable is a better predictor

## *Potential Developments*

- Accuracy can be improved with a different/improved data selection
- Comparison/Validation with analytical and experimental data
- Cascading risk application for fire risk

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# Thanks for your attention

*Flavia De Luca*

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# Thanks for your attention

# *Questions?*

*Flavia De Luca*