Progetto DPC-ReLUIS 2022-2024 WP3 T3

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Seismic Reliability of Existing Bridges

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DPC-ReLUIS 2022-24 WP3 Task 3: PROJECT OBJECTIVES

Collaborative research aimed at investigating the **seismic reliability of structures**, with specific focus on **existing bridges** considering selected structural typologies from the Italian design practice that are representative of the built environment in the **second half of the XX century**. The goal is to provide insights into the **actual seismic reliability levels** of existing bridges compared with the requirements of current seismic design codes and the **seismic reliability of code-conforming viaducts** investigated in a past DPC-ReLUIS research project.

1. BRIDGE TYPOLOGIES AND CASE STUDIES

Twelve case studies have been selected, including **eleven concrete bridges** (RC/PC) and **one masonry bridge** (Figure 1). Two of the case studies have been inspired to bridge structures included in the inventory of the **Seismic Observatory of Structures** (Osservatorio Sismico delle Strutture, **OSS**) of the Italian Department of Civil Protection.

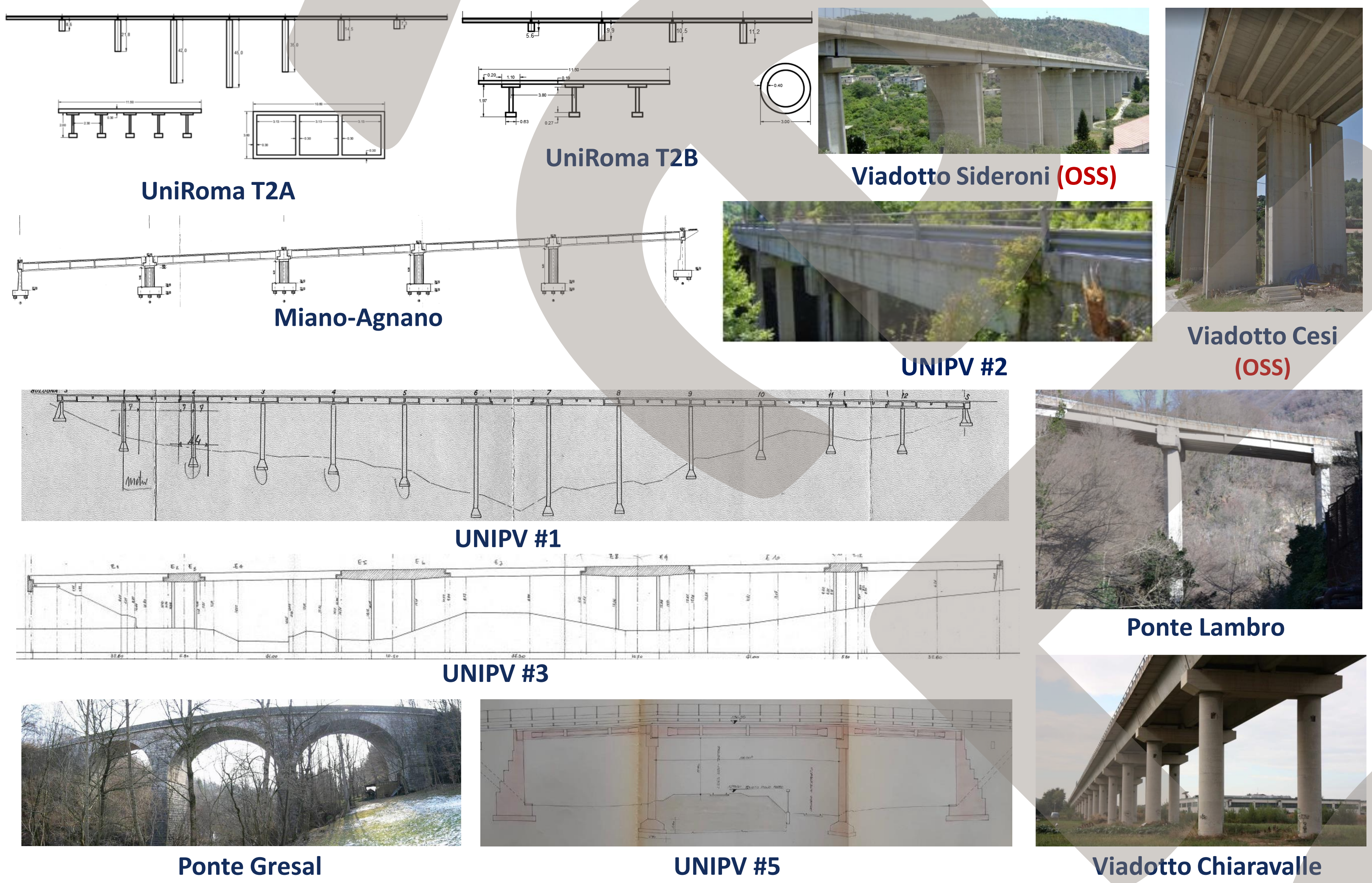

Figure 1. Case studies of existing bridges: pictures and technical drawings from archival information.

After the selection of the case studies, a re-design has been carried out. For this phase, the regulations relating to the time of construction of each work have been used. In cases where the regulations provided for this, the design choices were **differentiated according to the Italian locations selected for seismic risk characterization**. Three sites of increasing seismicity, **Milan, Naples, and L'Aquila**, have been selected.

2. STRUCTURAL MODELLING

A **structural model** for non-linear seismic analysis has been developed for each case study. The **piers** of concrete viaducts have been modelled using force-based beam finite elements with **fiber sections** (Figure 2). The modelling of the **supporting devices** takes into account the mechanical behavior of the elements in accordance with the technical characteristics adopted during the design phase. The **masonry** bridge has been modelled using to the **Distinct Element Method** (Figure 3). For concrete bridges, two cases with **(a) fixed base** and **(b) soil-structure-interaction based on macro-models** (Figure 4) compliant with the investigated sites of Milan, Naples and L'Aquila, have been considered.

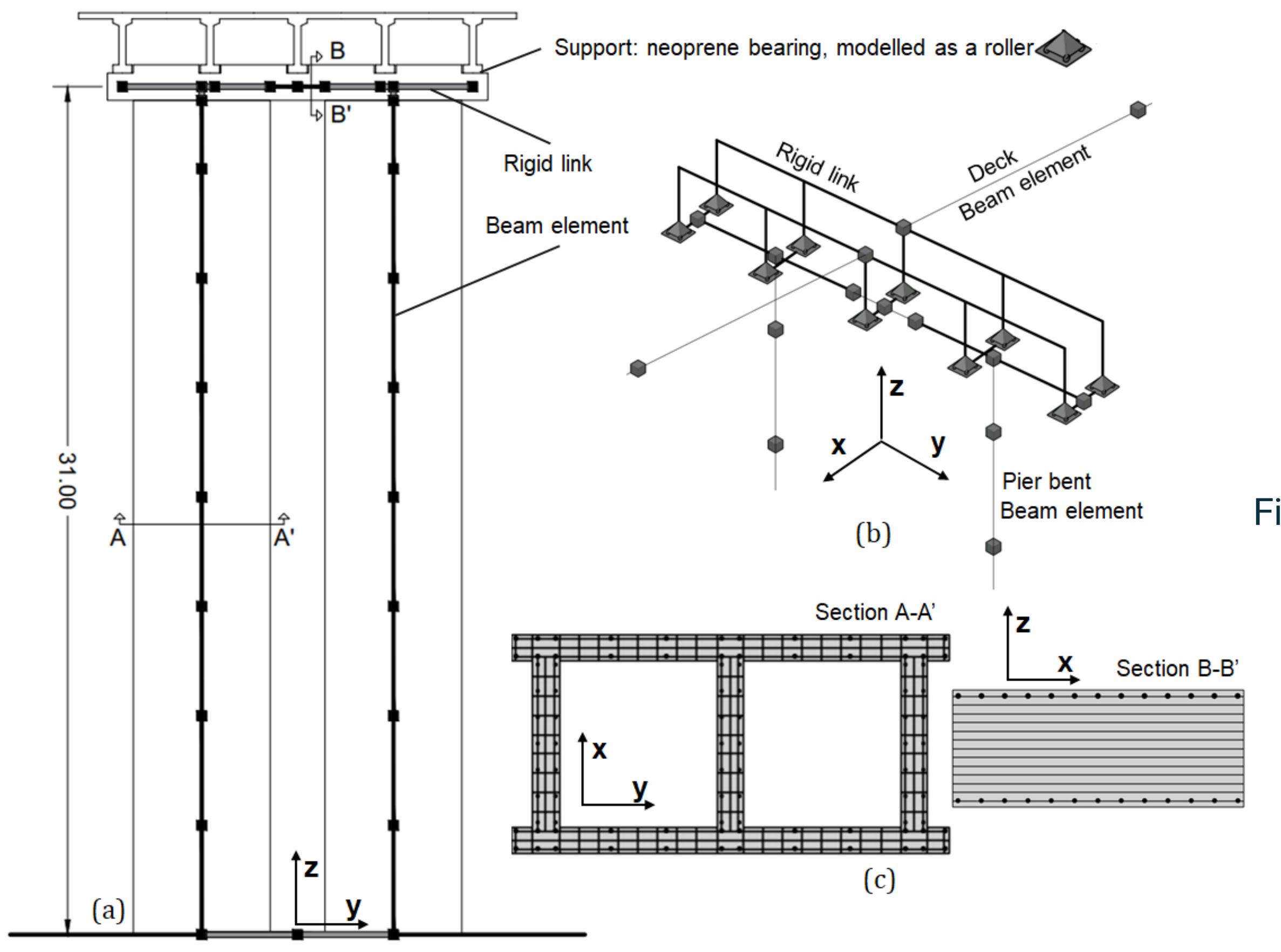

Figure 2. Structural modeling of the Cesi viaduct: (a) Bridge pier discretization [m]. (b) Pier cap modelling. (c) Fiber cross-sections.

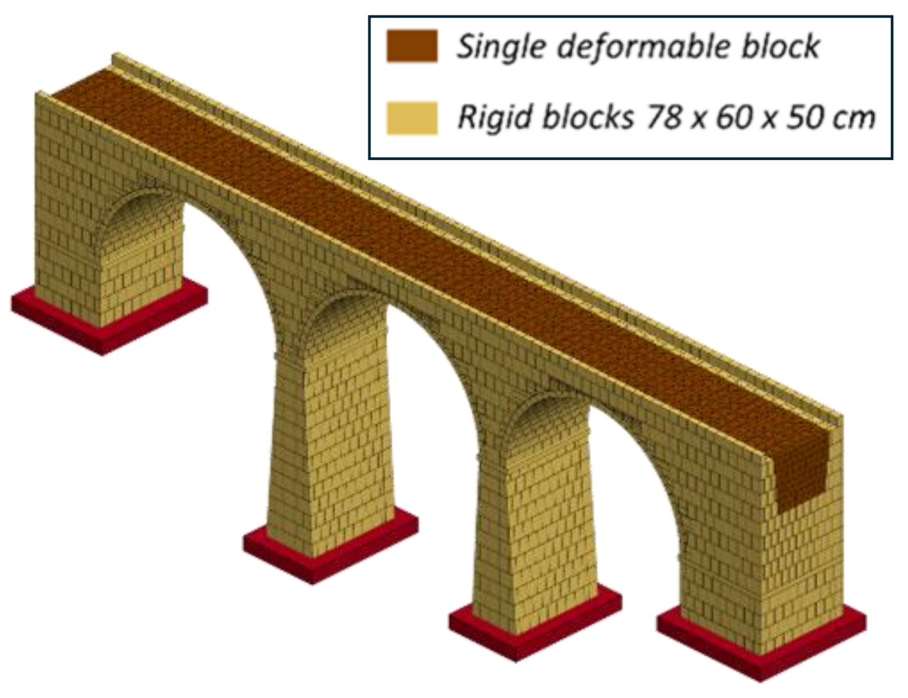

Figure 3. Structural model of Gresal bridge.

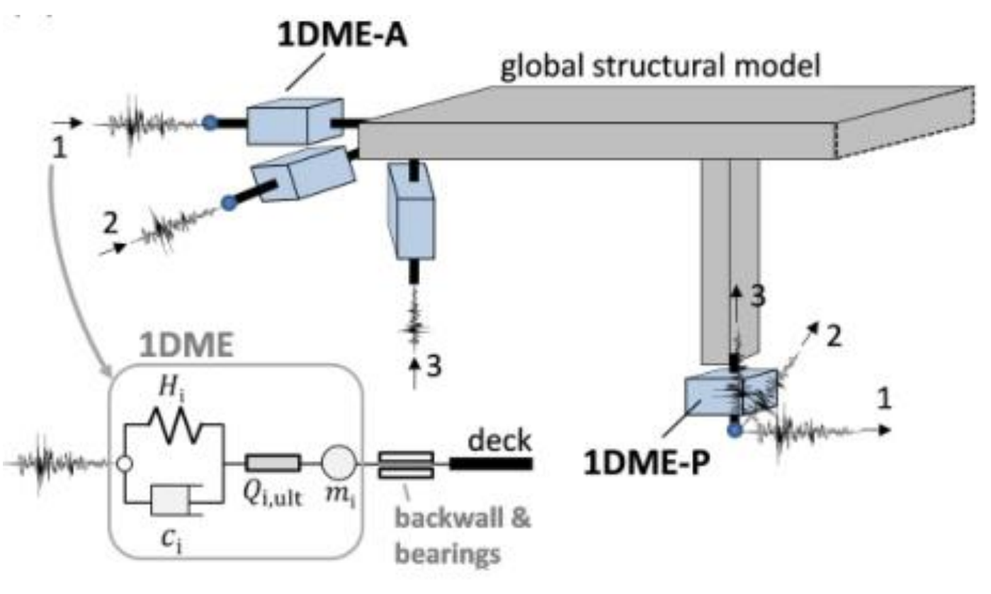

Figure 4. Macro-models.

3. ENGINEERING DEMAND PARAMETERS

Three limit states have been identified, which exceedance is related to increasing damage severity. Table 1 shows the **Engineering Demand Parameters (EDPs)** and **limit state thresholds** selected to characterize the seismic response of the bridges.

Table 1. Engineering demand parameters and associated thresholds for the three performance levels.

Component	Usability-Preventing Damage (UPD)			Severe Damage (SD)			Structural Failure (SF)		
	Description	EDP	Limit	Description	EDP	Limit	Description	EDP	Limit
Neoprene Pads	Friction/ Slipping	Relative horizontal displacement	d_{fr}	Exceedance of compression limit	Relative horizontal displacement	d_{60}=(d | N/A=60MPa)	Incipient unseating of beam from supporting device	Relative horizontal displacement	d_{uns}
Piers (Ductile mode)	Yielding	Chord rotation	θ_y	Significant residual displacements	Plastic hinge rotation	$\theta_y + 0.5(\theta_u - \theta_y)$	Very large residual displacements	Plastic hinge rotation	θ_u
Piers (Brittle mode)	Attainment of maximum strength	Shear force	V_u	Crack opening and significant residual displacements	Shear force	$-0.2Vu$	Loss of gravity load capacity	Shear force	$-0.5Vu$
Abutment backwall	Abutment-deck joint closure	Relative deck-backwall displacement	Gap	Attainment of lateral strength of abutment backwall-backfill system	Relative deck-backwall displacement	$Gap + F_{bw}/k_{bw}$	Extensive soil uplift	Relative deck-backwall displacement	$0.1h_{bw}$
Foundations	Piles' yielding	Top piles displacement	δ_y	Significant piles' residual displacements	Top piles displacement	δ_d	Attainment of piles' ultimate rotation	Top piles displacement	δ_u

4. SEISMIC RELIABILITY

The bridges are subjected to ten suites of ground acceleration of increasing intensity for each site. Each suite contains twenty ground motion time-histories. By combining the fragility curves, obtained from the multi-stripe analyses, and the hazard curves, the annual failure rates have been computed (Figure 5).

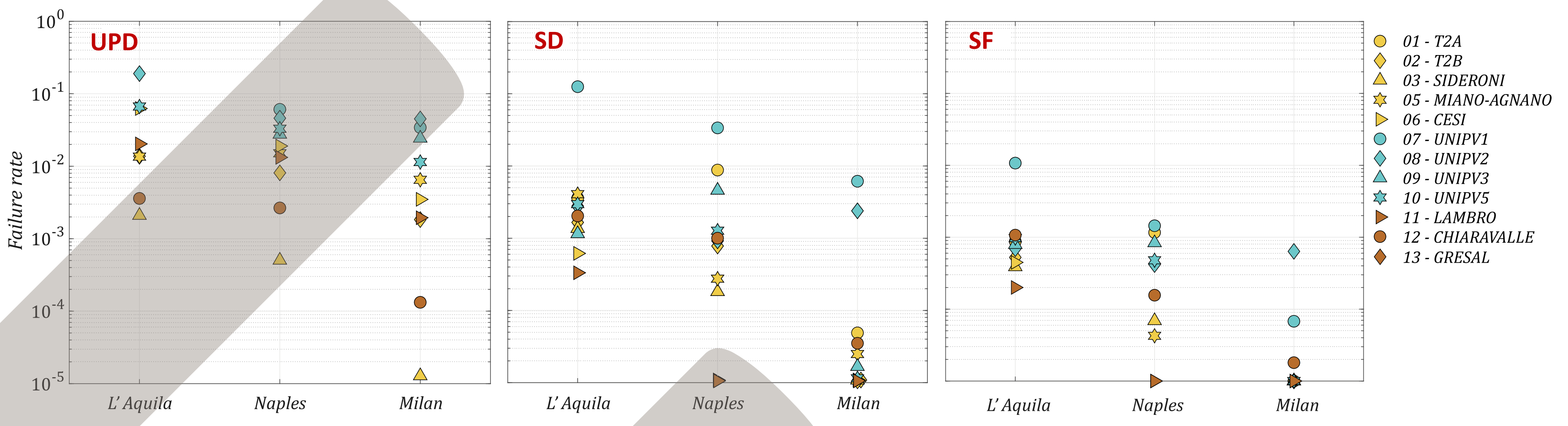

Figure 5. Annual failure rates of the bridges at different sites for the three investigated limit states.

5. EFFECT OF STRUCTURAL DETERIORATION

The effects of corrosion damage, due to concrete carbonation or chloride ingress, have been also investigated for two case studies over a 80-year lifetime (Figures 6, 7).

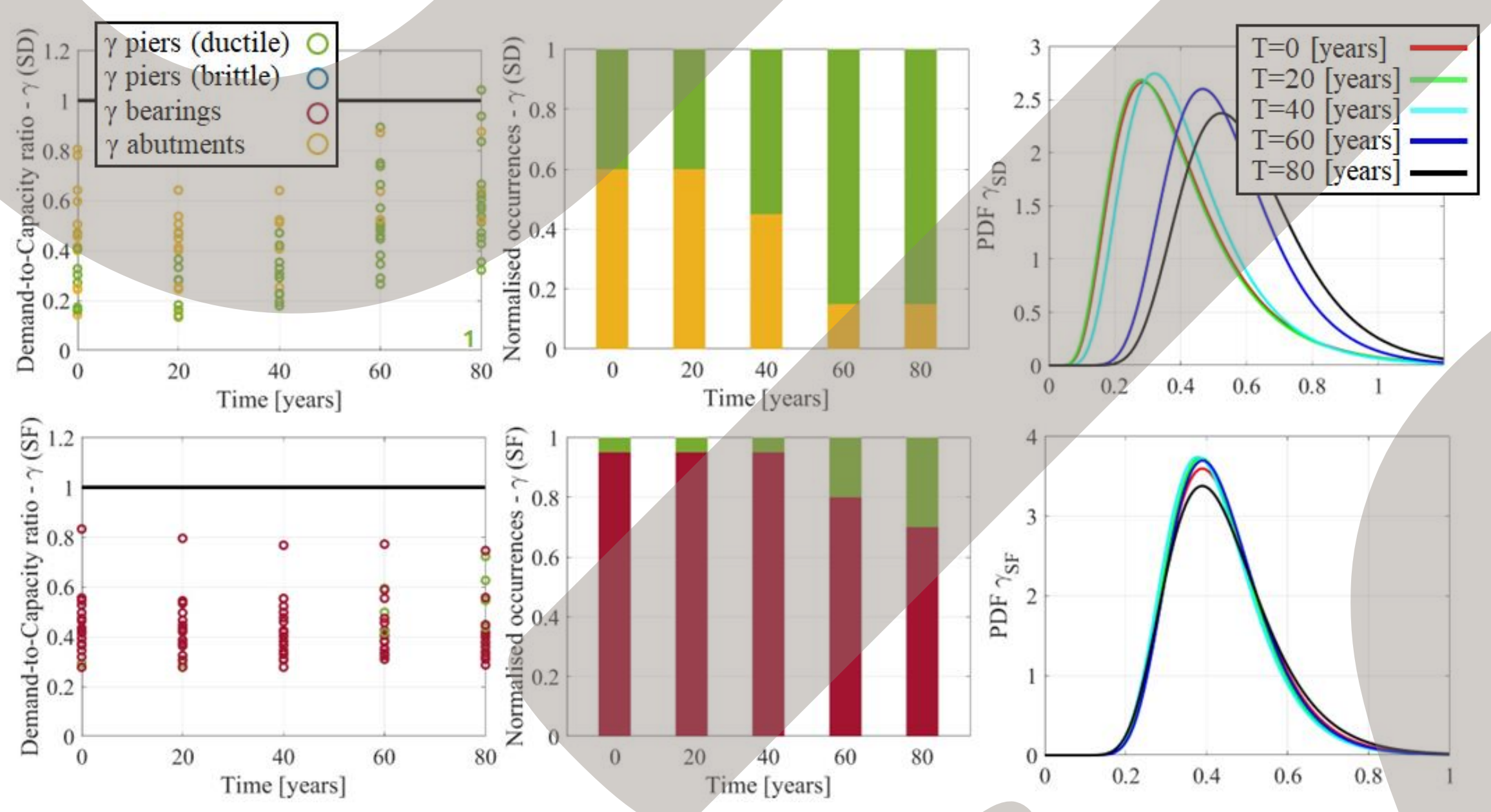

Figure 6. Cesi viaduct – **AQ** Site – Stripe **7**. Lifetime evolution of the Demand-to-Capacity ratio (γ) and probabilistic distributions.

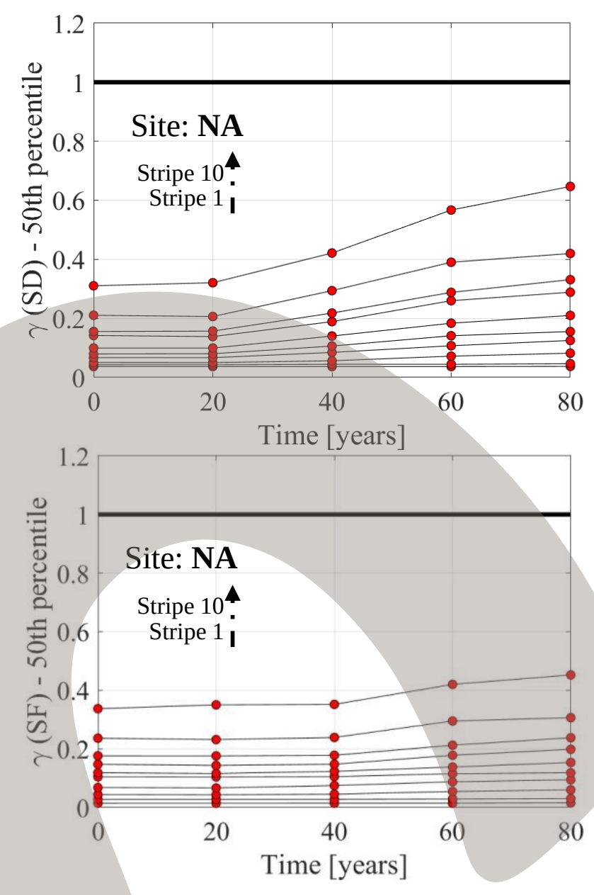

Figure 7. Cesi viaduct – **NA** Site. Mean γ-values over time.

6. CONCLUSIONS

- ☐ The vulnerability of bridges designed during the last century is significantly higher than those compliant with the current design codes.
- ☐ The prevalent failure mechanisms at UPD and SD states in the lower-hazard sites are closure of the expansion joints and impact against the abutment walls.
- ☐ At the higher-hazard site of L'Aquila, UPD and SD were also reached due to ductility demands at the piers. In all cases, the SF damage state was predominantly reached due to flexural pier failure and transverse deck unseating due to failure of the buffers upon impact.
- ☐ The effects of corrosion on the seismic behavior of the investigated bridges influence the distribution of the demand-to-capacity ratio, the failure rates, and the failure mechanisms.
- ☐ Regarding the failure mechanisms, the number of cases in which the piers are the most vulnerable elements of the structure increase with the increasing of the severity of corrosion.

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