**Assessment of Failure Frequencies of Pipelines caused by Earthquakes in the Natech Risk Assessment Framework**

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**1.Introduction**

During a seismic event, underground pipelines can undergo significant damages releasing relevant quantities of hazardous substances with severe implications in terms of life safety and economic impact. This type of scenarios falls under the definition of Natech [1]. In recent years, quantitative risk analysis became a pivotal tool to assess and manage Natech risk. Among the tools required to perform the quantitative assessment of Natech risk, vulnerability models are aimed to characterize equipment damages from natural events. This contribution is focused on the review of the pipeline vulnerability models available for the case of earthquakes. Furthermore, a comparison of the features of the models deemed more suitable for the application to a QRA framework for Natech events is proposed.

**2. Methods**

A review of the academic literature was carried out in order to find empirical vulnerability models for pipelines. The search focused on the Natech area using keywords such as “pipeline”, “earthquake”, “fragility curves”, “vulnerability model” and “Probit” and their combination. In addition, more references were found looking at each reference cited by the retrieved contributions [2]. For each model, information was collected on the number of earthquakes considered for its development, the type of model proposed, the inputs required and the damage states. Finally, the most suitable models for QRA analysis are implemented for a comparison.

**3. Results and discussion**

The overview of the complete models found in the literature is shown in Table 1 and Table 2, where the input parameters and the number of earthquakes considered in the development are also reported. Two main categories of models have been identified in the literature. A first category proposes the repair rate as a performance indicator for the damage of pipeline due to seismic load, and provides as output the number of required repairs per unit length. A second category proposes fragility curves associated with risk states depending on the mechanism of ground failure.

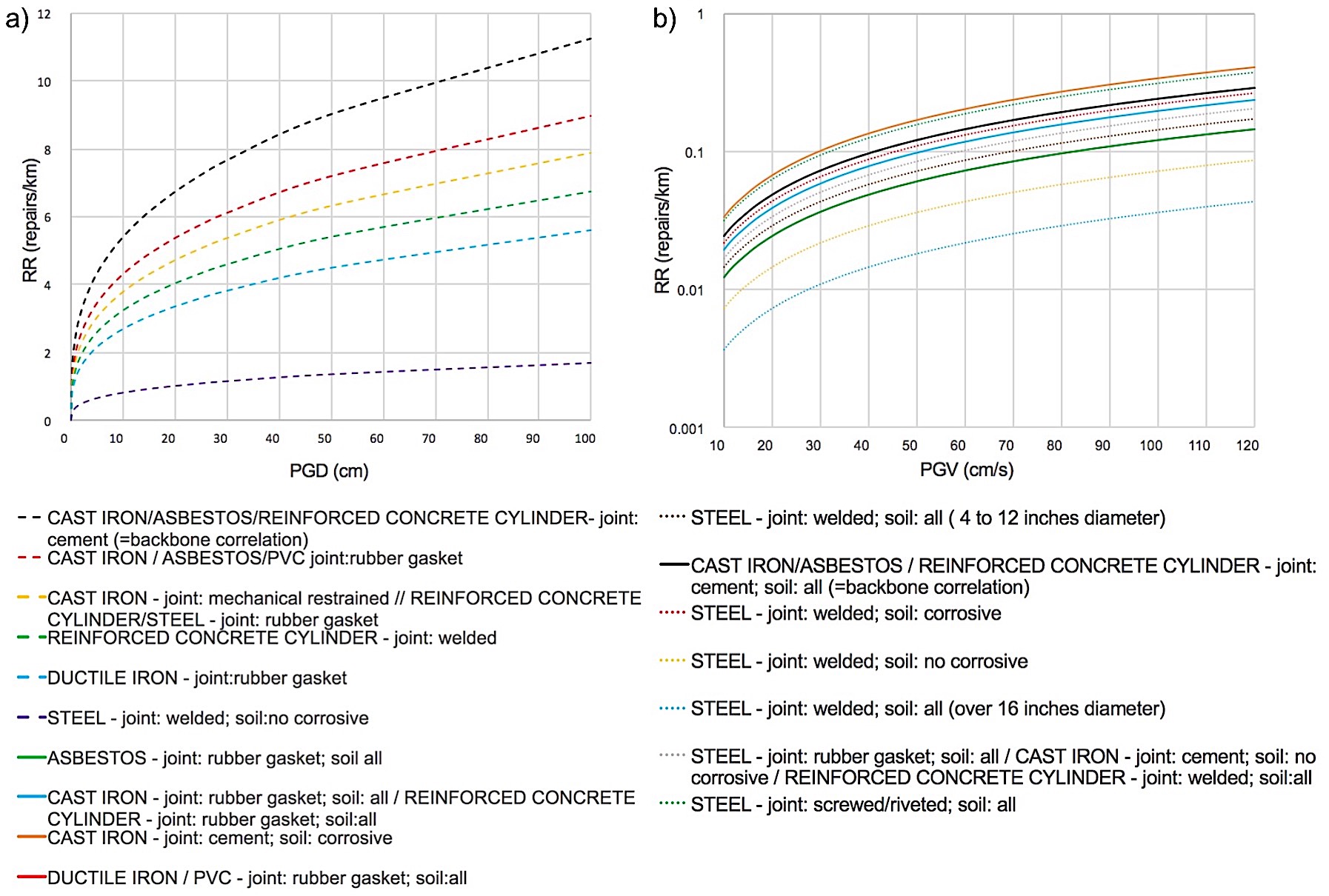
**Table 1** Summary of models expressing the result in terms of repair rate. N = Number of past earthquakes used to develop the models.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Reference | Seismic intensity parameter | N |  | Reference | Seismic intensity parameter | N |
| [3] | PGA | 6 |  | [4] | PGV, PGD | 3 |
| [5] | PGA | 6 |  | [6] | PGV | 1 |
| [7] | PGA | 1 |  | [8] | PGA | 1 |
| [9] | PGV | 3 |  | [10] | PGV, PGD | 12 |
| [11] | MMI | 4 |  | [12] | PGA | 1 |
| [13] | PGA | 2 |  | [14] | PGA, PGV | 1 |
| [15] | MMI, PGD | 7 |  | [16] | PGV | 1 |
| [17] | PGD | 2 |  | [18] | PGA, PGV | 1 |
| [19] | PGV | 6 |  | [20] | PGV | 5 |
| [21] | PGV | 7 |  | [22] | PGV | 1 |
| [23] | PGD | 5 |  | [24] | PGA | 1 |
| [25] | PGV | 7 |  | [26] | PGV2/PGA | 1 |
| [27] | PGA, PGV, PGD, MMI | 4 |  | [28] | PGV | 4 |
| [29] | PGA, PGV | 1 |  | [30] | PGV | 2 |

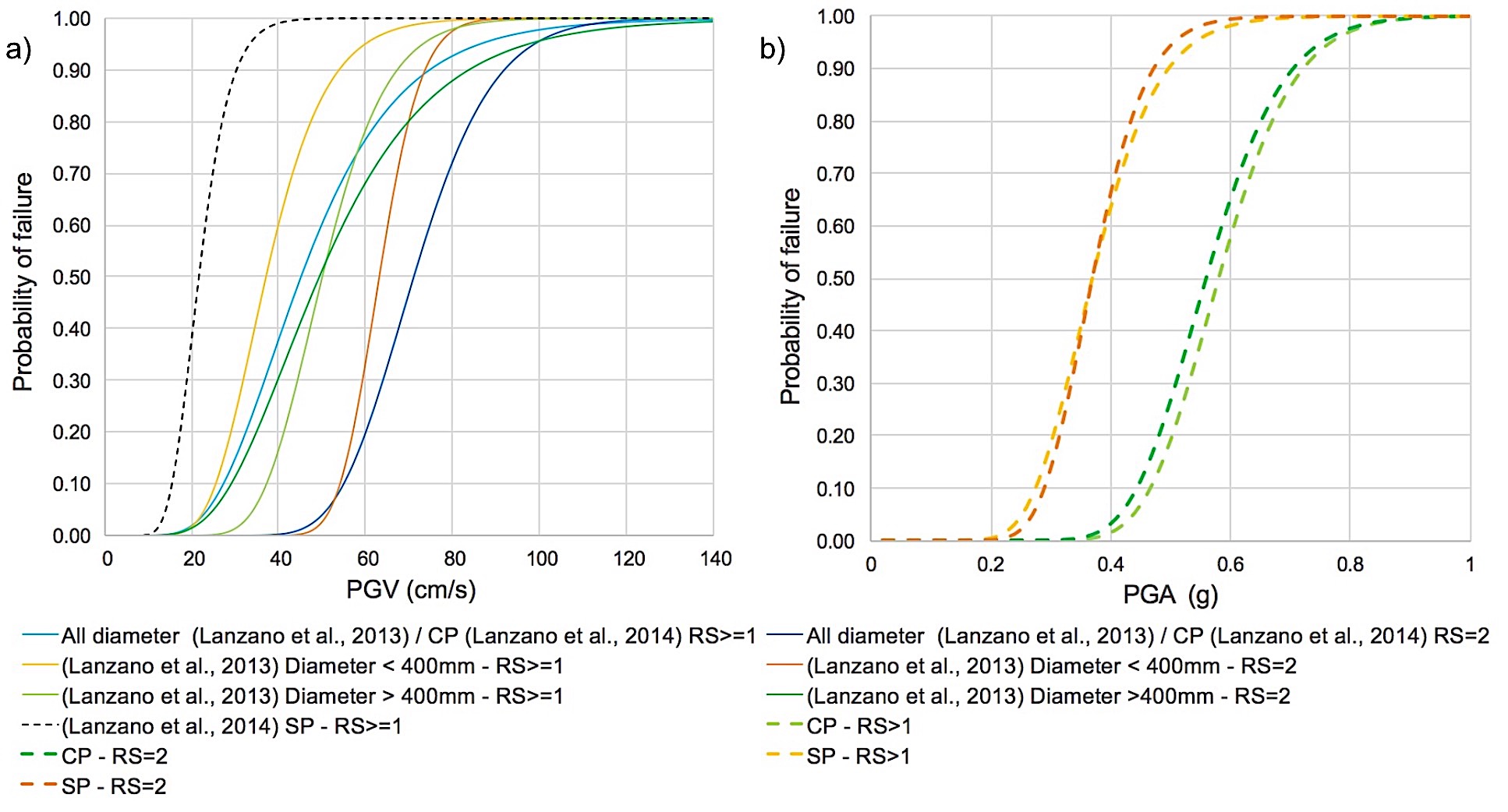
**Table 2** Summary of models expressing the result in terms of fragility curves. N = Number of past earthquakes used to develop the models.

|  |  |  |  |
| --- | --- | --- | --- |
| Reference | Seismic intensity parameter | N |  |
| [31] | PGV | 40 |  |
| [32] | PGA, PGV | 20 |  |

Only the models proposed by ALA [10] (12 earthquakes), by Lanzano [32] (20 earthquakes) and by Lanzano [31] (40 earthquakes) are suggested because they are developed on a consistent number of empirical data. Following, this subset is implemented to compare their relative merits and shortcomings. The curves for SGS (strong ground shaking) and GF (ground failure) are shown in **Figure 1** and **Figure 2**, specifying the material and (where present) also the types of joints and the damage state.



**Figure 1** Vulnerability model for buried pipes developed in [10] for a) GF and b) SGS



**Figure 2** Vulnerability model for buried pipes developed in a) [31,32] for SGS and in b) [32] for GF

The models proposed by ALA [10] have been conceived for water-carrying pipelines, whereas the curves developed in the works of Lanzano [31,32] are possibly more generalizable. In addition, the former is more detailed in the type of soil and joint material. For what concerns the definition of risk states, the works of Lanzano [31,32] are more rigorous, while the models by ALA [10] give only thumb rules on the typology of expected failures. But in spite of this, the models by ALA [10] are suggested because to use the models of Lanzano [31,32] it is necessary to make strong assumptions about the unit length for which the failure probability is calculated, unlike the ALA [10] model.

**4. Conclusions**

A review of vulnerability models for pipelines subjected to seismic events is presented. Furthermore, the models deemed most suitable for a Natech QRA are implemented and discussed.

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