

TOWARD A SIMPLIFIED SEISMIC RISK ASSESSMENT FOR PRECAST INDUSTRIAL BUILDINGS

Marius Eteme Minkada¹, Andrea Belleri¹, Paolo Riva¹, and Luca Danesi¹

¹ University of Bergamo
Via Marconi 5, 24044, Dalmine, Bergamo, Italy

{marius.etememinkada, andrea.belleri, paolo.riva, luca.danesi}@unibg.it

Abstract

Precast industrial buildings built in Italy until 2003 have a high potential for economic loss due to various risks, including seismic risk. Researchers have made considerable efforts to develop models to assess the seismic risk of existing and newly constructed prefabricated industrial buildings. However, many published and ongoing studies focus on the structural elements without considering the contents and equipment within the building, which are critical to an accurate assessment of the potential economic losses associated with a seismic event.

This study considers an existing precast industrial building built in the 1980s in L'Aquila (Italy) and compares its performance with that of an equivalent retrofitted structure. A simplified modelling approach and non-linear multi-stripe analyses are applied to derive demand curves for different structural and non-structural components. A damage assessment of these elements, as well as of some components commonly found in the industry, was carried out. Seismic demand curves are combined with specific fragility curves, which for the contained components were obtained from FEMA-P-58.

Keywords: Precast industrial buildings, seismic risk assessment, non-structural components, building content.

1 INTRODUCTION

Precast industrial buildings have been widely used in Italy since the mid-20th century and continue to be a common construction choice today. However, these structures have demonstrated significant vulnerability during recent earthquakes, including those in L'Aquila (2009) and Emilia (2012) [1], [2], [3], [4], [5]. The seismic vulnerability of precast structures has, therefore, been partly attributed to the late classification of the seismic hazard across the Italian territory.

Despite the apparent simplicity of precast structures, several studies have demonstrated that their seismic modelling is complex. Extensive research has focused on evaluating the seismic performance of these structures. This research has led to the development of advanced models to accurately capture their response [6], [7], [8]. However, such models are generally characterized by high computational costs, limiting their application outside the research community. To facilitate effective seismic risk assessment by professionals, such as engineers involved in retrofit design or insurance agents, the availability of simplified modelling techniques would be highly beneficial.

This study aims to address this gap by proposing a simplified methodology for evaluating the seismic risk of single-story precast industrial buildings, incorporating structural, non-structural and content elements.

2 REFERENCE BUILDING AND MODELLING APPROACH

The reference building (Figure 1) is a single-story industrial structure with a rectangular plan (42mx20m), located in L'Aquila. Its structural details reflect the design criteria established for earthquake-prone areas in the second half of the 1980s. This building was derived from a previous study [8], [9], which provides detailed information on the geometric and material properties of the structural elements and connections.

Two conditions of the building are considered: the as-is state and the retrofitted one. The latter was analysed in a previous study by Eteme et al. [9], where detailed information on the retrofit measures can be found. These measures primarily consisted of adding connection elements between different structural components and jacketing the columns.

Additionally, to extend the risk assessment to the equipment and building contents, it is assumed that the building includes drywall partitions, internal doors for office spaces, storage racks, an electrical elevator, distribution panels, and an air handling unit.

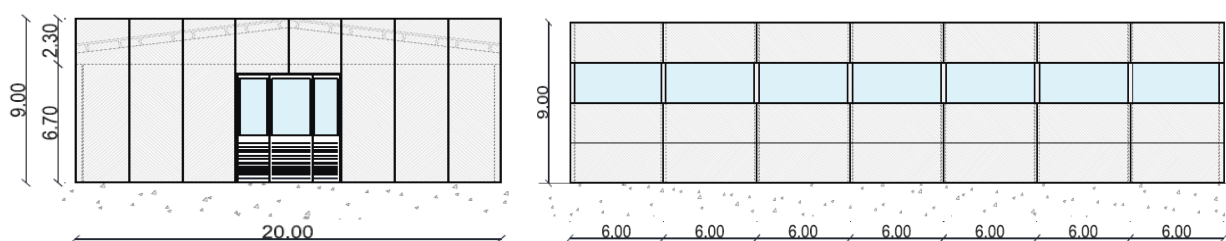


Figure 1: Reference building: transverse view (left) and longitudinal view (right)

2.1 Simplified modelling approach

The main concept of the proposed approach is to simulate the seismic response of the precast single-story building using two independent models. These models are equivalent representations of the structural system along the building's two principal directions. This approach is considered simplified, as it does not account for potential three-dimensional effects of the

structure. Instead, in the post-processing phase, an envelope of the response extracted from both models is considered.

In this study, these 2D models were developed using the OpenSees software [10]. Referring to the reference building shown in Figure 1, “Model 1” and “Model 2”, illustrated in Figure 2, correspond to the transverse and longitudinal directions, respectively.

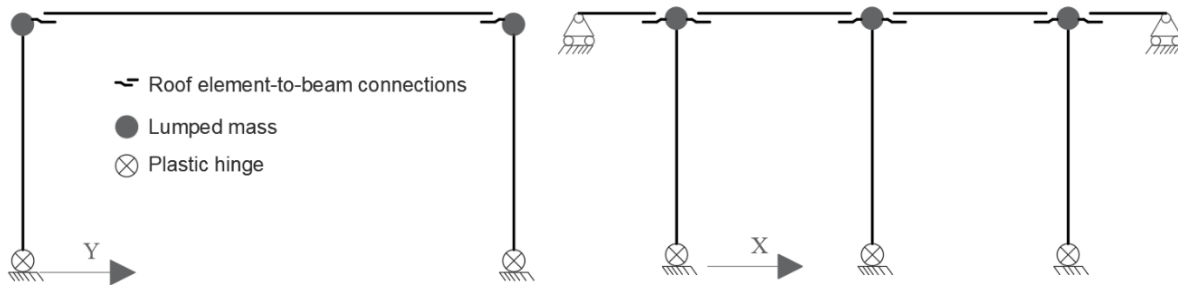


Figure 2: Modelling schemes: Model 1 (on the left), Model 2 (on the right)

Beams and roof elements are modelled as elastic components, assuming that they are not directly affected by seismic damage [8], [11]. Nonlinear behaviour is considered through lumped plastic hinges at the column bases and the hysteretic response of the beam-to-column and roof-to-beam connections.

2.2 Model validation

To validate the accuracy of the 2D models, the global seismic response of the reference building (Figure 1) was evaluated through non-linear time-history analyses in OpenSees [10]. As seismic input, an artificial accelerogram compatible with the response spectrum at the Life Safety Limit State for the L’Aquila site was used. This accelerogram was generated using the SIMQKE software [12]. Similar analyses were performed using a 3D model of the structure, developed in accordance with Bosio et al. [8].

Figures 3 and Figure 4 show the comparison between the 3D model and the simplified 2D modelling approach in terms of roof displacement and roof acceleration, respectively.

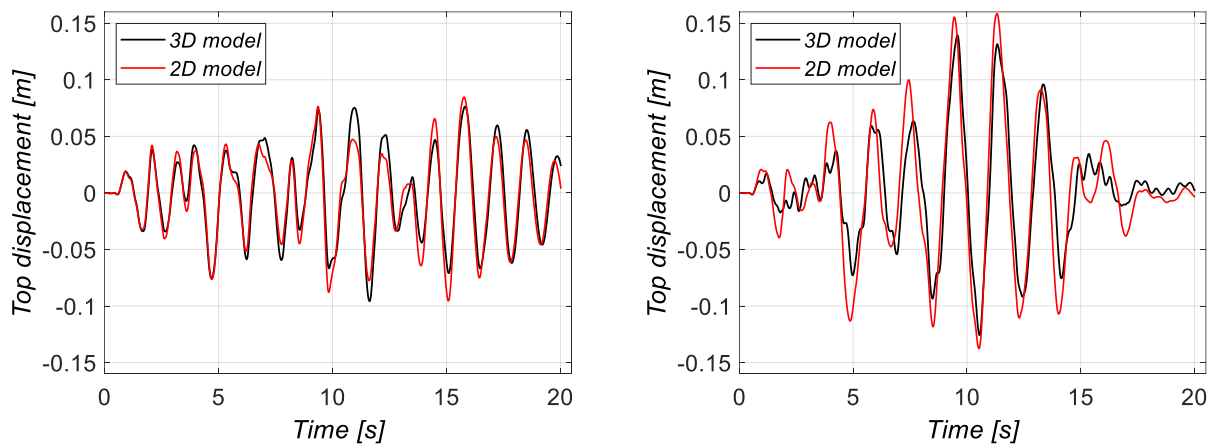


Figure 3: Time history results: roof displacement in transverse (left) and longitudinal direction (right).

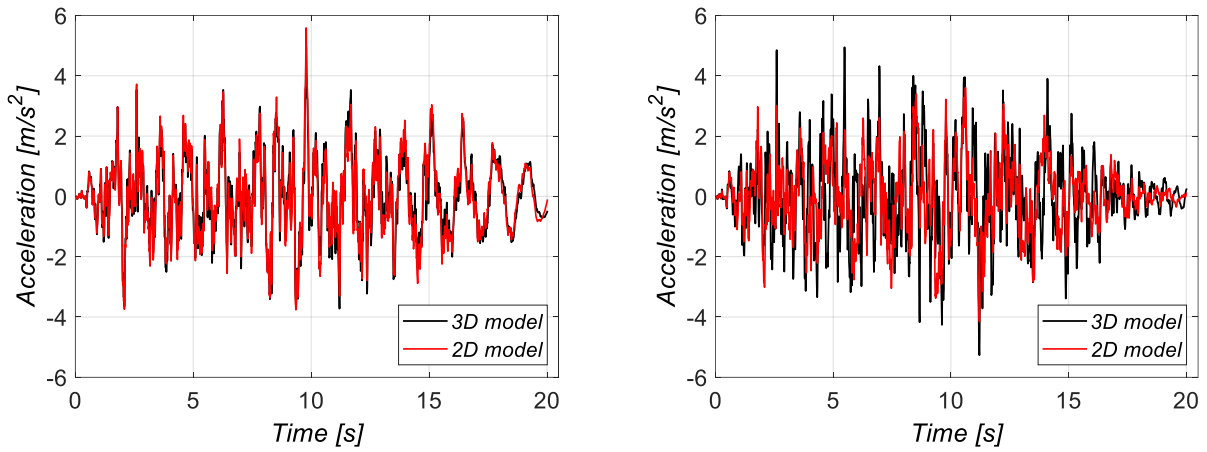


Figure 4: Time history results: roof acceleration in transverse (left) and longitudinal direction (right).

Overall, the simplified modelling approach provides a stable and consistent representation of the dynamic response, without significant deviations or inconsistencies.

After validating the proposed modelling approach and establishing that it accurately captures the global seismic response, nonlinear multi-stripe analyses were performed using simplified models. As previously mentioned, these analyses were conducted on the reference building in both its as-is and retrofitted conditions. As seismic input, 70 accelerograms were selected using REXEL v3.5 [13] to account for record-to-record variability.

The results of the multi-stripe analyses are presented in terms of structural response as a function of seismic demand, represented here by the spectral acceleration. The structural response includes roof drift, roof acceleration, and relative displacement demand at beam-to-roof connections. An example is represented in Figure 5. Each curve shown corresponds to the median value of the peak responses obtained from the seven analyses performed for each intensity stripe as envelope of the longitudinal and transverse direction.

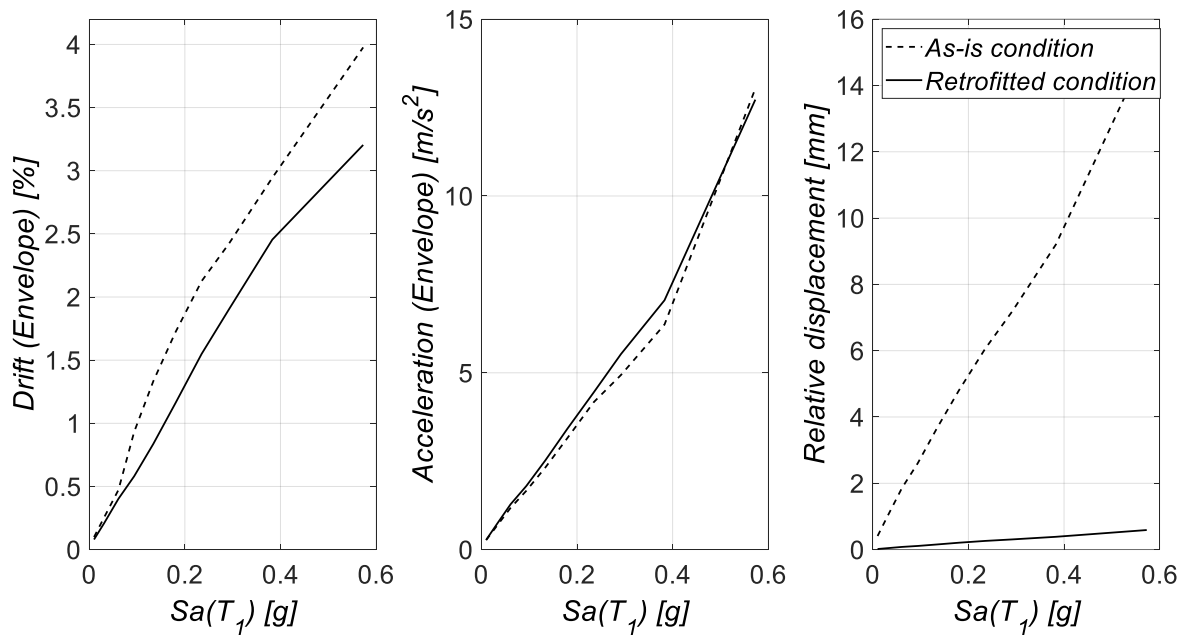


Figure 5: Results of the multi-stripe analysis: a) roof drift, b) roof acceleration, c) relative displacement roof-beam.

3 SEISMIC DAMAGE ASSESSMENT

A well-known tool for assessing the extent of damage is represented by fragility curves, which relate the probability of reaching or exceeding a given damage state to a specific engineering demand parameter (EDP). In this study, lognormal fragility curves were used; characterized by two parameters: the median (θ) and the dispersion (β).

For structural elements (columns and roof elements), the fragility curve parameters have been derived from recent studies [6], [8]. For non-structural elements and building contents, the fragility curves have been taken from FEMA P-58 [14]. The fragility curves used in this study are shown in Figure 6.

It is worth noting that for columns, two sets of fragility curves are considered, representing the as-is condition (column 1) and the retrofitted condition (column 2).

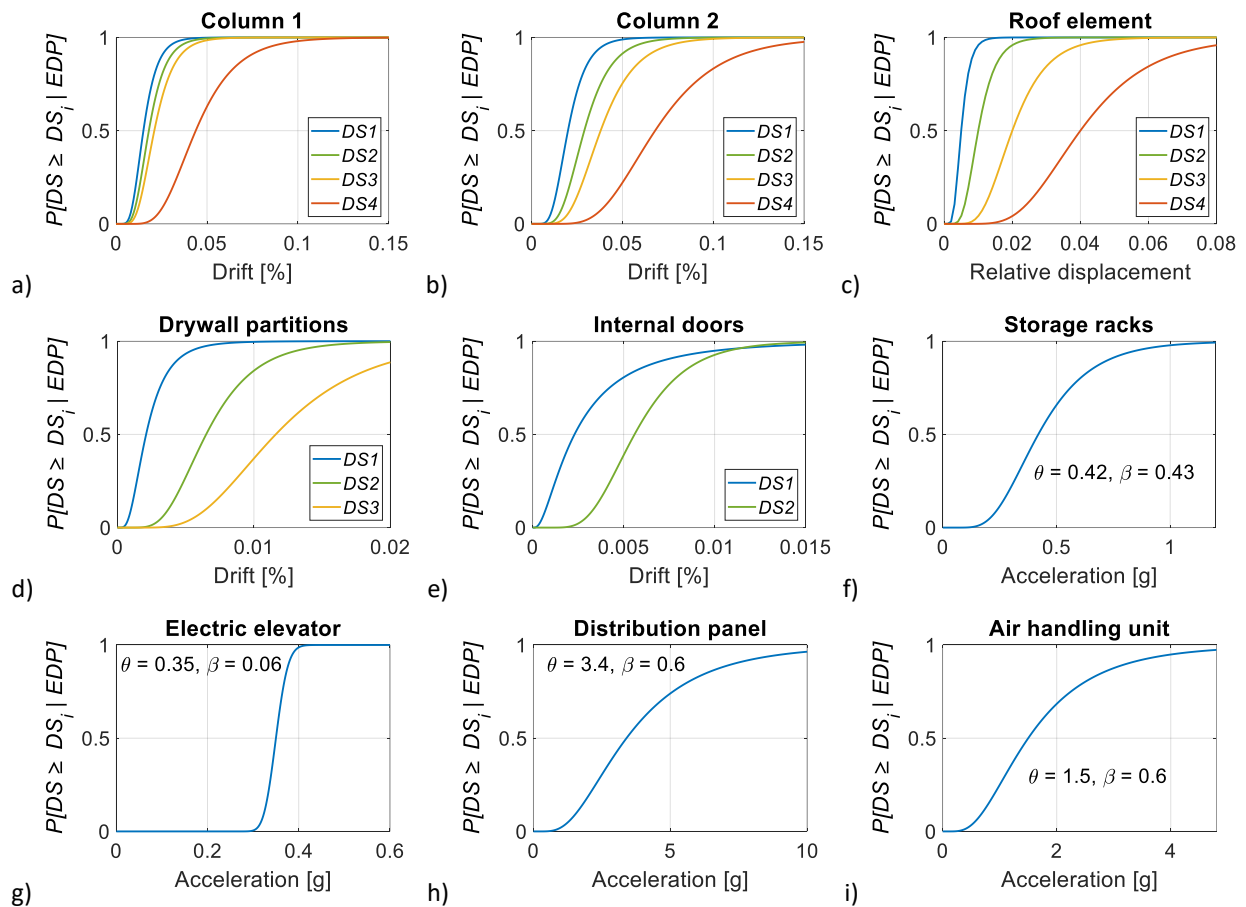


Figure 6: Fragility functions for: a) column 1, b) column 2, c) roof elements, d) drywall partitions, e) internal doors, f) storage racks, g) electrical elevator, h) distribution panel, i) air handling unit.

The seismic damage assessment results are summarized in Figure 7, which presents the probabilities of exceeding Damage States (DS) for both the as-is and retrofitted conditions.

To obtain these results, the Engineering Demand Parameter (EDP) values characteristic of each element's fragility were required. For the reference case, the EDP values were computed using 0.3g, determined from the design spectrum of L'Aquila at a period of 1.5s.

In the as-is condition, the seismic vulnerability of the building is evident from the high probability of exceeding the initial damage states for the primary structural elements. In the retrofitted condition, damage probabilities are significantly reduced, confirming the effectiveness of the seismic retrofitting measures.

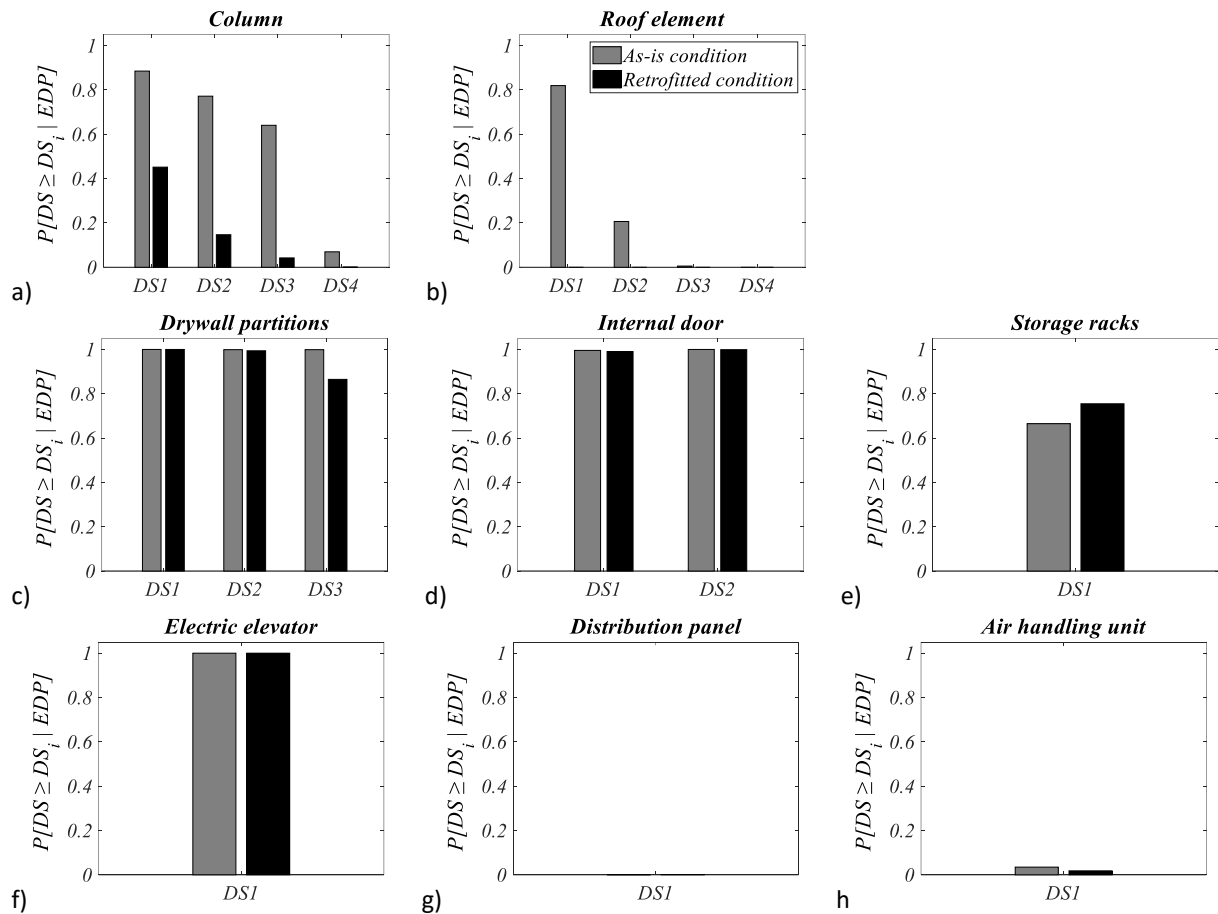


Figure 7: damage assessment results: probability of exceeding different damage states for: a) columns, b) roof elements, c) drywall partitions, d) internal doors, e) storage racks, f) electrical elevator, g) distribution panel, h) air handling unit.

4 CONCLUSIONS

This study presents a step toward a simplified procedure for seismic risk assessment of single-storey precast industrial buildings, integrating non-structural elements and contents, which are often overlooked despite their critical role in assessing economic seismic losses in this type of building. A simplified modelling approach was proposed, based on the development of two independent 2D frames, each representing the building in one of its principal directions. The ability of these models to accurately capture key engineering demand parameters (EDPs) under seismic loading was validated through time-history analyses. Subsequently, both the as-is and retrofitted conditions were analysed through multi-stripe analyses, providing $S_a(T_1)$ -EDP demand curves. These were then combined with fragility curves for structural, non-structural, and content elements, allowing the estimation of damage probabilities across different Damage States (DS). The results highlight the sensitivity of the proposed method in distinguishing between different structural configurations and quantifying seismic risk.

These findings, though preliminary, suggest that when focusing retrofit efforts on primary structural elements, attention should also be paid to potential interactions with other structural systems and the necessary adjustment of any equipment.

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