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Pre-Code RC Bare Frame: Seismic Retrofit with Alternative Strategies

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Abstract. In the last fifty years, a significant number of earthquakes that caused great economic losses and casualties have been recorded. In particular, in the last ten years, many seismic events occurred, and their medium magnitude caused great damage to the existing reinforced concrete buildings. In this context, the optimization of retrofitting strategies has become a crucial issue to evaluate the improvement of the probable seismic performance of the buildings in term of seismic risk reduction and repair costs. This paper deals with the seismic vulnerability of an existing reinforced concrete building not designed with the capacity design criterion. Different retrofitting strategies have been considered in order to evaluate more effective solutions in terms of seismic risk mitigation. The non-linear pushover analysis has been performed to evaluate the performance improvement of the building and compare the seismic behavior of the un-retrofitted and retrofitted building. Moreover, the seismic risk classes, pre and post-structural interventions, have been evaluated following the simplified methodology introduced with the Italian Ministerial Decree No 58/2017 about "Guidelines for seismic risk buildings classification".

INTRODUCTION

Reinforced concrete structures built before the seismic site classification and the seismic prescription represent an important part of the Italian building heritage [1]. Currently, it is estimated that 60% of the existing buildings in Italy have been built in areas, which are not classified as seismic. Non-ductile reinforced concrete buildings have been significantly spread in the worldwide and their crisis can determine serious economic losses [2, 3] and a great number of casualties The structural strengthening can be reached by alternative strategies: among them, different approaches have been considered, mostly concerning the improvement of the building strength, and/or altering stiffness or increasing ductility, like steel braced frames, or jacketing technique to confine RC columns by Fiber Reinforced Polymer (e.g. [4-8]). The design constraints, such as the performance objectives and the costs of the interventions, affect the choice of the different retrofitting strategies. In this paper, a 2D model of a three-floor building with three and five bays has been developed, by using SeismoStruct.

CASE STUDY BUILDING

An existing non-ductile RC frame building placed in Avezzano (AQ), designed for gravity loads only and characterized by the absence of any seismic design criteria, has been analyzed. Specifically, it is a part of a school complex built using the structural Italian guidelines of 1970s-1980s. The plan is rectangular in shape and has three

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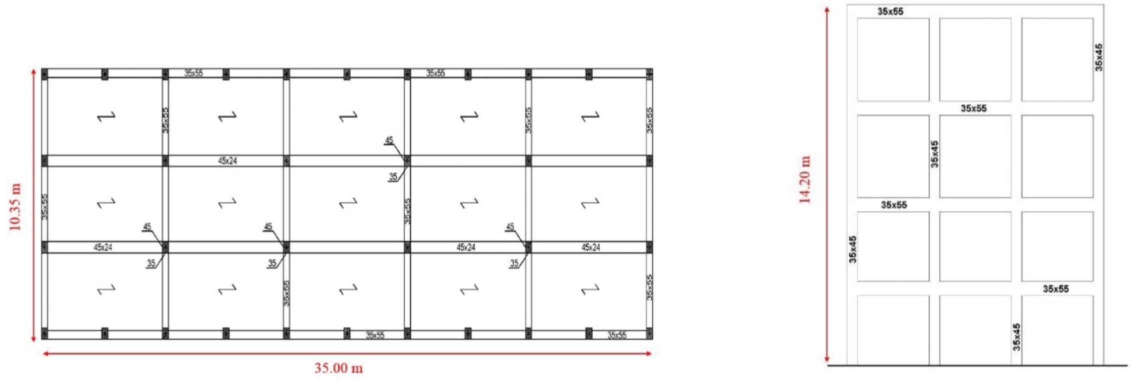
bays (each of length 3.45 m) on the short side and ten (each of length 3.50 m) on the long side. The overall extension is 10.35 m x 35.00 m, as shown in Fig. 1a. The structure spreads over four levels with different inter-floor height equal to 3.30 m, 3.30 m, 3.80 m, 3.80 m, respectively, for a total height of 14.20 m, as shown in Fig. 1b.

Like typical structural features of that period, it is affected by the lack of structural seismic details and overall by the absence of any Capacity Design (CD) principles. Taking into account these critical issues (due to poor structural detailing), this building was strongly damaged from the L'Aquila's earthquake (2009), showing a high seismic vulnerability. The results of destructive and non-destructive tests, carried out simultaneously with the surveys, were used to evaluate the mechanical properties of steel and concrete materials used in the building construction.



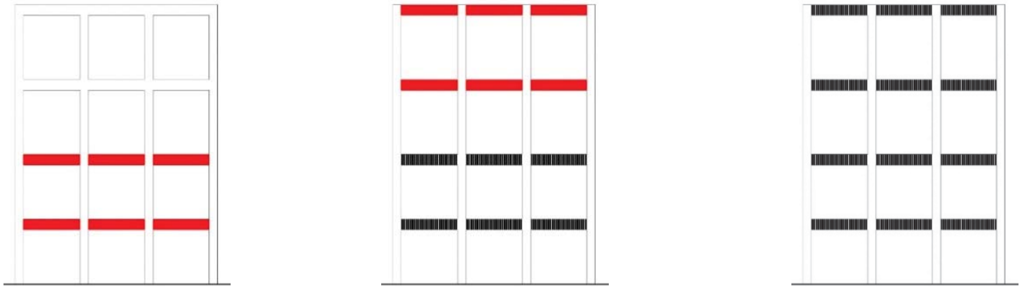
(a) (b)

FIGURE 1 Plan view, rectangular shape (a), bear frame front view, short side (b)

NUMERICAL MODEL AND RETROFITTING STRATEGIES

The numerical model, using distributed plasticity elements, has been developed for simplicity as a 2D frame in SeismoStruct, as represented in Fig. 2b.

The evaluation of the seismic capacity was carried out through non-linear static analysis (Pushover Analysis). The results were compared with the demand according to the N2 method, which allows to evaluate the performance point for the different limit states. Generally, the results of this method are reasonably accurate, provided that the structure oscillates predominantly in the first mode; it is clear that such results in the pushover analysis are conditioned by the particular choice of forces distribution [9, 10], which in this case is proportional to the first modal shape.



(a) (b) (c)

FIGURE 2 Bear Frame with shear beam crisis on first and second floors (a), FRP solution 1, seismic improvement (b), FRP solution 2, seismic retrofitting (c)

Taking into account the regulatory prescription, the aim was to conduct a multi-level check considering two limit states, i.e., two performance targets. The seismic analyses have been carried out by using different checks like the resistance and chord rotation criteria. The results from pushover analysis showed a clear shear crisis in the deep beams located on the first and second floor, where the system demand is greater than the element capacity (Fig. 2a).

Once the seismic vulnerability has been identified, the next step was to define the appropriate retrofit strategy. The case study building does not have seismic structural details, but due to their deep geometry, beams are the first structural elements which exhibit a shear crisis. These selected components of the structural system are upgraded to avoid the shear brittle mechanism. Following this way, two different strategies were chosen using FRP reinforcement (e.g. [5, 6, 8]). In the first one, represented in Fig. 2b, one uniaxial FRP U-Shape layer was placed in the bottom part of the beams (first and second floor). This strategy allows to increase the shear capacity of the beam involved elements realizing a seismic improvement of the building vulnerability but, at the same time, it moves the brittle mechanism to the beams of the upper levels. In the second one, represented in Fig. 2c, two uniaxial FRP U-Shape layers were placed in the bottom part of all beam, thus modifying the breaking mechanism from shear to flexural and realizing in this way a seismic retrofitting.

SEISMIC RISK CLASSIFICATION

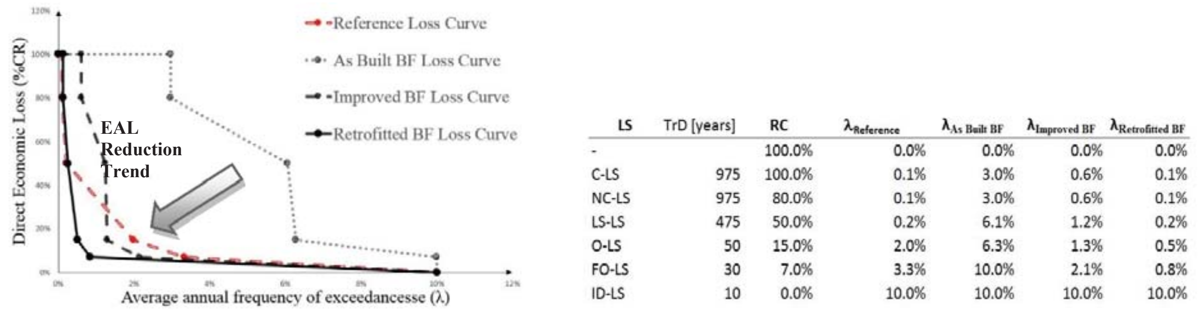
In terms of structural response, the case study building has been analyzed considering the "as-built" structure using the proposed retrofit solutions. The goal of this work, in each context, was to evaluate the expected structural losses both in terms of loss curves and Expected Annual Losses (EAL). There exist many methods in literature to evaluate the EAL index and the loss curves, e.g., the FEMA P58, which considers the performance based probabilistic assessment. In the present paper, the evaluation of the EAL index has been obtained by the simplified methodology introduced with the Italian Ministerial Decree No 58/2017. More precisely, the loss curve and the relative EAL, i.e. the area under the losses curve, can be estimated by defining the pairs of points (λ_i, RC_i), where $\lambda_i = 1/T_{rCi}$ is the average annual frequency of exceedance (defined for i-th Limit State), T_{rC} is the return capacity period and RC is the Repair Cost (defined a priori using the macroseismic data). EAL index is evaluated using the following expression:

$$\mathrm{EAL} = \sum_{\mathrm{i}}^{5} [\lambda_i - \lambda_{\mathrm{i}-1}] \cdot [RC_i + RC_{i-1}]/2 + \lambda(\text{C-LS}) \cdot RC(\text{C-LS})$$

where the subscript i represents the i-th limit state, among those covered [11], reported in Fig. 3b. Here C-LS denotes the Collapse Limit State. Moreover, it holds:

$$T_{rCi}/T_{rDi} = (Sa\,(T_1)_{\mathrm{Ci}}/Sa\,(T_1)_{\mathrm{Di}})$$

Here T_{rD} is the return period for the demand for each limit state; $Sa\,(T_1)_{\mathrm{Ci}}$ and $Sa\,(T_1)_{\mathrm{Di}}$ are the spectral accelerations assessed with reference to the period T_1, which have been used in order to evaluate demand and capacity of the structure.



LS	TrD [years]	RC	$\lambda_{\text{Reference}}$	$\lambda_{\text{As Built BF}}$	$\lambda_{\text{Improved BF}}$	$\lambda_{\text{Retrofitted BF}}$
-		100.0%	0.0%	0.0%	0.0%	0.0%
C-LS	975	100.0%	0.1%	3.0%	0.6%	0.1%
NC-LS	975	80.0%	0.1%	3.0%	0.6%	0.1%
LS-LS	475	50.0%	0.2%	6.1%	1.2%	0.2%
O-LS	50	15.0%	2.0%	6.3%	1.3%	0.5%
FO-LS	30	7.0%	3.3%	10.0%	2.1%	0.8%
ID-LS	10	0.0%	10.0%	10.0%	10.0%	10.0%

(a) (b)

FIGURE 3 Comparison between loss curves (a), (λ, RC) values for each Limit State (b)

For each value of $T_{rC,}$ evaluated by Pushover results and N2 method, the value of λ is determined. In addition to this, according to macroseismic data, in the proposed simplified methodology, the Initial Damage Limit State (ID-LS) and the Collapse Limit State (C-LS) are defined a priori. In this way, for the various structural elements, the sequence of plastic hinges has been determined, in relation to the Operational Limit State (O-LS) and to the Life Safety Limit

State (LS-LS), as required by the simplified approach adopted. Fig. 3a depicts the different loss curves for the case study building and compare them with the reference one, which represents, in terms of EAL, the performance of a new construction (see red dashed line in Figure 3a). The trends show that the as-built bear frame has the highest EAL index equal to 5.5%. The seismic improvement solution reaches the building to an EAL index equal to 1.4% and finally the seismic retrofitting reaches the building to an EAL index equal to 0.6%.

CONCLUSIONS

In this paper, a case study of a reinforced concrete building built around the 70s in the municipality of Avezzano has been analyzed. As a consequence of L'Aquila earthquake in 2009, it suffered considerable structural damage on the beam elements located on first and second floor. Seismic strengthening work was therefore necessary to mitigate the vulnerability and the seismic risk of the structure. In the first instance, a pushover analysis was conducted, assuming a forces distribution proportional to the first modal shape, to evaluate the structures capacity curve. Subsequently, the N2 method was applied in order to combine the pushover analysis of the multidegree-of-freedom model with the response spectrum analysis of an equivalent single-degree-of-freedom system. In conclusion, the loss assessment has been evaluated on the “as-built” structure, which presented an EAL index equal to 5.5%. This high vulnerability has made necessary a seismic improvement, enabled through the use of FRP technique. In this manner, using one FRP layer in the bottom part of the beams (first and second floor), the structure was found to be improved, reaching an EAL index equal to 1.4%. In addition to this, improving the structural performances, an additional FRP layer on the beams belonging to the last two levels was applied. In this way the structure has been subjected to a complete seismic retrofitting, reaching an EAL index equal to 0.6%.

The improvement obtained turns out to be so advantageous as to favor a funds request, made available by the Italian state.

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REFERENCES

1. R. Ferlito, M. Guarascio and M. Zucconi, “Assessment of a vulnerability model against post-earthquake damage data: The case study of the historic city centre of L’Aquila in Italy”, *9th World Conference on Earthquake Resistant Engineering Structures*”, pp. 393–404, 2013.
2. F. Romano, M. Faggella, R. Gigliotti, M. Zucconi and B. Ferracuti, “Comparative seismic loss analysis of an existing infilled RC building based on element fragility functions proposals”, *Eng. Struct.* **177**, pp. 707–723, 2018.
3. F. Romano, M.S. Alam, M. Faggella, M. Zucconi, A.R. Barbosa and B. Ferracuti, “Seismic loss analysis of a modern RC building accounting for uncertainty of infill strut modeling parameters”, in: Papadrakakis, M., Fragiadakis, M. (Eds.), *COMPDYN 2019*, pp. 24–26, 2018.
4. F. Nerilli and G. Vairo, “Strengthening of reinforced concrete beams with basalt-based FRP sheets: An analytical assessment”, *AIP Conference Proceedings* **1738,** 270016, 2016
5. F. Ceroni and M. Pecce, “Cracking behaviour of RC beams externally strengthened with emerging materials”, *Constr. Build. Mater.* **21**, pp. 736–745, 2007.
6. A. Balsamo, F. Nardone, I. Iovinella, F. Ceroni and M. Pecce, “Flexural strengthening of concrete beams with EB-FRP, SRP and SRCM: Experimental investigation”, *Compos. Part B-Eng.* **46**, pp. 91-101, 2013.
7. U. Akguzel and S. Pampanin, “Effects of Variation of Axial Load and Bidirectional Loading on Seismic Performance of GFRP Retrofitted Reinforced Concrete Exterior Beam-Column Joints”, *J. Compos. Constr.* **14** (1), pp. 94-104, 2010.
8. E. Tzoura and T. C. Triantafillou, “Shear strengthening of reinforced concrete T-beams under cyclic loading with TRM or FRP jackets”, *Mater. Struct.***49** (1-2), pp. 17-28, 2016.
9. P. Fajfar and M. EERI, “A Nonlinear Analysis Method for Performance Based Seismic Design”, *Earthq. Spectra* **16**, pp. 573-592, 2000.
10. B. Ferracuti, R. Pinho and M. Savoia, “Verification of displacement-based adaptive pushover through multi-ground motion incremental dynamic analyses”, *Eng. Struct.* **31**, pp. 1789-1799, 2009.
11. NTC2018, “Nuove norme tecniche per le costruzioni 2018”, DM (17/01/2018).