The Fourteenth International Conference on
Computational Structures Technology
23–25 August, 2022 | Montpellier, France

Proceedings of the Fourteenth International Conference on
Computational Structures Technology
Edited by B.H.V. Topping and J. Kruis
Civil-Comp Conferences, Volume 3, Paper 11.4
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.3.11.4

Vulnerability reduction of structures under dynamic loadings

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Abstract

In the present work a suitable retrofitting strategy is presented for reducing the vulnerability of under-designed structures subject to dynamic loadings. After the recent seismic events in Italy the seismic codes have been modified and the seismic risk associated to a large part of the territory has been substantially increased. Many structures build in the past with respect to obsolete standards no longer satisfy the current technical standards for the seismic codes. In the present work a retrofitting strategy for under-designed structures is investigated by the adoption of steel braces realized in series with innovative buckling restrained axial dampers in the nonlinear modeling of the dissipative behavior of structures under dynamic actions. The adopted retrofitting approach shows to be useful for the mitigation of the seismic risk of under-designed structures by providing a suitable increment of the safety degree of under-designed structures. A pushover analysis is performed in order to determine the capacity curve of the considered under-designed structure and the safety factors are evaluated for the structure before retrofitting and after the innovative retrofitting. The reported analysis shows that the investigated innovative retrofitting strategy can be usefully applied for an effective reduction of the seismic vulnerability of under-designed structures by suitably increasing the safety factors of the investigated structures subject to dynamic loadings.

Keywords: structural vulnerability, dynamic analysis, nonlinear structural analysis, seismic risk, irregular structures, structural retrofitting.

1 Introduction

In Italy the current structural code has been recently updated. In particular the new code is characterized by an increased seismic risk associated to many parts of the territory. In fact, due to the recent seismic events the seismic risk associated to many parts of the territory has been substantially increased, see e.g. the Italian seismic code NTC 2018 [1]. Accordingly, many existing reinforced concrete structures realized in the past with reference to old structural codes are nowadays not able to ensure a satisfactory safety degree with respect to the current technical standards [2]. At present such structures are required to conform to the seismic actions supplied by the design earthquakes prescribed by the current technical standards [3].

In this work a multi-storey reinforced concrete existing structure originally designed for only gravitational loads has been investigated. A nonlinear analysis is presented for reducing the structural vulnerability of under-designed existing structures. It is shown that the presented innovative strategy for reducing the structural vulnerability of under-designed existing structures provides a suitable increment of the safety factors associated to dynamic and seismic events.

2 Methods

In the present analysis a retrofitting approach is presented for the mitigation of the seismic risk of multi-storey reinforced concrete existing structures originally designed for only gravitational loads. The adopted retrofitting strategy takes into account hysteretic dissipators, known as Buckling Restrained Axial Dampers (BRADs), placed in series with a steel element to form the diagonal braces of the retrofitted structure. The adopted design methodology is based on a displacement based approach in order to ensure the compatibility condition between the displacement capacity of the structural frame and the displacement demand according to updated seismic codes [4].

In this work we study an innovative retrofitting strategy for under-designed existing reinforced concrete structures by adopting steel braces realized in series with the innovative BRAD devices [5][6]. The adoption of the BRAD devices within the diagonal braces introduced in the under-designed structure increases the damping of the structure and reduces the damage of the primary structural frame since part of the dissipation occurs in the adopted damper devices, see e.g. [7].

For the adopted acceleration elastic response spectrum in the analysis we have considered the damage limit state, the life preservation limit state and the collapse limit state. In the nonlinear analysis the influence of the confined concrete has also been considered in the definition of the proper constitutive law for the retrofitted columns.

3 Results

A displacement based approach is presented for the retrofitting strategy. Steel braces realized in series with the innovative BRAD devices have been adopted for the retrofitting strategy in order to reduce the structural vulnerability of the under-designed structures. In the nonlinear modeling of the behavior of the dissipative devices we have considered the suitable hysteretic modeling, see e.g. [8-11]. The adopted retrofitting methodology has been modeled by considering the structural behavior with respect to a displacement based approach. After retrofitting a nonlinear static analysis has been performed for the verification of the structure in order to evaluate the capacity curve of the structure. The adopted retrofitting approach shows to be useful for the mitigation of the seismic risk of multi-storey reinforced concrete existing structures originally designed for only gravitational loads, see e.g. [7]. Different approaches can be adopted for reducing suitably the vulnerability of solids and structures under static and dynamic actions, see e.g. [12-25].

	Safety factor before retrofitting	Safety factor after retrofitting
$F1_X$	0.74	1.78
$F1_Y$	0.49	1.54
$F2_X$	0.90	1.70
$F2_Y$	0.53	1.41

Table 1: Safety Factors for the structure before retrofitting and after innovative retrofitting with steel braces and BRAD devices at the life safeguard limit state.

A pushover analysis is performed in order to determine the capacity curve of the structure. In the analysis two cases are considered with two different distributions of forces. The first distribution of forces (F1) is proportional to the product of the masses of the floor times the displacement of the floor relative to the first vibration mode and it is considered as representative of the dynamic response of the structure in the elastic range. The second distribution of forces (F2) is proportional to the mass of each floor and it is considered as representative of the dynamic behavior of the structure in the plastic range. In Table 1 the safety factors are reported for the structure before retrofitting and after innovative retrofitting with steel braces and BRAD devices at the life safeguard limit state. For more details see e.g. [7].

4 Conclusions and Contributions

After the recent seismic events an update of the seismic codes has occurred in Italy with higher values of the seismic risks for many parts of the Italian territory. Accordingly, existing reinforced concrete structures realized in the past and built with strategies that no longer meet the current technical standards needs to be verified. In fact, such structures realized with reference to obsolete standards currently are not able to ensure an adequate degree of safety.

Nowadays, such structures are required to conform to seismic actions prescribed by the current technical codes. In the present investigation multi-storey existing structures originally designed for only gravitational loads have been analyzed. An under-designed structure has been considered and an analysis has been performed for reducing its vulnerability with respect to updated seismic actions. The adopted retrofitting strategy has taken into account steel braces realized in series with the innovative BRAD devices in the nonlinear modeling of the dissipative behavior of the structure. The nonlinear analysis has been performed and the retrofitting approach has shown to be useful for the mitigation of the seismic risk and for the improvement of the structural vulnerability with respect to the updated seismic codes.

References

[1] NTC 2008, Decreto Ministeriale 14/01/2008, Nuove Norme Tecniche per le Costruzioni, Gazzetta Ufficiale n. 29 del 4 febbraio 2008 - Suppl. Ordinario n. 30, Roma, (2008).

[2] Oliveto G., Decanini L.D., Repair and retrofit of a six storey reinforced concrete building damaged by the earthquake in south-east Sicily on the 13th December 1990, Soil Dynamics and Earthquake Engineering, Vol. 17, Issue 1, (1998), pp. 57-71.

[3] Paulay T., Priestley M.J.N., Seismic Design of Reinforced Concrete and Masonry Buildings, Wiley Interscience, New York, 1992.

[4] Fajfar, P., Capacity spectrum method based on inelastic demand spectra, Earthquake Engineering & Structural Dynamics, Vol. 28, Issue 9, (1999), pp. 979-993.

[5] Di Sarno, L., Manfredi, G., Seismic retrofitting with buckling restrained braces: Application to an existing non-ductile RC framed building, Soil Dynamics and Earthquake Engineering, Vol. 30, pp. 1279-1297, 2010.

[6] Di Sarno, L., Manfredi, G., Experimental tests on full-scale RC unretrofitted frame and retrofitted with buckling-restrained braces, Earthquake Engineering and Structural Dynamics, Vol. 41, pp. 315-333, 2012.

[7] Cancellara, D., De Cicco, S., De Angelis, F., Assessment and vulnerability reduction of under-designed existing structures: Traditional vs innovative strategy, Computers and Structures, Vol. 221, pp. 44-64, September 2019.

[8] De Angelis, F., Extended formulations of evolutive laws and constitutive relations in non-smooth plasticity and viscoplasticity, Composite Structures, Vol. 193, pp. 35-41, 1 June 2018.

[9] De Angelis, F., Taylor, R.L., An Efficient Return Mapping Algorithm for Elastoplasticity with Exact Closed Form Solution of the Local Constitutive Problem, Engineering Computations, Vol. 32, Issue 8, pp. 2259 - 2291, 2015.

[10] De Angelis, F., Taylor, R.L., A Nonlinear Finite Element Plasticity Formulation without Matrix Inversions, Finite Elements in Analysis And Design, Vol. 112, pp. 11-25, 2016.

[11] De Angelis, F., On the structural response of elasto/viscoplastic materials subject to time-dependent loadings, Structural Durability & Health Monitoring, Vol. 8, No. 4, pp. 341-358, 2012.

[12] Cancellara, D., De Angelis, F., Dynamic nonlinear analysis of an hybrid base isolation system with viscous dampers and friction sliders in parallel, Applied

Mechanics and Materials, Vol. 234, pp. 96-101, 2012. DOI: 10.4028/www.scientific.net/AMM.234.96

[13] Cancellara, D., De Angelis, F., Nonlinear dynamic analysis for multi-storey RC structures with hybrid base isolation systems in presence of bi-directional ground motions, Composite Structures, Vol. 154, pp. 464–492, 2016.

[14] Cancellara, D., De Angelis, F., A base isolation system for structures subject to extreme seismic events characterized by anomalous values of intensity and frequency content, Composite Structures, Vol. 157, pp. 285–302, 2016.

[15] Cancellara, D., De Angelis, F., Assessment and dynamic nonlinear analysis of different base isolation systems for a multi-storey RC building irregular in plan, Computers and Structures, Vol. 180, pp. 74–88, February 2017.

[16] Cancellara, D., De Angelis, F., Dynamic assessment of base isolation systems for irregular in plan structures: Response spectrum analysis vs nonlinear analysis, Composite Structures, Vol. 215, pp. 98-115, 2019.

[17] De Angelis, F., Cancellara, D., Dynamic analysis and vulnerability reduction of asymmetric structures: Fixed base vs base isolated system, Composite Structures, Vol. 219, pp. 203-220, 2019.

[18] De Cicco, S., De Angelis, F., A plane strain problem in the theory of elastic materials with voids, Mathematics and Mechanics of Solids, Vol. 25, Issue 1, pp. 46-59, 1 January 2020.

[19] De Angelis, F., A variationally consistent formulation of nonlocal plasticity, Int. Journal for Multiscale Computational Engineering, Vol. 5, Issue 2, pp. 105-116, Begell House Inc. Publishers, New York, 2007.

[20] De Angelis, F., A comparative analysis of linear and nonlinear kinematic hardening rules in computational elastoplasticity, Technische Mechanik, Vol. 32 (2-5), pp. 164-173, 2012.

[21] De Angelis, F., Computational issues and numerical applications in rate-dependent plasticity, Advanced Science Letters, Vol. 19, Number 8, pp. 2359-2362, American Scientific Publishers, USA, 2013.

[22] De Angelis, F., De Angelis, M., On solutions to a FitzHugh-Rinzel type model, Ricerche di Matematica, Vol. 70, Issue 1, pp. 51-65, 2021.

[23] De Angelis, F., Meola, C., Non-smooth evolutive laws in multisurface elastoplasticity with experimental evidence by infrared thermography, Composite Structures, Vol. 265, Art. n. 113156, pp. 1-9, 2021.

[24] De Angelis, F., A multifield variational formulation of viscoplasticity suitable to deal with singularities and non-smooth functions, Int. Journal of Engineering Science, Vol. 172, Art. 103616, pp. 1-16, 2022.

[25] Cancellara, D., De Angelis, F., Base isolation systems for structures subject to anomalous dynamic events, Lecture Notes in Mechanical Engineering, 24th Conference of the Italian Association of Theoretical and Applied Mechanics, AIMETA2019, Rome, Italy, 15-19 September 2019, Code 238859, pp. 175-187, Springer, 2020.