Dynamic analysis of reinforced concrete structures with hybrid base isolation systems subject to bi-directional ground motions

*DonatoCancellara

1) Department of Structures for Engineering and Architecture, University of Naples Federico II, 80125 Naples, Italy
1) donato.cancellara@unina.it

ABSTRACT

In the present paper base isolation techniques are analyzed in order to protect reinforced concrete structures from seismic and dynamic loadings. In the analysis bi-directional ground motions have been considered. The analyzed base isolation systems are the elastomeric spring dampers actuated in parallel with friction sliders, the lead rubber bearings actuated in parallel with friction sliders and the high damping rubber bearings also actuated in parallel with friction sliders. The analysis investigates the hysteretic cycles of the friction sliders and the hysteretic cycles of the rubber bearing isolators. The considered seismic actions correspond to recorded accelerograms characterized by bi-directional ground motions. The chosen recorded sets of accelerograms have been verified by a spectrum compatibility analysis. A nonlinear dynamic analysis has been performed by illustrating the response of the structure for the chosen sets of accelerograms. The time-history of the base shear and the time history of the base displacements are evaluated together with the maximum values of the base shear. The seismic response of the considered base isolated structure is discussed and analyzed by illustrating the results of the dynamic analysis.

1. INTRODUCTION

In the present work we present a comparative analysis of different base isolation techniques and a design strategy for separating the structure from the seismic effects associated to the ground accelerations. In particular we illustrate a nonlinear dynamic analysis for a structure base isolated with elastomeric and sliding isolation systems. The base isolation devices are composed by elastomeric materials and steel-teflon bearings. The effect of the isolation system is to elongate the fundamental period of the structure with respect to the fundamental period of the fixed base structure, see Naeim and Kelly (1999) and Ryan and Chopra (2004).

In order to protect the reinforced concrete (RC) structure in this paper we analyze three

1) Research Associate
different base isolation systems and compare the structural behaviour with respect to the fixed base structure. The nonlinear dynamic behaviour of the different base isolated structures and fixed base structure is investigated and analyzed. The considered structure is characterized by irregularity in plan. In the analysis we consider bi-directional ground motions by taking into account recorded accelerograms in the nonlinear dynamic analysis, see Park Wen and Ang (1986), Nagarajaiah et al. (1991a, 1991b) and Wilson (2002).

A first isolation system is realized by placing in parallel Elastomeric Spring Dampers and Friction Sliders, see e.g. Sorace and Terenzi (2001). This isolation system is characterized by the acronym ESD+FS. A second base isolation system is also a hybrid base isolation system realized by Lead Rubber Bearings combined in parallel with Friction Sliders, see e.g. Robinson and Tucker (1977) and Robinson (1982). This isolation system is characterized by the acronym LRB+FS. A third base isolation system is a hybrid base isolation system realized by High Damping Rubber Bearings placed in parallel with Friction Sliders with a low friction coefficient, see e.g. Wen (1976) and Mokha Constantinou and Reinhorn (1990a, 1990b). This isolation system is characterized by the acronym HDRB+FS. The dynamic behaviour of the different base isolation systems has also been compared with the dynamic behaviour of the fixed base structure, characterized by the acronym FB.

The base isolation systems have been designed with respect to the European seismic codes EC2 (2004) and EC8 (2003) and the Italian seismic code NTC 2018 (2018). Bi-directional ground motions have been adopted as dynamic actions. The considered recorded accelerograms have been derived by the European Strong-motion Database ESD, see e.g. Luzi et al. (2020).

In the nonlinear dynamic analysis we investigated the base displacement, the base acceleration, the maximum values of the base shear and the inter-storey drifts. The dynamic behaviour and the advantages of the different adopted base isolation systems are analyzed and compared with the dynamic behaviour of the fixed base reinforced concrete structure. Accordingly, a dynamic nonlinear analysis is described by illustrating the advantages of the considered different base isolation systems with respect to the fixed base structure subject to seismic events and dynamic loadings.

2. THE STRUCTURE INVESTIGATED IN THE ANALYSIS

We consider a structure positioned in Italy and identified by topographic category T1, and with soil type B. The structure is of class II and it has a nominal life of 50 years with a reference period of 50 years. For the seismic hazard we consider the Italian seismic code NTC 2018 (2018) and the Eurocodes EC2 (2004) and EC8 (2003). The considered structure is composed by a ground floor, three floors characterized by residential features and an attic. The building is irregular in plan with an L-shaped form. For more details on the geometry of the structure see e.g. Cancellara and De Angelis (20016a). In the dynamic analysis we adopted the bi-directional recorded accelerograms related to the earthquake occurred in Montenegro, on 15 April 1979, characterized by seismic magnitude 7.03 on a stiff soil, seismic input record 000196, see European Strong-motion Database ESD, Luzi et al. (2020).
Fig. 1: The structure with the disposition in plan of the different isolators for the base isolation system ESD+FS (top figure), for the base isolation system HDRB+FS (center figure) and the base isolation system LRB+FS (bottom figure). (Integrated with supplemental findings and modified from Cancellara and De Angelis, 2016a).
In the analysis of the dynamic behaviour of the structure we considered a fast nonlinear dynamic analysis algorithm, see e.g. Wilson (2002), by the adoption of the SAP2000NL code (2014). A nonlinear time history analysis has been derived, see e.g. Newmark (1959), Wilson et al. (1973), Hilber et al. (1977), Hughes (1987), Clough and Penzien (1975). The irregular in plan structure was designed in such a way so that beams and columns are requested to act within an elastic behaviour, see for instance Park et al. (1986), Nagarajaiah et al. (1991a, 1991b), Fenz and Constantinou (2008).

3. THE CONSIDERED THREE BASE ISOLATION SYSTEMS

In the present investigation we have studied a first base isolation system composed by Elastomeric Spring Dampers and Friction Sliders (ESD+FS), a second base isolation system composed by High Damping Rubber Bearings placed in parallel with Friction Sliders with a low friction coefficient (HDRB+FS). For the disposition in plan of the isolator devices the intent is to decouple the vibration modes of the structure and regularize the dynamic response of the structure, see e.g. Cancellara and De Angelis (2016a). The third base isolation system is composed by Lead Rubber Bearings (LRB) positioned in parallel with friction sliders with a low friction coefficient (FS). The intent of the base isolation system is to increase the fundamental period of vibration of the structure, so that the pseudo-accelerations obtained from the design spectrum are lower than the ones of the fixed base structure. For the elastomeric components of the isolators the hysteretic model presented by Wen (1976) has been considered. For other investigations of the dynamic nonlinear analysis of hybrid base isolation systems see, e.g., Cancellara and De Angelis (2012a, 2012b, 2012c, 2016b, 2017, 2019) and De Angelis and Cancellara (2019). For nonlinear proposals of inelastic material behaviour, see e.g. Alfano et al. (2001), De Angelis (2000, 2007a, 2012a, 2012b, 2013, 2015, 2018), De Angelis and Cancellara (2013, 2017), De Angelis and Taylor (2014, 2015, 2016), De Angelis et al. (2018). For investigations on other useful constitutive models see e.g. De Angelis (2007b, 2018), De Angelis and De Angelis (2021), De Angelis and Meola (2021), De Cicco and De Angelis (2020). For reducing the structural vulnerability due to dynamic and seismic events and alternative proposals see e.g. Cancellara et al. (2019).

The position in plan of the isolators is illustrated in Fig. 1, for the first base isolation system ESD+FS, the second base isolation system HDRB+FS and for the third base isolation system LRB+FS, see also Cancellara and De Angelis (2016a). The problems associated to the stability of the isolators can be studied by referring to De Angelis (2012c) and De Angelis and Cancellara (2012). The design of the base isolation systems was conducted by a linear analysis. Subsequently, a nonlinear dynamic analysis was conducted with the SAP2000NL (2014) finite element code.

4. COMPARATIVE INVESTIGATIONS OF THE THREE BASE ISOLATION SYSTEMS

The structural behaviour has been evaluated with each of the three base isolation systems by considering a nonlinear dynamic analysis and by comparing the performance of the base isolated structure with each of the three adopted base
isolation systems and the fixed base structure.
A comparative investigation is illustrated in Fig. 2 for the performance of the structure base isolated by the ESD+FS base isolation system, the structure base isolated by the HDRB+FS base isolation system, the structure base isolated by the LRB+FS base isolation system and the fixed base structure (FB). In the dynamic nonlinear analysis, for the seismic record due to the Montenegro earthquake (code 000196 in x-direction), we illustrate in Fig. 2 the maximum values of the base shear for the ESD+FS base isolated structure, the HDRB+FS base isolated structure, the LRB+FS base isolated structure and the fixed base structure FB. We observe that, with respect to the traditional fixed base structure, all the considered ESD+FS base isolation system, the HDRB+FS base isolation system and the LRB+FS base isolation system provide a suitable reduction of the maximum base acceleration and of the maximum base shear for the base isolated structure. For other analysis of base isolation systems see e.g. Cancellara and De Angelis (2012d, 2012e, 2012f), Cancellara et al. (2013b, 2013c) and Cancellara et al. (2013a).

Fig. 2: Maximum base shear (KN) for the structure base isolated by ESD+FS, base isolated by HDRB+FS, base isolated by LRB+FS and the fixed base structure FB. Recorded accelerograms for the Montenegro earthquake: record 000196x. (Integrated with supplemental findings and modified from Cancellara and De Angelis, 2016a).

5. CONCLUSIONS

In this investigation the nonlinear dynamic behaviour has been investigated for a base isolated structure by considering three different base isolation systems; the ESD+FS base isolation system, the HDRB+FS base isolation system and the LRB+FS base isolation system. The results of the dynamic analysis show that all the three considered base isolation systems provide an effective protection for structures characterized by irregularity in plan. The maximum values of the base shear have been evaluated for the structure base isolated by the three considered base isolation systems and for the fixed base structure. The three base isolated systems provide a suitable reduction of the maximum base shear with respect to the fixed base structure.
REFERENCES


Cancellara, D., De Angelis, F. (2012f), A nonlinear analysis for the retrofitting of a RC existing building by increasing the cross sections of the columns and accounting for the influence of the confined concrete, *Applied Mechanics and Materials*, 204-208, 3604-3616. DOI: 10.4028/www.scientific.net/AMM.204-208.3604


Cancellara, D., De Angelis, F., Modano, M., Pasquino, V. (2013a), Innovative strategy to reduce the seismic vulnerability of a RC existing building: assessment and


Cancellara, D., De Cicco, S., De Angelis, F. (2019), Assessment and vulnerability reduction of under-designed existing structures: traditional vs innovative strategy, *Computers and Structures*, 221, 44-64. DOI: 10.1016/j.compstruc.2019.05.016


