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 CONSIDEREDTHREE 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+FSbase 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 000196in 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).

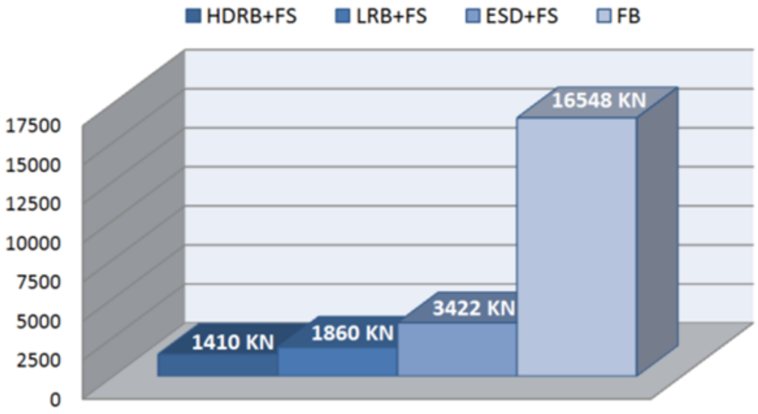

Fig. 2: Maximum base shear(KN)for the structure base isolated by ESD+FS, base isolated by HDRB+FS, base isolated by LRB+FS and the fixed base structure FB. Recorded accelerograms for the Montenegro earthquake: record 000196x. (Integrated with supplemental findings and modified from Cancellara and De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

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