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Multiobjective sizing optimization of seismic-isolated reinforced concrete structures

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Abstract

It is known that seismic isolation is able to protect structures from damage by reducing the earthquake effects on the superstructure rather than increasing the structural resistance. Base-isolated buildings are becoming more numerous all around the world, especially in areas subject to a high seismic hazard or where high safety levels are required. The cost of the isolation devices for ordinary buildings hinders a widespread adoption of the new technology. However, a well-designed base isolation system can largely reduce seismic loadings transferred to the superstructure and it not only enables to immediately reduce the superstructure building cost, but also to reduce the maintenance costs incurred after every earthquake during the building lifetime. To better understand these factors, this paper presents an efficient numerical optimization technique for comparing the responses of a base-isolated and a traditional fixed-base reinforced concrete ordinary building under the same type of solicitations and seismic spectra, as appropriate for each case. We start from a multiobjective optimization. The superstructure and the isolation system are generally designed separately in a building. In this work, we consider elastomeric isolators and we optimize at the same time the structural elements of the building (superstructure column and beam sections and reinforcements) and the isolator parameters (rubber type, maximum allowed displacement and elastomer size). We consider three objectives: minimization of the superstructure material cost, minimization of the top-floor acceleration and minimization of the top-floor displacement. This multiobjective optimization yields a set of trade-off optimal solutions (the so-called Pareto optimal designs) that can be post-processed with tools such as hierarchical clustering or decision-making algorithms and further analyzed. The purpose of this analysis is to identify similarities within data sets or choose a final optimal solution based on pre-defined priority criteria applied to the optimization objectives. We compare the base-isolated structure results with the solutions found for the same building with a traditional foundation fixed to the ground.

Keywords: Multiobjective sizing optimization ; Base isolation ; Genetic algorithms ; Clustering analysis

1. Introduction

The concept of seismic isolation is more than 100 years old but only in recent years it was adopted in practice and is becoming an alternative to conventional seismic construction methods especially for buildings of strategic importance

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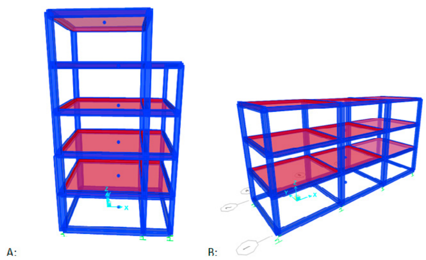

Fig. 1. Building three-dimensional extruded views from SAP2000. A: Asymmetric structure. B: Symmetric structure.

like hospitals or highly seismic regions. Base isolation uncouples a structure from the ground and significantly reduces both structural damages and damages to indoor furniture during an earthquake.

Recent studies appeared about the advantage of using base isolation also for standard buildings [1] and for structural design optimization in the base isolated case [2] [3].

In this work we performed a multiobjective sizing optimization of two simple buildings under seismic actions and with elastomeric isolators at the base. While the superstructure and the isolation system are generally designed separately, here we optimized at the same time the structural elements (superstructure column and beam sections and reinforcements) and the isolator parameters (rubber type, maximum allowed displacement and elastomer size). We considered three objectives: minimization of the superstructure material cost, minimization of the top-floor acceleration and minimization of the top-floor displacement. The purpose of this analysis is to identify similarities within data sets or choose a final optimal solution based on pre-defined priority criteria applied to the optimization objectives. A comparison with results found for a fixed based structure optimization is also presented.

2. Structural engineering application

We performed the seismic design of two structures isolated from the soil by means of elastomeric isolators, located in the Italian town of Reggio Calabria characterized by a high horizontal ground acceleration value ($a_g \simeq 0.27g$ for a life safety, or SLV, performance level spectrum). The structures are shown on Fig. 1. Structure [A] presents asymmetries both in elevation and in plan. It is composed by beams with two spans of length 6 m and 2 m in x direction and a span of 6 m in the y direction. There are six columns per floor, five floors for the first span and four for the second. Structure [B] is a symmetric three-storey building composed by beams with three spans of 6 m length in the x direction and a span of 6 m in the y direction. There are eight columns per floor. In both structures the floor to floor distance is 3 m. We considered a concrete of type C25/30 (confined characteristic compressive strength f_{ck} = 25 MPa and design compressive strength f_{cd} = 14.17 MPa) and a reinforcement steel of class B450A (yield stress f_{yk} = 450 N/mm^2).

Under each funding column there are equal isolators even if the columns are loaded differently. For structures of small dimensions it is not advantageous to use different isolators because this increases isolator testing and installation costs. We considered the elastomeric isolators of the "SI" series available from the *FIP Industriale* catalog [4]. These isolators are composed of alternating layers of elastomer and steel connected by vulcanization. The bearings usually have a circular section and are characterized by an adequate dissipative capacity, a high vertical stiffness and a small horizontal stiffness that makes them very flexible horizontally, thus enabling the building to move laterally under strong ground motion. These features enable an increase of the fundamental period of vibration and a reduction of the horizontal inter-floor displacement of the isolated structure, while still supporting vertical loads without appreciable failures. The vertical and horizontal stiffness of the isolators are determined by the dimensions of the layers of elastomer and steel and the mechanical characteristics of the elastomer. The isolator damping capacity is determined by the type of elastomeric compound. There are three types of compounds (soft, normal and hard) with a dynamic shear modulus varying from 0.4 to 1.4 MPa. The coefficient of equivalent viscous damping can be chosen in the interval from 10% to 15%. The isolators from the catalog are designed according to Italian seismic regulations [5] and [6] and are available for up to seven maximum allowed displacement values.