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Seismic evaluation and retrofitting of reinforced concrete buildings with base isolation systems

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ABSTRACT

A parametric study on the nonlinear seismic response of isolated reinforced concrete structural frame is presented. Three prototype frames designed according to the 1954 Hellenic seismic code, with number of floor ranging from 1 to 3 were considered. These low rise frames are representative of many existing reinforced concrete buildings in Greece. The efficacy of the implementation of both lead rubber bearings (LRB) and friction pendulum isolators (FPI) base isolation systems were examined. The selection of the isolation devices was made according to the ratio T_{is}/T_{fb}, where T_{is} is the period of the base isolation system and T_{bf} is the period of the fixed-base building. The main purpose of this comprehensive study is to investigate the effect of the isolation system period on the seismic response of inadequately designed low rise buildings. Thus, the implementation of isolation systems which correspond to the ratio T_{is}/T_{fb} that values from 3 to 5 is studied. Nonlinear time history analyses were performed to investigate the response of the isolated structures using a set of three natural seismic ground motions. The evaluation of each retrofitting case was made in terms of storey drift and storey shear force while in view of serviceability it was made in terms of storey acceleration. Finally, the maximum developed displacements and the residual displacements of the isolation systems are presented.

1. INTRODUCTION

Reinforced concrete buildings constitute a significant number of structures all over the world. The majority of these were designed according to old seismic codes. During the earthquakes that have occurred up till now, significant damage has been reported in these buildings. In the period referred to, the design philosophy was based on allowable stress design while mainly considering gravity loads, without adequate provision for seismic detailing (Thermou and Pantazopoulou 2011, Kunnath et al. 1995). Their main weaknesses are shortage of ductility, low strength, lack of damage hierarchy and small lateral stiffness. Owing to these factors the damage was caused in the columns of the structure and it was brittle, which render the earthquake response of these structures undesirable. Modern seismic codes suggest alternative strategies and methods for the retrofitting of existing buildings through which they aim to ensure an

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efficient energy absorption mechanism. Usually, traditional seismic retrofitting methods like concrete jacketing are applied in order to increase the cross sections' strength and the available ductility. There has been an examination of the upgrading of RC buildings with weak open ground stories by installing steel braces restricted to the open ground stories by Antonopoulos and Anagnostopoulos (2012), while Mistakidis et al. (2007) have investigated the implementation of low yield metal shear panels for the seismic upgrading of concrete structures.

Another option is to apply base isolation systems. Retrofitting an existing structure with base isolation devices is based on the isolation of the superstructure from the ground motion by reducing the seismic forces (Skinner et al. 1993, Naeim and Kelly 1999). With this technique structural damage can be minimized or even completely avoided. Storey displacements in the structure together with the accelerations will be reduced significantly, while the acceleration reduction protects the non-structural elements, the reduction in the storey displacements will allow both the structural and non-structural elements to survive the earthquake without any or with minimal damage. Parametric studies have been presented about the effectiveness of base isolation systems in reinforced concrete buildings (Providakis 2008, Cardone et al. 2013). Throughout the world there are examples of application of base isolation systems for the retrofitting of existing historic buildings (Kelly 1998, Mokha et al. 1996). Also there are studies examining acceleration-sensitive contents in facilities that allocate museums, healthcare facilities and manufacturing facilities Konstantinidis and Makris 2006, Alhan and Gavin 2005).

The isolators are installed at a specific level (Kelly 2001). This level may be either the foundation or the ground floor. In existing buildings which have been designed according to old seismic codes it is not easy to avoid any damage in the structural elements of the superstructure, thus the fundamental period of the isolated building (T_{is}) may need to be between 5-6 s. These very long periods result in very large lateral displacements that are incompatible. Nevertheless, limited plastic deformation could be proposed and that will lead us to a shorter period of the isolated structure.

The behavior and the simulation of the most practical isolation systems is bilinear, however all design codes invariably ask the design engineer to work with a vibration period that is the isolation system period. In view of this demand the concept of equivalent linear parameters has become central in the analysis and mainly in design of seismic isolated structures and this has led to the wide acceptance of the effective period and the associated effective stiffness.

While for the case of spherical sliding bearings, the concept of the effective period, is abandoned, and the period of the isolation system, is derived from the second slope of the bilinear system, $T_2 = 2\pi\sqrt{G/g}$, for other isolation systems the quantities of effective period and effective stiffness is used for estimating through an iterative procedure peak inelastic displacements and the associated peak shear forces according to most current design codes. (AASHTO 1991, FEMA 1998, Eurocode 2009) Nevertheless, recent studies (Makris and Kampas 2013) concluded that the period associated with the second slope of bilinear isolation system is a better approximation regardless the dimensionless strength $Q/(K_d \cdot D_y)=1/\alpha-1$, of the isolation system.

In this paper the results of a comprehensive study on the seismic response of underdesigned low rise reinforced concrete buildings with seismic isolation are