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Low-cycle fatigue effects on lifetime of circular bridges piers considering rocking-enable shallow foundation

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Abstract

Cyclic loading during large earthquakes induces low-cycle high-amplitude strain in longitudinal bar of bridge column piers. This phenomenon is known as low-cycle fatigue, which reduce design life of column pier due to longitudinal bars fracture. After recent large earthquakes (e.g. Christchurch in 2011), resilience became a public demand instead of conventional design methods. While conventional design methods mostly relay on plastic hinge formation in column pier as an earthquake resistance system (ERS), modern methods try to reduce demands on ERS in order to assure of resilience. Rocking shallow foundation (RSF) is an earthquake demand reduction system. This research demonstrates how RSF, prevent column pier design life reduction due to low-cycle fatigue. The obtained results confirm that RSF needs significantly smaller foundation design moments that could result in avoiding costly pile foundation and more importantly, extend life of column piers more than conventional design strategies.

Keywords: Low-Cycle Fatigue, Buckling, Shallow Foundation, Bridge

1. INTRODUCTION

After a large magnitude earthquakes (e.g., Christchurch 2011, L'Aquila 2012) it has been realized that although, conventional newly designed bridges are able to meet life safety performance limit state, but most of these bridges classify unsafe and needs to demolish because of unrepairable damages. Among them, low-cycle fatigue is in the first place of post-earthquake assessments and results shows that nearly entire lifetime of bridges could be consumed due to only one earthquake, despite of relatively low detectable damages in post-earthquake assessment of structure [1]. These damages necessitate expensive repairing or demolition-rebuilding, which leads to financial losses. So there is a growing call for a more resilience structures including bridges.

During nonlinear response of concrete elements, longitudinal bar rupture is primary failure mechanism [2]. Low-cycle fatigue is defined as failure in material due to relatively small number of load or deformation cycles (<1000) and typically involves large strain that exceeds the elastic limit [3]. This phenomenon which lead to longitudinal bars rupture, in relatively few high-amplitude strains, is unavoidable, unrepairable, and unfortunately is common in large earthquakes. Low-cycle fatigue damage is un-avoidable. This is because the strategy of current seismic design standards allow structures to experience some levels of nonlinear mechanism, even fully plastic hinge in column piers. These mechanisms impose tension-compression burdening to longitudinal bars which inherently must be bear by them based on their definition. Damages induced by low-cycle fatigue is also unrepairable because longitudinal reinforcement bars suffer from tension or shear cracks during high-amplitude strains results from loading. Avoiding these two inherent deficiency of long longitudinal bars in columns pier is a motivation of this research.

As mentioned above, conventionally designed earthquake resistance systems (ERS), rely on ductility concept. But, as an alternative design methodology, many researches tried to investigate resilience methods like column pier on rocking foundation [4]. This system shift earthquake demands from column pier to rocking foundation. So, nonlinear deformations develops in sub-foundation soil rather than column pier. Figure 1 schematically shows that