Nonlinear Finite Element Analysis of Non-Structural Components Anchorage under Extreme Wind Loads

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1 Abstract

Steel anchors are widely used to fasten structures and non-structural components (NSC) to rooftop concrete slabs, especially in high-rise buildings. However, several NSC anchorage failures have been observed in the last decades upon the incidence of hurricanes, resulting in loss of service in essential buildings, detachment of the component, and water intrusion, all of which significantly delayed the recovery of the affected communities. From the observed failures, three main mechanisms were identified: steel rupture, concrete breakout, and bond failure. In this study, a three-dimensional nonlinear finite element methodology using a concrete damaged plasticity approach is developed to predict the response of steel anchors installed into a concrete slab. The methodology is verified with experimental results for each failure mechanism and subsequently used to study the effect of service-load concrete cracking and elevated temperatures – common conditions at rooftop level – on the response of the anchors. In addition, a first-of-its-kind multi-scale model of an NSC and its anchorage is created using the proposed methodology to investigate its behavior under dynamic hurricane load application. The findings suggest that these conditions can compromise the performance of NSC or promote its failure.

Keywords: Anchorage to concrete; hurricane loading; finite element simulation; multi-scale modeling.

2 Introduction

The accelerated development of coastal cities and metropolises has exposed an ever-larger number of commercial and residential buildings to natural hazards, such as hurricanes and tropical storms [1, 2]. Consequently, rooftop non-structural components (NSC, e.g. HVAC units, solar panels, AC/DC converters) failures have been repeatedly reported [3] and significantly hindered the recovery of communities. The estimated repair costs associated with these events can reach 50% of the total storm repair cost [4], which can exceed tens of billions of dollars [5]. Hurricane Katrina alone caused an estimated $36bn damage to NSC [6]. Recent research indicates that climate change has been raising the destructiveness of these events [7].

Analyzing past NSC anchorage failures, potential causes were identified, including the presence of concrete cracks induced by the service load, long-term elevated temperature from exposure to solar radiation, and the dynamic nature of the wind load [8, 9]. Concrete cracks are commonly induced by

https://doi.org/10.2749/newyork.2019.1905