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ScienceDirect

Procedia Engineering 210 (2017) 326–333

Procedia Engineering

www.elsevier.com/locate/procedia

6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading, PROTECT2017, 11-12 December 2017, Guangzhou (Canton), China

Behaviour of undercut anchors subjected to high strain rate loading

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Abstract

The increase in global terrorism has culminated in the protection of high profile buildings and monuments against the effects of blast loading – a high strain rate loading event. Depending on the design basis threat, the level of protection can range from façade and fenestration upgrade to retrofit of the structural systems. Post-event surveys after the Oklahoma City Bombing and other similar events indicated widespread window glass damage. Most of the injuries reported were attributed to the glass shards, especially in buildings proximate to the target building. Thus, the least protection recommended for buildings is to retrofit window glass against glass shard injury. When the window retrofit consists of anti-shattered film anchored to the window frames, blast loads are transferred to the window frames and ultimately to the structure of the façade through discrete window retention steel anchors.

A lot of research has been conducted to investigate the response of upgraded windows however little research is available on the load transfer from the window frames to the façade structure through the window retention anchors. This paper presents results from a finite element analysis program to investigate the tensile behaviour of post-installed undercut anchors under high strain rates. Strain rates varying from 10^{-5} to 10^{3} s^{-1} were applied to single undercut steel anchors embedded in concrete blocks. Anchor diameters of 12 mm, 16 mm and 20 mm with various embedment depths were selected for the analyses. The analyses results show increased tensile capacity of undercut anchors with increase in strain rate. The maximum dynamic increase factor for tension of undercut anchors at strain rate of 10^{3} s^{-1} was about 1.60 for the anchors investigated.

Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading.

Keywords: Undercut anchor; strain rate; failure mode; finite element modelling; tensile load.

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Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading.
10.1016/j.proeng.2017.11.084

1. Introduction

The Bishopgate Bombing of 1993 in London, the Oklahoma City Bombing of 1995, the Australian Embassy Bombing in Jakarta in 2004 and many other terrorist attacks around the world have shown extensive damage to building façade elements and fenestration. The debris and glass shards are the primary source of injury and fatality to the building occupants and the population outside of these buildings. In a post-event assessment conducted by the Oklahoma State Department of Health after the Oklahoma City Bombing, the majority of injuries to building occupants were reported to be from window glass shards [1,2,3,4]. Over 40% of the glass injuries were to people within 3 m of walls with glazing [3,4].

Eliminating the glass hazard will essentially mitigate the risk of injury and fatality to the building occupants and the population outside the buildings. Many researchers have investigated the effects of blast loading on window fenestration and proposed many methods to upgrade window glazing in existing buildings and use of laminated glass and polycarbonate in new buildings to improve fenestration response to blast loading. The window upgrade through anti-shatter film anchorage and laminated glass or polycarbonate transfers blast loading from the glazing to the window frames and ultimately to the structure of the façade through discrete window retention steel anchors. In standard construction, the connection of window frames to the structure of the façade is achieved by the use of steel screws or nails, depending on the structure of the façade. These screws and nails, however, lack the resistance to adequately transfer blast loading from the glazing units to the façade structure. Moreover, the behaviour of steel anchors under high strain rates of loading such as encountered in blast is not adequately investigated.

Steel anchorage techniques are widely used in construction for joining steel components to concrete or masonry structures. Post-installed anchors such as undercut anchors are increasingly used in construction and for blast window retrofit applications due to their flexibility and ease of installation [5,6]. Undercut anchors are shown to safely and reliably resist dynamic loads and are thus suitable for applications that require high level of safety such as in nuclear power plants [7]. Several researchers have investigated the tensile and shear behaviour of post-installed anchors under static load [8–14]. The researchers investigated different parameters such as: effect of concrete compressive strength, anchor diameter, bond stress, embedment depth, anchor spacing, load direction and concrete cracking on the anchor resistance. However, limited research work is available on the behaviour of post-installed anchors under dynamic loads [15–18]. Rodriguez et al. [16] investigated the behaviour of cast-in-place and post-installed (expansion and undercut) anchors in concrete subjected to static and dynamic tensile load. The authors concluded that the normalized tensile capacity under dynamic load increased by 30% compared to the normalized capacity under static load [16].

Mahrenholtz and Eligehausen [17] investigated the qualifications of undercut anchors in nuclear power plants subjected to seismic dynamic tensile load. Two conditions: service and extreme cracked conditions, were investigated. The authors found that the seismic dynamic load increased the cumulative displacement of the anchor causing steel failure [17]. In another research, Mahrenholtz and Eligehausen [18] applied cyclic tension and shear loads to undercut anchors used in nuclear power plants and reported that crack widths affected the strength of the anchors subjected to tensile load and no significant influence on the anchor strength under shear loading. The authors observed concrete failure mode under cyclic tensile loading and steel fracture failure mode under cyclic shear loading [18].

The research reported in this paper aims to investigate the tensile behaviour of undercut anchors subjected to strain rates ranging from low (static) strain rate of 10^{-5} s^{-1} to high strain rate of 10^{3} s^{-1}. A general purpose finite element analysis program - LS-DYNA was used to model the steel undercut anchor–concrete anchorage system. A prescribed motion was applied to the steel anchor to simulate the required strain rate in order to investigate the behaviour of the anchorage system including load-displacement behaviour, failure modes, and ultimate load and displacement capacity of the anchors.

2. Background

Undercut anchors are mechanical anchors with carbide tipped segments used to undercut concrete during the installation process. The anchor installation can be accomplished in one of three techniques: load-controlled, displacement-controlled or torque-controlled [8,19]. According to Hilti, there are two types of undercut anchors: