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Strain rate behaviour of adhesive anchors in masonry

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ABSTRACT

Global terrorism has led to increasing use of anti-shatter film to upgrade window glass to mitigate the hazard associated with glass breakage. When the anti-shatter film is anchored, blast loading is transferred to the structure of the façade through steel anchors. Adhesive anchor are commonly used to fasten window frames to concrete and masonry elements. However, their behaviour in masonry is not very well researched.

This paper presents an experimental program to study the behaviour of steel anchors in masonry substrates under impact loading. The adhesive anchor-substrate systems consisted of steel rods bonded to clay brick or concrete masonry units with an epoxy-based adhesive. Two penetration angles of 45° and 90° and different embedment depths were investigated. The adhesive anchor-substrate systems were tested in a specially designed drop mass test frame.

Dynamic increase factors were recommended for design of anchors embedded in masonry under blast loading. The test results show that clay brick substrate is very brittle and leads to a dynamic increase factors of less than 1.0. For steel anchors in concrete masonry substrate, dynamic increase factors of greater than 1.0 are recommended for design of adhesive anchor-substrate systems under high rates of loading such as blast and impact.

1. Introduction

The global spate of terrorism has resulted in increased blast vulnerability assessments and retrofit of existing buildings to increase their blast resistance. At a minimum, window glass in buildings is upgraded by applying anti-shatter film to window glass to reduce injuries and fatalities caused by glass shards. When blast pressure waves from an explosion impinge on window glass it is likely to break into shards ("knives and daggers") which have a potential to cause injury and fatality to building occupants (Fig. 1). According to Mallonee et al. [1], 66% of respondents to a survey conducted by the Oklahoma State Department of Health after the attack on Alfred P. Murrah Building attributed their injuries to glass shards while Norville et al. [2] reported that over 40% of the glass injuries were suffered by people within about 3 m from walls with glazing. Thus, eliminating the hazard associated with glass breakage is essential for limiting injury and fatalities to building occupants in an explosion event. Whether in the target or neighbouring buildings, application of anti-shatter film to window glass can effectively mitigate glass shard injuries.

Anti-shatter film is a polyester-based material with high tensile strength and flexibility. When applied to window glass, anti-shatter film binds glass shards (Fig. 1) together and depending on the anchorage method can be thrown into the interior of the building or transfer blast loading to the window frames. There are, principally, three methods for applying anti-shatter film to window glass: daylight, wet-glazed and mechanical anchorage application methods. The daylight application method consists of bonding the anti-shatter film to the visible area of glass and terminating a few millimetres from the window frame. In the wet-glazed application method the anti-shatter film is bonded to the visible glass area and attached to the window frame with a high strength structural adhesive while in the mechanical anchorage method the anti-shatter film is bonded to the glass pane and mechanically fastened to the window frame with screws and battens [3].

When blast pressure waves from an explosion impinge on a glass window retrofitted with anti-shatter film applied by the daylight method, the glass breaks at approximately the same load level as the unretrofitted glass. Unlike the unretrofitted glass which breaks into "knives and daggers" (Fig. 1), the glass shards are bound together in the anti-shatter film and driven into the interior

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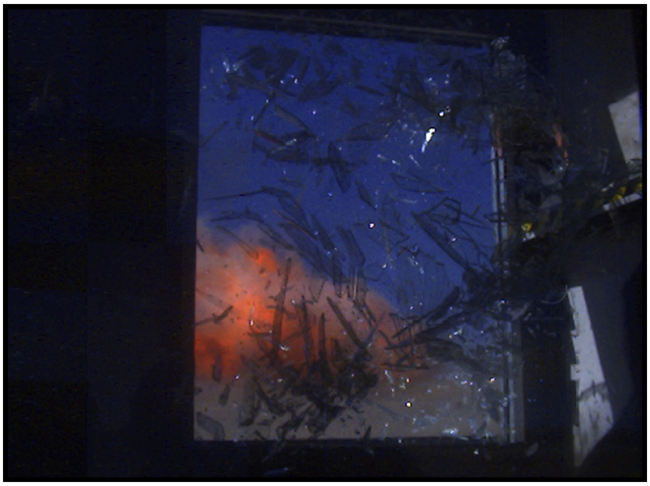

Fig. 1. Window glass shards under blast loading.

of the building with potential to cause blunt trauma to building occupants. When the anti-shatter film is attached to the window frame by the wet-glaze or mechanical anchorage application method, the blast load is transferred to the window frame and ultimately to the structure of the building facade. In existing buildings the anchorage of the window frames to the structure of the facade is often inadequate to resist the imposed loads. Failure of these anchorages is accompanied by dislodgement of the window frame, together with retrofitted glass, and driven into the interior of the building with capacity to injure occupants. It is recommended that window retrofit with anti-shatter film by the wet-glaze or mechanical anchorage application method be accompanied by upgrade of anchors attaching frames to the structure of the facade.

Post-installed anchors are good candidates for attaching window frames to the structure of the building facade because of their relatively lower cost in comparison with cast-in anchors, versatility, and ease of installation. Post-installed anchors are classified depending on the method of load transfer as mechanical, adhesive, or grouted anchors. The mechanical anchors transfer load by friction, keying or bearing whereas the adhesive and grouted anchors transfer load through bond between the steel anchor and bonding agent and between bonding agent and substrate material and micro-keying into cracks and pores of the substrate material.

The bonding agent in grouted anchors is a cementitious grout whereas for adhesive anchors the bonding agents are epoxy-based, polyester-based, or vinylester-based resins. Most of the resins are two-part; consisting of the resin and a hardener (accelerator). Depending on the method of dosage, adhesive anchors can be further sub-classed as cartridge or capsule systems.

Until recently, the literature contained few references to the performance and behaviour of post-installed anchors under different loading conditions [22,32,33]. The little information available is provided by the anchor manufacturers as guidelines to designers. The information is based on static test data with appropriate safety factors applied to give design data. Hardly any information is available for post-installed anchor performance under dynamic loading in concrete masonry and clay brick masonry substrate materials.

2. Objectives

The primary objective of this study is to investigate the dynamic behaviour of adhesive anchors in masonry substrate and to develop guidelines for the design and analysis of post-installed anchors under blast and impact loading. Specifically, the project was designed to:

1. investigate the dynamic response of adhesive anchors embedded in concrete block, and clay brick masonry,
2. compare the test results with the static strength results, and
3. establish dynamic increase factors (DIF) for use with static strength data to determine dynamic strength of adhesive anchors in concrete and brick masonry substrates for impact and blast load design.

The test program was developed for single masonry units and not sub-assemblages as is common in masonry construction. The results, however, will be useful in developing procedures for design of adhesive anchors in masonry structures.

3. Background

In the past two decades or so, investigations on the behaviour of adhesive anchors has concentrated on the effects of anchor diameter, embedment length, type of bonding agent, edge distances and spacing of anchors in a concrete substrate [4–8]. Several models have been proposed in the literature for determining the failure load of adhesive anchors in concrete. These models, in most cases, are designed for specific products and thus have limited applicability.

Very limited information is available on the dynamic behaviour of adhesive anchors in masonry substrate. Some information in the form of design tables are available in manufacturer literature [9,10] for adhesive anchor design under static loading conditions. Chen [11] carried out static testing on adhesive anchors embedded in concrete masonry and brick masonry and reported three typical failure modes: steel anchor fracture, combined cone-bond failure, and substrate material splitting and cracking. The author reported that smaller diameter steel anchors (6.4-mm diameter) achieved higher normalised strength in comparison to larger diameter steel anchors (9.5-mm diameter) in concrete masonry substrates for the same embedment depth. Similar results were reported for adhesive anchors in hollow clay brick substrate. Increased embedment depth generally led to increased failure load in both concrete masonry and clay brick substrates.

Hatzinikolas et al. [12,13] investigated the capacity of post-installed anchors (adhesive and expansion anchors) under pure tension, pure shear and combined shear and tension loading in concrete block and burned clay brick masonry substrates. Failure of the drilled-in anchors occurred in either the anchor or the masonry. The authors reported that the capacity of drilled-in anchors increased with increase in anchor diameter. The shear capacity of adhesive anchors was limited by the strength of the steel anchor and the base material. The capacity was however, adversely affected by small edge distances. At edge distances greater than or equal to 250 mm, the full shear capacity of anchors was developed. However, at edge distances of 50 mm the shear capacity reduced by about 50%.

The tension capacity of adhesive anchors was reported to be higher than that for expansion anchors of same size. The tension capacity of anchors depends on embedment depth and anchor size (diameter). For combined shear-tension, the failure mode depends on the applied tension load with anchor shear failure occurring near the masonry surface when the applied tension was low and masonry substrate splitting and cracking at higher tension loads [12,13].

Under blast loading, steel anchors and the substrate material are subjected to very high strain rates (10–100 s^{-1}). At high strain rates the apparent strength of both steel and substrate materials