Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 192 (2017) 177 – 182
Procedia Engineering
www.elsevier.com/locate/procedia

TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport

Design and analysis of blast loaded windows

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Abstract

The increasing number of terrorist attacks brings the need to research on the blast resistance of buildings and transportation systems. Most of these attacks are lastly concentrated on the so called "soft targets" as railways stations, airports, bus stations, shopping centers, etc. In them, high vulnerability is frequently given by fenestrations or novel glass façade systems in general. In this regard, the paper is focused on the analysis of the dynamic behavior of blast loaded glazing windows. Given a reference specimen geometry and wood or plastic frame representative of traditional or new fenestrations respectively, the blast performance of such system is assessed via analytical SDOF calculations. Refined Finite Element (FE) numerical simulations are then presented and discussed, as a preliminary outcome of further exploratory investigations. Following the actual research study, experimental tests will be in fact carried out on the same fenestration systems.

Peer-review under responsibility of the scientific committee of TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport

Keywords: blast loads; dynamic structural performance; glass; SDOF; Finite Element numerical model

1. Introduction

The crucial role of blast resistance in design of buildings and constructed facilities rapidly increased in last years, with the increment of terrorist attacks involving explosives. Most of those attacks are concentrated on the so called "soft targets" as railways stations, airports, bus stations, shopping centers etc. During any blast-related event, buildings can be damaged or collapse, hence defense of occupants and avoidance of possible injured people is of

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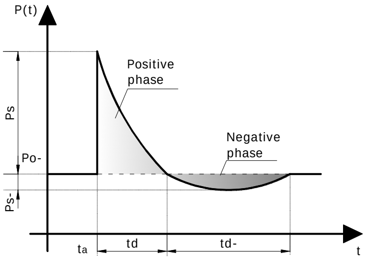
Peer-review under responsibility of the scientific committee of TRANSCOM 2017: International scientific conference on sustainable, modern and safe transport
doi:10.1016/j.proeng.2017.06.031

crucial importance. Various loading configurations are possible, including direct exposure to blast loading, impact of fragments and debris, impact with surroundings when either a structural element or a person is impelled by the blast waves, or structural collapse. In any case, the most vulnerable part of the building is represented by fenestrations (i.e. windows, doors, skylights) and glass façade systems, due to the fact that they are usually not designed as blast-resistant.

In this research study, the blast resistance of old wooden or new PVC windows for office buildings is assessed. Setup features and major results here discussed are aimed to provide support for further open air experimental tests, planned on the same fenestration systems.

2. Blast load description

The real detonation of a spherical charge runs in such a way that the detonation wave extends from the centre of the charge in all directions. Its front strikes against the surrounding environment at the charge brim. From this point the blast wave extends and after the gas explosions the reflected one is distributed. For design purposes, the blast wave due to an explosive event is usually described in the form of a time-pressure profile with two distinct phases – i.e. the positive and negative one. Its actual decaying form is approximated by a regular shape having a positive peak (being dependent on the charge weight, distance, height) and dropping below the ambient pressure in the range of few milliseconds.



Legend

t	*time after the pressure wave arrival*
P_s	*peak pressure*
P_0	*ambient pressure*
t_d^+	*duration time of the positive phase*
t_d^-	*duration time in the negative phase*

Fig. 1: Time-pressure profile of a typical blast wave

3. Standards for design and testing of blast loaded windows

3.1. Recapitulation of existing EU design regulations

Design of blast loaded glazing windows currently represents an issue of crucial importance. However, no comprehensive standard actually existing in Europe for design and verification of blast loaded windows and façades.

In the EU, the generally accepted, reference standard for design is represented by EN 1991-1-7 “Actions on structures - Part 1-7: General actions - Accidental actions”. Within the general actions for design, blast load should be considered as accidental. The standard itself, however, highlights that loads from “external explosion, war and terrorist activity” are not covered by the design provisions. The same EN 1991-1-7 deals with the topic only in Section 5 “Internal explosion”. Explosions shall be in fact taken into account in the design of all the components of a building or a civil engineering facility where gas is burned or regulated, or where explosive material such as explosive gases, or liquids forming explosive vapor or gas, are stored or transported (e.g. chemical facilities, vessels, bunkers, sewage constructions, dwellings with gas installations, energy ducts, road and rail tunnels). Annex D of EN 1991-1-7 hence provides guidelines for specific types of explosions, including dust or gas explosions, as well as explosions in tunnels, rail or road constructions. Finally, the standard defines the reference parameters for the powder of different materials such as brown coal, cellulose, coffee, corn, grain, milk powder, mineral coal etc. An updated version including Annex A1 to EN 1991-1-7 is available from April 2015, which makes corrections in formulas of original Sections D.1 - D.3. A novel Section D.4 “Explosion of dust, gas/vapors in pipelines” is also included in it.