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Dynamic response of lightweight wood-based flexible wall panels to blast and impulse loading

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HIGHLIGHTS

- E-glass FRP-reinforced wood wall panels were shown to perform well under blast loading.
- Laboratory testing of panels confirmed their ductility and damage resistance.
- Hysteretic damage model was successfully fitted to the measured load-deformation response.
- Dynamic simulations of blast were used to generate pressure–impulse diagrams.

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ABSTRACT

Recent research led to the development of lightweight, rapidly erected, structural wall panels constructed from solid sawn 2 × 4 softwood lumber studs and plywood sheathing coated in e-glass reinforcing. The objective of this study was to experimentally and numerically assess the dynamic blast response of these FRP-reinforced wood panels and explore the development of pressure–impulse (PI) diagrams based on a maximum deflection damage criterion. The results of five different field blast tests on the wall panels are reported. Laboratory pseudo-static bending tests of panels under fully reversed loading were performed to determine the panel's load-deformation properties. A hysteretic load-deformation model was calibrated to the blast and pseudo-static bend data and used in a nonlinear, numerically integrated SDOF dynamic response model. PI diagrams were generated using both linear and nonlinear dynamic analysis. The results of this study indicate that the blast response of the wall panels can be reasonably represented with a nonlinear SDOF dynamic model. However, the model results are sensitive to the parameters of the hysteretic model. The results also indicate that PI diagrams are a potentially valuable tool for assessing damage under a variety of blast loads.

1. Introduction

Recent research efforts led to the development of lightweight, flexible, fiber-reinforced polymer (FRP)-coated wood wall panels for the construction of rapidly erected blast-resistant structures [1]. These panels are constructed from solid sawn No. 2 SPF 2 × 4 softwood lumber studs and 9.5 mm thick CDX plywood sheathing, both coated with e-glass fiber reinforcement to provide enhanced strength and ductility. The coated sheathing was attached to the coated 2 × 4 studs with 64 mm long, 3.3 mm diameter, pneumatically driven Bostitch Hurriquake® nails spaced at 76 mm on center to form a 1.22-m by 2.44-m wall panel with two interior studs located at 40.6 cm on center from the outside of the panel. Results of initial blast testing and pseudo-static bend testing demonstrated that these panels exhibit significantly greater strength, ductility, and energy absorption capacity than conventional, unreinforced wood-framed construction. However, it is necessary to better quantify the level of blast protection provided by these reinforced wall panels by examining damage for a wide variety of impact conditions.

The response of the panel to a single threat can be obtained through a time history analysis using a single-degree-of-freedom (SDOF) system, which provides a single response mode. The properties used to describe the SDOF model are converted from an actual structural component to equivalent mass, damping, and resistance terms based on the shape of the response mode [2].

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A more expedient method for predicting damage to the wall panels can be the use of pressure–impulse (PI) diagrams. A PI diagram is an iso-damage curve that illustrates all combinations of pressure and impulse that produce a given level of damage in a structure or structural component [3]. Pressure and impulse are defined from the pressure–time curve of a blast wave, shown schematically in Fig. 1, where pressure is the peak positive pressure, and impulse is the area under the pressure–time curve for the positive phase of the blast wave.

Early PI diagrams were derived empirically from observed damage in brick houses by bombs dropped on the United Kingdom in the Second World War [3]. These diagrams were then used to predict damage to other houses, small office buildings, and light-framed industrial buildings [4]. Today, PI diagrams are most commonly generated numerically using SDOF analyses with a blast wave as the loading input [4,5].

When PI diagrams are generated with maximum deflection as the damage criterion for a structural component, the well-known PI curve is produced as shown in Fig. 2 [3,5]. The traditional PI diagram has three regions of loading: impulsive, dynamic, and quasi-static. The impulsive region of loading consists of blast waves of very short duration with the peak response occurring after the positive phase of the blast wave. In the dynamic region of loading, the peak response of the structural component occurs close to or at the same time as the positive phase duration of the blast wave. The quasi-static region of loading has long positive phase durations with the peak response occurring before the end of the positive phase.

The blast waves can be approximated using empirical curves obtained from the Unified Facilities Criteria Manual 3-340-02 [6] (released to the public by the United States Department of Defense) as done by Oswald [7] for concrete and steel structural components and Shi et al. [3] for reinforced concrete columns. Research was also presented using rectangular, triangular, and exponential pulse loads defined only by the peak pressure and impulse [4,5,8,9].

The objective of this study was to experimentally and numerically assess the dynamic blast response of the lightweight, highly flexible FRP-reinforced wood panels developed by Dumais [1], and explore the development of PI diagrams for these panels based on a maximum deflection damage criterion. Dynamic response simulations were based on wall properties developed from field blast tests and laboratory pseudo-static bending tests of panels under fully reversed loading. A hysteretic load-deformation model was calibrated to the blast and pseudo-static bend data and used in a nonlinear, numerically integrated dynamic response model.

2. Blast testing

During the summers of 2007 and 2008, blast tests were conducted on the e-glass coated wood wall panels in steel reaction frames illustrated in Fig. 3. The objectives of the blast tests were to demonstrate the effectiveness of the coated wall panel and to gather experimental data for improved model creation and verification. These tests were conducted at Fort Polk, Louisiana, and Eglin Air Force Base, Florida.

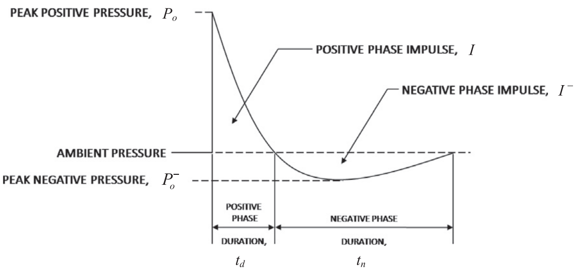

Fig. 1. Typical pressure–time curve for a blast wave.

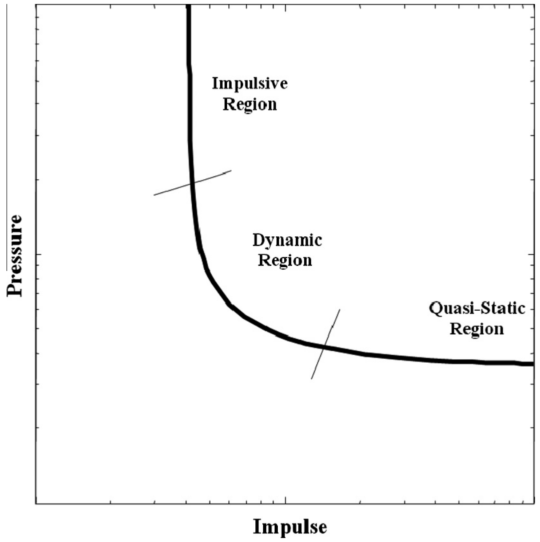

Fig. 2. Regions of PI diagram.

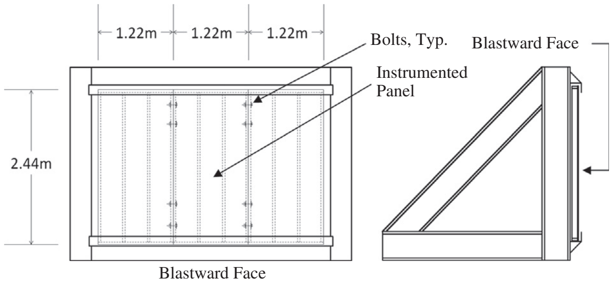

Fig. 3. Wall panel in steel reaction frame.

The tested specimens consisted of three wall panels joined together at the outside studs with four through bolts between each pair of panels to form a wall section as shown in Fig. 3. This was done to simulate a panel as part of a wall system in a building and to minimize any pressure edge effects on the instrumented center panel. These wall sections were then placed in steel channels on the steel reaction frames, which held the panels in place during the blast but did not limit the rotation of the top and bottom of the wall section. All panels were fabricated approximately one month prior to the blast tests.

Displacement versus time and reflected pressure versus time data were collected for the five blast tests listed in Table 1 to compare with the linear and nonlinear SDOF analyses described in Section 5. The specific explosive charge weights associated with threat levels I and II are defined in the Unified Facilities Criteria 4-010-02

Table 1
Summary of analyzed blasts.

Blast	Date	Threat	Standoff
1	July 2007	I	47 meters
2	July 2007	I	24 meters
3	July 2007	II	23 meters
4	July 2007	II	10 meters
5	August 2008	II	10 meters