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Piled-up configuration design of decelerators in drop test for aircraft seats

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ABSTRACT

To ensure the safety of aircraft seats, it is mandatory to perform a dynamic test under an acceleration pulse prescribed by the Federal Aviation Administration. This paper proposes a design method for a decelerator. The design involves the piling up of paper sandwich panels for use in a drop test. First, a quasi-static compression test of paper core sandwich panels was conducted to examine the displacement–load curve, from which the absorption energy of the panels was deduced. Then, a piled-up configuration of panels was designed via a method based on the rigid, perfectly plastic, locking model proposed by Reid and Peng—in which the dynamic effect of the panel is considered when the core height is constant or variable—under the assumption that the decelerator crushes in descending order starting with the upper panel. Second, a drop tower test was conducted to determine whether the designed decelerator achieves the required acceleration pulse. The results of the proposed method were compared with those of the decelerator design method by Shoji et al. based on the dynamic absorption energy of the panels. The test results indicate that decelerators designed with the proposed method—based on the absorption energy derived from a simple static compression test and employing the effect of dynamic crushing—can produce identical results to those designed with the method by Shoji et al., which is based on the absorbing energy derived from a complicated dynamic compression test.

1. Introduction

The safety of air- and rotorcraft passengers must be ensured during an emergency landing, when unexpected and irregular circumstances may prevail. In the U.S.A., therefore, the Federal Aviation Administration established the Federal Aviation Regulations. On the basis of these regulations, many other countries have also produced Airworthiness Standards. Aircraft structural design is required to comply with these standards, and several qualification tests must be conducted to verify airworthiness.

Among these tests, an impact test is essential to estimate the crashworthiness of a craft. For example, in 1997, Bou and Vaughan [1] presented impact drop tests for light planes hanging by a cable. In 2002, Jackson et al. [2] conducted drop tests with full-scale helicopters as part of the Advanced Composite Airframe Program and measured the dynamic load applied to a pilot dummy. In 2004, Jackson et al. [3] published a historical review of full-scale crash tests and simulations of aircraft and rotorcraft conducted at the NASA Langley Research Center.

Aircraft passenger and crew seat designs must carry out a dynamic impulse acceleration test prescribed by the Federal Aviation Administration [4]. Desjardins and Shane [5] published an overview of the structural testing of public helicopter seats, i.e., static test, dynamic test, and test methods and facilities. Carpenter et al. [6] described dynamic tests under low-level crash conditions with vertical and horizontal components.

There are two types of dynamic tests: drop tower tests and sled tests. The former involves a vertical initial velocity, whereas the latter involves a horizontal initial velocity. In the drop test, the object fastened to the test seat is dropped onto a decelerator to induce the required acceleration pulse [5]. The decelerator is usually made of honeycomb panels piled-up in a pyramid shape. The decelerator shape design must be precise to yield the necessary acceleration pulse. It is therefore important to establish a suitable design method for the honeycomb panels.

Shoji et al. [7] presented a decelerator design method consisting of three piled-up honeycomb paper panels based on the energy

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Nomenclature

a	acceleration [g]
A_n	area of nth layer panel of decelerator [m^2]
d	displacement [m]
D	depth of sandwich panel [mm]
E	energy absorption of sandwich panel [J]
e_a	energy absorption per unit area [J/m^2]
E_P	potential energy of falling body [J]
E_r	energy calculated by required time history [J]
E_{all}	required energy absorption [J]
g	gravitational acceleration [m/s^2]
$G_{\max}$	max. deceleration [g]
h	drop height of falling body [m]
H	height of decelerator [cm]
l	core height of sandwich panel [mm]
M	mass of falling body [kg]
M_d	mass of decelerator [g]
N	Nth layer panel of decelerator
N_{core}	effective number of core cells
P	peak load of sandwich panel [N]
t	time [s]
t_r	max. deceleration time [s]
u	displacement [mm]
v	velocity [m/s]
v_0	collision velocity [m/s]
V	compression rate [mm/min]
W	width of sandwich panel [mm]
δ	max. displacement of sandwich panel [mm]
ε_D	densification strain
ρ_0	density of core before crushing [kg/m^3]
ρ_D	density of core when fully crushed [kg/m^3]
σ_P	plateau stress [N/m^2]
σ_D	densification stress [N/m^2]

absorption derived from a dynamic crush test. They conducted a dynamic drop test for the designed accelerator and found good agreement with the required acceleration pulse curve.

In this paper, we propose a design method for a piled-up honeycomb panel based on the energy absorption derived from a quasi-static crush test that is simpler than the dynamic crush test used by Shoji et al. [7]. For the construction material of the honeycomb panels, we used a low-cost and easy-to-process paper sandwich panel, known as a hat cushion [8]. First, the quasi-static compression test was conducted, from which a displacement–load curve was derived. Then, the static energy absorption was calculated from the area under this curve. Next, we designed the cross-sectional area of each piled-up panel by comparing the energy that must be absorbed by each decelerator panel, counting back from the required acceleration curve and the absorbed energy of the sandwich panel being used.

In the analysis, two cases are considered. In the first case, the dynamic crush effect of a sandwich panel is neglected, and in the second case, the dynamic crush effect is considered taking into account the dynamic theory proposed by Reid and Peng [9]. The panels are assumed to crush in descending order starting with the upper panel. However, because of the design, the lower panels have a smaller cross-sectional area than the upper panels. As a result, the lower panels crush faster than the upper panels. To avoid this behavior, we varied the height of each panel such that the decelerator crushed the panels in descending order starting with the upper panel, even if the cross-sectional areas of the lower panels became small. Consequently, the core heights of the upper panels were greater than those of the bottom panels. We found that this method worked when, for example, we used aluminum honeycomb panels. However, as yet, we have not been able to obtain a precise relationship between the core height and peak load for the hat cushion paper sandwich panels.

Finally, a drop test was conducted to verify the proposed design method. In this test, two test decelerators—considering and neglecting the dynamic crush effect—were used. The decelerator test results that considered the dynamic crush effect were in good agreement with the prescribed acceleration pulse curve.

2. Piled-up design with constant core height panels

First, we propose a decelerator design method for a sandwich panel of constant core height (thickness).

2.1. Test panel

Hat cushion paper sandwich panels (Shin Nippon Feather Core Co., Ltd., Japan [8]) were used as test panels (see Fig. 1). In general, a honeycomb panel has a core whose cross-sectional shape is a regular hexagonal grid, whereas a hat cushion panel has a regular triangular grid of height 10.5 mm. The height (thickness) of the panel l was 25 mm.

To obtain material properties of the test panel, a quasi-static compression test was conducted with three square test panels of 55 mm length. Table 1 shows the test conditions and sizes of the test pieces. In this table, the effective number of core cells in the test specimen is presented as N_{core}, the cells of which are held in a triangular prismatic shape. Fig. 2 shows some examples of displacement–load diagrams measured in the test. In this figure, it can be seen that the test panel was compressed up to 5 mm, because the final displacement was almost $d = 20$ mm for the three panels.

Next, the energy absorption of the test panel was obtained as the area under the measured displacement–load curve by dividing the area under the curve into trapezoids 1.25 mm wide in the abscissa direction and by taking the summation of each trapezoidal area as the approximate area under the curve. In this case, the

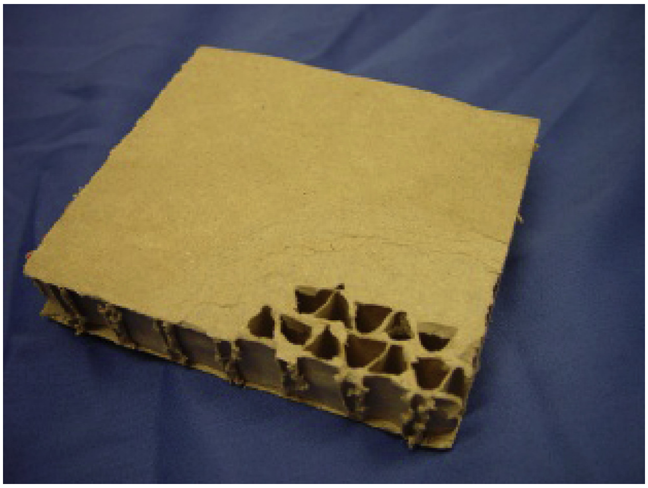

Fig. 1. Test sandwich panel, hat cushion.