Impact Resilience of a Fiberglass Composite Panel

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Background

With the growing population and changing climate, it has become more relevant to build structures using materials that will withstand a variety of stresses over their lifespan. Limiting damage induced on structural materials by impact from foreign objects is a design limit that has garnered more focus in recent years. This type of damage can be the result of flying debris during a hurricane, impact from material due to an explosion or projectile, or a swinging object during urban construction.

Composite materials made of fiberglass are being specified in the structural engineering industry as a replacement for traditional materials (e.g., steel and aluminum) due to their high strength-to-weight ratio, ease of constructability, and suitability for harsh environments (Oakley, 2013). Their increasing use had created the need to expand the knowledge base surrounding how they respond to different scenarios and loadings, as suggested by Luo (2000). Strongwell, a company in Minnesota, produces composite structural materials for demanding downstream applications, including storm-proofing for commercial and domestic properties in hurricane afflicted regions. Their products are quoted to be "stronger than steel and aluminum, pound-for-pound in [the] lengthwise direction" (Oakley, 2013).

Objectives

The primary objective of this undergraduate research opportunity (UROP) was to gather data through impact testing of fiberglass composite specimens using a drop tower. Specifically, the stiffness of the material and the energy dissipation upon impact were investigated. A limited test program was conducted to quantify force, displacement, and acceleration values for a single 3 in. x 24 in. DURASHIELD panel that was 42 in. long and had a mass of 28 lb.

Figure 1. Drop Weight Tower

Figure 2. Test Setup

Methods

A 16 ft tall drop weight tower housed in the Civil Engineering building, shown in Figure 1, was used to apply the impact loading on the specimen. The tower crosshead that drops had a mass of 279 lb. The mass of the crosshead was optimal because it was approximately 10 times greater than that of the specimen, which was discussed by Feraboli (2006) as it related to data collection recommendations for drop tower impact testing of composite panels. During these UROP tests, four force sensors were in-line to measure impact force (PCB Piezotronics, 2018) and an external accelerometer was used to measure vertical acceleration of the drop tower crosshead (BDI, 2019). Additionally, a 2 in. linear variable differential transformer (LVDT) was used directly under the center of the panel to measure the displacement upon impact (CDI-Schaevitz, 2020). Two separate trials were run on the specimen, both from a drop height of 6.125 in., to evaluate the impact resilience and structural behavior.

This project involved preparing the test setup (Figure 2), conducting several experiments, and analyzing data. Setup and testing followed the procedure described by Alemi-Ardakani et al. (2013), where the four corners of the specimen were clamped during the impact event. The impact energy was kept constant; the force, acceleration, and displacement history during impact were collected in an identical manner for each trial. The data collected included time, impact force, acceleration, and displacement. The data were used to compare force vs. time, acceleration vs. time, and displacement vs. time.

Analysis was conducted using Microsoft Excel; the effects of instrument-related low-frequency oscillations in the data due to the signal were considered. The relative effective structural stiffness of the specimen, K, was determined using Equation 1, where t is the contact duration for a purely elastic test and m is the impactor mass (Feraboli, 2006).

$$t = \pi\sqrt{(m/K)} \tag{1}$$

This equation can be used assuming the relative stiffness of the specimen and the mass of the impactor both are sufficiently high (Feraboli, 2006). The total energy dissipated during each test can be quantified by the area between the two portions of a force displacement curve; this curve was readily available with the use of an advanced data acquisition and analysis software (Feraboli, 2006).

Results

Unfortunately, the data collected during this limited test program did not allow for quantification of the specimen stiffness and energy dissipation. The contact duration for each trial was difficult to quantify and the collected displacement data indicated that the LVDT range was exceeded, which meant that an accurate peak displacement was not recorded in the two trials. Aside from all the difficulties that arose with the onset of the COVID-19 virus, force vs. time, displacement vs. time, and acceleration vs. time graphs were completed. Figure 3 displays three plots: (top) the total reaction force vs. time, where the total reaction force was the sum of data from all four force sensors; (middle) displacement of the center of the specimen under the impact load point vs. time; and (3) acceleration of the crosshead vs. time.

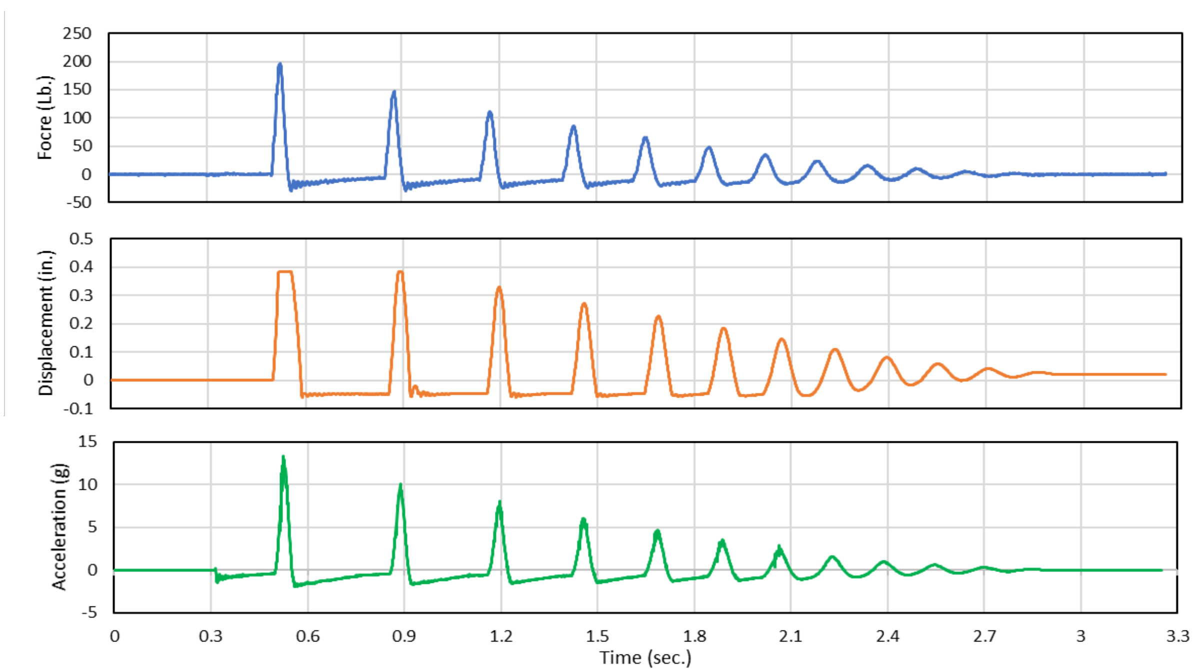

Figure 3. Total reaction force, specimen displacement, and crosshead acceleration vs. time

The peak total force recorded (a sum of data from all four sensors) was approximately 194 lb. When compared to the 279 lb crosshead mass, the peak force was significantly lower. This was most likely due to the small drop height of 6.125 in. Additionally, there is possibly a notable amount of energy dissipated during the descent of the carriage associated with friction occurring along the rails of the double-column drop tower. Therefore, velocity is not easily calculated (Feraboli, 2006).

The peak displacement was greater than 0.37 in., as seen by the initial peak in the middle plot of Figure 3; however, the actual value was inconclusive due to the range of the LVDT being exceeded on the initial impact. The negative displacement data in Figure 3 indicate that the panel was rebounding up from its original position during each cycle of crosshead impact. As expected, these oscillations in displacement visibly align with the peak acceleration of the crosshead.

The peak acceleration was approximately 13 g. There was no basis for comparison of this value to determine if it was high or low. The accelerometer sensor was calibrated using the manufacturer's calibration sheet. However, the accuracy was never verified, which could be done for more conclusive results in the future.

Recommendations

It is recommended that more testing be completed to gather a larger quantity of data. The calibration of each sensor should be double-checked. The LVDT should be placed so that its range is not exceeded on initial impact. Additionally, various drop heights should be used to average the stiffness of the material and energy dissipation on impact. Various specimens should be investigated during future research; the initial goal of this UROP was to also investigate the performance of 3 in. by 24 in. Baffle panels and DURAFRID HD4000-1.5" Grating panels. All the fiberglass composite data were also going to be compared to results from impact testing a 1 in. thick steel plate of the same length and width. Comparisons between each specimen, considering their respective weight and stiffness, could then be made to indicate the best structural option regarding impact resilience.

Summary

This UROP has allowed me to pursue my interest within Civil Engineering by providing me with the opportunity to learn something new, advance my problem-solving skills, and to challenge myself in new ways with hands-on research. I learned what it is like to work in a structures laboratory, both planning and conducting testing. Additionally, I was able to take the data collected and relate it to what I have learned in past classes, along with new research of past literature. Unfortunately, the lab closed about halfway through the semester from safety precautions that were put in place in response to the COVID-19 virus; therefore, I was not able to complete all of the testing that I wanted to. However, I think that also provided me with a valuable learning lesson, showing me that research does not always go as planned. So, while not all of the original educational objectives for this UROP were met, new ones surfaced as the focus for the UROP shifted to online educational and research methods. Unfortunately, I am graduating and will not be able to continue this research at the University of Minnesota Duluth, but it is my hope that a future student can use my findings to advance their own research.

References

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