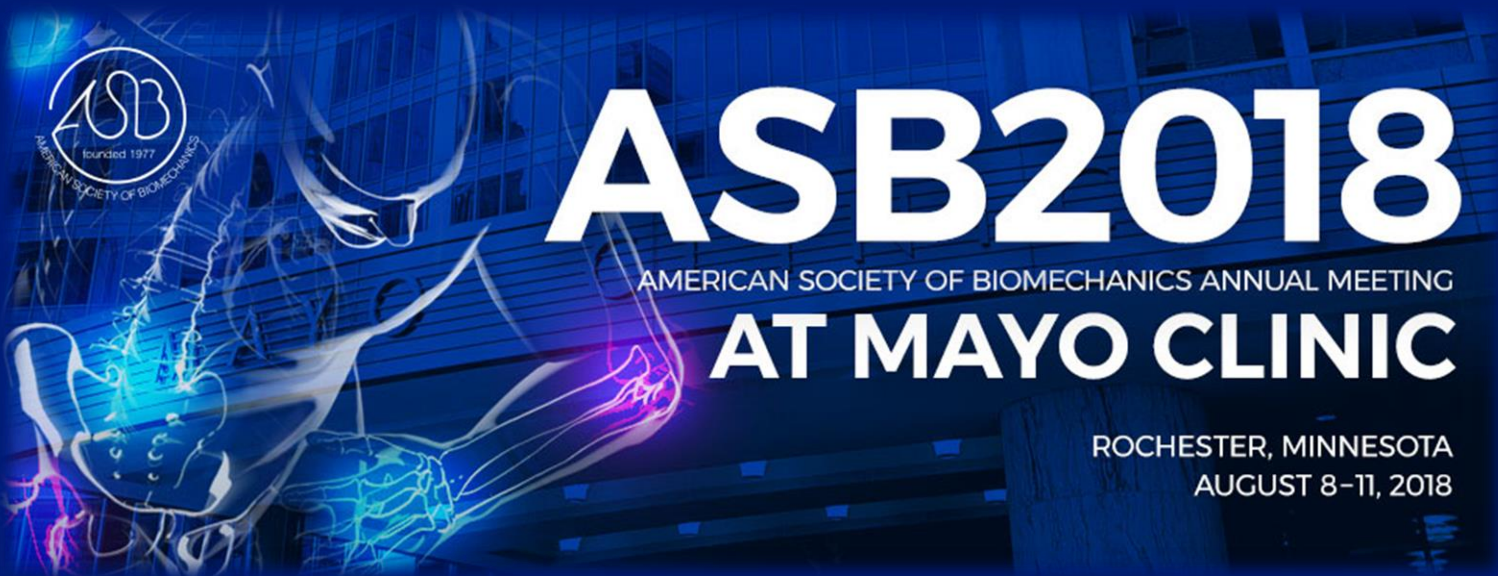
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ABSTRACTS

QUANTIFICATION OF THE SHOCK ABSORPTION PERFORMANCE OF CONSTRUCTION HELMETS IN TOP IMPACT

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INTRODUCTION

Traumatic brain injuries are among the most common severely disabling injuries in the United States. It is estimated that approximately 1.7 million cases occurred to civilians annually during 2002-2006 [1]. Work-related traumatic brain injury is one of the most common occupational injuries among construction workers [2, 3], resulting in extensive medical care and rehabilitation, multiple days away from work, permanent disability, or death. Industrial helmets are considered the most common and effective personal protective equipment available to protect against work-related traumatic brain injury [3]. There are numerous industrial helmets on the market, from basic models to advanced designs. Although all industrial helmets on the market are known to pass existing test standards [4-6], the shock absorption performance of them has not been quantified. In other words, the "two-level grading system" of pass/fail does not effectively characterize the performance of industrial helmets. The purpose of the current study is to develop an approach to characterize the shock absorption performance of industrial helmets.

METHODS

In the current study, we performed only Type 1 impact tests, i.e., the impact on the top crown of helmet shell. Helmet drop impact trials were performed using a commercial drop tower test machine (P. White Laboratory, MD, USA), which complies with the ANSI Z89.1 standard [4]. Twenty drop impact trials were performed; each dropped once at a particular height. The control parameter was the drop height; the acceleration of the impactor and the reaction force at the base of the headform (Fig. 1) were measured. The drop heights varied from 0.30 m (1 ft) to 2.23 m (7.33 ft), which resulted in impact velocities from 2.4 m/s to 6.6 m/s. The drop height was uniformly randomized within the range. The mass of the impactor was fixed at 3.6 kg. One representative Type 1 helmet model was used in this study. A Type 1 helmet is a basic helmet, and it is used widely at construction worksites. A Type 1 helmet is designed for the top impact protection only, not designed for the protection of the lateral impacts from the front, side, or rear.

RESULTS

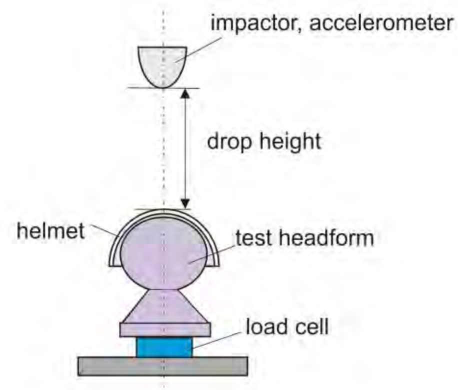

Figure 1. Schematic of the test procedure. The control parameter was the drop height; the accelerations of the impactor and reaction force at the base of the headform were measured.

The representative data plots of the force and acceleration generally show two peaks, corresponding to the initial and secondary impacts between the impactor and the helmet shell, as illustrated in Fig. 2. The magnitude of the peak force and acceleration decreased by about 70% and 50%, respectively, from the initial impact to the

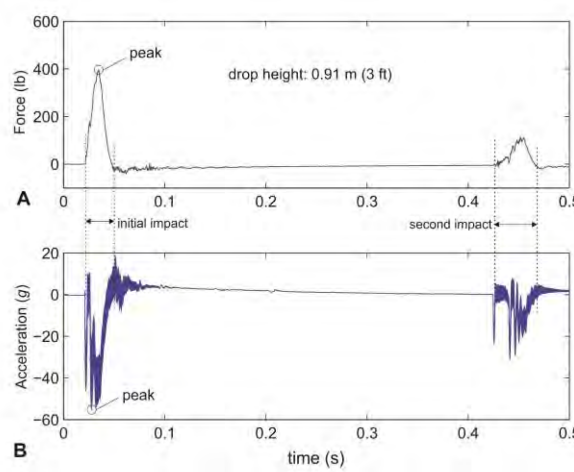

Figure 2. The representative time-histories of the force (A) and acceleration (B) around the impact.

second impact. In this study, we were mainly interested in the peak impact force and acceleration for the first impact.

For each of the force-time and acceleration-time curves, the peak forces and peak accelerations have been identified. The peak force and peak acceleration as a function of the drop height is shown in Fig. 3A and Fig. 3B, respectively. Our results show that both peak force and acceleration values increase gradually with the increase of the drop height, when the drop height is less than 1.75 m. When the drop height is above 1.75 m, both peak force and acceleration values increase dramatically.

DISCUSSION AND CONCLUSIONS

Our results indicate there exists a critical drop height, h_{cr} = 1.75 m, which is the cross point of the two regression lines (Fig. 3). The relationships of force-drop height and acceleration-drop height can be characterized by a flat toe region ($h < h_{cr}$), where the force or acceleration increases slowly with increasing drop height, and a steep linear region ($h > h_{cr}$), where the force or acceleration increases dramatically with even a slight increase in drop height (Fig. 3). The scattering of the test data is small when the drop height is below h_{cr}, and the pattern becomes large once the drop height is above h_{cr}, indicating mechanical characteristics

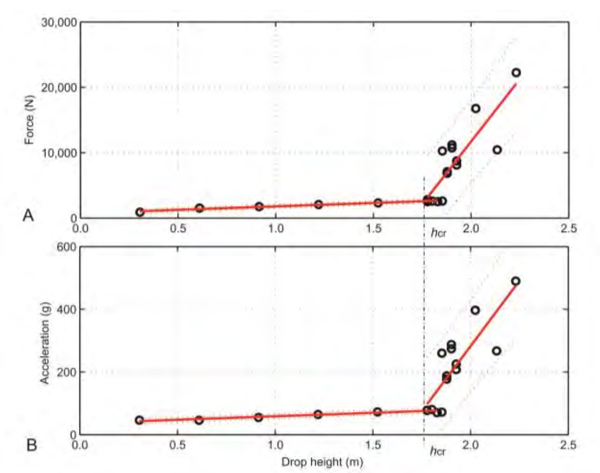

Figure 3. Peak force (A) and peak acceleration (B) as a function of the drop height. The data for the drop heights from 0.30 m to 1.75 m and from 1.75 m to 2.23 m were fitted using two separate lines (solid lines). The dotted lines are the 95% confidence intervals for the linear regressions.

became unstable once the drop height exceeds the critical height.

A helmet should never be subject to impacts beyond the critical drop height, not only because the transmitted impact force would increase dramatically, but also because of the compromised mechanical stability. Therefore, the critical drop height, h_{cr}, represents the shock absorption performance of a helmet. If a helmet passes a standard test, the safety margin of the helmet for that standard is defined based on the potential impact energy: $\rho = \left(\frac{h_{cr}}{h_{std}} - 1\right)\%$, with h_{std} being the drop height specified in the standard. For the current study, h_{cr} =1.75 m, $h_{\text{ANSI Z89.1}}$=1.54 m, and the safety margin of the helmet is 13.6%.

The advantage of the proposed approach over existing standard-based test methods is that the new approach can yield a performance spectrum of a helmet, and it can estimate the safety margin of the helmet if it passes the standardized tests. The proposed approach conceptually changed the conventional testing methods and would help improve helmet quality control and workers' safety.

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