Methods to Experimentally Derive Contact Characteristics for Hard Shelled Energy-absorbing Materials: Applications to Subway Pedestrian Fatality Mitigation

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I. INTRODUCTION

In multibody modelling, the contact between two bodies is commonly represented as a force-penetration curve. This contact information is typically experimentally derived through the use of Anthropomorphic Test Device (ATD) or post-mortem human subject (PMHS) tests [1-2]. In automotive safety, significant advances have been achieved through combining accident data analysis, physical testing, computational modelling and accident reconstruction. Extensive research has been conducted to improve pedestrian road vehicle safety, e.g. [2-4]. However, much less attention has been given to pedestrian incidents involving subway trains, despite high and increasing fatality rates in this setting, with deaths per 1,000,000 train miles increasing from 1.1 to 2.1 in the United States from 2013 to 2023 [5]. Here a method to define the complex contact interaction arising from pedestrian impact with foam and shell combinations is assessed for application to a subway-to-pedestrian impact at various velocities. A DYNAtest-500 impactor is used to propel a simplified headform ATD to experimentally derive the contact characteristics between the countermeasure and a pedestrian's head, where the countermeasure consists of different foam depths and different shell thicknesses. These contact characteristics are then used to simulate the collision in MADYMO and the effect of the energy-absorbing countermeasures (EAC) on the pedestrian's primary contact linear head acceleration are presented.

II. METHODS

Using the New York City (NYC) subway system as a reference, a multibody model of an R160 train was created using the software package MADYMO (MAthematical DYnamic Models, TASS International). A 0.3 m thick energy-absorbing material was placed onto the R160 model. To determine the contact characteristics between the Adult Male 50th Percentile (AM50) pedestrian model and the countermeasure, the following experimental setup was used (Fig. 1).

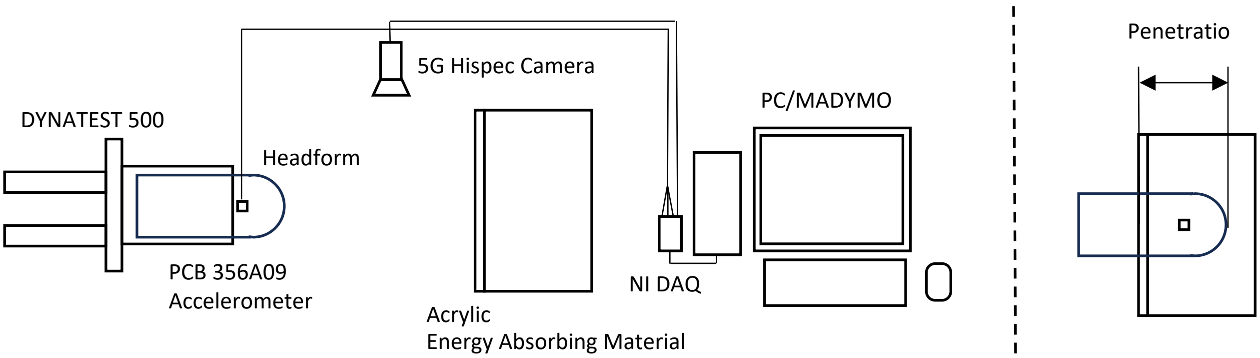

Fig. 1. Experimental setup for headform impactor tests.

The DYNAtest-500 uses compressed dry nitrogen to accelerate and propel the headform. The 5G Hispec camera at 525 fps is used to determine the impact velocity and maximum penetration distance of the headform into the EAC. A Matlab script is employed to determine the position time-history of the headform. The PCB 256A09 accelerometer provides the acceleration time history and with a known mass of 10 kg for the headform, the force-penetration relationship is calculated. This test is repeated both with and without an acrylic cover.

The force-penetration relationship is then used to inform the above-mentioned MADYMO subway-pedestrian collision model. Based on a recent study of NYC subway incident reports, the AM50 pedestrian model is given three jumping postures and three standing postures. Each impact posture is simulated three times, without EAC, with EAC and with covered EAC. For this short communication, a single jumping posture is simulated for a 6.5 m/s impact.

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III. RESULTS

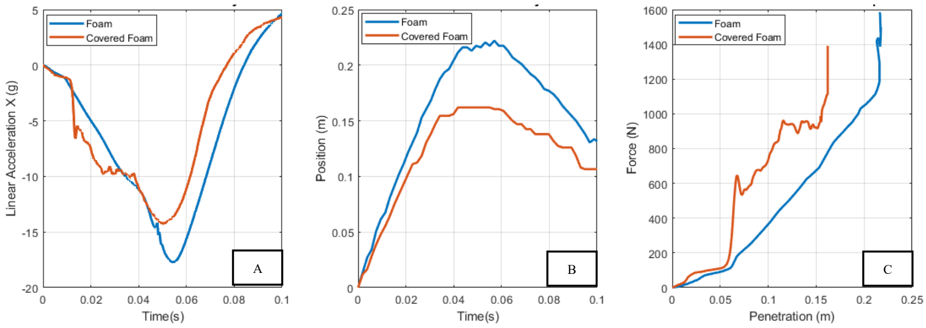

Fig. 2. (A) Acceleration, (B) position and (C) force-penetration relationship derived from experimental impact testing.

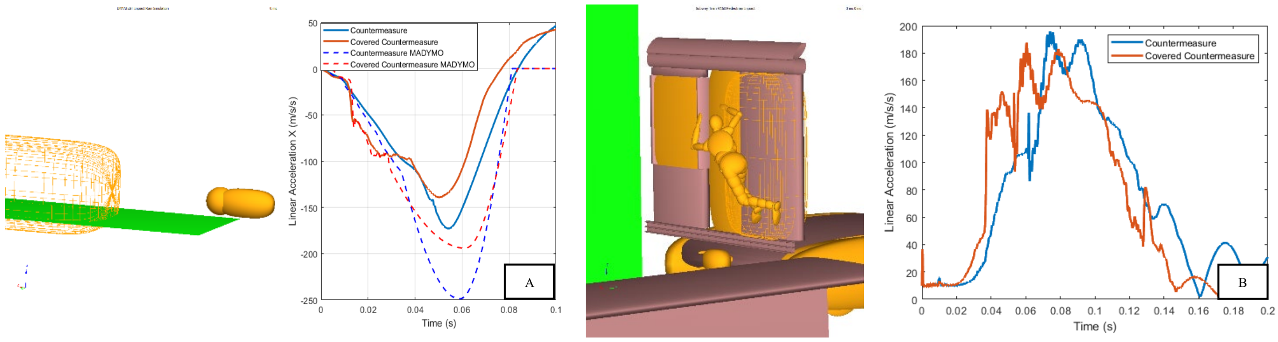

Fig. 3. (A) MADYMO linear acceleration of impacts with foam countermeasure (blue) and hard covered foam countermeasure (orange) for DYNATest impact comparisons. (B) A full subway-to-pedestrian collision.

The headform experienced a maximum acceleration of 17 g during a 6.5 m/s impact with the foam EAC. This high acceleration corresponds to the significant penetration of 22 cm or 74% strain into the countermeasure material. Through quasi-static testing, the foam stiffness was found to increase exponentially beyond 70% strain. The second test involved the same foam material with three 0.002 m acrylic sheets held in place directly in front of the countermeasure, to mimic a shell cover on the EAC. While the acceleration increases faster, the peak is lower at 14 g (Fig. 2). This is consistent with a lower penetration of 0.15 m or 50% strain into the countermeasure. The force-penetration relationship was derived and used to recreate the impact in MADYMO (Fig. 3A). MADYMO was then used to simulate a pedestrian struck by an R160 subway train at 6.5 m/s with an energy-absorbing countermeasure. The contact characteristics of both covered and non-covered countermeasures were used and the linear head accelerations were compared (Fig. 3B).

IV. Discussion and Future Work

Multibody contact characteristics between a headform and both an acrylic covered and non-covered foam EAC have been derived for a 6.5 m/s impact. The covered countermeasure shows an increased stiffness as the headform breaks through the acrylic, however the penetration depth is lower. The contact characteristic was used in MADYMO to recreate the acceleration time history, which shows promising results, although the acceleration is higher. Further investigation into the contact characteristics at higher penetration is underway to determine the cause of this peak acceleration difference. The full subway-pedestrian impact models show a faster increase in acceleration for the covered countermeasure simulating the hard shell. To further evaluate the effect of this hard shell, additional impact testing is underway using impact velocities ranging from 8 m/s to 14 m/s as well as covers of varying thickness (0–0.01 m). The derived contact characteristics will then be used for a larger simulation test sample, with initial conditions based on a recent review of subway-pedestrian incidents.

V. References

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