A Novel Method for Objective Assessment of Submarining Incidence in Simulations

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I. INTRODUCTION

Occupant submarining occurs when the lap belt slips off the pelvis or Anterior Superior Iliac Spine (ASIS) and directly loads the abdomen area, causing injuries to abdominal organs [1]. The assessment of submarining occurrence in sled tests and simulations typically involves visual inspection to confirm the lap-belt position and can lead to subjective judgements. This process can become more challenging when evaluating several test or simulation cases, for instance, in a design of experiments (DOE) simulation study. This paper presents an objective approach to assessing submarining in simulations and demonstrates its application.

II. METHODS

In simulations, interaction between two bodies is modeled using contact interface. Upon detecting the contact, a resistive force, known as contact force, is generated. A non-zero contact force exists while the bodies are in contact, but diminishes to zero as they separate. In the context of submarining, it implies a non-zero contact force between lap-belt and pelvis until the belt slips off the pelvis and shifts to the abdomen, thereby causing lap belt-to-abdomen contact force to rise from zero. Conversely, there should be no contact force between the lap belt and abdomen when there is no submarining. This indicates that the status of contact force can identify the position of lap belt, and thus the submarining occurrence. Since the contact force is a direct outcome of the force exerted by the lap belt while restraining the occupant, normalising them by the lap-belt force can simplify the method implementation. The ratios of contact force (belt-to-pelvis and belt-to-abdomen) to lap-belt force would then signify that in the case of submarining, the ratio for pelvis should drop to zero as the belt slips off the pelvis, and subsequently the ratio for abdomen should rise from zero as the belt starts loading the abdomen. For no submarining case, the ratio should not reduce to zero for pelvis but should stay at zero for abdomen. Furthermore, the method should estimate submarining risk in partial submarining cases, where only a portion of lap belt slips off to abdomen. It should also account for the differences in the propensity of belt slippage in the buckle and anchor sides.

Based on the above arguments, the proposed method involved tracking the contact forces between the lapbelt and both the pelvis and abdomen, and force in the lap belt. The method application was demonstrated through simulations for US NCAP full-frontal impact at 56 kph, using a 5^{th} percentile Hybrid-III (H305) dummy model positioned in a reclined seating position on a generic seat (Fig. 1(a)). Knowing that the submarining risk is a function of buckle position, two simulations were performed for two different buckle positions (Fig. 1(b)).

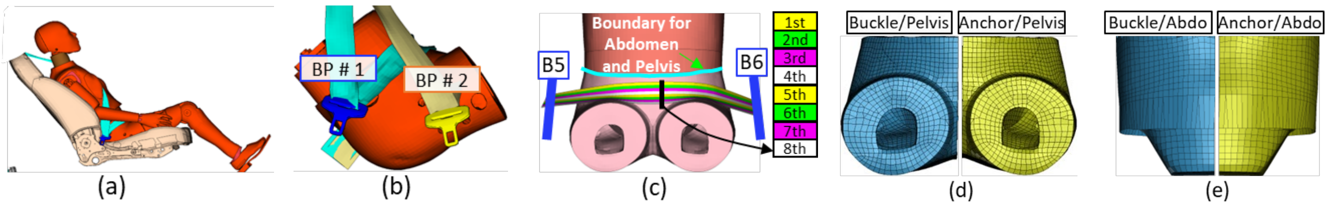

Fig. 1. (a) H305 on reclined seat, (b) buckle positions, BP#1 and BP#2, (c) eight rows of belt elements for force transducer definition, (d) two groups of pelvis elements, and (e) two groups of abdominal elements.

The contact force was obtained using *CONTACT_FORCE_TRANSDUCER, whereas belt force was obtained using *DATABASE_CROSS_SECTION feature in LS-DYNA. The pelvis and abdomen area were partitioned using their part definitions in the H305 (as indicated in Fig. (1c)). To account for the partial submarining, contact force from elements in each row across the lap-belt width to the dummy pelvis and abdomen were monitored. By analysing contact forces, the extent of webbing width on the pelvis or abdomen can be determined to

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eventually assess submarining risk. There are eight rows of elements across the belt width in the current model (Fig. 1(c)). To account for differences between buckle and anchor sides, elements in the pelvis and abdomen fleshes were grouped in two sets each by splitting them at the mid-sagittal plane (Fig. 1(d) and (e)). Separate transducer definitions were created for each row of lap-belt elements to each group of pelvis and abdomen flesh elements, resulting in a total of 32 transducers (8 rows of belt elements x 2 pelvis groups x 2 abdomen groups). The contact forces from all eight belt rows were then added to calculate the Total Contact Force (TCF) for each group. Furthermore, the lap-belt force was measured at two distinct belt sections: the buckle side (B5) and the anchor side (B6), as indicated in Fig. 1(c). Finally, the force ratios for the pelvis and abdomen on each side were calculated by dividing the TCF by the respective lap-belt forces (i.e. B5 and B6).

III. INITIAL FINDINGS

Figure 2 shows the results for both of the simulations. For BP#1, the belt-to-pelvis contact force dropped to zero in both buckle and anchor sides for all the belt rows, followed by an immediate increase in the belt-to-abdomen contact force. Furthermore, both the TCF and force ratio for pelvis dropped to zero in both sides, while TCF and force ratio for abdomen began to rise from zero. These observations indicate that the lap-belt completely slipped off the pelvis and loaded the abdomen, leading to submarining. The animation also supported this observation (Fig. 3), as it demonstrated that the timing of belt slippage matched to the time when force ratio for pelvis dropped to zero in both the buckle (at 50 ms) and anchor sides (at 60 ms). In contrast, for BP#2, the TCF and force ratio for pelvis did not drop to zero in either side, and the TCF and force ratio for abdomen remained at zero. This implies that lap belt stayed on the pelvis on both sides, indicating no submarining. The animation also confirmed this finding (Fig. 3).

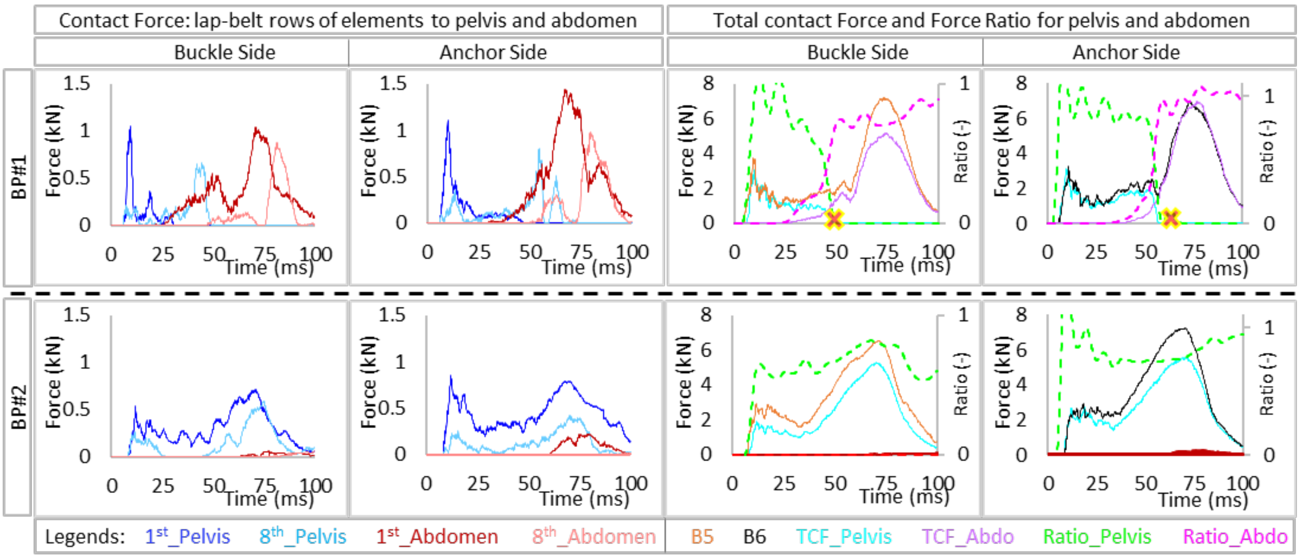

Fig. 2. Results for BP#1 (top) and BP#2 (bottom). Contact force from 1st and 8th rows are shown here.

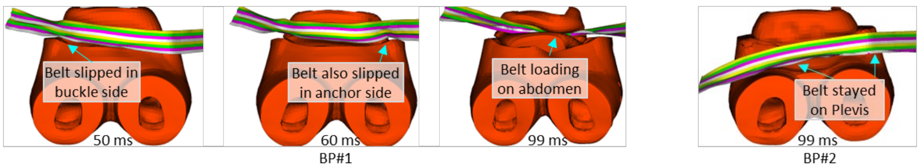

Fig. 3. Lap-belt position in simulations in BP#1 (left) and BP#2 (right).

IV. DISCUSSION

The method successfully assessed submarining occurrences in H305 simulations and can be automated for large DOE studies. However, the sensitivity of element segregation in the pelvis and abdomen groups requires more investigation. Further studies are ongoing for other dummies and human body models (HBMs). Additional challenges are expected especially with HBMs due to folding in the belt in the lap area.

V. REFERENCES

[1] Adomeit, D., *et al.*, SAE, 1975.