Output Location Sensitivity Analysis for Head Impact FEA Models in Pressure and Displacement using the BIPED Headform

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I. INTRODUCTION

Finite element (FE) models of the human head have been studied in impact testing for brain injury metrics. Pressure analysis and nodal displacement are the two common methods used to validate and test head models against experimental cadaver data [1]. Recently, a FE model of an anthropomorphic surrogate, called the BIPED, was tested against pressure and displacement data, with results adequately representing the physical experiment [2]. Selecting the correct output location in the FE model to match an experimental setup can be challenging, as model geometries vary both in size and shape [3]. Additionally, locations output from an experiment (for example, in existing literature) are not reported numerically, and only a description of location may exist [4]. This can cause variability in the location selected as model outputs. FE models have shown that the cranial pressure response is sensitive to location changes but have not characterised this amount numerically [3-4]. In this study, we analysed the sensitivity of an FE head model pressure and displacement to the output locations using the BIPED surrogate model.

II. METHODS

The BIPED headform has a Sylgard 527 brain, polyurethane skull, fluid layer, falx and tentorium membranes, and a urethane skin [5]. All of these components were modelled in ABAQUS (Dassault Systèmes) using CAD model geometry and reported material properties as shown in Fig. 1. Frontal impacts were performed on the physical BIPED using an impact pendulum for the pressure tests and a linear impactor for the displacement tests [2]. These data were simulated on the BIPED FE model in a dynamic explicit simulation using six degree-of-freedom kinematics as model inputs (linear accelerations and rotational velocities) that were collected by a 6DS Pro Accelerometer (DTS). Two displacements tests at approximately 2 m/s and 3 m/s were used, and nine pressure tests at 2.5 m/s, 3.4 m/s and 3.8 m/s. For the pressure tests, elements surrounding the pressure sensor location were chosen, as shown in Fig. 1, and the pressure was output from the model during the time of the impact. Four output points on a sagittal slice of brain (15 mm from the mid-sagittal plane) were chosen, with surrounding nodes for the displacement sensitivity study. On average, each point and element were separated by 5 mm. Points were analysed using the percent difference from the central output value at the maximum recorded magnitude.

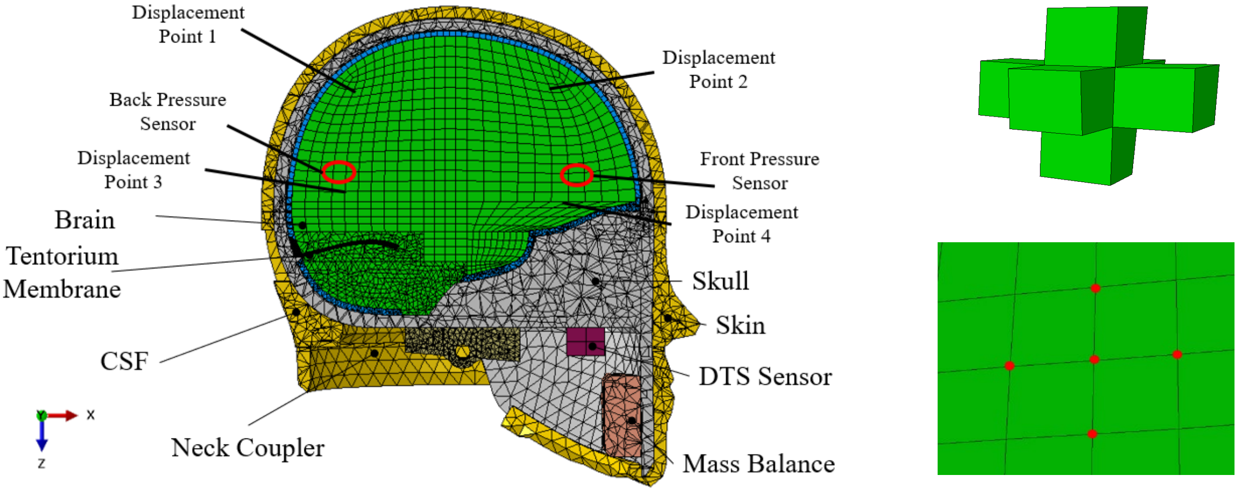

Fig. 1. BIPED Assembly, showing all parts with locations of the four displacement nodes and two pressure sensor elements. Pressure sensitivity element configuration (Top Right) and displacement sensitivity node configuration (Bottom Right).

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III. INITIAL FINDINGS

Time histories of the elements and nodes taken for both the pressure and displacement tests are shown in Fig. 2. The percent difference of peak displacement from the central displacement point is shown in Table I, where the results are shown as an overall total and the broken-down individual directions as well. In Table II, the results from the pressure test are shown. These are broken down by direction and sensor location for the peak pressure.

TABLE I

SUMMARY OF THE DISPLACEMENT SENSITIVITY DURING IMPACT

	X Direction %	**Z Direction %**	**Total %**
Displacement Sensitivity	13.3	15.8	14.6

TABLE II

SUMMARY OF THE PRESSURE SENSITIVITY DURING IMPACT

	Front Sensor %		**Rear Sensor %**		
	Parallel to Impact (x)	**Perpendicular to Impact (y,z)**	**Parallel to Impact (x)**	**Perpendicular to Impact (y,z)**	**Total %**
Displacement Sensitivity	7.8	1.2	16.4	4.5	6.0

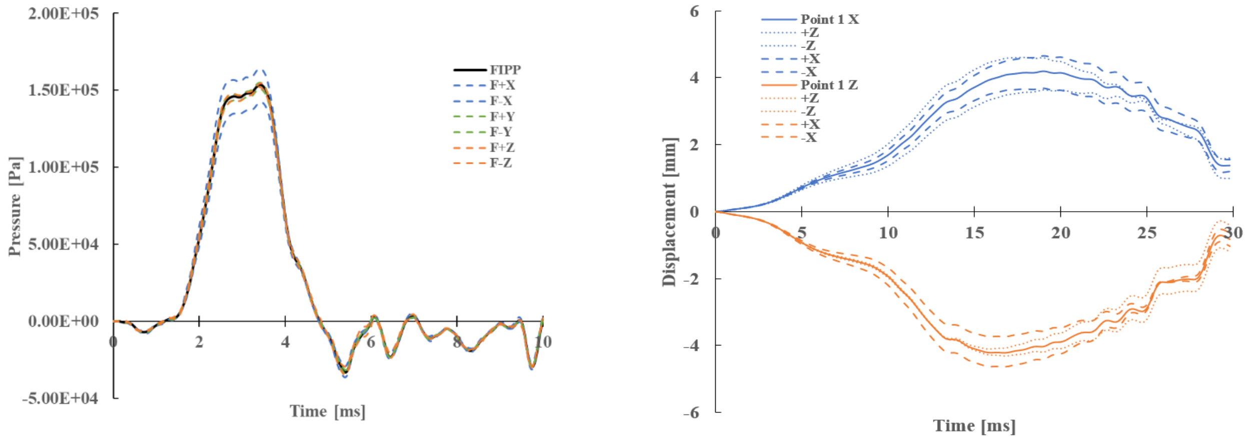

Fig. 2. Graph showing the sensitivity of the curves from pressure tests (3.4 m/s) at the front sensor location (Left). FIPP represents the frontal sensor location, and the F+X, F–X, F+Y, F-Y, F+Z and F-Z represent the pressure at one element adjacent in that direction. The sensitivity of the displacement test (2 m/s) at Point 1 (Right). Point 1 X represents the X displacement at Point 1, while the +Z, -Z, +X, -X represent a one node shift in that direction. Point 1 Z represent the Z displacement at Point 1.

IV. DISCUSSION

From Table I, the difference between neighbouring points and the central point, the X and Z directions, is small, and there is minimal directional bias. By moving 5 mm from the marker location, the displacement has a percent difference of approximately 14%. From Table II, we can conclude that direction plays a large part in the sensitivity for the pressure results. This is due to the pressure being a uni-directional gradient across the brain. In the direction of the gradient, the sensitivity was magnified to 7.8% in the frontal sensor and 16.4% in the rear sensor. The large discrepancies in the sensitivities between the front and back sensors are likely because the impacts were frontal, and thus the pressure wave is well defined at the impact site. This work is important in numerically defining how sensitive it is to select the proper location of the FE model output. For reference, parametric studies have demonstrated similar differences in pressure when investigating material models [6]. Our values show that diligent selection of the output locations could be just as important as these other factors.

V. REFERENCES

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