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Development of Numerical Child Dummy Model and the Analysis of Head Impact Criterion

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***Abstract*- This paper presents a development of numerical child dummy model and head impact criterion analysis of the numerical child dummy model. The model was developed using flexible component for crucial parts such as neck and thorax and less important parts was modeled using rigid body. As for the geometries of the child dummy, the measurement has been taken from Malaysian child and statistical analysis has been done to obtain the desired measurement.**

A simplified crash was performed in order to verify the development of numerical child dummy model after completed the design and meshing. Based on the simplified crash simulation, the head impact criterion (HIC) was calculated to evaluate head injuries of the baby during crash. Head Impact Criterion was used for all impacts to the head and it is the best predictor of brain concussion. From the simplified crash, it is found that the higher the velocities, the HIC readings also increase which indicate more severe head injuries.

I. INTRODUCTION

Approximately 500 000 people are killed and 20 million injured in vehicle crashes in the world every year. Among those numbers, 291 000 injuries were involved children between the ages 0 to 14 and 7810 were fatal crashes. Head injuries were the leading cause for most of the deaths and injuries in vehicles crashes through out the world. A study led on real world frontal and rear impacts show that the head is the most currently injured anatomical segment.

The main mechanical parameter that causes head injuries is assumed to be its linear acceleration. To calculate head injuries, the Head Injury Criterion has been therefore developed, based on the linear acceleration sustained by the head coupled with its duration. From an experimental point of view, this criterion is determined through the measurement of the three dimensional linear acceleration of the center of gravity of dummy head which has similar inertial properties to the human head. Even though the HIC is able to represent the global severity level of an impact, and the potential head injury level, the specialist agree to claim that the HIC is unable to predict diffuse brain injuries and subdural haematoma that are linked to the angular acceleration sustained by the head during the impact.

Finite element child dummy has been developed before but most of it was above one year old. In this study, a 6 month old child was developed and it will be used to calculate Head injury criterion during impact. This HIC value was compared to the tolerance limits proposed in the literature to validate severity of the injuries.

II. PART MODELING AND VALIDATION

For the child dummy modeling, 6 month old Malaysian child geometries have been taken as reference. A number of 30 child geometries were taken and statistical analysis has been made to obtain the desired measurement. LSTC adult hybrid III dummy was used as reference in designing most of the parts in the child dummy model. The child dummy was firstly designed using CAD software before converted to iges file and finally meshed using finite element analysis software. The child dummy model consist of 70 different parts with crucial part defined as deformable bodies and non crucial part defined as rigid body. Figure shows the general flow of the numerical child dummy model generation starting from literature review. As mention before, the geometry of the child dummy was taken from statistical analysis of child measurement. From the measurement obtained, the dummy was generated using CAD software before converted to finite element model.

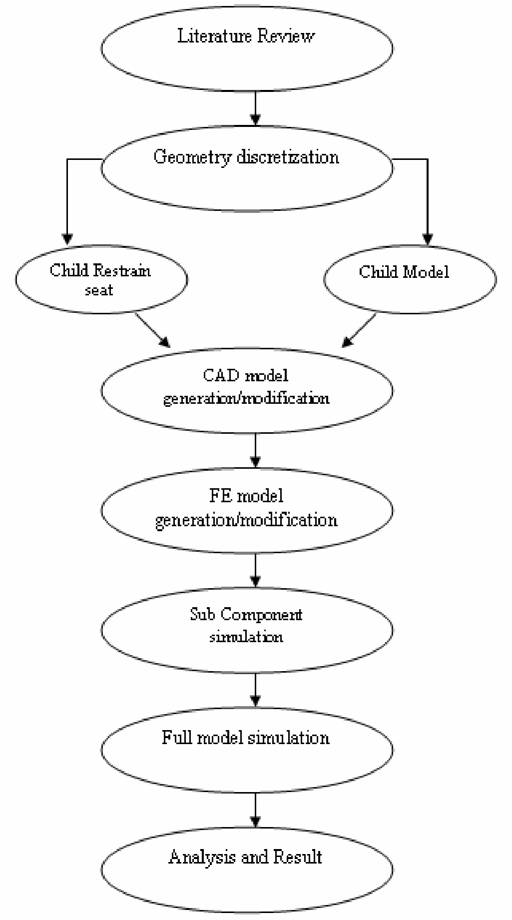

Fig. 1. Flow of the numerical child dummy development

III. HEAD AND NECK MODEL

The head assembly shown in figure 2 consists of vinyl skin, aluminium skull, ballast and neck connection bracket. All components were modeled as solid elements to ensure accurate inertia and mass distribution. The outer vinyl skin is connected to the skull using the contact TIED_NODES_TO_SURFACE option [1]. As for the neck model shown in figure, it consists of three rubber disc molded between four metal discs, steel cable at the center and upper neck bracket to spine mount [2]. The rubber discs have a partial depth horizontal slit on the anterior side to simulate less stiff response in neck extension than in flexion. The rubber components are modeled as solid elements and have the holes to fit in the steel cable. The metal disc was modeled as single layer of fully integrated solid elements and steel cable was also modeled using solid.

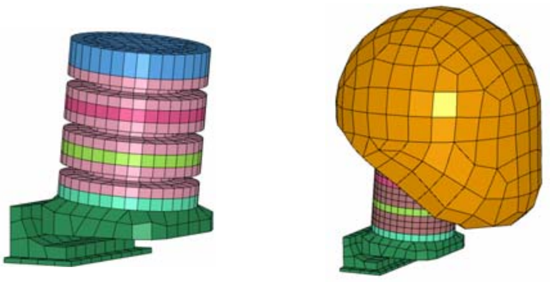

Fig. 2. Head and neck model of the dummy

IV. THORAX MODEL

The thorax assembly shown in figure 3 consists of chest jacket, rib, bib assembly and thoracic spine. Most of the components are modeled as solid element to ensure accurate mass and inertia distribution. The chest jacket is modeled with a fully integrated single layer of solid elements. The steel ribs were modeled with three layers of shell elements across their width to capture the correct bending behaviour. All the individual components were connected to each other using duplicate node merge and contact TIED_SURFACE_TO_SURFACE option [4]. A revolute joint was set for all the shoulder and hip joint of the dummy to ensure movement of the dummy.

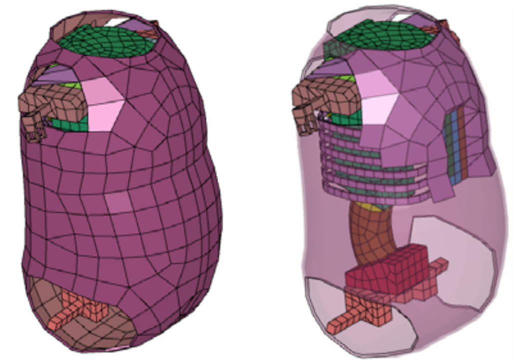

Fig. 3. Thorax of the dummy

V. LOWER EXTREMITY MODEL

The lower extremity model shown in figure 4 composed of upper leg, knee, lower leg and foot. It is attached to the pelvis at the hip through a revolute joint. Most of the components where feasible, are modeled as solid elements to ensure accurate mass and inertia distribution. The knee is connected to the lower leg by a revolute joint and this can allow rotational to the knee.

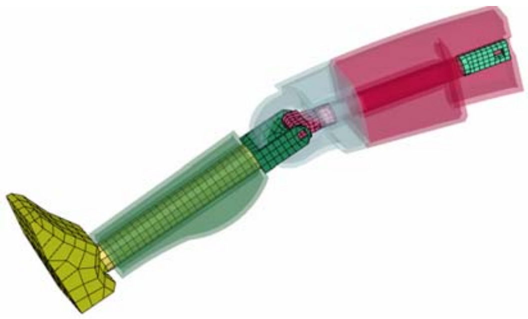

Fig. 4. Inner and outer model of lower extremity

VII. UPPER EXTREMITY MODEL

The upper extremity shown in figure consists of upper arm, lower arm and hand. The upper arm is made of elastic material and the inner piece modeled as shell elements. The upper arm and lower arm were connected through a revolute joint at the elbow. As for the hand, it was modeled as solid elements and attached to the lower arm by using contact TIED_NODE_TO_NODE [5].

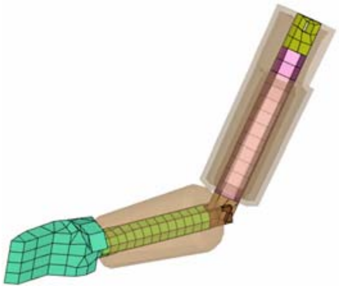

Fig. 5. Upper extremity model of the dummy

VI. CHILD RESTRAINT SEAT

As for the child restraint seat, a forward facing child restraint seat was used in the crash simulation. The child restraint seat design and measurement was taken from the most commonly used child restraint seat. The child restraint seat was designed using CAD software and then converted to finite element model as shell part. In the finite element software, the child restraint seat was assigned as polypropylene with mass density 8.55e-5 kg/mm^3 and 150 kN/mm^2 modulus of elasticity [3]. The child restraint seat was then fitted with 3 point harness to complete the overall finite element child restraint seat. Table 1 shows the model summary of the numerical child dummy model, child restraint seat and 3 point harness seat belt.

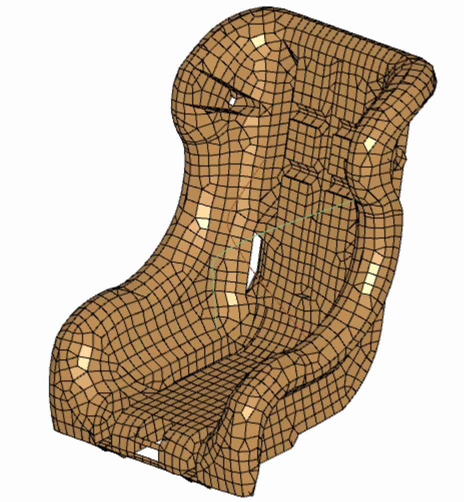

Fig. 6. Numerical model of the Child restraint seat

TABLE I. Model summary

Component	**Total**
No of Parts	70
No of shell element	12582
No of Solid element	6784
No of nodes	24482
No of joint	6
No of material used	11

VIII. HEAD INJURY CRITERION (HIC)

The head injury criterion (HIC) was developed to measure the acceleration acting on the head of occupants, computed with the following equation [7]:

$$\text{HIC}=\left\{\left(t^2-t^1\right)\left[\frac{1}{\left(t^2-t^1\right)}\int_{t^1}^{t^2} a\left(t\right)dt\right]^{2.5}\right\}$$

Where *a* is the resultant acceleration, t^1 and t^2 is the initial and end time during impact. This index used with head-on impacts. A HIC greater than 1000 for adult and 390 for 1 year old child is basically declared as the threshold value from which occupants injuries are expected [8].

IX. NUMERICAL SETUP

In this part of study, the child dummy model was coupled with the child restraint seat developed previously as shown in the figure 6. The child restraint seat then was fixed to a rigid shell part representing simplified car and the child dummy model was fitted with 3 point harness belt.

The rear and side impact was applied a velocity of 15 mph, 25 mph and 35 mph. Sudden deceleration was apply then to give an impact condition.

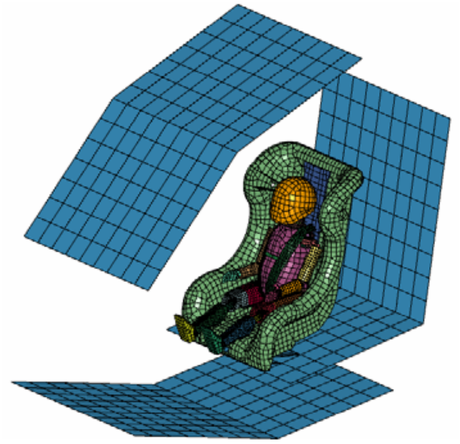

Fig. 7. Full model simulation

X. NUMERICAL RESULT

Based on the impact simulation that was performed, resultant acceleration of the head was taken. From the acceleration obtained, the HIC (Head Impact Criterion) were calculated (figure 8) from all impact and compared in table 2.

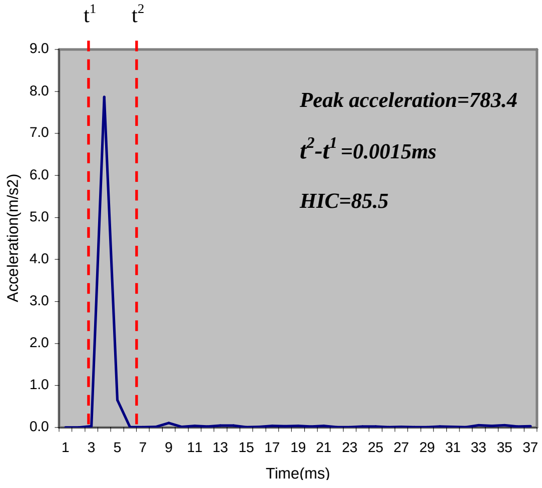

Fig. 8. Sample of HIC calculation

TABLE II. HIC value based on fontal and side impact

Rear Impact				
Impact velocity(km/h)	**a(m/s^2)**	**t^2(sec)**	**(m/s)**	**HIC**
25	36.9	0.017	2.55	0.5
40	783.4	0.0015	6.25	85.5
55	1900.5	0.0006	9.17	313
Side impact				
Impact velocity(km/h)	**a(m/s^2)**	**t^2(sec)**	**(m/s)**	**HIC**
25	23.3	0.01	2.13	0.35
40	44.0	0.025	5.89	2.13
55	120	0.014	9.02	7.33

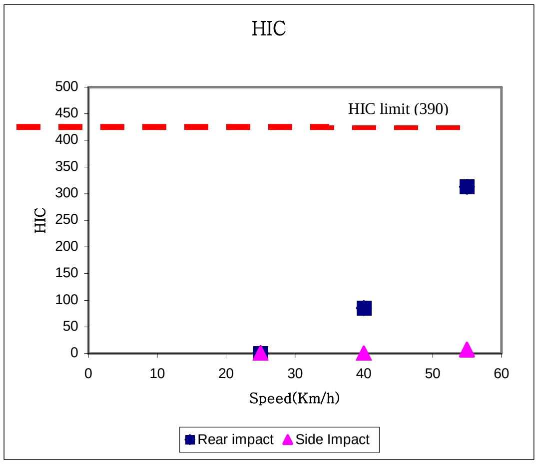

Fig. 9. Rear and side impact HIC comparison

Table 2 and Figure 9 show the comparison of HIC value between rear and side impact with different velocities. From both object, it show that 55km/h rear impact gives the highest reading of 313 HIC value. From figure 9, it shows that the HIC value from 55 km/h rear impact didn’t exceed 390(HIC limit for 6 to 12 month child) but it’s a value that need to be concern. From Figure 9 and Table 2 also, it shows that rear impact gives a much higher reading of HIC value compared to side impact. There's few reason why this reading vary and one of them is because of the HIC calculation itself. HIC calculation needs resultant acceleration of the head from an impact. From the simulation, the side impact didn't give any major impact to the head whereas rear impact gives a major impact to the head due to whiplash motion. The human neck tends to move much further on front back motion (whiplash) compared to side to side motion.

CONCLUSION

In this study, a full scale child dummy model was developed for rear and side impact analysis. The HIC was used as the injury estimation method in both impacts. Based on the result, it shows that rear impact gives much higher HIC readings compared to side impact which indicates a much severe injuries to the head. This numerical child dummy model can also be used for other injury estimation method such as Neck Injury Criteria, chest injury estimation and lower extremity injury estimation. This numerically measuring of human injury can be expanded to measure other human body limits during impact and gives design guidelines for safety precaution needed to protect occupants. This numerical study also can be used to validate, compare and improve experimental result due to its low cost to perform and consume less time to develop various scenario compared to the experimental setup.

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