Improving Shoulder Injury Index of WorldSID Dummy using CAE Parametric Studies in 32 km/h Oblique Pole

Kommanaboyina Venu, Shaik Rahman Basha, Arun Kumar Marimuthu and Raguraman Munusamy

Abstract To accurately predict passenger injuries in oblique side pole impacts, worldwide Harmonized Side Impact dummies [WSID] are utilized in New Car Assessment Programs [NCAP] and regulations. The WorldSID 50th percentile male (WSID-50M) has an improved oblique shoulder bio fidelity design compared to the existing side impact dummies [ES2/ES2-RE]. Following such transition, it is crucial to understand, predict and improve WSID dummy injuries using CAE simulations. Current studies indicate that achieving WorldSID dummy injury criteria for mid-sized vehicles for side pole impacts is quite challenging. In particular, the shoulder and chest injuries are highly sensitive to dummy arm movement and it is quite difficult to achieve the shoulder injury targets (2.4kN) as provided by NCAP's regulations. This study aims to identify and summarize the best design parameters of airbag to reduce shoulder dummy injuries using various CAE simulations. The results indicate that shoulder injury could be improved from initial design of 5.06kN to 2.0kN by choosing appropriate airbag deployment timing, shape and size.

Keywords CAE simulation, shoulder Injury, side pole impact, WorldSID dummy, Harmonized

I. INTRODUCTION

Recently, many countries have started to adopt regulations or NCAPs that are using the latest dummies, such as the Worldwide Harmonized Side Impact Dummy (WSID), for side impact performance evaluations. According to Sherer *et al.* [1], WSID has a good bio fidelity score of 8/10, which the EURO NCAP first started to implement from 2015. As per Haenchen *et al*. [2], 49.1% of collision accidents since 1991 that resulted in serious injuries involved a collision with roadside trees or poles. Similarly, according to Otte *et al*. [3], in side collisions with poles in Germany between 1999 and 2006 the probability of injury was approximately 40%. It was also reported that 32% of the injuries contributed to chest deflections, which form the second highest after head injury. Hence, there is need to reduce injuries associated with oblique pole impact. Shinobu *et al*. [4] reported that using a shoulder restraint and an appropriate side airbag could reduce the force to shoulder and chest according to finite element [FE] and Total Human Model for Safety (THUMS) model for 32 km/h oblique side pole impact condition. However, that study did not mention the influence of parameters such as arm rotation and airbag deployment on shoulder injury.

II. METHODS

Test Configuration

The vehicle pole impact test configuration includes a WSID seated in the front seat and struck by a rigid pole barrier of diameter 254 mm, at 75-degree angle, and at a velocity of 32 km/h, as shown in Fig. 1 and Table I.

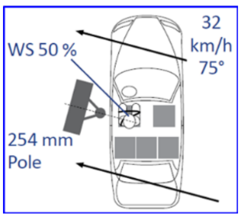

Fig. 1. Test configuration.

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TABLE I
TEST CONFIGURATION FOR THIS STUDY

Collision Speed	32 km/h
Collision angle	75°
Vehicle type	Passenger car
Dummy type & version	WorldSID AM50 ver. 3.3
Side Airbag	Available
Curtain Airbag	Available

Vehicle Model and component validation

A mid-sized vehicle equipped with side airbag and curtain airbag tested under the test configuration described above is selected to perform the CAE simulation. All CAE simulations are carried out using PAMCRASH version 2019. The FE Dummy of WorldSID is calibrated as per the component requirement (pendulum test) specified in the supplier's dummy validation test manuals. Similarly, the side airbag and curtain airbag folding are conducted as per design drawings.

III. RESULTS

Full Vehicle CAE Simulations

Figure 2 shows the body deformation mode of test and base CAE results, which are almost the same for various cross-sections. In addition, Fig. 3 shows the time history of pole intrusion for the test and base CAE results, where blue line represents CAE results and black line represents the physical test. From the time history plot it can be observed that both results are almost equal until 60msec. Therefore, based on the deformation mode and the time history plot, we can conclude that test and base CAE results are in good correlation.

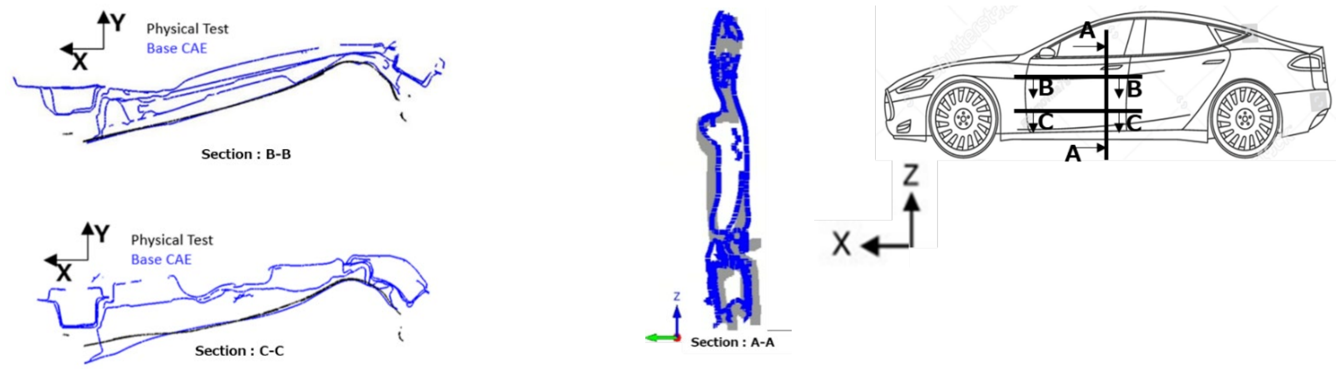

Fig. 2. Comparison of body deformation mode,

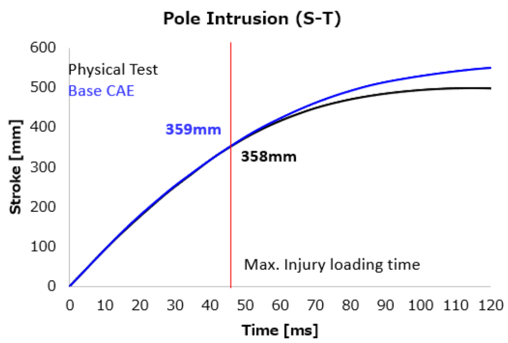

Fig. 3. Time history plot of pole intrusion.

However, Fig. 4 shows the WorldSID shoulder injury response not meeting the target of 2.4 kN. The CAE achievement is 5.08 kN. To reduce the value from 5.08 kN to below the target limit (<2.4 kN), several countermeasure strategies were studied in CAE, considering the shoulder loading pattern. This paper will explain the different methods to control shoulder load.

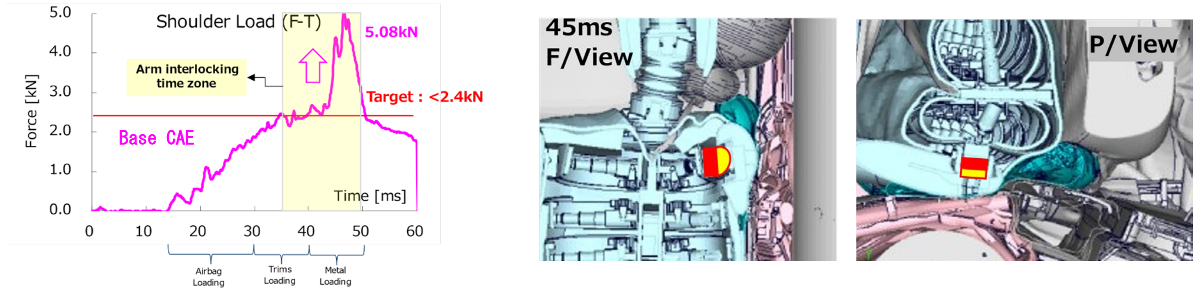

Fig. 4. Shoulder injury and shoulder kinematics in base CAE.

Shoulder injury mechanism

The shoulder injury mechanism is explained per Fig. 4, which shows shoulder loading occurring in three stages. The first stage of loading, between 15 ms and ~30 ms, is due to side airbag interaction with the arm and shoulder, causing 1.46 kN increase in shoulder load. Typically, side airbag will bottom out (complete deflation) around 30 ms. The second stage of loading starts after the side airbag bottoms out, with door or center pillar/B-pillar trims loading occurring between 30 ms and ~40 ms. As seen from the above shoulder force plot in Fig. 4, force almost reached 2.4 kN at 40 ms. Finally, the third stage loading occurred due to direct door metal parts contact at shoulder loadcell, as shown in the plan view image between 40 ms and 45 ms, resulting in a higher shoulder load value of 5.06 kN. The initial side airbag parameters used for the base CAE simulations are listed in Table II. From the arm rotation point of view, arm gets interlocked against door trim immediately after side airbag bottoms out, causing continuous increase of shoulder injury between 35 ms and 45 ms. Technically, this phenomenon is the root cause of the third stage loading.

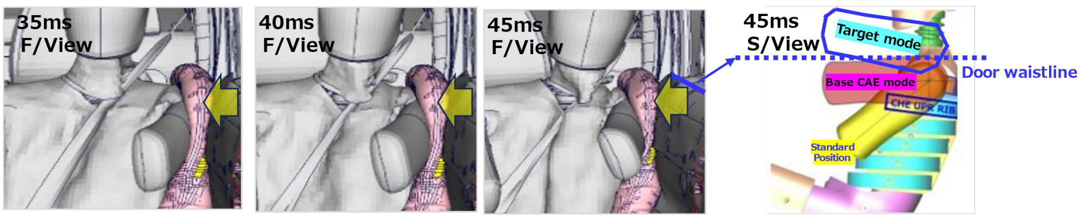

Fig. 5. Arm rotation influence on shoulder injury in Base CAE.

TABLE II

SIDE AIRBAG SPECIFICATION INFORMATION

Option	Parameter	Specification
Base CAE	Permeability of main fabric	49X49 sq. mm
	Venthole size	5X44 mm
	TTF (Time to Fire)	~8 ms

TABLE III

COUNTERMEASURE STUDY (AIRBAG PARAMETER) LIST

Option	Parameter	Specification
Option#1	TTF (Time to Fire)	~8 ms →13 ms
Option#2	Permeability of airbag fabric	49X49 → 54X54 sq. mm
Option#3	Size control	Airbag size and venthole size reduction
Option#4	Shape control	Flat top surface airbag shape

However, after detailed study of mechanism, countermeasures options (parameters), as listed in Table III, were studied using the CAE simulations. In Option/parameter#1, time to fire (TTF) of side airbag was delayed from ~8 ms to ~13 ms to avoid third stage loading by controlling the airbag deployment mode. The TTF was delayed by 5 ms so that side airbag deployment would occur behind the shoulder, allowing the shoulder to be pushed forward to avoid contact with the door metal. This is one common design solution to improve shoulder injury, as shown in Fig. 5, however concern is airbag cannot be fully deployed as shown in Fig. 6, which prevents this option from being implemented.

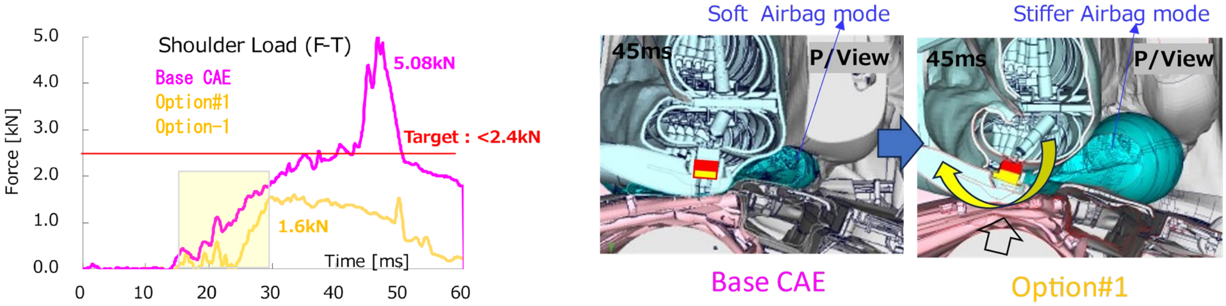

Fig. 6. Shoulder injury and shoulder kinematics in OPTION#1.

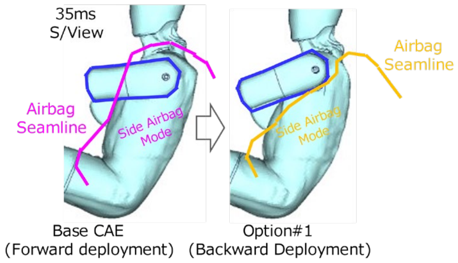

Fig. 7. Airbag deployment issue.

Option#2 also aims to avoid stage three loading by controlling the airbag deployment mode by adjusting the gas leakage parameters of airbag, shown in Table III. In this parametric study, airbag fabric material was changed to less permeable fabric, which can reduce the air leakage and thereby increase the pressure in the airbag and delay the bottoming-out phenomenon. The result of the simulation can be seen in the shoulder force plot in Fig. 7, where door metal input force is reduced from 5.08 kN to 2.56 kN.

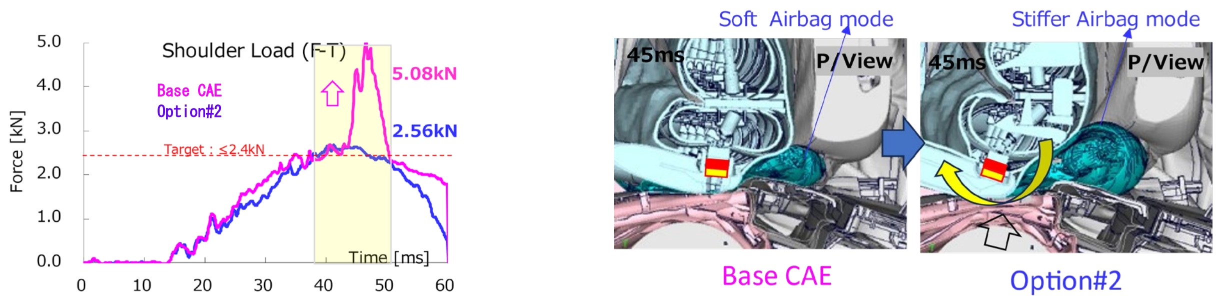

Fig. 8. Shoulder injury and shoulder kinematics in OPTION#2.

Option#3 focused on improving arm rotation behaviour. In the current base model, arm rotation about the Y-axis is limited, causing the arm stuck between shoulder loadcell and door metal during stage three loading. In this study, our aim is to transfer more load under the arm and lift the arm as early as possible above the door waistline to avoid direct loading from structure. Lifting the arm will reduce the load against pole intrusion at shoulder loadcell. The result, in Fig. 8, shows an improvement in arm rotation, but not enough lift was achieved, consequently the shoulder got stuck again, resulting in shoulder load increasing again to 2.67 kN.

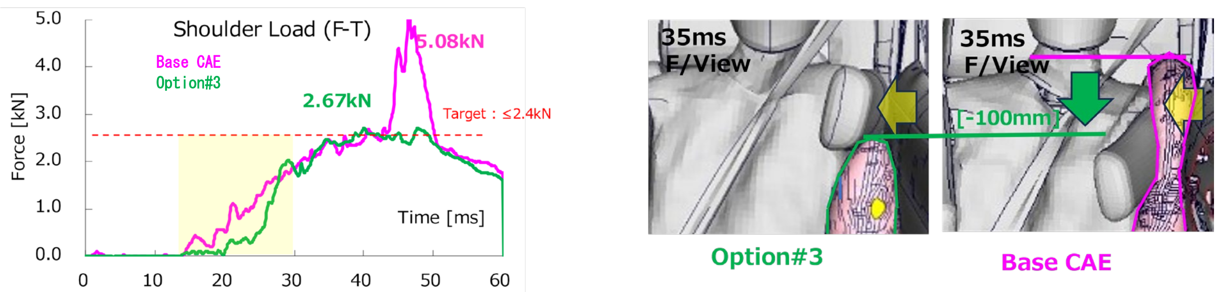

Fig. 9. Shoulder injury and shoulder kinematics in OPTION#3.

Option#4 focused on developing a robust solution based on the achievement of Option#3. It is evident that the arm lift can reduce shoulder load. Therefore, to make this arm rotation more robust, it was proposed to change the shape of the airbag, as shown in the schematic in Fig. 9. The theory is to keep the side airbag always under the arm while the arm is lifting. As a result, the shoulder load reduced from 5.08 kN to 2.0 kN, which achieves the target value. The schematic image in Fig. 9 shows the difference in side-airbag shape. The base CAE airbag shape is a conventional oval-type shape, while Option#4 uses a flat surface at top to generate support to lift the arm upwards.

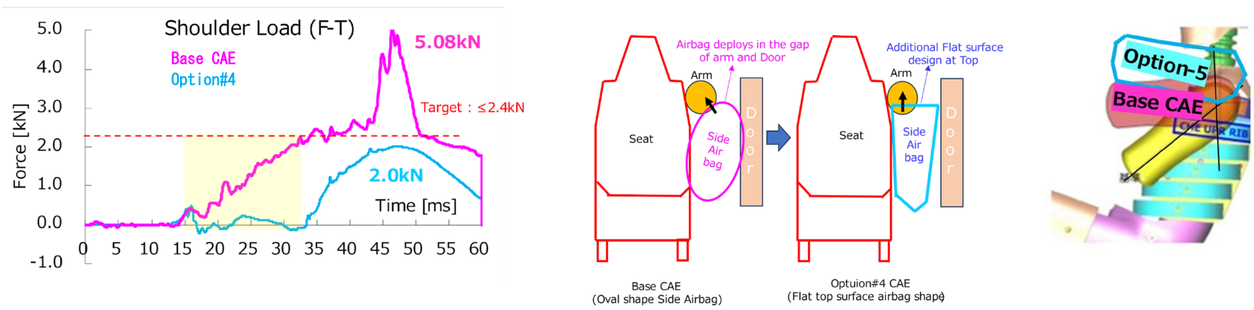

Fig. 10. Shoulder injury and shoulder kinematics in OPTION#4.

IV. DISCUSSION

From the Results section, shoulder force injuries range from 2.0 kN to 5.08 kN with feasible solutions. In Option#1, the dummy had started to move by the time the airbag deployed, resulting in no space for the airbag to deploy forward. Consequently, deployment accumulated behind the dummy with high pressure, creating low pressure in the dummy shoulder contact zone and resulting in a lower shoulder injury of 1.6 kN. As explained earlier, due to the limitation of delayed TTF of 13 ms, Option#1 could not be implemented. Treating the result of Option#1 as a hypothesis, other options were studied in detail to achieve the shoulder injury targets.

V. CONCLUSION

The parametric studies indicate that arm rotation significantly influences shoulder injury outcomes. Therefore, it is crucial to select the appropriate side airbag shape, size, and venthole configuration to achieve optimal shoulder injury indices, tailored to the dummy layout. Additionally, shoulder injury predictions can become unpredictable once the airbag bottoms out, underscoring the importance of carefully considering side airbag characteristics. Furthermore, the impact of these airbag modifications on other test modes, such as the Moving Deformable Barrier (MDB) test, was evaluated, confirming that all CAE simulation results remain within the target limits set by respective NCAPs or regulations.

VI. REFERENCES

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