Introducing Arup-Cellbond MDPB Shell Model

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Abstract

This Mobile Offset Progressive Deformable Barrier (MPDB) for frontal impact model has been developed to take advantage of the latest developments in the LS-DYNA[®] code and is designed to provide robust and efficient analysis. In this paper, some details of the calibration and validation process will firstly be presented, which not only satisfies performance requirements set by regulations (Euro NCAP 2020 Dynamic Tubular Impactor test) but also goes beyond through rigorous calibration against other physical tests (Vertical/Rounded Impactor Test, Quarter Wall test etc). Arup and Cellbond worked closely with Jaguar Land Rover in the UK for the development of this barrier model through ensuring correlation to full speed, real vehicle tests. Finally, methods of how to automate post-processing of results (including the calculation of Euro NCAP compatibility modifier) using the Oasys Software will be demonstrated.

Introduction

The new Mobile Offset Progressive Deformable Barrier (MPDB) for frontal impact will replace the existing fixed EEVC (European Enhanced Vehicle Safety Committee) ODB (Offset Deformable Barrier) in Euro NCAP (European New Car Assessment Programme) in its 2020 revision. The new frontal impact testing protocol for ODB involves the MPDB barrier striking a moving vehicle at an impact angle of 180° with 50% offset with the front end of the vehicle. Under regulatory conditions, both the vehicle and the barrier should approach each other at a speed of 50kph. The purpose of the update is so that vehicle safety assessment is not only concerned with the car/ passengers in question but also the opposing impacting vehicle. Earlier in 2019, it was also announced that C-NCAP (China New Car Assessment Programme) will also adopt the new MPDB standards in its next revision, although precise publication date is yet to be announced. It is therefore of high interest to many car manufacturers and associated industries across the globe that a reliable and robust method of modelling the MPDB crash performance is made available.

Arup and Cellbond have been collaborating closely with Jaguar Land Rover in the UK to develop a LS-DYNA model for the MPDB. This model has been developed to take advantage of the latest developments in the LS-DYNA code and is designed to provide robust and efficient analyses results. Details outlined in later sections show that the Arup-Cellbond MPDB model not only show good force-displacement correlations compared with physical test results, but also offers realistic barrier deformation behaviour. This has been achieved through extensive material calibration (at component level) and full barrier performance validation (facilitated by a comprehensive testing campaign, including whole vehicle tests).

Barrier Components

The MPDB barrier comprises of three blocks of stacked honeycomb cores. The front (C) and rear (A) honeycomb blocks offer a constant crush strength. The middle block (B) has a progressive crush strength. All three aluminium honeycomb blocks are processed such that the force deflection-curve, when statically crushed, is within the corridors defined by Euro NCAP [1]. The 3 blocks are bonded on both sides by an adhesive to the back/intermediate/contact aluminium plates. The back aluminium plate is used for mounting the impactor. Finally, the whole impactor is encased with a thin aluminium (composite) cladding, that is attached to the front by rivets. See Figure 1.



Figure 1. MPDB components [1]

Material Properties

- The following material properties are defined in the model in accordance with [1]:
- The front honeycomb block has a crush strength between 0.308N/mm2 and 0.342N/mm2.
- The rear honeycomb block has a crush strength between 1.540N/mm2 and 1.711N/mm2.
- The middle block thickness is etched so that the crush deflection curve stays within the following corridor: (6mm;0.616MPa) and (350mm;0.950MPa), (6mm;0.756) and (350mm;1.090).
- The cladding plate is manufactured from 5754 H22 aluminium and is 0.8mm thick.
- The contact plate is manufactured from 5754H22 aluminium and is 1.5mm thick.
- The intermediate plate is manufactured from 5754 H111 aluminium and is 0.5mm thick.

FE Model Set-Up

The specifications used for the development of the Arup-Cellbond MPDB model has been taken from [1] and are summarised, alongside overall model properties in Table 1.

Element Type	Number of Elements	Timestep	Validation Code	Regulation Test	Regulation Speed
Shell	1221651	0.9E-6	R9.3.0	EuroNCAP 2020 Frontal Impact Test	Vehicle and trolley have both a target speed of 50kph

Table 1 Specification and model properties

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The three honeycomb blocks are modelled using shell elements and *MAT_LINEAR_PLASTICITY (024) with failure enabled. The mesh of the main honeycomb approximates the actual honeycomb cells, i.e. the model cell size is ~30mm whilst the honeycomb cell size varies from 6.35mm to 19.1mm. The sides shared by two adjacent shells that are connected by adhesive are modelled with approximately two times the foil thickness. The honeycomb wall thicknesses are adjusted to allow for the same crushing strength specified in the regulation.

Both the cladding and the contact plates have been modelled using three overlapping layers of shell elements each. This modelling methodology is adopted to minimize the influence of the mesh directionality on the preferential direction for crack propagation. Material properties have been chosen so that the three layers are equivalent to one single layer of same mass, stiffness, strength and failure characteristics [2]. To verify its physical behaviour, a lab testing campaign was carried out in collaboration with Cellbond for the calibration of *MAT_PIECEWISE_LINEAR_PLASTICITY. *MAT_ADD_DAMAGE_GISSMO was used to model tearing of the barrier's cladding and contact sheets. Both triaxiality curves (for material instability and element erosion) and effective stress versus effective plastic strain curve are extrapolated from a series of tensile tests reaching failure for different plane stress states [3][4].



Figure 2. MPDB Overview

Blind rivets connecting the front cladding with contact plate and the bolts anchoring the barrier to the trolley are modelled with nodal rigid bodies.

*MAT_ARUP_ADHESIVE is used to model the adhesive connection between the cladding and the contact plate and the backplate. The adhesive connection between the honeycomb and the contact, intermediate and back plates is modelled by adjusting the material properties of the last layer of elements of the honeycomb blocks that is connected to the plates. This is done to reflect the failure characteristics of the adhesive. Honeycomb blocks are meshed in the connected plates to avoid the possibility of localized failure of the aluminium sheets due to instabilities of the honeycomb to plates connection for high speed impacts.

Calibration and Validation

The calibration and validation process of the Arup-Cellbond MPDB model goes beyond the regulation barrier specification tests. - we correlate our model to the model was correlated against additional dynamic tests at both component and full barrier levels. The full barrier level correlation was done against test results provided by Cellbond for four different impact conditions. These were a barrier on a trolley impacting a:

- 1. Euro NCAP [1] Tubular impactor
- 2. Rigid Rounded impactor
- 3. Flat Quarter wall
- 4. Vertical impactor

The force-deflection curves for the barrier (generated from analyses and tests) were compared.

Finally, and perhaps most significantly, the crash performance of the model was compared against 2 vehicle tests in collaboration with Jaguar Land Rover in the UK. Further details of calibration work are outlined in subsequent sections.

This validation work has been carried out in both SMP and MPP versions of LS-DYNA R9.3.0 to ensure performance and accuracy.

Component-Level Material Tests

Cladding and Contact Plates

Tests for the GISSMO damage model have been carried out on both the cladding and contact plates. These tests have been carried out for different plane stress states and used to extrapolate the material triaxiality curves, which were used to define material instability and element erosion).

A force-displacement graph (comparing test and FEA) is shown below together with the figures of the lab tests and the simulations.



Figure 3. Cladding plate force displacement plot comparison and images of material testing.

Honeycomb

Static crush tests were conducted to ensure compliance with the honeycomb strengths as specified by Euro NCAP [1] MPDB. See Figure 5 how the constant crushing strength target of the front and rear blocks (blocks C and A) were achieved.



Figure 4. Image of honeycomb crush test FE model.



Figure 5. Stress displacement plots for the front and rear honeycomb blocks.

Block B is tapered along the height. Its strength variation is bounded to increase linearly along the block height in accordance with the corridor defined in the barrier specification. The strength variation of the midhoneycomb block has been adjusted to be more representative on full scale barrier crash tests

Full Barrier Correlation

Euro NCAP Tubular Impactor

A detailed description of the impactor is provided by the Euro NCAP specification for the MPDB barrier [1]. The test involves the impact of the fixed MPDB barrier by a trolley with a rigid tubular impactor at a speed of 60kph. Figure 7 shows that the force-displacement performance of the barrier is within specified corridor limits.



Figure 6. Tubular impactor test.



Rigid Rounded Impactor

This test involves the barrier impacting a fixed rounded impactor at a velocity of 9.45m/s. A good match is confirmed through deformation profile comparison against test 3D scan and the force-displacement results.



Figure 9. Rounded impactor test comparison between test 3D scan and FE results.



Figure 10. Rounded impactor force-displacement plot.

Flat Quarter Wall

This test involves the barrier impacting a fixed rigid wall at a velocity of 9.45m/s. The wall covers a quarter of the barrier width. A good match is confirmed through deformation profile comparison against test 3D scan and the force-displacement results.



Figure 12. Flat quarter wall test comparison between test 3D scan and FE results.



Figure 13. Flat quarter wall force-displacement plot.

Vertical Impactor

This test involves the barrier impacting a vertical bar at a velocity of 9.45m/s. The barrier hits the supporting plate of the impactor leading to a peak in the force displacement force at the end of the test. A good match is confirmed through deformation profile comparison against test 3D scan and the force-displacement results.



Figure 15. Vertical impactor test comparison between test 3D scan and FE results.



Figure 16. Vertical impactor test force-displacement plot.

Whole Vehicle Tests

The barrier model was also tested against a full vehicle physical test, in collaboration with Jaguar Land Rover UK. Two types of vehicles were tested (1) standard passenger vehicle and (2) heavy-duty vehicle. Verifying the MPDB behaviour against different vehicle types is significant, as the barrier crash performance was found to be sensitive to (amongst other things) both the overall weight and the position of their centres of gravity. The Arup-Cellbond MPDB barrier model showed good correlation results for both crash barrier cases, which is a testament to its accuracy and reliability.

Automated Post-Processing of Results

The Arup-Cellbond MPDB model comes with an Oasys D3PLOT post-processing script as well as an Oasys REPORTER template which automate the post-processing of results and the calculation of the Euro NCAP compatibility modifier. The Oasys REPORTER template integrates all the Euro NCAP compatibility assessments and provides additional information to give a better understanding of the obtained scoring: time history of displacement and velocity of virtual occupant used to calculate the occupant load criterion; standard deviation and intrusion plot; barrier deformed shape; as well as injury criteria. Figure 17 shows an example of the information provided by the template.



Figure 17. Oasys REPORTER template outputs.

The reader should note that these tools have been produced with the intention of being used for post-processing to show compatibility with Euro NCAP. For post-processing requirements of other regulations (for e.g. C-NCAP), slight modifications to the workflow may be necessary.

Summary

In this paper, details of the calibration and validation process of the Arup-Cellbond MPDB LS-DYNA model were presented, which not only satisfies performance requirements set by regulations (Euro NCAP 2020 Dynamic Tubular Impactor test) but also goes beyond through rigorous calibration against other physical tests (Vertical/Rounded Impactor Test, Quarter Wall test etc). Arup worked closely with Jaguar Land Rover in the UK for the development of this barrier model to ensure correlation to full speed, real vehicle tests. Two types of vehicles were tested, one passenger vehicle and another heavy-duty vehicle, both of which showed satisfactory correlation with the Arup-Cellbond MPDB model. This is testament to the accuracy and reliability of the Arup-Cellbond model for predicting the physical deformation behaviour of the MPDB.

References

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