EVALUATION OF THE AFL ADVANCED EUROPEAN MOBILE DEFORMABLE BARRIER FOR SIDE IMPACT VERSUS THE ECE-R95 IN DYNAMIC LOAD CELL WALL TEST

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ABSTRACT

Many countries conducted side impact tests resulting in extensive safety measures for regulation. The IHRA conducted research activity in order to harmonized regulation worldwide, which was a challenging work. This had led to MDB improvements first and then to develop the deformable barrier representative for the EU-vehicle fleet so called Advanced European Mobile Deformable barrier AE-MDB.

This work is a first evaluation of both MDB-R95 and AE-MDB side impact barriers in their standard dynamic Load cell Wall tests knowing that AE-MDB will be introduced to EuroNCAP rating soon.

INTRODUCTION

Side impact protection is a very important part of any total vehicle protection system in order to design, develop and bring in the market the most safety vehicle. The challenge of the side impact protection is about ensuring that intrusions and door velocities are kept as low as possible in order to minimize the effects of the lateral impact onto the occupants. Obviously, car manufacturers and suppliers made great progress in the last 20 years introducing many new technologies like airbags, paddings, structure materials etc.

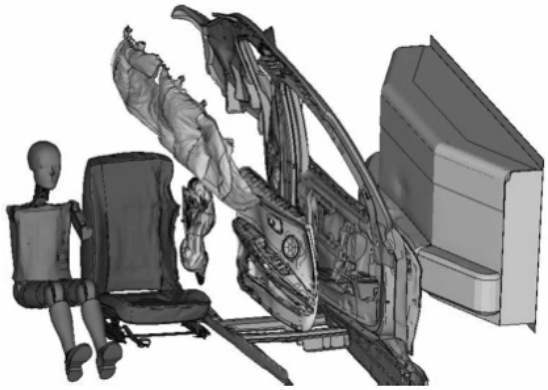

Figure 1: main side impact countermeasures [8]

Side impact issues have been reviewed by the European Enhanced Vehicle Safety Committee Working Group 13 (EEVC WG13 [4]). They conducted a review of injury issues observed in accident analysis, characteristics of different test methods, and cost benefit analyses of different solutions. Current side impact protection in Europe is controlled by a moving deformable barrier (MDB-R95) test in regulation (UNECE R95 and 96/27/EC) and both MDB-R95 and pole impact tests in consumer rating programs (EuroNCAP). The MDB-R95 barrier face is supposed to represent the force/deflection characteristics of a vehicle front. However, when the properties of the barrier were reviewed by the EEVC group, they were not found to be representative of current vehicles and hence a new advanced energy-absorbing barrier so called AE-MDB was developed to address this issue.

MDB-R95 and AE-MDB barrier faces question the relative distribution of forces on the side of the struck vehicle. With the future implementation of AE-MDB barrier as well as the new test procedure first in European NCAP tests, this will ensure the manufacture to continuously support their development and improve their products in side impact configuration.

MDB-R95

The European Enhanced Vehicle Safety Committee Working Group 13 (EEVC WG13 [4]) developed a side impact test procedure, which involved the use of a mobile deformable barrier so called MDB-R95. The deformable element of this barrier was defined in term of the force-deflection characteristics when impacting a six-element load cell wall together with some dimensional requirements. In 1998, this EEVC test procedure was used as the basis for ECE Regulation 95 [3] and the equivalent EU Directive including the MDB-R95 deformable barrier. In 1997, one year prior to this regulation taking effect, EuroNCAP decided to implement the research from the EEVC WG13 into their programs. In 2004, an EEVC WG13 proposal for an updated barrier was implemented into the existing ECE Regulation 95 [3].

In 2003, EuroNCAP decided to implement these modifications from the EEVC WG13 into their rating. This was four years before these modifications were mandatories for new vehicle in Europe.

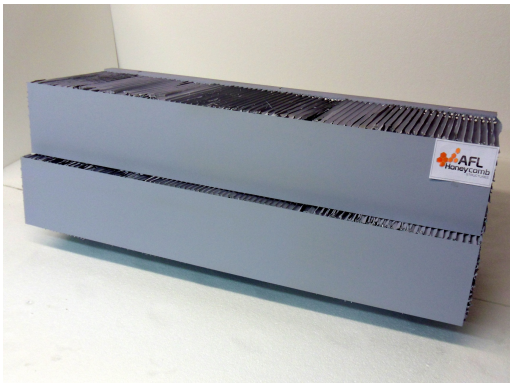

Figure 2: MDB-R95 AFL Honeycomb Structures

Based on the Aluminum Honeycomb technology, the AFL MDB-R95 side impact barrier (EEVC WG13) is used by car manufacturers and test laboratories worldwide for the assessment of motor vehicle passenger's protection in case of side impact collision. The AFL MDB-R95 side impact barrier is designed and manufactured according to the ISO 9001 (V2008) standard and certified for occupant protections (ECE-R95 am.3 & 96/27/EC for Europe; FMVSS 214 in the US; TRIAS 47-3-2000 in Japan; GB 20971-2006 in China; AIS-099/F in India; ADR 72/00 in Australia; KMVSS 102 in Korea) as well as NCAP tests (Euro-NCAP; USA-NCAP; Japan-NCAP; China-NCAP; Korea-NCAP; Australia-NCAP).

Main specifications

The MDB-R95 side impact barrier consists of six single blocks of aluminum honeycomb, which have been processed in order to give a progressively increasing level of force with increasing deflection. Front and rear aluminum plates are attached to the aluminum honeycomb blocks. The barrier is manufactured to absorb a total quantity of kinetic energy set to 45 kJ +/- 3 kJ. Main geometric characteristic are shown in the figures below [3].

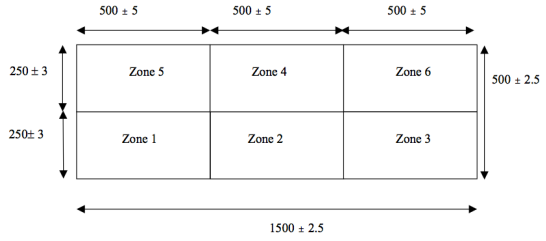

Figure 3: MDB-R95 geometry

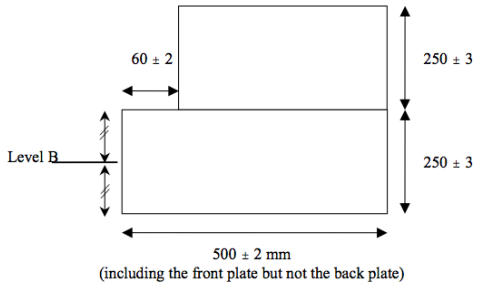

Figure 4: MDB-R95 geometry

A complete testing procedure for certification of aluminum honeycomb is performed in-house according to EEVCC-R95 amendment 3 [3]. The aluminum honeycomb blocks are processed such that the force deflection-curve when statically crushed is within the corridors defined for each of the six blocks.

AE-MDB

The initial IHRA draft protocol was to be representative of worldwide car-to-car side impact accidents. However, due to the differences between North America and European fleet, it has been decided to develop different deformable barriers. EEVC-WG13 was asked by IHRA to develop the deformable barrier representative for the EU-vehicle fleet so called Advanced European Mobile Deformable barrier AE-MDB, which started in 2001.

The European Enhanced Vehicle Safety Committee Working Group 13 (EEVC WG13 [4]) worked closely with the Japanese authorities to develop AE-MDB and then the activities resulted in different AE-MDB versions since more than 10 years. The first version of the AE-MDB has been presented at the ESV-2003 [9] and then the EEVC WG13 activities resulted in a specification version 2 of the AE-MDB, which has been presented at the ESV-2005 [5]. However due to the lack of agreement between EEVC members upon the final specification of the AE-MDB V2 (the resulting vehicle deformation was suggested as not to be in line with real car to car tests), the members continuously modified the AE-MDB barrier as several version 3. Many studies like the one performed by Honda [10] or from the EC funded FP6 project APROSYS 17 [1] have investigated side impact compatibility and updated the AEMDB versions 3. Their approach was first to investigate the effect of modifying the characteristics of a Mobile Deformable Barrier (MDB). These AE-

MDB evolutions have been mainly performed within APROSYS and resulted to the actual AE-MDB version 3.9 [2].

Figure 5: AE-MDB AFL Honeycomb Structures

Designed and manufactured according to the ISO 9001 (V2008), the AFL AE-MDB side impact barriers are used by car manufacturers and test laboratories worldwide for research and development since almost 10 years with several versions. Based on the AE-MDB version 3.9, EuroNCAP decided to implement the AE-MDB side impact barrier into their future rating.

Main specifications

The AE-MDB barrier design was taking into account the main following considerations:

- Reproduce the load path of a perpendicular car-to-car side impact with a stationary target and moving deformable barrier
- Not allow simultaneous loading of the A and C pillars which might prevent realistic loading of the occupants.
- Represent the mean European fleet dimensions for the front cars
- Match the width of standard load cell wall by a center section of 500mm

Main geometric characteristic are shown in the figures 6 and 7 below [2].

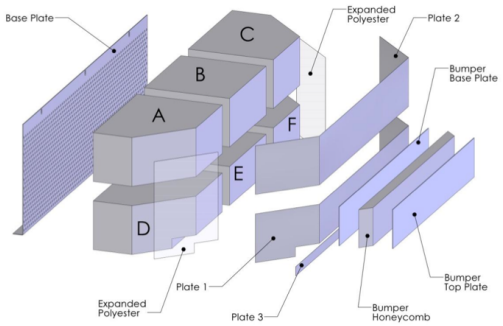

Figure 6: AE-MDB geometry

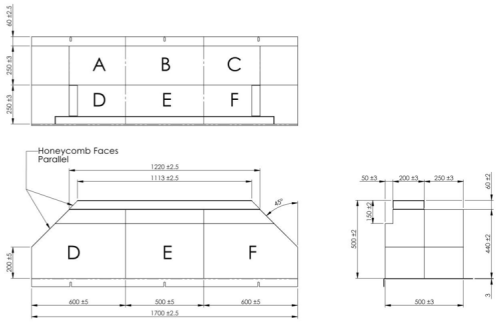

Figure 7: AE-MDB geometry

Based on the Aluminum Honeycomb technology, the AE-MDB V3.9 barrier face take into account the major concerns identified by EEVC WG13 members with the version 2 which did not compare well with that seen in baseline car-to-car tests [6]. Developed within APROSYS, the AE-MDB V3.9 has a bumper beam element in addition of reduced stiffness of the lower blocks by comparison to version 2. The outer blocks D and F version 3.9 have a stiffness set to 55% of the blocks version 2 and the middle block E has a stiffness set to 60% of the block version 2 [2].

As it is for the MDB-R95, the AE-MDB side impact barrier also consists of six single blocks of aluminum honeycomb, which have been processed in order to give a progressively increasing level of force with increasing deflection. An additional single element is attached of 60 mm depth to the front of the lower row of blocks. Front and rear aluminum plates are attached to the aluminum honeycomb blocks. The plates cover the angled surfaces. The AE-MDB barrier is manufactured to absorb a total quantity of kinetic energy set to 61.5 kJ +/- 5 kJ. A complete testing procedure for certification of aluminum honeycomb is performed in-house according to the AE-MDB Build Specification [2]. The aluminum honeycomb blocks are processed such that the force deflection-curve when statically crushed is within the corridors defined for each of the six blocks.

BARRIER TO RIGID LCW PROTOCOL

Procedure description

The test procedure for both barriers faces MDB-R95 and AE-MDB is based on the current test protocol describes in the specifications [2, 3]. The test specifications are the same for both AE-MDB and MDB-R95 impactor:

- The ground clearance, center of gravity, the wheelbase dimensions etc. including both barrier and trolley
- Barrier attachment to the trolley use six M8 bolts
- Ventilation device is mounting to the trolley
- Testing ground with LCW and plywood face as surface protection
- Impact alignment accurate to within 10 +/- 5 mm
- Impact velocity 35 +/- 0.5 km/h
- Loads filtering CFC 60 for all blocks
- Acceleration measured a 3 different location of the trolley and filtering with CFC 180 for integration

In addition of the barrier itself, the only difference is in the trolley mass set to 950 kg for MDB-R95 and 1300 kg for the AE-MDB. This means a dissipated total energy during impact equal to 61.5 kJ for AE-MDB and 45 kJ for MDB-R95. Initially set to 1500kg by IHRA to be worldwide representative, the trolley mass has been finally set to 1300 kg for better European fleet representation by EEVC-WG13.

Test condition

6 AFL barrier faces (3 MDB-R95 and 3 AE-MDB) have been tested at different crash Laboratories. MDB-R95 tests have been performed at UTAC in France and TNO in the Netherlands while AE-MDB tests have been performed at BAST in Germany. All the crash Laboratories are certified Euro-NCAP crash laboratories certified and have the ability to perform certification tests.

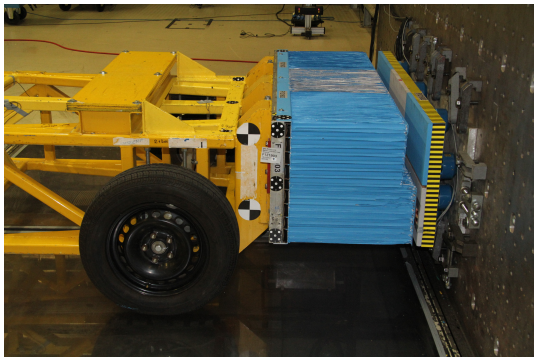

Figure 8: MDB-R95 test

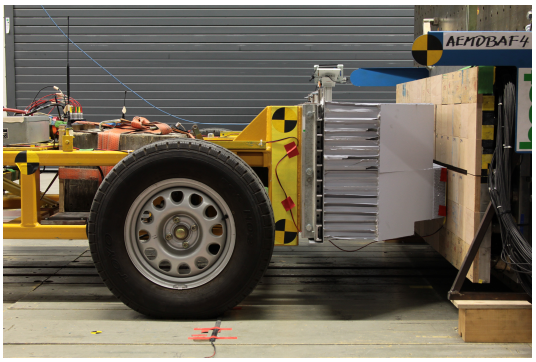

Figure 9: AE-MDB test

The tables 1 and 2 below show the trolley test weight, including deformable barrier and the impact test velocity.

Test Set-up	Mass (kg)	Impact velocity (km/h)
ECE R95 Directive	950 +/- 20	35.0 +/- 0.5
MDB-R95-PR333	957.0	34.8
MDB-R95-PR390	957.0	35.1
MDB-R95-PR102	957.0	35.1

Table 1: MDB-R5 test set-up

Test Set-up	Mass (kg)	Impact velocity (km/h)
AE-MDB Protocol	1300 +/- 20	35.0 +/- 0.5
AE-MDB PR032	1314.0	34.89
AE-MDB PR033	1314.0	34.94
AE-MDB PR034	1314.0	34.84

Table 2: AE-MDB test set-up

The results of the load cell wall tests for both MDB-R95 and AE-MDB barriers in standard dynamic certification tests are presented below with force/deflection per barrier blocks.

Barrier faces deflection

The deflection is calculated by double integration of mean acceleration of three accelerometers placed on the trolley. The maximum dynamic deformation measured during the test, when all of the kinetic energy has been absorbed, shall be 330 mm for MDB-R95 and 364 mm for AE-MDB. The results (see figure 10 and 11) show that all barriers are within the corridors for the complete barrier deformation as well as residual deformation.

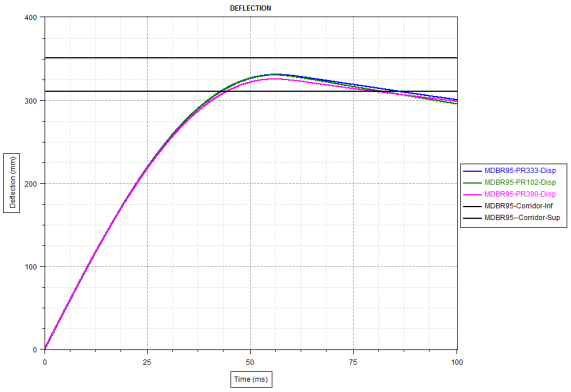

Figure 10: MDB-R95 barrier deflection

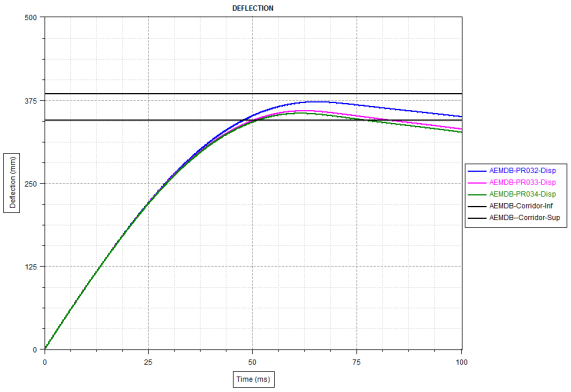

Figure 11: AE-MDB barrier deflection

The mean of maximum deflection is 328.14 mm for MDB-R95 and 361.46 mm for AE-MDB barriers. Global statistics (maximum, minimum, deviation etc.) are shown in appendix 1. The deviation noticed by the crash laboratories for all the 6 barriers are within the required specifications including uniform deformation of the barrier during the tests (see figure below).

Figure 12: MDB-R95 post-test

Figure 13: AE-MDB post-test

The MDB-R95 force/deflection per blocks are shown in the figures 14 to 20.

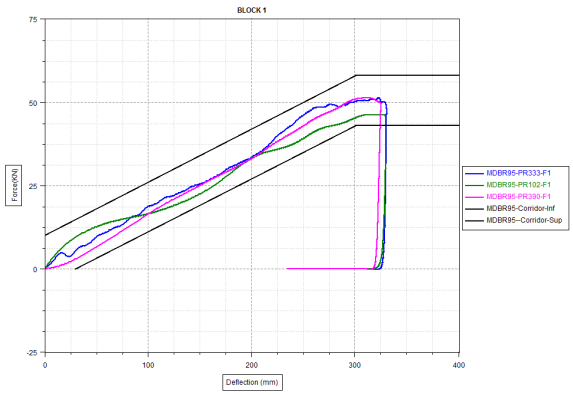

Figure 14: force/deflection MDB-R95 Blocks 1

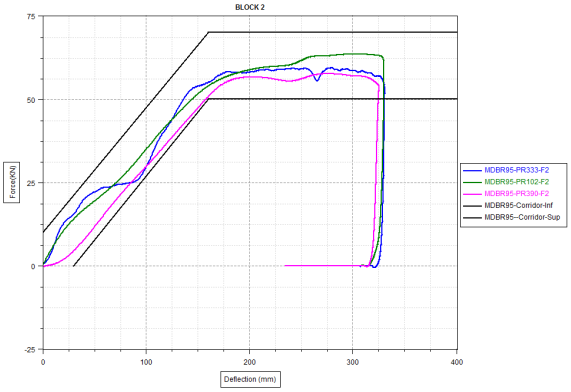

Figure 15: force/deflection MDB-R95 Blocks 2

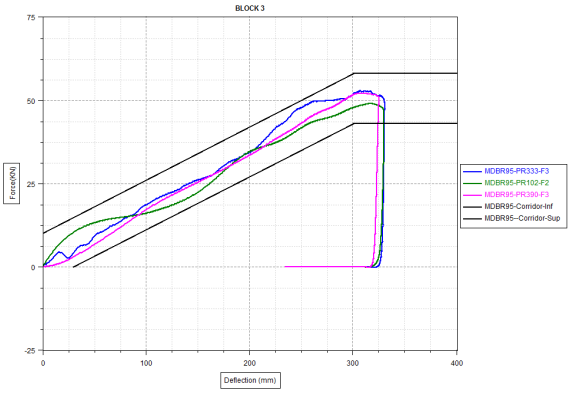

Figure 16: force/deflection MDB-R95 Blocks 3

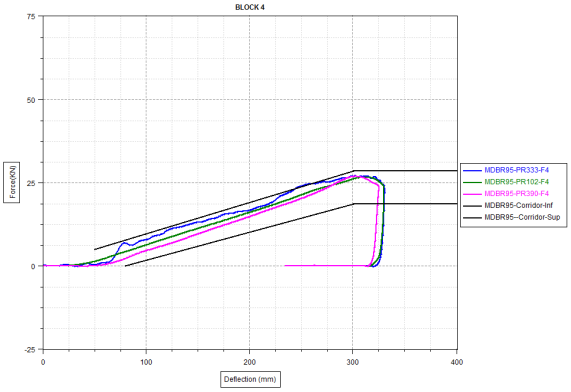

Figure 17: force/deflection MDB-R95 Blocks 4

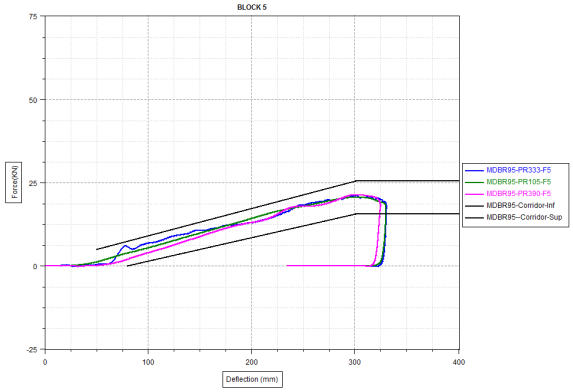

Figure 18: force/deflection MDB-R95 Blocks 5

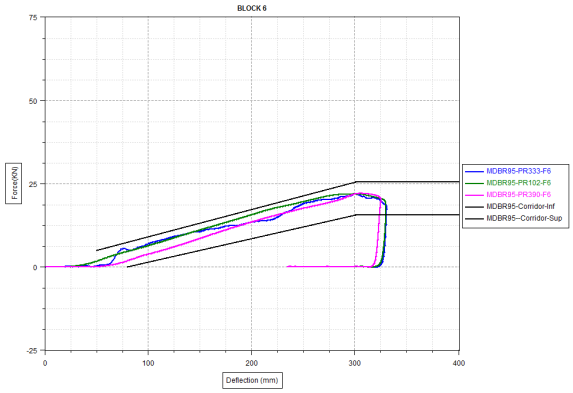

Figure 19: force/deflection MDB-R95 Blocks 6

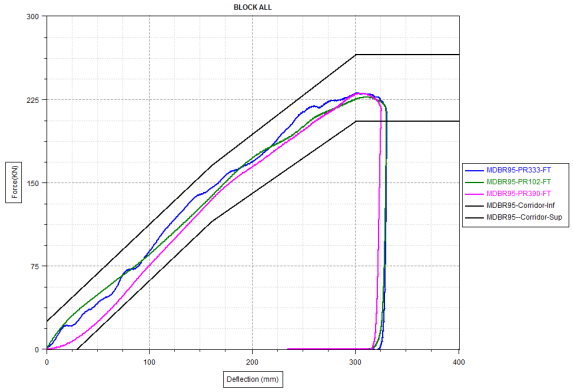

Figure 20: force/deflection MDB-R95 All Blocks

AE-MDB force/deflection per blocks

The AE-MDB force/deflection per blocks is shown in the figures 21 to 27.

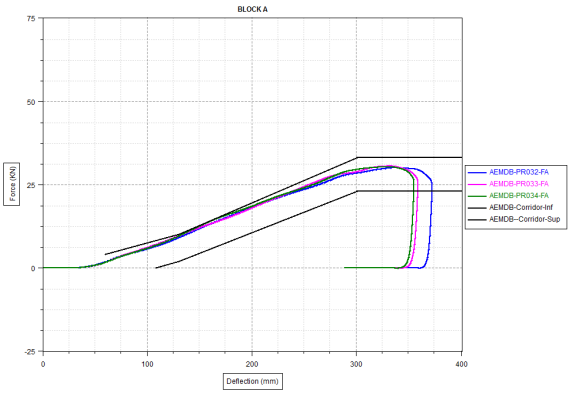

Figure 21: force/deflection AE-MDB Blocks A

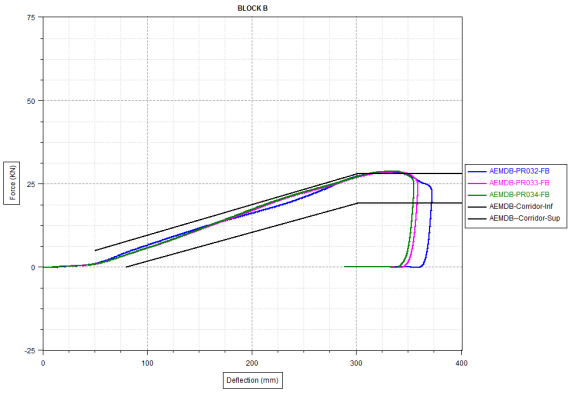

Figure 22: force/deflection AE-MDB Blocks B

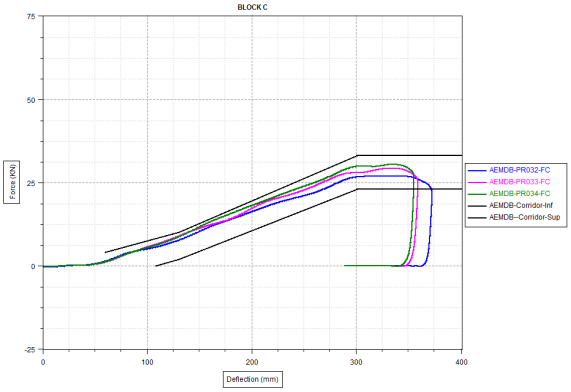

Figure 23: force/deflection AE-MDB Blocks C

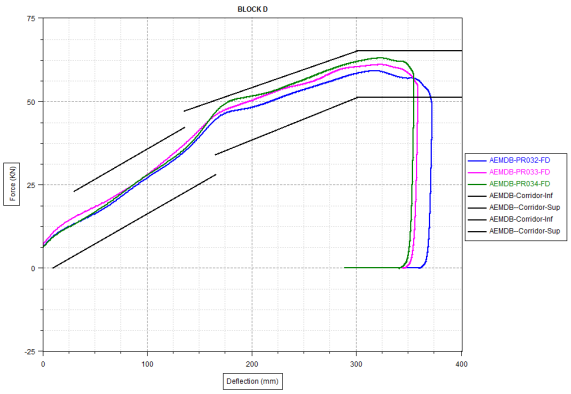

Figure 24: force/deflection AE-MDB Blocks D

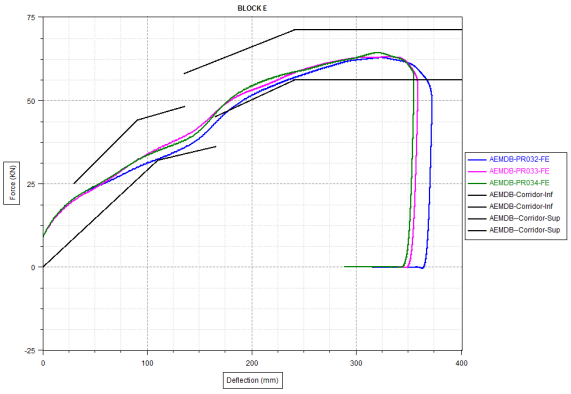

Figure 25: force/deflection AE-MDB Blocks E

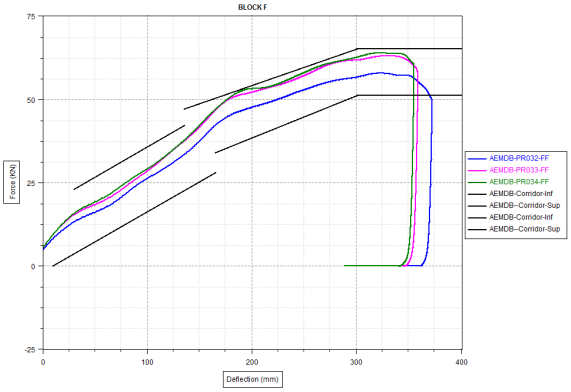

Figure 26: force/deflection AE-MDB Blocks F

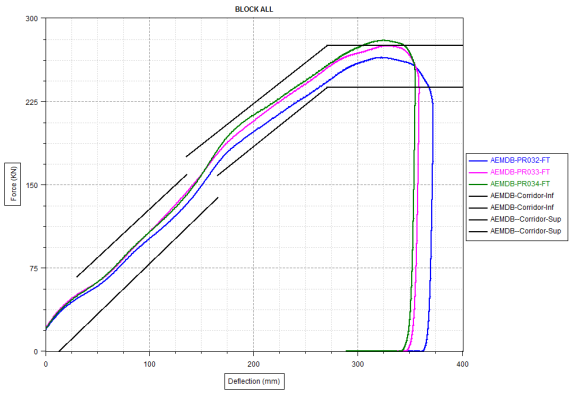

Figure 27: force/deflection AE-MDB All Blocks

EVALUATION METHOD

Methodology

The purpose of the evaluation module is to provide an objective and consistent way of comparing results in order to extract marks from models. To do so, a matrix base approach has been chosen. This approach is detailed below, while all the practical information related to use of this module are in the Hyperstudy User's Guide [7]. In this section we briefly describe the notation method used in Adviser's evaluation module. In our purpose, the scoring is made on the basis of the use of corridors to evaluate results position.

Distance error

The first point concerns the element level evaluation: considering the element corresponding to line i and column j, we first may express a local note Eij that will stand for the difference between experimental and simulation value of element ij. The note is computed as the relative difference between the two values so that we have:

$$E_{ij} = 100 \times \left| \frac{Ref(i,j) - Val(i,j)}{Ref(i,j)} \right|$$

Equation 1: note computed as relative difference between Ref and Val

This is called the "Distance Only Error Score". Please note that Ref or Val values may be themselves complex criteria. This formula implies that elementary scoring will always be between 0 and 100. In addition we have to notice that using a relative difference scheme will lead to a null score if difference between Ref and Val is higher than Ref value magnitude.

Corridor score

In Adviser evaluation module, the score of each element may be modified by analyzing whether the target value (Yij or Val(i, j)) belong to a user specified corridor. This corridor will lead to evaluation of a corridor score. This score, Fcij , will be used to create a global error report over the element. This score Fcij can be either used "alone" or in addition to the distance error Eij. Below is shown the definition of the score function:

$$Fc_{ij} = \begin{cases} \frac{a}{b-e}(Y_{ij} - e) & \text{if } Y_{ij} \in [e;b] \\ \frac{a-1}{b-M}(Y_{ij} - b) + a & \text{if } Y_{ij} \in [b;M] \\ \frac{a-1}{c-M}(Y_{ij} - c) + a & \text{if } Y_{ij} \in [M;c] \\ \frac{a}{c-f}(Y_{ij} - f) & \text{if } Y_{ij} \in [c;f] \\ 0 & otherwise \end{cases}$$

Equation 2: score function definition

In these relations we introduced:

- The bounds of the corridor: b and c
- The value of the function at the bounds of the corridor: a
- We consider the middle of the corridor has the reference point: M=(b+c)/2, so
- e and f are tolerances regarding X position in the corridor and k: e=b-k(c-b),
- f is an integer used to quantify this tolerance: f=c+k(c-b)

For example with k set to 1 and a set to 0.4 we obtain the following shape for the corridor function.

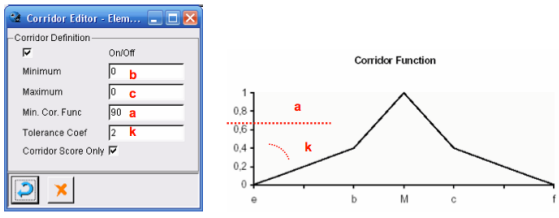

Figure 28: shape of the corridor function

The maximum note is obtained for a value of Yij lying in the middle of the corridor. The parameters a, b, c and k are the data given by the user.

Scoring

We used the scoring method describes above to evaluate both MDB-R95 and AE-MDB results (displacements, blocks forces et.) in front of the LCW tests. Maximum and minimum of the corridors are set as b and c variable. Parameters a and k are set to 0. This means that the score value will reflect how far we are from the middle of the corridor. The rating is set to 100% if we are perfectly in the middle of the defined corridor; set to 0% at the bounds of the corridor. If the results are out of the corridor, the score value will be automatically be set to 0%. The figures below show the evaluation matrix for both MDB-R95 and AE-MDB barriers and the main outputs in dynamic certification.

Figure 29: MDB-R95 evaluation matrix #1

Figure 30: AE-MDB evaluation matrix #1

DISCUSSION

None of the 6 barriers tested bottom out for LCW tests with 328mm crush for MDB-R95 and 361 mm crush for AE-MDB. For the barriers, the variance at peak deflection for MDB-R95 and AE-MDB are respectively 9% and 81%. For all the tests performed, we didn't see any imbalance between the outer blocks for MDB-R95 and AE-MDB tests as well. All the barriers were well aligned with the Load Cell Wall according to the crash laboratories measurement. The residual deformation measured after tests are within the specification for all barriers tested.

The 3 MBB-R95 barriers pass the certification for block forces and deflection according to the ECE-R95. Although all blocks are within the corridors and mainly closed to the mean corridors, the middle block of the upper row (blocks 4 for all MDB-R95 barriers tested) have stiffer responses than the median corridor and are closed to the upper corridor see figure XX. In case of barrier MDB-R95-PR102, we also noticed for deflection upper than 200 mm that the force is going down within the corridor. This behavior is less highlighted by he block 3 and not seen from the 2 other MDB-R95 barriers tested. For the upper row, the variance at peak force for blocks 1, 2 and 3 is less than 1%. For the lower row, the variance at peak force for blocks 4, 5 and 6 are respectively 8%, 9% and 4%.

The 3 AE-MDB barriers are compared to the APROSYS corridors [2]. The blocks D, E and F are in the corridors. For the upper row, the variance at peak force for blocks are respectively 3%, 1% and 10%. The blocks A and C are in the corridor with stiffness closed to the mean corridor and variance at peak force of 1% and 3% respectively. The block B for the 3 AE-MDB barrier tested is going above the top corridor from for deflection upper than 310 mm with maximum forces out of the corridor. The block B maximum peak deflection for AE-MDB barriers is 28.67 kN meaning just 0.67 kN outer the top corridor and the variance at peak force for blocks B is less than 1%. The blocks B have a stiffer behavior compared to the mean corridor, which is in line with the corresponding block 4 from MDB-R95.

In LCW tests, the MDB-R95 shows consistent results closed to the mean corridor for all blacks as well as all tests performed at different crash laboratories. The AE-MDB-PR032 has a softer behavior by comparison to the 2 others although the blocks B for all AE-MDB barriers tested are outside the corridor. However, the 3 AE-MDB barriers have consistent results to each other. The figure below shows the evaluation matrix for MDB-R95 and AE-MDB barriers recomputed with the following rating to better highlight the deviation from the middle of the corridor:

- Red if score is under 25% or out of the corridors
- Orange if score is in between 25% and 50%
- Yellow if score is in between 50% and 75%
- Green if score is in between 75% and 100%

Figure 31: MDB-R95 evaluation matrix #2

Figure 32: AE-MDB evaluation matrix #2

CONCLUSIONS

The objective of this work was to perform a first status of both MDB-R95 and AE-MDB side impact barriers regarding their respective Load Cell Wall tests configuration.

Due to its new design and materials in addition of the bumper, AE-MDB barrier is much more complicated to manufacture than the well-known MDB-R95. Although MDB-R95 results are all within the corridors which is not the case of the AE-MDB results, the repeatability and consistency of the barriers looks equivalent especially for the upper rows. Some additional tests for both barriers will be added to the work to increase the panel to more than 3 tests per barrier as presented in this paper. This would allow better statistics regarding barrier repeatability, especially for AE-MDB deflection, which seems having higher variance than the MDB-R95. Improvement will be also made for the rating evaluation, which is actually mainly based on the peak force and deflection. In addition, AE-MDB specifications will be updated according to the latest corridors, which will be published soon by EuroNCAP

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APPENDIX 1

MDB-R95	Points	Minimum	Mean	Maximum	Range	Ave Deviation	Std Deviation	|SDev/Mean|	Variance
Displacement - mm	3	324.70	328.14	330.18	5.48	2.29	3.00	0.01	8.98
Block_1 - kN	3	46.14	49.53	51.24	5.10	2.26	2.94	0.06	8.63
Block_2 - kN	3	57.54	60.12	63.46	5.92	2.23	3.03	0.05	9.21
Block_3 - kN	3	48.89	51.21	52.74	3.85	1.55	2.04	0.04	4.18
Block_4 - kN	3	26.58	26.77	26.95	0.38	0.13	0.19	0.01	0.04
Block_5 - kN	3	20.54	20.99	21.29	0.75	0.30	0.39	0.02	0.16
Block_6 - kN	3	21.71	21.85	22.01	0.30	0.11	0.15	0.01	0.02
Block_ALL - kN	3	226.48	228.96	230.56	4.08	1.65	2.18	0.01	4.74

AE-MDB	Points	Minimum	Mean	Maximum	Range	Ave Deviation	Std Deviation	|SDev/Mean|	Variance
Displacement - mm	3	354.48	361.46	371.65	17.17	6.79	9.02	0.02	81.44
Block-D - kN	3	59.06	60.94	62.85	3.79	1.28	1.90	0.03	3.60
Block-E - kN	3	62.65	63.21	64.11	1.46	0.60	0.79	0.01	0.62
Block-F - kN	3	57.71	61.47	63.80	6.09	2.51	3.29	0.05	10.82
Block-B - kN	3	28.28	28.45	28.67	0.39	0.15	0.20	0.01	0.04
Block-A - kN	3	30.02	30.27	30.49	0.48	0.17	0.24	0.01	0.06
Block-C - kN	3	26.91	28.85	30.42	3.51	1.29	1.79	0.06	3.19
Block-ALL - kN	3	263.96	272.59	279.36	15.39	5.75	7.86	0.03	61.82