

THE ADVANCED EUROPEAN MOBILE DEFORMABLE BARRIER SPECIFICATION FOR USE IN EURO NCAP SIDE IMPACT TESTING

Ellway, J.D
van Ratingen, M
European New Car Assessment Programme,
Belgium

Versmissen, T
van Montfort, S
TNO Science and Industry, The Netherlands

Langner, T
Dobberstein, J
BASt, Germany

Goutas, P
Gay, P
Cellbond, United Kingdom

Malak, A
AFL/CT Sim, Germany

Denker, C
Hallack, J
Plascore, Germany

Odanaka, K
Ogihara, T
Showa, Japan

Paper Number: 13-0069

ABSTRACT

Past European collaborative research involving government bodies, vehicle manufacturers and test laboratories has resulted in a prototype barrier face called the Advanced European Mobile Deformable Barrier (AE-MDB) for use in a new side impact test procedure. This procedure offers a better representation of the current accident situation and, in particular, the barrier concept is a better reflection of front-end stiffness seen in today's passenger car fleet compared to that of the current legislative barrier face. Based on the preliminary performance corridors of the prototype AE-MDB, a refined AE-MDB specification has been developed.

A programme of barrier to load cell wall testing was undertaken to complete and standardise the AE-MDB specification. Barrier faces were supplied by the four leading manufacturers to demonstrate that the specification could be met by all. This paper includes background, specification and proof of compliance.

INTRODUCTION

In European New Car Assessment Programme (Euro NCAP) consumer testing, the effectiveness of improved vehicle side impact protection is assessed in two full-scale laboratory crash tests: the mobile deformable barrier (MDB) test and the perpendicular pole test. Since side barrier testing commenced in 1997, Euro NCAP has closely followed the UN-ECE Regulation 95 (R95) in terms of the test specification, the driver dummy and the injury criteria. However it has applied more demanding limits and additional requirements to promote side impact protection beyond the legal requirements.

In 2010 the safety organisation started a review of its crash procedures that have formed the backbone of its vehicle safety rating over the last fifteen years. Included in the work is an update of the MDB test which takes into account the latest injury patterns and state-of-the-art test tools. In particular, the adoption of a revised mobile crash barrier, alongside more biofidelic adult and child dummies, is considered an important new catalyst for further enhancements to vehicle side impact performance.

PREVIOUS RESEARCH

It has been well documented that the European vehicle fleet has developed since the R95 barrier was first conceived; as a result the barrier face no longer accurately represents the average passenger cars on the market, particularly in terms of the accident situation. The first concepts for an alternative barrier were developed within the European Enhanced Vehicle safety Committee (EEVC) Working Group 13 as part of a contribution to the work of the International Harmonised Research Activities (IHRA). Early prototype barrier faces were constructed by Cellbond using multiple layers of honeycomb in the same way as the R95 'Multi-2000' barriers. Both homogeneous and non-homogeneous stiffness profiles were evaluated. The barrier faces had greater geometric dimensions than that of R95, different ground clearance and trolley mass of 1500kg. Further modifications were made including the addition of a 45 degree chamfer on the edges. This work was reported by Lowne at the 2001 ESV conference [1].

Once the geometry of the barrier face had been fixed, the non-homogeneous stiffness profile was chosen as it reflected data from a number of vehicle

to load-cell wall (LCW) impacts, supporting data was provided by a series of 'baseline' car to car side impact tests. This work was reported by Roberts et al at the 2003 ESV conference [2].

The R95 barrier specification was updated to the 'Advanced 2000' barrier face in the 2002 series of regulatory amendments. The honeycomb blocks were acid etched to produce progressive stiffness as opposed to multiple honeycomb layers increasing in stiffness. A revised version of the AE-MDB was produced by Cellbond using acid etched blocks and termed Version 1. A comparison between the prototypes and Version 1 was performed to ensure that the new construction techniques did not affect the stiffness profile of the barrier face.

In 2002 the AE-MDB build specification was then updated to Version 2 following further testing which included vehicle to LCW tests and barrier to vehicle tests. It is important to note the inclusion of steps in the corridors of Version 2. These steps were incorporated as a result of the new geometry of the AE-MDB. The corridors specified by WG13 for Version 1 were based on blocks that were 500mm x 250mm, as per the R95 blocks. However, version 1 corridors did not take into account the geometry of the AE-MDB blocks which are not always 500mm x 250mm. This work was reported by Ellway at the 2005 ESV conference [3].

After 2005, accident research suggested that the side impact regulation should first be improved by the addition of a mandatory pole impact test [4]. Consequently, the involvement of EEVC WG13 in further development of the AE-MDB diminished. The work on the AE-MDB barrier development continued in the research programme supported by the European Commission, Advanced Protection Systems (APROSYS) [5]. Based on the results seen with AE-MDB Version 2, modifications were proposed to reduce the stiffness of the lower row, outer blocks. New stiffness profiles were proposed and a bumper beam element was added to the barrier face, see Figure 1. When considering any version of the AE-MDB after Version 2, it is important to note that the stiffness specifications for all later barriers use the Version 2 corridors as an initial starting point.

The development work undertaken by APROSYS is reported in the task deliverable [6]. Various iterative modifications were evaluated, focusing specifically on the lower row of three blocks. The research culminated with Version 3.9, which utilised identical upper blocks to those of Version 2 but with lower blocks of reduced stiffness to 55/60/55 percent of the outer lower blocks D and F from Version 2. It is important to note that the Version 3.9 corridors shown in the APROSYS

project report do not fully account for the addition of the bumper beam, although some efforts were made to take this into consideration.

BARRIER CONSIDERATIONS

In 2011, Euro NCAP agreed to adopt the AE-MDB for future side impact testing. The side impact working group (SIWG), tasked to develop and validate the new MDB procedure, set up an ad-hoc Task Force to bring the barrier from its prototype stage to a well defined design and build specification. The SIWG and Task Force AE-MDB, agreed to the following items:

Barrier face

After consultation with experts previously involved in the development of the AE-MDB, it was agreed to adopt the Version 3.9 barrier face with a beam element as evaluated by APROSYS. Before this work began, the block E corridor was partly re-drafted to reflect the theoretical performance of the Version 3.9 barrier with bumper beam fitted. This was done by establishing the theoretical performance of the original corridor of Version 1 and applying the relevant geometry.

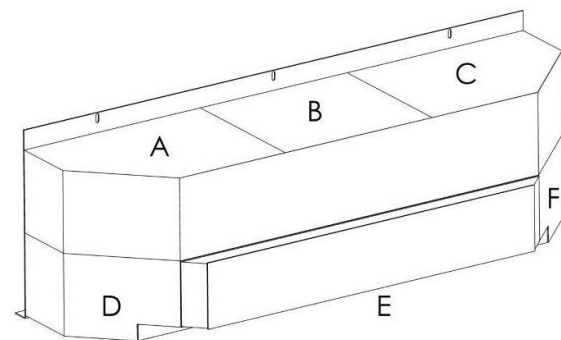


Figure 1: AE-MDB Version 3.9 consisting of six honeycomb blocks and with bumper beam fitted.

Trolley mass

The early development of the AE-MDB was part of a contribution to the work of the IHRA Side Impact Working Group. This work specified a trolley mass of 1500kg in an attempt to find global consensus. However, research conducted by the University Institute for Automobile Research (INSIA) Madrid, the German Institute for Highway Safety (BAST) using accident research (GIDAS/CCIS) data, Euro NCAP data and the European Environment Agency [7] showed that a total trolley mass of 1300kg would be more appropriate for use in Europe. Owing to the adoption of a lower trolley mass (1300kg) it was necessary to adjust the target requirements for peak dynamic displacement and static crush of the barrier face in certification load cell wall tests.

Test speed

The speed of the trolley used during the development of the AE-MDB in barrier to car impacts was 50km/h. Consideration was given to how appropriate this speed is for side impact testing. Some research has suggested that increasing the test speed to 65km/h might address a larger proportion of MAIS 3+ injuries. However, concerns were raised about the calculation method of delta V in side impacts in this study [8]. In particular the reliability was questioned in light of real world accident data which suggested similar delta V but showed considerable differences in vehicle deformation. Due to the lack of a more suitable test speed, it was agreed that the AE-MDB to car test would be run at 50km/h. This issue would be monitored in the future.

Barrier energy

Consideration was given to the amount of energy to be absorbed by the barriers during the impact. Previous versions of the barrier specification required that the barrier absorbs a total amount of energy equal to the kinetic energy of the trolley calculated using $mv^2/2$. However, there is additional energy in the rotating parts of the trolley such as wheels, hub assemblies and brakes etc. An analysis of wheel assemblies from three different test institutions suggested that, there can be up to 2kJ of additional energy provided by the rotating parts. However, it is acknowledged that not all of the rotational energy is absorbed by the barrier face.

AE-MDB to LCW testing

From previous experience, it is understood that performance corridors alone do not ensure that barriers of different suppliers behave identically. Hence, with the initial test conditions of trolley mass and speed defined, a programme was initiated to complete a full barrier build and performance specification.

The aim of this last phase was to define the construction of the AE-MDB in detail, evaluate the performance of a number of barriers constructed by multiple manufacturers and finalise the static and dynamic performance specifications. To that end, four barrier manufacturers AFL, Cellbond, Plascore and Showa agreed to construct and supply barriers for use in comparative barrier to LCW impacts.

The work began with a review of the draft build specification [5] to define the necessary materials and ensure that construction is consistent between manufacturers. Each barrier manufacturer then provided three barriers for use in the LCW evaluation tests. Testing was performed at two Euro NCAP test laboratories; BAST in Germany and TÜV Rheinland TNO Automotive

International B.V. (TTAI) in the Netherlands. The LCW configurations between the two labs were different: BAST used a high resolution wall with load cells measuring 125mm x 125mm. At TNO, six plates were used that corresponded to the barrier blocks with a smaller number of load cells. Close attention was paid to the accuracy of barrier displacement measurements. High speed film was used alongside multiple accelerometer measurements due to the known errors involved with calculating displacement from accelerometer signals.

RESULTS

The results of the 12 barrier to LCW tests are shown in Figure 2. The solid black line denotes an average force for the new barriers. As the data from each barrier was normalised to 1mm incremental displacements; anomalies appeared in the region of peak barrier displacement. This was due to the variation in peak displacement between barriers; the data was subsequently cropped at this point. One of the barrier tests shows a peak displacement of 371mm, above the permitted maximum. There were concerns regarding the validity of the data used in calculating displacement of this particular barrier, this data has been excluded from any further analyses.

The dotted black line is the data from an early Version 3.9 barrier that was published within the APROSYS research. The trolley mass in this test was 1500kg, hence the additional displacement, and the data filtering was not in accordance with the draft specification. However, this data serves as a baseline for the new barriers. It is intended that the updated specification reflects the performance of the barriers evaluated within APROSYS. The corridors shown in Figure 2 are based on those published by APROSYS with the corrections to block E which account for the addition of the beam element.

Blocks A, B and C

The data from the upper row of blocks always tended to be toward the top of the corridors. This was the case for the baseline test and for the tests to the most recent barriers. The largest difference between peak values in the upper row (ignoring the baseline data) was approximately 5kN for the upper row. At the peak force, the coefficient of variance for blocks A, B and C were 6%, 6% and 7% respectively.

Blocks D and F

Although most of the block D and F traces were within the corridors, albeit towards the top, three traces for each block did exceed the corridor. The spread in peak forces of blocks D and F was

approximately 5.5kN. Previous barrier data suggests that the AE-MDB will bottom out on the LCW at approximately 380mm crush. The baseline data shows a visible imbalance between the two outer blocks; this was thought to have been caused by a misalignment of the trolley (yaw) during the impact. The latest data did not show the same high impulse as that of the baseline data in the early stages of the impact. At the peak force, the coefficient of variance for blocks D and F were both 3%.

Block E

The initial corridor modifications that accounted for the addition of the bumper beam to block E are

apparent in Figure 2. As mentioned previously, this modification was based on how the honeycomb should perform theoretically and without consideration of the influence of other blocks and the beam element. Even when bearing in mind the heavy channel filtration class (CFC), the actual performance of the block produces a far smoother trace than that of the theoretical calculation.

All traces for this block were within the corridor. The peak variance between barriers was approximately 7kN with a similar coefficient of variation to that of the outer blocks.

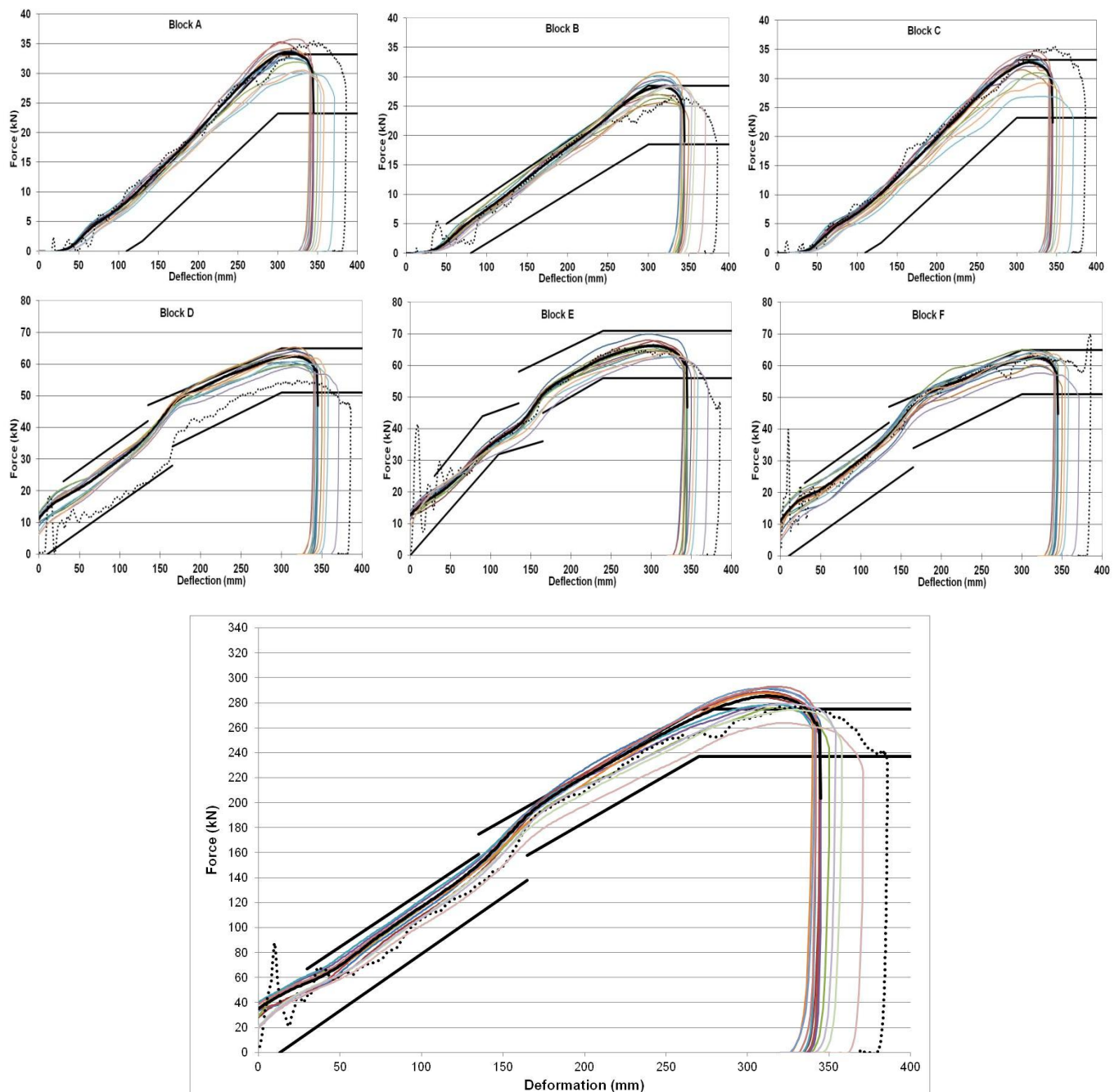


Figure 2: AE-MDB to LCW data (old corridors)

DISCUSSION

The variation of the data from the barrier to LCW tests (Figure 2) shows comparable performance between barriers of different makes tested at two different laboratories. The average data for each barrier is shown in Figure 3 along with revised corridors in solid black lines. The initial corridors are detailed as dotted black lines.

The corridor increases were based upon the difference between the average of the latest data and the theoretical trace that was used to produce the previous corridors. For example, the corridors for the upper row of blocks were increased by just under 5kN at 300mm. Proportionally smaller increases were made to the earlier parts of the corridors. This same method was applied to all of the blocks.

For blocks D and F, the initial part of the upper corridor was extended to 10mm to ensure that there is adequate control of the barrier stiffness in the early stages of barrier crush. There were initial concerns that the addition of the beam element to the lower row would result in high LCW forces in the very early stages of the impact. This was observed in the APROSYS barrier to LCW test between 0mm and 30mm of deflection. However, with correct application of the data processing and filtering requirements, detailed in the draft barrier specification, this will prevent such issues from arising.

It was also decided that the corridor for block E could justifiably be simplified. Consideration was given to using the corridor of blocks D and F for block E. However, differences in gradient in the latter part of the D and F corridor and the need for an inflection in block E at 260mm mean that this cannot be done. The principle behind block E was that it is a scaled down version of D and F, but it is important to note that the core material for block E is not the same as that used for D and F due to the very different geometry.

All of the lower corridors have been cropped at 330mm displacement as this corresponds to the smallest barrier displacement that is permitted in accordance with the energy absorption requirements.

There was no indication that any of the new barriers bottomed out on the LCW. The peak dynamic displacements of the individual barriers were all within 18mm of each other. Based on the barriers used in the evaluation, the revised AE-MDB specification details a peak dynamic displacement of $346 \pm 20\text{mm}$ and a static displacement at $340 \pm 20\text{mm}$. The upper

displacement limit is necessary to avoid the possibility of barriers being produced which are close to bottoming out.

An investigation was performed to establish the contribution of energy from the rotating parts of the trolleys. It was found that some of the barriers were absorbing up to an additional 1-2kJ above that calculated from the trolley mass and velocity ($mv^2/2$). However, the average data from all of the tests suggested that the additional energy absorbed by the barriers was not sufficiently substantial enough to warrant inclusion in the overall energy requirement. Furthermore, the overall tolerance of $\pm 5\text{kJ}$ was considered sufficiently large enough to account for this energy. The reduction in trolley mass to 1300kg results in a total energy of 61.5 $\pm 5\text{kJ}$ to be absorbed by the barrier.

The latest barrier to LCW tests highlighted the need for the further modification to the individual block corridors from those detailed in the APROSYS project report. It is important to note that the corridors were modified to account for the barriers that were evaluated by APROSYS and those tested in this programme of work. Therefore, any previous evaluations of AE-MDB Version 3.9 with a bumper beam are valid as those barriers would comply with this latest specification.

Data Filtering

The procedure requires that LCW data is filtered at a CFC of 60Hz. Such a 'heavy' filter results in LCW forces being observed earlier than physically possible. For example, the upper row does not contact the LCW until 60mm of barrier crush but forces are seen as early as 25mm crush. The filtered LCW data was correctly aligned with the displacement with the use of unfiltered data and contact switches between the barrier face and LCW. It is therefore accepted that, with filtered data, the LCW force will not be 0kN at 0mm displacement for the lower row.

Static data

In addition to dynamic performance corridors, the AE-MDB specification also details static requirements. Samples of each block were taken from the same batches used to produce barriers for use in the dynamic test and quasi-statically tested. Due to the small change in dynamic corridors, corresponding changes were also made to the static corridors. All samples tested by the barrier manufacturers met the static corridors.

With the final amendments introduced, the AE-MDB performance and build specifications have been completed. The final specification document is included in the Appendix of this paper for reference.

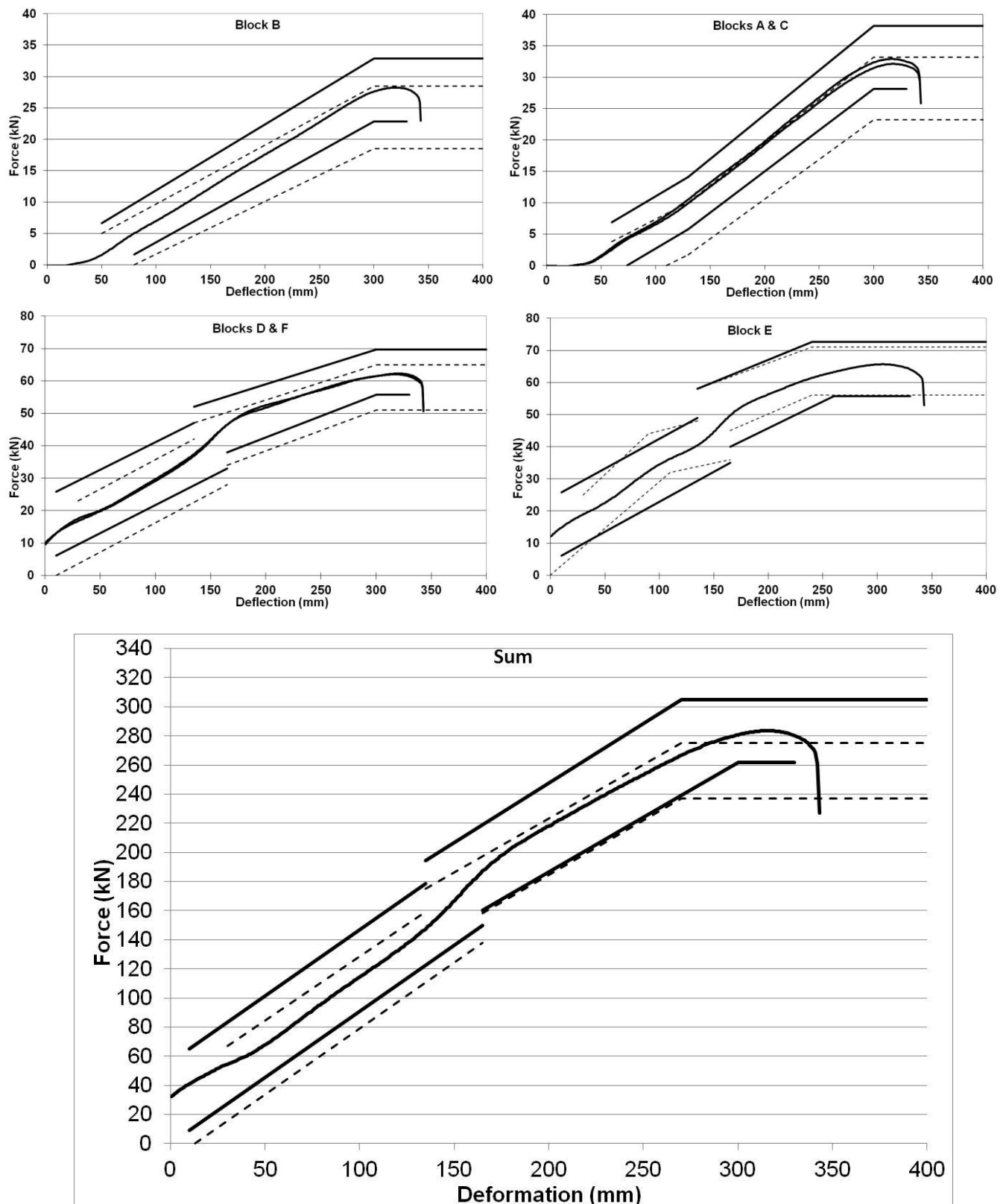


Figure 3: Modified AE-MDB Corridors

CONCLUSIONS

The aim of this work was to complete the specification for the AE-MDB for use by Euro NCAP in its revised side impact test procedures.

Based on the Version 3.9 draft specification, final build and performance specifications have been set. A series of LCW tests was performed using barriers manufactured by four independent manufacturers. Tests performed at two independent Euro NCAP test laboratories demonstrate that the results of all tests were comparable.

Revised corridors have been produced that reflect the barrier performance of both the latest barriers and those evaluated within the APROSYS project. The final AE-MDB specification is detailed in the Appendix to this paper.

ACKNOWLEDGEMENTS

Euro NCAP would like to express its thanks to Showa, Cellbond, Plascore and AFL for their support and participation in this programme and for their contribution to updating and finalising the AE-MDB specification. All drawings included in the AE-MDB specification were provided by Cellbond. The representatives of this group were:

James Ellway, Euro NCAP
Jan Dobberstein, BAST
Tobias Langner, BAST
Sjef van Montfort, TNO
Ton Versmissen, TNO

Christoph Denker, Plascore
Patrick Gay, Cellbond
Petros Goutas, Cellbond
Jason Hallack, Plascore
Arnauld Malak, AFL
Katsuhito Odanaka, Showa

Euro NCAP would also like to thank the members of the side impact working group:

Euro NCAP representatives

Michiel van Ratingen, Euro NCAP, Chairman
James Ellway, Euro NCAP, Secretary
Hans Ammerlaan, RDW
Luca Baroncelli, CSI
Aurelie Choulet, IDIADA
Tobias Langner, BAST
Jean-Philippe Lepetre, UTAC
Volker Sandner, ADAC

Richard Schram, Euro NCAP
Ton Versmissen, TNO

Industry representatives

Karsten Hallbauer, Takata
Paul Lemmen, Humanetics
Marc van Slagmaat, Autoliv
Fabien Duboc, Renault/ACEA
Erwin Segers, Honda/JAMA
Philipp Wernicke, BMW/ACEA
Christoph Weimer, HMC/KAMA

REFERENCES

- [1] Lowne, R, 2001 (on behalf of EEVC WG13). Research Progress on Improved Side Impact Protection: EEVC WG13 Progress Report. ESV 2001, Amsterdam, the Netherlands.
- [2] Roberts, A.K and van Ratingen, M, 2003 (on behalf of EEVC WG13). Progress on the Development of the Advanced European Mobile Deformable Barrier Face (AE-MDB). ESV 2003, Nagoya, Japan. Paper number 126.
- [3] Ellway, J.D, 2005 (on behalf of EEVC WG13). The Development of an Advanced European Mobile Deformable Barrier Face (AE-MDB). ESV 2005, Washington DC, USA. Paper number 05-0239.
- [4] M.J, Edwards et al, 2010 (on behalf of EEVC WG13 & WG21). Analysis to estimate likely benefits and costs for the EU of modifying Regulation 95, EEVC WG13 and WG21 Subgroup.
- [5] Advanced Protection Systems APROSYS, EC 6th Framework programme.
http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=7521834
- [6] Ellway, J.D et al, 2006 (APROSYS task 1.1.1.) Development and Evaluation of the Advanced European Mobile Deformable Barrier Face Test Procedure. APROSYS deliverable 1.1.1B.
- [7] European Environment Agency, 2010. Monitoring the CO2 emissions from new passenger cars in the EU: Summary of data for 2010.
- [8] M.J, Edwards et al, 2010. Side impact safety. UK Department for Transport report: 4/12/55.

APPENDIX: AE-MDB SPECIFICATION

1. CHARACTERISTICS OF THE MOBILE DEFORMABLE BARRIER

- 1.1 The mobile deformable barrier (MDB) includes both an impactor and a trolley.
- 1.2 The total mass shall be $1300 \pm 20\text{kg}$.
- 1.3 The centre of gravity shall be situated in the longitudinal median vertical plane within 10mm, $1000 \pm 30\text{mm}$ behind the front axle and $500 \pm 30\text{mm}$ above the ground.
- 1.4 The distance between the front face of the impactor and the centre of gravity of the barrier shall be $2000 \pm 30\text{mm}$.
- 1.5 The height of the barrier shall be such that the uppermost part of the front face of the beam element (the intersection between the upper and lower row of blocks) is $550\text{mm} \pm 5\text{mm}$ above ground level measured statically prior to impact.
- 1.6 The front and rear track width of the trolley shall be $1500 \pm 10\text{mm}$.
- 1.7 The wheelbase of the trolley shall be $3000 \pm 10\text{mm}$.

2. CHARACTERISTICS OF THE IMPACTOR

The impactor consists of six single blocks of aluminium 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 60mm depth to the front of the lower row of blocks. Front and rear aluminium plates are attached to the aluminium honeycomb blocks. The plates cover the angled surfaces.

2.1 Honeycomb blocks

2.1.1 Geometric characteristics

2.1.1.1 The impactor consists of six joined zones whose configuration and positioning are shown in Figure 4 and Figure 5. The principle dimensions of Blocks B and E are $500 \pm 5\text{mm} \times 250 \pm 3\text{mm}$ and the principle dimensions of blocks A, C, D, F are $600 \pm 5\text{mm} \times 250 \pm 3\text{mm}$, Figure 5. The 500mm and 600mm should be in the W direction and the 250mm in the L direction of the aluminium honeycomb construction, see Figure 6.

2.1.1.2 The impactor is divided into two rows. Both rows shall be $250 \pm 3\text{mm}$ high and $440 \pm 2\text{mm}$ deep.

2.1.1.3 A 45 degree chamfer is applied to the outmost blocks on both the upper and lower rows. The chamfer is not applied to the facing or backing plates of the beam element. See detail A on Figure 5.

2.1.1.4 A bumper element is added to the front of the lower row, making the complete impactor $500 \pm 2\text{mm}$ deep. The foil ribbon of this element will run parallel to the width dimension and the cell axis running parallel to the height dimension. The 1220mm should be in the W direction and the 200mm in the L direction of the aluminium honeycomb construction. See Figure 6 .

2.1.2 Pre-crush

2.1.2.1 Pre-crushing only applies to blocks A, B, C, D, E & F not to the bumper element.

2.1.2.2 The pre-crush shall be performed on the surfaces of the honeycomb that are parallel to the rear mounting face including the lower stepped section on Blocks D, E and F. Pre-crushing of the angled faces is not required.

2.1.2.3 All blocks (A, B, C, D, E & F) are to be pre-crushed by $10 \pm 2\text{mm}$ on the front surface prior to testing and shaping.

2.1.2.4 The angled faces on Blocks A, C, D and F should be cut after pre-crushing.

2.1.3 Material characteristics

2.1.3.1 The expansion direction of the Aluminium Honeycomb shall be as defined in Figure 6.

2.1.3.2 The cell dimensions shall be $19\text{mm} \pm 10$ per cent for all blocks A, B, C, D, E & F and $6.35\text{mm} \pm 10$ per cent for the bumper section, see Figure 7.

2.1.3.3 All honeycomb blocks must be made of 3003 aluminium.

2.1.3.4 The aluminium honeycomb blocks (A, B, C, D, E & F) should be processed so that the force deflection-curve when statically crushed (according to the procedure defined in Paragraph 2.1.4) is within corridors to be defined for each of the six blocks in Section 5.

- 2.1.3.5 The aluminium honeycomb blocks for the bumper element should be processed so that the strength is 1.586 to 1.793MPa when statically crushed (according to the procedure defined in NHTSA TP-214D).
- 2.1.3.6 The processed honeycomb material used in the honeycomb blocks to be used for construction of the barrier shall be cleaned in order to remove any residue that may have been produced during the processing of the raw honeycomb material.
- 2.1.3.7 The mass of the blocks in each batch shall not differ by more than 5 per cent of the mean block mass for that batch.
- 2.1.4 Static tests for all blocks
 - 2.1.4.1 A sample taken from each batch of processed honeycomb core shall be tested according to the static test procedure described in Section 5.
 - 2.1.4.2 The force-deflection characteristic for each block tested shall lie within the force deflection corridors to be defined in Section 8.
- 2.1.5 Dynamic test
 - 2.1.5.1 The dynamic deformation characteristics, when impacted, shall comply with the procedure described in Section 6.
 - 2.1.5.2 Deviation from the limits of the force-deflection corridors characterising the rigidity of the impactor, as defined in Section 9 may be allowed provided that:
 - 2.1.5.2.1 The deviation occurs after the beginning of the impact and before the deformation of the impactor is equal to 150mm.
 - 2.1.5.2.2 The deviation does not exceed 50 per cent of the nearest instantaneous prescribed limit of the corridor.
 - 2.1.5.2.3 Each deflection corresponding to each deviation does not exceed 35mm of deflection, and the sum of these deflections does not exceed 70mm.
 - 2.1.5.2.4 The sum of energy derived from deviating outside the corridor does not exceed 5 per cent of the gross energy for that block.
 - 2.1.5.3 The dynamic stiffness requirements for Block B is such that the force deflection curve falls between corridors of Section 9, Figure 18.
 - 2.1.5.4 The dynamic stiffness requirements for Blocks A and C are identical. Their rigidity is such that their force deflection curves fall between corridors of Section 9, Figure 19.
 - 2.1.5.5 The dynamic stiffness requirements for Block E is such that the force deflection curve falls between corridors of Section 9, Figure 20.
 - 2.1.5.6 The dynamic stiffness requirements for Blocks D and F are identical. Their rigidity is such that their force deflection curves fall between corridors of Section 9, Figure 21.
 - 2.1.5.7 The dynamic stiffness requirement for the complete barrier is such that the force deflection curve falls between corridors of Section 9, Figure 22.
 - 2.1.5.8 The force-deflection curves shall be verified by a test detailed in Section 6 consisting of an impact of the barrier against a dynamometric wall at $35 \pm 0.5\text{km/h}$.

- 2.1.5.9 The dissipated energy against blocks A and C during the test shall be equal to $5.0 \pm 1.0\text{kJ}$ per block.
- 2.1.5.10 The dissipated energy against block B during the test shall be equal to $4.6 \pm 1.0\text{kJ}$.
- 2.1.5.11 The dissipated energy against blocks D and F shall be equal to $14.8 \pm 2.0\text{kJ}$ per block.
- 2.1.5.12 The dissipated energy against block E shall be equal to $17.3 \pm 2.0\text{kJ}$.
- 2.1.5.13 The dissipated total energy during the impact shall be equal to $61.5 \pm 5.0\text{kJ}$. The tolerance takes into account any additional energy contribution from the rotating parts of the MDB.
- 2.1.5.14 The maximum impactor deformation from the point of first contact, calculated from integration of the accelerometers according to Section 6.5.3 shall be equal to $346 \pm 20\text{mm}$.
- 2.1.5.15 The final residual static impactor deformation measured after the dynamic test at a height of 425mm above ground and along the MDB centreline shall be equal to $340 \pm 20\text{mm}$.
- 2.1.5.16 The amounts of energy indicated are the amounts of energy dissipated by the system when the extent to which the impactor is crushed is greatest.
- 2.2 Front plates
 - 2.2.1 Geometric characteristics
 - 2.2.1.1 The three front plates (upper, lower & bottom) shall cover the full front surface of the barrier and have a thickness of $0.5 \pm 0.06\text{mm}$. The three plates shall be 250mm, 200mm and 50mm wide and of the appropriate length to cover the pre-crushed and angled surfaces in a continuous length. The bottom strip (50mm wide) shall not cover the angled sides of the barrier.
 - 2.2.1.2 When assembled the overall dimensions of the impactor shall be $1700 \pm 2.5\text{mm}$ wide and $500 \pm 2.5\text{mm}$ high. See Figure 5.
 - 2.2.1.3 The upper edge of the lower front plate and the lower edge of the upper front plate shall be aligned within 4mm.
 - 2.2.2 Material characteristics
 - 2.2.2.1 The front plates are manufactured from aluminium of series AlMg2 to AlMg3 with elongation ≥ 12 per cent, and a UTS $\geq 175 \text{ N/mm}^2$.
- 2.3 Bumper front and rear plates
 - 2.3.1 Geometric characteristics
 - 2.3.1.1 The geometric characteristics shall be according to Figure 4 and Figure 5.
 - 2.3.2 Material characteristics
 - 2.3.2.1 The bumper plates shall be manufactured out of aluminium 5251 H22, 5052 H32 or 5052 H34. The plates have a thickness of $3\text{mm} \pm 0.07\text{mm}$.
- 2.4 Barrier back plate
 - 2.4.1 Geometric characteristics

- 2.4.1.1 The geometric characteristics shall be according to Section 7.2.
- 2.4.1.2 The upper mounting flange shall be vertical. The lower mounting flange shall be bent through 90 degrees.
- 2.4.2 Material characteristics
 - 2.4.2.1 The back plate shall be manufactured from aluminium of series AlMg2 to AlMg3 with hardness between 50 and 67 HBS. The back plate is 3mm thick ± 0.2 5mm. This plate shall be perforated with holes for ventilation, the location, diameter and pitch are shown in Figure 8 and Figure 10.
- 2.5 Location of the honeycomb blocks
 - 2.5.1 The honeycomb blocks shall be centred on the perforated zone of the back plate.
- 2.6 Expanded polyester
 - 2.6.1 Synthetic polyester thermo bonded wadding shall cover the chamfered zone of block A, C, D & F as shown in Figure 4.
 - 2.6.1.1 The material shall have a weight of $60\text{g/m}^2 \pm 20\%$.
 - 2.6.1.2 The material shall provide a 'soft link' between the upper and lower row of blocks. It may be added to the chamfered zone as a single piece or in multiple pieces provided that divisions are in the vertical direction only. The height of each piece is equal to that of the chamfered face.
- 2.7 Bonding
 - 2.7.1 For both the front and the back plates, a maximum of adhesive film thickness of 0.5mm shall be applied evenly over the surface of the front plate. The adhesive to be used throughout should be a two-part polyurethane, (such as Ciba Geigy XB5090/1 resin with XB5304 hardener) or equivalent.
 - 2.7.2 For the back plate the minimum bonding strength shall be 0.6MPa (87psi), tested according to Section 2.7.3.
 - 2.7.3 Bonding strength tests
 - 2.7.3.1 Flatwise tensile testing is used to measure bond strength of adhesives according to ASTM C297-61.
 - 2.7.3.2 The test piece should be 100mm x 100mm, and 15mm deep, bonded to a sample of the ventilated back plate material. The honeycomb used should be representative of that in the impactor, i.e. chemically etched to an equivalent degree as that near to the back plate in the barrier but without pre-crushing.
 - 2.7.3.3 Back plate ventilation holes should be clean and clear of bonding material to enable free flow of air.
- 2.8 Traceability

- 2.8.1 Barriers shall carry consecutive serial numbers which are stamped, etched or otherwise permanently attached, from which the batches for the individual blocks and the date of manufacture can be established.
- 2.9 Impactor attachment
 - 2.9.1 The fitting on the trolley must be according to Figure 11. The fitting will use six M8 bolts, and nothing shall be larger than the dimensions of the barrier in front of the wheels of the trolley. Appropriate spacers must be used between the lower back plate flange and the trolley face to avoid bowing of the back plate when the attachment bolts are tightened.

3. VENTILATION SYSTEM

- 3.1 The interface between the trolley and the ventilation system should be solid, rigid and flat. The ventilation device is part of the trolley and not of the impactor as supplied by the manufacturer. Geometric characteristics of the ventilation device shall be according to Figure 12 and Figure 13.
- 3.2 Ventilation device mounting procedure
 - 3.2.1 Mount the ventilation device to the front plate of the trolley;
 - 3.2.2 Ensure that a 0.5mm thick feeler gauge cannot be inserted between the ventilation device and the trolley face at any point. If there is a gap greater than 0.5mm, the ventilation frame will need to be replaced or adjusted to fit without a gap of > 0.5mm;
 - 3.2.3 Dismount the ventilation device from the front of the trolley;
 - 3.2.4 Fix a 1mm thick layer of cork to the front face of the trolley;
 - 3.2.5 Re-mount the ventilation device to the front of the trolley and tighten to exclude air gaps.

4. CONFORMITY OF PRODUCTION

The conformity of production procedures shall comply with those set out in the Agreement, Appendix 2 (E/ECE/324-E/ECE/TRANS/505/Rev.2), with the following requirements:

- 4.1 The barrier manufacturer shall be responsible for the conformity of production procedures and for that purpose must in particular:
 - 4.1.1 Ensure the existence of effective procedures so that the quality of the products can be inspected;
 - 4.1.2 Have access to the testing equipment needed to inspect the conformity of each product;
 - 4.1.3 Ensure that the test results are recorded and that the documents remain available for a time period of 10 years after testing;
 - 4.1.4 Demonstrate that the samples tested are a reliable measure of the performance of the batch (examples of sampling methods according to batch production are given below);
 - 4.1.5 Analyse results of tests in order to verify and ensure the stability of the barrier characteristics, making allowance for variations of an industrial production, such as temperature, raw materials quality, time of immersion in chemical, chemical concentration, neutralisation etc, and the control of the processed material in order to remove any residue from the processing;
 - 4.1.6 Ensure that any set of samples or test pieces giving evidence of non-conformity gives rise to a further sampling and test. All the necessary steps must be taken to restore conformity of the corresponding production.
- 4.2 The manufacturer's level of certification must be at least ISO 9001-2008 standard.
- 4.3 Minimum conditions for the control of production: the holder of an agreement will ensure the control of conformity following the methods hereunder described.
- 4.4 Examples of sampling according to batch
 - 4.4.1 If several examples of one block type are constructed from one original block of aluminium honeycomb and are all treated in the same treatment bath (parallel production), one of these examples could be chosen as the sample, provided that they are not shaped and care is taken to ensure that the treatment is evenly applied to all blocks. If not, it may be necessary to select more than one sample.
 - 4.4.2 If a limited number of similar blocks (say three to twenty) are treated in the same bath (serial production), then the first and last block treated in a batch, all of which are constructed from the same original block of aluminium honeycomb, should be taken as representative samples. If the first sample complies with the requirements but the last does not, it may be necessary to take further samples from earlier in the production until a sample that does comply is found. Only the blocks between these samples should be considered to be approved. All samples must remain unshaped.
 - 4.4.3 Once experience is gained with the consistency of production control, it may be possible to combine both sampling approaches, so that more than one groups of parallel production can be considered to be a batch provided samples from the first and last production groups comply.

5. STATIC TESTS

- 5.1 One or more samples (according to the batch method) taken from each batch of processed honeycomb core shall be tested, according to the following test procedure:
 - 5.1.1 The samples for all blocks (A, B, C, D, E and F) shall be 250mm x 500mm x 440mm.
 - 5.1.2 The samples should be compressed between two parallel loading plates which are at least 20mm larger than the block cross section;
 - 5.1.3 The compression speed shall be 100 millimetres per minute, with a tolerance of 5 per cent;
 - 5.1.4 The data acquisition for static compression shall be sampled at a minimum of 5Hz;
 - 5.1.5 The static test shall be continued until the block compression is at least 300mm for all blocks (A, B, C, D, E and F);

6. DYNAMIC LOAD CELL WALL TESTS

For every 200 barrier faces produced, the manufacturer shall make one dynamic test against a dynamometric wall supported by a fixed rigid barrier, according to the method described below.

6.1 Installation

6.1.1 Testing ground

6.1.1.1 The test area shall be large enough to accommodate the run-up-track of the mobile deformable barrier, the rigid barrier and the technical equipment necessary for the test. The last part of the track, for at least five metres before the rigid barrier, shall be horizontal, flat and smooth.

6.1.1.2 Fixed rigid barrier and dynamometric wall

6.1.1.3 The rigid wall shall consist of a block of reinforced concrete not less than 3 metres wide and not less than 1.5 metres high. The thickness of the rigid wall shall be such that it weighs at least 70 tonnes.

6.1.1.4 The front face shall be vertical, perpendicular to the axis of the run-up-track and equipped with a minimum of six load cell plates, each capable of measuring the total load on the appropriate block of the mobile deformable barrier impactor at the moment of impact. The load cell impact plate area centres shall align with those of the six impact zones of the mobile deformable barrier face. Their edges shall clear adjacent areas by $20\text{mm} \pm 2\text{mm}$ such that, within the tolerance of impact alignment of the MDB, the impact zones will not contact the adjacent impact plate areas. Cell mounting and plate surfaces shall be in accordance with the requirements set out in the annex to standard ISO 6487:1987.

6.1.1.5 The load cell wall must consist of at least 6 load cells, with the centre load cell having a loading surface area 500mm wide and 250mm high, and the outer load cells, covering Blocks A, C, D and F, having a loading surface area 600mm wide and 250mm high. If more than six load cells are used the aggregated area must be 500mm by 250mm at the centre and 600mm by 250mm outside.

6.1.1.6 The area surrounding the load cells ($<1700\text{mm}$ by $<500\text{mm}$) must have a surface common to that of the load cell wall face for at least 150mm ($>2000\text{mm}$ by $>800\text{mm}$). This is required to ensure that the barrier face is uniformly crushed and does not wrap around the edge of the load cells if the barrier impact is not in perfect alignment.

6.1.1.7 Surface protection, comprising a plywood face with a thickness of $18\text{mm} \pm 5\text{mm}$ shall be added to each load cell plate such that no degradation of transducer responses occurs.

6.1.1.8 The rigid wall shall be either anchored in the ground or placed on the ground with, if necessary, additional arresting devices to limit its deflection. A rigid wall (to which the load cells are attached) having different characteristics but giving results that are at least equally conclusive may be used.

6.1.1.9 The load cells must align with the principle axes of the MDB face with Blocks B and E aligned with the central load cells. The intersection of all blocks must align with intersections between load cells.

6.2 Propulsion of the mobile deformable barrier

- 6.2.1 At the moment of impact the mobile deformable barrier shall no longer be subject to the action of any additional steering or propelling device. It shall reach the obstacle on a course perpendicular to the front surface of the dynamometric wall. The impact alignment shall be accurate to within $\pm 15\text{mm}$.
- 6.3 Measuring instruments
 - 6.3.1 Speed
 - 6.3.1.1 The impact speed shall be $35 \pm 0.5\text{km/h}$ the instrument used to record the speed on impact shall be accurate to within 0.1 percent.
 - 6.3.2 Loads
 - 6.3.2.1 Measuring instruments shall meet the specifications set forth in ISO 6487:1987
 - CFC for all blocks: 60Hz
 - CAC for all blocks: 100kN
 - 6.3.3 Acceleration
 - 6.3.3.1 The acceleration in the longitudinal direction shall be measured at three separate positions on the trolley, one centrally and one at each side, at places not subject to bending.
 - 6.3.3.2 The central accelerometer shall be located within 500mm of the location of the centre of gravity of the MDB and shall lie in a vertical longitudinal plane which is within $\pm 10\text{mm}$ of the centre of gravity of the MDB.
 - 6.3.3.3 The side accelerometers shall be at the same height as each other $\pm 10\text{mm}$ and at the same distance from the front surface of the MDB $\pm 20\text{mm}$
 - 6.3.3.4 The instrumentation shall comply with ISO 6487:1987 with the following specifications:
 - CFC 1,000Hz (before integration)
 - CAC 50g
 - 6.3.4 Contact timing
 - 6.3.4.1 Two foil contact switches shall be fitted at the outboard ends of the face of the beam element which contact the load cell wall first.
 - 6.3.4.2 The contact switches must have a depth of 3mm or less.
- 6.4 General specifications of barrier and impactor
 - 6.4.1 The individual characteristics of each mobile deformable barrier shall comply with Section 1 of this specification and shall be recorded.
 - 6.4.2 The suitability of an impactor as regards to the dynamic test requirements shall be confirmed when the outputs from the six load cell plates each produce signals complying with the requirements indicated in this specification.
 - 6.4.3 Impactors shall carry consecutive serial numbers which are stamped, etched or otherwise permanently attached, from which the batches for the individual blocks and the date of manufacture can be established.

- 6.5 Data processing procedure
 - 6.5.1 Raw data
 - 6.5.1.1 At time $T = T_0$, all offsets should be removed from the data. The method by which offsets are removed shall be recorded in the test report.
 - 6.5.1.2 T_0 shall be established using the two contact switches fitted to the beam element.
 - 6.5.2 Filtering
 - 6.5.2.1 The raw data will be filtered prior to processing/calculations.
 - 6.5.2.2 Accelerometer data for integration will be filtered to CFC 180, ISO 6487:1987.
 - 6.5.2.3 Accelerometer data for impulse calculations will be filtered to CFC 60, ISO 6487:1987.
 - 6.5.2.4 Load cell data will be filtered to CFC 60, ISO 6487:1987.
 - 6.5.3 Calculation of MDB face deflection
 - 6.5.3.1 Accelerometer data from all three accelerometers individually (after filtering at CFC 180), will be integrated twice to obtain deflection of the barrier deformable element.
 - 6.5.3.2 The initial conditions for deflection are:
 - 6.5.3.2.1 Velocity = impact velocity (from speed measuring device);
 - 6.5.3.2.2 Deflection = 0;
 - 6.5.3.3 The deflection at the left hand side, mid-line and right hand side of the mobile deformable barrier will be plotted with respect to time.
 - 6.5.3.4 The maximum deflection calculated from each of the three accelerometers should be within 10mm. If it is not the case, then the outlier should be removed and difference between the deflection calculated from the remaining two accelerometers checked to ensure that it is within 10mm.
 - 6.5.3.5 If the deflections as measured by the left hand side, right hand side and mid-line accelerometers are within 10mm, then the mean acceleration of the three accelerometers should be used to calculate the deflection of the barrier face.
 - 6.5.3.6 If the deflection from only two accelerometers meets the 10mm requirement, then the mean acceleration from these two accelerometers should be used to calculate the deflection for the barrier face.
 - 6.5.3.7 If the deflections calculated from all three accelerometers (left hand side, right hand side and mid-line) are NOT within the 10mm requirement, then the raw data should be reviewed to determine the causes of such large variation. In this case the individual test house will determine which accelerometer data should be used to determine mobile deformable barrier deflection or whether none of the accelerometer readings can be used, in which case, the certification test must be repeated. A full explanation should be given in the test report.
 - 6.5.3.8 T_0 will be defined for both force and acceleration data using the two contact switches placed on the beam element. Due to the effects of filtering, it is expected that force levels

at T0 will be above 0kN for the lower row of blocks. Force data must NOT be shifted to establish 0kN at T0.

- 6.5.3.9 The mean deflection-time data will be combined with the load cell wall force-time data to generate the force-deflection result for each block.

6.5.4 Calculation of energy

- 6.5.4.1 The absorbed energy for each block and for the whole MDB face should be calculated up to the point of peak deflection of the barrier.

$$E_n = \int_{t_0}^{t_1} F_n \cdot ds_{mean}$$

where:

t_0 is the time of first contact

t_1 is the time where the trolley comes to rest, i.e. where $u = 0$.

s is the deflection of the trolley deformable element calculated according to Paragraph 6.5.3.

6.5.5 Verification of dynamic force data

- 6.5.5.1 Compare the total impulse, I , calculated from the integration of the total force over the period of contact, with the momentum change over that period ($M \cdot \Delta V$).

- 6.5.5.2 Compare the total energy change to the change in kinetic energy of the MDB, given by:

$$E_K = \frac{1}{2} M V_i^2$$

where:

V_i is the impact velocity

M the whole mass of the MDB

- 6.5.5.3 If the momentum change ($M \cdot \Delta V$) is not equal to the total impulse (I) ± 5 per cent, or if the total energy absorbed (E_{En}) is not equal to the kinetic energy, $E_K \pm 5$ per cent, then the test data must be examined to determine the cause of this error.

6.6 Post test

- 6.6.1 The crush of the AE-MDB should be recorded after the LCW impact at a representative point on the barrier. The crush measurement shall be compared to the deflection calculated from the trolley accelerometer data. If the calculated deflection is 20mm or more below the crush measured after the impact, the individual test house will determine if any of the accelerometer data can be used, in which case, the certification test must be repeated. A full explanation should be given in the test report.

7. DESIGN OF THE IMPACTOR

All dimensions are in mm.

7.1 Barrier face

- 7.1.1 The tolerances on the dimensions of the blocks allow for the difficulties of measuring cut aluminium honeycomb. The tolerance on the overall dimension of the impactor is less than that for the individual blocks since the honeycomb blocks can be adjusted, with overlap if necessary, to maintain a more closely defined impact face dimension.

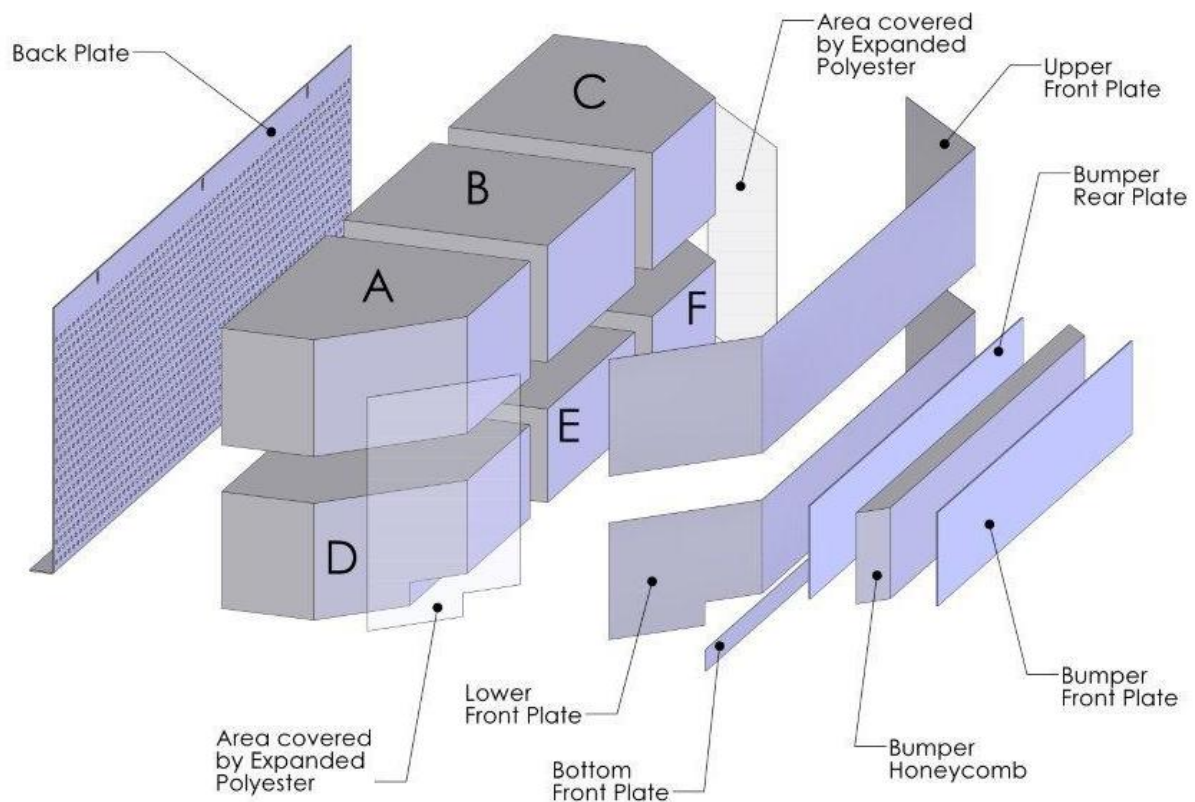


Figure 4: Exploded isometric view of AE-MDB

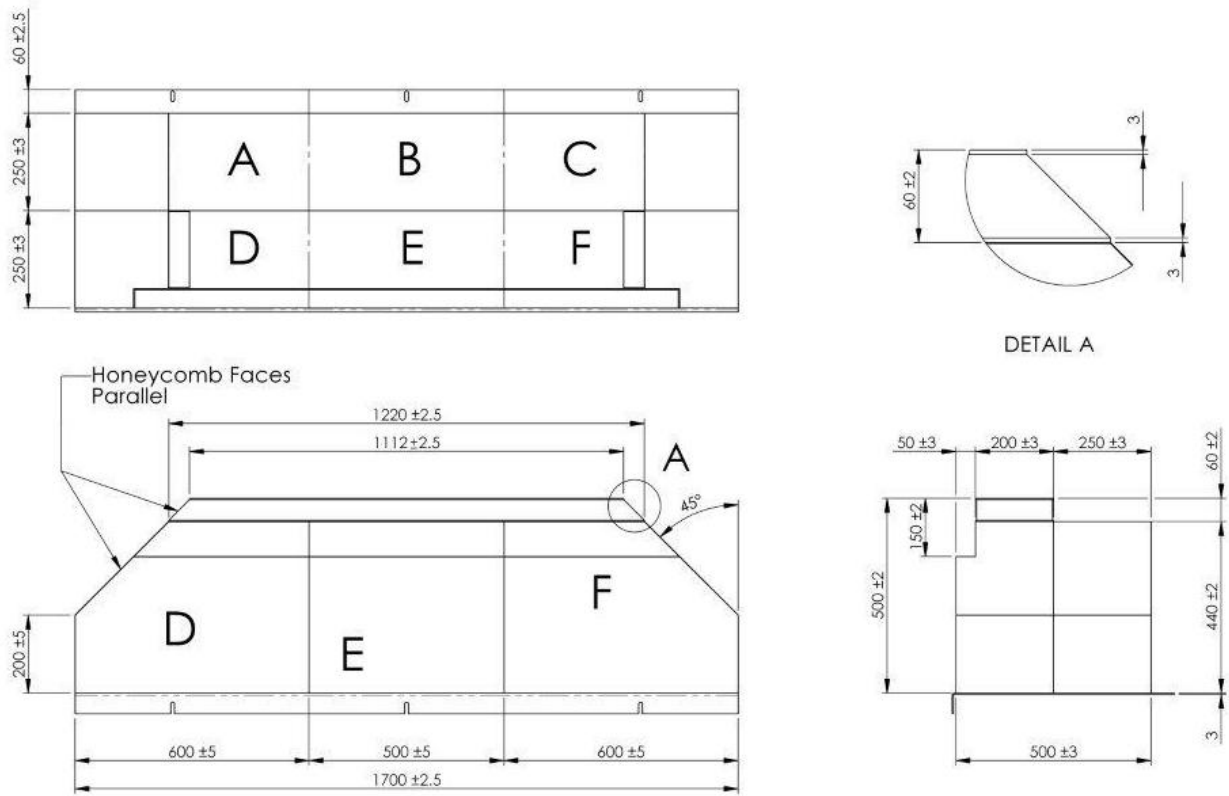


Figure 5: AE-MDB dimensions

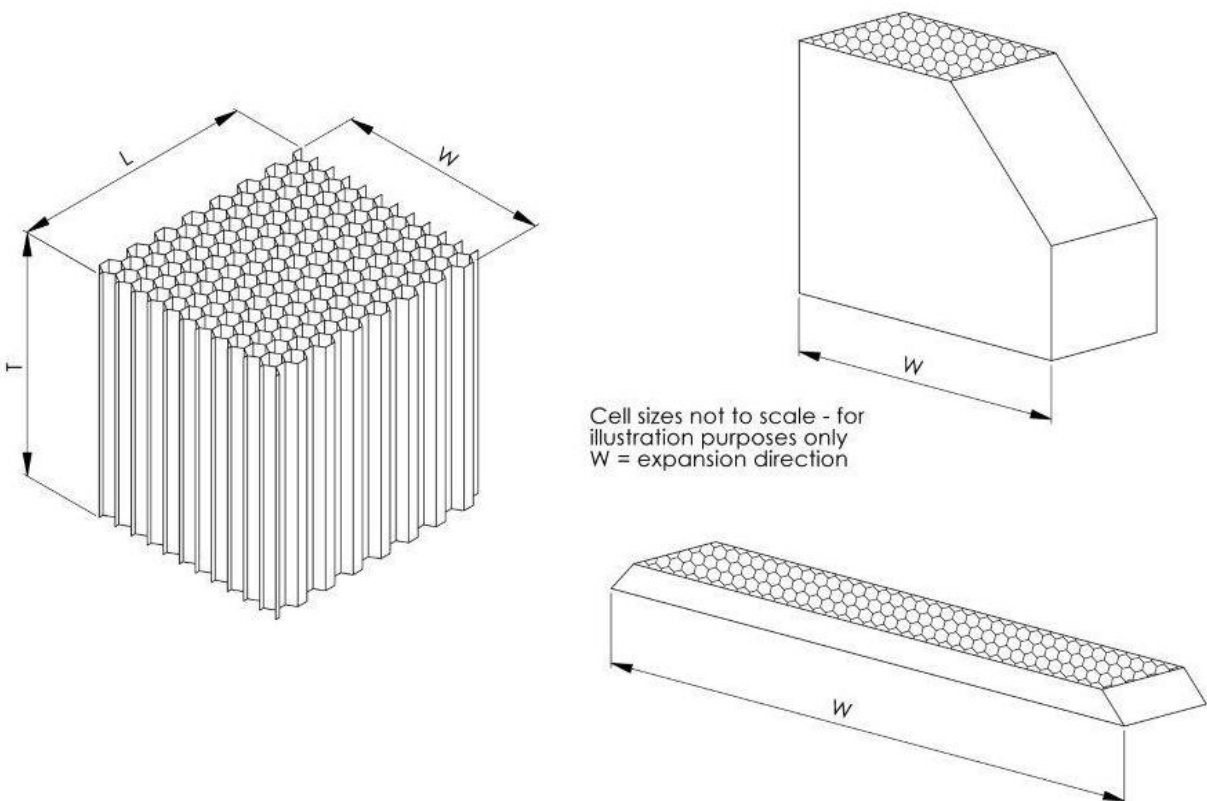


Figure 6: Aluminium honeycomb orientation

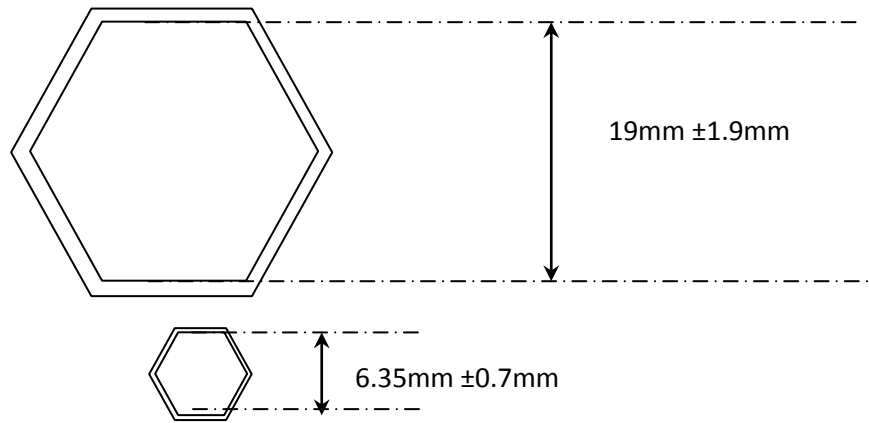


Figure 7: Dimension of Aluminium Honeycomb Cells

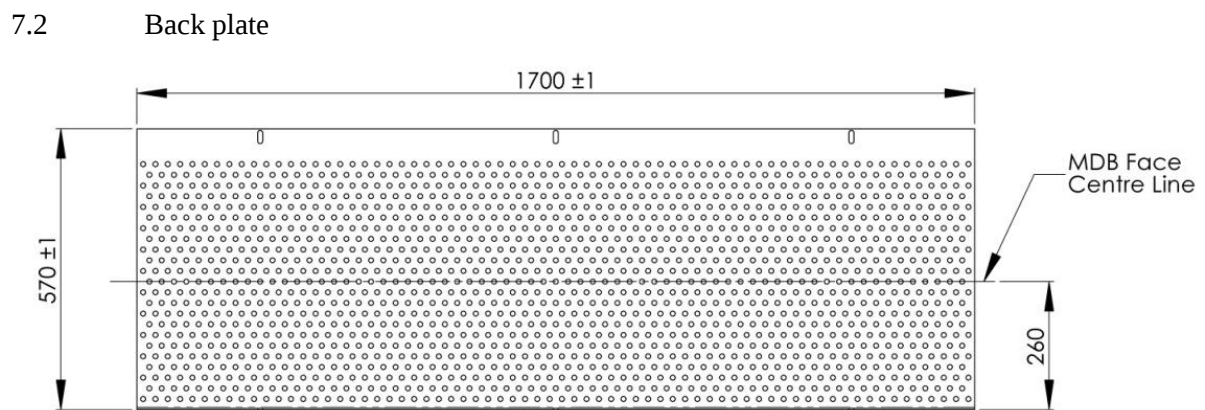


Figure 8: Rear view of the back of the barrier face

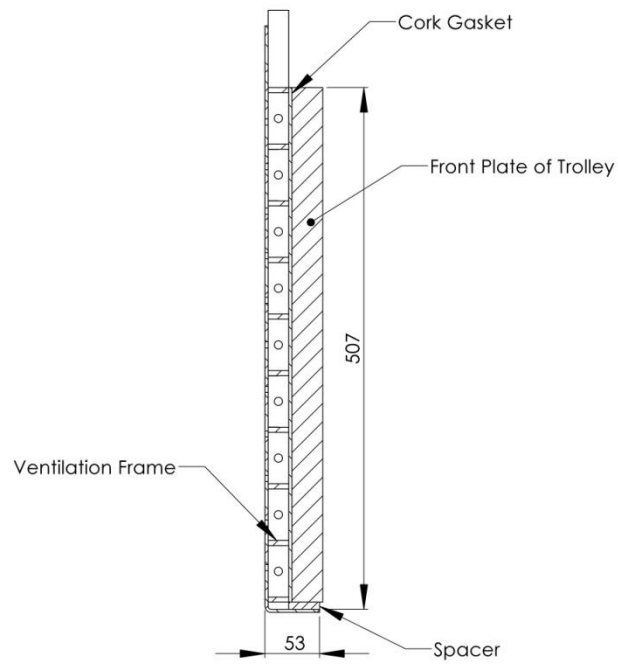


Figure 9: Attachment of backplate to ventilation device and trolley face plate

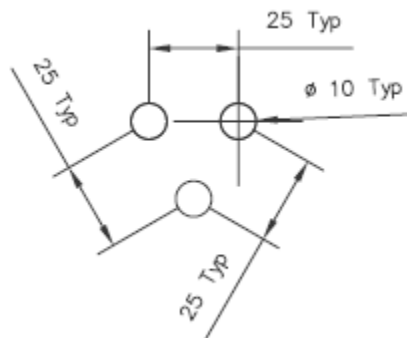


Figure 10: Staggered pitch for the backplate ventilation holes

7.2.1 Top and bottom back plate flanges

7.2.2 The attachment holes in the bottom flange may be opened to slots, as shown below, for ease of attachment provided sufficient grip can be developed to avoid detachment during the whole impact test.

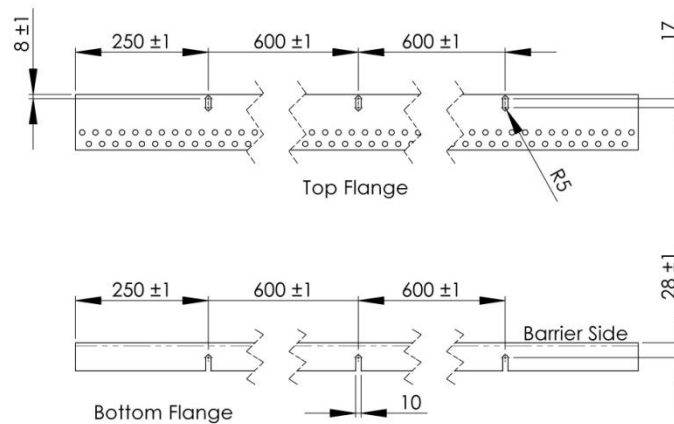


Figure 11: Top and bottom AE-MDB mounting flanges

7.3 Ventilation frame

7.3.1 The ventilation device is a structure made of a plate that is 5mm thick and 20mm wide. Only the vertical plates are perforated with nine 8mm holes in order to let air circulate horizontally.

7.3.2 It is acceptable for ventilation frames that are 1500mm in with to be extended up to 1700mm in width provided that the correct pattern of venting and fixation is used.

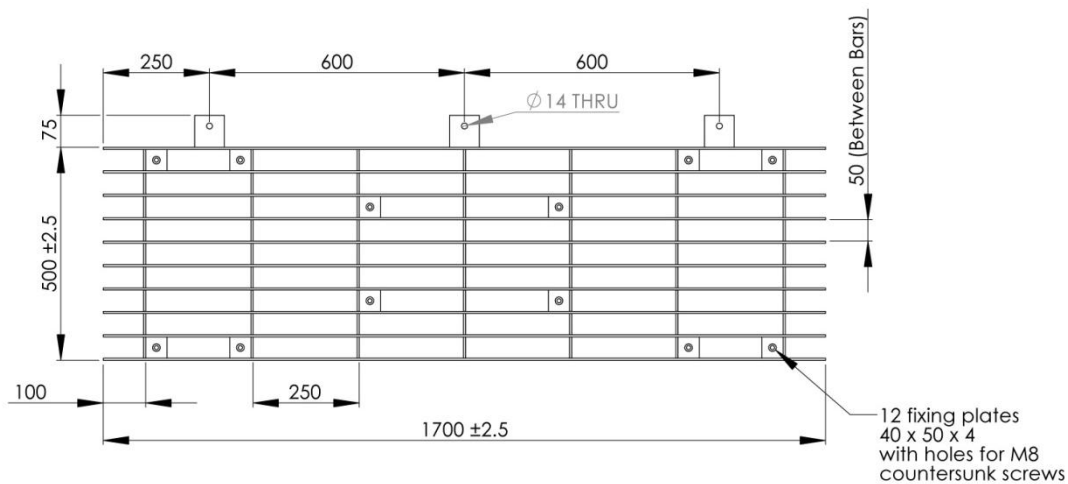


Figure 12: AE-MDB trolley ventilation frame

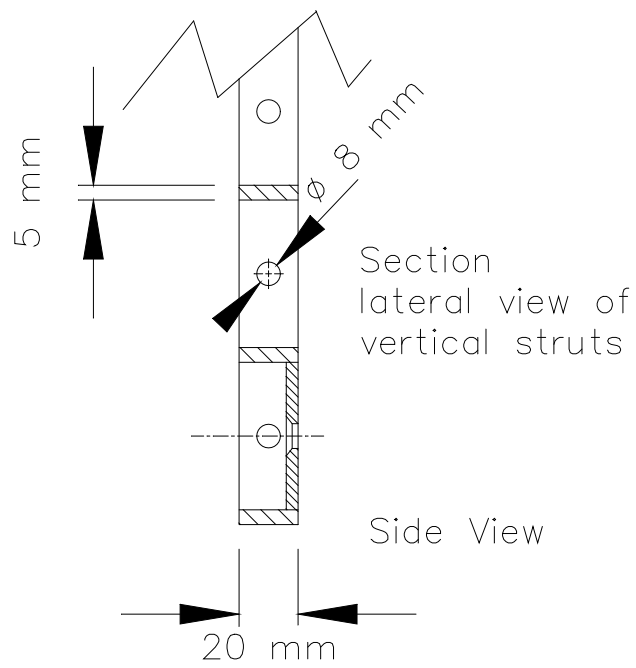


Figure 13: AE-MDB trolley ventilation frame – side view

8. STATIC FORCE DEFLECTION CORRIDORS

Force deflection corridors for quasi-static crush tests to test samples measuring 250 x 500mm for all blocks.

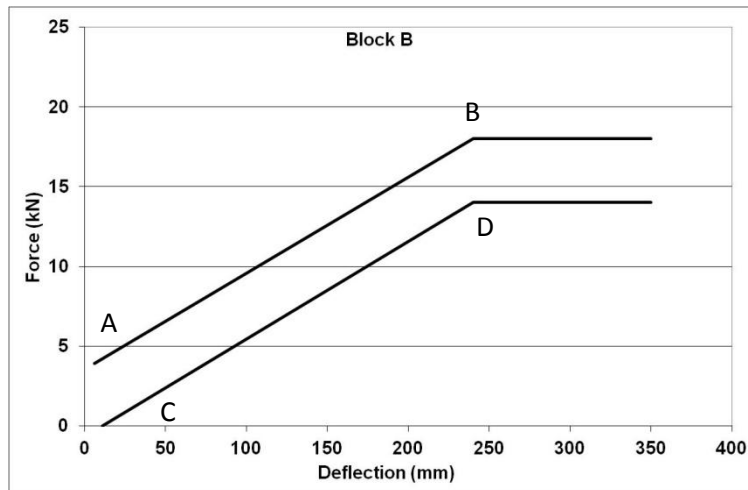


Figure 14: Block B static corridor

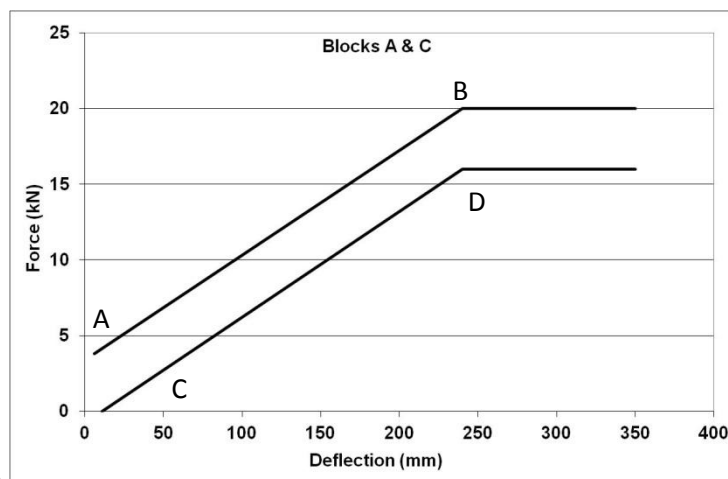


Figure 15: Blocks A & C static corridor

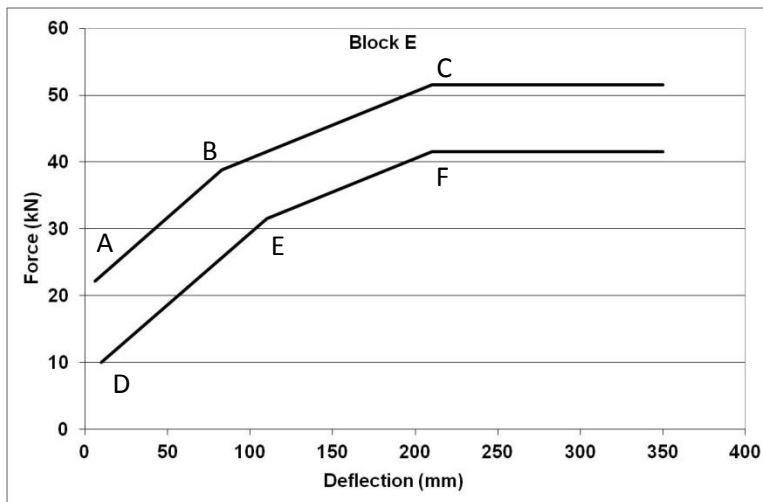


Figure 16: Block E static corridor

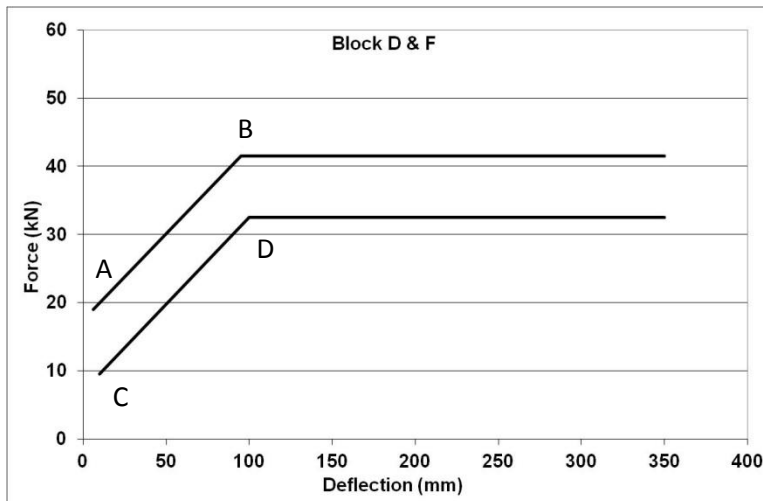


Figure 17: Blocks D & F static corridor

9. DYNAMIC FORCE DEFLECTION CORRIDORS

Force deflection corridors for dynamic barrier to LCW tests.

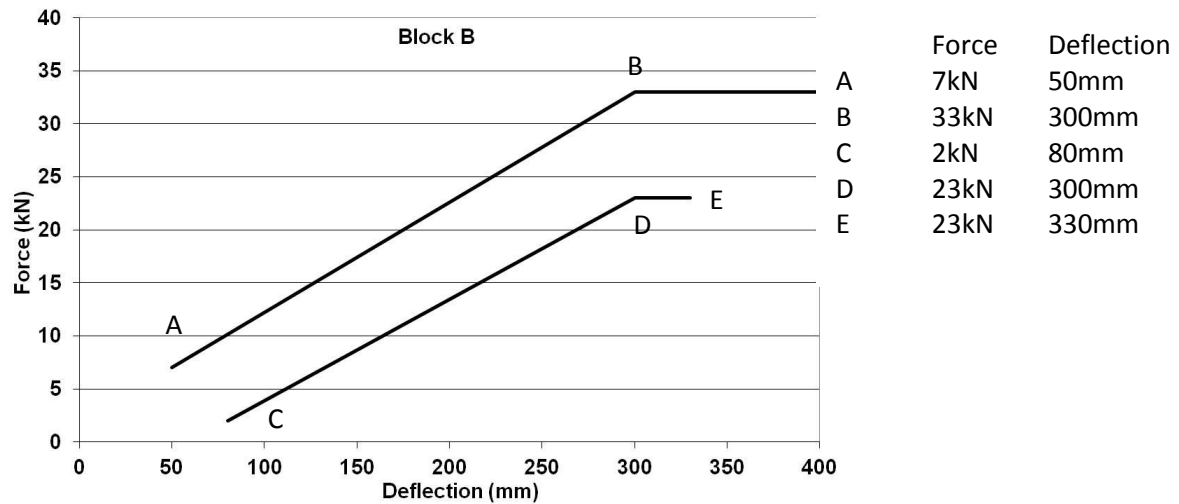


Figure 18: Block B dynamic corridor

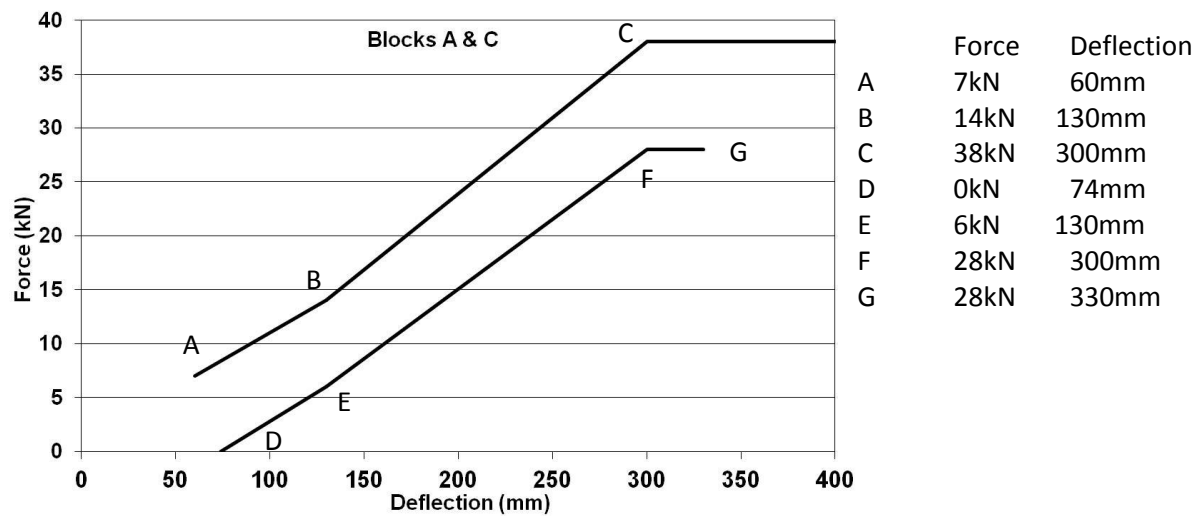


Figure 19: Blocks A & C dynamic corridor

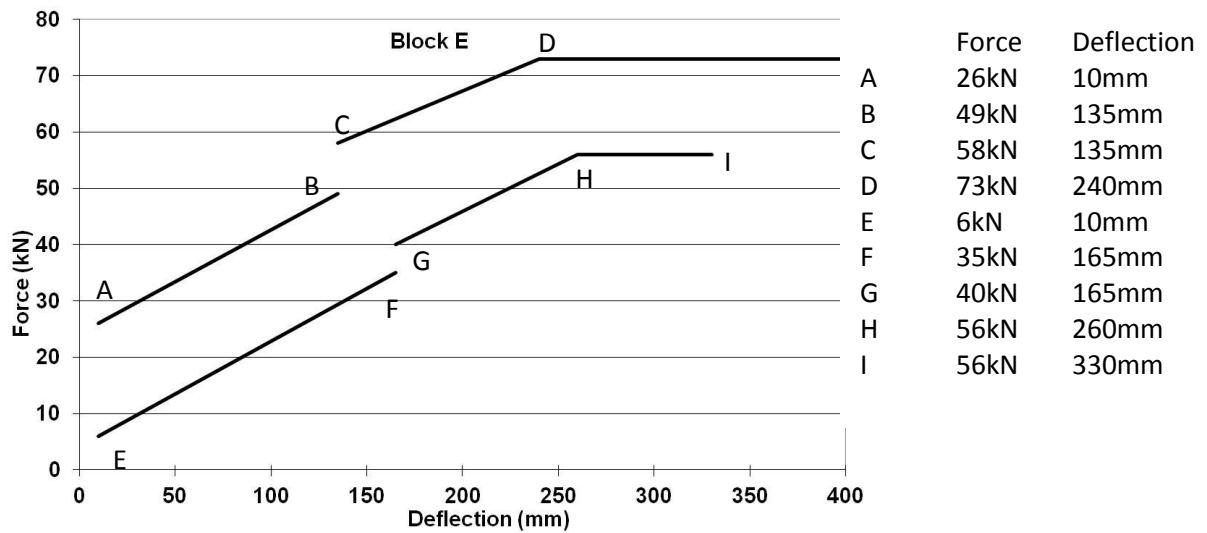


Figure 20: Block E dynamic corridor

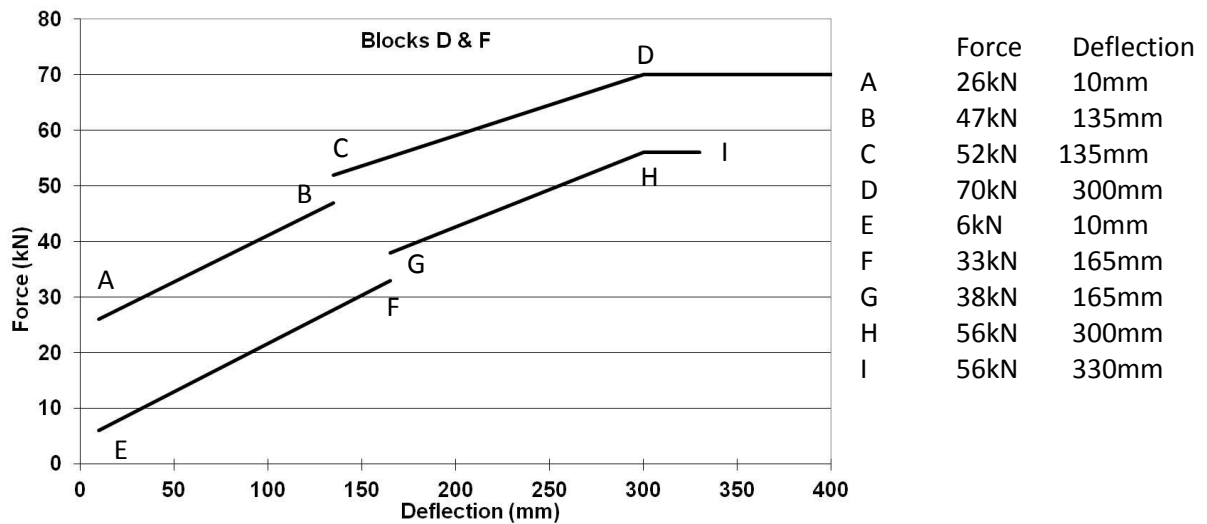


Figure 21: Blocks D & F dynamic corridor

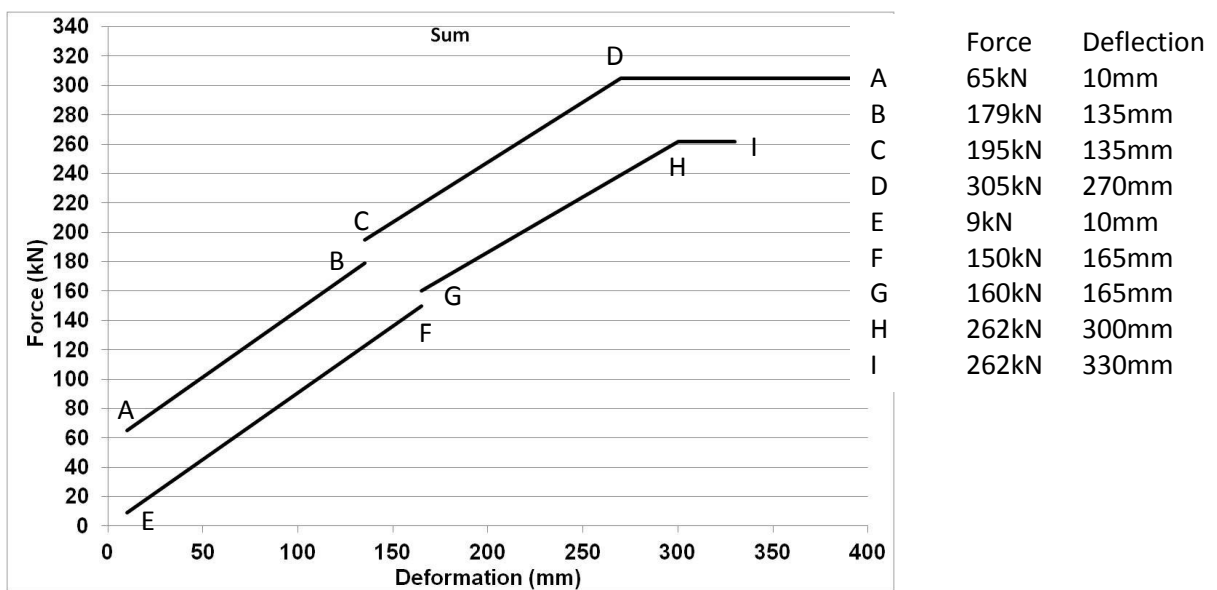


Figure 22: Full barrier dynamic corridor

