The Efficiency of PRE-SAFE® Systems in Pre-braked Frontal Collision Situations

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Paper No: 11-0207

ABSTRACT

Vehicle safety today is evaluated on the basis of standardized crash tests. The goal is to classify the level of safety using tests which can be reproduced and repeated at any time. In laboratory tests, the evaluation of safety systems and their assessment for effectiveness commonly begins after the time of collision.

In a real accident situation, conditions could, however, be different. In accident situations, passenger car occupants are already exposed to lateral or longitudinal acceleration forces resulting from emergency braking or skidding. These accelerations lead to occupant displacements and thus to situations in which occupants are no longer in their initial positions when the collision occurs. This naturally affects the protective efficiency of the restraint systems. The development of modern systems to prevent accidents or reduce their severity will cause such situations to occur much more frequently in the future. Autonomous emergency braking systems accordingly reduce the impact energy on the one hand, but have a considerable influence on the occupants' interaction with the vehicle on the other hand.

There are currently no tools available for determining the impact of a dynamic driving situation and of the resulting change in a restraint system's protective efficiency. Nor are there any comparisons available on the behavior of human beings, as opposed to crash test dummies, in the low g-phase immediately before a collision.

The objective of this paper is to find and evaluate a method for approximating the crash test for exemplary dynamic driving responses in the case of longitudinal traffic escalation. This paper thus begins by identifying, by means of selected examples, the problems faced when comparing real accidents and crash methodology.

In studies on the behavior of real vehicle occupants and crash test dummies in dynamic driving situations, movements are analyzed and differences described. The behavior of the dummies tested in such dynamic driving situations is analyzed with regard to shortcomings and potential points of action. To assess points of action for their efficiency, specifically performed crash tests including previous dynamic driving brake responses are discussed and evaluated. A concluding assessment of the behavior of both the occupant and the dummy aims to determine the suitability of crash measurement data for evaluating the overall situation.

INTRODUCTION AND MOTIVATION

Automotive safety has made significant strides in the last 30 years. Today, vehicles are equipped with effective restraint systems such as airbags, seat belts with belt tensioners and force limiters, integrated deformation zones and deformation-resistant passenger cells, as well as coordinated structural and restraint measures. All of these features have resulted in an optimization of the effectiveness of the safety systems. In addition to these passive safety features, today's vehicles feature a very high level of safety thanks to supplementary active safety systems such as antilock systems ABS, electronic stability program ESP and brake assist system BAS. These systems are already, to a very large extent, available as standard and are supplemented by optional support systems. Vehicles may be equipped with active safety systems for distance warning and control, including the emergency braking function, as well as systems for lane holding. In the transition area between active and passive safety, new functions (e.g. PRE-SAFE®) can help create advantageous occupant positions in critical situations. Reversible measures are implemented if these systems detect situations, via sensors for monitoring the vehicle environment, which are critical and could result in an accident. These reversible measures, such as belt tensioning or the correction of unfavorable seat settings, help to improve the situation for the occupants. To accomplish this, the systems use sensors such as wheel speed, yaw, roll, pitch and deceleration sensors for early accident detection and to determine the accident severity by means of algorithms which have been specifically formulated for interpreting the vehicle environment. The automated response of the vehicle is comparable to how a person responds, in terms of their reflexes, in a critical situation. The vehicle responds and thus protects the occupants. Sensors and actuators are heavily interlinked for this purpose.

Current crash test methodologies do not include the influence of dynamic driving variables on the occupant/vehicle position prior to a crash test. However, this is required in order to conduct a thorough assessment of the entire accident situation in a holistic manner. No simulation or experimental tools currently exist for evaluating the effects of pre-crash dynamics. This paper is intended to highlight a pragmatic method for this purpose.

PROBLEM IDENTIFICATION

The German In-Depth Accident Study database (GIDAS) was analyzed to evaluate frontal collisions in which the braking deceleration was documented. A deceleration greater than/equal to 4 m/s^2 was documented in 49% of the resulting 7421 cases. Approximately one third of all cases documented severe braking deceleration levels greater than 6 m/s^2 (Figure 1).

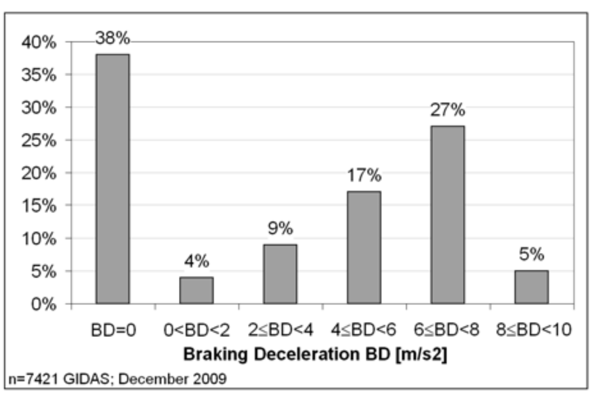

Figure 1: Distribution of the braking deceleration in the case of a frontal impact

This high proportion of accidents preceded by severe braking deceleration justifies an investigation of the effects of deceleration on the position of the occupants at the start of the accident and the effects of these positions on occupant loads. If emergency braking is initiated by the driver or an autonomous braking system before a potential collision, then this results in a forward displacement of the occupants with a correspondingly high deceleration. Passengers are, in particular, often surprised by the accident prevention response and cannot, therefore, counteract the displacement with an appropriate body response.

PRE-SAFE® can reduce the forward displacement during emergency braking by means of a reversible belt tensioner as shown in Figure 2. Two restraint scenarios are compared in this figure. In one situation, the occupant has been restrained in an emergency braking situation by means of reversible belt tensioning, while the occupant is restrained by means of the vehicle-sensitive belt lock in the other depicted situation. The resultant forward displacement path depends on the vehicle deceleration, the size and weight of the occupant, the leverage ratios between the hip and clavicle as well as the seating position and the resulting geometry of the three-point seat belt. These diverse parameters and how precisely they affect an average occupant displacement thus had to be ascertained in a road test study involving human test subjects.

ROAD TEST STUDY, INVOLVING HUMAN TEST SUBJECTS, ON OCCUPANT BEHAVIOR IN BRAKING SITUATIONS

A road test study, involving human test subjects, was carried out prior to the crash tests in order to determine occupant behavior in emergency braking situations.

Figure 2: Longitudinal displacement of the occupant in the case of a braking maneuver with/without PRE-SAFE®

Braking tests were initially carried out with human test subjects representative of 50th percentile characteristics. Their behavior was analyzed by means of the following measured values:

- Forward displacement of the chest and neck
- Belt force on shoulder and pelvis
- Belt extension
- Chest acceleration
- Vehicle longitudinal deceleration
- CAN signals for BAS, ABS and trigger status
- Occupant behavior recorded via camera

Reference tests were also carried out on the vehicle in order to determine the deceleration performance (Figure 3).

The occupant sizes and seating positions were standardized in accordance with the European New Car Assessment Program test protocol. The size and weight of the human test subjects corresponded to the 50th percentile classification. A 50% H III dummy was used for comparison purposes.

The occupant behavior under the influence of braking deceleration was tested on the front passenger seat of a current Mercedes-Benz E-Class model.

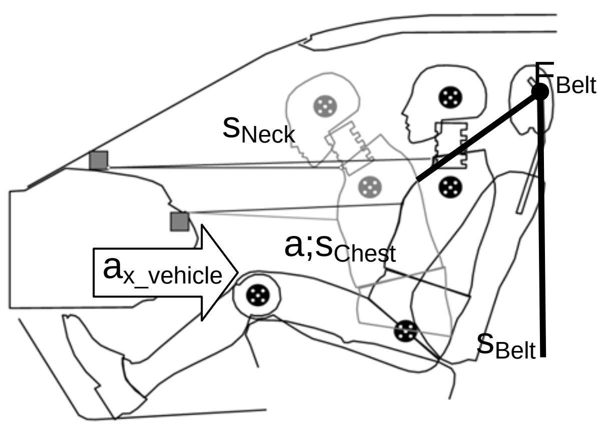

Figure 3: Use of cable and point measurements for the forward displacement of the dummy and real person

The tests were carried out on a straight test route. The initial velocity before the start of deceleration was a constant 65 kph. The brake application was carried out automatically in order to be able to generate reproducible deceleration curves.

An automated braking device was installed in the vehicle for this purpose, in which a pneumatic ram, with a defined pedal operation curve, applied the pedal force after a specified start condition.

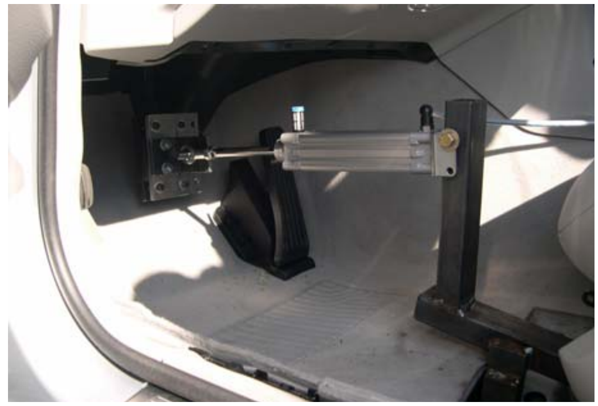

Figure 4: Automated braking device

In view of use in the subsequent crash tests as well, the device is not allowed to influence the dummy behavior. This is accomplished by means of the device shown in Figure 4.
With this device, the dummy feet can be positioned without being negatively influenced by the automated braking device.

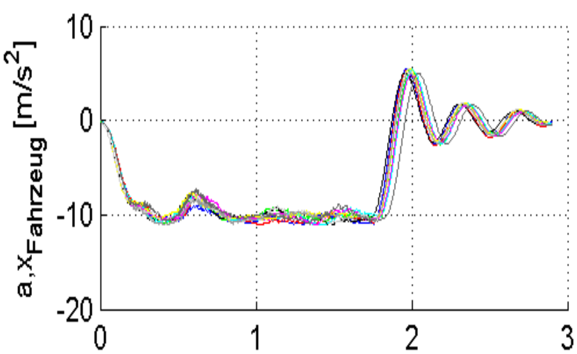

Figure 5: Five examples of longitudinal deceleration measurements, actuated by the pneumatic ram

The pedal curve was selected so that the vehicle is able to control itself at its slip limit by means of its own brake assist system (BAS) and antilock brake system (ABS). This curve was determined during a prior assessment of the test subjects. A reproducible pedal force and deceleration curve are possible thanks to the mechanically supported brake application (Figure 5). Five braking tests were carried out, with and without PRE-SAFE®, for each human test subject; the maximum displacement values are shown by means of box plots (Figure 6).

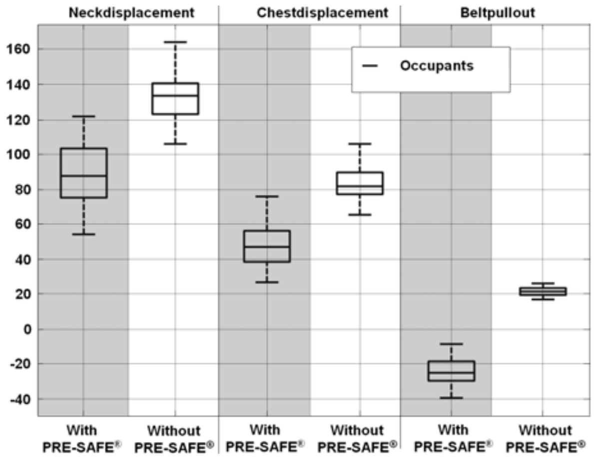

Figure 6: Occupant behavior measured via neck and chest forward displacements, as well as belt unwinding with and without PRE-SAFE®

The median forward neck displacement of the occupants with the PRE-SAFE® belt tensioner could be reduced for all human test subjects from 134 mm to 88 mm (i.e. by 34%) in comparison with tests conducted without PRE-SAFE®.

The median forward chest displacement of the occupants with PRE-SAFE® could be reduced for all human test subjects from 82 mm to 47 mm (i.e. by 42%).

The described tests were repeated with the H III 50% frontal impact dummy in order to compare dummy behavior under the same conditions. The same measured values were recorded during these tests. The results indicate that dummy motion during braking is significantly different from that of the human test subjects. Although the reversible belt tensioning via PRE-SAFE® minimized the forward displacement of the test dummy, the absolute forward displacement of the dummy was less than that of the median human test subject as described below.

The median forward neck displacement of the dummy with PRE-SAFE® could be reduced from 90 mm to 49 mm (i.e. by 46%). The median forward displacement for the dummy chest was reduced from 59 mm to 32 mm (i.e. also by 46%). However, as noted above, the dummy behavior at both measuring points (neck and chest) did not correspond to the behavior of the human test subjects in terms of forward displacement.

In terms of interaction with the seat belt, the dummy behaves in a much more rigid manner during the braking phase and accordingly with less forward displacement than the average value for a human test subject. The data clearly indicate that the scatter range of the measured values for the occupants is greater than that for the dummy.

The analysis of the difference between the human test subjects and the dummy, in terms of the forward displacement, was further supported by means of video analysis.

The human occupant behaves differently than the dummy as deceleration increases once the brakes have been applied. This is particularly noticeable when the vehicle deceleration reaches approximately 3 m/s^2, as the seat belt retractor then locks to prevent further seat belt unwinding, while the occupant continues to move forward. This added motion was not observed with the test dummy. This additional displacement is nearly equivalent to the difference in the forward displacement between the human occupant and the dummy. The cause of this difference is the unique elasticity of the human occupant and dummy bodies. Unlike human subjects, the dummy has no elastic "tissue-like" padding or bulky clothing which would permit the dummy to continue moving forward despite a locked seat belt.

Figure 7: Foam layer on dummy for optimizing the occupant kinematics in the braking phase

The body elasticity parameters were examined in greater detail in a third series of tests, which were developed based on these findings. For this purpose, different rigid foams were positioned between the dummy and seat belt in an attempt to reproduce the displacement variation observed with human subjects.

Figure 7 shows the optimized 2-piece foam configuration (material PUR-E; density 35 kg/m^3; dimensions 160 x 100 x 40 mm and 80 x 100 x 40 mm) between the belt and dummy. This simulation of adipose tissue within the overall occupant/belt system resulted in the following kinematic values in comparison to the respective median occupant value (Figure 8):

In the case of the tests without PRE-SAFE®, the forward neck displacement of the dummy falls between the lower quartile and median value. The maximum forward displacement was thus ideally reproduced at this measuring point.

When these tests were reproduced with PRE-SAFE®, the measured dummy neck displacement was consistent with the values obtained with human test subjects; however, it tended to lie at the lower end of the value range.

The forward chest displacement of the dummy -- both with and without PRE-SAFE® -- fell within the interquartile range and thus ideally in the human test subject scatter band.

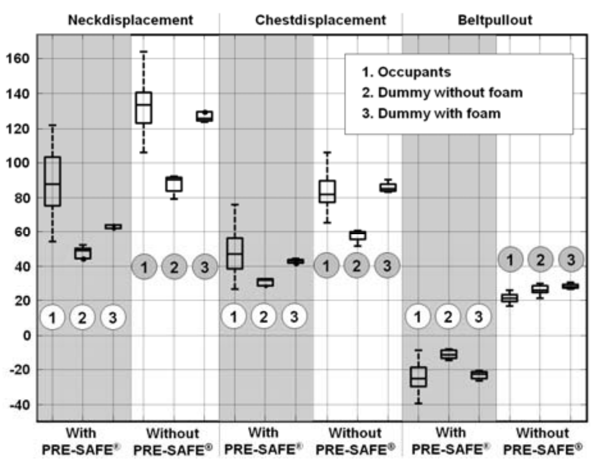

Figure 8: Occupant and dummy behavior measured by means of neck and chest forward displacements as well as belt unwinding with/without PRE-SAFE®

In the case of the tests with PRE-SAFE®, all measured values for the belt unwinding fall within the upper quartile; in the case of the tests without PRE-SAFE®, the measured values fall within the top scatter band of the human test subjects.

It can therefore be said that the interaction between the dummy with foam was comparable to that of the human test subjects. A preliminary comparison of the kinematics of the human test subjects and dummy without foam modifications showed no similarity during the preliminary braking phase. Because the kinematics and position of the dummy relative to the airbag immediately before the impact are key factors with regard to performance during the accident, a precise simulation of this kinematics was required in order to conduct an additional test in the vehicle crash.

The documented values show that the occupant kinematics of a human test subject can be approximated by an H III frontal impact dummy fitted with foam insert. What is important with regard to the modification using the foam insert is that the behavior is only influenced during braking. However, this modification must not influence the dummy behavior during the crash.

To confirm this, an analysis of crash tests with and without foam inserts was carried out. The results have shown that the same force is applied at the shoulder belt; the dummy / vehicle interaction can thus take place with a uniform belt force and the crash response is not affected by the foam insert.

DETERMINATION OF THE DECELERATION PERFORMANCE OF THE PRE-SAFE® BRAKE

The PRE-SAFE® brake for autonomous deceleration in longitudinal traffic has been part of the optional DISTRONIC PLUS since model year 2009 in the E- and S-Class Models. The system detects if the vehicle is approaching stationary objects or objects that are driving in the same direction via one short-range sensor and two long-range sensors (Figure 9).

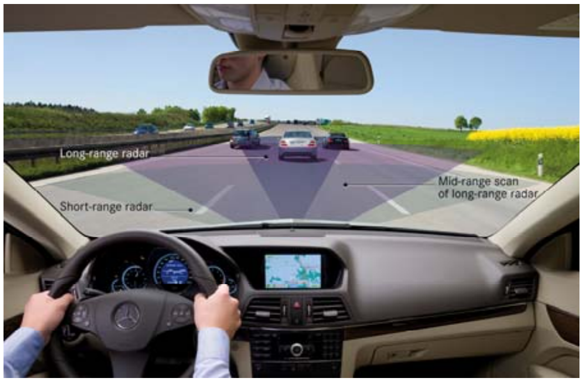

Figure 9: Area covered by short- and long-range radar

If the vehicle is approaching a stationary obstacle or an obstacle that is driving in the same direction, the system emits both a visual and acoustic warning to the driver approx. 2.6 s before the calculated point in time of the crash. If the driver does not respond, the vehicle starts, approx. 1.6 s before the crash, with partial brake application and restraint of the occupants by means of the reversible belt tensioners. At this point in time, the driver still has approx. 1 second in which to prevent the accident. This is no longer possible from approx. 0.6 s before the calculated point in time of the crash (Figure 10).

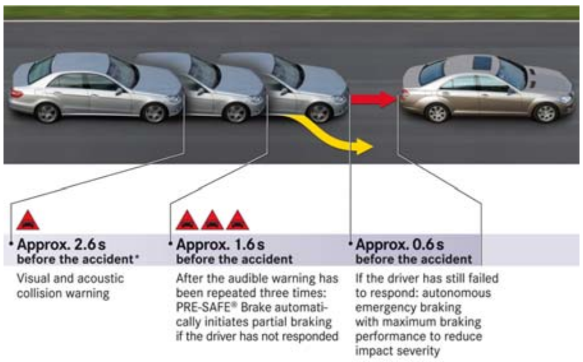

Figure 10: Escalation in longitudinal traffic

A test collision obstacle was used in the controlled test environment for determining the potential of the PRE-SAFE® brake (Figure 11).

Figure 11: Collision with test obstacle

This obstacle represents a vehicle with regard to the reflected intensity for the sensor system. 50 kph was selected as the starting velocity. Several tests were carried out with the obstacle and the velocity reduction was documented by means of deceleration and velocity measurements. The average velocity reduction determined for all the tests was 25 kph. The test velocity was thus specified as 25 kph for a starting velocity of 50 kph.

SETUP FOR DETERMINING THE POTENTIAL OF PRE-SAFE® AND THE PRE-SAFE® BRAKE

Three crash tests were initially carried out (Figure 12) in order to determine the potential offered by reversible protective systems in frontal collisions.

Braking was initiated around 500 ms before the start of the collision in scenario A. The pneumatic ram described earlier was activated by means of a light barrier for this purpose. This decelerated the vehicle with the support of the brake assist system and at the same time simulated emergency braking initiated by the driver followed by a collision.

The deceleration, which was regulated in each case by the antilock system ABS, took place at the slip limit. The activation of the brake assist system BAS and with it the PRE-SAFE® actuators, in particular the reversible belt tensioners, was ensured due to the selected actuation parameters of the pneumatic ram. The braking distance was selected so that the velocity was reduced from 65 kph to 50 kph. A maximum deceleration of around 10 m/s^2 was achieved similar to the preliminary tests at a high friction coefficient.

The same test configuration was repeated in scenario B, but without activation of the PRE-SAFE® system, in contrast to scenario A. The forward displacements determined in the braking tests were carried out in both configurations with the foam insert in order to enable the required forward displacements by the dummy. Scenario C corresponded to a conventional crash test, that is, without pre-braking. The same impact velocity of 50 kph was selected in the first three tests so that the crash energy could be factored out as an influencing factor. In each case, braking initiated by the driver was simulated. Scenario D corresponded to a situation in which the vehicle is automatically decelerated to the measured collision velocity of 25 kph via the PRE-SAFE® brake system without driver intervention.

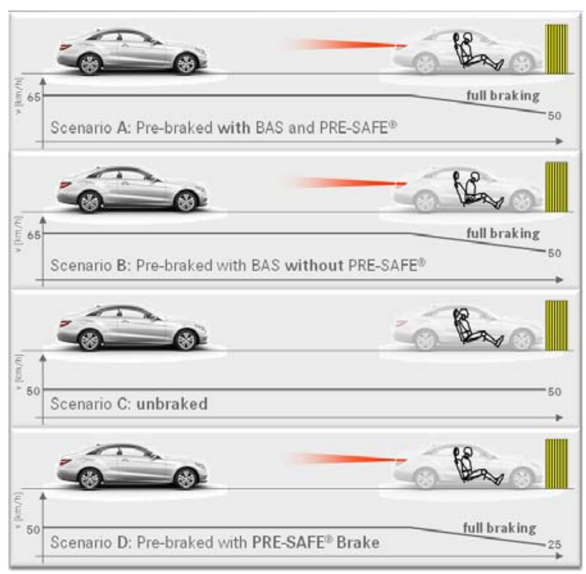

Figure 12: Crash scenarios

The comparison of the results from tests A and B reveals the full extent of the effect that occupant restraint - via the reversible belt tensioners - has on the occupant loads. The comparison of the results from tests A, B and C allows us to draw conclusions on how occupant contact is influenced during braking deceleration. The comparison of the results from tests C and D, in turn, shows how the reduction in the collision velocity by the vehicle itself, i.e. without driver intervention, can influence the occupant loads.

DISCUSSION OF RESULTS

The ride-down effect (RDE) was initially calculated in order to determine the extent of the front passenger contact in both tests with pre-braked collision in comparison to scenario C. For this purpose, a best-fit straight line was drawn through the 25% and 75% values of the first maximum in the initial increase of the resulting chest acceleration for the first three tests with the same collision energy, and the intersection of these lines was determined via the time axis. The vehicle has already covered a certain deformation path by the time the first noticeable energy transmission is transferred to the occupant via the blocked belt due to the vehicle deceleration. The RDE was determined by calculating the extent of the front end deformation at this point in time in relation to the maximum deformation length.

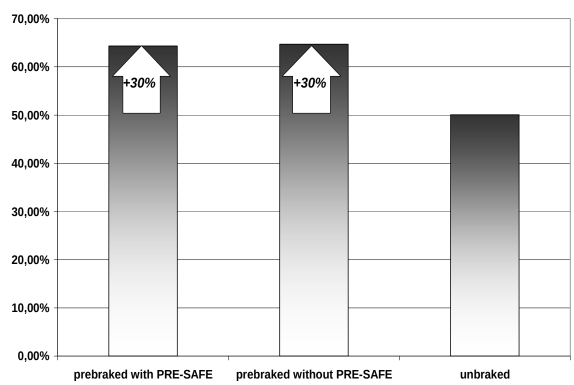

Figure 13: Ride-down effect

An improvement of around 30% can be determined for the ride-down effect (RDE), in relation to the unbraked test C (Figure 10), when the two braked tests (A and B) are compared. This value shows that the vehicle deceleration and pitch initially have a positive effect on occupant contact when the same restraint system is used and with the same collision energy (Figure 13).

This is merely a required condition and not a sufficient condition for low occupant load values.

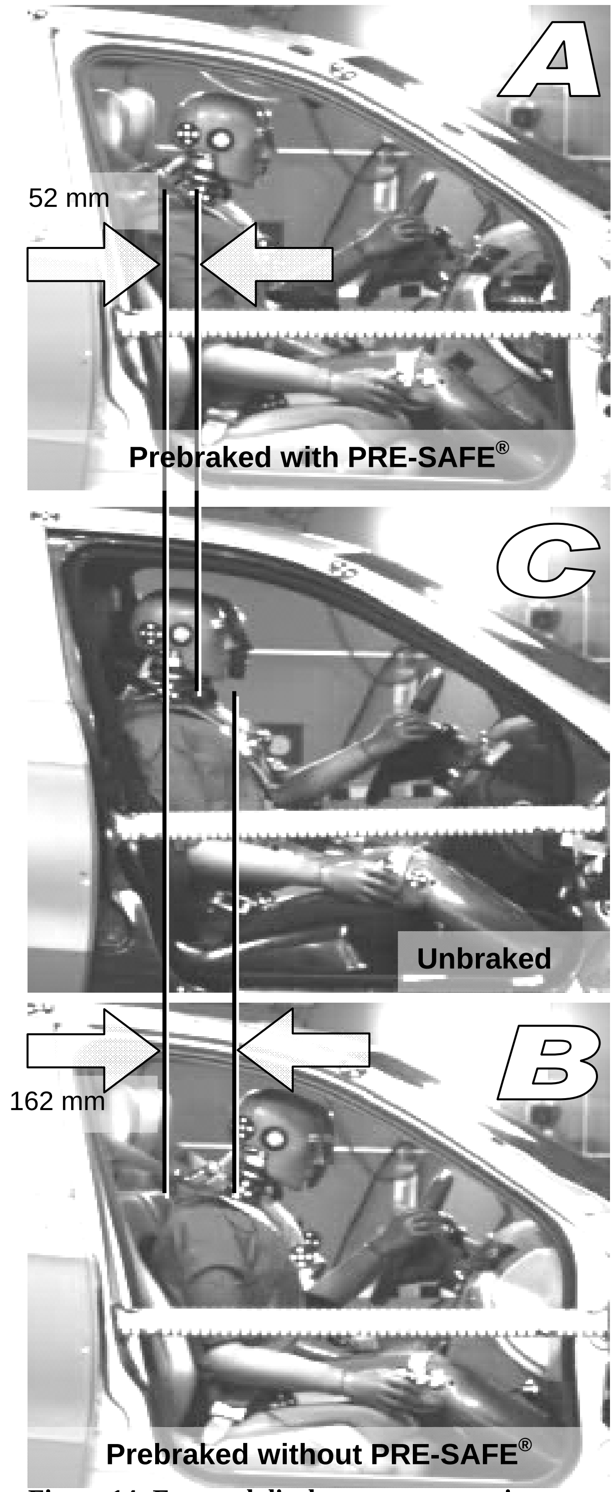

Figure 14: Forward displacement comparison

Another condition involves optimizing the restraint systems and occupant position at the time of collision.

The occupant's position relative to the airbag can affect the loads to which the occupant is subjected, in particular the head, neck and chest loads.

The vehicle movements and the resulting occupant movements were similar to those observed in the preliminary tests with human test subjects due to the use of the vehicle's own systems. These were calculated by means of a visual measuring method at the very moment the collision began (Figure 14).

The effects of the forward displacement and of the ride-down effect shall now be analyzed in greater detail. Ordinates scaled as percentages are used for this purpose, whereby the basic test from scenario C represents the 100% value, with the X-axis representing the chronological sequence in seconds.

Figure 15 shows airbag inflation contact at 36 ms during the resulting head acceleration of both braked tests. This does not have a negative effect on the maximum load. Instead, the load values have fallen by approx. 30% relative to the standard load case due to the improved contact via the seat belt system as well as due to the quicker pressure increase in the airbag system due, in turn, to the lower inflation volume.

The occupant position in scenario A is an optimum compromise between forward displacement and contact, with a 40% reduction in the head acceleration.

Due to the lower crash energy in scenario D, the maximum load of the resulting head acceleration can be further reduced to just 30% of the initial load.

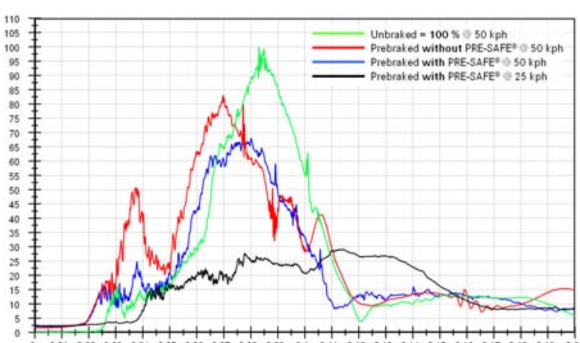

Figure 15: Resulting head acceleration a_r

Due to the early load applied to the head, an increase in the neck shearing force in scenario B can also be observed, although this does not have a negative effect on the maximum load.

In Figure 16, a significant deterioration in the neck moment (extension) around Y can be observed. The cause for the significant increase, by approx. 120%, in scenario B (braked load case without PRE-SAFE®) is the forward displacement of the head position together with the rapid pressure increase in the pre-compressed airbag. This stops the head from being "plunged" any deeper into the airbag; the thorax, however, moves further forwards due to the kinematics determined by the belt force limiter. The load due to the severe extension of the neck thus increases. In load case D, the moment loading in the extension movement could again be significantly reduced, due to the lower collision energy in connection with the early occupant contact, which in turn is due to the occupants being appropriately restrained with PRE-SAFE®. The slight increase in the flexion load direction is to be classified as uncritical with regard to the absolute flexion load value.

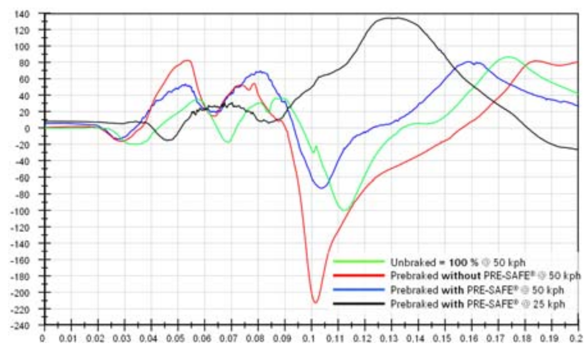

Figure 16: Neck moment M_y

An improvement can also be seen in both chest acceleration and chest deflexion, due to the improved dummy contact via the belt. Early occupant contact due to the braking deceleration can be identified on the one hand; this effect can be further improved via a prior belt tensioning with PRE-SAFE® (Figure 17).

This advantage of the contact can, on the other hand, also be seen in the maximum load. When the brakes are applied, the chest deflexion value decreases by 23% due to the early and homogeneous force effects acting on the dummy. This decrease can be as much as 33% where the PRE-SAFE® belt tensioner is used for contact. Reduced collision energy in connection with PRE-SAFE® occupant restraint also represents the optimum here from among all four tested load cases. The load can be reduced to 45% of the original load.

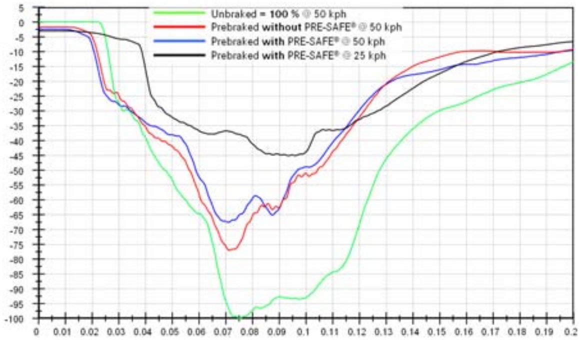

Figure 17: Chest compression D_s

Although the effects of braking deceleration can be observed in the resulting pelvis acceleration, no difference can be ascertained between the tests with and without PRE-SAFE®. This is because the reversible belt tensioner and occupant restraint acts mainly on the upper body (Figure 18). The reduction in the collision energy becomes apparent, however, in the maximum load in test D: The load recorded here was 67% lower than the original load.

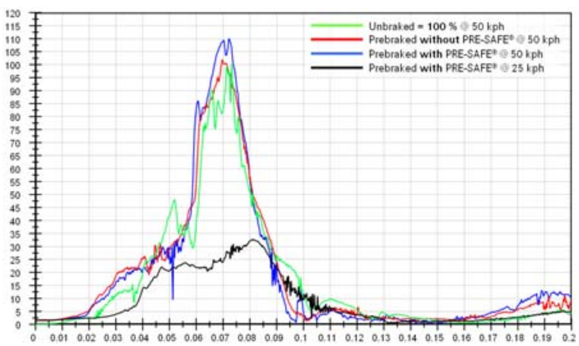

Figure 18: Pelvis acceleration a_r

A 75% decrease in collision energy meant that vehicle intrusion was 50% lower (Figure 19).

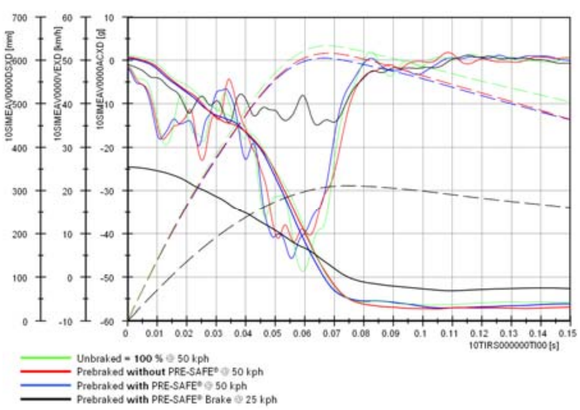

Figure 19: Decelerations and deformations

SUMMARY

The study has shown the effect that pre-braking has on occupant movement and subsequent occupant loading. This use case represents a relevant constellation worth investigating, as braking with a deceleration of > 4 m/s^2 was initiated in almost 50% of the documented frontal collisions, while braking with a deceleration of > 6 m/s^2 was initiated in a third of the documented cases.

The study began by comparing and assessing the initially inadequate forward displacement values of the H III dummy by means of tests with volunteers. The dummy behavior during the braking phase could be adapted via measures in the belt/dummy system so that the movement was within the range for volunteers. The preliminary test showed that the measures did not have any effect on the crash results.

This simple model of the test before and after t_0 initially only applies for the front passenger. Tests on volunteers have shown that braking initiated by the driver results in supporting forces at the interfaces to the vehicle that reduce forward displacement. The driver can, however, also be taken by surprise by the braking situation and no longer have the opportunity to counteract the introduced braking force in the case of maneuvers initiated by automatic emergency braking systems.

The braking deceleration itself has a positive effect on the contact and restraint of the occupants. Some variables have been improved solely via the ride-down effect, acceleration curves tend to be more homogeneous, and the energy is reduced over a longer period due to the improved contact.

It is important that the head-to-torso interaction in particular is controlled in a positive manner by the PRE-SAFE® belt tensioner. The kinematics can be positively influenced through preventive restraint in braked crash situations. The neck load is significantly less than in the unbraked test. All head, neck and upper torso values are also, once again, below the loads that can be achieved by occupant contact alone.

However, besides any occupant protection measures, the most efficient way to reduce the occupant load when a hazard has been detected is to initiate emergency braking that reduces the accident severity. The protection of occupants as well as of other road users can again be significantly increased in this way.

Figure 20 shows the load distribution of all four tests relative to the standardized unbraked crash (scenario C). For individual load criteria, the reduction in the collision energy by 75% can be directly passed on to the occupants. What is important though is that the dynamic driving situations prior to a collision are supported by reversible occupant protection measures.

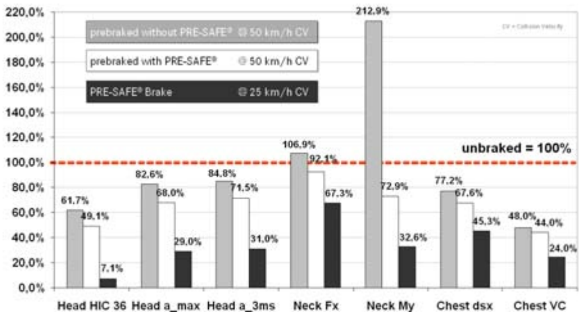

Figure 20: Comparison of the maximum loads

The risk of the front passenger experiencing serious injuries (AIS3+) in one of the constellations was determined for all four tests (Figure 22). The risk curves for the head, neck, chest and femur were calculated using the NHTSA injury risk criteria for the 50th percentile dummy, in order to be able to classify a serious injury as being AIS3+.

$p_{JointAIS3+}$=1-(1-p_{Head}) x (1-p_{Neck}) x (1p_{Chest}) x (1-p_{Femur})

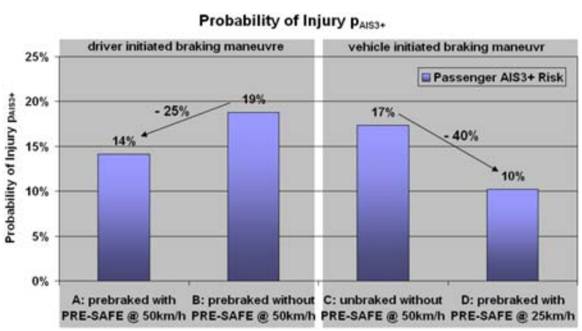

Figure 21: Probability of injury $p_{JointAIS3+}$

Looking at the two scenarios on the left in Figure 21, the risk of sustaining a serious injury (AIS3+) is reduced from 19% to 14%, if, as simulated, braking is initiated by the driver before the collision occurs and the occupant is restrained via a reversible belt tensioner.

This corresponds to a risk reduction of 25%.

The diagram on the right in Figure 21 shows the case where the vehicle is decelerated in advance via the PRE-SAFE® brake, without driver intervention, when a risk of collision has been detected.

If the collision is detected in advance by the vehicle and the speed is automatically reduced, as measured, via the PRE-SAFE® brake, the risk of a serious injury (AIS3+) can be reduced from 17% to 10% due to the reduction in speed together with the occupant contact. This corresponds to a risk reduction of approx. 40%.

The results confirm the findings of an initial study on the topic, which was carried out by the largest German automobile club ADAC in 2006. The refinement of the method employed at that time means that we can now see the potential benefits that can be attributed to the PRE-SAFE® reversible belt tensioning system and the contact through braking deceleration. The test methodology employed means that a systematic statement about the actual potential can be made thanks to the validated interaction between the dummy and vehicle during braking deceleration. The occupant and dummy behavior must initially be examined before testing involving severe longitudinal decelerations, as the initial position of the dummy immediately before the collision is crucial for the arising load values.

A significant reduction in the vehicle repair costs, including for possible accident partners, is another benefit besides the reduction in the accident severity. A 52% reduction in the repair costs has been calculated for a reduction in the collision velocity from 50 kph to 25 kph as a result of the PRE-SAFE® brake.

OUTLOOK

The growing number of reversible protective systems and driver assistance systems means that an integral analysis of occupant safety is becoming ever more important. It is not enough merely to examine the reduction in speed prior to the start of collision – the occupants also need to be analyzed in terms of how they interact with the vehicle immediately prior to the collision. This applies to all types of collisions, not just frontal impacts.

Modeling under test conditions has, of course, its limits, as it only enables us to simulate specific, simple and one-dimensional processes.

The virtual simulation of integral constellations, however, has great potential. Validated occupant or human models will, in the future, provide us with an insight into the benefits of pre-triggering systems.

The aim here will be not just to restrain occupants so that they stay in the required position, but to show that proactive, moving systems require state-of-the-art tools for calculating the efficiency of these proactive safety systems.

REFERENCES

ADAC Motorwelt magazine, issue 12/2006

K.-H. Baumann, R. Justen, R. Schöneburg: A Vision for an Integrated Safety Concept, 2001 ESV Conference, Amsterdam, Netherlands, Paper 01-493

R. Schöneburg, T. Breitling: Enhancement of Active and Passive Safety by Future PRE-SAFE® Systems, 2005 ESV Conference, Washington DC, USA, Paper 05-0080

U. Mellinghoff, T. Breitling, R. Schöneburg, H. Metzler: The Mercedes-Benz Experimental Safety Vehicle 2009, 2009 ESV Conference, Stuttgart, Germany, Paper 09-0165

M. Fehring, K.-H. Baumann, R. Schöneburg: The Experimental Safety Vehicle 2009, VDI 2009 Conference Berlin Innovative Occupant and Partner Protection, Germany

R. Bachmann, M. Fehring, M. Paurevic: The impact of dynamic driving situations on the safety potential of occupant restraint systems. Airbag 2010 Conference, Karlsruhe, Germany, Paper V18

F. Kramer; Passive Safety of Motor Vehicles, 2nd edition, May 2006, Vieweg-Verlag