Influence of rust on crashworthiness

Crash tests of rusty cars

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Influence of rust on crashworthiness - Crash tests of rusty cars

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Summary

Knowledge regarding the impact of rust on a car's impact properties is very limited. There have never been any controlled tests that compare the crash test results between a new car model and a rusty counterpart. If you study the strength properties of a metal part, they are generally negatively affected by rust. But the impact protection structure of a car consists of a system of beams whose energy absorbing function can be affected by the fact that some part of the beam system has been weakened by rust corrosion. That the crash protection properties of the car would be impaired through certain beams incurring rust corrosion is not a given, as there are several crash force transmission paths, and a robust construction can maintain protection if one part of the impact structure is weakened. Nor is the spread of rust in a car homogeneous in all its impact beams. The car's body can be significantly corroded by rust without the impact protection structures being rusty.

The purpose of the tests was to evaluate to what extent various degrees of rust influence crashworthiness in a passenger car. This knowledge is lacking and is something that a car owner and car buyer would benefit from when buying both newer and older cars.

To investigate the impact of rust on crash safety Folksam and Villaägarna conducted crash tests with old rusty cars of models already tested by Euro NCAP in 2003/2004. The results of the tests with the rusty cars were compared with the original Euro NCAP tests. Two car models were chosen with different degree of rust; a fifth generation VW Golf 2003-2009 with moderate rust and first generation Mazda 6 2002-2008 with extensive rust (also on the energy absorbing structure). The cars purchased were inspected and approved for traffic at the time of purchase. The VW Golf V was chosen to show the impact of rust on crash safety caused by wheelhouse inner fenders. Inner fenders, especially around the wheelhouse, collect a lot of dirt on the inside that gets lodged. As these inner fenders are rarely removed, there is a build-up of dirt that binds moisture to the wheelhouse plate and side beams (thresholds).

The rust spread in the Golf was mainly located alongside the side beams, partly as a consequence of accumulated dirt inside the wheelhouse inner fenders. Inner side beams and frame beams were in relatively good condition, as was the front-wheel suspension frame.

The Mazda 6 was chosen to show the consequences of more penetrating rust corrosion in multiple structures that are close to not passing the vehicle inspection. In the Mazda 6, the side beams had incurred relatively serious rust corrosion, but also the transverse beams behind the wheelhouse and inner side beams. Frame beams exhibited extensive surface rust but no widespread deep-seated rust. The front-wheel suspension frame was rusted through at points and had extensive deeper surface rust.

The results showed that the VW Golf as new received 33 points in the area of adult protection in the Euro NCAP crash test in 2003, now reduced to 32 points in the crash test with the rusty car model. Although this difference in points corresponds to a reduction of one Euro NCAP star, from five to four, the difference is considered to be non-existent. The Mazda's original rating for adult protection was 26 points when tested new, which is equivalent to four stars. The crash test with a rusty car gave the Mazda 18 points, corresponding to three stars.

The conclusion is that extensive rust in the car's energy absorbing structure can have a relatively large impact on the car crashworthiness. The tests with the VW Golf show that the rust can appear to be relatively widespread on the car's outer body parts without the inner structures necessarily being corroded by rust and thus affecting crash safety. In order to demonstrate an impact on crashworthiness, the rust needs to be so extensive that several beams are weakened by rust. In the example with the Mazda, the limit in impact force was estimated to be close to what the extensively rusty car could handle.

Recommendation

Our recommendation is applicable to maintaining crash safety with regard to rust. Depending on how the superficial rust looks, we provide some advice on how to proceed. At present, there is only one motor magazine (Vi Bilägare) that systematically assesses the rust resistance of a car model in the long term. A five-point scale provides an assessment of rust protection and construction. At the vehicle inspection facilities around Sweden, you have the possibility to do an extra inspection of the car's rust status:

If the car has a little rust or none at all

- Rust grade ≤2 according to the magazine Vi Bilägare
  - Apply rust protection
- Rust grade ≥3 according to the magazine Vi Bilägare
  - Does not require extra rust protection for crash protection purposes

If the car has extensive external rust.

- Ask the seller to permit a more detailed inspection of the car's impact beams at an inspection facility, regardless of whether the car was approved on the last inspection.
  - If the inspection reveals extensive deep-seated rust or worse in beams, do not buy the car.
  - If the inspection reveals limited or no surface rust in beams, a rust treatment of the beams can slow or prevent more rust.

Purpose

The purpose of the tests was to evaluate whether different degrees of rust impact on energy absorption structures in a passenger car lead to poorer crash safety. This knowledge is lacking and is something that a car owner and car buyer would benefit from when buying both newer and older cars.

Background

Rust corrosion on passenger cars' energy-absorbing impact beams can vary depending on the extent of the rust protection, type of rust protection and various design solutions that are more or less favourable to rust formation. External factors can also play a part, such as the extent of driving on salted roads, if the car is parked outside or inside, and general care of the vehicle. Therefore, you can see large variations in corrosion between different copies of the same car model.

Traditionally, rust protection has consisted of various surface treatments of panels and beams together with the zinc plating of certain parts. Over the last decade, it has become increasingly common to use plastic or felt inner fenders to protect the wheelhouses from stones and dirt from the wheels. Plastic panels are also used underneath the car's bottom plate to protect the undercarriage, but also to provide aerodynamic benefits. The introduction of these measures has been criticised as the car industry is considered to have simultaneously reduced the traditional rust protection. The consequence may be that moist sand and dirt penetrate behind fenders and panels without the possibility of being dislodged (Figure 1). Packaged moist dirt is then in some cases situated directly against the undercarriage. In particular, inner fenders in the front wheelhouses gather dirt against the front edge of the side beams and accelerate corrosion alongside beams and wheelhouses. These areas cannot be cleaned without removing the inner fenders.

Figure 1. Dirt behind plastic inner fender.

Rust that corrodes the outer parts of the body does not affect crash safety because they are not included in the car's energy-absorbing structures (Figure 2). But the extent to which rust that corrodes beams and load-bearing structures affects the car's crash safety is something on which no consensus has been reached.

Figure 2. The car's roll cage

There are no studies or tests on how rust in a passenger car's structure affects crash safety. It is assumed in principle that the strength of a steel structure is adversely affected by significant rust formation. Bilprovningen examines rust corrosion in load-bearing structures and fails the vehicle if the rust is too extensive. But a car does not rust uniformly everywhere, making it difficult to get an idea of the affect of a rusty section on the impact properties. The construction of a car is such that the forces in a crash are directed along several so-called crash force transmission paths (Figure 3). If a transmission path is weakened, the limit of the car's ability to absorb impact energy will be affected. But it is not certain that the construction will buckle under the impact force in the event of multiple collisions; instead, the forces find other paths through structures that are not affected by rust.

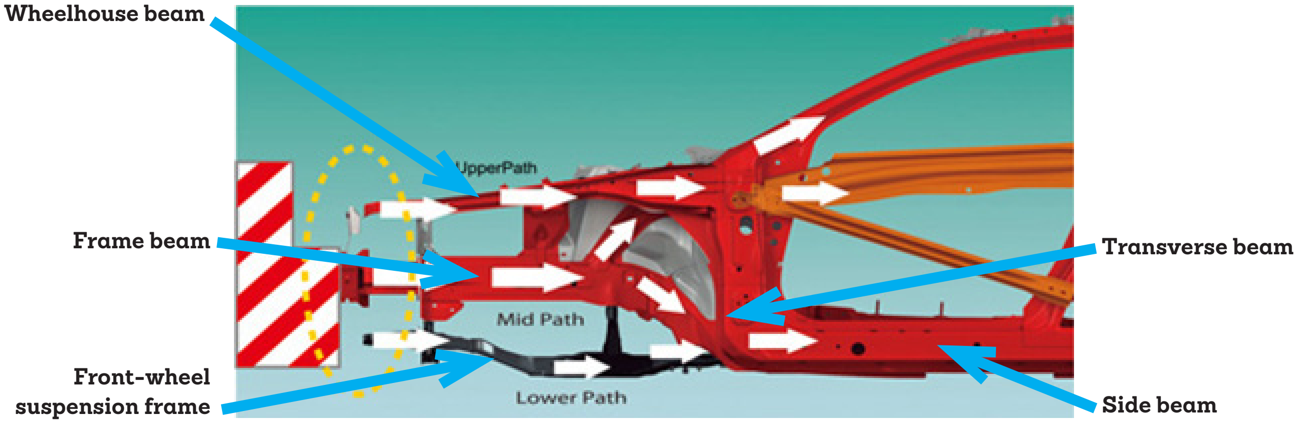


Figure 3. Crash force transmission paths energy-absorbing structure

Euro NCAP's crash test is carried out at a speed that represents a crash force corresponding to a severe collision with a risk of death and serious injury. If the construction is robust with several alternative crash force transmission paths and the corrosion is localised, it is possible that the impact properties are not affected at all. On the other hand, if the car has fewer alternative transmission paths, or weaknesses in the construction, a weakened part in the crumple zones could lead to major deformations caused by rust, which means diminished crash protection.

The fact that cars fail the vehicle inspection due to rust in load-bearing structures is relatively unusual. According to a compilation by Bilprovningen of 3.1 million inspections in 2012, 0.7 per cent of the twelve-year-old cars failed due to rust in load-bearing structures (press release 26/12-13). The distribution across different models was wide, where the models that most often failed for rust could constitute up to 15 per cent of the inspected cars. The survey also showed that the scale of the rust corrosion increased rapidly for some car models once they were 10-12 years old.

The cars selected for the tests were of the 2003-2004 (Mazda) and 2004-2007 (VW Golf) models. The cars had been in traffic up until the time of purchase. The search for test objects was focused on finding corrosion-damaged cars that passed the inspection and which had not been fixed or repaired. The purpose of the car selection for the first crash test was to find a regular car, 10-12 years old, with good basic crash protection, where the rust had been exacerbated by plastic inner fenders in the wheelhouses. For the second crash test, a car model was chosen that would be so badly damaged by rust that passing its next vehicle inspection would be a close call.

Material and method

Crash test

To determine the impact of the rust on crash safety, two used car models were tested according to the same test protocols in Euro NCAP as when the car models were new. The crash test was carried out according to the Euro NCAP test protocols from 2004 with the fifth generation VW Golf (2004-2009) and according to the 2003 protocols with the Mazda 6 (2003-2004). The crash tests were conducted at Thatcham Research in England, certified to test according to Euro NCAP's protocols.

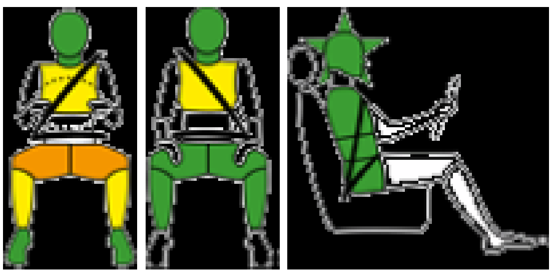
A complete crash test in Euro NCAP 2003/2004 included star ratings within three areas; adult occupant protection, child occupant protection and pedestrian protection. In this test, the focus was solely on calculating how the adult protection was affected by the car's rust corrosion. The three crash tests that were done only included the elements needed to calculate the points for "adult protection". The crash tests that were included in the calculation of adult protection involved a frontal crash (ODB, Offset Deformable Barrier), where 40 per cent of the front was driven into a deformable barrier at 64 km/h. A side impact test, where the stationary car is hit by a carriage with a deformable barrier at 50 km/h, and a pole impact test where the car is propelled laterally towards a fixed pole at 50 km/h.

The VW Golf was subjected to all three tests while the Mazda was only tested in two – the frontal impact test and the side impact test. Table 1 shows the points for adult protection received by the VW Golf V and Mazda 6 (first generation) when tested new. The limit for five stars was 33-37 points, four stars 25-32 points, three stars 17-24 points and two stars 9-16 points. In the frontal test and side impact test, at least 13 points must be obtained for five stars, 9-12 points for four stars, 5-8 points for three stars and 2-4 points for two stars.

Table 1. Adult protection

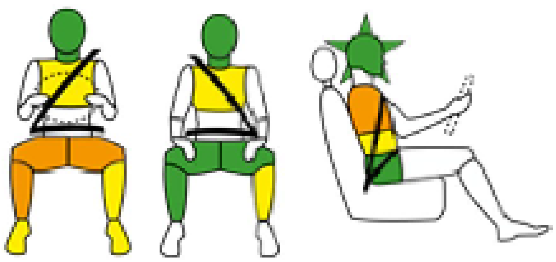
Test element	Adult points max. points	VW Golf (test year 2004)	Mazda 6 (test year 2003)
ODB frontal 64 km/h	16	13	11
Side impact 50 km/h	16	16	13
Pole test 50 km/h	2	2	2
Seat belt reminder	3	2	0
Total points adult protection	37	33	26

The points allocated in each element are based on the crash test dummies' test data. However, the crash test dummy has no sensor in the feet. The yellow markings on the feet come from the measurements of interior deformations that were made after the original test. The levels from the crash test dummies' test data from the original tests are presented in figure 4 and 5.



Driver Passenger Side impact test

Figure 4. VW Golf V dummy data.



Driver Passenger Side impact test

Figure 5. Mazda 6 2003-04 dummy data.

Crash test cars

Before the crash tests, the cars were prepared and examined. Primarily, the front-wheel suspension and steering were adjusted on the car that would be driven in the frontal test so that the test cars would hit the barrier in the right way. Other necessary checks were carried out on trailing brakes to secure the test speed. The cars included in the tests are shown in table 2.

Table 2. Crash test cars

Test	Test cars	Figure	Test cars	Figure
ODB (Offset deformable barrier)	VW Golf 1,6 FSI -04	6	Mazda 6 2.0 estate -04	9
Side impact	VW Golf 1,6 -06	7	Mazda 6 2,3 Sport saloon -03	10
Pole test	VW Golf 1,6 -08	7	Not tested	-

The selection of test cars was made on the basis of certain criteria. The choice of the VW Golf (Figure 6-8) was made according to the following criteria:

- A relatively common model with good crash safety features (5 stars)
- Large compact or mid-range
- Rust corrosion caused by front plastic inner fenders
- Privately-owned cars that passed vehicle inspection with activated car registration
- Max. 200,000 km
- Not previously involved in a crash
- Not treated for rust
- Version, engine gearbox as in Euro NCAP test model 2004


Figure 6. ODB frontal test.


Figure 7. Side impact test.


Figure 8. Pole test.

The choice of the Mazda 6 (Figure 9-10) was made according to the following criteria:

- Medium quality crash safety features (4 stars)
- Model that often receives rust remarks according to Bilprovningen
- Large compact or mid-range
- As much rust corrosion as possible
- Cars in traffic approved until the next inspection
- Not treated for rust
- Not previously involved in a crash
- Manual gearbox, petrol engine
- Model generation as in the Euro NCAP test model 2003


Figure 9. ODB frontal test.

Figure 10. Side impact test.

Rust corrosion Golf

Images 12-14, 18-20 and 24-26 show what the rust damage looked like on each respective car along the outside of the threshold section. Images 15-17, 21-23 and 27-29 show how it looked on the inside of the threshold of each car. A fibre optic camera was used to document the front edge of the threshold and the pictures were taken horizontally from inside the threshold with an angle out from the car and in towards the car (Figure 11).

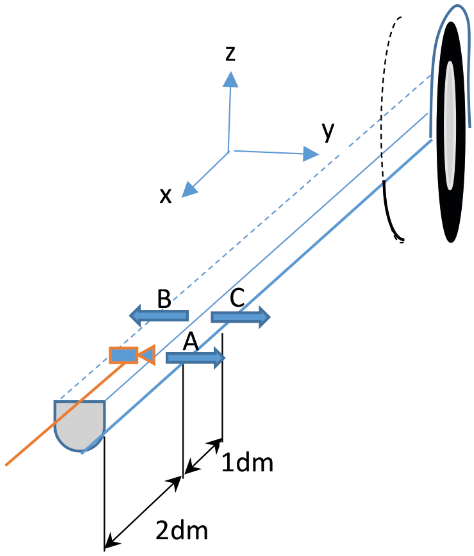


Figure 11. Fibre optic camera photo angle on VW Golf side beam.

Rust corrosion VW Golf 1.6 2004 – ODB

Car 1 had extensive rust damage along the side beam up to about 50 centimetres behind the front wheelhouse. The outer side of the side beam had extensive rust corrosion but it was located primarily on the outside of the side beam, which is why the inner sections were in relatively good condition. Figure 12 shows that the corrosion on the front end of the side beam was extensive but the corrosion was most extensive in the first decimetre. Figures 15-17 show the inside of the side beam at 2 and 3 decimetres respectively behind the wheelhouse.

Figure 12. Side beam - left wheelhouse front.

Figure 13. Bottom plate.

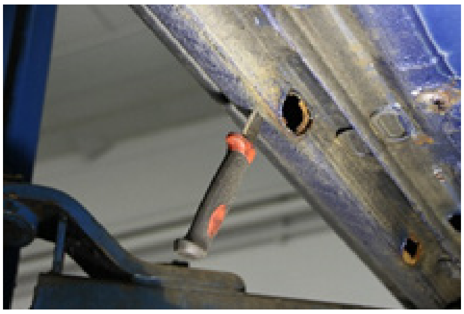


Figure 14. Left side beam.

Figures 15-17 show the inside of the left side beam according to the camera view shown in Figure 11. Figure 17 shows a drainage opening and is not a rust hole. However, there is visible corrosion on the edges.

Figure 15. Camera view A.

Figure 16. Camera view B.

Figure 17. Camera view C.

Rust corrosion VW Golf 1.6 2006 – side impact test

In the side impact test, the Golf had extensive rust damage in the front part of the side beam and was rusted through on the inside of the side beam around 3-5 decimetres behind the front wheelhouse. Less extensive rusting was visible on the bottom plate.

Figure 18. Side beam – left wheelhouse front.

Figure 19. Bottom plate.

Figure 20. Left side beam..

Figures 21-23 show the inside of the left side beam according to the camera view shown in Figure 11. Figure 23 shows a drainage opening and is not a rust hole. However, deep-seated rust is visible on the edges and surrounding surfaces.

Figure 21. Camera view A.

Figure 22. Camera view B.

Figure 23. Camera view C.

Rust corrosion VW Golf 1.6 2007 – pole test

Car 3 was in the best condition but also had deep-seated rust in the front edge of the side beam. No rusting through further back along the side beam.

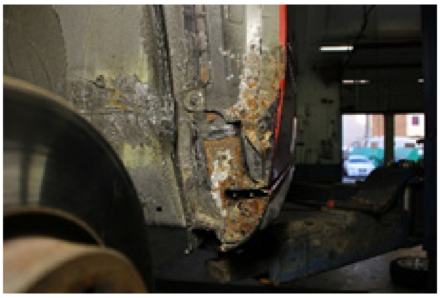


Figure 24. Side beam - left wheelhouse.

Figure 25. Bottom plate.

Figure 26. Left side beam.

Figures 27-29 show the inside of the left side beam according to the camera view shown in Figure 11. Figure 29 shows a drainage opening in the side beam. Minor surface rust is visible around the drainage hole.

Figure 27. Camera view A.

Figure 28. Camera view B.

Figure 29. Camera view C.

Rust corrosion Mazda

The two Mazda cars included in the test had extensive rust damage but the rust was unevenly distributed between the two cars. An expert group made an ocular assessment of the extent of the corrosion in a number of sections using a fibre optic camera, as shown in Table 4. The inside of the examined sections was analysed using a camera and given a rating of 1-5 as per Table 3.

Table 3. Extent of corrosion

Rating	Explanation
1	No corrosion
2	Surface rust
3	Deep-seated rust
4	Rusted through
5	Extensive through-rusting

Table 4. Level of corrosion for different crash structures

	Mazda 6 estate	Mazda 6 saloon
Rust assessment	**ODB**	**Side test**
Longitudinal side beam left	3	5
Longitudinal side beam right	3,5	3
Longitudinal side beam inner left	2	2
Longitudinal side beam inner right	2	2
Transverse beam wheelhouse left	5	5
Transverse beam wheelhouse right	4	5
Frame beam lower/wheelhouse beam left	3,5	3
Frame beam upper left	4	3
Frame beam lower/wheelhouse beam right	3	3
Front-wheel suspension frame	4	3

Rust corrosion Mazda 6 estate – ODB test

The longitudinal side beams are in an exposed position behind the front wheels and had widespread deep-seated rust where it was rusted through at certain points. The outer panel on the outside of the left side beam (Fig. 30/31) was rusted through to a greater extent but the inner part of the side beam was in a relatively good condition.

Figure 30. Left side beam inside.

Figure 31. Left side beam outside.

Figure 32 shows how the inside of the left inner side beam looked. The surface has extensive surface rust adjacent to deep-seated rust.

Figure 32. Camera entry point left side beam.

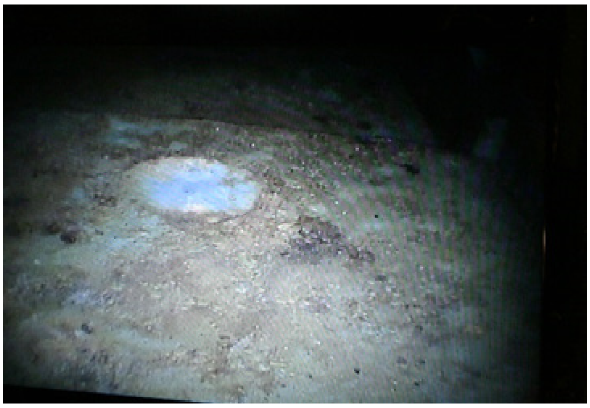


Figure 33. Left side beam inside.

The front-wheel suspension frame belongs to the lower of the crash force transmission paths (Figure 3). The front-wheel suspension frame was severely corroded and was assessed as having large areas of deep-seated rust (Figure 34).

Figure 34. Camera entry point back part of left front-wheel suspension.

Figure 35. Inside back part of left front-wheel suspension.

The lower part of the frame beam had sections of deep-seated (Figure 36) while other parts of the frame beam had lighter surface rust. The frame beam was assessed as having a rust level of 3.5 (Table 4).

Figure 36. Frame beam left front.

Figure 37. Frame beam left front inside.

Left transverse beam's outer surface behind the front wheelhouse was completely rusted through and the inner section had widespread surface rust (Figure 38).

Figure 38. Left transverse beam behind front wheel.

Upper wheelhouse beam is the upper crash force transmission path (Figure 3). Upper wheelhouse beam was rusted through at certain points (Figure 39).

Figure 39. Left wheelhouse beam.

Rust corrosion Mazda 6 saloon – side impact test

Figure 40 shows widespread surface rust but no deep-seated rust. The camera's position was in the front part of the inner side beam (Figure 40).

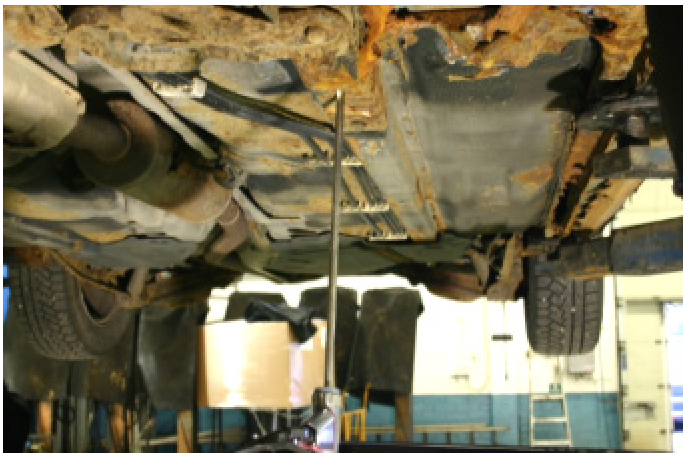


Figure 40. Camera entry point left inner side beam.

Figure 41. Left inner side beam.

Framvagnsramen (Figur 42) hade något bättre roststatus i sidotestbilen än frontaltest-bilen. För sidotestbilen bedömdes framvagsramens rostangrepp vara en trea (Tabell 4) som innebar omfattande gravrost vilket syns i Figur 43.

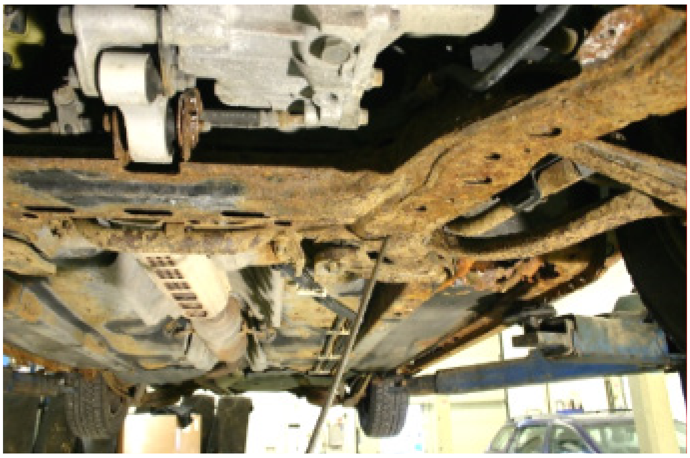


Figure 42. Camera entry point back part of left front-wheel suspension.

Figure 43. Inside back part of left front-wheel suspension.

The lower frame beam (Figure 44) had sections adjacent to deep-seated rust (Figure 45) and was given a rust grade of three. The side test car's frame beam was however in better condition than the frontal test car and did not have as extensive a rust spread.

Figure 44. Frame beam left front.

Figure 45. Frame beam left front inside.

The left transverse beam's outside by the wheelhouse was completely rusted through and the inner section had some surface rust. The driver's foot space by the pedals can be seen behind the transverse beam. Both the test cars were given a rust level of five (Table 4) on the transverse beam behind the wheelhouse.

Figure 46. Left transverse beam behind front wheel.

The left side of the wheelhouse beam has widespread surface rust and was rusted through at certain points (Figure 47). Both test cars had the same degree of rusting on the wheelhouse beam and were given a rust level of three (Table 4).

Figure 47. Left wheelhouse beam.

Results

VW Golf – ODB test (Offset Deformable Barrier)

Figure 48 shows the frontal impact test (ODB) with the VW Golf V from the original frontal test in 2004 and Figure 49 shows the test with the rusty Golf.

Figure 48. Euro NCAP original test in 2004.

Figure 49. ODB Frontal Impact test.

Table 5 presents the points from the frontal impact test. The score has been calculated directly from the dummy data and shows that the total points for the driver was 14.147. In Appendix 1, four points is given as the driver score for "Knee, Femur & Pelvis". According to the 2004 protocol, point deductions were made according to a so-called "modifier" due to knee contact with the dashboard. Two points were therefore deducted – one for contact with the dashboard and one for concentrated knee load – which is why the final score for the frontal test ended up at 12.147.

Table 5. VW Golf (rust) frontal impact test protocol ODB.

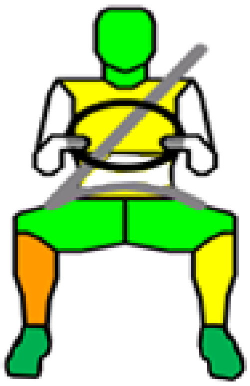
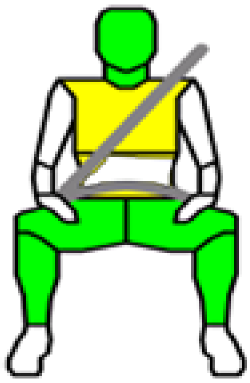
Sum	14.147	15.877
only modifiers from ATD data are included Points * 4.000 * 2.670 - 3.999 * 1.330 - 2.669 * 0.001 - 1.329 * 0.000		

Figure 50 shows the foot space that passed without deformation. No movement of the dashboard or steering wheel could be detected. However, the dummy's right lower leg struck the dashboard, resulting in a point deduction.

Figure 50. Foot space

VW Golf – side impact test

Figure 51 shows the car after the side impact test with a deformable barrier. The side impact test gave 15.585 points (Table 6), which is the same as the original test.

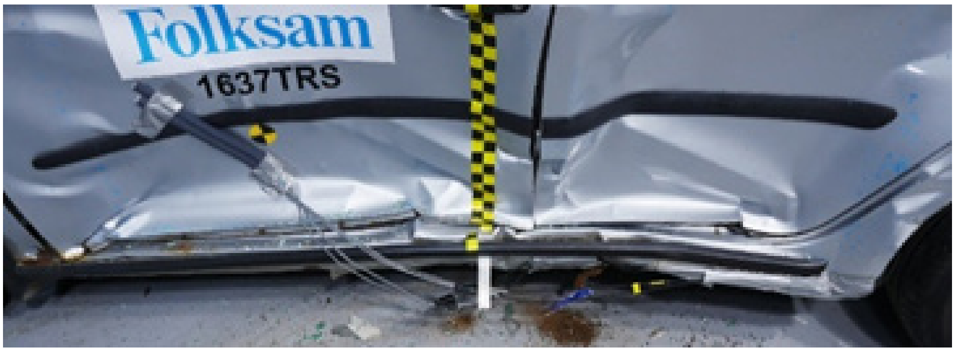
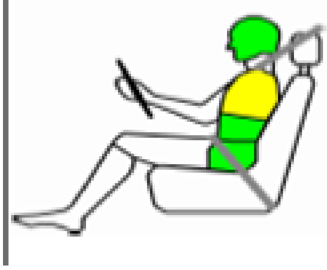


Figure 51. VW Golf (rust) Side impact.

The side impact test showed good crash performance with only a reduction in the score for indentation of the lower part of the chest, which therefore gave the second highest intermediate score. There the chest score was reduced from green to yellow (Table 6). The score for the head was reduced from green with a star to green without a star. The points for the side impact test ended up at 15.808. Appendix 2 shows the test data from the dummy's individual measurements.

Table 6. VW Golf (rust) test protocol side impact.

Sum	15.858
Points * 4.000 * 2.670 - 3.999 * 1.330 - 2.669 * 0.001 - 1.329 * 0.000	

VW Golf – pole test

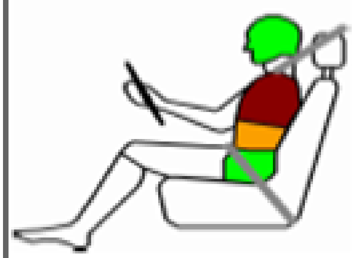
Figure 52 shows the deformation from the pole test. Table 7 shows that the data from the chest measurement was worse than the original test (Figure 4). However, this drop did not affect the final score. The 2004 protocol includes only data for the head in the pole test so the final score was a two, the same as the reference test in 2004. Individual measurements from the pole test are shown in Appendix 3.

Figure 52. VW Golf (rust) pole test.

Table 7. VW Golf (rust) pole test.

Sum	11.880

Points
- ★ 4.000
- ★ 2.670 - 3.999
- ★ 1.330 - 2.669
- ★ 0.001 - 1.329
- ★ 0.000



Mazda – frontal impact test (ODB)

Figure 53 shows higher dummy points, 12.289, compared to the original test, 11 points (Figure 5). The data from the original test has been supplemented with so-called "modifiers" which reduce the dummy values according to certain criteria relating to interior penetration, behaviour of the impact beams or other changes that are not clearly reflected in the data from the crash test dummy. The feet marked in yellow come from the calculation of "modifiers" since the dummy has no sensors in the feet. As complete test data from the original test is not available, it is not known how much of a point deduction has been made in the original test. The respective dummy data is presented in Appendix 4.

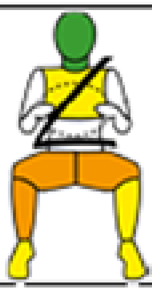
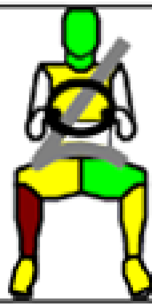
	Driver
2003 Test at TRL	
Score (worst)	11
2018 Test at Thatcham	
Score (worst)	12.289

Figure 53. Adult points frontal impact

The crash test with the rusty car caused major deformations by the foot space and deformation of the crash beams affected by the "modifiers", resulting in a point deduction. According to Euro NCAP's protocol, point deductions are made for compartment deformations that the dummy does not measure. The criteria for point deductions are specific for the respective crash test type. Here are the deductions made for adult protection in the frontal impact test ODB:

- One point deduction for the head bottoming out the airbag at about 122 ms.
- One point deduction because the inner side beam was deformed (Figure 53) in such a way that the car could not maintain its ability to resist further deformation forces. After a collision, the car must be able to demonstrate the ability to deform in a controlled manner via at least two crash force transmission paths for an increased impact force. The damage to the inner and outer side beam showed that this condition is not met.
- An extensive deformation of the driver's legroom results in a point deduction. The deduction reflects the increased risk of severe foot injury that the dummy does not measure.
- One point deduction for the force to the lower leg exceeding 3.8 kN. The right fibula of the dummy showed a measurement of 4.59 kN.
- One point deduction for concentrated force against the knee. The right knee was exposed to focused pressure that reflects the increased risk of severe knee injuries.

With a four-point deduction in the frontal impact test due to the "modifiers", the driver's score for the frontal test was 7.289 points (Table 8) compared with 11 points in the original test.

Figures 54-55 show the left frame beam which had extensive rust adjacent to deep-seated rust on the outside and joint. The underside of the frame beam (Figure 56) had deep-seated rust in the flanges indicating that the corrosion has spread significantly. Nonetheless, the inside of the frame beams looked better than the outside (Figure 37). Despite the rust corrosion, the frame beam has still been deformed in a way that suggests the rust has not changed the deformation properties of the frame beam.

Figure 54. Frame beam side view.

Figure 55. Frame beam from above.

Figure 56. Frame beam underside

Figure 57 shows the inner side beam on the left side which had areas with widespread surface rust with some areas of localised deep-seated rust (rust level two). The inner side beam was deformed through it being bent in four different places (Figure 57) and pushing the floor upward. The inner side beam also separated from the floor (Figure 58). The transition between frame beam and inner side beam was heavily corroded by rust, which probably weakened that section. In turn, this contributed to a significant deformation of the driver's legroom. The type of deformation indicates that the inner side beam has reached the limit to be able to maintain its deformation properties for increased load. The consequence of the deformation of the inner side beam was that the floor on the driver's side and left passenger side deformed vertically about 15 centimetres with the consequence that the driver's seat mountings were moved. The deformation was greatest on the right-hand side of the driver's seat, which at the same time was violently tilted forward during the collision course. This impacted the forward motion of the dummy and contributed to the head of the crash test dummy bottoming out the airbag and twisting to the left.

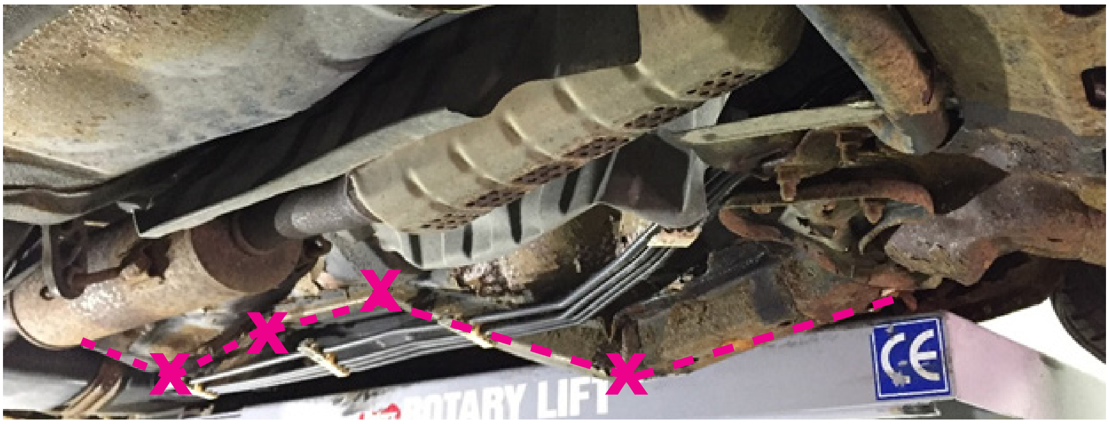


Figure 57. Inner side beam

Figure 58. Frame leg backside transition to beginning of inner side beam.

Figure 59 shows the transverse beam behind the front wheelhouse and the beginning of the inner side beam. The side beam has been deformed downwards, which the driver's foot space also has done. The deformation in the foot space has also become longitudinal as a consequence of the weakened transverse beam and the bend of the inner side beam downward and backward.

Figure 59. Transverse beam behind front wheelhouse.

Figure 60 shows the left side beam whose rust level was set at three with extensive corrosion along the entire beam. Behind the front wheel, the side beam was rusted through in several places (Figure 60). The side beam is one of the structures that takes the most load in the frontal impact test, and a weakening here is most likely to result in increased deformation of the compartment. From measurements of crash scenarios, the side beam has been deformed about one decimetre more than the regular test, which corresponds to approximately 35 per cent greater longitudinal deformation of the threshold. The weakening of the side beam also caused a greater load on the inner side beam, which resulted in a greater deformation than in the original test.

Figure 60. Left side beam.

Figure 61. Side beam behind left front wheel.

Figure 62 shows the deformation in the foot space. The deformation consisted of both longitudinal deformation of the pedal panel and the underlying surface and a vertical deformation of the floor. The floor deformation probably contributed to the points deductions given for increased contact forces on the lower leg and knee.

Figure 62. Foot space driver's seat.

The deformation of the foot space also made the floor separate from the threshold, an indication that the section was overloaded (Figure 63).

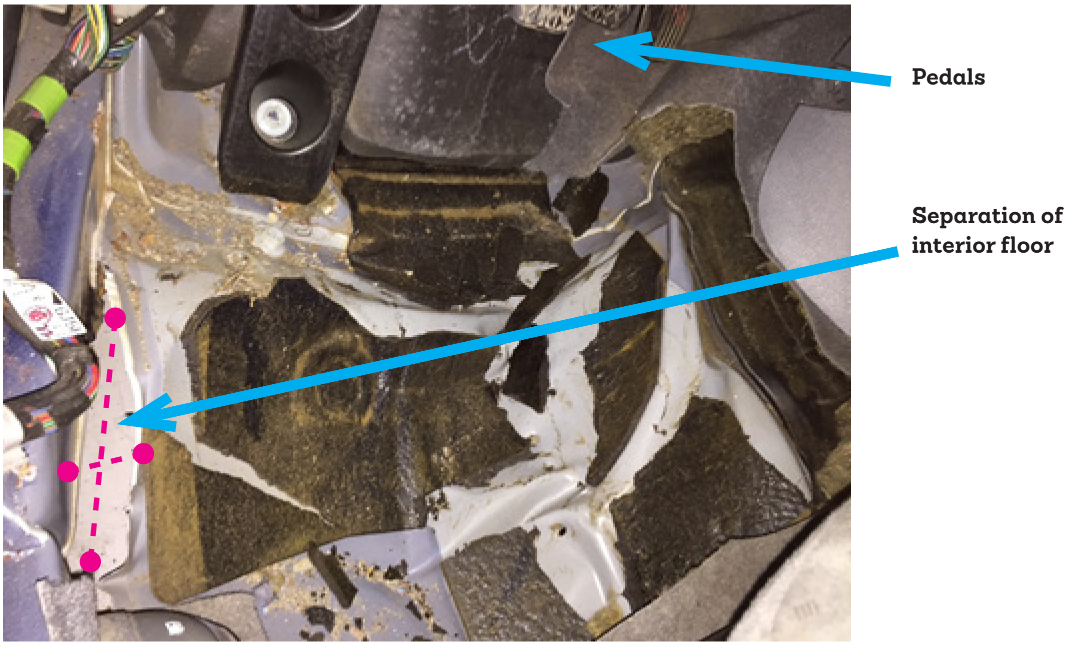


Figure 63. Foot space driver's seat.

Mazda – side impact test

Figure 64 shows that adult protection based on the crash test dummy's test data was 9.520 points compared with the 13 points from the original test. It was primarily the dummy's data from the upper chest that showed higher measurement values than the original test. The higher dummy measurement were mainly due to the penetration of the driver's door being larger than in the original test. The chest struck the side airbag as intended and the airbag inflated as it should. Thus, the chest was protected to the same extent by the side airbag as in the original test.

Dummy Score

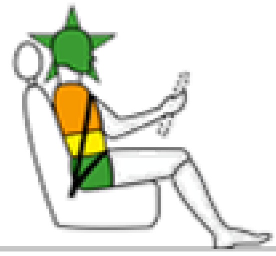
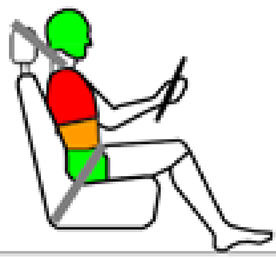
	Driver
2003 Test at TRL	
Score	13
2018 Test at Thatcham	
Score	9.520

Figure 64. Adult points side impact test.

Deduction ("modifiers") in the adult protection were also made in the side impact test. For the adult protection of 9.520 points, a deduction of 1,187 points was made. The reason is that the dummy has a back plate behind the ribs that senses major lateral movements that are not measured by the sensors in the chest. The backplate has sensors that recorded such a high measurement that a compensation of the adult points was made.

The side impact test resulted in greater compression of the dummy's chest, probably due to a greater deformation of the side beam (threshold) and floor compared to the original test. The deformation, in turn, caused extensive deformation and lateral movement of the driver's seat. Since deformation data from the original test is lacking, the cause of the increased compression of the dummy's chest cannot be attributed to greater deformation in the rust test. The side airbag has been hit and activated correctly, which cannot have contributed to the increased compression of the dummy's chest.

Figure 65. Side beam exterior

The close-up of the side beam's underside (Figure 66) shows that the deformation did not occur in a controlled manner, indicating being close to the fracture limit. The outer layer of the side beam has been spilt as a consequence of overload.

Figure 66. Side beam exterior askew from below.

The overall results show that the Golf's adult protection fell from 33 points to 32 points, which in practice is not considered a real difference. The point limit nevertheless meant that the rusty VW Golf dropped just below the limit for five stars.

The Mazda lowered its crash rating for the driver (adult protection) from 26 points to 18 points. This corresponds a shift in star rating from a weak four to a weak three. This correlates to a real risk increase in fatal and disabling injuries of about 20 per cent in a possible collision. In the frontal impact test with the Mazda new, remarks regarding deformation in the foot space, as in Table 8, are considered to result in a one-point deduction. The point value that is known is the 11 points received in the new car test.

Table 8. Score summary adult protection

Test element	VW Golf (rust) driver	VW Golf (new) driver	Mazda 6 (rust) driver	Mazda 6 (new) driver
ODB frontal test adult points	14,147	13	12,289	(12)
Deduction head contact airbag	0	0	-1	0
Deduction impact structure	0	0	-1	0
Deduction penetration foot space	0	0	-1	(-1)
Deduction lower leg force >3.8 kN	-1	0	-1	0
Deduction concentrated knee load	-1	0	-1	0
Total ODB points	12,147	13	7,289	11
Side test	15,858	16	9,520	13
Deduction "Back plate"	0	0	-1	0
Total Side test points	15,858	16	8,520	13
Total Pole test points	2	2	(2)	2
Seatbelt reminder points	2	2	0	0
Total points adult protection	32,005	33	17,809	26
Total points adult protection rounded	32	33	18	26

Discussion and conclusions

The results of the crash tested car models could not be compared to the original test in all aspects because all measurement protocols from the original tests are not public.

The crash test with the Golf shows that surface rust is not a problem with regard to crash safety. The Golfs that were tested exhibited more or less corrosion along the outer part of the side beam. Inner side beams further in on the bottom plate were only subject to lighter surface rust in some parts but were essentially completely free of corrosion. It cannot be established that the rust alongside the side beam is insignificant in terms of crash safety. Although the rust was evident along the outer shell of the side beams, there were still healthy parts further in along the side beam. The side beams are generally an important crash force transmission path both from the front and the side. It seems that a weakening of the side beams was not decisive in either the offset test or the side test. Had the rust been more extensive along the side beams, the result could have been different, but in the crash tests that were carried out the impact was negligible. The results show the difficulty in visually determining the impact a rusty section of the car's chassis has on crash safety.

The Golfs tested were, for their time, equipped with a good rust protection in the form of cavity wax. The effective rust protection has probably prevented corrosion on other structures besides the outer side beams. This may have contributed to the fact that a relatively corroded side beam has not generally weakened the crash safety features of the car.

The tested car model (VW Golf V) was given a new crash safety rating of 5. Depending on where the rust is located and how the design of the crumple zones looks, the outcome may be varied. A construction that already from the start has poorer crash protection and is therefore close to the limit for keeping the compartment intact, is likely to be more sensitive to corrosion in the impact structure. The Mazda 6, which in the new car test had a lower grade for adult protection than the VW Golf, indicates that Mazda's margins were less than those of the VW Golf. The Mazda 6 received a new remark regarding deformation in the foot space, indicating that the structure around the foot space was close to its limit for maintaining an intact compartment space. Because the Mazda had significantly worse corrosion, it is not possible to make a direct comparison between the car models.

In the frontal test with the Mazda, the difference in the dummy measurements at the driver's seat was relatively small compared with the original test. The five-points deduction from "modifiers" was at least three points more than in the original test. In the original test, the Mazda received remarks regarding a certain amount of deformation in the legroom which could lead to a deduction for contact between the lower leg and dashboard. Some deformation of the foot space could be observed in the original test but was very likely far from the extensive deformation, both horizontally and vertically, that could be seen in the crash test with a rusty car.

Since some data from the regular Mazda tests is not public, certain measurements were made based on video clips and pictures. The measurements showed that the wheelbase became about one decimetre shorter in the test involving the rusty car. The measurements are an approximation and an overall assessment of several measurements.

In the frontal test with the Mazda, the floor was deformed vertically over one decimetre from the driver's seat to the rear foot space. As a result, the driver's seat tipped forward and outward.

The centre console also moved due to the floor deformation. This movement has probably affected the motion of the dummy and contributed to the dummy's head being very close to hitting the steering wheel. Analysis of videos showed that the airbag was very close to bottoming out.

In the frontal test with the Mazda, the floor mounting (at the driver's seat) to the threshold beam separated completely in two welds so that a 20 centimetre-long opening was created. This indicates that the structure between the floor and side beam has been overloaded.

In the frontal test with the Mazda, the inner left side beam was significantly deformed, with four folds in the beam, resulting in the floor deforming vertically. This also meant that the driver's seat with the dummy was shifted forwards and upwards and changed the position of the dummy compared with the original test. The inner side beam also gave way in the attachment to the floor. The deformation of the side beam therefore showed signs of uncontrolled deformation and indicated that the beam had become overloaded and close to collapse.

In the side test with the Mazda, the driver dummy's measurement values for the head were green compared to the green star in the original test. The driver dummy's data for the upper chest region resulted in a drop of two grades compared with the original test. Other comparative measurements with the original test could not be done. The dummy's test data clearly indicated poorer values compared with the original test and showed that there was more extensive interior penetration in the rusty car.

The Golf V's crash rating dropped from 33 points to 32 points, equivalent to a reduction from five stars to four stars according to Euro NCAP's standard. In practice, this difference is to be considered so minor that the crash safety of the rusty Golf was not diminished.

The Mazda's crash rating for the driver (adult protection) dropped from 26 points to 18 points, equivalent to a reduction from four stars to three stars according to Euro NCAP. This correlates to a real risk increase in fatal and disabling injuries of about 20 per cent in a possible collision.

The conclusion is that extensive rust in the car's structure can have a relatively large impact, as in the case of the Mazda. The tests with the VW Golf show that the rust can appear relatively widespread on the car's outer body parts without the inner structures necessarily being corroded by rust and thus affecting crash safety. In order to demonstrate an impact on crash safety, the rust needs to be so extensive that several beams are weakened by rust.

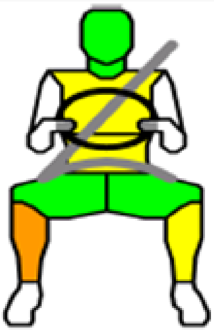
In the example with the Mazda, the limit in impact force was estimated to be close to what the car could handle. In the crash tests with the VW Golf, there was no difference in the crash safety features between a new and a rusty car.

A test series similar to this can give an indication of the impact of rust on crash safety. Questions that remain to be answered include the following: how long does it take for the rust to result in such significant corrosion that essential parts of the impact structure are affected? How much does the deterioration of crash safety caused by rust vary across car models?

Appendix 1 – VW Golf V ODB

1638TRF Laboratory Test Ref No. 1638TRF Customer Test Ref No. 2016-11-30	Type of Test Regulation **1638TRF Folksam Golf** ODB Frontal Impact Test Euro NCAP 2014	Thatcham Research

Criterion	Driver SP 1 (H3)				Passenger SP 3 (H3)			
Head & Neck			4.000	★			4.000	★
Head								
HIC 36	523.03				410.37			
Acceleration Resultant	51.41	g	4.000	★	52.12	g	4.000	★
3ms cumulative	50.62	g		★	51.43	g		★
Neck								
Shear Force Fx+	0.62	kN	4.000	★	0.13	kN	4.000	★
Shear Force Fx-	-0.23	kN	4.000	★	-0.48	kN	4.000	★
Tensile Force Fz+	1.52	kN	4.000	★	1.00	kN	4.000	★
Extension My-	-13.00	Nm	4.000	★	-10.21	Nm	4.000	★
Chest			3.480	★			3.877	★
Deflection	-25.64		3.480	★	-22.86		3.877	★
VC max	0.11		4.000	★	0.08		4.000	★
Diagonal belt upper force	4.48				4.83			
Knee, Femur & Pelvis			4.000	★			4.000	★
Left								
Femur Force Fz-	-0.45	kN	4.000	★	-0.36	kN	4.000	★
Knee Slider Displacement	-0.98	mm	4.000	★	-0.45	mm	4.000	★
Right								
Femur Force Fz-	-2.25	kN	4.000	★	-0.53	kN	4.000	★
Knee Slider Displacement	-2.25	mm	4.000	★	-2.10	mm	4.000	★
Tibia			2.667	★			4.000	★
Left								
Compression Upper Fz-	-1.79	kN	4.000	★	-1.08	kN	4.000	★
Compression Lower Fz-	-2.03	kN	3.980	★	-1.52	kN	4.000	★
Tibia Index Upper	0.43		3.867	★	0.29		4.000	★
Tibia Index Lower	0.49		3.600	★	0.20		4.000	★
Right								
Compression Upper Fz-	-2.97	kN	3.353	★	-1.34	kN	4.000	★
Compression Lower Fz-	-3.70	kN	2.867	★	-1.67	kN	4.000	★
Tibia Index Upper	0.55		3.333	★	0.26		4.000	★
Tibia Index Lower	0.70		2.667	★	0.24		4.000	★
Sum			14.147				15.877	



only modifiers from ATD data are included

Points
- ★ 4.000
- ★ 2.670 - 3.999
- ★ 1.330 - 2.669
- ★ 0.001 - 1.329
- ★ 0.000

63.40 km/h 1533 kg Driver Left	**Results Occupants** Front Vehicle 1	Laboratory: Thatcham Research Contact: Tom Leggett Customer: Folksam 2/86

Appendix 2 – VW Golf V side impact

1637TRS Laboratory Test Ref No 1637TRS Customer Test Ref No 2016-12-01	Type of Test Regulation **1637TRS** **Side Barrier Impact Test** **Euro NCAP 2015**	Thatcham Research

Criterion	Driver SP 1 (E2)				Occupant SP 6 (Q3)	
Head			4.000	★ (green)	★ (green)	
HIC 36	101.12		4.000	★ (green)		
Acceleration Resultant	39.34	g				
3ms cumulative	38.25	g	4.000	★ (green)		
				★ (green)	★ (green)	
Chest			3.858	★ (yellow)		
Deflection						
Upper	13.73	mm	4.000	★ (green)		
Middle	15.11	mm	4.000	★ (green)		
Lower	22.71	mm	3.858	★ (yellow)		
VC max						
Upper	0.09	m/s	4.000	★ (green)		
Middle	0.10	m/s	4.000	★ (green)		
Lower	0.14	m/s	4.000	★ (green)		
Backplate						
Force Y	0.76	kN	0.000	✓		
Spine						
Spine						
T12 Force Y	0.42	kN	0.000	✓		
T12 Moment X	-104.89	Nm	0.000	✓		
Abdomen			4.000	★ (green)		
Sum Force	0.49	kN	4.000	★ (green)		
Pelvis			4.000	★ (green)		
Pubic Force Y	-1.72	kN	4.000	★ (green)		
Sum			15.858			

only modifiers from ATD data are included

Points
- ★ (green) 4.000
- ★ (yellow) 2.670 - 3.999
- ★ (orange) 1.330 - 2.669
- ★ (brown) 0.001 - 1.329
- ★ (red) 0.000

Folksam Golf Side 0 km/h 1411 kg Driver Left	Mobile Barrier 50.21 km/h 958 kg	**Assessment Occupants** **Front** **Vehicle 1**	Laboratory: Thatcham Research Contact: Tom Leggett Customer: Folksam 4 / 41

Appendix 3 – VW Golf V pole impact

1636TRP Laboratory Test Ref No. 1636TRP Customer Test Ref No. 2016-12-06	Type of Test Regulation	1636TRP Side Pole Impact Test Euro NCAP 2014	Thatcham Research

Criterion	Driver SP 1 (E2)				Occupant SP 6 (Q3)	
Head			4.000	*	*	
HIC 36	308.88		4.000	*		
Acceleration Resultant	54.89	g	4.000	*		
3ms cumulative	54.47	g				
				*	*	
Chest			1.320	*		
Deflection						
Upper	33.68	mm	1.664	*		
Middle	26.78	mm	3.044	*		
Lower	35.40	mm	1.320	*		
VC max						
Upper	0.44	m/s	3.294	*		
Middle	0.21	m/s	4.000	*		
Lower	0.27	m/s	4.000	*		
Backplate						
Force Y	0.17	kN	0.000	✓		
Spine						
Spine						
T12 Force Y	1.15	kN	0.000	✓		
T12 Moment X	-53.51	Nm	0.000	✓		
Abdomen			2.560	*		
Sum Force	1.54	kN	2.560	*		
Pelvis			4.000	*		
Pubic Force Y	-1.73	kN	4.000	*		
Sum			11.880			

only modifiers from ATD data are included

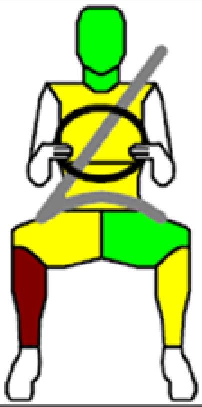
Points
- * 4.000
- * 2.670 - 3.999
- * 1.330 - 2.669
- * 0.001 - 1.329
- * 0.000

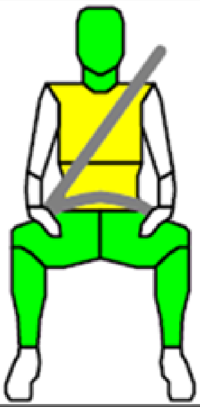
29.12 km/h 1480.5 kg Driver Left	**Assessment Occupants** Front Vehicle 1	Laboratory: Thatcham Research Contact: Tom Leggett Customer: Folksam 4 / 42

Appendix 4 – Mazda 6

1802TRF 1802TRF 2018-02-13	Folksam ODB ODB Frontal Impact Test Euro NCAP 2014	Thatcham Research

Criterion	Driver SP 1 (H3)			Passenger SP 3 (H3)		
Head & Neck			4.000			4.000
Head						
HIC 36	476.90		4.000	369.28		
Acceleration Resultant	144.61	g		49.48	g	4.000
3ms cumulative	51.65	g	4.000	47.68	g	
Neck						
Shear Force Fx+	0.10	kN	4.000	0.09	kN	4.000
Shear Force Fx-	-0.40	kN	4.000	-0.83	kN	4.000
Tensile Force Fz+	1.29	kN	4.000	1.25	kN	4.000
Extension My-	-10.26	Nm	4.000	-15.38	Nm	4.000
Chest			3.911			3.643
Deflection	-22.62	mm	3.911	-24.50	mm	3.643
VC max	0.07	m/s	4.000	0.08	m/s	4.000
Diagonal belt upper force	5.69	kN		5.75	kN	
Knee, Femur & Pelvis			3.400			4.000
Left						
Femur Force Fz-	-1.09	kN	4.000	-0.51	kN	4.000
Knee Slider Displacement	-0.03	mm	4.000	-0.90	mm	4.000
Right						
Femur Force Fz-	-4.59	kN	3.400	-0.11	kN	4.000
Knee Slider Displacement	-0.18	mm	4.000	-1.76	mm	4.000
Tibia			0.978			4.000
Left						
Compression Upper Fz-	-2.43	kN	3.713	-1.51	kN	4.000
Compression Lower Fz-	-2.95	kN	3.367	-1.95	kN	4.000
Tibia Index Upper	0.51		3.511	0.20		4.000
Tibia Index Lower	0.50		3.556	0.23		4.000
Right						
Compression Upper Fz-	-3.38	kN	3.080	-1.42	kN	4.000
Compression Lower Fz-	-3.76	kN	2.827	-1.83	kN	4.000
Tibia Index Upper	1.08		0.978	0.40		4.000
Tibia Index Lower	1.03		1.200	0.27		4.000
Sum			12.289			15.643





only modifiers from ATD data are included

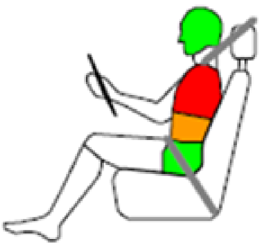
Points
- ★ 4.000
- ★ 2.670 - 3.999
- ★ 1.330 - 2.669
- ★ 0.001 - 1.329
- ★ 0.000

Mazda 6 64.08 km/h 1621 kg Driver Left	**Results Occupants** Front Vehicle 1	Laboratory: Thatcham Research Contact: Tom Leggett Customer: Folksam 5/92

Appendix 5 – Mazda 6 side impact

1801TRS Laboratory Test Ref. No. 1801TRS Customer Test Ref. No. 2018-02-15 Date of Test	Type of Test Regulation	**1801TRS** **Side Barrier Impact Test** **Euro NCAP 2015**	Thatcham Research

Criterion	Driver SP 1 (E2)				
Head			4.000	★	
HIC 36	83.16		4.000	★	
Acceleration Resultant	32.53	g			
3ms cumulative	31.46	g	4.000	★	
Chest			0.000	★	
Deflection					
Upper	19.83	mm	4.000	★	
Middle	29.86	mm	2.428	★	
Lower	36.99	mm	1.002	★	
VC max					
Upper	0.16	m/s	4.000	★	
Middle	0.47	m/s	3.118	★	
Lower	0.83	m/s	1.000	★	
Backplate					
Force Y	2.78	kN	-1.187	!	
Spine					
Spine					
T12 Force Y	1.48	kN	0.000	✓	
T12 Moment X	-70.79	Nm	0.000	✓	
Abdomen			1.520	★	
Sum Force	1.93	kN	1.520	★	
Pelvis			4.000	★	
Pubic Force Y	-2.79	kN	4.000	★	
Sum			9.520		



only modifiers from ATD data are included

Points
- ★ 4.000
- ★ 2.670 - 3.999
- ★ 1.330 - 2.669
- ★ 0.001 - 1.329
- ★ 0.000

Mazda 6 0 km/h 1499.5 kg Driver Left	50.18 km/h 958 kg	**Assessment Occupants** Front Vehicle 1	Laboratory: Thatcham Research Contact: Tom Leggett Customer: Folksam 6 / 46