The ageing of safety barriers.
Functional limits for safety barriers that deviate from the nominal in height and/or perpendicular position

Issued by: Göran Fredriksson, BARRIER TECH AB

Date: 2013-03-28 Report number:1301-1

Ordered by: Hans Holmén, Technical Specialist. Swedish Transport Administration

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Vägutrustningars åldring, funktionella gränser för vägräcken som avviker i höjd och/eller lutning.

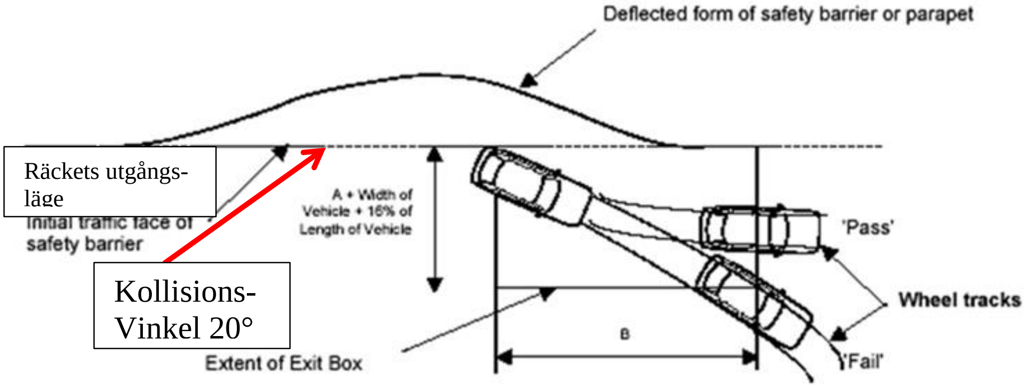
Rapport nr: 1301-1

Sammanfattning

Med tiden så hamnar vägräcken ofta betydligt lägre än den ursprungliga nominella montagehöjden, även en tilltagande lutning utåt från vägbanan är vanlig. Dessa avvikelser kan dessutom vara kombinerade på ett för räckesfunktionen än mer ogynnsamt sätt.
Avvikelserna kan uppkomma av flera orsaker:

- Ny beläggning ovanpå den gamla som höjer nivån på vägbanan i förhållande till vägräcket
- Sjunkning och/eller sättningar
- En kombination av ovanstående
- Vägkroppen trycks ut åt sidorna med tiden och ståndarna följer med
- Påkörningar och snötryck från plogning vintertid
- Tjällossning och liknande

Driftavtal anger idag gränser för när korrigerande åtgärder ska sättas in, frågan är dock hur korrekta dessa gränser är och vad händer med räckets funktion bortom dessa gränser? ? Vägutrustningars åldring i allmänhet, och i synnerhet den gradvisa försämringen av funktionen som följer, är en viktig angelägenhet för väghållaren. Av den anledningen startades ett projekt i syfte att undersöka hur ett väl beprövat och vanligt förekommande räcke skulle uppföra sig gentemot förväntad funktion om det medvetet monterades med bestämda avvikelser från nominella mått avseende position. Utifrån detta beslutades att genomföra fullskaleprov med samma förutsättningar som i ett TB 32 prov enligt SS-EN 1317-2, se figur 1 och 2, men utan krav på mätning av arbetsbredd och ASI. Det vanliga W-profilräcket med 3 mm tjock horisontell profil och c-c 4 m (vanligen betecknad EU4), valdes att representera genomsnittsräcket på det svenska vägnätet .



Figur 1. Kollisionsprov enligt EN 1317. Exit box och godkänt eller underkänt anpassades till projektets krav.

Figur 2. Test fordon vid kollisionspunkten med 20° angreppsvinkel innan kollisionstesten genomförs.

Godkänt eller underkänt kollisionsprov baseras endast på om fordonet kör över räcket, voltar eller beter sig på något annat uppenbart trafikfarligt sätt.
I syfte att kunna besluta om de inledande räckespositionerna för test användes datasimulering för att finna ut var gränserna verkar gå. Beroende på det verkliga utfallet i fullskaleprovet bestämdes sedan hur provserien skulle fortsätta. Projektets budget tillät totalt 8 kollisionsprov och inga prov på andra typer av räcken, t ex lin- eller rörräcke var möjligt.
För ett räcke som monterats för lågt men fortfarande lodrätt, var det ganska enkelt att fastställa den funktionella gränsen till ca 450 mm (till W-profilens horisontella centrumlinje) något som även överensstämde med vad som tidigare simulerats och som anges i driftkontrakten från Trafikverket.
Detsamma kan sägas för räcket som testades med lutning utåt från vägbanan men med fullt stolputstick, simuleringsresultatet och fullskaleproven visade i båda fallen att gränsen för lutning går vid ca 30˚ innan fordonet kör över räcket.
När lågt räcke kombinerades med samtidig lutning visade det sig att man åstadkommit något mycket oförutsägbart och farligt. Datasimuleringen gav varierande resultat som indikerade att räcket inte var vare sig stabilt eller förutsägbart vad gäller funktion. Detta visade sig stämma väl överens med utfallet i verkliga prov. Fyra kollisionsprov behövdes innan det kunde fastställas en position där räcket höll tillbaka fordonet, men även i detta fall uppförde sig bilen på ett icke acceptabelt sätt. Fordonet voltade med räcket monterat med endast 50 mm reducerat stolputstick och en lutning på måttliga 9˚!
Resultaten från kollisionsproven visar tydligt hur viktigt det är att justera läget på räcken som har felaktig position och att en kombination av lågt räcke som dessutom lutar snabbt blir farligt och oförutsägbart.
Ett räcke som inte blir justerat när det passerat dessa funktionella gränser bör avlägsnas då det i annat fall ger en falsk känsla av säkerhet, samtidigt som det kan förvärra utgången av en kollision då bilen kan få en rampeffekt och volta istället för att köra av vägen med hjulen fortfarande mot marken.
Med denna kunskap rörande EU4 räcket är det nödvändigt att finna samma funktionella gränser även för andra typer av räcken så som linräcke, skiljeräcken med stålprofil och rörräcken. Projektet visar att det finns goda chanser att finna dessa gränser m h a verifierad datasimulering som visat sig ge resultat som ligger väldigt nära de som verkliga fullskaleprov också visar, men till en betydligt lägre kostnad.

Summary

It is a known fact that over time safety barriers tend to be positioned lower than their nominal height over the road surface. This height deviation is sometimes combined with the posts leaning outwards from the roadside. The causes of this are typically:

- Gradual lowering of the barrier as the posts gradually sink deeper into the soil.
- New paving being performed on the road with no corresponding height adjustment of the safety barrier.
- A combination of the above.
- Tilting outwards can be caused by frequent pressure from snow removal operations.
- Light, narrow angle collisions.
- “Flattening” of the soil under the road pressing it out towards the sides.

Maintenance contracts calls for corrective action, but are the current given limits where this action has to be activated really correct and what happens to the barrier functionality beyond the limits for repair or restoration of safety barriers stated in the maintenance contracts?
The ageing of road equipment in general and particularly the functional degrading of road barriers is a main concern of the road owner. Therefore a project was launched in order to investigate an established and common longitudinal barrier with pre-fabricated deviations compared to its nominal position and functionality. As a consequence it was decided to do full scale tests using the same set-up as for the TB32 tests according to SS-EN 1317-2, see figure 1 and 2 below, but excluding measurement of working width and ASI. The “standard” W-profile with sigma posts at 4 m spacing (known as EU4) was used to represent the common longitudinal barrier.

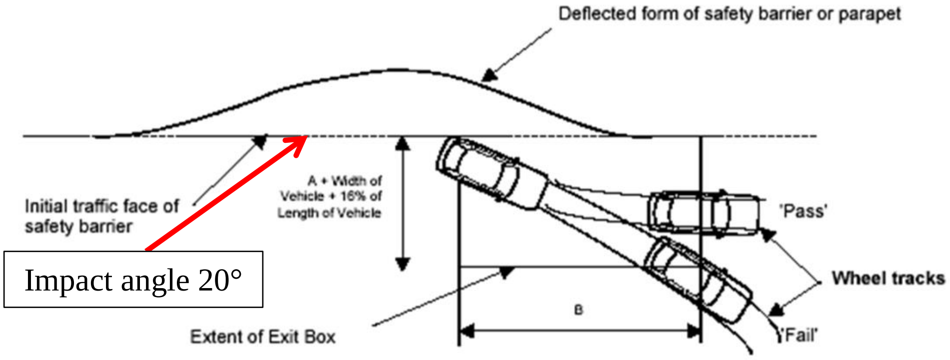


Figure 1. Test set-up as described in EN 1317. Exit box and pass or fail as shown above was modified for the project.

Figure 2. Test car at impact point using the 20° approach prior to collision test.

Pass or fail would be based only on override of barrier, vehicle roll over any other hazardous behavior.
To decide on initial positions to be tested, computer simulation was used to find out where the limits seemed to be. Depending on outcome in reality it was then decided how to proceed. Project budget allowed for a total of 8 collisions and no tests on other types of barriers such as wire rope or tubular profiles.
For a barrier that was mounted too low but still vertical it was relatively easy to establish the functional limit, approx. 450 mm (to horizontal centerline of the W-profile) which also corresponded to simulation results as well as current Swedish Transport Administration, regulations in maintenance contracts.
The same can be said for a barrier at an inclined position outwards from the road, but still with full post length above ground, where simulation and practice both indicated that an inclination angle exceeding 30° can cause override.
The combination of low position and inclination however proved to be a very dangerous and unpredictable. Simulation results indicated that the barrier was not robust and predicable in behavior. In practice it was also evident that this was the case. 4 collisions had to be used to finally establish the point where the barrier retained the vehicle, but even in doing so it caused roll over in a way that is not acceptable. This roll over came at a post protrusion only 50 mm below nominal height and a tilt angle of only approx. 9°!

The results from the test clearly show the importance of correcting barriers that are out of position and that a combination of low position and inclination very soon becomes hazardous and unpredictable.
A barrier that cannot be adjusted when it has passed the functional limits should be removed as it otherwise gives a false sense of safety and can cause more damage on impact than letting the vehicle go off the road while still on its wheels.
With this knowledge of the EU4 barrier it would be necessary to establish the same kind of functional limits also for other types of barriers such as wire rope, steel box beam and tubular profiles. The project shows that this can be done with verified computer simulation providing results that reflect real collision outcome in a reliable way at a considerably lower cost than crash tests.

1. Background

1.1 General requirements on safety barriers

Vehicle Restraint Systems, VRS, are required to be CE marked and as from 1st of July 2013 this is also a legal requirement. CE-marking of construction products is obtained by the fulfillment of certain requirements. These requirements are set down in a harmonized standard related to the specific product and its intended use. The requirements for vehicle restraint systems are set down in the harmonized standard EN 1317-2, which consists of 15 steps, each and every with raised demands on containment of vehicles (containment levels), from the smallest 900 kg passenger car to, at the other end of the scale, a 38 ton semitrailer HGV. More about the origin of the European 1317-series of standards can be found in appendix 1.
In Sweden, the responsible road authority the Swedish Transport Administration has chosen the containment level N2 as a basic requirement for most rural roads. The level N2 is tested with a 1500 kg passenger car vehicle travelling at 110 km/h into the barrier under test at an angle of 20 degrees. (The specific test is given the name TB32 inside the document EN1317-2, which is why it is often referred to as a TB32 test.) The barrier shall contain and redirect the vehicle, with certain restrictions on the accelerations measured inside the vehicle, restrictions on the deflection and strength of the barrier as well as some restrictions on the vehicle behavior during and after contact with the barrier. Given that all recently installed barriers (at least most) are tested according to this N2-level of EN1317-2, it was for this project an opportunity to use that particular test as a kind of starting point or calibration point, making reasonable variations from that tested and approved configuration.

1.2 Deviations from original barrier position

Safety barriers that are erected along the road side have a life span that varies depending on different factors such as:

- how frequent they are hit
- where they are placed geographically from a corrosiveness point of view
- how soon they become technically obsolete.
- in which soil conditions they are placed and gradual changes in these conditions

Safety barriers typically require very little maintenance during their service life. Apart from occasional cleaning the most common measure is adjustment of barrier position as it has shifted over time compared to the original values for height and inclination.
Height deviations are caused by gradual sinking into the soil and/or new paving being performed. Inclination is usually the result of forces from snow removal, light impacts from vehicles and/or the road flattening out whereby the soil is pressed outwards.

Contracts for road maintenance have limits for minimum height and max inclination before corrective action has to be taken. The current demands are: “centerline of horizontal beam on a safety barrier must be a minimum of 45 cm and a maximum of 65 cm above the road surface. The post must not be leaning more than 5 cm from a perpendicular position on class 1- 3 roads and not more than 10 m from a perpendicular position on class 4 – 5 roads. Measurement of how much it is leaning is done one at the top of the post”.

How accurate are these limits and what happens when they are passed?

Little is known about the combined deviation of low position and inclination. When does the functionality of the barrier change from retaining the errant vehicle to instead posing an additional hazard in the same case?
The Swedish Transport Administration had decided to allocate funds to a project with the aim to study behavior and functional limits of safety barriers deviating in position due to ageing.

The project was initiated in May 2012 and crash tests completed at the end of September. Project participants were: the Swedish Transport Administration (Project control), Barrier Tech AB (Management & co-ordination), DYNAmore Nordic AB (Simulation), the Swedish National Road and Transport Research Institute, VTI (Crash testing) and Dahlströms Smidesverkstad AB (barrier installation).

2. Project set-up

To be able to compare the results from collisions with a barrier out of position to those initially performed as part of the ITT it was decided to replicate the original test set-up for the project collisions. The barrier chosen was the common and well known W-profile (A-profile) as it was originally tested by the Swedish Road Administration in 1995 at VTI. Profile thickness is 3 mm with 4 m post spacing, known as EU4. It is decided to use the TB32 run according to SS-EN 1317-2, i e 1 500 kg car, 20° angle and speed 110 km/h.
Length of barrier 76 m full height (nominal 550 mm, see fig. 1 below) and 2 x 12 m sloped anchored terminals.
Point of impact is 20 m from end of barrier as in the original tests.

Ideally the set-up and barrier positions chosen should result in 6 collisions needed to determine the critical values for barrier position:

1. Low barrier able to re-direct the vehicle
2. Low barrier not able to contain the vehicle or resulting in other hazardous behavior of the test vehicle.
3. Tilted barrier able to re-direct the vehicle
4. Tilted barrier not able to contain the vehicle or resulting in other hazardous behavior of the test vehicle.
5. Low and tilted barrier able to re-direct the vehicle
6. Low and tilted barrier not able to contain the vehicle or resulting in other hazardous behavior of the test vehicle.

It was however not expected to be able to pinpoint the limit positions for all six cases at the first attempt so the need for additional collisions was foreseen. Project budget allowed for a total of 8 tests.
It was decided to exclude measurement of impact severity as it is not a part of the pass or fail criteria as stated above. That decision would also help in keeping costs down as well as reducing preparation time in between collisions.

3. Computer simulation

The summary below is based on the report from Dynamore Nordic AB, Doc.no 120391, rev 2, project no. E12039, which is enclosed in full as appendix 2.

3.1 Pre-simulation planning

Results from original tests performed in 1995 was used to validate the simulation model of the EU4 barrier used in the project to find the critical pass or fail positions.
A total of 40 simulations were performed (more than anticipated) by Dynamore Nordic who decided to do additional simulation runs at their own expense to gain more knowledge.
The simulation of collision results is necessary to be able to determine in theory where the functional limits of the barrier are and from that decide on the test positions. As the project budget allowed for a maximum of 8 tests to establish the real limits, reliable simulation results were crucial to be able the right decisions regarding the barrier positions to be tested.

Barrier position was defined as shown in figure 3 below.

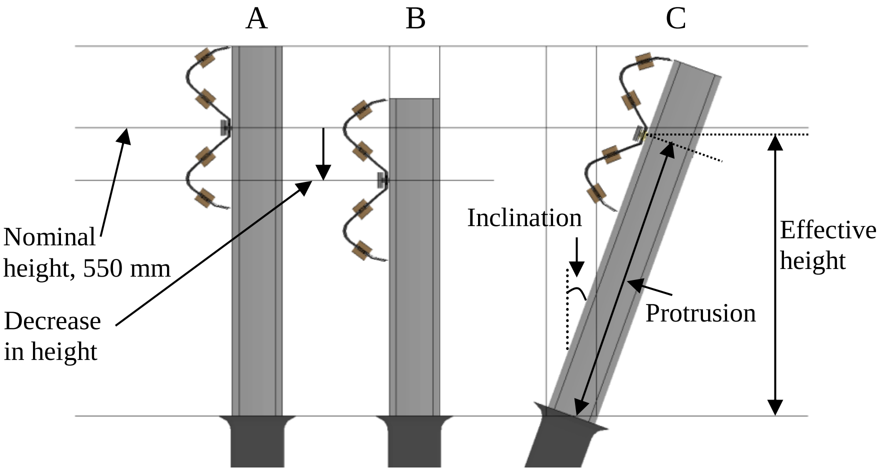


Figure 3. Description of the parameters in the parameter study.

The term “effective height” was established by the project team to describe the perpendicular distance between the centreline of the horizontal beam and ground level when the barrier was mounted with an inclination and variation in protrusion. In figure 3, barrier position C above, this is illustrated. The term is useful as a reference to compare height of centreline when the barrier is in a perpendicular position to the height achieved with the barrier at an inclined position and different post protrusions.

3.2 Simulation results

During simulation the pass criteria was that the barrier contained and redirected the vehicle and fail that it overrode the barrier. The case of the vehicle rolling over after impact was not included although this tendency could be seen in some cases.

The results from the simulations showed that a barrier mounted too low but perpendicular ceased to contain the vehicle at a height of 450 to 400 mm which is a 100 to 150 mm lower than nominal.
Simulation of an inclined barrier indicated that when approaching 40° angle the limit for pass criteria was exceeded.
However when inclination and low position was combined in the simulation then it was not that clear where the critical position was. A deviating point appeared among the “pass-points” and it was uncertain why this occurred, but it indicates that the barrier behavior is not robust in the sense that it is at, or close to the limit where it cannot any more reliably uphold its function.

Simulation points and their outcome as pass (green) or fail (red) is presented in figure 4:

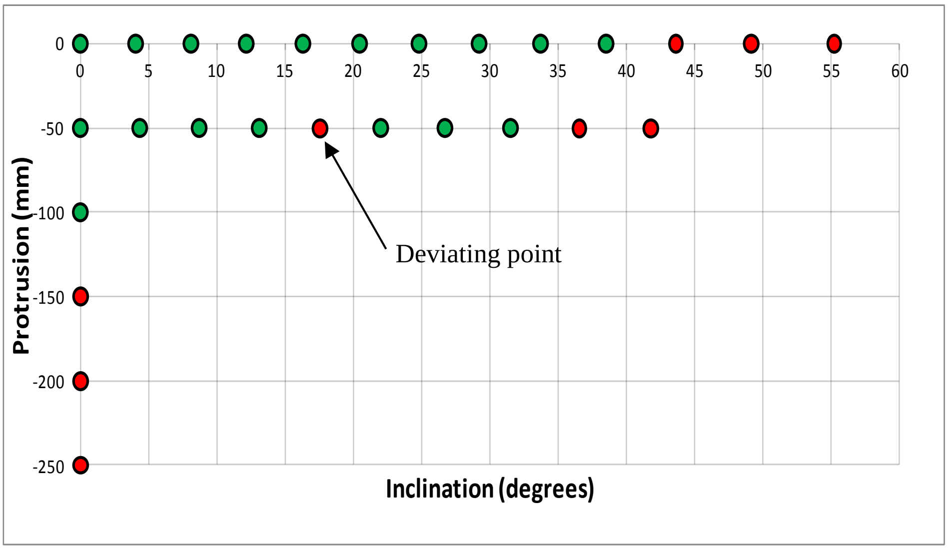


Figure 4: Parameter study results.

4. Crash test set-up

4.1 Crash test planning

Based on the results from the computer simulation the project team decided to start the test series on a straight barrier in perpendicular position with decreased height.
First test was decided to be for a post protrusion of 450 mm. Depending on the outcome (expected to pass) of that collision the second test would be:

- Pass = lower barrier 50 mm to 400 mm (fail expected)
- Fail = Increase post protrusion to 500 mm (pass expected)
- If expected outcome is not fulfilled the barrier will be lowered or raised another 50 mm until the desired result is achieved.

Once these limits had been established the next step would be to test a barrier with inclination and full post protrusion but inclined until the effective height (see fig. 1) was the same as fail height for previous tests with a low barrier.
From there it was decided to meet up in the project team after each collision to plan and decide on barrier position for the next crash test as the outcome would form a basis for deciding on new barrier test position.

The installation crew would be given a simple drawing showing the position of the barrier to be erected for the test to come and some measurements that could be checked in a convenient way, also in practice.

4.2 Erection of test barriers

There are a number of possible ways to carry out the installation that had to be decided up on, these were:

- Installation should contain “slack” to simulate a real installation. Meaning that the profiles are not pulled apart before tightening the screws at the joints.
- Anchoring of the barrier at the ends are done in an ordinary straight position as these should not be the cause of failure and the barrier can be gradually incloined anyway to the desired position. It would also save doing the anchoring all over again before each test run.
- Holes were punched at the desired angle instead of the post being pushed sideways whilst still in the ground until the inclination angle was achieved.

The installers were given a simple drawing of the barrier position clearly showing some “practical” measurements that could be checked during installation work to make sure it the right position was achieved. The crew decided then on the method to be used for erection as well as how to perform final inspection of measurements.

Installing a barrier at almost 45° angle is not a straight forward everyday job, but due to the ability of the machine to tilt the punch it could be achieved with relative ease.

Below are some photos showing the installation.

Punching of holes for an inclined barrier.


Post inserted

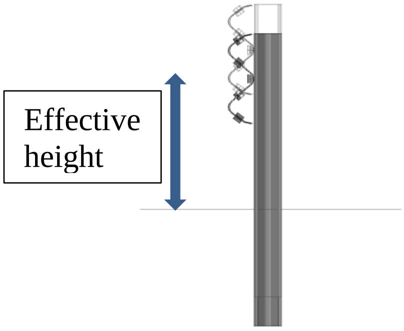

Final result

4.3 Pass or fail criteria

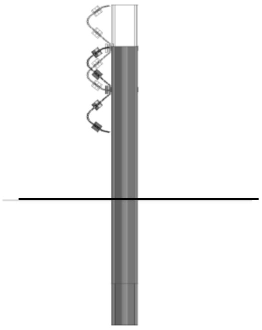
Each simulation was studied and categorized as “fail” or “pass”, where “fail” means that the vehicle passes over (overrides) the barrier. The simulation ended approx. where the far side of the exit box acc. to EN 1317-2 would be situated.
During the real test collisions the full duration of the impact is to be included and vehicle roll over would mean fail, just as it would at an ordinary ITT.

4.4 Tested safety barrier positions

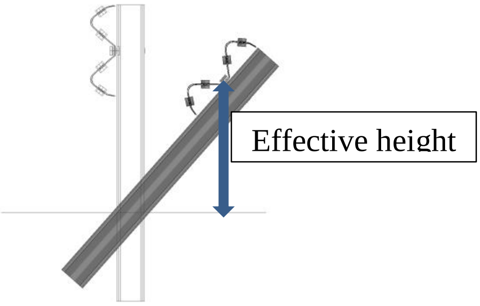
The collision tests are shown in the order in which they were performed in the figures below, were the correct nominal position of the barrier is also indicated as a reference:



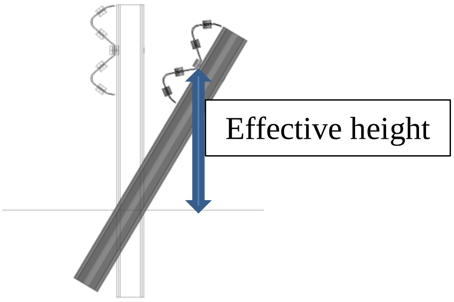
Test 1: Post protrusion decreased 100 mm, perpendicular position. Compare effective height to that shown in test 3 below.



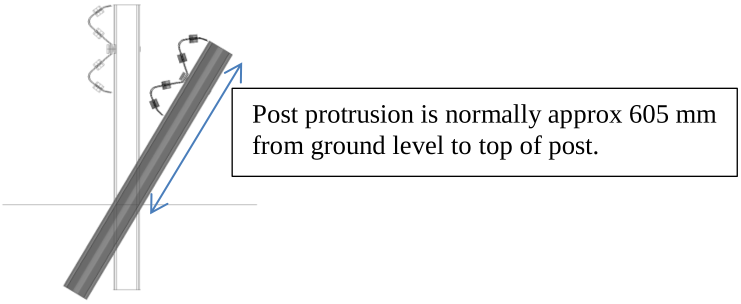
Test 2: Post protrusion decreased 150 mm, perpendicular position


Effective height

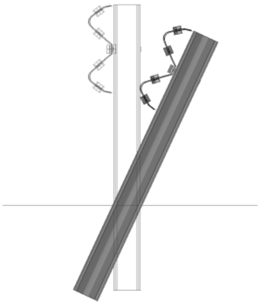
Test 3: Barrier inclination 41.5°. At this stage the term effective height was used, see also “3.1 Pre-simulation planning” earlier. It is 450 mm as illustrated above.


Effective height

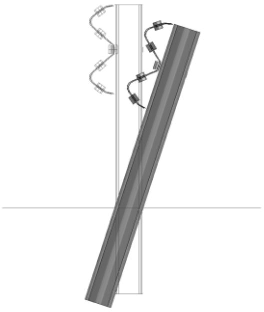
Test 4: Barrier inclined approx.30.8°, eff. height 500 mm


Post protrusion is normally approx 605 mm from ground level to top of post.

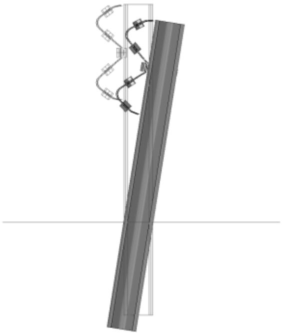
Test 5: Inclination of barrier, approx. 30.8 °, is combined with a reduced post protrusion of – 60 mm.



Test 6: Inclination approx. 25°, post protrusion – 50 mm.



Test 7: Inclination approx. 18°, post protrusion – 50 mm.



Test 8: Inclination approx. 9°, post protrusion – 50 mm.

Below, in figure 5, the actual positions tested and the order in which they were performed are shown on a chart.

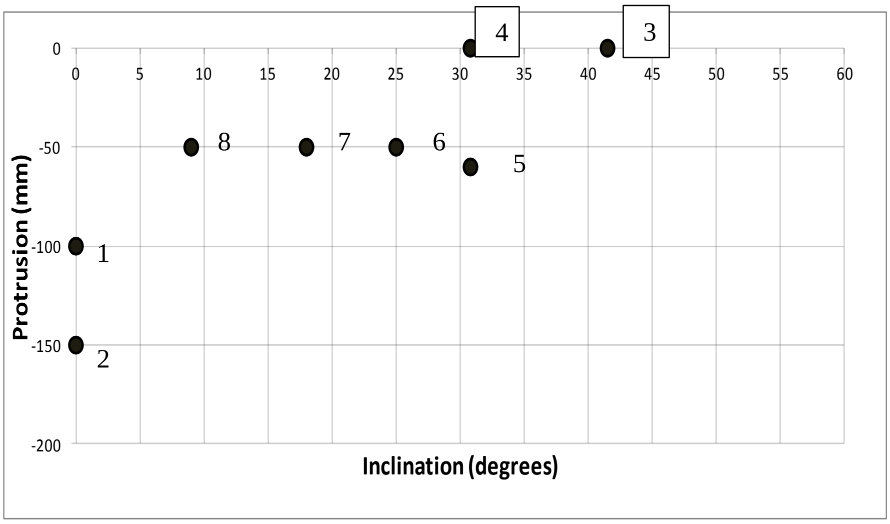


Figure 5, Tested barrier positions, numbered in the order they were performed.

It is evident, that when only height or inclination was tested it took only two impacts to establish limits between pass or fail whereas the combination of the two parameters was not entirely clear even after 4 impacts. This is because even at 50 mm decreased post protrusion and approx. 9° inclination the test vehicle rolled over in a manner that is not acceptable, although still on the “right” side of the barrier as it did not override, see 4.5 Results of crash tests.

4.5 Results of crash tests

The results from the crash tests are presented in full, with photos, in the report from VTI enclosed as Appendix 3.

Figure 4 below shows the outcome of the crash tests in the same type of chart as previously presented. Green points mean pass and red points fail. The yellow point also represents fail, but then due to the vehicle not overriding barrier but rolling over after impact instead.

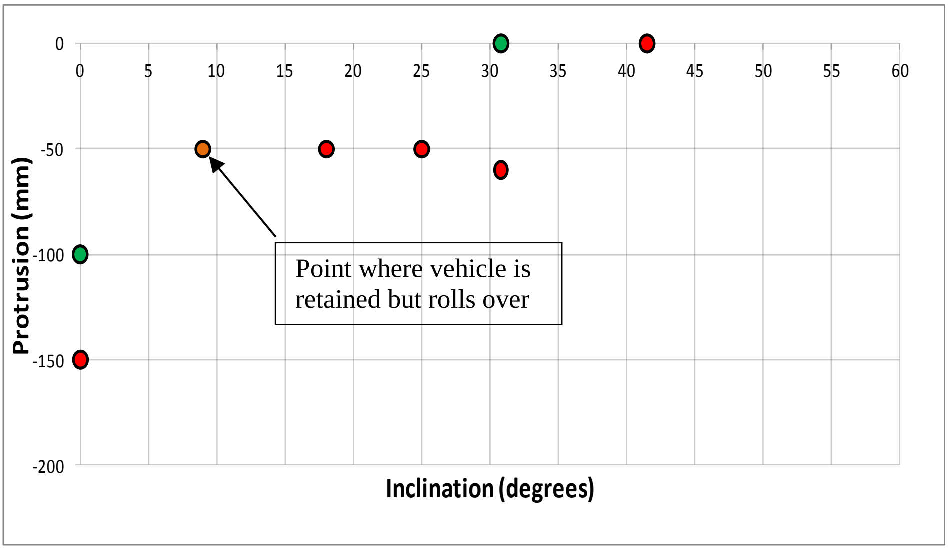


Figure 4, results of crash tests. Pass = green, fail = red or yellow.

The results and knowledge from the crash tests are expected to constitute a good basis for further simulations. This could be for instance using a heavier vehicle and/or higher such as the SUV type of car in a collision, impacting the barrier at say a 5° angle.

5. Evaluation

The series of crash tests that were performed proved to be very informative as to the functional limits of the safety barrier, but they also raised some new questions, such as:

- How representative are these collisions compared to a typical real life situation where a vehicle collides with a safety barrier?
- How would a heavier more common vehicle behave? Assuming a weight of say 1700 kilos and a speed of 90 km/h as an average in today's traffic.
- Are there other points of impact on the barrier that would give even more overrides? Simulations indicate that there are more unfavorable collision points than the one chosen here with the intent to copy the original test situation.
- Are these tests on the W-beam representative for similar positions and corresponding vehicle behavior on other barrier types such as wire ropes or tubular safety barriers?

The tests were performed on a barrier with a post that was a straight steel profile but mounted at an inclination, as it is not bent it means that it has no pre-deformation at ground level that could affect the result further in a negative way. A barrier with an inclination in a real situation could very well already have a slightly bent post caused by an earlier light impact or snow removal. If this is the case it can be assumed to contribute to the barrier failing even earlier as initial resistance to bending has been reduced.

6. Conclusions and recommendations

There are some conclusions that can be drawn with confidence and some that are more speculative and would possibly require more investigation to be verified.

The more certain conclusions are:

A. Lifelike computer simulation of the type used in this project, validated against real test conditions, is a powerful and reliable tool to predict behavior of a barrier, even in extreme positions.

B. A safety barrier at an inclined position outwards from the road, combined with reduced height, very soon becomes unsafe and is prone to overrides as well as sending a colliding vehicle rolling over. The effective height resulting from this combination of positional deviations is a very important parameter when deciding on the functionality of a barrier.

C. A safety barrier that has been allowed to reach deviating positions well below the limits observed in these tests creates a hazard rather than providing safety. If they are not adjusted it is better to have them removed as a vehicle is likely leave the ground and/or roll over when impacting instead of going off the road while still on its wheels.

D. Contracts for road operation and maintenance should clearly state the positional limits for the barriers before which corrective action has to be taken and the frequency in which safety barriers are to be inspected.

E. A modern vehicle such as a SUV would cause the barrier to fail at an even earlier stage due to the higher weight combined with a higher center of gravity.

Looking at the experience gained from the collisions, modern vehicles, status of existing safety barriers and real traffic situations the following conclusions can also be drawn:

a. Existing safety barriers mounted along our Swedish roads are many times erected in soil that is inferior (looser/softer) compared to the soil at VTI and often also mounted with insufficient ground support behind the posts. This may further contribute to a “fail” situation during impact and corrective action needs be taken at an even earlier stage, which could mean an all new installation.

b. The results from the tests carried out indicates that it would be better to mount the W-barriers at the continental height which is some 50-60 mm higher than the Swedish standard (550 mm from ground to centerline of W-beam). This would prolong the time before the functional limits are reached and barriers would also be more adapted to modern vehicles with higher center of gravity.
c. Snow removal not only contributes to the forces that make the barrier starting to be tilted away from the roadside but also deforms the W-beam profile itself. The deformation that is considerable in places, see photo below, is yet another factor that would make barrier behavior even more unpredictable when combined with a deviating position. A longer distance than the commonly used 50 mm between paving edge and barrier front to roadside would reduce the forces and damages from snow removal to the benefit of barrier function as well as general lifetime expectancy.

Examples. W-profiles deformed from snow removal.

Recommendations.

From the results of the impacts it is obvious that there are limits in deviation from original position that transforms the barrier from being a safety device to being quite the opposite. How do we best use this knowledge in practice?
First it is clear that there will always be deviations from the nominal position on site. They could be marginal but they will always be there. The supplier also states tolerances to be met during assembly so that the barrier can be expected to perform as intended.
These tolerances are there to be maintained during the life time of the barrier under normal circumstances. However, there are safety barriers that have been allowed to end up in

positions far from the stated tolerances (if any were given at the time of installation) and also barriers that have been damaged from collisions and/or snow removal.
The following applies to these latter cases and can be regarded as a way to put priority on corrective action as well as for deciding on what measures to take.

First, how certain are we that the functional limits from the tests are “correct” and apply also to real traffic situations?

There are a number of reasons to argue that the limits observed in the tests should be “adjusted” in one direction or another.

Examples of “forgiving” arguments:

- Real impacts (at least the initial one) are usually at a more narrow angle than 20°
- Many impacts occur at lower speeds than 110 km/h.
- The driver can influence the outcome of the impact in a positive way.

Examples of “harsh” arguments:

- The average new car sold weighs more compared to the test vehicles 1500 kg.
- There are many vehicles with a higher center of gravity and more unfavorable geometry such as higher ground clearance.
- Real life conditions could mean loose soil and insufficient support of the posts.
- The barrier could also be deformed in different ways in addition to being in a deviating position.
- In real accidents, the non-tracking impacts of vehicles on slippery roads are not at all addressed by the test procedures of EN1317-2. Rotation and translation speed as well as undefined (maybe steep) impact angle calls for rather strict acceptance criteria for a barrier and for the related maintenance criteria for the same.
- Why should demands in terms of safe function on an already installed barrier be less than if it was newly installed?

All in all it is the very last argument above that should guide the recommendations made, together with a consideration of the actual road and its speed limit. After all kinetic energy does influence the outcome of a collision and if it is highly unlikely that a colliding vehicle would reach speeds above 80 km/h (where the kinetic energy is nearly half of that at 110 km/h) it can also be said to be a reasonable ground for lower priority on corrective action to be taken and wider functional limits.

Based on experience gained from the tests performed and their results as well as the reasoning above, it is recommended that:

I. Contracts for operation and maintenance of roads are to include limits for corrective action as stated below:

Planned maintenance action required.

- ✓ HEIGHT: Barrier minimum height at which height adjustment should be done is 450 mm to centerline of horizontal profile(s). Barrier vertical, max 4° deviation.
- ✓ INCLINATION: Maximum inclination of barrier is 15° from roadside with full protrusion of post (= nominal as given from manufacturer) measured from ground level. (15° is chosen due to the difficulty in determining full protrusion which also can be combined with other factors affecting the outcome of a collision in a negative way).

Immediate action required.

- ✓ A barrier height of 400 mm from ground to centerline of horizontal profile(s) must be adjusted without further delay or removed. Barrier vertical.
- ✓ A barrier inclination of 35° from roadside with full protrusion of post is to be adjusted without further delay or removed.
- ✓ Decreased post protrusion exceeding 50 mm combined with tilting 5° outwards from roadside is to be adjusted without further delay or removed.

These are general guidelines for all barriers on roads with a speed limit of 80 km/h or more, unless the supplier of the barrier in question has stated otherwise.
Information about these limits and the measures to be taken are to be informed nationally to all road maintenance districts when official.

II. If new paving of a certain height is done on top of the existing layer, a corresponding adjustment of barrier height is performed as a routine measure at the same time.

III. Suppliers of other types of safety barriers simulate performance (acc. to applicable containment level from EN 1317-2) of their barrier when it is in a combined position of tilting and decreased height to determine the functional limits. Both in terms of when corrective action should be taken as well as when the barrier no longer will contain the vehicle. These limits are to be included as part of the general product information.

IV. An instrument intended for road side use to perform reliable and efficient checks of barrier position (indicating: OK – adjust - danger), is developed.

V. Further testing with a modern car representative for the vehicles on the roads today is carried out. Minimum 2 tests, “1317-impact, TB 32” on a low, inclined barrier (-50 mm, 9°) and a more common impact angle of 5-10°.

VI. Testing the standard EU4 barrier, TB 32 impact, but mounted 55 mm higher than the nominal 550 mm (continental std. height).

VII. Testing of the recommended functional limits for a straight barrier but with the barrier mounted as an outside curve instead with a “typical highway radius”.

Västerås 2013 – 03 – 28

Göran Fredriksson
Barrier Tech AB

APPENDIX 1.

EN1317 crash test procedure for Vehicle Restraint Systems – a short background;

The American crash test procedures for roadside equipment, the report NCHRPR 230 (National Cooperative Highway Research Program Report), was published in March 1981. An update, NCHRPR 350, was published in 1993.

In April 1991 there was a meeting in Bron in France, the first meeting of CEN/TC226/WG1, where the work of writing a similar European test- and classification standard for Vehicle Restraint Systems, VRS, was initiated. The work was inspired by what was achieved in the US. The first European version was published 1998 and was given the name EN1317. The work is closely related to requirements defined by the demands of the Constructions Product Directive 89/106/EEC. This document is more about the classification of products and to tear down trade barriers in the European Union. Can probably best be described as an encyclopaedia of performance parameters, making it possible to understand and request a certain performance on a uniform and common basis.

The various parts of EN1317 do cover barriers, barrier terminals, crash cushions, transitions and removable barrier sections. Additional there is yet not finished parts, part 6 and 8, covering yet optional pedestrian parapets and motorcycle protection systems.
EN1317-2 is the document dealing with test of barriers. There is no difference in a bridge parapet, a median barrier or any barrier positioned on the verge of a road in respect of test procedure. It is just an impact test to show the functionality of the barrier. Somewhat simplified, EN1317 consists of 15 steps, each and every with raised demands on containment of vehicles, from the smallest 900 kg passenger car to, at the other end of the scale, a 38 ton semitrailer HGV. Testing has nothing to do with the final use of the barrier, the final installation etc. Testing is just a way of showing the product functionality in a given situation. Objective testing is to keep control over all parameters that could influence the outcome and isolate those factors that can be said emanating from the product under test. This calls for the test laboratory to keep close control of the vehicle mass, the vehicle inspect speed, the vehicle impact angle, the flatness and smoothness of the test surface, control of the installation soil and also full control of the evaluation process of the product, ensuring equal and objective results giving equal performance and functionality.

By negotiations between traffic safety experts, a kind of typical representative test situation, still possible to reproduce, has been agreed upon. This test situation or “accident” is constructed to cover the majority of the most probable impact situations, but will still not be a worst case scenario. (A worst case scenario would be high speed, steep angle, high vehicle mass, high centre of gravity etc.) It is better to think that this is more of a typical accident, but turned more to an aggressive side of the average accident scenario.)

To be able to objectively evaluate the impact test scenario, it is also crucial to understand that certain parameters are excluded, even though the traffic safety experts do understand that such parameters in reality does influence traffic safety. Examples of such deliberately excluded parameters are slipper winter conditions, frozen ground, non-tracking impacts, vehicles with variation frontal structure and/or variation in centre-of-gravity height. The installation parameters are as well excluded, the barrier is always tested as a short installation on a level flat ground, knowing that in reality barriers are installed on verges, in a bend, in a slope, near a ditch, in intersections (where steeper impact angle can be anticipated) etc.

The controlled, but at the same time slightly unrealistic impact test, is the only way to objectively ensure that good barriers are distinguished from bad barriers in a correct way.
In Sweden, the responsible road authority Swedish National Transport Administration, SNRS, has chosen the containment level N2 as a basic requirement for most rural roads. Level N2 is somewhere in the middle of the 15 step ladder of requirements. This does tell us that there are barrier with a higher capacity and there are barriers with a lower capacity. But the long term experience has shown that, for Sweden, the level N2 is a good compromise in most situations. On most bridges there are bridge parapets in containment level H2 installed, which is about 2 steps up the containment ladder.

The level N2 is tested with a 1500 kg passenger car vehicle travelling at 110 km/h into the barrier under test at an angle of 20 degrees. (The specific test is given the name TB32 inside the document EN1317-2, which is why it is often referred to as a TB32 test.) The barrier shall contain and redirect the vehicle, with certain restrictions on the accelerations measured inside the vehicle, restrictions on the dynamic deflection of the barrier and some restrictions on the vehicle behaviour during and after contact with the barrier.

Given that all recently installed (at least most) are tested according to this N2-level of EN1317-2, it was for this project an opportunity to use this test as a kind of starting point or calibration point, making reasonable variations from that tested and approved configuration.

APPENDIX 2

	Doc. no. 120391	*Revision* 2	*Project no.* E12039
	Approved by Dr Daniel Hilding	*Release date* Oct. 22, 2012	*Pages* 17

Author(s) Klas Engstrand	*Type* Technical Report
Prepared for Hans Holmén (the Swedish Transport Administration)	

Title

Calculation of impact on a safety barrier that is mounted with deviation in height and tilt

Summary

This report is part of a project funded by the Swedish Transport Administration where the functionality of ageing safety barriers is studied. Due to different reasons the height of an ageing barrier can deviate from the nominal, i.e. new installed, barrier. Typically the height of a barrier may decrease with time. In some cases a barrier may also start to tilt with time.

The functionality of ageing barriers is in this project studied by performing crash tests on a barrier that is mounted with various degrees of deviation in height and tilt. First, a significant number (~40) of calculated, i.e. FE-simulation, crash tests were performed. The primary aim of the simulations was to provide data/knowledge for the set up of a Design-Of-Experiments (DOE) for the subsequent physical crash tests. A total number of eight physical tests were scheduled in this project. It was crucial to create an effective DOE in order to be able to take maximum advantage of the relatively few physical tests.

It turned out that the DOE, based on data from the simulations, worked well for the physical crash tests. Critical tilt and height was determined with only four tests as hoped for. The combined “Decrease in height” and “Tilt” case was, as predicted by the simulations, more complicated.

This project has been rewarding. It has resulted in valuable knowledge. The work method used, i.e. to perform many relatively cheap simulations in order to decide a test matrix (DOE), which is able to take maximum advantage of the more expensive physical tests, has been shown to be very cost effective.

Contents

1 Introduction

This report is part of a project funded by the Swedish Transport Administration (TRV 2010/37107) where the functionality of ageing safety barriers is studied.

Due to different reasons the height of an ageing barrier can deviate from the nominal, i.e. new installed, barrier. Typically the height of a barrier may decrease with time. In some cases a barrier may also start to tilt with time.

The functionality of ageing barriers is in this project studied by performing crash tests on a barrier that is mounted with various degrees of deviation in height and tilt. First, a significant number (~40) of calculated, i.e. FE-simulation, crash tests were performed. The primary aim of the simulations was to provide data/knowledge for the set up of a Design-Of-Experiments (DOE) for the subsequent physical crash tests. A total number of eight physical tests were scheduled in this project. It was crucial to create an effective DOE in order to be able to take maximum advantage of the relatively few physical tests.

The simulations, which are described in this report, were performed by DYNAmore Nordic AB.

The participant in this project are the Swedish Transport Administration (steering group), Barrier Tech AB (management), DYNAmore Nordic AB (simulation), the Swedish National Road and Transport Research Institute (crash testing) and Dahlströms Smidesverkstad AB (barrier montage).

The crash test that is, in this project, simulated and subsequently performed physically is SS-EN 1317:1998 [4][5] test TB32, i.e. a 1500 kg car impacting the barrier at 20 degrees impact angle. The impact speed is 110 km/h.

The barrier that is studied is the formerly Swedish Road Administration standard barrier EU4 [6], which has a steel w-profile beam and a steel sigma-profile post. The posts are positioned four meter apart.

The computer simulation was performed with the FE program LS-DYNA [1]. The pre-processing was done with ANSA [2] and LS-PrePost [3]. LS-PrePost was used for the post-processing.

2 Simulation model

A simulation model was built of the test situation. The test installation includes the EU4 barrier and a test vehicle. Initial conditions for the vehicle is impact point, impact angel and impact speed. The blueprint for the model was the previously performed, by VTI in 1995 [7][8], EN 1317 N2 test of this barrier. The model was built in two versions where the only difference was the test vehicle, i.e. a TB11-version with a 900 kg car and a TB32 version with a 1500 kg car.

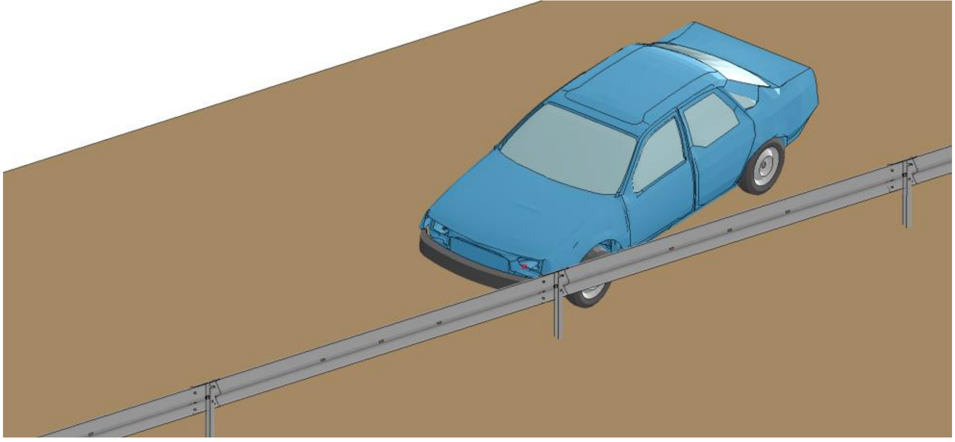


Figure 1: Simulation model of the test situation (TB32-version).

3 Validation of simulation model

The model was validated by simulating the two previously performed crash tests, in 1995 by VTI [7][8], and compare the results. The validation results are shown in Table 1and Table 2. Altogether, the simulations are estimated to agree well with the physical tests. The simulations can be seen in Appendix A and B.

Table 1: TB32-simulation and corresponding physical test

	Simulation	Physical test
Vehicle model	Ford Taurus (1991)	Volvo 244 (1976)
Total mass [kg]	1438	1438 [7]
Impact speed [km/h]	111	111 [7]
Impact angle [degrees]	20	20 [7]
Length of contact [m]	16	20 [7]
Working width [m]	1.5	1.7 [7]
ASI	0.83	0.63 [7]
THIV [km/h]	16.3	17.2 [7]

Table 2: TB11-simulation and corresponding physical test

	Simulation	Physical test
Vehicle model	Geo Metro (1997)	Ford Fiesta (1979)
Total mass [kg]	894	894 [8]
Impact speed [km/h]	107	107 [8]
Impact angle [degrees]	20	20 [8]
Length of contact [m]	12	12 [8]
Working width [m]	1.1	1.1 [8]
ASI	0.84	0.83 [8]
THIV [km/h]	18.3	22.3 [8]

4 Parameter study

The validated model, i.e. the TB32-version, has been used to perform a parameter study where the studied parameters are barrier "Decrease in height" and barrier "Tilt". Figure 1 explains "Nominal height" (A), "Decrease in height" (B) and "Tilt" (C). There is a forth variant for combinations of "Decrease in height" and "Tilt". The nominal height of the barrier, i.e. the distance between ground and the post-to-w-beam connection bolt is 550 mm, see A in Figure 2.

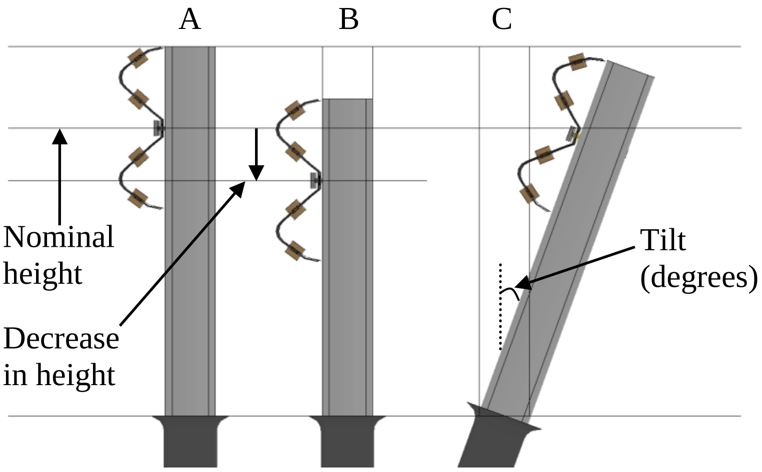


Figure 2: Description of the parameters in the parameter study.

The Design-Of-Experiments (DOE) for the parameter study is shown in and Figure 3. The DOE consists of 27 simulations. Each simulation was studied and estimated as "fail" or "pass", where "fail" means that the vehicle passes over (override) the barrier.

Remark: An additional ~15 (undocumented) simulations were performed in a pre-study phase in order to quickly investigate some aspects of the impact as for example the sensitivity to vehicle geometry as well as impact point. Those pre-study simulations were not included in the project plan but performed on our own initiative, and expense, in order to gain knowledge.

Table 3: DOE for the parameter study (table form)

Simulation	Decrease in height (mm)	Tilt (angle)
1 (nominal)	0	0
2	50	0
3	100	0
4	150	0
5	200	0
6	250	0
7	0	4.05
8	0	8.10
9	0	12.15
10	0	16.30
11	0	20.45
12	0	24.8
13	0	29.2
14	0	33.7
15	0	38.5
16	0	43.6
17	0	49.1
18	0	55.2
19	50	4.35
20	50	8.7
21	50	13.1
22	50	17.55
23	50	22
24	50	26.7
25	50	31.5
26	50	36.55
27	50	41.8

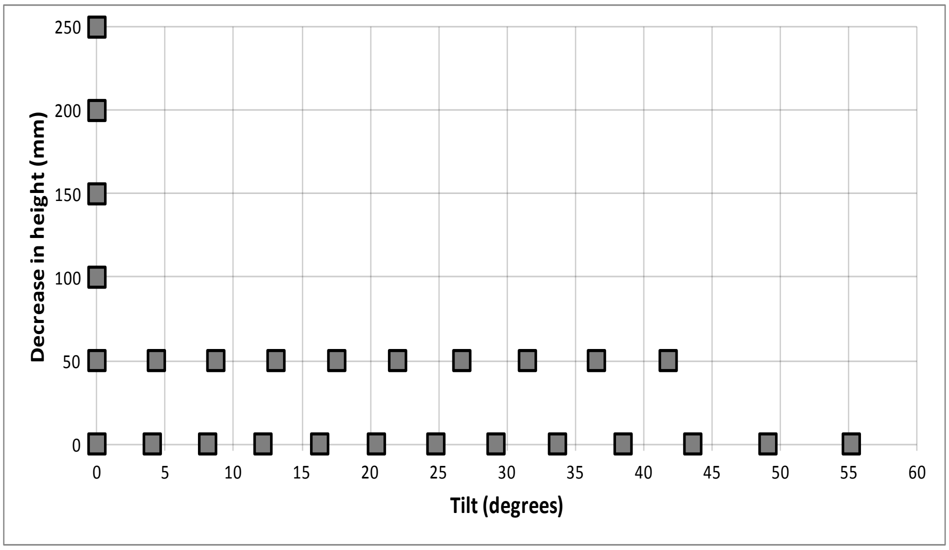


Figure 3: DOE for the parameter study (diagram form).

5 Results of parameter study

Each of the 27 simulations in the parameter study was checked and estimated as “fail”, see red squares in Figure 4, or “pass”, see green squares in Figure 4, where fail means that the vehicle passes over (override) the barrier. The first red square on the y-axis, i.e. for a decreased height of 150 mm is shown in Appendix C.

Remark: the ground clearance of the vehicle bumper is in the simulations generally 400 mm, see Figure 5. However, the evaluation of “pass” or “fail” is for the points on the y-axis determined based on a model variant with bumper height 350 mm, due to that the lower bumper (later) turned out to agree better with the geometry of the physical car.

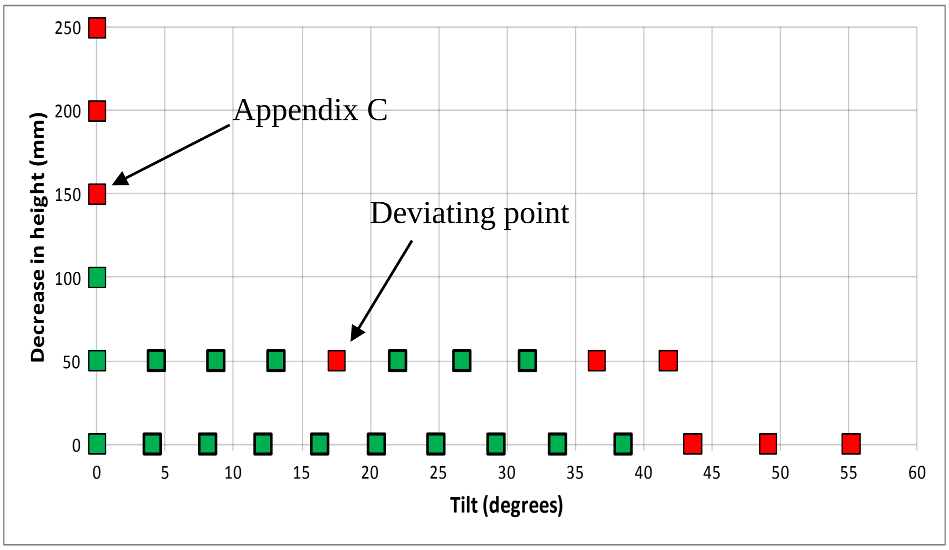


Figure 4: Parameter study results.

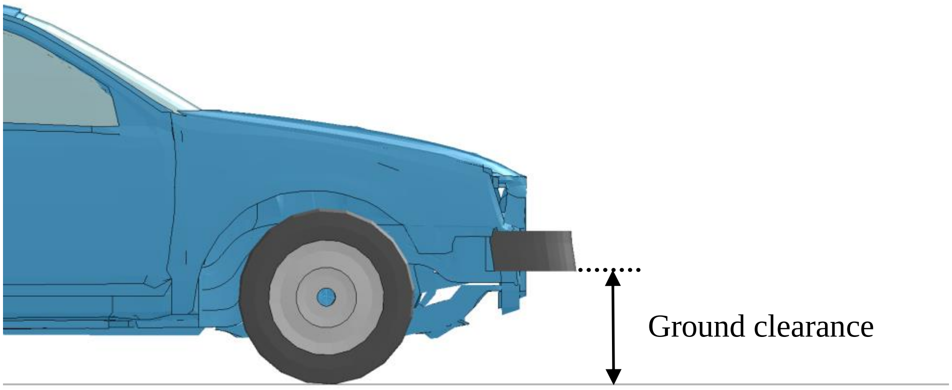


Figure 5: Bumper ground clearance.

6 Design-Of-Experiments for subsequent physical tests

The next task for the project team was to create a Design-Of-Experiments (DOE) for the subsequent physical tests. The DEO was created based on the experience gained from the simulations, i.e. the parameter study.

The strategy was to, hopefully, be able to determine the x and y axes of the “Decrease in height” vs. “Tilt” diagram with a minimum amount of physical tests. Optimally, only four tests would be needed to determine the x and y axes with reasonable accuracy leaving four tests to the, what it seemed, more complicated case with combined “Decrease in Height” and “Tilt”. Our experience from the simulations were that the x and y axes would be rather straight forward to determine. I.e. we needed one green “pass” point and one red “fail” point on each axis of the diagram. The simulation results for the combined “Decrease in height” and “Tilt” cases were more difficult to interpret. There was one deviating “red” point among the green points, see Figure 4. Our interpretation was that this deviating point may indicate sensitivity in the barrier. I.e. a moderate decrease in height, i.e. 50 mm, could make the barrier vulnerable for tilt. A construction that is not robust is difficult to test, which is why we thought we needed as many physical tests as possible, optimally four tests, for the combined “Decrease in height” vs. “Tilt” case. The test chart for the physical tests is shown in Figure 6.

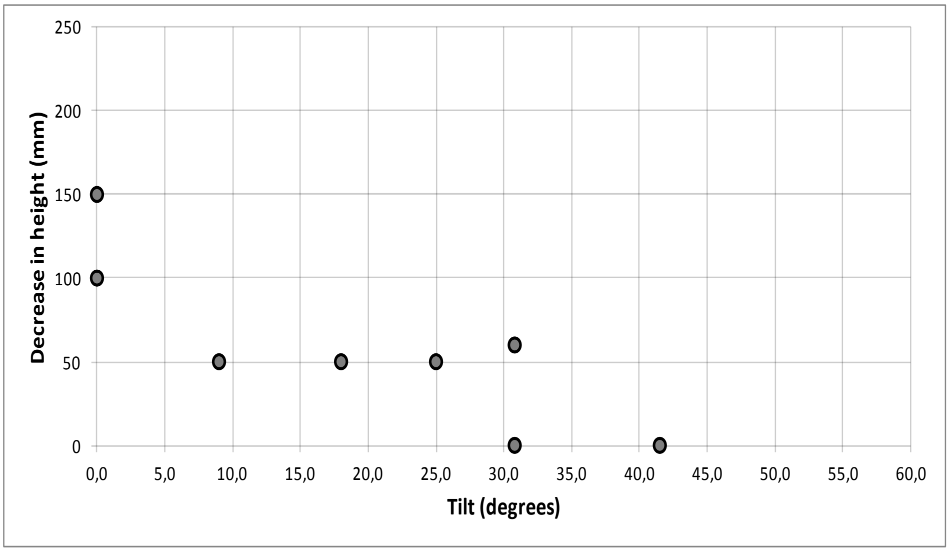


Figure 6: DOE for the physical tests.

7 Physical test results

The physical test results are shown in Figure 7. It turned out that the DOE worked well. Critical tilt and height was determined with only four tests as hoped for. The combined “Decrease in height” and “Tilt” case was, as predicted by the simulations, more complicated. We had three red “failed” tests were the vehicle overrode the barrier and a final test where the vehicle did not override the barrier but vaulted as it left it. The test was not a “fail” based on our, in this project, definition of fail, i.e. it did not override the barrier. However, it would not be approved in an EN 1317 test. In addition, vaulting is potentially dangerous. It was decided to make this point “yellow”. The point is in between green and red.

The primary aim of our simulations was to predict when the vehicle would override the barrier. Prediction of vaulting was not a target. However, we did see in the simulations that the vehicle often did leave the barrier with a considerable “roll” similar to what we later could see in some physical tests. The simulation corresponding to the yellow point is shown in Figure 8.

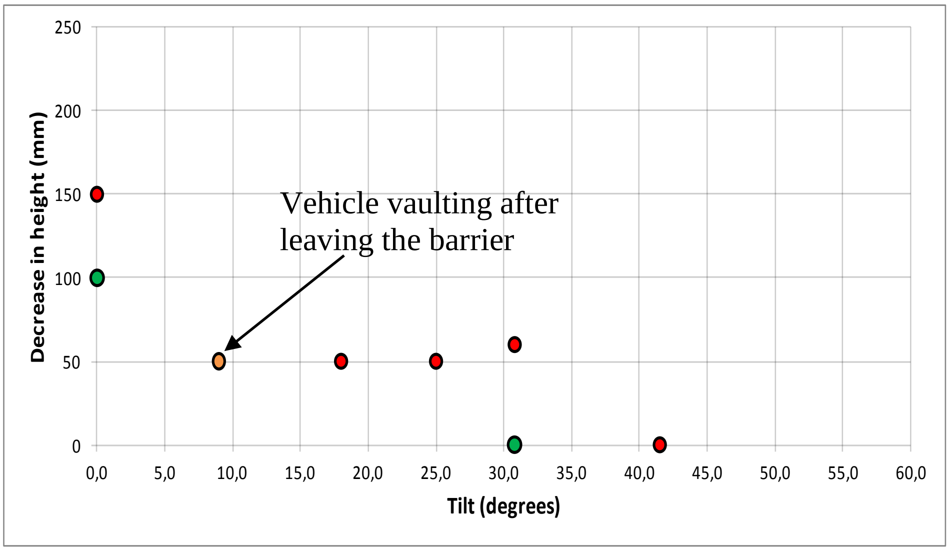


Figure 7: Physical test results.

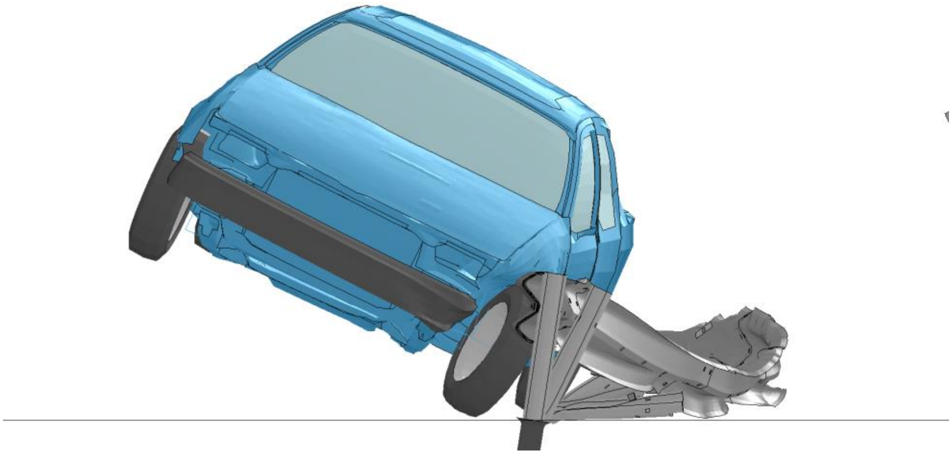
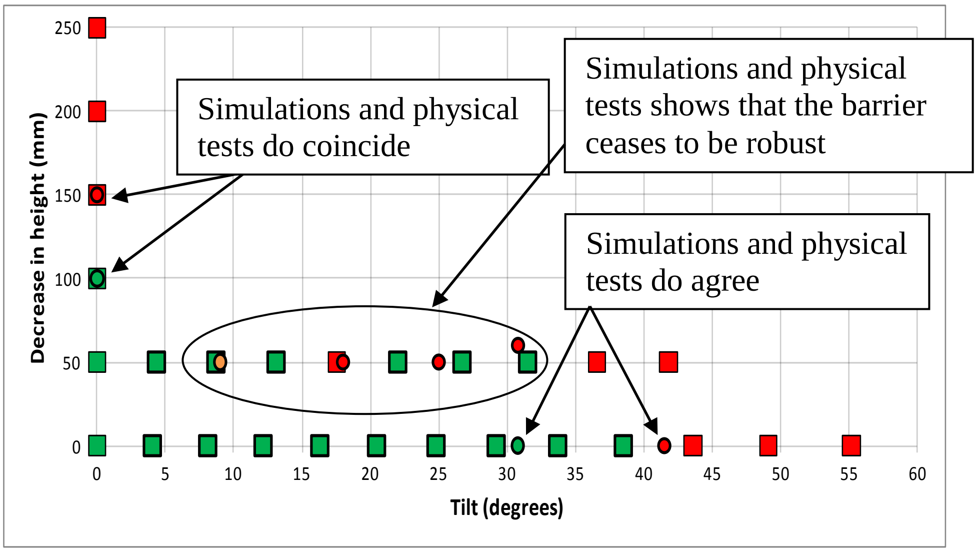


Figure 8: Vehicle leaving barrier with a considerable “roll” angle.

8 Evaluation of simulations and subsequent physical tests

The simulation results and the subsequent physical tests results are shown in the same diagram, see Figure 9. The squares are the 27 simulations and the circles are the 8 physical tests. The x and y axes agree or coincide. It turned out that when the height of the barrier is decreased by only 50 mm the barrier ceases to be robust when tilted. This has been shown both by simulations and physical tests.



Simulations and physical tests do coincide

Simulations and physical tests shows that the barrier ceases to be robust

Simulations and physical tests do agree

Figure 9: Simulation results and subsequent physical tests.

9 Discussion

This project has been rewarding. It has resulted in valuable knowledge. The work method used, i.e. to perform many relatively cheap simulations in order to decide a test matrix (DOE), which is able to take maximum advantage of the more expensive physical tests, has been shown to work well. The advantage was that there was no “waste” of physical tests due to bad choice of test points. It was interesting to see that a barrier of nominal height could be tilted as much as 31° and still redirect the impacting vehicle. However, it was also worrying to see that a moderate decrease in barrier height, i.e. 50 mm, made the barrier much more sensitive. In fact, the vehicle vaulted for a moderate tilt of 9°.

Figure 10 shows the results with two trend-lines (polynomial of order 2) drawn between the physical test red points as well as the physical test green/yellow points. This is one way of interpreting the results.

Remark: It would have been desirable to been able to draw a green line between green “pass” points in the diagram. However, there was a test where the vehicle did not override the barrier but vaulted after leaving the barrier. It was decided that this test was between a “pass” test and a “fail” test according to the definition used in this project. Hence the test was given a yellow point instead of a green or red point in the diagram. This is why the line is set yellow between the two green points and the yellow point in between.

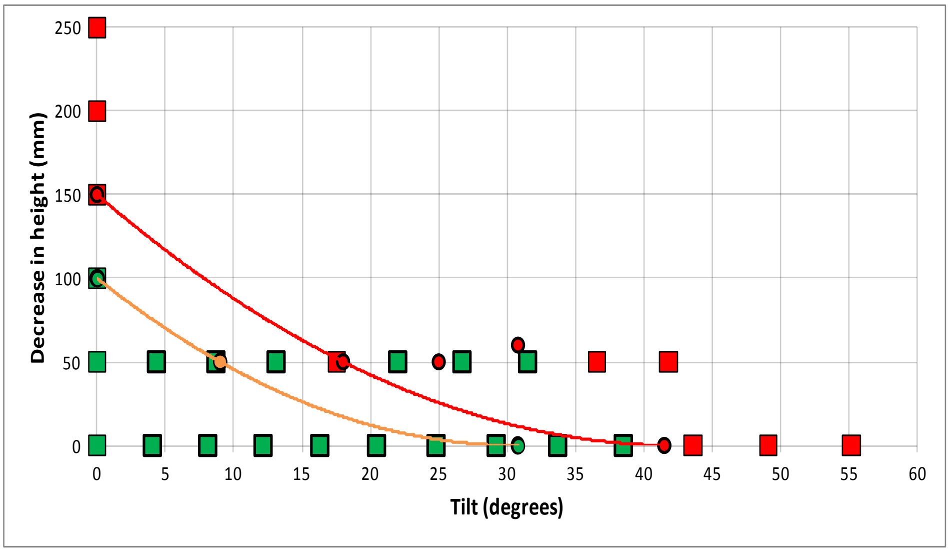


Figure 10: Trend-lines between physical test points.

10 Appendix A: TB32 validation simulation

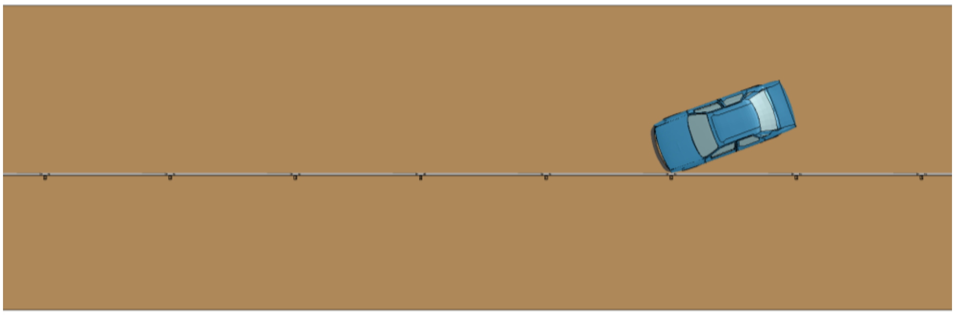


Figure 11: Test at 0.0 s

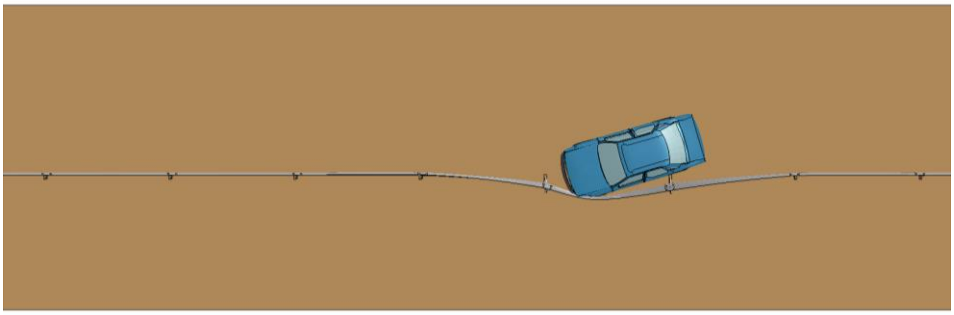


Figure 12: Test at 0.1 s

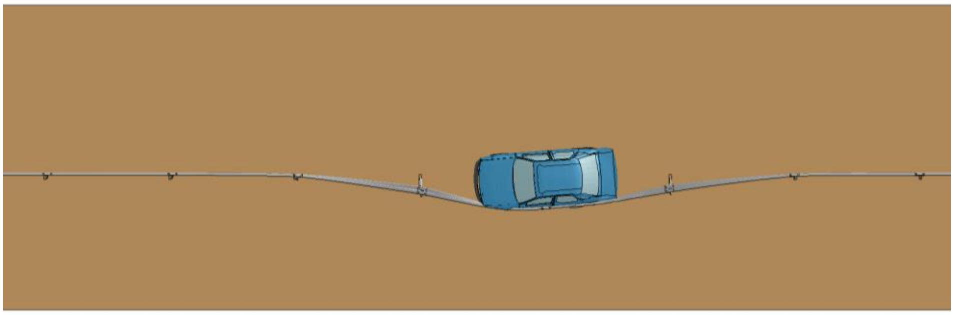


Figure 13: Test at 0.2 s

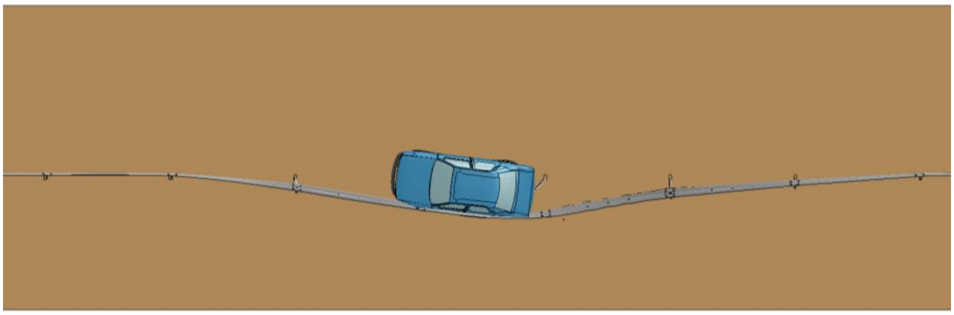


Figure 14: Test at 0.3 s

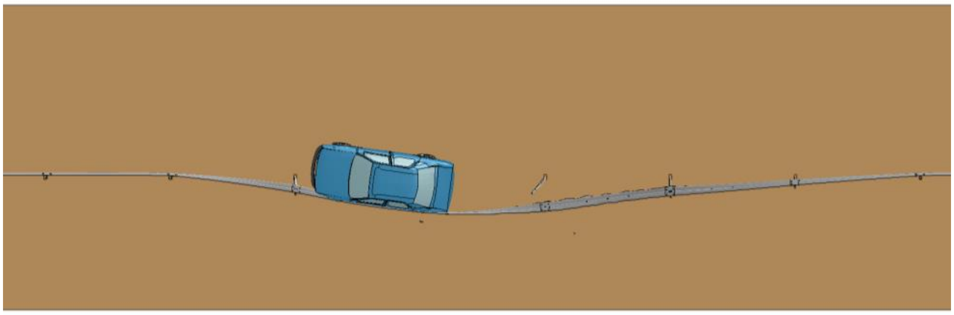


Figure 15: Test at 0.4 s

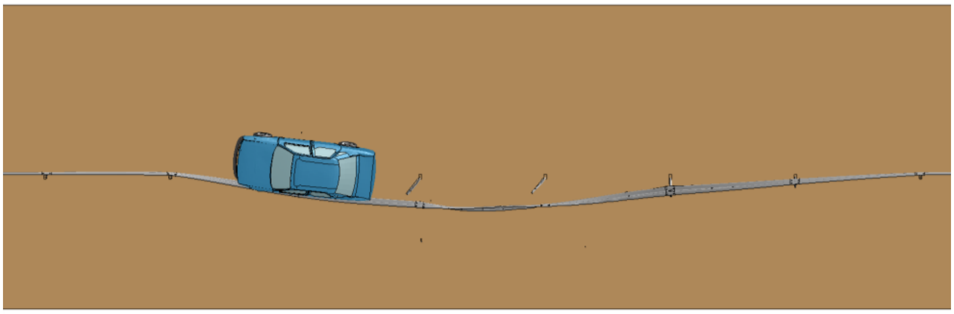


Figure 16: Test at 0.5 s

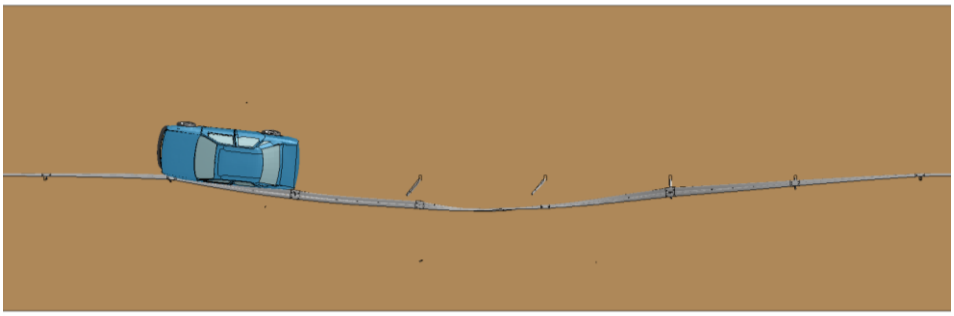


Figure 17: Test at 0.6 s

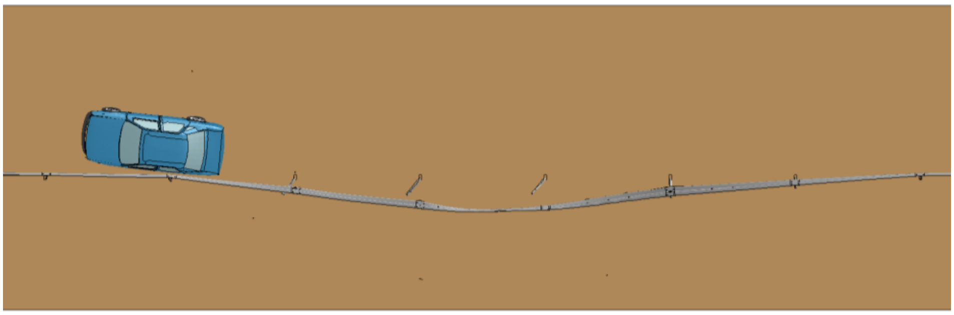


Figure 18: Test at 0.7 s

11 Appendix B: TB11 validation simulation

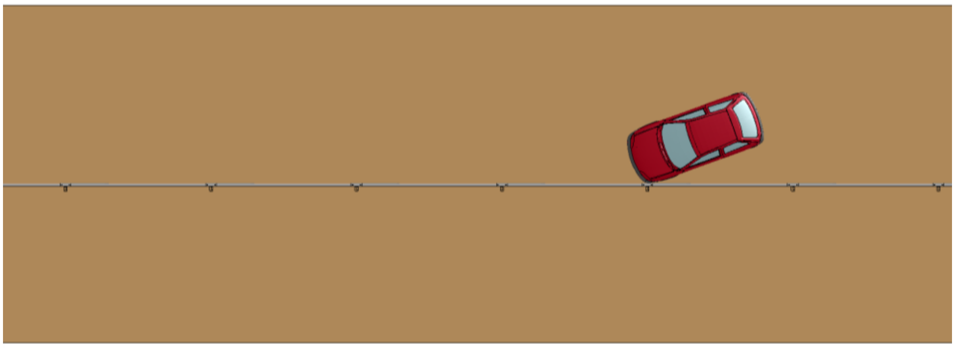


Figure 19: Test at 0.0 s

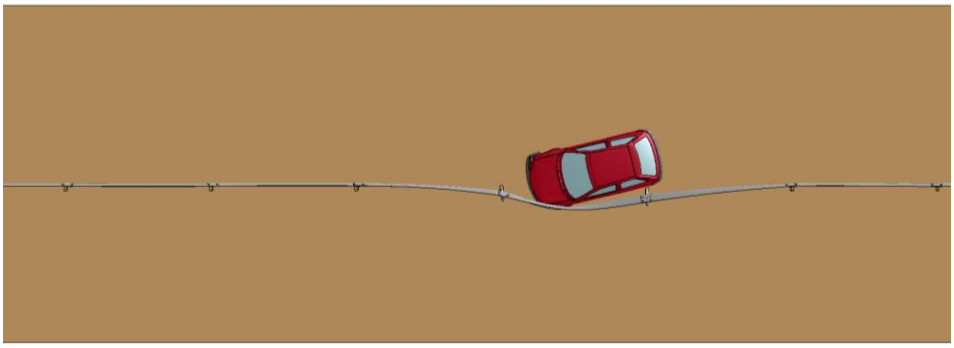


Figure 20: Test at 0.1 s

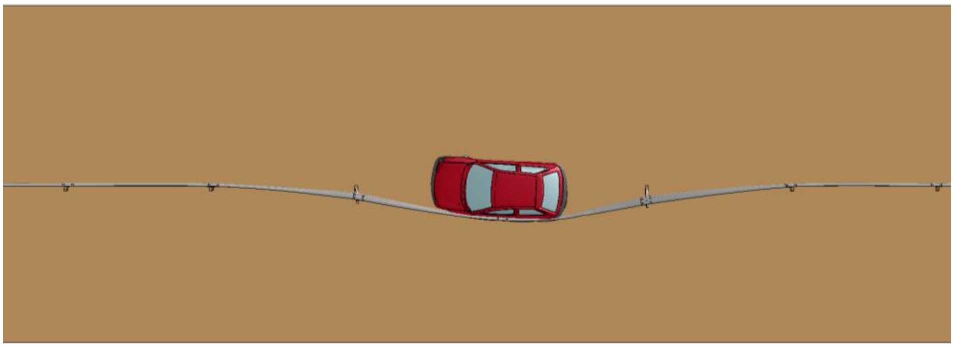


Figure 21: Test at 0.2 s

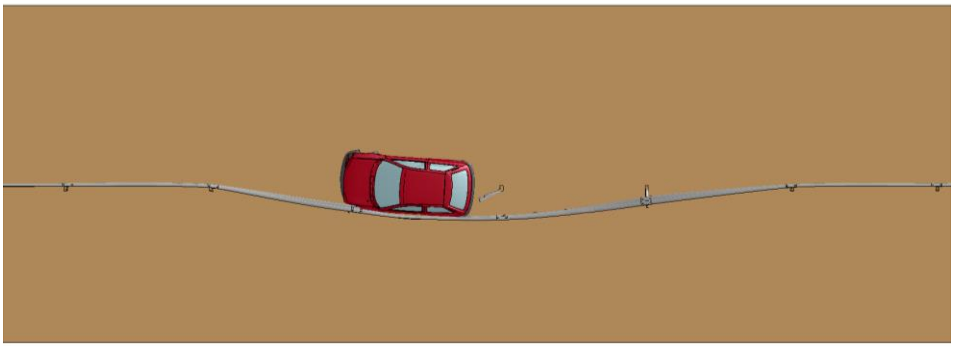


Figure 22: Test at 0.3 s

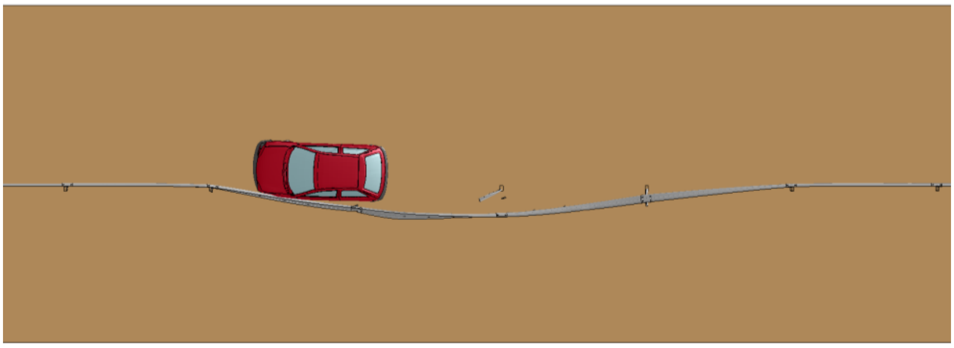


Figure 23: Test at 0.4 s

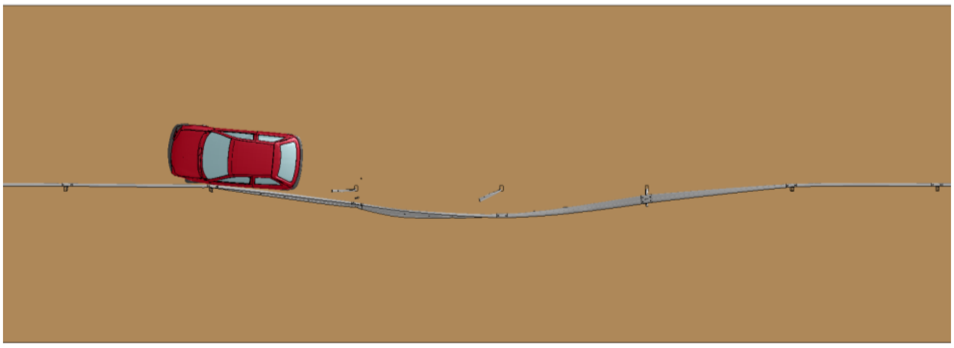


Figure 24: Test at 0.4 s

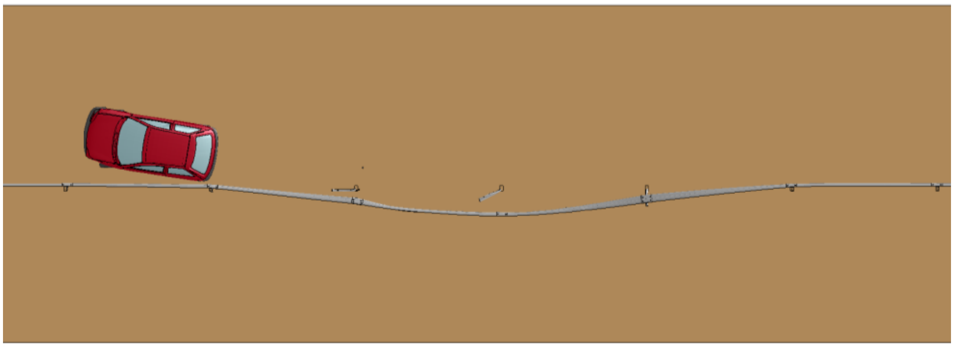


Figure 25: Test at 0.5 s

12 Appendix C: Decreased height 150 mm (zero tilt)

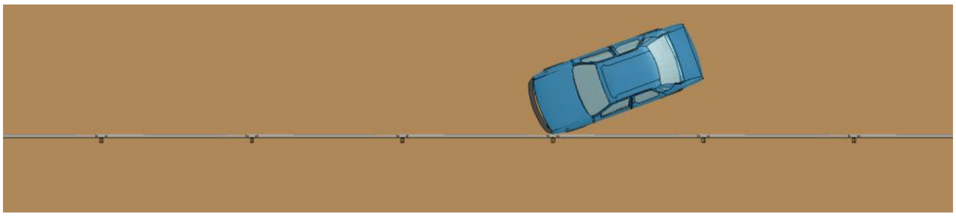


Figure 26: Test at 0.00 s

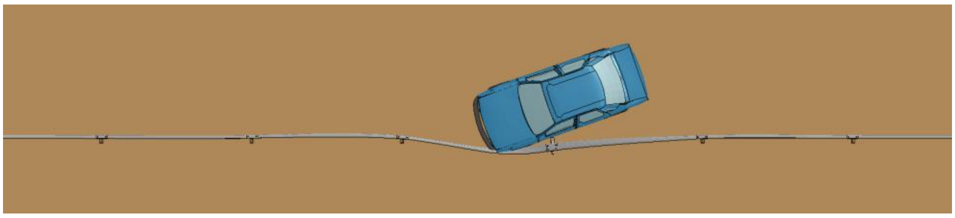


Figure 27: Test at 0.05 s

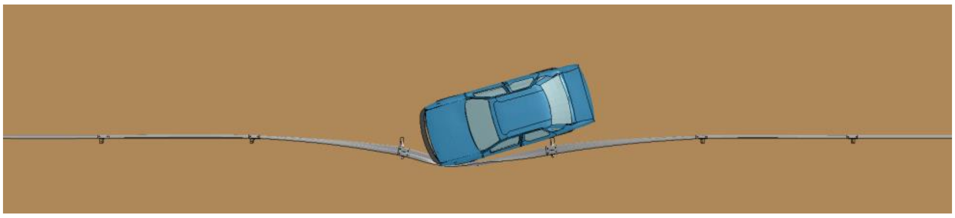


Figure 28: Test at 0.10 s

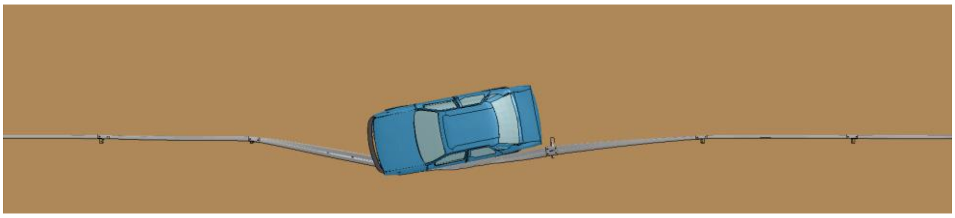


Figure 29: Test at 0.15 s

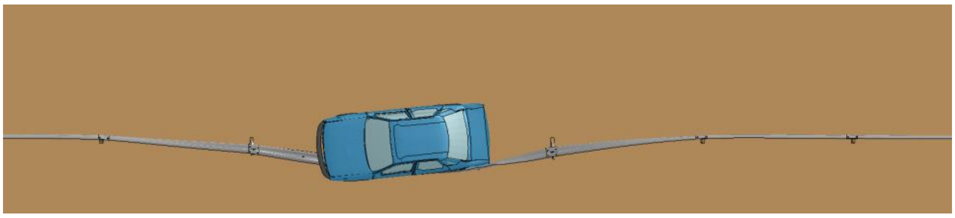


Figure 30: Test at 0.20 s

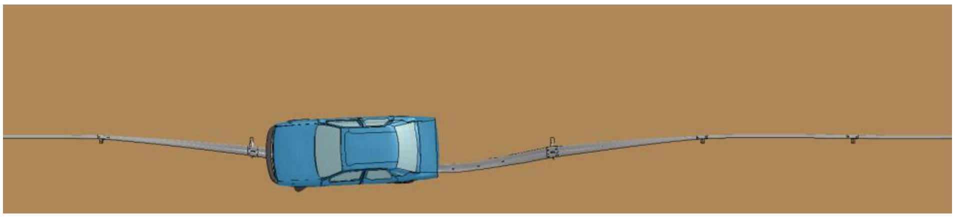


Figure 31: Test at 0.25 s

13 References

[1] LS-DYNA Keyword User's Manual, version 971, Livermore Software Technology Corporation, Livermore, 2012.

[2] ANSA v13.2.2, BETA CAE Systems SA, Thessaloniki, 2012.

[3] LS-PrePost v3.2, http://www2.lstc.com/lspp, Livermore Software Technology Corporation, Livermore, 2012.

[4] Svensk Standard SS-EN 1317-1, Swedish Standards Institution (SIS), Stockholm, 1998.

[5] Svensk Standard SS-EN 1317-2, Swedish Standards Institution (SIS), Stockholm, 1998.

[6] Statens Vägverk, Tekniska Avd. Brosektionen, drawing 401:8s-a rev. d, ”Vägräcken W-Profil - Översiktsritning, Stockholm, 1975.

[7] J.Wenäll, VTI test report No. 56452, the Swedish Road and Transport Research Institute, VTI, Linköping, 1996.

[8] J.Wenäll, VTI test report No. 56453, the Swedish Road and Transport Research Institute, VTI, Linköping, 1996.

Crash tests at VTI during the period 12th of September to 26th of September 2012.

Barriers with different height and variable tilting.

Background

In a project looking at ageing effects of roadside furniture, sponsored by Swedish Transport Administration, and in cooperation with Dynamore and SVBRF, the functionality of roadside barriers was studied. While roads over time undergo re-pavement and other maintenance actions, the roadside barriers are sometimes not adjusted accordingly, causing barriers to become too low over time. For this project Dynamore had predicted barrier heights, barrier tilting and combinations of the both, where proper barrier functionality was ambiguous, and by eight different crash tests these combinations was assessed.

Purpose

The purpose is, of course, to understand the functionality of barriers and the relevant combinations calling for maintenance action.

Tests

Eight tests were run. The barrier was, in all tests, a EU4 barrier, which is a W-beam horizontal crossbeam with standard sigma posts with spacing 4 meters and no spacer attached between crossbeam and post. The post was installed in standard soil, gravel of sieving 0-32 mm. The installation was done by a hydraulic hammer, making a cylindrical hole where the post was downed before the hole was filled with more gravel or crushed aggregate of somewhat finer sieving.

The vehicle used was a standard Volvo 940, and all vehicles were carefully calibrated by weight to pass the criteria of EN1317-1:2010 for the vehicle, i.e. 1500 kg and a given centre of gravity for the vehicle. In general, these used vehicles were all the same. But as this was used vehicles, one can never guarantee the vehicle. They are always slightly individual, due to their history, even though checked carefully.

Test 1

The first test was run on the 10th of September 2012 (2012-09-10). The installation was a vertical post with no angle, but cross member intentionally installed 100 mm to low, which equals a height of 450 mm to the middle line of the W-beam. Speed was 113,6 km/h.

The prediction was that it was about 50% probability of breaching the barrier. The test did nevertheless result in a redirection, even though the roll angel of the vehicle was about 90 degree. In a more formal EN1317-2:2010 T32 crash test, this had been regarded as a failure, since rolling on to the vehicle side during or after impact is not allowed.

Test 2

The second test was run on the 11th of September 2012 (2012-09-11) and for this test the barrier was lowered yet another 50 mm, still being vertically oriented, or now with the middle line/middle screw of the W-beam situated only 400 mm above the asphalt surface. The result was, as expected, a full breach of the barrier with the vehicle hitting an extra safety barrier behind the tested barrier (causing more severe vehicle damage than produced by the tested barrier). Speed was 113,6 km/h.






It is quite obvious that, for this combination of vehicle, barrier type, soil strength and angel of supporting post, the limit for functional performance in respect of barrier height is situated somewhere between test 1 and 2, i.e. between the height 400 and 450 mm.

By this, we had a kind of footprint for the performance limit by height.

Test 3

The third test, run on the 12th of September 2012 (2012-09-12—1) was then aiming for the performance on barriers where the posts had been pushed backwards, a tilting post. We started with a barrier that held an effective height of 450 mm, going back to test 1 where 450 mm had held the vehicle back, but with a quite extreme tilting of the post at 48,5°. Although extreme, the simulation had indicated a possibility of acceptable performance. Speed was 113,6 km/h.

Might as well point out that the angled installation process was not that easy either.

It did result in a full breach of barrier. Really interesting to see that no bolts were sheared off, the angled beam did press the posts to ground without disconnecting from the posts. Obviously, the tilted W-beam does start pressing the posts already at first contact with vehicle.

Test 4

In test 4, performed on the afternoon of the 12th of September 2012 (2012-09-12—2), the barrier was slightly raised from the previous tilted installation. The new angle was 59,2° and the resulting barrier height (for the middle line of the cross beam) was now 500 mm. Although aggressive, we now had a test where the vehicle was still contained by the barrier. Speed was 113,2 km/h.

Bolts were shered off. At the same time, it is interesting to notice that the tilted posts did result in posts being pulled out of the ground.

Test 5

For test five, run on the 13th of September 2012 (2012-09-13), the angle of posts was kept from previous test, 59,2°, but the effective height of the barrier was adjusted downward 50 mm to 450 mm from previous test 500 mm. This resulted in yet another breach of barrier, the cross-member being pushed down by vehicle front a front wheel of vehicle. Speed was 116,5 km/h.

It is obvious that the combination of height and angle once again contributed to that the posts was pressed down towards ground without disconneting the crossmember from the posts, and essential factor for barrier success. We did as well also note a tear in the W-beam, although not investigated never the less an interesting detail.

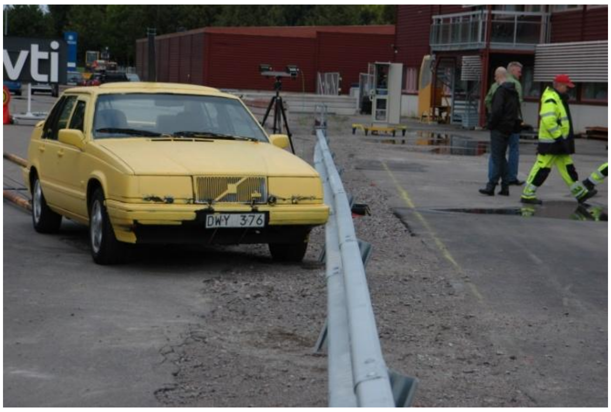
Test 6

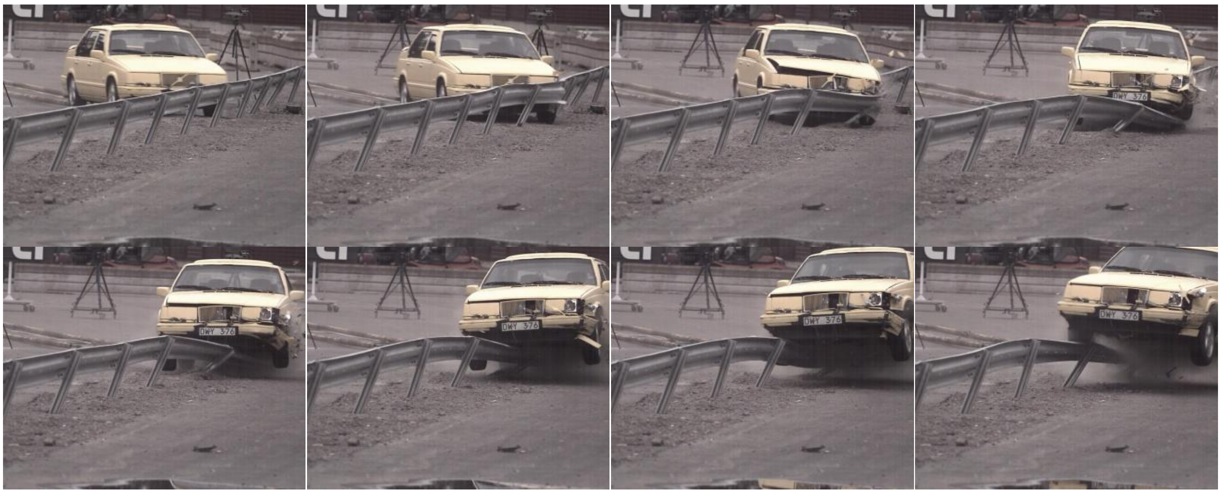
The test 6 was run on the 24th of September 2012 (2012-09-24—1). For this test the posts was once again raised, this time to 65°. The effective height of (middle line) of barrier was 475 mm. Speed was 113,6 km/h.

Barrier was to low and to angled, bolts did not shear off, resulting in a breach of barrier. Did see cracks and tear of the cross member.

Test 7

For the seventh test, performed on the 24th of September 2012 (2012-09-24—2), the post was once again raised to a more upright position. This time 72° and with the cross member at 493 mm height. Speed was 113,6 km/h.

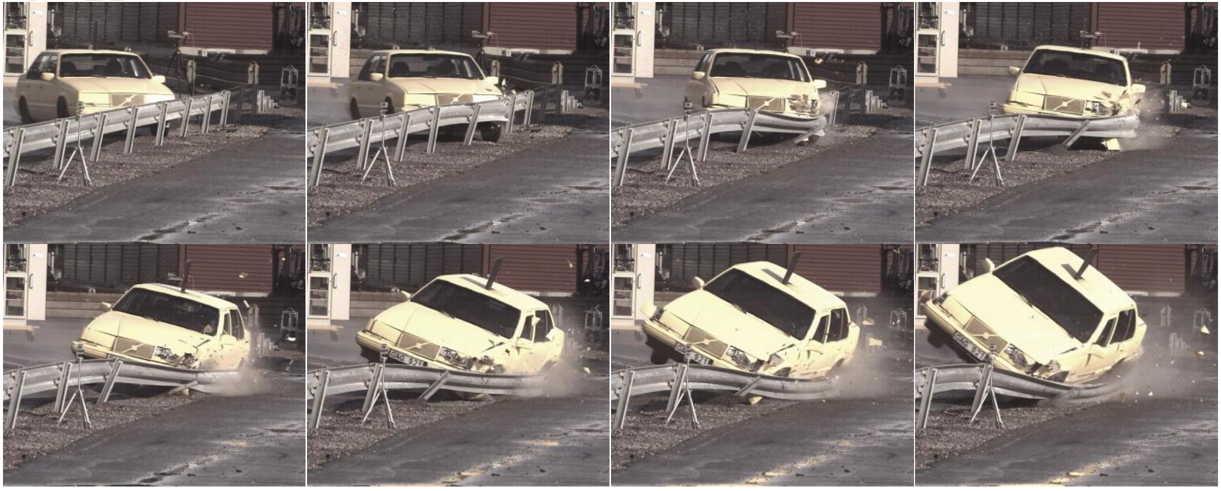


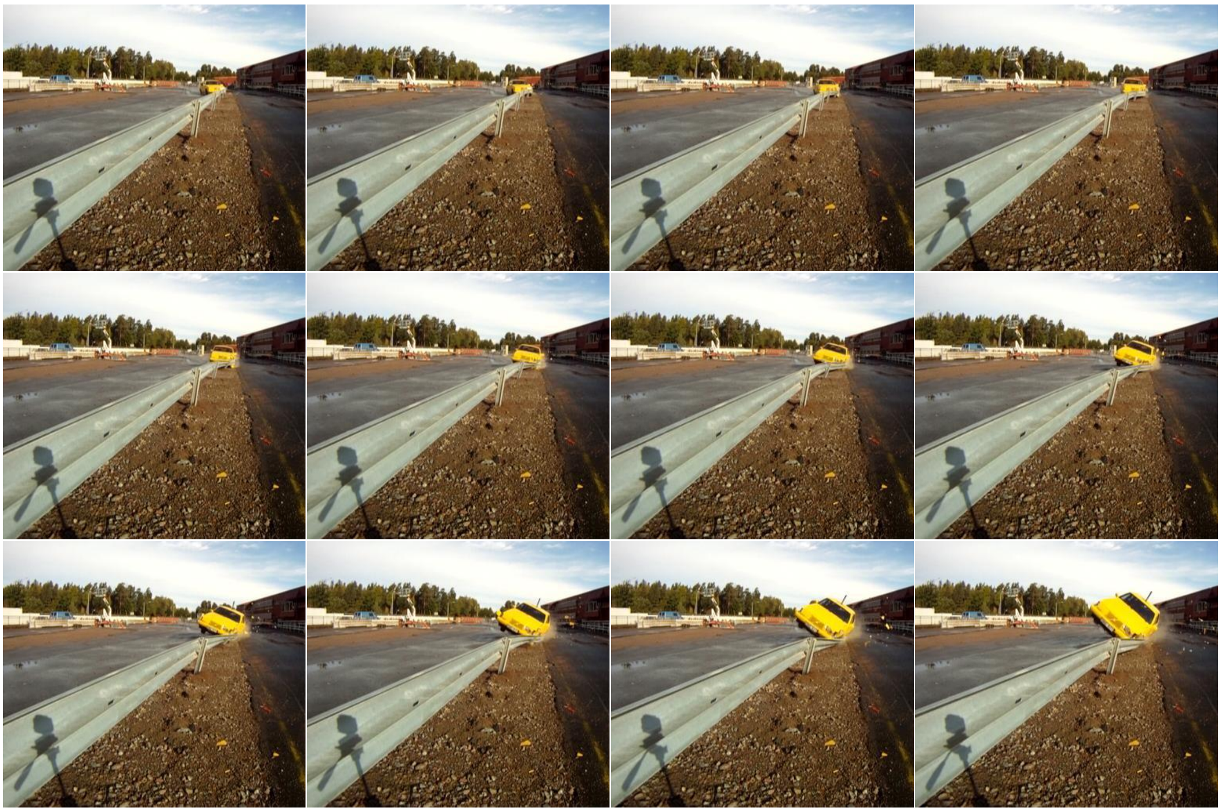


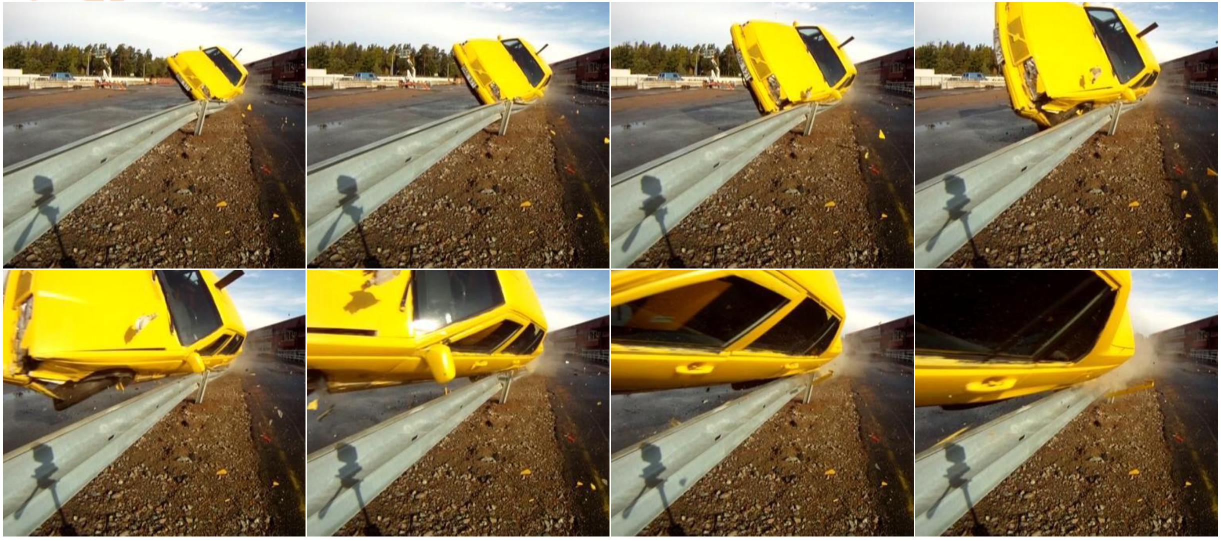
Even for this combination, the vehicle does breach the barrier. One post is sheared off, as it should be, but most of the barrier is once again pressed down under the vehicle front and wheel and does not disconnect properly.

Test 8

Last test, performed on the 26th of September 2012 (2012-09-26), at the speed 112,1 km/h. For this test, the posts were erected slightly more, now to 81°. (90° regarded to be a fully vertical post.) The effective height of the cross member was 503 mm.







We are almost back to the original number one test, the vehicle is contained but the vehicle roll is substantial. In an approval test according to EN1317-2:2010, this would have been a failure. It seems that already this slight post angle causes some severe rotation of the test vehicle, and some of the posts and screws does not detach as supposed.

Results

Eight different crash tests were performed, varying post angle, cross member effective height and combination of these. For all eight tests, vehicle were more or less the same and speed variation was from 112,1 km/h at the lowest to 116,5 km% for the highest. Most of the tests were run at speeds around 113,5 km/h. For those case where the vehicle did breach the barrier, the cross member did not detach correctly or partly did not detach from posts, making the cross member follow the posts towards ground. This may be an effect of the low installation, making vehicle contact point hitting high on the barrier, or it can be an effect of the vehicle wheel hitting the posts.

Post was partly pulled out of ground due to the tilted installation, which made performance even less effective for the cases where sever tilting was at hand.

All tests, except test 4, would have been classed as failure tests in respect of vehicle trajectory and/or vehicle roll during and after impact, if judged by the current version of EN1317-2:2010. Some of the tests might have been OK by the elderly version EN1317-2.1998, due to the fact that the requirements for vehicle roll, pitch and yaw have been slightly changed.

It might be good to note that no acceleration measurements were made in the vehicles, thus no ASI and THIV values can be presented, nor evaluated.

Discussion

It is, by these tests, quite clear that the tested barrier is far more sensitive to post tilting than expected. Even a post angel of 9° from perfectly vertical position proved dangerous inn respect of the evaluation criteria of EN1317-2:2010. On the other hand, maybe this is not that dangerous in real life, but would have resulted in a rejected approval if tested according to EN1317-2. The effect of the barrier installation height was somewhat more difficult to judge. For the perfectly vertical installation there was a clear demarcation line between pass or fail when the barrier was lowered from 450 mm to 400 mm. But is that a general result, or valid only for this barrier at the given installation angle. It was interesting to note the sensitivity to angle in combination with height, leading to the conclusion that post angle ought to be monitored more precisely, but that, for correctly installed posts, barrier height is not that dramatically important.

On the other hand, there are quite lot vehicles on the road with a front structure far higher than this Volvo 940 type of vehicle.