

TB11 test for short w-beam road barrier

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1 Introduction

FEM (Finite Element Method) is well-suited and widely used tool for simulating a range of phenomena: from these with simple and static behaviour, up to those complicated, highly nonlinear and involving many contacts. In present paper we use one of the advantages of FEM: parametric study could be easily performed and is more economical than series of in-situ tests. If recommended practices is carefully followed, results obtained from simulations may be considered as reliable.

Current research is a part of scientific project RID 3A, some previous results could be found in paper [1]. TB 11 standard test was analysed in few papers, e.g. [2][3][4][5].

In particular, we simulate TB11 test [1] performed on short section of typical road barrier. Even thou typical polygon test is performed on e.g. 60 m long barrier section, few circumstances necessitate use of shorter sections, e.g. existence of intersections close to each other or point obstacle on the road side which need to be protected (Fig.1:). In this study we try to throw some light on general question: are short section barriers as secure as their full-length parent? This paper do not aspire to give unequivocal answer to this question, we intend to show FEM and LS-DYNA in particular as reasonable tool to investigate this and similar cases.



Fig.1: Short barrier erected at the roadside. Probably the tree is an obstacle to be protected.

2 Vehicle model

In TB11 collision test, 900 kg weight small car (Geo Metro) was used. In our study, vehicle model is obtained from ROBUST project repository (<http://www.vegvesen.no/s/robust/>) and subjected to minor modifications (Fig.2:). Accelerometer is placed near centre of mass.

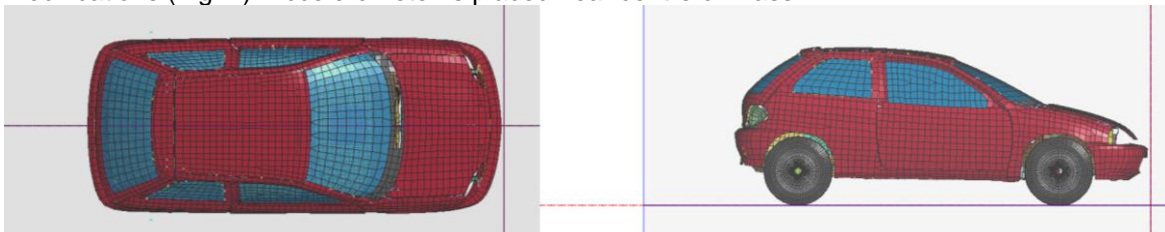


Fig.2: Geo Metro FEM model with coordinate system axes (x along vehicle's axis, y perpendicular to axis, z vertical).

The vehicle model has been checked whether it fulfils standard's [1] requirements. Results of this investigation are listed in Table 1:. Only distance lateral distance from centre line (CGY) is slightly exceeded, which should not noticeably affect the results of calculation.

	BS EN 1317 [1]	Numerical model	Is value in range?
Total mass, kg	900 ± 40	926,08	Yes
Dimensions, m (limit deviation ± 15%)			
Wheel track	1,35 ± 0,2	1,409 (front) 1,330 (rear)	Yes Yes
Centre of mass location			
Longitudinal distance from axle (CGX) ± 10%	0,90 ± 0,09	0,83	Yes
Lateral distance from vehicle centre line (CGY)	± 0,07	0,09	No
Height above ground (CGZ) ± 10%	0,49 ± 0,05	0,51	Yes

Table 1: Geo Metro model parameters compared to EN1317 requirements.

3 Barrier model

Barrier model is inspired by Megarail SL system, manufactured by Saferoad company (<http://www.saferoad-rrs.com/en/products/guardrails/stationary-guardrails/megarail-sl2/>). It is strongly emphasized that the present paper does not corresponds to any real-scale collision test of this barrier, we do not discuss its performance parameters (e.g. containment level).

3.1 Model description

Finite element model consist of shell elements of approximate size 12 mm. Connectors are assumed as screws modelled with four element solid weld (Fig.3:, Fig.4:). Total number of 252 523 nodes and 245 008 finite elements are used. Shell elements have parameter ELFORM = 2 (Belytschko-Tsay) and due to reduced integration incorporated, hourglass control is necessary to get results not affected by non-physical deformations. This control is achieved by introducing keyword:

```
*CONTROL_HOURGLASS
      4      0.03
```

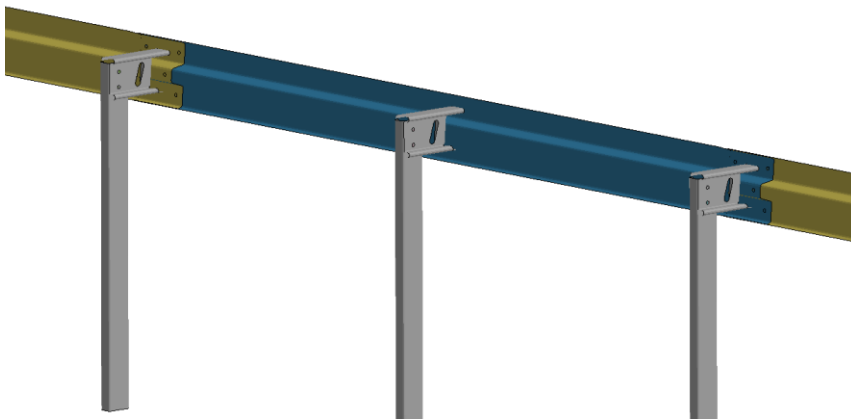


Fig.3: Short barrier numerical model.

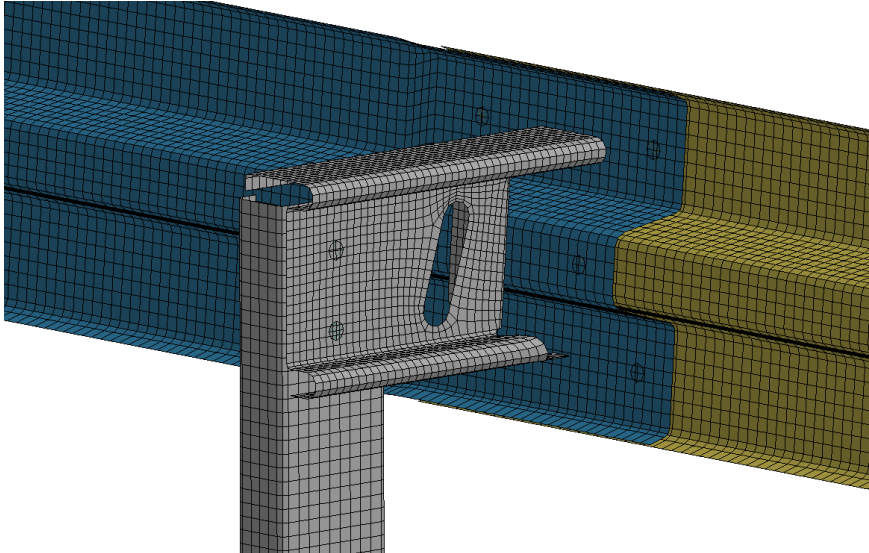


Fig.4: Short barrier numerical model discretization detail.

3.2 Material

According to barrier's documentation it is made of S235 steel. Material parameters have been obtained from report [1] and used to fill `*MAT_PIECEWISE_LINEAR_PLASTICITY_TITLE` keyword data:

```
*MAT_PIECEWISE_LINEAR_PLASTICITY
      17.85000E-9  210000.0      0.3      235.0      0.0      0.0
      4000.0      5.0          0          0          0.0
      0.0      0.019      0.198
      235.0      238.4      360.0
```

All screws in an assembly have been modelled as four element solid weld, 16 mm diameter, with a material definition:

```
*MAT_SPOTWELD
      17.80000E-9  210000.0      0.3      240.0      500.0      0.0
      0.4          0.0          0.0      0.0      0.0      0.0
```

4 Short barrier TB11 test

4.1 Test conditions

In this report we investigate numerical crash tests performed on short section of w-beam road barrier. In numerical analysis 20 m long section with two 8 m long end sections is simulated, impacted by 900 kg car at $\alpha = 20^\circ$ angle. Vehicle is moved $b = 14$ m away from barrier, to fulfil standard [1] requirement of acceleration values registration. Total number of 31 simulations were performed ($a = -5, -4, -3, \dots, 23, 24, 25$ m), giving insight into car behaviour and ASI, THIV, PHD parameters value with variation to initial place of contact along the barrier.

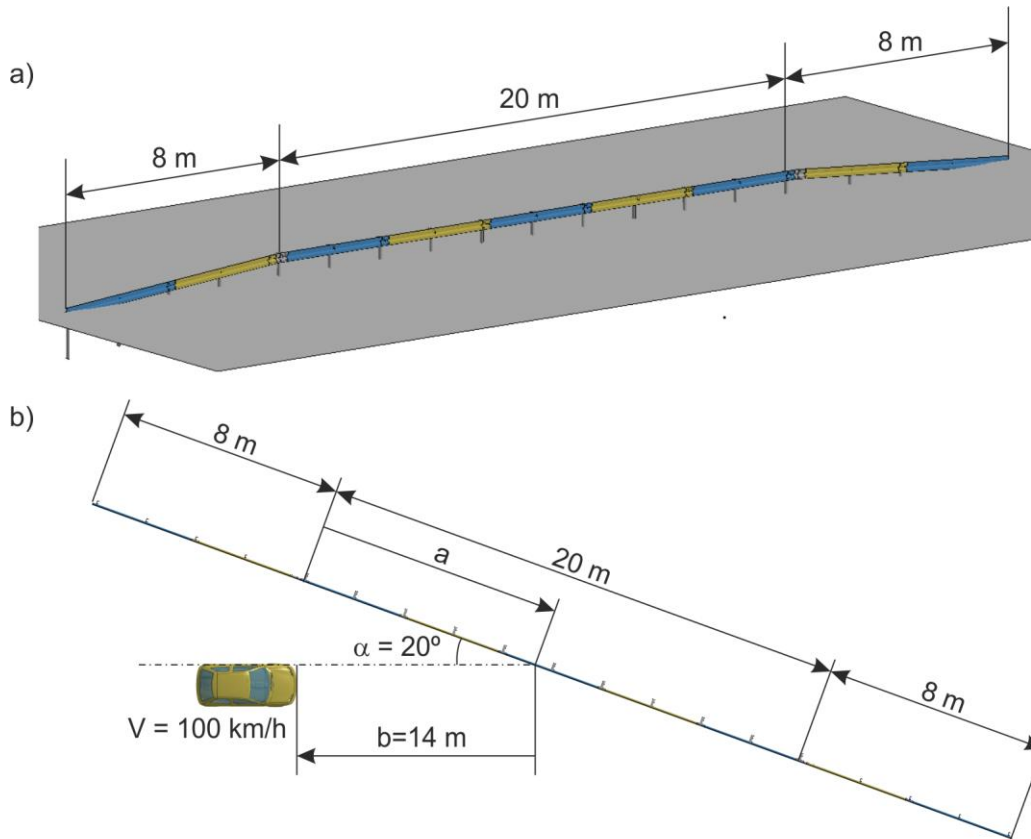


Fig.5: Short barrier a) overall view b) TB11 test aerial view with basic angle and dimensions marked.

4.2 General results

Results of 31 simulations have been collected in Table 2: and in Fig.6:, Fig.7:, Fig.8:. Some of the analyses ($a = -4, -2, 10$) didn't reach assumed termination time, due to numerical problems. One of them is presented in Fig.9: - nonphysical deformation of front wheel that caused numerical problem in $a = 10 \text{ m}$ analysis. Those analysis have been replaced with other where impact point is moved by 0.05 m.

In the series of test, barrier managed to keep vehicle in the lane in almost all of the cases. Only impact at leading or trailing terminal section led to rollover. The same effect may occur in the case of full-length barrier (terminal sections are considered as potentially insecure). General performance of short barrier is satisfactory.

ASI values are kept in reasonable range, rendering class B ($ASI = 1.0 \div 1.4$) in several cases where car is kept in the lane. Also THIV and PHD parameters do not reach any disturbing values.

Sequence of selected cases ($a = -4, 2, 10, 18, 24$) reveals variety of vehicle-barrier interaction (Fig.10:, Fig.11:). Case $a = -4$ reveals most brutal case of collision – car reverse upside down, what may lead to serious injuries of occupants. Collision parameters $ASI = 1.44$, $THIV = 23.1$ and $PHD = 22.9$ do not reveal this behaviour, so these are not sufficient to describe collision as safe for participants. Case $a = 2$ shows rather smooth vehicle exit from contact. Such vehicle exit is the most desirable. When $a = 10$ car yaws and skids, what is caused by driving the bonnet under barrier's rail. Impact into the trailing terminal $a = 18$ and $a = 24$ is not as dangerous as collision with the leading one, but can end up with leaving the lane and going on the shoulder.

Impact location (a), m	Vehicle leaves the lane	ASI, -	THIV, km/h	PHD, g
-5	yes	1.33	20.2	-
-4 (-3.95*)	yes	1.44	23.1	22.9
-3	no	0.78	23.1	13.4
-2 (-2.05*)	no	0.81	23.5	15.6
-1	no	0.99	29.9	16.9
0	no	0.84	24.0	13.0
+1	no	0.70	24.0	16.9
+2	no	0.85	23.0	19.5
+3	no	0.91	25.1	18.8
+4	no	0.82	23.1	19.2
+5	no	0.69	23.1	20.5
+6	no	0.76	25.7	14.9
+7	no	1.22	36.3	15.0
+8	no	0.96	35.6	18.9
+9	no	0.94	24.7	35.7
+10 (+10.05*)	no	1.00	23.8	20.3
+11	no	0.82	26.9	14.5
+12	no	0.82	24.9	18.1
+13	no	1.24	29.7	19.5
+14	no	0.82	26.2	14.1
+15	no	1.40	38.5	12.4
+16	no	1.14	28.6	22.9
+17	no	0.86	26.0	17.1
+18	no	0.90	24.3	19.3
+19	no	0.86	22.8	19.4
+20	yes	0.62	24.4	12.8
+21	yes	0.77	22.3	7.1
+22	yes	0.76	20.4	8.3
+23	yes	0.87	18.7	6.7
+24	yes	0.61	15.8	7.6
+25	yes	0.68	12.9	6.8

* result obtained for this parameter, due to numerical problem in assumed (integer) parameter value

Table 2: Results of TB11 tests

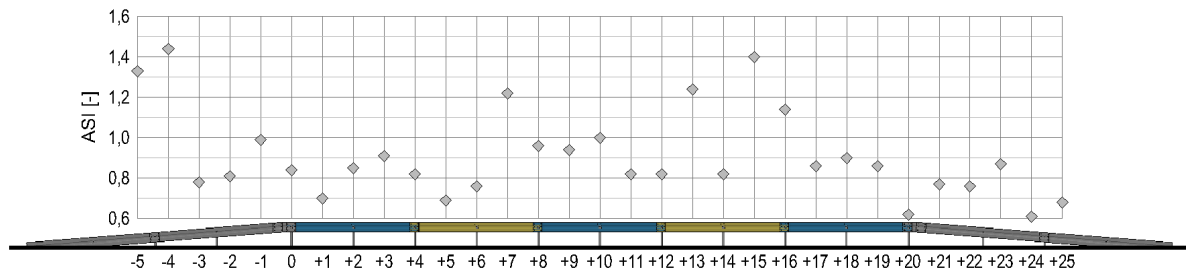


Fig.6: Acceleration Severity Index (ASI) depending on impact location

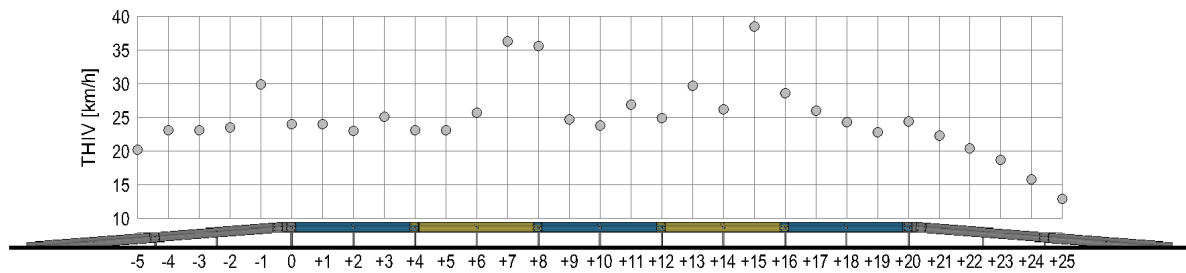


Fig.7: Theoretical head impact velocity (THIV) depending on impact location

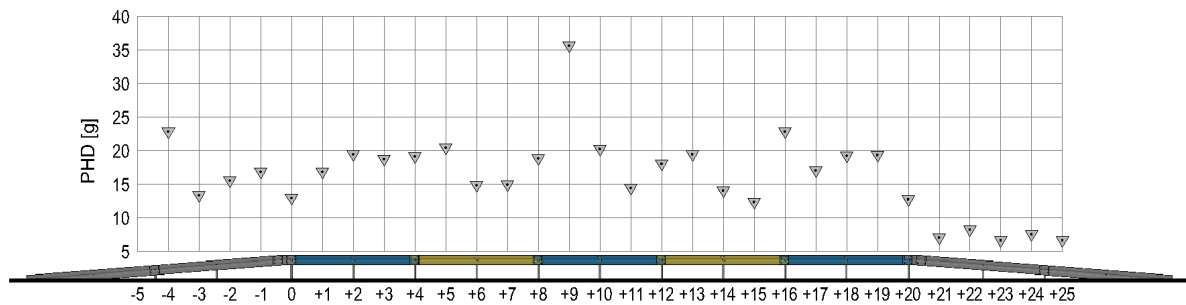


Fig.8: Post-impact Head Deceleration (PHD) depending on impact location

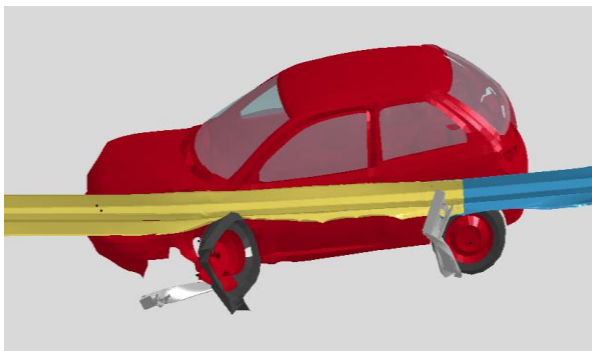


Fig.9: Nonphysical deformation of front wheel that caused numerical problem in a = 10 m analysis.

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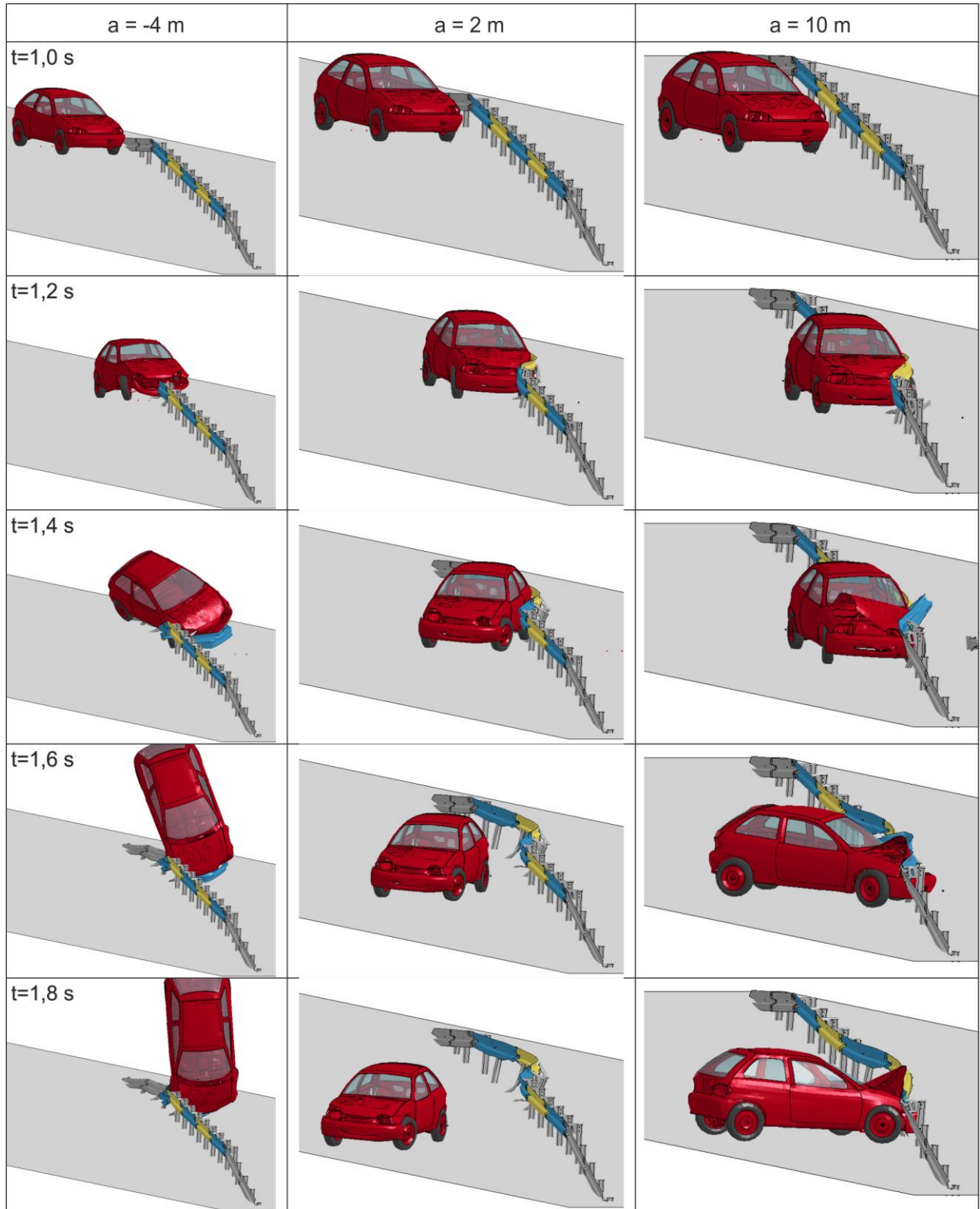


Fig.10: Sequence of collision for a = -4, 2, 10 m.

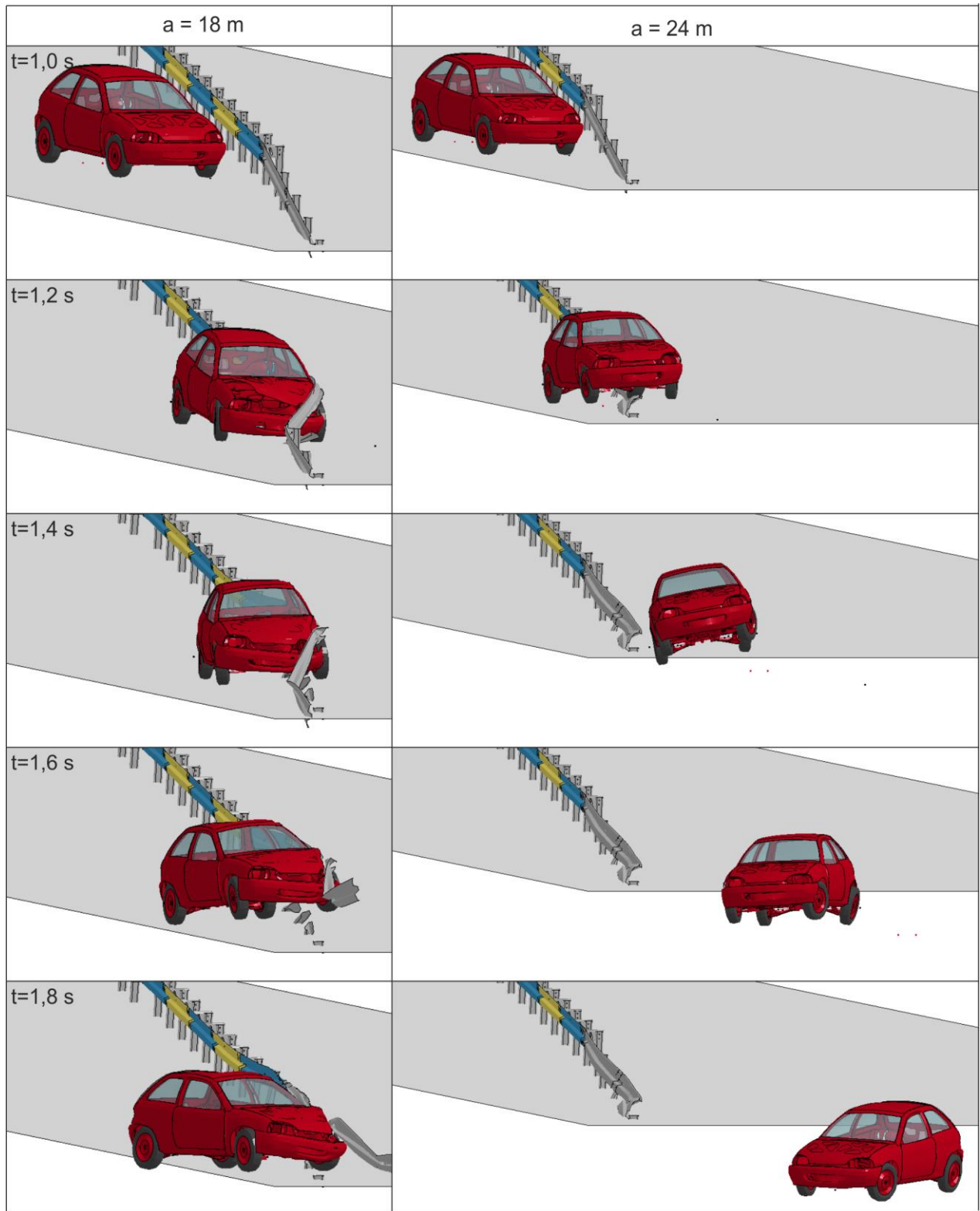


Fig.11: Sequence of collision for a = 18, 24 m.

4.3 Detailed results of a=+15 impact location

Here we present the detailed analysis of impact point $a = 15$ m. This case was chosen due to outstanding large value of $ASI = 1.4$. Small variation of impact point is introduced, namely cases $a = 14.9, 14.95, 15.05, 15.1$ m are additionally analysed. Fig.12: shows that these small changes may lead to meaningful difference in driving track. In Table 3: ASI , $THIV$ and PHD values are collected. As it can be noticed, moving of the impact point by 0.05 m can change ASI from 1.4 to 1.09 $THIV$ from 38.5 to 28.9 km/h, which in turn changes predicted impact severity level from B to C [1].

Case of $a = 14.9$ m is distinctive. Typically, contact between vehicle and barrier lasts up to about 0.3 s, while in this case it is not true. Vehicle is fully stopped (Fig.13:) by barrier, which is caused by nonphysical deadlock in the contact of door and rail (Fig.14:). It is numerical issue characteristic for this type of simulations, where complicated, finite sliding contact occurs, additionally with finite element meshes of different density.

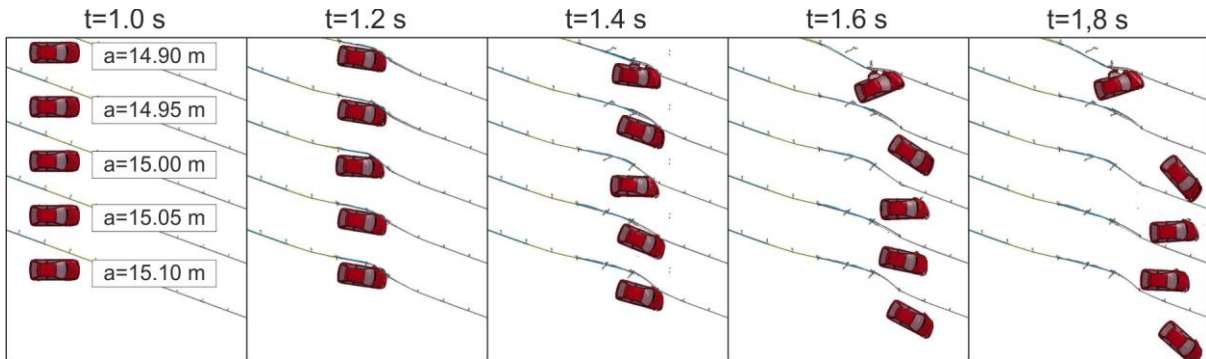


Fig.12: Sequence of collision for $a = 14.9 \div 15.1$ m.

Impact location (a), m	ASI, -	THIV, km/h	PHD, g
+14.90	1.12	31.5	18.0
+14.95	1.10	31.0	13.4
+15.00	1.40	38.5	12.4
+15.05	1.09	28.9	14.5
+15.10	1.16	30.3	14.2

Table 3: Influence of small variation of impact location on the results

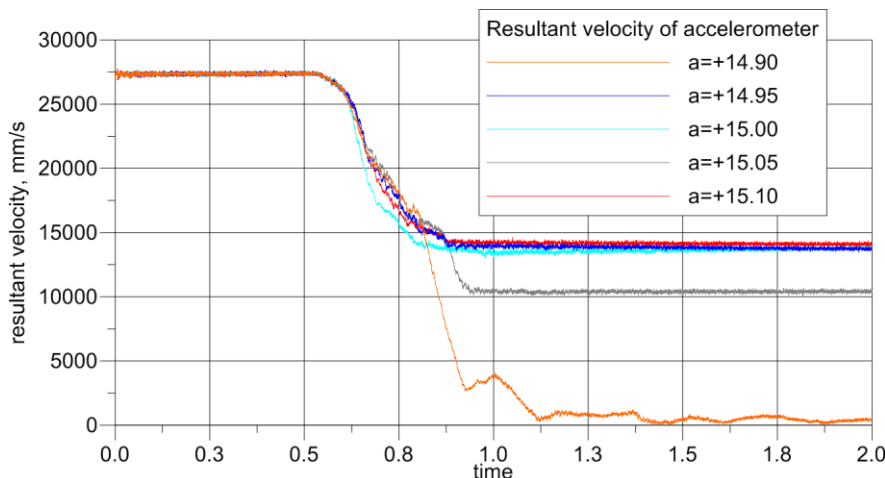


Fig.13: Resultant velocity of accelerometer for cases $a = 14.9 \div 15.1$ m.

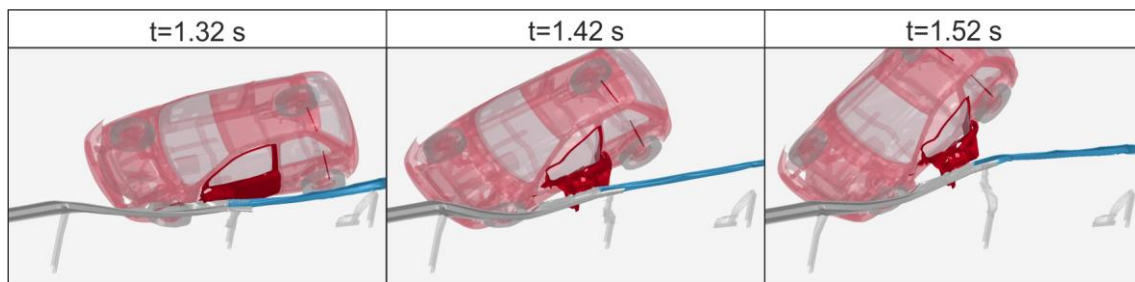


Fig.14: Details of collision for $a = 14.9$ m.

5 Summary

Report presents series of numerical collision simulation between 900 kg small car and short section (20 + 2x8 m) of road barriers in regime of TB 11 standard test.

As demonstrated, short barrier is capable of safely preventing vehicle from going to the shoulder. Most dangerous is collision with trailing sections.

Detailed analysis of small variation of impact point shows that minor change of initial conditions may lead to important changes in performance parameters. Namely, impact severity index changed from C to B.

Every numerical simulation should be carefully reviewed to eliminate and avoid any nonphysical behaviour, like deadlocks and not released contacts. Fulfilment of this requirement is essential to threat simulation as reliable tool in crashworthiness analysis.

6 Acknowledgements

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7 Literature

- [1] Jamroz K., Burzyński S., Witkowski W., Wilde K.: "Numerical methods for the assessment of bridge safety barriers." In: Kleiber M, editor. Adv. Mech. Theor. Comput. Interdiscip. Issues, London: Taylor & Francis Group; 2016, p. 231–4.
- [2] Goubel C., Di Pasquale E., Massenzio M., Ronel S.: "Comparison of crash tests and simulations for various vehicle restraint systems", 7th European LS-DYNA Conference, Salzburg, Austria, DYNAmore GmbH, 2009, s. 1-12.
- [3] Vasenjak M., Borovinšek M., Ren Z.: "Computational simulations of road safety barriers using LS-DYNA", 6. LS-DYNA Anwenderforum, Frankenthal, DYNAmore GmbH, 2007, s. 1-8.
- [4] Teng T., Liang C., Tran T.: "Effect of various W-beam guardrail post spacing and rail heights on safety performance", Advances in Mechanical Engineering, Vol. 7, No. 11, 2015, s. 1-16.
- [5] Ren Z., Vesenjak M.: "Computational and experimental crash analysis of the road safety barrier", Engineering Failure Analysis, 12, 2005, s. 963-973.
- [6] BS EN 1317-1,2:2010, "Road restraint systems", European Standard, 2010.
- [7] DET NORSKE VERITAS AS. „Determination of Structural Capacity by Non-linear FE analysis Methods“ 2013.