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ACCESS BRIDGE DESIGN MEASURES FOR SAFETY INCREASE OF ROAD INFRASTRUCTURE

ABSTRACT

Solid barriers represent danger for the driver in case of traffic lane escape. This threat can be represented by a drainage ditch culvert face. The access bridge is not usually conspicuous enough near the traffic lane so that the driver could ditch and crash this barrier in case of an exceptional situation such as avoidance manoeuvres. This work deals with a technical solution of access bridges with an integrated deformation zone which was designed on the ground of a detailed analysis of current types of the construction. The new technical solution was proved by means of a numerical simulation of passenger car impact and compared with the current design of culvert faces.

KEY WORDS

traffic accident, passive safety, road infrastructure, access bridge, drainage ditch, solid barrier, deformable block

1. INTRODUCTION

Road accident consequences are influenced by many factors. The destruction effect on passengers in case of road traffic accident is decreased especially due to deformation zones optimization and application of a restraint system. There is still a significant reserve as for the reduction of aggressiveness of solid barriers. The danger of solid barriers can be illustrated by the stiffness and firmness of the barrier which affects the impact hardness. From statistical point of view traffic accidents with solid barriers represent in the Czech Republic one sixth of all accidents in the given year, but they are more serious because they are responsible for one fourth of all traffic accident victims. There are generally two kinds of solid barriers involved in traffic accidents; natural (such as a tree) or artificial (such as traffic light columns, posts with advertising banners). Road design and its surrounding have an effect on more than 30% of all accidents. [1] Safety measures applied to roads and their surroundings bear great potential for diminishing accident consequences. An ideal solution would be to operate modern and safe vehicles on the roads that meet urgent requirements. Modern and safe road construction avoids aggressive barriers, which are critical in case of an accident. Solid barriers can be represented by a drainage ditch culvert face (short industrial bridges, self-supporting pas-

Figure 1 - Contemporary construction of over-passes (access bridges)

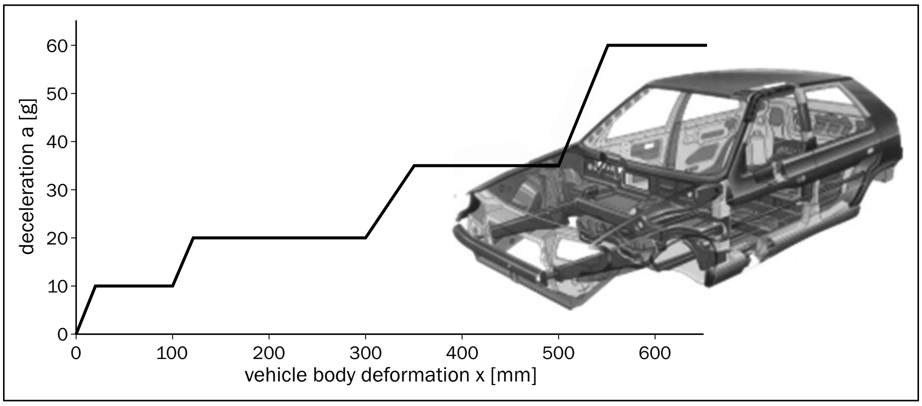


Figure 2 – Typical characteristic of deformation [2]

sage to field) – so far rather neglected as an accident cause (*Figure 1*). The access bridge is not usually conspicuous enough near the traffic lane so that the driver could ditch and crash this barrier in case of an exceptional situation such as avoidance manoeuvres. The driver does not really expect a crash with this artificial barrier. For this reason the above mentioned barrier is extremely dangerous for the traffic participants.

2. BASIC HYPOTHESIS

The vehicle can hit the barrier with various parts of its body. The deceleration function of the vehicle is not linear during the impact, because the course of the resulting contact force F_d and the deceleration course of an undistorted part of the body are affected not only by girders but also by engine(s) and by bodywork equipment. The ability to absorb the impact energy is the fundamental feature of the vehicle body (*Figure 2*). The structure has to have sufficient ability (depending on the type of strain) to transform the kinetic energy into the deformation work during the impact, so that the limit values of biomechanical criteria were not surpassed. Also, the deformation must not occur within the passenger space, where it might cause compression or cutting injuries to passengers.

The vehicle is deformed both elastically and plastically. The equation of energy balance describes the parity of kinetic energy at the moment of impact and deformation energy during maximum deformation. [3]

$$\frac{1}{2} m \cdot v_0^2 = \int_0^{x\,\max} F dx \qquad (1)$$

where m [kg] stands for the weight of the vehicle, v_0 [m/s] stands for impact velocity, F [N] stands for instant deformation force, and x [m] stands for the magnitude of the vehicle deformation. The elastic deformation (material tension, which has not done any deformation work) will be reflected in the restitution coefficient k after termination of the first impact phase. The restitution coefficient is a negative ratio of the velocity of repercussion from and the velocity of impact on the solid barrier. At higher impact velocities it is recommended to take into account the plastic deformation only, because the restitution coefficient does not even reach the value of 0.1. The equation of vehicle motion after the moment of barrier impact is:

$$m \cdot \ddot{x} + F_{def} = 0 \qquad (2)$$

where m [kg] stands for the weight of the vehicle, $\ddot{x}$ [m.s^{-2}] is the second derivative of an undistorted part of the vehicle body and F_{def} [N] stands for the deformation force.

A simple mathematical model in *Figure 3* simulates the front impact of a passenger car on a solid barrier this way:

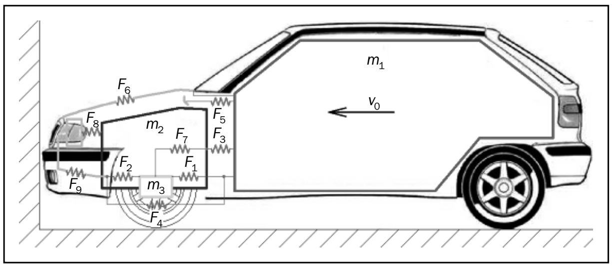


Figure 3 - Simple dynamic model simulating front impact

Weights m_1, m_2 and m_3 represent body, engine and axle, respectively. Forces F_1 to F_9 represent deformation forces between particular components and v_0 represents velocity of the vehicle.

Figure 4 - Collision of an automobile with an access bridge – car body deformation

The velocity of passenger's body v_c is at the moment of impact equal to the velocity of vehicle v_a. The vehicle transforms its kinetic energy to the deformation work at its body front from the moment of impact, thus decreasing its velocity to present velocity v_v. In case the passenger does not use the seat belt, their body hits the interior of the vehicle with initial velocity v_c. In case the passenger uses the seat belt, the impact velocity of their body hitting the interior of the vehicle can be recorded as:

$$v_n = v_c - v_v = \sqrt{2 \cdot h \cdot a_v} \tag{3}$$

where a_v [m.s^{-2}] stands for deceleration of the vehicle during collision, h [m] stands for free displacement of the passenger's body before the restraint effect of the seat belt starts to apply to it. Energy of the impact is given as:

$$E_n = \frac{1}{2} \cdot m_t \cdot v_n^2 \tag{4}$$

where m_t [kg] stands for weight of the body and v_n [m.s^{-1}] stands for impact velocity. During the impact of the body on the barrier, its motion changes from uniform motion to (non-uniformly) decelerated motion. The energy of the impact has to be absorbed by tissues – injury is caused due to surpassing the limit values. This process lasts from the moment of impact until the moment when the velocity of the passenger is equal to the vehicle velocity again.

The passenger using the seat belt is connected with the vehicle by the seat belt, and thus the difference of v_c and v_v is negligible. The free inertial motion (displacement) of the body h was eliminated by the activation of the seat belt pre-stretcher ($h \to 0$). During high collision velocities, the seat belts can actually cause fatal injury (the boundary is about 5 kN); therefore there are force limiters installed in the loop of the seat belt. These construction measures decrease the instant force effect of the seat belt, but on the other hand, they put the passenger in danger of hitting the vehicle interior with higher collision velocity. The calibration of this sensitive boundary is subject of permanent research.

Despite success achieved in this area, it is necessary to search for reserves in the cooperation of particular types of restraint systems and Pre-Crash sensors.

3. SURVEY METHOD

There have been analysed 1,356 traffic accidents in the solid barrier section (walls, bridges, parts of bridges) from the sources of the police in the Czech Republic. There were 135 accidents in Central Bohemia extracted based on the entry key criteria; impact of car into access bridge with passenger injuries. It has been found that firm barrier does not primarily have to be the cause of accident, but it affects in a serious manner the impact consequences. There were 59 passengers injured during the impacts, 32 of them were slightly injured, 19 passengers were seriously injured and 8 persons died. In 45% of cases the drivers deviated and consequently impacted the culvert face on the left side of the road, in 55% on the right side of the road. It means that it is absolutely urgent to secure both faces of the access bridge i.e. in both traffic directions. [4]

Three fundamental accident scenarios have been identified on the base of deep analysis of 36 accidents with injury consequences.

3.1 "Scenario No. 1"

This "Scenario No. 1" group of accidents represents 8% of the monitored statistic file of 36 accidents. The vehicle swerves to a shallow ditch (type A, exceptionally B, C; see *Figure 9*), where it collides with a non-deformable face of the access bridge, which is hit with its front lower edge of the bumper or even only with the front wheel tire. The developed deformation energy is used to deform the front wheel suspension, which is then pushed backwards. In the next step, the front wheel props against the bodywork of the vehicle, while the upper edge of the barrier is under the centre of rotation of the wheel, which means that after the deformation of the wheel, the vehicle is "thrown upwards", released from the ditch and "rubs" on through the surrounding terrain until it reaches its final position. So the kinetic energy is not wasted only in the impact. There is danger of secondary injuries then. Usually no severe injuries occur during this type of accident. Commonly, the front part of the vehicle, the front wheel suspension, the bodywork around the A-pillar and the flooring are damaged. The primary deformation zones of the vehicle are not affected by the impact. As for older vehicles, such damage is evaluated as uneconomical to repair, i.e. total loss (*Figure 5*).

3.2 "Scenario No. 2"

This "Scenario No. 2" group of accidents represents 73% of the monitored statistic file of 36 accidents. The vehicle swerves to a ditch (type B or C, exceptionally A; see *Figure 9*) in the immediate proximity of the access bridge, where it collides with a non-deformable face of the access bridge, which is hit by the edge of the front bumper (the longitudinal beam of the bodywork is not affected). The developed deformation energy is used to deform the front wheel suspension, which is then pushed backwards. In the next step, the front wheel props against the vehicle body, while the upper edge of the barrier is now above the centre of the rotation of the wheel, that means that after the deformation of the wheel and the bodywork, the vehicle is "captured". The deformation force is not applied to deformation zones of the vehicle, devices in the engine compartment are affected by the deformation only partially. The activation of restraint systems does not proceed

Figure 5 - Model situation from Scenario No. 1

Figure 6 - Model situation from Scenario No. 2, final position of the vehicle after the accident – IRS intervention

in a standard way. The deformation force does not begin to have full effect until the deformation reaches the firewall, i.e. the boundary between the front part of the vehicle and the section for passengers. The bodywork in its central part is not endowed with enough space for controlled deformation of the deformation zones. There is danger of bodywork collapse, i.e. the bodywork does not create sufficient space for the survival of passengers. This type of accidents usually causes severe injuries of passengers and total loss of the vehicle. The large-scale damage of the vehicle body combined with passenger injuries does not allow the passengers to leave the vehicle after the accident without someone else's help (*Figure 6*).

3.3 "Scenario No. 3"

This "Scenario No. 3" group of accidents represents 19% of the monitored statistic file of 36 accidents. The vehicle swerves to a ditch (type C, exceptionally B; see *Figure 9*) where it collides with the non-deformable face of the access bridge, which is hit by the vehicle front. Most of the kinetic energy is transformed only by the primary impact, the rest of the kinetic energy can, in case of an eccentric impact, roll over the vehicle. The developed deformation energy is used to deform the front deformation zone and the devices in the engine compartment (*Figure 7*). The restraint systems are usually activated (if the vehicle is equipped with them).

Figure 7 - Model situation from Scenario No. 3

The most frequent causes for swerving into the road ditch are: avoiding the oncoming vehicles, fatigue (micro sleep), uncontrolled overtake manoeuvre with avoiding oncoming vehicles and skidding of the vehicle after passing the curve.

Here there are several strategies how to reduce the consequences of car collision with the solid barrier:

– to increase the car passive safety, which means higher weight, hence an increased energetic balance during the considered impact. At the end it brings greater construction, material, technological and economic requirements both for car design and production;

Figure 8 –Access bridges on road II/605 in the section Cerhovice – Žebrák, example of the construction

– to develop such car active safety systems, which minimize occurrence of collisions (virtual rails with an aim to eliminate the human factor and the driver's role);
– to change the solid barrier construction or alternatively to separate this barrier with additional technical measures from traffic and therefore to reduce its danger.

4. METHODOLOGY OF CLASSIFICATION OF ACCESS BRIDGE DANGEROUSNESS

From the survey of the access bridge design, made by the first author, on the roads of II. and III. category in the Central Bohemia region (315 objects), it was possible to formulate 3 model geometries of the whole construction inclusive the ditch geometry (*Figure 9*). In option A, the width of the ditch reaches 0.5 m and the ditch depth is 0.25 m. On the contrary, in option C the width of the ditch reaches 2 m and the ditch depth is 1 m. Seven percent of the surveyed access bridges were non-typical regarding their construction (for example: the width of the ditch reached 4.5 m and the ditch depth was 2.25 m), so that they could not be included in the survey.

Parameter X_2 can reach values of D, E or G according to the following specification:

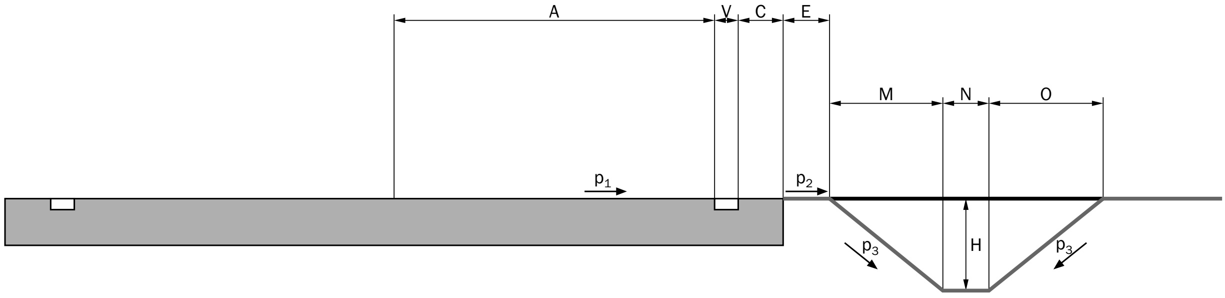
D – rigid, non-deformable face (compact), such a face is usually composed of a concrete monolith. Concrete lintels with a narrow impact edge also belong to the category D, E - rigid, non-deformable face (brick), such a face is usually composed of a lining from concrete bricks, stones or burnt bricks joined with cement mortar, F – rock-fill face of the access bridge, G – face with a rigidity decreased by means of some construction measure.

Note: In specific cases, the present conditions of the access bridges were assessed and the access bridges were then sorted into specified categories based on these assessments. In other words, a significant damage or aging of the face could lead to reassessment of parameter X_2.

4.1 Class of dangerousness [5]

The class of dangerousness of each access bridge is assessed according to a particular code of dangerousness CD_X_1X_2, where:

– 1st Class has the Code of dangerousness CD_BD, CD, or CE and represents serious threat to passengers in the vehicle. In these cases, the anticipated collision scenarios are of type 2 or 3. The face of the access bridge is usually a concrete monolith and its height is between 0.5 and 1 metre.
– 2nd Class has the Code of dangerousness CD_BE, CF, BF or AD and represents threat to passengers



Parameter X_1	A [m]	V [m]	C [m]	E [m]	M [m]	N [m]	O [m]	H [m]	p_1	p_2	p_3	face width	face height
A	3.5	0.25	0.5	0.5	0.15	0.2	0.15	0.3	2%	8%	1:0.5	0.5	0.25
B	3.5	0.25	0.5	0.5	1.25	0.5	1.25	0.5	2%	8%	1:2.5	2	0.5
C	3.5	0.25	0.5	0.5	1.25	0.5	1.25	1	2%	8%	1:1.25	2	1

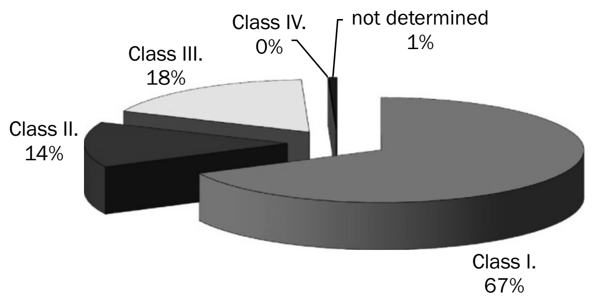
A [m] the traffic lane width
V [m] the edge line width
C [m] the hard shoulder width
E [m] the soft shoulder width
M [m] the width of the ditch slope
N [m] the width of the bottom of the ditch
O [m] the width of the ditch slope
H [m] the depth of the bottom of the ditch
p_1 the cross slope of the traffic lane and the hard shoulder
p_2 the cross slope of the soft shoulder
p_3 the cross slope of the ditch

Figure 9 – Specimen of geometrical layout of the access bridge construction site

in the vehicle. In these cases, the anticipated collision scenarios are type 2 or 3. The face of the access bridge is usually composed of a rigid, non-deformable material and its height is between 0.5 and 1 metre.

– 3rd Class has the Code of dangerousness CD_AE or AF and represents little threat to passengers in the vehicle. In these cases, the anticipated collision scenarios are of type 1 or possibly 2. The face of the access bridge is not rigid, strong or high enough to "capture" the colliding vehicle. The face of the access bridge is usually composed of a rock-fill material and its height is between 0.2 and 0.5 metre.

– 4th Class has the Code of dangerousness CD_BG, CG, AG and represents faces of access bridges which are adjusted for the potential impact of the vehicle.



Class	Code CD_	Quantity
I.	CD_ BD	73
I.	CD_ CD	127
I.	CD_ CE	13
II.	CD_ BE	17
II.	CD_ CF	2
II.	CD_ BF	2
II.	CD_ AD	23
III.	CD_ AE	23
III.	CD_ AF	33
IV.	CD_ BG	0
IV.	CD_ CG	0
IV.	CD_ AG	0
X.	not determined	2

Figure 10 - Classes of dangerousness of the access bridges [5]

5. SUGGESTED MEASURES

The suggested measures are based on the analysis of collision sites, analysis of the access bridge constructions, the study of reference sources and relevant standards and the knowledge base.

5.1 Reduction of the number of access bridges

As it follows from the access bridge research and from its assessment many access bridges are not in operation any more, there is no maintenance (they are clogged) and no one performs their repairs (the access bridges are still damaged even several years after the collision). There are no exact records of the access bridges – the property rights are not exactly defined. In case of road reconstruction, the non-functional and the non-permitted access bridges should be removed. [6]

5.2 Relocation of the access bridge

The design of the road has to contribute to the uniformity, recognisability and intelligibility of the route.

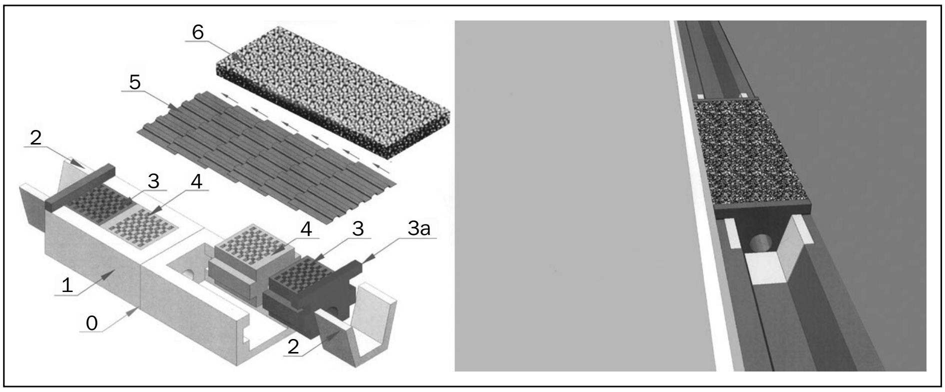


Figure 11 – Construction of the access bridge with the integrated deformation zone [5]

Note: 1 – pre-cast monolithic base, 2 – front base, 3 – deformation face, 3a – bumper, 4 – deformation block, 5 – enclosure, 6- fill, 0 – symmetry plane.

Nevertheless, this prevention, which is already included in the design phases, fails in the Czech Republic. Based on the police statistics, it is obvious that the most common cause of traffic accidents is the inappropriate speed, but it is still possible to find cases of execution of dangerous solid barriers on new or newly reconstructed roads, too. In the analysis of the collision process there are causes of the development of accidental situations and circumstances under which the vehicle leaves the road surface in the collision way:

– straight stretch – avoiding the oncoming vehicles, micro sleep, technical failure,
– curve – skid, wrong road design.

Based on the analysis of real traffic accidents, it is possible to say that the collision sites are spread out through the entire roadway network and thus it is not possible to decrease the risk of the collision with the rigid face of access bridges just by means of relocating this bridge. Therefore, it is necessary to adopt different measures which are mentioned further in the text.

5.3 Adjustments of the face of the access bridge

– The optimization of the shape of the face of the access bridge – altering its inclination (skew) is one of the possibilities how to minimize the probability of the development of biomechanical injuries of the passengers, which is connected with the collision of the vehicle with the face of an access bridge. This innovative solution has been used recently, but no research of the influence of a particular oblique execution of the face upon the development of the motion after collision of the vehicle has been conducted.
– Impact absorbers in front of the access bridge – the access bridge of a classical construction can be (if there is enough space) equipped with impact absorbers, which can be placed on the present, vertical, non-deformable face of the access bridge. The absorbers have to be designed in such a way that they do not block the water flow in the drainage ditch. Such technical measures have to be executed, which prevent the vehicles using the access bridge to drive on the construction of the impact absorber with low-bearing capacity as well.
– Restraint safety systems – the road restraint systems (as defined) are restraint systems designed and installed for the purpose of diminishing the consequences of the vehicle potentially leaving the road surface in locations where such leaving of the road would be dangerous. These systems can prevent the vehicles from swerving to the ditch and thus from the collision with the face of the access bridge (prevention), but they do not diminish the consequences in case of collision.
– Design changes in access bridge construction – idea for a new technical solution of access bridges is based on the possibility of vehicle crash energy transformation into deformation work of the access bridge itself. The new technical design of the safe access bridge over the road ditch consists of the elements enabling horizontal deformation and at the same time providing vertical sustainability for the situation when the vehicle crosses the ditch. Such a construction replaces the deficits of the existing ones, so that it increases substantially absorbance in potential impact zone and reduces the impact force indicating the rate of load affecting the passengers and the rate of vehicle deformation. The newly designed access bridge consists of the prefabricated element and of minimally one front part serving as the deformation zone with an integrated rigid buffer. Both the front part and the buffer enable a water flow through the bridge. This construction assembly makes it possible to adjust its stiffness according to the nature of the traffic nearby the passage (*Figure 11*).

6. RESULTS

The benefit of the designed construction was proven by the mathematical model simulation in Virtual Crash and MADYMO software (*Figure 12*). The results are published in *Table 3*. A course of accidental motion of the vehicle Skoda Fabia 1st generation (loaded from the database) was created in the Virtual Crash environment, simulating the collisions with the solid barrier. [7] The resultant values of the position of the centre of gravity of the vehicle and the inclination of the vehicle served as an input to MADYMO, which evaluates the process of an accident from the perspective of a biomechanical load affecting car passengers. The generated models proved the effectiveness of the designed technical measures in dependence on the simulated impact and the post-impact motion process. On the other side, the models endorsed mathematically determined characteristics of the deformable blocks of the access bridge with the integrated deformation zone.

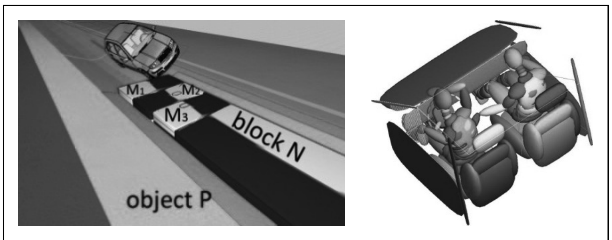


Figure 12 - Impact configuration (Virtual Crash), effect on car passengers (MADYMO)

The deformation forces capable of activating the protection function of the access bridge are dependent on the rigidity of the bodyworks of ordinary vehicles. *Figure 13* depicts the deformation forces applied to the front of the vehicle during the impact on the rigid non-deformable barrier. The curves represent the "old design" vehicles and one modern vehicle using modern trends in the passive safety of a vehicle. No deformation force curve of a van is available. The theoretical curve (dashed curve) is the "Step-progressive" deformation characteristic of the body front structure".

The deformation-force curves of the body fronts from *Figure 13* have determined the deformation levels of the deformation blocks to be between 100 kN to 300 kN.

The optimization (tuning) of particular deformation levels is done according to the calculation where from the kinetic energy of the vehicle the deformation energies needed for the block deformations are subtracted.

$$\frac{1}{2} m \cdot v_n^2 = \int_0^{x\max} F dx \tag{5}$$

where m [kg] stands for the weight of the vehicle, v_n [m/s] stands for the impact velocity, F [N] stands for the instantaneous deformation force and x [m] stands for the deformation strain.

$$E_K - \left(E_{K\ veh-def} + E_{K\ block-def}\right) - E_{Kr} = 0 \tag{6}$$

where E_K stands for the kinetic energy at the moment of impact, $E_{K\ veh-def}$ stands for the kinetic energy used

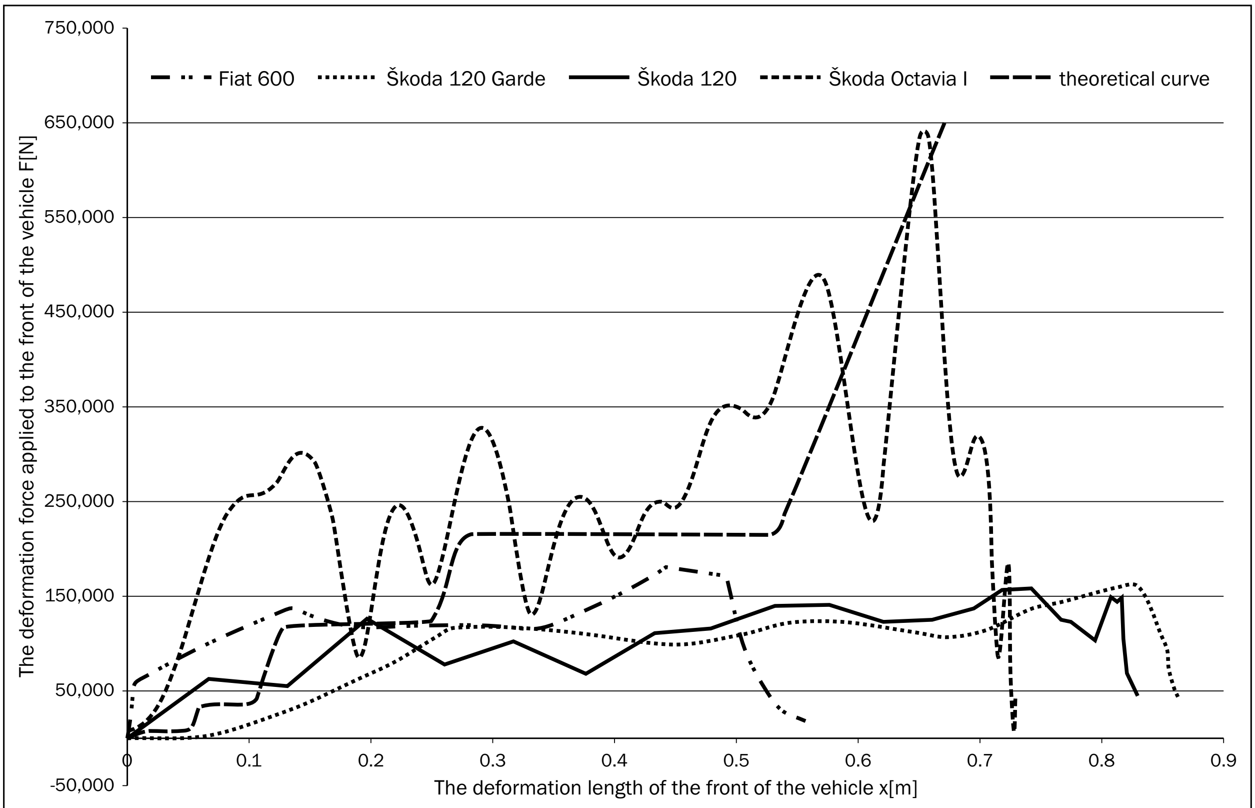


Figure 13 – Deformation characteristics of the body fronts – step-progressive deformation characteristics [5]

for the destruction of deformation zones of the vehicle, $E_{K\ block-def}$ stands for the kinetic energy transformed into the deformation work deforming the block in the access bridge and E_{Kr} stands for the remaining kinetic energy, which was not transformed into the deformation work by any deformation zone. The vehicle impacts on the partition of the monolithic base with the remaining kinetic energy. This energy is absorbed by the whole vehicle body.

The performed calculations verify the restraint levels A, B and C (*Table 1*) but they do not take into account the passive safety of the vehicle itself because of the lack of corresponding input data (the calculation is performed for the most unfavourable case – vehicle with minimum passive safety level). They were carried out for three levels of vehicles (*Table 2*):

- small passenger vehicles – of a weight of 950 kg,
- middle class passenger vehicles – of a weight of 1,750 kg,
- large passenger vehicles and vans – of a weight of 3,500 kg.

Table 1 - Restraint levels of the deformation block

Retention level	Maximum speed limits	Intended impact speed
A	≥ 110 km/h	100 km/h
B	90 km/h to 109 km/h	80 km/h
C	< 90 km/h	50 km/h

The remaining speed [km/h] is the speed of impact of the vehicle on the rigid, non-deformable partition of the monolithic base. The E_{Ka} *Absorbed deformation energy* [%] represents the efficiency of deformation blocks for every variant (value ≥ 100% means that the vehicle was stopped by deformation blocks).

The *penetration distance* [m] represents the utilization of the length of the deformation blocks in the access bridge. The length of the deformation block depends on its construction. The testing speed is in relation with the speed limit of the particular road stretch. [8]

To compare the efficiency of the proposed construction measures on the access bridge during all collision process scenarios (see *Table 3*), the following biomechanical criteria [9] were computed using the dummy Hybrid III:

- HPC criterion

  The head performance criterion is defined by the following formula:

$$HPC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a \cdot dt\right]^{2.5} (t_2 - t_1) \qquad (7)$$

  where a = resultant acceleration in g, t_1 a t_2 = time points, which determines the beginning and the end of the time interval, where the HPC value is maximum. HPC limit value is 1,000.

- 3MS criterion

  This criterion defines the acceleration limit values measured on the chest of a testing dummy during the vehicle crash test. The acceleration higher than 60 g must not act longer than 3 ms.

- CTI (Combined Thoracic Index) criterion

  CTI is defined by the following formula:

$$CTI = \left(\frac{A_{max}}{A_{int}}\right) + \left(\frac{D_{max}}{D_{int}}\right) \qquad (8)$$

  where A_{max} is the maximum acceleration acting on an upper thoracic spine for 3 ms, D_{max} is maximum thoracic deformation and A_{int} and D_{int} are constants dependent on dummy properties.

- VC criterion

  V*C criterion is used while testing at a collision velocity of 30 m/s and above (over 100 km/h). It is calculated by using this formula:

$$V * C = \frac{d[D(t)]}{dt} * \frac{D(t)}{D} \qquad (9)$$

Table 2 – Design of the deformation properties of the deformation blocks in the access bridge

The proposed vehicle weight m [kg]	The proposed impact speed I [km/h]	The block name	The working length of the block [m]	The deformation force acting on the block: Phase I.	The deformation force acting on the block: Phase II.	The deformation length of the block: Phase I.	The deformation length of the block: Phase II.	The remaining vehicle speed [km/h]	Absorbed deformation energy [%]	The penetration distance [m]
950	100							0	132	2.58
	80							0	206	1.92
	50							0	527	0.92
		BLOK M1	1	100 kN	150 kN	2/3	1/3			
1,750	100							53	72	3.00
	80	BLOK M2	1	100 kN	200 kN	2/3	1/3	0	112	2.83
	50							0	286	1.57
		BLOK M3	1	100 kN	300 kN	2/3	1/3			
3,500	100							80	36	3.00
	80							53	56	3.00
	50							0	143	2.44

Table 3 - Biomechanical criteria of the passengers (in dependence on the simulation variant)
(Example: Test A 50 C – letter C means concrete (rigid) culvert face, Test A 50 B – letter B means deformable block)

TEST		BIOMECHANICAL CRITERION										CHANGE in %
		HPC - 15 ms		HPC - 36 ms		3 ms		CTI		VC		
						[g]				[m/s]		
		driver	passenger	driver	passenger	driver	passenger	driver	passenger	driver	passenger	
Access bridge VARIANT A	A_50_C	2.6072	4.0829	3.7307	5.4539	195.34	172.71	0.29309	0.2392	2.03E-03	1.87E-03	
	A_50_B	2.6072	3.7307	4.0829	5.4539	195.34	172.71	0.29309	0.2392	6.83E-03	1.85E-03	
	Decrease[%]	0	8.6	-9.4	0	0	0	0	0	2.9	1	-0.3
	A_80_C	2.8364	3.5761	3.6282	4.8477	199.87	169.19	0.31067	0.25621	6.18E-03	2.69E-03	
	A_80_B	2.8364	3.5761	3.6282	4.8477	199.87	169.19	0.31067	0.25621	6.18E-03	2.69E-03	
	Decrease[%]	0	0	0	0	0	0	0	0	0	0	0
	A_100_C	2.8364	3.5761	3.6282	4.8477	199.87	169.19	0.31067	0.25621	6.18E-03	2.69E-03	
	A_100_B	2.8129	3.5831	3.6917	4.8686	199.56	169.49	0.33208	0.25811	1.87E-02	3.31E-03	
	Decrease[%]	0.8	-0.2	-1.8	-0.4	0.2	-0.2	-6.9	-0.7	-202.2	-22.7	(0)
Access bridge VARIANT B	B_50_C	308.03	1300.3	519.37	1300.3	815.31	815.31	1.4677	1.6012	0.57426	0.71597	
	B_50_B	22.962	25.387	42.427	28.743	199.55	198.12	0.48646	0.49173	9.87E-02	8.76E-02	
	Decrease[%]	92.5	98	91.8	97.8	75.5	75.5	66.9	69.3	82.8	87.8	-83.8
	B_80_C	97,049	3.93E+05	97,049	3.93E+05	1,206.5	2,490.4	2.1864	3.6157	1.5396	1.3378	
	B_80_B	109.39	132.99	183.69	153.87	316.35	329.64	0.72028	0.75422	0.18723	0.20393	
	Decrease[%]	99.9	100	99.8	100	73.8	86.8	67.1	79.1	87.8	84.8	-87.9
	B_100_C	73,769	15,436	73,769	15,436	2,192	1,900.4	3.4061	3.1557	1.8613	2.2437	
	B_100_B	201.01	334.36	278.4	367.06	342.13	356.06	0.81618	0.84042	0.24627	0.2381	
	Decrease[%]	99.7	97.8	99.6	97.6	84.4	81.3	76	73.4	86.8	89.4	-88.6
Access bridge VARIANT C	C_50_C	106.39	95.611	139.08	125.64	357.54	291.99	0.82697	0.75021	0.34922	0.25601	
	C_50_B	16.444	14.247	28.623	22.25	255.12	173.38	0.50989	0.41271	0.10693	0.10524	
	Decrease[%]	84.5	85.1	79.4	82.3	28.6	40.6	38.3	45	69.4	58.9	-61.2
	C_80_C	38,723	29,976	38,723	29,976	822.94	1,014.9	1.3483	1.6781	0.26042	0.52298	
	C_80_B	42.635	138.1	60.367	138.1	361.19	640.78	0.64015	1.0405	7.18E-02	0.19808	
	Decrease[%]	99.9	99.5	99.8	99.5	56.1	36.9	52.5	38	72.4	62.1	-71.7
	C_100_C	6,158	2,233	6,158	2,233	752.05	875.03	1.2615	1.5292	0.2173	0.39747	
	C_100_B	437.64	621.41	502.92	621.41	932.66	1,101.7	1.39	1.7427	0.22966	0.29076	
	Decrease[%]	92.9	72.2	91.8	72.2	-24	-25.9	-10.2	-14	-5.7	26.8	-27.6

where $D(t)$ stands for chest deformation during time *t*. Letter *D* represents the defined quantity of the half of the size of the deformed chest.

The maximum allowable value of this criterion is 1.0 m.s^{-1} and the maximum deformation in the rib area is 42 mm. According to ECE Regulation No. 94 and 95 it is applied to both front and lateral impact.

7. DISCUSSION

After comparison of the results from the chapter Mathematical modelling we can say that the changes made in the construction of the access bridge diminish the biomechanical stress applied to the passengers after the collision with the solid barrier.

Variant A – the access bridges of a small size of construction, where the impact is anticipated according to Scenario No. 1 (the upper edge of the barrier is under the centre of the rotation of the wheel, after the deformation of the wheel, the vehicle is "thrown up", released from the ditch and "rubs" on through the surrounding terrain to its final position) cannot be effectively protected by executing the access bridge with the integrated deformation zone. The found values of the biomechanical criteria are negligible in both subvariants (with the deformation zone or without).

The protection executed according to the proposed measures 1 to 3 (see chapter 5) can effectively diminish the damage to the vehicle.

Variant B – represents the eccentric impact according to Scenario No. 2.

The primary impact causes the vehicle body to rotate (yaw) and the passengers are thrown slantwise (approx. 20°) towards the A-pillar of the bodywork – the contact with the A-pillar and door glass can be expected. These parts can be equipped with additional restraint systems (airbags). According to Scenario No. 2, the deformation zones of the vehicle are not activated, the impact on the unprotected face of the access bridge causes hard and short impulse. The post-accidental process is very complicated; therefore, it is possible to anticipate the development of injuries even during the post-impact motion to the final position. According to executed simulations, the access bridges with the integrated deformation zone can diminish the values of the biomechanical criteria of the head and the chest, and eliminate unacceptable post-accidental motion, including the rotation (bouncing) of the vehicle to the positions out of/across the road surface while the deformation element of the access bridge stops the vehicle in its proximity.

Variant C – the access bridges large in size of construction, where the impact is anticipated according to Scenario No. 3 (a vehicle hits the access bridge with a large part of its front - the kinetic energy is wasted in the primary impact) can be effectively protected by executing the access bridge with an integrated deformation zone. Deformation blocks have diminished the biomechanical criteria of the head, partially even the chest, but for the impact speed of 100 km/h. The deformation blocks provide the intended protection.

8. CONCLUSION

The paper deals with the issue of dangerousness (aggressiveness) of the solid barriers on the roadway network, pointing out the fatal consequences of collisions with the solid barrier arising from statistics of traffic accidents.

The survey part was focused on the analysis and assessment of real traffic accidents occurring in the Central Bohemian Region, with the focus on assessing the angle of the vehicle as it swerves from the road surface, the impact angle on the access bridge, secondary collisions, performance of the deformation zones of the vehicle and the passengers' injuries.

A new methodology of assessment of the danger of access bridges in connection with the spatial layout of the road was created afterwards. After the analysis of the vehicle body deformations, generalization of the collision process regarding the design of the construction measures, the suggestion of a new design of the access bridge with an integrated deformation zone was demonstrated by mathematical simulations in the Virtual Crash and MADYMO software. The performed simulation confirmed the significant passive safety contribution of the authors' project, especially in the case of large access bridges (variant C).

For further research it is necessary to create more precise models, including a detailed design of the deformation zone of the access bridge and to find a convenient material for the construction.

The demonstrated method of the simulation can be used even in the forensic practice.

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ABSTRAKT

NÁVRH KONSTRUKCE SAMOSTATNÝCH SJEZDŮ PRO ZVÝŠENÍ BEZPEČNOSTI DOPRAVNÍ INFRASTRUKTURY

Pevné překážky představují velké nebezpečí pro posádku vozidla v případě vybočení z jízdního pruhu. Toto nebezpečí může být reprezentováno například tuhým čelem samostatného sjezdu. Tyto objekty jsou často nenápadné a vyskytují se hustě podél sítě pozemních komunikací, takže řidič je v případě havarijního pohybu, který může být zapříčiněn například vyhýbacím manévrem, vystaven značnému riziku kolize s touto pevnou překážkou. Tento příspěvek se zabývá technickým řešením konstrukce samostatného sjezdu, které bylo navrženo na základě podrobné analýzy současných typů konstrukcí. Nové technické řešení bylo ověřeno matematickou simulací nárazu osobního vozidla a výsledky porovnány s výsledky nárazu do současného typu konstrukce.

KLÍČOVÁ SLOVA:

dopravní nehoda, pasivní bezpečnost, samostatný sjezd, odvodňovací příkop, pevná překážka, deformační blok

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