Road Safety Barriers, the Need and Influence on Road Traffic Accidents

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Abstract. Constantly increasing intensity of road traffic and the allowed speed limits seem to impose stronger requirements on road infrastructure and use of road safety systems. One of the ways to improve road safety is the use of road restraint systems. Road safety barriers allow not only reducing the number of road traffic accidents, but also lowering the severity of accidents. The paper provides information on the technical requirements of road safety barriers. Various types of road safety barriers and their selection criteria for different types of road sections are discussed. The article views an example of a road traffic accident, which is also modelled by PC-Crash computer program. The given example reflects a road accident mechanism in case of a car-to-barrier collision, and provides information about the typical damage to the car and the barrier. The paper describes an impact of the road safety barrier type and its presence on the road traffic accident mechanism. Implementation and maintenance costs of different barrier types are viewed. The article presents a discussion on the necessity to use road safety barriers, as well as their optimal choice.

1. Introduction
Along with the increasing road traffic intensity, the issue of road traffic safety is becoming more important requiring further attention from all the institutions. Road traffic accidents (RTA) are generally caused by vehicle diversion from the intended direction. If the driver loses attention, but the vehicle remains steerable, the presence of rumble strips along the centrelines and outer edges of undivided rural two-lane roads alerts the distracted, fatigued, or speeding motorist. This is an effective and relatively inexpensive installation system that can decrease the RTAs by approximately 14% [1]. However, if the vehicle has lost control, road safety barriers (hereinafter – barriers) play an important role in decreasing the RTA consequences provided that there are very few motorized two-wheel...
vehicles using the roadway [2].

To decrease the number of RTAs and improve the overall traffic safety, a safety performance audit is required, which has proved to be an effective practice in enhancing road safety. Safety performance audit in China confirms that barrier systems, which are installed complying with the necessary requirements, improve traffic safety. It is also necessary to introduce more stringent requirements and improve standards [3].

The aim of this article is to show the necessity of barriers and their impact on the collision mechanism and collision consequences. A reference to all barrier types will lead to the optimal choice of barriers depending on their installation site.

2. Types of road safety barriers

Barriers are used to separate oncoming traffic, to isolate objects on the roadside (trees, buildings, water reservoirs and others) from possible interaction with the vehicle, and prevent animal access to the roadway. Based on their function, barriers are divided into two types – flexible (figure 1) and rigid systems [4] (figure 2). In some cases, designation of semi-rigid systems is also found. As a result of vehicle collision, flexible barriers undergo permanent deformation. Collision energy is absorbed by both the barrier (barrier deformation) and the vehicle (vehicle deformation). Flexible barriers are usually made of steel or other deformable material (for example, aluminium and wood). Rigid barriers undergo insignificant deformation as a result of vehicle collision. Collision energy is dissipated to vehicle deformation, movement of barrier elements, friction between the vehicle and the barrier, as well as lifting up the vehicle onto the barrier.

![Figure 1. Flexible barrier.](image1)

![Figure 2. Rigid barrier.](image2)

The choice of a barrier is primarily based on the technical requirements, but also on its appearance. In national parks or along scenic roads, it is desirable that barriers look as natural as possible and fit into the surroundings. Wood barriers blend into the overall landscape [5, 6], figure 3. Alternatively, composite material barriers may be chosen as a safe, energy absorbent, lighter-weight, easier to install, more durable and economically competitive alternative to existing steel guardrails [7].

Cable median barriers (see figure 4) are cost effective and flexible systems that cause less impact force than concrete barriers and are easier to maintain than the W-beam guardrails. However, there is a 3.6% chance of penetrating the cable median barriers [8], [9].
The most common barrier is the W-beam steel guardrail, with properties that can change depending on the height. Rigid systems – concrete barriers – are the second most commonly used type of barriers. These offer a temporary solution or are used where the road width and barrier deformation is limited. Portable water-filled road safety barriers as a semi-rigid barrier may also be used at roadwork sites (figure 5). The main advantage is the ease of transportation and installation [10].

2.1. Technical requirements of barriers
In case of a collision, the primary goal of a barrier is to restrain vehicles from an impending collision, and slowly dissipate the kinetic energy to the greatest possible barrier surface. This would prevent relatively sharp overloads (ride down acceleration) to the people in the vehicle. After collision with the barrier, the vehicle should glide along the barrier or move back to the driving lane until it stops. It is important to prevent the vehicle from hanging over the barrier.

On public roads in Europe, the barriers are installed in compliance with the European Standard EN 1317 [11]. In Latvia, barriers are installed in accordance with the Latvian Standard (LVS EN 1317). This is identical to the consolidated European Standard EN 1317 with three main criteria: a containment level, impact severity level and deformations, expressed by the working width W and the dynamic deflection D. The three criteria are based on test results, which confirm a barrier ability to absorb the vehicle impact load.

2.2. Barrier containment level
In case of a collision, the barrier should contain the vehicle. The barrier must not separate into pieces, be torn or break loose from the supports, and be thrown up on the roadway where it may collide with other vehicles or users of the roadway. Depending on the hazard level of the road, barriers will have different containment levels.
| Containment level characteristics | Designation |
|----------------------------------|-------------|
| Low angle containment             | T1          |
|                                  | T2          |
|                                  | T3          |
| Normal containment               | N1          |
|                                  | N2          |
|                                  | H1, L1*     |
| Higher containment               | H2, L2*     |
|                                  | H3, L3*     |
| Very high containment            | H4a, L4a*   |
|                                  | H4b, L4b*   |

* Additional vehicle impact test at 110km/h

Barrier containment level may be anywhere from low to very high. At a low containment level, the barrier has to survive a collision from a 1,300kg automobile moving at 80km/h and a collision angle of 8°. At a very high containment level, the barrier has to endure a collision of up to 38,000kg truck at 65km/h and collision angle of 20°. The classification of barrier containment levels is provided in table 1.

The barrier containment level is determined from the permitted vehicle driving speed, traffic intensity, terrain and other criteria. For example, a normal containment level N2 is used on common road sections, but a high containment level H2 or very high H4a and H4b is used on bridges. A safety barrier will always satisfy the requirements of a lower level.

A low containment level is used where temporary safety barriers are required, such as sites for roadwork. If required, temporary barriers can also have higher containment levels.

2.3. Working width and dynamic deflection

When a vehicle collides with a barrier, part of the kinetic energy absorbed by the barrier goes to deforming and moving the barrier. Barrier deformation is determined from the dynamic deflection D and barrier working width W, figure 6. Working widths are classified in levels from W1 to W8, where W1 level allows a barrier movement up to 0.6m, whereas W8 level allows movement up to 3.5m.

![Figure 6. Schematic representation of barrier dynamic deflection – D, working width – W and vehicle overhang – O.](image)
The installation of a barrier requires sufficient space on the side of the road, as defined by the deformation (W). Where barrier deformation is limited, the barrier must support the vehicle with an overhang (O), figure 6.

2.4. Impact severity level
The risk of injury is mainly determined by the deceleration force of the driver and the passengers. Impact severity is assessed by ASI (acceleration severity index) and THIV (theoretical head impact velocity) indices. Impact severity is classified in three levels – A, B and C. Level A ensures a higher degree of safety than level B, which, in turn, is higher than level C. Level A and level B are unlikely to cause injury to the passengers. Level C impact severity will however cause significant injury and so barriers leading to undesirable outcomes are used as the last resort [4].

3. Barrier impact on road traffic accident mechanism
To visually show the effect of the barrier on the RTA mechanism, it is necessary to make reference to a collision; a BMW car and a SCANIA bus. In this case, the car collided into a barrier and had an initial impact with a bus. The maximum permitted driving speed was 70km/h. The car in the left lane (intended for higher speed traffic in Latvia) impacted a bus changing to the left lane. The right front corner of the car contacted the left rear corner of the bus. The car was deflected left until it contacted the barrier. After the collision with the barrier, the car continued movement forward turning until it stopped. Meanwhile, the bus continued traveling forward until it stopped. The sequence of event is shown in figures 7-12.

The accident was modelled with a computer program PC-Crash (figure 12). As measurements of friction coefficients and other parameters were not taken at the collision site, the friction coefficient between the driving lane and vehicle tyres was assumed to be 0.7, the friction coefficient of the asphalt pavement – 0.4, kinematic coefficient of restitution – 0.1. Energy spent on the car and bus deformation was determined with the comparison method using Dr. Melegh EES catalogue data [12]. The RTA mechanism was acquired from modelling, using the collision tracks, vehicle location, etc. It was determined that the initial car speed was ~145km/h, but the bus was moving at ~80km/h.

To demonstrate the impact of the barrier on the RTA mechanism by using the same data, modelling was performed, but this time without the barrier that separated the oncoming traffic. From the second modelling case, it can be observed (figure 13) that the car was hit left from its initial direction and continued to move left until it reached the opposite lane. After contact with the bus, the steering system of the car was damaged due to which it became uncontrollable. If there had not been the barrier installed in this road section, the car driver would have entered the opposite lane leading to more severe consequences.
It should be noted that for the given RTA mechanism, the barrier had to absorb a relatively small amount of energy from the car, which allowed the barrier system to easily meet the requirements – to divert the car back to the driving lane where it moved along the barrier until it stopped.

In many RTAs involving one vehicle, greater driving speeds are recorded. In such cases, barriers experience relatively large loads, and so the technical requirements of the barriers are a critical issue [3]. For W-beam guardrail systems, the soil is an important factor as barrier supports are fixed in it; the guardrail can fail to redirect the vehicle due to soft ground [13]. Lowering the height of the barrier by 40mm (for example, a renewed road surface with an additional asphalt layer) can still function to
redirect pickup trucks and large SUVs, but a further lowering to 60mm can cause the vehicle to override the barrier [14].

4. Choice of barrier types, their economic feasibility
Although wooden barriers may be used in separate places in Latvia, the application of wooden elements should be assessed based on the lifetime of the structure and climate conditions. This type of structure may be chosen from the standpoint of the overall landscape, but cannot be justified as the most economically advantageous solution. Despite the fact that M. Borovinšek [5] indicated that in car to barrier Crash-test – “no load carrying parts of the barrier were separated from the barrier”, in the photos it can be observed that relatively large pieces of wood separate from the barrier that can be dangerous to both people in the vehicle and other road users, especially, where there is a roadside footpath. It should be noted that standard EN 1317 binding for Latvia does not allow the barrier structure to break or separate at the moment of collision.

Despite wide use of composite materials in road construction (sign supports, lighting poles, highway delineators and small sign posts) [7], composites have not been used in barriers. Cable median barriers also cannot satisfactorily meet EN 1317 requirements; therefore, in the countries complying with this standard cable median barriers have almost no application.

In Latvia, flexible W-beam guardrails (figure 1) and rigid concrete barriers (figure 2) are the most frequently used barriers. As both of these types of barriers could be the most used delimiting systems in the world, large amounts of resources are devoted to their studies and improvement of structure.

Effectiveness of W-beam guardrail depends on the location of a car contacting the barrier – whether the car collides with the barrier at a far distance between the posts, or in the vicinity of a post. With an aim to improve W-beam guardrail containment level and decrease barrier deformations, a barrier has been developed equipped with rubber dampers and lamellar shock absorbers [15]. It should be noted that this barrier system increases the costs as well as its total weight. To decrease the barrier costs and weight, Atahan [16] suggests simplifying W-beam guardrail system, using 3 instead of its 5 elements, gaining the system weight of 18.6 kg/m and ensuring containment level L1.

For a concrete barrier, the concrete composition is improved making it sufficiently resistant to impacts and at the same time crumbling at the collision moment, thus absorbing part of vehicle energy, as well as at the moment of barrier crumbling into fragments smaller than 4.75mm, its elements are not dangerous to other traffic participants [17]. Besides, recycled waste – tire rubber – is added to concrete, thus decreasing the barrier total weight and improving acceptable workability [18].

Safety criteria for barriers were developed primarily for cars and heavier vehicles rather than motorcycles, and both types of barriers – W-beam guardrails and concrete barriers – induce particularly severe motorcyclist injuries. In case of collisions with a barrier, a motorcyclist is 15 times more likely to be killed than people in a car. In Australia and New Zealand, the total length of W-beam barrier is 5,565km; whereas the total length of concrete barrier is 673km. Statistical data show that from 2001 to 2006, 73% of motorcyclist fatalities involved collisions with W-beams and 10% – collisions with concrete barriers. As the study does not include the data on collisions of motorcyclists with barriers where the motorcyclist survives, it is not possible to assess the impact of barrier structure on the collisions of motorcyclists with barriers [19], [20]. In reducing motorcyclist casualties, the structure of the barrier is more important than the energy absorption. It is important that a motorcyclist falling and gliding over the driving lane does not get caught by the barrier fixing posts. In this case, as the concrete barrier is a continuous system without gaps, it has an advantage in comparison with a W-beam barrier, where a motorcyclist gets caught on barrier fixing posts.
Gaps between barriers of different containment levels are not permitted. Figure 14 provides an example with two barrier structure types, where one barrier system is installed in a road section and the other system, with a higher containment level, is installed on a bridge. There is a gap between both barriers, which is not permissible from the standpoint of road traffic safety. After the reconstruction works, the barrier structure was made without the gaps combining the barriers of different containment levels, figure 15.

Installing a concrete barrier behind the W-beam guardrail, in such a case gaps between different barrier systems are also not permitted, and it is necessary to install a transition barrier system (figure 16). As a steel barrier system is usually replaced by a concrete barrier with a higher containment level delimiting a more dangerous road section, this transition system has to ensure optimal occupant impact ride-down acceleration, vehicle overhang over the barrier is also not permitted [21], [22]. In compliance with EN 1317, the height of both barriers is ~0.8m.

Figures 14–15. Barrier fragment before and after road reconstruction works.

Figure 16. Transition barrier system between a W-beam and concrete barrier.

Transition to the barrier system without gaps allows significantly improving road traffic safety, in case of collision implementing a completely different collision mechanism, ensuring a higher safety level for people in the vehicle.

It should be noted that in case of collision both barrier systems (concrete barrier and steel barrier) have a relatively high difference in friction coefficients. Friction coefficient between the vehicle and concrete barriers varies in the range of 0.7-0.8, and the friction coefficient between the steel barrier and vehicle is 0.3 or less. This difference in friction coefficients can pose a substantial impact on the RTA mechanism. When a car collides with a steel barrier, collision of a more gliding nature can be observed, as a result of which the car is exposed to smaller rotation forces compared to collision with a concrete barrier.

Along with ensuring road traffic safety, costs of road construction and maintenance are considered. Barriers are designed in such a way that after a collision their damage would be minimal and the damaged barrier parts would be relatively quickly replaced investing minimum means. In accordance with the information provided by Ltd. Tilts, procurement and installation costs up to their containment...
level H1 are lower for steel barriers. However, taking into account the specified barrier lifetime (concrete – 35 years, steel barrier – 15 years), barrier system maintenance costs, as well as renewal of barriers after the potentially possible RTA, assuming that there is one collision in one year on average in a road section of 4km, concrete barrier system costs are lower for a period of 35 years than that of an analogue steel barrier.

5. Conclusions

Barriers for redirecting out-of-control vehicles on the road are undergoing several improvements. There is a need for both permanent and temporary road traffic barriers. The need for road resurfacing requires temporary barriers. They are made from natural materials where possible so that they blend into the surroundings more effectively. Regardless of the change in the barrier type and setting, further work needs to assess the impact of friction between various barriers and the car. This is believed to influence the movement of the car after collision.

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