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Long-term analysis of the impact of longitudinal barriers on motorway safety

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ABSTRACT

The objective of this study was to assess the influence of longitudinal barriers located on the median strips and hard shoulders of toll motorways on crash severity in vehicles running off the roadway. The study was based on crashes involving injury and property damage only, recorded from 1996 to 2010 on a French toll motorway network of about 2000 km.

In run-off from the roadway onto the hard shoulder, injury risk was halved by a longitudinal barrier. A specific one-sided W-beam guardrail ("GS4") appeared to be the best solution for cars, and even for LUVs and trucks. This does not affect the advisability of specific guardrails for bridges or of concrete barriers, when narrow working widths are required. In run-off onto median strips, a specific guardrail ("GS2") appeared to be the most efficient, followed by the three other metal guardrails currently installed. Concrete barriers, however, are much more effective in preventing complete crossing of the median, which is uncommon and mainly involves trucks, but often with very serious consequences.

Longitudinal barriers make an important contribution to highway-user safety, providing a "forgiving" infrastructure in the event of a vehicle going off the road, provided that there are very few motorized two-wheel vehicles using the roadway.

1. Introduction

In 2010 in France, the 8500 km of toll highways (motorways) accounted for less than 1% of the road network, but about 15% of road traffic. The number of road-user fatalities on the motorway network that year was 167, an approximate rate of 2.0 fatalities per billion kilometers traveled (BKT). This compares to 9.2 fatalities per BKT on minor roads. Thus, despite a speed limit of 130 kph (and an observed average speed of 104 kph), the motorway network, which is overwhelmingly inter-city, appears to provide a good level of safety. The main means of ensuring this level of safety are, firstly, specific access ramps for entering and exiting the motorway and, secondly, separation of directional flow by a median strip, almost completely preventing the head-on collisions which very often cause serious injury. In some countries, such as the U.S., this is achieved by having very wide median strips. With a narrow median strip (less than 10 m), the probability of median crossover crashes increases (Donnell et al., 2002; Tarko et al., 2008; Villwock et al., 2008; Chitturi et al., 2011). The AASHTO Design Guidelines (AASHTO, 2006) provide installation guidelines for median barriers on high-speed roadways, depending on median width and average daily traffic. On the French motorway network, median strips are generally narrow (typically, 5 m), and in that case are systematically equipped with longitudinal barriers.

Motorway hard shoulders are also designed for both active safety, with an emergency lane, and passive safety, by systematically equipping them with longitudinal barriers in two cases: (1) when a fixed obstacle such as a tree, pole or bridge pier is close enough to the roadway to present a high risk of being hit by a vehicle going off the road (Council and Stewart, 1996; Holdridge et al., 2005), and (2) when the roadside is more than 2.50 m below the roadway.

Recommendations for the equipment of median strips and hard shoulders on inter-city motorways are set out in an official handbook, the ICTAAL (SETRA, 2000), which is the French technical reference document for the design of motorways in inter-urban areas: divided carriageway roads with at least two lanes in the link sections and split level junctions, isolated from their surroundings. Following these recommendations, motorway safety services implement their safety equipment policy according to operating requirements; this includes choice of longitudinal barrier types, locations and installation. In Europe, the EN 1317-2 standard serves

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as a basis for the CE marking of road safety systems such as safety barriers and guardrails, crash cushions, barrier extremities and transitions. CE marking is a declaration by the manufacturer that the product is in conformity with all applicable European Economic Area legislation and that all appropriate conformity assessment procedures have been completed.

Most knowledge about longitudinal barriers comes from experimental data for many different devices (Ross et al., 1993; Bullard et al., 2012), mainly strong steel post W-beam guardrails and concrete barriers. If experimental results are essential, it is also necessary to observe the effect of longitudinal barriers on the consequences of crashes in terms of injury in the real world.

The objective of the present study was to assess the influence of longitudinal barriers located on toll motorway median strips and hard shoulders on the crash severity observed in vehicles running off the roadway (run-off).

2. Data

The study was based on fatal, injury and property damage crashes, recorded from 1996 to 2010 on the southern French ASF (Autoroutes du Sud de la France) network, which comprises about 2000 km of inter-city motorways. Information was gathered by the highway patrols for any damaged vehicle towed away following an accident.

Data included information on the circumstances of the accident, the vehicles involved and the number of victims in each vehicle. In case of run-off, detailed information was gathered on the type of barrier encountered, the position of impact and the behavior of the vehicle after the collision (rollover, or secondary impact against another vehicle or obstacle). Specifically, for each vehicle involved in a crash, every impact with other vehicles or item of infrastructure was coded in such a way as to record, for example, that a vehicle traveling in the left-hand (i.e., fast or inside) lane ran off the roadway to the left side, struck an LB and was hit by another vehicle when rebounding onto the roadway. Information about the type of barrier observed on the spot was checked by comparing with information from the roadway infrastructure database.

Many different types of LB have been installed on motorways. Some are too rare for meaningful analysis of vehicle impact, and the corresponding observations were therefore excluded from the study. The remaining LBs are those known as GBA, DBA, SMV, GS4, GS2, DL4, GL4, BN4, DE2 and DE4. Cross-sectional drawings are shown in Fig. 1 for these types of LB, which have the following main characteristics:

- The GBA type LB is a one-sided New Jersey profile concrete barrier poured onto pavement. The DBA type is the same but double-sided, and was grouped together with GBA for analysis because of their similar performance in case of vehicle impact. These barriers are H2 containment level (Capable of restraining a 13 t bus running at 70 kph at a 20° impact angle).
- The SMV (Modular Lane Separator) type LB is also a double-sided New Jersey profile concrete barrier with an H2 containment level, but consists of 4 m length units simply placed on the paved median strip, each concrete block being secured to the two neighboring blocks.
- The GS4 type LB is a one-sided steel guardrail, with a two-wave rail (W profile) fitted to posts by a welded spacer. Posts are hammered into the ground every 4 m. The GS2 is the same device, except with posts every 2 m. These devices are N2 containment level (capable of restraining a 1.5 t vehicle running at 110 kph at an impact angle of 20°).
- The DL4 and GL4 type LBs are one-sided steel guardrails with 4 m post spacing. They are designed mainly as a specific median device, easily removable if necessary (for maintenance work, or in case of an incident blocking traffic in one direction). The two were not distinguished for analysis, because their characteristics are very similar.
- The BN4 type LB is an H2 one-sided steel guardrail, with 3 horizontal tubular beams installed at various heights, and fitted to welded posts on base-plates. This guardrail is mainly installed on bridge rails. Posts are linked to the bridge deck by fusible bolts every 2.5 m.
- The DE4 type LB is an H2 double-sided steel barrier with an W-profile guardrail fitted to posts by a welded brace. Posts are hammered into the ground every 4 m. The DE2 type LB is the same device, except with posts every 2 m.

Concerning median strips, the distance from inner shoulder to barrier is always the same on these toll motorways, i.e. 1 m, whatever the type of barrier (concrete barrier, strong or weak post and beam guardrail). Concerning hard shoulder equipment, the distance from outer shoulder to barrier is greater because of systematic presence of an emergency lane, mostly 3.0 m wide, sometimes reduced to 2.8 m (for a very few short motorway sections), which is adjacent to and abutting a traveling lane and intended for use by vehicles in the event of difficulty. This is in accordance with the recommendations given by the above mentioned reference book (ICTAAL), similar to the ASHTOO guidelines for high speed highways.

Barrier-type can be summed up as follows:

- GS4: single-sided W-beam 4-mps guardrail (4-mps: 4-m post spacing)
- GS2: single-sided W-beam 2-mps guardrail
- DL4/GL4: box-beam 4-mps guardrail
- DE4: double-sided W-beam 4-mps guardrail
- DE2: double-sided W-beam 2-mps guardrail
- DBA/GBA: New jersey (NJ) concrete barrier
- SMV: multi-block concrete barrier
- BN4: thrie-beam bridge barrier

3. Methods

Ideally, an LB should contain and redirect the vehicle leaving the roadway whilst avoiding casualties or fatalities in the vehicle. It should therefore reduce the proportion of energy dissipated within the vehicle on impact, prevent intrusion into the vehicle, keep it on its wheels (except for two-wheelers, which are a special case) and, if possible, prevent it rebounding onto the roadway so as to minimize secondary impact with other vehicles. The vehicle should, of course, not be able to cross the LB. A number of these criteria have been tested in experimental regulatory trials; dissipated energy, for example, can be calculated from acceleration or velocity at impact (Goubel et al., 2009). Not being able to be crossed by the colliding vehicle is a prerequisite for LB approval. Other criteria, such as the rate of secondary impact or overturn, or associated injury, on the other hand, can only be assessed in real world conditions.

3.1. LB efficiency assessment criterion

The efficiency of each type of LB was assessed as the ratio between the number of vehicles hitting the device with at least one occupant injured or killed, divided by the total number of vehicles hitting the device. In case of secondary collision with another vehicle, any casualties in the second vehicle were counted as casualties concerning the first vehicle, thus increasing the value of this variable in case of secondary damage resulting in injury. In case of multiple collisions on the longitudinal barrier, only the first