In-depth Investigation of Run-off-the-Road Crashes on the Motorway Naples-Candela

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ABSTRACT

In the paper, results from in-depth investigation of 1,092 run off the road (ROR) crashes on the motorway A16 (Italy) are presented. The research is aimed at pointing out risk factors that can address highway agencies and designers toward the selection of safety countermeasures aimed at reducing ROR crashes frequency and severity. Crash data were collected trough the analysis of police crash reports and relate to the period 2001-2005. Basing on police and hospital reports, each crash was categorized in six injury levels. To determine whether a specific crash pattern of the analysis group was significantly different from that of the control group, the Chi Squared (χ^2) test with Yates' correction was performed.

Severity of motorcycle crashes was significantly higher than severity of other vehicle types. In adverse environmental conditions (night time and wet pavement), crash severity was lower than in favourable conditions. Crashes against ditches, walls, foreslopes, and backslopes were more severe than crashes against roadside steel safety barriers. Comparison between severity of crashes against longitudinal safety barriers and their blunt end terminals showed a dramatic increase in crash severity against the terminals. Thrie-beam roadside barriers that meet EN 1317 performance criteria showed a smaller crash severity and a better performance compared to older W-beam roadside barriers. Median New Jersey concrete barriers, compared to median steel safety barriers, showed greater crash severity and greater proportion of rollovers, not counterbalanced by a significant better behaviour in relation to penetration and override.

Keywords: run-off-the-road crashes, injury levels, concrete New Jersey safety barriers, steel safety barriers, blunt end terminals.

INTRODUCTION

Run-off-the-road (ROR) crashes involve vehicles that leave the travel lane and encroach onto the shoulder and beyond and hit one or more of any number of natural or artificial objects, such as ditches, poles, embankments, safety barriers, and trees. Unfortunately, roadside crashes account for far too great a portion of the total fatal highway crashes. In the U.S., about thirty percent of the fatalities, or almost one in every three fatalities, are the result of a single vehicle ROR crash (*1*). These figures mean that the roadside environment comes into play in a very significant percentage of fatal and serious-injury crashes.

When an errant vehicle does encroach on the roadside, fatalities and injuries can be reduced if an agency either can minimize the likelihood of the vehicle crashing into an object or can reduce the severity of the crash (*2*). If the motorist travels onto the roadside, the probability of a crash occurring and the crash outcomes depend upon the roadside features, such as the presence and location of roadside hardware, fixed objects, sideslopes, ditches, and trees. To date, few in-depth studies of ROR crashes in relation to the roadside features, the vehicle types and the environmental conditions have been carried out, although these studies would be helpful for the selection of appropriate safety countermeasures. Indeed, highway agencies are continually faced with decisions relating to roadside safety, and it is important to ensure that the best use is made of the limited funds available (*3*). In the paper, results from in-depth investigation of 1,092 ROR crashes on the motorway A16, in Italy, are presented. The research is aimed at pointing out risk factors that can address highway agencies and designers toward the selection of safety countermeasures aimed at reducing ROR crashes severity.

LITERATURE REVIEW

Study Methodologies

Many studies have addressed roadside safety hardware design and simulation, whereas roadside crashes have been investigated to a lesser extent.

In the main benefit/cost analysis procedures for the selection of roadside safety features *(3 - 5)*, crash costs are calculated in relation to the severity index, which is an index ranging from 0 to 10 associated with fixed percentages of fatal, injury, and property damage only crashes. While research since the 60s has sought to quantify severity indices for a range of object types, road types, and impact conditions, there remains a wide variation in the values reported in literature *(6)*. In order to clarify the state of the practice in understanding and using severity indices, Hall et. al. *(7)* conducted a survey of U.S. state highway agencies. More than 70% of respondents indicated that they encountered problems in selecting and justifying severity indices values. The recent FHWA's RSAP software *(5)* still uses the severity index approach for severity estimation, but a new approach to directly estimate the probabilities of injury was developed. The new severity estimation procedure will be used when data become available in the future.

In-service performance evaluations explicitly measure the amount of injury and property damage resulting from crashes against roadside features. In-service evaluations measure the typical or average performance of the feature since a wide range of vehicles may strike it at a wide range of impact conditions *(8)*.

Terminals of Safety Barriers

Experience with the impalement of crash vehicles on the exposed ends of safety barriers has amply demonstrated the grave consequences for errant vehicles striking the untreated ends of barriers *(9)*. Subsequently, the roadside safety community has been engaged in a sustained effort aimed at developing guardrail end-treatments to mitigate this hazard.

Schwall (*10*) reported on a study of crashes occurring at or near bridges in the state of Iowa. Sixty-one of the 90 fatal bridge crashes investigated in the study involved impacts with unprotected bridge ends.

Griffin (*11*) reported on the performance of turned-down guardrail terminals in the state of Texas. Fatal collisions were overrepresented at turned-down guardrail terminals.

In the study performed by Ray et al. *(12)* in Connecticut, Iowa, and North Carolina, the in-service crash performance data for the breakaway cable guardrail terminals (BCT) and modified eccentric loader breakaway cable guardrail terminals (MELT) indicate that these terminals are performing reasonably well. Over 60 percent (64%) of the 115 police-reported BCT and MELT crashes resulted in property damage only, and only five percent involved severe occupant injuries.

In the study performed by Igharo et al. *(9)* in Washington State, the installation characteristics measured for Breakaway Cable Terminals (BCT) and Slotted Rail Terminals (SRT), along with the related crash data for these devices, showed overall acceptable performance when struck. Sixty-three percent of the BCT and SRT crashes resulted in property damage only.

Holdridge et al. *(12)* analyzed the in-service performance of roadside hardware on urban State Route system in Washington State by developing multivariate statistical models of injury severity in fixed-object crashes using discrete outcome theory. The results show that leading ends of guardrails and bridge rails increase the probability of fatal injury.

In the deliverable 6 of the EU RISER project *(13),* it is stated that safety barrier ends which do not fulfil the requirements of EN 1317 or NCHRP 350 standards can be point hazards themselves. Blunt ends of safety barriers are well-known hazards, but also ramped ends of guardrails parallel to the road can easily cause a vehicle vault or rollover and hence lead to more severe consequences. In RISER detailed crash database, there are 41 crashes where the barrier was the only obstacle involved. In 14 cases, the termination of the barrier was impacted; in four of those cases, the vehicle travelled along the top of the barrier until it came to a stop or impacted another object, in 10 cases, the vehicle was launched into the air.

In the U.S., the Federal Highway Administration formalized the evaluation and certification process for roadside safety hardware with the net result that all guardrail terminals to be used on the National Highway System must satisfy the full-scale crash test and evaluation requirements of the NCHRP Report 350 *(14).*

Longitudinal Safety Barriers

Ray et al. *(8)* conducted in-service performance evaluations and assessments of the in-service performance of several types of roadside hardware. The following longitudinal barrier systems were compared: the concrete median barrier (CMB), the G2 weak-post W-beam guardrail, and the G1 weak-post cable guardrail. Only property damage resulted from approximately 80 percent of the flexible guardrail (84% for the W-beam guardrail, 79% for the cable guardrail) crashes, whereas rigid CMB crashes resulted in only property damage just under 70 percent of the time (68%). The difference between the property damage only rate for the CMB and W-beam guardrails is statistically significant at the 90 percent confidence level. The more flexible barrier, therefore, results in a lower proportion of injury crashes.

Perera and Ross *(15),* using a modified version of the Highway-Vehicle-Object-Simulation Model (HVSOM), determined that overturns could be expected for small cars in non tracking and/or high –angle impacts with the concrete safety-shape barriers.

Mak and Sicking *(5)* performed computer simulations and analyses in order to examine the issue of rollovers caused by concrete safety-shaped barriers. A number of impact conditions were identified from accident studies and confirmed by simulation as potential contributory factors to rollovers in crashes against New Jersey concrete barriers.

Martin *(16)* collected detailed information on all crashes (injury or damage only) on the motorway between Paris and Perpignan in order to compare crash severity for vehicles impacting against steel and concrete safety barriers. The study covered a total of 224 km of motorway. The observation period was from 1986 to 1995. In the case of a first impact on the central reservation, a concrete New Jersey safety barrier, compared to a steel safety barrier, leads to a statistically significant increase by a factor of 1.9 in the risk of personal injury. In a subsequent study relative to a 2000 km French motorway network, Martin and Quincy *(17)* found that the number of casualties in crashes involving concrete devices is 1.7 times the number of casualties in crashes involving steel barriers.

Motorcycle Crashes

In EU, motorcyclist risk of death is 20 times higher than for a car passenger *(18).* Motorcycle crashes against safety barriers are widely recognized as a major safety issue. In the US, motorcycles compose only 2% of the vehicle fleet, but account for 42% of all fatalities resulting from guardrail collisions *(19).* Over two-thirds of motorcycle riders who were fatally injured in a guardrail crash were wearing a helmet. Approximately one in ten motorcyclists striking a guardrail were fatally injured – a fatality risk nearly 100 times higher than for car occupants involved in a collision with a guardrail. In the Spanish regional road network of Castilla y León (CyL), ROR constituted 43% of the fatal motorcycle crashes *(20).*

MOTORWAY DESCRIPTION

Motorway A16 Naples-Canosa, in Italy, is part of the Trans European Road Network (Road E841). It is a divided highway with two lanes for each direction (lane width = 3.75 m, right shoulder width = 0.50 - 3.50 m, median width = 2.00 m), access control, and interchanges. The section Naples-Candela, with length equal to 127.5 km, was studied.

The corridor is connected to the road network by 11 interchanges. Part of the route is in mountainous terrain with 11 tunnels (total length = 4.032 km) and 38 bridges (total length = 8.114 km). General speed limit is equal to 130 km/h, which is the maximum legal speed in Italy. Local speed limits equal to 80 km/h are present in both travel directions. Sections with local speed limit have total length equal to 50.245 km in east carriageway and equal to 26.595 km in west carriageway.

Radius of horizontal curves varies between 245 and 4,000 m (mean = 813 m, standard deviation = 586 m). Spiral transitions are not present. Radius of vertical curves varies between 3,000 m (sag curve) and 30,000 m (crest curve). Maximum longitudinal grade is equal to 6.4% (mean = 2.4%, standard deviation = 1.7%).

Longitudinal roadside safety barriers installed were W- beam, double W-beam, and thrie beam with rubber rail. Longitudinal median safety barriers included W-beam, double W-beam, thrie-beam, and concrete New Jersey shaped barriers. Longitudinal bridge safety barriers were W-beam, thrie beam, and New Jersey shaped barriers. Other roadside obstacles consisted of embankment foreslopes, retaining walls, parallel ditches, and cut backslopes.

Average annual daily traffic, in the period 2001-2005, ranged between 7,266 and 15,667 vpd. Heavy vehicles traffic ranged between 1.70% and 16.48% of the total traffic (mean = 11.10%, standard deviation = 4.23%). The proportion of motorcycles was very small (mean = 0.24%, standard deviation = 0.14%).

CRASH DATA

General Information

Crash data were collected by analysis of police reports, integrated with detailed site inspections. Crash data refer to the period 2001-2005. Crashes at the interchanges ramps, at rest areas and at tollbooths were excluded basing on the location description of the police reports.

Crash Severities

Severity is defined as the level of injury sustained by the most severely injured vehicle occupant. Basing on police and hospital reports, each ROR crash was categorized in one of the following six injury levels: fatal, severe injury (invalidating injury), moderate injury (micro permanent injury, e.g. ordinary fractures or concussion), slight injury (no micro permanent injury, e.g. bruises or abrasions), property damage only level 2 (vehicle can't leave the crash scene), and property damage only level 1 (vehicle can leave the crash scene). In order to carry out statistical analyses with significant number of elements in each class, an aggregation of injury levels was carried out (Figure 1): major injury (fatal, severe, and moderate injury), slight injury, and property damage only (property damage only level 2 and level 1). Crash types different from ROR were classified as fatal, injury, and property damage only.

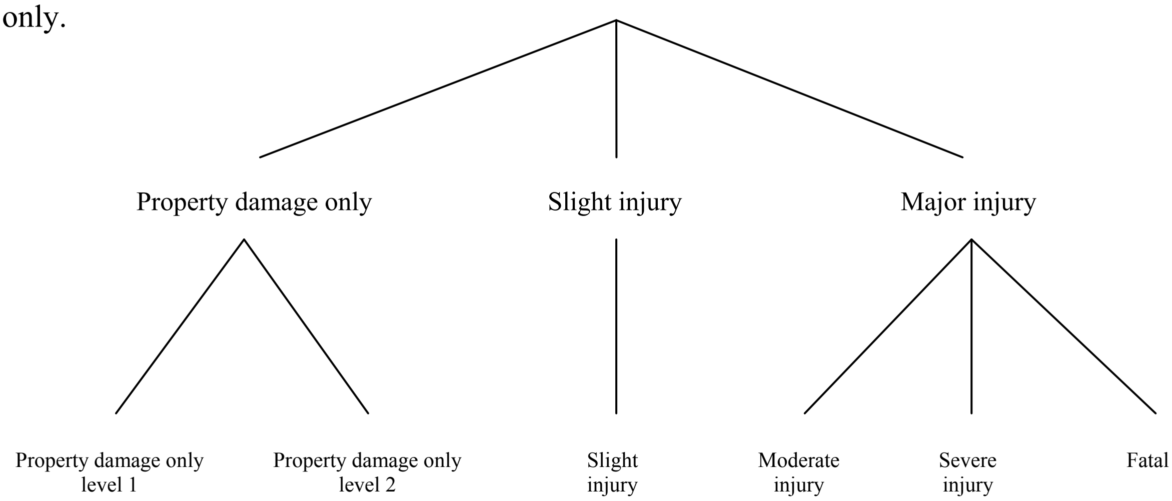

FIGURE 1 Crash injury levels.

Crash Types

In the analysis period, 2,245 total crashes occurred (Table 1). ROR crashes were the most frequent crash type (n = 1,092, 48.6% of the total). Many crashes involved the collision against an obstacle in the carriageway (n = 532, 23.7% of the total), even if this crash type was characterized by a small severity (PDO crashes equal to 95.9%). Relevant crash types were also rear end (n = 393), sideswipe (n = 163), hit stopped vehicle (n = 32), and angle crashes (n = 10). Other crash types accounted only for 1% of total crashes.

TABLE 1 Crash Types

Crash type	PDO		Injury		Fatal		Total crashes	
	N	%	N	%	N	%	N	% (total)
Run off the road	703	64.4	376	34.4	13	1.2	1092	48.6
Hit obstacle in the carriageway	510	95.9	22	4.1	0	0.0	532	23.7
Rear end	168	42.7	220	56.0	5	1.3	393	17.5
Sideswipe	121	74.2	42	25.8	0	0.0	163	7.3
Hit stopped vehicle	14	43.8	17	53.1	1	3.1	32	1.4
Angle	2	20.0	7	70.0	1	10.0	10	0.4
Others	7	30.4	16	69.6	0	0.0	23	1.0
Total	**1,525**	**67.9**	**700**	**31.2**	**20**	**0.9**	**2,245**	**100.0**

ASSESSMENT OF CRASH SEVERITY CONTRIBUTORY FACTORS

Statistical Significance of Results

To determine whether a specific crash pattern (e.g., proportion of injury crashes) of the analysis group is significantly different from that of the control group, the Chi Squared (χ^2) test with Yates' correction was performed. Yates' correction overcomes the inaccuracies that occur when applying the Chi Squared test to data such as crash frequency that can only have whole number values and is strongly recommended if any of the values in equation 1 are less than 5 *(21)*.

Chi Squared (χ^2) value is computed by the formula:

$$\chi^2 = \frac{n \times (|a \times d - b \times c| - \frac{n}{2})^2}{e \times f \times g \times h} \qquad (1)$$

where:

- χ^2 = test value (if $\chi^2 > 10.83$ the confidence level is 99.9 %, if $\chi^2 > 6.64$ the confidence level is 99%, if $\chi^2 > 3.84$ the confidence level is 95%, if $\chi^2 > 2.71$ the confidence level is 90%, if $\chi^2 \le 2.71$ the test was considered not significant);
- a = number of observed crashes with the pattern i in the analysis group;
- b = number of other observed crashes in the analysis group;
- c = number of observed crashes with the pattern i in the control group;
- d = number of other observed crashes in the control group;

e = total number of observed crashes in the analysis group;
f = total number of observed crashes in the analysis group;
g = total number of observed crashes with the pattern i;
h = total number of other observed crashes;
n = total number of observed crashes.

Crash Severity in Relation to the Vehicle Type

Almost 90% of the ROR crashes were passenger car crashes (89.2%), trucks accounted for 9.9% of the total ROR crashes, motorcycle crashes were only 0.9% of the total ROR crashes (Table 2).

Even if not noticeable in the traffic stream and in the total crashes, motorcycles accounted for 30.8% of the fatal crashes: three motorcycle fatal crashes were collisions against a steel safety barrier, and one was a collision against a New Jersey concrete barrier. High severity of motorcycle crashes against safety barriers is consistent with literature results *(19, 20)*. In comparison to the other vehicle types, motorcycle fatal crashes (40.0% vs. 0.8%, $\chi^2 = 98.07$, level of confidence = 99.9%), major injury crashes (70.0% vs. 7.2%, $\chi^2 = 46.03$, level of confidence = 99.9%), and injury crashes (100.0% vs. 35.0%, $\chi^2 = 15.52$, level of confidence = 99.9%) were overrepresented. Given a ROR crash, probability of a motorcyclist fatality is 48.1 times the same probability for car and truck occupants, probability of a major injury is 9.7 times, probability of an injury is 2.9 times.

Severity of truck crashes was significantly lower than severity of passenger cars. Truck injury crashes (22.2% vs. 36.4%, $\chi^2 = 8.03$, level of confidence = 99.0%) were underrepresented in comparison to passenger cars. Given a ROR crash, probability of truck occupants' injury was 0.6 times the probability for car occupants.

TABLE 2 Crash Outcomes in Relation to the Vehicle Type

Vehicle type	PDO1		PDO2		Slight injury		Moderate injury		Severe injury		Fatal		PDO		Slight injury		Major injury		Total crashes	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	% (total)
Passenger cars	345	35.4	274	28.1	284	29.2	49	5.0	13	1.3	9	0.9	619	63.6	284	29.2	71	7.3	974	88.6
Motorcycles	0	0.0	0	0.0	3	30.0	2	20.0	1	10.0	4	40.0	0	0.0	3	30.0	7	70.0	10	0.8
Trucks	64	59.3	20	18.5	17	15.7	6	5.6	1	0.9	0	0.0	84	77.8	17	15.7	7	6.5	108	10.6
Total	**409**	**37.5**	**294**	**26.9**	**304**	**27.8**	**57**	**5.2**	**15**	**1.4**	**13**	**1.2**	**703**	**64.4**	**304**	**27.8**	**85**	**7.8**	**1092**	**100.0**

Crash Severity in Relation to the Object Struck

In order to evaluate the severity of different obstacle types, objects struck were classified in relation to the most harmful event (Table 3 and Figure 2). For example, if a motorist struck a roadside barrier, penetrated the barrier and then rolled over on a foreslope (embankment with fill slope), the impact severity was evaluated as consequent a ROR in the foreslope. The most common obstacle was a safety barrier (71.8%, n = 784), almost 15% of the ROR crashes (n = 146) involved a vehicle hitting a wall, 68 ROR crashes (6.2%) were against ditches, 52 ROR crashes were on a foreslope, 26 were on a backslope, and 15 were against other obstacles (trees, sign poles, steel lighting poles, etc.). As far as the severity is concerned, only 13 fatal crashes occurred (1.2%), whereas the most common consequences were property damage only (64.4%, n = 703). Slight injuries were 304 (27.8%), moderate injuries were 57 (5.2%), and severe injuries were 15 (1.4%). Overall, major injuries (moderate injuries, severe injuries, and fatalities) were 85 (7.8%).

TABLE 3 Crash outcomes in relation to object struck (most harmful event)

Pavement condition	**PDO1**		**PDO2**		**Slight injury**		**Moderate injury**		**Severe injury**		**Fatal**		**PDO**		**Slight injury**		**Major injury**		**Total crashes**	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	% (total)
Roadside W-beam (h=75cm)	101	42.4	65	27.3	60	25.2	9	3.8	0	0.0	3	1.3	166	69.7	60	25.2	12	5.0	238	21.8
Roadside thrie-beam (h=110cm)	31	43.7	28	39.4	8	11.3	3	4.2	1	1.4	0	0.0	59	83.1	8	11.3	4	5.6	71	6.5
Median W-beam (h=75cm)	134	46.2	89	30.7	56	19.3	6	2.1	2	0.7	3	1.0	223	76.9	56	19.3	11	3.8	290	26.6
Median double W-beam (h=120cm)	27	39.1	23	33.3	15	21.7	4	5.8	0	0.0	0	0.0	50	72.5	15	21.7	4	5.8	69	6.3
Median thrie-beam (h=110cm)	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	0	0.0	1	100.0	0	0.0	0	0.0	1	0.1
Median New Jersey (h=100cm)	18	30.5	12	20.3	25	42.4	2	3.4	1	1.7	1	1.7	30	50.8	25	42.4	4	6.8	59	5.4
Bridge rail (h=110cm)	1	9.1	5	45.5	4	36.4	1	9.1	0	0.0	0	0.0	6	54.5	4	36.4	1	9.1	11	1.0
Bridge steel New Jersey (h=155cm)	10	50.0	5	25.0	4	20.0	1	5.0	0	0.0	0	0.0	15	75.0	4	20.0	1	5.0	20	1.8
Blunt end terminal (roadside w beam)	2	12.5	3	18.8	7	43.8	3	18.8	0	0.0	1	6.3	5	31.3	7	43.8	4	25.0	16	1.5
Blunt end terminal (roadside thrie beam)	0	0.0	1	16.7	1	16.7	4	66.7	0	0.0	0	0.0	1	16.7	1	16.7	4	66.7	6	0.5
Blunt end terminal (bridge rail)	0	0.0	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	0	0.0	1	100.0	0	0.0	1	0.1
Bridge steel New Jersey terminal	0	0.0	0	0.0	2	66.7	0	0.0	1	33.3	0	0.0	0	0.0	2	66.7	1	33.3	3	0.3
Bullnose	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	100.0	0	0.0	0	0.0	1	100.0	1	0.1
Wall	44	30.1	33	22.6	51	34.9	12	8.2	5	3.4	1	0.7	77	52.7	51	34.9	18	12.3	146	13.3
Foreslope	7	13.5	8	15.4	23	44.2	9	17.3	4	7.7	1	1.9	15	28.8	23	44.2	14	26.9	52	4.8
Backslope	4	16.0	5	20.0	14	56.0	1	4.0	1	4.0	0	0.0	9	36.0	14	56.0	2	8.0	25	2.3
Ditch (rounded)	23	39.7	12	20.7	20	34.5	2	3.4	0	0.0	1	1.7	35	60.3	20	34.5	3	5.2	58	5.3
Ditch (trapezoidal)	3	30.0	1	10.0	6	60.0	0	0.0	0	0.0	0	0.0	4	40.0	6	60.0	0	0.0	10	0.9
Sign pole	2	40.0	2	40.0	1	20.0	0	0.0	0	0.0	0	0.0	4	80.0	1	20.0	0	0.0	5	0.5
Steel lighting pole	0	0.0	1	33.3	2	66.7	0	0.0	0	0.0	0	0.0	1	33.3	2	66.7	0	0.0	3	0.3
Tree	0	0.0	0	0.0	1	50.0	0	0.0	0	0.0	1	50.0	0	0.0	1	50.0	1	50.0	2	0.2
Other	2	40.0	0	0.0	3	60.0	0	0.0	0	0.0	0	0.0	2	40.0	3	60.0	0	0.0	5	0.5
Total	**409**	**37.5**	**294**	**26.9**	**304**	**27.8**	**57**	**5.2**	**15**	**1.4**	**13**	**1.2**	**703**	**64.4**	**304**	**27.8**	**85**	**7.8**	**1092**	**100.0**

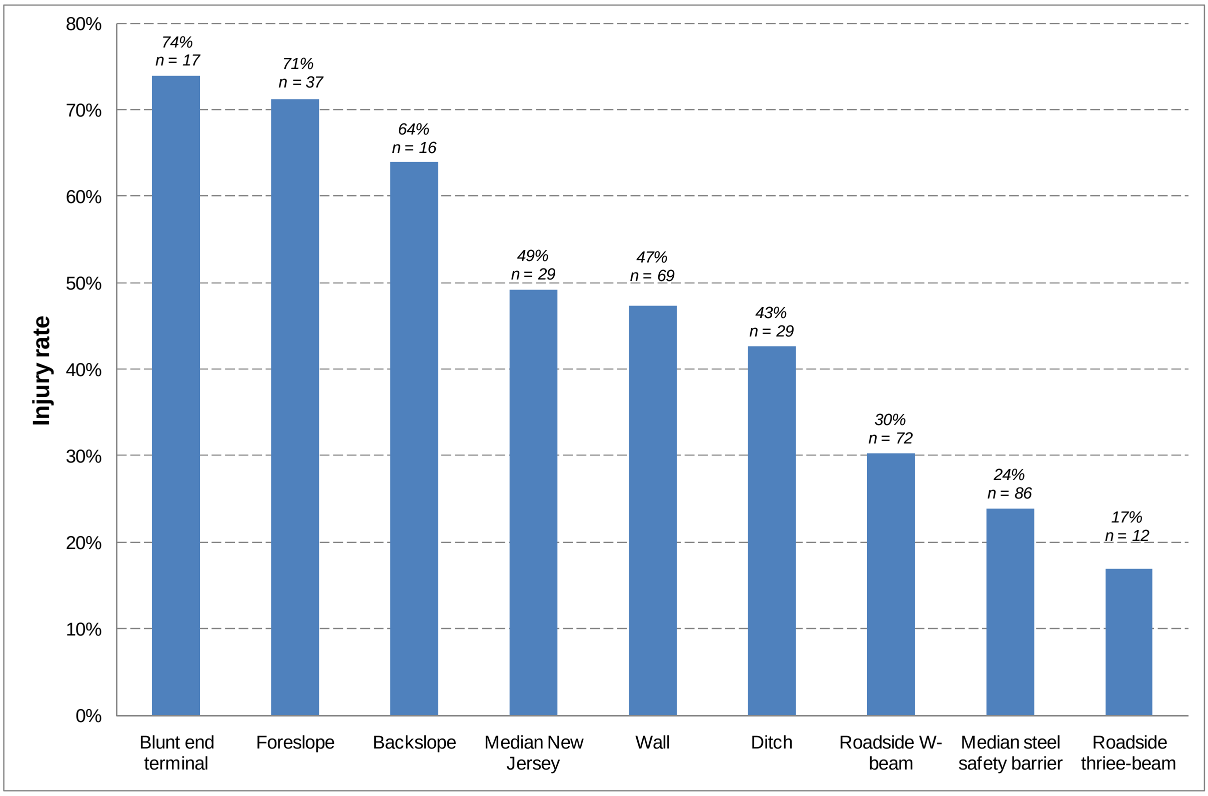

FIGURE 2 Injury rate (injury and fatal crashes/total crashes) in relation to the object struck.

Longitudinal Safety Barriers

Roadside safety barriers were W-beam (h = 75 cm) and thrie-beam equipped with rubber rail (h = 110 cm). Thrie-beam barriers (recent installations) were tested and approved according the standard EN 1317-2, with Containment Levels H2 and H3 and Impact Severity Level A (ASI ≤ 1.0, THIV ≤ 33 km/h). Median barriers were W-beam, double W-beam (h = 120 cm), thrie-beam with rubber rail, and concrete New Jersey (h = 100 cm). Bridge barriers were rails (W-beam retrofitted, h = 110 cm) and steel New Jersey (New Jersey shape with a beam on the top, h = 155 cm).

Median New Jersey and steel safety barriers showed a significant difference in percentage of injury crashes, which were overrepresented in New Jersey barriers (49.2% vs. 23.9%, χ^2 = 15.00, level of confidence = 99.9%). Total crashes against median concrete barriers were equal to 59 (29 injury crashes) and injury rate (injury crashes/total crashes) was equal to 49.2% (Figure 2). Total crashes against steel median barriers were equal to 360 (86 injury crashes) and injury rate was equal to 23.9%. Ratio of percentage of injury crashes between concrete and steel median barriers was equal to 2.06. Differences in major injury crashes were not statistically significant. These results are consistent with the findings of the studies carried out on French motorways median *(16,17)*.

Roadside W-beam and thrie-beam safety barriers showed a significant difference in percentage of injury crashes, which were overrepresented in W-beam barriers (30.3% vs. 16.9%, χ^2 = 4.27, level of confidence = 95.0%). Total crashes against roadsides W-beam barriers were equal to 238 (72 injury crashes), injury rate was equal to 30.3%. Total crashes against roadsides thrie-beam barriers were equal to 71 (12 injury crashes), injury rate was equal to 16.9%. Ratio between the injury rate for the W-beam and thrie-beam roadside barriers is equal to 1.79. This result is meaningful for highway agencies, since shows that replacement of old safety barriers with new barriers tested and approved according EN 1317 criteria may be effective in reducing crash severity.

Terminals of Safety Barriers

ROR crashes against safety barriers terminals were equal to 26: 16 against a blunt end W-beam terminal, 6 against a blunt end thrie-beam terminal, 1 against a blunt end bridge rail terminal, and 3 against a bridge steel New Jersey terminal.

Severity of crashes against terminals was much greater than severity of crashes against longitudinal barriers. Blunt end terminals of W-beam, thrie-beam, and bridge rails, compared to the longitudinal barriers, showed overrepresentation of major injury (34.8% vs. 5.3%, χ^2 = 23.39, level of confidence = 99.9%) and injury (73.9% vs. 27.8%, χ^2 = 19.25, level of confidence = 99.9%) crashes. Ratio between the major injury rate (major injury crashes/total crashes) for the blunt end terminals and longitudinal barriers is equal to 6.55. Ratio between the injury rate for the blunt end terminals and longitudinal barriers is equal to 2.66. All crashes against bridge steel New Jersey terminals were injury crashes (n = 3). Terminals of bridge steel New Jersey barriers, compared to longitudinal barriers, showed overrepresentation of injury (100.0% vs. 25.0%, χ^2 = 3.58, level of confidence = 90.0%) crashes.

Ditches

ROR crashes against roadside ditches were equal to 68: 58 against rounded ditches, and 10 against trapezoidal ditches. Trapezoidal ditches showed a higher proportion of injury crashes (60.0% vs. 39.7%) but the difference is not statistically significant. Injury crashes in collisions against ditches were overrepresented in comparison to both roadside W-beam barriers (42.6% vs. 30.3%, χ^2 = 3.14, level of confidence = 90.0%) and roadside thrie-beam barriers (42.6% vs. 16.9%, χ^2 = 9.87, level of confidence = 99.0%). Ratio between the injury rate for the ditches and W-beam (thrie-beam) roadside barriers is equal to 1.41 (2.52). These results suggest that shield roadside ditches with safety barriers may contribute to reduce ROR crash severity.

Walls

ROR crashes against roadside walls were equal to 146: 18 major injury crashes (12.3%), 51 slight injury crashes (34.9%), and 77 property damage only crashes (52.7%). Both injury crashes (47.3% vs. 30.3%, χ^2 = 10.55, level of confidence = 99.0%) and major injury crashes (12.3% vs. 5.0%, χ^2 = 5.70, level of confidence = 95.0%) were overrepresented in comparison with roadside W-beam barriers. Ratio between the injury (major injury) rate for the walls and W-beam roadside barriers is equal to 1.56 (2.45). Injury crashes (47.3% vs. 16.9%, χ^2 = 17.54, level of confidence = 99.9%) were overrepresented also in comparison to roadside thrie-beam barriers. Ratio between the injury rate for the walls and thrie-beam roadside barriers is equal to 2.80. Even if many existing roadside walls are not shielded with roadside barriers, the study results strongly support the installation of roadside barriers for the walls protection.

Foreslopes

Foreslopes (embankments with fill slope) have slope equal to 2/3 (2V:3H). Height varies between 0.7 and 10.0 m (mean = 3.0 m, standard deviation = 2.6 m). ROR crashes against foreslopes were equal to 52: 14 major injury crashes (26.9%), 23 slight injury crashes (44.2%), and 15 property damage only crashes (28.8%).

Both injury crashes (71.2% vs. 27.2%, $\chi^2 = 36.67$, level of confidence = 99.9%) and major injury crashes (26.9% vs. 5.2%, $\chi^2 = 24.84$, level of confidence = 99.9%) were overrepresented in comparison to roadside barriers. Ratio between the injury (major injury) rate for the foreslopes and roadside barriers is equal to 2.62 (5.20).

In order to investigate the effect of embankment height on crash severity, foreslopes were divided in two classes: height less or equal to 2 m, height greater than 2 m. Higher embankments showed greater injury rate (75.0% vs. 67.9%), although the difference is not statistically significant. Results highlighted the great severity of ROR crashes on embankments with high slopes (2/3), independently from the foreslope height, and the potential benefits of slopes flattening. Almost 60% (n = 31, 59.6% of the total) of crashes against embankments involved vehicle rollover. A greater proportion of rollovers occurred on higher embankments (79.2% vs. 42.9%, $\chi^2 = 5.65$, level of confidence = 95.0%).

10.6 Backslopes

Backslopes have slope equal to 1/1. ROR crashes against backslopes were equal to 25: 2 major injury crashes (8.0%), 14 slight injury crashes (56.0%), and 9 property damage only crashes (36.0%).

Injury crashes were overrepresented in comparison to roadside barriers (64.0% vs. 27.2%, $\chi^2 = 13.24$, level of confidence = 99.9%). Ratio between the injury rate for the backslopes and roadside barriers is equal to 2.35. High severity of ROR crashes against backslopes mainly depends on the high proportion of rollovers (n = 19; 76.0%). Even if backslopes are generally not shielded with roadside barriers, ROR crashes against backslopes with high slopes showed greater severity than crashes against roadside safety barriers.

Longitudinal Safety Barriers Performance Evaluation

Longitudinal safety barriers performance (Table 4) was evaluated considering all crashes against safety barriers (n = 784), i.e., considering also crashes where impact against the barrier was not the most harmful event (n = 48). Safety barriers behaviour was considered acceptable (86.6% of the total crashes against longitudinal safety barriers, n = 679) if the vehicle was stopped in contact (5.0%, n = 39) or was redirected (81.6%, n = 640). It was considered unacceptable (13.4%, n = 105) if the vehicle was redirected with rollover (7.3%, n = 57) or if it penetrated or override the barrier (6.1%, n = 48). Overall, the safety barriers behaviour was satisfactory but the different systems showed statistically significant differences that should be taken into account.

Proportion of unacceptable behaviour in truck crashes was significantly greater than in passenger car crashes (31.4% vs. 11.3%, $\chi^2 = 21.88$, level of confidence = 99.9%). The ratio of penetrated/override proportion between trucks and cars is equal to 5.7 (23.3% vs. 4.1%, $\chi^2 = 38.84$, level of confidence = 99.9%), while the proportion of rollover crashes did not show significant difference.

TABLE 4 Longitudinal Safety Barriers Performance

Barrier type	Stopped in contact		Redirected		Acceptable		Redirected with rollover		Penetrated/ Override		Unacceptable		Total crashes
	N	%	N	%	N	%	N	%	N	%	N	%	N
All vehicles													
Roadside W-beam (h=75cm)	22	8.5	193	74.2	215	82.7	22	8.5	23	8.8	45	17.3	260
Roadside double W-beam (h=120cm)	0	0.0	0	0.0	0	0.0	0	0.0	1	100.0	1	100.0	1
Roadside thrie-beam (h=110cm)	4	5.5	65	89.0	69	94.5	2	2.7	2	2.7	4	5.5	73
Median W-beam (h=75cm)	6	2.1	256	88.3	262	90.3	11	3.8	17	5.9	28	9.7	290
Median double W-beam (h=120cm)	2	2.9	59	85.5	61	88.4	5	7.2	3	4.3	8	11.6	69
Median thrie-beam (h=110cm)	0	0.0	1	100.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Median New Jersey (h=100cm)	3	5.1	39	66.1	42	71.2	16	27.1	1	1.7	17	28.8	59
Bridge rail (h=110cm)	0	0.0	9	81.8	9	81.8	1	9.1	1	9.1	2	18.2	11
Bridge steel New Jersey (h=155cm)	2	10.0	18	90.0	20	100.0	0	0.0	0	0.0	0	0.0	20
Total	**39**	**5.0**	**640**	**81.6**	**679**	**86.6**	**57**	**7.3**	**48**	**6.1**	**105**	**13.4**	**784**
Passenger cars													
Roadside W-beam (h=75cm)	8	3.6	180	80.0	188	83.6	19	8.4	18	8.0	37	16.4	225
Roadside thrie-beam (h=110cm)	2	3.2	58	92.1	60	95.2	2	3.2	1	1.6	3	4.8	63
Median W-beam (h=75cm)	3	1.2	241	93.4	244	94.6	8	3.1	6	2.3	14	5.4	258
Median double W-beam (h=120cm)	2	3.2	54	85.7	56	88.9	4	6.3	3	4.8	7	11.1	63
Median thrie-beam (h=110cm)	0	0.0	1	100.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Median New Jersey (h=100cm)	2	3.6	37	67.3	39	70.9	16	29.1	0	0.0	16	29.1	55
Bridge rail (h=110cm)	0	0.0	7	87.5	7	87.5	1	12.5	0	0.0	1	12.5	8
Bridge steel New Jersey (h=155cm)	1	5.6	17	94.4	18	100.0	0	0.0	0	0.0	0	0.0	18
Total	**18**	**2.6**	**595**	**86.1**	**613**	**88.7**	**50**	**7.2**	**28**	**4.1**	**78**	**11.3**	**691**
Trucks													
Roadside W-beam (h=75cm)	14	41.2	12	35.3	26	76.5	3	8.8	5	14.7	8	23.5	34
Roadside double W-beam (h=120cm)	0	0.0	0	0.0	0	0.0	0	0.0	1	100.0	1	100.0	1
Roadside thrie-beam (h=110cm)	2	22.2	6	66.7	8	88.9	0	0.0	1	11.1	1	11.1	9
Median W-beam (h=75cm)	3	10.7	11	39.3	14	50.0	3	10.7	11	39.3	14	50.0	28
Median double W-beam (h=120cm)	0	0.0	5	83.3	5	83.3	1	16.7	0	0.0	1	16.7	6
Median New Jersey (h=100cm)	1	33.3	1	33.3	2	66.7	0	0.0	1	33.3	1	33.3	3
Bridge rail (h=110cm)	0	0.0	2	66.7	2	66.7	0	0.0	1	33.3	1	33.3	3
Bridge steel New Jersey (h=155cm)	1	50.0	1	50.0	2	100.0	0	0.0	0	0.0	0	0.0	2
Total	**21**	**24.4**	**38**	**44.2**	**59**	**68.6**	**7**	**8.1**	**20**	**23.3**	**27**	**31.4**	**86**
Motorcycles													
Roadside W-beam (h=75cm)	0	0.0	1	100.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Roadside thrie-beam (h=110cm)	0	0.0	1	100.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Median W-beam (h=75cm)	0	0.0	4	100.0	4	100.0	0	0.0	0	0.0	0	0.0	4
Median New Jersey (h=100cm)	0	0.0	1	100.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Total	**0**	**0.0**	**7**	**100.0**	**7**	**100.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**7**

All motorcycles were redirected (n = 7), but 4 crashes were fatal and the other 3 crashes produced injuries. Bearing in mind also the data published in literature, it is stressed there is a critical need to adopt improved barrier designs and new crash test procedures to protect these vulnerable road users. A positive example is the Spanish UNE 135900 standard *(22),* which defines procedures for the assessment of the performance of the motorcyclist protective devices' (MPDs). MPDs are devices installed on a steel safety barrier to protect motorcyclists from impacts against the barrier posts or to prevent motorcyclists from crossing the safety barrier through the space between the posts.

Thrie-beam roadside barriers equipped with rubber rail showed a smaller severity and a better performance than W-beam roadside barriers (Figure 3). Indeed, proportion of unacceptable behaviour in W-beam crashes was significantly greater than in thrie-beam crashes (17.3% vs. 5.5%, χ^2 = 5.45, level of confidence = 95.0%). Thrie-beam roadside barriers also showed the smaller proportion of unacceptable behaviour in truck crashes (11.1%), even if this result was not statistically significant.

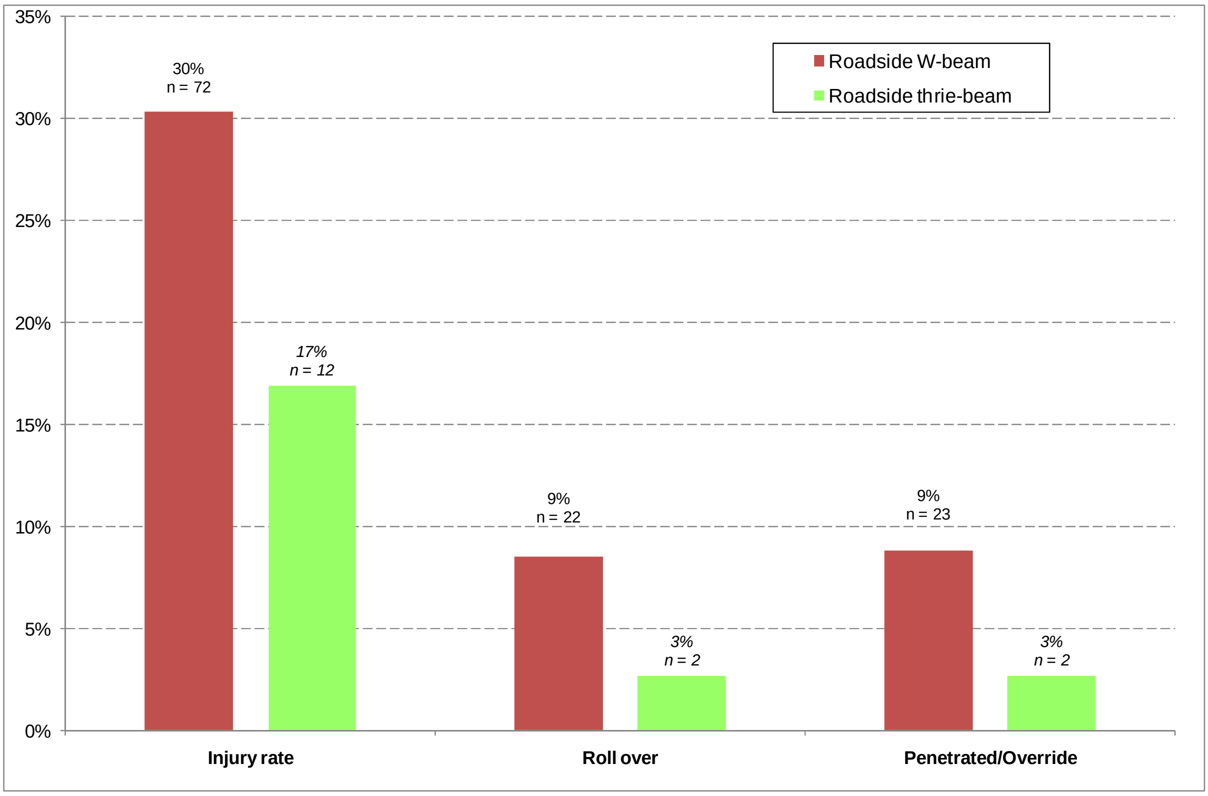

FIGURE 3 Comparison between W-beam and thrie-beam roadside safety barriers.

Median New Jersey concrete barriers, compared to the steel median barriers, gave rise to a worrying proportion of rollovers (27.1% vs. 4.4%, χ^2 = 33.80, level of confidence = 99.9%). Median New Jersey concrete barriers showed a better behaviour in relation to penetration and override, but the difference with the steel road safety barriers was not statistically significant (1.7% vs. 5.6%, χ^2 = 0.92, level of confidence = 66.3%) (Figure 4).

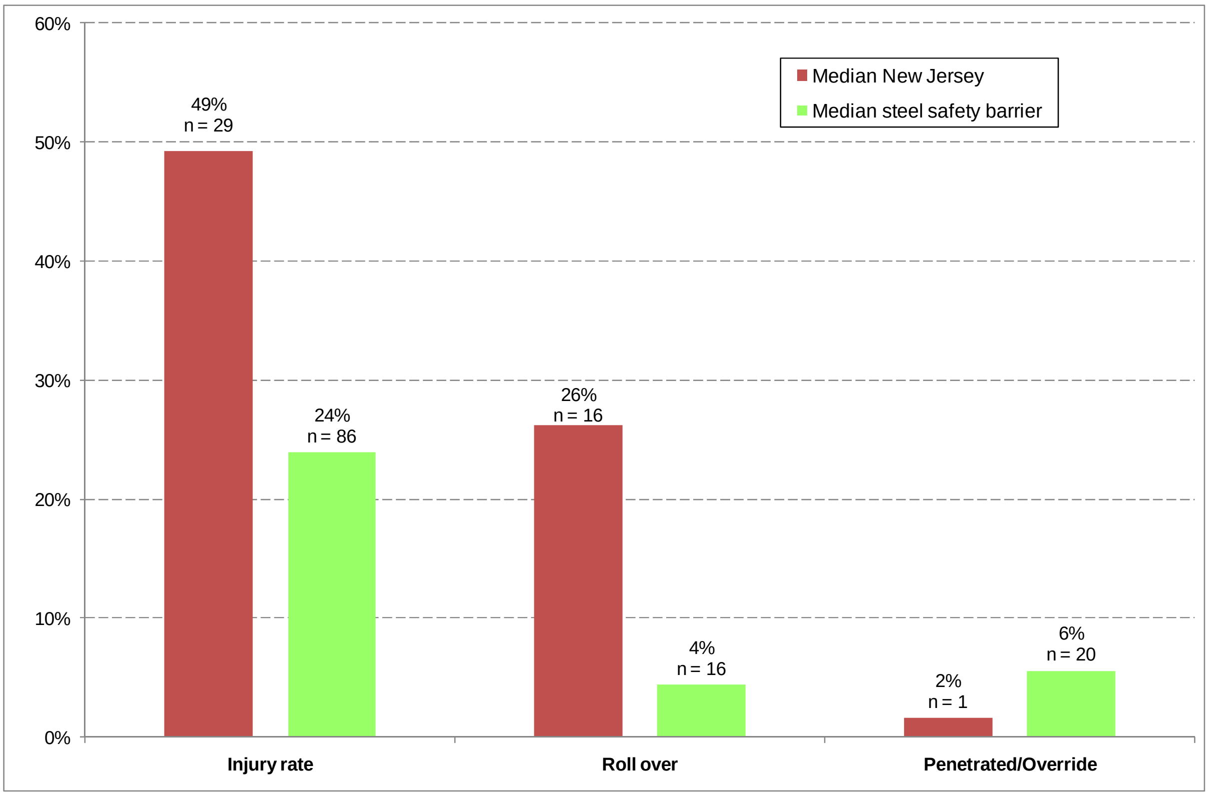

FIGURE 4 Comparison between median concrete New Jersey and median steel safety barriers.

SELECTION OF ROADSIDE SAFETY MEASURES

Results of the study showed many situations where roadside improvements may give rise to reduced crash severity, that is fewer injuries and fatalities associated with ROR crashes. Nevertheless, because of the limited funds available, not all the safety measures can be implemented. In the US, benefit/cost analysis procedures, like the programs ROADSIDE *(4)* and RSAP *(5)*, have been widely accepted as a rational method for evaluating roadside safety treatment alternatives. In Italy, a model for the selection of roadside safety barrier performance level according to EU standards has been developed *(3)*. Benefit/cost analyses provide a logical and systematic approach to evaluate roadside safety treatment alternatives, by comparing alternatives and selecting only projects for which the expected benefits would exceed the expected direct costs of the project. Benefits are measured in terms of reductions in crash or societal costs from decreases in the frequency or severity of crashes. Direct highway agency costs are initial installation, maintenance, and crash repair costs. In the existing procedures, crash costs are calculated in relation to the severity index, which is associated with fixed percentages of fatal, injury and property damage only crashes, but this approach showed many drawbacks *(5-7)*. Results of the study can be used in order to directly estimate the probabilities of injury, thus improving reliability of the analyses.

CONCLUSIONS

This study provided an in-depth investigation of ROR crashes frequency and severity in relation to the roadside features, vehicle types and environmental conditions. Study results give some insights that might be helpful for the selection of safety countermeasures aimed at reducing ROR crashes severity.

Severity of motorcycle crashes was significantly higher than severity of other vehicle types. Crashes against ditches, walls, foreslopes, and backslopes were more severe than crashes against roadside safety barriers, thus suggesting the installation of safety barriers as a severity mitigation measure.

Comparison between severity of crashes against longitudinal safety barriers and their blunt end terminals showed a dramatic increase in crash severity against terminals. Basing on this result, which is consistent with literature findings, replacement of blunt end terminals with energy absorbing terminals that meet the performance standard outlined in EN1317-4 or NCHRP 350 is a priority task.

Thrie-beam roadside barriers equipped with rubber rail that meet EN 1317-2 performance criteria showed a smaller crash severity and a better performance compared to older W-beam roadside barriers. These results show that replacement of old safety barriers with new barriers which fulfil EN 1317 criteria may be effective both in reducing crash severity and in reducing vehicle rollover and barrier penetration or override.

Median New Jersey concrete barriers, compared to median steel safety barriers, showed greater crash severity and greater proportion of rollovers. This result is consistent with the findings of the studies carried out on French motorways median. Median New Jersey barriers, compared to W-beam median barriers, gave rise to a worrying proportion of rollovers. This unfavourable behaviour was not counterbalanced by a significant better behaviour in relation to penetration and override. These results, combined with findings of studies carried out on French motorways, suggest the installation of steel median safety barriers.

Results of the study showed many situations where roadside improvements may give rise to reduced crash frequency and severity. Nevertheless, because of the limited funds available, not all the safety measures can be implemented. Benefit/cost analyses provide a logical and systematic approach to evaluate roadside safety treatment alternatives. In the existing benefit/cost procedures, crash costs are calculated in relation to the severity index, which is associated with fixed percentages of fatal, injury and property damage only crashes, but this approach showed many drawbacks. Results of the study can be used in order to directly estimate the probabilities of injury.

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