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New research opportunities for roadside safety barriers improvement

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Abstract. Among the major topics regarding the protection of roads, restraint systems still represent a big opportunity in order to increase safety performances. When accidents happen, in fact, the infrastructure can substantially contribute to the reduction of consequences if its marginal spaces are well designed and/or effective restraint systems are installed there. Nevertheless, basic concepts and technology of road safety barriers have not significantly changed for the last two decades. The paper proposes a new approach to the study aimed to define possible enhancements of restraint safety systems performances, by using new materials and defining innovative design principles. In particular, roadside systems can be developed with regard to vehicle-barrier interaction, vehicle-oriented design (included low-mass and extremely low-mass vehicles), traffic suitability, user protection, working width reduction. In addition, thanks to sensors embedded into the barriers, it is also expected to deal with new challenges related to the guidance of automatic vehicles and I2V communication.

1. Introduction

The importance and usefulness of road restraint systems (RRS) are uncontested principles of a scientific and technical approach to the road safety; the general aim is to enhance safety levels by means of these protection systems, because the infrastructure can substantially contribute to the reduction of accidents consequences.

Many products and devices are currently available in order to install longitudinal barriers, crash cushions, transitions, terminals, and so on. The research efforts performed in the last decades, in fact, together with the contribution of industry, have allowed to really improve the technical and physical characteristics of road safety systems [1] [2] [3].

However some performances of road barriers nowadays should be improved, especially for specific topics like: vehicle-barrier interaction, pre-crash information, traffic characteristics and working width reduction. The statistical analyses, in fact, highlight that the accidents in which the barriers are involved have a higher risk of injuries and fatalities. A study leaded in UK on the basis of the STATS 19 DataBase [4] (sample: 1,584,605 accidents on major roads in England, Scotland and Wales, in 1992-2005, involving 3,029,100 vehicles and resulting in 2,233,288 casualties) showed that the severity of crashes involving RRS is higher than the general one. In RRS-involving incidents 2.0% of occurrences are fatal (1.4% for the general incidents); 13.9% serious (12.9% for the total) and 84.0% slight (85.7%).

To deal with this problem, above all it seems necessary to develop new barrier shapes or structural design, in order to moderate crash severity in the case of barriers having high (or very high) containment level. Furthermore, the dynamic interaction of these restraint systems with low mass vehicle and/or very low mass vehicles is another interesting research objective [5] [6] [7], because the deformation of barrier and the controlled redirection of vehicles can significantly reduce the injury risk for users.

On the basis of a review of the technological advancement history and of the analysis of the most critical points in the state of the art, new developments can be outlined, especially by using advanced research tools like simulation models and high-performing materials. The new proposed perspectives deal with these issues and aim to propose new research actions to improve the safety performances of RRS.

2. State of the art analysis

According to a commonly accepted approach, the road safety can be ensured by active and passive measures [8] [9], where the former are devoted to the accidents prevention and the latter are aimed to the protection of users and goods by mitigating the consequences of critical events.

In the field of passive safety factors, the RRS play an important role, since they can significantly contribute to the reduction of risk (especially for run-off-road accidents). As regard of technology of roadside systems, some important developments have been achieved in the last decades, regarding both physical and structural characteristics of the devices.

In particular, for the specific case of longitudinal road barriers, various generations of them have been developed and used, over the time, especially along the UE road networks.

We can remember, for example, about thirty years ago a sort of revolution that changed the conception of roadside safety; in fact, after the previous positive experiences in the U.S., the introduction and the diffusion of the modern concrete barriers came in Europe. New shapes and profiles (in particular: the New Jersey profile [11] [13], see Figure 1) were successfully experimented and new restraint systems were largely installed along primary roads, especially because of their containment performances, using both precast technology and in-situ construction processes.

Figure 1. The New Jersey concrete barriers came in Europe between '80s and '90s of the 20th century, after the previous positive experiences in the U.S.

Later on, in the middle of '90s, the steel industry proposed other high performing devices (three-waves barriers [11] [13], see Figure 2), able to ensure the same containment levels of the concrete barriers. Since then, however, the main technical conception of roadside safety systems have no more significantly changed.

Figure 2. The steel barriers can ensure high containment performances by means of the three-waves profile.

Nowadays, it is important to consider that the vehicle characteristics are not comparable to those of twenty, fifteen or just ten years ago (Figure 3). Technical features like mass, dimensions, shapes, crashworthiness, speed have really changed. Consequently, the typical crashes and their severity are changed too: in particular the protection of vehicle's occupants should be differently addressed, especially because accidents can involve vehicles having various characteristics (trucks or passenger cars, but also motorcycles, low mass vehicles, and so on) [10].

Figure 3. The comparison between road vehicles can immediately show the today's needs for improvement of barrier technology.

In addition, there are new problems related to the automatic guidance technologies and the coexistence between automatic vehicles and traditional ones [14] [15]; in both cases the roadside systems are requested to ensure high containment and low severity characteristics.

In fact, the road barriers can be also used for contributing to the automation technology [16] but, mainly, they have in charge an important role for the roadside safety; these aims require that the marginal spaces of a road infrastructure should be well designed and effective restraint systems should be installed there.

For all the above presented reasons, now it is the right time to improve the features of road edges and performances of roadside safety systems, adapting them to the new needs coming from vehicles and safety issues. A new generation of roadside systems and devices can be explored by means of original and well-addressed research activities.

3. New research opportunities

The control of road exercise and the protection of road users still represent important challenges for the next decades. Big opportunities, in this sense, are provided by possible improvements of road edges, both for passive and active safety issues.

Considering that the road carriageway normally does not allow deep changes in its features, the new problems related to changes in vehicles characteristics should be addressed toward a new conception of road edges and roadside devices and systems. These parts of road infrastructure, in fact, can be developed in order to assist vehicles guidance, to avoid some kinds of accidents and to mitigate their consequences when accidents happen.

The new research opportunities which can be now investigated essentially concern how to obtain barriers having high (or very high) containment level, while maintaining moderate crash severity level. In particular, it is important to control the dynamic interaction of restraint systems with low mass vehicle, in order to obtain lower injury risk for passengers, by means of vehicle post-crash redirection.

To consider how the current standards in concept and design of RRS can be implemented, it is necessary to remind some theoretical fundamentals. The longitudinal road barriers work by means of a complex combination of processes and effects due to their primary properties. In fact, they are able to achieve both containment of errant vehicles and mitigation of crash effects because of their structural resistance and their aptitude to dissipate the kinetic energy transmitted by colliding bodies.

These principles are valid for both concrete and steel barriers, but while the former generally dissipate the energy by means of friction effects on their base, the latter can rely on their internal deformations that allow to absorb a wide part of the crash energy [17] (Figure 4). In addition, the shape and the structural behaviour of the barriers are defined with the aim to redirect the vehicles after the crash, so maintaining a controlled trajectories and avoiding to involve other vehicles in the accident.

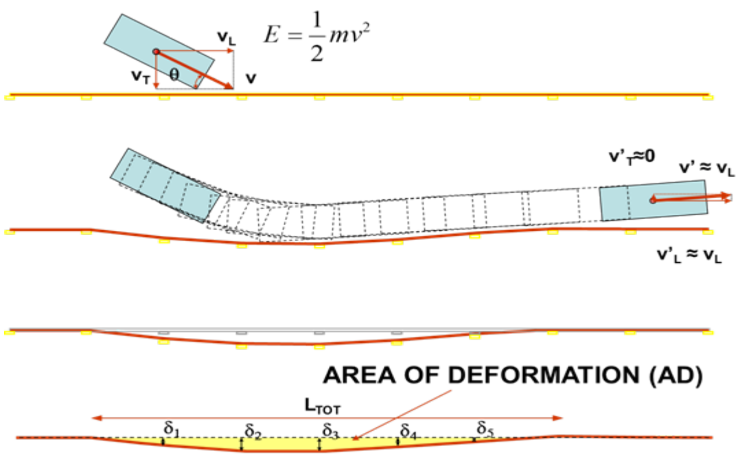

Figure 4. Impact phenomenon evolution for run-off crash collision and energy dissipation by internal and external deformation [17].

In order to pursue the described working principles, the barriers should be designed and realized on the basis of the actual dynamic interaction with the bumping vehicles, considering all possible types of vehicles that can hit the barrier and all crash conditions (i.e.: trajectories, speed and angles, …). To optimize the barriers' conception and their design, it is essential to consider their detailed shape and the properties of material they are made of.

After the important advancements achieved in the last decades, the design criteria and the construction technology of road safety barriers can now further be improved by means of an advanced use of the properties of different materials, also considering their combination and some integration opportunities.

In addition, it seems important to explore also new shapes and profiles [18], with the aim to obtain a more performing behaviour of the restraint systems under crashes. A comprehensive assessment of the whole technical properties of barriers should also include construction technologies and processes; these can be enhanced, for example, by means of widening of the in-situ activities, in order to obtain a more effective adaptation to the local conditions and characteristics of roads.

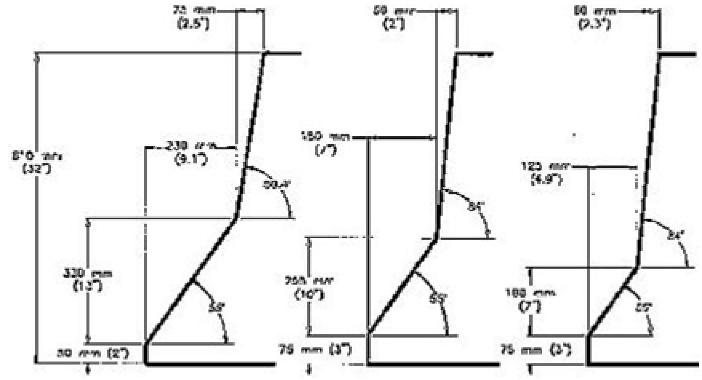

Figure 5. Example of evolution of shapes for concrete safety barriers [11].

It seems now necessary to overpass the traditional division between concrete and steel barriers and/or between high and low containment (low and high severity level) properties. A new generation of road barriers (and/or other restraint systems) should combine different materials, to allow a multi-stage deformation behavior in order to optimize the reaction of barriers in case of crash with both light vehicles and heavy ones.

The research topics, above presented, can be investigated by means of FE models and crash simulations; however, several laboratory tests are needed in order to calibrate the models and to obtain a better knowledge of dynamic actions during impact events.

Another important item should be included in the research on the design and construction processes of road barriers: the integration with sensors and devices needed for the transition toward the guidance of autonomous vehicles. In fact, the predictable developments of the road system and research trends for vehicles, propose a new request in order to provide the road infrastructure of sensors and systems needed for these aims. In this sense, the road edges and, particularly, the restraints systems are the most suitable elements for obtaining the demanded improvements. Special wireless sensors could be embedded in the road barriers, so providing a continuous reference path along the road (Figure 5).

The sensors should preferably be conventional and common devices, in order to ensure easy and low-cost installations together with the interoperability of the system. Nevertheless, it is important to study various possible difficulties or problems regarding the reliability and the effectiveness of the system addressed to the autonomous vehicles guidance (as an example: the shadow areas). The strengths and weaknesses of the integration between safety barriers and wireless sensors has to be specifically evaluated, considering the consistency and redundancy of the system, in case of crashes or other undesired events, that can occur during the road exercise.

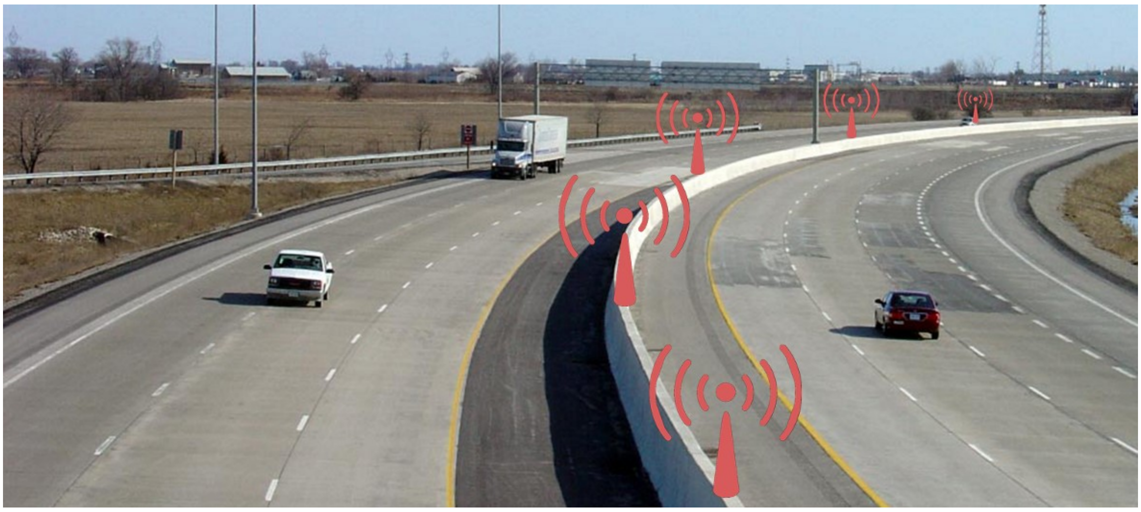

Figure 6. Roadside barriers can also provide a I2V infrastructure, but their main task still remain the passive safety performances for both traditional vehicles and innovative ones.

4. Expected Impact

The proposed approach to the research on a new generation of RRS is mainly aimed to consider vehicles characteristics, properties of component materials, safety performances, and I2V communication.

As regard of this last feature, on one hand the future restraint system could enhance the "passive forgiveness" of the roadside respect to light and heavy vehicles: I2V communication warns the vehicle that the upcoming impact will be against a barrier. Therefore, the passive safety devices will activate with the specific countermeasures as earlier time to fire, deployment of side airbags, etc.. On the other hand the barrier will be able to communicate its own plastic-elastics characteristics to the vehicle's on-board intelligence, allowing future generation vehicles to optimize the internal countermeasures, e.g. to set the optimal pre-tensioning of safety belts. The system will be able to communicate the exact location of the impact and its severity to the road operator and the emergency services: this will be extremely useful during the transitional period needed before having a new generation of intelligent vehicles on the roads. In the future, it will also act as a redundant safety system for those new vehicles running on the road network.

More general, the barriers technology implementation will a relevant contribution to the reduction of fatalities and injuries. According to a CEDR publication on forgiving roadside [18], in fact, 45% of fatal accidents are single vehicle, primarily classified as run-off-road accidents, where the vehicle leaves the road and enters the roadside. This indicates that working on a more forgiving roadside can actually have a high safety impact.

After all, a large part of deaths and injuries in run-off-road crashes is related to the imperfect behaviour of the RRS; this is due to a well-known problem: to obtain high containment levels (especially for HGV) the barriers must be very rigid and slightly deformable; but this increases the severity of crashes for passengers cars and low-mass vehicles, together with potential injuries suffered by their occupants. The main research area to provide advancements in the technology of RRS is the pursuit of a better balance between containment, deformation and severity crash level, especially in all those road stretches having very limited space for roadside barriers.

In fact, a new kind of specifically studied restraint system will allow to deal with the problem of RRS installation in sites where there is not enough side space and the design solution leads to ensure the containment of heavy vehicles. This will be a noticeable contribution to the development of "forgiving roadsides", also for some special traffic components.

New researches should also provide proposals for improving technical standards and regulations, both for roadside systems production and installation. Several stakeholders (institutions, professionals and economic operators) are requesting a revision of technical standards and regulations, since restraint systems have a high part in national markets and solutions often differ between countries. Technical standards develop very slowly compared to the situation on the roads: obtaining an updated protocol of installation and use of types of barriers would improve the safety of all roads around Europe. This fact will contribute to obtain a global view of the accidents with the same road conditions and it will be able to compare and analyse accidents between different countries. Moreover, it would be easier to implement safety improvements, protocols and techniques to decrease the accidents in all the interested Countries.

5. Conclusion

After the evaluation of the state of the art and the recall of theoretical fundamentals of roadside safety, it is clear that an improvement of concept and technical characteristics of RRS is now actually needed. The evolution of vehicles, circulation and safety requirements, together with the new challenges due to autonomous vehicles guidance and I2V communication needs, make evident the deficiencies of currently adopted systems respect to the requested performances.

Thus, the paper has highlighted new research opportunities in this field, based on a new approach that overpasses the traditional division between concrete and steel barriers and/or between high and low containment (low and high severity level) properties.

The general objective of a new research is the development, demonstration and validation of a new generation of road barriers and restraint systems, combining different materials, to allow a multi-stage deformation behavior in order to optimize the reaction of barriers in case of crash with both light vehicles and heavy ones. The research can also develop and test innovative uses and functions for roadside devices: in particular, the embedded wireless sensors and other ITS devices, with the aim to provide an advanced infrastructure for autonomous vehicle guidance, pre-crash information (or other on-board safety systems), I2V and V2I communication, as well as the information about conditions of the barrier itself and its maintenance needs.

New barriers should be able to optimize their behavior in case of crash with both heavy and extremely low-mass vehicles and, at the same time, should realize an infrastructure for I2V communication, so promoting an effective advancement of the industrial and commercial standards in the field of RRS technology.

Proposals for improving technical standards and regulations are also requested, both for the production and installation of roadside systems, since a revision of these documents is being waited by various institutions, professionals and economic operators.

Finally, the potential development of new barriers, like the ones whose requested performances have been here described, will contribute to improve the passive safety protection currently offered by road infrastructure. This could be an important strategic target for research, industry and economical system, especially considering that in a large part of European road networks the existent RRS must be implemented or substituted by the next 20 years.

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