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Development of a continuous motorcycle protection barrier system using computer simulation and full-scale crash testing

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ABSTRACT

Road restraint systems are designed to minimize the undesirable effects of roadside accidents and improve safety of road users. These systems are utilized at either side or median section of roads to contain and redirect errant vehicles. Although restraint systems are mainly designed against car, truck and bus impacts there is an increasing pressure by the motorcycle industry to incorporate motorcycle protection systems into these systems.

In this paper development details of a new and versatile motorcycle barrier, CMPS, coupled with an existing vehicle barrier is presented. CMPS is intended to safely contain and redirect motorcyclists during a collision event. First, crash performance of CMPS design is evaluated by means of a three dimensional computer simulation program LS-DYNA. Then full-scale crash tests are used to verify the acceptability of CMPS design. Crash tests were performed at CSI proving ground facility using a motorcycle dummy in accordance with prEN 1317-8 specification. Full-scale crash test results show that CMPS is able to successfully contain and redirect dummy with minimal injury risk on the dummy. Damage on the barrier is also minimal proving the robustness of the CMPS design. Based on the test findings and further review by the authorities the implementation of CMPS was recommended at highway system.

1. Introduction

Motorcyclists are among the vulnerable road users (SWOV Institute for Road Safety Research, 2012). It is obvious that powered two wheels or PTWs are less stable and less visible than cars on the road and lack occupant compartment protection for riders. Thus, motorcycle accidents, though not necessarily more frequent than other types of accidents, are more likely to result in serious injury or death of the motorcyclists (Nordqvist et al., 2015; European Commission, 2015; Lenné et al., 2015).

Motorcycle safety is an important topic all over the globe. There are about 33 million PTWs in Europe where Greece, Italy, France, UK, Spain and Germany have the highest motorcycle fatality rates in the EU. According to the CARE database, there were 32.951 people killed on EU-15 roads, 3.998 of those are riders and passengers of PTWs (Garcia et al., 2009). Porter (Porter, 2011) mentioned that in the European Union the risk of motorcyclist fatality is 20 times that of a car passenger. On the other hand, the US statistical data suggest that per mile travelled in 2006, there were 35 times more deaths from motorcycle accidents than from car accidents (IIHS, 2013). In 2006, motorcycles accounted for approximately 1% of traffic on UK roads, but accounted for 19% of fatal and serious casualties indicating that they are over-represented in the national casualty statistics (Williams et al., 2008). According to a recent study the most common motorcycle crash type is when automobile maneuvers into the path of an oncoming motorcycle at an intersection (McCarthy et al., 2007).

Even though the number of motorcyclist killed on roads has decreased in the EU between 2010 and 2013, the number of fatalities still represent a fairly large percentage. One of the prime reasons for motorcyclist fatalities during roadside accidents are the presence of non-motorcycle friendly steel guardrail barrier systems with posts. Research by FEMA (FEMA, 2015) showed that unprotected guardrail posts are the leading cause for most serious injuries and high rate of fatalities for motorcyclists.

Abbreviations: ATD, anthropomorphic test device, Hybrid III 50th percentile male ATD; CEN, European Standardization Committee; CMPS, continuous motorcycle protection system; DMPS, discontinuous motorcycle potection system; EN, European Norm; EU, European Union; FEMA, The Federation of European Motorcyclists' Associations; MAIDS, Motorcycle Accident In Depth Study; MPS, motorcycle protection System; PTW, powered two-wheelers; SMC, The Swedish Motorcyclists Association; TC, Technical Committee; prEN, European pre-Norm; Wd, working width; SL, severity level; RRS, road restraint system

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Although the alarming situation of the motorcyclist safety in Europe the use of Motorcycle Protection Systems, or MPS, are still non-mandatory. Motorcycle Protection System is any device installed on a barrier or in its immediate surroundings, the purpose of which is to reduce the severity of a PTW rider impact against the barrier. Nevertheless, there is a detailed testing and evaluation specification, prEN 1317–Part 8 that exists in the Europe (CEN/TC226/WG1, 2011). This specification was developed on the basis of Spanish norm UNE 135900 for "Performance evaluation and acceptance criteria of motorcyclist protection systems in safety barriers". MPS manufacturers in Europe use this specification for the development of state-of-the-art motorcycle friendly designs.

In this paper an existing steel road restraint system was upgraded with a MPS to improve its safety performance. The crash test performance and acceptability of the new MPS design was fully evaluated using finite element analysis and full-scale crash testing. Results of the study show that MPS contains and redirects impacting dummy with minimal risk of injury. The rest of the paper explains the testing and evaluation details of MPS design.

2. European standard prEN 1317-8 on motorcyclist protection

The prEN 1317-8: "Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers" test specification separates MPDs in two classes: The first type is CMPS, which are MPS placed continuously along a barrier with the purpose of retaining and redirecting an impacting rider, usually preventing direct impact with aggressive elements of the barrier such as posts, anchorages or module connections. It also prevents a sliding rider from passing between the posts of a barrier and coming into contact with any potential hazard that may be behind the barrier. The second type is DMPS, which are MPS placed locally around a potentially aggressive element of a barrier, such as a post, anchorage or module connection, with the purpose of reducing the severity of a direct impact of the rider against it. This type of system is not intended to contain fallen PTW riders due to the discontinuous protection along the length of the barrier (CEN/TC226/WG1, 2011). The design evaluated in this paper is a continuous MPS or CMPS.

2.1. Full scale crash testing details of MPS in prEN 1317-8

According to prEN 1317-8, for a full-scale impact test the minimal length of the test item has to be sufficient to demonstrate the full performance of the MPS and must be installed according to the installation manual provided by the manufacturer, test person or organization. The installation manual also specifies the height above the ground of the lower edge or the elements designed to retrain the PTW rider.

Full-scale tests consist of launching an ATD against the test item in accordance with a determined approach path and test condition. As shown in Fig. 1, for each TM the ATD is launched lying face-up in a "supine decubitus" position, e.g., face up in a horizontal position and completely stretched out on its back, with its upper limbs parallel and adjacent to its trunk, with the palms of its hands oriented towards its trunk, sliding with its back and legs stably in contact with the ground (CEN/TC226/WG1, 2011). The ATD, equipped with an integral type, production motorcycle helmet weighing 1.3 kg with polycarbonate shell, is dressed in one-piece motorcycle suit, leather gloves, and leather boots. The surfaces of the helmet and the test item in the impact area have to be clean, dry and free of any item or substance that may affect the contact between both surfaces.

Table 1 lists test details and performance classes specified in prEN 1317-8 for the testing and evaluation of a MPS (CEN/TC226/WG1, 2011). As shown in this table, tests are run at either 60 or 70 kph. Table 2 illustrates the tests specified for CMPS in prEN 1317-8 based on classes C60 and C70. TM shown in these tables abbreviate Test of Motorcycle. The numbers 1, 2 or 3 come after TM describe the launch configurations for the dummy to the barrier (CEN/TC226/WG1, 2011). Fig. 2 illustrates directions 1, 2 and 3 representing post centered, post offset and mid span, respectively. For the post-centered impact test, designated as TM1, the approach path of the ATD is defined by a line, parallel to the ground, passing through the center of the post section and forming a 30° angle with respect to the centerline of the undeformed test item. This test is required to measure the effectiveness of CMPS in protecting dummy.

For the mid-span impact test, designated as TM3, the approach path of the ATD is also defined by a line, parallel to the ground, passing through the two consecutive posts of the barrier. This test is launched to test the robustness of the test item where it is most flexible and to evaluate the potential for the trapping of limbs in the area where this is most likely to occur. The dynamic deformation of the test item during the test with the ATD is characterized by the working width, Wd. As shown in Fig. 3, if a hand of the ATD protrudes past the rearmost part of the system during the test then the position of this ATD part is taken into account in the determination of the Wd. Protrusion of any other ATD part is constituted as a failure of the test.

2.2. Full scale crash test evaluation criteria in prEN 1317-8

On basis of full scale crash tests of MPS the following three performance indicators are reported:

1. Speed class, which is determined by the impact speed of the tests performed;
2. Severity level, which is determined by the level of the biomechanical indices from data obtained from the ATD instrumentation during the test;
3. Working width (Wd), which is the distance between the foremost part of the un-deformed system and the maximum dynamic lateral position of any part of the system.

The severity levels of an MPS are determined by the maximum values of the biomechanical indices measured from the head and neck regions of the dummy during a full scale crash test. Table 3 provides severity level thresholds for the evaluation (CEN/TC226/WG1, 2011).

Severity levels, SL, defined as Level I or Level II in prEN 1317-8, are determined based on full scale crash test results as indicated in Table 3. Values Fx, Fz_{ten} and Fz_{comp} are taken from Figs. 4–6 and finally severity level is determined by the level of the biomechanical indices from data obtained from the ATD instrumentation. Either SL is achieved only when the values of all biomechanical indices in the table are equal or less than the corresponding maximum limits. The SL that will apply to a MPS, for a given speed class, is the highest of the SL obtained from the impact tests performed.

Following the test, the ATD is not allowed to remain trapped in the test item and is deemed to be trapped when in contact with the test item in such a way as to require further deformation or displacement of the test item, or dismantling of the ATD, in order to remove the ATD from the test item. No limb nor the head or neck of the ATD is allowed to become totally detached from the ATD following the impact with the test item, no lacerations to the ATD flesh resulting from the test. If the Wd of the test item exceeds the working width of the barrier tested according to EN 1317-2, then the working width of the complete tested item is equal to the Wd of the MPS test. In addition, any barrier incorporating a MPS design must also meet to the requirements of EN 1317-2 for the appropriate containment level.

3. Details of CMPS design developed

The CMPS design used in this study was developed by the Pass + Co engineers. Since MPS design are not separate systems CMPS design studied herein was incorporated onto an existing vehicle restraint