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Kid-Shell: safety system protection for child passengers travelling on powered two-wheeled vehicles

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Abstract

The KID-SHELL project aims to design and develop a protection system addressed to children who are travelling as PTW passengers, since motorcycles are by far the most dangerous means of transport. Moreover, children are especially vulnerable due to their instability on the motorbike and their physical weakness, reflexes and reaction to the accident. The European Commission is not aware of any specific national standard in the Member States, apart from requiring the use of helmets by motorcycle drivers and passengers.

The first stage of this project analyzed the principal characteristics of traffic accidents involving child motorcycle passengers and what injuries they suffer. Both urban and non-urban areas were considered, as well as the type of accident scenario, type of accident, actions of the passenger and injuries suffered by child PTW passengers. Also, the data gathered was not only by frequency, but also by severity. The study included statistics and data of motorcycle accidents in Barcelona and the problems specific to children as motorcycle passengers, including a study of how the different stages of child development affect an accident.

The aim of the second stage of the project was to define the design of the child protection system and develop an assessment protocol.

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A design, called the KID-SHELL, was made which covered the most exposed parts of the child passenger in a PTW such as the back, cervix and shoulders. The system is adjustable, being able to be used between 7 and 12 years; it is a one-piece vest with a rigid back part to protect the child in case of falling from the motorcycle or an accident.
The test protocol developed aims to evaluate the level of safety of the KID-SHELL protector and at the same time be able to reproduce the real case scenarios where the KID-SHELL may be involved such as: fall down abrasion, back fall down, lateral fall down, asphalt sliding.
The energy absorption that this system needs to provide in the event of an impact was evaluated and a test protocol was defined consistent with it. The dummies, impactors, setup and requirement specifications for the test were specified. Furthermore, a pattern of the target zones where the impactor has to collide were defined. In order to make the test repeatable and reproducible it was carried out by the Dynamic Impact Test System (DITS). Concerning the results, three levels of qualification were specified in order to be able to do an assessment of the KID-SHELL system protection.

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Keywords: safety; test protocol; accident analysis; children protection; crash test

1. Introduction

Motorcycles are by far the most dangerous means of transport, and according to the CARE database, in 2008, 5,126 fatalities among motorcyclists (EU-24), accounted for 14% of the total 37,234 road traffic fatalities in these 24 Member States. Taking into account the fact that two-wheeled motor vehicles account for just 2% of all road vehicles, this underlines the potential risk for motorcyclists on Europe's roads. The number of motorcycles is increasing every year in the European Union; between 2001 and 2008 the number increased from 16 million to more than 22 million (ACEM, 2011). In 2008, approximately 33 million powered two-wheeled motor vehicles (PTW's) were registered (CARE, 2008).

In the first phase of the KID-SHELL project, an in-depth analysis of PTW accidents involving passengers between 6 and 13 years old and the body safety protection regulations was carried out (Boix et al, 2014). A study in the city of Barcelona was carried out, and showed that the most usual and severe accident configurations for motorcyclists were accidents with frontal collision, off-road accidents, lateral collision, accident with an obstacle, rear-end collision and accident by lateral scraping. Although most of the accidents were slight, the most common injuries were contusions and fractures and the most damaged areas were the extremities and the head.

Additionally, people who want to transport children between these ages by motorcycle cannot easily find protective clothing on the market and assume risks such as equipping the child with a wrongly-sized helmet, rarely incorporating any additional safety clothing such as protective gloves or a jacket. Moreover, safety clothes for children are not usually used because of their cost and the fact that children quickly grow too big for them. The KID-SHELL protection system that has been designed offers an effective solution by protecting the child's back in case of falling from the motorcycle or accident.

This paper describes the second part of the project which defines the simulation of the child protection system. The development of an assessment protocol for child back protection is also explained. The aim is also to evaluate the level of safety of the KID-SHELL protector and at the same time be able to reproduce the real case scenarios where the KID-SHELL may be involved.

2. Protocol test

A protocol test has been developed in order to validate child back protection systems, taking into account the most usual accidents and their consequences and with the aim to design the minimum requirements of the KID--SHELL system. Moreover, the protocol should ensure repeatability, reproducibility and guarantee the fulfilment of specific requirements, for that reason the protection will be in fixed position and its strength will be tested with an impactor that will always give the same impact force in the same point and the same direction. Two different tests will be carried out:

Firstly, to ensure the force absorption of the protection materials, the protection will be placed on a load cell surface where an impactor will be dropped on 8 different points (see 2.4. sample preparation). The transmitted force over the load cell surface will be assessed and the force peaks of each impact will be analyzed in order to determine the safety level of the protection.

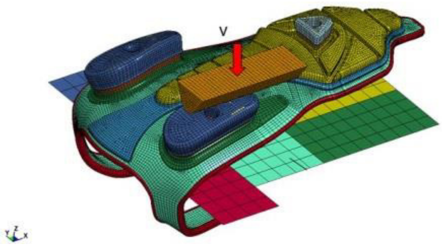


Fig. 1. Simulation of Kid-Shell protection test.

The second test will verify the correct adjustment of the system protection at the children's bodies and their correct behavior during an impact. A child dummy, which will be lying face down on the load cell surface with the KID-SHELL protection placed on its back, will receive 8 impacts on different points and the behavior of the protector will be analyzed. The same 8 impacts will be given to the dummy without the protector and the response will be compared.

Fig. 2. Simulation of dummy wearing the Kid-Shell protection test.

2.1. Requirements

The back protection system has to fulfil the following conditions:

- It has to protect the back in case of different kinds of impact
- It has to fulfil the level of protection in the impact zone
- It has to fulfil the correct behavior in the dummy back protection
- It has to be comfortable to wear and also to take off and put on

2.2. Level of protection in the impact zone

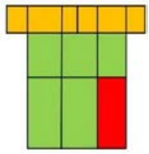
The system's protection will be classified depending on the level of force that has been transmitted. Regulation EN 1621-2-2013 establishes a minimum energy impact of 50 ± 1,5 J for back protectors (EN 1621-2:2013). Following the same regulation as a reference, a classification of transmitted force level has been made:

Table 1. Safety levels for the protection system.

Description of part	Average peak value cell force must be less than…	No individual value shall exceed…
Acceptable	18 kN	24 kN
Good	9 kN	12 kN
Excellent	3 kN	4 kN
Not valid	If any impact received by the system protection has a value registered higher than 24 kN	

The maximum peak force registered in each rectangle after the 8 drops of the impactor, will be compared with the established limit. For a more visual display of the test results, a color will be designated at the rectangle mark where the test has taken place. The color of the rectangle will indicate the safety level of that part of the system protection, as can be seen in the following table:

Table 2. Safety level of the results.

Safety level	Colour	Example
3	Excellent	
2	Good	
1	Acceptable	
Not valid	Not valid	

2.3. Correct behavior in dummy back protection

The protector must not be displaced from the original position in any of the 8 impacts and the impactor should not impact the dummy directly when the system protection is placed at the dummy's back.

The load cell will record values when the dummy is wearing the KID-SHELL back protector and will compared with the recorded values in tests where the dummy was not wearing it. The results must show at least weaker force peaks when the system protection is placed at the dummy's back.

2.4. Sample preparation

In order to delimitate the safety area assessment of the system protection, a template with a T form will be marked on top of the protection. The dimensions of this template will be based on three measurements of the child's body as shown in the following table:

Table 3. Measurements for the safety area assessment.

Shoulders width	Distance between shoulder/hip	Hip width
350 mm	360 mm	250 mm

The defined protection zone to be tested will be divided by vertical and horizontal lines with a separation of 50 mm from each vertical line and 120 mm of separation from each horizontal line. In that way the back protection zone will be defined by a grid.

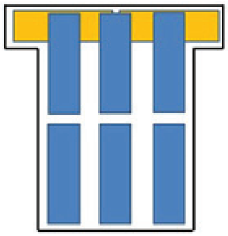


Fig. 3. Final grid of the back protection testing zones.

2.5. Throwing system

The throwing system must be constituted by a structure that guides the impactor in a vertical fall to the system protection direction with a given impact velocity.

2.6. The impactor

The impactor has to be a stiff piece with a triangular prism formed with a round tip which will impact the protection system at speed. The impactor simulates the backwards fall of a passenger motorist against the floor. The impactor dimensions and impact velocity are as follows:

Table 4. Impactor dimensions and value.

Description of part	Requested	Tolerance	Actual
Length of the impactor (h1)	160 mm	+/- 2 mm	160.0437 mm
Width of the impactor (h2)	50 mm	+/- 1 mm	49.7302 mm
Height of the impactor	30.8 mm	+/- 0.5 mm	30.644 mm
Dimension of the radius	12.5 mm	+/- 1 mm	12.497 mm
Weight of the impactor	5000 gr	+/- 0.50 gr	5005 gr
Angle of the radius	60º	+/- 05º	60.005º

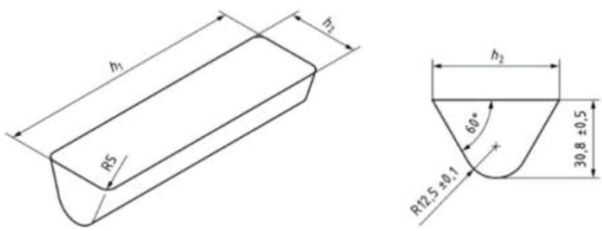


Fig. 4. Impactor dimensions.

2.7. Impactor test parameters

The parameters that are needed to be followed in order to fulfil the protocol established in this paper are shown in the following table:

Table 5. Test parameters.

Parameter	Value	Magnitude
Energy	50	J
Mass	5	kg
$V_{impactor}$	4.47	m/s

2.8. Testing dummies

To carry out the tests, P6 and P10 child dummies will be used. The following figure and table show the dimensions:

Table 6. Dummies P6 and P10 dimension.

No.	Description	P6 (mm)	P10 (mm)
3	Head width	140	140
6	Hip width	230	255
7	Shoulders width	295	345
8	Height seated position	635	725
9	Total length	1170	1380
10	Back length	30.5	31
11	Hip line	58.5	70

3. System simulation

The simulation is focused on the system protection behaviour and reactions of the impact. This simulation follows the specifications of regulation EN 1621-2:2013. In the simulation, 8 impacts were carried out following the final grid impact setting from protocol section 2.3. No dummy is needed in order to know only the system protection reactions. The initial energy was 50J, the impactor's mass 5 kg and the impactor's initial velocity was 4.47 m/s in each impact.

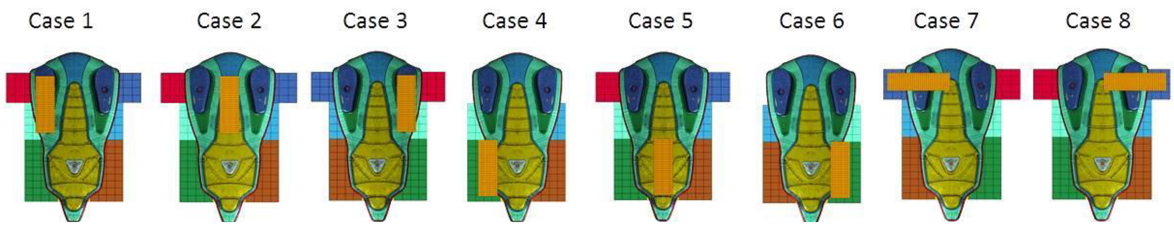


Fig. 5. Load cells zone and range of data acquisition.

In the simulation, the load cell surface under the KID-SHELL protector was divided into 8 regions where a transducer was placed. These regions simulate the perimeter of the T-Zone explained in section 2.3. Each region will receive an impact and the transducer of that region will register the impact force. The final configuration of the test grid can be seen in the following figure:

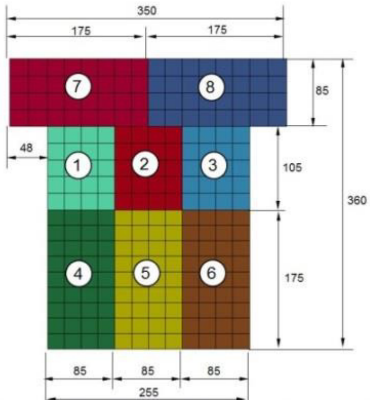


Fig. 6. Transducers test zone.

The following chart shows the impact forces (kN/ms) received at the KID-SHELL in case 2. In case 2 the impact takes place at the middle of the protection. The results show that transducer number 2 has the maximum peak of force at 4.03 kN at 19 ms.

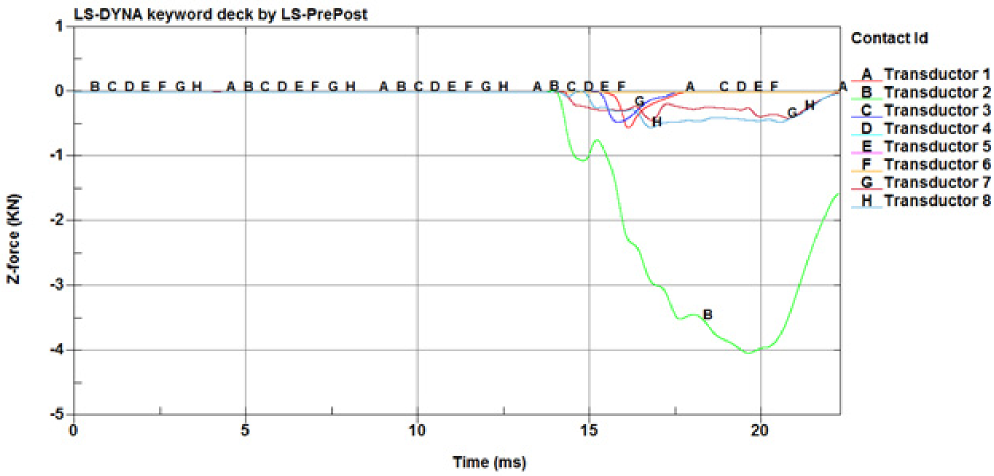
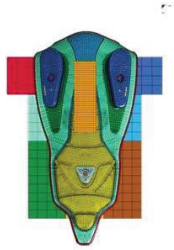
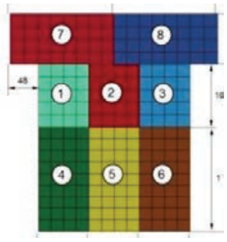


Fig. 7. Dummies P6 and P10 dimension.

The results are values of total force of contact on each region, obtained from the transducers placed in each region. The charts obtained from the results are the total resultant force in each zone versus the time. The results from the case 2 are shown in figure 7 are summarized in the following table.

Table 7. Results of the maximum force reaction in case 2.

Transducer	Maximum force Kid-Shell without Dummy	Case 2	Transducer positions
1	-0.5510		
2	**-4.0327**		
3	-0.4611		
4	0		
5	0		
6	0		
7	-0.4295		
8	-0.5505		

The results of case 2 show that transducer Nº2 has the greatest impact force, as it is the impact point target. Also, it is observed that the impact energy is dissipated to the other transducers that surround the impact point.

The peak force at transducer 2 is 4,03 kN. As it can be seen at table 1 in order to have an excellent result the limit for an individual peak is 4 kN. The transducer Nº2 has an individual value of 4.03 kN, due to that assessment at the impact in that zone is Good and it will be represented at the grid with the yellow colour.

The same simulations were carried out for all the cases and in each one the force peak value in the corresponding transducer was noted to present the final assessment of the protector.

The following image shows the maximum peak forces of the 8 cases that were simulated. This represents the worst case scenario. As KID-SHELL is a symmetric protection system, the simulated results are the same at both sides of the protection. Transducers no. 4 and no. 6 have no value as the impactor did not have enough surface of the protection to impact and the results were not accepted by the protocol.

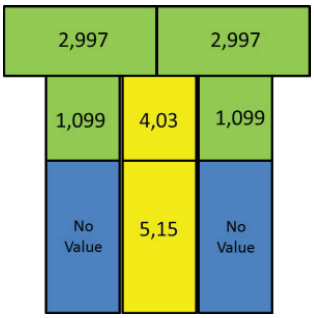


Fig. 8. Results of the maximum peak forces of the 8 impact cases simulated (kN).

As a final result of this simulation, the KID-SHELL protection obtains good results, and fulfils the regulation of back protection.

4. Conclusions

The aim of this paper is to present a new testing protocol for a protection system for children travelling as passengers on motorcycles.

The protocol has proven to be repeatable and reproducible and to assess not only the fulfilment of the minimum force absorption, but also the safety level of each back protection region. Moreover, it assesses the adaptability to the child's body using kid dummy P6 and P10 wearing the KID-SHELL protector in impact tests. The new protocol displays the results in different level colours that help to distinguish and identify the improvements required in the system. Also, the limit parameters that have been defined from regulation EN 1621-2:2013, make these tests more realistic and bolstered.

A simulation study was carried out to know the behaviour of the new designed back protector for children and validate the testing protocol. The results show that the KID-SHELL protector fulfils the testing protocol limits in force transmission and that most of the results are excellent. However the central positions in cases 2 and 5 have only a good value.

The next stage of this project is, firstly, to carry out the simulation of the impact tests with the dummy wearing the back protection KID-SHELL and then to carry out the real tests to achieve a real validation test. Moreover, the protector will be revised in order to improve the central parts which have achieved a Good, but not excellent, classification. Furthermore, the testing protocol will be revised to improve the assessment of the protector's lowest part corresponding to test cases 4 and 6.

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