PEDESTRIAN PROTECTION: FLEX-PLI AGAINST TRL IMPACTOR

Christian Pinecki,
Richard Zeitouni,
Marie Estelle Caspar.
PSA Groupe
France

Julien Vincent,
Marc Dieudonné,
ACTOAT
France

Cédrick Chapelet,
UTAC CERAM
France

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ABSTRACT

The pedestrian protection given by a vehicle is assessed according to four independent impact test procedures, related to different body segments. Four impactors were developed specifically: leg, upper-leg, child head and adult head. These impactors, which are thrown against specific zones of the front face of the vehicle, allow the measurements of biomechanical criteria simulating the injury risk during the impact .Such test procedures are used by Euro NCAP and by the European regulation on pedestrian protection.

Concerning the leg, the first impactor used was the TRL impactor, but since 2014, the TRL impactor was replaced by the FLEX-PLI impactor for the Euro NCAP tests. The conception and the biomechanical criteria are different between the TRL and the FLEX-PLI. A specific study is carried out, to quantify behavioural differences between these two impactors tests.

In the first part of this study, various tests are performed with FLEX-PLI and TRL impactors on vehicles with different heights of front face. In these tests we check if vehicles that respect the Euro NCAP criteria with the TRL impactor, also respect the Euro NCAP criteria with the FLEX-PLI impactor. These tests are carried out with the cooperation of UTAC CERAM.

Then, in the second part, after analysis of the tests results, we identify the least favourables front face geometries for the FLEX-PLI impactor for the respect of the Euro NCAP requirements. Then using numerical simulations, we identify design and conception levers that allow to improve the results for the FLEX-PLI test for this kind of front face geometries. The numerical study is conducted with the cooperation of ACTOAT company.

LEGFORMS PRESENTATION

The assessment of pedestrian protection offered by a vehicle is made through three different and independent component test procedures corresponding to different body segments:

- the first one is related to the assessment of the protection of the leg. The test is called “legform to bumper test”
- the second one is related to the upper leg. The test is called “upper legform to bonnet”
- the last one is related to the head, adult head impact and child head impact. The tests are called “Adult and Child headforms to bonnet and windscreen test”

These tests are made by European New Car Assessment Program, Euro NCAP [1]

Four specific body form impactors are used in these tests. They are propelled against the front part of the vehicle (from the bumper up to the windscreen depending on the type of test) and they are equipped with several sensors in order to measure biomechanical criteria that are used to assess the risk of injuries (see Figure 1).

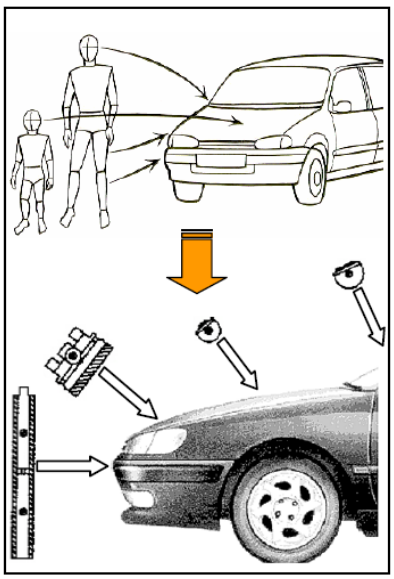


Figure 1. Euro NCAP Pedestrian tests made of body form impactors propelled against the car front-end.

There is two different impactors for the leg : the TRL impactor, and the FLEX-PLI impactor.

The TRL legform was used by the Euro NCAP until 2013. The legform is made out of two rigid elements corresponding to the tibia and the femur, which are connected by an articulation representing the knee joint. The test procedure consists in propelling the legform against the bumper, in free motion at 40 km/h (see figure 2)

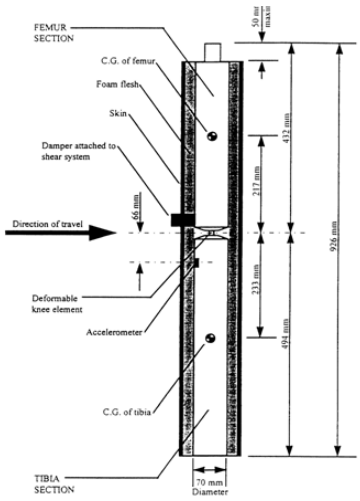


Figure 2 : the TRL impactor

At the time of first contact the lower part of the legform shall be 25mm above ground.

The FLEX-PLI legform is used by the Euro NCAP since 2013. The legform is made out of a lot of articulated elements corresponding to the tibia and the femur, which are connected by an articulation representing the knee joint. The test procedure consists in propelling the legform against the bumper, in free motion at 40 km/h.

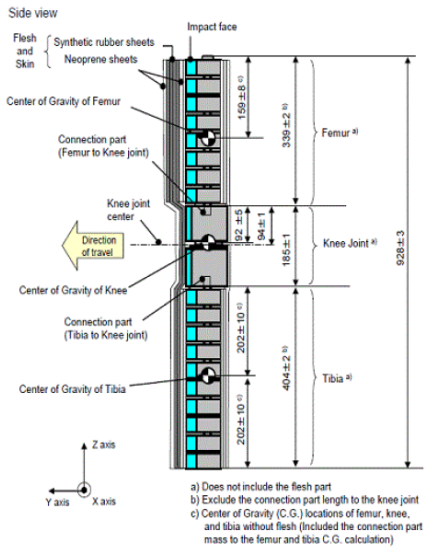


Figure 3 : the FLEX-PLI impactor

During Euro NCAP tests, the biomechanical criteria are recorded, and this criteria are compared with the limits fixed by the Euro NCAP (see tables 1 and 2)

TRL criteria	Euro NCAP higher performance limit	Euro NCAP lower performance limit
Deceleration	150 g	200 g
Knee bending angle	15°	20°
knee shear displacement	6 mm	7 mm

Table 1 : TRL criteria

FLEX-PLI criteria	Euro NCAP higher performance limit	Euro NCAP lower performance limit
Bending moment max	282 N.m	340 Nm
Medial collateral ligament elongation (MCL)	19 mm	22 mm
Anterior cruciate ligament (ACL) elongation	10 mm	10 mm
Posterior cruciate ligament elongation (PCL)	10 mm	10 mm

Table 2 : FLEX-PLI criteria

TRL AND FLEX-PLI PHYSICAL TESTS COMPARISON

For this study three different vehicles, with different front faces heights, are tested with the FLEX-PLI and the TRL legforms:

- Vehicle A
- Vehicle B
- Vehicle C

For this three vehicles, the height of the hood nose shall be measured as shown in the section below : (see figure 4) :

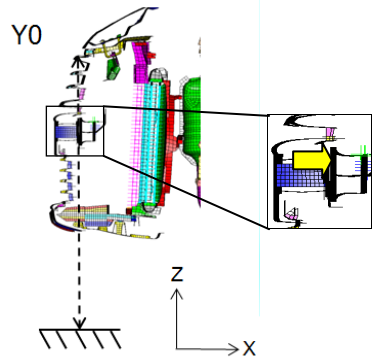


Figure 4

This height of the front end to the ground is measured in front of the reparability beam.

So the heights of the front end for the 3vehicles are:

- vehicle A : 845 mm
- vehicle B : 763 mm
- vehicle C : 677 mm

Vehicle A is the highest and vehicle C is the lowest (see figure 5).

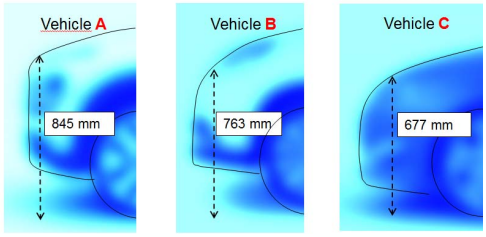


Figure 5

For each vehicle, we performed two tests with the FLEX-PLI impactor: one at the center of the vehicle, and one at a lateral position. And for each vehicle, we performed two tests at the same position with the TRL impactor (see figure 6) : Y central and Y lateral.

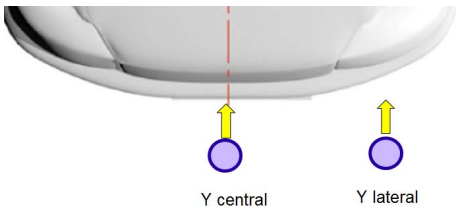


Figure 6

TESTS RESULTS

Vehicle A Test Results

In the tables below, we compare the FLEX-PLI and TRL results that we obtain with vehicle A.
First at Y central (see table 3) :

Y central		
TRL results test Y0		Limits
Deceleration (g)	102	150
Bending angle (°)	3,4	15
Shear displacement (mm)	2,1	6,0
FLEX-PLI results test Y0		Limits
ACL elongation (mm)	6,10	10,0
PCL elongation (mm)	5,20	10,0
MCL elongation (mm)	10,2	19,0
Moment tibia max (N.m)	204	282

Table 3

And at the Y lateral (see table 4) :

Y lateral		
TRL results test Y488		Limits
Deceleration (g)	93	150
Bending angle (°)	7,1	15
Shear displacement (mm)	3,0	6,0
FLEX-PLI results test Y488		Limits
ACL elongation (mm)	6,80	10,0
PCL elongation (mm)	1,52	10,0
MCL elongation (mm)	12,0	19,0
Moment tibia max (N.m)	154	282

Table 4

All Euro NCAP criteria are respected with margin with the TRL and the FLEX-PLI.

Vehicle B Tests Results

In the tables below, we compare the FLEX-PLI and TRL results that we obtain with vehicle B.

First at Y Centre (see table 5) :

Y central		
TRL results test Y0		Limits
Deceleration (g)	133	150
Bending angle (°)	13,1	15
Shear displacement (mm)	5,18	6,0
FLEX-PLI results test Y0		Limits
ACL elongation (mm)	6,28	10,0
PCL elongation (mm)	5,38	10,0
MCL elongation (mm)	15,7	19,0
Moment tibia max (N.m)	131	282

Table 5

And at the Y lateral (see table 6) :

Y lateral		
TRL results test Y460		Limits
Deceleration (g)	109	150
Bending angle (°)	7,05	15
Shear displacement (mm)	3,98	6,0
FLEX-PLI results test Y460		Limits
ACL elongation (mm)	5,28	10,0
PCL elongation (mm)	5,09	10,0
MCL elongation (mm)	13,7	19,0
Moment tibia max (N.m)	126	282

Table 6

All Euro NCAP criteria are respected with margin with the TRL and the FLEX-PLI

Vehicle C Tests Results

In the tables below, we compare the FLEX-PLI and TRL results that we obtain with vehicle C.

First at Y centre (see table 7) :

Y central		
TRL results test Y9		Limits
Deceleration (g)	111	150
Bending angle (°)	12,4	15
Shear displacement (mm)	2,34	6,0
FLEX-PLI results test Y9		Limits
ACL elongation (mm)	5,92	10,0
PCL elongation (mm)	5,81	10,0
MCL elongation (mm)	**20,3**	19,0
Moment tibia max (N.m)	168	282

Table 7

And at the Y lateral (see table 8) :

Y lateral		
TRL results test Y460		Limits
Deceleration (g)	132	150
Bending angle (°)	10,3	15
Shear displacement (mm)	2,97	6,0
FLEX-PLI results test Y460		Limits
ACL elongation (mm)	4,91	10,0
PCL elongation (mm)	8,12	10,0
MCL elongation (mm)	13,1	19,0
Moment tibia max (N.m)	121	282

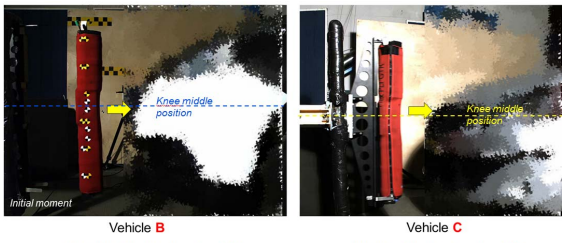
Table 8

All Euro NCAP criteria are respected with margin with the TRL, but not all Euro NCAP criteria are respected with the FLEX-PLI : MCL exceeds the 20 mm limit value with a maximum of 21

WHY THE RESULTS COULD RESPECT THE EURO NCAP LIMITS WITH THE TRL LEGFORM BUT NOT WITH THE FLEX-PLI LEGFORM ?

A vehicle designed to meet success with TRL tests (with margins), can give bad results with the FLEX-PLI tests. Why vehicle C results respect the Euro NCAP limits with TRL but not with the FLEX-PLI ?

The legform kinematic is different with the vehicle C (see figure 8) :



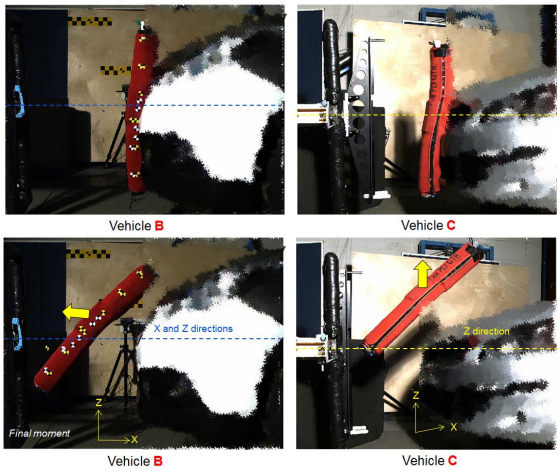


Figure 8 : kinematic comparison between vehicule B and C

Because of the difference of height of the front end, with the FLE-PLI legfom, during the test on the vehicle C the legform rotates more on the front end and is more ejected in Z direction.

More the front face of the vehicle is lower, more the legform will rotate on the front face, and more the MCL elongation will increase. Because the FLEX-PLI legform is more flexible than the TRL legform (see figure 9).

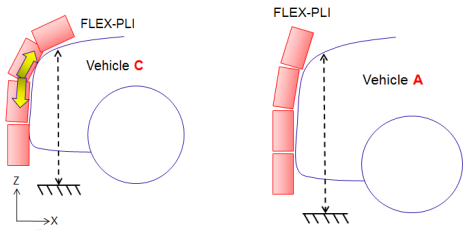
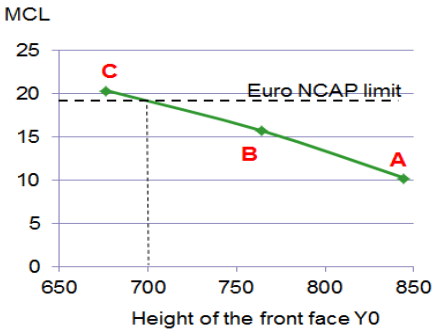


Figure 9 : FLEX-PLI rotation with the front face

So, because the legform rotates more on the front face with the FLEX-PLI, MCL elongation can exceed the limits fixed by the Euro NCAP for vehicles with a lower front end.

The MCL elongation depends on the front face height (see graphic 1).



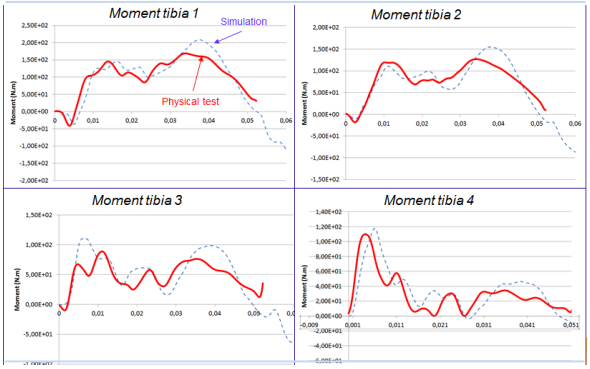
Graphic 1 : kinematic comparison between vehicule B and C

HOW TO REDUCE THE MCL ELONGATION FOR VEHICLES WITH A LOWER FRONT FACE ?

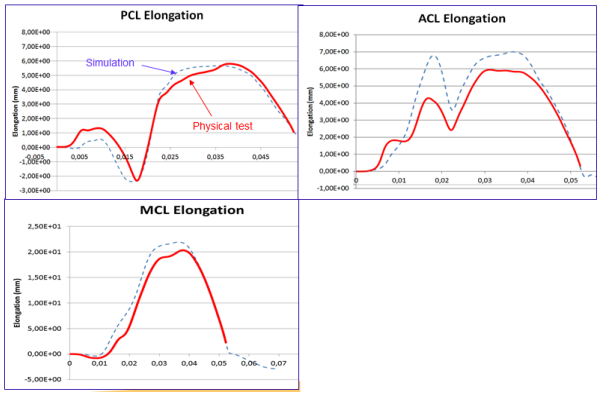
Vehicle C Comparison Between Simulations And Physical Results

To find, how to reduce the MCL elongation for vehicles with a lower front face, we use computer simulations with the RADIOSS code (RADIOSS is a finite element solver developed by Altair Engineering).

First, we check the correlation between the computer simulations and the physical tests for the vehicle C (see graphic 2 and 3).



Graphic 2 : moments comparison between physical tests and simulations (red curves: simulations, blue curves: physical tests)



Graphic 3 : elongations comparison between physical tests and simulations (red curves: simulations, blue curves: physical tests)

Except tibia moment number 3, physical phenomena are correctly reproduced, but the simulation overestimates the values.

For elongations, simulation overestimates the values for the ACL, but physical phenomena are correctly reproduced. And correlation is correct for the MCL and the PCL.

So simulation can be used to find a solution to reduce the MCL

Solutions Research With Simulation To Reduce MCL Elongation For Wehicle C

To find a solution we modified thickness of different vehicle parts (see figure 12):

- top of the bumper,
- pedestrian absorber in front of the reparability beam,
- lower pedestrian absorber with deflector.

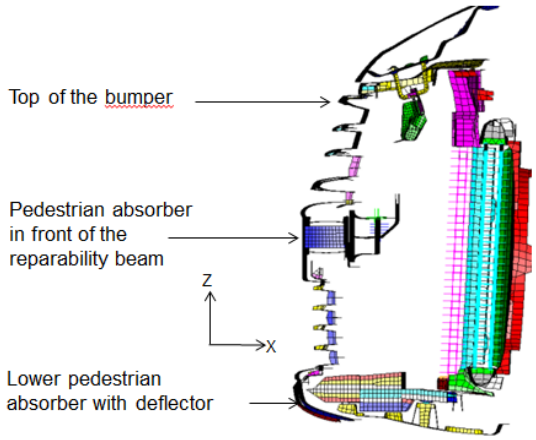


Figure 12 : vehicle C front face parts

The simulations results without modifications is summed up in table 12 :

FLEX-PLI results simulation Y9		Euro NCAP limits
ACL/PCL max (mm)	7,02	10,0
MCL max (mm)	21,8	19,0
Moment max (N.m)	209	282

Table 12 : simulation results whitout modifications

First, we multiply the stiffness of the top of the bumper by two. It's the solution number 1.

⇨ No improvement with this solution (see table 13)

FLEX-PLI results simulation Y9 with **solution number 1**		Euro NCAP limits
ACL/PCL max (mm)	6,97	10,0
MCL max (mm)	22,0	19,0
Moment max (N.m)	205	282

Table 13 : simulation results whit solution number 1

Second, we multiply the thickness of the lower pedestrian absorber by two. It's the solution number 2.

⇨ This solution reduces the MCL elongation but, not enough (see table 14)

FLEX-PLI results simulation Y9 with **solution number 2**		Euro NCAP limits
ACL/PCL max (mm)	5,85	10,0
MCL max (mm)	18,2	19,0
Moment max (N.m)	200	282

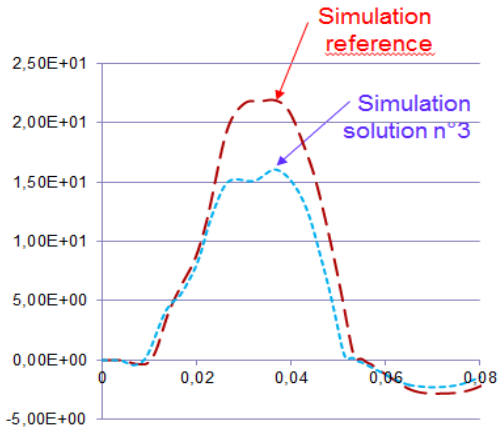
Table 14 : simulation results whit solution number 2

Third, we multiply the thickness of the lower pedestrian absorber by two and we multiply the thickness of the pedestrian absorber by two. It's the solution number 3.

⇨ MCL elongation reduces and meets now Euro NCAP limits with margin and moments increase but moments are overestimated in simulations (see table 15 and graphic 4)

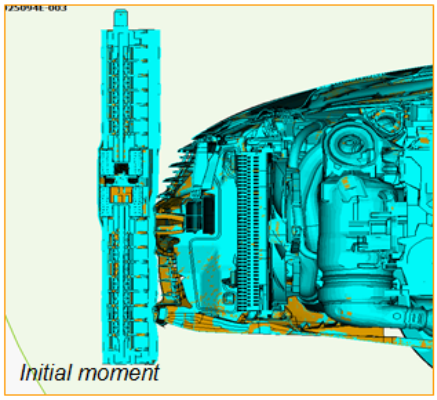
FLEX-PLI results simulation Y9 with **solution number 2**		Euro NCAP limits
ACL/PCL max (mm)	6,96	10,0
MCL max (mm)	16,1	19,0
Moment max (N.m)	236	282

Table 15: simulation results whit solution number 2



Graphic 4 : simulations MCL elongations comparison

If we compare FLEX-PLI kinematic in simulation wihout modification and the simulation number 3, we can see that lower part of the leg is faster ejected when absorber thickness increases and this kinematic of the lower part of the leg, helps to reduce the MCL (see figure 13).



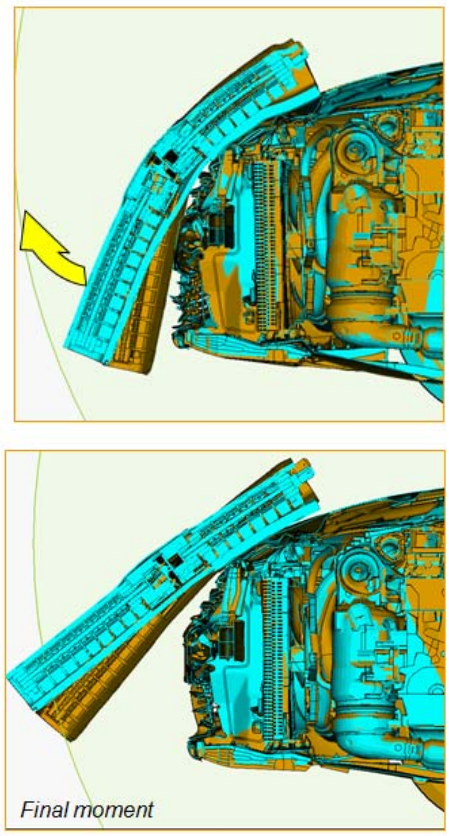


Figure 8 : kinematic comparison between simulations wihout evolution and with solution number 3 (in blue : simluation with solution number 3, in orange : simulation without evolution)

CONCLUSIONS

A vehicle designed to meet requirements with TRL tests (with margin), can give bad results with the FLEX-PLI tests. Because FLEX-PLI legform rotates more on the front face, MCL elongation can exceed the limits fixed by the Euro NCAP for vehicles with a lower front face. The lower is the front face of the vehicle, the more the legform will rotate on the front face, and the more the MCL elongation will increase.

Conception of the vehicle has been adapted to reduce the MCL elongation. So we decided to increase the absorber thickness to have a more favorable leg kinematics. Lower part of the leg is faster ejected when absorber thickness increases. This kinematic of the lower part of the leg, helps to reduce the MCL

REFERENCES

[1] Pedestrian Test Protocol v8.0, Euro N.C.A.P. http://www.euroncap.com/en/for-engineers/protocols/pedestrian-protection/