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SYSTEM OF MOTOR VEHICLE SAFETY BELT DESIGN ELEMENTS AND CASE STUDY

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ABSTRACT: In recent years, serious and fatal accidents have decreased in number. The reason is that more and more people begin to understand the importance of using safety belts and the introduction of airbags and crash-testing has helped the number of people killed or injured to decline in many countries. In the first part of this paper were presented the design elements of safety belt system, namely the seatbelt pretensioner and limiter effort device, and to determine the force on the car and the driver during impact. The second part presented the importance of experimental tests and computer simulations on passive safety systems, subsystems or components for testing, such as airbags, seat belts, seat configurations, special requests under dynamic and aerodynamic or temperature.

KEYWORDS: safety belt system, pretensioner, effort limiter, crash-test

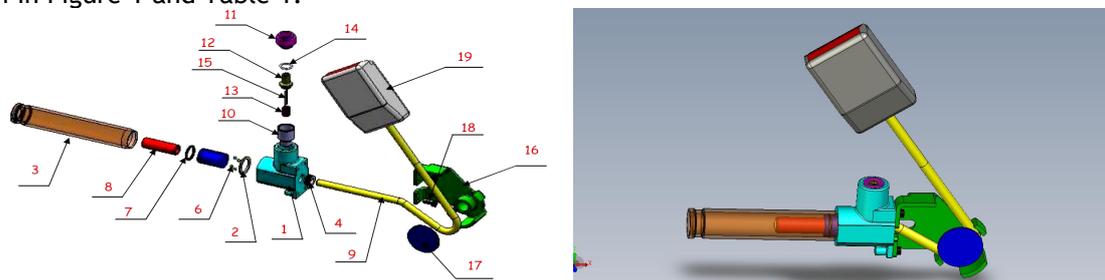
❖ INTRODUCTION

Currently, the most common type of belt is hung on three points, provided with roller device retractors and pretensioner. Since 2003, *Toyota's* construction company has installed a sign warning light, audible signal, to fasten a seat belt of the driver and passengers. There are also adjustable shoulder restraint systems, belt height change allowing for increased comfort and safety. Thrown out from the vehicle is one of the most injurious events that can happen to a person in an accident. In fatal accidents, 75% of car occupants who were thrown out of the vehicle were killed. Seat belts are effective in preventing total throw of the car.

Seatbelts are estimated to reduce the overall risk for serious injuries in crashes by 60-70% and the risk for fatalities by about 45 percent. In non-collisions, mainly rollovers, the reduction in fatalities is about 75%. In the United States numbers for 2007 showed that of 37,248 people have died as a result of car accidents, about 30% did not wear seatbelts. There is also a section of the population who actively dislike wearing belts.

❖ ELEMENTS OF DESIGN SAFETY BELT SYSTEM - PRESENTATION PRETENSIONER DEVICE

Scheme exploded and 3D model of the pretensioner device and nomenclature of the parts are shown in Figure 1 and Table 1.



a. Scheme exploded of the pretensioner device b. 3D model of the pretensioner device

Figure 1. Pretensioner device

Pretensioner device characteristics:

- The length of time between initiation pretensioner device and the airbag is $t = 5\text{ms}$.
- Speed pretensioner of safety belt, for $d = 100\text{ mm}$ movement the piston in the cylinder of the device is:

$$v = \frac{d}{t} = \frac{100 \cdot 10^{-3} \text{ m}}{5 \cdot 10^{-3} \text{ s}} = 20 \frac{\text{m}}{\text{s}} \quad (1)$$

The onus is on airbags final damping shock after safety belts have absorbed most of the energy of the occupant.

Table 1. Note of pretensioner device elements

Landmark	Pieces	Designation	Observations	10	1	Detonator	Cu Sn 8
1	1	Body		11	1	Detonator Corp	
2	1	Sealing Ring		12	1	Connector	
3	1	Cylinder		13	1	Detonator capsule	
4	1	Ring assembly	PVC	14	1	Elastic ring detonator	
5	1	Conical Piston	Al Cu4 Mg Si	15	1	Electrode detonator	
6	4	Ball bearing		16	1	Cable guide	
7	1	Tapered element assembly		17	1	Ax support	
8	1	Pawl		18	2	Screw M3-10	
9	1	Cable Belt	Fixed with 8	19	1	Belt coupling device	

❖ DETERMINATION AND ANALYSIS EFFORT PRETENSIONERS

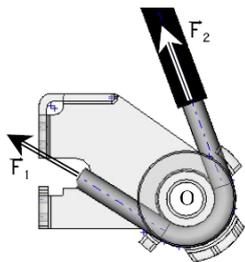


Figure 2. Isolation the forces system for determining the belt pretensioner effort

Static analysis of cable sub-assembly - handle, items marked with landmarks 9 and 16 in Figure1a was performed by isolating it under representation in Figure 2, isolation followed by solving the system of equations of equilibrium:

$$\begin{cases} \sum F_{ext} = 0 \\ \sum M_{F_{ext}} = 0 \end{cases} \quad (2)$$

In solving the system with values forces F1 = 400 daN and F2 = 350 daN apparent effort pretensioners, F = 710 daN.

Belt model under study is equipped with an integrated effort limitation, known as progressive restraint system (SRP1). This system equipped with an integrated torsion bar retractor, Figure 3, is

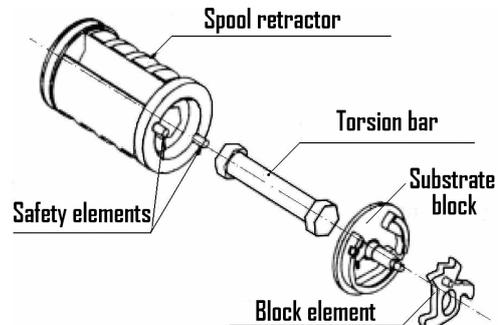
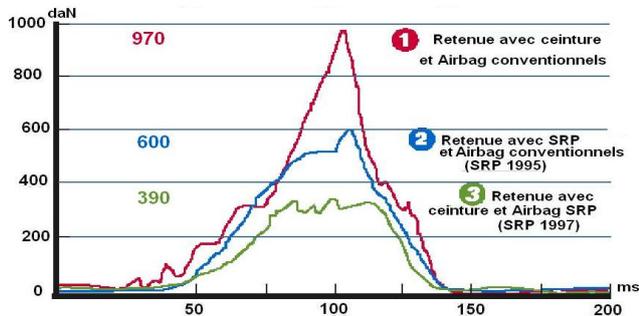


Figure 3. Scheme integrated effort limitation
Limiting effort is achieved through controlled release of the band belt, an action that is provided by the deflection torsion beam axle positioned coaxially with the roller retractor. The effort suffered from chest, neck and head occupant vehicle is reduced so approx. 30% - 50%, as shown in Table 2, based on data from the completed diagram represented in Figure 4 [source: "Sécurité passive Renault / Le Moniteur Automobile, n ° 1135"].

to diminishing injuries in the shoulder and chest in the event of front violent shocks, by limiting the crushing effort exerted by ring at this level.

Table 2. The maximum effort suffered

Seatbelt type	Maximum effort
Classic	970 daN
With SRP 1	600 daN
With SRP 2	390 daN



1 - Safety Belt Classical; 2 - 1 SRP: progressive retention system; 3 - 2 SRP: progressive retention system, generation 2

Figure 4. Evolution of the force strength in the chest during a shock, for different protection systems

Analyzing the evolution of the intensity of the force acting on the chest during a shock,

that:

- The maximum force exerted by the classic seat belt, without stress reducer, which can reach 1000 daN in the middle of the range of approx. Shock lasts 100 ms, Figure 4 (which can cause deformity by compressing the rig cage with 75mm, maximum allowable value for the human body) exceeds, according to data from Figure 5, for all age groups, the critical resistance of the thoracic cavity. This system can not provide effective protection to occupants for any of the age groups;
- The maximum values located in the time zone within 7-130 ms of the effort exerted in the chest, neck and head vehicle's occupant equipped with progressive retention system, be reduced by 30% - 50%, as shown in Table 2, respectively diagram of Figure 4.

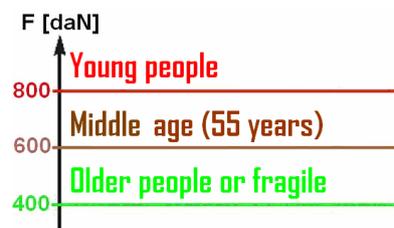


Figure 5. Limit values of force supported by the thoracic cavity, depending on the ages of the occupants of a vehicle

The system SRP1 and SRP2 provides distribution maximum effort for a period of approx. 50-70ms, allowing both flattening and peak load reduction in the permitted range of age groups - young and middle aged people, otherwise the predominant occupants of a vehicle.

❖ CALCULATION OF RESISTANCE EXERCISE LIMITER - TORSION BAR SPRINGS

Torsion springs are made of straight bars circular cross section or ring constant throughout its length, which may accumulate mechanical work from the request, respectively the strain of twisting

Effort limiter shown schematically in Figure 6 is a torsion spring coaxial winding roller belt strap, which is a schematic diagram constructive and mechanical stress.

From Figure 6 follows: a torsion bar; shaft loading (called leverage) 2; fixed end 3; point load theory (point of force application) 4. Lever 2 may exist, in general, or only at one end of the bar or at both ends.

The calculation of deformation and resistance, in order to determine the bar diameter d and angular distortion, is based on the scheme in Figure 6. The force F applied at the loading lever has the effect of turning the bar with the twist moment M_r :

$$M_r = a \cdot F \text{ [Nm]} \quad (3)$$

On the relationship for calculating the maximum tangential unified effort of twisting the bar, and respectively with allowable tangential stress yields:

$$\tau_r = \frac{M_r}{W_p} = \frac{a \cdot F}{\frac{\pi \cdot d^3}{16}} \leq \tau_{ar} \Rightarrow \quad (4)$$

of the required diameter of the bar is:

$$d_{nec} = \sqrt[3]{\frac{16 \cdot a \cdot F}{\pi \cdot \tau_{ar}}} \quad (5)$$

Or, in the circumstances of existing torsion bars, the effort is able to determine with the relation:

$$F_{cap} = \frac{\pi \cdot d^3 \cdot \tau_{ar}}{16 \cdot a} = \frac{\pi \cdot 10^3 \cdot 800}{16 \cdot 20} = 7850 \text{ N} = 785 \text{ daN} \quad (6)$$

the quantities that occur have the following meanings: $a = 20$ mm, is arm force that causes twisting moment; $d = 10$ mm, the diameter of the torsion spring; $l = 100$ mm, maximum stroke of the piston; $\tau_a = 800$ MPa, is admissible tension of torsion spring material.

Since the webbing belt pretensioner effort has value $F = 710$ daN, and how:

$$F_{cap} = 785 \text{ daN} > F = 710 \text{ daN}$$

results that torsion spring meet the condition of resistance.

Maximum angle deflection of the arc, considering that it is loaded to the limit when $\tau_{ef} = \tau_a$, it is:

$$\Delta\varphi = \frac{M_{r\max} \cdot l}{G \cdot I_p} = \frac{W_p \cdot \tau_a \cdot l}{G \cdot I_p} = \frac{\frac{\pi \cdot d^3}{16} \cdot \tau_a \cdot l}{G \cdot \frac{\pi \cdot d^4}{32}} = \frac{2 \cdot \tau_a \cdot l}{G \cdot d} \quad (7)$$

$$\text{i.e. :} \quad \Delta\varphi = \frac{2 \cdot \tau_a \cdot l}{G \cdot d} = \frac{2 \cdot 800 \cdot 100}{81000 \cdot 10} = 0,19 \text{ rad} \quad (8)$$

Mechanical work stored in the spring from the distortion will be:

$$L = \frac{M_{r\max} \cdot \Delta\varphi}{2} = \frac{1}{2} \cdot \frac{\pi \cdot d^3}{16} \cdot \tau_a \cdot \frac{2 \cdot \tau_a}{G \cdot d} \cdot \frac{1}{2} \cdot \frac{\pi \cdot d^2}{4} \cdot l \cdot \frac{\tau_a^2}{2 \cdot G} = 0,5 \cdot V \cdot \frac{\tau_a^2}{2 \cdot G} \quad (9)$$

where is observed the coefficient of use $k_f = 0,5$.

Result:

$$L = 0,5 \cdot \frac{\pi d^2}{4} \cdot l \cdot \frac{\tau_a^2}{2 \cdot G} = 15 \ 506 \text{ daNcm} = 1550 \text{ Nm} \quad (10)$$

The calculations made that the item analyzed is designed properly.

❖ CALCULATION OF FORCE ON CAR AND DRIVER IN CASE OF IMPACT. CALCULATION OF STOPPING DISTANCE FOR AUTO

If the vehicle weight is 1,500 kg, which corresponds to 14,700 N and move it with velocity $v=50$ km / h = 13.888 m / s and if we have an obstacle to stop the car at a distance $d = 2$ m, it will result in an impact force $F = 72337.9629$ N = 8.1315 tons.

In an accident, car and driver are the ones who take all the kinetic energy and energy conservation principle shows that a greater distance required for stopping leads to lower impact force. The role of seatbelt is to stop the passenger in the car, so the stopping distance decreases by 4-5 times compared to the situation they did not wear a belt.

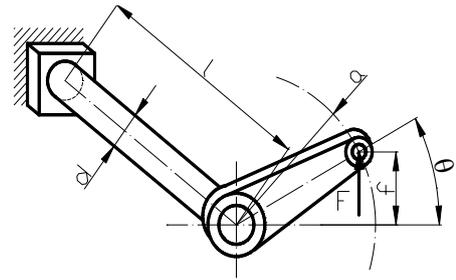


Figure 6. Constructive scheme and application of effort limiter torsion spring

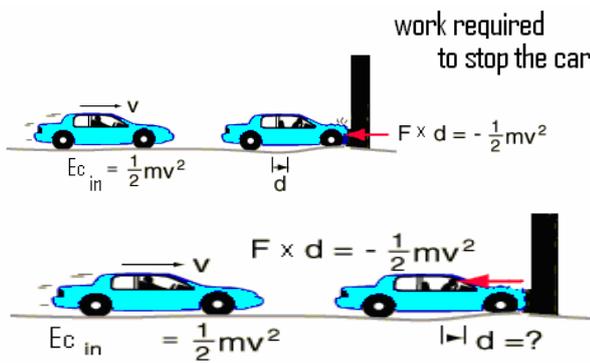


Figure 7. Force which acts on the vehicle and driver during impact

windshield or steering column. Stopping distance is estimated to decrease to about one fifth compared to the situation when he wore a seatbelt, and the impact force will increase about five times, in this case, the stopping distance is 0.12 m and the force acting on head is 12 tons.

Moderate amount of safety belt tightening may lead to an expansion of the stopping distance and a reduction of force of impact on driver, compared with no seatbelt pretensioners. In this example, in Figure 8c, we can see that stopping distance increases by 50%, with value of 0.45 m and the impact force will be 1.6 tones.

If we have an air bag, Figure 8d, it put an equal pressure on all points in contact with him, according to Pascal's Principle, thus, the same force is spread over a larger area and decreases pressure on the body .

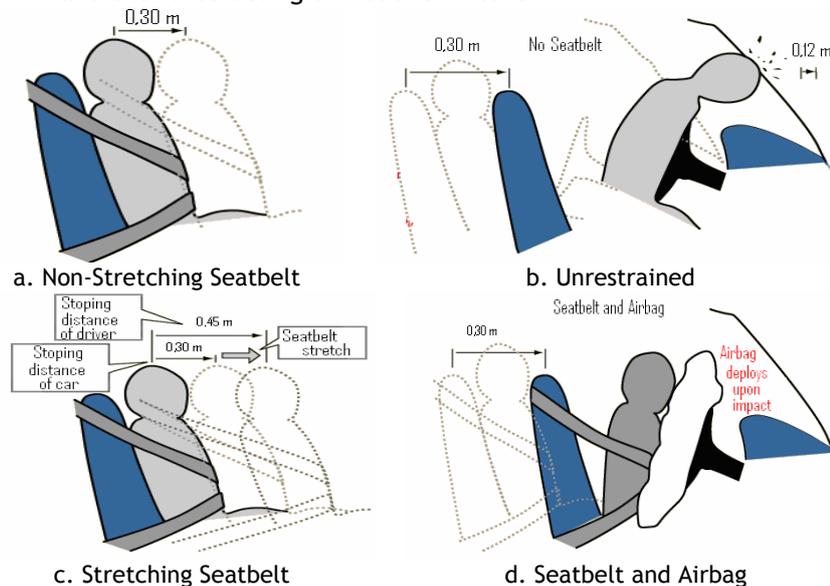


Figure 8. Force which acts on the driver during impact

❖ STOPPING DISTANCE CALCULATION

Assuming proper operation of the brakes, the minimum stopping distance for an automobile is determined by the effective coefficient of friction between the tires and the road. The friction force of the road must do enough work on the car to reduce its kinetic energy to zero (work-energy principle), as shown in Figure 9. If the wheels of the car continue to turn while braking, then static friction is operating, while if the wheels are locked and sliding over the road surface, the braking force is a kinetic friction force. To reduce the kinetic energy to zero:

$$\text{Work}_{\text{friction}} = -\mu mgd = -\frac{1}{2}mv_0^2 \tag{11}$$

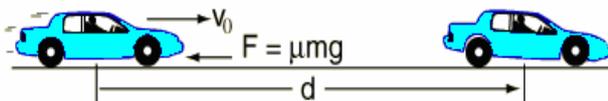


Figure 9. Vehicle stopping distance

For calculating minimum stopping distance, a value of 0.8 is a nominal value for the coefficient of static friction between good tires and a good road surface. Generally, coefficients of kinetic friction are less, and may be dramatically less for wet, icy, or oily surfaces. For many existing tires, the coefficient of kinetic friction on a dry road surface may approach 0.8 if the braking is not so prolonged as to cause tire melting. The stopping distance is given by:

$$d = \frac{v_0^2}{2\mu g} \tag{12}$$

If the vehicle speed is $v = 50 \text{ km/h} = 13.88 \text{ m/s}$ and the coefficient of friction between the tires and the road is $\mu = 0.7$, the stopping distance is $d = 14.059 \text{ m}$. Note that this implies a stopping distance independent of vehicle mass. It also implies a quadrupling of stopping distance with a doubling of vehicle speed.

❖ CURRENT TESTING CAPABILITIES OF PASSIVE SAFETY SYSTEMS

With the introduction of airbags and crash-testing, the number of people killed and injured by motor vehicles has decreased in many countries. *International NCAP (New Car Assessment Program)* ratings provide a useful basis for comparing vehicle safety.

In the United States - the *National Highway Traffic Safety Administration (NHTSA)* provides safety information for a large number of vehicles through their *New Car Assessment Program (US-NCAP)*, using an outdated crash-testing procedure and featuring only vehicles built after 1994. The *Insurance Institute for Highway Safety (IIHS)* does its own testing for the insurance industry, but data is only available for a few late-model vehicles.

In Europe - the most popular models are crash-tested by the *European NCAP*, a consortium of governmental and auto clubs overseen by the *FIA*. Pedestrians and bicyclists are much more vulnerable than vehicle occupants when a crash occurs. The *European NCAP* pedestrian evaluation tests the most hazardous areas of each model.

Euro NCAP released a separate star rating for child protection valid from November 2003 to January 2009. The child protection rating is for a combination of a car with specific child seats that have been recommended by the car manufacturer. The combination could earn up to five stars for child protection. As of 2009, the child score has become integral part of the overall rating scheme; however the technical assessment has remained the same.

A series of tests are carried out to replicate accidents involving child and adult pedestrians where impacts occur at 40kph (25mph). Impact sites are then assessed and rated fair, weak and poor. As with other tests, these are based on *European Enhanced Vehicle-safety Committee* guidelines. *Euro NCAP* released a separate star rating for pedestrian valid from 1997 to 2009. The pedestrian protection rating was based on the adult and child head form tests and the two leg form tests. As of 2009, the pedestrian score has become integral part of the overall rating scheme; however the technical assessment has remained the same.

In Australia - the *Australian NCAP (ANCAP)* has recently adopted the *Euro-NCAP* testing procedures (they formerly used *NHTSA* test procedures).

The seatbelt remains the single-most effective item of safety equipment in any car. It is the most fundamental part of any restraint system and manufacturers are continuing to develop new and better seatbelt systems to provide ever greater protection. Many of those who do not routinely wear their seatbelts would do so if prompted by a signal. Research shows that occupants are much more likely to wear their belts in cars equipped with a seatbelt reminder (*SBR*) than in those without. *Euro NCAP* rewards any effort made to ensure that seatbelts are worn.

Carmakers aim is to prevent, correct and protect any participant when an accident occurs. In the area of accident prevention using: audible seatbelt reminder - a buzzer goes off over 20 kph if a seatbelt is unfastened or poorly fastened, automatic headlights and windscreen wipers, additional cornering lights, xenon and bi-xenon headlights, or a tire pressure monitoring system warns drivers of punctures and insufficient pressure.

To help drivers anticipate high-risk situations, the carmakers equips its vehicles with driving aids designed to give drivers a greater sense of responsibility, inform them of risks, give them a better understanding of their environment and help them to concentrate on the road. In the area of correction is aimed to keep the car on course, so in unexpected situations, the driver can lose control of the car. A number of systems can provide assistance, including *ABS* and emergency brake assistance (*EBA*).

Because some accidents cannot be avoided, carmakers equips its vehicles with systems designed to protect all passengers, regardless of their age, body shape and position in the car, however being performed by seatbelts, airbags, vehicle structure and the *Isofix* anchor point system.

Stages in the testing process with every aspect of testing (from the test method development, pre-test preparations and computer simulations to the crash testing, post-test analysis and safety improvement recommendations) are presented in Figure10.

New cars face a series of four crash tests: front impact, side impact, the pole test and pedestrian impact. Dummies are covered in sensors that make it possible to evaluate the degree of possible trauma which each part of car occupants' or pedestrians' bodies may undergo. Each measurement gives rise to a corresponding score. After reformulation and weighting, an overall

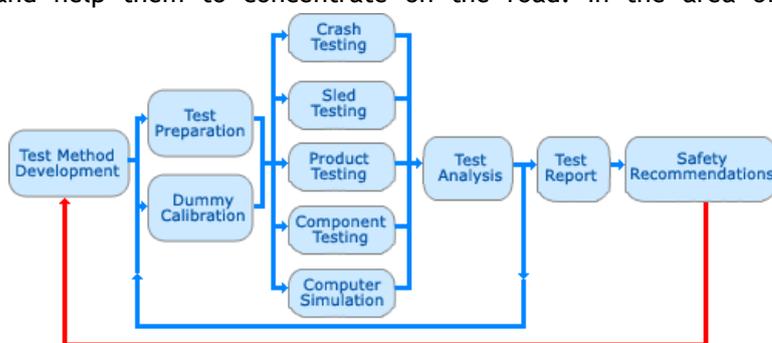


Figure 10. Steps in testing process

assessment of the vehicle is delivered in the form of stars, with a maximum attribution of five which quantify a car's level of safety.

- Frontal crash tests performed at 64 km/h into a barrier
- Side impact crash tests at more than 50 km/h
- Pedestrian crash tests at 40 km/h.

Each impact gives rise to a score, according to the level of safety that is offered by the car. The front impact test is worth up to 16 points, as is the side impact test. The pole test can provide up to 2 bonus points. The total score is thus awarded on the basis of 34 points: 16 points (front impact) + 16 points (side impact) + 2 bonus points. Note that the front impact test has some specific marking criteria. They are based on the measurements carried out on the driver dummy, unless the trauma sustained by the passenger dummy is greater. In this case, the less favorable of the two scores is taken into account.

The results are synthesized in the form of stars. The number of stars qualifies the overall level of protection. The side impact test against a pole gives rise to a specific evaluation presented in Figure 11c. Dummies packed with sensors are used to evaluate traumas suffered by each part of the body. The color codes that denote severity for each zone, the number of stars qualifies the overall level of protection crash tests can be seen in Figure 11.

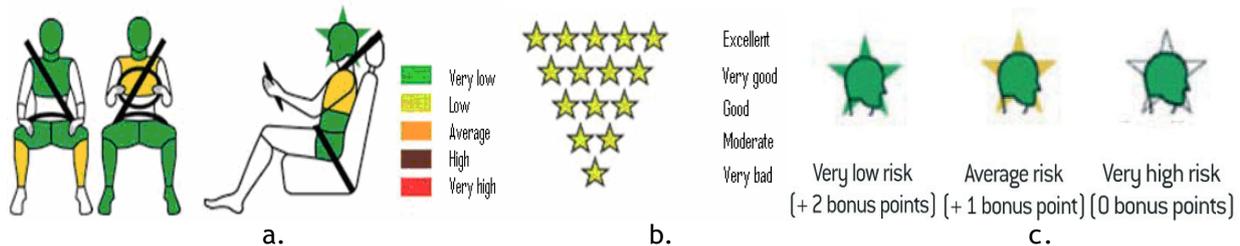


Figure 11. Scoring system

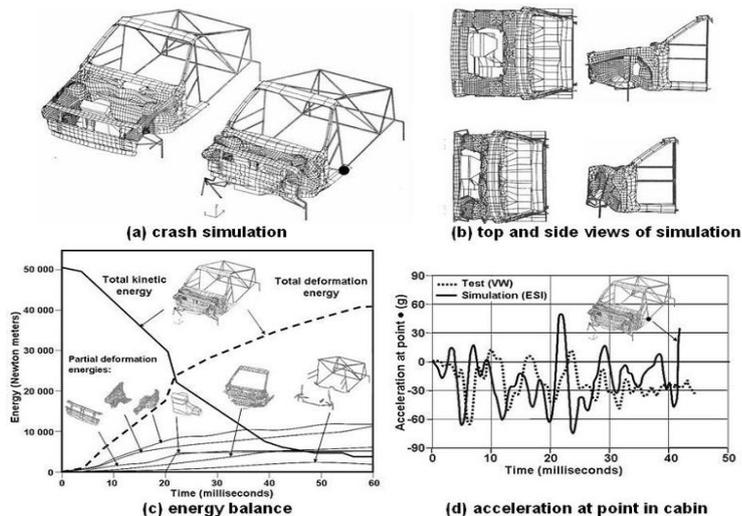


Figure 12. Crash tests graphic simulation

Experimental tests are completed and correlated with results obtained by computer simulations, Figure 12, used by a number of representative companies in the field as effective and economical alternative to physical testing, particularly for studying the behavior of materials and / or design new solutions.

Computer simulation is used to test some subsystems or components, such as airbags, seat belts, seat configurations, the special conditions of dynamic loads and wind, temperature, etc. The results of simulations performed on virtual models are validated based on information obtained from physical tests.

❖ THE IMPORTANCE OF OPTIMIZATION AND EFFICIENCY OF SAFETY BELTS

For over 10 years, serious and fatal accidents have decreased in number. The reason is that more and more people begin to understand the importance of using safety belts. In USA, the *National Highway Traffic Safety Administration* said: "seatbelts, when are used, reduce the risk of fatal injury to occupants of the car by up to 45%." From 1975 to 1999 an estimated 123,213 lives were saved thanks to the seatbelt.

For our analysis, we used data provided by the *National Center for Statistics and Analysis, Fatality Analysis Reporting System (FARS)*, *National Highway Traffic Safety Administration (NHTSA)* and the *National Occupant Protection Use Survey (NOPUS)* we only provide data based on probabilistic data obtained from observation of safety belt use in the U.S. *NOPUS* is conducted annually by the *National Center for Statistics and Analysis of the National Highway Traffic Safety Administration*.

Our Society, i.e. supplier, manufacturer or final customer, together we become more aware of the importance of traffic safety. Thus, as a process of reflection following the demonstrations, tests conducted by manufacturers using the media, promoters and also of our experience, the participants to traffic, we started to use the security options offered by producers of cars and using them more often, there was a decrease in the number of accidents.

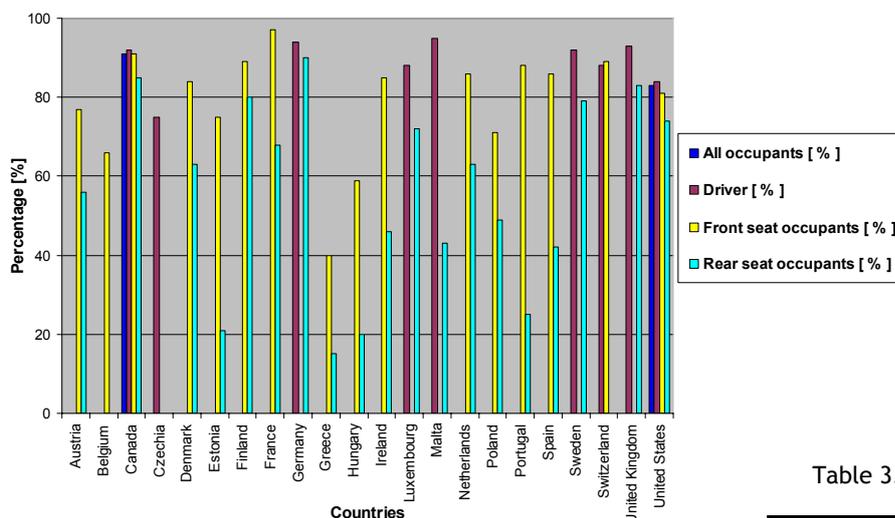


Figure 13. The rate of safety belt use

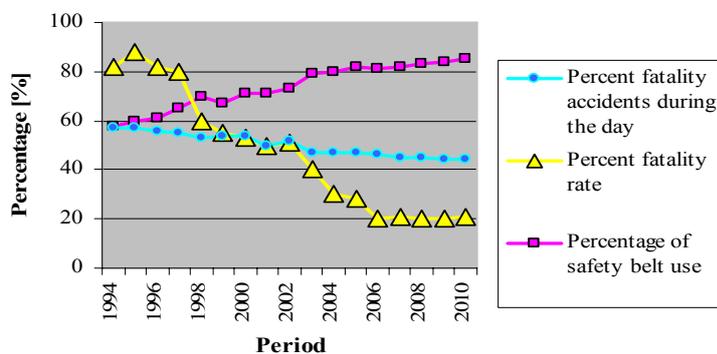


Figure 14. Evolution of safety belt use and rate fatality

Seat belt use varies widely between different parts of the world and different countries. The three-point safety belt has been saving lives for 50 years. The rates of safety belt use in different countries around the world can be seen in Figure 13, and the evolution of safety belt use in recent years is shown in Table 3 and Figure 14.

Table 3. Evolution of safety belt use in recent years

Period	Percentage of safety belt use [%]	Percent fatality rate [%]	Percent fatality accidents during the day [%]
1994	58	82	57
1995	60	88	57
1996	61	82	56
1997	65	80	55
1998	70	60	53
1999	67	55	54
2000	71	53	52
2001	71	50	50
2002	73	51	50
2003	79	40	47
2004	80	30	47
2005	82	28	47
2006	81	20	46
2007	82	20	45
2008	83	21	45
2009	84	20	44
2010	85	20	44

❖ CONCLUSIONS

The paper has been tackled important milestone in the design of automotive safety systems, has introduced the scheme and characteristics pretensioners device and made strength calculation of limiter effort, aiming at the item to be designed properly analyzed by calculation of deformation resistance and to provide maximum safety in use. Also, we determined the forces acting on the vehicle and driver, which may occur in case of an accident, and what are the consequences of such actions. Have shown current testing capabilities, the conditions under which these tests realize which is the importance of these, both through experimental tests and graphical simulation and the importance of efficient use of safety belts and witch was the evolution of its use during years.

❖ REFERENCES

- [1.] <http://www.etsc.eu/enforcement-seatbeltuse-whyincrease.php> Seat Belt Article. 2006.
- [2.] <http://www.tc.gc.ca/eng/roadsafety/tp-tp2436-rs200601-menu-194.htm>.
- [3.] <http://www.bfu.ch/English/statistik/Pages/Statistik.aspx> . Swiss Council for Accident Prevention. 2006. Retrieved 2010-12-10.
- [4.] National Highway Traffic Safety Administration, <http://www-nrd.nhtsa.dot.gov/> . Seat Belt Use in 2008 - Overall Results. Retrieved 2010-12-10.
- [5.] <http://www.crash-test.org/techno/passive.htm>
- [6.] <http://www.autoliv.com/wps/wcm/connect/autoliv/Home/What+We+Do/Crash%20testing>
- [7.] <http://www.passivesafety.com>
- [8.] http://ec.europa.eu/transport/road_safety/topics/behaviour/seat-belts/index_en.htm
- [9.] <http://hyperphysics.phy-astr.gsu.edu/hbase>

