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Ana TODERIŢĂ (căs. Sântean)

Studiu privind comportarea mecanică a chingii centurilor de siguranță ale autovehiculelor

Study on the mechanical behavior of the vehicle safety belt webbing

Conducător ştiințific

Prof.dr.hab.ing.mat. Sorin VLASE

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Introduction

The present thesis deals with the performance study and behavior of the webbing material in safety belts when the final user mishandles the product.

The paper is structured in six chapters:

In Chapter I , PRESENT STUDIES REGARDING SAFETY SYSTEMS, the current research on safety systems is presented and also the evolution of active and passive safety systems. This chapter highlights the issue that not everyone owning a vehicle pays importance to the integrity and correct usage of safety systems. At the moment, occupant safety holds a significant spot in the automotive industry. The production chain of vehicles recognizes the importance of this topic and constantly update their technologies and products. Consumer awareness programs plays a key role in highlighting the importance of safety systems.

A study conducted on the webbing properties where the production process is analysed, the types of materials used and their specifications are also presented.

In CHAPTER II, OBJECTIVE AND PURPOSE OF THE PAPER, a short overview of the main and secondary scope of the thesis is explained. The main objective is the elaboration of a model for studying the safety belt webbing with regards to functionality and behavior in the case of typical defects , followed by system calculus and experimental studies. The authors propose to determine in which way these defects can influence its behavior in case of a crash.

The applicability area of this research is the automotive safety domain.

In CHAPTER III, REPRODUCING THE DEFFECTS FOR ANALISYS, the author details the method in which these defects are reproduced, their causes and a short description of the equipment used to test the samples. Three types of defects are analysed, cuts, scratch marks and burn marks, the main issues encountered in final user products.

In CHAPTER IV,MODELISATION OF SEAT BELT WEBBING LOADS a calculus model is presented along with using analytical mechanics to determine the dynamic solicitations that appear in the product in case of a crash. The most important step in the dynamic analysis of a multibody system with elastic elements is writing the evolution equations for the system. The next steps that follow, namely, assembling the equations of motion and solving them will be done according to the classical methods used in finite element method software. Obtaining the equations is therefore the most difficult problem to solve, considering the multitude of terms that appear in such a description. As a result, finding a formalism that makes it possible to write these equations as easily as possible is an important step in this analysis. Analytical mechanics provides several formulations, equivalent to each other and equivalent to Lagrange's equations. We can state here Gibbs-Appell equations, Hamilton equations, Maggi equations, Jacobi equations and other equivalent forms can be used in this way. The most important step in the dynamic analysis of a multibody system with elastic elements is writing the evolution equations for the system. The next steps that follow, namely, assembling the equations of motion and solving them will be done according to the classical methods that translate the finite element method into applications. Obtaining the equations is therefore the most difficult problem to solve, considering the multitude of terms that appear in such a description. Therefore, finding a formalism that makes it possible to write these equations as easily as possible is an important step in this analysis. The method used almost exclusively in this type of analysis, until now, has been the method of Lagrange's equations. This is primarily due to the fact that researchers are very familiar with this method and use fundamental notions frequently used today (kinetic energy, potential, mechanical work, ...). But analytical mechanics offers several formulations, equivalent to each other and equivalent to Lagrange's equations. Gibbs-Appell equations, Hamilton equations, Maggi's equations, Jacobi's equations, and other equivalent forms can be used for this type of problem. These methods are presented comparatively in the thesis, finally choosing the Gibbs-Appell method for the presented application.

In Chapter V, EXPERIMENTAL TRIAL RESULTS, the tensile test results for each sample were detailed in the case of each type of deffect, identifying the situation that has a significant impact in terms of performance.

Chapter VI, entitled WEBBING SOLICITATTIONS IN THE SAFETY BELT aims to determine the behavior of the seat belt, in the presence of a passenger, belted in a vehicle equipped with a front attenuator, which has the role of reducing shocks. In this way the forces and stresses occurring in the seat belt are determined. A finite element method (FEM) modeling is used to determine the loads at which the passenger is subjected but also how the seat belt withstands the shock to which it is subjected. The determination of the forces that occur during the shock is done using the Gibbs-Appell method. The results can be useful to designers, to see if the system can provide minimum safety in a race.

In Chapter VII, ORIGINAL CONTRIBUTIONS,CONCLUSIONS, DISSEMINATION OF RESULTS AND FUTURE DIRECTIONS FOR RESEARCH are presented. In this chapter, useful recommendations for future applications are made and future research directions are presented. I would like to thank you for all the support I have received, directly or indirectly, and for the guidance I have received from the Transylvania University staff. The activities for the elaboration and scientific substantiation of this work were possible as a result of a scientific guidance of high professionalism and quality.

Chapter I.

THE CURRENT RESEARCH REGARDING SAFETY SYSTEMS

1.1 Literature analisys of the studied domain

Safety systems are a central element in the design of a motor vehicle. The passive safety elements have been used for a long time in manufacturing and consist of the structure that ensures the resistance of the car, the elastic impact attenuators located mainly in the front part of the car (ar and side), seat belts, airbags, adaptive control, passenger compartment in main. The seat belt is the element that you will have studied in the case of the work before you. Active safety systems include improvements to the braking, steering, suspension, lighting systems, and they are frequently used in the equipment of passenger cars now found on the automotive market.

Road traffic accidents are the cause of a significant proportion of morbidity and mortality and lead to more years of life lost than most human diseases. As a result, the behavioral factors that collectively represent the main cause of three out of five accidents and contribute decisively to the remaining ones have been studied. A classification of behavioral factors is necessary and feasible. Thus, the behavioral factors can be:

(i) those that reduce long-term ability (inexperience, aging, illness and disability, alcoholism, drug abuse);

(ii) those that reduce short-term capacity (drowsiness, fatigue, acute alcohol intoxication, short-term drug effects, overeating, acute psychological stress, temporary distraction);

(iii) those that promote risk-taking behavior with long-term impact (overestimation of capabilities, aggressive attitude, habitually excessive speed), disobeying traffic rules, indecent behavior at the wheel, not using a seat belt or helmet, inadequate seating in driving time, accident proneness);

(iv) those that promote risk-taking behaviors with short-term impact (moderate ethanol consumption, psychotropic drugs, vehicular crime, suicidal behavior, compulsive acts).

The gliding of the lap belt over the iliac crest of the pelvis during frontal crashes can substantially increase the risk of passenger injury. A multitude of factors, related to occupants or seat belt design, are associated with this phenomenon. To make a study of it, the most important parameters are identified and a finite element model is developed [34]. Belt angle, belt tension and body belt friction are the main parameters identified as having a role in accidents. In order to identify whether the driver is wearing a seat belt that is correctly put on, a seat belt wear detection algorithm based on the position of the characteristic points of human joints is proposed in [35]. An experimental platform for seat belt testing is proposed in [36]. This platform can safely and efficiently carry out the vehicle acceleration experiments to check the seat belt and has economic benefits. Methods for analyzing the stresses and strains that appear in the seat belt are presented in [37,38]. Problems related to the transmissibility of the seat when using the seat belt are reported in [39]. Transmissibility serves to evaluate the vibration damping performance of seats. Because the seat and driver interact with each other, the transmissibility of the seat is affected by the dynamic characteristics of the driver. The restraint of the driver's movement caused by the seat belt results in the modification of the dynamics of the driver's seat and the transmissibility of the seat.

Vibration accelerations were measured on the seat cushion and seat base when the driver was wearing a lap belt or a four-point seat harness. Based on the analysis of these parameters, it was studied how the seat belt affects the driver dynamics and the transmissibility of the seat. Models used for the design and calculation of seat belts are presented in [40-44]. The role of the seat belt in avoiding serious accidents is relevant in the works [45-48]. We find that most of the papers refer to constructive solutions, to legislation, to medical issues, to methods of promoting belt wearing, and only a few papers deal with the calculation and sizing of seat belts.

1.2.Systematisation of safety systems and domain challenges

1.2.1 Safety systems-general description

Today, passenger safety is a top priority in the automotive sector. Researchers in the automotive value chain recognize the importance of passenger safety and are constantly upgrading their products to deliver safety technologies that protect passengers and pedestrians. Proactive policy implementation and consumer awareness have played a key role in the popularization of automotive safety systems. Passive safety systems are already known and their role is well defined. Passive safety systems play a role in limiting damage/injury to the driver, passengers and pedestrians in the event of an accident. Airbags, seat belts, crash protection system are common passive safety systems installed in vehicles today.

Frontal airbags are standard on all new cars since 1998 and on light trucks since 1999. Most vehicles had them before that. Impact sensors connected to an on-board computer detect a frontal collision and deploy the airbags. They inflate in a few milliseconds, after which they begin to deflate.

Characteristics of the safety belt

The seat belt pretensioner immediately retracts the belt to restrain the passenger during a frontal impact. This also helps seat occupants to take advantage of an airbag properly. Force limiters, a companion feature to pretensioners, manage the force the belt exerts on the occupant's chest.

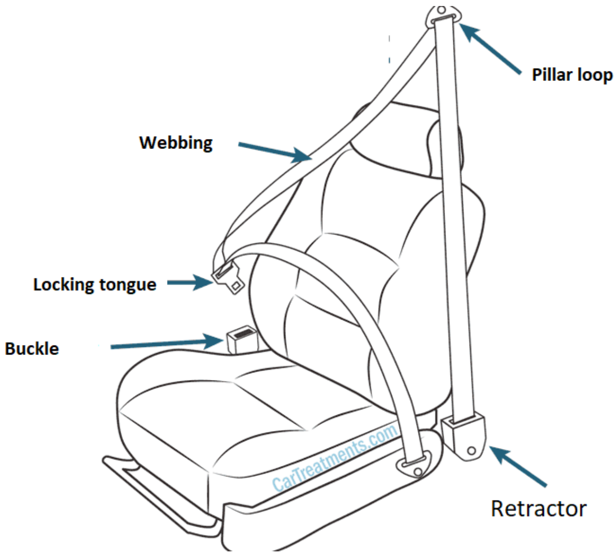


Figure 1.1. Components of the safety belt [49]

Some vehicle models have safety belts with an inflatable airbag on the webbing, reducing the forces excerted on the passengers in the case of a crash.

LATCH (inferior anchorages and child protective safety systems)

All vehicles must now have the LATCH system to make child seat installation easier and safer. The system features built-in lower anchors and upper anchor points for LATCH-compatible child seats.

Anti-lock brake system (ABS)

Before the ABS, it was easy for the wheels to lock during sudden braking. Front tire slip makes steering impossible, especially on slippery surfaces. ABS prevents this by using sensors at each wheel and a computer that maximizes braking action at each individual wheel to prevent locking. ABS allows the driver to maintain steering control while braking so that the car can be maneuvered around an obstacle if necessary.

This is the system that quickly applies the brakes to provide maximum power and control.

Traction control

This electronically controlled system limits wheel spin during acceleration so that the drive wheels have maximum traction. Some traction control systems only work at low speeds, while others work at all speeds.It has become common especially in the case of SUVs. Automakers tend to have a proprietary name for their stability control systems.

1.2.2. Performance in safety systems

A presentation on the performance capability of the safety systems is given below. In the field of active safety there are the following systems frequently used by manufacturers:

- The PRE SAFE system
- DISTRONIC PLUS with PRE-SAFE brake
- 2017 PRE-SAFE sound
- Assistance in maintaining the running path
- Caution when leaving the taxiway
- Warning regarding changing the traffic lane
- Active safety package provided by LSS_DW
- LCS lane change support radar
- DAS-W Video Alert Assistance System
- HWSS-AC Adaptive Cruise Control
- ESP-BAS1 electronic stability system

Performance in the passive safety systems domain

- **The safety belt**

The safety belt is a component part of a restraining system with the role of keeping the passenger's body in the seat.

The seat belt was invented by George Cayley, an English engineer in the late 1800s who created these belts to help keep pilots inside their vehicles. However, the first patented seat belt was created by American Edward J. Claghorn on February 10, 1885 to keep tourists safe in taxis in New York City. Over time, seat belts began to appear in car manufacturing to help passengers and drivers stay in their car seats. At the time there was no emphasis on passenger and driver safety.

Once the idea of the safety benefits of seat belts caught the attention of the U.S. public, sales of seat belts exploded. Car companies offered seat belts as optional equipment and they were even sold at local gas stations.

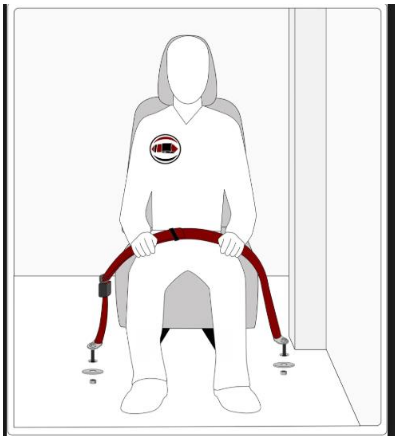


Figure 1.4 2 point safety belt [51]

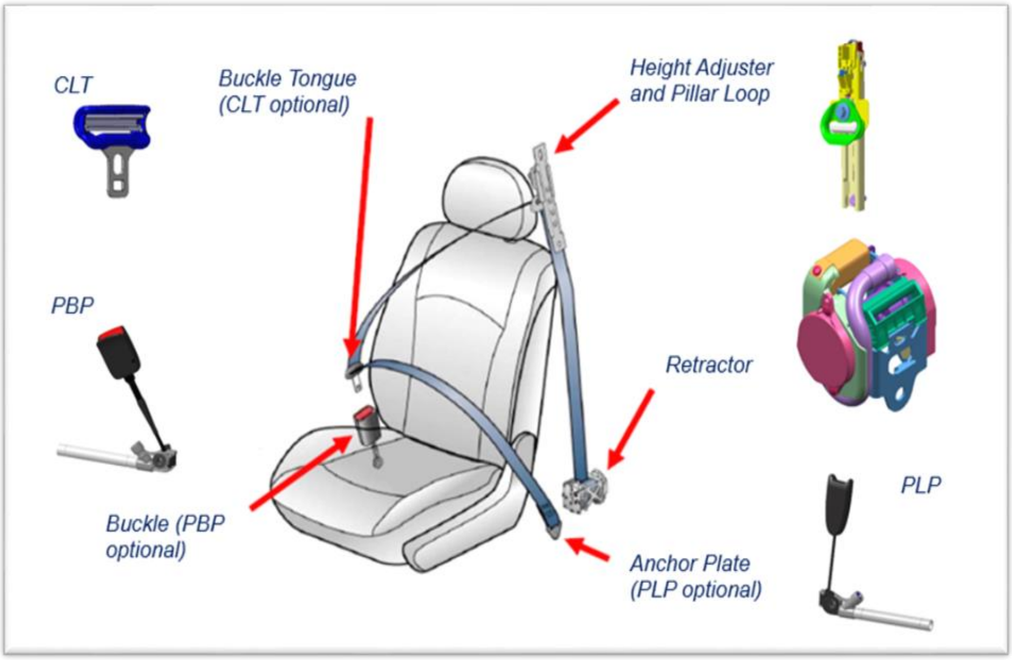


Figure 1.5. Passive safety elements in a vehicle [52]

The assembly is composed of:

- elements retaining the weebing;
- elements for fixing on the vehicle body;
- elements for locking the safety belt;

When the vehicle is functioning in traffic , the passenger is protected by two blocking systems :

- System sensitive to decelerations of the webbing – webbing sensitivity;
- System sensitive to accelerations, deceleraions and inclinations of the vehicle-car sensitivity;

From the complexity point of view, safety belts can be categorised as follows:

-static safety belts with standard blocking systems ;

-pyrotechnical safety belts which offer the pretensioning function;

A pretensioning device is a mechanism that retracts a portion of webbing (10-15 mm) during an impact in order to maintain a correct position of the passenger body in the vehicle seat and to protect from contacts with steering wheel and dashboard.

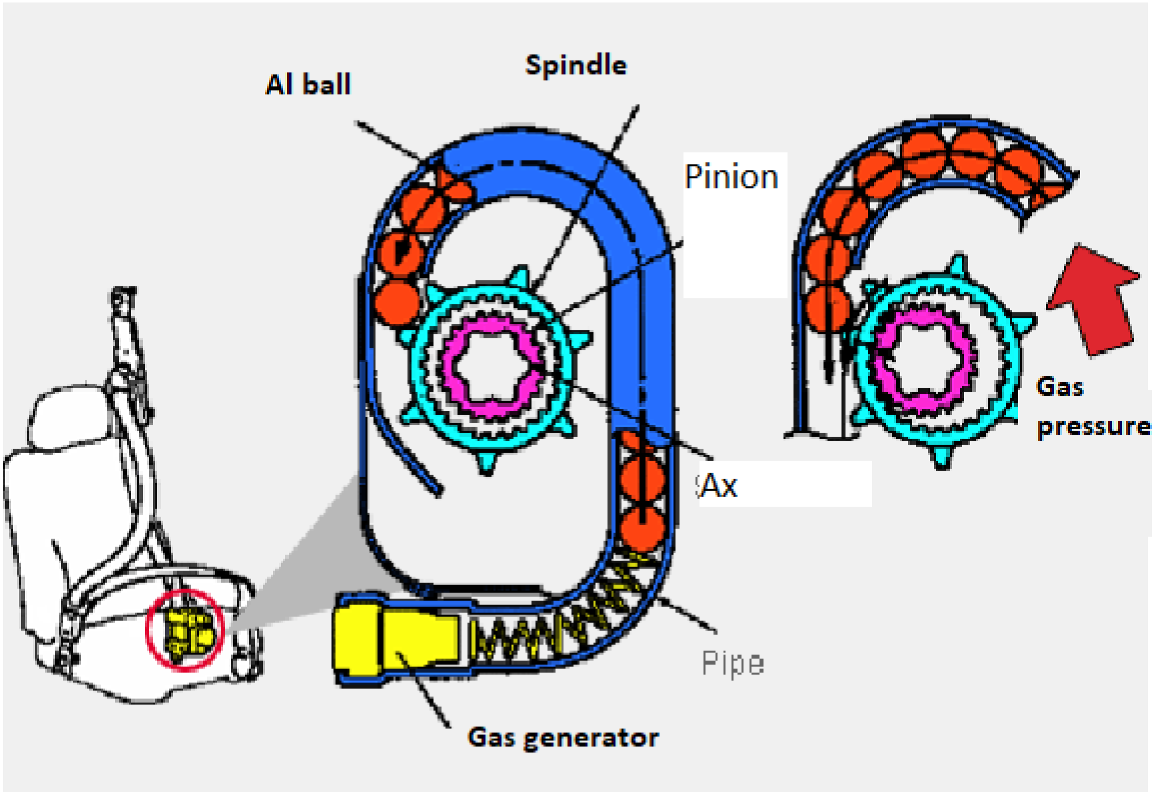


Figure 1.6. Pretensioning system of safety belt [53]

This system, presented in Figures 1.6 and 1.7, consists of a tube, a chain of aluminium balls and at the end there is a pill with pyrotechnic powder called gas generator. At the moment of impact, a signal is sent to the gas generator and it explodes. That explosion produces a force that pushes the balls into a collector, guided by a pinion. This in turn is connected to the assembly on which the webbing is wrapped and automatically retracts 120 mm of webbing into the storage system.

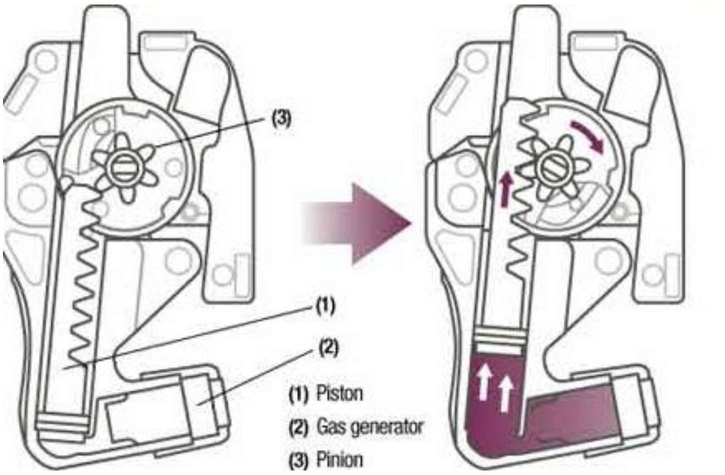


Figure 1.7. Pretensioning system with crane [54]

Evaluating vehicles from safety point of view

In order to distribute the final products on the market, vehicles must meet certain safety requirements.

• Requirements fulfilled for buyers:

To inform and help in making decisions regarding safety performance, objective institutions were created such as Euro NCAP in Europe, US NCAP and IIHS in America, J-NCAP in Japan, C-NCAP in China....

• Legal requirements:

The minimum to meet specifications in a given region;

e.g. ECE-R94 for Europe, FMVSS in America, CCC in China.

• Customer requirements:

Internal requirements and specifications;

• Product development objectives;

Euro NCAP introduced the overall safety rating in 2009, based on assessment in four important areas:

- Protection of adult-occupants (for driver and passenger);
- Protection of child occupants;
- Pedestrian protection which has been extended to include cyclists and is now known as Vulnerable Road User (VRU) protection;
- Safety Assist, which evaluated driver assistance and accident avoidance technologies.

Safety Assist

The safety assist score is determined from tests of the technologies in assiting the driver to use the vehicle in safety conditions in order to avoid a crash and reduce injuries. In these tests, Euro NCAP checks the functionality of the system and the performance in normal driving conditions and typical crash scenarios.

1.2.3 Active safety systems

Active safety features are those that help prevent or mitigate road accidents. Unlike passive safety features - which are designed to protect vehicle occupants once a crash has occurred - active safety features will commit to either preventing the crash from occurring or reducing the severity of an unavoidable crash (Figure 1.12).

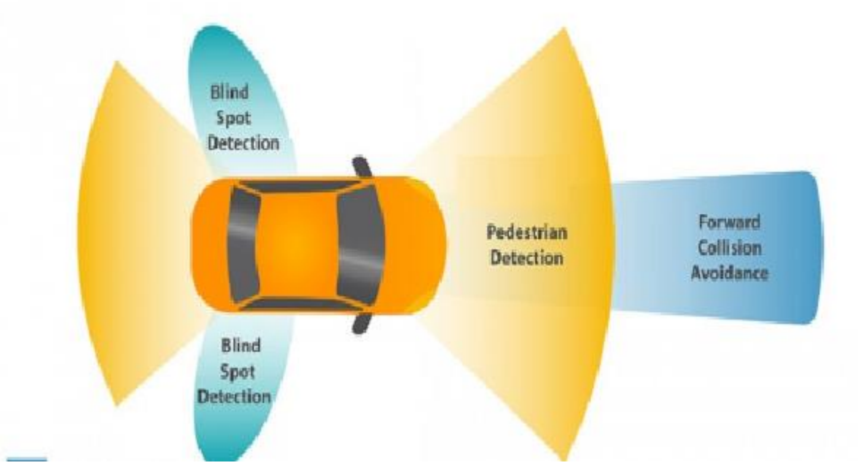


Figure 1.12. Active safety systems on a vehicle[58]

Active safety systems have become more efficient over the past years as the technologies keep evolving and collision avoiding technologies are being installed on a wider range of vehicles.

Examples of active safety systems:

1. Positioning the driver's seat for better visibility;
2. Low indoor noise level;
3. Chassis balance and handling;
4. Low weight;
5. Better tire grip;
6. Legible warning instruments and symbols;
7. Display head up;
8. Collision warning / avoidance;
9. Anti-lock braking system;
10. Braking assistance;
11. Early warning of severe forward braking;
12. Electronic stability control system (ESP);
13. Traction control;
14. Adaptive or autonomous cruise control system;
15. Intelligent adaptation to speed;

1.3 Designated institutions in establishing safety performance

Euro NCAP is committed to providing clear, comprehensive and timely information on the safety of vehicles on the market. The process is believed to ensure a fair assessment in terms of performance.

Each Euro NCAP member organization sponsors the assessment of at least one car model per year. They can choose a vehicle that is relevant to their own home market or one that is particularly important in a certain market segment. In addition, vehicle manufacturers can sponsor their own cars. The process followed is exactly the same for both cases.

Up to 4 cars are required for an assessment by Euro NCAP. Once the cars are at the testing lab, the manufacturer is informed of the vehicle identification numbers (VIN) and asked to confirm the specifications.

The classification complies with the following standards:

5 stars for safety: Good overall performance in crash protection. Well equipped with robust crash avoidance technology

4 stars for safety: good overall performance in crash protection; additional crash avoidance technologies may be available

3 stars for safety: average passenger protection, but no crash avoidance technology

2 stars for safety: nominal crash protection but no crash avoidance technology

1 star in terms of safety: marginal impact protection;

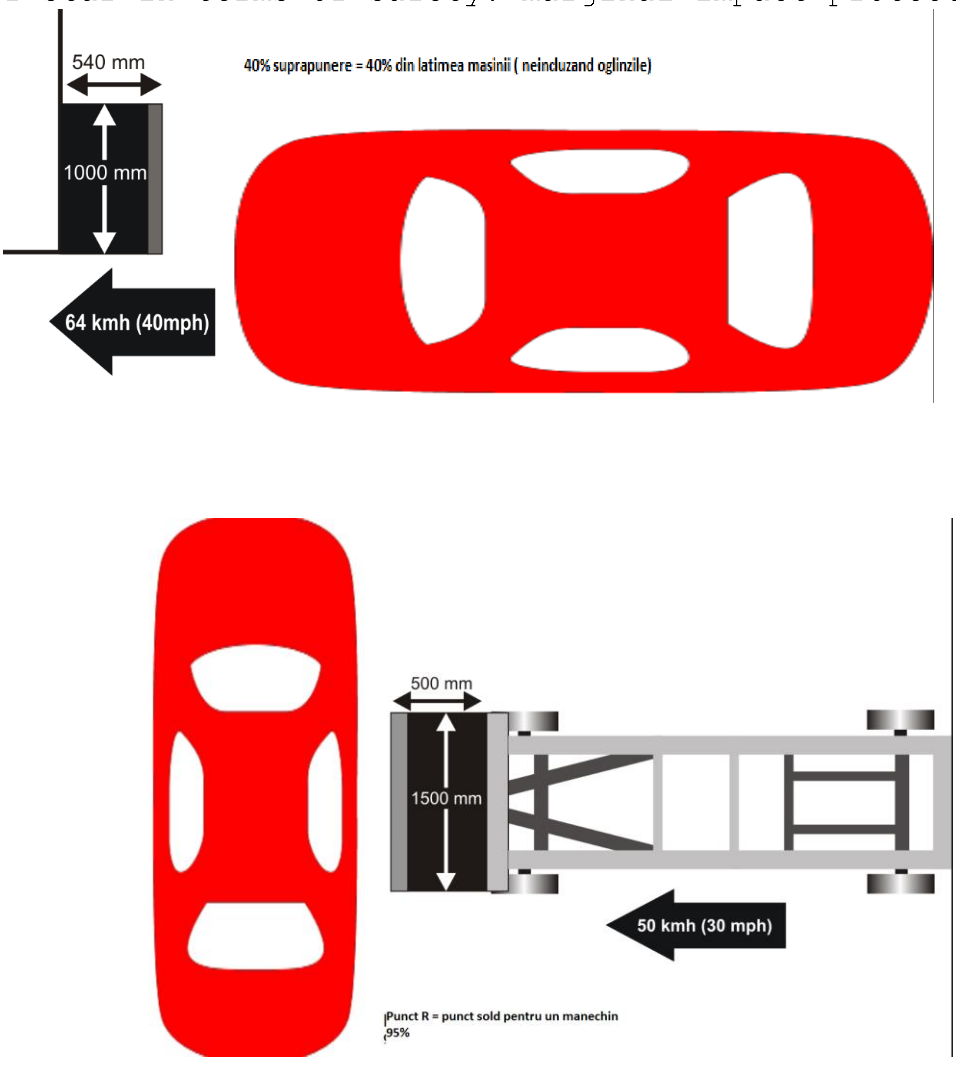


Figure 1.13. Sketch of two types of impacts simulated (frontal and lateral) [59]

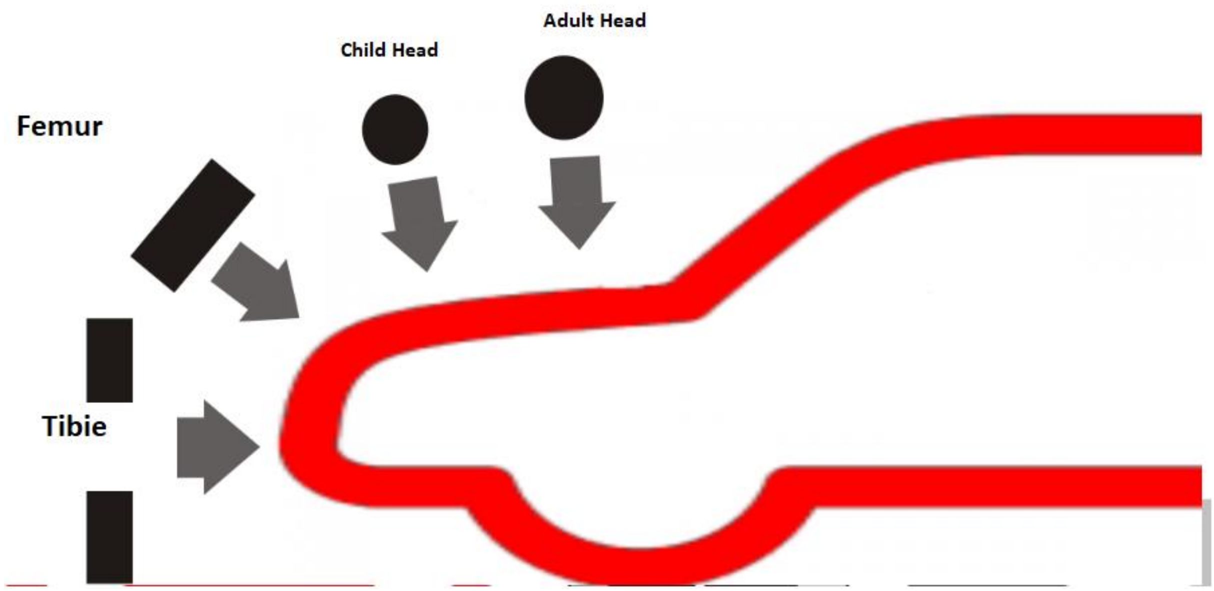


Figure 1.14. Impact test pedestrain-vehicle [59]

Regulations for safety systems

Vehicle safety in European Union countries is mainly regulated by international standards and regulations developed by the European Union (EU) and the United Nations Economic Commission for Europe (UNECE).

With the primary objective of eliminating trade barriers, the international harmonization of vehicle standards by the UNECE began in 1958 under the supervision of the Vehicle Construction Working Party of the Inland Transport Commission [149] in Geneva. This provided the framework for a voluntary type approval system based on UNECE regulations.

In 1970, the EU and its Member States developed a new framework for international agreement and cooperation on vehicle safety initiatives, culminating in the mandatory common type-approval of vehicles (which entered into force in 1998) and for engines with two and three wheeled vehicles (effective 2003).

UN Regulations As of 2015, there are 135 UN Regulations annexed to the 1958 Agreement; most regulations cover a single vehicle component or technology. A partial list of the current regulations applicable to cars appears (different regulations may apply to heavy vehicles, motorcycles, etc.)

Failure to comply with these standards can endanger the lives of passengers and the driver of the vehicle as well as pedestrians. The moment a problem is detected that could affect safety, the affected vehicles are recalled in the factory/service. Over time there have been several such situations[181].

1.4 Incorrect use of safety systems

Although vehicle manufacturers and their suppliers check the compliance of their products with the legislation, as a result of mishandling or incorrect use of the product, these safety safety systems can be affected if they are not used according to the instructions or maintained correctly.

A 2016 study of 300 women aged 17-34 by Behavior & Attitudes on behalf of the RSA found that:

- 28% admitted to misusing their seat belt by wearing it under their arm, rising to 35% among younger women.
- 53% of those surveyed said their friends wore their seat belts under their arms
- The main reasons cited for wearing a seat belt under the arm were neck strain relief (49%) and general comfort (47%).
- 9% said it was to protect their tan, or 7% to protect clothing.

Although seat belt compliance is consistently very strong among young women, it is not universal: for example 23% do not always wear a seat belt as a rear passenger.

Following a general study, the following wrong practices were found among passengers and drivers in terms of wearing seat belts:

- seat belt positioned under the arm (2% of drivers and 2% of all passengers);
- seat belt positioned behind the seat (0.5% of all drivers; 1 case);
- belt positioned on the arm (9% of drivers and 21% of all passengers);
- belt positioned close to the neck (8% of drivers and 8% of all passengers;
- twisted belt (20% of all drivers and 23% of all passengers);
- belt with excess material (8% of drivers and 9% of all passengers);
- hip positioned on the abdomen (4% of drivers and 9% of all passengers);
- seat positioned with an exaggerated angle at the back (6% of all drivers and 9% of all passengers).
- seat positioned far back (9% of drivers and 17% of all passengers);
- non-optimal position of the adjusted B-pillar of the anchor point (19% of all drivers and 38% of all passengers).

Another topic among passengers is the wearing of seat belts by pregnant women. According to the analysis of the responses to the questionnaire by 1931 participants, the use of seat belts during pregnancy is 91.9%, however, the results showed that a very small proportion, only 4.3% of pregnant women positioned their seat belts correctly. Three out of four women seem to position their sections either "across the abdomen" or "Flat over the upper thighs". 3 point seat belts, used correctly, are crucial locking systems for the safety of both the fetus and pregnant women.

With a properly used three-point belt, the passenger has inserted the tongue into the buckle and there is a strap both transversely and in the abdominal area, it will act in the event of an impact in a different way than a belt where the passenger only has the strap in the chest area (the tongue inserted into the buckle but the belt is pulled through the back of the seat).

If the belt is not washed according to the instructions, light washing with soap and non-abrasive material may lead to scaling of the belt, damage to the structure.

A study by NHTSA (National Highway Traffic Safety Administration) (Figure 1.15) shows that there is an opportunity to improve safety systems. Considering that many vehicle passengers including drivers find ways to not wear seat belts, this study focused on installing sensors in key locations (Figure 2.13) to detect possible variations that can be brought from the outside such as :

- Insertion of the false tongue in the fastener (marker not connected to the belt assembly);
- Safety belt engaged in the buckle, pulled through the back of the seat;
- Safety belt engaged in the buckle, the strap on the chest area pulled through the back of the seat;
- Safety belt engaged in the buckle, the strap on the chest area held behind the driver;
- Right passenger seat belt engaged in the driver's side buckle - the driver is not insured;

The selected sensor combination included the following:

- Original seat occupant detection;
- RFID system for matching the buckle with the corresponding locking tongue;
- Sensors for detecting the length of the extracted webbing;
- Angle sensors for the Dring;

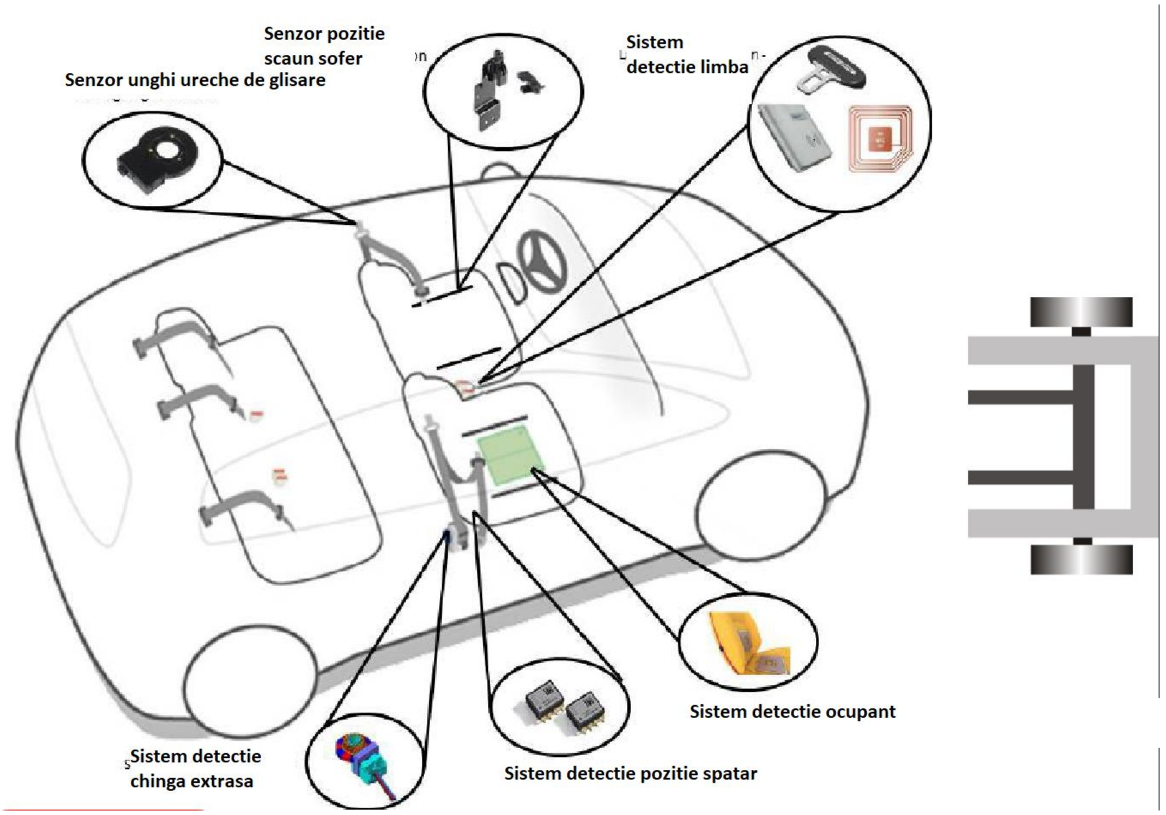


Figure 1.15. Sensor positioning in NHTSA study

The system was able to detect incorrect use of the belt in 95% of cases, the study was based on a sample of 34 participants with a height between 155 cm and 189 cm and a weight varying between 47 and 118 kg.

Another way of incorrect use of safety systems is not checking their integrity and not properly maintaining them.

Maintenance is another essential strapping consideration. As a general rule, most fabrics should be kept clean and dry, although some materials such as polypropylene are water resistant. A mild detergent is recommended to clean the canvases, although it is essential to note that the materials mentioned above are manufactured in colours, which may fade or bleed when exposed to certain conditions or cleaner treatments. Therefore, consult the manufacturer for the best maintenance approach. To increase the use of seat belts and encourage people to use them, vehicle manufacturers have developed reminder systems that warn occupants that seat belts are not being worn. The systems tend to work by detecting the weight of an occupant in the seat and whether the seat belt is on. If it detects that an occupant is not wearing a seat belt, an alarm will sound. These systems are now mandatory. Since November 2014, SBRs are mandatory in Europe on the driver's seat for new cars.

The strap is a material resistant to UV and temperature changes, but it can be damaged if we interfere with it with sharp objects or objects that can hang (ex: clothes/bag accessories).

Although most interior and exterior vehicle maintenance companies offer belt cleaning services, not all customers ask for it, and it is not done correctly in all places.

·Washing the webbing with various chemical solutions for rapid dirt removal may result in fiber damage depending on the composition of the solution;

.Washing the strap with various abrasive materials may result in damage to the strap;

·Washing the strap, not drying it completely and storing it inside the retractor, can damage the metal parts by causing corrosion and automatically affecting the functionality of the product.

The same can happen if the owner is transporting animals that can gnaw the leash.

Figure 1.16. Webbing deteriorated after incorrect animal transportation

1.5 Materials used in the production of a safety belt

The fast development and usage of composite materials has begun in 1940. The polymer industry has grown and tried to exploit the plastics market in a variety of applications. The discovery of new polymers in research laboratories has offered a possible solution of plastic exploitation in various industries with the condition of enhancing the mechanical properties. Four composite generations can be mentioned:

- First generation (1940's)-Composites with fiber glass ;
- Second generation (1960's) : Composites with high performance post SPutnik era ;
- Third generation (1970's and 1980's) : new market research and properties sinergy ;
- Fourth generation :Hybrid materials, nanocomposites and biometric strategies ;

The webbing material is an engineering innovation not just due to the equipment that extracts and tensions the webbing. The material in the webbing is conceived to withstand up to 3000 kg. The original webbing was manufactured using a loom

that could produce up to 200 connections per minute. TSarting with 1975, the biigest webbing is manufactured on needle looms that make 1000 connections per minute. Modern equipments reach up to 3000 .
Today, seat belt material is woven from 100% polyester. Nylon was the most popular material, but nylon stretches more than polyester and is more prone to wear. Small abrasions and damage to the belt reduce the tensile strength, so this difference really matters. The seat belts also have specially designed protection sills reinforced with strong wires that still allow the belts to remain flexible.
Research has also found that less energized wires create more durable seat belts because the wires can pack more tightly. Typically, seat belt webbing has about 300 threads per 46 mm of webbing (Figure 1.17)

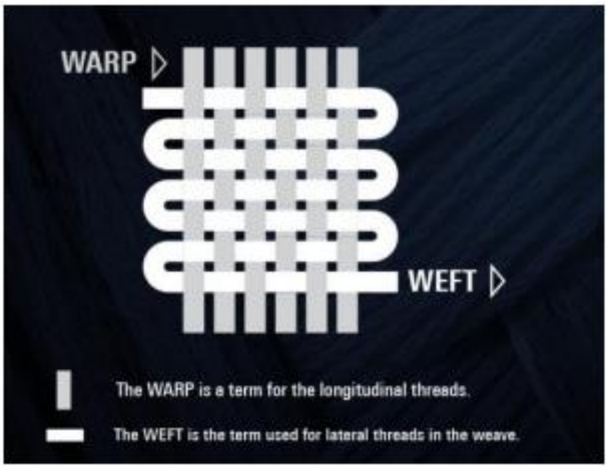


Figure 1.17 weaving pattern for webbing [60]

Nylon is a high-strength elastic material that is commonly used for webbing applications (especially flat nylon). This material tends to stretch about 2% of the cord length when wet. When looking at how to make nylon webbing, experts caution that nylon fabrics should not be exposed to water continuously, as the material tends to absorb liquid and can harbor mold if not properly maintained.

Nylon webbing has the following properties: Heavier than polypropylene, less bulk and coverage, higher cost; High strength, abrasion resistance; Higher temperature resistance, high melting point (220-250 C.); Resistant to damage from mold, bacteria, sweat, rot and moisture; Weak resistance to acids, inert to alkaline; Moisture absorption of 4.5%; Less stain resistance (poor resistance against water-based stains); Good sun resistance (with UV additive); Normally dyed nylon is not as fast as color-dyed nylon.

Polyester webbing has the properties: high strength, good abrasion resistance; high melting point (230-240 C.);

resistant to damage from mold, bacteria, sweat, rot and moisture; fair resistance to acids and alkalis at room temperature; low moisture absorption (0.40%), quick drying; better resistance to water-based stains, poor resistance to oil stains; good resistance to the sun; higher cost for painting.

Figure 1.21 shows the different defects that can appear on a seat belt during its use.Inţepături;

- Pulled threads;
- Deviations in the webbing;
- Pulled webbing(bottle neck effect)
- Spots;
- Cuts;

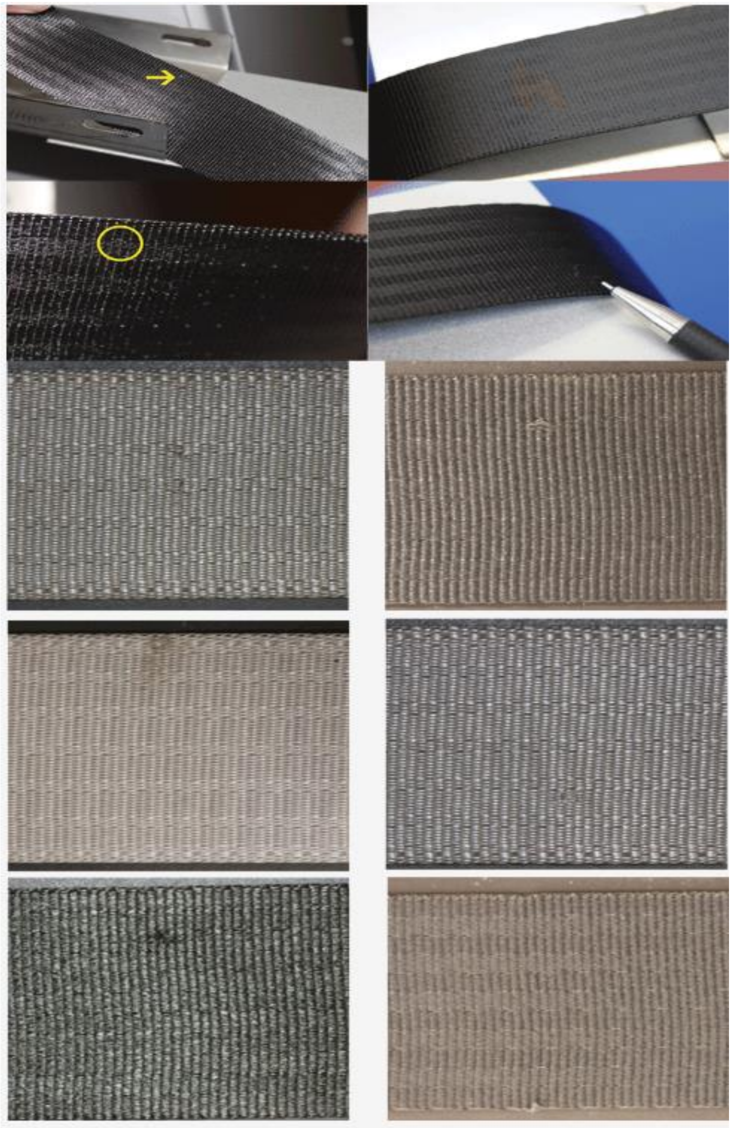


Figure 1.21 Deffects that can be detected in webbing production

1.6 Conclusions

Following the analysis of the specialized literature regarding the current state of research in the field of safety systems, we can draw the following conclusions:

- In the last fifty years the safety of passengers in the vehicle has evolved considerably, from lap belts to belts with pretensioning systems and airbags.
- Specialized institutions were formed to ensure compliance with the requirements from the safety point of view EURO NCAP, US NCAP. They change their evaluation methods depending on how the automotive market develops.
- Although there are many awareness campaigns and studies, we can observe that not many know how a safety belt works and how we can affect its functionality if it is not positioned correctly.
- The most vulnerable road users are children and pregnant women where there is no access to sufficient information related to car insurance.
- A way of maintaining safety systems and checking their integrity is not clearly described.
- There are few papers dedicated to a calculation of the loads that appear in the safety belt and also few mathematical models that analyze in depth the crash phenomena that occur in a very short interval but can have dramatic effects on the driver and passengers. In this sense, the present work comes to fill this lack in the study of appropriate models and in the analysis of the phenomena produced during the action of a safety belt. There are also no studies showing the tensions that appear in the belt at maximum stress.

Chapter II.

OBJECTIVE AND PURPOSE OF THE PAPER

2.1. Paper objectives

Based on the study presented in the previous chapter, several objectives can be formulated.

The main objective is represented by creating a model for the study of safety belt webbing with respect to functionality and behaviour in the case of typical defects, followed by calculus for the study for this type of system. The author proposes to determine how these different defects in the structure of the webbing can affect its behaviour in case of a crash.

The applicability field of this research is in the passive safety of the automotive domain.

The general objective that is to be realised in the main steps leads to connex objectives, that will be defined and lead to the acomplishing of the study. A few of the connex objectives are as follows :

1. An analysis of the research in the selected domain and identifying the present stage of research. The domain is interdisciplinary and it was necessary to study papers from literartures such as : mechanics, mathematics, numerical methods, finite element analysis experimental methods. In the bibligraphy it is mentioned only the literature considered suggestive for the studied domain.
2. Identifying new research directions in the area containing paths never explored from this point of view.
3. A critical analysis of the modelisation methods for determining the solicitations which appear in the safety belt webbing.
4. Selecting the most appropiate methods for describing the movement equations for these types of systems and their quality interpretation ;
5. Critical analysis of the obtained equations and their solving ;
6. Identifying ana analysing the best calculus methods for resolving the topics imposed by our thematic.
7. System modelisation using Finite Element Method ;
8. Theoretical study of the materials and determining their characteristic properties ;
9. Experminetal trials for determining the materials properties.

10. Critical analysis of the obtained results , conclusions and proposals for future research.
11. Dissemination of the results through article publishing in specialised journals.
12. Identifying future research and development directions.
13. Formulationg conclusions and indications for engineers in the automotive industry.
14. Bringing awarenes to drivers and passangers on the correct use of the safety belt and its integrity.

Chapter III

REPRODUCING THE DEFECTS FOR ANALYSIS

3.1 Preparing the samples for testing

For evaluating the tensile strength of the webbing, a comparison between new state samples and those with simulated defects was done. For this the following defects were chosen:
-scratched webbing(Figure 3.1): can appear because of pets incorrectly transported in the vehicle or by friction contact with sharp accessories(belt, studs).

Figure 3.1 Webbing with scratch marks

- burnt webbing(Figure3.2): A significat part of drivers and passengers are smokers, there are many cases in which the ash or the cigarette itself is droped by accident and it is not put out immediately.

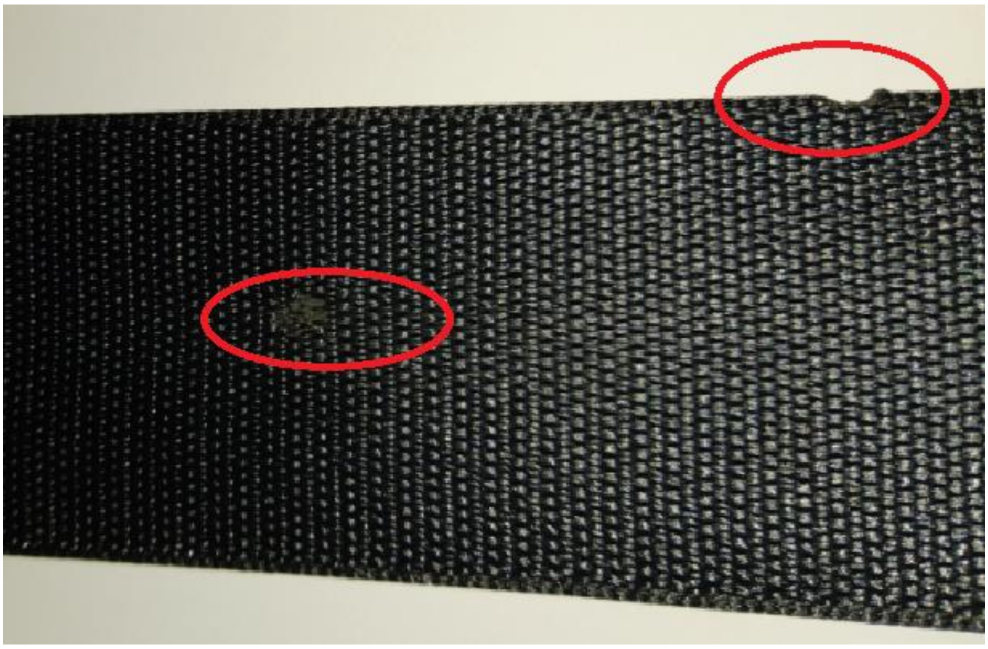


Figure 3.2. Webbing with burn marks

-cut webbing(Figure 3.3) : There are many cases in which someone accidentaly produced cuts on the setabelt webbing, by using a cutter to open a package in the vehicle, by example.

Figure 3.3 Webbing with marks after retention button was

In the study case, the same type and colour of webbing was used : the standard type, black. The study aims to identify the degradation degree and the danger at which the ocupants of the vehicle are exposing themselves and the actions that must be taken in these types of situations.

3.2 Reproducing the scratch defect on the webbing

The webing can be scratched because of various situations. For exaple , by transporting pets without a cage, or by exposing the webbing to a sharp object. The defect was reproduced through continous and fast passings of a sharp object on the surface without excerting too much pressure.

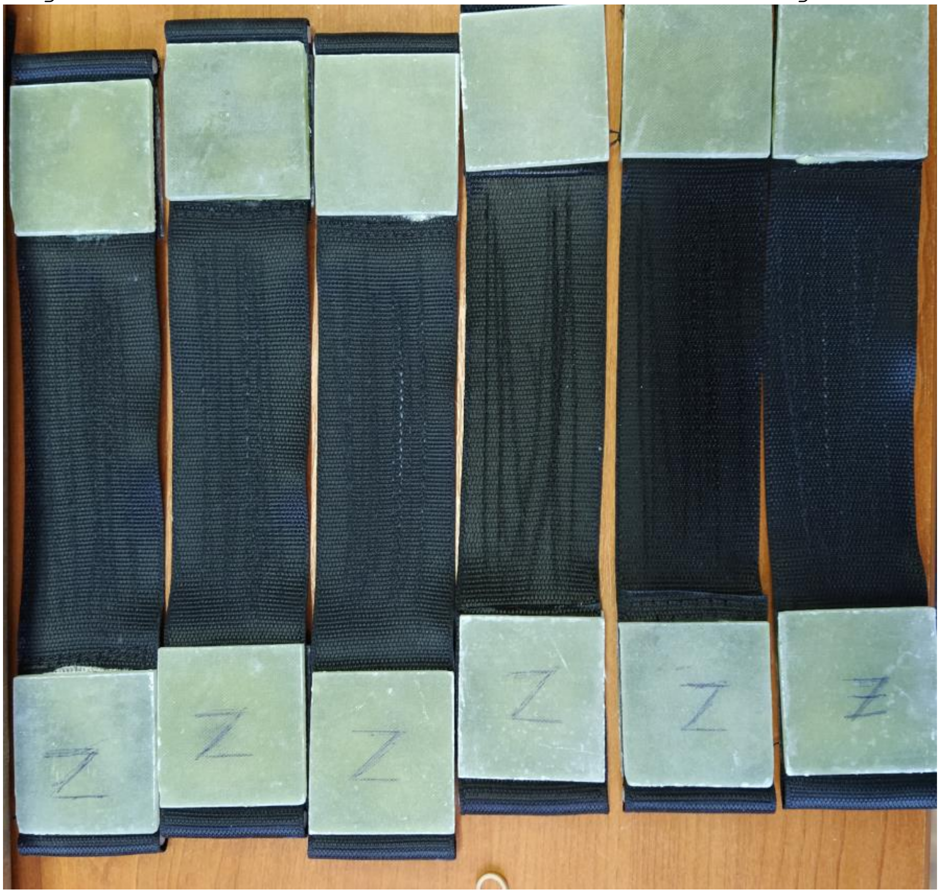


Figure 3.4. Webbing with scratch marks reproduced

Se poate observa ca există defecte vizibile pe chingă în ţesatură.

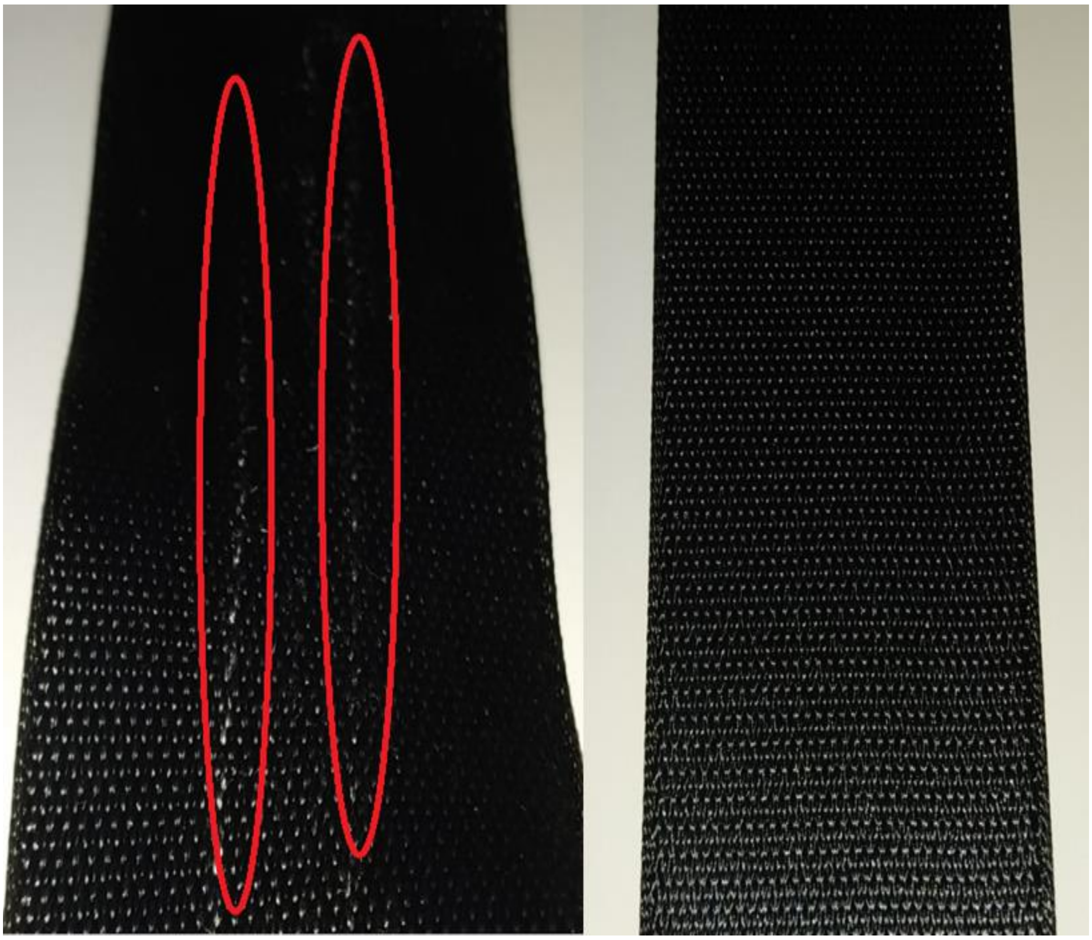


Figure 3.5.Webbing with scratch marks

Due to the fact that webbing has a soft surface as to not cause discomfort to its users it has a low roughness. When preparing the samples, it was discovered that it will be difficult to instal them in the equipment for testing whithout the risk of slipping. All samples were treated with a composite resing the strengthen and create a griping area.

3.3 Reproducing the burnt webbing defect

Altough the traffic laws state that ocupants of the vehicle are not allowed to smoke in a company issued car, this rule does not apply to the personal one. Often times , the cigarette or ash falls on the carpet or seatbelt. Even 10 seconds is enough to produce a visible mark on the fabric.

Reproducing this defect was done by exposing the material to a lit cigarette until it went out.A burn mark in the middle of the sample will not produce significant or visible damage but one located on the edge of the sample could lead to a decrease in performance.

Figure 3.6. Webbing with burn marks

3.4 Reproducing the cut defects on webbing

For this type of defect , small cuts were made on the edges of the samples. In day to day life these cuts could appear by handling sharp objects in the webbing area (using a cutter for opening a package).

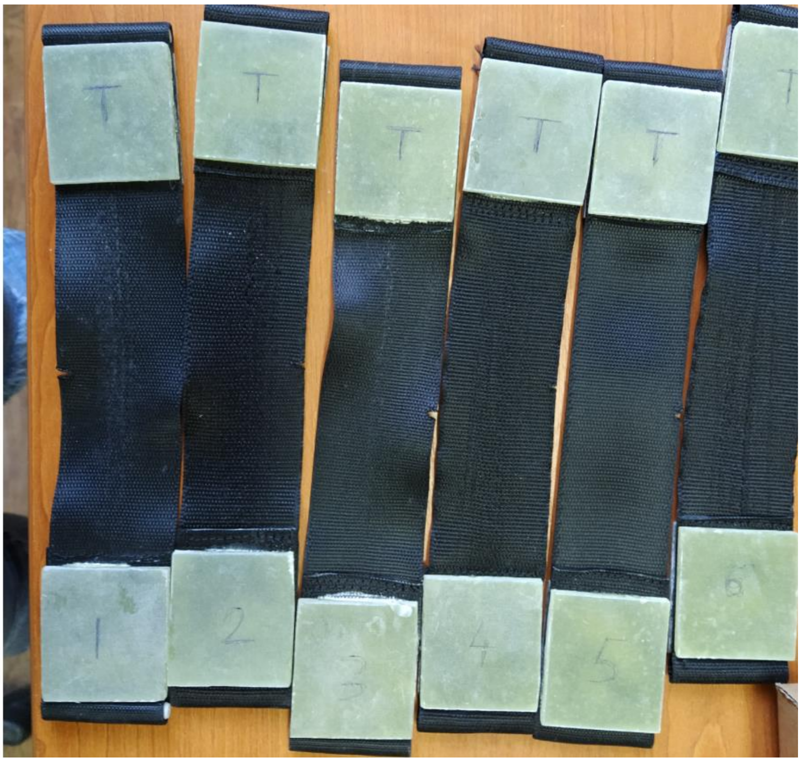


Figure 3.7. Webbing with cuts

3.5 Preparing the testing equipment

The LS100PLUS incorporates a vast area of function testing, it is ideal for complex tests and routine ones ofr up to 100 kN.

Characteristics :

- Easy to configure, operate and maintain ;
- High precision measurin ;
- Sampling data 8 kHz ;
- Control of speed load ;
- 600 result data upload ;
- 10 testing setups;
- Multiple stage testing with software NEXYGENPlus ;
- Extension resolution < 0,03 microns ;
- Results display in various languages ;
- Results display in various units of measurements ;
- Updated flash;
- A high variety of testing grips, levers, extensions;

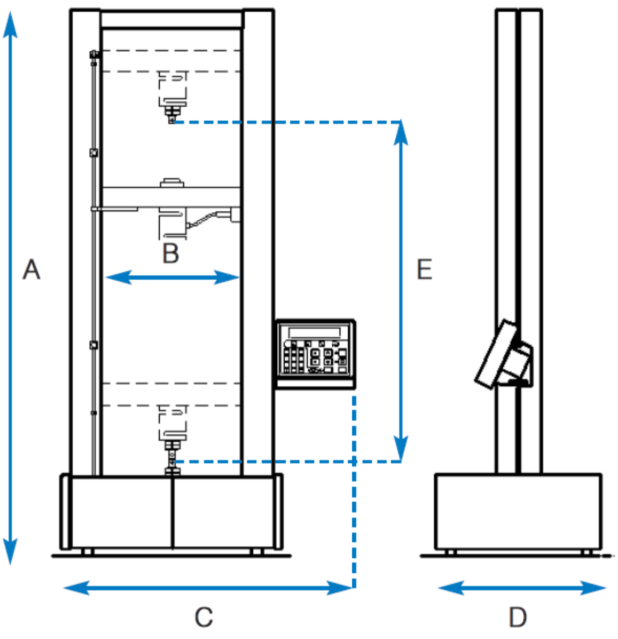


Figure 3.8. Testing equipment sketch

		mm
A	(Standard machine height)	1567
A	(Extended machine height)	1857
B		404
C		868
D		596
E	(Standard machine travel)	824
E	(Extended machine travel)	1012

Figue 3.9. Testing equipment LS100Plus

Chapter IV.

MODELISATION OF THE SEATBELT WEBBING LOADS

4.1. Introduction

Recent research, generated by multiple practical applications in engineering, where complex equipment is used in a difficult environment has lead to the development high deformable mechanical systems.Studies are lead to the multibodysystems with deformable elements. For this analisys , researchers have developed and reevaluated the existing methods in order to apply them to present situations.

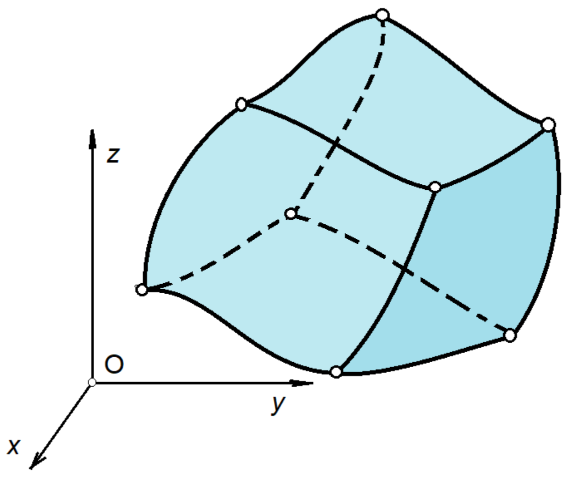
The development of this domainis based on finite element method FEM, used in analitical mechanics. This has the advantage of general methods, in which the procedures are applied in a certain whatever the situation. These methods can be used to construct algorithms.

The practical applications for solving specific problems were supported by theoretical papers which developed the basis of mathematics for numerical modelisation. The purpose of these papers is to offer methods for computer analisys of precis models in order to capture significat elements in the functioning of mechanical systems. Developing sucha algorithms allow to analise systems which can not be resolved using commercial softwares.

Researchers use three ways to approach such problems. The first of these approaches uses algorithms that involve successful simulations by establishing an interface between existing software. The second way implements algorithms aimed at studying multibody systems into existing finite element algorithms. The third way used is the finite element formulation applied directly to the model of the mechanical system with elastic elements, which requires a great effort to implement in computational algorithms [72-74]. Papers dealing with the integration of the equations of motion show results obtained to facilitate this step in [75]. Accurate modeling of such systems is an important contribution to the development of engineering computational methods, but the potential is low due to the numerical computation involved. Integrating the equations of motion of a complex multibody system is a time-consuming step. For example, simulating the behavior of a crankshaft interacting with surrounding elements requires a CPU processing time of several hours and makes a significant contribution to the total time required for such a calculation. Methods to improve this step are presented in [75]. A general integration procedure using symbolic calculus is presented in [76]. Comparison with other models used in the literature highlights the advantages of this approach.

4.2.Finite element analysis of a multibody system with elastic elements

The finite element method is an approximation method to determine the deformation field of an elastic elastic body. For this, the elastic body is discretized into independent bodies, linked together by nodes, which ensure the transmission of forces between elements. Each node is defined by parameters that represent the independent coordinates of the element. The principle of the method is the approximation of the displacement field of the element with known polynomial functions. Each type of finite element chosen for study is characterized by specific interpolation functions (shape functions). In this way, the displacement of each point belonging to the finite element is defined by the displacements or rotations of the nodes of the studied element. In this way, the differential equations of the mechanics of the continuous medium can be applied, considering the functions that determine the known displacements to be known analytical functions. For a single finite element, the evolution equations of the element can then be written, which are second-order differential equations with constant coefficients. To obtain these equations, established methods in Analytical Mechanics are used, such as, for example, the method of Lagrange's equations. The matrix coefficients of the resulting equations are determined by the shape functions chosen to define the finite element.



Figuea 4.1 Finite element

The equations are derived, for a finite element, generally in a local reference frame. The next step is to assemble all the equations of motion, written for each individual element, into a system of differential equations that characterizes the motion and deformations of the entire system. To achieve this, it is necessary to write all these equations of motion, each related to a local reference system, in a single global reference system. At this level, all the mentioned operations are well documented and verified by commercial software.

An important problem is to obtain the equations of motion for a single element using a method chosen in such a way that the number of operations required to solve the problem is minimal.

The study of this problem has been done for a long time, the research carried out being presented in a rich literature. The first researches dealt with mechanical elements in motion that can be discretized by one-dimensional finite elements, and the motion was considered planar [94-96].

Complex, two- and three-dimensional finite elements were studied and applied in [97]. Recently, analysis methods have been developed and more sophisticated models have been studied [98–103].

Lagrange's equations are the primary tool to obtain equations of motion for a finite element discretizing an MBS system, regardless of whether one-, two-, or three-dimensional finite elements are used, or the type of motion of the MBS system elements. This method has proven over time, very useful, relatively convenient to apply and verified by the countless applications studied with it. The major advantage is the use of notions with which researchers are very familiar. At the moment, in studies, Lagrange's equations are the most widely used method for studying such problems.

4.3 Kinematics and dynamics

The mobile reference system participates in the overall movement of the MBS system. For this element the angular velocity is known $\overline{\omega}$, angular acceleration $\bar{\varepsilon}$, velocity $\bar{v}_o$ and acceleration $\overline{a}_o$. We will use two indicators L (from local) and G (from global) will be used to designate the dimensions corresponding to the local/global coordinate system. The orthonormal operator [R] transforms the components from the local system to the global one, $\{a\}_G = [R]\{a\}_L$.

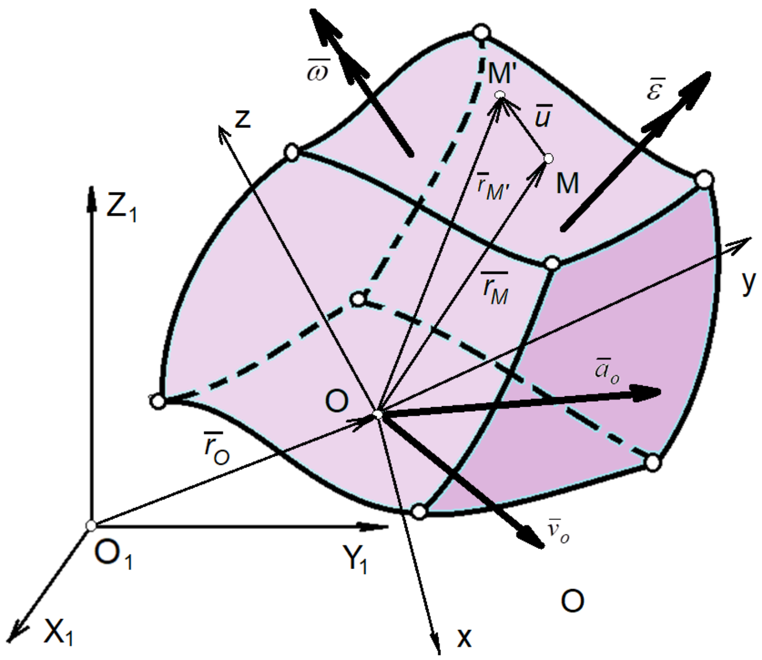


Figura 4.2

The following notations are considered :

$$[R]=\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix};\ \{r_O\}_G=\begin{Bmatrix}X_{O,1}\\ X_{O,2}\\ X_{O,3}\end{Bmatrix}\ ;\ \{r_M\}_G=\begin{Bmatrix}X_{M,1}\\ X_{M,2}\\ X_{M,3}\end{Bmatrix}\ ;$$

$$\{r_M\}_L=\begin{Bmatrix}x_{M,1}\\ x_{M,2}\\ x_{M,3}\end{Bmatrix};\ \{r_{M'}\}_G=\begin{Bmatrix}X_{M',1}\\ X_{M',2}\\ X_{M',3}\end{Bmatrix};\{r_{M'}\}_L=\begin{Bmatrix}x_{M',1}\\ x_{M',2}\\ x_{M',3}\end{Bmatrix}\ ;\ \{r\}_L=\begin{Bmatrix}x_1\\ x_2\\ x_3\end{Bmatrix};\ \{u\}_L=\begin{Bmatrix}u_1\\ u_2\\ u_3\end{Bmatrix}.$$

$$\{u\}_L=\begin{Bmatrix}u_1\\ u_2\\ u_3\end{Bmatrix}.$$

where $\{r_{M'}\}_G$ and $\{r_M\}_G$ represent the position vectors of point M, respectively M'; $\{u\}_L$ – is the displacement vector $\{r_O\}_G$ is the position vector of origin.

An arbitrary point M of the finite element becomes after deformation, point M'.Its coordinates are :

$$\{r_{M'}\}_G=\{r_O\}_G+[R](\{r\}_L+\{u\}_L). \qquad (1)$$

The conection between the independent displacement of a knot and displacement of a current point is defined in FEA by :

$$\{u\}=[N]\{\delta\} \qquad (2)$$

where:

$$\{\delta\} = \{\delta\}_L = \begin{Bmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \\ \delta_p \end{Bmatrix}$$

is the vector for independent coordinates and δ_1, δ_2, …. , δ_p are the independent coordinates. The position of M′ is, considering equation 2):

$$\{r_{M'}\}_G = \{r_O\}_G + [R]\{r\}_L + [R][N]\{\delta\} \tag{3}$$

The components of the velocity vector of M′ are :

$$\{v_{M'}\}_G = \{\dot{r}_{M'}\}_G = \{\dot{r}_O\}_G + [\dot{R}]\{r\}_L + [\dot{R}][N]\{\delta\} + [R][N]\{\dot{\delta}\}. \tag{4}$$

And acceleration:

$$\{a_{M'}\}_G = \{\ddot{r}_O\}_G + [\ddot{R}]\{r\}_L + [\ddot{R}][N]\{\delta\} + 2[\dot{R}][N]\{\dot{\delta}\} + [R][N]\{\ddot{\delta}\}. \tag{5}$$

If there is a need to express velocity in local coordinate system:

$$\{v_{M'}\}_L = [R]^T\{v_{M'}\}_G = \{\dot{r}_O\}_L + [R]^T[R]\{r\}_L + [R]^T[RT][N]\{\delta\}_L + [N]\{\dot{\delta}\}_L =$$

$$= \begin{bmatrix} E & [ROT]^T[R\dot{O}T] & [ROT]^T[R\dot{O}T][N] & [N] \end{bmatrix} \begin{Bmatrix} \{\dot{r}_O\}_L \\ \{r\}_L \\ \{\delta\}_L \\ \{\dot{\delta}\}_L \end{Bmatrix}. \tag{5}$$

$$\{a_{M'}\}_L = [ROT]^T\{a_{M'}\}_G = \{\ddot{r}_O\}_L + [ROT]^T[R\ddot{O}T]\{r\}_L + [ROT]^T[R\ddot{O}T][N]\{\delta\}_L + 2[ROT]^T[R\dot{O}T][N]\{\dot{\delta}\}_L + [N]\{\ddot{\delta}\}_L$$

$$= \begin{bmatrix} E & [ROT]^T[R\ddot{O}T] & +[ROT]^T[R\ddot{O}T][N] & 2[ROT]^T[R\dot{O}T][N] & [N] \end{bmatrix} \begin{Bmatrix} \{\ddot{r}_O\}_L \\ \{r\}_L \\ \{\delta\}_L \\ \{\dot{\delta}\}_L \\ \{\ddot{\delta}\}_L \end{Bmatrix} = . \tag{6}$$

The kinetic energy is expressed:

$$E_c = \frac{1}{2}\int_V \rho \{v_{M'}\}_G^T \{v_{M'}\}_G dV = . \tag{7}$$

Taking into account equation 5), the equation for kinetic energy is obtained::

$$E_c =$$

$$= \begin{bmatrix} \{\dot{r}_O\}_L & \{r\}_L & \{\delta\}_L & \{\dot{\delta}\}_L \end{bmatrix} \begin{bmatrix} E & [ROT]^T[R\dot{O}T] & [ROT]^T[R\dot{O}T][N] & [N] \\ [R\dot{O}T]^T[ROT] & [R\dot{O}T]^T[R\dot{O}T] & [R\dot{O}T]^T[R\dot{O}T] & [R\dot{O}T]^T[ROT][N] \\ [N]^T[R\dot{O}T]^T[ROT] & [N]^T[R\dot{O}T]^T[R\dot{O}T] & [N]^T[R\dot{O}T]^T[R\dot{O}T] & [N]^T[R\dot{O}T]^T[ROT][N] \\ [N]^T & [N]^T[ROT]^T[R\dot{O}T] & [N]^T[ROT]^T[R\dot{O}T][N] & [N]^T[N] \end{bmatrix} \begin{Bmatrix} \{\dot{r}_O\}_L \\ \{r\}_L \\ \{\delta\}_L \\ \{\dot{\delta}\}_L \end{Bmatrix} \tag{8}$$

It is noted:

$$[m]=\int_V \rho[N]^T[N]dV \text{ ;} \tag{9}$$

$$\left[m_O^i\right]=\int_V \rho[N]^T dV \text{ ;} \quad \left\{q^i(\varepsilon)\right\}_L=\int_V \rho[N]^T[\varepsilon]_L\{r\}_L dV \text{ ;} \tag{10}$$

$$\left\{q^i(\omega)\right\}_L=\int_V \rho[N]^T[\omega]_L[\omega]_L\{r\}_L dV \text{ ;} \tag{11}$$

$$[k(\varepsilon)]=\int_V \rho[N]^T[\varepsilon][N]dV \text{ ;} \tag{12}$$

$$[k(\varepsilon)]=\int_V \rho[N]^T[\omega]_L[\omega]_L[N]dV \text{ ;} \tag{13}$$

$$[c]=\int_V \rho[N]^T[\omega]_L[N]dV \text{ ;} \tag{14}$$

$$\{m_{ix}\}=\int_V \rho\left[S_{(i)}\right]^T xdV \quad ; \quad \{m_{iy}\}=\int_V \rho\left[N_{(i)}\right]^T ydV \quad ; \quad \{m_{iz}\}=\int_V \rho\left[N_{(i)}\right]^T zdV \text{ .} \tag{15}$$

The classic equation for the internal (potential) energy is:

$$E_p=\frac{1}{2}\int_V \{\sigma\}^T\{\varepsilon\}dV=\frac{1}{2}\int_V \sigma_{ij}\varepsilon_{ij}dV \text{ ,} \tag{16}$$

where $\{\varepsilon\}$ is the specific deformation vector and $\{\sigma\}$ is the load vector. Hook’s generalized law is:

$$\{\sigma\}=[H]\{\varepsilon\} \text{ .} \tag{17}$$

The specific deformation can be expressed:

$$\{\varepsilon\}=[b]\{u\}=[b][N]\{d\} \text{ .} \tag{18}$$

Using equations(17-18)the following are obtained:

$$E_p=\frac{1}{2}\{\delta\}_L^T\left(\int_V [N]^T[b]^T[H]^T[b][N]dV\right)\{\delta\}_L \text{ .} \tag{19}$$

Matrix $[k]$ is the rigidity matrix:

$$[k]=\int_V [N]^T[b]^T[H]^T[b][N]dV \text{ .} \tag{20}$$

Equations (19)is:

$$E_p=\frac{1}{2}\int_V \{\delta\}_L^T[k]\{\delta\}dV \text{ .} \tag{21}$$

The concentrated forces$\{q\}_{L_C}$ and volume forces:

$$W^c=\{q\}_L^T\{\delta\}_L \text{ ,} \tag{22}$$

and:

$$W = \int_V \{p\}_L^T \{f\}_L dV = \left(\int_V \{p\}_L^T [N] dV\right)\{\delta\}_L = \{q^*\}_L^T \{\delta\}_L \ . \tag{23}$$

The Lagrangian expression is [119]:

$$L = E_c - E_p + W + W^c \ , \tag{24}$$

Using equation (19-21) the Lagrangian has the following equation:

$$L = E_c - \frac{1}{2}\int_V \{\delta\}_L^T [k]\{\delta\}_L dV + \{q^*\}_L^T \{\delta\}_L + \{q\}_L^T \{\delta\}_L \ . \tag{25}$$

The momentum for the element is:

$$\begin{aligned}\{p\}_G &= \int_V \rho \{v_{M'}\}_G dV \\ &= \int_V \rho\left(\{\dot{r}_O\}_G + [R\dot{O}T]\{r\}_L + [R\dot{O}T][N]\{\delta\}_L + [ROT][N]\{\dot{\delta}\}_L\right) dV \\ &= m\{\dot{r}_O\}_G + [R\dot{O}T]\{\bar{S}\}_L + [R\dot{O}T]\left(\int_V \rho[N]dV\right)\{\delta\}_L + [ROT]\left(\int_V \rho[N]dV\right)\{\dot{\delta}\}_L \\ &= m\{\dot{r}_O\}_G + m[\dot{R}]\{\bar{r}_C\}_L + [\dot{R}][m_O^i]\{\delta\}_L + [R][m_O^i]\{\dot{\delta}\}_L\end{aligned} \tag{26}$$

Notation $m = \int_V \rho dV$ is the total mass of the finite element, $\{\bar{S}\}_L$ static moment and $[m_O^i] = \int_V \rho[N]dV$ the inertia matrix of the element(see Eq. (11)).

In local coordinate system there is the expression:

$$\begin{aligned}\{p\}_L &= [ROT]^T \{p\}_G = \\ &= m\{\dot{r}_O\}_L + m[ROT]^T [R\dot{O}T]\{\bar{r}_C\}_L + [ROT]^T [R\dot{O}T][m_O^i]\{\delta\}_L + [m_O^i]\{\dot{\delta}\}_L \ .\end{aligned} \tag{27}$$

The following can be computed:

$$\{p\}_L = \left\{\frac{\partial L}{\partial \{\dot{d}\}_L}\right\} . \tag{28}$$

The vectors for velocity can be obtained: $\{\dot{\delta}\}_L$

$$\{\dot{\delta}\}_L = [m_O^i]^{-1}\left(\{p\}_L - m\{\dot{r}_O\}_L - m[ROT]^T [R\dot{O}T]\{\bar{r}_C\}_L - [ROT]^T [R\dot{O}T][m_O^i]\{\delta\}_L\right) . \qquad 29)$$

Using anterior notes the Hamiltonian becomes:

$$H = \left\{\frac{\partial L}{\partial \{\dot{\delta}\}_L}\right\}^T \{\dot{\delta}\}_L - L = \{p\}^T [m_O^i]^{-1}\left(\{p\}_L - m\{\dot{r}_O\}_L - m[ROT]^T [R\dot{O}T]\{\bar{r}_C\}_L - [ROT]^T [R\dot{O}T][m_O^i]\{\delta\}_L\right) - L \ . \tag{30}$$

Where Lagrangian was used in Ec.(25).

4.4. Analytical method of FEA in MBS

4.4.1. Lagrange equations

Classic Lagrange equations are :

$$\frac{d}{dt}\left\{\frac{\partial L}{\partial \dot{\delta}}\right\}_L - \left\{\frac{\partial L}{\partial \delta}\right\}_L = 0 \quad . \tag{34}$$

Through $\left\{\frac{\partial E}{\partial X}\right\}$ it is noted:

$$\left\{\frac{\partial E}{\partial X}\right\} = \begin{Bmatrix} \frac{\partial E}{\partial x_1} \\ \frac{\partial E}{\partial x_2} \\ \vdots \\ \frac{\partial E}{\partial x_n} \end{Bmatrix} \quad \text{și :} \quad \{X\} = \begin{Bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{Bmatrix} . \tag{35}$$

Using the Lagrangian obtained in ec(25), the following is obtained:

$$[m]\{\ddot{\delta}\}_L + [c]\{\dot{\delta}\}_L + ([k]+[k(\varepsilon)]+[k(\omega)])\{\delta\}_L = \{q\}_L + \{q^*\}_L - \{q^i(\varepsilon)\}_L - \{q^i(\omega)\}_L - [m_O^i]\{\ddot{r}_O\}_L \ . \tag{36}$$

4.4.2 Gibbs-Appell Equations

The Gibbs-Appell equation is an alternative to Lagrange's equations. To use them, it is necessary to know the energy of the accelerations, obtained in Eq. (30). The Gibbs-Appell equations are [82]:

$$\frac{\partial E_a}{\partial \ddot{q}_j} = Q_j \quad j = \overline{1,n} \ . \tag{37}$$

Equations (30) have, in their component, the following terms:

E_{a2} containing the quadratic terms in the accelerations:

$$E_{a2} = \frac{1}{2}\int_V \rho\left(\{\ddot{\delta}\}_L^T [N]^T [N]\{\ddot{\delta}\}_L\right) dV \ ; \tag{38}$$

E_{a1} containing the linear terms in the accelerations:

$$E_{a1} = \int_V \rho\Big(\{\ddot{\delta}\}_L^T [N]^T [ROT]^T \{\ddot{r}_O\} + \{\ddot{\delta}\}_L^T [N]^T [ROT]^T \left[R\ddot{O}T\right]\{r\}_L + \{\ddot{\delta}\}_L^T [N]^T [ROT]^T \left[R\ddot{O}T\right][N]\{d\}_L + 2\{\ddot{\delta}\}_L^T [N]^T [ROT]^T [R$$

Equations (37) can be written, if the previous notations are taken into account:

$$\left\{\frac{\partial E_a}{\partial \ddot{d}}\right\}_L - \{Q\}_L = 0 \ ; \tag{40}$$

E_a is:

$$E_a = E_{ao}(\dot{q}) + E_{a1}(\dot{q},\ddot{q}) + E_{a2}(\ddot{q}) \ ; \tag{41}$$

and:

$$\{Q\}_L = [k]\{\delta\}_L + \{q\}_L + \{q^*\}_L \; ; \tag{42}$$

If we differentiate, we get:

$$\frac{\partial E_{a2}}{\partial\{\ddot{d}\}_L} = \left(\int_V \rho[N]^T[S]dV\right)\{\ddot{d}\}_L = [m]\{\ddot{d}\}_L \; ; \tag{43}$$

$$\frac{\partial E_{a1}}{\partial\{\ddot{d}\}_L} = -\left[m_O^i\right]\{\ddot{r}_O\}_L - \left\{q^i(\omega)\right\} - \left\{q^i(\varepsilon)\right\} + \left([k(\omega)] + [k(\varepsilon)]\right)\{d\}_L + [c]\{\dot{d}\}_L \; ; \tag{44}$$

$$\frac{\partial E_{a0}}{\partial\{\ddot{d}\}_L} = 0 \; . \tag{45}$$

Compared to Lagrange's method, this method requires a smaller number of differentiations. In this way the number of calculations decreases, so the time required to solve such problems. If it is taken into account that finite element models involve a large number of degrees of freedom, therefore a large number of calculations, reducing the number of operations offered by this method can lead to significant savings in computer time.

4.4.3 Hamilton equations method

The use of the Lagrange formalism leads to a system of second-order differential equations. Technically, solving this second-order system of equations is done by transforming it into a two-dimensional first-order system of differential equations. Hamiltonian mechanics uses 2n unknowns, and the resulting system of differential equations is from the start a system of first-order differential equations of size 2n. The unknowns are the generalized coordinates and the canonical conjugate moment:

$$\{p\}_L = -\left\{\frac{\partial L}{\partial\{\delta\}_L}\right\} \; . \tag{46}$$

So the main difference between Lagrange's method and Hamilton's method is the use of the imposed instead of the generalized velocities. The major advantage of applying the method could be precisely to directly obtain a system of first-order equations, which can be solved directly, using the usual commercial software.

Hamilton's equations are a system of first-order differential equations [80].

$$\{\dot{\delta}\}_L = \left\{\frac{\partial H}{\partial\{p\}_L}\right\} \quad ; \quad \{\dot{p}\}_L = -\left\{\frac{\partial H}{\partial\{\delta\}_L}\right\} \; . \tag{47}$$

FRom equations(27)-(29)it results:

$$\{\dot{\delta}\}_L = \left[m_O^i\right]^{-1}\left(\{p\}_L - m\{\dot{r}_O\}_L - m[ROT]^T\left[R\dot{O}T\right]\{\bar{r}_C\}_L - [ROT]^T\left[R\dot{O}T\right]\left[m_O^i\right]\{\delta\}_L\right);$$

$$\{\dot{p}\}_L = \{p\}^T\left[m_O^i\right]^{-1}[ROT]^T\left[R\dot{O}T\right]\left[m_O^i\right] + \int_V \rho\left(\{\dot{r}_O\}_L^T[ROT]^T\left[R\dot{O}T\right][N]\right)dV$$

$$+\int_V \rho\left(\{r\}_L^T\left[R\dot{O}T\right]^T\left[R\dot{O}T\right][S]\right)dV+\int_V \rho\left([N]^T\left[R\dot{O}T\right]^T\left[R\dot{O}T\right][N]\{\delta\}_L+[N]^T\left[R\dot{O}T\right]^T[ROT][N]\{\delta\}_L\right)dV$$

$$-\int_V [k]\{d\}_L\,dV+\{q^*\}_L^T+\{q\}_L^T$$

These represent the equations of motion sought.

The main advantage of Hamilton's method is that it gives us a system of first-order differential equations. But in which the number of unknowns to find is double. In the case of using other methods, the obtained differential equations are of the second order. Solving techniques require transforming them into first-order differential systems by introducing new variables. In the case of Hamilton's method, these new variables are obtained directly and have physical meaning.

4.4.4 Maggi equations

Se consideră un sistem mecanic cu coordonatele q1, q2,… , qn legate între ele prin m relaţii lineare:

$$\sum_{k=1}^{n} a_{kj}\left[\left(\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{q}_k}\right)-\frac{\partial E_c}{\partial q_k}\right)-Q_k\right]=0 \quad ; \quad j=\overline{1,n-m} \tag{49}$$

,

Considering d'Alembert-Lagrange equations:

$$\sum_{i=1}^{N}\left(\overline{F}_i-m_i\overline{a}_i\right)\delta\overline{r}_i=0 \quad , \tag{50}$$

The use of these equations becomes simpler for the analysis of a mechanical system, from the point of view of formal description. In this case, only the kinetic energy is needed to obtain the equations of motion. The kinematic connections that exist between the elements offer the possibility to eliminate the connection forces from the equations and thus the calculation can be simplified.

4.5. Conclusions

The most important step in the dynamic analysis of a multibody system with elastic elements is the writing of the evolution equations for the system. The next steps that follow, namely, assembling the equations of motion and solving them, will be done according to the classical methods used in commercial finite element method software. Obtaining the equations is therefore the most difficult problem to solve, considering the multitude of terms that appear in such a description. As a result, finding a formalism that makes it possible to write these equations as easily as possible is an important step in this analysis. The method used almost exclusively in this type of analysis, until now, has been the method of Lagrange's equations. This is primarily due to the fact that researchers are very familiar with this method and use fundamental notions currently frequently used by researchers (kinetic energy, potential, mechanical work, ...). But Analytical Mechanics offers several formulations, equivalent to each other and equivalent to Lagrange's equations. Gibbs-Appell equations, Hamilton equations, Maggi's equations, Jacobi's equations and other equivalent forms can be used in this way.

Maggi's method also has the advantages of simplicity in approaching problems, being essentially equivalent to the Gibbs-Appell method. The method of Hamilton's equations turns out to be the least profitable for the type of problems studied, in general, the time required to obtain the equations is not economical and the complexity of the intermediate calculations is high. However, we do not deny that this approach could prove useful in certain applications because the system of differential equations obtained is of first order and thus avoids a calculation step, used in the classical solution of these systems, where the systems of equations obtained are differential by second order.

If taken all these considerations into account it can be assumed that alternative and equivalent methods developed in analytical mechanics (and which, for now, do not seem to have practical applicability) will be re-evaluated and developed, due to more faithful modeling.

Chapter V

EXPERIMENTAL TRIAL RESULTS

The description of the equipment used in the trial and the preparation method of the samples was described in Chapter 3. In the first phase it was observed that the samples could not be correctly placed in the machine grips because the webbing samples would slip and the results were inconclusive so the samples had to be altered. The webbing ends were treated with a polimer resin to have adherence to the equipment grips.

5.1 Tensile strength results for new state webbing samples

In Table 1 are presented the datas and results for the trial of the control samples.

Table 1. Dimensions and trial conditions for new state webbing

Sample	Acceleration (mm/min)	Width (mm)	Thickness (mm)	Section (mm^2)	Maximum tensile srength(kN)	Tension at maximum load (MPa)	Elongation (mm)
1	100	47	1,5	70,5	19,101	270,948	73,08
2	100	47	1,5	70,5	17,148	243,240	62,95
3	100	47	1,5	70,5	18,581	263,567	84,13
4	100	47	1,5	70,5	19,884	282,046	69,85
5	100	47	1,5	70,5	17,540	248,797	62,90
6	100	47	1,5	70,5	15,798	224,085	55,50

The smallest value obtained was 15,798 kN and the highest was 19,884. Next will be presented the diagrams for strength vs elongation for the trials.

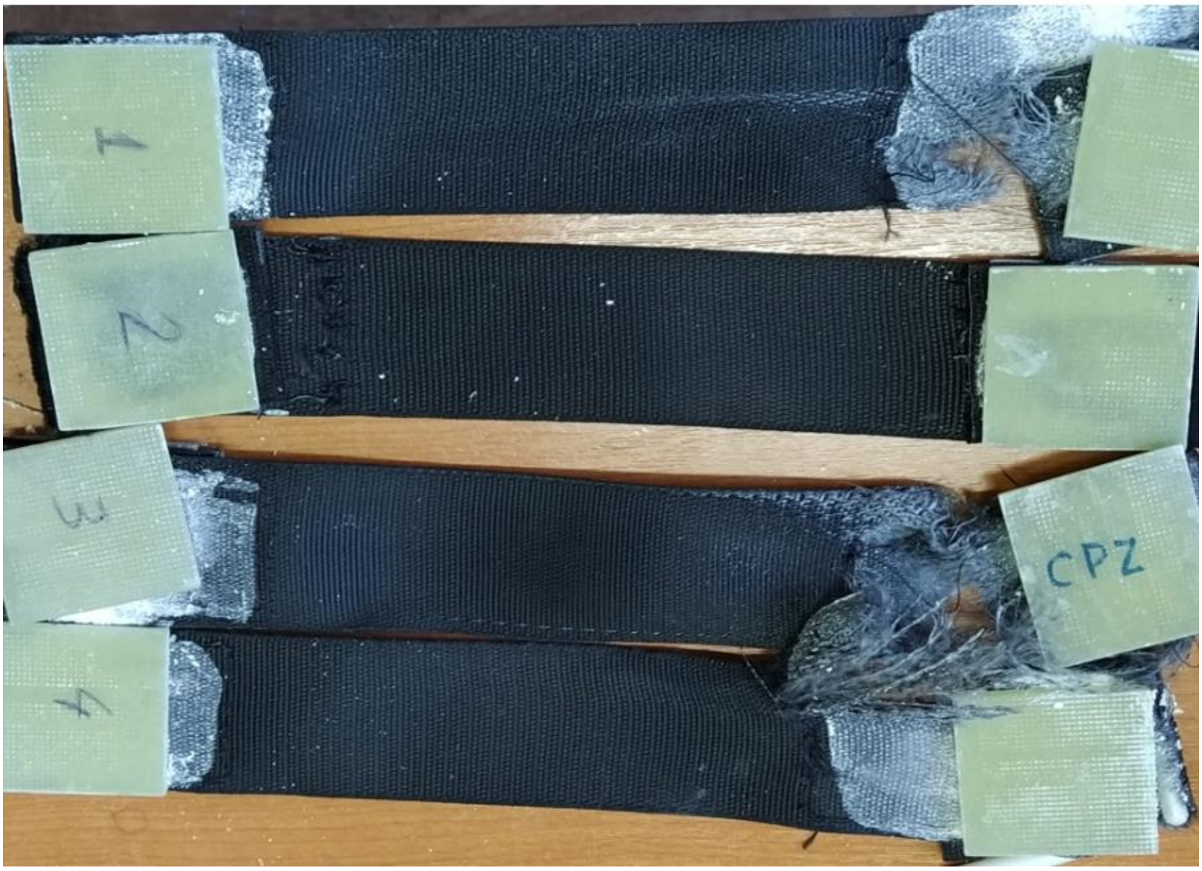


Figure 5.7 Samples after testing

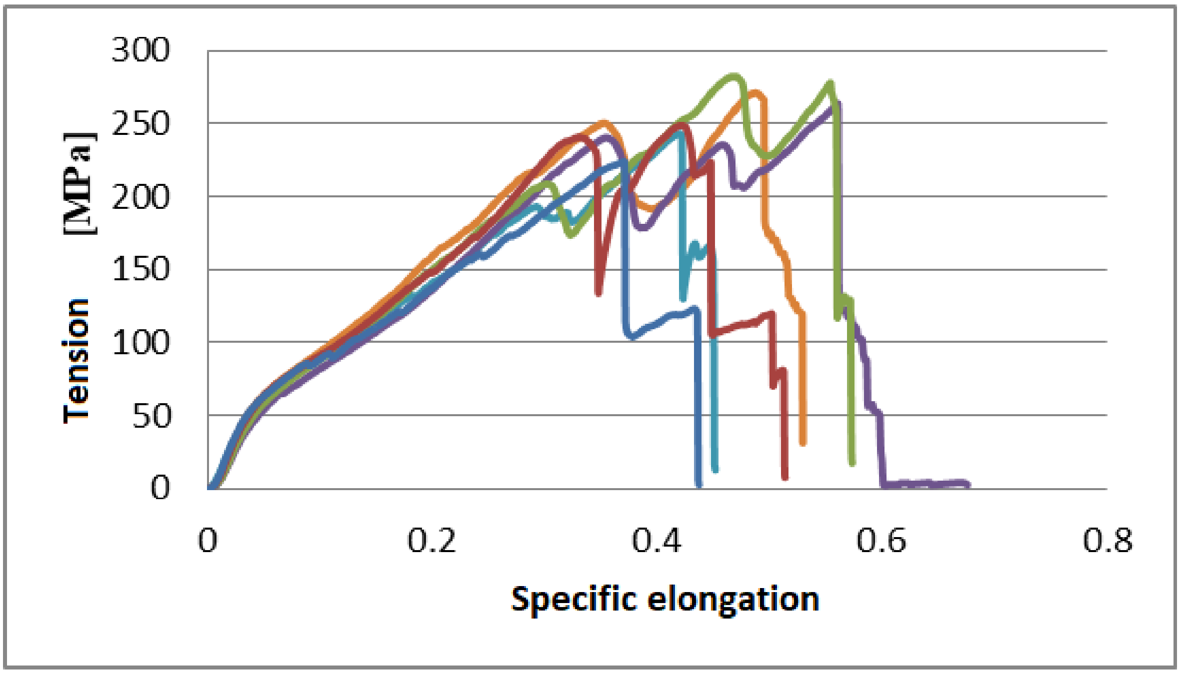


Figura 5.8 Multiload of tensile strength of new state webbing

5.2 Tensile strength reults for burnt webbing

In Table 2 is the data for the webbing samples with burn defects.

Tablw 2. Dimensions and trial conditions for burnt webbing

Sample	Acceleration (mm/min)	Width (mm)	Thickness (mm)	Section (mm^2)	Maximum tensile srength(kN)	Tension at maximum load (MPa)	Elongation (mm)
1	100	47	1,5	70,5	17,875	253,555	64,73
2	100	47	1,5	70,5	19,147	271,599	66,24
3	100	47	1,5	70,5	19,460	276,032	86,61
4	100	47	1,5	70,5	18,836	267,185	70,62
5	100	47	1,5	70,5	10,577	150,033	46,37
6	100	47	1,5	70,5	18,756	266,055	67,60

The lowest value obtained was 10,557 kN and the highest was 19,460 kN .

Sample 5 had an abnormal behavior compared to the rest and was removed from the data used .(see Fig.5.14)

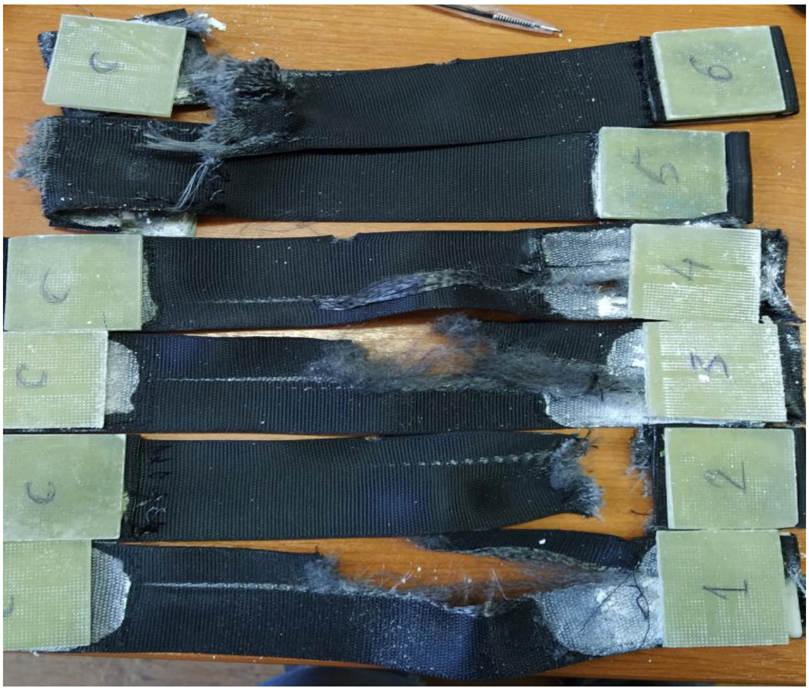


Figure 5.14 Burnt webbing samples after testing

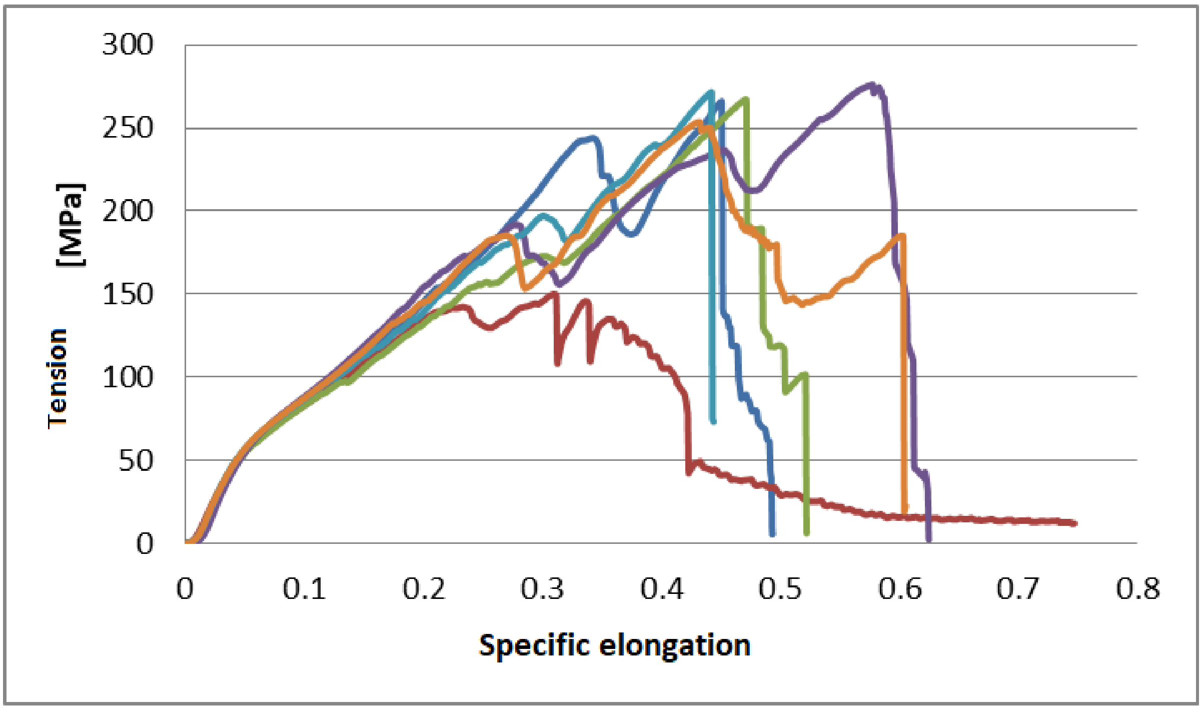


Figura 5.15 Multiload tensile strength for burnt webbing

5.3 Tensile strength results for webbing with cuts

In Table 3 are presented the datas used and some results from the trial.

Table 3. Dimensions, trial conditions and results for cut webbing

Sample	Acceleration (mm/min)	Width (mm)	Thickness (mm)	Section (mm²)	Maximum tensile srength (kN)	Tension at maximum load (MPa)	Elongation (mm)
1	100	47	1,5	70,5	13,913	197,359	61,64
2	100	47	1,5	70,5	16,934	240,205	52,40
3	100	47	1,5	70,5	14,864	210,842	62,58
4	100	47	1,5	70,5	14,750	209,230	50,07
5	100	47	1,5	70,5	18,346	260,231	51,72
6	100	47	1,5	70,5	13,267	188,190	55,59

The lowest values obtained was 13,127 kN and the highest 18,346 kN.

Figure 5.22 Samples after testing for cut webbing

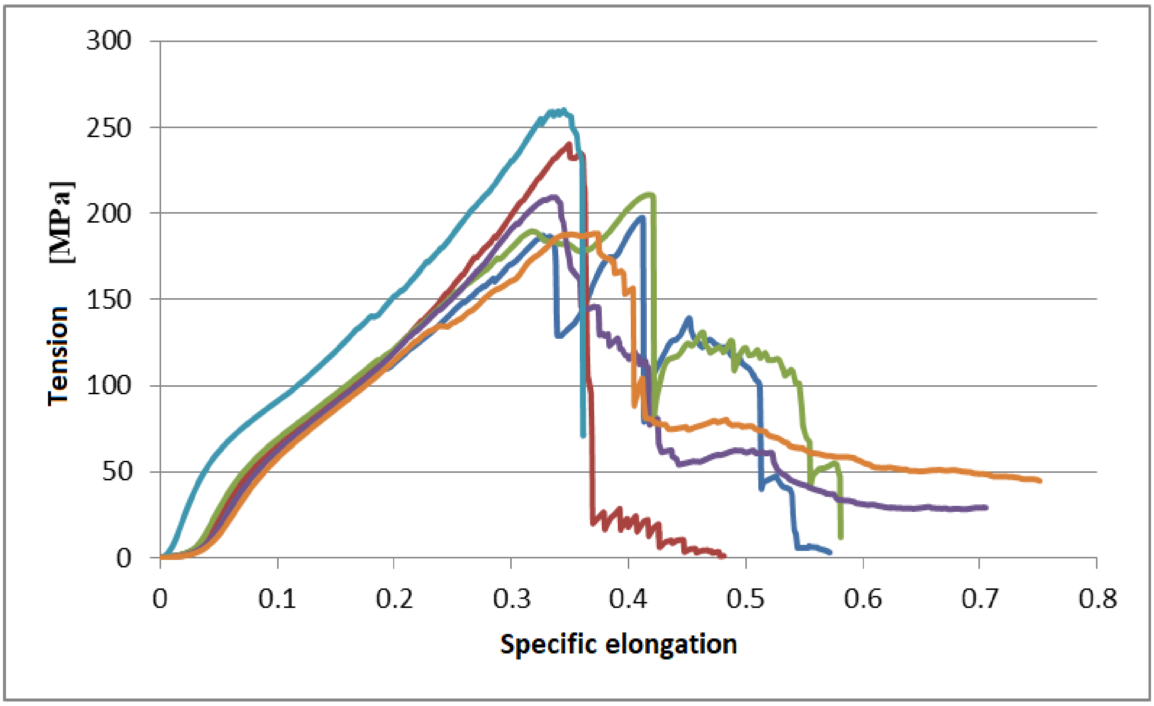


Figure 5.23 Multiload for tensile strength for cut webbing

5.4 Tensile strength results for scratched webbing

Tabelul 4. Dimensions and results for scratched webbing

Sample	Acceleration (mm/min)	Width (mm)	Thickness (mm)	Section (mm²)	Maximum tensile srength (kN)	Tension at maximum load (MPa)	Elongation (mm)
1	100	47	1,5	70,5	16,553	234,796	64,95
2	100	47	1,5	70,5	19,490	276,461	83,41
3	100	47	1,5	70,5	15,158	215,017	69,03
4	100	47	1,5	70,5	19,385	274,967	89,55
5	100	47	1,5	70,5	15,361	217,889	61,86
6	100	47	1,5	70,5	19,381	274,917	90,56

The lowest value obtained was 15,158 kN and the highest was 19,490 kN.

Figure 5.31. Samples after testing for scratched webbing

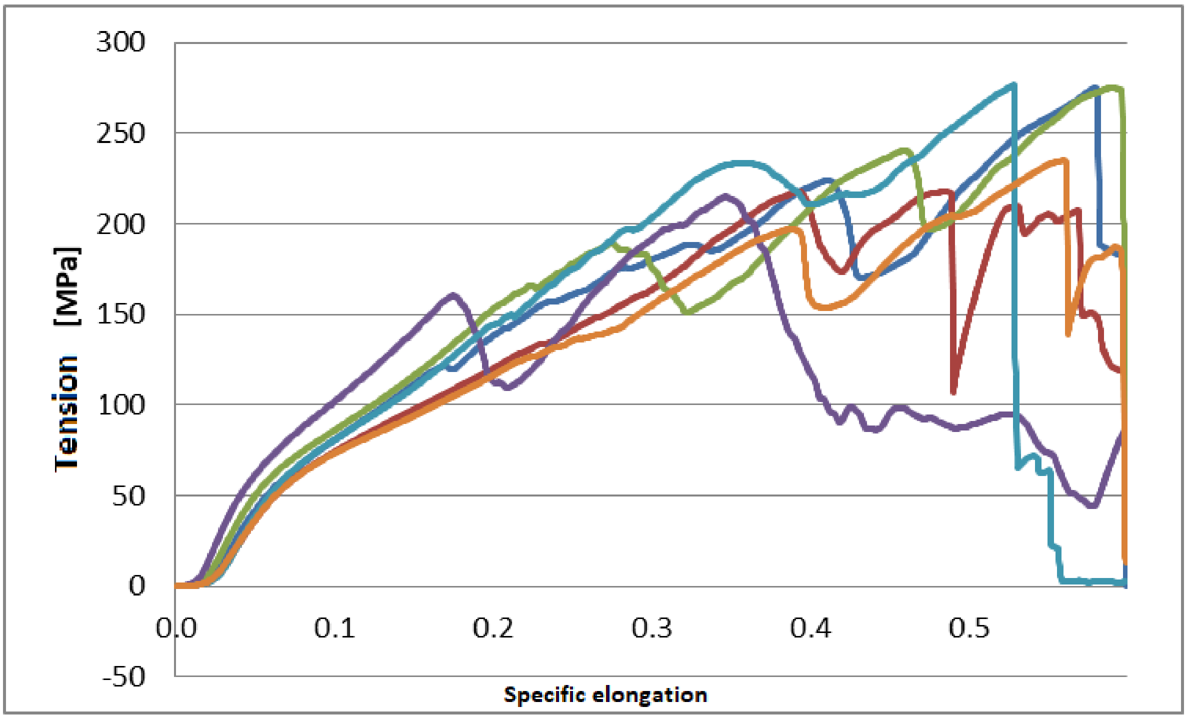


Figure 5.32 Multiload tensile strength results for scratched webbing

Chapter VI

WEBBING SOLICITATIONS IN THE SAFETY BELT

6.1. Introduction

Today, passenger safety is essential in the vehicle manufacturing industry. The automotive industry recognizes the importance of passenger safety and is constantly upgrading its offers to provide safety technologies to protect passengers and pedestrians. In this direction, passive safety systems play an important role in limiting the damage/injury to the driver, passengers and pedestrians in the event of an accident. Airbags (front, dual front, side), anti-lock braking systems (ABS), traction control, electronic stability control (ESC), seat belts, crash protection system, etc. are common passive safety systems installed in vehicles today. This chapter will analyze the effects of shocks occurring on a dummy in the case of a vehicle (a racing car) undergoing a frontal collision equipped with a crash protection system and a seat belt.

The findings of post-accident inspections of seat belt systems are extremely important for evaluating seat belt performance. Based on these, the paper provides solutions for current and future design improvements. Belt material is M19_fabri, with Young's modules $E_{11} = E_{22}$ = 2.500MPa; Poisson ratio ν = 0,2; bending modulus G = 1040 MPa; density ρ = 1000 kg/m^3.

In [128] a solution to improve the mechanical properties of the belt by optimizing the webbing topology is presented. This reduced the maximum deflection of the damper width by 36.7% and reduced the maximum tension by 17.6%. In this way, a significant increase in the mechanical performance of the belt was achieved.

Various aspects of the construction and operation of seat belts are presented in [129-131]. Experimental studies were presented in [132-134] and other aspects are presented in [135,136].

In the presented context, passenger safety in the event of a frontal collision is an important objective for the automotive industry. The paper studies the stresses that occur in a vehicle's seat belt and the accelerations that occur at different points of a dummy, in the case of a frontal collision of a vehicle. Modeling is done for the specific case of a racing car.

The purpose of the study is to determine the loads to which the driver is subjected, in the first part of the interval following a frontal collision. For this, a FEM model of the entire vehicle system, driver, seat belt is done. The application is made for a real racing car, used by Transilvania University in some student car competitions. The airbag is not taken into account in this case. The obtained results open a wide research horizon, since the behavior of the system is influenced by many factors, and the current descriptions are still insufficient. The mechanical response of the system is studied in this very short time frame after the collision to see if the system can provide a minimum safety in a race. In the case of this chapter, a convenient mathematical model is presented using the Gibbs-Appell method, in order to quickly determine the demands that appear in the system and which will then be used in the FEM model [104-109,119-121,156,157]. The modeling of a real racing car, used in student competitions, allows to obtain some results presented in the paper. Obviously, many problems remain open for further studies, such as the study of a four-point seat belt or the study of the biological effects of acceleration sustained by the driver or passenger.

6.2. Numerical model of a race vehicle

In this moment the automotive industry has developed a system for protecting the driver and pasengers as much as possible, but for experiments we do not have a real human body. In time, an evolution of testing dummies took place , creating models very similar to the human body.
The main disadvantage is that although they are very precise from the kimetics and values point of view, it is difficult to asses the real effects with possible consequences. For this, dummies with improved biofdelity and higher posibility for measurements were created.There are special dummies for types of crashes. There are manequins created for men, women children. Most reasearch uses the standard adult dummy, of average height and weight. The MEF model used is presented in Figure 6.1. The odel contains the kart structure with a shock absorber and a crash dummy secured with a 3 point safety belt. The role of the shock absorber is to diminish the impact energy transmited to the manequin after a full wall crash .
The FEA model is a type FE Hybrid III 50th Male, representing the average adult, the most used crash dummy in testing for evaluating the retaining systemsin automotive passive safety[161].

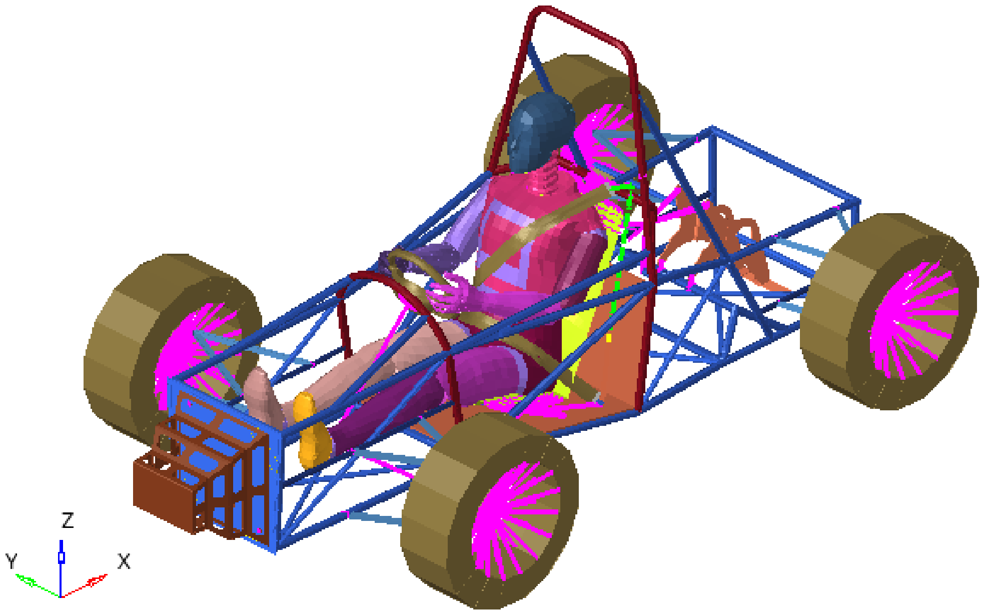


Figure 6.1. Kart with sock absorber and safety belt.

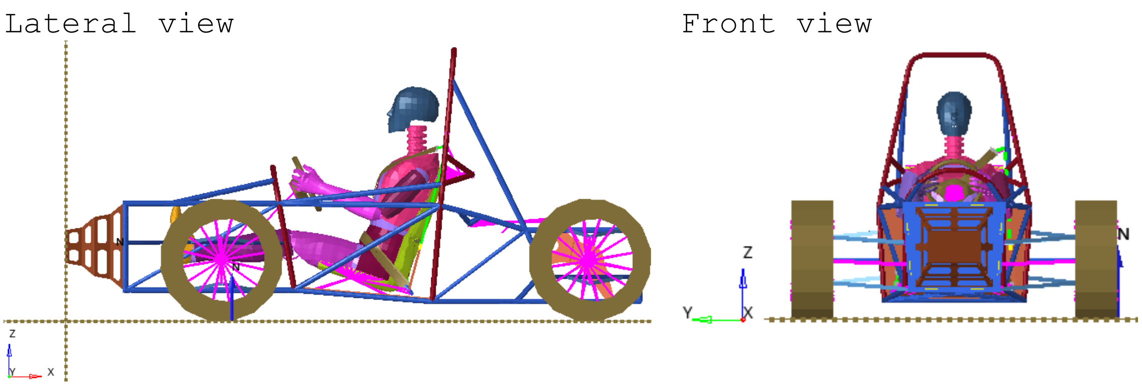


Figure 6.2. Kart with shock absorber and safety belt, lateral and front view.

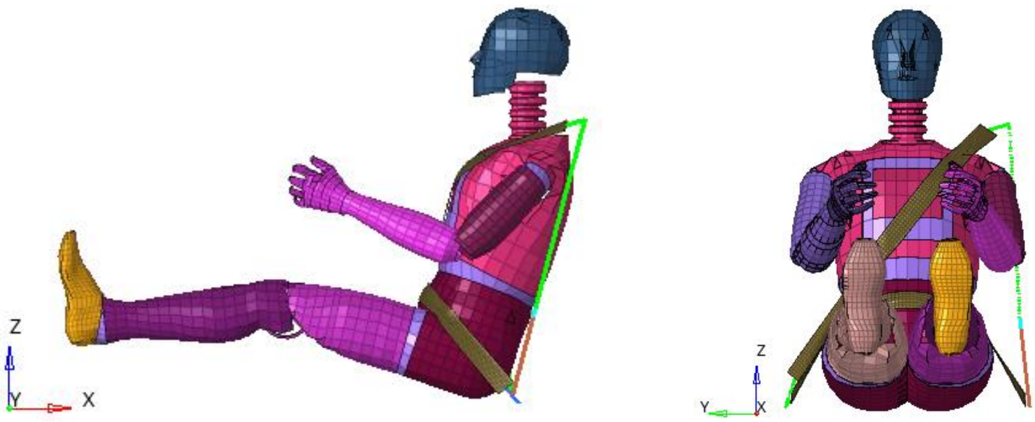


Figure 6.3. Manequin and safety system (lateral view and fron view of the - Hybrid III 50th Male FE)

Two types of the crash absorber were studied, one with 2 mm thickness and another version of 3,5 mm . Based on this

design, we consider a vehicle equiped with a frontal shock absorber with the purpose of attenuating the forces in case of a full wall impact and a safety belt acting on a dummy placed in the drivers seat.(Figure 6.3). [161,162].
In Figure 6.4 a square shock aborber is presented, composed of 2mm thick tin assembled on a race vehicle. This part has the role to absorb the energy from a crash instead of the driver in a frontal crash.

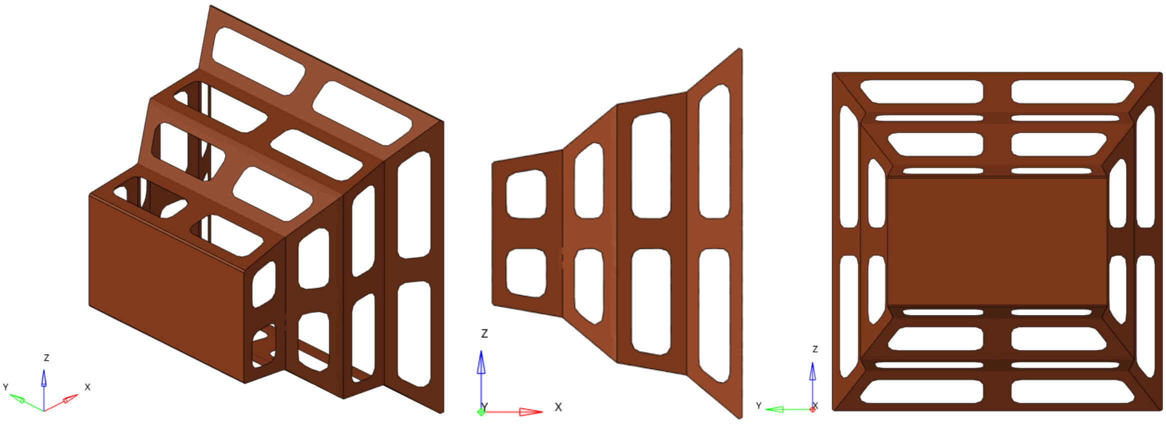


Figure 6.4. The shock absorber system-various views

The material use dis carbon steel and the mechanical properties of the material are : Young Modulus- 200 GPa; Poison ratio - 0,3; Maximum tensile resistance- 438 MPa; Elongation at break - 30%.

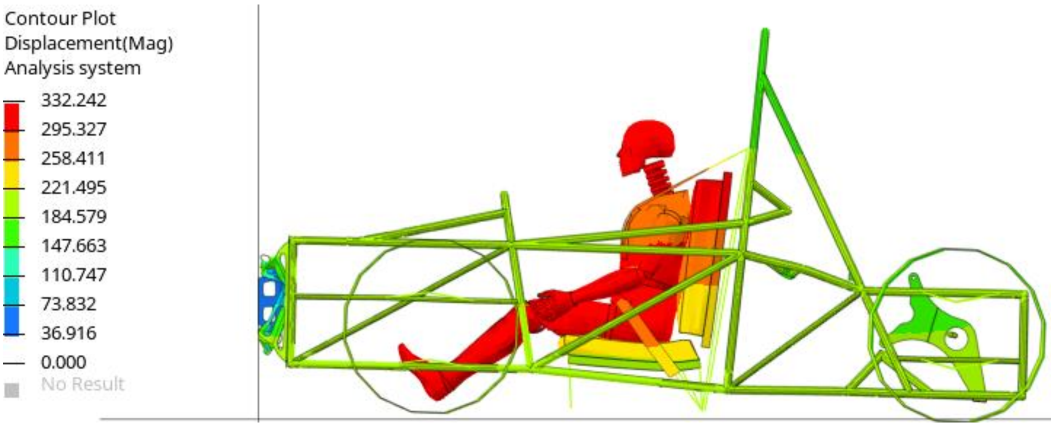
The kart structure was modeled with frame elements of 1 wih 4 corner nods, every nod having 6 DOF. The engine mass was added as a concentrated mass conected to the structure through rigid element body. The shock absorber was created with fram type elements.

The preprocessing stage of the FE model was done using Hypermesh and post processing was done using the ALTAIR Hyperworks package. The impact simulation of the kart was realised using RADIOSS which can be considered a solution for evaluating and optimising the performance of the product in nonlinear and dynamic load problems.

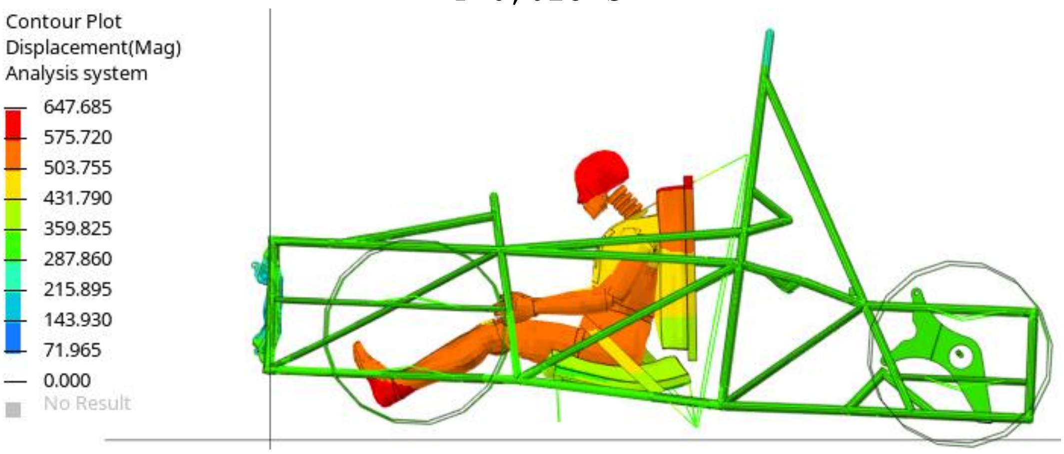
In order to obtain information on the dummy behaviour after a crash simulation, three virtual accelerometers were taken in consideration : head, thorax and pelvis.
The impact velocity of the kart structure with a rigid wallconsidered in the thesis was 7m/s(25,2 km/h), and this velocity was increased to take into account a risk factor.

6.3. Results

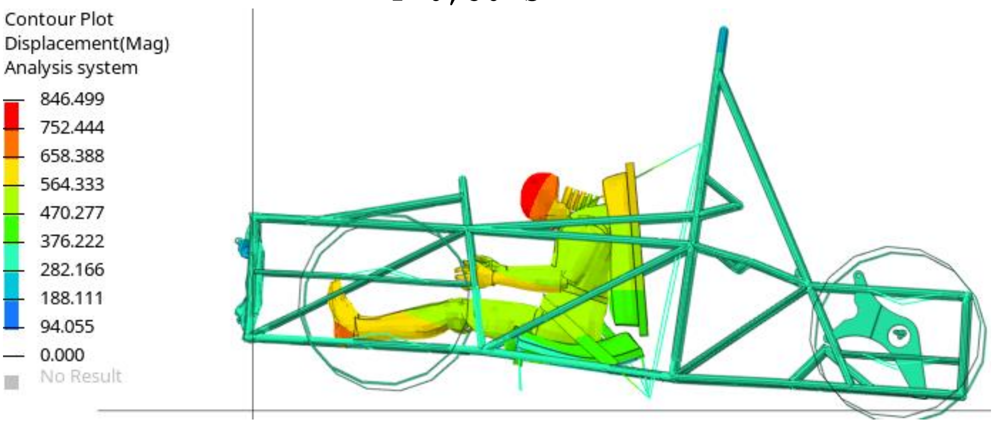
The system behaviour in different stages of crash simulation is presented in Figure 6.7



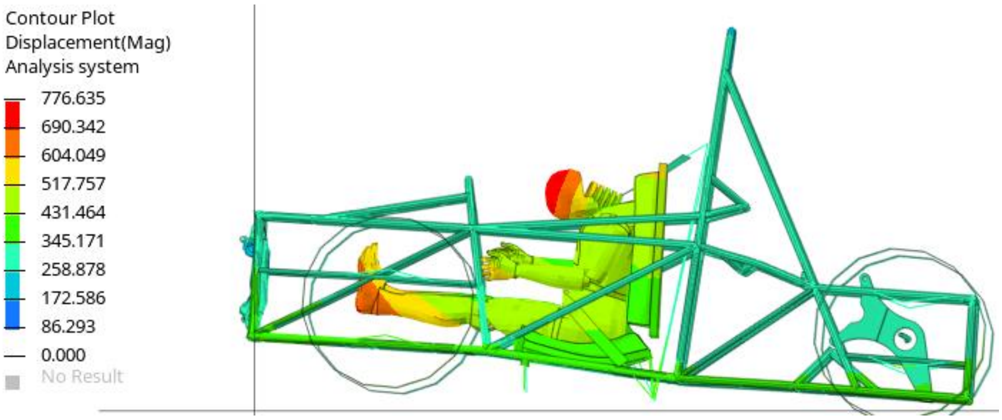
T=0,025 s



T=0,50 s



T=0,075 s



T=0,100

Figure 6.7. Position after: a) 0,025s ; b) 0,050s; c) 0,075 s; d) 0,10 s. Dimensions are in mm.

In Figure 6.8, the forces excerted on the thorax and pelvis area of the belt when using a 2 mm shock absorber are presented and in Figure 6.9 , the same forces but when using a 3,5 mm absorber.

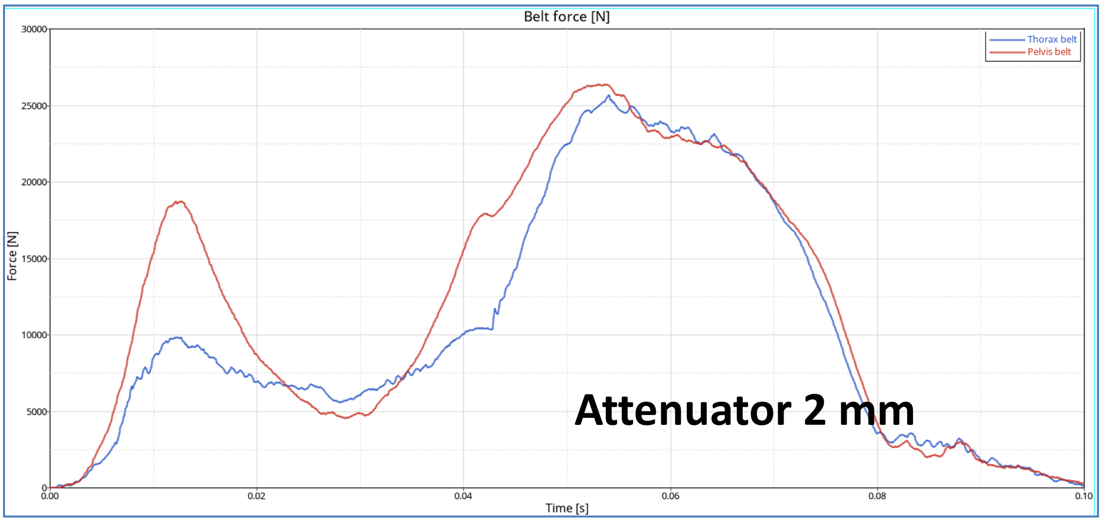


Figure 6.8. Forces in thorax and pelvis area. Attenuator thickness 2 mm

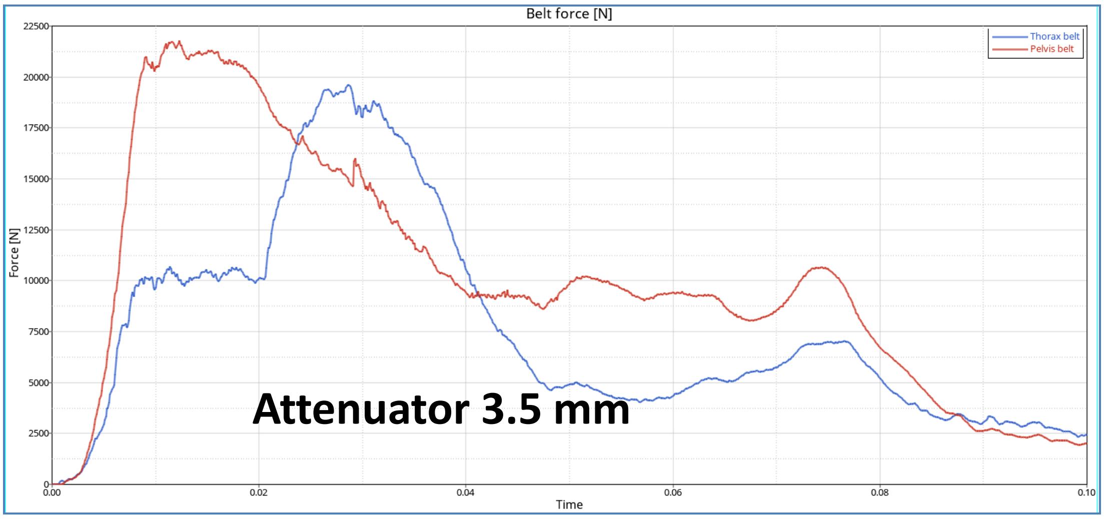


Figure 6.9. Forces in thorax and pelvis area. Attenuator thickness 3,5 mm

In Figures 6.17-6.19 the decelerations determined using virtual accelerometers placed on pelvis, thorax and head are shown.

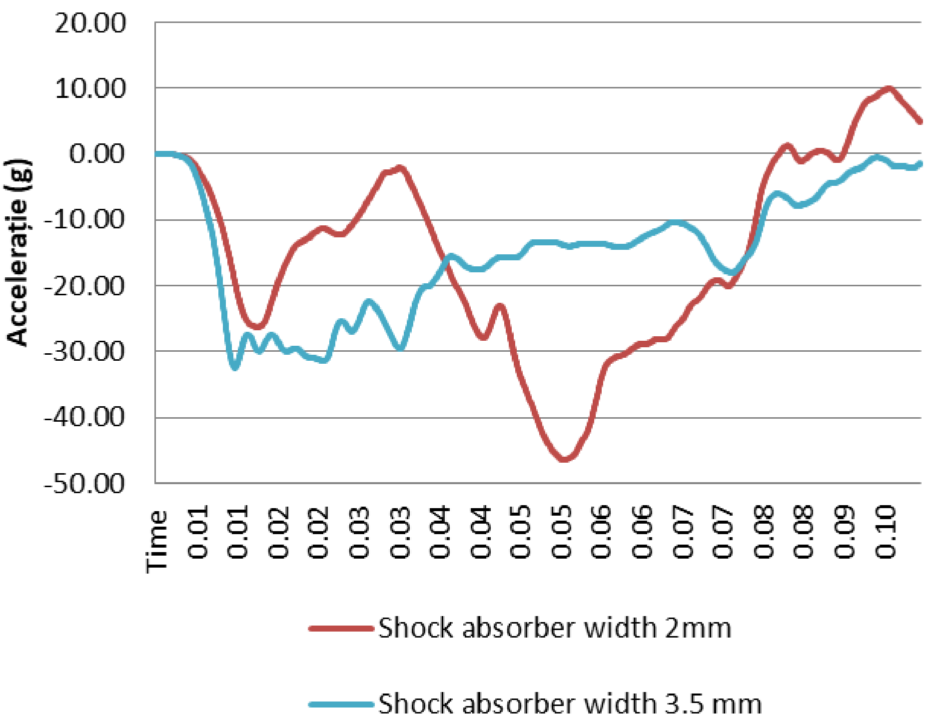


Figura 6.17. Registered acceleration X axis with accelerometer on pelvis rea v = 13 m/s

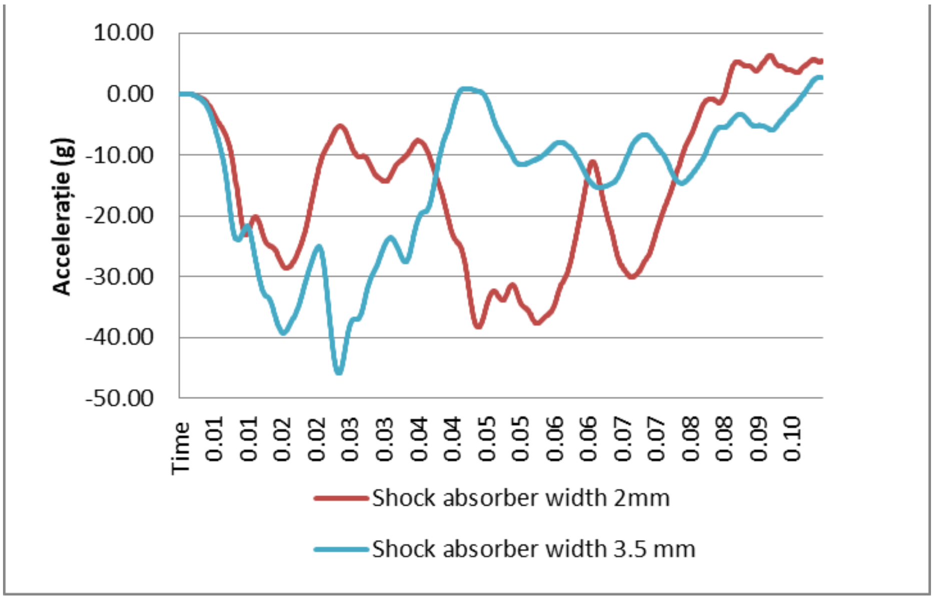


Figura 6.18. Registered acceleration in thorax area v=13 m/s

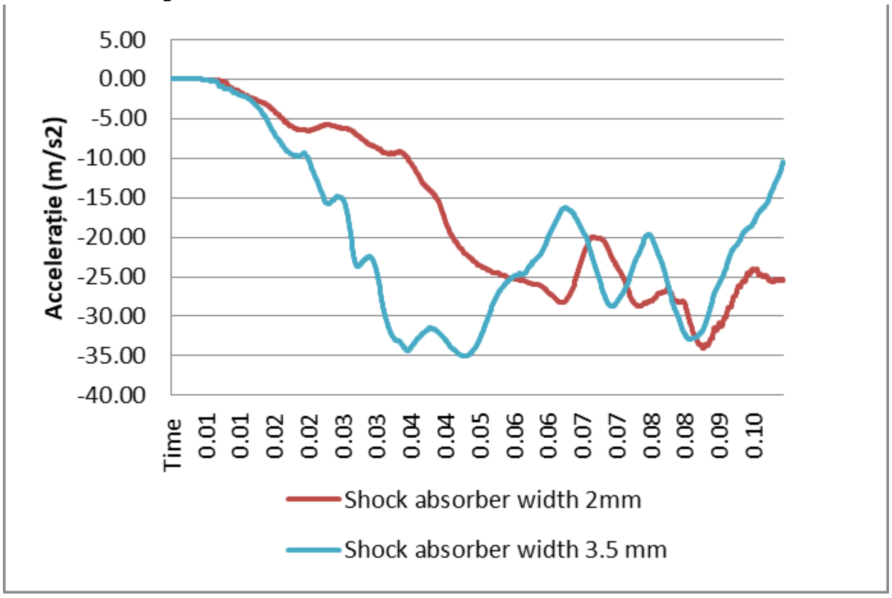


Figura 6.19. Registered acceleration in head area v=13 m/s

Peak deceleration obtained is 40 g and average deceleration is 20 g with mentioned criteria(Figure 6.21).In figure 6.22 we have the second order acceleration.

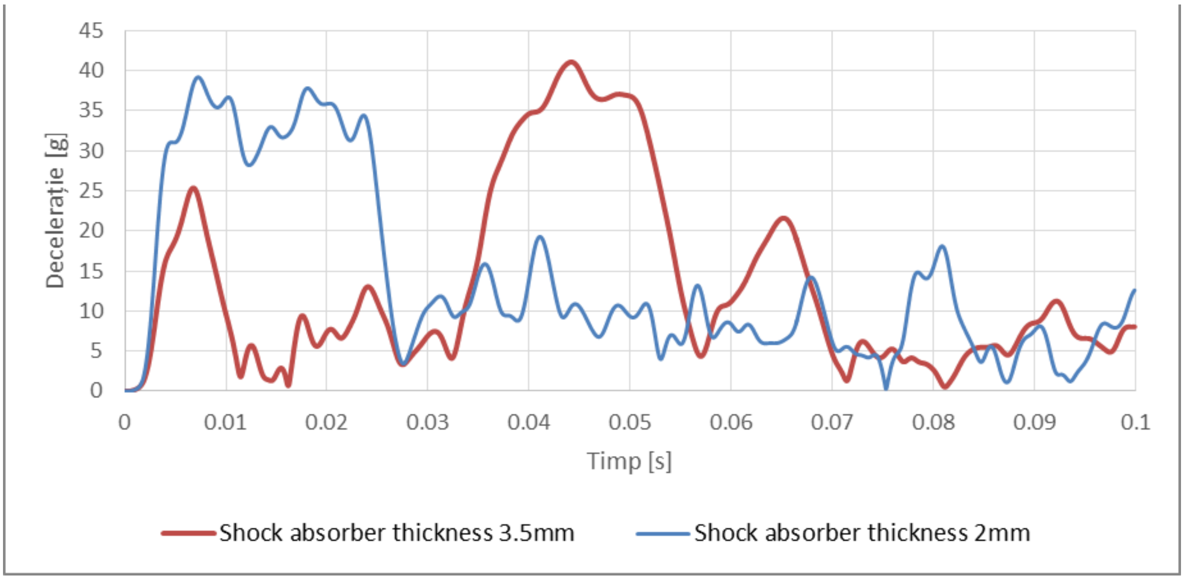


Figura 6.21. Vehicle decelartion in a 7 m/s crash

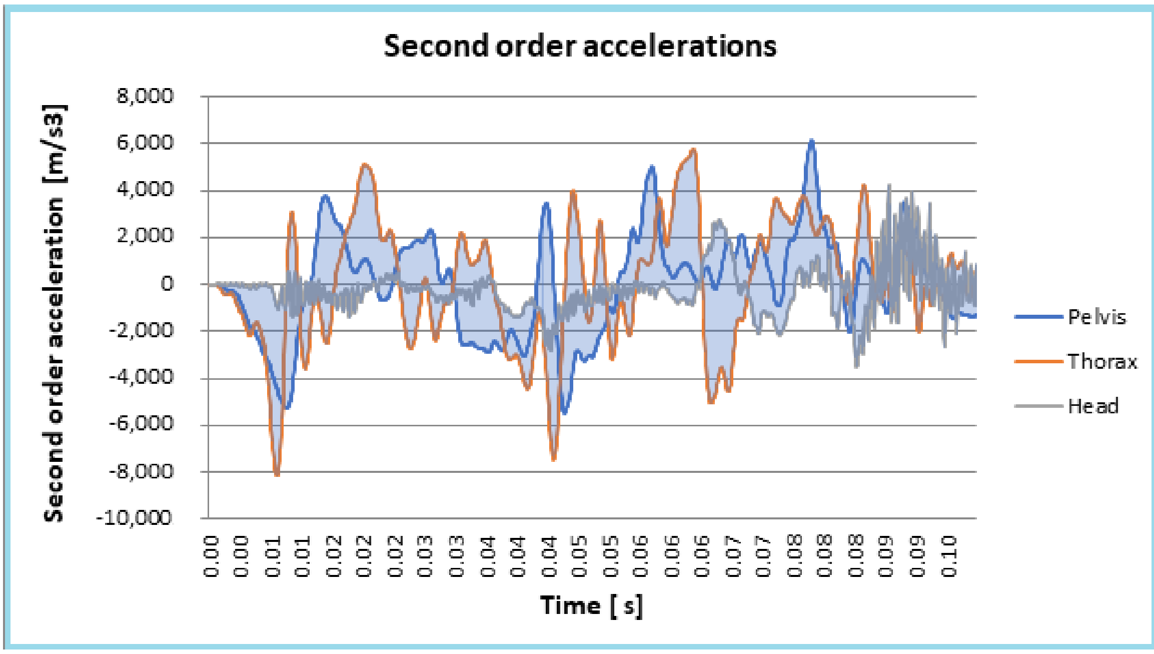


Figura 6.22. Second order accelerations

6.4. Discussions

The chapter proposes to determine the behaviour of a passenger, with the safey belt buckled in a vehicle equipped with a shock attenuator. In parallel , the forces which appear on the safety belt are presented. A MEF modelisation is used to determine the loads at which the passenger is exposed. Determining the forces that appear during a crash is done using the Gibbs-Appell method. Using a 3,5 mm thick attentuator is proven to be a better solutionfrom the passenger and the maximum force in the safety belt point of view.The purpose of the paper was not to determine the biological effects of the accelerations and second order accelerations on the human body , but the values obtained can be used in further studies.

The results obtained open a wide horizon for research because the behaviour of the driver and passenger are determined by many factors and present descriptions in literature are insufficient. The modelisation of an actual race kart used in student competitions was used in the thesis to obtain results.It should be highlighted that numerous topics are still open for research , such as the study of a 4 point safety belt.

The topic studied in the paper needs further study as it involves various engineering areas. Besides the mechanical modelisation which is complex, further studies are necessaryregarding the biological behaviour of the crash dummy.

6.5. Conclusions

In this chapter, the behavior of a crash dummy was studied when exposed to a crash with a rigid wall in order to determine the loadsthat act on the human body . Based on a complex model of a vehicle equipped with safety belts and crash attenuator, the data is obtained.The data in the head, thorax and pelvis area is determined. The Gibbs-Appell method is applied for the motion equations. It can be determined the safety beltcan function in case of defects such as scratches, burns, cuts.

Chapter VII

ORIGINAL CONTRIBUTIONS,CONCLUSIONS, DISSEMINATION OF RESULTS AND FUTURE DIRECTIONS FOR RESEARCH

7.1. Conclusions

Taking into account the values obtained we can observe small deviations in performance compared to new state webbing for the samples of webbing with burns and scratches, 3,2% and 2,5%.

Considerable deviations in performance were observed on the samples with cuts on the webbing , a decrease of 14,8%.

Case type	Tensile strength(kN)	Medium stress at maximum load (MPA)	Performance compared to new state samples(%)
New state webbing	18	255.44	n/a
Webbing with burns	17.43	247.4	-3.20%
Webbing with scratches	15.34	217.67	-14.80%
Webbing with cuts	17.55	249	-2.50%

We can conclude that only a defect that affects in depth the structure of the webbing can lead to a decrease in performance.

Both the samples of new state webbing and those with deffect type of burn and scratches failed in the grip area unlike the samples with cuts that failed in defect area.

The medium tensile strength of the tested samples is between 15,34 kN and 18 kN, the minimum value being the force excerted on a 75 kg passenger in a vehicle impact with a wall.

7.2. Original contributions

The main direction of this paper was to identify the main defects that appear in case of faulty manipulation of the safety belts by the final user. These results can be used in further studies on the properties of he materials used in producing webbing. The issue of incorrect usage of the safety belt was studied in numerous scientific papers, from incorrect use of the child seat to implementing sensors that can detect a wrong position of the safety belt, small tricks that can put the passengers lifes in danger.

The approach of the paper was studied in a series of scientific papers and this study is an addition to the previous ones. The results obtained are original and are added to other research in the passive safety area using elements secific to Mechanical Engineering.

The results obtained open a wide horizon to research due to the fact that the behaviour of the driver and passenger is determined by a number of factors and present research is still insufficient. A number of problems still remain open for study such as the study of a 4 point safety belt or the study of the biological effects of the accelerations sustained by the driver and passenger. The topic studied in the paper needs further development and is required by its complexity which involves more domains. Studies on the biological behaviour of the manequin used in the modelisation are necessary in addition to the complex mechanical modelisation elaborated.

In addition, the main contributions done in the study are highlighted:

1. A critical analysis was done in the studied domain and the current stage of research was identified. The automotive industry has recently started to develop high tech safety systems. At the moment, we are witnessing a high development in active and passive safety systems. The safety belt, although among the first to appear , still remains one of the key components for our safety and a sudy of the webbing materialadapted to the present numerical calculus that allows to determine its behavior is added value.

2. Pentru elementul pe care ne-am concentrat în lucrare în sistemul centurii de siguranță și anume chinga centurii s-au identificat cele mai comune defecte provocate involuntar pe sistemele de siguranță și practici considerate nesigure (rework-ul centurilor pirotehnice după un accident). În urma unei analize atente s-au ales cele mai relevante defecte pentru testarea ulterioara.

3.Due to the fact that finding complete safety belt assemblies that presented our defects of interest was difficult it was necessary to reproduce these samples in the laboratory. By doing this we were able to have a satisfactory number of samples for trials.

4.In the laboratory , tensile tests were done on the samples and the results were registered. The tests were done on samples with the defects stated above and control samples for comparison.

5.The results from the tests helped identify the defect with the most impact in the behavior of the webbing of the safety belt.

6.A critical analysis was done on the mechanical alaitical methods that could be applied in the modelisation using FEM of the assembly passenger-seat belt in order to identify the forces that act on the passenger during a vehicle crash.

7.A dummy positioned in race vehicle was studied in orderto observe the loads acting during a crash .Using a complex vehicle model, equipped with a safety belt and shock absorber system, the behavior of the mannequin was obtained.The accelerations in different points of the body were determined and also the forces excerted on the webbing of the belt.The Gibbs-Appell equtions were used to evaluate the loads acting on the system.

8.FEM Altair Hyperworks II software was the programme used to determine in simulation if the safety belt could fulfill its role in case of defects in a crash case.

9.The solicitations at which the driver is exposed in the vehicle in the first part of the crash simulated were determined. Using FEM, the modelisation of the entire system vehicle-driver-safety belt was completed. The modelisation was done using as subject a real monpost used in auto cmpetitions by Transilvania Unverity students. The airbags were not taken into account for this.

10.The mechanical response of the system was studied in this short interval after the impact in order to observe if the system could ensure the minimal safety standards in a race.

11.Future research directions were identified. The results obtained open a wide horizon for research as the system is influenced by numerous factors and present descriptions are not complete.

12.Reconsidering some classic methods of analytical mechanics in the context of developing numerical methods are necessary.

13.Numerous problems need further investigation, for example, the sudy of a four point seat belt or a study on the biological effect of the accelerations sustained by the driver or passenger.

14.The results obtained were promoted by publishing a number of ten scientific articles in international dedicated magasines, WoS(7),BDI(3) and 2 more articles due to be published this year.

7.3. Dissemination of results

Pe parcursul pregătirii tezei de faţă au fost publicate 10 lucrări în tematica strictă a tezei sau în tematici derivate din studiul inițial, alte două lucrări urmând a fi publicate după prezentarea lor la o conferință internațională:

ISI Web of Science papers(7)

1. Itu, C., Toderita, A., Melnic, L.V., Vlase, S. Effects of Seat Belts and Shock Absorbers on the Safety of Racing Car Drivers. MATHEMATICS,2022, VL 10, IS 19, AR 3593, DI 10.3390/math10193593. **IF 2,592**.
2. Bencze, A., Scutaru, M.L., Marin, M., Vlase, S., Toderita, A. Adder Box Used in the Heavy Trucks Transmission Noise Reduction. SYMMETRY-BASEL, 2021, VL 13, IS 11, AR 2165, DI 10.3390/sym13112165. **IF 2,94**.
3. Itu, C., Vlase, S., Marin, M., Toderita, A. Use of the Symmetries in the Study of Vibration Response of a Hollow Cylinder. SYMMETRY-BASEL, 2021, VL 13, IS 11, AR 2145, DI 10.3390/sym13112145. **IF 2.94**.
4. Toderita, A., Vlase, S., Reliability Study on PUR Injection Machine. 13TH INTERNATIONAL CONFERENCE INTERDISCIPLINARITY IN ENGINEERING (INTER-ENG 2019), Procedia Manufacturing, Targu Mures, ROMANIA, 2020, VL 46, pp. 885-890, DI 10.1016/j.promfg.2020.05.004.
5. Toderita, A., Vlase, S. Impact of extraction agents in mold part for PUR injection. 12TH INTERNATIONAL CONFERENCE INTERDISCIPLINARITY IN ENGINEERING INTER-ENG 2018), pSE Procedia Manufacturing, OCT 04-05, 2018, Tirgu Mures, ROMANIA, 2019, VL 32, pp.74-78, DI10.1016/j.promfg.2019.02.185.
6. Bratu,P., Vlase,S., Dragan, N., Vasile, O., Itu, C., Nitu, C.M., Toderita, A. Modal Analysis of the Inertial Platform of the Laser ELI-NP Facility in Magurele-Bucharest. Romanian Journal of Accoustic and Vibration, vol. 19, issue 2, 2022, pp. 112-120.
7. Chircan,E., Scutaru,M.L., Toderița,A., Modrea,A. Motion Equation of a Rectangular Finite Element with a Two-Dimension Motion in a Membrane State. Procedia Manufacturing, Vol.46, 2020, pp.209-216

BDI papers (Scopus, Google Scholar)

8. Chircan, E., Scutaru, M.L.Toderiţă, A. Dynamical Response of a Beam in a Centrifugal Field Using the Finite Element Method. 15th Conference on Acoustics and Vibration of Mechanical Structures, AVMS 2019, 30 May 2019, Timisoara, Springer Proceedings in Physics, Volume 251, pp.101 -113, 2021.
9. Toderita,A.,Vlase,S. TENSILE STRENGTH STUDY ON SAFETY SYSTEMS. International Conference COMAT 2020, October 2020,Brasov, Romania; pp.167-171, http://hdl.handle.net/123456789/2537
10. Toderita, A.;Vlase, S. IMPACT OF CARBON FIBER IN PUR INJECTION, International Conference COMAT 2018, October 2018,Brasov, Romania, pp.53-56, http://hdl.handle.net/123456789/2285

Papers due to be published Web of Science

11. Toderiţă (Santean) Ana, Chircan Eliza and Omar Shrrat Abulah Omar The study of the front safety belt webbing with defects from cuts. Inter-Eng 2023, Targu Mures
12. Toderiţă (Santean) Ana, Chircan Eliza and Teooresсu Draghicescu Horatiu Stress in the strap of the safety belt with accidental burns. Inter-Eng 2023, Targu Mures

7.4.Future reasearch directions

Improving the mathematical model for calculating the forces which appear in the webbing of the safety belt.

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