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ESTIMATION OF EES VALUES BY VEHICLE 3-D MODELLING

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RESEARCH ARTICLE

ABSTRACT: Energy Equivalent Speed value (EES) is the base of energy method for crash velocity assessment. Estimation of EES value is based on deformation depth and a vehicle stiffness coefficient. Vehicles that are damaged in traffic accidents are usually unavailable for accidents experts so they have to rely on photographs of those vehicles. Development of 3-D photogrammetry and leading software solutions in the field of photogrammetry allowed more detailed overview of deformation on vehicles that were involved in accidents. One of those software solution, that provide 3D models from pictures taken in the planned photo session, is PhotoModeler Scanner. By comparing 3D models of a damaged and undamaged vehicle, experts can get more insight into the type and damage intensity. Analysing those 3D models, information about deformation depth are obtained. This paper shows the procedure of forming a 3D model of an undamaged vehicle created from photographs that were taken in the planned photo session and processed in PhotoModeler Scanner software. This model was compared with a 3D model of the same type of vehicle made from photographs taken at the accident spot. Based on measurements that are taken from those 3D models, the main elements for EES estimation are determined.

KEY WORDS: EES, PhotoModeler, 3-D model, deformation

PROCENA EES VREDNOSTI TRODIMENZIONALNIM MODELIRANJEM VOZILA

REZIME: Vrednost brzine ekvivalentne energije (EES) je osnova energijskog metoda za procenu brzine udara. Procena EES vrednosti je zasnovana na dubini deformacije i koeficijentu krutosti vozila. Vozila koja su oštećena u saobraćajnim nezgodama obično nisu dostupna stručnjacima za nezgode, pa se oni moraju osloniti na fotografije tih vozila. Razvoj 3D fotogrametrije i vodećih softverskh rešenja iz oblasti fotogrametrije omogućio je detaljni prikaz defomacije na vozilima koja su bila uključena u nezgode. Jedno od tih softverskih rešenja, koje pružaju 3D modele sa slika snimljenih tokom planiranje foto sesije, je PhotoModeler Scanner. Poredeći 3D modele oštećenih i neoštećenih vozila, stručnjaci mogu imati više uvida u tip i intezitet štete. Analizirajući ove 3D modele, dobijene su informacije o dubini deformacije.

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Ovaj rad pokazuje proceduru formiranja 3D modela neoštećenog vozila od fotografija snimljenih na planiranoj fotosesiji obradjenih u PhotoModeler Scanner softveru. Ovaj model je upoređen sa 3D modelom istog tipa vozila napravljenog od fotografija snimljenim na mestu nezgode. Na osnovu merenja koja se uzimaju od tih 3D modela, odredjeni su glavni elementi za procenu EES-a.

KLJUČNE REČI: EES, PhotoModeler, 3-D model, deformacija

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1. INTRODUCTION

Basis for efficient and reliable reconstruction of every traffic accident is documentation compiled during car accident investigation. Photograph of the site of the accident is an integral part of investigation documentation, by which, in the most objective way, the information related to the place of an accident, involved objects and subjects can be collected and transferred. Due to the technology development, a photograph has become a source of a great number of information. In other words, a photograph has become irreplaceable in many aspects of people’s lives, in which it is not only used for documentation purposes, but also as a part of a technological process. Using a photograph for measuring purposes is an example where its documentation quality is put into background, and primary use is for its geometric quality. Scientific discipline that deals with photograph usage for measuring purposes is called photogrammetry. This refers to a measuring method by which position, dimension, and shape of a recorded detail is reconstructed using one or more photographs, without direct contact with them. One of the main photogrammetry tasks is measurement of individual points, that is determining point position in two-dimensional or three-dimensional space using photographs. Today, photogrammetry is used in different fields. The widest usage has found in geodesy and architecture for the purposes of terrain and object surveying. With the improvement of measuring tools, the photogrammetry accuracy is becoming even bigger, so today it is also used in industry during production of complex models and it reaches accuracy from 0.01 mm.

With the introduction of computer technology, photogrammetry is more economic and efficient. Photographs can easily be transferred between devices, and by additional software tools the process of photogrammetry analysis is considerably simplified, more automatic and faster. Due to its numerous advantages, photogrammetry is more and more applied in forensic engineering. Using photogrammetry at a scene investigation process, time investigation is considerably shorter and what is avoided are the mistakes that can occur due to subjective oversight or current inability to find and identify all the clues that can be used in further event analysis. Photogrammetry recording of accident scene and vehicles involved in the accident provides a permanent archive recording, based on which all future measurements could be done, for the purposes of determining dynamic parameters of the accident, finding new clues and evidences, etc.

Deformation on the vehicle caused by a collision represents safe and reliable data which can be used when making conclusions regarding clarifying the circumstances at which the traffic accident occurred. If the damaged vehicle is photographed properly, information about its deformations will be available for a long time, and by applying photogrammetry very usable. Based on a 3D vehicle model made by photogrammetry recording measurements can be done of individual characteristic points on a vehicle and, if needed, do model orientation and use it for:

- measuring the depth of vehicle damage
- calculation of vehicle energy lost on deformed work in collision process
- determining collision speed of a vehicle
- determining collision position of a vehicle
- determining movement direction of vehicles before collision, etc.

Experts who are dealing with traffic accident reconstruction, are most often available only photographs recorded during the site accident investigation, at which, depending on the circumstances during the investigation and equipped personnel who did it, are shown damaged parts on a vehicle, with more or less details. Due to numerous limitations at scene investigation process, number of vehicle photographs involved in the accident is usually not enough to form a detailed 3D model, but it is quite sufficient for damage analysis on it. On the other hand, it is much easier to make a 3D model of an undamaged vehicle, of the same type as the vehicle that had been in a traffic accident, when there are no limitations regarding number of photographs and angles of recordings. This way, it is possible to do an overlap of contours of undamaged parts on both vehicles, while the damage of a vehicle that had been in an accident will be clearly visible.

2. THE BASIS OF 3D PHOTOGRAMMETRY

Getting necessary geometric information about recorded terrain can be done by measuring one tape of recorded terrain (or object). Considering that at two-dimensional objects all points lie in one plane, reconstruction of that object would be possible based on only one photograph, with the knowledge of referent length visible on them. This is done by copying planes of copied object into a picture plane, in other words, by transforming its perspective into a perspective of a strictly vertical recording.

3D photogrammetry is applied when it is necessary to reconstruct an object in three-dimensional system, meaning to perform a recovery of information lost in a process of recording. Photograph represents two-dimensional image of three-dimensional objects, therefore in process of its making the third dimension of photographed object is being lost. Therefore, the lost information in the photograph is actually the third dimension. Transformation into 3D recording is done by recovering information lost in the process of recording, i.e. by determining from which exact position along the trajectory of caught ray the information was received. To have a three-dimensional insight in a photographed object, the photograph must be composed from at least two different positions, where recordings must include the same parts of objects that are visible on them, but from different angles and perspectives

(Figure 1).

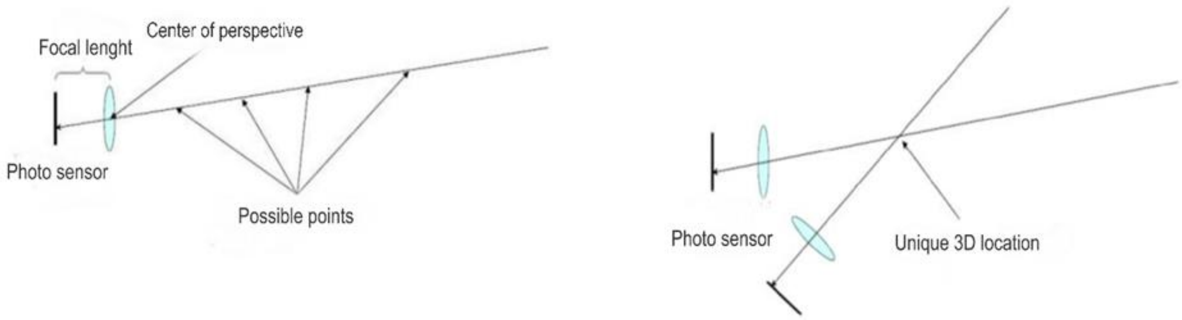

Figure 1. Determining the unique 3D location point-space

Geometric relations between photographs are established by mathematical principals of determining coordinate points of recorded objects. Without computer technology, it is very difficult to provide production of precise stereo photograph couples. Modern software in photogrammetry field provides finding 3D coordinate object points in space using points coordinates projection of an object on the photograph plane, all this is done using two photographs by choice of the same object. During the marking of mutual object points on the photograph plane, an error can occur that can influence the precision of measurement or object modeling. This problem is solved by recording the coordinate points in space using more photographs, so that the precision of the process is bigger.

3. THREE-DIMENSIONAL MODELING USING PHOTOMODELER PACKAGE PROGRAM

Photomodeler Scanner is currently among top three best software solutions whose primary purpose is photogrammetric process of recordings and creation of 2D and 3D models. The software itself is created in that way that due to a high level of automation, which is not the case with previous programs, covers the needs of aero as well as the close-range recording of terrain and objects.

Information gathering at a terrain must satisfy basic principals of photogrammetric recording with which is ensured the necessary level of accuracy that in well-calibrated projects is measured in millimeters. This level of accuracy, though desirable, is not necessary when photogrammetric video rectification is done, however it is of great significance during the determination of depth of vehicle damage through photogrammetry of the given 3D model. Camera calibration, by which the information gathering is done, has a crucial role when it comes to the amount of achieved accuracy. Photomodeler in its data base contains a large number of basic parameters for cameras from various manufacturers so that it can recognize with what camera the recording had been done, apart from that, calibration is necessary for parameter characterization specific for every individual camera. Parameters for camera calibration are the following:

- sensor specification
- pixel size in millimeters
- focal length[48]
- radial curving of camera lenses
- distortion due to non-centric camera elements
- linear distortion.

Calibration is done according to established procedure that can be found in the Photomodeler manual package and it is not different than standard calibration procedures in any other software for the same purpose.

It is desirable that recording area during calibration has similar size as future calibration projects so that manually set focal length is the same, with which the level of accuracy is enhanced.

When the calibration is successfully done, a good basis is formed for the high level of project accuracy. Practical use of Photomodeler Scanner, unlike standard Photomodeler package, as well as the other software solutions in this field is portrayed in the high level of process automation when determining unique 3D point positions in space. When generating 3D model of a object or item, basically it is necessary to make as many photographs as possible from different positions, and photograph selection with a good angle of overlap can be done during later work. If for some reason there are not enough photographs to start automatic orientation (in reality this is less than 4 recordings) or it is not possible from another reason, as a possibility there is manual connecting of points in space and then photographs should be chosen according to this principle:

- Make sure that the distance between two positions of camera when taking pictures is at least 10-20% (or more) from the average distance between referent points. This is an important principle for the first two photographs at which orientation is done
- Make sure that referent points, which are used for orientation, are spread out in two directions, or even better, if possible, in three directions. Relative orientation will be done easier if referent points do not lie in one area
- One should bear in mind that the bigger angle of intersection between two or more rays the coordinates (XYZ) will be determined better
- Where possible, one should make sure that referent object points fulfill as bigger picture format as possible. This will increase precision and reliability of relative orientation
- One should always decide to have more referent points. Even though in theory there should be 5 points per photograph minimum (during stereo orientation), appropriate number should not be less than 12, if we want to be sure that photogrammetry orientation will work
- Not all referent points have to be present in all photographs but they have to be present in enough photographs.

If the previous principles are respected, project will be successfully oriented manually. For automation orientation, apart from above mentioned, one should pay attention to the following as well:

- avoid surfaces at which there is no texture
- avoid moving scenes; object must be in focus
- avoid reflection (common problem when photographing vehicles).

Using Automated Point Clouds & SmartMatch options, automation orientation of a video is done and characteristic points are assigned to project (Figure 2 and 3).

Figure 2 and 3. Undamaged vehicle and generated cloud points with camera positions at the moment of recording

The project is oriented in photogrammetry sense which means that camera positions are determined at the moment of recording as well as the positions of characteristic points. Further process of connecting and model forming is done by automation generating of thick point cloud DanseSurface, and then manually, outlining vehicle contours based on the points on it, so that the measurement of damage depth is done following the contours.

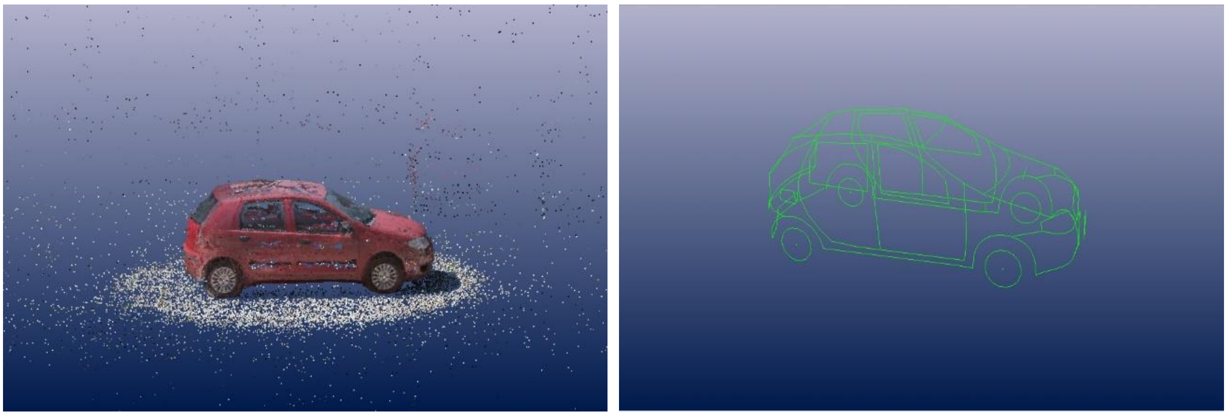

Figure 4 and 5. 3D model made by DanseSurface option and connecting points at vehicle contours

The same generating model process is applied on the photographs of a damaged vehicle that are gathered in the field. In the project are used photographs of a damaged vehicle made by auto service, right before vehicle repair. Considering that the damaged vehicle no longer exists, these photographs are the only source of information about damage depth.

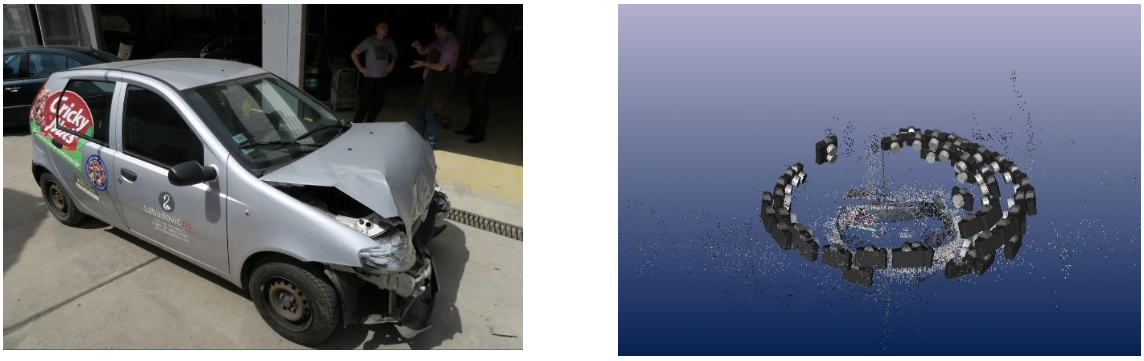

Figure 6 and 7. Damaged vehicle and generated point cloud with camera positions at the moment of recording

Finished model is shown in the next Figure.

Figure 8. 3D model with DanseSurface option

In this occasion, making the 3D model based on the damaged vehicle contours is not done because that process takes up a lot of time, and since undamaged parts of the damaged vehicle completely suit undamaged vehicle based on geometrics, this is not necessary.

Measurements acquired from photographs of damaged vehicle will be paired (connected) with undamaged parts of given damaged vehicle. As already mentioned, these damaged parts represent the carriers of precise vehicle geometrics and therefore it is clear why exactly these parts are used in the process of matching. After creating a 3D model of damaged vehicle and matching mutual points of two models, damages on the vehicle are clearly shown by comparing 3D model contours.

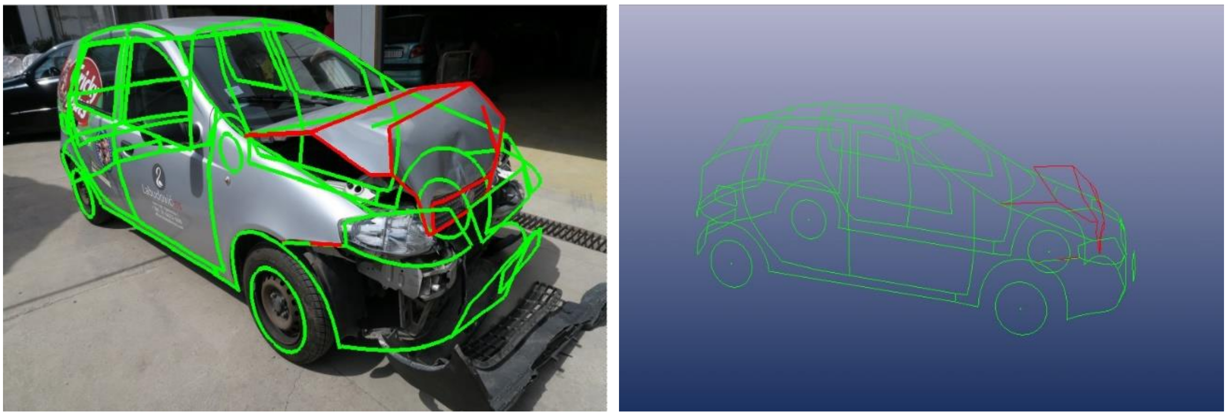

Figure 9 and 10. Removing contours of damaged and undamaged vehicle

Figure 9 shows how undamaged vehicle fits into geometrics of undamaged vehicle parts that had been involved in a traffic accident. It is clearly visible that contours of undamaged parts almost perfectly fit together, and all deviations of these two models are concentrated at the front part, i.e. are formed as a result of deformation in the process of a collision. By measuring deviations in contours of 3D model of damaged and undamaged vehicle at the front part, average front part deformation is set to be around 0.15 m.

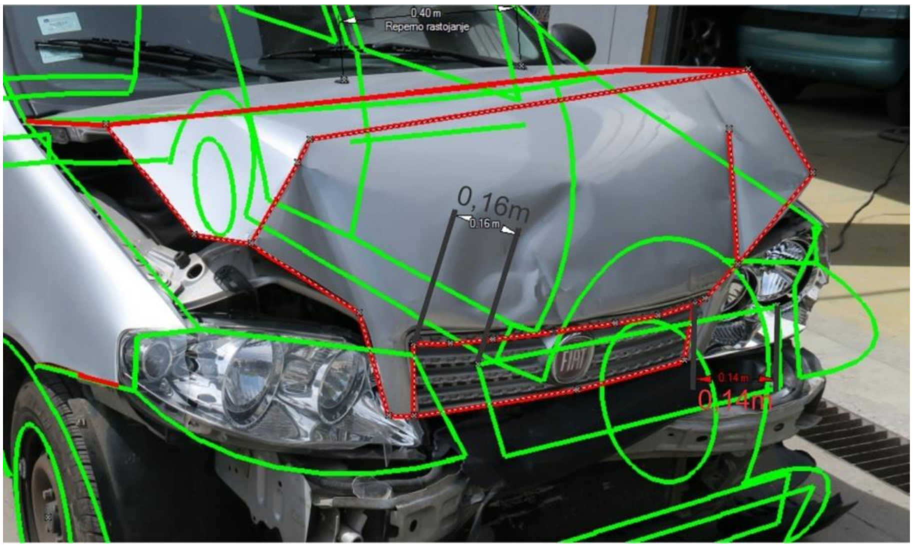

Figure 11. Damage depth

4. DETERMINING EES VALUES APPLYING PC CRASH PACKAGE PROGRAM

The deformation energy, i.e. the energy consumed during the complex process of a vehicle collision for the structure deformation, is of utmost importance for both passive and active safety. It is also a basis for the calculation of kinematic and dynamic parameters of the vehicle, determined during the retrospective research of road events.

The deformation magnitude determines the deformation energy, taking into consideration the vehicle's design parameters expressed by the stiffness coefficients.

The profilometer method is the classical method for determining the deformation magnitude, and it uses a Cartesian coordinate system. Furthermore, new methods based on photographic technique have been developed, such as the PhotoModeler method.

4.1 Car deformations and the deforming energy

In the majority of cases, one of the main goals of reconstruction of road accidents is the determination of vehicle speed prior to collision. Main methods used for approaching the road accidents reconstruction are: impulse method, based on the laws of conservation of the linear and angular impulse and the deformation method based on the laws of conservation of the linear impulse, angular impulse and energy.

The use of the deformation method implies the adoption or existence of certain models of deformation which express the connection between the deformation magnitude and the collision normal force per unit width of the deformed area. The deformation models can be either static or dynamic. The determination of deformation energy for the dynamic deformation models is done based on the dynamic deformations, while the static models use the magnitude of the remnant static deformations for calculating the deformation energy. In contrast to the dynamic models which express the relationship between force and dynamic deformation of the vehicle body, the static models are showing the relationship between force and the plastic remnant deformation of the vehicle, assimilating this dependence as linear.

It can be concluded that determining the total kinetic energy consumed during the impact is done based on the deformation of the vehicle constructive elements, in particular the car body elements. In order to measure the vehicle's deformations, the magnitude of these deformations in several points of the deformed area needs to be determined. The energy consumed for the deformation of the vehicle constructive structure during the impact may be determined on the basis of the remnant deformation of the car body elements, using the vehicle's stiffness coefficients specific to the deformed area.

The PC Crash software uses the following relation in order to calculate the deformation energy.

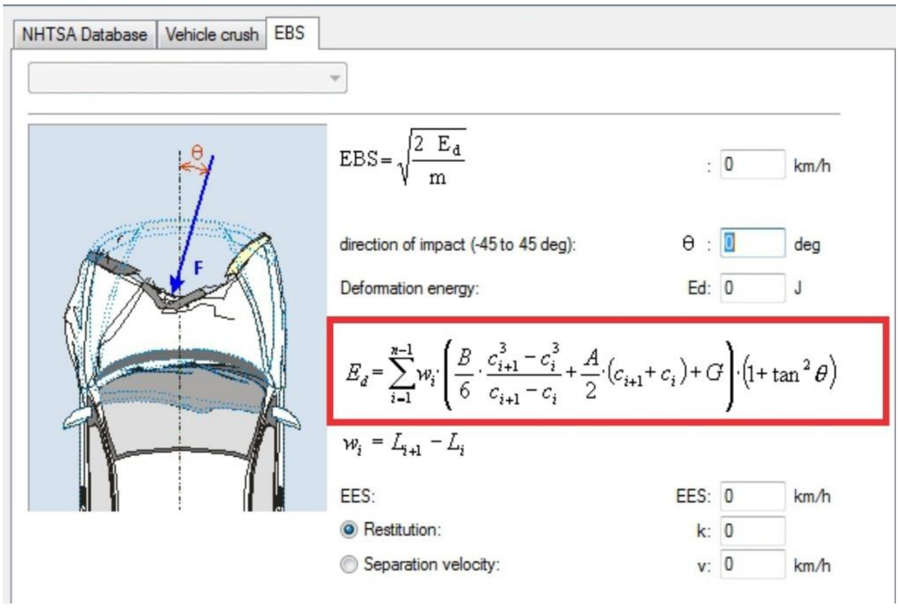

Figure 12. Relation used to calculate the deformation energy in the PC Crash software

where:

E_d - deformation energy (J);

A, B, G – stiffness coefficients;

C_i, C_i+1 – the deformation measured at point i and point i+1 (m);

L_i, L_i+1 – the rate of the measuring station from point i, and point i+1 (m);

w_i – the distance between two consecutive measuring stations (m);

Θ – angle between the longitudinal axis of the vehicle and the direction of the main impact force (degree).

The deformation energy thus calculated corresponds to the remanent deformation. The car body dynamic deformation reaches the maximum value at the impulse point during compression. Afterwards, during the restitution phase, the deformation magnitude is decreased to the static deformation value.

5. CALCULATION EBS VALUES IN CRASH3 STANDARD

Determining EBS values in PC-Crash program package is done through CRASH3 (Computer Reconstruction of Accident Speeds on the Highway) program that is implemented in PC Crash.

The assumptions of standard CRASH3 are as follows. Cars were generally divided into mini, sub-compact, compact, intermediate, and full-size, excluding trucks and buses. Currently, databases are being extended with pick-up and van vehicle types. Three impact directions are distinguished: front, side, and rear, assuming that body stiffness structure in these areas is uniform. Taking into consideration all unavoidable errors at a particular analysis stage, such simplification is acceptable, nevertheless, the analysis of accident mechanics has to be done in a wide field of tolerance.

Measurement of deformation profile has been standardized by NHTSA and is described in NASS protocol (National Accident Sampling System (71)).

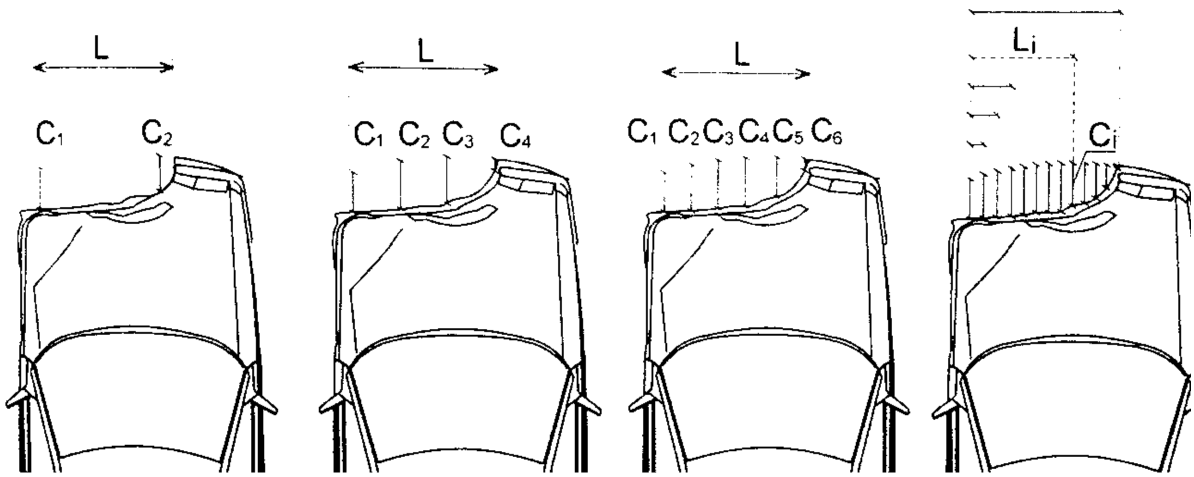

Figure 13. Measurement of vehicle deformation profile

1. Deformation width measure L.
2. Divide length L into several sequences and in these points measure deformation depth in direction perpendicular to vehicle front, side or rear surfaces, regardless of impact force displacement direction. Most frequently, six points are selected, traditionally called C_1-C_6 and this is how data from crash tests are usually given.
3. Depth measurement refers to deformation profile (i.e. so-called contact delmageformation), rather than the total range of induced deformations.
4. Perform measurement parallel to roadway plane.
5. Additionally, measure impact force angular displacement of vehicle longitudinal or lateral axis.

6. CALCULATION EBS VALUES

The contact deformation profile of Fiat Punto was measured in six points. Since the damage is considerable, we can adopt a simplifying assumption that EBS≈EES.

The contact deformation profile of Fiat Punto was measured in six points. Since the damage is considerable, we can adopt a simplifying assumption that EBS≈EES.

Parameters that provide figures in the EBS calculation (stiffness parameters of vehicle A and B) are calculated based on the data acquired by crash tests.These data for given vehicle can be found in NHTSA data base that is listed by manufacturers and vehicle models in the first tab Crash 3 EBS Calculation window. If a vehicle for which we want to do EBS calculation values is not found in the mentioned data base, we can enter stiffness parameters of a vehicle manually, if they are familiar to us, or, what is also the recommendation of PC-CRASH software manufacturer, we can take a benchmark vehicle of similar characteristics. During the selection of a benchmark vehicle, based on which stiffness coefficient will be determined, damage at a front part of tested vehicle must be taken into account to match the damages of our vehicle, i.e. that the damages' width and depth are approximately equal. Since in the NHTSA database are no data for the vehicle Fiat Punto, during EBS calculations values, as a benchmark vehicle is taken Ford Fiesta.

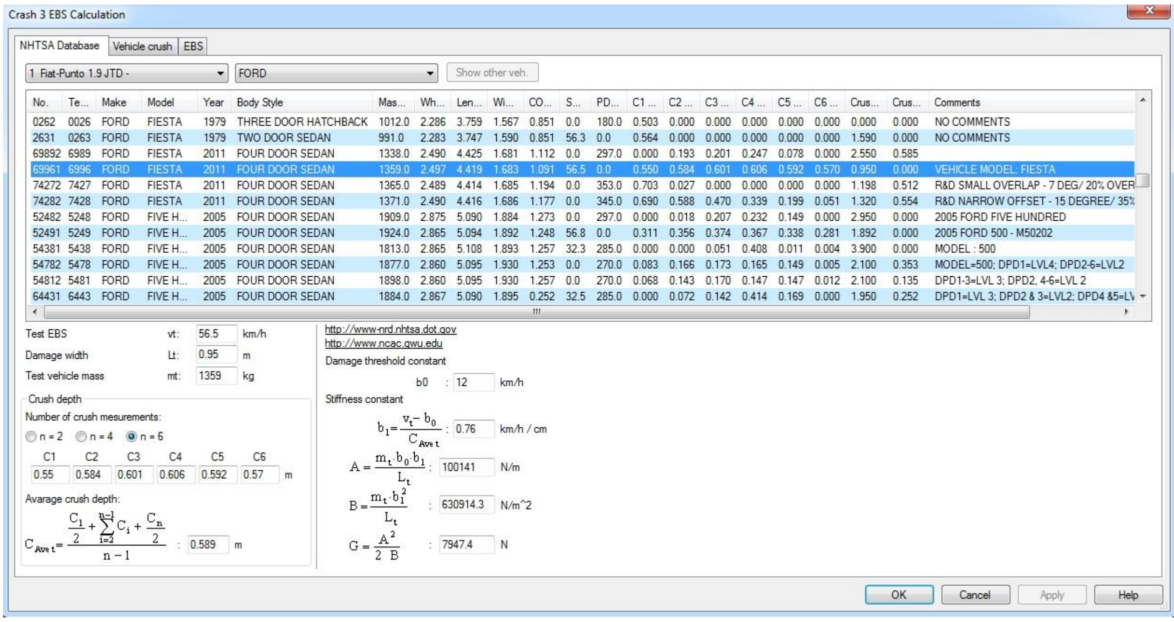

Figure 14. Choosing Crash test and benchmark vehicle

When crash test, which by characteristics and vehicle type matches our vehicle (or if crash test parameters are entered manually: impact velocity V_t, deformation width L_t, vehicle mass m_t, contact deformation profile and permanent deformation boundary velocity b_0), is chosen, i.e. when we have relevant parameters of vehicle stiffness, we can move on to defining the measured depth of our damaged vehicle in Vehicle crash tab. Here is firstly important to determine based on how many points the damaged depth is measured, the depth of every point, as well as its distance in relation to the front left vehicle angle, i.e. point C_1. In our case, measuring had been done based on six points along the front part of the vehicle. Measures and point positions at the measuring moment are given in the next Figure.

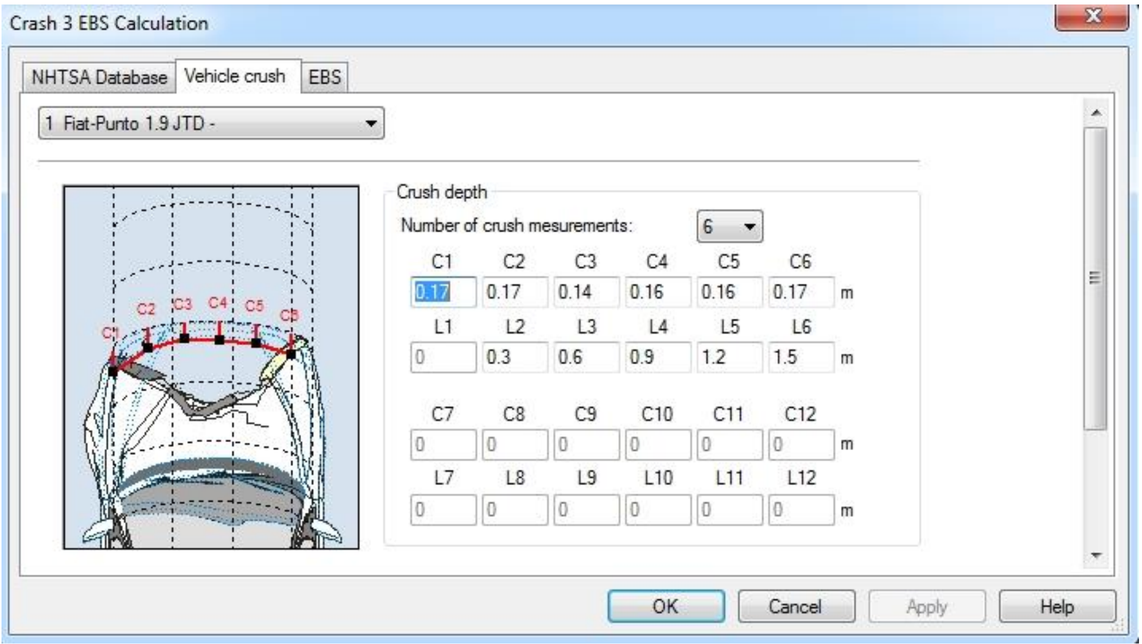

Figure 15. Defining the damage

After the damages of the front part of the vehicle are defined, in the last tab, and based on the data collected from the crash test, energy lost on deformation in a process of collision Ed is calculated, and based on that, EBS values are calculated as well. If necessary, correct the EBS value by entering Θangle of impact force deviation of the vehicle longitudinal axis.

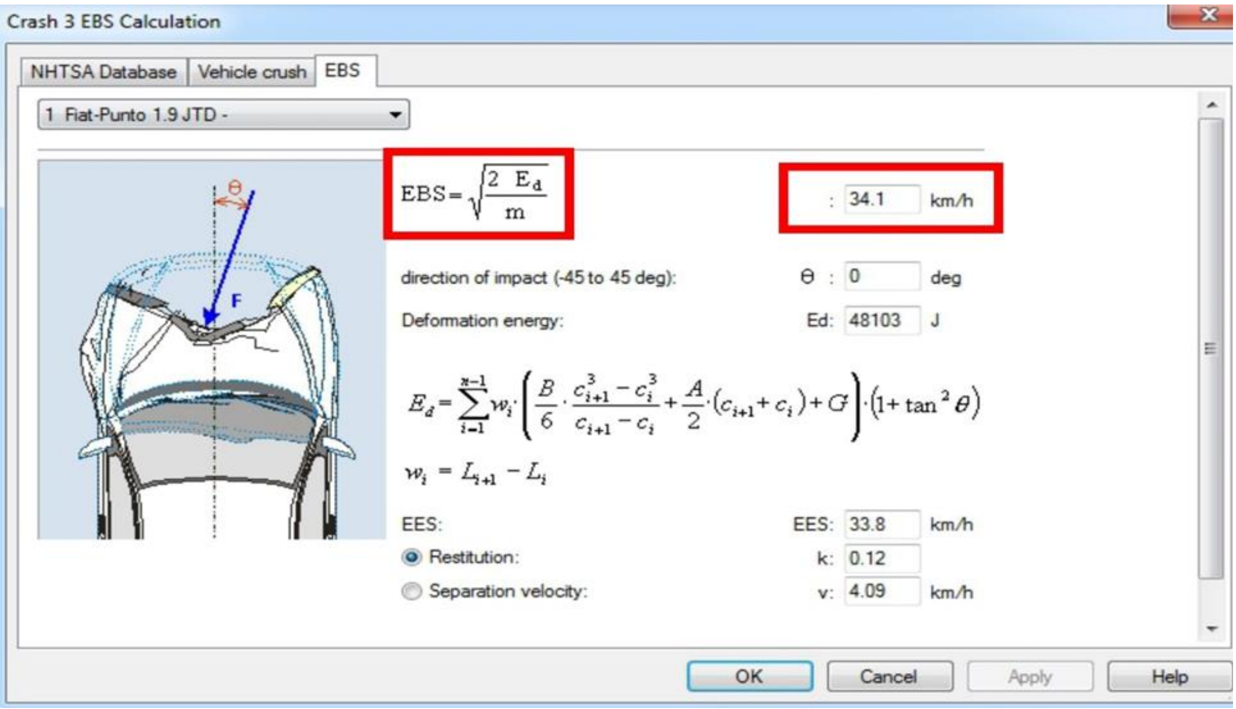

Figure 16. Calculation of deformation energy and EBS values

In our case, the EBS value for damaged vehicle Fiat Punto is 34.1 km/h, while the EES is slightly smaller and is 33.8 km/h.

It was explained that EBS and EES parameters are equivalents of energy dissipated on vehicle deformation (neglecting the work required to e.g. cover the post-crash distance with braking or skidding). But: EES is the velocity at which an impact against a rigid, non-yielding barrier should be performed to get only identical plastic deformation, while EBS additionally takes into account elastic deformation (so EBS≥EES). It is the elastic part that was included in G factor in deformation energy equation Ed.

At the bottom of the box three fields were added:

- EES
- k - coefficient of restitution
- V – vehicle separation velocity difference.

This makes it possible to check what EES value would be if for the velocity of impact against a rigid non-yielding barrier V=EBS coefficient of restitution was k, or alternatively, the difference of vehicles separation velocity was V. The results of EBS or EES calculations are not transferred to any other place in the program.

7. CONCLUSIONS

Photogrammetric method represents one of the fastest methods of data collecting about vehicle geometrics. On the other hand, PhotoModeler package program provides an efficient solution and high quality realistic end results. It is easy to use, but also capable of modeling very complex details with satisfactory preciseness. If to this is added a possibility of creating a 3D model based on photographs from site accident investigation documentation that are made by an unknown camera, then it is clear what advantages has a modern 3D photogrammetry software solution. Apart from a possibility to directly measure damage depth on vehicles, given models can be exported into various formats and further used in CAD programs. Information about damage depth can also be further used for calculations of EES values, position of impact direction, determining mutual damage compatibility, etc. and in combination with software that deal with traffic accident simulations make very powerful tool at court proceedings.

REFERENCES

[1] PhotoModeler Scanner, User manual.

[2] Coyle, F., Digital close-range photogrammetry in motor vehicle accident reconstruction ,Dublin Institute of Technology, 2008.

[3] Burtch, R. Lecture notes-Analytical photogrammetry, The Center for PhotogrammetricTraining, August 2000.

[4] Tomasch E., Accident Reconstruction Guidelines, Graz University of Technology, AT, October 2004.

[5] Wojciech, W., „Simulation of Vehicle Accidents using PC-Crash“, Institute of Forensic Research Publishers, Krakow, 2011, ISBN 83-87425-68-0.

[6] Burg H., Moser A., „Handbuch Verkehrsunfallrekonstruktion“, Friedr. Vieweg & Sohn Verlag | GWV Fachverlage GmbH, Wiesbaden, 2007, ISBN 978-3-8348-0172-2.