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A New Methods for the Evaluation of the Quality of Accident Reconstructions

Abstract

In order to improve the protection of children transported in cars, within the CHILD programme (GR3D-CT2002-00791) real world road accidents are thoroughly analysed and then reconstructed in laboratory.

Prior to comparing injury severities of real victims to physical parameter values measured on the dummies, the quality of the reconstructions is evaluated by experts who use their experience based on the investigation of numerous and various accidents.

This paper presents a new tool aiming at better evaluating and validating accident reconstructions. It is based on statistical evaluation of vehicle deformations which gives weighing factors for every part of the car body structure finally leading to a specific Reconstruction Quality Score (RQS indicator). Furthermore, the reliability of this score, depending on the number of measured points, can be established.

This tool includes a function aiming at adjusting the speed for a further reconstruction and at defining the launching speed and the pulse shape for complementary sled tests.

Finally, the functions of the RQS software and database are presented.

Introduction

Biomechanical knowledge for passive safety purpose is currently based on experimentations performed with PMHS's. The advantages, legal conditions and scientific limitations of this method are well known. The main experimental parameter reducing the application of test results for the protection of human life is the mean age of the subjects.

An alternative to experiments performed with anatomical body parts is represented by real-life accident investigations supplemented by their experimental reconstructions. The main advantage of this research way is that the panel of victims is representative of the whole population exposed to the risk of collision.

Moreover, for such specific occupants like children, for whom it is very difficult or even impossible to perform PMHS testing, it is the only way for acquiring reliable biomechanical data.

In both methodologies, the ultimate goals are identical. These are:

a identification and description of injury mechanisms;

b definition of relevant injury criteria;

c determination of reliable injury risk curves and protection reference values for the crash anthropomorphic dummies used for regulation purpose or comparative crash tests performed for consumers information.

The advantages of the accident investigation/ reconstruction method are however balanced by some difficulties which may lead to unreliable results. These difficulties are mainly due to the fact that accident analyses are carried out a posteriori. Hence, equivalent energy speed (EES), overlap, angulations and body vehicle heights are assessed by experts and partly based on empirical methods. Moreover, particularly in the case of injured children using CRS's, parameters such as adjustment of belt or harness and especially misuses are difficult to determine. Consequently, it seems necessary to develop methods aiming at eliminating those approximations leading to weak correlations. It is the case of accident speed, overlap and angulations which have an effect on the car(s) deformations and consequently on the loads sustained by the occupants. Over the years, a lot of effort has been devoted to increase the accuracy of the evaluation of these accident parameters from accident scene evidences (see for instance McHENRY et al., 2003, or MOSER et al., 2003). But in the evaluation of the quality of the reconstruction, the deformation sustained by the vehicle(s) in the reconstruction cannot play an important role, either because they are calculated by simulation or they are considered globally. It seems that no systematic approach based on the study of the deformation of well identified vehicle structural points has been tried so far. In the present work, the vehicle deformations have to be measured on the crushed parts, compared and submitted to basic statistical functions such as average value, standard deviation and variance in order to establish a quality score of the reconstruction.

Objective and Priciples of the RQS Method

This method is intended to help experts to assess the quality of the reconstruction of a real world accident in terms of correlation of dissipated energy between a vehicle involved in a real world accident and its homologue used for the reconstruction.

For this purpose, a “Reconstruction Quality Score” based on the deformations of the main relevant vehicle body parts – longitudinal members, damper housing, A-pillar, foot well, etc, (see figure and table in annex) – is calculated.

There is an infinite number of ways to calculate a reconstruction quality from the comparison of vehicle deformations. The present work, after an extensive comparison of various candidate indicators and score weighing methods, led to define a composite score based on:

- The absolute values of the deformation differences
- The relative values of the deformation differences:
- weighing factors depending on the deformation variability at each considered point and depending on its position with respect to the impact point

For each point, a score is computed from an absolute and a relative deformation indicator and then, all scores are weighted and mixed in order to give a global quality score.

Definition of Deformation

The deformations values are obtained by measurement of the location of relevant points on the car body, before and after the crash (see figure in annex 1). They are projected on relevant vehicle axes:

- the longitudinal components of the deformations, for the frontal collision
- the transversal components of the deformations, for the lateral collision

D_{acc} is the deformation on the real world accident vehicle whereas D_{rec} represents the deformation sustained by the vehicle used in the reconstruction.

Indicators Evaluated to Calculate the Local Reconstruction Quality Score

The simpler deformation indicator is the absolute one:

$I_{abs} = | D_{acc} – D_{rec} |$

Of course, an absolute difference between two deformations does not have the same meaning if the deformations are small or large. A 1cm difference between 5 and 6cm is not the same as a 1cm difference between 99 and 100 cm. To deal with this problem, a relative indicator can be considered:

$I_{rel} = | D_{acc} – D_{rec} |/| D_{acc} |$

But, at low deformation values, the relative indicator can lead to unrealistic values. For instance, in a real accident D_{acc} can be very small, even zero, while D_{rec} can take any value. In this case, the values of I_{rel} cannot be considered reliably.

In fact, both absolute and relative differences values have to be taken into account for the following reasons. In a real word collision at low speed, for instance, with an average real world deformation value of 10cm, if the deformation recorded for its reconstruction is 20cm, the absolute difference value I_{abs} is 10 while the relative difference value I_{rel} is 100%. In this case the score based on the I_{rel} would be nearly “0”. However, since car peripheral stiffness is low, experts consider in such cases that the crash test is acceptable. Consequently, for low energy crashes, I_{abs} will be considered for establishing the score.

On the opposite, for high severity situation, with deformation values ranging from 80cm up to 120cm, it is preferable to consider I_{rel}: a difference of 10cm in this range represents a I_{rel} of 8.3 to 12.5%. For such values experts decide that correlations can be validated.

A lot of other indicators have been tested and compared, but none of them could bring a decisive advantage; hence the two first indicators described above have been kept. The absolute indicator is used for deformation under a maximum value D_{max}; the relative indicator is used only if the deformation difference is smaller than the absolute deformation measured in the accident:

$$| D_{acc} – D_{rec} | < | D_{acc} |$$

Then, a local score, ranging from 0 to 10, is calculated from the indicator using a function. The simplest function is the linear one giving a decreasing score along with an increasing deformation difference (figure 1). When the difference reaches D_{max}, the score drops to zero:

$$S_{abs} = 10 – (10/D_{max})*I_{abs}$$

Other functions have been also considered (parabolic, hyperbolic, exponential) for calculating the local score. A good result comes from the exponential one especially with the relative deformation indicator (figure 2).

$$S_{rel} = \exp (-(I_{rel}/100)^a/b)$$

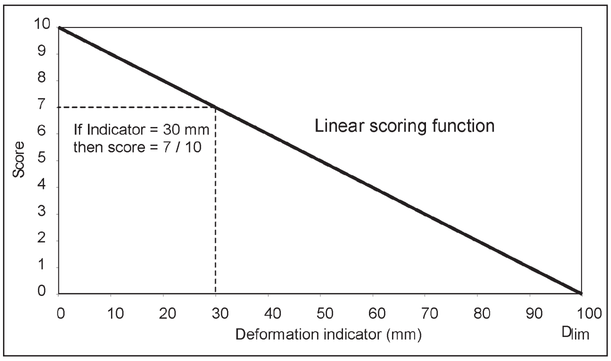

Fig. 1: Linear function giving the score as a function of absolute deformation

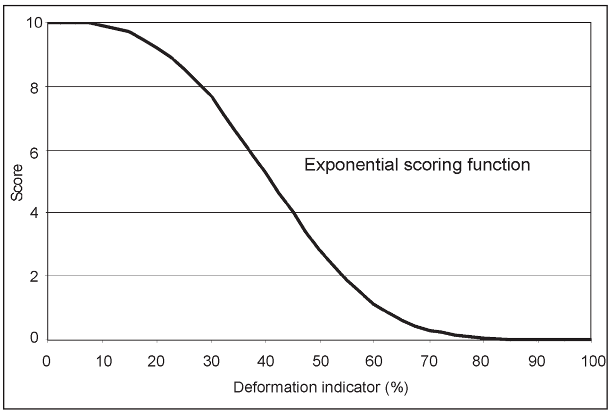

Fig. 2: Exponential function used to built the score from relative deformation

With appropriate values of a and b, the score drops rapidly to zero when the deformation indicator goes beyond a certain percentage, eliminating too high relative deformations.

Then, the reconstruction quality score RQS_i can be built for a given point P_i. It includes several terms weighted by 2 coefficients α and β:

$$RQS_i = \alpha\, S_{abs1} + (1 - \alpha) [\beta\, S_{abs2} + (1 - \beta) S_{rel}]$$

The coefficients α and β determine the ratio between absolute and relative differences used for the calculation of RQS. These coefficients depend on thresholds D_{lim} and E_{lim} and on the value of γ_1 and γ_2. These two last parameters determine the slope of the curves defining the values of α and β respectively. These coefficients are determined according to the following expressions:

$$\alpha = 1 \quad \text{if } D_{moy} = (D_{acc} + D_{rec})/^2 < D_{lim}$$

$$\alpha = \exp (-1*((D_{lim} - D_{moy})/D_{lim})^2/\gamma_1) \text{ otherwise}$$

$$\beta = \exp (-1*((E_{lim} - | D_{acc} - D_{rec} |)/E_{lim})^2/\gamma_2) \text{ if } | D_{acc} - D_{rec} | < E_{lim}$$

$$\beta = 1 \text{ otherwise}$$

The values of D_{lim}, E_{lim}, γ_1 and γ_2 can be tuned in order to get the best correlations between the RQS and the evaluation given by the experts as described later on. The variation of α along with increasing average deformation (D_{moy}) is depicted by curves of figure 3. Variations of β with increasing deformation differences are depicted by curves of figure 4.

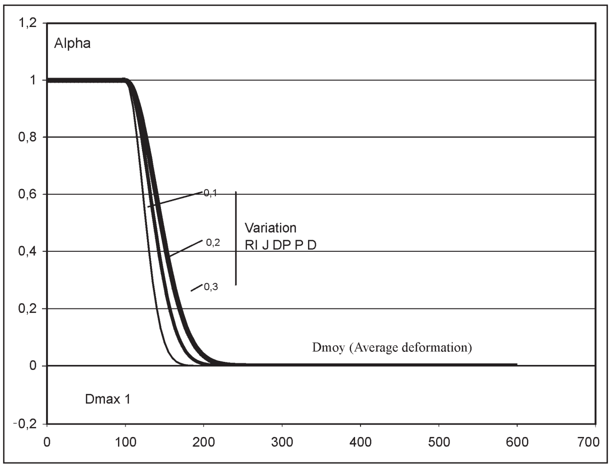

Fig. 3: Variation of coefficient α as a function of the average of the deformations measured on the real world vehicle and on the reconstruction vehicle. D_{lim} and γ_1 condition the shape of the curve

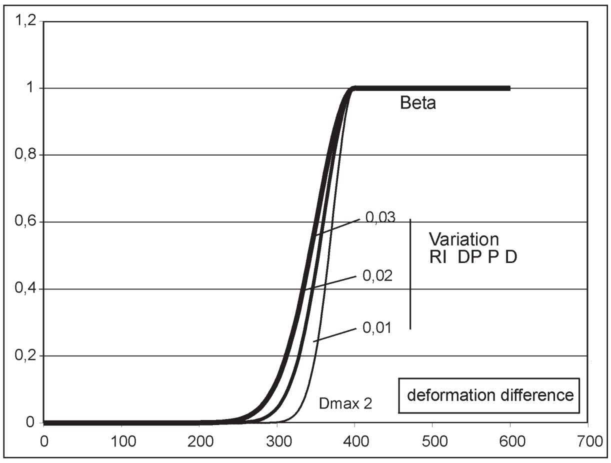

Fig. 4: Variation of coefficient β as a function of the relative difference of deformations measured on the real world vehicle and on the reconstruction vehicle. E_{lim} and γ_2 condition the shape of the curve

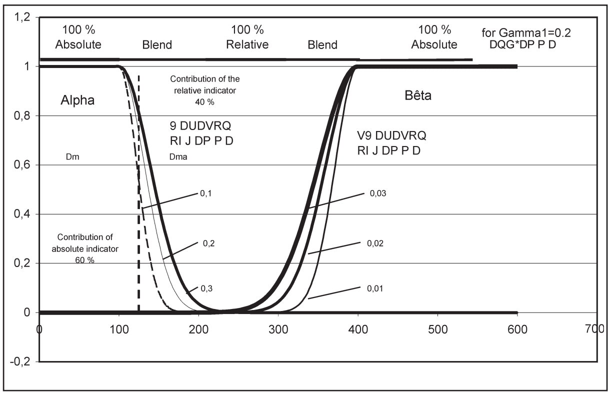

Fig. 5: Evolution of parameters α and β along with deformation and contribution of absolute and relative indicators in the score definition

Weighing Facors

Weighing coefficients (W) are assigned to the reference points measured on the vehicle structure. The values of these coefficients have been calculated from about 26 accident reconstructions selected in the CREST[1] database. Measured structure deformations have been normalised taking into account the global energy dissipated in the crash (weight and speed of the car(s)):

- For every point, standard deviations have been determined.
- Statistical calculation led to weighing factor values which are inversely proportional to the variance ($W_i = 1/\sigma_i^2$).

The variability of the deformations measured at various points of the vehicle structure is graphically shown in figure 6. For each point, this variation is expressed by the standard deviation converted into a percentage value. Its value partly depends on the distance separating the considered point and the initial impact point. The value of the standard deviations for different structure points have been calculated on 43 cases of reconstructed frontal-left collisions. They are given in table 1 sorted by increasing order of deviation magnitude.

[1] CREST = EC funded project devoted to the safety of children transported in automobiles (1996-2000)

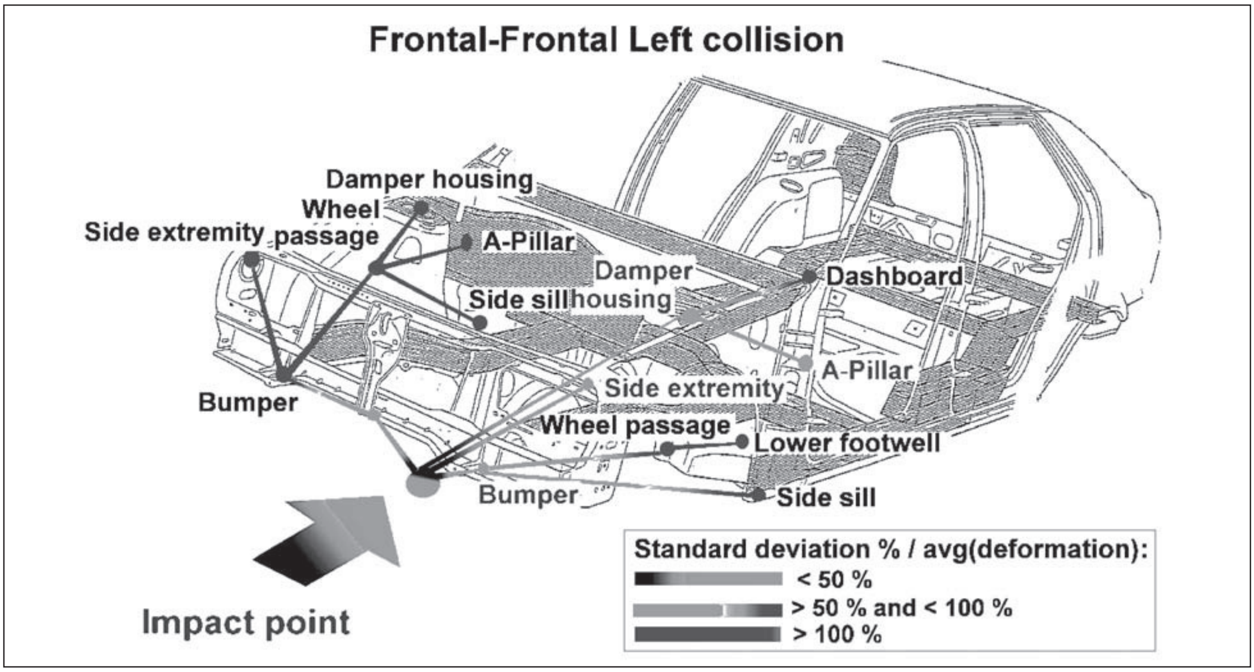

Fig. 6: Variability of deformations measured at various locations of the vehicle structure

Structure control points	Standard deviation %	Mean deformation (mm)	Number of cases
Max Intrusion	29	-863	24
Bumper Left	30	-735	14
Extremity Left	30	-889	9
Side Extremity Left	34	-837	10
Damper Housing Left	44	-410	20
Vehicle Axis	45	-655	20
A-Pillar (Front Pillar) Left	61	-206	20
Wheel Base Left	67	-348	23
Bumper Right	75	-288	13
Dashboard Left	76	-213	23
Upper Footwell Occ Axis Left	76	-190	18
Upper Footwell Left	86	-206	8
Side Sill Left	88	-208	19
Upper Footwell Occ Axis Right	99	-57	19
Lower Footwell Right	110	-44	10
Extremity Right	115	-193	8
Side Extremity Right	118	-241	8
Lower Footwell Left	120	-169	10
Upper Footwell Right	139	-22	8
Damper Housing Right	144	-81	20
A-Pillar (Front Pillar) Right	192	-22	20
Dashboard Right	215	-40	23
Side Sill Right	527	-4	19
Wheel Base Right	5164	-2	22

Tab. 1: Deformation variability for various structure points calculated on 26 reconstructions of frontal left collisions (CREST database)

Global Reconstruction Quality Score

The global reconstruction quality score is the weighted sum of local quality scores for all the points of the structure

$$\mathrm{RQS} = \frac{\sum_{i=1}^{n} RQS_i \times \frac{1}{\sigma_i^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

Where:

- n is the number of measured points
- RQS_i is the score for every point P_i
- s_i^2 the variance for point P_i

Reliability of the Score

It is essential to take into account that all the measurements points could not be available for calculation. In such cases, the method can be used but obviously, the reliability of the score is reduced. The calculation of the reliability is based on the following formula:

$$\text{Reliability (\%)} = \left(\frac{\sum_{i=1}^{n} \times \frac{1}{\sigma_i^2}}{\sum_{i=1}^{n'} \frac{1}{\sigma_i^2}} \times 100 \right) - Cste$$

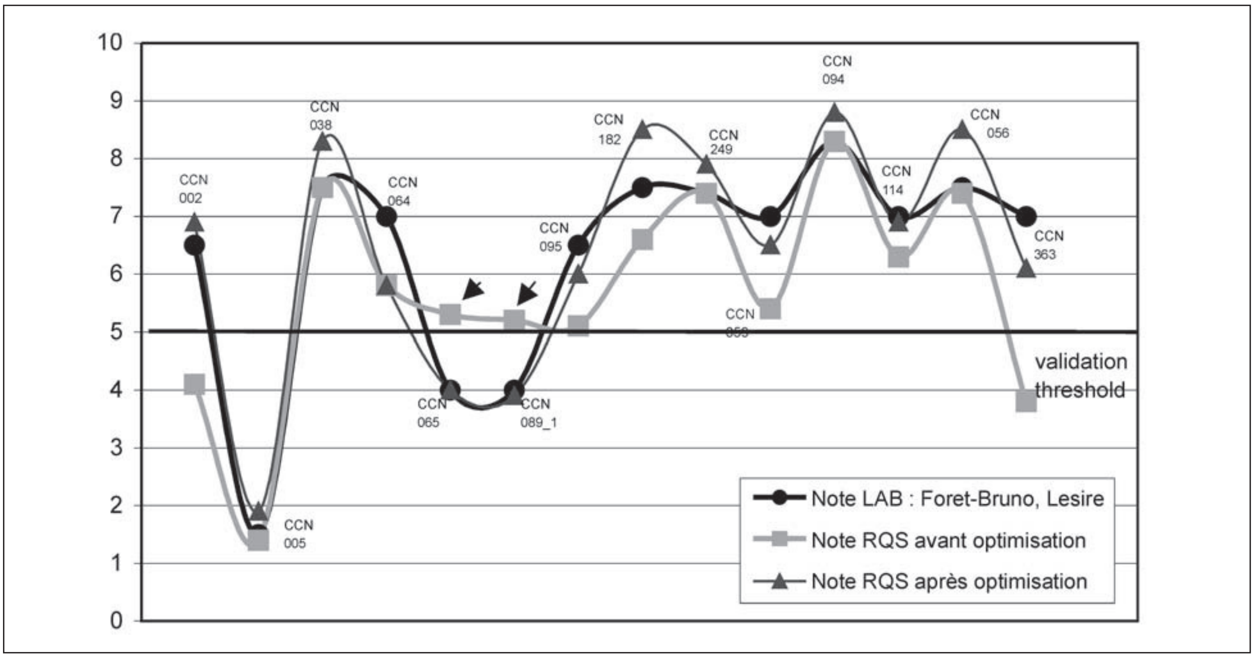

Fig. 7: Score values before and after adjustment of the α and β coefficient to match the experts' scores on several accident reconstructions

Where n is the number of points considered for the calculation of the score and n' is the total number of points of the structure. Thus, the reliability depends not only on the number of measured deformations but on the weight of the considered body component too.

Validation of the RQS Method

In a first phase, the weighing factors were discussed, adjusted and validated with the accidentologists of the LAB Renault Peugeot Citroën. Then, calculated scores and scores empirically assessed were compared in order to tune the values of parameters α and β. Finally, a genetic algorithm was used to find their optimum values. On figure 5 are shown the score values for different accident reconstructions. The three curves correspond respectively to the expert scores, the calculated scores before optimisation and the calculated scores after optimisation.

Complemtary Application of the RQS Method

The results of the calculations and more particularly the average value of deformation furthermore enable:

- the adjustment of the speed for another reconstruction;
- the calculation of the precise velocity and pulse characteristics for sled tests if parametric tests are necessary to complement the full scale test (see figure 6).

The calculation is based on the principle that the average deformation is linked to the change of velocity. The adjusted velocity and deceleration pulse (for the sled) are determined owing the following hypotheses:

- The average weighed sum of the deformations is proportional to the displacement calculated by double integration of vehicle acceleration; hence the lack or excess of deformation may be used to adjust the vehicle velocity.
- The crushing force acting on the car body remains constant when the deceleration plateau is reached and the deformation difference is due to a different duration of the deceleration plateau.

These hypotheses enable the calculation of the correct test car velocity which will generate the same deformations as those observed on the real world accident car.

Conclusion

The RQS method is an attempt to help accidentologists to get a more objective evaluation of the quality of accident reconstructions performed in order to better identify injury mechanisms and establish injury risk curves. It seems that no previous such attempt has been conducted so far.

The method is parametric which enables to easily take experts' experience into account. Its reliability will improve significantly with the increase of the number of cases included in the data base.

A first validation of the method and of the software has been obtained owing to the accident reconstructions performed in the frame of the CREST programme. This will be continued with the reconstructions performed in the CHILD programme.

Presently, only reconstructions of frontal collisions can be analysed. Further development is needed to deal with other crash configurations such as lateral impact and rear impact.

Of course, the method can be improved, particularly in adjusting the weighing factors. This progress will be possible if a large number of laboratories use this tool and return the results to the developers.

Acknowledgement

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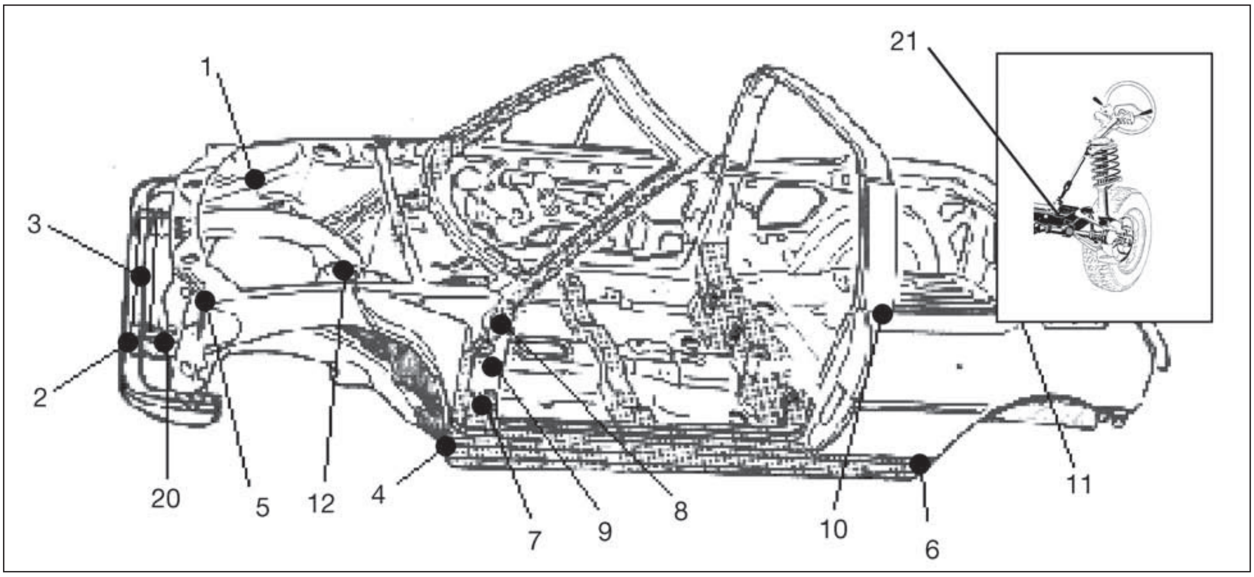
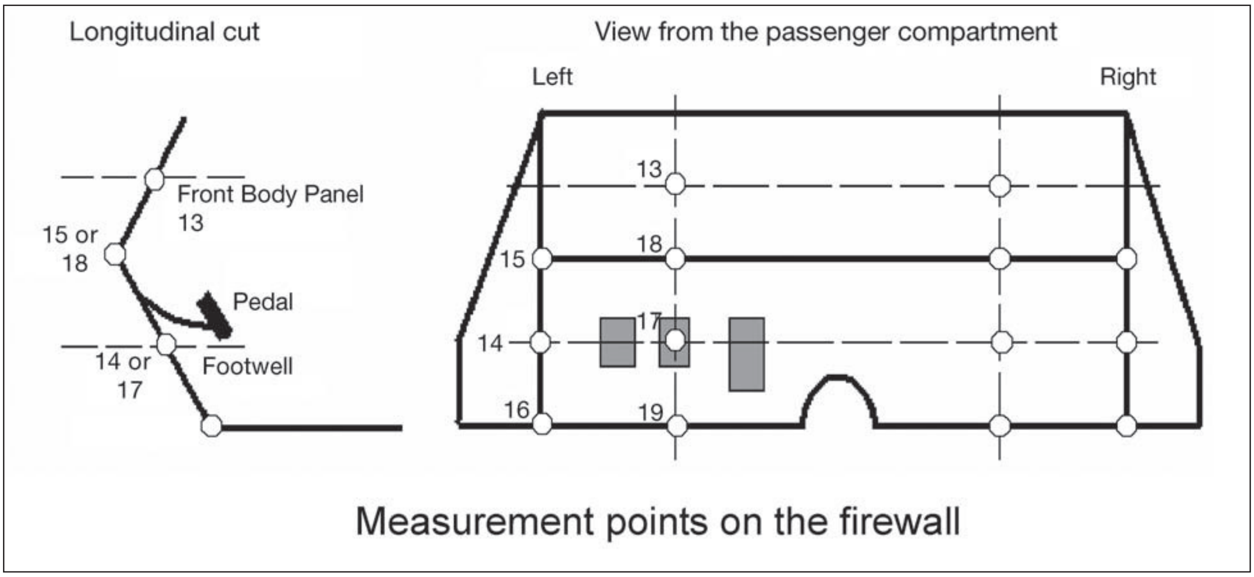
ANNEX 1

Relevant Vehicle Body Part Points Used for Calculation

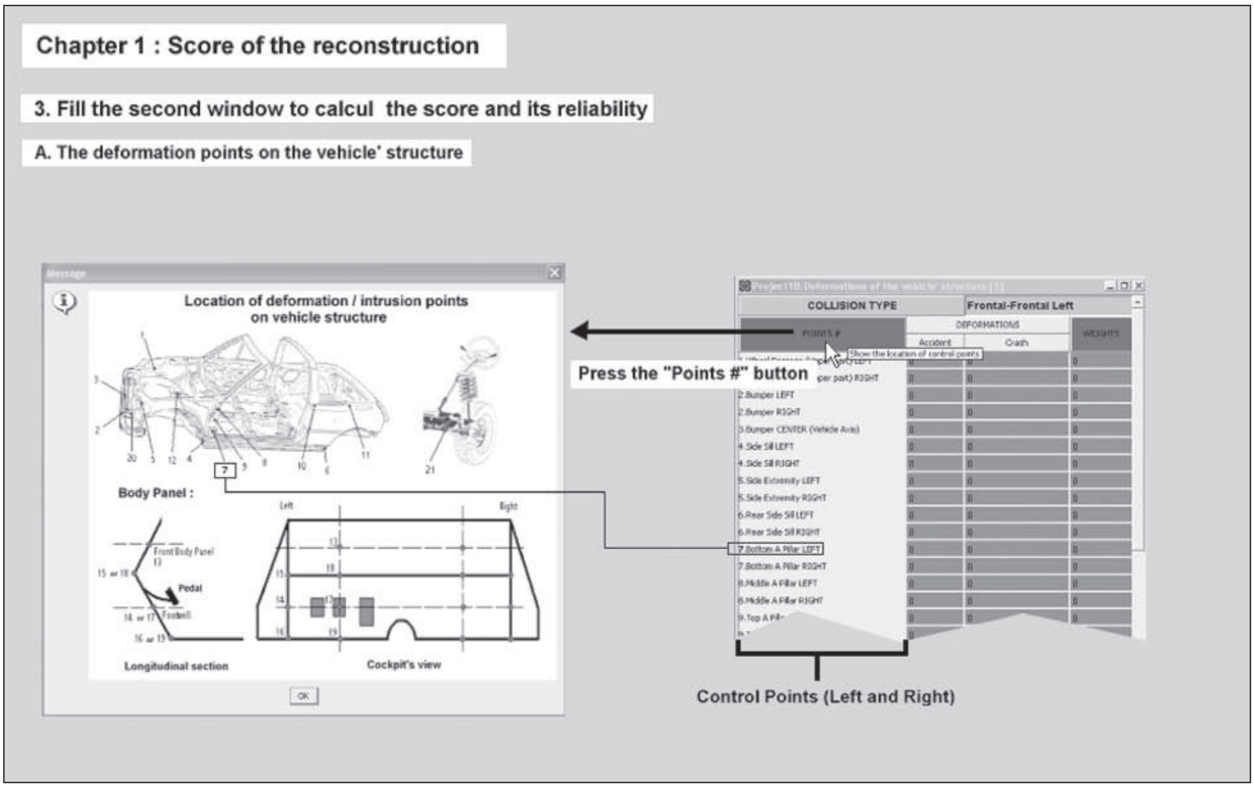




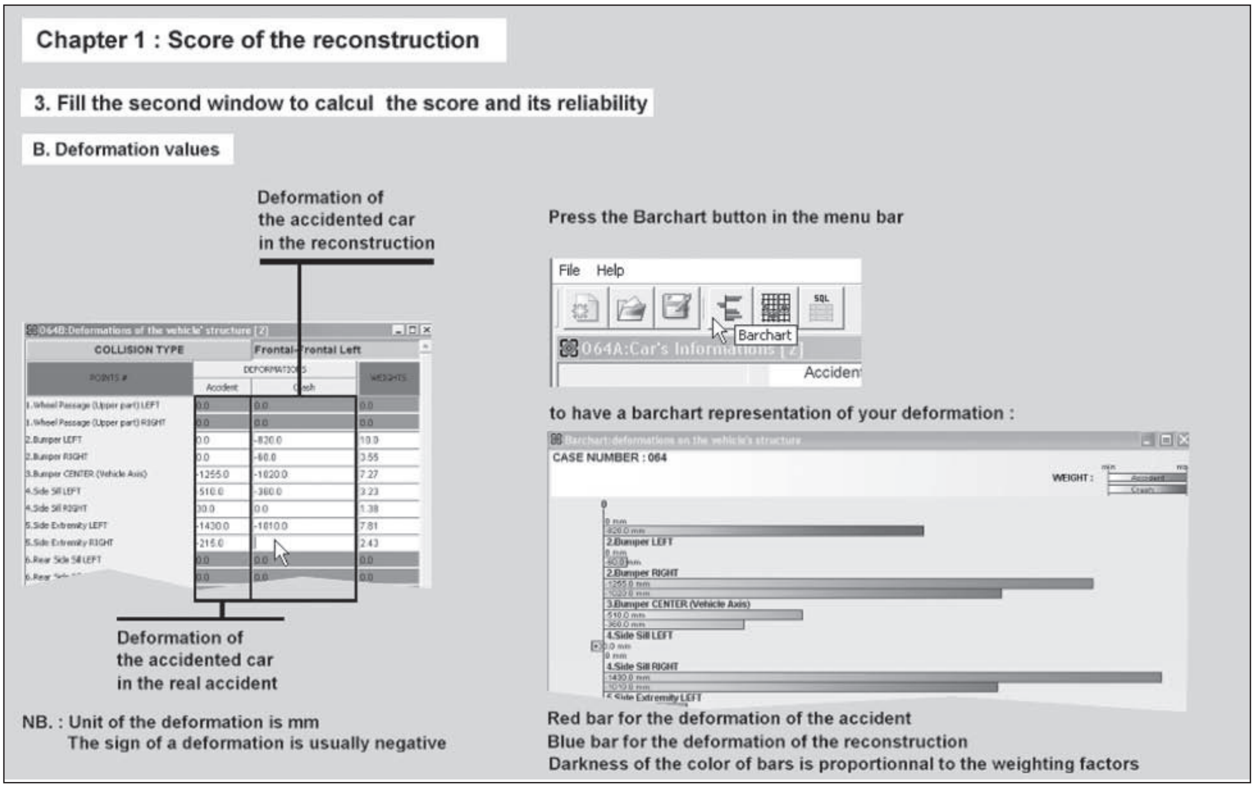
Points #	Designation	Points #	Designation
1	Wheel Passage (Upper part)	12	Damper Housing
2	Bumper	13	Front Body Panel
3	Bumper Centre (Vehicle Axis)	14	Middle Foot well
4	Side Sill	15	Upper Foot well
5	Side Extremity	16	Lower Foot well
6	Rear Side Sill	17	Middle Foot well occ. Axis
7	Bottom A-Pillar	18	Upper Foot well occ. Axis
8	Middle A-Pillar	19	Lower Foot well occ. Axis
9	Top A-Pillar	20	Longitudinal Beam
10	B-Pillar	21	Unit/Lower wheel arm attach point
11	C-Pillar	22,23	Dashboard, Dashboard Centre

Annex 2: The RQS Sofware

Entering the Deformation Values



Visualising the Entered Deformation Values and the Corresponding Weighing Facors



Calculation of Score and Reliability

Chapter 1 : Score of the reconstruction

3. Fill the second window to calcul the score and its reliability

D. Calcul the score of the reconstruction

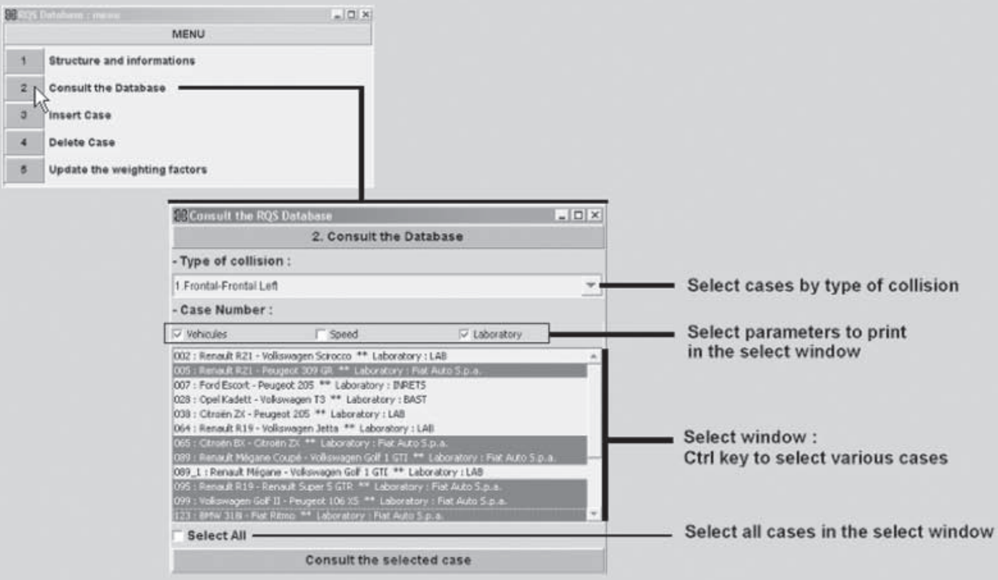
Press the CALCUL button
to have the score and its reliability
The reliability depends on the number of using points and on the weight of these points

RQS Database Functions

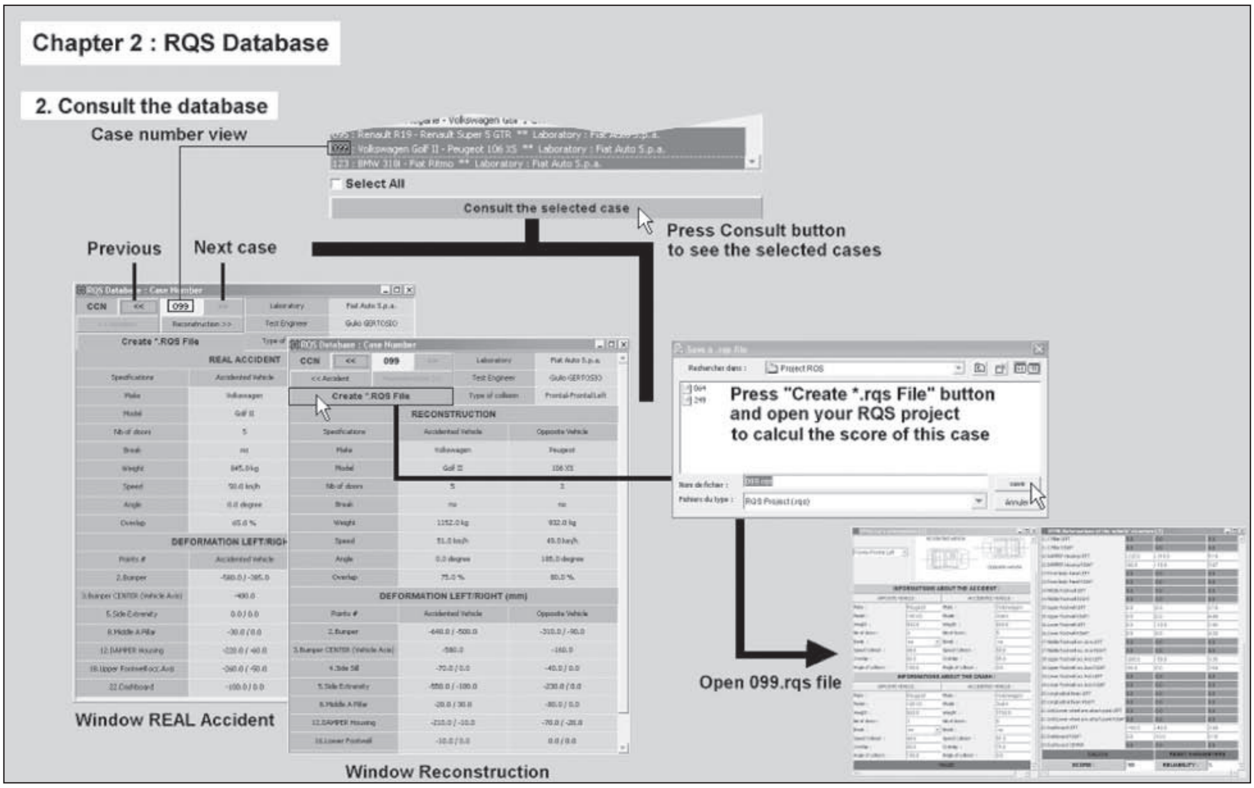
Chapter 2 : RQS Database

2. Consult the database

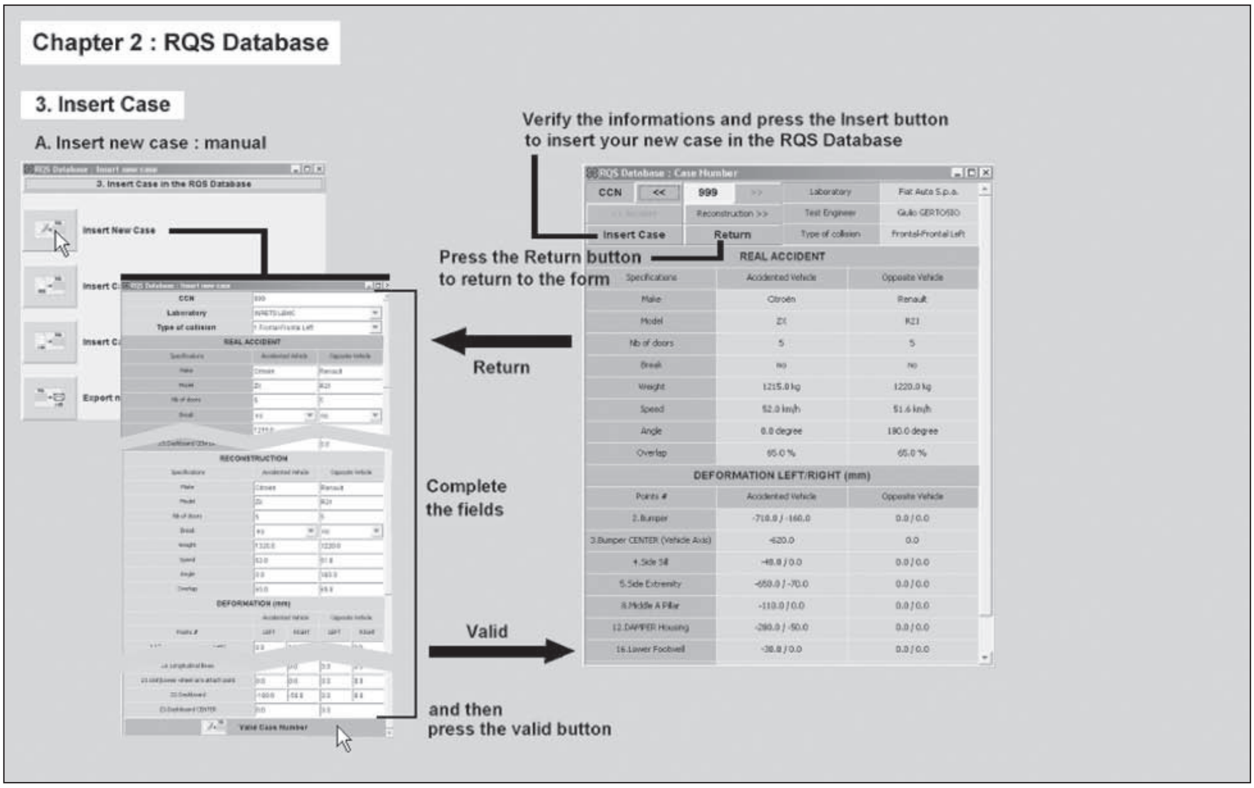
Select cases in database



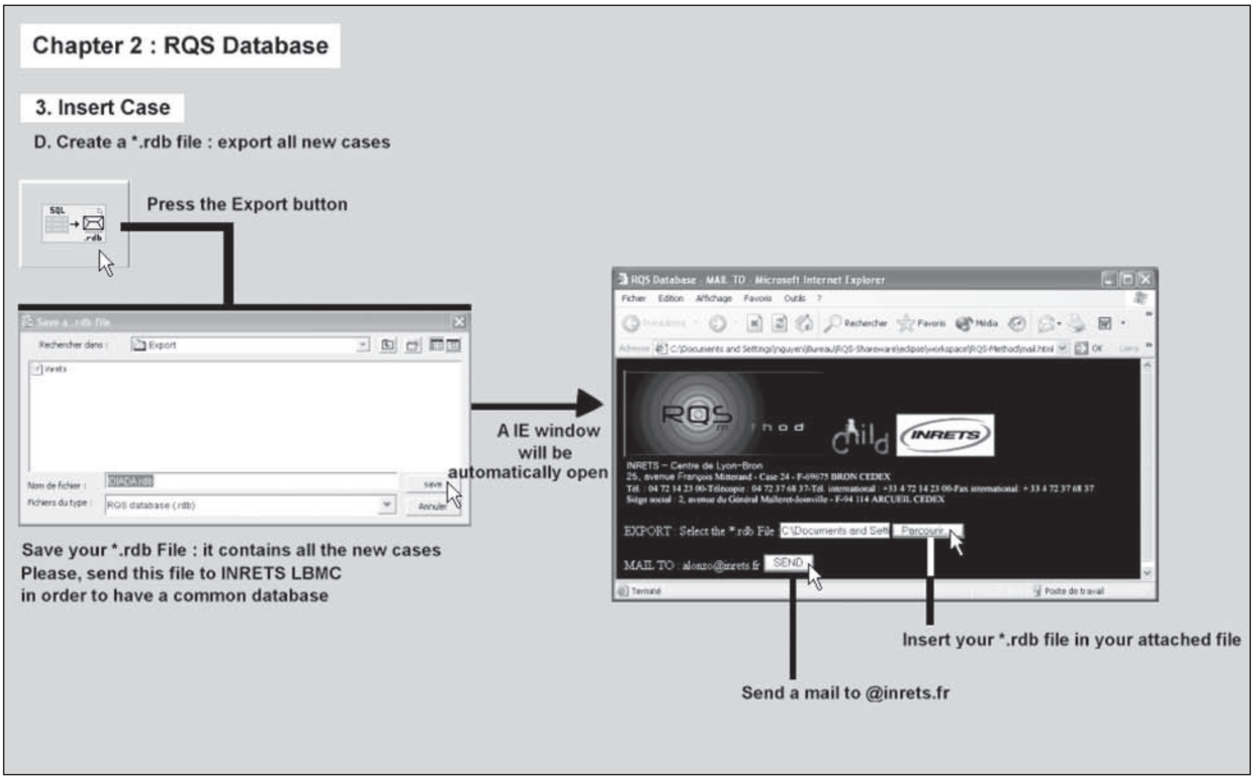
RQS Database: Access to the Stored Cases and Score Calculation



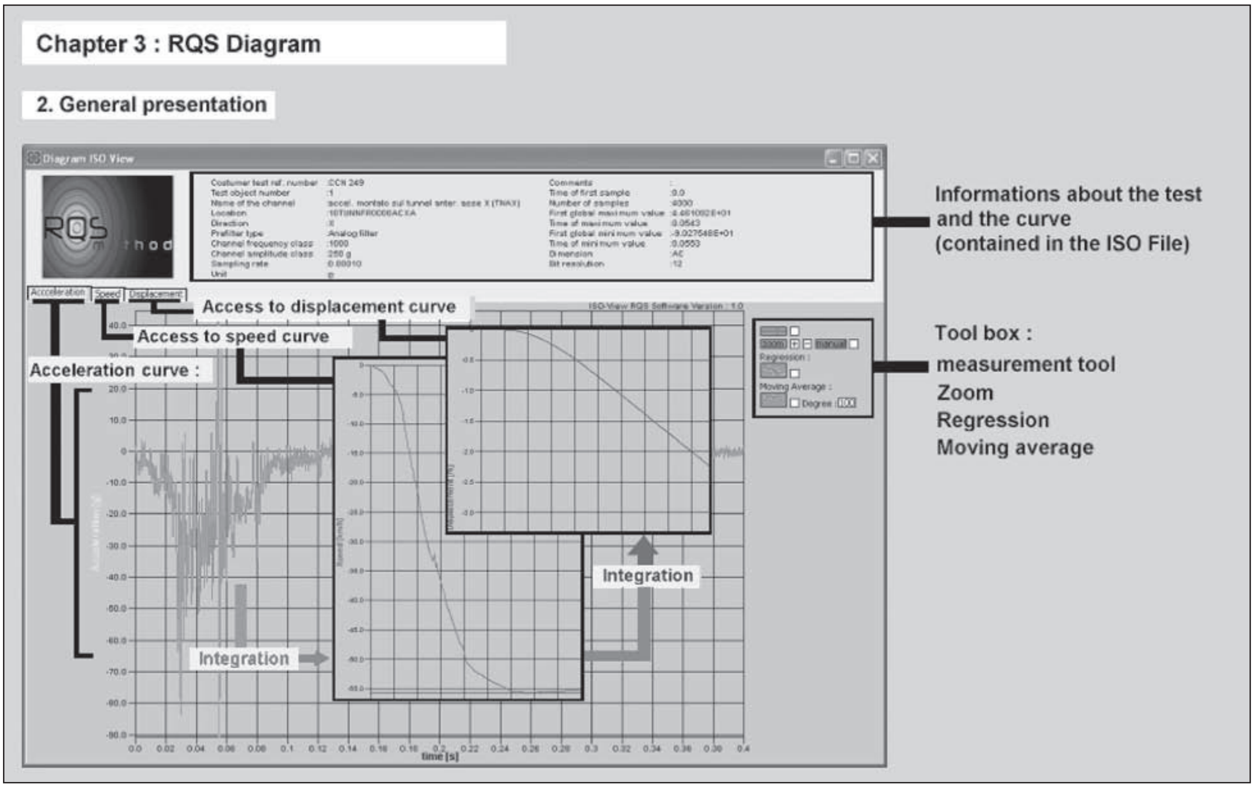
RQS Database: Insertion of a Case



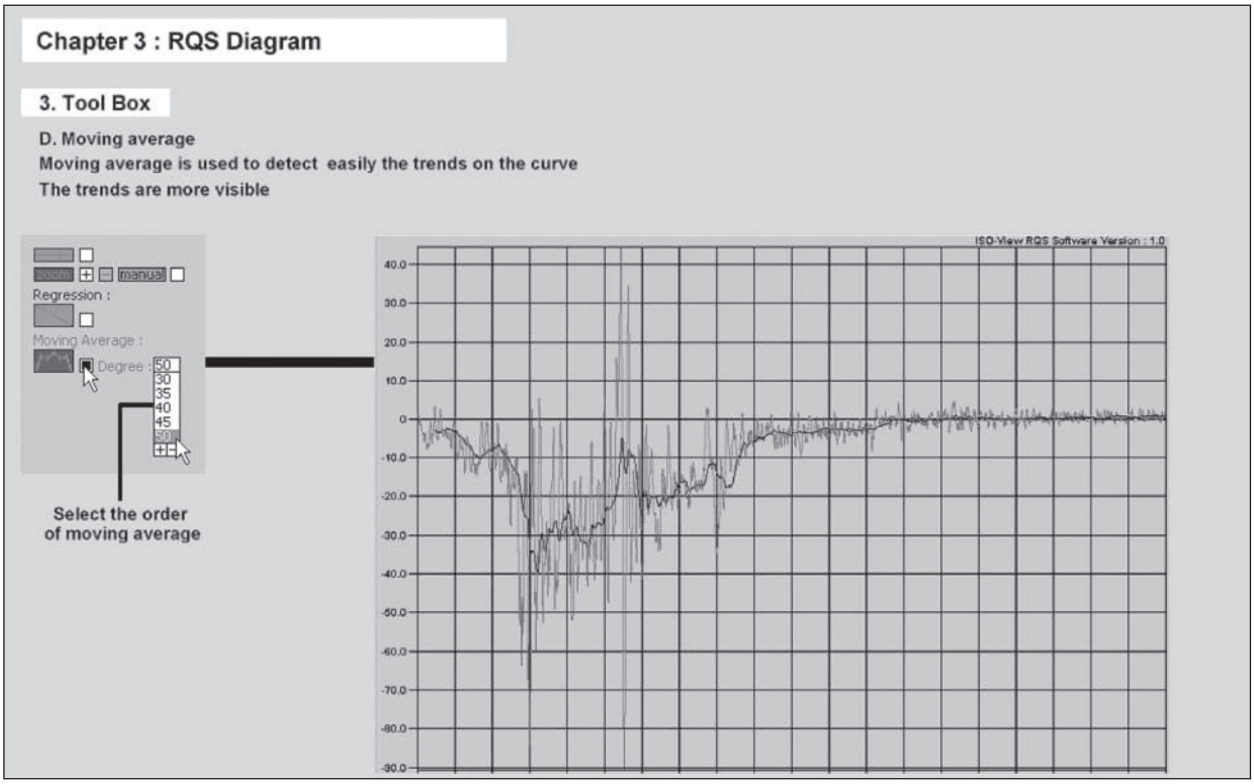
RQS Database: Up-Dating the Database at Inrets



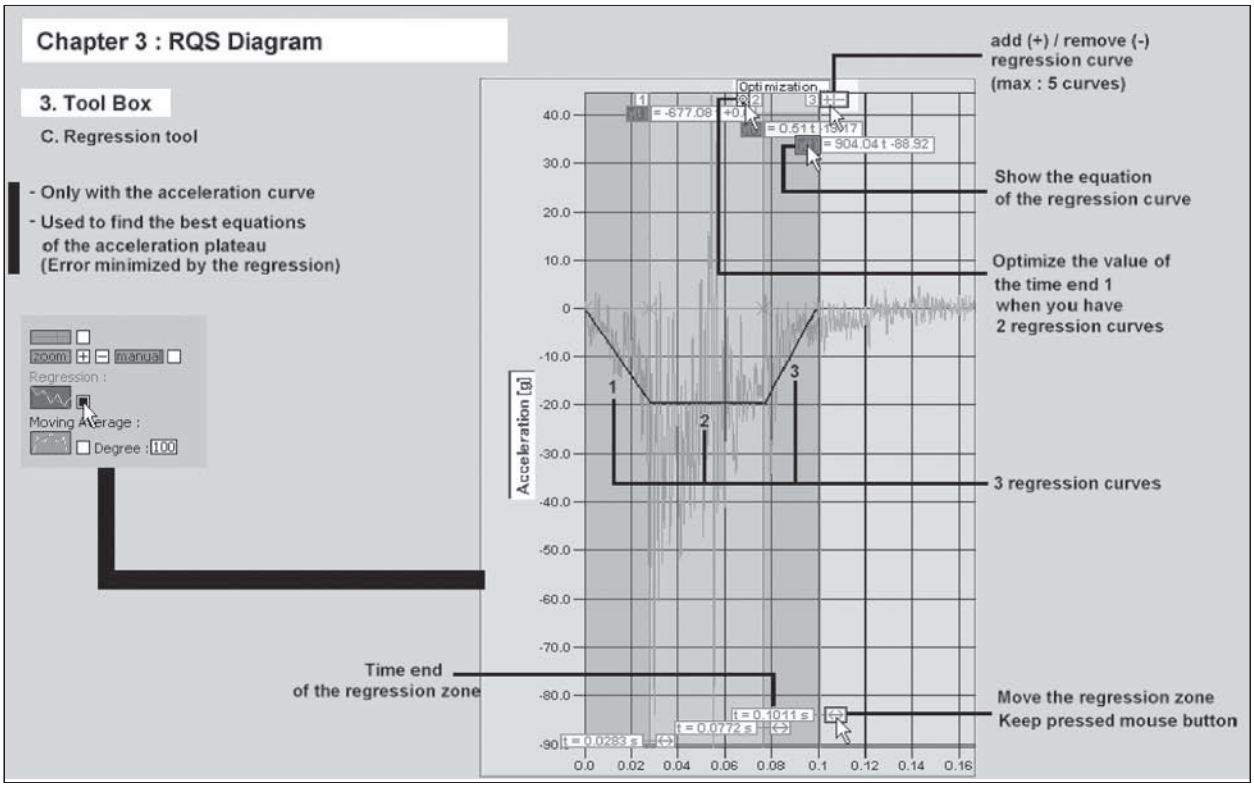
Calculation and Curve Edition Funktions



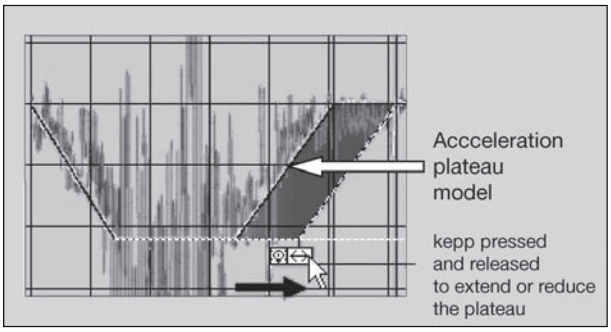
Calculation of Moving Average



Calculation of a Sled Pulse based on the Deceleration of the Case Vehicle



Adjustement of the Speed for a Second Reconstruction or for Determination of Initial Speed and Deceleration Law of the Sled Used for Complementary Parametric Tests



The effect of extension or reduction of the plateau length in terms of speed and displacement is calculated and visualised. The right adjustment value is reached when the effect on displacement corresponds to the difference of average deformations between the accidented and the tested vehicle.