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ACCIDENT RECONSTRUCTION EXAMPLE – A POSSIBLE MODALITY FOR ROLLOVER “AFTER THE FACT” STUDY

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KEYWORDS

accident reconstruction, rollover, rigid body mechanics, 2D model, reverse kinematics

ABSTRACT

The accident reconstruction tries to find the circumstances that generated the driving accident. The most used method to estimate these conditions appeals to the “reverse kinematics”, which starts the study with the final positions of the vehicles and go in time, step by step, toward the initial situation. The analysis bases on the knowledge and the experience of the expert and consists in making suppositions about the way the things happened. The computations results conjugate with elements found on the accident place can confirm or infirm the assumptions made.

The accident studied in this article consists in a road living followed by a “flight” and some rollovers. Because the sad fact occurs in wintertime, the snow existing on the place retained the marks where the front and rear ends of the car hit the ground. Using these elements and the laws of rigid body movement (ballistics and momentum conservation), the reconstruction was possible with high level of certitude.

This way of judgement can be useful in other analyses that imply vehicle rollover, including short displacements thru the air.

MAIN SECTION

INTRODUCTION

This article relates to a tragic traffic accident. In a winter night, witnesses found in the road neighbourhood a crashed car and two dead bodies, of the driver and of the passenger. The snow existing at the accident scene permitted to the police officers that first investigate the incident to obtain good marks. They realised photos (figures 1 to 6) and measurements that permitted to obtain later a schematic with the main distances between marks (figure 7).

Fig. 1 Global view of the accident scene

Fig. 2 Place of first impact (point 3, left-front knock)

Fig. 3 Place of second impact (points 4 and 5, back knock)

Fig. 4 Place of third impact (point 6, back knock)

Fig. 5 Damaged vehicle – front-right view

Fig. 6 Damaged vehicle – front-left view

The judicial analyse of the circumstances that drove to the accident was made by the first author of this article, in his quality of technical expert.

The first impression was that is the case of an off-going, the vehicle quitting the traffic way, hitting with power the bank of ditch and then suffering more ground leavings and rollovers. That the situation was like this, results from any marks missing from long distances.

ACCIDENT RECONSTRUCTION METHOD

The marks leaved by the car are schematically presented in figure 7, together with the trajectory of the centre of gravity. The most important points for the accident dynamics were numbered in order from 0 (place where first marks appear in the snow from the left side of the road, in respect to the sense of displacement) to 8 (place where the car stops). All references to these points conform to their position in figure 7.

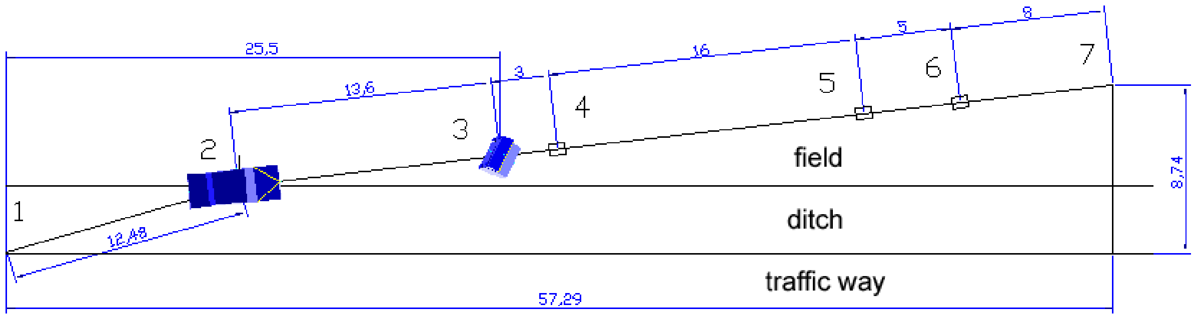

Fig. 7 Main distances between accident marks

The reasoning key of the reconstruction of this accident can be explained by help of scheme in figure 8 and is based on the conservation of energy principle. When the vehicle impacts an obstacle, he owns a certain amount of energy. During the knock, part of this energy consumes by the vehicle's body and obstacle deformations and the remaining part make the vehicle to continue the displacement, even as a "flight" thru the air.

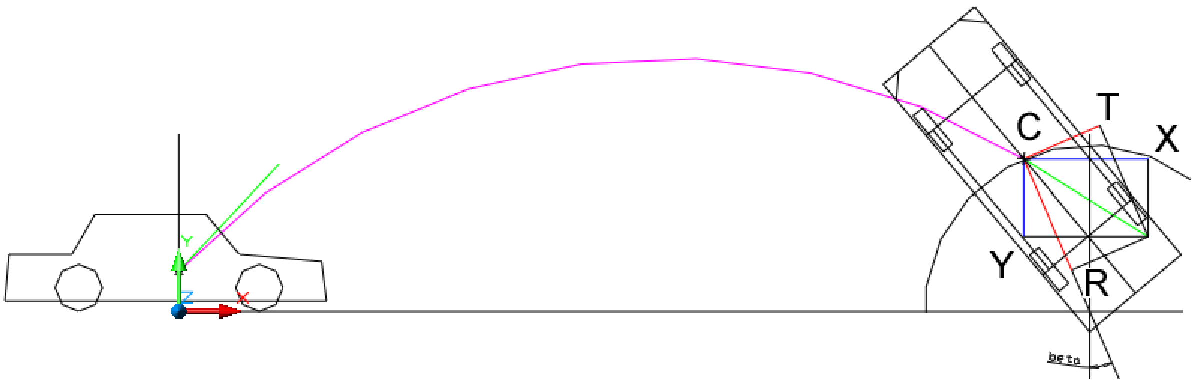

Fig. 8 2-D schematic for ballistic study

For computational simplicity considers the impact vehicle-ground as a theoretical percussion (phenomenon happens instantly and with no energy frictional loses) and neglects the vehicle-air friction and vehicle-ground slip.

If i and $j=i+1$ are indices indicating two successive points where the vehicle impact the ground (in figure 8, i for the initial position, at the left side, and j the next position, at the right side) and if indices d, e and l indicating deformation, respectively entering and leaving the point, then next equations can be written:

$$E_{\mathrm{il}} = E_{\mathrm{ie}} - E_{\mathrm{id}} \qquad (1)$$

$$E_{\mathrm{je}} = E_{\mathrm{il}} \qquad (2)$$

The first equation means that vehicle's leaving energy from a point is the entering energy to the same point minus the energy corresponding to the vehicle and soil deformations; the second equation shows that the vehicle's leaving energy of a point is equal to the vehicle's entering energy of a next point.

In addition, the entering and living energies have two components each: potential and kinetic.

The potential energy depends on the vehicle's mass m and on the height h of the centre of gravity:

$$E_{\mathrm{p}} = m\,g\,h \qquad (3)$$

where g=9.81 m/s^2 is the gravitational acceleration.

The kinetic energy has also two components, one for translation and one for rotation. The translational kinetic energy is:

$$E_{\mathrm{kt}} = m\,v^2 / 2 \qquad (4)$$

and the rotational kinetic energy is:

$$E_{\mathrm{kr}} = J\,\omega^2 / 2, \qquad (5)$$

where J [$kg\ m^2$] is the moment of inertia over the rotation axis – that can be well approximated using the literature (1,2,3,5) and ω is the rotational speed of the vehicle body.

In concordance with figure 8, total translational speed of vehicle's centre of gravity in the point j (the green vector on the right side) has vertical and horizontal components (CY and CX, the blue vectors). Entering CX component in point j (right side) is equal with leaving CX component in point i (left side):

$$v_{\mathrm{jx}} = v_{\mathrm{ix}} \qquad (6)$$

The "flight" time between points i and j (from left to right) is

$$t_{\mathrm{ij}} = s_{\mathrm{ij}} / v_{\mathrm{ix}}, \qquad (7)$$

where the space s_{ij} can be obtained by the distances between accident marks and by geometric constructions.

The centre of gravity height h_{j} in point j depends on the ballistics laws:

$$h_{\mathrm{j}} = h_{\mathrm{i}} + v_{\mathrm{iy}}\,t_{\mathrm{ij}} - g\,t_{\mathrm{ij}}^2 / 2 \qquad (8)$$

Between vehicle position angles φ_i, φ_j, in points *i* and *j*, and the through-air rotation speed ω_{ij}, next relation exists:

$$\varphi_j = \varphi_i + \omega_{ij}\, t_{ij} \qquad (9)$$

Coming back to the schematic from figure 8, total translational speed of vehicle's centre of gravity in point *j* (the green vector on the right side) is given by the equation

$$v_j^2 = v_{jx}^2 + v_{jy}^2 \qquad (8)$$

This speed v_j (the green vector) decomposes also in two components v_{jr} and v_{jt} (the red vectors CR and CT). The kinetic energy corresponding to the radial component CR (that vanishes at the impact) produces the crash of the body and deforms the soil:

$$E_{id} = m\, v_{jr}^2 / 2 \qquad (9)$$

The energy remaining to the vehicle that leaves the point *j* corresponds to the translational tangential component CR (that "launches" again the vehicle in air) and to the rotational speed

$$\omega_{jj+1} = v_{jt} / R_j\,, \qquad (10)$$

where R_j is the distance between the centre of gravity and the point *j* and that can be computed from an geometric construction.

Using the foregoing equations, the analysis starts with the final (repose) position of the vehicle and goes back in time, step by step, toward the initial situation. This "reverse kinematics" permits to determine successively the angles φ_i that define the impact positions, the times t_{ij} of "flight" between each pair of adjacent points and also any interest value that can be obtained with the previous mentioned equations.

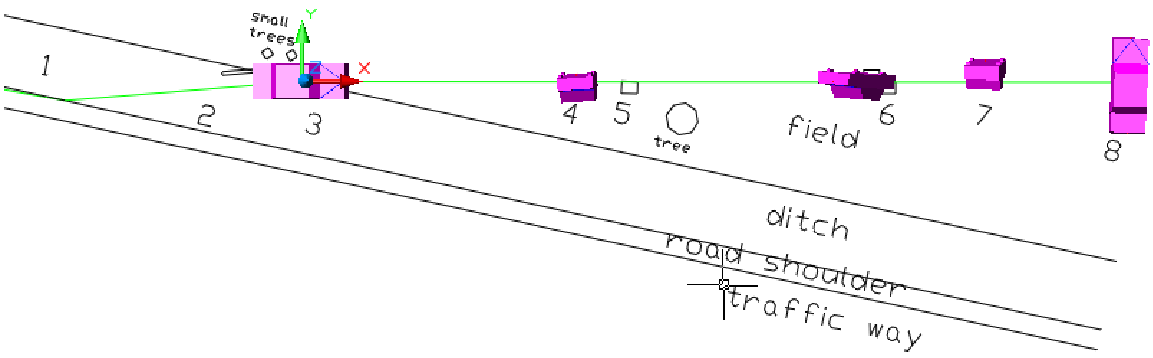

Fig. 9 Vehicle's successive knock positions – simulation – upper view

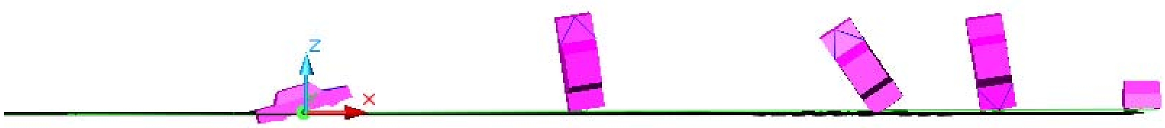

Fig. 10 Vehicle's successive knock positions – simulation – lateral view

Using the presented algorithm, a Mathcad program was realised. This permitted to find the entire kinematics of accident, including the speed at off-going initial moment (105 km/h) and the total duration (4.5 s between point 0 and 8). Knowing the translational and rotational speeds of the vehicle, a successive three-dimensional representation of the most important moment of the accident (impacts with the ground) was made using the AutoCAD software (figures 9 and 10).

In short, the accident happened like this: due to the nighttime and the slippery road, the driver lost the control and the car deviates to the left. Impacting the bank of the road ditch (point 3 in figure 9), the car elevates from the front-left end simultaneously with an anti-clockwise rotation and a small deviation to the right. Then the car impacts the ground with the rear-left corner (point 4) and immediately with the rear-right corner (point 5), changing the sense of rotation. The rollover continues with an almost entire clockwise rotation and the car knock the ground a second time with the rear side, losing the passenger on the opened door (point 6). A new half rotation produces and the car hit the ground with the front side (point 7) and ejects the driver too. A last rollover occurs and the car stops (point 8).

CONCLUSIONS

In the accident reconstruction, the evidences and the marks are capital to find the circumstances that generates the accident. Knowing vehicles kinematics during traffic accidents permits to the responsible factors to determine who generates the undesired events and to act for their reducing in the future.

The reconstruction of the accident presented in this article was easier than others usually are because the marks were in a sufficient amount. The authors consider that the way they followed to solve this kinematic analyse can be useful also in other cases that include vehicle rollovers and where evidences or marks aren't so numerous.

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