Computer simulation and vehicle front optimisation

Paper contributed to 26th International Symposium on Automotive Technology and Automation, Dedicated Conference on Road and Vehicle Safety, Aachen, Germany, 13-17 September 1993

D-93-3
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Leidschendam, 1993
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Introduction

In 1991, the Dutch Ministry of Transport commissioned the SWOV Institute for Road Safety Research to execute a computer simulation study of side collisions of cars against bicyclists. Aim of the study was to establish a description of an ideal car-front in terms of shape and stiffness. An ideal car-front was defined as the front that will cause minimal injury to the bicyclist in case of side collisions. The computer program VEDYAC was used to perform the simulations on a VAX 4300 computer.

In most European countries unprotected road users account for a significant proportion of the road accident casualties. The last decade the research in the EEC has been focused on pedestrian safety. These studies have resulted in various recommendations for the car-front structure design and test methods to asses pedestrian protection.
In The Netherlands the safety of another group of unprotected road users, the bicyclists, is at stake. When a car-front is optimised in relation to pedestrian safety, bicyclist safety is not necessarily assured. For this reason the study discussed in this paper was conducted.

The approach of the safety problem of unprotected road users in this study differs from the research reported in the past years. In most publications the existing car-fronts are examined with regard to their behaviour during car-pedestrians collisions. Only relatively small shape and stiffness modifications are taken into account. Furthermore the collision process is investigated and described.
The starting point of the study published in this paper was to find a car-front, which will cause as little harm as possible to the bicyclist in case of a side collision. Beforehand no restrictions in terms of shape and stiffness of the car-front were taken into account. In this case, computer simulation is a powerful tool since the shape of the car-front can be modified very easily. The computer program VEDYAC was used to simulate side collisions between a bicyclist and a number different shaped car-fronts.

Though simulation is very suitable for the described project, the method has some limitations. The models used must be verified with experiments. Another problem is that the simulation output, like acceleration, force, and other physical quantities, must be interpreted in terms of injuries and injury severity of the bicyclist.

The simulation program VEDYAC

In cooperation with SWOV the simulation program VEDYAC (VEhicle DYnamics And Crash) was developed by Program Developement & Technical Appliance SPAT from Milano, Italy. SWOV and SPAT cooperate since 1970 in the the developement of computer programs to simulate impacts between vehicles and barriers [1].

With VEDYAC various three dimensional dynamical problems can be simulated including crashes. The program provides the user with several tools to model the human body and objects, e.g. cars, barriers. Inertial properties are modelled with point masses. The point masses can be connected with each other by elements which can have an elastic plastic characteristic. To simulate crashes the program has contact bodies of different shapes, e.g. cylinder, torus, sphere and plane. In a VEDYAC model contact bodies are rigidly connected to a point mass. The program checks each time step if there is an intersection between two contact bodies. If an intersection exists a contact force is calculated on base of the intersected volume. Since the control of contacts takes a lot of computer time, the user of VEDYAC prescribes which contacts have to be taken into account during the simulation. The program can supply different types of output. All physical quantities can be printed in tables or plotted in graphs. Furthermore it is possible to make drawings.

VEDYAC has proven to be very useful for road safety research. The program has been used to investigate and to develop various safety barriers, to investigate the behaviour of a light pole during a car-impact. Also train-car collisions at level-crossings have been studied with VEDYAC simulations [1], [2], [3].

The study set-up

The objective of the project was to describe an ideal car-front in terms of shape and stiffness with regard to the safety of bicyclists during side collisions. To find the ideal car-front the following steps were performed.

- Development of VEDYAC models of the car-front, bicycle and bicyclist
- Verification of the models with experimental data of side collisions to obtain a so-called standard simulation
- Determination of parameters to be varied during simulation
- Perform the simulations
- Interpretation of the simulation results

The reliability of the result of a mathematical simulation depend largely on the quality of the used models. For this reason the required VEDYAC models to simulate a side collision between a car-front and a bicyclist have been based on experimental simulations performed by TNO Road Vehicles Research Institute [5].

The results of the TNO experimental simulations were also used to verify the VEDYAC models. The verified simulation (standard simulation) was the starting point for the investigations to find an ideal car-front. There is an infinite number of ways to design a car-front, but it is impossible to investigate the influence of all variations in shape and stiffness on the safety of a bicyclist. To reduce the number of simulations, simplifications were necessary. In Figure 1 a view of the car-front used in the TNO experiments [5] is shown.

The general shape of the car-front is mainly determined by the bonnet angle. In order to keep a link with the standard simulation, only the bonnet angle has been varied in the performed simulations. To determine the influence of the bonnet angle, the head accelerations, both linear and angular, the force applied to the left shoulder, the acceleration of the torso, pelvis and the left knee of the bicyclist are compared for each simulation.
It is assumed that the maximum values of the accelerations found are a measure for the injury severity of the bicyclist.

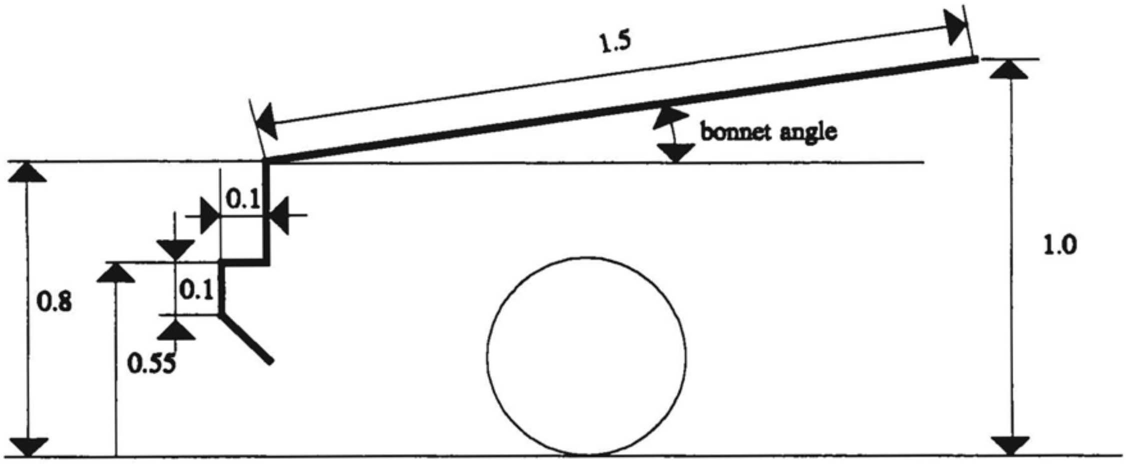

Figure 1. *View of the car front used in the TNO bicycle side collision test.*

The VEDYAC model

In Figure 2 the TNO experiment set-up is shown. A Part 572 dummy seated on a men's bicycle is impacted by a poly-urethane front which is mounted on a moving barrier. The impact direction was 90°, the vehicle speed 30 km/h and the initial speed of the bicycle/bicyclist was 0 km/h or 15 km/h. The experimental TNO simulation consist of three

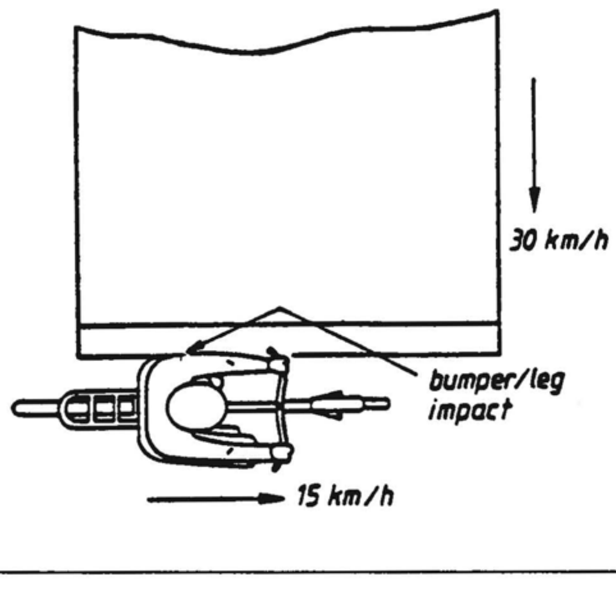

Figure 2. *Test set-up TNO moving bicycle experiment.*

objects, the bicyclist, the bicycle and the car-front. In the simulation study described in this paper of each object a sub-model was developed. To optimize the interaction between the sub-models several mathematical simulations have been performed.
Some properties of the VEDYAC bicyclist model were copied from a MADYMO model of a Part 572 dummy [5]. In Figure 3 the VEDYAC model is shown. The bicyclist is modelled with eight masses. The masses are connected to each other with deformable elements, which model the joints. Contact bodies are attached to the body parts to describe the geometry of the bicyclist. The VEDYAC program knows several contact bodies like, a cylinder, sphere, torus, plane, or two dimensional polygons. The VEDYAC model of the bicyclist contains both contact cylinders and polygons.

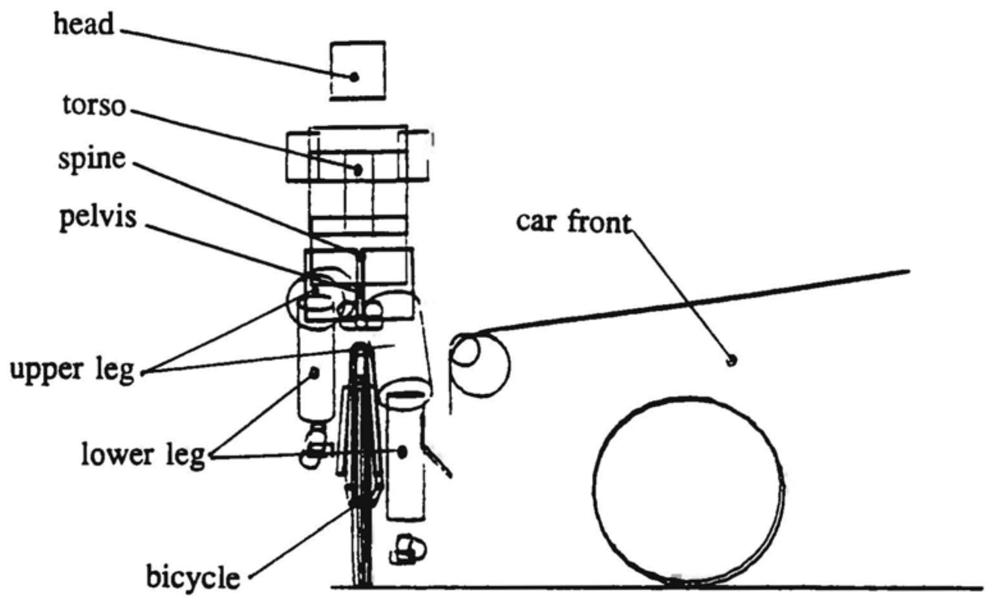

Figure 3. *The VEDYAC-models used in the mathematical simulations.*

The VEDYAC model of the bicycle consist of one mass. Hence the movements of the steer are neglected otherwise a second mass would be needed to model the inertial properties of the steer. Two wheels and several cylindrical contact bodies describe the geometry of the bicycle.
The car-front is modelled with one mass and four wheels. The shape of the car-front is described by polygons and two cylindrical contact bodies. These two contact cylinders were added to de model to optimize contact force calculation between the left upper leg and the leading edge of the hood.

Model verification

After the VEDYAC models were developed two simulations have been performed with identical initial conditions as applied during the TNO experimental simulations. In Table 1 the initial conditions of the TNO experiments and the mathematical simulations are shown. The difference between the two mathematical simulations was the initial speed of the bicyclist.

VEDYAC simulation [-]	TNO exp. number [-]	impact angle [°]	bicyclist speed [km/h]	car-front speed [km/h]
T0	8303 8306	90	0	30
T1	8501 8502	90	15	30

Table 1. *The initial conditions of the verified mathematical simulations.*

To verify the VEDYAC simulations, computer animations were compared with video recordings of the experimental simulations. Also measured accelerations of the dummy during the experimental simulation were compared with calculated values. It was found that the VEDYAC simulation results correspond quite well with the experimental simulations for the first 0.2 seconds after the initial contact between bicyclist and the car-front. After 0.2 seconds the difference between the mathematical simulations and the experiments became to large. The maximum accelerations of the bicyclist occur within the first 0.2 seconds of the collision, therefore most of the serious injuries will arise in this period.
It was concluded that the VEDYAC model was suitable to investigate the influence of the bonnet angle on the bicyclist safety.

The results

Two series of mathematical simulations were performed with similar initial conditions as simulation T1 in Table 1. In the first series the bonnet angle was increased from 9.5° (standard simulation) to 90°. In the standard simulation the head of the bicyclist was considered not to hit the windscreen. It is obvious that when the bonnet angle is increased the influence of the windscreen will also increase, because the windscreen has moved closer to the front end of the car.
In the second series a windscreen was modelled having four times the stiffness of the bonnet. In Table 2 the executed mathematical simulations are summarised.

Bonnet angle	9.5°	30°	45°	60°	75°	90°
without windscreen	T1	E1	E2	E3	E4	E5
with windscreen	-	E21	-	E23	E24	-

Table 2. *The performed mathematical simulations.*

A comparison of the mathematical simulations E1 to E5 shows clearly that the bonnet angle effects the simulation results. When bonnet angle is increased the maximum values of the head accelerations (both linear and angular) of the bicyclist decrease. However the effect stops at a bonnet angle of 75°. The head accelerations of simulation E5 (bonnet angle 90°) are as big as the accelerations found with simulation E3 (bonnet angle 60°).

The accelerations of the torso and spine become larger with an increasing bonnet angle. The acceleration of the torso is always smaller than the accelerations of the head.
Computer animations of the simulation show that the mechanism of the collision is influenced by changes of the bonnet angle.
The maximum acceleration of the left upper leg is not influenced by changes of the bonnet angle, while the maximum values of the pelvis accelerations increase clearly with increasing bonnet angle.

When a windscreen is taken into account (E21, E23 and E24) the same effects occur as described for the simulations E1 to E5: The head acceleration decrease when the bonnet angle is increased. However, the accelerations of the head, torso, spine, and pelvis are much higher during the simulations with the windscreen.

Conclusions

The influence of the stiffness and shape of a car-front on injuries of bicyclists caused by side collisions was studied by computer simulation. Simulation was a suitable method in this case because of two reasons: variation of shape and stiffness is more difficult to perform in case of an experimental model than when a computer model is used. Furthermore experimental simulation results were available to verify the standard simulation.

Simulation gives the opportunity to vary a large number of parameter. In the study discussed in this paper however, only the influence of the bonnet angle was investigated.

From the performed mathematical simulations it is concluded that a greater bonnet angle has a positive effect on the head acceleration. This effect also occurs when a windscreen is simulated.

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