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Sensitivity of Car with Guardrail Impacts with a Multibody Simulation Tool

Abstract

The European Union has set a target to reduce all road fatalities (over 40,000) with 50% in 2010. This target percentage remained unchanged with the introduction of the ten new member states within the EU as by May 1st, 2004. According to Eurostat [1], 34% of all fatalities in 1998 in the, then, fifteen states of the European Union were the result of single vehicle collisions. This represents over 14,000 lives lost each year of which many can likely be saved through better roadside infrastructure design. The challenge for road safety professionals is to find methods and design strategies that help to reduce these casualties.

Procedures for full-scale vehicle crash testing of guard rails were first published in the US in 1962. Present European regulation is mainly based on these procedures and later developments. Since then the vehicle fleet has changed considerably. Due to the complexity of the actual safety problem the numerical simulation approach offers a good opportunity to evaluate the different parameters involved in road safety, such as infrastructure properties, vehicle type, vehicle occupants and injuries. The ideal situation would be that simulation tools are coupled or integrated and all involved effects would be related. At the moment this is not the case yet, but initiatives are taken and a new virtual era has started.

This paper offers a method looking at two components that encompass the driving environment: the car and the guardrail.

As part of the EC-funded project, RISER (Roadside Infrastructure for Safer European Roads) a multi body simulation program study is carried out to determine sensitivities of some parameters in car to guardrail collisions and gives insides in performance of the car with passive safety equipment, the guardrail and the interaction of these objects with each other.

By offering a set of methods that includes these two aspects and their intertwining relations, more confidence can be gained in actually reducing fatalities due to single vehicle collisions with, or due to, roadside furniture. Reducing the number of fatalities of single vehicle crashes would contribute greatly to the stated goal of reducing casualties altogether.

Introduction

In the RISER project different simulation techniques were used. The simulations give insights in the infrastructure-vehicle interaction and the vehicle-occupant interaction. The used simulation tools are the multibody program MADYMO with ADVISER. Details about the work carried out have been reported in the deliverable D03 Critical vehicle and infrastructure interactions [3].

MADYMO (Mathematical Dynamic Model) is a computer program that simulates the dynamic behavior of physical systems especially those emphasizing the analysis of vehicle collisions and assessing injuries sustained by passengers. MADYMO is a combined multibody-finite-element code.

ADVISER is a tool that manages stochastic simulations and analysis, which provides insight in the effect of parameter variations on e.g. the injury criteria. The tool also automatically correlates numerical and experimental data and provides a corresponding objective quality rating for a numerical model.

Guardrail impacts

A countermeasure to avoid single run off accidents with passenger cars is to install guardrails. The guardrail is a device to change the direction of the passengercar. By changing the direction of the car a run off into the roadside is avoided. During and after redirecting the passenger car the guardrail will also slow down a vehicle, so energy is dissipated. Lower energy level results in lower crash speed and will therefore cause lower injuries.

For the RISER project a specific methodology was set up. First a car and a guardrail model were built up and then combined in a simulation. This simulation was the basis for a study with stochastic simulations.

With the software package ADVISER it is possible to perform stochastic simulations. ADVISER offers three sample approaches, of which Monte Carlo is the most basic and Best Latin Hypercube the most advanced. The concept is described in [1] and [2]. For each parameter in the numerical model, N samples can be generated according to a pre-defined distribution (uniform, Gaussian, etc.). The amount of samples is not pre-determined as with DoE but depends on the degree of certainty that is required by the researcher and is independent of the number of parameters varied. Each sample set of parameter values is used to run a deterministic simulation of the model. These N simulations can be run in arbitrary order, as all simulations are independent. This allows to efficiently distributing the sample over a large number of CPUs, thus being able to run even larger samples within a reasonable time frame. The result of this method is N solutions of the stochastic model. So, instead of a single deterministic result, there is a cloud of solutions, which provide a better understanding of the sensitivity of the model. The method is different from the standard parameter variation, where only one parameter at a time is varied. In stochastic simulation the user only defines a range by the minimum and maximum values for all parameters, which are then randomly distributed over the range for all simulations. The output measures can be analyzed for trends and correlations with statistical methods.

Parameters	Symbol	Unit	Min	Max
Impact speed	v	[m/s]	10	28
Impact angle	β	[°]	5	35
Vehicle orientation	φ	[°]	0	45

Table 1: Parameters and ranges of variation

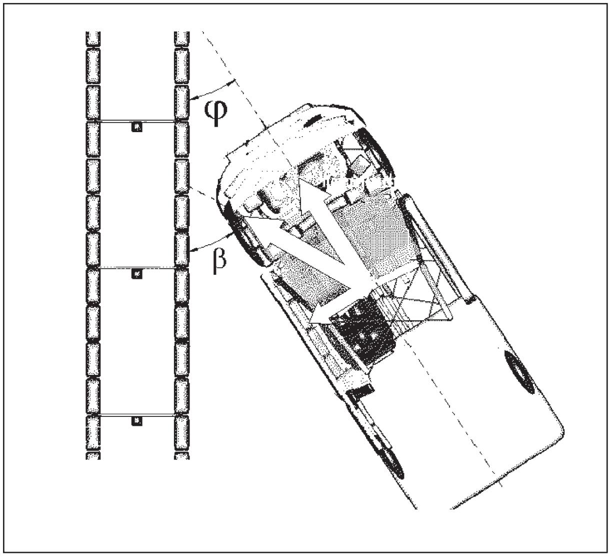

Figure 1: Definition of v, β and φ

The parameters are varied stochastically around those used in the test (impact speed 100km/h, impact angle 20°, vehicle orientation 20°). The aim of this parameter study is to determine sensitivity of certain parameters on the impact response and to investigate whether there is a relationship between the human-based HIC and the vehicle-based ASI.

Stochastic model set up

The impact speed, the velocity angle and the orientation of the vehicle are varied. The specific parameters including their minimum and maximum values are shown in Table 1.

In Figure 1 the vehicle and parameters are visualized. Samples of different parameter combinations are generated with the Best Latin Hypercube method, creating a random and uniform distribution that fills the whole parameter space. A total of 22 samples are generated. The trends and correlations are analyzed with linear regression analysis (LRA).

Results

It is expected that there is a positive correlation between ASI and the velocity. The trend shown between velocity and ASI gives confidence in the model sensitivity to changes in velocity. The scatter in the 22 tests is partially caused by the fact that besides variations in impact velocity also the impact direction and orientation of the vehicle were varied.

In the simulations also the HIC-values are calculated from the Hybrid III dummy model. A relationship between HIC and ASI exists as shown in Figure 3. Most of the test runs have ASI values below 2.00 and HIC values below the tolerance limit of 1000. The spread on the results is caused by the complexity of the three variables that are altered within this study; impact velocity, impact direction and vehicle orientation. The injury parameters taken into account in this study are HIC, VC and chest deflection and also the vehicle based criteria ASI, THIV and PHD. As shown in Figure 2 and Figure 3 a reasonable correlation between the varied parameters (such as velocity) and the responses (such as HIC and ASI) can be observed. Similar correlations exist for other injury parameters.

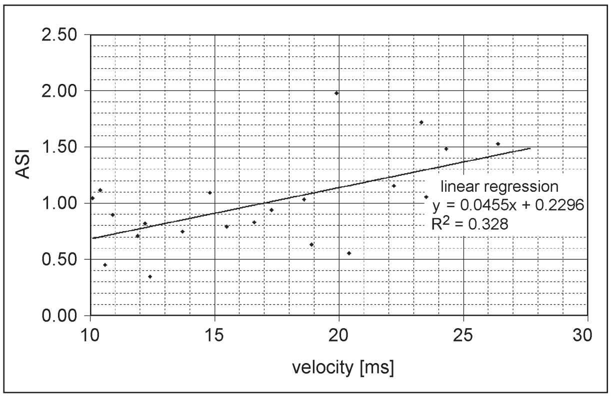

Figure 2: Relationship between velocity and ASI

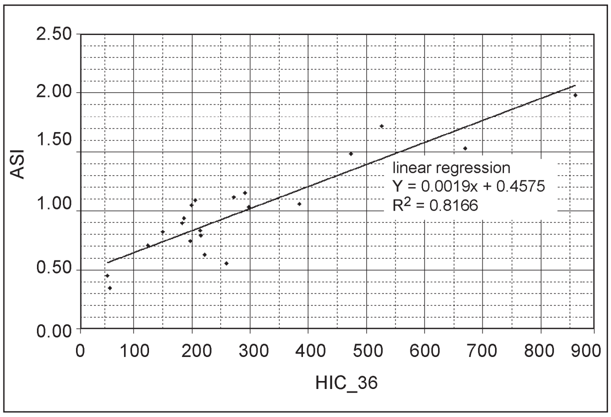

Figure 3: Linear correlation between HIC and ASI

Conclusions of the Stochastic Simulation

- The MADYMO model of the guard rail replicates reasonably the guard rail impact. The vehicle was successfully redirected. Future work however should be based on validating the response of the vehicle with respect to the guard rail. Also the guard rail model needs validation on component level in future studies.
- A stochastic approach provides insight into the system behavior on a multi-parameter and multi-scenario level. Stochastic simulations allow for the variation of both environmental parameters, such as impact speed and angle, as well as structural parameters, such as guard rail stiffness or vehicle mass. Generating a large sample of runs with multiple parameters does not result in perfect correlation due to a large spread of parameters in the stochastic models. However, it does result in trends between parameters, and further research is reasonable.
- The stochastic study showed that the model response, in terms of ASI, is sensitive to changes in impact velocity, as is expected for the defined combination ‘vehicle and guard rail’. In addition, a relationship between ASI and HIC is shown for the simulated scenarios of impact speeds ranging from 35 to 100km/h at impact angles between 5° and 35°. The result indicates that ASI is a reasonable predictor of injury in guard rail impacts. This would justify certification of guard rail systems based on vehicle accelerations instead of dummy readings, hence saving the cost of using a dummy in regulatory tests.
- The relatively long duration of a vehicle-to-guardrail collision leads to long simulation times compared with a vehicle-to-vehicle collision simulation. This makes multibody approach very efficient with respect to finite element computer simulations.
- Extensive model validation is a pre-requisite for an absolute qualification of a guard rail system, however, a non-validated but realistic model provides insight in trend and sensitivity studies.

References

[1] ADVISER USER_S Guide; Version V1.4, MECALOG Business unit Safety; May 2004

[2] ADVISER Reference Guide; Version V1.4, MECALOG Business unit Safety; May 2004

[3] Critical vehicle and infrastructure interactions, RISER, February 2006