

## MOTORCYCLE-CAR SIDE IMPACT SIMULATION

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### ABSTRACT

[ISO13232] specifies four configurations of motorcycle-car side impact tests. In this study a Kawasaki GPZ motorcycle and Toyota Corolla were used to conduct crash tests according to ISO specifications at the Japan Automobile Research Institute (JARI). Finite element models of the motorcycle and car were developed in PAM/CRASH™ based on CMM measurement and component test data. In this paper we present the results of the simulation of four ISO standard crash configurations. The kinematics in these simulations is compared with those in the experiments.

### KEY WORDS

COMPONENT TESTS, HYBRID III, DUMMIES, SIDE IMPACT, ISO, KINEMATICS, PAMCRASH™

IN MANY ASIAN COUNTRIES motorcycle (M/C) crashes constitute a significant proportion of all road crash fatalities and injuries and safety measures can be successful only if much more attention is devoted to this issue. In this paper we investigate car-motorcycle side impact simulations which have been compared and validated using crash tests conducted earlier.

Earlier experimental as well as simulation based studies to evaluate the effectiveness of Leg Protectors (LPs) for motorcyclists have been carried out by [Chinn,1986]. Studies have also been presented on the modeling of airbags in motorcycles [Nieboer,1991]. Subsequently, [Nieboer,1993] have reported development of rigid body models of the motor cycle. We concur with their observation that , MC simulations turn out to be far more difficult compared to the simulation of car occupants. This is due to the multiplicity and complexity of the interactions involved. Use of rigid body models in these simulations have the drawback that the energy absorption is underestimated specially in cases of large deformations [Nieboer,1993]. As a result we have initiated research using FE based tools to understand the important issues in the crash behaviour of MCs. This paper describes initial work in that direction.

The ISO 13232 specifies seven crash configurations, four of which are side impacts. In this paper we present the results of crash tests simulations involving a Kawasaki GPZ motorcycle (with a dummy rider) and a Toyota Corolla. The crash tests were conducted at the Japanese Automobile Research Institute (JARI) and the computer simulations at TRIPP, Indian Institute of Technology, Delhi. Simulations of four side impact situations have been developed. The study has been sponsored by the Japan Automobile Manufacturer's Association (JAMA).

The Kawasaki GPZ, 1990, 400 cc model, the Toyota Corolla, 1989 model and the MATD dummy were used in the experimental tests. Simulation models for the vehicles were developed using geometric data obtained from a Coordinate Measuring Machine (CMM). This includes surfaces like M/C headlight, seat, tank, engine, side panels and leg protectors, car bonnet, bumper, side panel. This data was used to develop the geometric model of the motorcycle in IDEAS™. The modelled

components were further verified against ISO standard static tests in IDEAS™ and impact tests by porting to PAM/CRASH™. Simulation of the full motorcycle assembly using PAM/CRASH™ was verified against an experimental wall crash. Sufficient confidence has been established for the behaviour of the motorcycle model in impact conditions. The H-III dummy model available in PAM/CRASH™ was used. The current work concentrates on the kinematics and the dynamics of the M/C rider. The details of the methodology followed are described in [Chawla, 2001]. The detailed finite element modelling of the M/C has provided a relatively reliable tool for assessing motorcycle-car crash details under differing crash configurations.

## METHODOLOGY

The exact geometric data in the form of CAD model or drawings and constitutive properties of the material used in car and motorcycle components were not available. A coordinate measuring machine (CMM) was used to collect geometric data of components. Static and dynamic testing of the components were conducted at JARI to measure the material properties of components like bumper, bonnet, Motor Cycle (M/C) seat foam, front suspension and tire, to name a few. In dynamic tests, components were impacted at speeds set in the ISO standards. Further, to get the static material properties of some materials, load deflection characteristics were recorded using an Ultimate Tensile Machine (UTM).

Finite element models were developed for components of the car and motorcycle. For geometric definition and mesh generation, IDEAS™ was used. Static validation of component models against experimental data was also carried out in IDEAS™. The mesh was then exported and assembled in PAM/CRASH™ in order to validate and build the complete model of the car and the motorcycle under impact conditions. Material properties and the boundary conditions were defined in PAM/CRASH™. Experimentally recorded curves of displacement, velocity and acceleration were compared against the values obtained by simulation. This helped in selecting the material properties of components where properties were not known otherwise and gave confidence in their fidelity [Chawla, 2001].

While we used FE models of the car and the MC, we have used a rigid body model for the dummy. The dummy model used is the H-III dummy model available with PAM/CRASH™. The dummy used in the car – motorcycle tests is an MATD dummy. This change does affect the simulations. However, in this paper we are looking primarily at the overall kinematics of the car – MC impact and the overall MC behaviour would not change much. A more appropriate dummy model will however have to be used for looking at the finer aspects of the simulations.

## FINITE ELEMENT MODEL OF THE CAR

As mentioned above, the initial modeling of the car components was done in IDEAS™ to capture the geometry. Component models were then transported to PaM/Crash and the complete car model was assembled. For meshing, four node shell elements and beam elements were used. The elements on the impacting side of the car were more refined (smaller) compared to the rest of the car. This was done to minimize the simulation time. The complete car model consists of 14828 Shell elements, 432 brick elements, 465 beam elements, 4 kinematic joints and 4 spherical Joints.

For the side impact of the car with motorcycle, the components of the impacting side of the car, the front and rear door, side panel and B-pillar were modeled with dense mesh. The non-impacting side of the car, far away from the impact zone, the bonnet, bumper, engine, radiator, windscreen, tires of the car were initially defined as rigid null material so that the internal forces and deformation are not computed during the simulation to save on simulation time. Subsequently, appropriate properties are given to these parts as well.

The front door of the car was modeled using the 4730 four node thin shell elements and 148 beam elements. Similarly the rear door of the car has been modeled using 4421 shell elements and

134 beam elements. The side panel of the car consisting of A-pillar, B-pillar, the roof rail and the bottom rail has 1955 shell elements.

The chassis of the car has initially been modelled using beam elements. During the impact with the motorcycle the chassis of the car has little or no permanent deformation. Consequently equivalent beam elements were used to speed up the computation.

The suspension has been modelled as translating kinematic joints, whose stiffness and damping characteristics were determined. The spin of the wheel has been modelled as a spherical joint element constrained to have free rotation only about the wheel axis. An initial linear velocity is assigned to the entire car when needed. The corresponding angular velocity is defined for the car tires. Contact interactions and friction are defined between contacting surfaces like tires and road, doors and frames, inside and outside surfaces of door, to name a few. Mass and moment of inertia of the car was made equivalent to that of the car by introducing point masses at appropriate locations. Exact geometric models were not built for the engine, the transmissions and seats as these do not have a significant contribution to the car-M/C impact.

#### FINITE ELEMENT MODEL OF THE MOTORCYCLE

The geometry of the motorcycle was also reproduced in IDEAS<sup>TM</sup> software a component at a time. Components were validated and assembled in PAM/CRASH<sup>TM</sup>. Particular attention was given to reproduce the front suspension characteristics and the rear suspension mechanism as they play a significant role in determining the trajectory of the dummy in impact situations. The motorcycle model currently consists of 96 solid elements, 850 shell elements, 102 beam elements, 1 bar element, 2 kinematic joints and 9 spherical joints.

For the car tire, the geometry has been preserved. The load deformation characteristics of the tire have been clubbed together with the suspension. However for the motorcycle, fidelity of the tire is important, as it is the initial impact body. The motorcycle tire is a shell mesh with material characteristics of rubber. An internal tire pressure of 200 KPa was defined for the front and rear tire of the motorcycle. The model has been built in accordance with the methodology validated by [Takatori, 1999].

The finite element model of the motorcycle was validated using the experimental data of a motorcycle-wall crash. For the validation, the wall forces and the acceleration of the CG point and point under the seat were compared.

The motorcycle dummy used was the 50<sup>th</sup> % Hybrid III rigid body model available with PAM/CRASH<sup>TM</sup>. The dummy segments were reoriented for it to sit on the motorcycle. The MATD dummy used for the experimental tests has joint stiffness that differ from that of the Hybrid III. The affect of some of these differences is being discussed in subsequent sections.

#### SIMULATION ENVIRONMENT OF CAR MOTORCYCLE SIDE IMPACT

In the ISO 13232 the four different configurations of the side impact of car motorcycle impact are:

- Case I: Car stationary, motorcycle impacting at velocity of 13.4m/s at right angle
- Case II: Car moving at 6.7m/s, motorcycle moving at 13.4m/s at angle from front of 45<sup>0</sup>
- Case III: Car moving at 6.7m/s, motorcycle impacting at a velocity of 13.4m/s at right angle
- Case IV: Car moving at 6.7m/s, motorcycle moving at 13.4m/s at angle from rear.

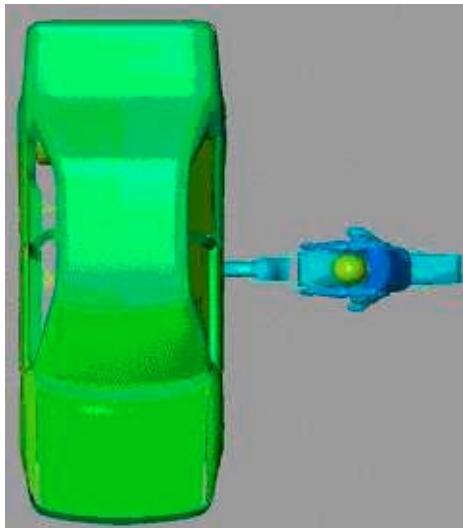


Fig. 1 : Top view of M/c & Car impact configuration for – Case I

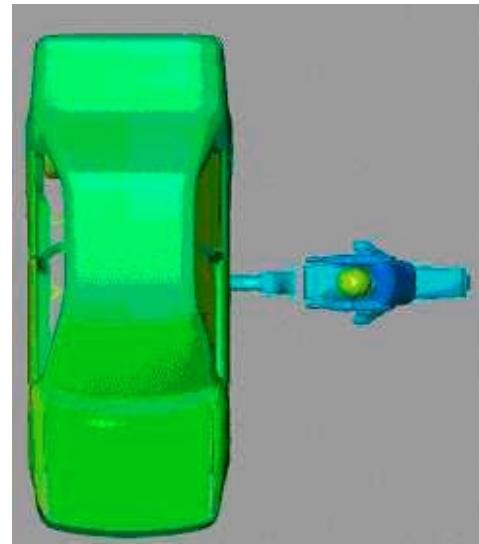


Fig. 2 : Top view of M/c & Car impact configuration for – Case II

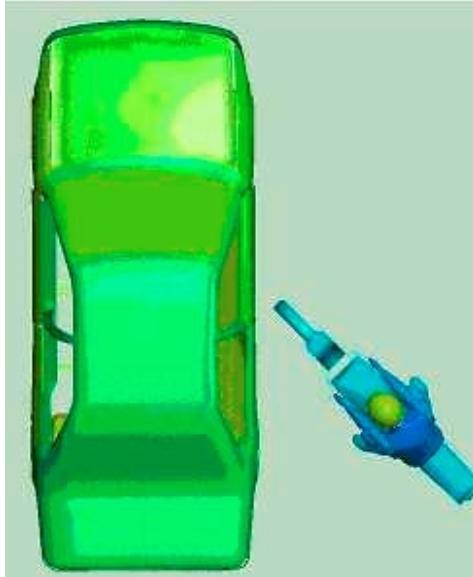


Fig. 3 : Top view of M/c & Car impact configuration for – Case III

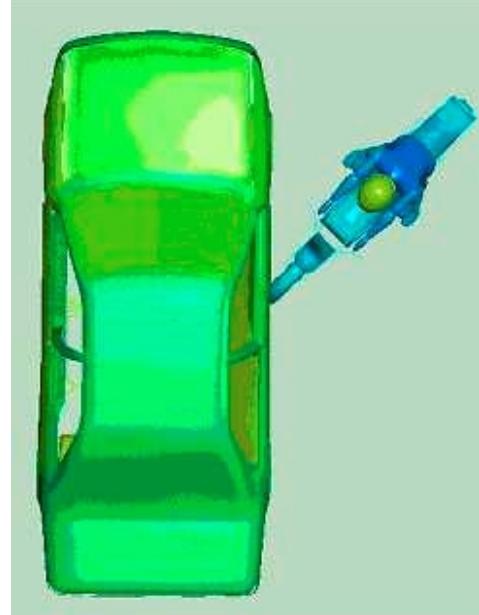


Fig. 4 : Top view of M/c & Car impact configuration for – Case IV

In all the configurations the motorcycle is to impact at the center of the car i.e. at  $L/2$  of the car where  $L$  is the length of the car. The four different configurations are shown in the figures [1-4]

Contact interactions were defined between the dummy hip, thighs, legs and foot and the complete motorcycle. Contact interactions were also defined between the forward segment of the motorcycle and the side of the car. The reader may recollect that the side of the car near the impact area had refined mesh geometry for good fidelity. A helmet model, verified through drop test was assembled on to the head of the dummy. Contact interactions were defined between the head and the helmet and between the helmet and the car. Figure 5 shows the complete model of the car motorcycle side impact. IN the next section we describe the kinematics in these simulations.

## RESULTS

**RESULTS OF THE CASE I SIMULATIONS:** For the four different configurations the simulation and the experimental results were compared. The kinematics of the dummy was evaluated after every 20ms. For the first configuration of the car-motorcycle side impact the results are shown in the Figure 6.

In the crash test, the dummy helmet just clears the still of the car. In the simulation shown above, the face guard of the helmet of the dummy impacts the still and the helmet then gets lodged in the still. This amounts to approximately a 50mm difference in head height between the simulation and crash data.

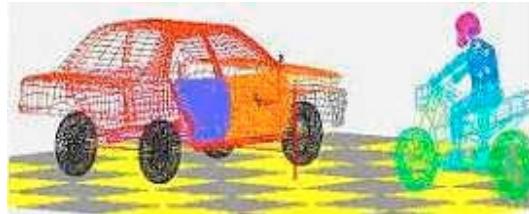


Fig. 5: The complete model of the car-M/C side impact.

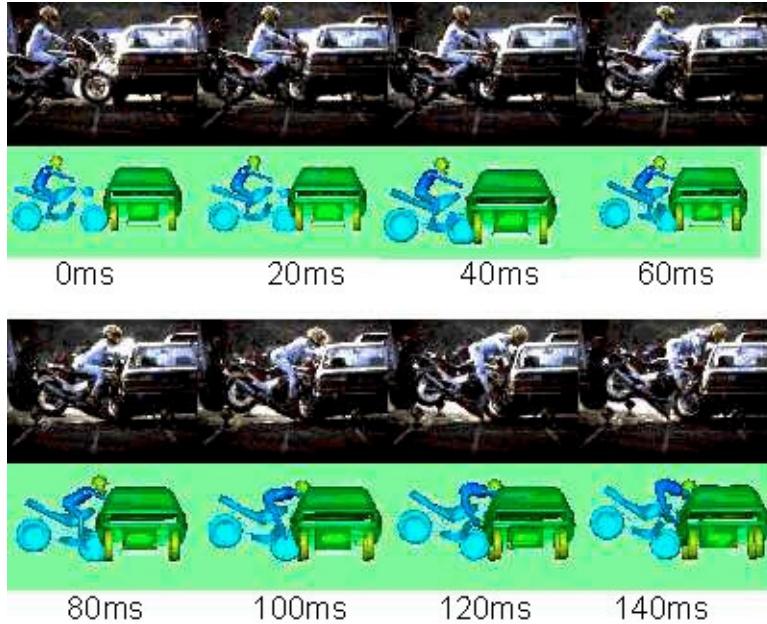


Fig 6: Comparison of the simulation kinematics with the crash test at 20msec intervals.

The difference in the results can be assigned to the way the grip of the palm on the handle of the motorcycle has been modelled. In the simulation no interaction was defined between the palm of the dummy and the handle of the motorcycle to model the fact that the grip is lost on impact. In the crash test the hand of the dummy has an encircling grip on the handle. We tested the grip and measured that it requires a force of about 250N to open the grasp. Consequently, the dummy continues to hold on to the handle of the M/C well beyond the point when the M/C impacts the car. This effect is verified in the crash test film where it was clearly seen that the dummy's hand does not

leave the M/C handle. Without incorporating the complete effect of the M/C dummy hand, we ran simulations in which the dummy hand stays attached to the handle for 100 ms. The figure 7 shows the dumps from the simulation, and it is seen that the dummy head does gain height in this case.

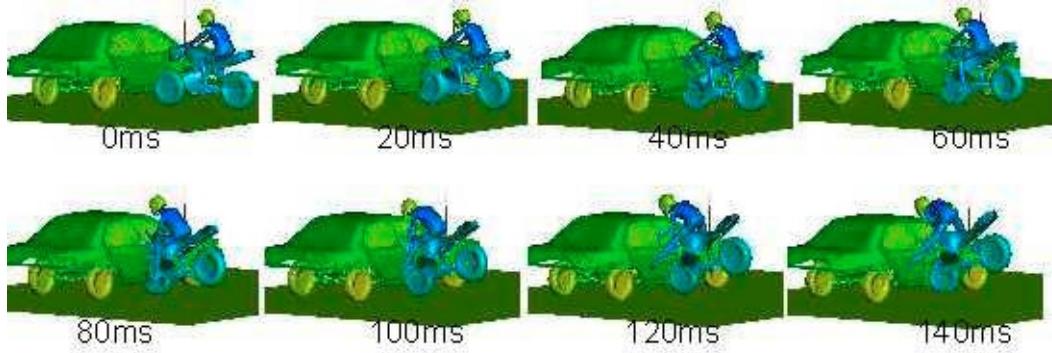


Figure 7: Kinematics in the simulation when the dummy hand remains attached to the handle for about 100ms.

The kinematics of the motorcycle, rider and helmet are reproduced in the simulations. The point of impact of the head is near the top still, and is very critical as it can end up with the helmet sliding on the roof or getting lodged on the sill due to a difference of about 30-50 mm in the impact height. Thus the point of release of the handle has a significant effect on the height gained by the dummy.

The grip and joints for the MATD seem to be designed to prevent the dummy from collapsing when seated in the forward leaning posture on the motorcycle. While a better dummy model will definitely bring the simulations closer to the experiment, a point worth conjecturing is whether the behavior of the dummy due to the grip does mimic real life situations. For purposes of establishing a crash standard, these details would influence results significantly.

**RESULTS OF THE CASE II SIMULATIONS:** In this case the car is moving at 6.7m/s, the motorcycle is moving at 13.4m/s at an angle of 45<sup>o</sup> from the front. We see a high sensitivity to the impact point. As per the [ISO13232] configuration, the front wheel of the motorcycle should impact the car at the half-length point of the car, which comes out to be 18cm ahead of the B-pillar. The actual impact location in the test carried out is very close to the B-pillar. Further, through simulations it is also observed that a slight change in the location of the point of impact causes qualitative change in the kinematics of the motorcycle and the rider.

The effect of B-pillar is shown in Figure 8. In the first simulation the M/C impacts behind the B-pillar and the front tire of the motorcycle moves towards the rear side of the car. This matches well with the experimental results. In the second and the third simulations shown in Figure 8, the front tire of the motorcycle hits ahead of the B-pillar location. In both cases the tire of the motorcycle moves towards the front side of the car. The tire seems to be wedged in front of the B-pillar in these cases. Consequently the car twists the wheel forward. When the impact point is behind the B-Pillar, the tire slides along the car body as shown in the figure 8.

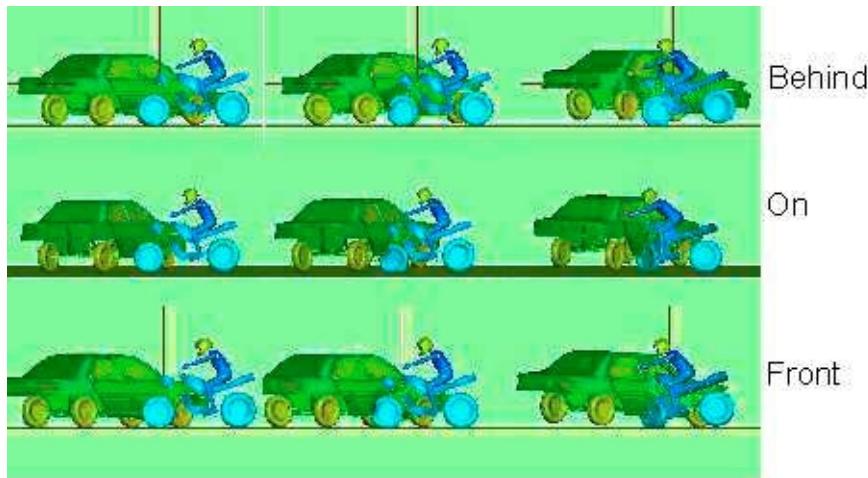


Fig. 8: Affect of the point of impact of the M/C in the car-M/C Case 2 impact.

In the crash tests it is difficult to control the point of impact to few cm precision in the presence of lateral movement. Slight error in the experiment may give the results that are not reproducible. The crash test, in which the impact point was behind the B-Pillar is one such example.

**RESULTS OF THE CASE III AND CASE IV SIMULATIONS:** For these two configurations the comparison of the experiment and the simulation is shown in the Figures 9 and 10. There is a reasonable match and the observations are similar.

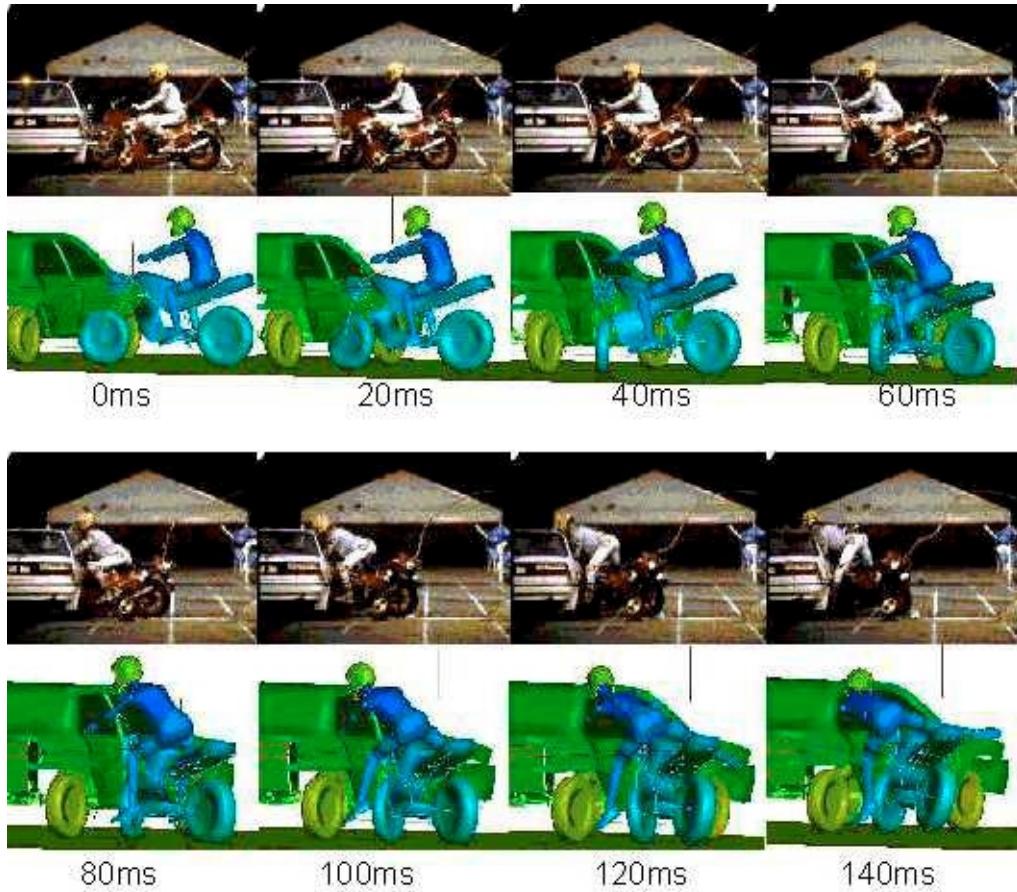


Fig 9. Comparison of the simulation kinematics with the crash test at 20msec intervals for the Case III impact.

In all the cases we have qualitatively discussed the kinematics. As shown, the overall kinematics depends on many factors. Since many of these factors are not very reproducible, a quantitative comparison of the accelerations at this stage is not very meaningful.

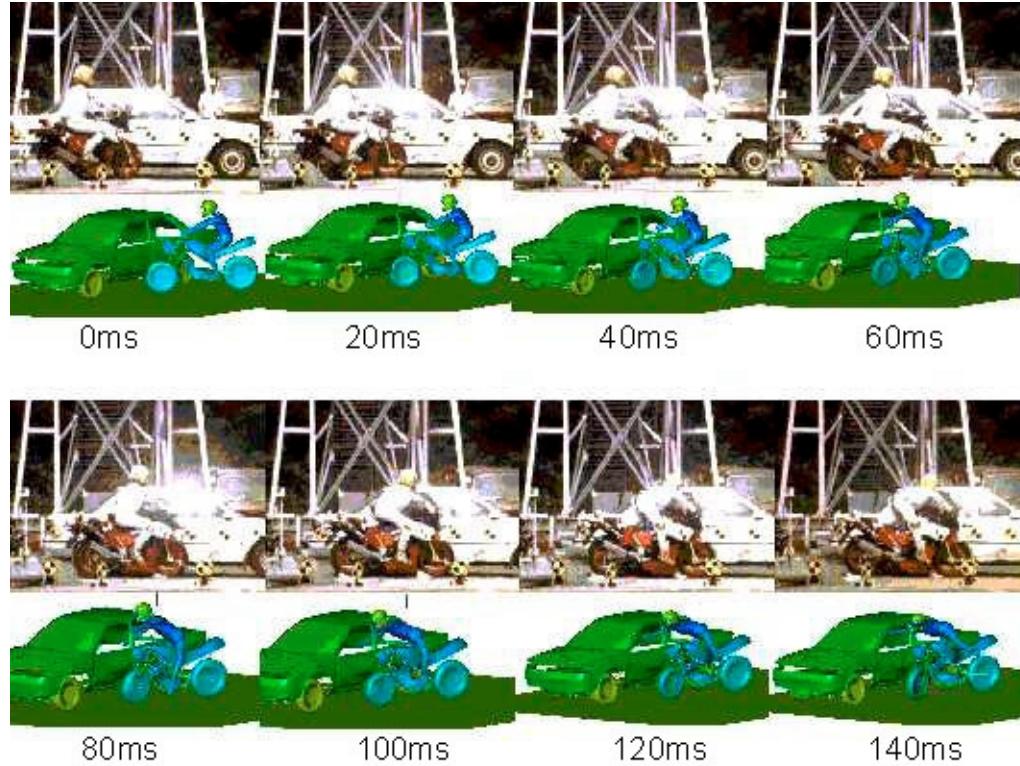


Fig 10. Comparison of the simulation kinematics with the crash test at 20msec intervals for the Case IV impact.

## CONCLUSIONS

The qualitative results of the car-M/C side impact simulations presented in this paper show close match with the experimental observations. The simulations presented highlight the effect of some of the differences between the H-III and the MATD dummy. These differences play an important role in the car-M/C impacts. It is also observed that some configurations listed in [ISO13232] are very sensitive to the impact location. In order to ensure the repeatability of the [ISO13232] tests it will be important to control the impact location within a small range. Since the experimental data is limited to four impacts under differing configurations, there is insufficient data to generate confidence levels in the quantitative data. The repeatability of the crash tests, we feel, also needs to be established to have a better confidence on future simulations. Also, a Hybrid-III dummy like model, which deviates somewhat from the MATD, is used in the simulations. Due to the above uncertainties, a quantitative comparison of accelerations is not relevant at this stage. The limitations above lead us to fresh areas of study, which are being addressed. These simulations have undoubtedly thrown new light on many aspects of the car-M/C impact study.

The simulation results presented here match the experimental observations quite closely. It has been further demonstrated that the affect of some critical parameters in the experiments can be

demonstrated effectively by altering them suitably in the simulations. We conclude that these simulations offer an important tool to study the car-M/C (and other) impacts and the sensitivity of many parameters in them.

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