FE SIMULATIONS OF MOTORCYCLE - CAR FRONTAL CRASHES, VALIDATIONS AND OBSERVATIONS

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ISO 13232[1](1996) requires 7 configurations for full scale tests (FSTs) between the motorcycle (MC) and the car (also called the opposing vehicle, OV). Of these, 3 involve the impact of the MC with the front of the OV. In this paper we discuss Finite Element (FE) based simulations of these impact configurations. We do not evaluate the efficacy of any safety devices but refer to parts of ISO 13232 for developing these simulations. This paper analyses FE based simulations of the above-mentioned impacts. The simulations have been developed using the PAM-CRASH™ solver. In this paper an attempt has been made to compare the kinematics of the simulations with those obtained from the FSTs. The simulations indicate that the MC-OV impacts are sensitive to many phenomena. The objective of this paper is to highlight some of the important aspects of MC-OV simulations.

This paper has been revised from an earlier version of the paper[2](2003).

KEYWORDS: PAM-CRASH™, Finite Element Method, Models, Dummies, Full Scale Tests.

1. INTRODUCTION

ISO 13232 Part 2 incorporates data describing road accidents involving MCs. The data in part 2 were used to determine the frequency of impact orientations and speeds of the MC and the OV involved in accidents. Based on this, three configurations were identified for the impact of the MC with the front of the OV. The impact configurations are shown in Figure 1 below.

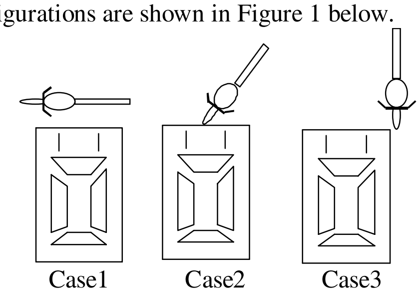


Figure 1 Impact configurations between the MC and the front of the OV.

Case1 in Figure 1 shows the front of the OV impacting the stationary MC perpendicularly. Case2 in Figure 1 shows the schematic of a frontal oblique impact with the MC and the OV heading towards each other at an angle of 135degree. The MC impacts the center of the OV bumper. Case 3, shown in Figure 1, is the MC impacting the stationary OV at an angle of 180degree. The MC hits the front corner of the OV in this case. The impact points are defined in ISO 13232. The relative angles and speeds of MC-OV frontal crash tests have been taken as in ISO 13232 and are represented in Table 1.

Table 1 Major parameters of impact configurations between the MC and the front of the OV.

Configuration number in Figure 1	Relative angle (degree)	OV speed (m/s)	MC speed (m/s)
Case 1	90	9.8	0
Case 2	135	6.7	13.4
Case 3	180	0	13.4

Earlier experimental as well as mathematical studies have been carried out by Chinn[3](1986). Subsequently, a lot of work has been done by Rogers[4](1991),[5](1996),[6](1998),Zellner[7](1994),[8](1996), Kebschull[9](1998). This work has finally culminated in the development of ISO 13232 which is the standard for evaluating the feasibility of safety devices in MCs. Nieboer[10] and Yettram,et al.[11] have reported the development of rigid body models of MCs. We concur with the observation that MC simulations turn out to be far more difficult compared to the simulation of OV occupants. This is due to the multiplicity and complexity of the interactions that are involved.

These problems can be studied by using FEM which can describe large deformations. We have initiated research using FE based tools to understand the important issues in modeling the crash behaviour of MCs. This paper describes initial work in that direction.

For the parameters and impact configurations listed above in Table 1, simulations were carried out in PAM-CRASH™. As defined in ISO13232 these parameters are given in terms of cell range nominal values. For the computer simulation nominal values of the impact conditions have been used. In this work, we do not use ISO 13232 to evaluate the efficacy of any safety devices but use aspects of them to highlight some of the important issues in ISO 13232 and in MC-OV simulations.

2. DEVELOPMENT OF MODELS AND SIMULATION

In our previous paper[12)](2001), we have discussed the impact simulations in which the MC impacts the side of the OV. For this impact simulation, the OV model has been developed as indicated in Chawla,et al.[13)](2001). Briefly, models of MC and OV components were built using the Coordinate Measuring Machine data collected from the actual vehicles. Other relevant properties like structure details and material properties were obtained by conducting suitable tests and measurements. The modeling was done using I-DEAS™ and PAM-CRASH™. The OV model used in this case is that of a Toyota Corolla car**.** Components in the MC and the OV that came into contact during impact, and components in close proximity to such contacting surfaces have been modeled with greater detail and parts not bearing the direct impact have been modeled with coarser mesh. For the side structures (left and right), only the door panel including the A, B and C pillars has been modeled. The door structures have been replaced by equivalent masses so as to simplify the model as they have insignificant effect in frontal kinematics.

Features of the OV model that could be critical in case of frontal impact are the bumper, bonnet, radiator, fender and head light structure. Therefore, separate component validation tests have been conducted to validate the models of these parts. Mukherjee[14)](2000) describes the windshield model developed and validated in this manner. The final OV model is shown in Figure 2.

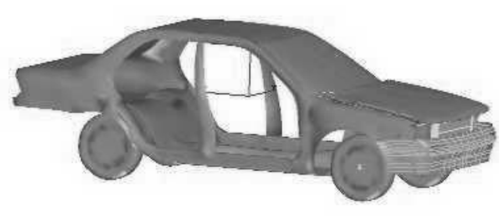


Figure 2. the OV model.

The MC model (of Kawasaki GPZ) used for these frontal impact simulations is described in Chawla,et al.[13)](2001). Since a validated Motorcycle Anthropomorphic Test Device (MATD) dummy model was not available, in the simulations the Hybrid III 50% adult male dummy model developed by ESI was used after modifying some critical parts like the wrist, elbow joint, pelvis, head etc. Figure 3 shows the MC model with the dummy positioned on it.

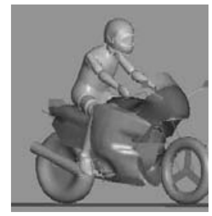


Figure 3 the MC model with the dummy positioned on it.

Some modifications were introduced from the MC-OV FE model discussed in our previous paper[12)] (2001). It was observed in the FE simulations that the dummy's leg was entering the gap between the seat and the tire, and interfering with the normal simulation. The chain cover and accessories were then modeled so as to take care of the problem. It was observed that small details in the FE models become critical in MC-OV simulations as they affect the kinematics and the force histories. MC-OV FE simulation models therefore, have to be prepared taking these into account.

In some of the simulations, the OV bumper impacts the MC front shock absorber. The front shock absorber had earlier been modeled as a beam with appropriate kinematic joints. It was observed that the interaction of the bumper with the shock absorber was not being captured accurately. In order to model it accurately, the front shock absorber was modeled using cylindrical structures reflecting the true geometry. Interaction between the bumper and the shock absorber was then redefined. The OV model finally contains 522 solid elements, 18459 shell elements, 2394 beam elements and 4 translation joints. The motorcycle model contains 180 solid elements, 3619 shell elements, 346 beam elements, one bar and 2 translation joints.

The OV was given an initial linear speed corresponding to the nominal test conditions in Table 1. The OV wheels were also given an initial angular speed. For different configurations, the OV and the road were translated or rotated as required. The point of each impact has been modeled as specified in ISO13232. The simulation was carried out for 570 msec, which is long enough to model the first contact between the dummy and the OV. The orientations of the MC-OV simulation models for the three cases are as shown in Figure1.

3. VALIDATION OF THE KINEMATICS AND MODELING PARAMETERS

We were interested in comparing the kinematics of the dummy in the simulation and the FST. The goal of this comparison is to establish that these simulations capture details of the MC–OV impact very effectively. We are comparing the kinematics qualitatively at the moment, and a quantitative comparison of the accelerations and the injury indices can be done after the MATD model is updated. In this paper ISO 13232 is not being used to evaluate the effectiveness of safety devices. Hence quantitative evaluations as required by ISO13232 have not been done in this work. In the subsequent sections we discuss the simulations of the three cases.

Case 1: the front of the OV with the side of the MC

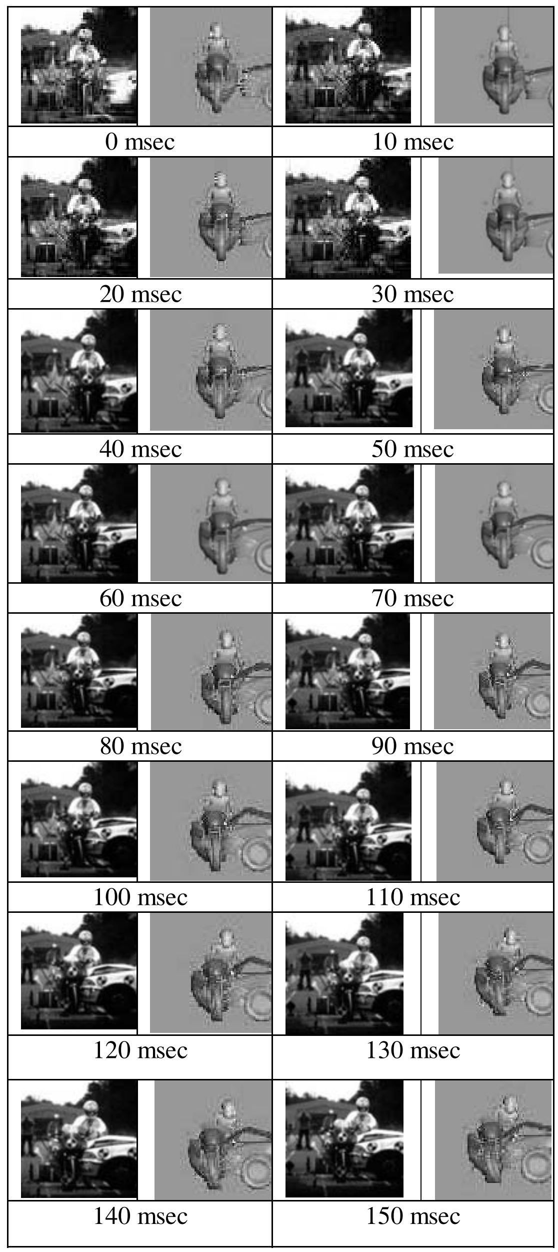
Case1, shown in Figure 1 shows the front of the OV impacting the stationary MC perpendicularly. Upto 150 msec, the successive frames are taken at intervals of 10 msec.

The MC-OV impact starts with the left leg protector (LP) coming in contact with the bumper, and this instant of time is marked as t=0 as shown in the simulation in Figure 4. At 20msec, the left LP strikes the bonnet hood. From 50msec, the bonnet hood starts to bend from the middle and forms a 'V' shape. The deformation observed in the simulation is similar to that in the FST, but the bending in the simulation is more prominent and is a little faster. From 60 msec, the left arm loses contact with the grip and falls over the bonnet. In order to model the grip of the MATD on the handle bar, the Hybrid III hand has been modified so as to capture this phenomenon effectively. After this, the entire dummy falls off to its left almost onto the bonnet hood. The MC silencer also comes in contact with the OV bumper and contributes to the impact.

In the simulation as well as in the FST the dummy starts bending from the initial vertical position at around 80-90 msec. The inclination of the dummy with the vertical in the simulation is reproduced quite closely in the FST. The dummy head approaches the edge of the bonnet / windshield but head impact does not occur as the MC and the dummy start moving away from the OV due to the impact. The inclination of the dummy and the height gained by the right leg is large in the simulation.

We think this disparity is due to use of a Hybrid III dummy model in the simulations while a MATD dummy was used in the FST. The Hybrid III joint structure is different from that of the MATD dummy. Of the variations present in the MATD upper body structure, one of the most significant is that the MATD neck allows more twist than the Hybrid III neck. This motion is absent in the Hybrid III. Also the MATD joints are assembled with more tension than the Hybrid III joints to maintain stability in the run up to the impact[1)15)16)]. Similar variation between the FST and the simulation in the head movement in spite of consistent torso movement is seen in other cases as well.

The kinematics in simulations are quite close to those in the FST. The LP comes first in contact with the OV bonnet. In the absence of the LP, the fuel tank and the front portion of the MC will establish the initial contact. The phenomenon of the bonnet bending near the midline may be of significance and may alter the impact to the dummy. We feel that the bending characteristics of the bonnet should be validated for realistic results. This effect has of course been well captured in the simulations. The bending of the bonnet has been captured in the simulations by the dynamics of the surface model. This model has been made with care so as to get the appropriate curvatures (and the resulting bending) correctly. The preciseness of the model is limited by the lack of CAD data of the vehicles [13)](2001).



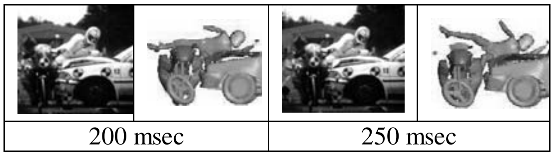


Figure 4 Comparison of the kinematics of the FST and simulation (Case1).

Case 2: the front of the OV with inclined MC

In this case the MC approaches the OV from the front at an angle of 135degree as shown in Figure1. The kinematics for the FST and for the simulation is compared in Figure 5 below.

The sequence of events during the frontal oblique crash in the simulation is as follows. The impact starts with the front tire of the MC striking the OV bumper which is marked as t=0. At 20msec the front tire of the MC turns towards its right and so the bumper comes in contact with the left LP. From 30 msec the bonnet comes in contact with the LP and then starts bending from the middle. At 40 msec the bumper contacts the MC radiator. From 80msec the MC rear tire starts lifting off the ground and dummy starts lifting off from the seat from 90msec and falls over the bonnet. The helmet hits the bonnet at 140msec and by 250msec the entire dummy is over the OV bonnet.

The FST and the simulation match quite closely, especially for the first 150msec. Subsequent variations like those in rotation of body joints, can be explained on account of the differences in the MATD and the Hybrid III. The kinematics of the MC after the dummy leaves the MC is also slightly different. In the simulation the MC rear wheel does not clear the ground as much as it does in the FST. At this point the dummy has already left the MC and there is no substantial contact between the two. So, at this stage the MC does not affect the dummy kinematics in a big way.

In this case also, the LP comes in contact with the OV bonnet. The bonnet bending phenomenon in this case is not as prominent as in the FST. The bonnet bending phenomenon in the simulation in this case is less than in the FST. If the bonnet folding is small, the bonnet flattens under the weight and momentum of the dummy after the dummy lands on it. The bonnet folding may affect the kinematics of the dummy significantly. The folded bonnet acts as a barrier between the dummy and the hard areas of the OV, modifying the impact and changing the point of head impact on the OV. In the simulation, though the bonnet folds, the folding is not as pronounced as in the FST and there is thus a mismatch in the eventual impact point.

We feel that effects such as bonnet folding cannot be effectively modeled without incorporating the detailed geometry along with appropriate material models. For these simulations, we feel that it is important to conduct a validation of the bonnet buckling behavior in addition to the calibration tests mentioned in ISO13232. Even though we are using FE models, we have not yet validated the bonnet model for this folding. In addition, the differences between the MATD and the Hybrid III model have also contributed to the differences in the kinematics of the simulation and that of the FST.

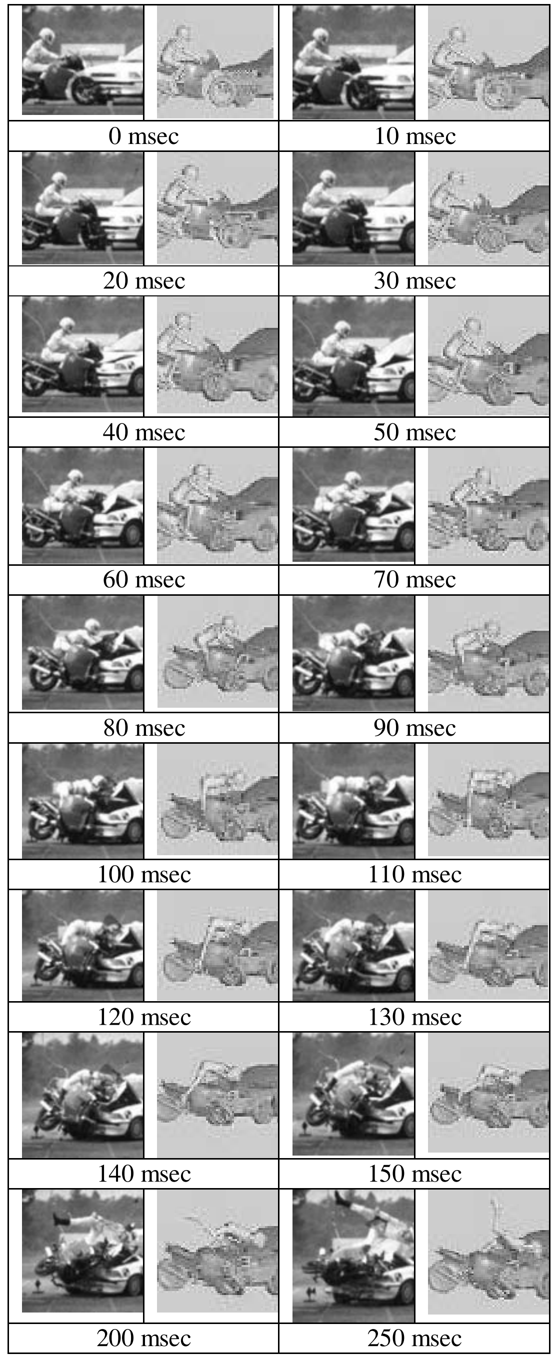


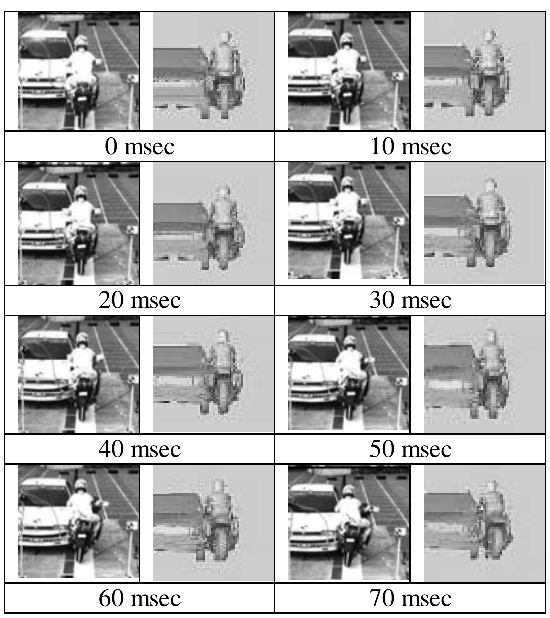
Figure5 Comparison of the kinematics of the FST and the simulation (Case2).

Case 3: Glancing impact at the corner of the OV

In this case the MC approaches the OV from the front and hits the front corner of the OV as shown in Figure 1. In this orientation the offset between the centerlines of the MC and the OV is critical as even a small change in this offset can modify the MC kinematics. The kinematics for the FST and for the simulation are compared in Figure 6 below.

In the simulation, the sequence of events during the frontal oblique crash is as follows. The MC LP hits the bumper of the OV on the corner, which is marked as the t=0 time instant. From 30msec the MC starts tilting to its right. At 50msec the dummy starts rising from the seat. Subsequently the left arm contacts the A-pillar of the OV, following which the dummy's head starts bending down and comes close to the MC headlight area at around 110msec. By 200msec the dummy is totally off the MC.

In the kinematics shown in Figure 6, we see that while some differences are there, the kinematics of the MC matches reasonably well with that in the FST. While the time at which the MC loses contact with the OV in the simulation and the FST is close, the inclination of the MC after the impact is at variance. By running repeated simulation, the kinematics are found to vary considerably with change in the gap between the MC and the OV. This is to be expected because of the glancing nature of the impact. The impacting surfaces are almost tangential at the point of impact. The first point of contact in the FST is difficult to determine for a comparison. The simulation reported has been developed as per nominal initial conditions specified in ISO 13232.



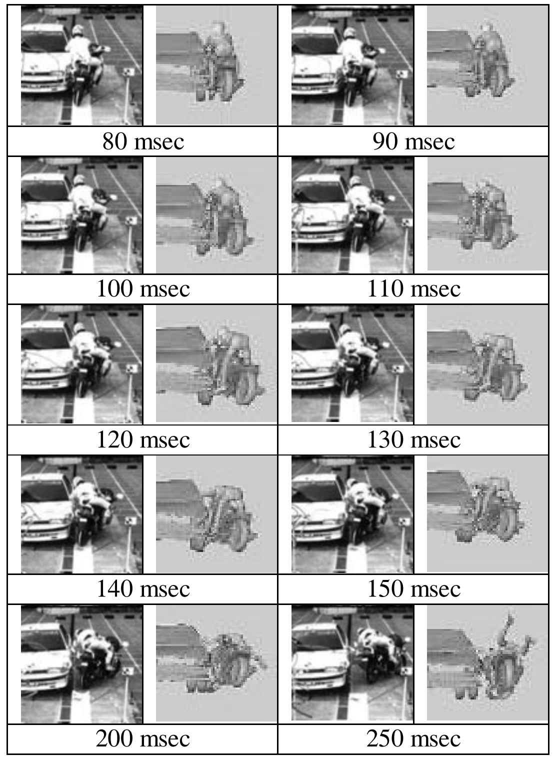


Figure 6 Comparison of the kinematics of the FST and the simulation (Case3).

4. CONCLUSIONS AND DISCUSSION

The kinematics of the three impact configurations show that the simulations predict the general behavior of the OV and the rider. Some of the components of the MC and the OV that are critical for simulating these impacts include the bumper, the radiator and the bonnet for the OV, and the silencer, the fuel tank and the shock absorber of the MC.

In running the simulations it is essential to ensure proper contact interaction between colliding parts as problems related to 'nodal sticking' are observed. Nodal sticking is the phenomenon in which the node is assumed to have approached the interacting surface from the wrong side. This is a known problem in all FE based simulations but in MC-OV simulations it assumes greater significance because of the complexity of interactions involved.

These simulations show the effect of including detailed geometry and properties of many components in these impact simulations. In this paper we have stressed the importance of these details and have shown their relevance for these MC-OV impact configurations. Simulations indicate that some of the impact configurations might be sensitive to some impact parameters. On the basis of our simulations we feel that the repeatability / reproducibility of these impact configurations should be investigated.

At this stage, we have not done a quantitative comparison of the accelerations and the injury indices. In addition, as mentioned earlier, we have not used ISO 13232 to evaluate the efficacy of any safety devices, but have referred to parts of them for developing and studying MC-OV simulations. In the process of qualitatively studying the MC-OV simulations, we have also demonstrated the usefulness of FE simulations as a tool to study the impact behaviour of vehicles at the design stage.

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