FE SIMULATIONS OF MOTORCYCLE – CAR FRONTAL CRASHES, VALIDATION AND OBSERVATIONS

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ABSTRACT - The ISO 13232 document recommends a set of 3 frontal impact test configurations between the motorcycle (MC) and the car (also known as the opposing vehicle, or OV). This paper reports Finite Element (FE) based simulations of the above-mentioned frontal impacts for the OV and their detailed analysis. The simulations have been carried out in PAM-CRASH^{TM}. The kinetics of the crash simulation has been matched with the Full Scale Test (FST) conducted at Japan Automobile Research Institute (JARI) The simulations indicate the sensitivity of the different parameters in the various MC – OV impact configurations.

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

INTRODUCTION - The ISO:13232 document lists data regarding major road accidents involving motorcycles. This analysis has been used to determine the frequency of impact orientations, relative speeds of the MC and OV involved in the accident. Based on this study three major impact configurations have been identified for the MC impacting the front of the OV. The impact configurations are shown in the figure 1 below.

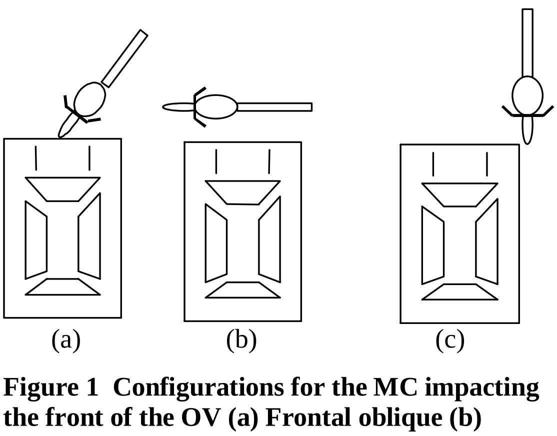


Figure 1 Configurations for the MC impacting the front of the OV (a) Frontal oblique (b) Frontal side (c) Frontal Glance.

Figure 1a shows the schematic of a frontal oblique impact with the MC and OV heading towards each other at an angle of 135°. The MC impacts the center of the OV bumper. In the second configuration the front of the OV impacts the stationary MC perpendicularly. The third case, shown in figure 1c, is the MC impacting the stationary OV at an angle of 180°. The MC hits the side fender of the OV in this case. The relative angles and velocities of MC-OV frontal crash tests have been formulated based on accident data and are represented in the table 1.

Table 1
.Frontal Impact Crash Configuration Parameters

Configuration No.	Relative angle (deg.)	OV Speed (m/s^2)	MC Speed (m/s^2)
1	135	13.4	6.7
2	90	9.8	0
3	180	0	13.4

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) and Yettram, etal (1994) have reported development of rigid body models of the motor cycle. We concur with the observation that, MC simulations turn out to be far more difficult compared to the simulation of car occupants [Neiboer, 1993]. 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.

For the parameters and impact positions listed above in **Table 1**, simulations were carried out in PAM-CRASH^{TM}. As defined in [ISO13232] these parameters are given in terms of cell range values. For the computer simulation nominal values have been used. We present results of simulations for the cases when the MC is equipped with a leg protector (LP).

Development Of Models And Simulation Using Pam-Crash - In [IRCOBI 2001] we have discussed the side impact simulations between the MC and the car. For the frontal impact simulations, the OV model has been refined in the frontal region to make it more suitable for frontal impacts. [Chawla etal, 2001] describes the detailed methodology used by us for developing the FE models. Briefly, models of the MC and the OV components were built using the CMM data collected from the actual vehicles. 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 MC and OV forming new contacts 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 have been modeled. The door structures have been removed to simplify the model as they have insignificant effect in frontal impact kinematics.

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

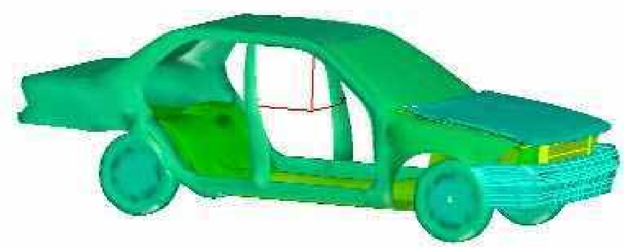


Figure 2. FE Model of OV Used for the Frontal Impact Simulation.

The MC model (of Kawasaki GPZ) used for these frontal impact simulations is described in [Chawla etal, 2001]. A model of the MC with an LP has been used in these simulations. The dummy used in the case is Hybrid III 50% adult male dummy as developed by ESI. Figure 3 shows the MC model with the dummy positioned on it.

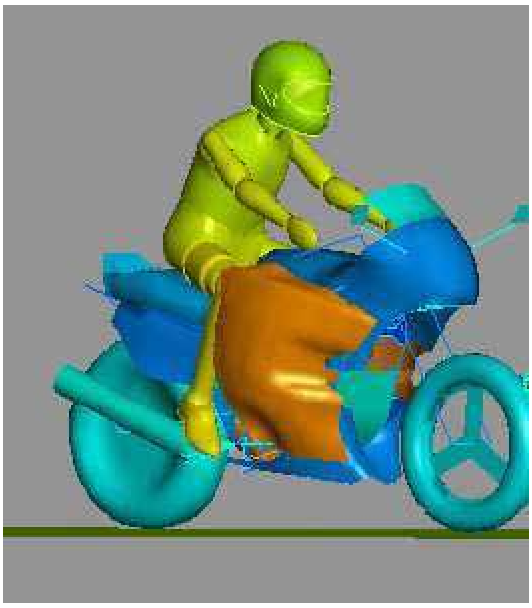


Figure 3 . MC Model with the Dummy Positioned on it

Some modifications were introduced from the motorcycle FE model discussed in [IRCOBI 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. On close look it was observed that this was because the chain cover and accessories in that area had not been defined. A cover was modeled in that area so as to take care of this problem. It was observed that even small details in the FE models become critical in MC – OV simulations as they effect the kinematics and the force histories. MC – OV 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 velocity corresponding to test conditions. Wheel of the cars was also given initial angular velocity to start spin. For different configurations, the OV and the road were translated or rotated as required. The point of impact has been modeled as specified in [ISO13232]. The simulation was carried out for 570 milliseconds, which is long enough to model the first contact between the dummy and OV. The orientation of the MC - OV simulation model for the three cases is as shown in Figure 1.

Validation Of The Kinetics And Modeling Parameters - We were interested in comparing the kinematics of the dummy in simulation and the experiment. The goal of this comparison is to establish that these simulations capture details of the MC – OV impact very effectively. Therefore at this stage we are comparing the kinematics qualitatively and a quantitative comparison of the accelerations and the injury indices is not being done right now. In fact, the main purpose of ISO13232 is to compare the difference of existence of safety devices. This ISO is not to evaluate the safety quantitively. The comparison for the three cases is being done separately.

Case I (Frontal Side Crash- Mc With Lp): In the FST as well as in the simulation the dummy starts bending from the initial vertical position at around 80-90 msecs. The inclination of the dummy with the vertical is reproduced quite closely in the simulation. In the FST as well as in the simulation the dummy head approaches the edge of the bonnet / windshield and 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 larger 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 torso structure, one of the most significant is that the MATD neck allows a twist about the neck. This motion is absent in the Hybrid-III. Also the MATD joints are assembled stiffer than the Hybrid III joints to maintain stability in the run up to the impact [ISO13232], [STLaurent, 1991], [Newman, 1994]. Similar variation between simulation and experiment in the head movement in spite of consistent torso movement is seen in other cases as well.

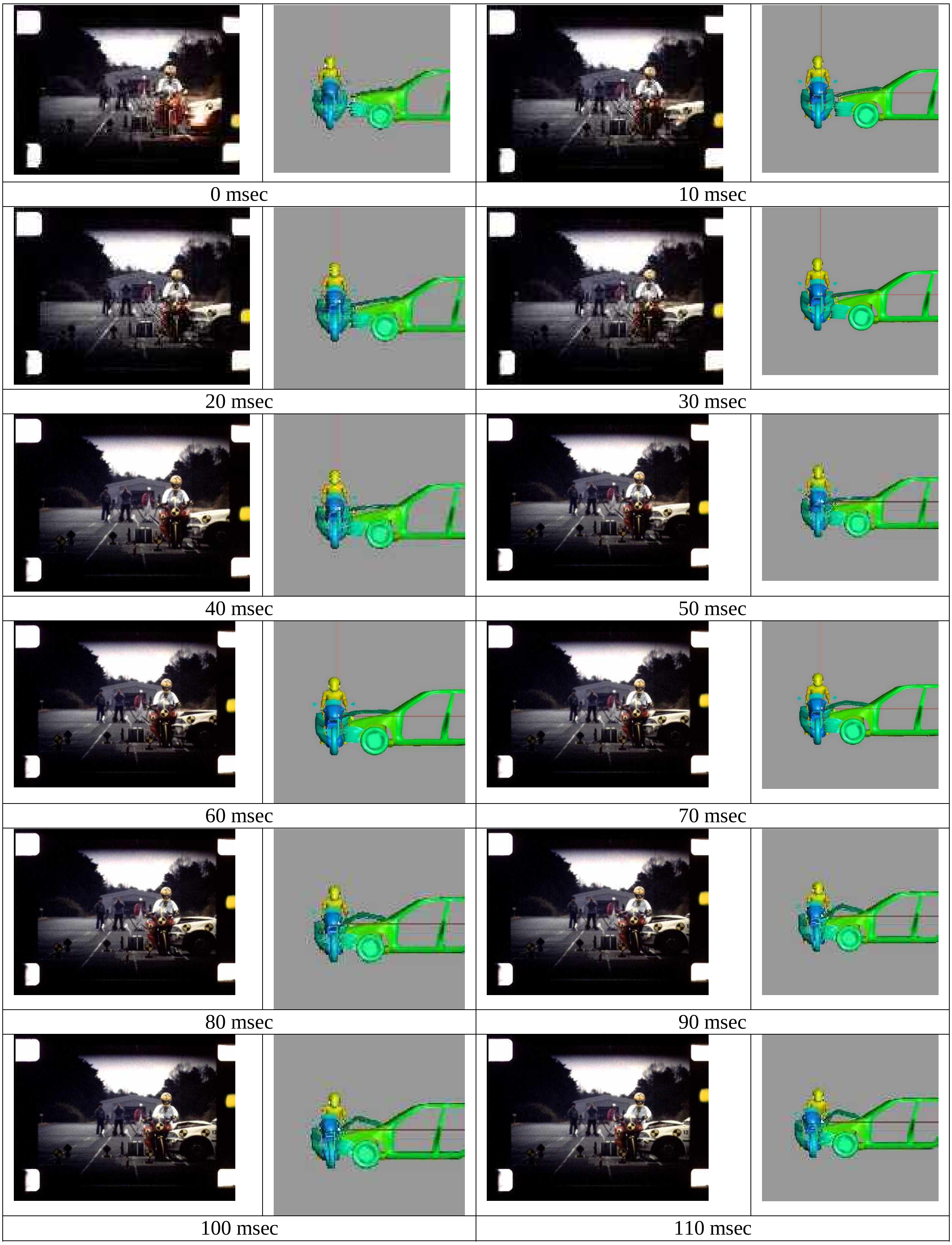
The kinematics in simulations is quite close to those in the FST (Figure 4). The LP comes first in contact with the OV bonnet. In the absence of the LP, the fuel tank and the front portion of the MC will establish the initial contact. The phenomenon of the bonnet bending near the midline is important and can alter the impact of the dummy. We feel that the bending characteristics of the bonnet also need to be validated. 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 only by the lack of CAD data of the vehicles [Chawla etal, 2001].

The MC OV impact starts with the left LP coming in the contact with the bumper, this time instant is marked as t=0. At 20ms, the left LP strikes the bonnet hood. From 50ms, the bonnet hood starts bending from the middle and forming a 'V' shape. Similar deformation is observed in the FST but the bending is not as prominent and slightly delayed. From 60 ms, the left arm loses contact with the grip and falls over the bonnet, following which the entire dummy falls off to its left almost on to the bonnet hood. At around 150ms, the dummy rests on the bonnet and has both grips have lost contact with the MC. The MC silencer also comes in contact with the OV bumper and contributes to the MC impact.

Case Ii (Frontal Oblique Crash - Mc With Lp) In this case the MC approaches the OV from the front at an angle of 45^o as shown in Figure 1. The kinematics for the FST and for the simulation is compared in **Figure 5** below. Successive frames are taken at intervals of 10 ms. The FST and the simulation match quite closely, especially for the first 150msecs. Subsequently variations caused by discrepancy in the MATD and the Hybrid-III can be seen. Especially the affect of the rotation in the neck (in MATD) and the effect of stiffer joints (in MATD) can be clearly noticed by comparing the kinematics. The kinematics of the MC after the dummy leaves the MC is also slightly different. In the FST, the rear wheel of the MC clears the ground more than in the simulation. At this point the dummy has already left the MC and there is no substantial contact between the two. So this does not affect the dummy kinematics in a big way.

In this case also, the LP comes first in contact with the OV bonnet while if the LP was not there, the fuel tank and the front portion of the MC would establish the initial contact. As a result the bending phenomenon of the bonnet would be different if the LP were not present. The bonnet bending phenomenon in the FST in this case is more than in the simulation.

If the bonnet folding is less, the bonnet flattens under the weight of the dummy after the dummy lands on it. The bonnet folding affects the kinematics of the dummy significantly. The folded bonnet acts a soft barrier between the dummy and the hard areas of the car, moderating the impact and changing the point of head impact on the car. 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.



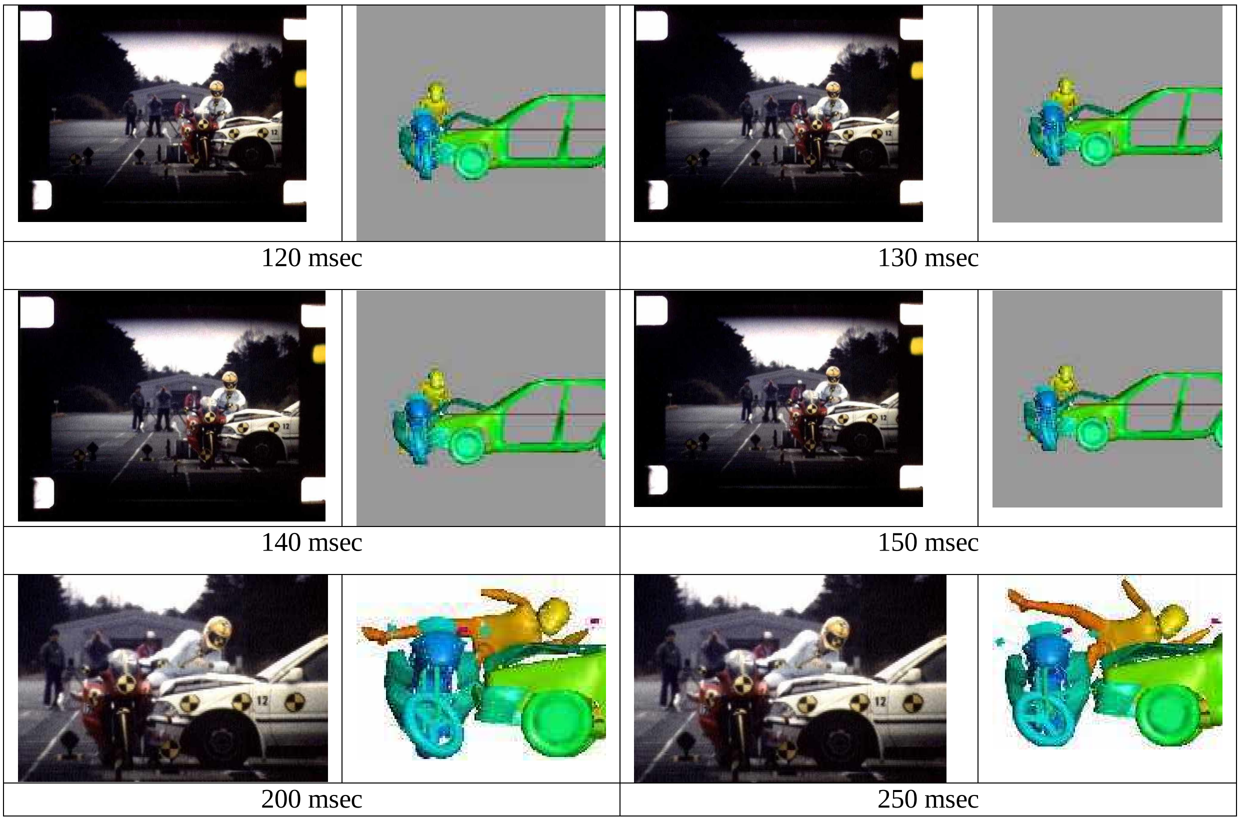


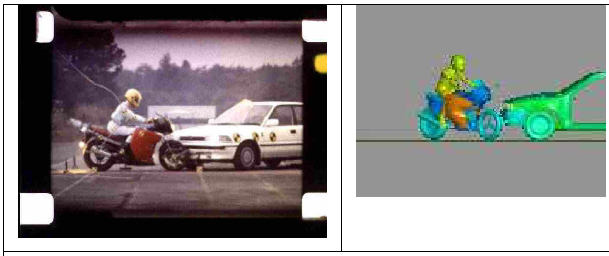
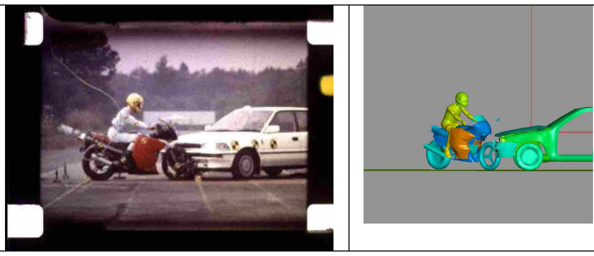
Figure 4 Comparison of the Kinematics of the FST and Simulation.

Effects such as the bonnet folding (buckling) cannot be effectively modeled using rigid body models as have been used in computer simulations in the past. For FE simulations, we feel that it might be important to include validation of the bonnet buckling behaviour in [ISO 13232] . Even though we are using FE models, we have not yet validated the bonnet model for this folding. In addition, the affect of the twisting of the MATD also remains the same as in the previous case. Thus the differences between the simulation and the FST can be explained on account of these differences.

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

Case III (Frontal Glancing Crash At The Fender - MC With LP) In the case the MC approaches the OV from the front and hits the fender of the OV as shown in Figure 1. In this orientation the offset between the centerlines of the MC and the OV are found to be critical. Even a small change in this offset modifies the MC kinematics in a big way. The kinematics for the FST and for the simulation is compared in Figure 6 below.

The sequence of events during the frontal side glancing impact is discussed below. The MC front tire hits the side bumper of the OV, which is marked as the t=0 time instant. From 30ms the MC starts tilting to its left. At 50 ms the dummy starts rising from the seat subsequently the right arm contacts the A-pillar of the OV. Following which the dummy's head starts bending down and impacts the MC headlight area at 110ms. By 200 ms the dummy is totally off the MC.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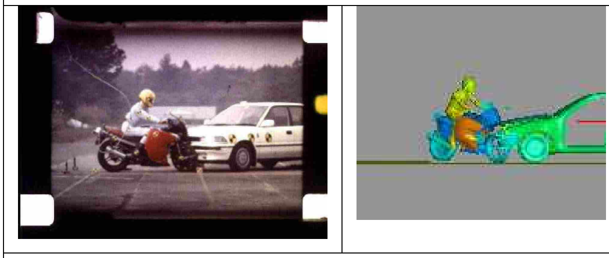	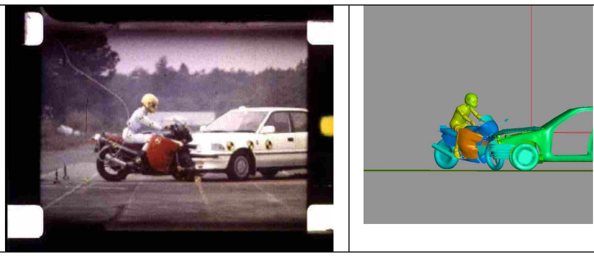
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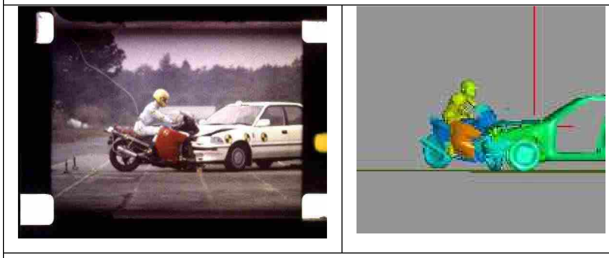	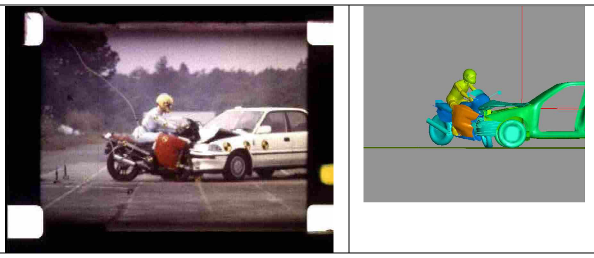
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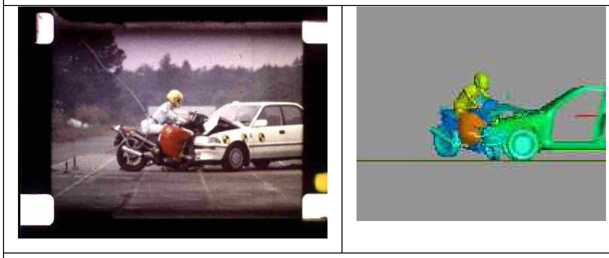	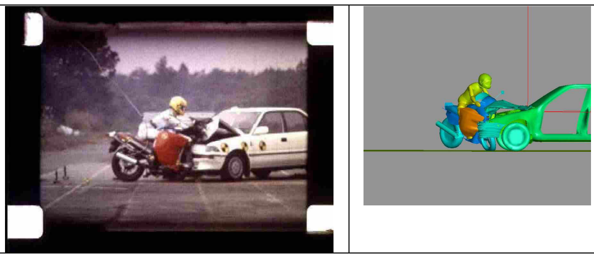
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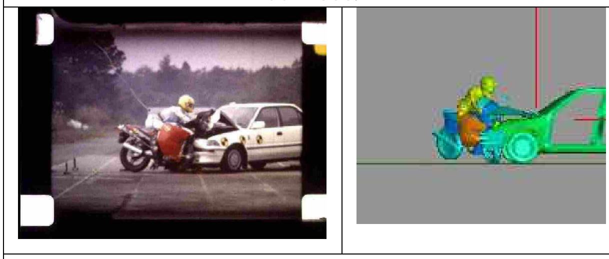	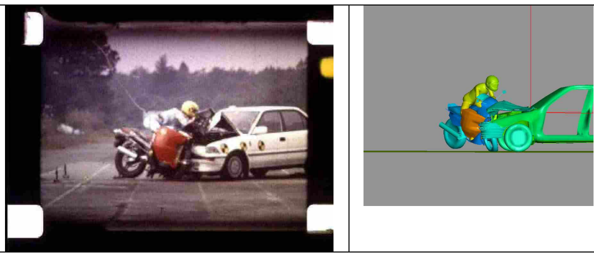
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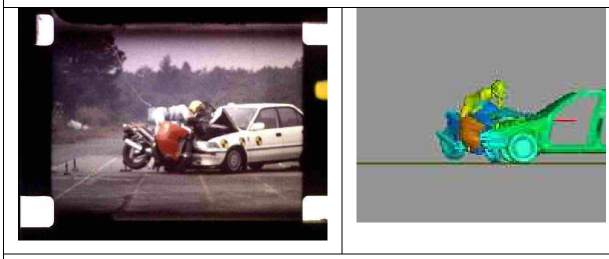	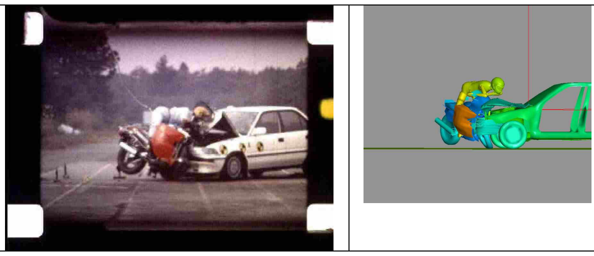
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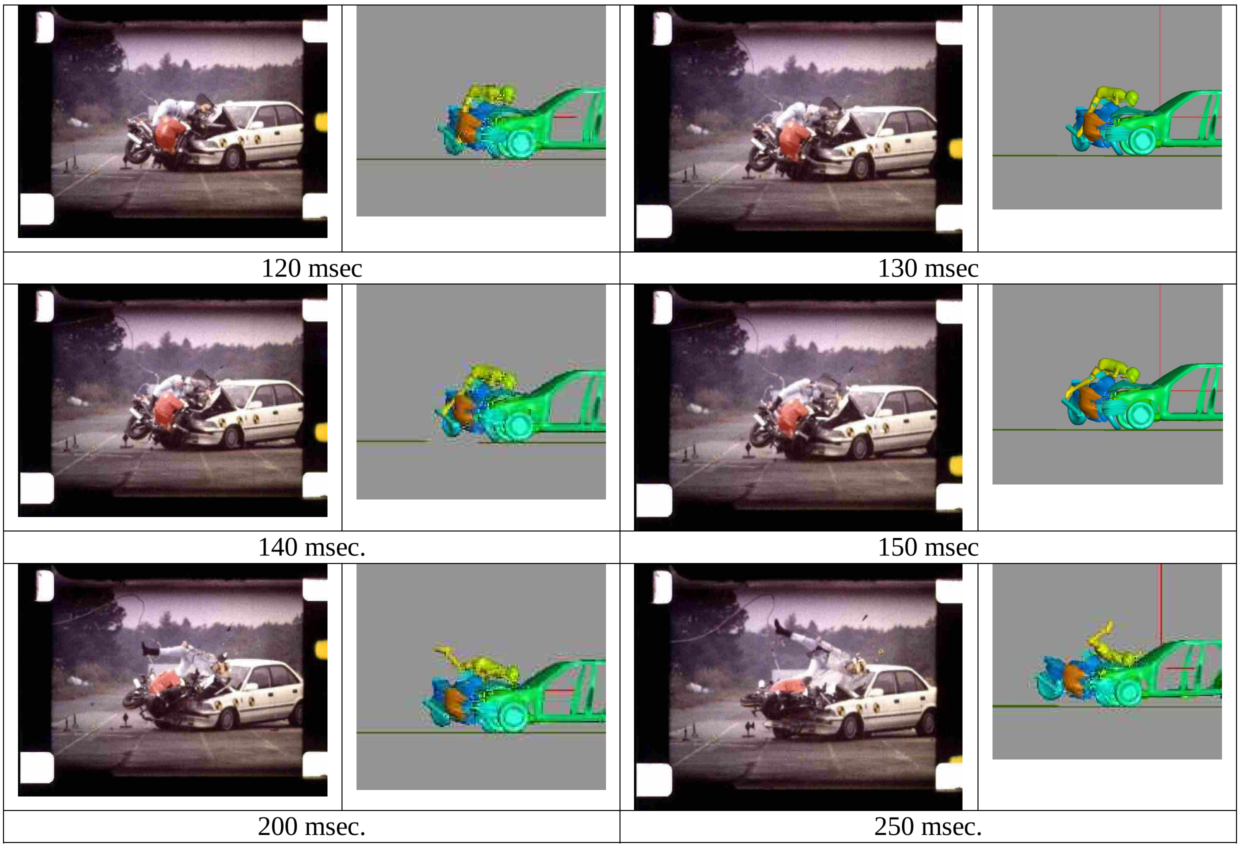

Figure 5: Comparison of the Kinematics of the FST and the Simulation (frontal oblique impact)

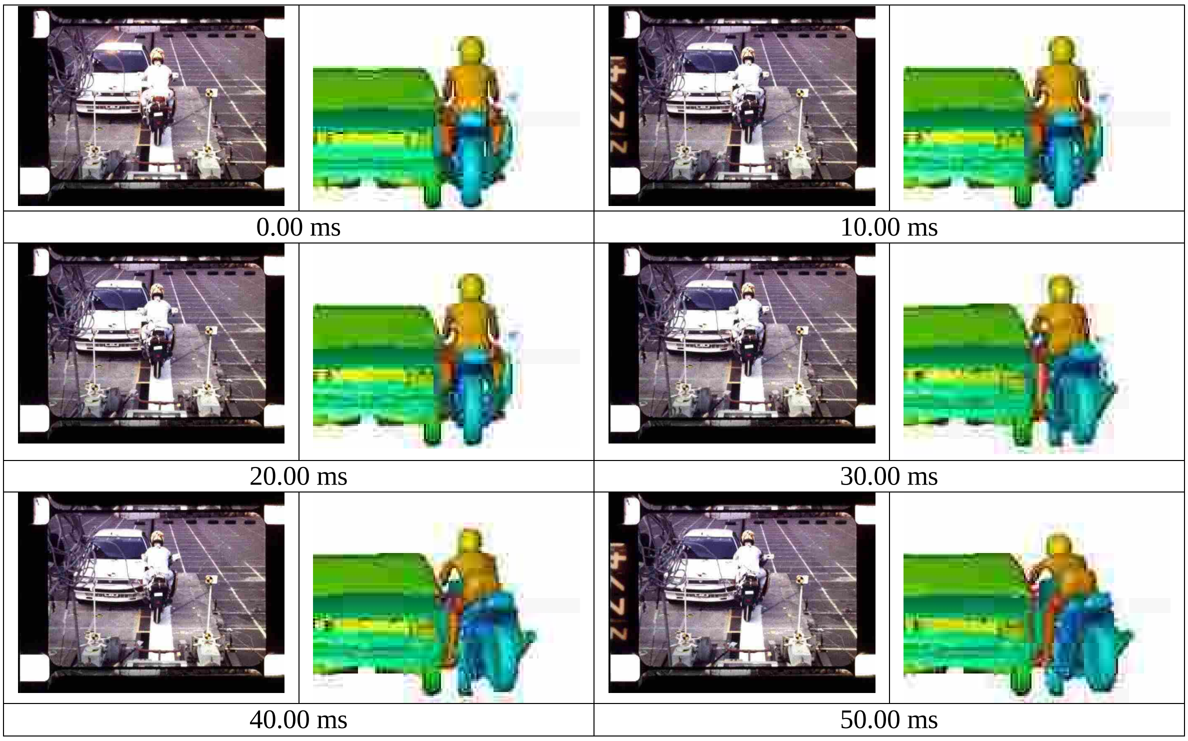

Figure 6: Comparison of the Kinematics of the FST and the Simulation (frontal glance)

In the kinematics shown in Figure 6, we see that the kinematics of the MC matches reasonably well with that in the FST. A small difference is noticeable. While the time at which the MC loses contact with the OV in simulation and FST is close, the inclination of the MC after the impact is at variance. By running repeated simulation, the kinematics is found to vary considerably with change in the gap between the MC and the car. This is to be expected because of the glancing nature of the impact. The impacting surfaces are almost tangential at the point of impact. Further, the exact point of impact in the FST is also difficult to determine after the experiment. The simulation shown is as per the ISO specification.

CONCLUSIONS - The kinematics of the three impact-configurations show that the behavior of the vehicles and the rider as observed in the FST is close to the predictions from the FE simulations. The components of the MC and the OV that are critical for simulating these impacts are, the bumper, the radiator and the bonnet for the OV, the silencer, fuel tank, and the shock absorber of the MC. The LP plays an important part during the crash as it initiates contact with the components of the OV. For accurate simulation, accurate assessment of geometric and material properties needed for these components.

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.

The ISO specifies a number of tests for the MC and the OV components. These tests are aimed at developing rigid body simulations, but in many instances, phenomena like the buckling of the bonnet are not captured realistically by such rigid body analyses. The ISO does not recommend tests for material properties of the individual components. But, the simulations show that both the buckling phenomenon and the properties of the components are important determinants in deciding the outcome.

In the third impact configuration (frontal side glance), the offset amount is very critical as it modifies the kinematics of the MC after impact significantly. Further, this offset cannot be controlled very precisely in the experiments. Consequently, we feel that this impact configuration is inherently very sensitive and even with the best care during the FST, it will not give repeatable quantitative data for making judgements regarding the utility of safety devices.

These simulations establish the importance of including detailed geometry and properties of many of the components in these impact situations. In this paper we have stressed upon establishing the importance of these details, have shown their relevance for MC - the OV frontal impact configuration and have highlighted the need of repeatability / reproducibility in the FST. We have therefore not done a quantitative comparison of the accelerations and the injury indices. In fact as mentioned earlier, the main purpose of ISO13232 is to compare the difference of existence of safety devices. This ISO is not to evaluate the safety quantitatively. In the process of qualitatively studying the repeatability of these configurations, we have also demonstrated the importance of FE simulations as a tool to study the impact behaviour of vehicles at the design stage.

ACKNOWLEDGEMENTS The work has been supported by a grant from the Japan Automobile Manufacturer's Association, JAMA. We are indebted to them for their financial support as well as for permission to publish these findings.

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