Influence of Contact Parameters on Short-Event Crash Simulation Results

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Abstract:

The aim of a vehicle crash simulation is to characterise and quantify the performance of specific regions in terms of energy dissipation, distribution and intensity. Such detailed understanding of the crash event will enable the analysis and prediction of occupant and / or pedestrian injuries. To achieve this, an interacting chain of individual components and systems need to be studied in terms of its energy management and absorption capacity. A study should consider the unique contact interactions between the key components and systems involved. More so, these unique contact interactions have to be numerically captured and formulated in a manner that is faithful to the actual physical event.

The premise of this paper is to report initial findings from a study of the sensitivity of short crash events to different contact parameters and conditions. The relevant CAE modelling representations which lead to better agreement between virtual and physical results are explained. The aim is to increase the predictive capability not only of the nominal accuracy of the CAE predictions, but also to fully capture the chronological sequence of events and behaviours during the real short-event crash simulation.

Keywords:

Contact Parameters, CAE Crash Analysis, Crash Curve Correlation, Statistical Analysis

1 Introduction

Vehicle crash simulation involves advanced CAE modelling and mathematical tools. These assess and investigate the behaviour of various structures and regions of the vehicle, in terms of energy dissipation, distribution and intensity. The use and importance of these models extend to the detailed quantification and qualification to many occupant and pedestrian injuries.

Vehicle crash simulation models (FE models) are used intensively in vehicle design and development including its assemblies, sub-assemblies and components. To successfully achieve this, detailed and refined correlated models need be compiled and assessed. To compile and support such sophisticated models, many factors and parameters need to be fully considered. Amongst these factors and parameters is the modelling of the contact interactions between the modelled parts.

The use of contact algorithms when numerically modelling part contact interactions is a classic and fundamental CAE model prerequisite. Numerous studies and experiments have been conducted. Their key findings have now become the source of various academic and conference papers ([1], [2]). Amongst these, one can appreciate the breadth and depth of the numerical formulation and modelling challenge. In general, most of these papers agree that small contact changes may result in noticeable differences to the simulation output. However, there are not many with detailed investigations into the simulation output as a direct consequence of such contact choices.

The fundamental desire of a vehicle crash simulation is to characterise and quantify the performance of specific regions in terms of energy dissipation, distribution and intensity. However as a rule of thumb only a small proportion of these contact changes may yield a measured difference to the simulation output. Usually, this simulation output must be tracked and traced back to it original impact source. This impact source may manifest its propagation via several mechanisms / load paths. To comprehend these mechanisms the understanding of contact behaviour is significant. This can be even more so for short event crash simulation.

2 Short Event Crash Simulation

Short event crash simulations can be defined as all those studies with a simulation run time (less than 30 to 35ms). These simulations can be very distinct for the following reasons;

- Study of significant high speeds (i.e. greater than 8m/s)
- Impact yields small displacements / deformations (i.e. smaller than 125mm)
- Fairly regional impact footprint (i.e smaller than 250mm^2 area)
- Significant stiffness differences amongst impacting and impacted parts

Short event crash simulations are not unique or rare. They occur frequently in the real world automotive studies. The following cases are just a sample of such applications;

- Crush Can Development
- Side Crash
- Cabin and Cockpit Impact Cases
- Pedestrian Head Impact
- Pedestrian Lower & Upper Leg
- Frontal low speed cases
- Other investigative sub cases

2.1 Simulation output observation

Many simulation outputs maybe viewed and post-processed but frequently decision making is based predominantly on stipulated headline figures and labelling. For example on an acceleration pulse plausible labels may be maximum acceleration or pulse intensity within a specific dt or rate of change etc. All these labels somehow then become an empirical interpretation of an impact.

During the phase of post processing labelling some significant and consistent observations were made for certain models. The simulation output changed significantly due to changes in contact definition. One may argue that this was as expected since the implications of changes to the contact definition are well documented. Even so these particular models were used for optimisation, robustness and correlation purposes when their results were out of the required deviation corridor. An example is shown in Fig. 1 illustrating a models calculated deviation. The actual 4 simulated outputs from which Fig. 1. was derived from, can be seen at Fig 2.

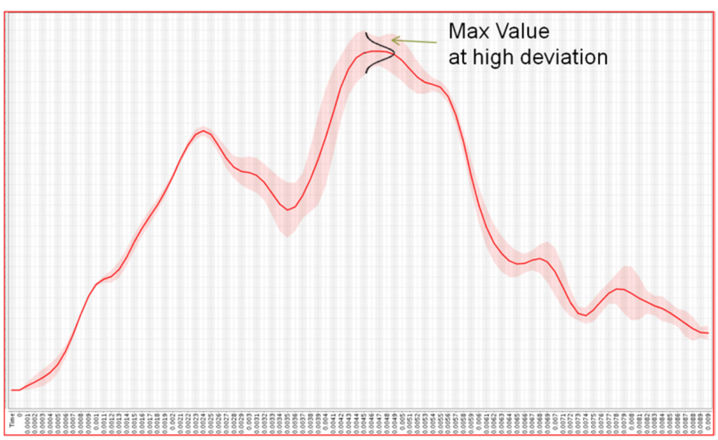

Fig.1: Deviation graph of 4 simulated outputs

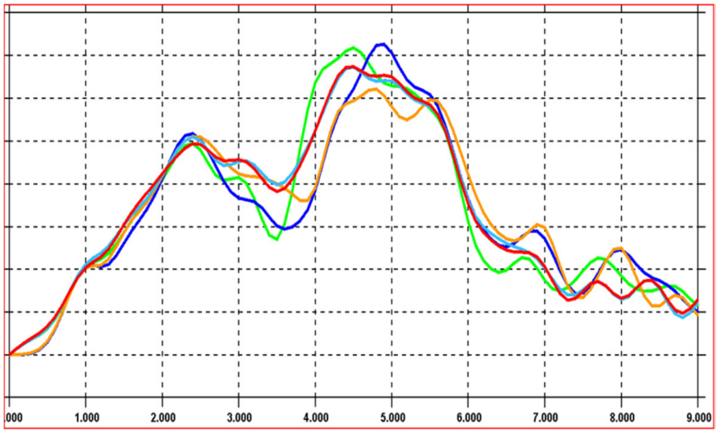

Fig. 2 – The actual 4 simulated outputs which fig. 1 was derived

This observation highlighted several other related issues;

- Contact Type Definition
- Best contact parameters
- Case based contact parameter study
- Optimisation, Robustness & Correlation parameter assumptions and conditions

3 Development of basic models to confirm the observations

In order to enhance understanding and calculate sensitivity from the main contact parameters, numerous simple simulation models have been tried and many more have been considered. Each one has its own unique advantages and disadvantages. More so models have to be simple in order to comprehend, control and capture all of their minor parameters.

For the initial stage of this study it was decided to use a metallic sheet dome impacted by two basic shape impactors (Sphere & Cylinder). These are very simple system models but adequate to determine the interactions between *Master* and *Slave* parts. The detailed study and findings of these systems are considered for further development and implementation to the detailed CAE models.

3.1 Sphere Impacting a Dome Model

The sphere impacting a dome is illustrated in Fig. 3. This is a very simple model with 30,000 elements. Only elastic material model definition was used to describe both dome and sphere. Mesh type and size between the sphere and dome were kept compatible. The rear area of sphere was defined as rigid. Each model run kept the same mesh whilst the contact definition and parameters were changed according to a full factorial DOE parametric study. Each run was executed to 10ms simulation time using 4CPUs.

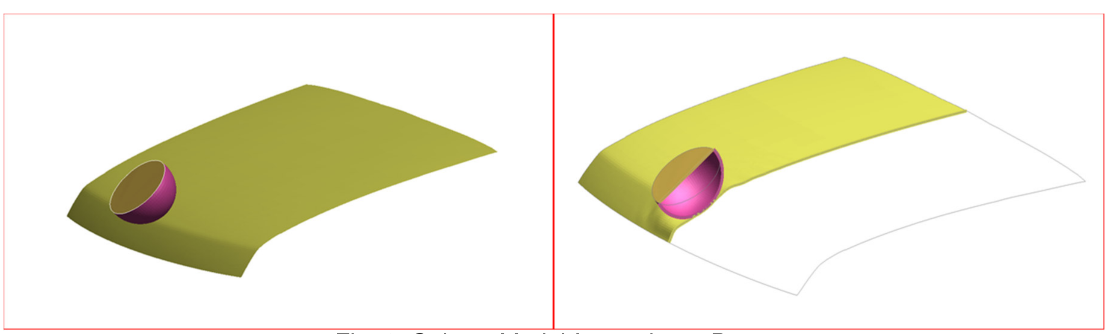

Fig. 3: Sphere Model Impacting a Dome

3.2 Cylinder Model Impacting a Dome

The cylinder impacting a dome is illustrated on Fig. 4. This again is a very simple model with 40,000 elements. Only elastic material model definition was used to describe both dome and cylinder. Mesh type and size between the cylinder and dome were kept compatible. The rear area of cylinder was defined as rigid. Each model run kept the same mesh whilst the contact definition and parameters were changed according to a full factorial DOE parametric study. Each run was executed to 10ms simulation time using 4CPUs.

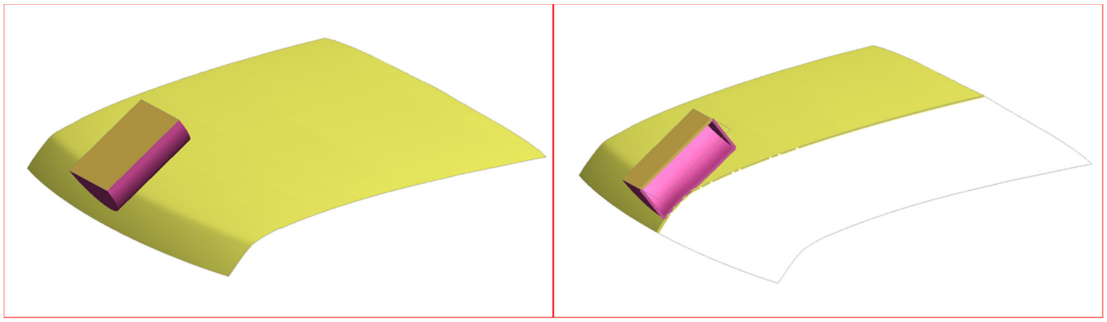

Fig.4: Cylinder Model Impacting a Dome

4 Contact type definition and parameters

Considering the stipulated observation and the requirement to support sophisticated and consistent vehicle crash simulation, several main contact types and parameters were considered. LS_Dyna has numerous contact types and parameters which numerically capture various aspects of the actual physical contact condition [3]. The reasoning and specific type use are outside the scope of this paper. What was considered though was the choice of two, mathematically and application similar, contact types (Surface to Surface & Single Surface). To this extent and for practical reasons only some of the parameters that define these contacts will be mentioned. Although these parameters may limit the reader in his appreciation to the full breadth and depth of the design interactions, they should be sufficient to provide a reasonable insight.

4.1 Choice of Contact Parameters

As already stated two contact types were selected;

- Automatic Surface to Surface and
- Automatic Single Surface

All of the DOE studies assumed the same ‘Control Contact’ cards. The selected contact parameter brief and considered values were as follows;

4.1.1 Stiffness ratio between slave and master

Stiffness ratio between slave and master has more to do with the amount of penetration, displacements and deformations the interacted parts will experience. In detail the corresponding assumptions for this parameter were;

- For the master surface, the part was defined with Aluminium Elastic Material Model.
- For the slave surface, the part was defined with an Elastic Material Model having 1/10th and 1/30th of the master surface stiffness

4.1.2 Penalty to slave and master

Penalty scale factor provides means of changing the contact stiffness. Generally too high contact stiffness yield noisy simulation output. In contrast too low contact stiffness may yield higher penetration and slightly damped simulation output. In detail the corresponding assumptions for this parameter were;

- For the master surface, the part was defined with 10 and 50 values.
- For the slave surface, the part was defined with 5, 10, 25, 40 and 50 values

N.B. SLSFAC = 0.1

4.1.3 Friction (Static & Dynamic)

In order to model and characterise contact interactions, static and dynamic friction properties need to be defined. Considering a basic study of the trajectory and de-acceleration between two parts, one needs to appreciate the unique differences and distinct characteristics between static and dynamic friction. Static friction resists initial movement between two bodies (empirically static friction normally yields a noticeable initial trajectory change and at times noticeable different peaks i.e. force, acceleration, etc). Dynamic friction opposes the movement between two bodies once this has started (empirically dynamic friction will have an identifiable influence on the trajectory and the shape of these peaks i.e. force, acceleration, etc).

Usually crash models set the static and dynamic friction to be equal. This is done in order to avoid noisy simulation outputs and avoid definition to the decay coefficient. However one needs to consider that these remarks need to be seen in relation to the amount of deformation the interacted surfaces or parts will show during impact. Considering a short event crash study and for the purposes of optimisation, robustness or correlation investigation, it maybe palatable to model these parameters in greater detail.

In detail the corresponding assumptions for this parameter were;

- For the static friction, values were defined as 0.1, 0.25, and 0.4.
- For the dynamic friction, values were defined as 0.1, 0.25 and 0.4

4.1.4 Soft = 1 Option Scale factor

Soft = 1 scale factor provides means of changing the contact stiffness.
For the DOE the chosen values were; 0.1, 0.2, 0.3, 0.4, 0.5

4.1.5 Bucket Sort

Bucket sort defines contact searching in order to identify potential master contact segments to any given slave node. Bucket sort is related to overall computing run time. For the DOE the chosen values were; 10, 50

5 Results and Statistical Analysis of the findings

Statistical analysis is used in this study to calculate CAE model effectiveness and sensitivity on specific contact types and parameters. The aim is to increase the predictive capability of the CAE models in terms of quantifiable metrics (i.e. acceleration, displacement etc.) and chronological events. This implies an accuracy between simulated output and actual measured physical pulses.

The initial statistical analysis treats a whole unique pulse as 2 numbers (i.e the *<u>1st peak's max value</u>* at *<u>dt</u>* that this value occured). Evidently this may hide potential real curve differences such as those seen in Fig. 2, however after much deliberation it was a metric we agreed to pursue for this initial study. Despite this, the utilisation of statistical analysis was proven to be fruitful. Specifically the following remarks can be made;

- Run Iteration 1 – Surface to Surface type definition full factorial DOE parametric study to all corresponding parameters;
  - Multivariability study Fig.5. Both sphere and cylinder studies yield lower max peak for higher dynamic friction. Considering dt in the sphere study it only gets longer for the highest dynamic friction value where in the cylinder it gets consistently shorter
  - Multivariability study Fig. 6. Processing cylinder findings for static friction, it appears that static friction has a negligible effect. One obvious reason is that the DOE study considered only those runs that static coefficient was equal or higher than the dynamic one. Another reason is that the cylinder model yield a sliding impact effect.
  - Main effect plot Fig. 7. It can be observed that in the sphere study, penalty on master surface and dynamic friction yield considerable variations. In the cyclinder study, main variation is observed only from the dynamic friction
- Run Iteration 2 –Single Surface type definition full factorial DOE parametric study to all corresponding parameters;
  - Main effects plot Fig. 7. It can be observed that in the sphere study, penalty values have no significant effect. However soft scale option does yield a small variation. In the cyclinder study, main variation observed some unusual variation from the dynamic friction.
    N.B. LS-Dyna ignores penalty values on master surface
- Run Iteration 1 and 2 – Surface to Surface versus Single Surface type definition.
  - Main effects plot Fig. 8. It can be observed that in both sphere and cylinder studies, significant variations are observed.

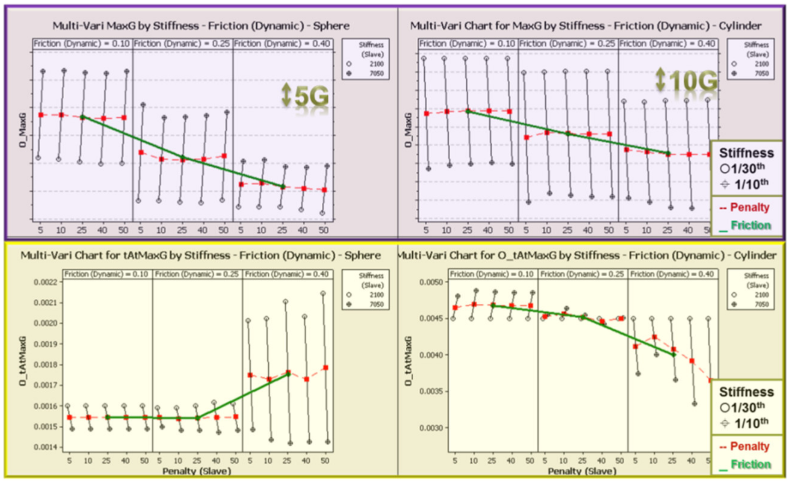

Fig.5: Multivariability Study by Stiffness – Sphere Model

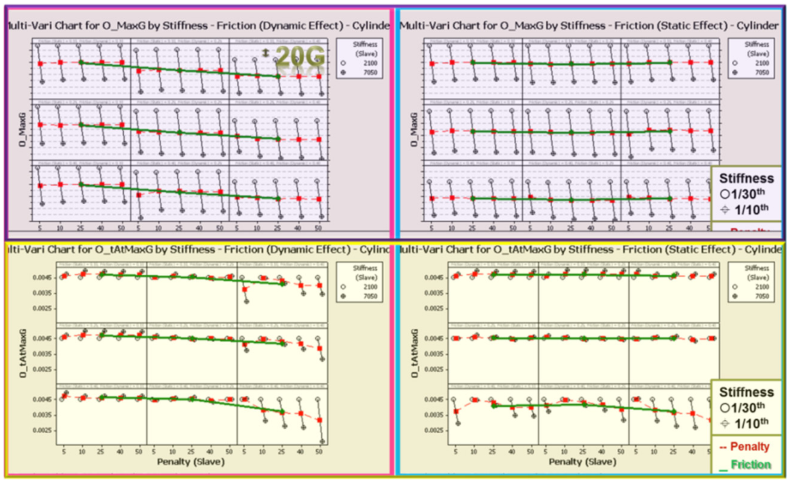

Fig.6: Multivariability Study by Static Friction - Cylinder Model

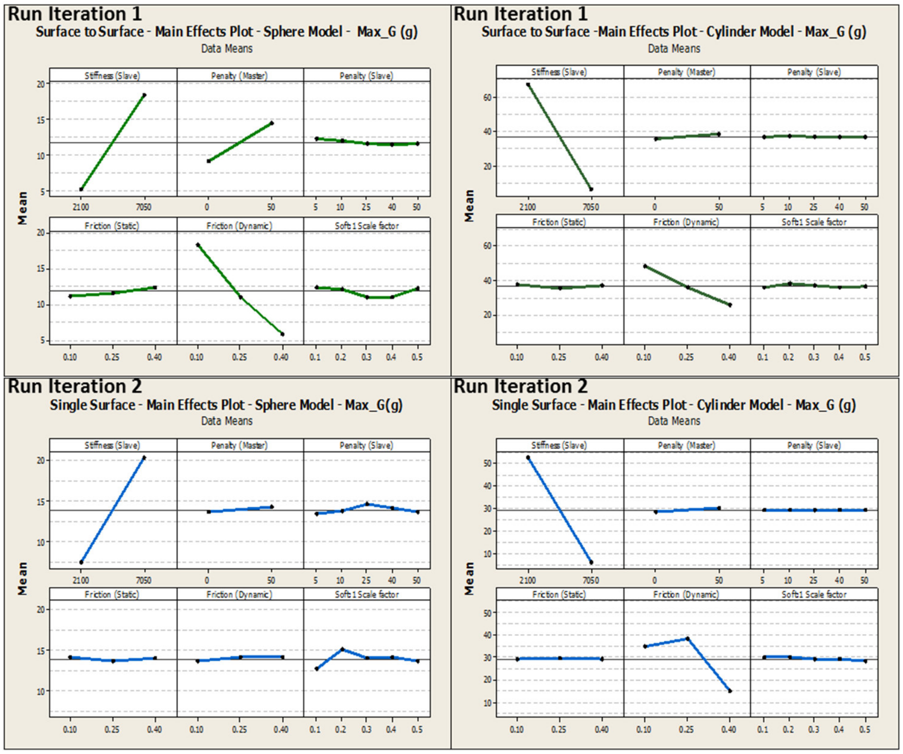

Figure 7: Sphere & Cylinder Main Effects plot (Surface to Surface, Single Surface & Single Surface Enhanced)

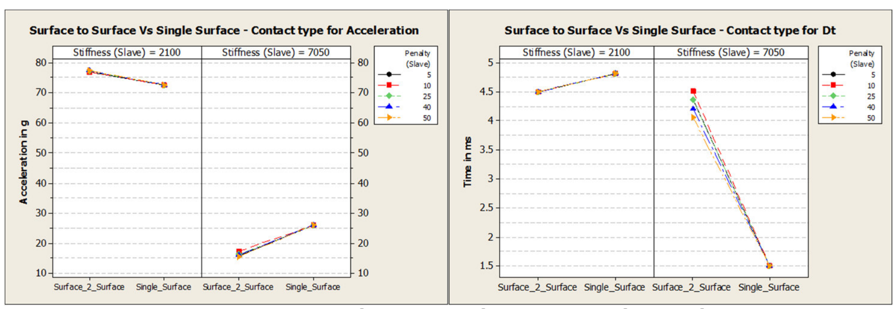

Fig.8: Difference between Surface to Surface and Single Surface Type

6 Application of the findings

Statistical analysis results suggest that a considerable delta between '*Surface to Surface*' and '*Single Surface*' can be seen on the simulation output pulses. To confirm this, a study on the cylinder to dome and one of the two real FE load cases was conducted.

With reference to the cylinder to dome study Fig. 9 illustrates results acquired from all Soft=1 scale factors when '*Surface to Surface*' and '*Single Surface*' contact type are chosen. Evidently from this figure '*Single Surface*' type yields higher deceleration values at the initial stages of the pulse. As a result the pulse develops with lower propagation values.

With reference to the two real FE load cases the above observation does not apply. Results from these two cases are in Fig. 10 and 11. From these graphs one can conclude that the opposite is true. Obviously there is noticeable difference in the real FE Case 1 and significant difference in real FE Case 2. In the real FE Case 2 the pulse develops to a noisy signal and further investigation is in progress to address better contact stiffness parameters including damping.

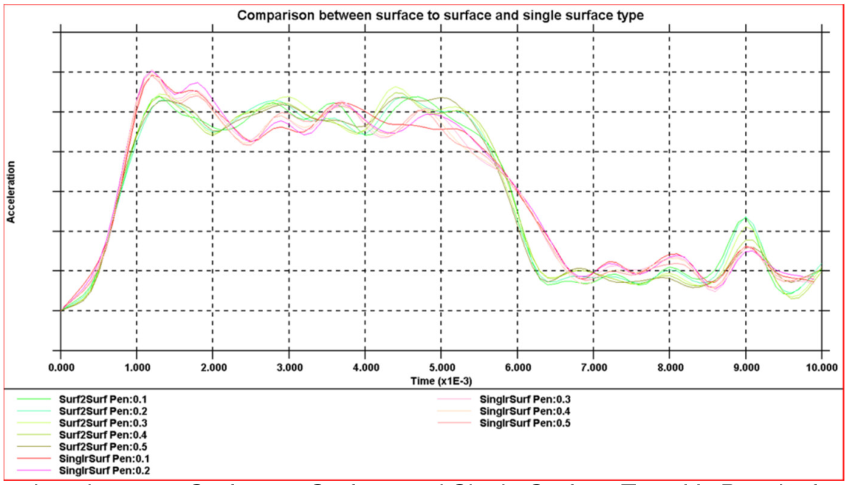

Fig. 9: Comparison between Surface to Surface and Single Surface Type Vs Penalty factor - Cylinder to Dome

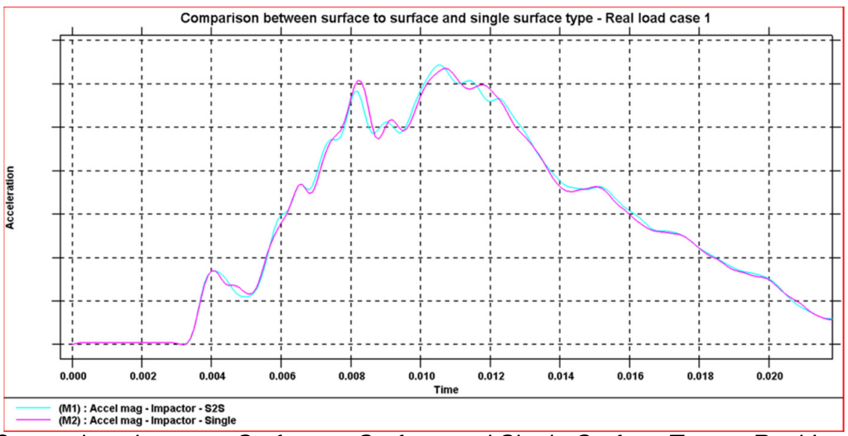

Fig. 10: Comparison between Surface to Surface and Single Surface Type – Real Load Case 1

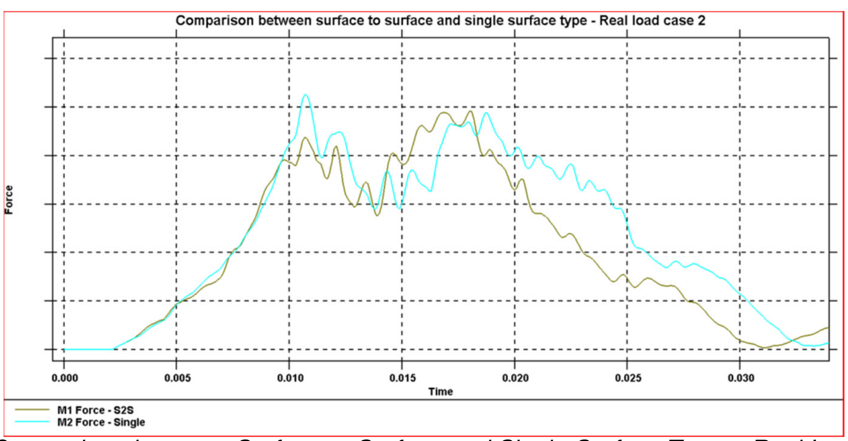

Fig. 11: Comparison between Surface to Surface and Single Surface Type – Real Load Case 2

Regarding the dynamic friction effects Fig. 12 the pulse develop higher pertubation when a higher coefficient is used. The application of this is cumbersome since dynamic friction is challenging to define. More so there is always the question to the mesh's regularity and length. However further studies are in progress to establish a robust modelling approach.

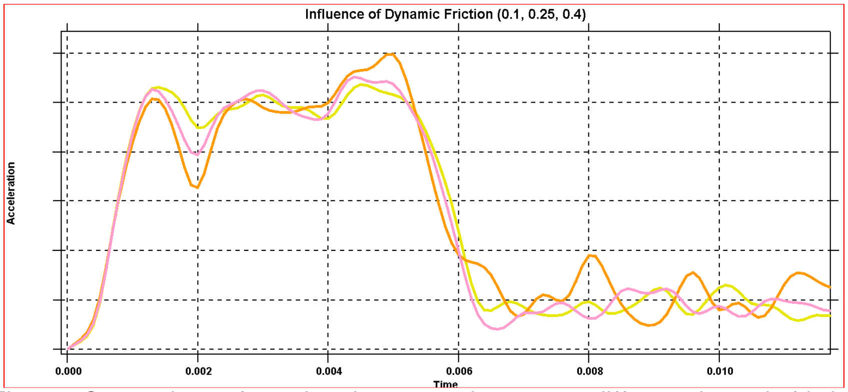

Fig. 12: Comparison of acceleration output between 3 different dynamic friction

7 Discussion

Short crash event contact type and parameters are influencing noticeably the accuracy of the simulation output. This accuracy has to do with the manner in which defined contact surfaces react to one another as well as the nature of their interaction. The manner of the defined contact surfaces influences quantifiable outputs such as (acceleration, velocity, rotation, displacement, crumpling effects etc). These differences have a direct effect on the nature of the impact propagation and therefore to the subsequent chronological sequence of events.

In this paper the initial findings from two models were studied as means to provide comparison amongst the basic contact parameters and types. The metrics compared, were the maximum acceleration and the dt time that this occurred. All the acquired acceleration profiles were noticeably different with those from the dynamic friction and contact type to be most sensitive.

Considering the results from the dynamic friction as a sensitive contact parameter one can argue that this was to be anticipated. However, dynamic friction on an impact study is very challenging to define and even more so to measure accurately. Robustness studies do consider this to be very significant. Even if scientific test could potentially establish an optimal value, this can only be one part of the answer. Precision and accuracy will still be required from the FE model; hence multiple levels of model refinement will be needed. Mesh definition may influence results due to the fact that detailed interactions are captured differently between coarser and finer mesh.

Considering the results from the contact type definition between '*Surface to Surface*' and '*Single Surface*' this came more of a surprise. Single surface type appears to be less influenced by the defined contact parameters on simple models. However on enhanced (higher articulated) model studies this may not be the case. On going studies hopefully will produce the necessary data to answer this conclusively.

In spite of the considerably simple model runs, considerable agreement on the findings couldn't be reached. Even so all of the studied models yielded consistent findings regarding Penalty (Master & Slave), static friction and bucket sort variables. The above findings reinforced the original plan to proceed with further detailed and enhanced (higher articulated) model studies. In particular this investigation will concentrate on load case specific studies with the expectation to conclude on recommended contact type and parameter definition.

However so far these initial studies have highlighted the following;

- Need to establish realistic friction models. These models need to give priority and seek further quantification to the dynamic parameter. So far studies have shown the static parameter to be more consistent.
- Contact surface type definition appears to be an important factor. Automatic Single Surface type maybe quicker to define on a model but will yield different results.
- When a choice of unique contact definition is made the user needs to consider;
  - Additional model compilation and run time

    - Quality checks in place in order to avoid redundant contacts (i.e. 2 or more contacts producing forces due to the same penetrations)
    - Current level of understanding to the actual physical event. A CAE model is nothing but an engineer's interpretation of a specific perspective, instance and reality.
- For critical Impact studies the distinction of ***Master*** and ***Slave*** surface need to be considered. So far studies have shown that slave surface parameters are more consistent.

Further along these studies the computational time effects have been considered adding the soft = 2 option for completeness. Results and findings will be analysed and discussed at the conclusion of this study.

8 Summary

In summary, contact type and parameters influence the accuracy of the simulation output. So far the two simple models yielded noticeable differences to the results. Consistent findings were observed for penalty (master & slave), static friction and bucket sort variables. However agreement has yet to be reached, regarding the choice of contact type and dynamic friction. The findings from these simple models have been used on two real load cases and these support the initial observations. Finally these findings may shape differently at the conclusion of this study, results of which will be the subject of another paper.

9 References

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