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Enhancement of FEM representation of Piezo-electric sensors with comobining RBE2 and Solide propreties

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Abstract. In automotive industry, numerical crash analysis is a mandatory test before going to tooling kick off phase, this test makes engineers able to predict the vehicle behavior face to side, frontal, and rear impacts. Where EURONCAP protocols have become international standards for vehicle safety ranking. The coherence between physical test and FEM test has become the main challenge for making simulations more realistic, with ensuring optimization of automotive modeling and the best representation of physical sensors. This communication proposes an enhancement of FEM modeling of piezo-electric sensors (Accels) for acceleration measurement in object to get the deceleration data under impact using RBE2 and solid FEM properties in object the avoid deviations causing data errors. Moreover, a verification test has been able to validate the proposed approach where the curve of acceleration is the same for solid representation of accelerometer and aligned mesh with X, where with using deviation of the edge the result changed**.**

Keywords: Crash analysis; Euroncap protocol; FEM test; piezo-electric sensors;altair Radioss

1 Introduction:

In the field of numerical simulation of crash in object to improve vehicle safety, the representation of acceleration data is crucial for estimating the forces exerted during an impact event. The the most widely used finite element analysis (FEA) software tools in automotive crash simulations is Radioss Altair, and its offers a very sophisticated approach to the modeling and simulation of accelerometers, essential for capturing and analyzing the dynamic response of structures [1] .

Radioss, developed by Altair Engineering, is known for its high-performance capabilities in simulating complex, nonlinear dynamics, particularly in crash and safety simulations. Its accelerometer representation is focused on integrating sensors that can measure acceleration at specific points on the vehicle, providing essential data for the evaluation of impact severity and occupant safety. This software uses as modeling tool moving skews oriented by 3 nodes from mesh, and in case of complexed geometries the orientation of skews with longitudinal axis and ensuring quality criteria become impossible. Other hand, adding a simplified box representing the accelerometer attached by a rigid body element to an assembly point coincides with the original node of skew can offer an alternative approach for sensor modeling, with specific attention to how accelerometer data is processed within its environment to reflect real-world conditions.

This study aims to compare and contrast the representation of accelerometers in both traditional moving skew and solid simplified solid element, focusing on ANSA methodologies for modeling sensor placement, calibration, and the accuracy of acceleration measurement. Through this comparison, will identify the strengths and weaknesses of each approach package, providing insights into their effectiveness in vehicle crash simulations, especially when adhering to industry standards like those set by Euro NCAP.

This communication structured into 4 sections, aiming to present the proposed enhancement in a compressive way. Where the first section introduces the main idea and outlines the following contents.

The second section focuses on the detail about the proposed methodology with presenting the functionality of piezo-electric sensor and the protocol of physical insertion for crash test, before going to explain the Accelerometer representation with moving skew and explaining the new simplified representation.

The section 3 is dedicated to test the proposed methodology in a case of a crash box impact manufactured in steel, the aim idea of this simulation is to use two types of mesh, the first one is structured and aligned with the X axis where the second mesh kwon a deviation from X axis on the element of Skew application in object to compare the box solid with REB2 representation for each case before listing advantages and limitations of the two methodologies.

In conclusion, the manuscript summarizes the findings, with methodology's effectiveness emphasizing in case for crash analysis project. This new practice was compared to traditional modeling with moving skew, with demonstrating that it significantly enhances the realism of simulations and makes it more practical for industrial applications.

1. Methodology:

2.1 Sensors representation using Lagrange description:

Theoretically, one of the most approach to calculate the displacement between two time steps is Lagrange description, where is mathematically defined by:

$$\mathrm{X}(t_{\mathrm{i+1}}) \ = \ \mathrm{F}(t_{\mathrm{i}})\,\mathrm{X}(t_{\mathrm{i}}) + \mathrm{C}(t_{\mathrm{i}}) \tag{1}$$

Where X (t_{i}) refers to the coordinates of an arbitrary point at the timet_{i}, F refers to the gradient of the transformation operator, A is the initial coordinates vector, and C is the vector of correction of the trajectory.

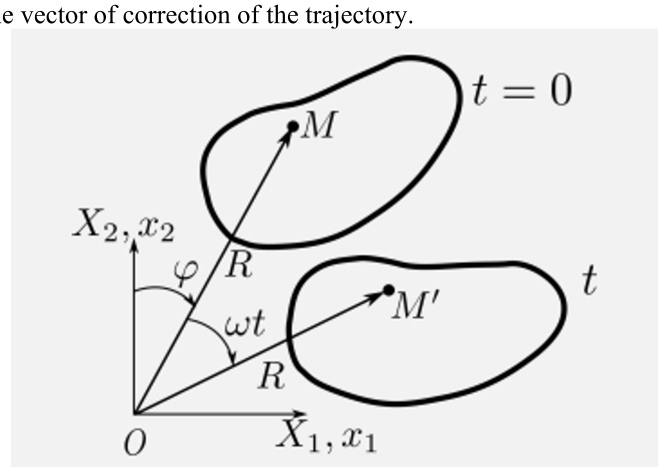

Fig.1: System transformation

The displacement is calculated basing on the difference between the vectors $\mathrm{X}(t_{\mathrm{i+1}})$ and $\mathrm{X}(t_{\mathrm{i}})$, and basing on this definition the velocity can be easily deduced by the time derivation of the vector displacement as follow:

$$V(t) = \frac{dX(t)}{dt} = F(t)X(\dot{0}) + \dot{c}(t) \tag{2}$$

The acceleration is also can be calculated by the derivation of velocity vector, where the dynamic modeling should obligatory start by calculating it. Moreover, exerted forces, stress, strain can be deduced easily after being able to write an algorithm dedicated to calculate acceleration.

Crash specialist engineers use accelerometer sensors to measure the intensity of collusion regarding the enforcement effort and the level of displacement on safety part in object to make iterations to improve the safety by changing parts and architecture each step.

2.2 Piezo-electrical accelerometer sensors:

Following recent mechatronics evolutions physical data acquisition become easy due the potential of **piezoelectric sensors** deployed as accelerometers in crash tests for measuring dynamic acceleration during impact events. These sensors take advantage of the piezoelectric effect, where certain materials generate an electrical charge when subjected to mechanical stress or pressure. Respecting EURONCAP protocol, piezoelectric accelerometers should be placed at strategic points on vehicles or dummies to capture the acceleration that occurs during collision periods, where the sensors convert rapid acceleration forces into an electrical signal that allows for precise measurement of the forces involved in the crash. In order to assess the severity of impact and understand the forces exerted on various parts of the vehicle, the crash test dummy, and the instrumentation system under study, accurate results are essential. In fact, it is impossible to optimize safety features without high-sensitivity, fast-response accelerometer sensors. These characteristics make accelerometers ideal for real-time measurements during crash tests, which are crucial for improving safety standards and vehicle design [2].

Fig. 2: A64C Sensors.

In automotive crash analysis, the A64C is most known used due to its high sensitivity to acceleration. This sensors is useful for minute vibrations and in case of small accelerations need to be measured in high precision.
This accelerometer is capable of measuring a broad range of frequencies, which is essential for capturing both low-frequency vibrations (such as those that occur during a slow impact) and high-frequency spikes (such as those that happen during high-speed crashes). The A64C typically has a frequency range that allows it to effectively capture the full dynamics of a crash event.

2.3 Sensor representation using moving SKEW :

In object to establish a local coordinates system, it's obligatory to use three nodes from the finite elements representation of the structure. In Radioss, this repair is called Skew, where the coordinate system is subject to change regarding the deformation of the part at each time step. So it's clear that the acceleration can be deduced from the velocity and the time step.. For moving skews, the coordinate system is dynamic and is defined by the node identifiers: node_ID1, node_ID2, and node_ID3. The axis definition is determined by the input for the direction (Dir).

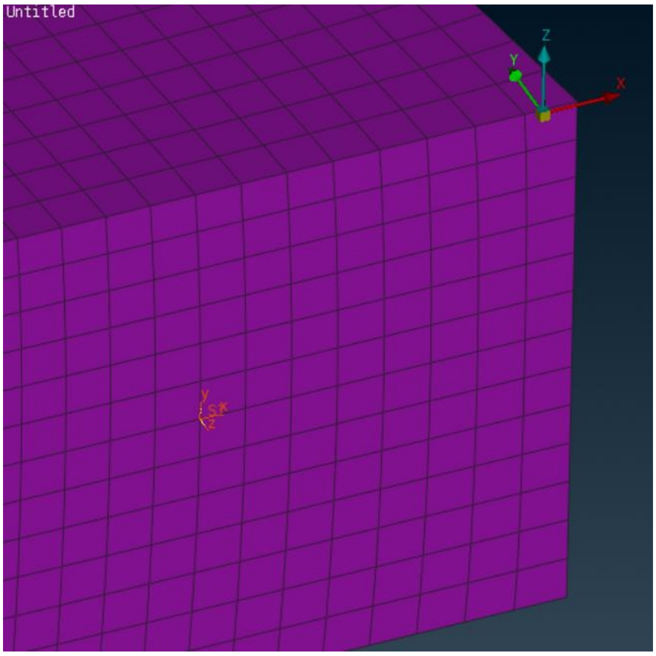

Fig.3: Moving System with Dir_X

As shown in fig.2, the accelerometer orientation depends of the mesh; as a result, this approach can generate errors in case of non-structured mesh.

2.4 Sensor representation using the proposed approach:

The proposed approach in this communication is to improve sensors representation in object to avoid any deviation caused by the orientation of mesh edges, the technics is to use rigid body type 2 and a box in solid property oriented following the global coordinates system as shown in fig.3:

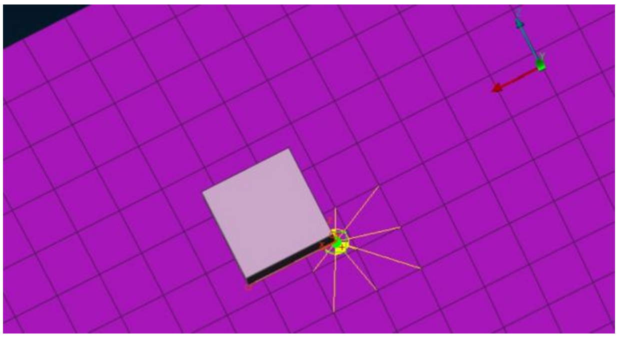

Fig.4: Box representation of accelerometer sensor linked with RBE2

The selection of RBE2 is not arbitrary [3],in fact RBE2 is a linking element defined by 2 kinds of nodes , master and slaves, where the slaves are linked hardly with master node, and follow the same displacement in the presence of boundaries and limit conditions, than the displacement of the node of the structure will be the same of node master included in the box side.

3. Numerical simulation and results:

3.1 Simulation input data:

In object to test the efficiency of this methodology, a simple crash box in Steel has been used with a structured mesh, this first one will be used as a reference to compare using the same geometry but non structured mesh in the zone of skew orientation the result of deceleration of accelerometer using traditional Radioss representation and the new proposed technic.

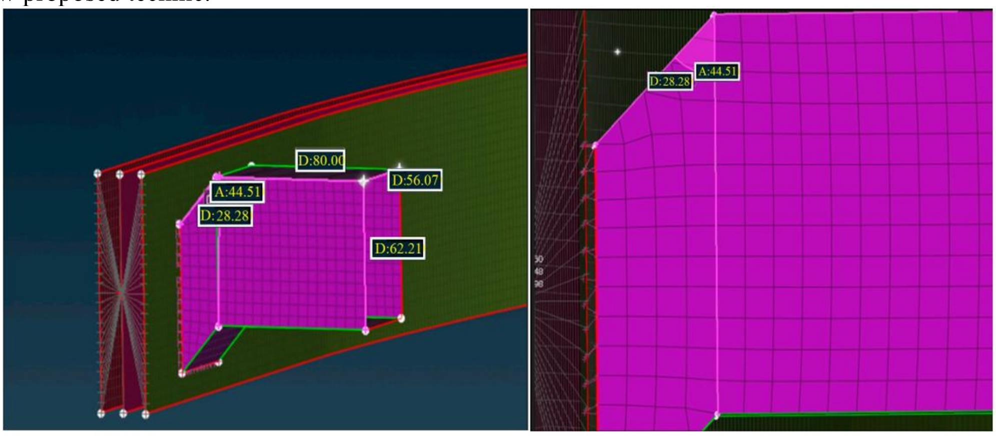

Fig.5: Crash box dimensions.

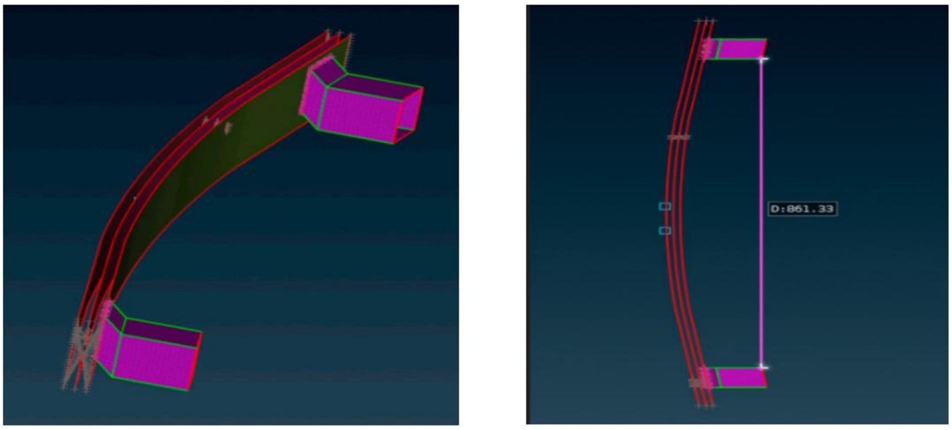

Fig.6: Crash box + transversal bar representation

The used material for this study is Ultra-High-Strength Steel [4]; It is a category of steel known for its **exceptionally high tensile strength** and **excellent performance** in demanding applications like automotive crash safety components. The mechanical properties of UHSS are highly variable depending on the specific grade and processing method (e.g., cold-rolled, hot-rolled, or press-hardened), but in general, UHSS offers superior strength and ductility compared to other steels. Here are the typical mechanical properties of UHSS:

.

Table 1. Material input data

UHSS material	Mechanical properties		
	tensile strength	*yield strength*	*elongation*
interval	700 MPa to 2000 MPa	500 MPa to 1900 MPa	5% to 15%

A rigid wall with 1100 kg moving with a velocity of 60 km/h has been deployed as an impactor [5]. The following figure shows the ANSA representation of this load case (Fig.6 and Fig.7):

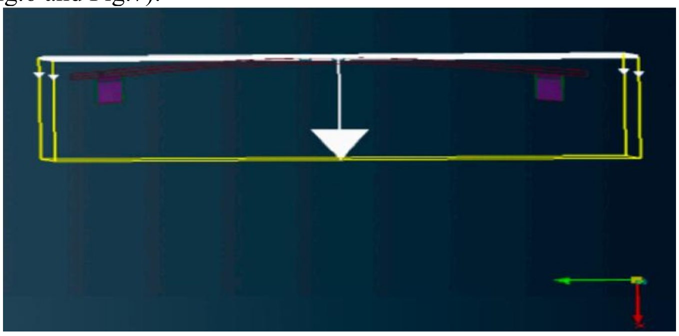

Fig.7: Moving rigid wall impact.

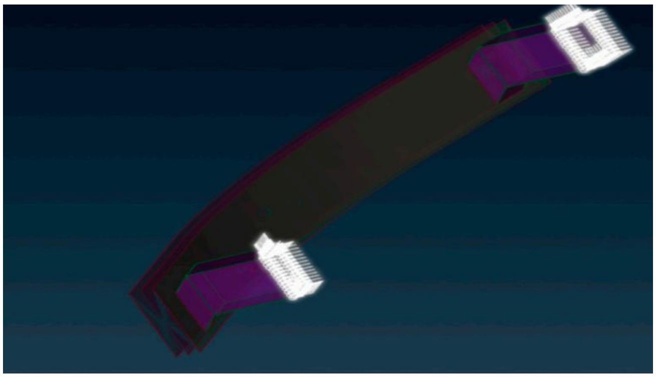

Fig.8: Fixation of the crash box

3.2 Result and discussion:

By using described input data for simulation in case of structured mesh, a post processing of result using Meta, gives a normal behavior of a ductile material under crash , that why it can be used as a reference of result's validation. A necessary condition for ensuring efficiency of this manuscript's proposal is to find the same graphical curve of deceleration for the box method and the referential result.

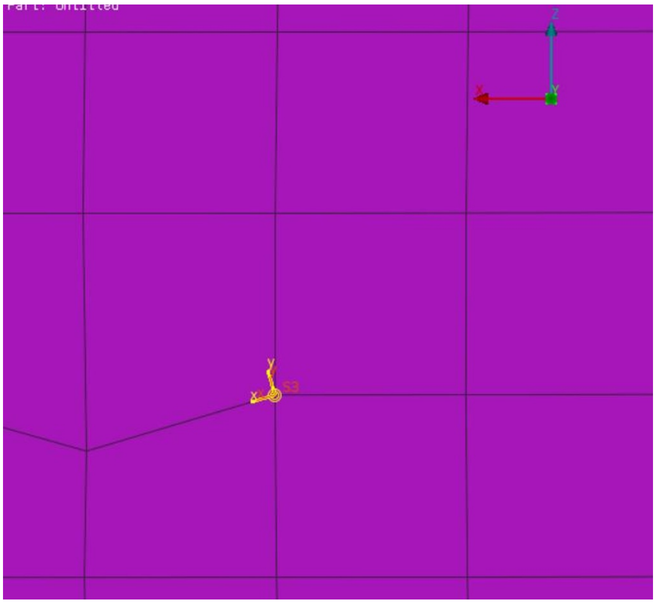

Fig.9: Radioss accelerometer using deviatory mesh element

The representation described in fig.8 contents a modification in the direction of the edge used for skew's orientation. The same mesh is applied with the box accelerometer linked by RBE2 (Fig.9) to measure in different case the deceleration.

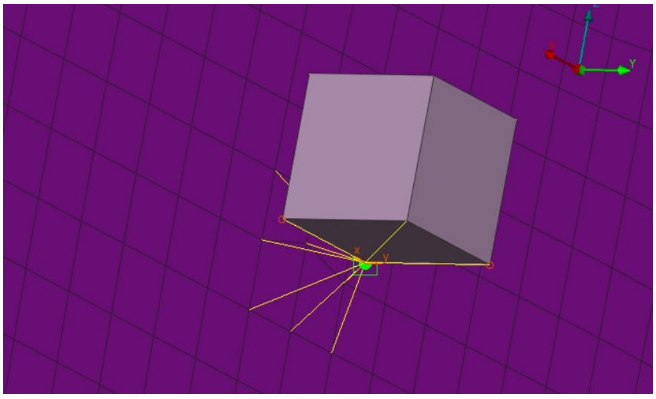

Fig.10: Radioss accelerometer using external box and RBE2

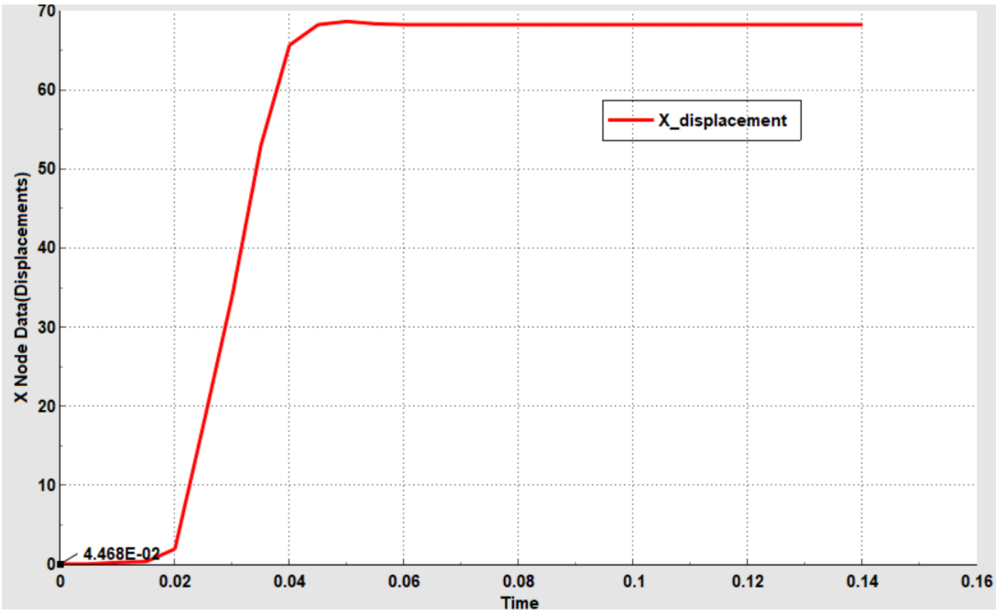

Fig.11:X_displacement under crash

Fig.10 describes the nodal displacement under crash for the original point of sensors installation, this value is the same for all methodologies, because when the mesh was changed on the area of skew application , this node have saved the same coordinate, and as shown the maximum value of displacement was 68 mm. Where figure 11 shows how the proposal methodology since to give an exact deceleration value, otherwise, the curve concerning traditional mythology gives a precise value but not an exact one due to small deviation of X_edge (15.9 deg).

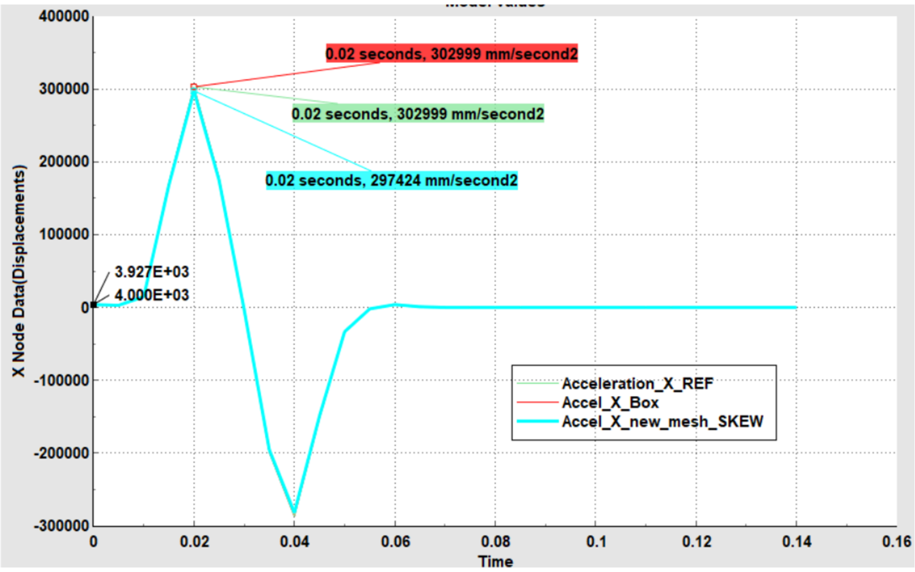

Fig.12:Deceleration under crash for all methodologies

Conclusion:

In conclusion, both traditionnal Radioss methodology and proposed one offer valuable applications for accelerometer analysis, yet each has its own set of strengths and limitations that make them suitable for different contexts. box accelerometer application excels in scenarios where rigid body dependency is acceptable, but this reliance on rigid elements limits its flexibility and accuracy in more complex, deformable simulations. On the other hand, Radioss provides a more dynamic approach to accelerometer modeling, with a strong focus on handling complex material behavior and non-linearities. However, it is constrained by the potential for mesh instability, particularly when dealing with fine or highly detailed mesh configurations. In summary, while both methods are powerful, choosing between them depends on the specific requirements of the simulation, such as the need for rigidity or the risk of mesh instability. Addressing these limitations often requires careful consideration of model setup and parameter tuning to ensure accurate and stable results.

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