Exploring simplification methods in reducing simulation time for drop test analysis

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Abstract. – Automotive electronics can produce an unprecedented level of passenger comfort and optimized performance of engine and components. However, the increasing intricacy of these electronic devices makes them more susceptible to damage due to thermal loads, mechanical drops, and engine vibrations. While physical handling of automotive components is comparatively rare, the weight and complexity of specific components such as the ECU, power module, and sensor modules, makes any drop functionally fatal. Simulation approach is considered to be essential in solving these problems by minimizing costs and effort. This paper attempts to solve the issue of mechanical drops using an explicit dynamics finite element analysis solver. Moreover, simplification methods are applied to further minimize solution costs.

1. Introduction

Automotive electronics have become increasingly useful in optimizing the performance of a vehicle’s drive and engine power, while providing unprecedented passenger comfort. Keeping up with a benchmarked quality, or eventually surpassing it is necessary for these companies and manufacturers to remain competitive in their industry. Thus, semiconductor devices and electronics are key in their success. Electrical components need to work after exposure to harsh environmental conditions of the automotive housing, and mechanical conditions or issues due to power supply.

Portable electronics are a subject of most drop tests due to their decreasing size [1], while automotive electronic components will rarely be ever handled in their life cycle. Save for installation or replacement, mishandling and dropping these devices should be rare. However, certain electronics such as the Electronic Control Units (ECUs) and power modules are heavy components with complex intricacy. Furthermore, components such as camera or proximity sensors are attached together with heavier components on the PCB structure, making drops more severe and functionality fatal to the electronic systems.

The semiconductor package must protect a device from external factors that could degrade the performance of a semiconductor chip. Increased complexity and functionality coupled with the sleekness of design has translated into more interconnections, increasing intricacy and vulnerability [2]. Manufacturers of integrated circuit (IC) components need to guarantee the reliability of their products under mechanical drop or shocks, utilizing a standard drop test. The standard method of drop testing for
semiconductor devices since 2005 is the JESD22-B111, formulated by the Joint Electron Device Engineering Council (JEDEC) [3]. The procedure and test rig are a board level drop test meant to evaluate and compare drop performance of surface mount electronic components for handheld electronic product applications [4]. Acceleration devices quantify the force and speed of a drop. This test rig best assesses designs sensitive to excessive flexure of a circuit board. The JESD22-B111 is a standardized procedure that can reproduce results of similar and normally observe situations. The test rig is a reportedly excellent basis for tests of automotive electronic control units [5].

The packaging technology being tested, the Ball Grid Array (BGA), is very popular in mobile devices for its dense interconnectivity and high lead count [6]. It is known to be self-centering and possesses an ease of installment, due to having no leads, while fulfilling high performance and high thermoelectrical requirements. The BGA package has a small footprint yet high transistor count [7]. However, this technology is known to experience solder joint cracking between the interconnections and PCB material due to hard drops [1].

Shirangi et al. [8] formulates a novel drop test method for automotive Electronic Control Units (ECU), specifically to test high-shock conditions and expected intense vibration in automobiles. Their test rig and procedure allow the testers to vary the weight of the semiconductor device while monitoring speed of a test subject using an on-board accelerometer. By confirming their findings via FEA, they find the data reliable. Such research also opens the possibility of applying structural Finite Element Analysis (FEA) simulations to replicate the standard JESD22-B111.

Research by Balakrishnan et al. [9] presents a comparison of a set of different explicit and implicit impact simulations using the ANSYS LS-DYNA solver, in simulating a standard, 1-meter drop of an ECU. The research finds explicit/implicit transient methods to best simulate the drop as a dynamic system; however, at high computational cost and time. An explicit method is able to capture strain and damage due to impact force on the drop at relatively lower time and computational costs. It is noted by the research of Balakrishnan et al. that FEA analysis needs to strike a balance between convergence time, computational costs, and accuracy of results. Chung and Kwak [6] present a comparative study between an FEA model using a detailed geometry of a BGA package and a simplified version of the geometry using beam elements. Their research used a drop test rig following the JESD22-B111a standards to confirm their results. The experiments were able to make a fair trade between accuracy and computational time and costs, creating accurate results at a shortened time frame.

This study aims to explore additional methods that can significantly reduce computational time while maintaining accuracy for an explicit dynamics analysis of a BGA drop test.

2. Materials and Methods
The material assignment, properties, and geometry used in this study are detailed in this section. Material properties for the analysis were derived from papers that have utilized BGA in FEA analysis [10,11] and were summarized in Table 1.

| Component         | \( \rho \) (kg·m\(^{-3}\)) | \( E \) (MPa) | \( v \) |
|-------------------|-----------------------------|--------------|-------|
| Die Chip          | 2300                        | 170000       | 0.2   |
|                   |                             | 8            |       |
| EMC               | 1900                        | 17000        | 0.2   |
|                   |                             | 5            |       |
| Substrate         | 3950                        | 11600        | 0.4   |
|                   |                             | 2            |       |
| Lead Free Solder  | 7360                        | 35440        | 0.3   |
|                   |                             | 6            |       |
The geometry construction was based on a generic BGA model [7] using SolidWorks 2019. Explicit Dynamics analysis system from ANSYS Workbench 2020 R1 was utilized for the drop test analysis via the research license of De La Salle University with supervision from the Thermomechanical Analysis Laboratory. The simulation was done using a workstation with Intel Xeon Gold with 20 cores and 128 GB RAM.

To alleviate the load in the analysis, a quarter model is employed as shown in Figure 1., this is made possible due to the symmetric nature of the package. This is an established practice to improve simulation time without compromising its accuracy [12].

| Material         | Density (g/cm³) | Yield Strength (MPa) | Elongation (%) |
|------------------|-----------------|----------------------|----------------|
| PCB              | 1850            | 17200                | 0.4            |
| Structural Steel | 7850            | 200000               | 0.3            |

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Finite Element Analysis and explicit dynamics analysis

Finite Element Analysis (FEA) has been increasingly applied in manufacturing and production of several industries [13]. It is widely used as an alternative to costly design evaluation and prototype testing. In FEA, several factors and parameters can be assessed under defined boundary conditions. For the analysis in this study, a drop test is simulated which is a standard test conducted to ensure that the product condition is maintained from manufacturing to the end consumers. In such advanced analysis, simulation software such as ANSYS explicit dynamics can provide adequate tools necessary to arrive at accurate results with regards to capturing the physical phenomenon that the model undergoes through. The explicit dynamics analysis system is designed to predict large material deformations, and stresses and failure in the interactions between multiple bodies due to high impact loading.

Drop test analysis

In this study, the drop test is conducted by dropping the BGA assembly from a 1 m height to a structural steel platform. However, in order to simplify the simulation and improve the calculation time a variable simulated height is used that would reduce the end time analysis required, hence reducing solution time as can be seen in Figure 2.

In order to properly simulate the drop test conditions of a 1 m drop height, initial conditions were determined to be applied to the model. Kinematic free fall equations were employed to determine the instantaneous velocity of the BGA at a defined distance towards the structural steel platform assuming it was initially dropped at a height of 1 m with 0 initial velocity.
The height difference can be determined by subtracting the variable simulated height from the original 1 m drop height. Placing it in (1) will yield the time it takes for the object to reach the desired variable height. Substituting this time in (2) will give the resulting instantaneous velocity or the initial velocity input needed for the analysis, assuming \( v_0 \) to be zero.

Another necessary input for the drop test analysis is the end time step. This defines the time frame where the analysis is being evaluated. It is important to determine the optimal end time that would yield the desired result from the drop test without overestimating it as this also directly affects the solution time. In this study, the end time is determined by subtracting the time determined in (1) from the time it takes for the model to hit the ground assuming it is dropped at a 1 m height, which is \( \sim 0.4516 \) s. Standard earth gravity was applied in the overall BGA assembly to simulate the dropping motion aside from the set initial velocity. Moreover, a fixed support is added in the bottom surface of the structural platform to counteract the dropping of the semiconductor package.

2.3. Meshing and Shared topology

The general meshing algorithm is applied in the model. Hexagonal elements of second degree are prioritized in order to minimize the number of elements generated while a more refined meshing is applied towards the solder balls as this is the area of concern for this analysis. The meshing configuration is illustrated in Figure 3.

The factor influence of shared topology is also explored in this study. By applying shared topology, components that are meant to have a bonded condition will be sharing nodes; hence the total number of nodes and elements should be reduced.

2.4. Design of experiment

A full factorial design will be applied in this study considering two independent factors (variable simulated height and shared topology) in order to identify how each factor affects the dependent factors (simulation time and accuracy). Three variable simulated heights were identified, primarily 0.5mm, 1mm, and 5mm. An “N” in the shared topology column indicates that no shared topology feature was applied while a “Y” indicates that the run has applied shared topology. A summary of the identified factors is shown in Table 2.
Figure 3. Meshing of model

Table 2. Full factorial design of experiment

| Variable Simulated Height (mm) | Shared Topology (Y/N) | Simulation Time (hrs) | Impact Stress (MPa) |
|-------------------------------|-----------------------|-----------------------|---------------------|
| 0.5                           | Y                     | -                     | -                   |
| 1.0                           | Y                     | -                     | -                   |
| 5.0                           | Y                     | -                     | -                   |
| 0.5                           | N                     | -                     | -                   |
| 1.0                           | N                     | -                     | -                   |
| 5.0                           | N                     | -                     | -                   |

3. Results and discussion
This section presents the findings of the simulation runs.

3.1. Meshing and Shared topology
The following table summarizes the number of nodes and elements generated with and without the application of shared topology.

Table 3. Node and element reduction after shared topology

|                      | Without Shared Topology | With Shared Topology | Percent Decrease (%) |
|----------------------|-------------------------|----------------------|----------------------|
| Number of Nodes      | 90854                   | 65016                | 28.44                |
| Number of Elements   | 396086                  | 226448               | 42.83                |

By applying shared topology in the model setup, the total number of nodes and elements have been significantly reduced. In principle of FEA, the lesser nodes/elements would require less computing.
power and yield faster computational time. Nonetheless, it is important to also consider maintaining the accuracy of the solution even after reducing the number of nodes/elements in the model.

![Stress profile of solder balls for 5mm variable simulated height and shared topology]

### Table 4. Full factorial design of experiment

| Variable Simulated Height (mm) | Shared Topology (Y/N) | Simulation Time (hrs) | Impact Stress (MPa) |
|-------------------------------|-----------------------|-----------------------|---------------------|
| 0.5                           | Y                     | 1.7                   | 123.52              |
| 1.0                           | Y                     | 2.8                   | 125.54              |
| 5.0                           | Y                     | 9.3                   | 124.87              |
| 0.5                           | N                     | 3.2                   | 123.71              |
| 1.0                           | N                     | 4.1                   | 125.48              |
| 5.0                           | N                     | 12.9                  | 124.69              |

A multiple regression analysis was initially made in order to determine the parameter estimate or influence of the two factors: variable simulated height and shared topology on the simulation time. The overall model fit has an R square of 0.983 and a p-value of 0.002 indicating that there is at least one factor that influences the simulation time. The calculated p-value for the variable simulated height is 0.001 while the p-value for the shared topology factor is 0.038, both of which are less than the alpha 0.05 implying that both factors affect the simulation time.
Another regression analysis was made with regards to the impact stress calculated in each run. However, the overall p-value of the model fit is 0.922 which is greater than 0.05. This suggests that there is no significant difference in varying the factors in terms of the calculated impact stress.

4. Summary and Conclusion
In this study, the main objective was to determine methods that can further simplify FEA, specifically explicit dynamic drop test analysis. A standard drop test was simulated for a BGA assembly by dropping the package at a 1 m height from a structural steel platform. For this analysis, two factors were explored in minimizing the solution time while maintaining the accuracy of the solution. A variable simulated height is introduced where the model is made close to the structural steel platform and by applying initial conditions such as initial velocity, it would simulate a 1 m free fall drop. Next, model simplification is also done by applying shared topology. This method connects the nodes of shared surfaces; thereby reducing the total number of nodes and elements.

Significant reduction in the nodes and elements was observed after applying shared topology. A full factorial design of experiment was generated in order to determine the influence of the variable simulated height and shared topology towards simulation time and accuracy of solution. After conducting the six runs, statistical tests were made and it was found out that both factors affect the simulation time with both p-values being greater than 0.05. At the same time, both factors do not significantly affect the accuracy of results as the calculated p-value for the overall fit model is 0.92, which is greater than 0.05. Hence, it would be preferable to have a setup with the least simulation time without affecting the accuracy of the analysis. Further analysis that employs drop tests can apply these simplification methods that reduce simulation time while maintaining solution accuracy.

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