Board-Level Drop Test: Comparison of Two ANSYS Modeling Approaches and Correlation with Testing

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Abstract— Two ANSYS-based transient analysis approaches for simulating the board-level drop test of an electronic packaging assembly and correlation with measured responses are described. The procedures for the two finite element approaches, the Large Mass Method and the Direct Acceleration Input method, are discussed. Additionally, a method for including damping estimation for numerical transient analysis, based on measured data, is presented. Both modeling analysis techniques provide reasonable correlation to the test data, however, the large mass method more closely mimics the initial acceleration response as observed in the measurements and it is therefore the recommend approach within ANSYS.

1 Introduction

During service life, electronic devices and products are prone to accidental drops as well as robust service conditions. Therefore, reliability studies involving both testing and finite element modeling of these products during drop/impact loadings is essential.

JEDEC standards [1-3] provide the details of the reliability tests for electronic assemblies subjected to mechanical shock environments. Finite element modeling has been widely used in simulating the dynamic responses of circuit board assemblies under impact. While testing provides failure data, modeling provides insight into the mechanical behavior of the assembly during the loading (e.g., stress levels at critical locations). Various studies have considered analytical and finite element approaches to this problem. Yeh et al. [4,5] derived the equation of motion of the board-level drop test and compared the effect of solvers, drop orientation and structural damping of the dynamic responses of electronic assemblies under shock loading. Pitarresi et al. [6,7] presented two simplified modeling methods: global property smearing and simple block modeling and studied their efficiency. In this report, the test assembly was subjected to the JEDEC condition B with 1500-g level and 0.5-ms nominal loading. Two modeling approaches, both using ANSYS, were compared in relation to acceleration response data measured from the drop test.

Various aspects of drop test parameters, such as assembly damping and tightening torque on the PCB mounts were presented in [8,9]. Tee et al. [10-14] proposed different finite element modeling methods of simulating board-level drop test, free-fall, support excitation, input-G and input-D methods. The free-fall method [11,12], simulates the entire drop test process, which is very time consuming and computationally expensive as it typically employs an explicit time-marching numerical scheme. In input-G and input –D methods [13,14] the accelerations (-G) or displacements (-D) can be applied on the test vehicle as a means for providing mechanical shock input to the model. The numerical basis for these approaches is an implicit time-marching scheme, which is typically more numerically stable than other methods and less costly in terms of computer run times. This report summarizes the comparison of these two methods.

In ANSYS the two implicit time-marching approaches are referred to as the Direct Acceleration Input (DAI) method and Large Mass Method (LMM). These techniques were extensively studied and compared by Dhiman et al. [15-17]. Jordy [18] addressed the dynamic responses for different assemblies and presented correlation procedure for modeling shock and vibration.

This report presents experimental results of board-level drop test correlated with finite element analysis. Two techniques have been used and compared, direct acceleration input (DAI) method and large mass method (LMM).

2 Experimental Details

JEDEC condition B with nominal 1500-g acceleration level and 0.5-ms duration was selected as the input for the test vehicle under study. Table 1 presents the dimensions of the printed circuit board, solder joint, and component for the test assembly used in this study.

TABLE 1
DIMENSIONAL PARAMETERS

Parameter	Dimension
PCB width*Length	76.2*76.2 mm^2
PCB Thickness	1.0 mm
Solder joint height	0.5 mm
Solder joint diameter	0.762 mm
Pitch	1.27 mm
Component width*length	30*30 mm^2
Component thickness	1.5 mm

Figure 1 shows a close-up of the test assembly mounted on the drop table ready for testing (note: the assembly is mounted with the component facing downward). As can be seen, a very small accelerometer (0.18 grams) was used to measure the dynamic response of the populated board. The effect of the mass was neglected in the modeling.

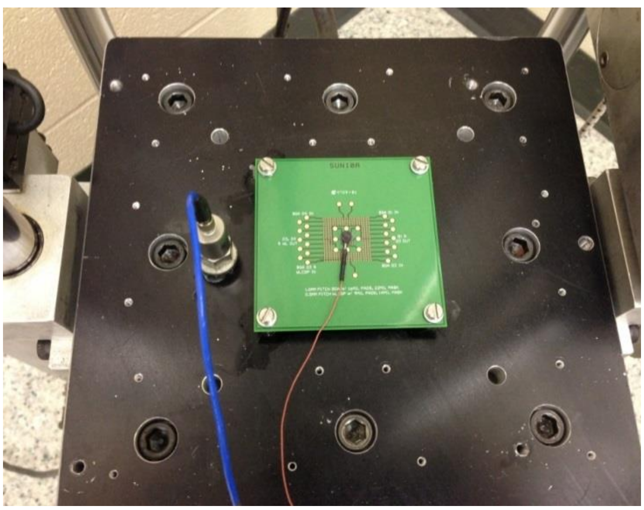

Figure 1. Experimental setup of assembly (face down) mounted to the drop table. Two reference accelerometers are shown.

Three consequent drops were performed; the average response of these drops was calculated and then correlated with FE responses.

3 FINITE ELEMENT MODELING AND APPROACHES

This section presents the details of the finite element model developed in this study, formulation of the problem, and different load application methods used: Direct Acceleration Input method and Large Mass method. The structural damping estimation is also addressed.

3.1 Finite Element Model

A detailed three-dimensional finite element model has been developed using the commercial finite element software ANSYS (version 14.5). The element used to mesh PCB, solder joints and the component is ANSYS "solid45" element; this element is defined by eight nodes, each node has three translational degrees of freedom, namely, u_x, u_y and u_z. In this model care was taken to carefully generate a refined mesh in the corner solder joint and less refined mesh elsewhere. Material properties used in this model were previously obtained through correlating the vibration characteristics (natural frequencies and mode shapes) of the FE model with measurements [20]. Note that the PCB and component substrate are FR-4 material. The material properties are listed in table 2.

The SAC305 solder material properties were obtained from [22]. In this reference, the values of Young's modulus found to be higher than expected. However, they were used in the current study because they are for actual solder joint, where the effect of the intermetallic layers is included, while literature values are for bulk solder. SAC305 properties are shown in Table 2. All material properties are assumed linear. While mechanical drop testing can produce significant loads, the short time duration material response of the solder is typically taken as linear. This is also true of the other assembly materials.

TABLE 2
UPDATED MATERIAL PROPERTIES FOR THE PCB, AND COMPONENT [20]

Material Property	PCB	Component
E_x	35.1 GPa	20.4 GPa
E_y	35.1 GPa	20.4 GPa
ν_{xy}	0.136	0.136
G_{xy}	12.7 GPa	6.9 GPa
Density	3030 Kg/m^3	2000 Kg/m^3

Material Properties for SAC305 [22]

Material Property	Value
E_x	90.0 GPa
ν_{xy}	0.36
Density	7400 Kg/m^3

The modeling procedure was started by building a "unit solder" model as shown in Figure 2. This unit was copied as needed for the geometry of the assembly (20×20 Perimeter, 256 I/O package). The remaining portions of the component and PCB are then extruded up to the desired dimension. The total number of elements for this model is 147,468. Figure 3 shows the isometric view of the full model.

The modeling in this effort is focused on transient analysis to simulate the drop test. With the methods described herein, the resulting models can be then used to explore the dynamic response of the assembly to a wide range of load conditions.

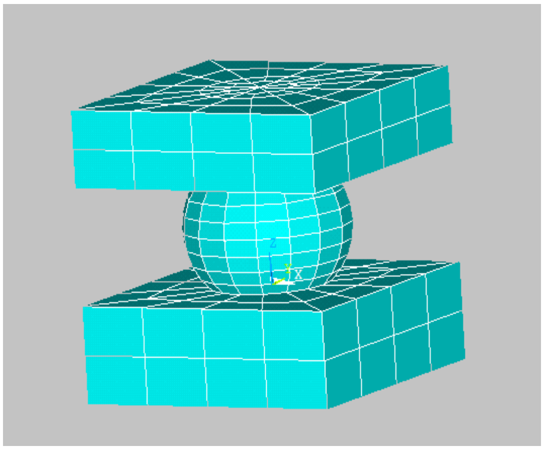

Figure 2. Typical solder joint unit.

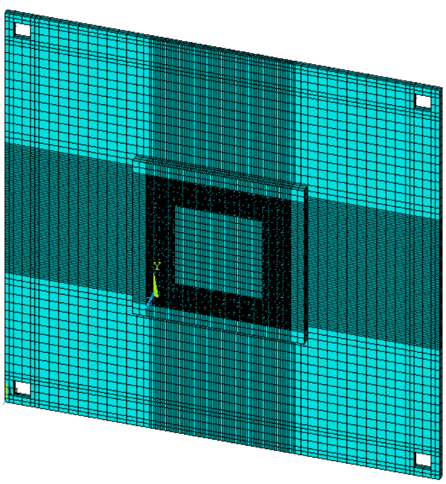

Figure 3. Full model mesh.

3.2 Problem Formulation

During the drop measurement, the assembly is mounted on the drop table using typical standoffs and screws, as shown in Figure 4. Therefore, the assembly can be isolated from the drop table by imposing the pulse on the screw locations. The mathematical formulation of our problem becomes [15]:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = 0 \qquad (1)$$

With initial conditions $\{x_o\} = 0$ and $\{\dot{x}_o\} = \sqrt{2gh}$

And boundary conditions (at the mounting holes)

$$\{x(\ddot{t})\} = \begin{cases} 1500g \sin\frac{\pi t}{T} & ,t \leq T \\ 0 & ,t \geq T \end{cases}$$

Where *[M], [C]* and *[K]* are the mass, the damping and the stiffness matrices, respectively. $\{x\}, \{\dot{x}\}$ and $\{\ddot{x}\}$ are the displacement, velocity and acceleration of board, respectively. The drop height is *h*, the gravity acceleration *g*. *T* is the pulse duration, in our case *T* = 0.5 ms, and *t* is the time.

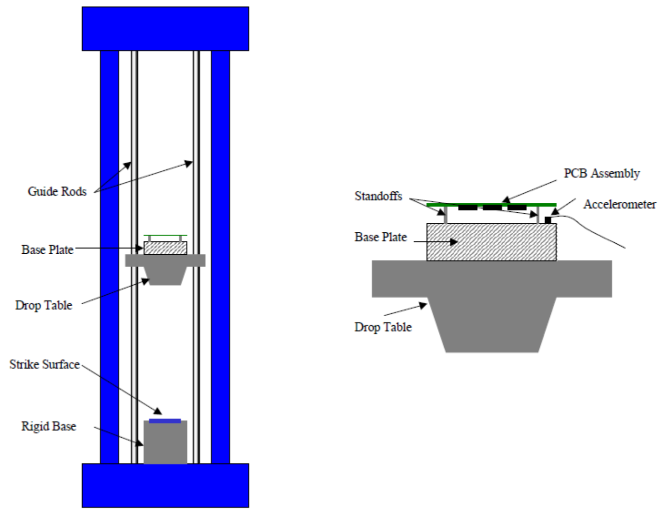

Figure 4. Schematic of JEDEC Drop Test [1].

The above problem can be solved in ANSYS using transient analysis, i.e., direct numerical integration of the equation of motion (Eqn. 1). The following two subsections illustrate the two input methods used in this study and their formulations.

3.3 Direct Acceleration Input (DAI) method

In this method, an acceleration impulse is applied as a body force to the FE model. And the mounting holes surfaces i.e., boundary conditions are fixed in all directions. Therefore, the problem can be formulated as:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} =$$

$$\begin{cases} -\{M\}1500g \sin\frac{\pi t}{T} & ,t \leq T \\ 0 & ,t \geq T \end{cases} \qquad (2)$$

With initial conditions $\{x_o\} = 0$ and $\{\dot{x}_o\} = \sqrt{2gh}$

And boundary conditions (at the mounting holes) will be:

$$\{x(t)\} = 0.$$

The load application in this method is easy and straightforward in FE packages, such as in ANSYS. However, the drawback of this method is that it does not simulate the real problem which will lead to a mismatch with the experimental responses.

3.4 Large Mass Method (LMM)

The concept behind this method is to attach a “very large” mass to the FE model at the locations of screws i.e., boundary conditions, which mimics the base excitation scheme. Thus, the acceleration input can be converted into force input on the boundaries via Newton’s Law. This force (F) can be calculated as

$$F = M_{Large}a = \begin{cases} M_{Large}1500g\sin\frac{\pi t}{T} & ,t \le T \\ 0 & ,t \ge T \end{cases} \quad (3)$$

Where M_{Large} is the very large mass (this is a few orders of magnitude larger than the test piece). Then, the force (F) is to be applied directly on the large mass. Consequently, the mathematical formulation of the problem can be addressed as:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = 0 \quad (4)$$

With initial conditions $\{x_o\} = 0$ and $\{\dot{x}_o\} = \sqrt{2gh}$

And boundary conditions (at the mounting holes)

$$\{x(\ddot{t})\} = \begin{cases} 1500g\sin\frac{\pi t}{T} & ,t \le T \\ 0 & ,t \ge T \end{cases}$$

These two methods, (DAI) and (LMM), can be proved to be equivalent as described in [15]. However, their implementation in ANSYS can lead to discrepancies in the results as computed with the internal algorithms within ANSYS. Hence, the motivation for comparing the two approaches.

3.5 Damping estimation

In ANSYS, the only way to define damping in a transient analysis is to use Rayleigh damping [21]:

$$[C] = \alpha[M] + \beta[K] \quad (5)$$

Where α is the mass matrix multiplier and β is the stiffness matrix multiplier. Equation (5) can be re-written in modal form as [21]:

$$\xi_i = \alpha\frac{1}{2\omega_i} + \beta\frac{\omega_i}{2} \quad (6)$$

Where ξ_i and ω_i are damping ratio and natural frequency corresponding to the i^{th} mode, respectively. The damping ratio and natural frequency can be estimated experimentally from modal data, using two independent frequencies. Alternatively, random or harmonic test measurements can be used. From previous modal measurements, α and β can be calculated accordingly and for the case considered here, we have ω_1 = 533 Hz, ξ_1 = 0.014 and ω_2 = 1762 Hz, ξ_2 = 0.0058, we found that α = 90.3 and β = 3.1e-7.

4 RESULTS

A snapshot of a typical result of the experimental drop test and the two FE solutions are considered. Figure 5 shows a typical acceleration versus time plot of the acceleration measurement at the center of the board. In addition, the direct acceleration input (DAI) method and large mass method (LMM) are also plotted. It is seen that both numerical approaches correlate well with the measurement for the initial maximum peak, with some overshoot at the secondary peaks in the response. Both numerical solutions trend almost identically throughout the majority of the response, however, the LMM eliminates the large fictitious peak at the beginning of the time trace as shown with the DAI method. This can be justified by the previously presented equations, as it can be seen that the formulation of LMM is the same of the original problem formulation.

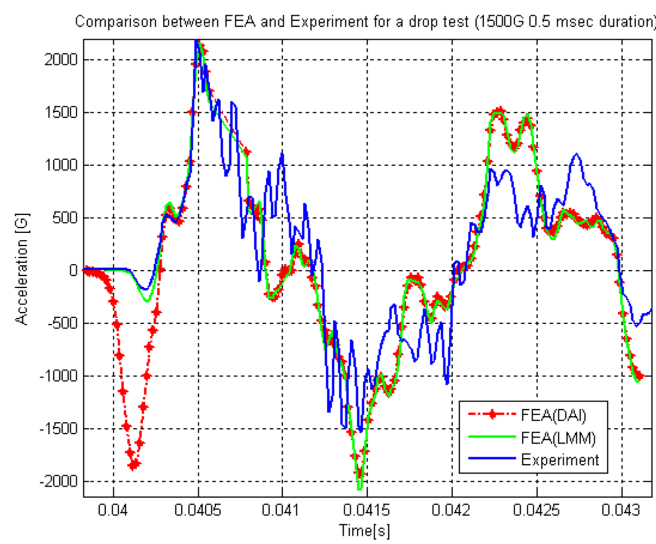

Figure 5. Dynamic Response Comparison.

CONCLUSIONS

Information regarding competing ANSYS-based numerical analysis methodologies for mechanical shock simulation have been presented. The general approach was based on comparing the results extracted from the finite element models (built using ANSYS), with the experimentally obtained acceleration response from a board-level drop test. Specifically, accelerations at the board center were compared. Two ANSYS analysis methods were presented and validated: the direct acceleration input (DAI) method and large mass method (LMM). It was seen that both numerical approaches correlate well with the measurement for the initial maximum peak, with some overshoot at the secondary peaks in the response. In general, good overall correlation with measurement was observed. Furthermore, the large mass method (LMM) was shown to better capture the initial dynamic response compared to the direct acceleration input (DAI) method. Further work is proposed aimed at improved modeling of the standoffs used in the testing and extracting stress values at critical locations.

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