

Design of Drop Test Apparatus for Electronic Packages

Chang-Lin Yeh, Yi-Shao Lai*

Stress-Reliability Lab, Advanced Semiconductor Engineering, Inc.
26 Chin 3rd Rd., Nantze Export Processing Zone, 811 Nantze, Kaohsiung, Taiwan

*Corresponding author: Email: yishao_lai@aseglobal.com

Abstract

In this paper transient structural responses of a drop test apparatus are investigated during drop testing. Parametric studies are carried out to examine the effect of drop heights, composition of materials and component geometries of the apparatus on the pulse duration and the peak acceleration at an observation point. The finite element analysis applies an explicit time integration scheme, which is feasible in dealing with the nonlinear transient structural behavior. Results suggest that an effective design of the drop test apparatus could be performed by changing the composition material of the strike surface and subsequently by adjusting the height of the drop table.

Keywords:

Drop test, Pulse, Peak acceleration, Duration, Finite Element Analysis (FEM), Surface Mount

1. INTRODUCTION

The board-level drop test is intended to evaluate and compare the drop performance of surface mounted electronic components for handheld electronic product applications in an accelerated test environment, where excessive flexure of a circuit board causes product failure. Owing to the complex nature of the impact behavior during drop testing, the test results of electronic components would dramatically change when different test apparatus and procedures are applied. It is therefore important to set up a standard test apparatus and corresponding methodology in order to obtain reproducible assessments of drop performance of the surface mounted components. The development of a standardized board-level drop test has become an even larger issue due to concerns of the dynamic reliability of solder joints that are transitioning from lead-containing to lead-free solder alloys.

In recent years, many experimental and numerical studies for different drop test methodologies have been performed. Several of the studies presented drop tests that were controlled primarily by the drop height (e.g., [1,2]). However, it should be noted that not only the drop height but also the materials and geometries of the test vehicle and the strike surface play significant roles in a drop impact process. The drop test produces results which are neither

objective nor repeatable if only the drop height is considered. To compensate for this drawback, the regulations, JESD22-B110 [3] and JESD22-B111 [4], proposed by Joint Electron Device Engineering Council, JEDEC, characterize test conditions according to the acceleration profile of the drop impact process. These standards have gradually demonstrated the potential of becoming the mandatory standard for the board-level drop test of electronic packages.

According to the JEDEC standard for the shock test [3,4], Table 1, the drop test apparatus should be capable of providing shock pulses up to a peak acceleration of 2,900 multiples of gravity (G) with a pulse duration (t_w) between 0.3 ms and 2.0 ms at a certain observation point on the body of the device. The acceleration pulse, as determined from the unfiltered output of the transducer with a natural frequency greater than or equal to five times the frequency of the shock pulse being established, should be in a half-sine waveform with an allowable distortion not greater than $\pm 20\%$ of the specified peak acceleration (A_0). The pulse duration should be measured between the point at 10% of the peak acceleration during rise time and the point at 10% of the peak acceleration during decay time. Absolute tolerances of the pulse duration should be $\pm 30\%$ of the duration specified in Table 1. It was also recommended that the test velocity change should be within the range of $\pm 10\%$ of the specified magnitude.

Table 1: JEDEC shock test conditions [3,4].

Service condition	Equivalent drop height (inches) / (cm)	Velocity change (in/s) / (cm/s)	Peak acceleration (G)	Pulse duration (ms)
H	59 / 150	214 / 543	2900	0.3
G	51 / 130	199 / 505	2000	0.4
B	44 / 112	184 / 467	1500	0.5
F	30 / 76.2	152 / 386	900	0.7
A	20 / 50.8	124 / 316	500	1.0
E	13 / 33.0	100 / 254	340	1.2
D	7 / 17.8	73.6 / 187	200	1.5
C	3 / 7.62	48.1 / 122	100	2.0

For drop test studies related to the JEDEC standards, Wong et al. [5] numerically investigated stress distributions of a test vehicle subjected to board-level drop tests whose configuration involves an impact cone, a metal block, and a rigid impact surface. A very high acceleration greater than 10,000 G with the pulse duration of 0.05 ms was observed near the ends of the test vehicle. Tee et al. [6-8] performed a series of board-level drop tests similar to the JEDEC standard with a half-sine acceleration pulse applied on their test vehicle and the dynamic responses were investigated both numerically and experimentally. However, the peak acceleration of their input pulse was 3,700 G, whose magnitude is much higher than the JEDEC recommendation of 1,500 G.

In general, the impact duration of a pulse load is not only a function of material properties, but also a function of the geometry and dimension of the structure. For example, one of the simplest impact problems is the longitudinal impact of two flat-ended rods. The impact duration for this problem is [9]:

$$t_w = \min \left[\frac{2l_1}{c_1}, \frac{2l_2}{c_2} \right] \quad (1)$$

where l_i and c_i are the length and the wave speed of the i -th rod, respectively. The wave speeds within the rods are

$$c_1 = \sqrt{\frac{E_1}{\rho_1}} \quad c_2 = \sqrt{\frac{E_2}{\rho_2}} \quad (2)$$

where ρ_i and E_i are the mass density and the Young's modulus of the i -th rod, respectively. On the other hand, for the impact of two spheres, the impact duration is [10]:

$$t_w = 2.94 \left(\frac{5\sqrt{2\pi\rho} (1-\nu^2)}{4E} \right)^{2/5} \frac{R}{(V)^{1/5}} \quad (3)$$

where ν is the Poisson's ratio, R the radius of the sphere, and V the impact velocity. From these two equations, we notice that the duration of impact is proportional to the dimension of impact components. For components with complicated geometries such as spheres, the impact duration is also a function of the impact velocity.

In this paper we investigate transient responses of a drop test apparatus. Parametric studies are carried out to investigate the effect of drop heights, composition of materials and component geometries of the apparatus on the pulse duration and the peak acceleration. The analysis applies an explicit finite element scheme, which is appropriate for studying the nonlinear transient structural behavior.

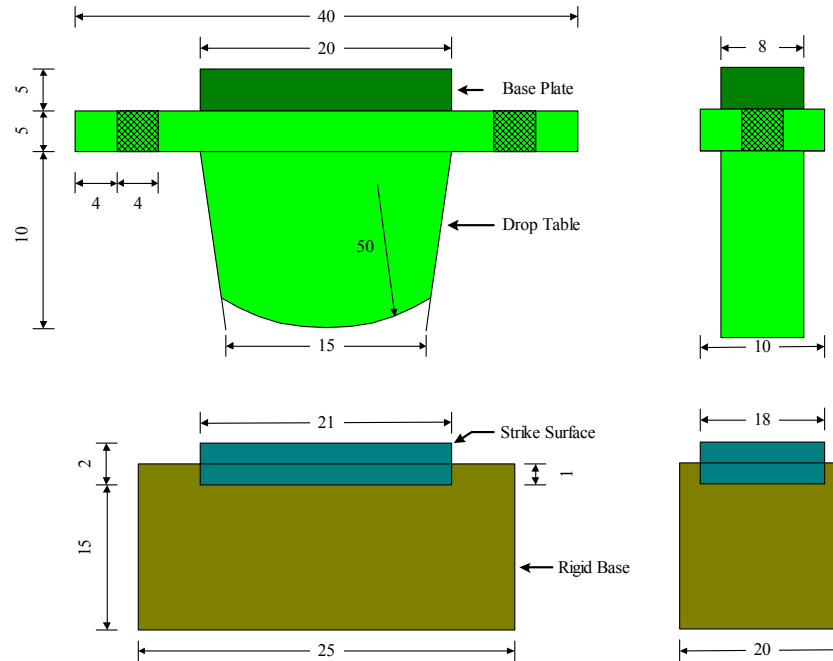


Figure 1: Geometry and dimension of the drop test apparatus (unit: cm, not drawn to the scale).

2. FINITE ELEMENT MODELING

The geometry and dimension of the drop test apparatus utilized in this paper are shown in Figure 1. Unless otherwise indicated, this apparatus is applied in the studies that follow. Notice that the ‘rigid base’ is a conventional terminology. It is in fact a deformable component, which in this case is made of steel.

A quarter symmetry finite element model, as shown in Figure 2, is built up for the numerical analysis. In the model we make use of linear hexahedral solid elements. In general, the finite element results are more accurate when finer meshes are employed. However, numerical

execution with extra-fine meshes is impractical with limited computational resources. In this paper, we employ the finite element model with the finest possible meshes on a P-4 personal computer with 1 GB RAM. The model consists of 25,704 elements and 89,478 degrees of freedom. The analysis is carried out using ANSYS/LS-DYNA v. 7.0. All degrees of freedom on the bottom surface of the base are fixed. In reality the boundary condition on the bottom of the base is somewhere between totally fixed and simply supported. The thickness of the base is large enough to negate the effect of different boundary conditions on the transient responses at a location sufficiently far away from the bottom of the base.

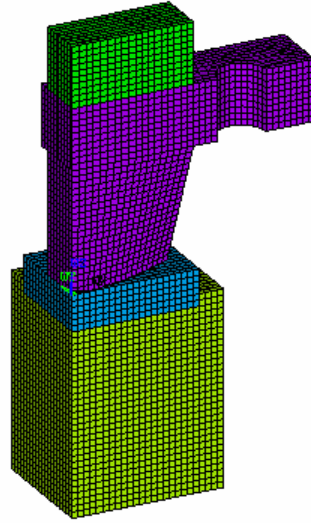


Figure 2: Quarter symmetry finite element model.

The materials and their properties applied in this study are shown in Table 2. Unless otherwise indicated, steel is used in the parametric studies that follow.

As is shown in Figure 3, an observation point on the base

plate, whose location is suggested by the JEDEC standard [1], is chosen for data monitoring. In practice, an accelerometer is attached at this location. The drop height between the drop table and the strike surface is 1.0 m.

Table 2: Material properties.

Material	Young's modulus (GPa)	Poisson's ratio	Mass density (g/cm ³)	Wave velocity (km/s)
Tungsten	360	0.20	1.90	13.765
Steel	190	0.30	7.85	4.920
Copper	120	0.33	8.90	3.672
Titanium	110	0.33	4.50	4.944
Aluminum	72	0.33	2.80	5.071
Magnesium	45	0.35	1.80	5.000
Wood-like	12	0.10	0.60	4.472
Polyimide	2.7	0.30	1.35	1.414

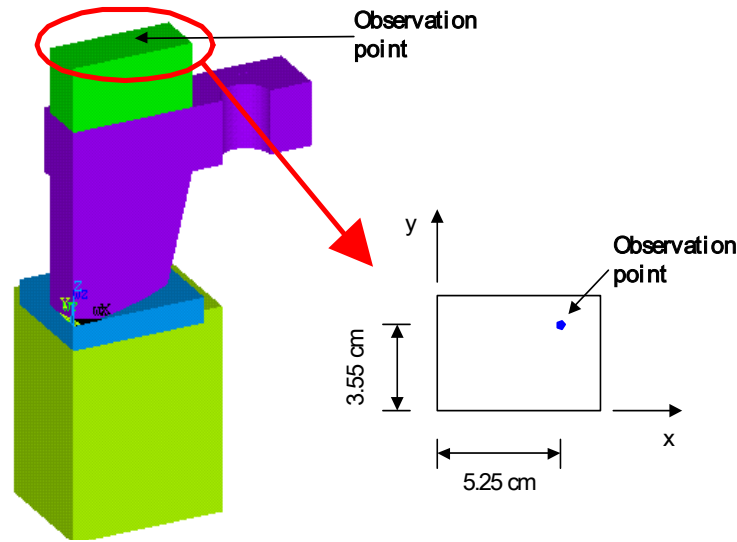


Figure 3: The observation point.

3. PARAMETRIC STUDIES

In this section we investigate the effect of drop heights, composition of materials and component geometries of the apparatus on the pulse duration and the peak acceleration at the observation point. In the following studies, the pulse duration is defined as the period from time zero to the time when the acceleration first drops to zero.

3.1 Curvature of drop table

Different radii of curvature, R , can be imposed on the contact surface of the drop table. For a flat table, whose $R \rightarrow \infty$, the area of the contact surface does not change with time. In contrast, when the contact surface of the drop table is curved, area of the contact surface is a function of time. Figure 4 and Figure 5 show plots of the acceleration of a curved table of $R = 8000$ cm and a flat table, respectively.

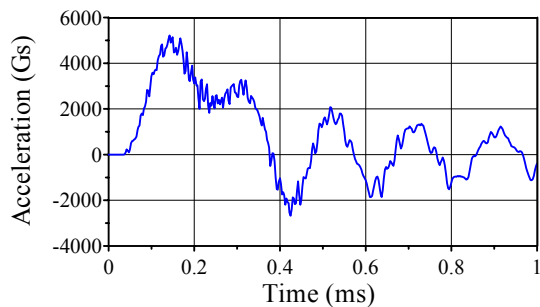


Figure 4: Acceleration of the curved table ($R = 8000$ cm) at the observation point

($A_0 = 5,219$ G; $t_w = 0.357$ ms).

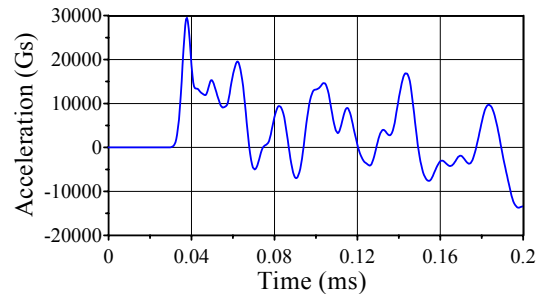


Figure 5: Acceleration of the flat table at the observation point
($A_0 = 29,138$ G; $t_w = 0.052$ ms).

From the figures we notice that the pulse duration of the flat table is approximately equal to the period of the stress wave traveling back and forth from the top of the base plate to the bottom of the drop table, which is similar to the impact of two flat-end rods. The pulse duration of the flat table is shorter than that of the curved table. Figure 6 and Figure 7 show plots of the velocity of a curved and a flat table, respectively. Apparently, the transient structural behavior of the flat table involves higher frequencies.

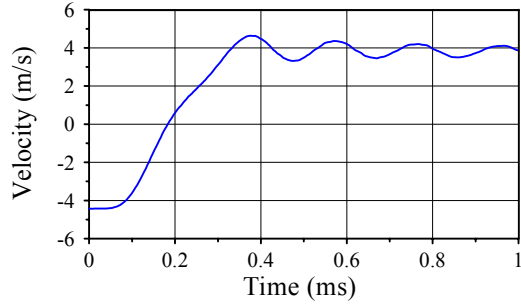


Figure 6: Velocity of the curved table at the observation point.

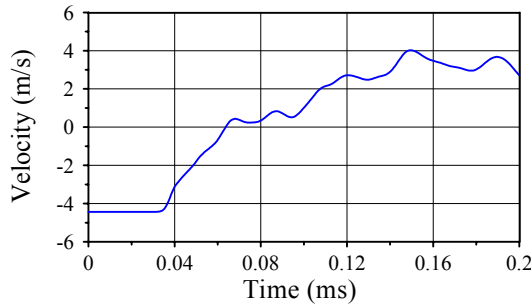


Figure 7: Velocity of the flat table at the observation point.

Figure 8 shows the peak acceleration and the pulse duration with respect to R . From the figure we notice that as R increases, the peak acceleration increases while the pulse duration decreases. The peak acceleration and the pulse duration converge to 9,832 G and 0.163 ms, respectively, when R is greater than 5000 cm up to 8000 cm.

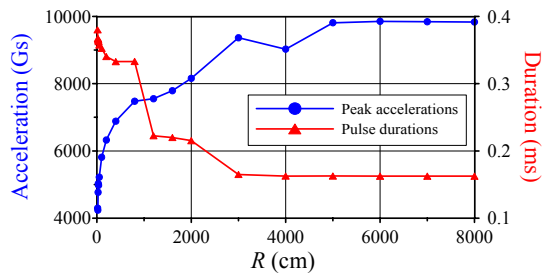


Figure 8: Peak acceleration and pulse duration with respect to R .

It is interesting to figure out from Figure 5 such that the pulse duration of a flat table is around 0.052 ms, much smaller than that for a curved table with a large R , which converges to 0.163 ms for R up to 8000 cm. Theoretically, when $R \rightarrow \infty$, a curved table must behave the same as a flat table. Apparently, the greatest R of the curved table we examine in this paper, 8000 cm, is not large enough to approach a flat table. In terms of the numerical analysis, a

flat table leads to a perfect surface-to-surface impact while a curved table a point-to-surface impact. These two types of impact create distinct stress wave propagation patterns within the drop table, affecting transient structural responses for this particular problem. Moreover, the mesh density we apply may not be high enough to sensitively capture the decrease of the pulse duration for the curved table with a gradually increasing R . The sudden drop of the pulse duration around $R = 1000$ cm may support this argument. We therefore expect that the pulse duration would decrease with the increase of R and eventually would reach the one for a flat table.

3.2 Drop height

According to the laws of conservation of energy and momentum, the relationship between the drop height, H , and the impact velocity, V_i , of a half-sine pulse can be written as

$$V_i = \sqrt{2GH} = \frac{2A_0 t_w}{C\pi} \quad (4)$$

where C is the rebound coefficient (1.0 for no-rebound; 2.0 for full-rebound). From the above equation, we notice that the impact velocity is proportional to the square root of the drop height or to the product of the peak acceleration and the pulse duration.

Figure 9 shows the acceleration plots for different drop heights and Figure 10 the peak acceleration and the pulse duration for different impact velocities. It is noticed that the pulse duration does not change according to the drop height. However, the peak acceleration is linearly proportional to the impact velocity.

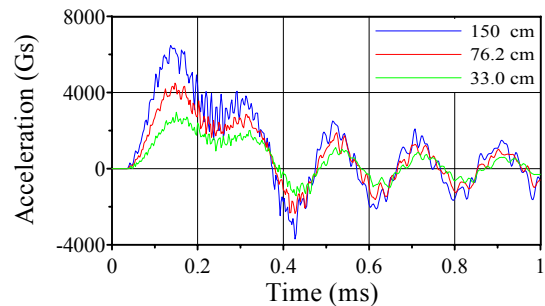


Figure 9: Acceleration for different drop heights.

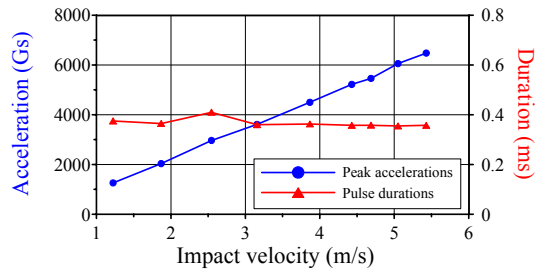


Figure 10: Peak acceleration and pulse duration corresponding to different impact velocities.

3.3 Composition of drop table

From Eq. 4 we notice that the impact velocity is inversely proportional to the rebound coefficient. Since the rebound coefficient is determined by the composition and geometry of the apparatus, in this subsection we study the effect of drop tables made from materials that have different compositions. Notice that the strike surface is made of steel.

The materials and their mechanical properties are listed in Table 2. Table 3 summarizes the results. It is noticed from

the results that the apparatus made of tungsten, whose wave speed and Young's modulus are the greatest among all, has the shortest pulse duration and the largest peak acceleration. In contrast, the apparatus made of polyimide, whose wave speed and Young's modulus are the smallest among all, has the longest pulse duration and the smallest peak acceleration. The peak acceleration and the pulse duration for different composition materials are shown in Figure 11. From the figure we notice that the peak acceleration is linearly proportional while the pulse duration is inversely proportional to the wave speed of the material.

Table 3: Results for different drop table materials.

Material	Peak acceleration (Gs)	Pulse duration (ms)
Tungsten	12183	0.142
Steel	5113	0.357
Copper	4355	0.462
Titanium	5654	0.348
Aluminum	6035	0.332
Magnesium	6254	0.330
Wood-like	5022	0.385
Polyimide	2182	0.678

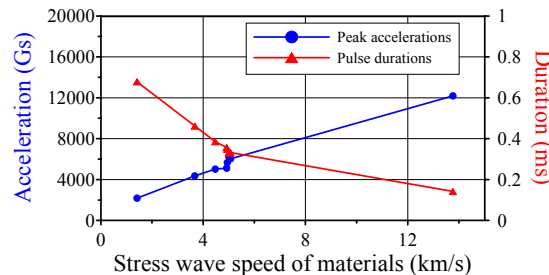


Figure 11: Peak acceleration and pulse duration for different drop table composition materials.

3.4 Composition of strike surface

Similar to the previous subsection, in this subsection we investigate the effect of different material compositions of

the strike surface. Notice that the drop table is made of steel. Results are summarized in Table 4. The peak acceleration and the pulse duration for different composition materials are shown in Figure 12.

Table 4: Results for different strike surface materials.

Material	Peak acceleration (Gs)	Pulse duration (ms)
Tungsten	5433	0.353
Steel	5219	0.357
Copper	5269	0.350
Titanium	4760	0.368
Aluminum	4348	0.373
Magnesium	4047	0.390
Wood-like	2032	0.813
Polyimide	1752	1.120

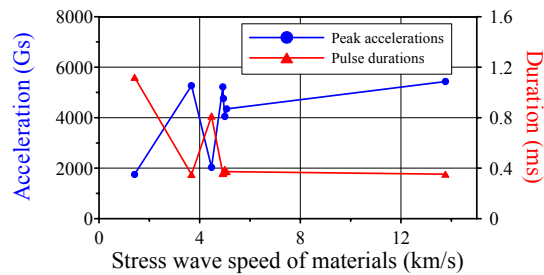


Figure 12: Peak acceleration and pulse duration for different strike surface composition materials.

The trend of results presented in Figure 12 is not as deterministic as in Figure 11. The longest pulse duration is 1.12 ms for the strike surface made of polyimide. Nevertheless, by comparing the results in Table 3 and Table 4, we notice that when impact components consist of steel-made drop table and other material-made strike surface, the pulse duration is longer than that when the above materials are exchanged. The only exception is the combination of steel and copper. Therefore, we suggest that an effective design for the drop test apparatus based on different test conditions can be done in following steps:

1. Switch the strike surface composition material to fit the desired pulse duration.
2. Adjust the drop height to obtain the required acceleration level.

4. CONCLUSION

In this paper, numerical analyses are performed to study transient structural responses of the drop test apparatus. Parametric studies are carried out to investigate the effect of drop heights, material compositions and component geometries of the apparatus on the pulse duration and the peak acceleration at an observation point. Results are summarized as follows:

1. As the radius of curvature of the contact surface of the drop table increases, the peak acceleration increases while the pulse duration decreases. These two quantities converge when the radius of curvature is greater than 5000 cm up to 8000 cm.
2. The pulse duration does not change according to the drop height. However, the peak acceleration is linearly proportional to the impact velocity.
3. For the drop table, the peak acceleration is linearly proportional while the pulse duration is inversely proportional to the wave speed of the composition material.
4. In order to evaluate drop performance of surface mounted electronic components based on different drop test conditions, the strike surface composition material can be changed to fit the desired pulse duration and the drop height can then be adjusted to obtain the required acceleration level.

References

- [1] Xu, L., Wang, J., Reinikainen, T., Han, Z. X. and Wang, B. P., "Numerical Studies of the Mechanical Response of Solder Joint to Drop/Impact Load", Proc. 5th Electronics Packaging Technology Conference, Singapore, pp. 228-232, 2003.
- [2] Tan, L. B., Seah, S. K. W., Wong, E. H., Zhang, X., Tan, V. B. C. and Lim, C. T., "Board Level Solder Joint Failures by Static and Dynamic Loads", Proc. 5th Electronics Packaging Technology Conference, Singapore, pp. 244-251, 2003.
- [3] JEDEC Solid State Technology Association, *JESD22-B110: Subassembly Mechanical Shock*, 2001.
- [4] JEDEC Solid State Technology Association, *JESD22-B111: Board Level Drop Test Method of Component for Handheld Electronics Products*, 2003.
- [5] Wong, E. H., Lim, K. M., Lee, N., Seah, S., Hoe, C. and Wang, J., "Drop Impact Test – Mechanics & Physics of Failure", Proc. 4th Electronics Packaging Technology Conference, Singapore, pp. 327-333, 2002.
- [6] Luan, J. E., Tee, T. Y., Pek, E., Lim, C. T. and Zhong, Z. W., "Modal Analysis and Dynamic Responses of Board Level Drop Test", Proc. 5th Electronics Packaging Technology Conference, Singapore, pp. 233-243, 2003.
- [7] Tee, T. Y., Luan, J. E., Pek, E., Lim, C. T. and Zhong, Z. W., "Novel Numerical and Experimental Analysis of Dynamic Responses under Board Level Drop Test", Proc. 5th International Conference on Thermal and Mechanical Simulation and Experiments in Microelectronics and Microsystems (EuroSimE), pp. 133-140, 2004.
- [8] Tee, T. Y., Luan, J. E., Pek, E., Lim, C. T. and Zhong, Z. W., "Advanced Experimental and Simulation Techniques for Analysis of Dynamic Responses During Drop Impact", Proc. 54th Electronic Components and Technology Conference, Las Vegas, NV, USA, 2004.
- [9] Graff, K. F., "Wave Motion in Elastic Solids", Ohio State University Press, pp. 95-108, 1975.
- [10] Timoshenko, S. P. and Goodier, J. N., "Theory of Elasticity", 3rd ed., McGraw-Hill, pp. 420-422, 1970.