Free-drop simulation and analysis of Full-screen smartphone based on ABAQUS/CAE

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Abstract Finite element analysis (FEA) provides numerical modeling and testing methods of stress analysis for products. The time of products development cycle can be shortened and the cost for products physical testing can be reduced with FEA. Drop test is one of the important tools uses for the impact behaviour study of cell phones, which identifies weak design points during the impact behaviour of cell phone. With the development of technology and growing of people's demand, the screen of cell phone is getting bigger and bigger. Full-screen smartphones have become a trend. It is necessary that modeling and analyzing for full-screen smartphones are considered. This study conducts free-drop simulation and analysis on full-screen smartphones based on ABAQUS/CAE.

1. Introduction

With the development of technology, portable electronic products, such as cell phones, tablet and notebook computers, have gradually become indispensable tools for work and life. Smartphones, a kind of media devices, are becoming more and more powerful and portable. Since the Vivo company released the world's first full-screen smartphone on June 12, 2018, the full screen era of smart phones has begun. Full-screen smartphone increase the display space of the phone without increasing the size of the phone, which takes better user experience. However, the structural changes of smartphone will bring some troubles due to increase in the proportion of smartphone screens, such as screen fracture easily, the greater probability of the impact point and more probability of drop for full-screen smartphone. As a result, the reliability and durability of smartphones have already drawn attention from manufacturers and researchers.

It is not unusual for the device to be accidentally dropped onto hard surface under the course of using a cell phone. Impact and shock to a cell phone can cause functional and physical damages to its internal components or external housing, especially the phone screen. Accordingly, one of the most common causes of failure for cell phones is from drop impact. Therefore, it is essential to analyse the mechanical reliability of cell phones under dynamic loading, when the structure change is considered. The impact tolerance of cell phones by using both analysis and high-speed photography has been studied [1], which pointed out the result that the traditional construction method for cell phone battery packs can lead to fracturing of the battery housing in a drop due to multiple impacts. A simple remedy for improving the battery pack’s drop performance was recommended. Reference [2] proved the role of rigidity of the housing in determining the impact tolerance of a cellular phone and indicated that the thin-walled clamshell structure may not have sufficient rigidity to withstand impact induced loads. Some experiments on portable electronic products were conducted from different impact orientations and drop heights using drop tester and verified the impact orientation for various impact orientations PDAs by using a high-speed camera [3, 4]. It is concluded that horizontal drop orientations generally give the largest impact responses and impact responses will differ for various products with different dimensions and material compositions. In addition to mechanical shock tests, intensive numerical simulations have also been conducted to study drop/impact reliability of electronic devices [5-7]. Reference [8] studied conducts drop tests on cell phones according to related test standards. It was shown experimentally that damage to the inner LCD modules of cell phones occurs mostly when the cell
phone drops with its front or back facing up. The probability of the aforementioned damage can be effectively reduced using the Taguchi method to modify design.

How to simulate and analyse the impact for cell phones from drop is important, which is indispensable in the design and development process. Reference [9] demonstrated the damage of a two dimensional bi-material strip owing to thermal loading by means of an implicit finite element implementation of peridynamic(PD) in ABAQUS. Experimental tests were done on columns of FEC under axial loads and compared with a non-linear 3D finite element model of FEC columns using the ABAQUS finite element code [10]. Reference [11] introduced the ABAQUS simulation of fully encased composite columns and compared to reinforced concrete columns of different concrete strengths. Axial load capacity deformation, stress and strain patterns are determined for reinforced concrete columns and composite columns with I-section steel confinement. In recent years, secondary development based on ABAQUS has developed rapidly. A dual PD for brittle fracture was implemented in ABAQUS by means of UEL/VUEL and UMAT/VUMAT subroutines, which takes peridynamic finite element method (PDFEM) [12]. Reference [13] investigated the behavior of posttensioned concrete beams and attempted to examine the concrete damage behavior using a concrete damaged plasticity (CDP) model in ABAQUS.

Although significant investigations into the drop/impact reliability for electronic devices have been conducted experimentally and computationally as mentioned above, no paper employing the methodology of quality design for full-screen smartphone has been published so far. In this study, the finite element analysis for full-screen smartphone, Huawei P40 as an example, is proposed to study the drop/impact response of cell phones. It aims to study that how to improve the anti-impact performance for full-screen smartphones.

2 Free-drop impact algorithm

It was decided that the best method to adopt for this investigation was to analyse the collision between the full-screen smartphone and the floor. The type of collision is usually in a short time, and it also has nonlinear characteristics due to the complexity of the full-screen smartphone. The problem of impact process belongs to the contact problem in elasticity. Therefore, explicit dynamic finite element method can be used to obtain the stress history output data of full-screen smartphone nodes.

The finite element analysis of explicit time integration can be formulated into the following differential equation:

\[ Ma + Cv + F = R \]  \( (1) \)

where \( M, C, F, \) and \( R \) are the global mass matrix, a node of damping matrix, internal force vector, and load vector, respectively. While \( a, v \) are the acceleration vector and velocity vector, respectively.

To solve the equation (1), the central difference system should be used. In the equation (1), it is time-sensitive. Therefore, the velocity and acceleration equations of a node at time \( n \) can be obtained from the equation (2).

\[
\begin{aligned}
  v_n &= \frac{1}{2\Delta t} (s_{n+1} - s_{n-1}) \\
  a_n &= \frac{1}{\Delta t^2} (s_{n+1} - 2s_n + s_{n-1})
\end{aligned}
\]  \( (2) \)

In the equations, \( v_n, s_n, \) and \( a_n \) are a node of velocity, displacement, and acceleration at \( n \) time, respectively. \( \Delta t \) is time increment.

Due to Courant-Friedrichs-Levy criterion, the \( \Delta t \) can be obtained from the equation (3).

\[ \Delta t_{\text{min}} = \frac{L}{C} \]  \( (3) \)

where \( \Delta t_{\text{min}} \) is minimum time increment, \( L \) is a node of length, and \( C \) is sound transmission in material.

In addition, the \( C \) is obtained from the equation (4).

\[ C = \sqrt{\frac{(1-\delta)E}{(1+\delta)(1-2\delta)\rho}} \]  \( (4) \)

In the equation, \( \delta \) is Poisson’s ratio, \( \rho \) is material density, and \( E \) is young’s modulus of elasticity.

Finally, a simultaneous solution is in equation (5).

\[ s_{n+1} = \frac{\Delta t^2(r_n-F_n)+2Mv_n-(M-\frac{\Delta t^2}{C})s_{n-1}}{M} \]  \( (5) \)
where $R_n$, $F_n$ are external load vector and internal force vector at $t_n$, $s_{n+1}$ is a node of displacement at $t_{n+1}$.

To solve non-linear problems, such as collision in ABAQUS, the explicit dynamic finite element method can be used to avoid problems that cannot be converged, and it has high efficiency and accuracy.

3 Modeling for full-screen smartphone

3.1 Modeling and simulation

Free-drop simulation and analysis for full-screen smartphone can use ABAQUS/CAE throughout the entire process.

In this paper, free-drop test of full-screen smartphone has two mainly processes, cellphone modeling and free-drop analysis for full-screen smartphone. In modeling process, the components of the full-screen smartphone and floor should be established. Then material properties to each part have be assigned to them. Following that, each component should be meshed for Subsequent stress analysis. The interaction between each component should be assigned according to actual free-drop process of full-screen smartphone. The free-drop analysis process is mainly to establish the load of the full-screen smartphone, and set the analysis step. Finally, the model for analysis and view the result in visualization is submitted. We can easily complete the entire process from modeling to analysis, making the entire process more efficient Using ABAQUS/CAE

3.2 Detailed procedure of modeling and simulation

The aim of the paper is to analysis the collision between the full-screen smartphones and the floor. The full-screen smartphone, Huawei P40 as an example, is proposed to study the drop/impact response of cell phones include modeling, and establishing the initial model of the collision between the phone and the floor.

Modeling the components of the full-screen smartphone and floor. In this paper, modeling a full-screen smartphone model consist of seven modules including Screen Glass, LCD, Middle Frame, two main Boards, Battery and Back Cover. It is shown as Fig. 1.

![Figure 1. Exploded view of full-screen smartphone](image)

Each component structural parameters of Huawei P40 are shown in Table 1.

| Part           | L(mm) | W(mm) | H(mm) |
|----------------|-------|-------|-------|
| Screen Glass   | 148.9 | 71.6  | 1.2   |
| LCD            | 142.9 | 65.06 | 0.1   |
| PCB_1          | 17.86 | 65.06 | 5.2   |
| PCB_2          | 53.59 | 65.06 | 5.2   |
| Battery        | 71.45 | 65.06 | 5.2   |
| Middle Cover   | 148.9 | 71.6  | 5.3   |
| Rear Cover     | 148.9 | 71.6  | 2     |
In order to get closer to the reference phone, the four corners are chamfered. The outer fillet radius is 8mm, and the inner fillet radius is 5mm. Finally, a floor which type is rigid body is assumed, which is impaction with the free-drop phone.

The material properties of each component of the full-screen smartphone are established, and the materials to each component are assigned, which are shown in Table 2.

Table 2. Material properties of each component

| Part            | Material | \(\rho\) (tonne/mm\(^2\)) | Young’s modulus (MPa) | v   |
|-----------------|----------|----------------------------|-----------------------|-----|
| Screen Glass    | Corning 5| 2.43E-09                   | 77000                 | 0.210 |
| LCD             | LCD      | 2.40E-09                   | 10700                 | 0.430 |
| PCB 1           | PCB      | 2.40E-09                   | 11000                 | 0.250 |
| PCB 2           | PCB      | 2.40E-09                   | 11000                 | 0.250 |
| Battery         | Battery  | 2.57E-09                   | 70000                 | 0.290 |
| Middle Cover    | Steel    | 1.20E-09                   | 2190                  | 0.350 |
| Rear Cover      | Glass    | 2.50E-09                   | 46200                 | 0.245 |

All component of P40 should be meshed. First in global seed, Approximate global size is set to 2, other keep the default. The element type and element library are explicit, and geometric order is linear. Family is 3D stress and Hex is C3D8I. Finally, all components are meshed according to that unit setting. The meshing result of top screen glass is shown in Fig. 2.

Figure 2. Meshing result of top screen glass

All components should be assembled together, and a suitable collision angle of the full-screen smartphone with the floor should be assumed. In this paper, seven different collision position for the free-drop have been adopted, including the back, bottom corner, bottom edge, front, side, top corner, and top edge. The top corner free-drop assembly position is shown in Fig. 3.

Figure 3. Top corner free-drop assembly position

To create the tangential behavior in the contact property, the friction coefficient is 0.2. The define constraint, which is to constrain all components of the full-screen smartphone, and the type is Tie. The effect is that the contact surfaces between the constrained parts are firmly bonded together, and cannot be separated during analysis.

To create gravitational acceleration and collision velocity in load, the floor is encastrate so that the floor cannot move. Then, a drop analysis step for full-screen smartphone is established. Finally, a job with the model is submitted, and the analysis results is shown by visualization.
4 Simulation and analysis

4.1 Simulation conditions and stress nephogram display
Considering the actual situation, the height and angle of the full-screen smartphone free-drop are the main parameters in this paper. One meter is considered the height of the free-drop smartphone, which simulates the smartphone dropping from the trouser pocket. This is also one of the most common free-drop situations for smartphones. The vertical downward acceleration of gravity is applied to the entire model, and the acceleration of gravity is taken as $9.8m/s^2$. The article equates the height as the speed of the smartphone when it first touches the floor, which is $4.427m/s$. For the collision position of the smartphone with floor, the analysis object changes with the force position of the smartphone changes. The analysis of seven different objects correspond to seven different collision position of the smartphone with floor.

The constraints of the surface adopt the Tie constraint under using ABAQUS/Explicit to perform FEA on the full-screen smartphone with different design schemes and considering the interaction of smartphone components. Set the ABAQUS/CAE analysis time to 3ms.

Considering the actual situation, a common angle at which the smartphone touches the floor after a free-drop is the bottom right corner. Fig. 5 shows the stress nephogram of the bottom right corner for free-drop of full-screen smartphone at the height of 1 meter. The stress nephogram of the smartphone 2.85ms after touching the floor is shown in left of Fig. 4. The stress nephogram of other drop angles is no longer shown here.

![Figure 4. Stress nephogram of the bottom right corner](image)

4.2 Analysis of the results
The total energy of the bottom right corner for free-drop of the full-screen smartphone at the height of 1m is shown in Fig. 5. It can be analyzed from the Fig. 4 that when the full-screen smartphone is dropped, the response time of the full-screen smartphone collision with the floor. The collision response time of other drop angles is given in Table 3.

![Figure 5. Total energy of the bottom right corner](image)

It can be seen from Table 3 that the contact area between the smartphone and the floor is smaller, the collision response time is longer by the smartphone.
Table 3: The collision response time of the smartphone under different drop angles

| Drop angle                  | Collision response time/ ms |
|----------------------------|----------------------------|
| Top                        | 0.9                        |
| Bottom                     | 0.95                       |
| Top right corner           | 1.5                        |
| Bottom right corner        | 1.5                        |
| Front                      | 0.75                       |
| Back                       | 0.75                       |
| Side                       | 1                          |

To accurately analyze the results of the free-drop of the full-screen smartphone, three nodes with different positions of smartphone are selected to obtain the time changing course of stress, velocity, and acceleration at the nodes. To investigate the impact of impact force on the phone, the different nodes selected for the bottom right corner drop of the phone is shown in Fig. 6. One of the nodes at the bottom right corner of the phone is the point closest to the floor (node 726), and the other two nodes (node 59 and 761) are next to it. These three nodes form a triangular area, which is the area where the phone hits the floor with the most stress.

The node selection principle for other drop angles of the smartphone is similar to the selection principle of bottom right corner drop, which is no longer displayed here.

Figure 6. Three different nodes selected for the bottom right corner.

It can be seen that the stress value change of the node closest to the floor at the bottom right corner of the smartphone is larger than that of the other two nodes from Fig. 7, indicating that the impact force is the most severe at this position of the smartphone.

Figure 7. Stress diagram

The velocity and acceleration curves with time under different drop angles of the smartphone are shown in Fig. 8 and 9, respectively.
Fig. 8. Speed diagram

Fig. 9. Acceleration diagram

From Fig. 8 and 9, it can be analyzed that when the smartphone collides with the floor, the velocity and acceleration of the three nodes have the largest numerical change in the range of 0~0.5 ms, which indicates that the impact force of the smartphone is the most severe during this time period.

The node diagram of the maximum stress value of other drop angles of the smartphone is shown in Fig. 10.

Fig. 10. Maximum stress point of smartphone at different drop angles.

The maximum stress value and node number of the smartphone under different drop angles are shown in Table 4.
Table 4. The maximum stress value and node number of the smartphone under different drop angles

| Drop angle          | Node number | Maximum stress value/MPa |
|---------------------|-------------|--------------------------|
| Top                 | 12          | 1932.97                  |
| Bottom              | 719         | 2761.68                  |
| Top right corner    | 659         | 16229.7                  |
| Bottom right corner | 726         | 22749.7                  |
| Front               | 3238        | 317.575                  |
| Back                | 726         | 377.495                  |
| Side                | 39          | 3559.16                  |

It is shown experimentally that the stress of the smartphone is also different for different drop angles of smartphones from Table 4. The drop at top and bottom right corner of the smartphone has the greater impact than other drop angle on the smartphone. It is noted that the maximum von Mises stress (node 726), 22749.7MPa, occurs bottom right corner of the screen glass plate.

5 Conclusion
A free-drop simulation and analysis of full-screen smartphone based on abaqus has been studied and applied to Huawei P40 mobile phone. In order to achieve the stress condition of the smartphone at different drop angles including the maximum stress point, the analysis is required and proposed. The proposed method is based on AbAQUS/CAE. Experiment and analysis results indicate that the stress act on screen of smartphone will be different and the maximum stress point will change according to different drop angles. In the design and manufacture of full-screen smartphone, more research in the maximum stress point should be done to improve the performance of drop impact. Meanwhile, the smartphone user will get the analysis, where should be obtained more protections for phone screen.

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