Study on the Effects of Numerical Parameters on the Precision of Springback Prediction

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ABSTRACT

Accurate prediction of springback is the precondition of controlling the springback. The precision of springback prediction is affected by many parameters in both forming process and springback process. The 2-D draw bending benchmark of NUMISHEET'93 is used as an example to investigate the influencing of numerical parameters in LS-DYNA and LS-NIKE3D, which includes solution approach, dynamic effect, number of the dies' corner elements and blank element size on the springback simulation. Comparing the simulation results with experimental results, some basic principles have been given for springback simulation.

INTRODUCTION

Springback simulation is always the focus of study on sheet metal forming. There are benchmarks about springback prediction in all of the recent three times of NUMISHEET since 1993. Due to development in the past two decades, the finite element method is widely used in the field of sheet metal forming. Although wrinkle and cracking could be accurately simulated, the precision of springback prediction is still not satisfactory. Many studies have been done in this area. Prior(1994) indicated that the combination of Explicit FEM and Implicit FEM provides a powerful and efficient solution to springback simulation. Onate(1995) and Finn(1995) approved this method. Zhang(1998) pointed that the influence of cyclic material models and springback calculation methods on the stress or residual stress distribution were large. Lee(1998) showed that the blank element size and the number of corner elements are the most significant parameters influencing springback. Park(1999) considered that the stress change in the springback process was underestimated erroneously if the coarse mesh is used.

The above research results are helpful for springback simulation, but many of the numerical parameter selections in the application have not been confirmed yet. Also, simulation efficiency should not be reduced remarkably for getting precision prediction. The precision of springback simulation is affected by many numerical parameters in both the forming process and springback process, such as solution approach, dynamic effect, and the number of the dies' corner elements and the blank element size. The main objective of this paper is to further clarify the influence of those parameters in LS-DYNA and LS-NIKE3D on springback prediction. The 2-D draw bending benchmark of NUMISHEET'93 has been studied as an example.

2-D DRAW BENDING PROBLEM

Figure 1.a) is the schematic of the 2-D draw bending benchmark of NUMISHEET'93 and Figure 1.b) shows measuring methods of springback in both the experiment and simulation.

The holder force is 2.45kN and the punch stroke is 70mm. Experimental results are shown in Figure 2 and Table 1. The finite element model used is shown in Figure 3, where the two types of shell elements named Belytschko-Tsay and Hughes-Liu are respectively used in Explicit and Implicit code. Blank element size is 2×2mm and the number of corner elements is 5. Material of aluminum-alloy was simulated with mechanical properties and friction as shown below:

Young's Modulus: 71GPa
Poisson's Ratio: 0.33
Length×Width×Thickness: 350×35×0.81mm
R value: 0.64
Friction: 0.162

True stress-strain curve: $\sigma = 579.79\left(0.01658 + \varepsilon^{p}\right)^{0.3593}\ MPa$

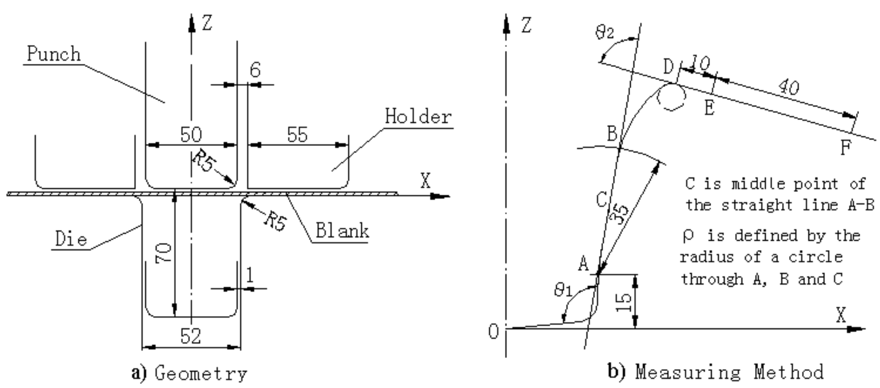

Figure.1 Schematic of the 2-D Draw Bending Benchmark (NUMISHEET'93)

Figure.2 Profile of Experimental Part

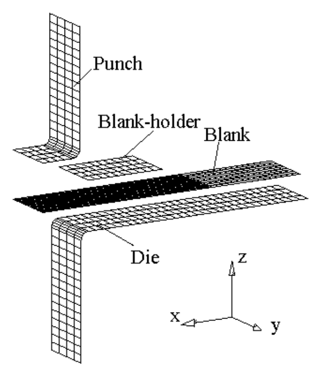

Figure.3 Finite Element Model

Table.1 Experimental Results of NUMISHEET'93

	θ1(°)	θ2(°)	θ1-θ2(°)	ρ(mm)
Max.	101.5	68.0	24.0	81.0
Min.	116.0	77.5	47.7	217.0
Avg.	112.4	72.8	39	106.0

SIMULATION OF UNLOADING PROCESS

Selection of Nonlinear Solution Methods

Linear solutions can be useful if springback deformations are small, but most springback problems exhibit geometric non-linearity due to large deformation. To obtain an accurate springback prediction, nonlinear equilibrium iterations must be utilized. There are fourteen nonlinear solution methods in LS-NIKE3D. The most used are BFGS, Modified Newton and Full Newton. Considering both convergence and CPU time, the method of BFGS has been adopted.

Penalty Stiffness for Artificial Stabilization

Numerical round-off errors from ill-conditioned systems can impair convergence of the iteration process. Artificial stabilization and automatic time step control can be used to automatically gain the most accurate solution. Artificial stabilization is used to improve convergence of the nonlinear equilibrium iteration process. Virtual "springs" are added to the model to inhibit springback and improve numerical conditioning. These "springs" are removed as the analysis approaches the termination time and vanish when the termination time is reached. The selection of penalty stiffness for artificial stabilization (PENSTAB) is very important. 1, 0.1, 0.01, 0.001 and 0.0001 of PENSTAB have been investigated. Simulation results are shown in Figure 4, where d is the springback displacement of the outer flange along Z-direct. When PENSTAB is 1, d is underestimated. When 0.0001 is used, the program error appeared. The value of 0.01 has been selected for giving the largest springback displacement, which is closer to the experimental results.

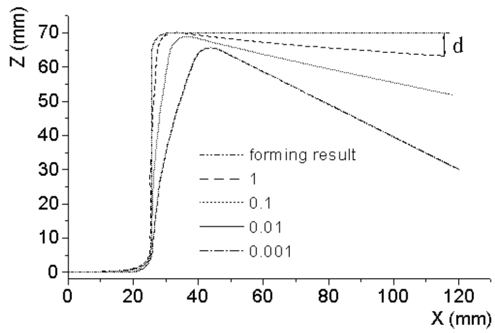

Figure.4 Effect of PENSTAB on Springback Simulation

STUDY ON THE NUMERICAL SIMULATION PARAMETERS OF FORMING PROCESS

Dynamic Effects of Forming Simulation

To a dynamic process, the work done by the outer force equals to the sum of the systemic internal energy, kinetic energy, spring and damper energy, system damping energy and sliding interface energy. However, the sheet metal forming process is actually a quasi-static process. During the sheet metal forming process, the dynamic effects should be reduced, which was aroused by the dynamic explicit finite element method. The dynamic effects include two aspects. One is the incremental kinetic energy aroused by the virtual velocity of the punch. The other is aroused by variation of the blank holder force caused by the momentum of the blank holder.

Analysis the Virtual Velocity of Punch. The central difference method is used in the time integration of dynamic explicit FEM software, which is stabilized conditionally. The limited time step has a relation with the dimensions of the least element and the velocity of the material sound, which can be estimated by the equation as follows:

$$\Delta t \le K\frac{L}{C} \qquad (1)$$

Where K is a proportional constant (usually as 0.9), L is the length of the characteristic (usually as the length of the least element) and C is the velocity of the material sound. In order to reduce the calculation time, the velocity of the punch in the simulation is often magnified, which is called the "virtual velocity of the punch". When the least time step is unchanged, the number of calculation time steps will be reduced and the calculation time is reduced. Since the calculation time of the forming simulation is proportional to the velocity of the punch, it will be reduced to 1/n of the primary time if the velocity of the punch is magnified by n times. However, magnifying the velocity of the punch will affect the accuracy of the calculation, which can be controlled by the ratio r_{ki} of the systematic kinetic energy to the systemic internal energy. Karafillis(1996) has pointed out that the calculation results of dynamic explicit FEM is close to the results of the quasi-static process when r_{ki} is less than 5%.

To study the effects of virtual velocity of the punch on the accuracy of the springback prediction, we simulated the forming process of the models in SECTION 2, where the virtual velocity of the punch was taken as 10000mm/s, 5000mm/s and 1000mm/s respectively. Table 2 shows the simulation results, where tf is the CPU time of the forming simulation. Compared to the experimental results, the accuracy of the prediction springback is the highest when the virtual velocity of the punch was taken as 1000mm/s.

During the forming process of 2-D draw bending, the side-wall is the main deforming area, which is deformed by bending and drawing. Generally, the relaxing springback depends on forming stress field of the side-wall. When the virtual velocity of the punch was taken as 10000mm/s, 5000mm/s and 1000mm/s respectively, the corresponding tangential stress were 91.35Mpa, 122.45Mpa and 160.68Mpa respectively. It is shown that the dynamic effects of the punch velocity are very obvious and the corresponding springback displacements of the flange are various. When the tooling is meshed with the coarse elements, use a smaller velocity of the punch to simulate the forming process benefits to improve the accuracy of prediction springback. However, CPU time of the simulation forming process increases dramatically along with the decreasing velocity of the punch.

Table.2 Effect of Punch Velocity on Springback Simulation

v (mm/s)	r_{ki} (%)	d (mm)	tf (s)
10000	4.978	39.58	4503
5000	1.430	42.39	9022
1000	0.07875	46.96	41452

Analysis of Holder Force. The interaction between blank and holder is a contact-impact process when dynamic explicit code is used. Undesirable oscillation of the holder force will appear in the beginning stage of the forming simulation if the initial momentum of the holder is high, which can be shown as the dash line in Figure 5. To obtain an accurate holder force, a low density of holder may be helpful. The solid lines in Figure 5 shows an improved holder force curve with lower density. In addition, a contact damping perpendicular to the contacting surfaces can be applied. When these two measures are adopted, the Z-direct displacement of the springback prediction is increasing from 39.58mm to 41.87mm, which is closer to the experimental results.

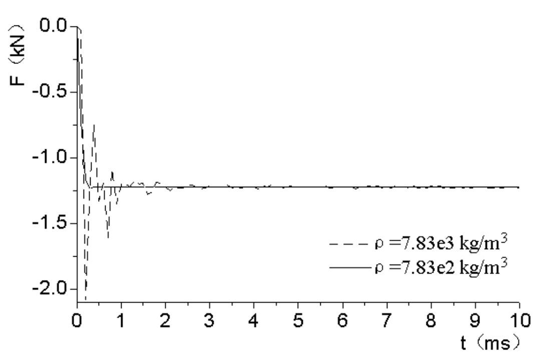

Figure.5 Holder Force vs. Simulation Time

Number of Corner Elements

The number of corner elements directly affects the description of the dies' geometry. Fine die mesh is one of the most important preconditions of the simulation of sheet metal forming. Elements of the side-wall are drawn in from the flange area and go through a very complicated bending-straightening path. Because springback attributes to the non-uniform stress across the sheet thickness, the precision of the simulating blank elements' deformation through the corners is significant. Numbers 5, 7, 15 of the corner elements have been analyzed. To save CPU time, the punch velocity of 10000mm/s was used and blank element size is 2×2mm. Simulation results are shown in Table 3. CPU time became a little longer from the number of 5 to 15 while blank element keep constant. When the number of corner elements is 15, the simulation result is closer to the experimental results. Subsequently, under this case with a punch velocity of 5000mm/s and 10000mm/s were also simulated. Springback predictions are almost the same. Compared with Table 2, it is found that fine die mesh with the high punch velocity can give a more accurate springback prediction than a coarse die mesh with the low punch velocity can do and the former costs shorter CPU time of the forming process.

Considering both precision of the springback prediction and the CPU time of the forming process, fine die mesh should be used. Punch velocity can be selected by the value of r_{ki}, which is the ratio of kinetic energy to internal energy. If r_{ki} is lower than 5%, explicit simulation can be acceptable for a quasi-static process.

Table.3 Effect of Number of Corner Elements on Springback Simulation

Number	5	7	15
CPU time (s)	4335	4406	4503
d (mm)	39.58	48.09	51.44

Blank Element Size

Generally, fine blank mesh can give an accurate geometry description, but it will add the number of blank elements and diminish time steps of the explicit code and then more CPU time will be needed. Based on the result of 4.2, a model with 15 elements of the corner was used to investigate the condition when the blank element size is 1.5×1.5mm. Results of the springback prediction are shown in Figure 6 and Table 4. It can be seen that a more accurate prediction can be obtained by using an element size 1.5×1.5mm and the simulation results are very close to the experimental results.

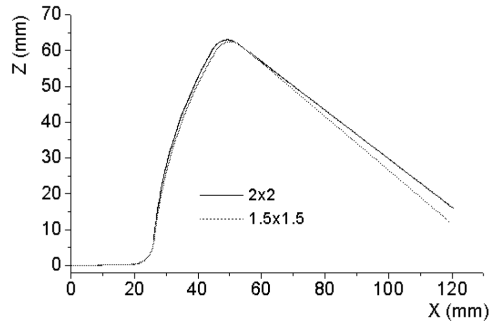

Fig.6 Profiles after Springback with Different Blank Element Sizes

Table.4 Comparison between Results of Experiment and Simulation

	θ1(°)	θ2(°)	Δθ(°)	ρ(mm)
Avg. (Exp.)	112.4	72.8	39	106.0
2×2mm	107.2	75.0	32.2	131.4
1.5×1.5mm	108.6	71.8	36.8	124.1

DISCUSS

Simulation of both the forming process and springback process affects the precision of the springback prediction. Selections of some numerical parameters are very important.

1) Artificial stabilization is useful to improve convergence of the nonlinear equilibrium iteration process. To gain a reasonable result, penalty stiffness for artificial stabilization should be 0.01.

2) To obtain an accurate holder force, a low density of the holder may be helpful. In order to avoid an undesirable oscillation in the contact, a contact damping perpendicular to the contacting surfaces can be applied.

3) Considering both the precision of the springback prediction and CPU time of the forming process simulation, a fine mesh should be used for dies. Fifteen elements can be meshed for a corner. Punch velocity can be selected by the value of r_{ki}. If r_{ki} is lower than 5%, an explicit simulation can be acceptable for a quasi-static process.

4) Simulating the forming process by a small blank element is propitious to obtain an accurate springback prediction although CPU time cost is high.

CONCLUSION

Careful selections of numerical parameters are crucial for the precision of the springback prediction by commercial FEM codes. Further study of developing new code that gives springback results slightly influenced by the above parameters should be done.

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