Spot-Weld Failure & Stress-Redistribution Analysis

A hands-on tutorial on spot-weld simulation and analysis using NEiNastran.

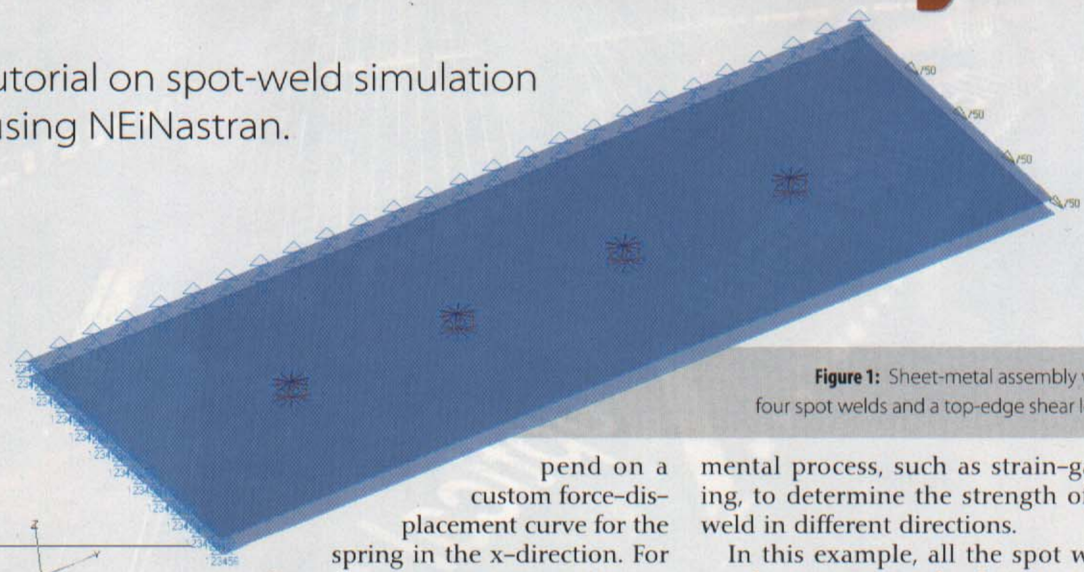

Figure 1: Sheet-metal assembly with four spot welds and a top-edge shear load.

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The spot weld is one of the most common fastening techniques used in industries such as aerospace, automotive, and maritime. Often, engineers are interested in predicting the response of an assembled sheet-metal structure when there is a progressive failure of one or more spot welds for a given applied loading. Engineers know that design changes may be required if one or more spot welds fail and the structure cannot withstand loading.

But how do you simulate redundant load redistribution using FEA (finite element analysis) software? NEiNastran can simulate this effect using a variety of techniques that are easy to set up.

PREPROCESSING

Figure 1 (*above*) shows a simple sheet-metal example. Both the sheets measure 5 × 2 × 0.1 inches. The spot welds are modeled using two element types: rigid elements (blue) and spring elements (red). The sheets are modeled using 4-node quad elements (bluish gray).

To simplify the problem, the stiffness of the weld has been modeled to depend on a custom force-displacement curve for the spring in the x-direction. For demonstration purposes, a maximum F/x strength of 5.0E5 PSI has been used. But for a real-world application, this force displacement curve could be extracted from an experimental process, such as strain-gauging, to determine the strength of the weld in different directions.

In this example, all the spot welds use the same curves for their strengths. The force displacement curve is shown in Figure 2 (*below*). For simplicity, stiffnesses in other directions are ignored. The sheet metal is modeled using steel

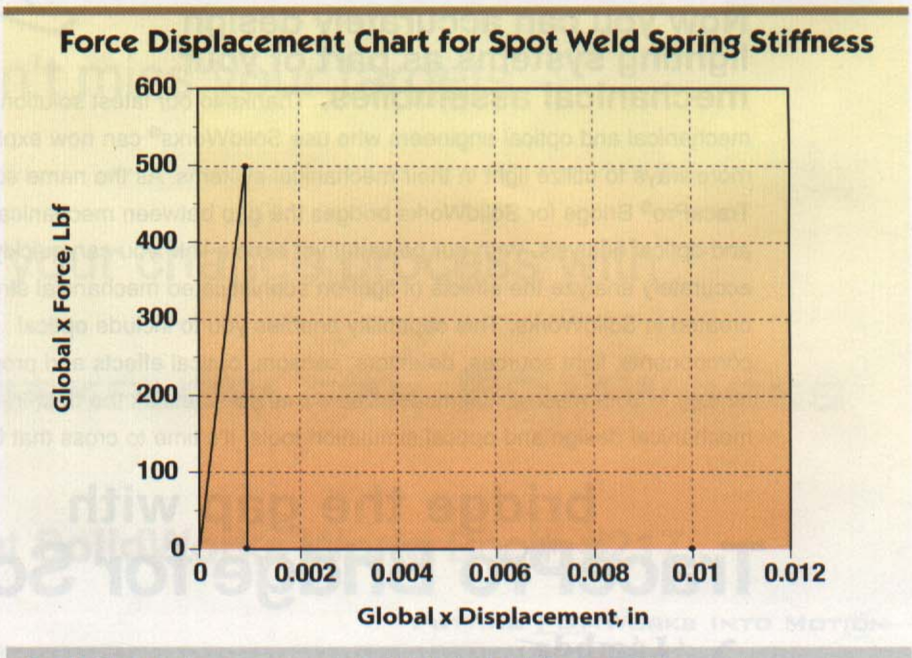


Figure 2: Force-displacement curve along global-*x* for the weld spring stiffness.

with a Young's modulus of 2.9E7 PSI and a Poisson's ratio of 0.32.

LOADING AND CONSTRAINTS

A total shearing edge load of 750lbf is used on the top sheet. The sheets are not allowed to move out of plane. One side of both sheets—the short edge—is fixed; one side of the bottom sheet—the long edge—is fixed in the *x*-direction. Thus, most of the load is taken up by the welds and the top sheet, as seen in Figure 1 (*previous page*).

ANALYSIS

A nonlinear static analysis is carried out to capture the response of the model. As the structure is loaded, the force induced in the weld elements (springs) is governed by the force displacement curve (*see Figure* 2). Once it exceeds 500lbf, the force that the spring can carry is drastically reduced to simulate the effect of a failing spot weld.

RESULTS

At about 60 percent of the total load, the spot welds still hold up and take the entire applied load. The major principal stress distribution shown in Figure 3A (*above*) is before any failure has occurred. (Note: displacements are exaggerated.)

Figure 3a

In the next increment (*Figure 3B, right*), the left-most weld fails. This is followed immediately by the failure of the next two adjacent welds due to the load transmitted to them (i.e., redistributed load) exceeding the limit. Hence, the stresses are redistributed due to the failure.

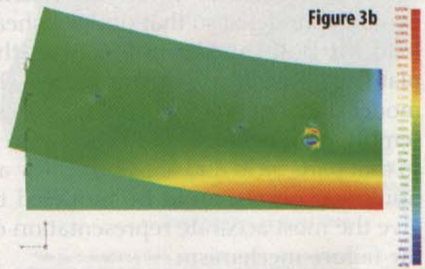
Thus, most of the load is now being taken up by the sheet metal itself with some of it taken up by the last remaining spot weld. As we continue on the loading (*Figure 3C, next page*), we see that at after approximately 78% of the load, all the spot welds fail, and the stresses are redistributed again with the sheet metal carrying the entire load.

MORE DETAILED SIMULATION MODELS

The model presented here is just one example of how nonlinear analysis can be used to model complex behavior such as redundant load redistribution. The details of the spot welds were simplified but generally represented the actual structure quite well.

Other similar nonlinear analyses could simulate bolted connections. In this case, you would simulate bolts instead of spot welds, which could also fail sequentially forcing load redistribution and requiring some level of redundancy to prevent catastrophic failure.

Figure 3b



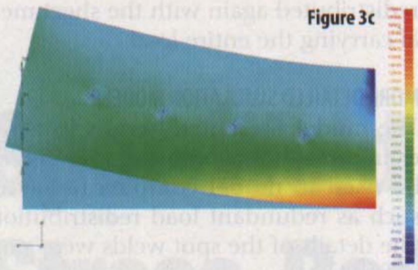


Figure 3c

At the detailed level, you could model two solid plates that are connected with detailed bolts that include features such as washers, a bolt head, and a nut. You would specify surface contact between the plates and around the bolted connection. Bolt preload could be simulated using an initial strain distribution in the bolt, and friction under the washer could be modeled so that under a shear load the bolt can slip and contact the plate hole resulting in bearing stress. To model the actual failure of the bolt assembly, nonlinear materials can be used so that parts yield and fail. In this way all nonlinear effects could be modeled to give the most accurate representation of the failure mechanism.

Other less-detailed models can be created where the bolt shanks are represented using line elements connected to plates to represent the bolt head and nut. With surface contact it would still be possible to model the bolt slippage but with less fidelity on the bearing stresses around the hole.

NEINASTRAN EDITOR

NEiNastran Editor is another useful tool that can enable designers and analysts to control the analysis, modify settings on the fly, look at real-time results as the analysis progresses, and diagnose any problems in the model with context-sensitive help. In the spot-weld failure example, you might want to change the force displacement function, the number of increments, the plate thickness, and so forth. Thus, you can also use NEiNastran Editor to quickly make changes based on the progress of the analysis, which can help minimize the total time to complete the design cycle.

CONCLUSION

This technique is quite flexible. The simulation can include all six degrees of freedom and corresponding spot-weld stiffnesses, provided that force-displacement data is available. In our spot-weld example, the sudden drop in the force carried by the weld may represent a brittle failure of the spot weld. Sheet-metal buckling effect can also be simulated.

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Animations

Animations can be a helpful tool in understanding the behavior of a deforming structure. They can provide useful insights into modeling errors, load redistribution, mechanism response to various boundary conditions, and so on.

Animations can be especially useful in case of Eigenvalue problems like normal modes analysis and dynamic analyses. In a normal modes analysis, the displacement contour results are intended for display purposes, so often the only way to make sense of the mode shape of the structure is to animate the frequency results.

The NEiNastran Modeler provides easy to use techniques to handle and store animations from analysis results. The animations can show the response of the structure either through the load increments or, in case of a nonlinear transient analysis, through actual time increments.

Animations for different analysis types that NEiNastran supports can be found in the digital version of this article on deskeng.com. You can also access the animations at nenastran.com/animation.php.

For animation of the sequential spot-weld failure, go to this sidebar on the digital version of this article on deskeng.com.

—SB

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PRODUCT INFORMATION

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