Improvement of Energy Absorption for the Side Member Using Topography Optimization

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Abstract

This paper describes a design system to optimize the non-linear responses computed from LS-DYNA® using various optimization techniques, especially with large-scale (large number of design variables) optimization, and demonstrates the system as it improves the energy absorption for the side member of the vehicle. The proposed design system uses the equivalent static load (ESL) method, which requires the iterative process of non-linear structural analysis (LS-DYNA) and linear structural optimization (Genesis®). Unlike general-purpose optimization software packages, it does not require many analysis calls when a large number of design variables are used to design a structure. Therefore, non-parametric techniques, such as Topology, Topometry, and Topography optimizations, which often require thousands of design variables, can be easily employed. To demonstrate, the side member of the Dodge Neon was optimized to improve its energy absorption using Topography optimization.

Introduction

As computer hardware has become both more affordable and dramatically more powerful in recent years, the simulation of crash analyses are becoming common practice during routine design and engineering processes to save time and cost. When crash simulations were performed mostly on super computers or very expensive high performance computing systems, optimizations of such non-linear analyses were merely research topics or the future dreams. Today, however, CAE analysts and designers have started to use general-purpose optimization packages to design and to optimize crash performances to improve real design problems.

Although general-purpose optimization packages offer various optimization algorithms and methods, there is a limitation on the number of independent design variables used in optimization problems due to the design time constraints. Therefore, powerful techniques, such as Topology [1], Topometry [2], and Topography [3] type optimizations, requiring a large number of design variables, are not feasible in the general-purpose optimization packages for practical reasons.

Since these optimization techniques are powerful and easy to use, and most importantly yield superior results in some cases, they are heavily used in the linear structural optimization area, having been well established many years ago. Due to the above advantages, it is desirable to be able to apply these techniques to solve non-linear analysis optimization problems. Therefore, a design system to solve such optimization problems was developed and demonstrated in the paper. The design system uses the ESL method, which couples LS-DYNA [4] as a non-linear analysis computation and Genesis [5] as a linear structural optimization.

First, a brief introduction of the ESL method and its algorithms is reviewed and summarized. Then the main difference between traditional optimization techniques using general-purpose optimization software packages and this emerging optimization technique are compared. As a demonstrative problem, the energy absorption of the side member in the Dodge Neon is optimized. As a measure of energy absorption, the internal energy of this sub-system is maximized as a design goal. In the conclusion, important remarks and future works are summarized.

Equivalent Static Load (ESL) Method

The algorithm and detailed ideas behind ESL method are well described in [6], therefore, the relevant part of the ESL method for the developed system is only briefly reviewed and summarized in this section. ESL-based Optimization is a method to optimize the non-linear analysis responses using linear structural optimization. For example, non-linear responses such as displacements, accelerations, and/or energies are calculated from LS-DYNA. Genesis, a linear structural optimization code, is used to optimize these responses. In this case, the corresponding FE meshes in each data format needs to be prepared to run both codes. First, non-linear analysis (LS-DYNA) must be run to obtain responses (e.g. displacement fields) and they must be printed in a result (e.g. nodout) file. Then using the obtained responses, the ESL, which reproduces the exact same responses in the linear FE (Genesis) analysis, must be calculated. Genesis will optimize the linear model using ESL. However, if the optimization process changes the model (e.g. size, shape, etc.), as a result, ESL is no longer equivalent since non-linear analysis (LS-DYNA) does not produce the same responses with an updated model obtained by the optimization. Therefore, we need to re-calculate the non-linear responses using the updated FE model, then repeat the process of optimization until a convergence criteria is met.

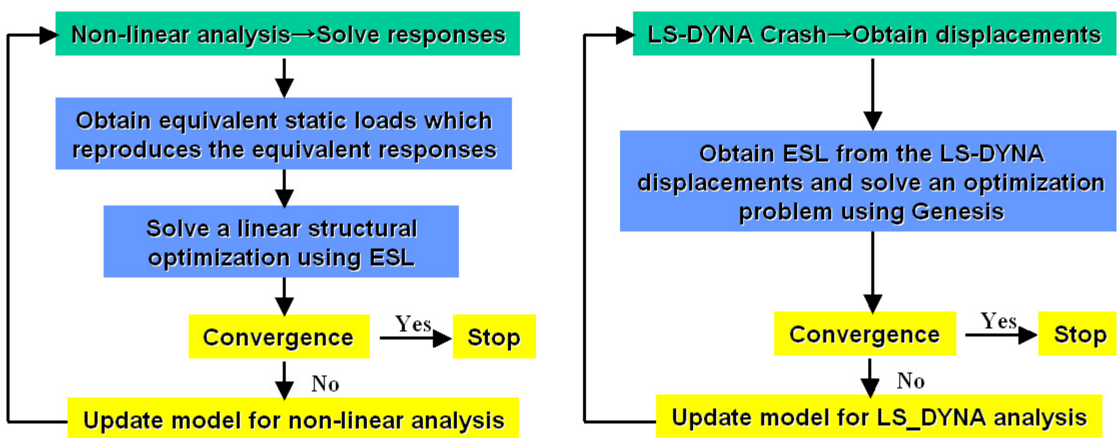

Figure 1 (a) Flow of the ESL based optimization, left, and (b) Flow of the ESL based optimization using LS-DYNA and Genesis, right

Figure 1(a) shows the general flow of the ESL based optimization and Figure 1(b) shows the ESL based optimization for non-linear displacements using LS-DYNA and Genesis. The second (obtaining ESL) and third (performing optimization) steps designated as blue boxes in the Figure 1(a) can be performed by Genesis in the same run, (i.e. Genesis load nodout file and convert the displacements into ESL, then perform optimization using ESL). Therefore, the two steps are combined into one step in Figure 1(b). The green, blue, and yellow parts of flow steps are performed by LS-DYNA, Genesis, and the developed design system, respectively.

General Purpose Optimization vs. ESL based Optimization

As previously mentioned, both approaches have advantages and disadvantages depending on types of analysis and optimization used. In this section, the pros and cons are summarized below.

Advantages of ESL based optimization:

1. Large number of independent design variables can be used in optimization, i.e. powerful optimization techniques such as Topology, Topometry, and Topography optimization can be performed. General-purpose optimization cannot use these techniques due to the design time constraint unless the analysis time is very inexpensive.
2. The total design time can be faster for the optimization problem with 10 or more design variables.

Advantages of general-purpose optimization:

1. Because of its generality, any analysis inputs and outputs can be used in optimization problems. On the other hand, ESL based optimizations are limited to the capabilities in the linear structural optimization package (e.g. Genesis).
2. Many optimization algorithms and methods can be used, e.g. gradient based, response surface approximation based, and heuristic (GA, PSO, etc.) optimizations. Additionally, the various optimization post-processing are available to study design space, e.g. statistical tools, approximation viewer, data analysis tools, etc. Extended optimization methods, such as multi-objective (with pareto frontier plot), stochastic, and robustness optimizations, can also be performed although they can be prohibitively expensive for most cases. The ESL based optimizations are mostly limited to gradient-based optimization.

As described above, ESL based optimization is not held as uniformly superior over general-purpose optimization; however, it is the only way to perform optimization in certain classes of (medium to large number of design variable) problems.

Optimization on the Energy Absorption for the Side Member

When front vehicle crashes occur, the impact load is transmitted first through the bumper, then through the side members and many other surrounding parts, before finally to the passenger compartment. It is desirable to absorb kinetic energy as much as possible before it is passed to the passengers. The energy absorption is measured as the internal energy in LS-DYNA analysis, therefore the design goal was placed on the maximization of internal energy in this sub-system. Since the ESL method uses an equivalent linear FE model to optimize responses in the linear system using ESL calculated from the LS-DYNA displacements, responses other than the displacements are not equivalent between linear and non-linear systems. In another words, there is not an equivalent internal energy response in the linear system; thus, a composite response of strain energy and displacements are constructed and used as a linear system objective function. Figure 2 shows the Dodge Neon model from NCAC [7], with its side member being optimized to demonstrate. In order to maintain the stampable condition, (i.e. maintain the constant shell thickness) and to avoid mass increase, Topography optimization was employed to re-design the side member.

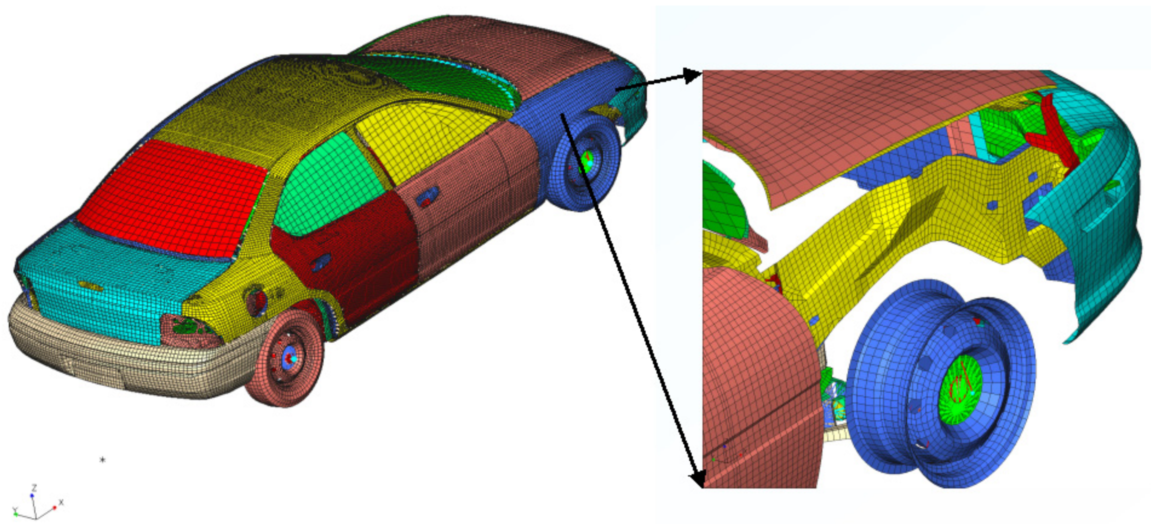

Figure 2 Dodge Neon (left) and side member (right)

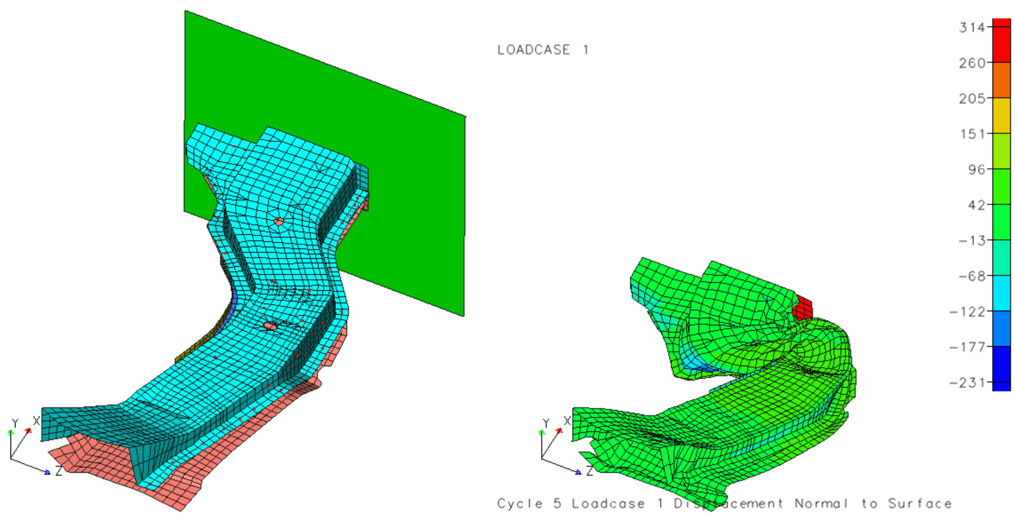

Figure 3 Side member original shape (left) and deformed shape (right)

Figure 3 shows the original shape of the side member and its deformed shape due to a rigid wall crash into the bumper side end of the structure. The side member consists of 3 pieces of parts being connected together by spot welds. The left side of Figures 4, 5, and 6 show the individual components of the side member, with only the pink part of the structures being designed to prevent de-bonding of the welded parts due to shape change. Topography optimization, automatically generating perturbation vectors normal to the designated shell surfaces, was employed to re-design them. The objective functions are placed to minimize strain energy and simultaneously maximize the displacement of three selected points. Therefore, this sub-system was made stiffer, but was also made to deform in certain directions as much as possible. It created 758 independent shape design variables. The right hand side of Figures 4, 5, and 6 shows the optimized shapes, with their colors representing the normal to the surface grids movement due to optimization.

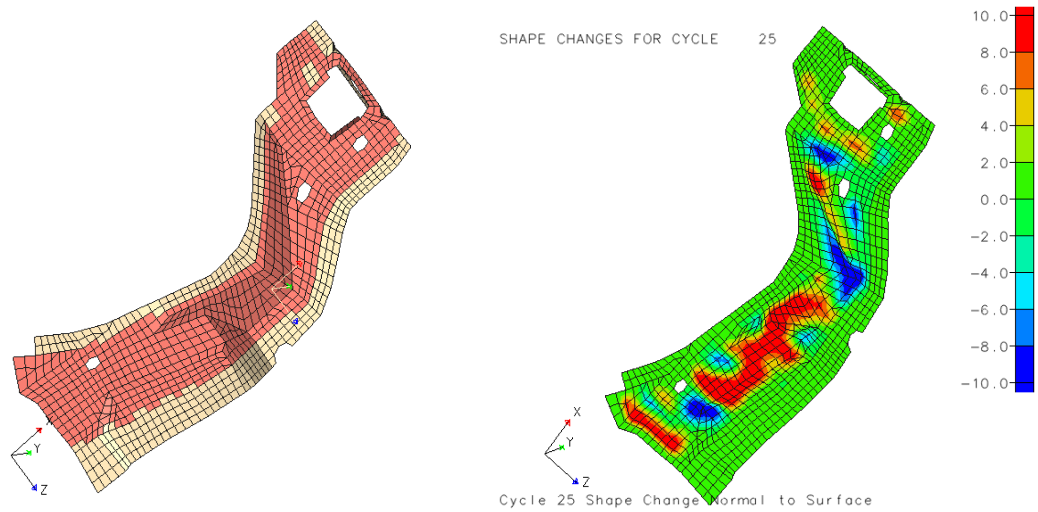

Figure 4 Original part (left) and optimized part (right)

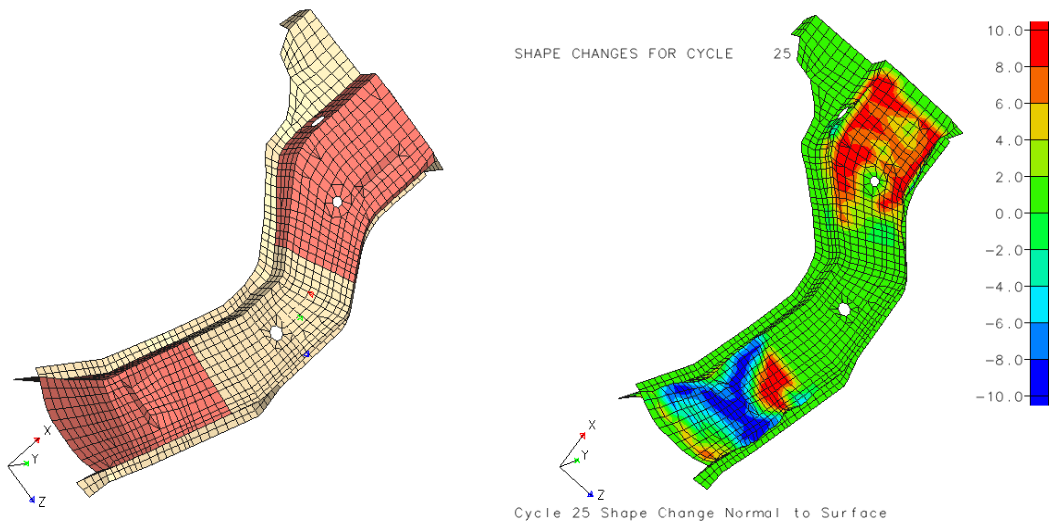

Figure 5 Original part (left) and optimized part (right)

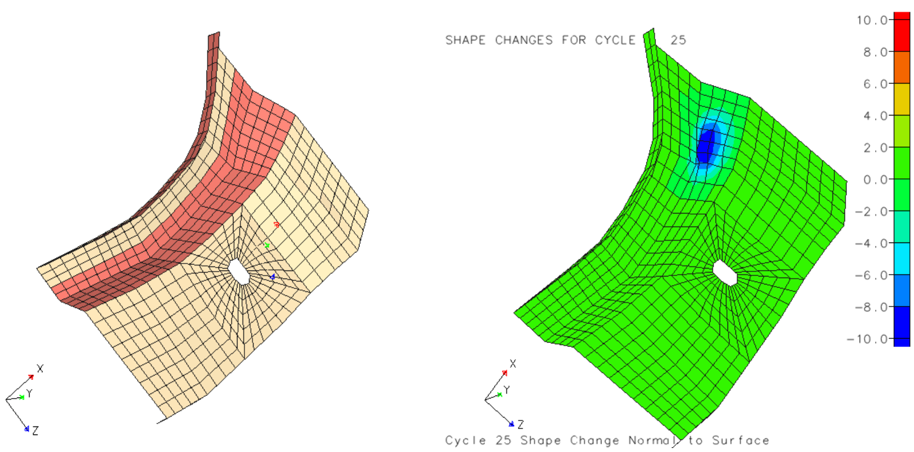

Figure 6 Original part (left) and optimized part (right)

ESL based optimization found the solution in 16 iterations (16 LS-DYNA analyses and 16 Genesis optimizations) and the internal energy calculated from LS-DYNA was improved from 1.16E07 to 1.35E07 without increasing the mass. The table 1 shows the elapsed time spent by each program. Although Genesis iterates within the linear structural optimization process, run time is much shorter than the LS-DYNA analysis time.

Table 1 CPU time (in seconds) spent in optimization

	LS-DYNA	Genesis	Total
CPU Time (Sec.)	3281	165	3486

Summary

The ESL based optimization system, coupling LS-DYNA and Genesis, was developed and presented in the paper. As a measure of energy absorption, the internal energy of this sub-system calculated from LS-DYNA was successfully maximized using the Topography optimization technique. Topography optimization is very easy to use and is an effective approach to designing bead patterns on stampable shell surfaces. However, it generates many independent design variables and makes general-purpose optimization software impossible to solve reasonably sized analysis problems.

ESL based optimization is an ideal way to solve large-scale optimization problems using non-linear analysis, like LS-DYNA. Topology, Topometry, and Topography optimizations using the developed system were already implemented and successfully tested. However, certain non-linear responses that do not exist in linear solvers must be investigated to pose better optimization problems. In addition, convergence criteria and several other parameters need to be tuned for efficiency.

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