Shape and parameter optimization with ANSA and LS-OPT using a new flexible interface

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Summary:

Optimization techniques becomes increasingly popular both in the early design stages of the product and during the final testing using the Finite Element Analysis. Furthermore, the computational power now available is sufficient for using optimization on realistic product simulation models. As a result, the increasing complexity of the optimization problem and the subsequent complexity of the optimization software, render essential the use of a tool that organizes the definition of such processes and evaluates the results.

Pre-processing for parametric optimizers is possible through the Task Management functionality of ANSA which provides flexibility, reusability and knowledge transfer.

At the same time ANSA's Morphing Tool provides all the necessary functionality for shape optimization definition and easy coupling with the LS-OPT optimizer.

Keywords:

optimization, shape, parameter, morphing, task management

1 Introduction

The definition of complicated optimization problems leads to considerable scripting work and customization according to the needs of each individual case. The use of the Task Manager Tool of ANSA which introduced for the definition of such problems, minimizes the use of scripting while standardizes the process of connecting the pre-processing with parametric optimizers. However the use of the ANSA Scripting Language remains the most advanced tool for extreme cases where any entity of the model or complicated process can parameterized and connected with the design variables of the optimization problem.

Using ANSA's Morphing Tool, shaping of the model is possible in various ways which gives the user great flexibility. Morphing is driven by special parameters which organize the shaping and makes possible the connection of shaping with the design variables of the optimization problem. With the latest enhancements in Morphing Tool is also possible to apply morphing not only on FE-Model but also in geometry. In this case, after the optimization run, the optimum geometrical model can be easily feedback the CAD department. Also the user has available all the functionality that ANSA provides on geometry.

The recommended practice for defining an optimization problem in ANSA and connect the process with LS-OPT is described through a simple example.

2 Defining the optimization problem

The definition of an optimization problem is demonstrated by a case study (Figure 1). Combined shape and parameter optimization will be applied to the model. Also complicated tasks such as opening holes on the model will be applied, driven by design variables. A geometrical model of a vehicle's sub-frame member is subjected in static load. The model is ready to run in the LS-DYNA implicit solver since it is meshed and boundary constraints and properties have been defined (Figure 2).

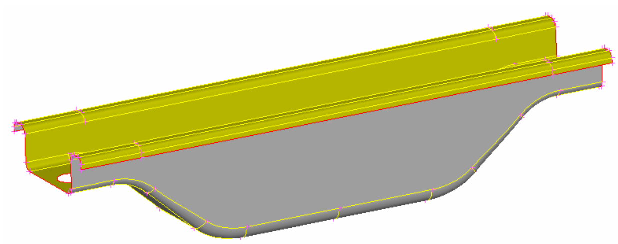

Fig. 1. Geometry model

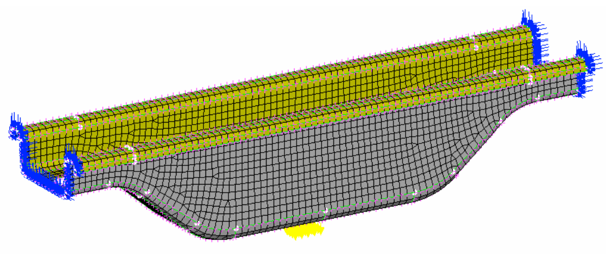

Fig. 2. Ready to run model

The objective of the optimization problem is to minimize the model's weight by modifying its shape and parameters. Several holes open on the sides of the sub-frame reducing the weight. The maximum stress that appears in the model must be kept within a specific range.
The design variables that are used to control model's shape (see Figure 3) are:
- ***Depth :*** The distance between upper and lower body of the model
- ***Slope :*** The movement of the two curved areas of the model in order to modify the inclination.

The design variables that are used to control the parameters are:
- ***Thickness :*** The shell thickness of the model
- ***Holes Diameter:*** The diameter of the holes that appear on the model

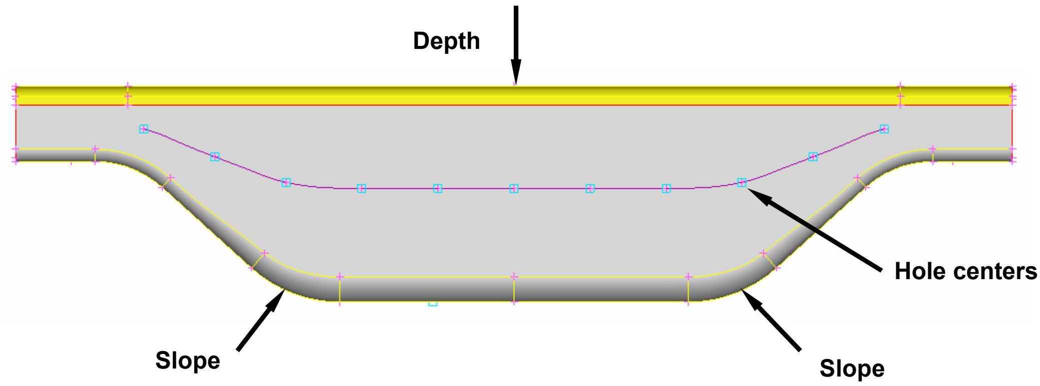

Fig. 3. Design variables of the model

2.1 Appling Morphing Parameters

To facilitate the shaping of the model the Morphing Tool is used. Special entities of this tool, the Morphing Boxes, are fitted around the model. The shape of the Morphing Boxes can be modified in several ways and handled by Control Points. The model surrounded from the Boxes, follow the modification thus the shaping takes place. In case of FE-Model, the elements are modified giving the new shape as in case of geometry the model's Faces are morphed affecting the existing mesh. In this example is possible to apply morphing on geometry. However the recommended practice is to release the mesh from the geometry and apply morphing on the created FE-Model. Morphing on FE-Model is faster and since this process is repeated for every optimization loop this will be a considerable saving of time.

Since the model is symmetrical to the XZ plane, only the half of the Boxes have to be defined on the one side of the model. On the opposite side linked Morphing Boxes are created by mirroring the original ones. In this way every morphing action on the Original Boxes will be duplicated to the Symmetry Link Boxes ensuring symmetrical morphing (see Figure 4).

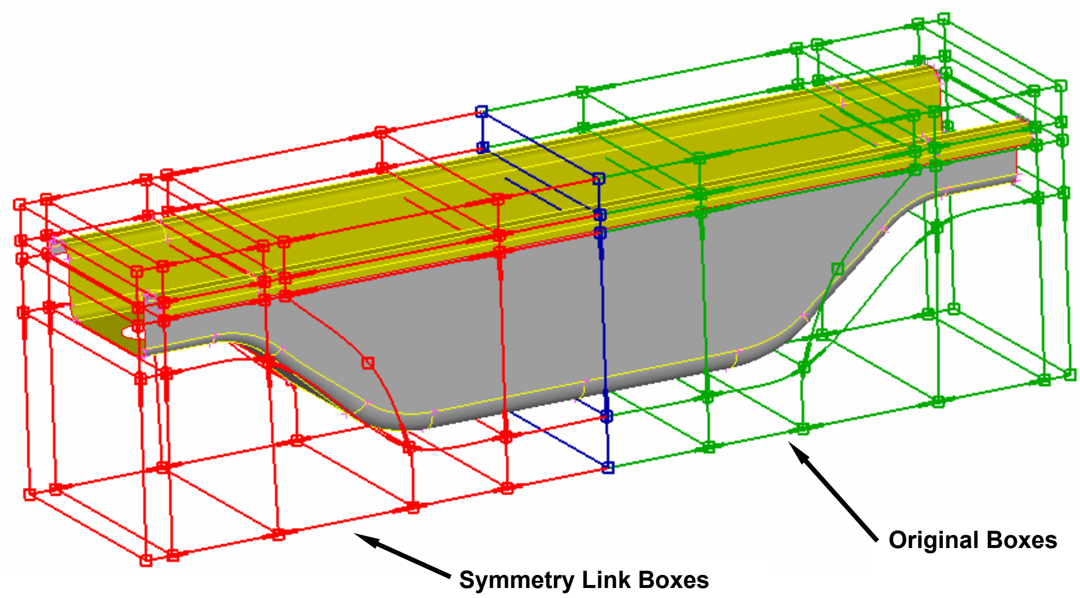

Fig. 4. Symmetry Link Morphing Boxes

The design variables must drive the morphing process that will be applied on the model. Therefore the modification of the Boxes shape is controlled parametrically by special entities, the Morphing Parameters which later on will associated with the design variables.

In Figure 5 the selected Control Points of the Boxes are moved along specified directions driven by two Morphing Parameters (depth_middle, depth_side). Changing the parameters' value leads to the shaping of the model (Figure 6).

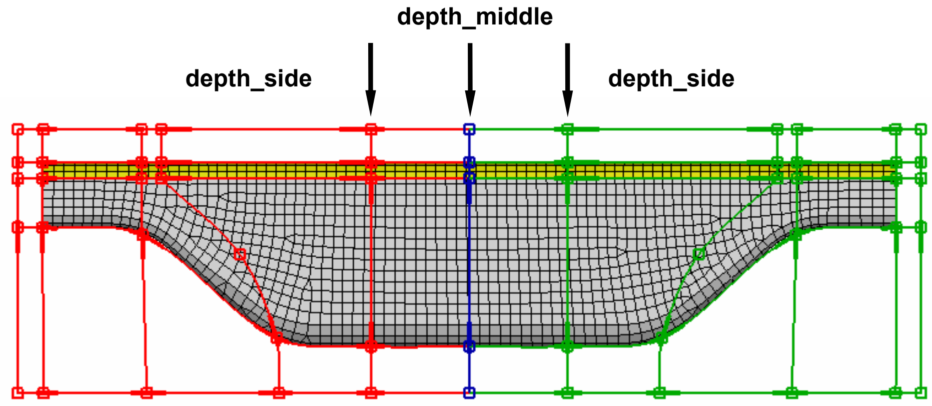

Fig. 5. Morphing Parameters handle Control Points

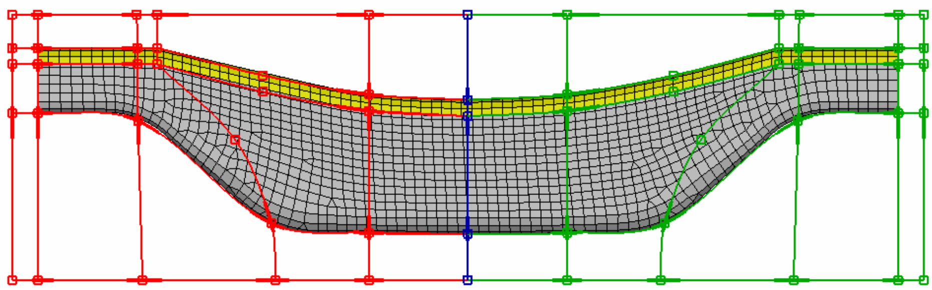

Fig. 6. The modified shape

2.2 Opening holes

Holes for weight reduction can open on the model sides(Figure 7). The definition of holes on the FE-Model can be achieved using ANSA functionality by giving the center position and diameter. The holes centers are grids loaded to the Morphing Boxes, so when morphing is applied, the centers are moved accordingly. The holes have a liner distribution of diameter from the side to the middle of the model. One design variable control the diameter of all holes proportionally. The above process is defined using a custom script in the ANSA Scripting Language. Later on the script will connected with the relative design variable (Figure 8).

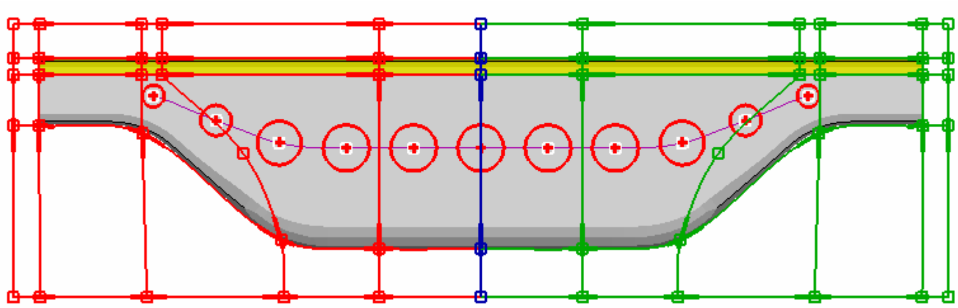

Fig. 7. Opening holes on the model side

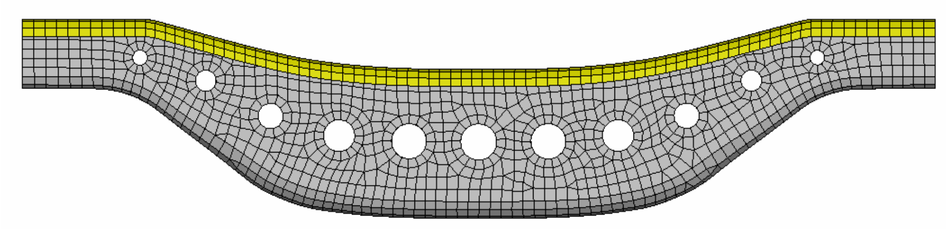

Fig. 8. The modified shape

2.3 ANSA Parameters

The last design variable should control the shell thickness of the model. Almost any value in ANSA is possible to be defined parametrically using the ANSA Parameters. ANSA Parameters are entities which can be used to transfer values among ANSA cards or make calculations using values of ANSA cards. In this example the shell thickness (T1) in the SECTION_SHELL card is substituted by an ANSA Parameter (par1). This Parameter will be connected with the relative design variable. As a result the thickness value will be always equal to the current value of the design variable.

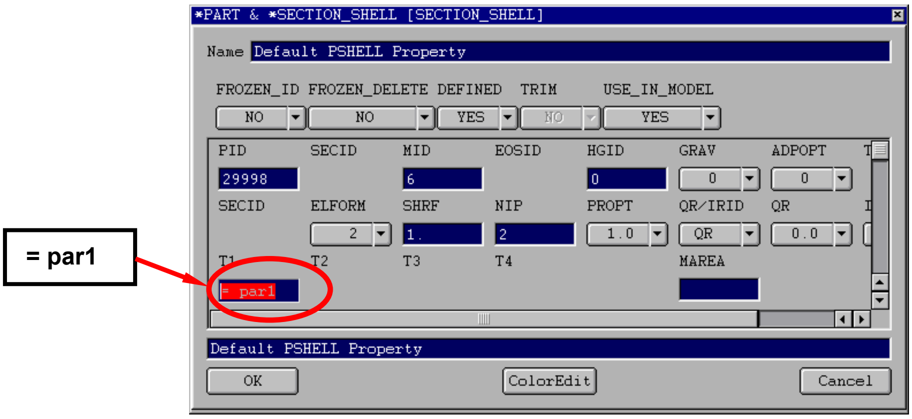

Fig. 9. ANSA Parameter in SECTION_SHELL card

3 Defining the Task Manager sequence

The Task Manager is a powerful tool of ANSA which can organize and automate the set up of specific pre-processing tasks, like frontal or side crash, for a given solver. The Task Manager is also able to set up an optimization problem for parametric optimizers.

The Task Manager can organize the sequence of all the actions that must executed in an optimization loop. Design variables are defined here and connected with the Morphing Tool, ANSA parameters or with a user's script to perform a complicated action. Once the sequence is defined, the Task Manager is able to check if every entity is properly defined and help the user to complete the case. In addition, the know-how of setting up the problem can be easily used in other cases or shared among the users.

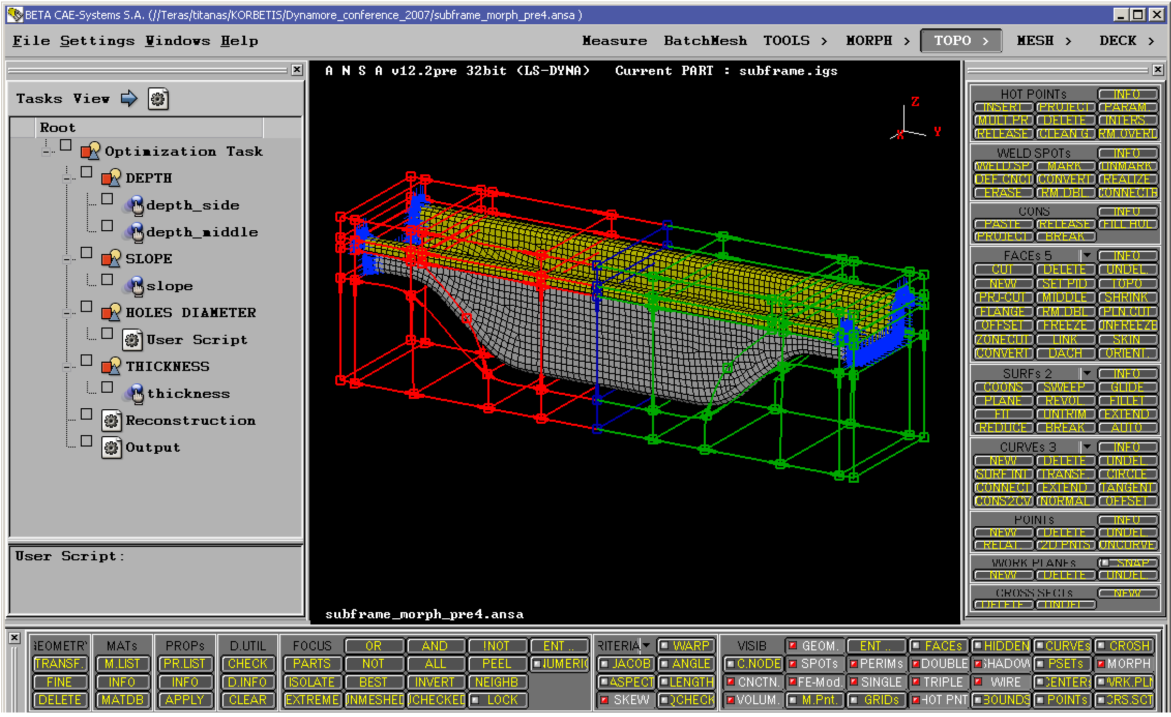

Fig. 10. Task Manager for the set up of optimization problem

3.1 Defining design variables

The definition of the optimization problem starts with the set up of the design variables that will control the model. The type of the values and the bounds of the design variables are defined in the relative cards. The type of the design variables values is *Real* for the DEPTH, SLOPE and HOLES_DIAMETER while the THICKNESS is *Discrete*.

The design variables are connected with the morphing parameters. Now any change in the current value of the design variables will drive the morphing parameters and hence the morphing action. Two morphing parameters are connected with the DEPTH design variable, the “depth_side“ and the “depth_middle“. In order to achieve smooth morphing during the optimization the value of “depth_middle“ must be bigger from the “depth_side“ by a factor of 1.1. For this reason a calculation can be inserted between the design variable value and the resulted value of the morphing parameter (Figure 11).

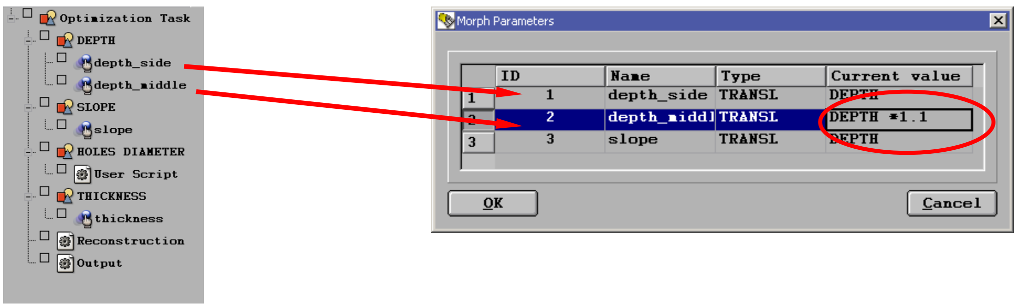

Fig. 11. Connecting design variables with morphing parameters

The HOLES_DIAMETER design variable is connected with a user script which opens holes on the model sides. In each optimization loop the script reads the current value of the design variable and uses it for the calculation of the diameter values.

The THICKNESS design variable is connected with the previously defined ANSA Parameter (par1) which controls the model’s shell thickness (Figure 12).

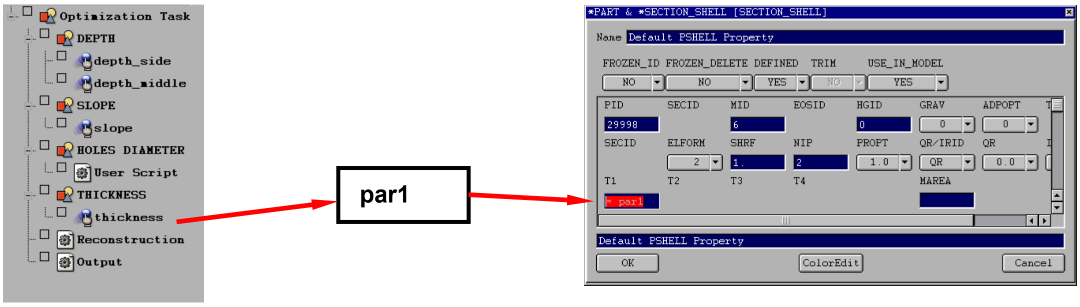

Fig. 12. Connecting shell thickness to design variable

3.2 Checking model validity

The optimization sequence is almost ready. However before running the problem it is very important to check for any failure of the model which may occur for different combinations of the design variables. This check will guide the user to apply realistic bounds for the design variables. Also the user can decide to apply specific functionality in the optimization loop which will check the model and improve its quality. In this example extreme values are applied to the DEPTH and SLOPE parameters which lead to failed elements due to minimum element length and aspect ratio (Figure 13).

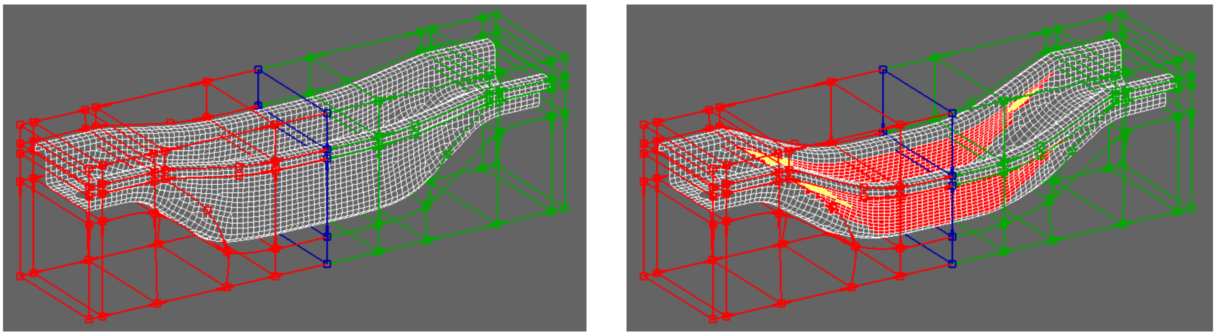

Fig. 13. Failed elements due to morphing in extreme values

To improve the model quality the Reconstruction functionality is applied on the model as an item in the Task Manager sequence. The Task Item is applied after the definition of the holes and re-meshes the whole model with specific parameters (eg. element length) and quality criteria.
In more complicated cases many checks can be applied like penetration check or check for contacts or spotwelds. In addition, reports can be created with the results of the checks for each optimization loop.

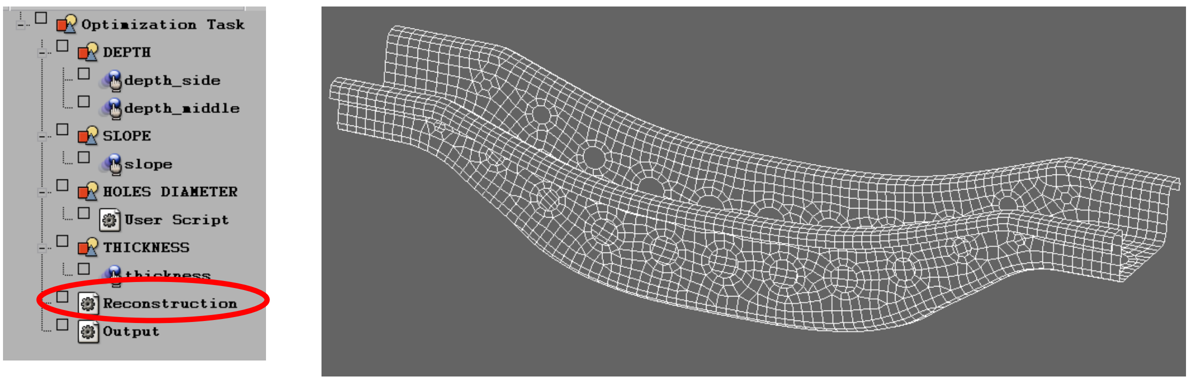

Fig. 14. Re-meshing the model

3.3 Output

Finally a last Task Item is added which creates an output ascii file. This file contains the design variables and their bounds and current values. Using this file the optimizer can easily extract the design variables values (Figure15). The optimizer will change the current values and the model will updated in every optimization loop.

```
$ DESIGN VARIABLES
$-----------------------------------------------------------------------------------
$ ID | DESIGN VARIABLE NAME | TYPE | RANGE | CURRENT
VALUE | MIN VALUE --> MAX VALUE | STEP
$-----------------------------------------------------------------------------------
 1  DEPTH  REAL    BOUNDS   5. 0. 50.
 2  SLOPE  REAL    BOUNDS   0. 0. 10.
 3  HOLES DIAMETER  REAL    BOUNDS   0. 0. 20.
 4  THICKNESS  REAL    LIST   1. 1. 1.2 1.4
$-----------------------------------------------------------------------------------
```

Fig. 15. Output ascii file

3.4 Connect ANSA with LSOPT

The whole sequence that is defined in ANSA can run through a simple shell script. This script and the design variables file are declared in LS-OPT (Figure 16).
To complete the definition of the optimization problem, the responses, constraints and objective function are defined in LS-OPT.

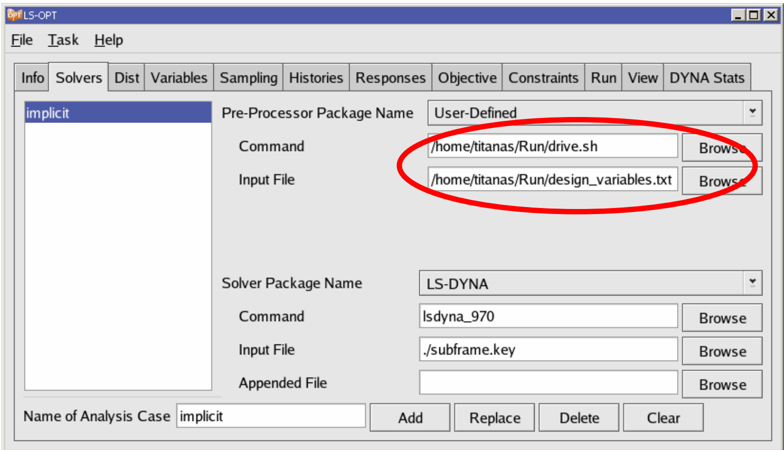

Fig. 16. Connecting ANSA with LS-OPT

4 Morphing capabilities

Two morphing functions can provide great flexibility to the shape optimization set up. These are the Direct Morphing and the Deformation Parameter.

4.1 Direct Morphing

The Direct Morphing functionality of the Morphing Tool is a way to morph the model without the need of Boxes. Using this functionality the user can select the entities that will be moved, the constrained entities and the elements that will be affected by this movement. Direct Morphing is possible to be driven by Morphing Parameters so it can be connected to the Task Manager sequence. In Direct Morphing it is also possible to affect the model shape using different algorithms. These algorithms refer to the different way that the selected elements are modified by a specific Direct Morphing movement.

In the following example (Figure 17) of a planar FE-Surface, the middle node is moved upwards by the Direct Morphing function, while the edges of the surface are constrained. The intermediate elements will be affected by this movement. For these elements a Linear or Cubic algorithm can be applied. The results from the Cubic algorithm can be controlled by a variable.

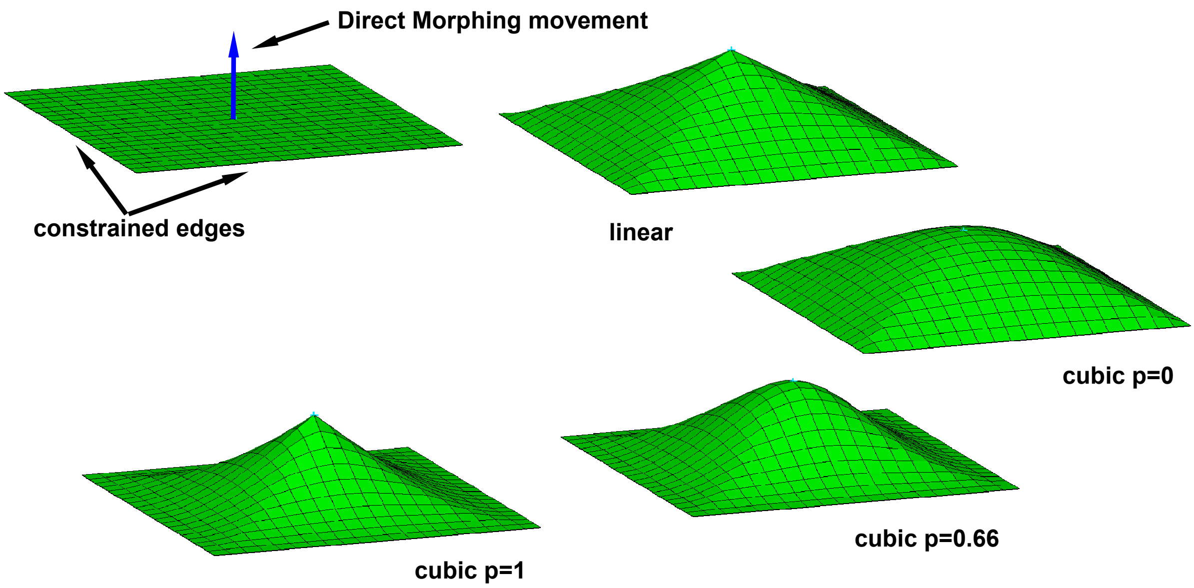

Fig. 17. Applied different algorithms on FE-Surface

By adding morphing with different algorithms on the same FE-Surface (Figure 18), it is possible to get complicated shapes beginning from only a basic geometry. This can proved to be very useful for the definition of shape optimization, since many design variables can be applied to a basic geometry searching for a complex optimal shape.

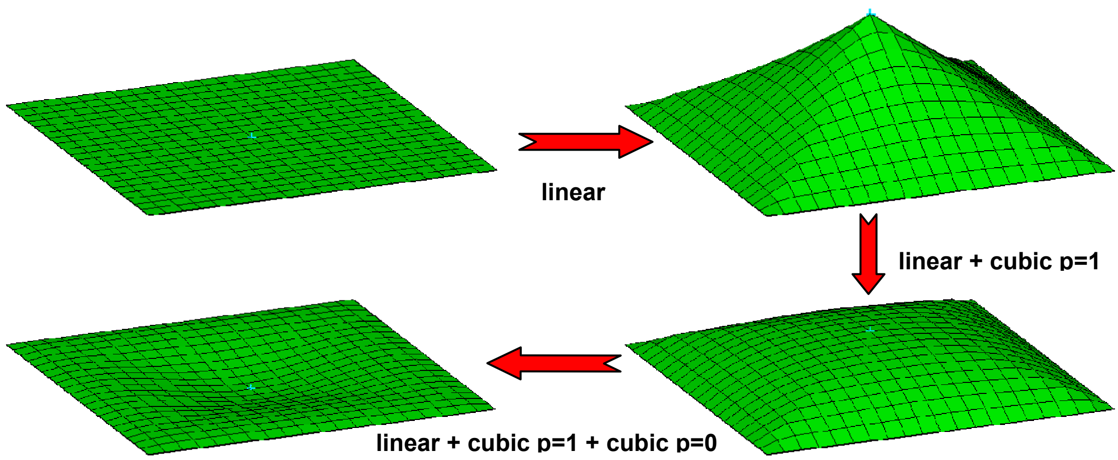

Fig. 18. Combined morphing algorithms on FE-Surface

4.2 The Deformation Parameter

In many cases, many morphing functions must be applied in order to define the way that a design variable will affect the model shape. Even though most of morphing functions can be controlled by Morphing Parameters, this is not possible for any manual adjustments that may be needed. As a result the manual adjustments cannot be connected to the Task Manager. Also the connection of the Morphing Parameters to the Task Manager sequence becomes a complex task when a big number of Parameters have to be connected in a specific order to one design variable (Figure 19).

A new type of Morphing Parameter can facilitate this process. The Parameter of type Deformation can record all the morphing actions that take place from the initial to the deformed shape even if there is morphing through Parameters or manual adjustments.

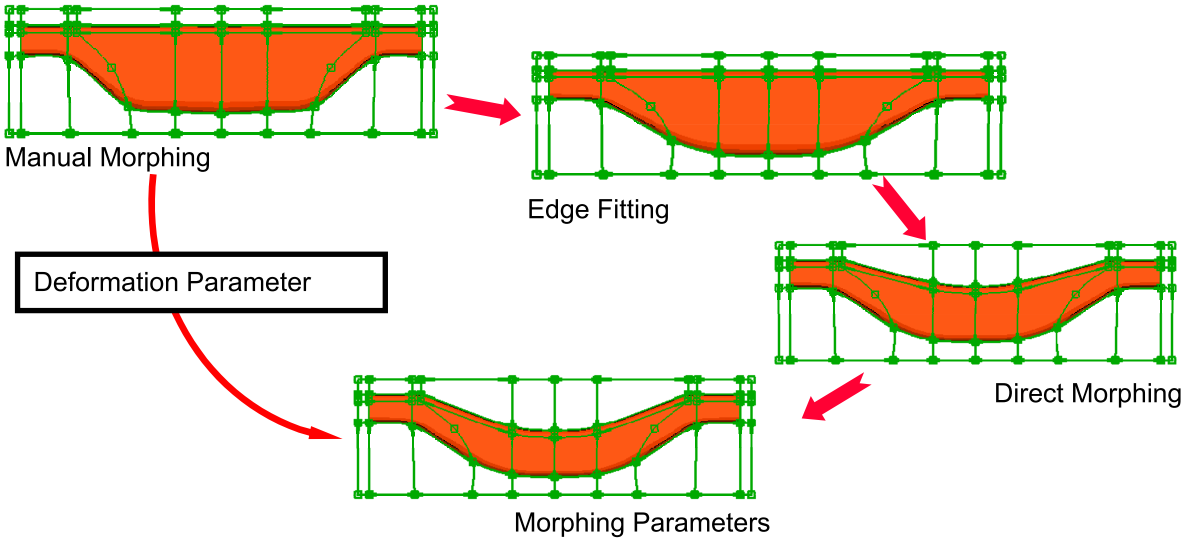

Fig. 19. Deformation Parameter

Using this Parameter the initial or the deformed shape can be reached at any time by giving the value 0 or 1 respectively (Figure 20, 21). Furthermore, it is possible to reach any linear interpolation or extrapolation of the two shapes.

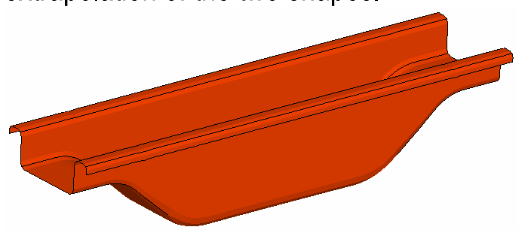

Fig. 20. Initial shape. Parameter value =0

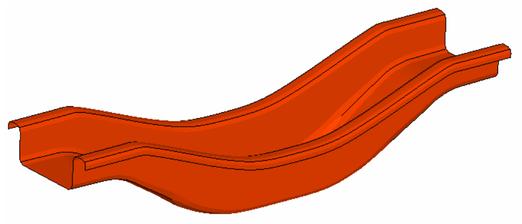

Fig. 21. Deformed shape. Parameter value =1

Using this functionality even a complicated morphing application with many manual adjustments can be driven by a single Morphing Parameter and connected easily to the Task Manager sequence.

5 Running the optimization problem

After the connection of ANSA with LS-OPT the task is ready to run. The following actions take place in an optimization loop (Figure 22):

- LS-OPT invokes the shell script which :
  - opens ANSA
  - loads the model
  - reads the design variable values from the relative ascii file
  - runs the Task Manager sequence using the above values. Here the model is morphed, the holes are open on the sides of the model and the shell thickness changes according to the relative design variable. Finally the re-meshing algorithm takes place to improve model's quality
  - output the model in LS-DYNA format
- LS-DYNA solve the model
- LS-OPT calculates the responses and the objective function
- the optimization algorithm calculates new values for the design variables
- the process is repeated until the optimal solution is found (Figure 23).

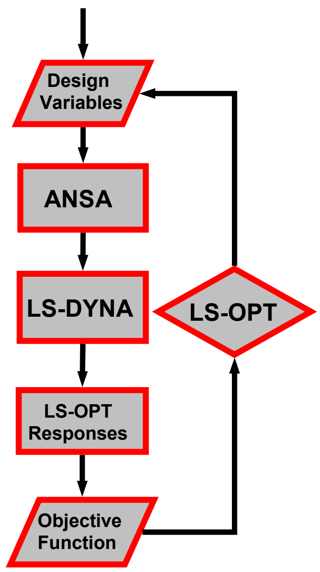

Fig. 22. The optimization loop

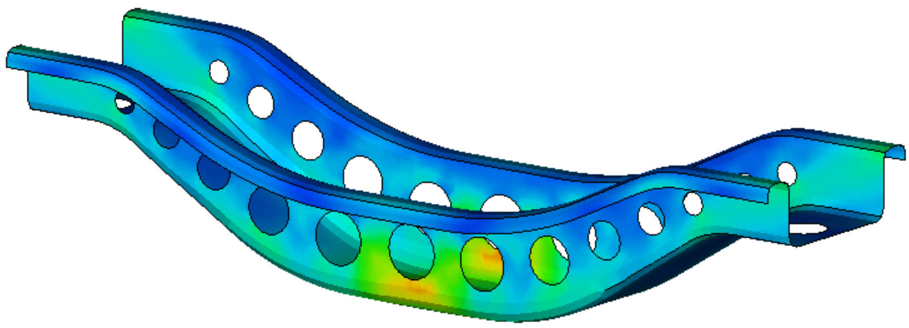

Fig. 23. The optimal solution

6 Morphing the geometry

The optimal values for the design variables have been found and can be applied to the initial model to morph the geometry. In that case the geometrical model gets the same shape with the FE-Model. However the holes have not been applied and the mesh is not identical between FE-Model and geometry. The morphing of geometry is shown on figures 24, 25.

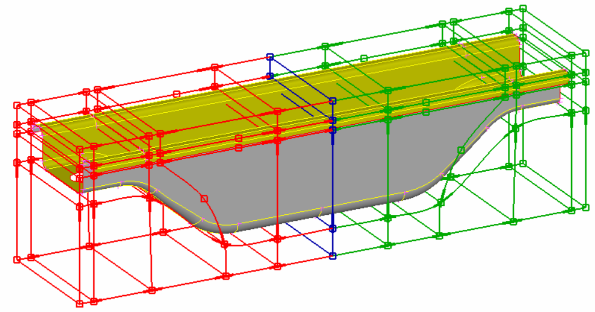

Fig. 24. The initial geometrical model

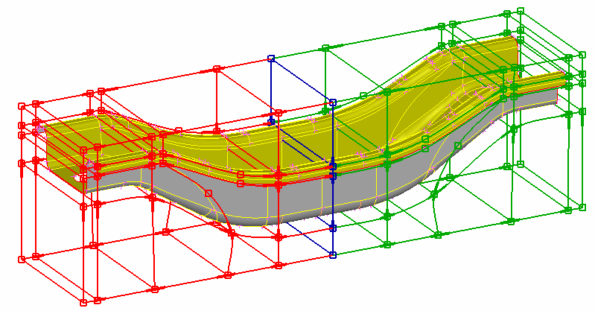

Fig. 25. The modified geometrical model

The resulted holes of the modified FE-Model can be projected to the geometrical model in order to open the same holes on geometry.

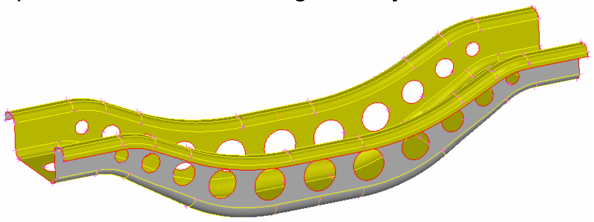

Fig. 26. Holes on the geometrical model

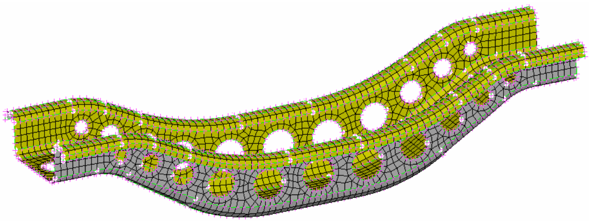

Fig. 27. The final meshed

Finally the geometrical model can re-meshed using the Batch Mesh functionality. Using the Batch Mesh all the needed parameters for the meshing can be defined in advance. In this example one zone of elements is applied in each hole. Also the quality of the mesh is improved according to defined quality criteria (Figures 26, 27).
The geometrical model in the optimal shape is ready. As the geometry is kept, it can be easily feed back to the CAD or CAE departments for further treatment. In addition the model is independent from the applied mesh as it can be re-meshed at any time with different meshing parameters without losing any feature information.

7 Summary

The set up of shape and property optimization for LS-OPT is possible in the ANSA pre-processor.

The Morphing Tool provides a powerful functionality for shaping FE or geometrical model which is the key for the shape optimization. The use of various morphing algorithms enables the definition of complicated shapes using a small number of design variables.

The pre-processing of the optimization problem can be automated by the Task Manager. The connection of the Morphing Tool with the Task Manager offers a powerful interface for the shape optimization set up.

8 Literature

[1] LS-DYNA KEYWORD USER'S MANUAL VOLUME I, "LSTC", 2007, 2206
[2] ANSA v12.1.2 User's Guide, "BETA CAE Systems S.A.", 2007, 1300