Summary

Current design problems are getting more complex because of increased awareness on economical and environmental impact. To minimize economical and environmental impact a minimum of material usage is stimulated, nevertheless the overall stiffness and allowable stress must remain within its design values. In case of complex minimization problems finite element computer programs with topology optimization scripts can be used to reduce the material usage.

The purpose of this study is to develop a compact topology optimization script which can be used in an Ansys working environment. First a basic compact script is made based on compliance. Furthermore another method using a stress criterion is analyzed. Add-ons are analyzed to enhance the basic script, such as: un-optimized sections, perimeter constraint and compliance level input. All methods and add-ons are tested using simple topology designs on the basis of calculation time, compliance, ease of use and interpretation. After a proof of concept all methods and add-ons are tested on a practical numerical example: a 52.5 ton container crane.

The basic topology optimization script for use in an Ansys working environment is based on the material distribution method. The script searches for an optimum based on the stiffness objective function. Supposing that an element is removed from the structure, the resultant change in the mean compliance is derived on a sensitivity analysis, which consists of the strain energy. Elements of small strain energy can be removed without significant reducing the overall stiffness. To obtain an optimal design the steps shown in figure 1 are used.

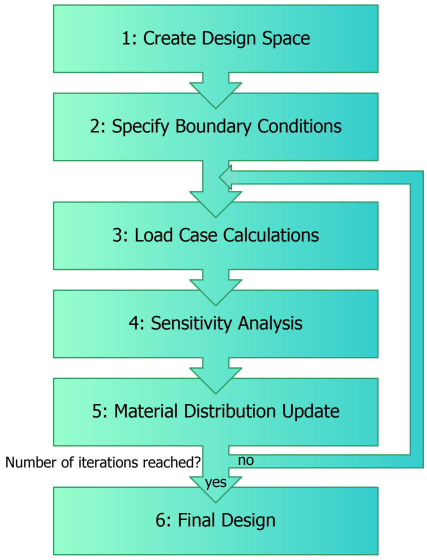

Figure 1 Topology optimization diagram used for the basic script

Apart from stiffness other optimization techniques exist which optimize strength. An optimization code was developed for stress based analysis using the equivalent Von Mises stress. The stress based method produces less practical results and high compliances. Although results are sometimes similar, the compliance based method produces minimum stress levels almost equal, or even higher, compared to the stress based method and also minimizes compliance.

Besides the basic program, add-ons were analyzed to improve the usability of the program for more design problems. The following add-ons are analyzed: un-optimized sections, perimeter constraint and a compliance level input. The un-optimized add-on is a valuable extension off the basic optimization script. Many design problems have got vital sections, which shouldn't be optimized, this add-on provides this possibility.

The perimeter control is used to damp or enforce checkerboard structures. Checkerboard of material in a uniform grid of square elements has a stiffness which is comparable to the stiffness of a $\rho = ½$ variable thickness sheet. Although the checkerboard phenomena can easily be interpreted as a sheet for a 3D problem, it isn't always desirable in the solution. Two perimeter control methods are examined: 6 faces method and 8 nodes method. Results from the 6 faces and 8 nodes method are very similar. The compliance level of the 8 nodes method is slightly better with 0.8%. By far the biggest difference is the calculation time which deteriorates significantly with 366% when the 8 nodes method is used. The final add-on will consist of the faster 6 faces method.

Instead of a volume reduction input the compliance cut-off value could also be user defined. This can be a valuable add-on because the optimum volume reduction is often unknown. Because it's quite hard to assess the compliance level cut-off value up front, a more easily determined parameter is used, minimum stress. Some issues with compliance level input still remain. Firstly the minimum stress input doesn't equal the minimum nodal stress in the final model, due average element stress. Secondly the minimum stress input cannot be used when different element volumes or elasticity modulus exist. Thirdly the interpretability is questionable, due to practical engineering problems. The resulting stress are often not equal to stresses in the real design, due to the use of more practical materials.

Because all examples used to test the add-ons weren't complex design problems a 52.5 ton container crane is used as a practical example. Almost all optimization methods and add-ons produced interpretable topologies. The topology optimization can be used to examine the first concept. The final topology, figure 2a, with 32 load cases is very similar to a real-life design. When this topology is interpreted towards a real design, figure 2b, the resulting crane has many similarities with the container crane designed by Krupp, figure 2c.

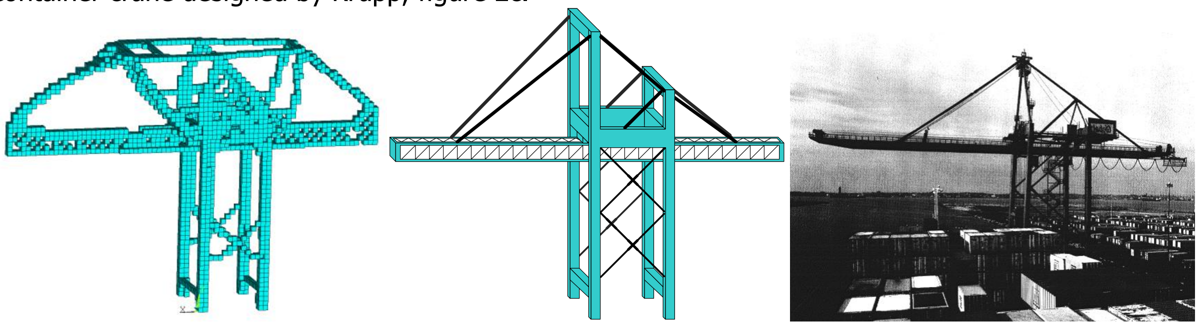

Figure 2a) resulting topology with 32 load cases b) real design interpretation c) real design used by Krupp

A compact topology optimization script has been developed for use in an Ansys working environment with success. The use of a compliance (stiffness) based method has the preference, it produced more interpretable results compared to a stress based method, table 1.

Three add-ons were developed to enhance the basic script, table 1:

- Un-optimized sections
- Perimeter control
- Compliance level

Un-optimized sections are desirable for a significant amount of engineering problem, and thus a valuable enhancement for the basic topology script. The add-on slightly increases compliance, due to less available elements to increase stiffness. However interpretation benefits can be significant.

Perimeter control can be used to enforce or damp the checkerboard phenomena, thus controlling the design containing more plates or cross members. When the checkerboard phenomena is enforced compliance can be lowered. However, when cross members are stimulated compliance will be higher.

Compliance level add-on is used to attain a user-defined cut-off compliance by input of a minimum stress. This can be a valuable additions when optimum volume reduction is unknown, but approximate minimum stress levels are easily calculated. However, for complex design problems this can be hard to asses due to solid elements in the topology which aren't solid sections in practice.

	Calculation time	Compliance	Ease of use	Interpretation
Compliance based	+/-	+/-	++	+
Stress based	+	- -	++	- -
Un-optimized sections	+	-	++	++
Perimeter control	- -	+/-	+/-	++
Compliance level	+/-	+/-	-	+/-

Table 1 Methods and add-ons with their evaluated criteria

The topology optimization script can be used for complex design problems, such as a container crane. The resulting topology can be used as a basis of for a first design concept. The add-ons can be used to increase interpretability of complex design problems.

Recommendations for further study

- Extend perimeter control for use on all element types
- Extend compliance level input for use with different element properties and reduce calculation time
- Topology optimization using genetic algorithms