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Optimization of a wedge-shaped hopper stiffened with L-section ribs using genetic algorithms

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Abstract

This paper presents the optimization of a steel wedge-shaped hopper. The flat wall of the hopper on the outer side is stiffened with L-section ribs which run paralel to one another. We search for the optimal set of the design variables, that makes the objective function minimum. The number of design variables is 4 plus the number of ribs. The objective function is the production cost of the structure. We analyse the whole structure with finite element method and use genetic algorithms to find the solution.

1. INTRODUCTION

Hopperrs are widely used in the industry for temporarily storing bulk materials. Different hopper shapes can be chosen for the same purpose and in some cases the wedge shape is more advantageous than the conical or pyramidal shape. The wedge shape requires usually less headroom than the other shapes, and less sensitive to the flowability properties of the bulk material. The wedge shape has drowbacks as well. If the outlet requires a gate it is more expensive than in the other cases.

In this paper we suppose that a wedge-shaped hopper is chosen and the main dimensions have been determined.

Using ribs makes it possible to apply thin steel plates and it reduces the material cost, on the other hand ribs increase welding costs. This fact means that the cost minimazition of such a structure is an important engineering task.

We examine the whole structure considering the connections of the parts. This kind of detailed analysis can be carried out only numerically. We use finite element method which provides sufficiently precise results but computationally can be expensive. The analysis of the structure may be repeated some thousand times.

Our goal with the optimization is to determine the chosen design variables so that the whole production cost may be minimum.

2. CONSTRUCTON OF THE HOPPER

The examined hopper (Fig. 1) is made of common structural steel and the parts are welded together. We use standard plates and rolled sections. The structure is bordered by two rectangular and two trapezoidal walls. These walls are stiffened with L-section ribs. L-section provides effective stiffening for the walls, it is not sensitive to plate buckling and can be connected easily at the corners. We use non-continuous welding to connect the ribs to the walls. The open L-section is advantageous from corrosion respect compared to closed sections. The upper edge of the hopper has a U-section rim. It protects the edge in case of loading and the plate legs are also welded to this rim. The bottom outlet opening has an L-section rim. The gate can be bolted to this rim. These L-sections are connected together with plates in four places. This provides an effective stiffening and does not hinder the flow of the bulk material.The legs of the hopper are made of plates, too. These are inclined to a little extent in order to provide enough room for the support structure.

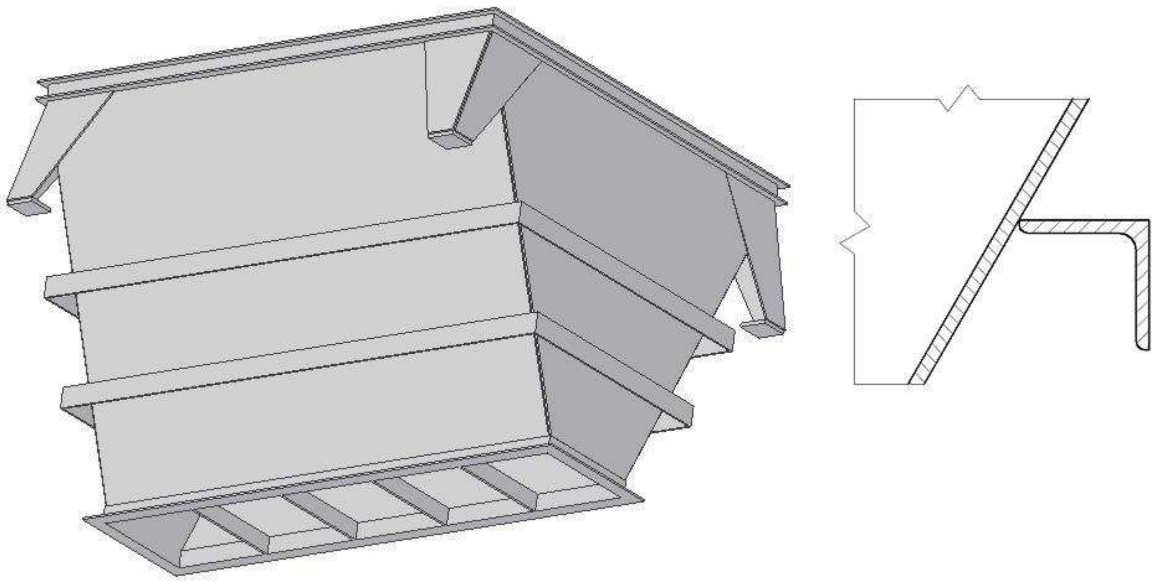

Fig. 1
Wedge-shaped hopper stiffened with L-section ribs

3. THE COST FUNCTION

The cost function of the structure is set according to reference [2]. This contains the material cost and the manufacturing related costs. Amortization, transportation, site erection costs are not included. The cost function is:

$$K = K_m + K_f = k_m \rho V + k_f \sum_i T_i \,, \tag{1}$$

where K is the whole production cost, K_m is the mass cost, K_f is the manufacturing cost, k_m=0,5-1 \$/kg is the unit mass cost for structural steel, ρ=7,85 kg/dm^3 is the steel density, V is the structural material volume, k_f=0-1 \$/min is the unit manufacturing cost, T_i is the required time for the different manufacturing phases.
The unit costs depend mainly on the development level of the country where the production is carried out. Considering the above value limits the rate k_f/k_m can be between 0 and 2 kg/min. Some typical values for normal structural steel are the following:

- Manufacturing cost is zero, optimization for minimum weigt: k_f/k_m=0.
- Developing countries, cheap labour: k_f/k_m=0,5.
- Western-Europe, expensive labour: k_f/k_m=1-1,5.
- Japan, USA, expensive labour: k_f/k_m=2.

We use the cost function in the following form:

$$\frac{K}{k_m} = \rho V + \frac{k_f}{k_m} \sum_i T_i \,. \tag{2}$$

We suppose that the rate k_f/k_m is the same for all manufacturing phases.

The manufacturing times are the following:

$$\sum_i T_i = T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 \, , \tag{3}$$

where T_1 is the time for preparing welding, T_2 is the actual welding time, T_3 is the time for additional manufacturing activities at welding (changing electrode, slag removal, burr removal), T_4 is the time for plate aligning, T_5 is the time for surface preparation before painting (cleaning, rust removal, sand blasting), T_6 is the painting time, T_7 is the time for plate cutting and edge grinding.

4. DESIGN VARIABLES AND FIXED DATA

Design variables are the parameters of the structure which can be changed during the optimization. These parameters are the following:

- Wall plate thickness (standard);
- Size of the L-section ribs (standard);
- Size of the L-section at the outlet (standard);
- Periodicity of the rib welds (number between 0,25 and 1);
- Position of the ribs (distance from the upper edge).

Since plate thickness and L-section sizes are chosen from standards we consider the design variables as discrete variables.
During the optimization we set the number of rib levels but this can be chosen arbitrarily. The other dimensions of the structure have been determined from a previous calculation and these are fixed. The numerical calculation refers to a hopper with a capacity of 7 m^3. The main dimensions are shown in Fig. 2. The density of the bulk material is 1800 kg/m^3, the rate k_f/k_m is 1.

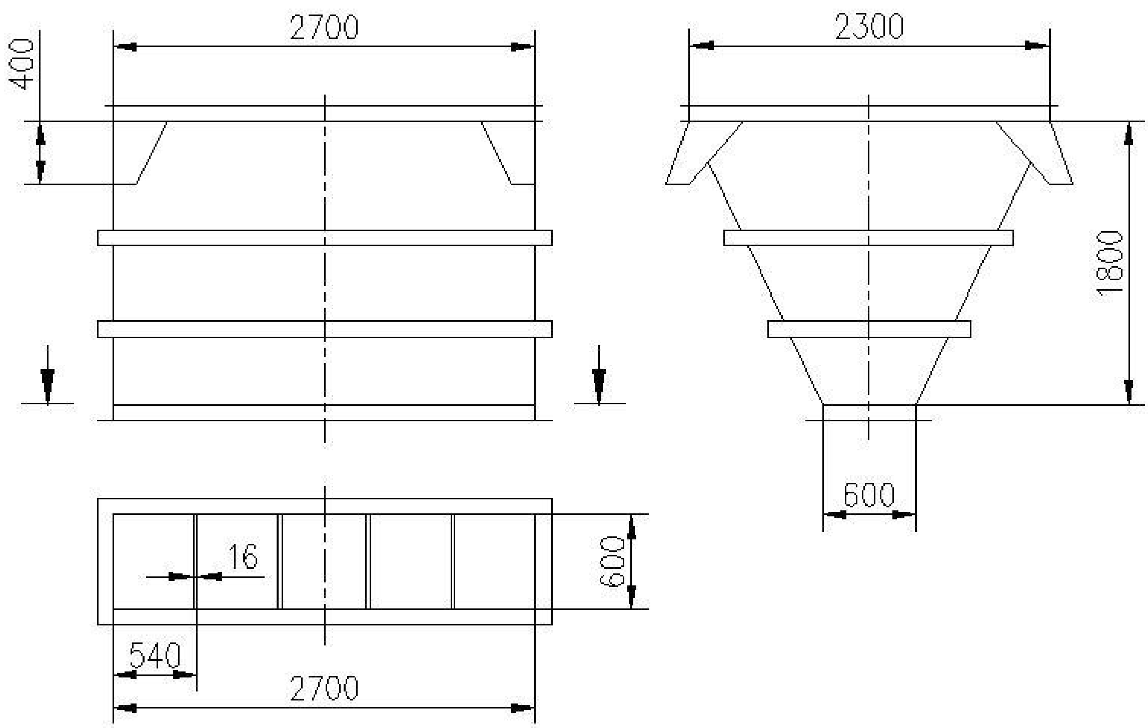

Fig. 2
Main dimensions of the hopper

5. CONSTRAINTS

Geometric constraints:
- We set the minimum distance between the ribs and between the ribs and the edges of the hopper.

Mechanical constraints::
- The equivalent stress may not exceed a limit stress (200 N/mm^2).
- The shear stress in the welds of the ribs can not exceed a limit stress (141 N/mm^2).
- The deflection of the plates may not exceed a limit deflection that is 2.5-times the plate thickness.

The constraints are taken into consideration in a way that we exclude the inconvenient individuals from the population and generate new ones.

6. MECHANICAL MODEL

From mechanical point of wiev we handle the hopper as a shell structure. Load is derived from the weight of the bulk material and this varies linearly according to the height of the stored material. This is determined according to the so called earth pressure theory. The dead load is considered, too. The hopper is supported by joint connections at the four legs in the middle of the foot plates. Since the hopper has two symmetry planes it is enough to examine the one fourth of the whole structure if we apply symmetry conditions for the the proper edges.

7. COMPUTER PROGRAMS

We use two commercial programs for the numerical calculations. Genetic algorithms and other algorithms run in MATLAB environment. The finite element analysis is carried out by COMSOL. These two programs have direct connection. COMSOL can be controlled from MATLAB. The main functions of the genetic algorithms were created by Pohlheim [3] and we extended these algorithms to handle constraints.

8. GENETIC ALGORITHM

Genetic algorithms are stohastic search methods. The structure of a genetic algorithm is shown in Fig. 3.

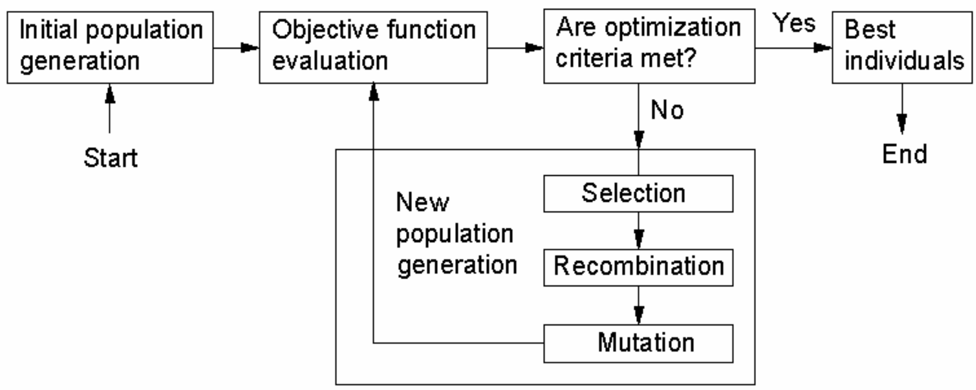

Fig. 3
Structure of a genetic algorithm

9. RESULTS OF THE OPTIMIZATION

We have carried out the optimization in case of three hoppers which differ in the number of rib levels. Fig. 4 shows the deformations and the pattern of equivalent stresses of the hoppers which can be considered as optimal ones.

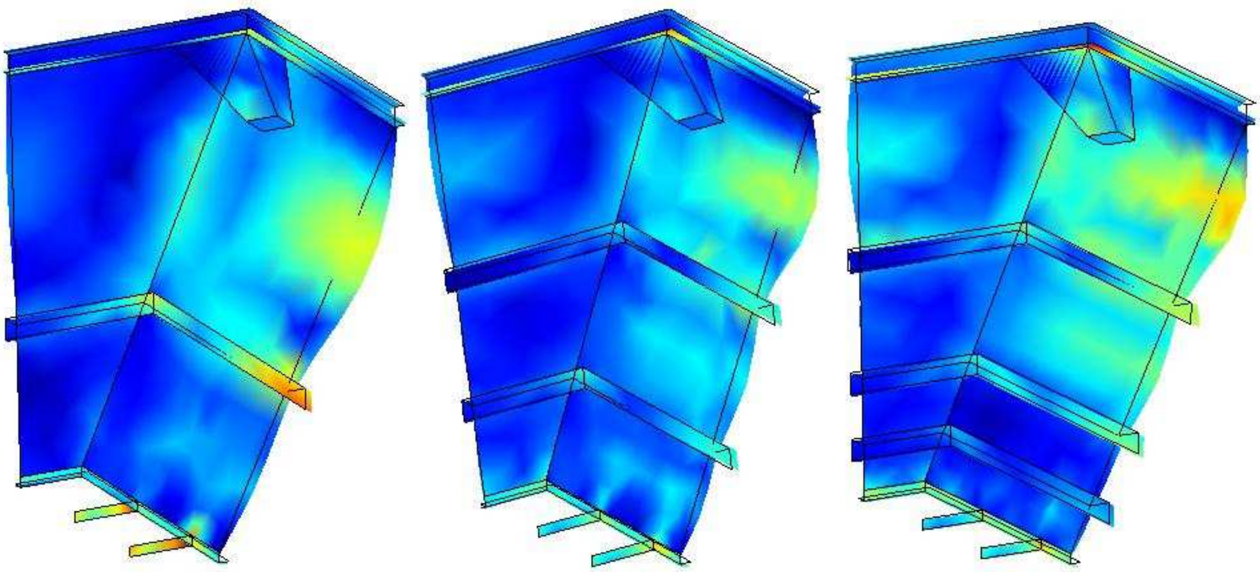

Fig. 4
Optimal hoppers

The cost components are shown in Fig. 5. The cost unit is kg according to equation (2).

Cost components	Number of rib levels		
	1	2	3
1	1233	976	1074
2	314	306	347
3	1628	944	1055
4	181	197	212
5	576	627	674
6	102	96	100
Sum	**4036**	**3146**	**3462**

Fig. 5
Cost components

Names of the cost components are: material (1), welding preparation (2), welding (3), surface preparation (4), painting (5), plate cutting and edge grinding (6).
Comparing the costs of these optimal solutions it can be seen that using 2 rib levels results in the least cost. In this case the values of the design variables are the following: wall thickness is 5 mm, sizes of L-section ribs is 100x100x10, sizes of L-section at the outlet opening is 50x50x5, the parameter value for the non-continuous welds at the ribs is 0.4, the rib level distances from the top of the hopper are 800 mm and 1390 mm. The relative costs of the three hoppers are shown in Fig. 6.

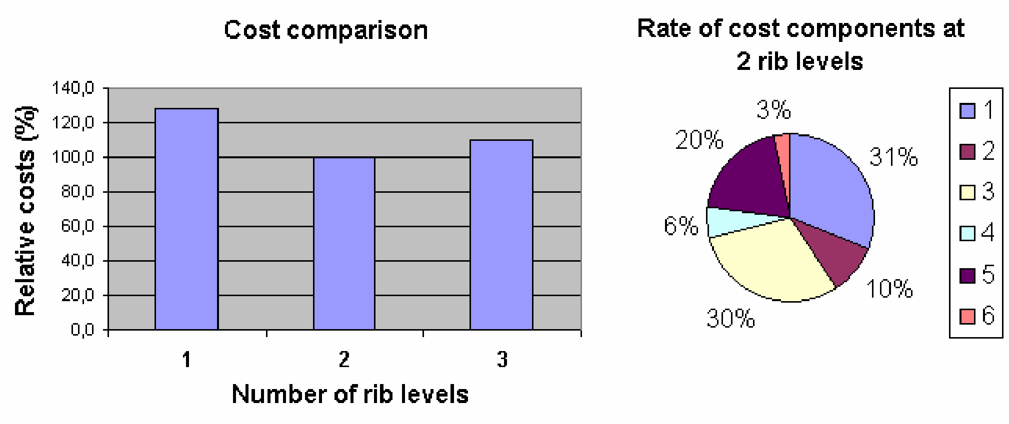

Fig. 6
Costs and cost components

The diagram on the left in Fig. 7 shows the best objective values in case of each generation at 2 rib levels. As the number of generation grows the searching process finds better and better individuals. The calculation ran up to 50 generation. The diagram on the right shows the costs of the 20 individuals in the last generation.

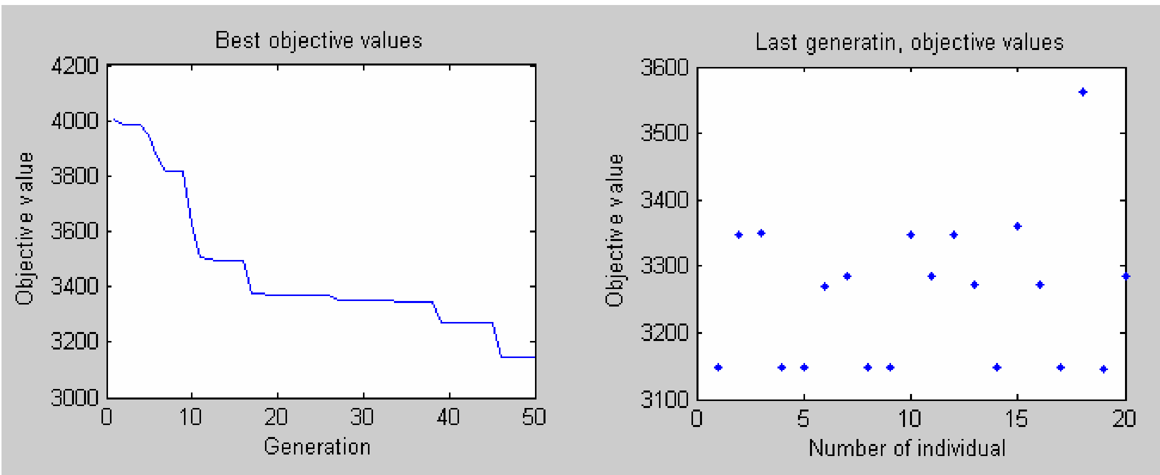

Fig. 7
Change of objective values at 2 rib levels

10. SUMMARY

The solved problem shows that with the combination of finite element method and genetic algorithms even complicated structures can be optimized. The way of constraint handling has a great effect on the efficiency of the search process, so additional research is needed in this direction.

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