

SIMPRO – Task 2-1 – Guide Rail Optimization by Isight

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Summary		
<p>The objectives of this Simpro subproject work was to create an optimization model by applying an industrial real case. The KONE Oy used elevator guide rail system was used as an example to the demonstration purposes. KONE produced the original guide rail model including also the external frame, connection brackets and the roller wheels. The model development in VTT was divided to the two parts. The guide rail based on the one dimensional beam element modelling enable lighter models which gives benefit in model modifications and computational times, Jani Wennerkoski continued the work with the beam models. Applying the solid element mesh to the guide rails enable more detailed modelling but on the contrary is heavier in terms of the computing times and model modifications. The solid mesh approach is reported in this study.</p> <p>In practise the guide rails were created again since the cross section was defined parametric. The existing sketch can be modified and updated. The length of the guide rails were made parametric when extruding them. The brackets used here are as they came from KONE and the horizontal pipes were cut from the external frame. The locations of the each brackets were made parametric by applying a python code which moves them. In a same way also the height of the elevator was made parametric and the exact location of the roller wheels. The elevator can be driven throught the existing guide rail in steps but without the dynamics and time which can be added later. The buckling of the guide rail is also calculated in the model.</p> <p>Both the Design of Experiment (DOE) and optimizations results of the solid model case are described and discussed in this report. There exist lack of the perfect optimizations results available. In order to achieve the trustable and comprehensive results more work is needed to update and modify the Abaqus CAE model for the optimization.</p>		
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1. Preliminary Guide Rail Optimization Demo

1.1 Introduction

This document is a part of the Simpro project subtask 2.1 optimization case of the KONE Oy elevator case in which the guide rail system is analysed. The main content of the work reported here was to develop an optimization model for a Isight optimization software and create a demonstration example by using the simplified guide rail system. The actual simulation is based on the Finite element method (FEM) applied in the Abaqus CAE software.

1.2 Basic model

The preliminary simulations based on the FE model provided by KONE to VTT on February 2013. As a first step the solid frame pipes were replaced by the Abaqus shell elements by the 6.3mm thickness in the pipe frame walls. The main cross section dimensions of the guide rail were made parametric by the Abaqus CAE sketching tool. The constraints of the sketch must be considered carefully since these can easily make errors to model in the optimization phase. The length of the guide rails are created and made parametric by extruding the cross sections sketches. The other details of the preliminary optimization model were the same with the original model (one frame, four guide rails, five brackets, fishplates between the guide rails etc.). The main dimensions (6 dimensions) of the cross section were made parametric. This sketch can be updated to correspond even better the reality in the future.

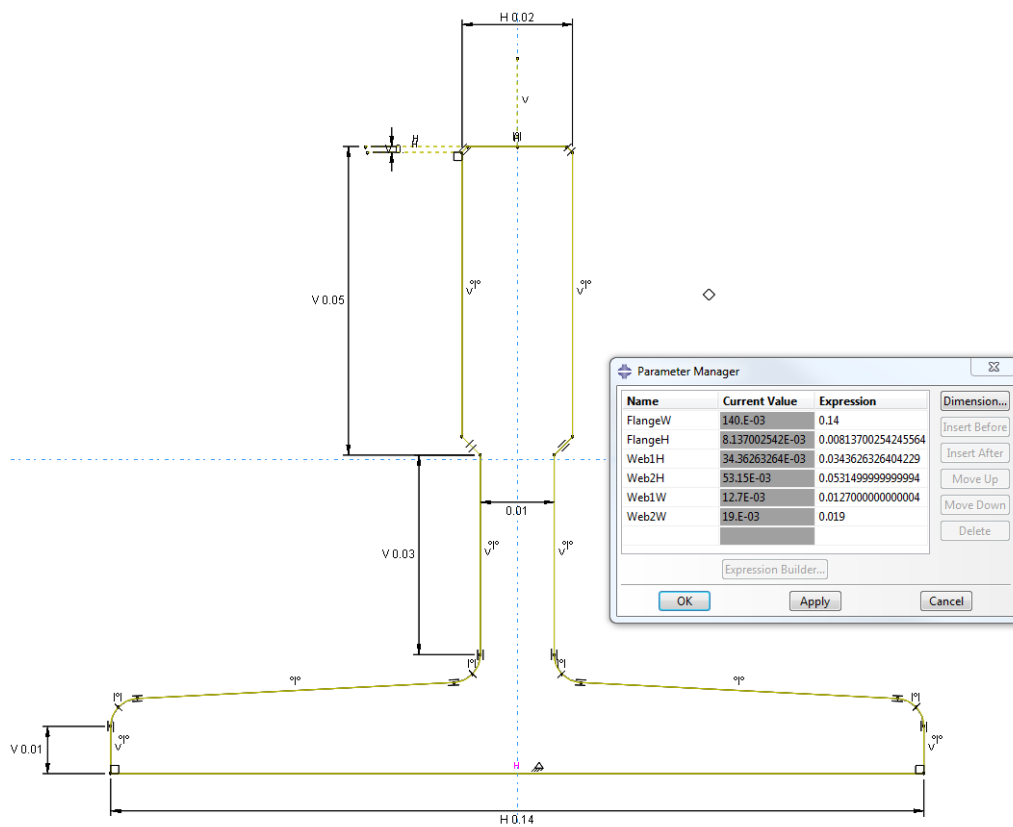


Figure 1. The cross section of the guide rail made parametric.

In order to make a computationally “lighter” model for the heavy optimization purposes, a simpler Abaqus beam model including also the supporting frame was created. An important point for this was also possibility to control the distance between the brackets and make it parametric for the optimization purposes when the supporting frame is present. This is not possible in practise in Abaqus CAE when the frame is modelled by the shell or solid elements without the geometry behind. In this frame as the simple beam model the frame is sketched which enable the control of the distance between the guide rail brackets. The cross sections of the simple frame pipes are easy to be defined by the Abaqus Edit Profile function.

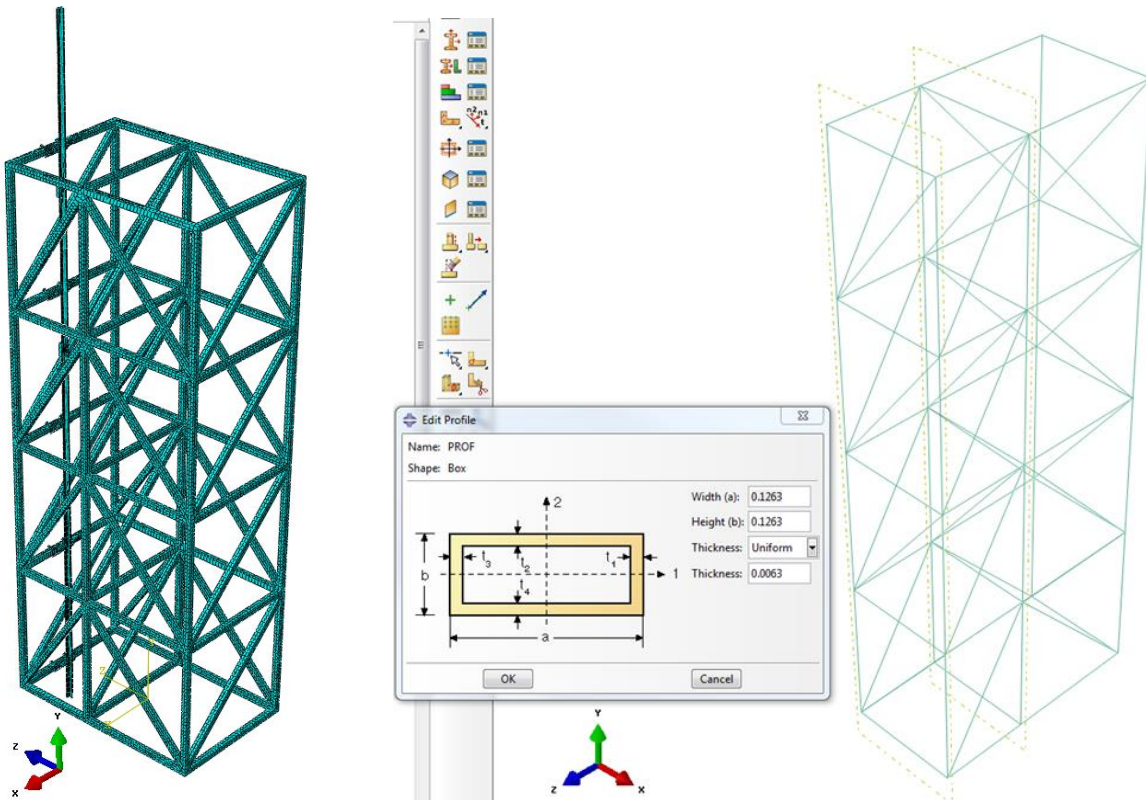


Figure 2. Preliminary simulations when the frame was also present.

The use of the beam element seems not to enable very detailed guide rail profile due to the limitations in the Abaqus Edit Profile option. Existing alternatives are limited to the I or T – profile or just applying the generalized profile in which the basic anonym cross section surface area and the needed moment of Inertia values in two directions are made parametric.

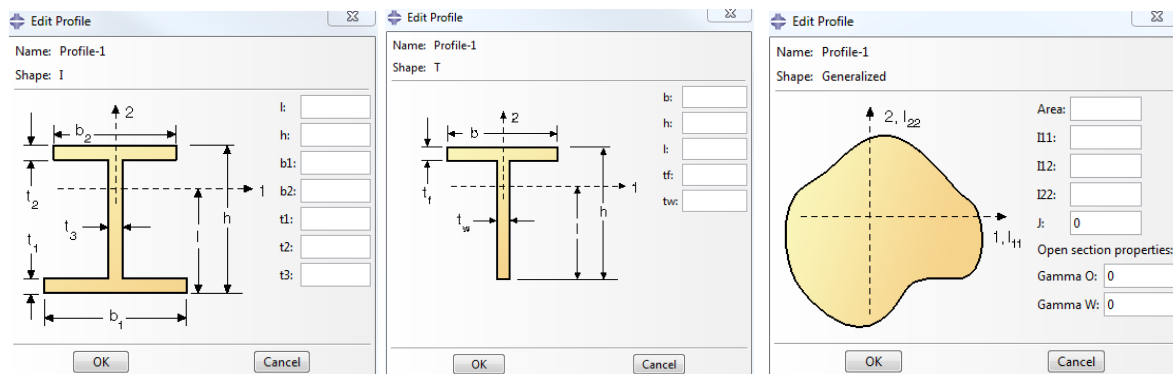


Figure 3. Alternative profiles for the guide rail in the simple beam model.

The simplified solid FE model is cut from the original from the both ends of the transversal pipes that have a close connection to the brackets. The guide rail and the perpendicular short pipes were remeshed again but the mesh of the bracket was remained as it came from KONE. In fact, the mesh of the brackets should be regenerated as well because according to the Abaqus rules at least four element layers are needed in the thickness direction of the plate when the element type C3D8R is applied. The applied Python script must include the meshing and assembly update commands if e.g the geometry is changed, in this study this is not needed since the question is about the movement of the components.

The gravity of the guide rail is added as a first loading step of the solution. Symmetry boundary conditions are applied in the both ends of the guide rail system. This gives a little bit wrong results since the ends of the simulated system are not symmetric in practise (different lengths of guide rails in the ends). The boundary condition in the ends of the perpendicular short pipes is all fixed except the y direction (elevator moving direction) left free which enable the parametric movement of the brackets. The static loads are applied in the elevator rollers.

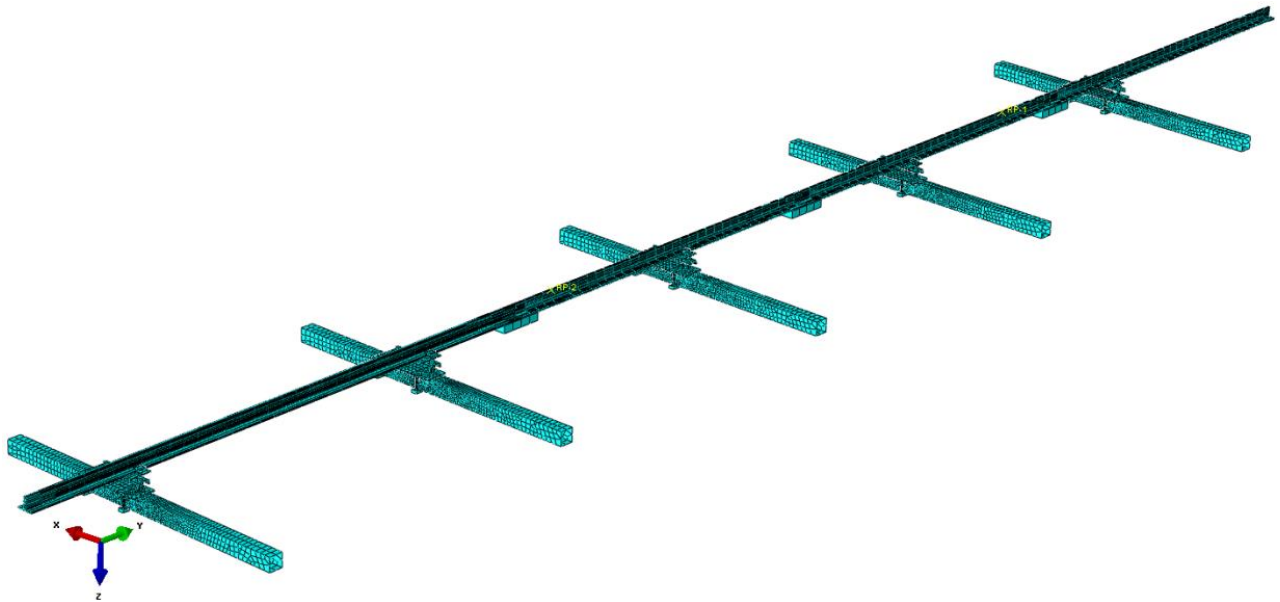


Figure 4. The element mesh of the simulated guide rail system.

The static roller wheel forces were defined close to the values during the elevator car running. The vertical forces applied in the both roller wheels were 180N and in the horizontal direction 100N. The roller wheel positions applied in the static forces case were in the middle between the brackets. These locations were just estimated as the “worst case” conditions for the preliminary analysis.

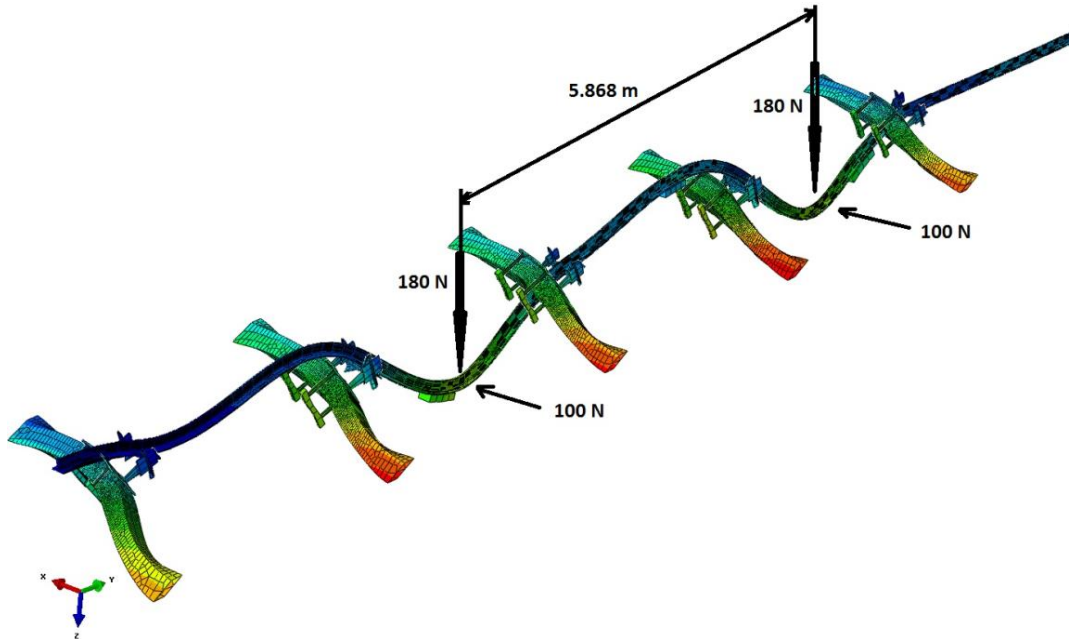


Figure 5. The used static forces in two directions, the 5m guide rail is located in the left side.

The Isight component chain is quite simple in this guide rail example since most of the important issues can be included in preliminary CAE model itself (e.g different loadings in own steps) and the applied userscript (userscript_cae_pre.py). The calculator component was used here to couple the roller wheel force locations together in a way that the height of the elevator (= distance between the rollers in the guide rail) and the position of one of the rollers were made parametric.

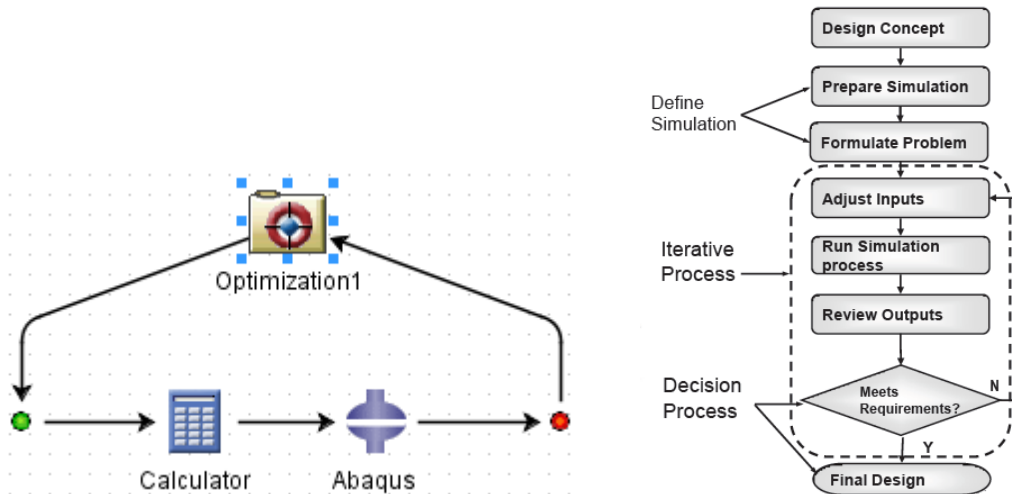


Figure 6. The simulation flow of the demonstration case and overall in Isight.

1.3 Design of Experiment by Isight

1.3.1 Basics of DOE analysis

Design of Experiment (DOE) as the sensitivity analysis describes and makes possible to compare the importance of the different input design parameters. The objective parameters develop to the target value or the most possible extreme value according to these design variables. The following examples hopefully clarify this. The default DOE technique in Isight is Latin Hypercube. It allows many more points and more combinations for each factor.

1.3.2 The guide rail beam parameters

The following DOE results were calculated by using the static roller force locations according to the figure 5 and the bracket locations as in the original model. The influence of the flange width of the guide rail is more dominating on the maximum displacement and Von Mises stress than the two other dimensions. These two other dimensions were the height and width of the top part of the web in the guide rail cross section. The maximum displacement covers the simplified solid guide rail model including also the brackets and the vertical pipes.

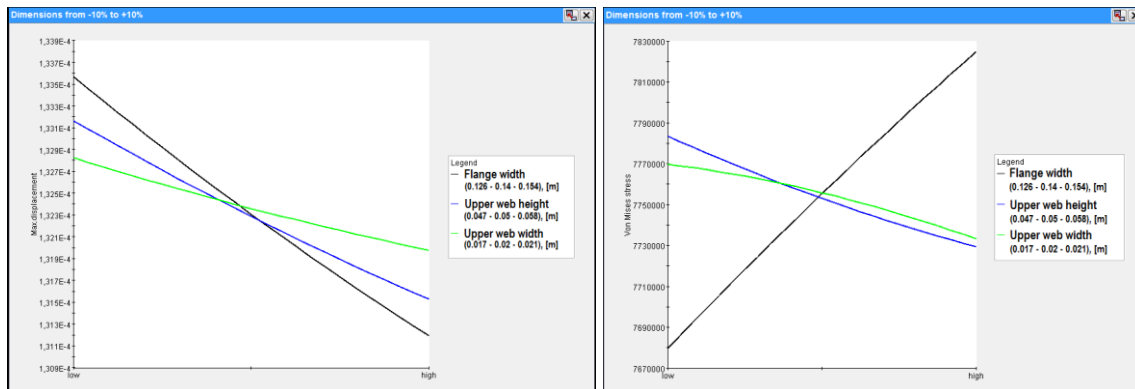


Figure 7. The influence of the guide rail profile parameters by the static force locations.

The results look different in the case of the moving roller force locations. The elevator is moved 9.5m through the existing guide rail from the end to end, distance between the rollers is constant. The importance of the width of the flange is still dominating in the terms of maximum displacement and stress but not e.g single detection point of the guide rail.

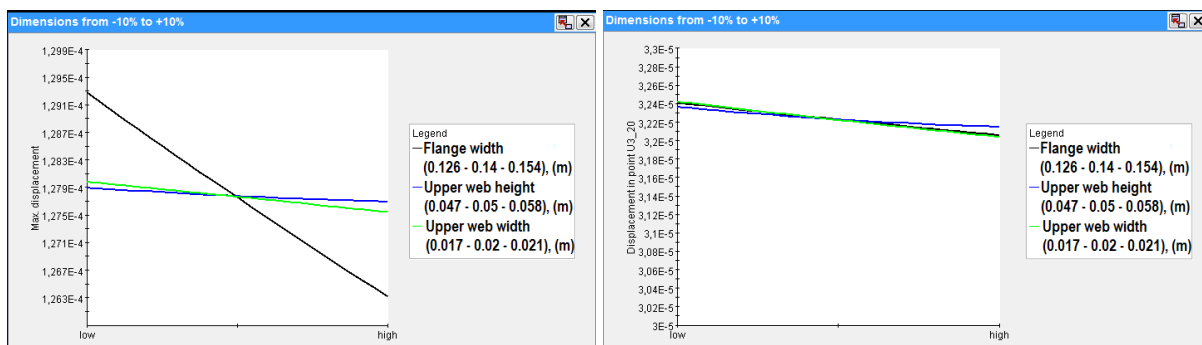


Figure 8. The influence of the guide rail profile to the max. overall and a single point displacement by the moving roller force locations.

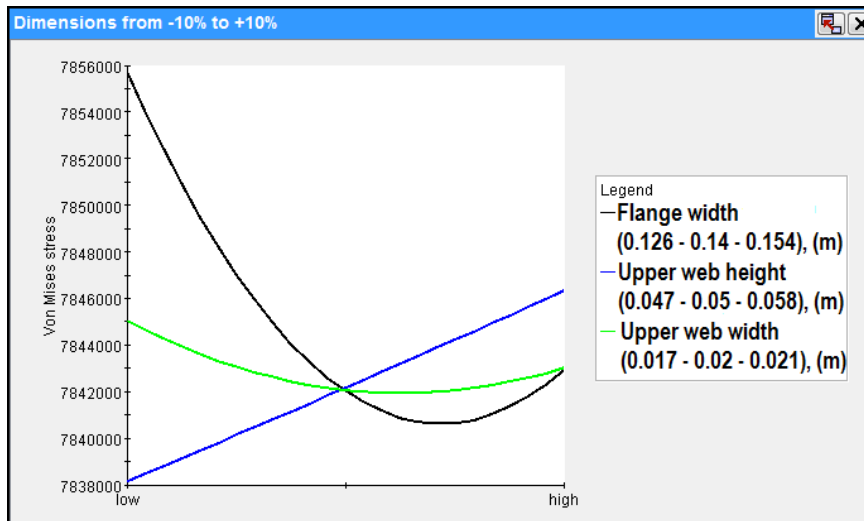


Figure 9. The influence of the guide rail profile parameters on the max. Von Mises stress by the moving roller forces.

The influence of the 3.5 m guide rail on the maximum displacement is described. The importance of the three 3.5m guide span on the displacement is clearly higher compared to the single 5m guide rail alone according to the Pareto plot (linear results). Pareto plots in Isight software use normalized coefficients of fitted 2nd order polynomial, which represent the % total effect on the response. The larger the magnitude the greater the influence on the response. Higher 2nd order effect indicates a single parameter's effect on a response is not linear which doesn't seem to be a case in the following figure.

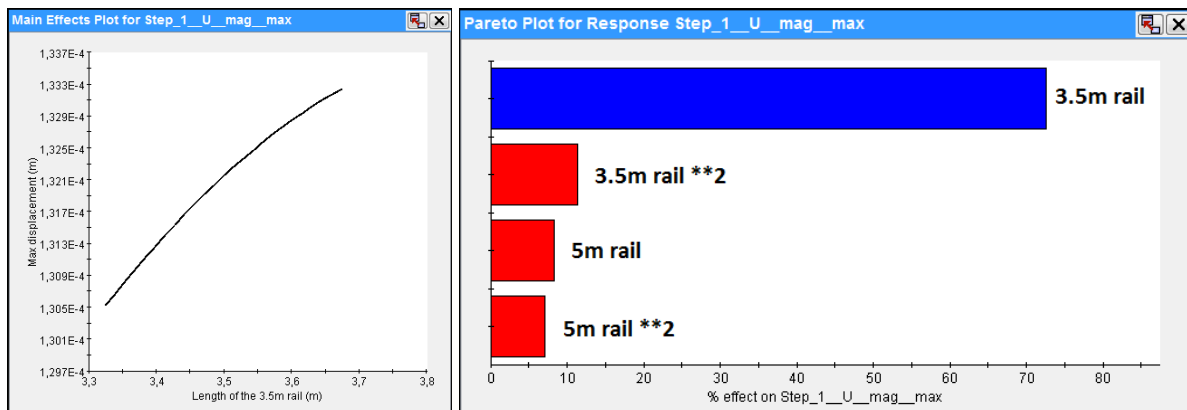


Figure 10. The influence of the guide rail length on the displacement. by static forces.

1.3.3 Move of the brackets as a parameter

The potential move of the each five bracket instances were also made parametric. The brackets were firstly named according the following figure. The "low" status means the starting from -0.4m and continuing up to the "high" +0.4m around the original bracket locations. The coordinate axes are also described in the figure. The maximum volume of the each four guide rails were minimized as the objective function.

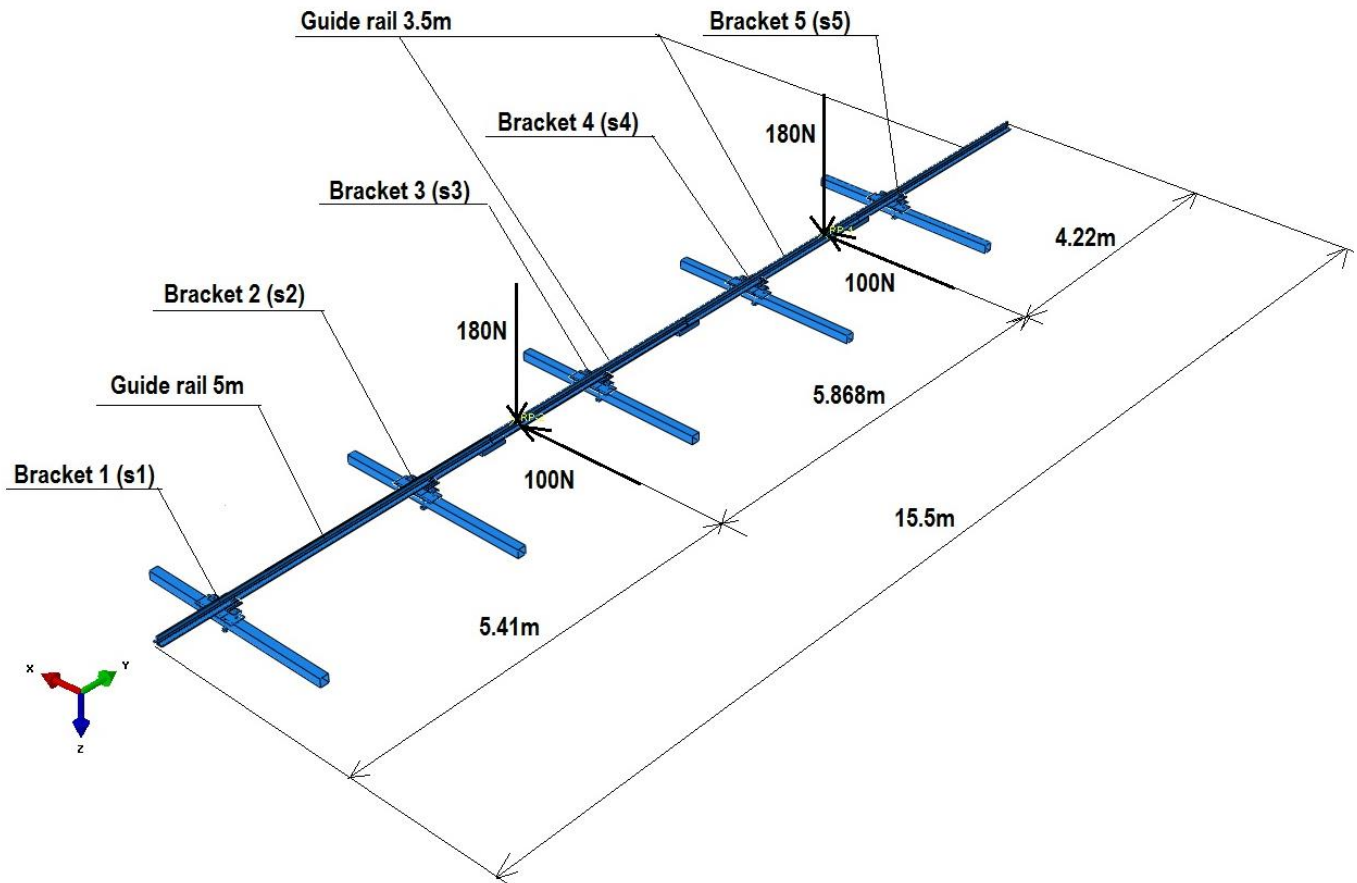


Figure 11. The guide rail brackets added to the model, static roller wheel loads used.

The next graph describes what is the influence of moving the brackets to the volume of the 3.5m guide rail. The location of the bracket 1 and 3 seem to have the most clear influence, the move of the bracket 1 to the minus direction would give benefit as the bracket 3 has the best position in the original position.

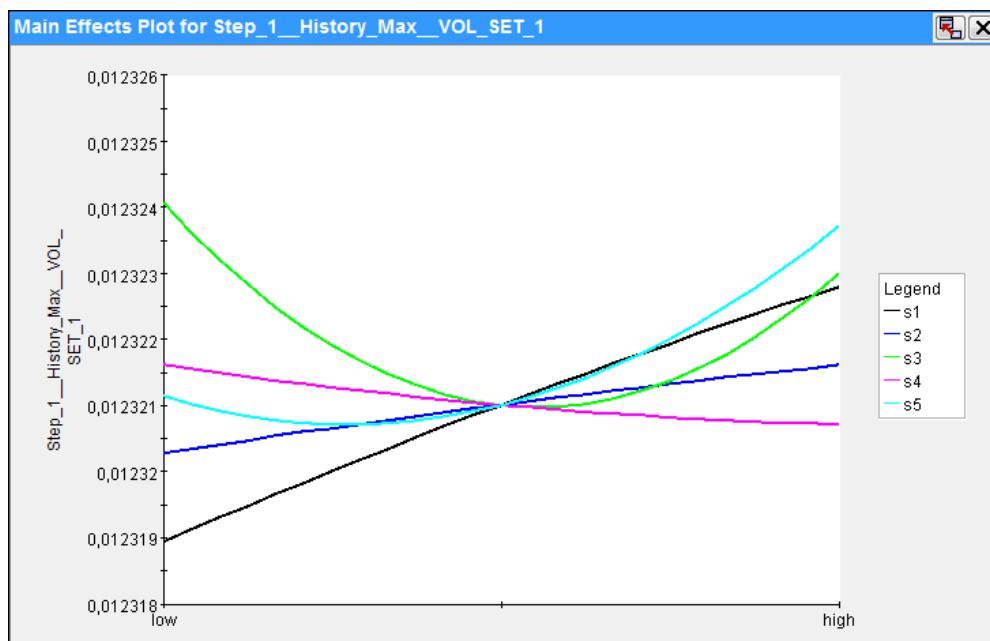


Figure 12. The influence of the moving the brackets to the first 3.5 m guide rail volume.

Naturally the brackets s4 and s5 have the most clear influence to the volume of the 5m guide rail since they are in a physical contact to that.

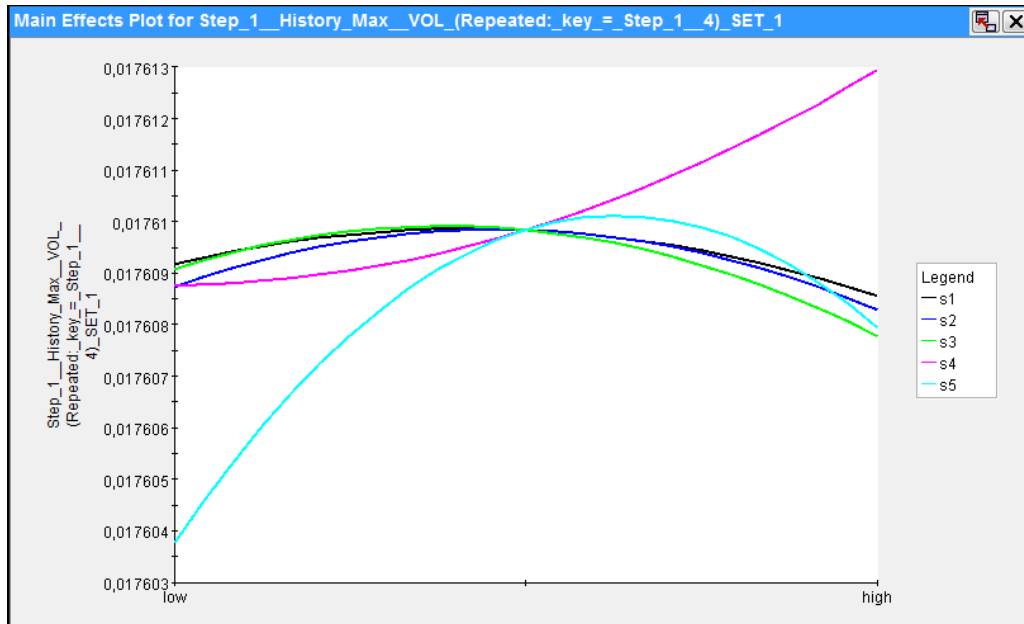


Figure 13. The influence of the moving the brackets on the 5.0 m guide rail volume.

The pareto plot describes the influence of the different combinations of the brackets on the 5m guide rail volume as well as the most important single bracket movements (linear s2 and s5). The higher the magnitude the greater the influence on the response. The higher interaction effects like e.g s3-s5 in the plot indicate that changing two parameters together will greatly influence the response. Higher 2nd order effect indicates a single parameter's like s3² effect on a response is nonlinear. The blue colour represents positive main effect when as factor increases then also the response increases. On the contrary the red colour represents the negative main effect which means as factor increases then responses decreases.

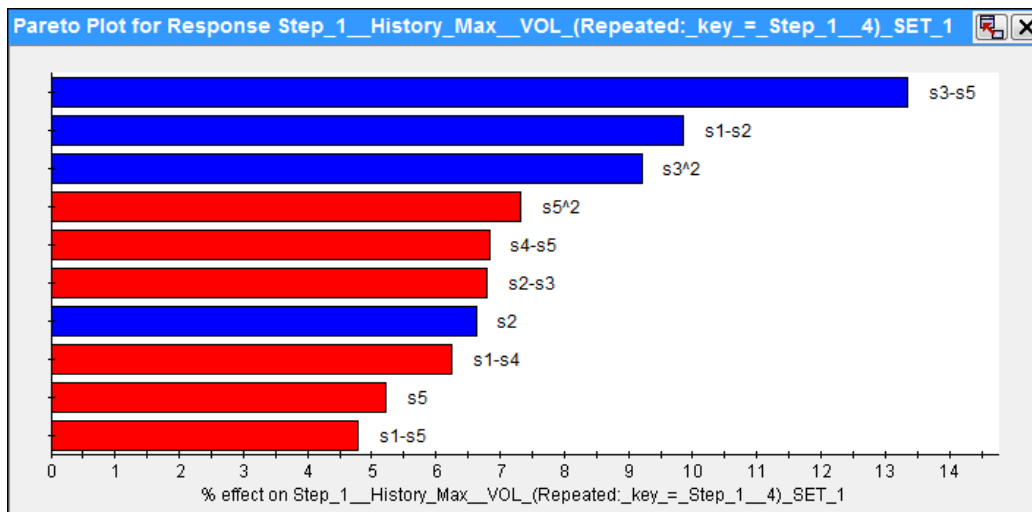


Figure 14. The Effect of the moving the brackets in terms of the 5m guide rail mass minimization.

The influence of the moving the brackets are visualized in the following figure. Left side describes the displacement in one single point of the guide rail between the brackets s2 and s3 (in the joint of two guide lines) which explains the reason why the corresponding curves separate clearly from others. According to the picture in right side the variations in the bracket coordination along the guide rail do not make big change to the maximum overall displacement which take place in the brackets itself (not in the guide rail).

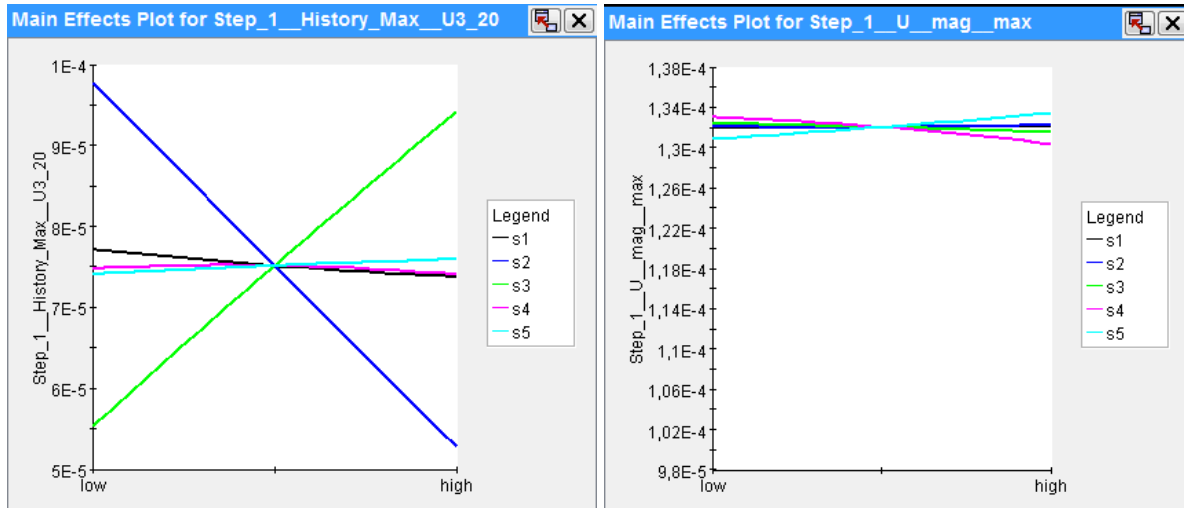


Figure 15. The influence of moving brackets to the max. displacements a) guide rail, b) total.

As an example by applying the parameters ($s1=0.22$, $s2=0.041$, $s3=-0.318$, $s4=-0.188$, $s5=0.318$) according to the DOE simulation gives very minimal reduction in the guide rail mass (less than 1%), but increase lightly the displacements in the model. It could indicate that there is not a lot of available benefit to make changes in the existing locations of the brackets.

1.3.4 Move of the roller wheel locations

The influence of the roller wheel locations were firstly calculated by the fixed distance 5m between the roller wheels. Then the both existing roller force locations were included inside one single parameter. This common parameter can get values starting from one end of the guide rail up to the opposite end minus the named 5m distance between the rollers. Here in this simple DOE run the movement of the elevator was the only design parameter and objectives were defined to be minimizations of the parameters max Von Mises stress, max overall displacement, displacement in a single point (figure 16).

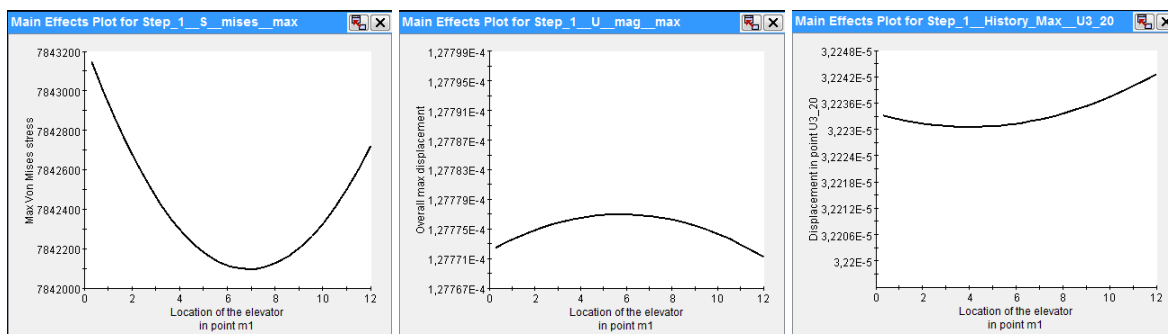


Figure 16. The responses according to the elevator location (height=5m).

The optimum roller force locations would look like following with the 5m height of the elevator car.

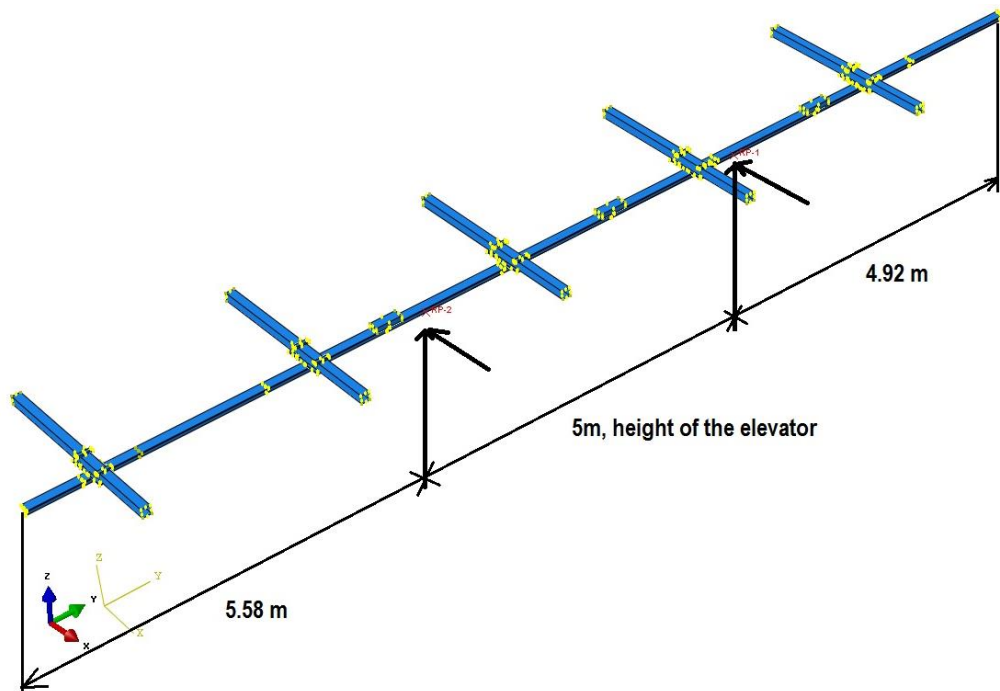


Figure 17. Optimum roller wheel locations by the constant 5m elevator height.

In the next step the height of the elevator car in other words the distance between the rollers is also included as a design variable.

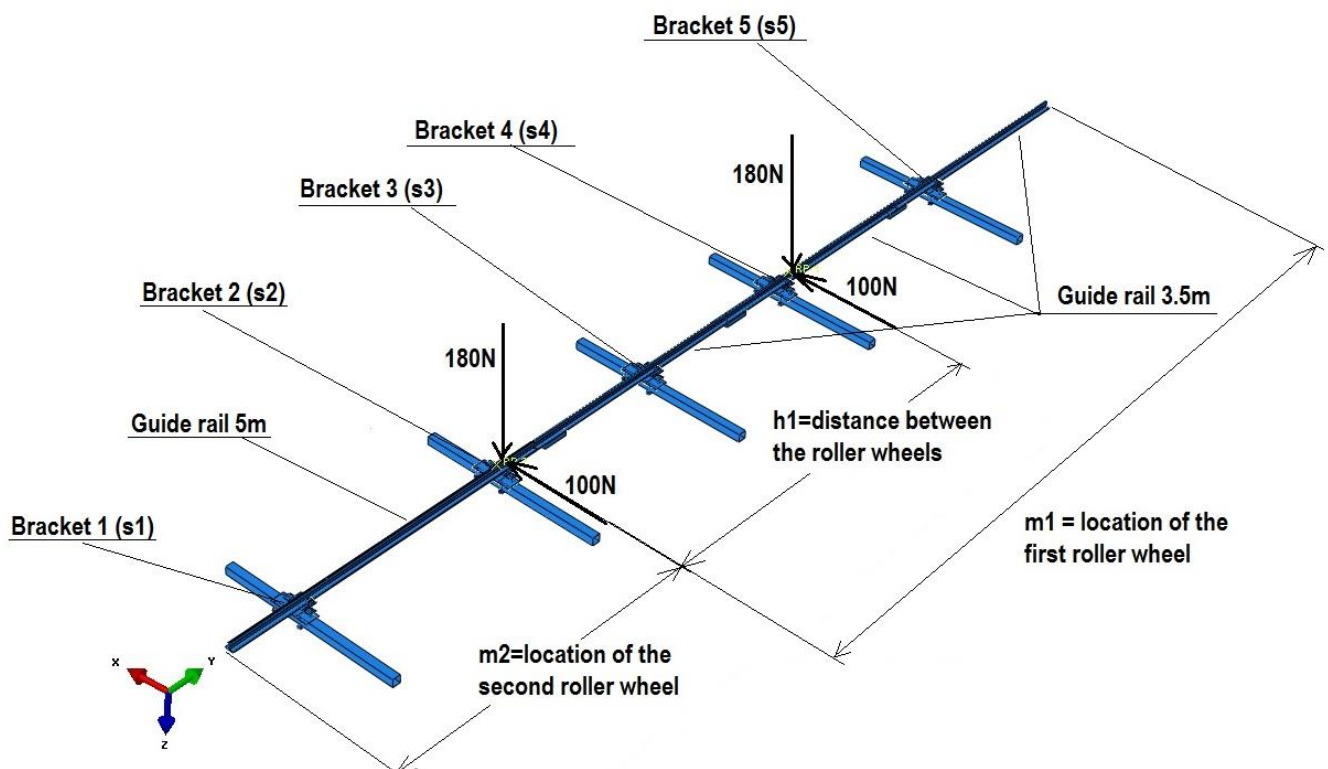


Figure 18. The roller wheel locations added to the sensitivity analysis of the guide rail.

The overall maximum Von Mises stress has a minimum point at the elevator rolling location 9.1m from the end of the guide rail with the height of the elevator car 5.18m. The height of the elevator (distance between the rollers) has a minor influence on the stress compared to the elevator location along the guide rail. By increasing the height of the elevator (distance between the rollers) increase lightly the overall maximum stress.

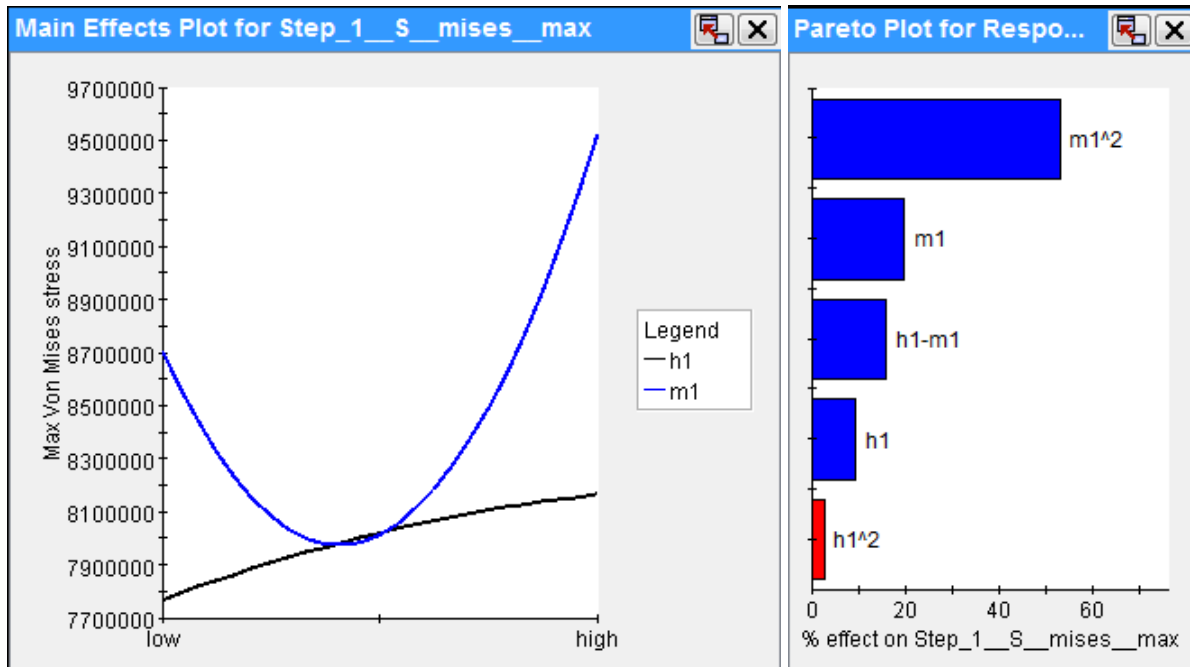


Figure 19. The influence of the elevator location ($m1$) and height ($h1$) on the overall max. Von Mises stress.

The situation is a little bit different with the overall maximum displacement. Both the location and height of the elevator seem to have roughly equal influence on the displacement.

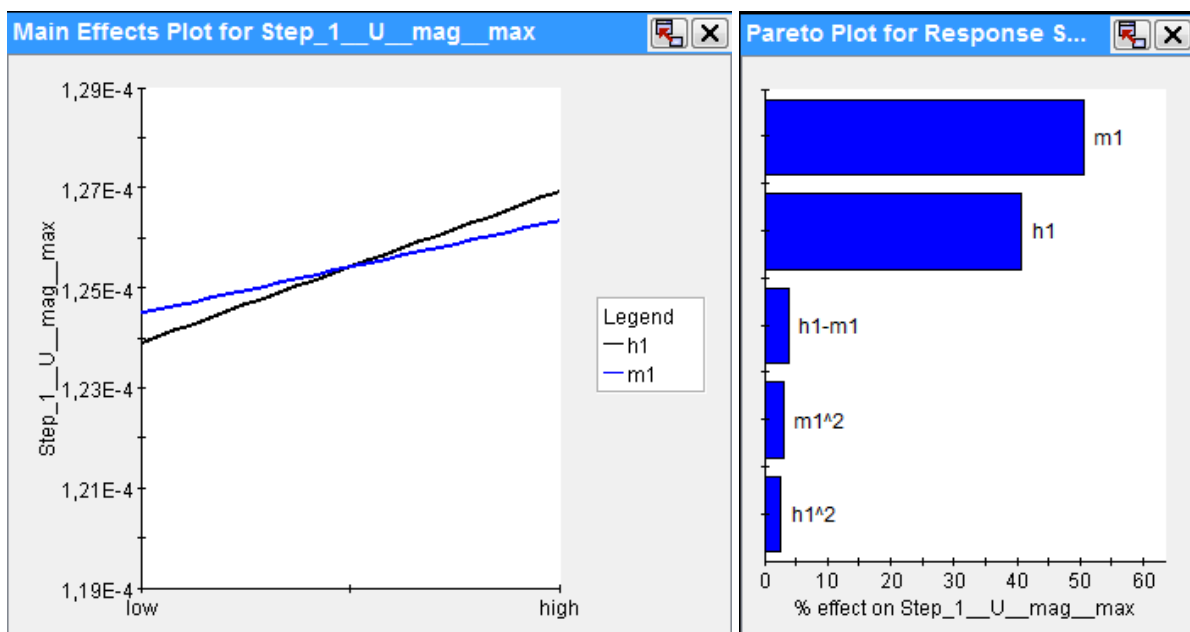


Figure 20. The influence of the elevator location ($m1$) and height ($h1$) on the overall max. displacement.

The location of the elevator has the maximum influence in the low values since the detecting displacement point is located there. The height of the elevator has a small influence.

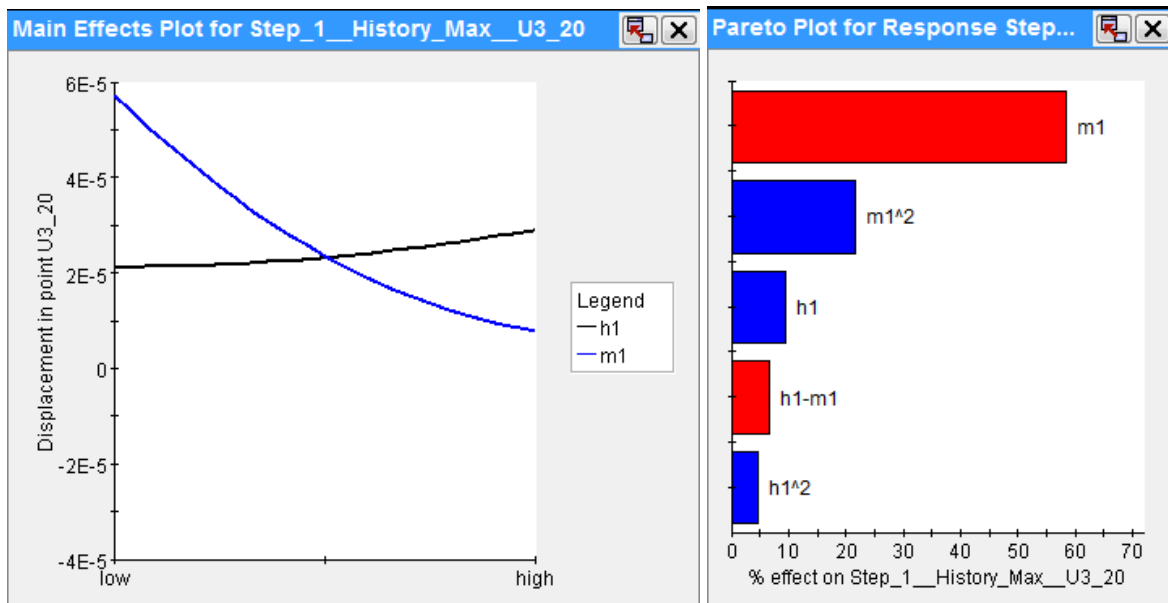


Figure 21. The influence of the elevator location ($m1$) and height ($h1$) on the displacement in a single point of the guide rail.

The influence of the all acute design variables to the guide rail volume are visualized in the next picture. The results looks different when comparing them to the maximum Von Mises stress results.

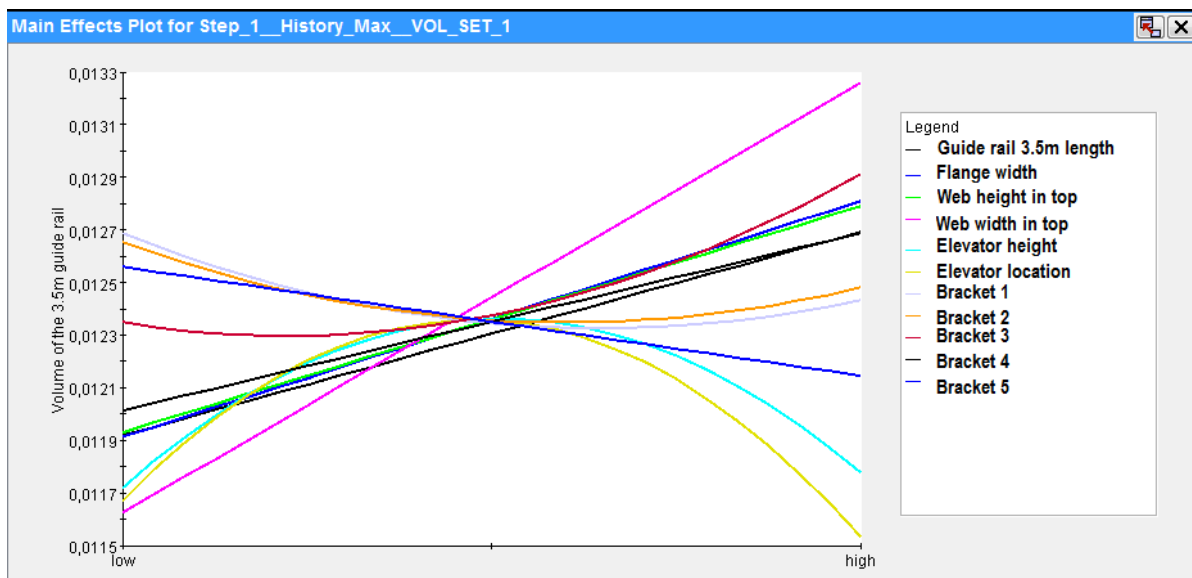


Figure 22. The influence of the guide rail design variables on the volume of the 3.5m rail.

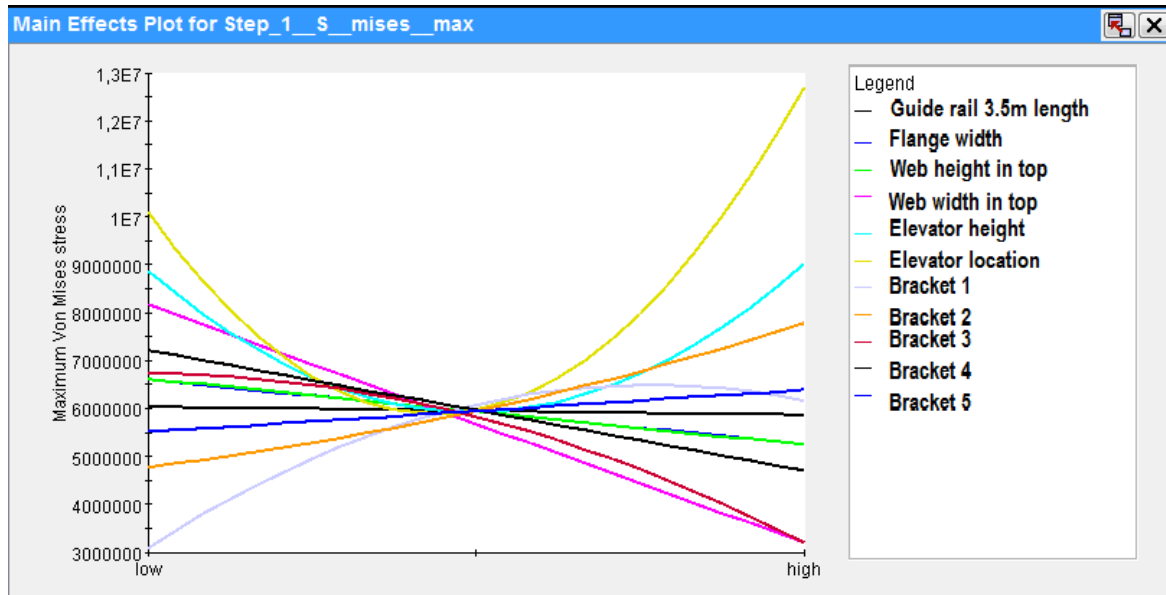


Figure 23. The influence of the guide rail design variables on the max. Von Mises stress.

The width of the flange is the most dominating parameter in the next pareto plot according to the linear results. The parameter “Web width top” has also the magnitude as strong but it’s effect on the mass of the guide rail is quite nonlinear. The mass of the guide rail decreases by increasing the value of the elevator location as the red colour describes the negative main effect but the relationship includes a lot of nonlinearity. The height of the elevator car is less dominating according to the magnitude percent.

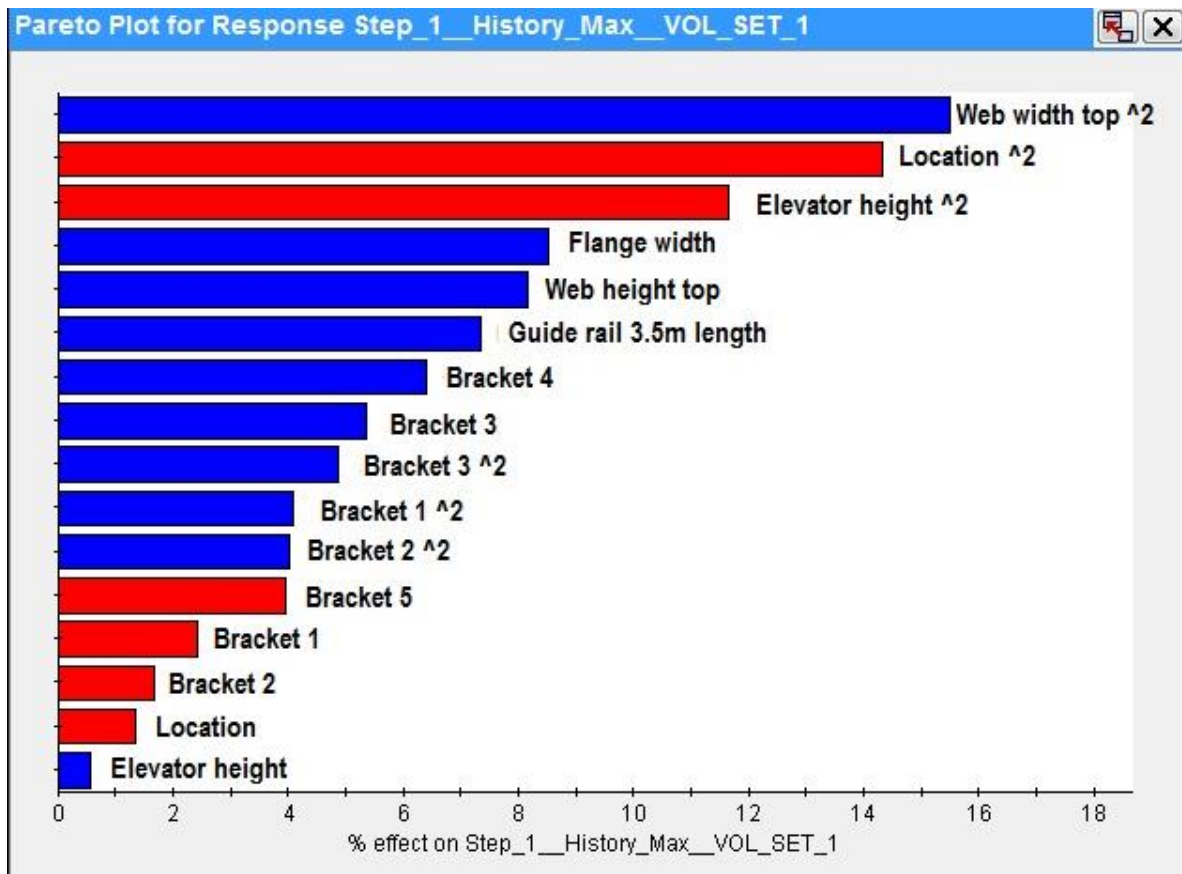


Figure 24. Pareto plot describes the importance of the design variables to the 3.5m guide rail.

1.4 Optimization by Isight

1.4.1 Basics of optimization

The optimization idea can simply be described by the following figure. The objective target is to find the highest point in the hill which means the most optimum point in the design. In the elevator guide rail case typically this is the total mass which is wanted to be minimized. The longitude and latitude curves in the figures describe the design variables, parameters that can be looped in the given frames. The small dog must stay inside the fences which create the constraints to the system (the optimization solution can be anyway started outside the fences). Typically constraints are maximum allowed displacements, stresses, certain natural frequencies, parameters where the variations are limited to the given exact values. In each optimization step target is to find a search direction that will improve the objective while staying inside the fences. Search takes place in certain direction until no more improvement is made.

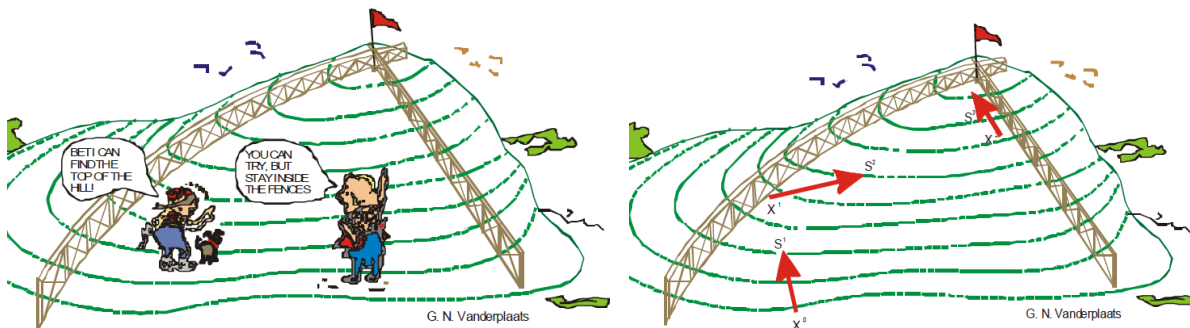


Figure 25. The simple illustration of the optimization.

The DOE (Design of Experiment) analysis is typically solved before the optimization. That describes the importance of the different parameters. In the optimization procedure the main task is to find the ultimate point meaning typically minimum, maximum or target value for the objective function. In our example the total volume of the guide rails are defined as the objective function since the volume means the same as the mass (density given). The design variables are listed in the following table with the original and the resulting optimum value. The applied constraint here was the maximum displacement in the total and guide rail model. The maximum Von Mises stress is also listed but it was not used for the optimization. The resulting design variables differ from the table in the case when the Von Mises stress is applied as the objective function.

Table 1. Conclusion of the optimization example.

		Original	Optimum
Flange width	Design Variable	0.14 m	0.126 m
Upper web height	Design Variable	0.053 m	0.05025 m
Upper web width	Design Variable	0.02 m	0.0170 m
Rail-3.5m-length	Design Variable	3.5 m	3.348 m
Volume-rail-3.5m	Objective Function	0.0123m ³ / 96.6kg	0.0105m ³ / 82.5kg
Volume-rail-5.0m	Objective Function	0.0176m ³ / 138.1kg	0.0150m ³ / 117.9 kg
Max.displacement	Constraint	1.32e-4m bracket 8.80e-5m rail	1.33e-4m bracket 9.40e-5m rail
Max.Von Mises stress	Constraint	7.622e+6 bracket 2.185e+6 rail	8.611e+06 bracket 2.468e+06 rail

The maximum displacement and Von Mises stress distributions are described in the following figures.

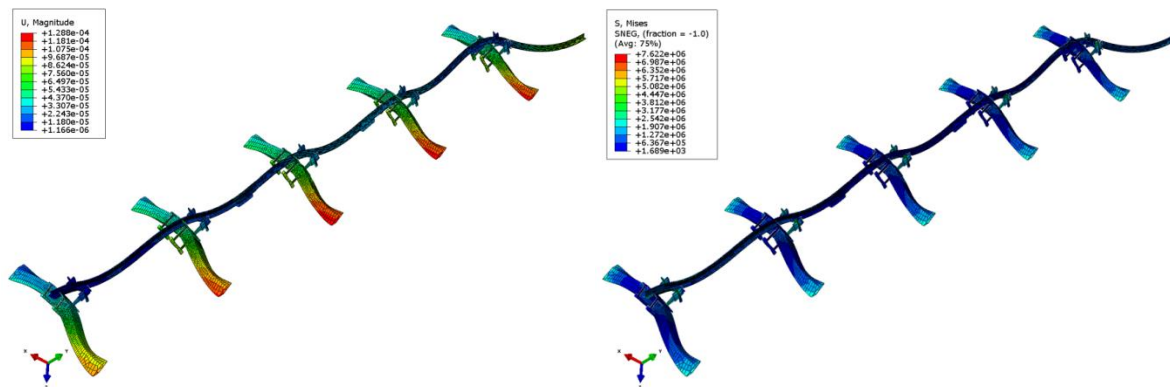


Figure 26. Maximum displacement and Von Mises stress distributions in the optimized case.

Isight uses Sequential Quadratic Programming (NLPQL) as a default optimization algorithm technique. It suits well to the long running simulation and to the highly nonlinear design spaces but not well to the discontinuous design spaces. It exploits the local area around initial design point and rapidly finds a local optimum design. It handles inequality and equality constraints directly.

1.4.2 Optimization algorithms

Different Isight optimization algorithms calculated results are compared in table 1. The operation range of the design variables as the dimensions in the following table was defined from -10% to +10% except in the distance between the roller wheels and location coordinate parameter m1. Constraints were defined according to the displacements calculated from the original model, stress was not defined as the constraint in the next table. The objective function was to minimize the volume of the guide rails. There are more optimization algorithms available in Isight but some of them need stronger cluster resources in computing or they are not directly suitable to this case. In case of errors Abaqus model would require more updating steps to be applied. There is a list of the optimization algorithms presented in the appendix 1 and information how they behaved with this guide rail example. Quite typical message appearing in the Isight optimizations refers to the missing of the final solution when the software gives a warning: “No feasible design found to satisfy all constraints”. Then it is better to try smaller runs (e.g in minimum starting from one simple loop of the acute component itself), make tests by a different optimization parameters or modifying the cae model itself.

Table 2. Conclusion of the few Isight used optimization algorithms compared to the DOE run.

	Original	DOE Analysis	NLPQL (Default)	Downhill Simplex	Evol	MISQP	Multi-Objective Particle Swarm
Objective							
Guide rail total volume		11 % reduction	10 % reduction	7.5 % reduction	11.5% reduction	9% reduction	1% reduction
Design variables							
Rail 3.5 m	3.5m ± 10%	3.325 m	3.437 m	3.470	3,400	3.500	3.675
Flange web width	0.14 ± 10%	0.128	0.126	0.127	0.127	0.126	0.134
Web top height	0.053 ± 10%	0.048	0.058	0.0526	0.050	0.047	0.0541
Web top width	0.019 ± 10%	0.0196	0.0209	0.0188	0.018	0.021	0.0170
Elevator height	4.5 – 7m	5.18 m	6.80 m	7.18 m	6.66 m	5.62 m	5.98 m
Elevator location	4.7 – 11m	m1 9.1m	m1: 9.2m	m1 10.8m	m1 11.9m	m1 9.1m	m1 12.8
Bracket 1	± 0.4m	-0.262	0.228	0.060	0.228	0.080	-0.310
Bracket 2	± 0.4m	0.097	0.4	0.223	0.148	0.206	-0.331
Bracket 3	± 0.4m	-0.014	-0.263	0.219	-0.204	-0.4	0.063
Bracket 4	± 0.4m	-0.015	0.114	0.236	-0.028	0.027	-0.180
Bracket 5	± 0.4m	0.124	0.083	0.134	0.244	0.071	-0.002
Constraint							
Max total displacement	1.27e-4	1.261e-4	1.271e-4	1.290e-4	1.30e-4	1.272e-4	1.28e-4
U3_20	3.21e-5	4.76e-5	3.974e-5	4.184e-5	2.78e-5	3.61e-5	2.56e-5
U3_5822	1.078e-5	3.89e-6	1.207e-5	1.168e-5	1.097e-5	1.22e-5	1.15e-5
U3_8363	-9.12e-6	2.81e-6	-1.06e-5	-9.03e-6	-9.41e-6	-9.7e-6	-9.9e-6
Max Von Mises stress	7842380	8740570	8181730	8001120	8346550	7970170	8165810

There seems to be surprisingly large differences in guide rail results appearing between the different Isight optimization algorithms as described in table 1. The values of the parameter in meters as the elevator location (roller wheel point m1) seem to be pretty close to each other when the values of the height of the elevator (distance between the top and bottom roller wheels) seem to differ clearly. Anyway typically 10% mass reduction in guide rail could be possible according the existing Isight optimization results. The optimum locations of the roller wheels could be for example as in the next picture in which they are calculated by the default NLPQL algorithm.

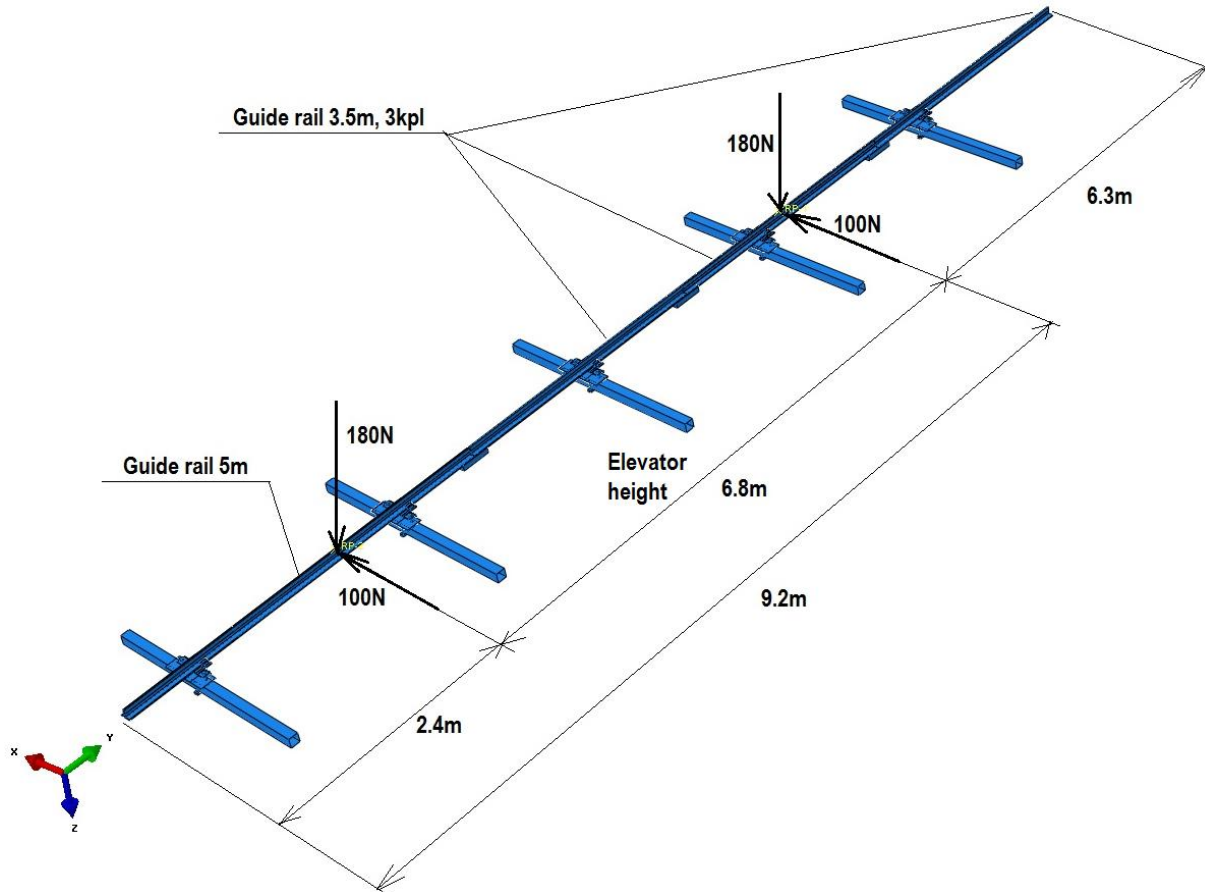


Figure 27. Optimized rolling load locations.

The most disadvantageous roller wheel locations were optimized by asking the Isight to maximize the displacements in the guide rail. The results look like following.

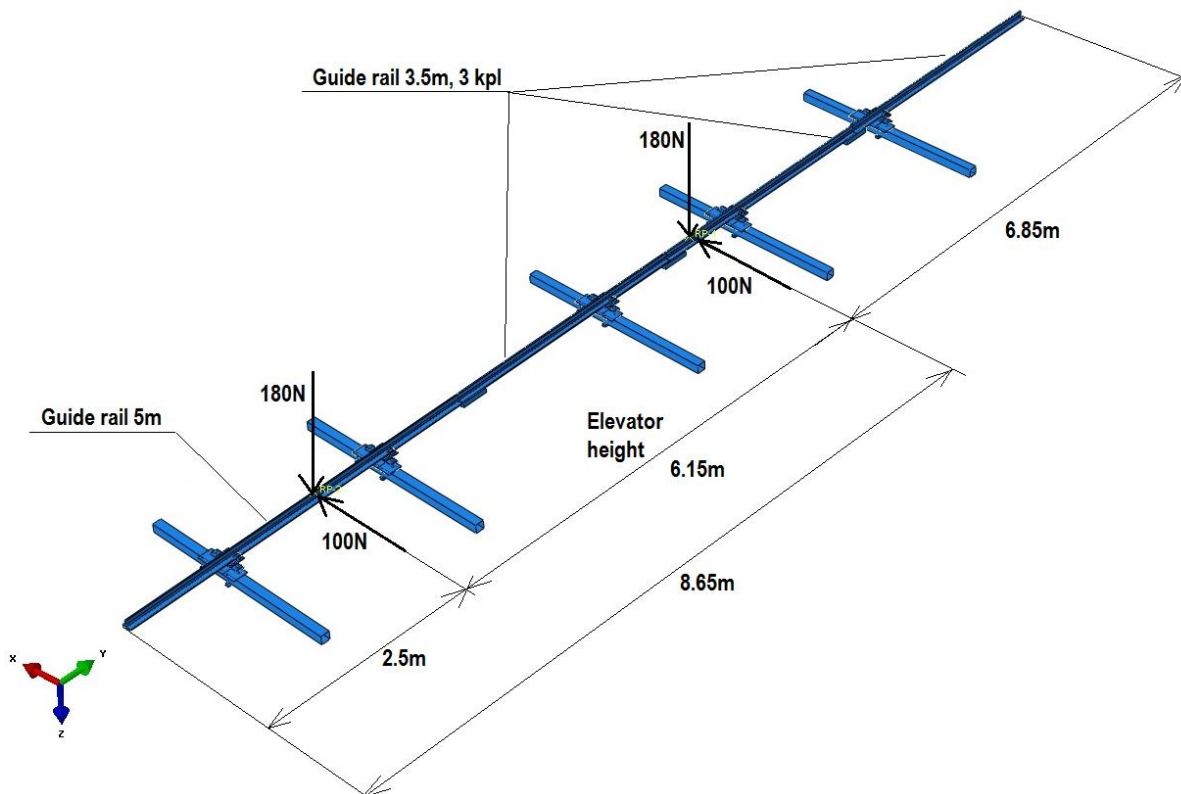


Figure 28. The most bad loading conditions by the optimization.

1.5 Buckling

The buckling analysis was tested in Abaqus CAE included to the Isight loop. The buckling is a linear axial buckling eigensolution with the first mode read as the lowest buckling load result. The buckling is defined as an own load step with the changed boundary conditions before coupling to the Isight. The unit force as the buckling load was applied to the same nodesets in which the earlier roller related forces were deleted, as described an example of the buckling forces in the next figure. The direction of the buckling loads are in the axial direction of the guide rails. Any changes were not made to the buckling FE – mesh in terms of the idealization.

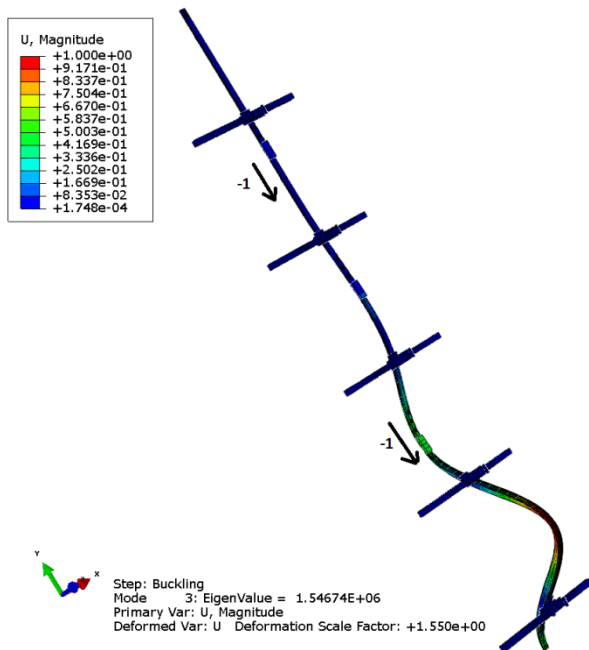


Figure 29. Buckling bending in the y-z plane, two forces, lowest buckling load 1.5MN.

As the second example the buckling load was applied 0.3m offset from the guide rail top surface (against the top roller). The offset was created by the MPC beam element. The lowest buckling load (left) is 1.98 MN and the second one 2.06 MN which are clearly above the 150 KN based on the Mathcad calculations.

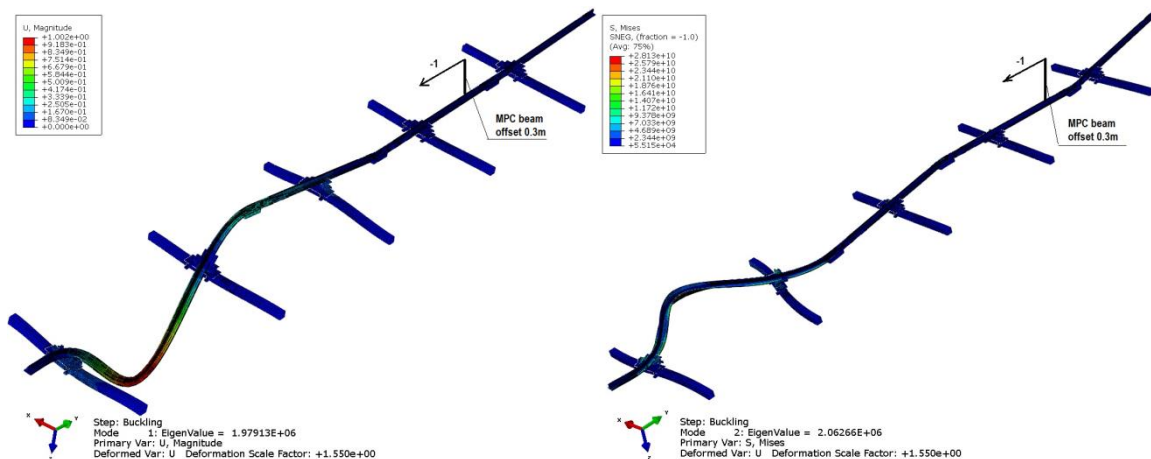


Figure 30. The buckling model coupled to the Isight, buckling load roughly 2MN by the described modes.

As the third example the buckling force was applied to the end of the guide rail as well the longitudinal displacement is free. The Abaqus encastre boundary condition was used in the opposite end of the guide rail to prevent all the displacements. The resulting buckling loads are clearly above the 150 kN. In the case of leaving the force end boundary condition free without any fixing, the buckling load crushes down to the 91 kN. The buckling seems not to be a problem in the studied one guide rail module, but the situation can be different in the larger systems. Anyway the used force and the boundary conditions are in a key position.

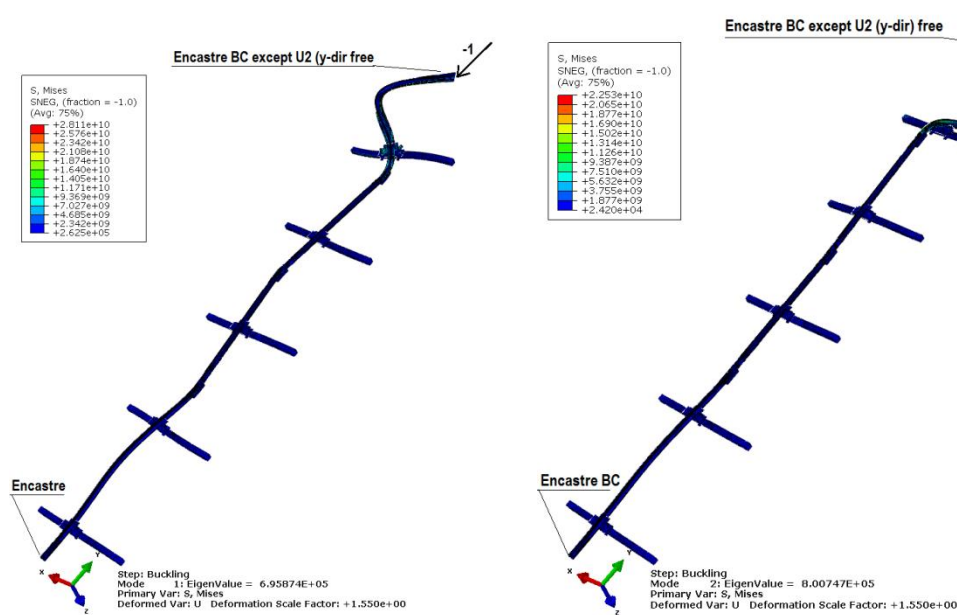


Figure 31. Force in the end, lowest buckling modes by the load 0.7 kN (left), 0.8 kN (right).

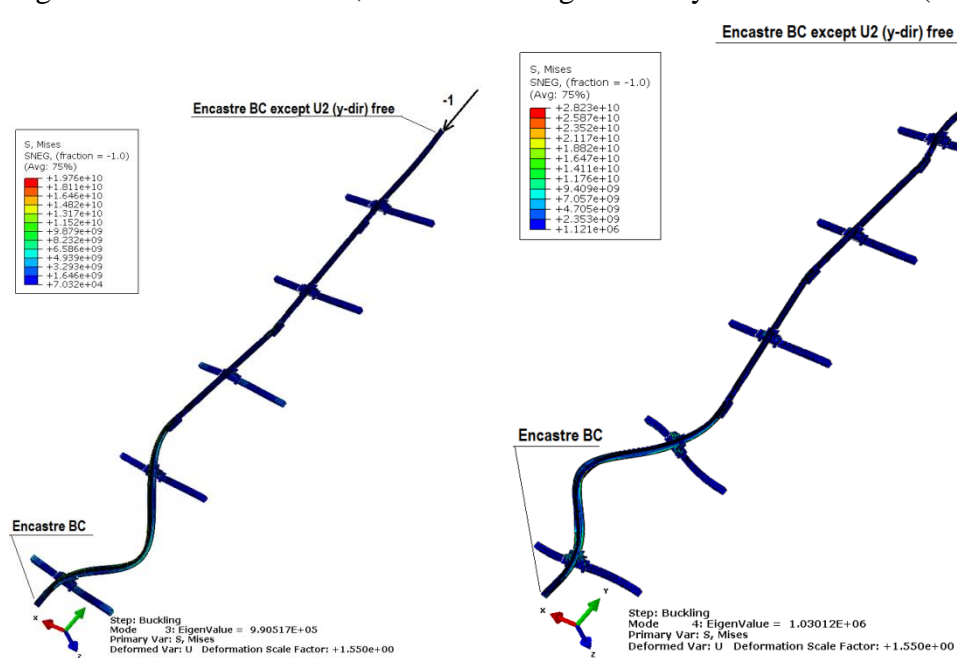


Figure 32. Force in the end, third/fourth buckling modes by roughly by the load 1.0 MN.

1.6 Discussion

All the results shown in this document are basically meant for demonstration purposes only. There are several uncertain details involved in the used optimization models.

The solid model enable more detailed design to be optimized, e.g the loads, detection points in the right locations etc. Also extra holes are possible to be included with certain dimensions made parametric in the guide rail web. On the contrary solid model is naturally heavier alternative compared to the one dimensional beam model in terms of both computing and update modification.

Each parameter must be created in Abaqus CAE, some are very straightforward but some require e.g use of the constraints, python scripting etc. and the coupling in Isight. The multiparametric model may cause problems because these can be in contradiction to each other e.g certain parameters require use of the constraints but may be harmful for some other.

Isight updates automatically the element mesh in Abaqus CAE when the element sizes are exactly defined. In the case of the number of the elements per dimension Abaqus naturally keeps this definition and basically not update the mesh. This can cause element quality problems (distorted elements) if the dimensions of the body part are changed a lot. In this case it showed that the optimization was possible in a quite narrow parameter range. In order to expand these limits the optimum solution should be raked to find more accurately the right sector and again concentrate the optimization there. Different optimization algorithms have own prons and cons depending on the actual case. Certain algorihms may offer better solutions for “raking” than others in the larger range of the parameter dimensions and finally find out the optimum solution more efficiently than others. Finally the preliminary Abaqus CAE model should be updated by cutting the acute guide rail parts to the shorter complexes.

The total number of the guide rails can be up to 76 (300m). Here was only applied the four as a fixed number of the guide rails. The model do not include the loop to find out the optimum number of the guide rails with the optimized lentgths. Now the model tries to optimize the length of the three 3.5m and one 5m guide rails.

The deflection angle in the guide rails (same position with the brackets) as the basic parameter for the ride comfort is not yet included to the solid model. That would clearly add the complexity of the Abaqus CAE model since it requires several extra parameters to be defined e.g the angles between the guide rails itself, locations to cut the guide rails in a same position with the bracket, connection to the length of the each guide rail etc.

1.7 References

[1] Demirsoz R, Imrak E, Targit S., Finite Element Analysis of Elevator Guide Rails during Safety Gear Operation., ASRAY Company, Turkey.

[2] KONE internal document.

[3] KONE internal document.

[2] Wikipedia article at: <http://en.wikipedia.org/wiki/Meta-optimization>

APPENDIX 1: Optimization algorithms used in Isight

AMGA – Archive based Micro Genetic Algorithm, not works, gives error immediately in the beginning:

ASA – Adaptive simulated annealing, Error related to the overconstraint in some nodes, algorithm requires computing in VTT cluster since the amount of the iterations is roughly 20 times larger compared to the NLPQL.

LSGRG – Large Scale Generalized Reduced Gradient, works yes but needs the cluster resources because of the huge amount of iterations.

Hooke-Jeeves – Direct search, often used when feasible design can not be determined. Here this didn't work and not found the optimum solution. Run was ended to the errors.

MMFD – Modified Method of Feasible Directions, used best when starting from a feasible design point, works yes but needs the cluster resources because of the huge amount of iterations.

MISQP – Mixed Integer Sequential Quadratic Programming, works yes but needs the cluster resources because of the huge amount of iterations.

MOST – Multifunction Optimization System Tool, works yes but needs the cluster resources because of the huge amount of iterations.

Multi-Island GA Genetic Algorithm, finished to the errors.

Multi-Objective Particle Swarm, works (some errors involved) but needs the cluster resources because of the huge amount of iterations.

NCGA – Neighborhood Cultivation Genetic Algorithm, run was ended to the errors, computation cluster is needed

Stress Ration, NSGA-II – Non Dominated Sorting Genetic Algorithm, solving stops to the errors

Pointer Automatic Optimizer, solving stops to the errors.