Department of Civil, Geo and Environmental Engineering
Chair of Metal Structures

Technische Universität München

Parametric Optimization of Steel-Concrete Composite Columns under Blast Impact

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11. Weimarer Optimierungs- und Stochastiktage
06.-07.11.2014 in Weimar

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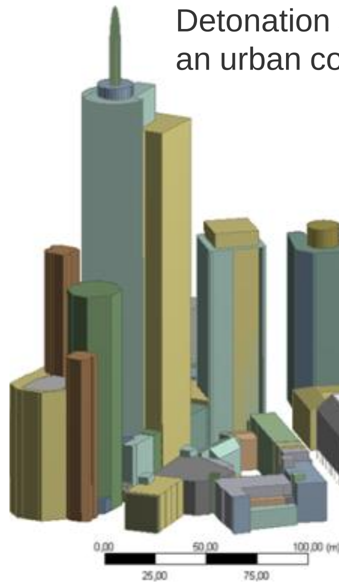
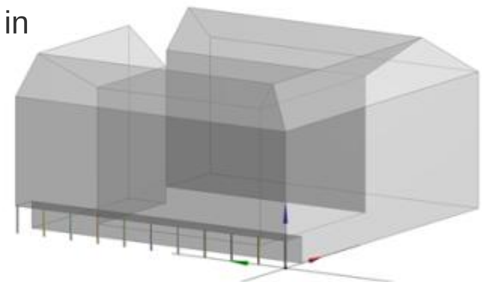
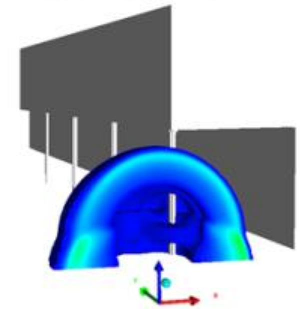
Introduction



Detonation scenario in an urban context

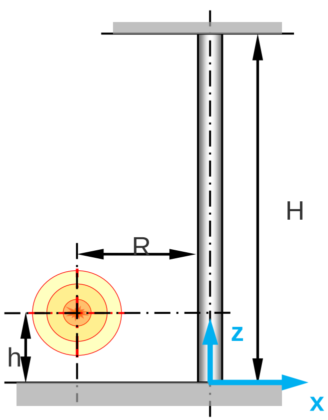




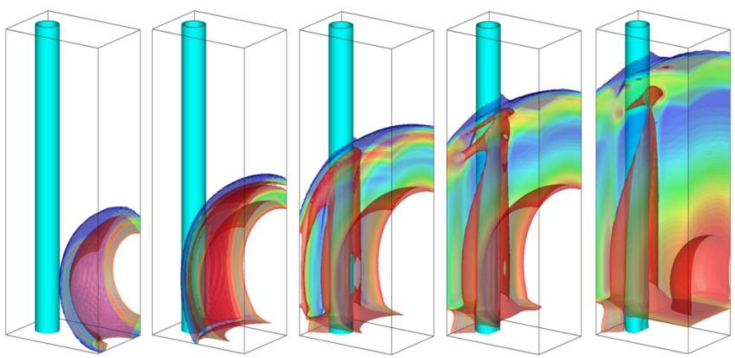
Objectives

→ Representative example of an ground floor column of an exposed building

→ Increasing the load bearing capacity under impacts from close-range detonations in combination with a realistic axial loading of the column



Ground floor column with close-range detonation scenario



Propagation of blast pressure wave along the column surface

Challenges

→ Complex material models ✓

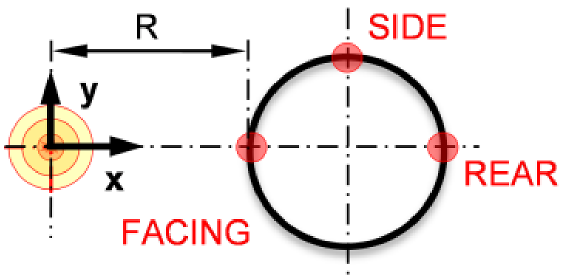
→ Verification of numerical analysis ✓

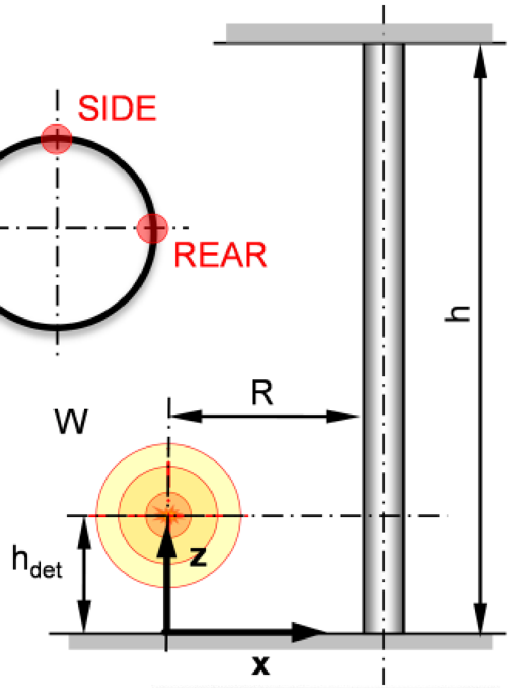
→ Fluid-Structure-Coupling ✓

→ Simulation costs (time) of 3D explicit nonlinear simulations ✓

→ Multi-dimensional optimization ✓

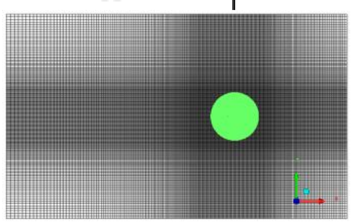
Detonation Scenario





$$Z = \frac{R}{W^{1/3}}$$

Scaled distance Z



Source: Santiago Diez Vadillo

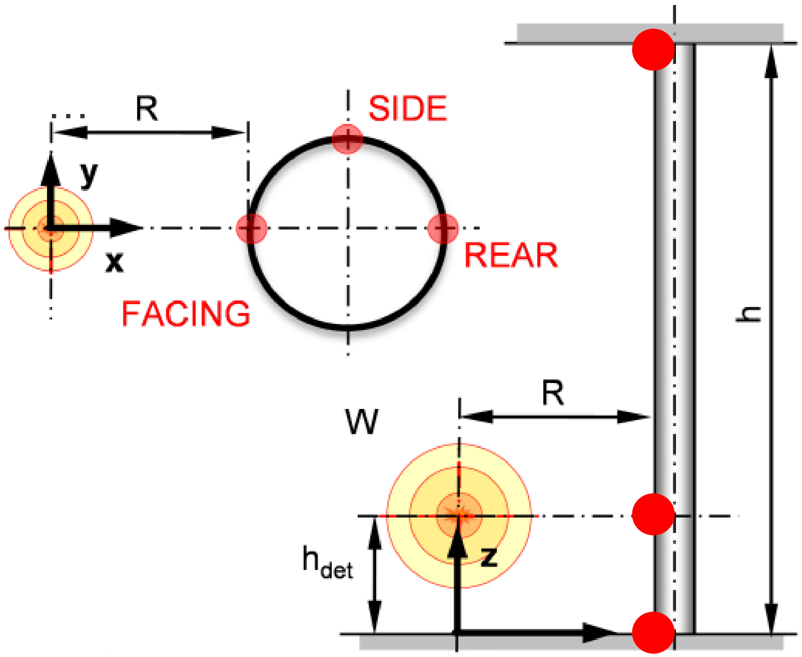
Detonation Scenario		
Distance Det.	R	1,5 m
Height Column	h	5,0 m
Height Det.	h,det	1,0 m
Scaled Intensity	Z	0,20 – 0,50 m/kg^1/3

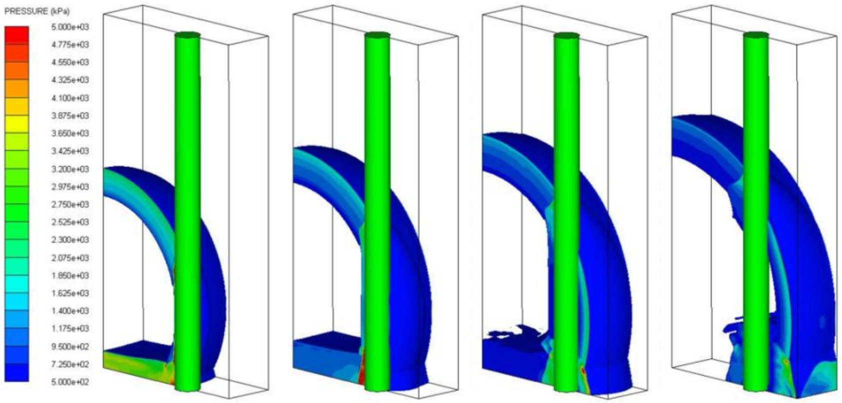
→ Close-Range detonations with high impact intensities

Numerical model of the eulerian domain

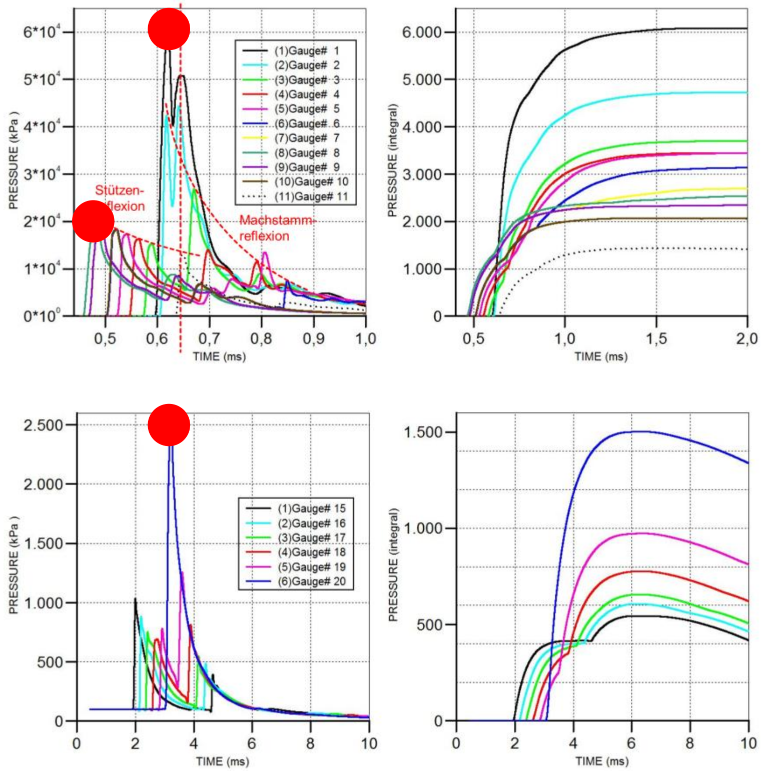
→ ANSYS AUTODYN
→ MME|FCT-Solver 1D|2D|3D domain
→ Discretisation 5/10 mm
→ Number of cells 4-16 Mio.
→ Local mesh confinment (Zoning Box)
→ Utilization of symmetry
→ Verification according to UFC 3-340-02

Blast Pressure Propagation





Column head | Column base



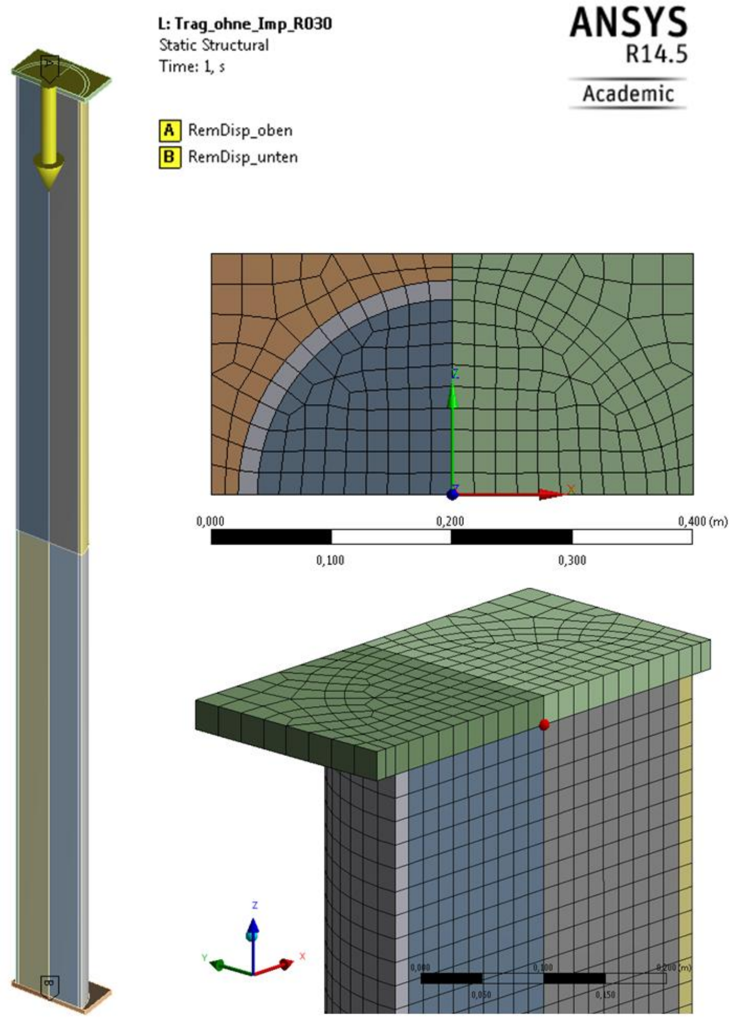
Pressure history | Impulse history

→ Complex superposition of different reflexion phenomena

→ Peak loading on the column surface from 60 MPa to 250 MPa within 5 ms

Numerical Analysis

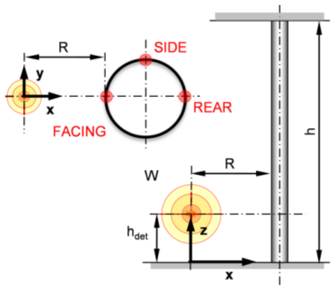
- → ANSYS AUTODYN R14.5
- → Axial pre-stress with 50% N_{pl} (!)
- → Implicit-explicit coupling for static pre-stress and dynamic blast analysis
- → Detailed sensitivity and verification analysis regarding discretization, contact, imperfections, symmetry, coupling were conducted
- → Later optimization analysis only with respect to the acceptable and verified model simplifications (!)

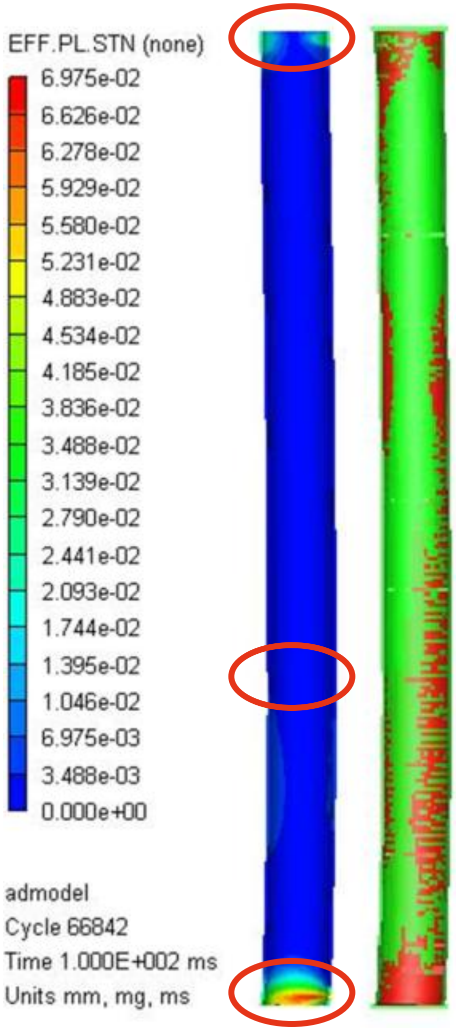


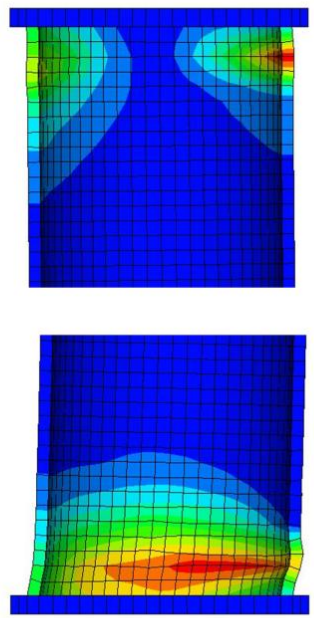
- → CHS ∅ 355,6 x 16,0 mm
- → No additional reinforcement
- → System length 5000 mm
- → Friction coefficient μ = 0,3
- → Explicit material models
  - → Steel: *Johnson & Cook*
  - → Concrete: RHT *Riedel, Hiermaier & Thoma* (EMI Freiburg)

Stahl S 355 [MPa]	
f_{yk}	355
f_{uk}	490
E_a	210000
Beton C 35/45 [MPa]	
f_{ck}	35
$f_{ck,cube}$	45
f_{ctm}	3,2
E_{cm}	34000

Load Concentrations & Failure Modes





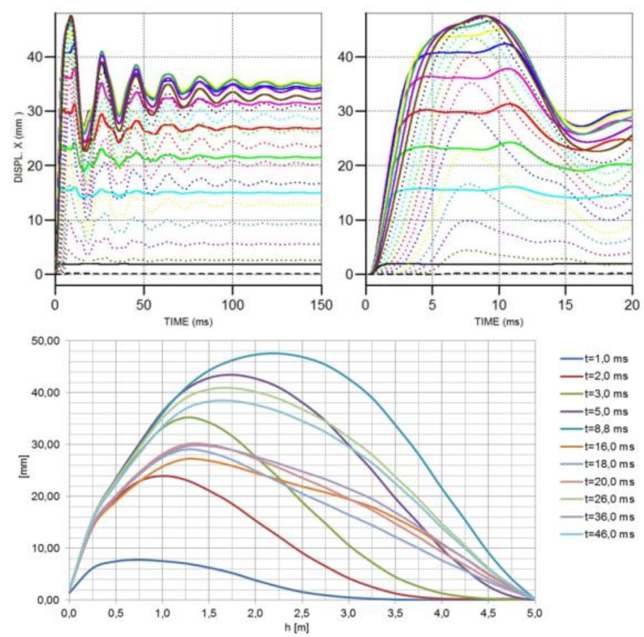


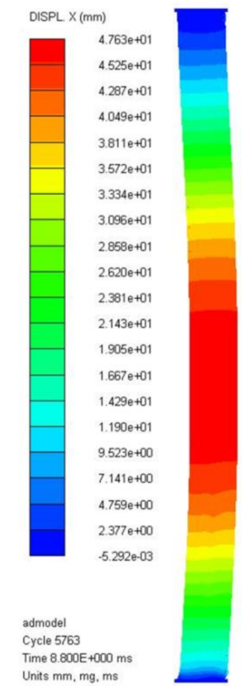
Load concentrations (EPS) and assigned crack pattern of the concrete core

→ For the highest impact intensity

→ Load concentration and shear failure mode at column base define the starting point of the optimization analysis

Horizontal deflections (DispX)

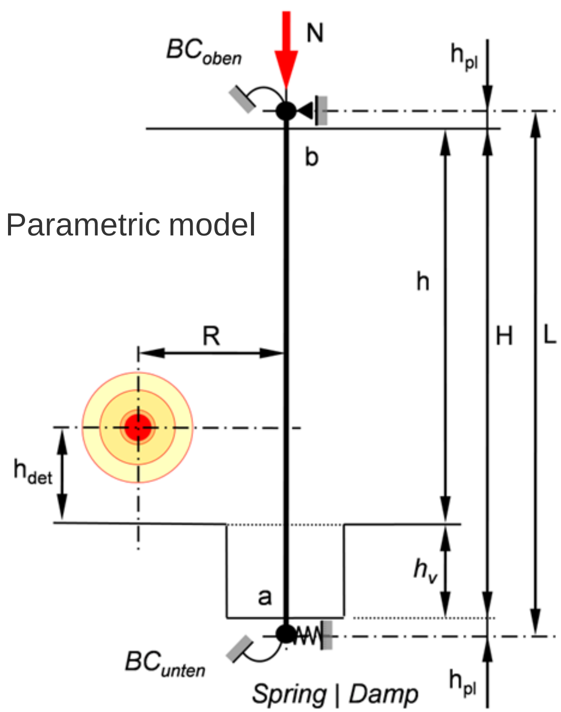




Parametric Model

→ Parameter definition with 5 input variables and 24 output variables (strains, displacements, velocities, bearing reactions,…)

Variable	Description	Min	Max	Dim.
BC_oben	Rotational DOF at column head	0 (stiff)	1 (hinged)	[-]
BC_unten	Rotational DOF at column base	0 (stiff)	1 (hinged)	[-]
h_v	Deepening	0,00	0,50	[m]
Spring	Horizontal spring stiffness	1,00E+04	1,00E+07	[N/mm]
Spring_log	Logarithmic spring stiffness	4	7	[-]
Damp	Damping at column base	1	50	[Ns/mm]



OptiSLang representation

	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range		Range plot
1	BC_oben	Deterministic	0	☐	REAL	Ordinal discrete by value	0; 1		
2	BC_unten	Deterministic	0	☐	REAL	Ordinal discrete by value	0; 1		
3	h_v	Deterministic	0	☐	REAL	Continuous	0	0.5	
4	Damp	Deterministic	1	☐	REAL	Continuous	1	50	
5	Spring_log	Deterministic	7	☐	REAL	Continuous	4	7	

Parametric Model

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Spring_log	Logarithmic spring stiffness	4	7	[-]
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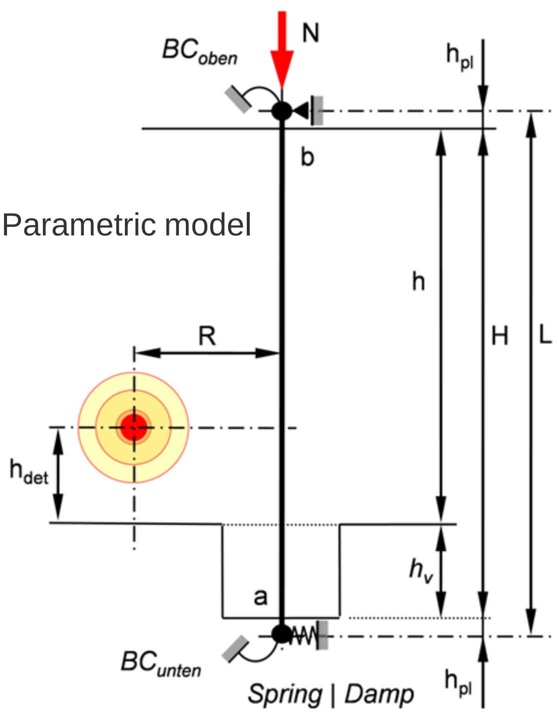
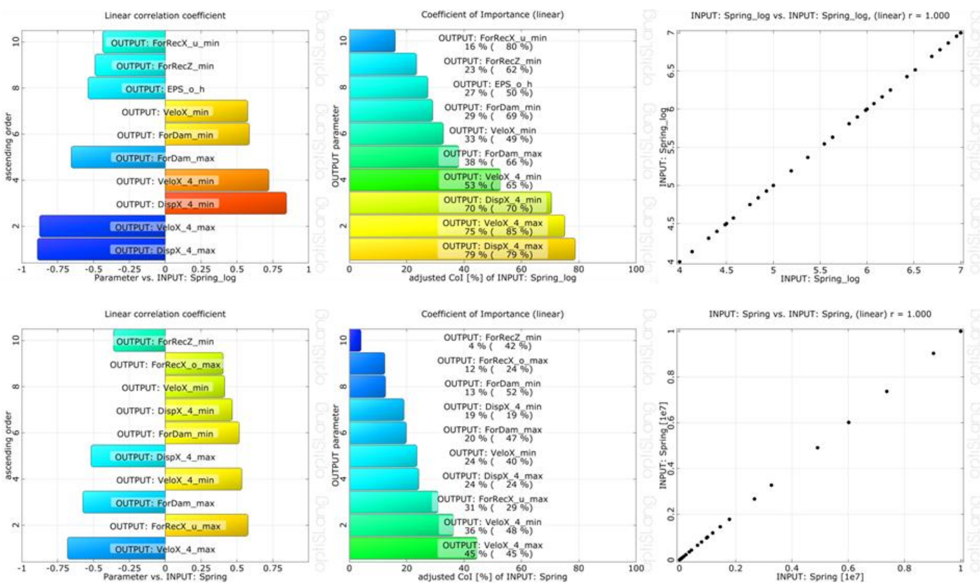
Parametric model



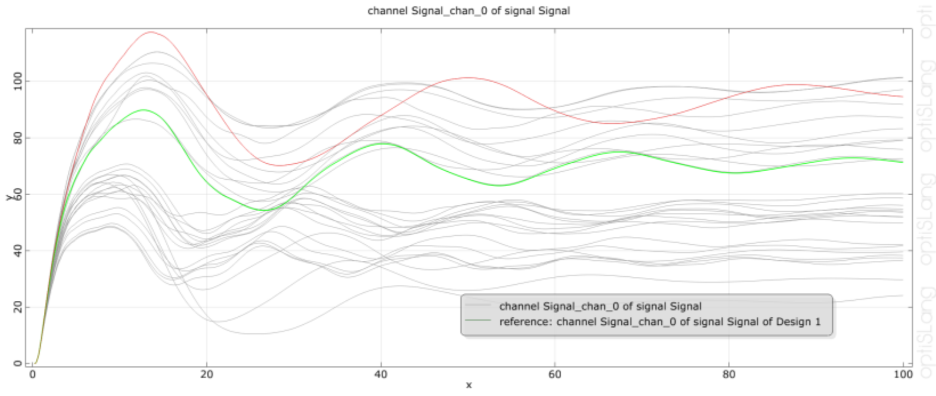
Model improvement by the logarithmic definition of the spring input variable



Sensitivity Analysis

Sampling
→ 6 predefined designs at the “corners”
→ ALHS-Sampling with 24 Designs
→ Limitation of designs due to complex nonlinear models

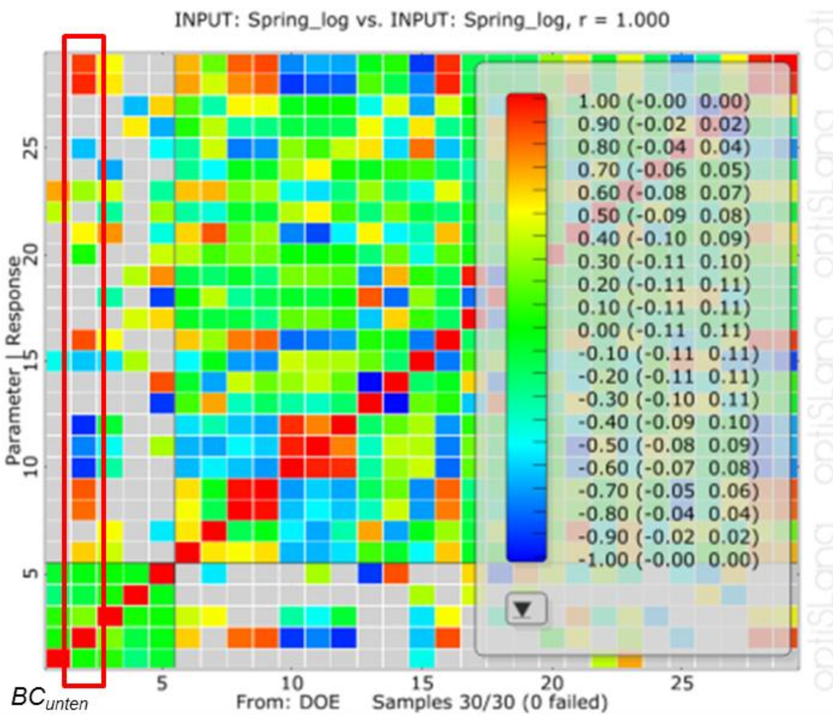
Signal: Derived history of maximum system deflections



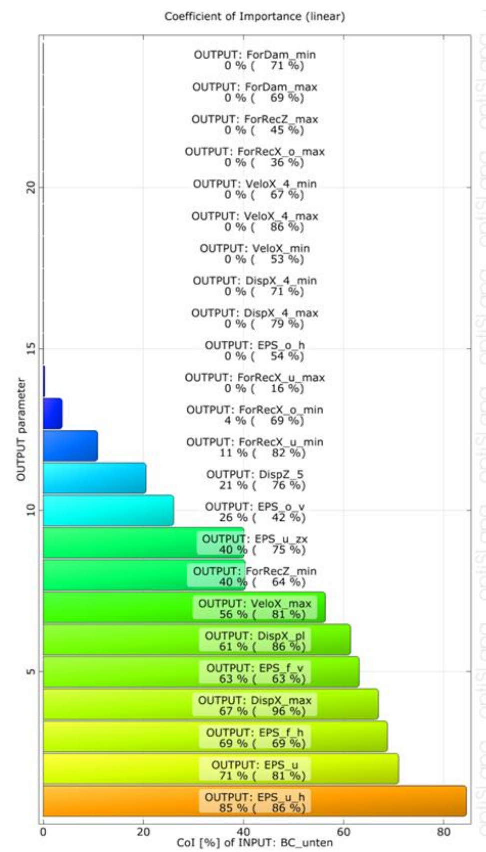
Design	BC_oben	BC_unten	h_v	Spring	Spring_log	Damp
1	0	0	0,00	1,00E+07	7,00E+00	1
2	1	1	0,50	1,00E+07	7,00E+00	1
3	1	1	0,50	1,00E+04	4,00E+00	1
4	0	1	0,10	3,16E+04	4,50E+00	25
5	1	0	0,20	1,00E+05	5,00E+00	10
6	0	1	0,30	1,00E+06	6,00E+00	50
7	0	1	0,15	4,91E+06	6,69E+00	10
8	1	0	0,25	6,02E+06	6,78E+00	39
9	1	1	0,45	3,75E+04	4,57E+00	20
10	1	0	0,20	3,06E+04	4,49E+00	26
11	0	0	0,40	3,27E+06	6,51E+00	29
12	1	0	0,05	4,29E+05	5,63E+00	42
13	1	0	0,10	5,62E+04	4,75E+00	5
14	0	0	0,20	1,36E+04	4,13E+00	36
15	1	0	0,00	2,67E+06	6,43E+00	16
16	1	0	0,30	1,45E+06	6,16E+00	6
17	1	1	0,50	9,03E+06	6,96E+00	46
18	1	1	0,05	6,89E+04	4,84E+00	2
19	0	0	0,45	1,78E+06	6,25E+00	35
20	1	0	0,00	7,89E+05	5,90E+00	49
21	0	0	0,40	9,67E+05	5,99E+00	7
22	1	0	0,50	6,44E+05	5,81E+00	33
23	0	1	0,25	2,33E+05	5,37E+00	25
24	1	0	0,15	8,44E+04	4,93E+00	18
25	1	1	0,15	7,37E+06	6,87E+00	9
26	0	1	0,15	1,18E+06	6,07E+00	38
27	1	1	0,40	2,04E+04	4,31E+00	44
28	0	0	0,25	2,49E+04	4,40E+00	45
29	0	0	0,10	3,50E+05	5,54E+00	48
30	1	1	0,25	1,55E+05	5,19E+00	13
141	0	1	0,00	1,00E+07	7,00E+00	34
397	0	1	0,20	7,89E+06	6,90E+00	41

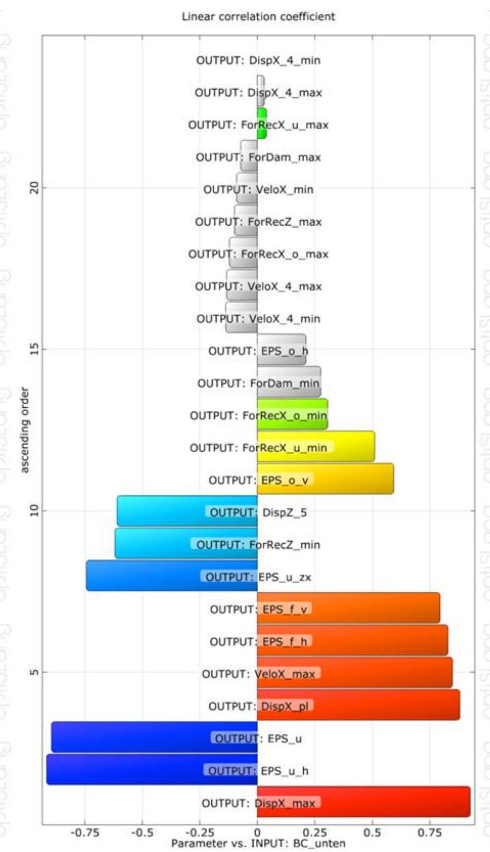
Sensitivity Analysis

→ Good descriptiveness of the system behaviour by the chosen parametric model



Input → | ← Output Variables



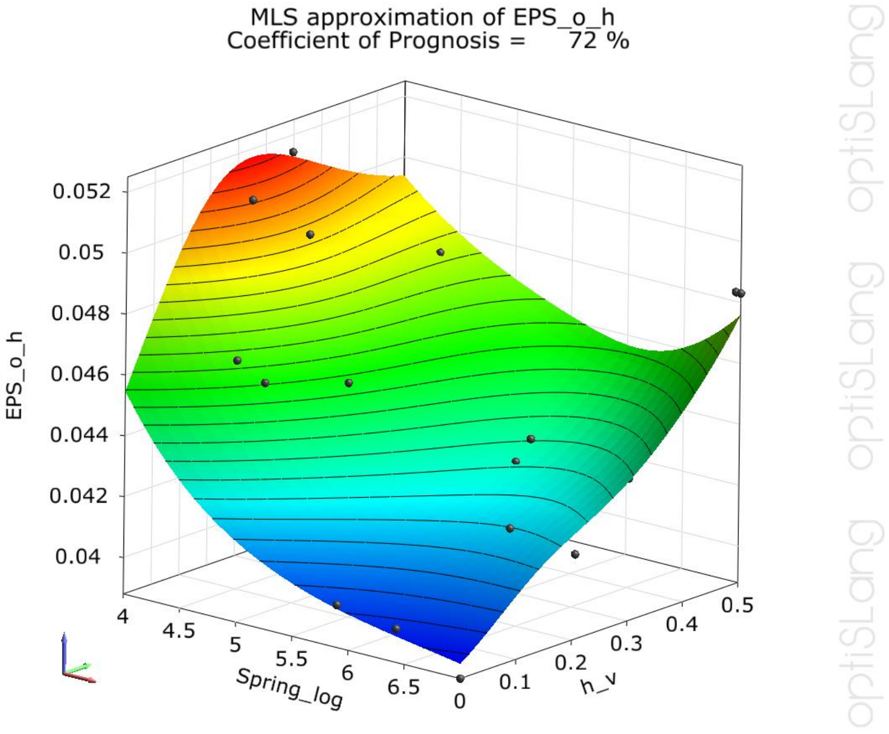


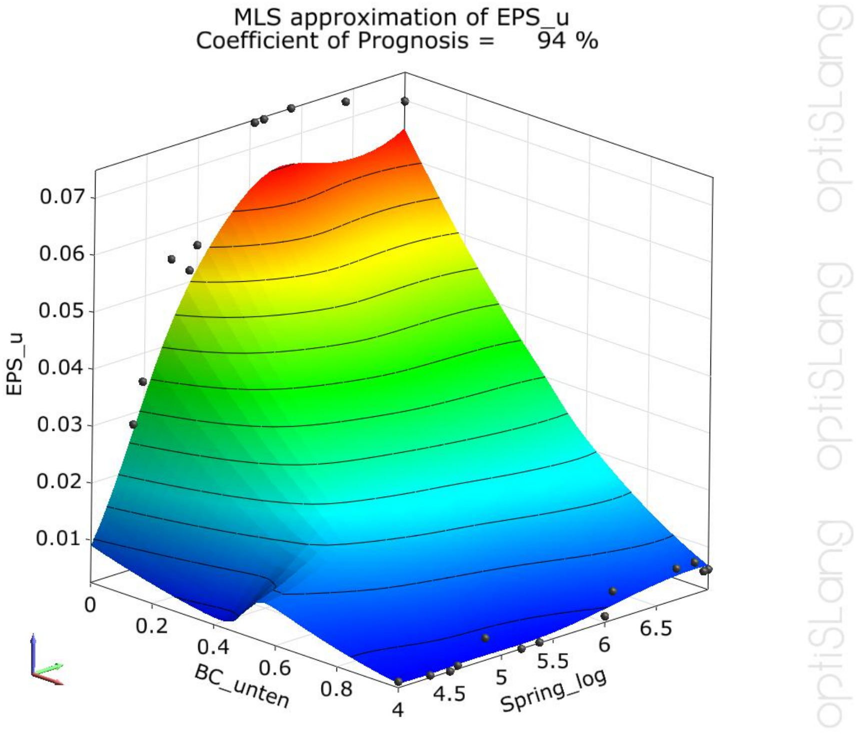
CoI and linear correlation coefficients
for input variable BCunten

Sensitivity Analysis

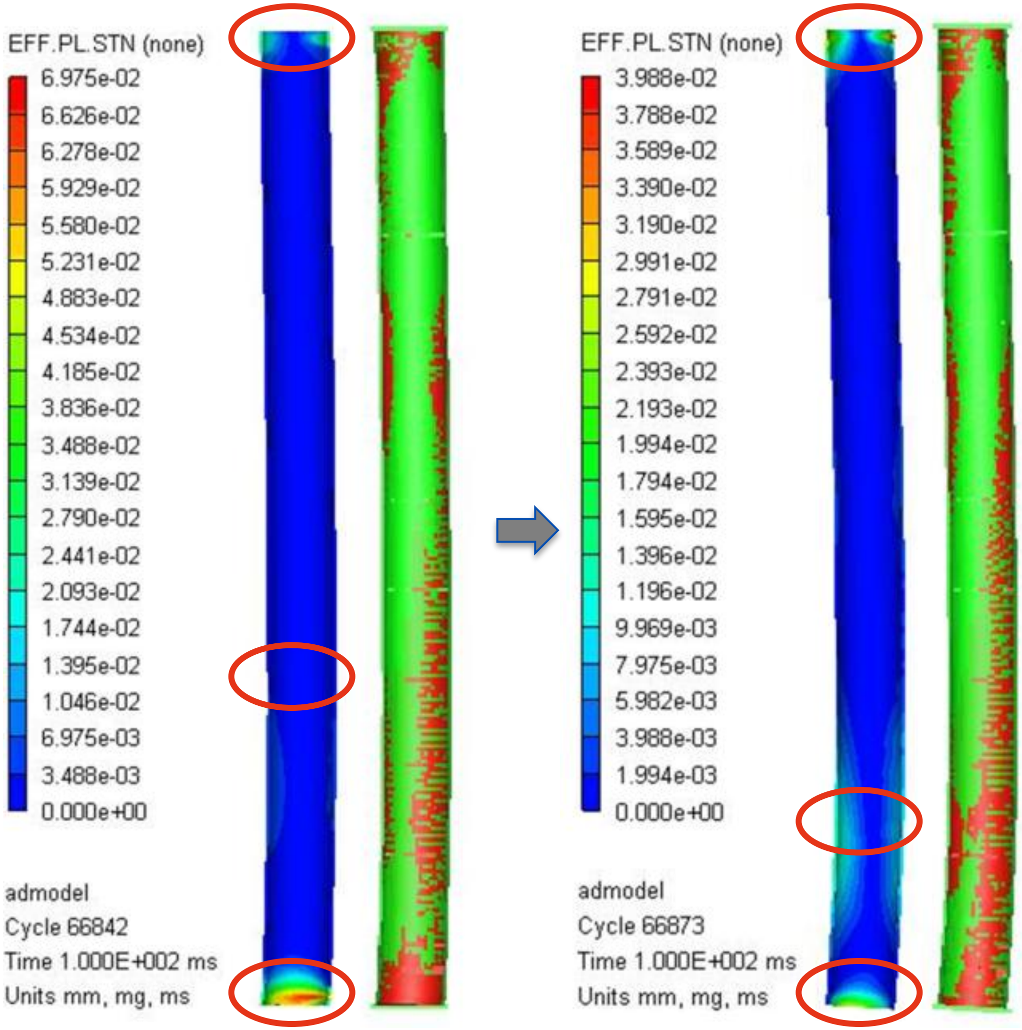
→ Good descriptiveness of the system behaviour by the chosen parametric model

Descriptiveness (CoP) of load concentrations by output variables EPSi





Optimization – Minimizing Load Concentrations

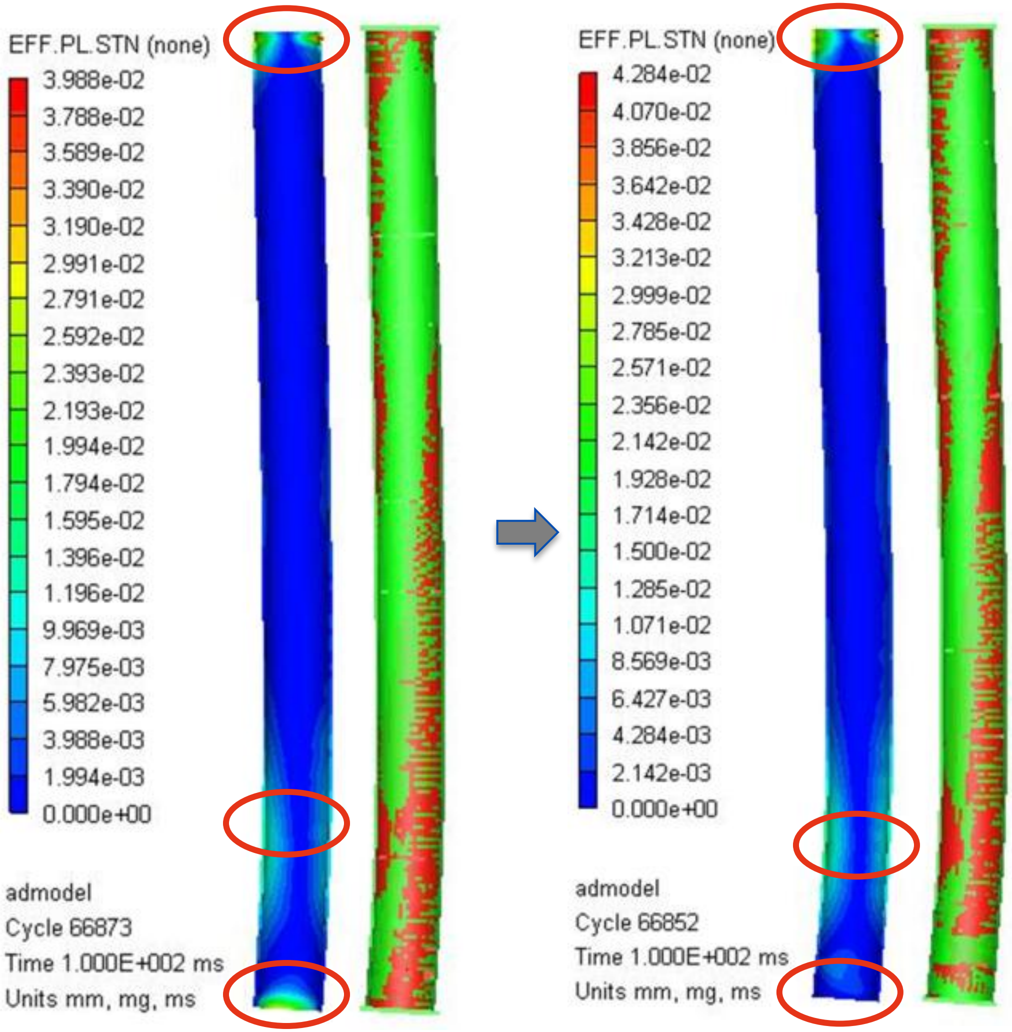


History of Optimization with MOP

Input-Variable	Design (141)
$Spring_{log}$	7,0
Damp	34
H_v	0
BC_{unten}	**1**
BC_{oben}	0

- → Optimization using the Metamodel of Optimal Prognosis (MOP) with Evolutionary Algorithm (EA)
- → Objective: Minimum EPS
- → No additional numerical analysis needed
- → Reduction of the dimensioning load concentration to less than 60%
- → (But increase of maximum deflections)
- → Inaccuracy by verification limited to 1,5%

Pareto Optimization – 2 Objectives



Objective Pareto Plot

Input-Variable	Design (397)
$Spring_{log}$	6,9
Damp	41
H_v	**0,20**
BC_{unten}	**1**
BC_{oben}	0

- → Pareto optimization using the MOP with a Particle Swarm Algorithm (PSO)
- → Objectives: 1) Minimum EPS
  2) Min horizontal bearing loads
- → No additional numerical analysis needed
- → Resulting Pareto-Front gives minimum combinations for objectives
- → Inaccuracy by verification limited to 2,3%

Conclusion

Achieved objectives for increasing the capacity of the column structure

- → Reduction of load concentration → general increase of resistance ✓
- → Avoiding the shear failure mechanism ✓
- → Controlled redistribution of loads ✓
- → Reduction of peak bearing loads ✓
- → Comparison of different optimization strategies ✓
  - → bearing characteristics
  - → variable deepening at column base
  - → controlled horizontal flexibility at column base

General amendments

- → Logarithmic variable definition increased the descriptiveness of the model
- → Designs at the "corners" of the parameter space guarantee the mitigation of failed designs
- → Limited number of designs achieved good results for the verification
- → Guideline for similar dynamic engineering problems

Research Focus

Blast Protection in Civil Engineering

→ New since October

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Thank you for your kind Attention!