Technische Universität Hamburg

Bahnprojekt Stuttgart–Ulm
Talquerung mit Hauptbahnhof

Numerical Methods in Geomechanics

Numerical Calculations for Foundation and Structure of the Main Station Stuttgart S21

Alexander Mühl, Michael Brunner, René Luna (CDM Smith)

Clemens Neugart, Torsten Noack (Werner Sobek Stuttgart AG)

INGENIEURGEMEINSCHAFT
STUTTGART 21
GEOTECHNIK

Main Station Stuttgart S21

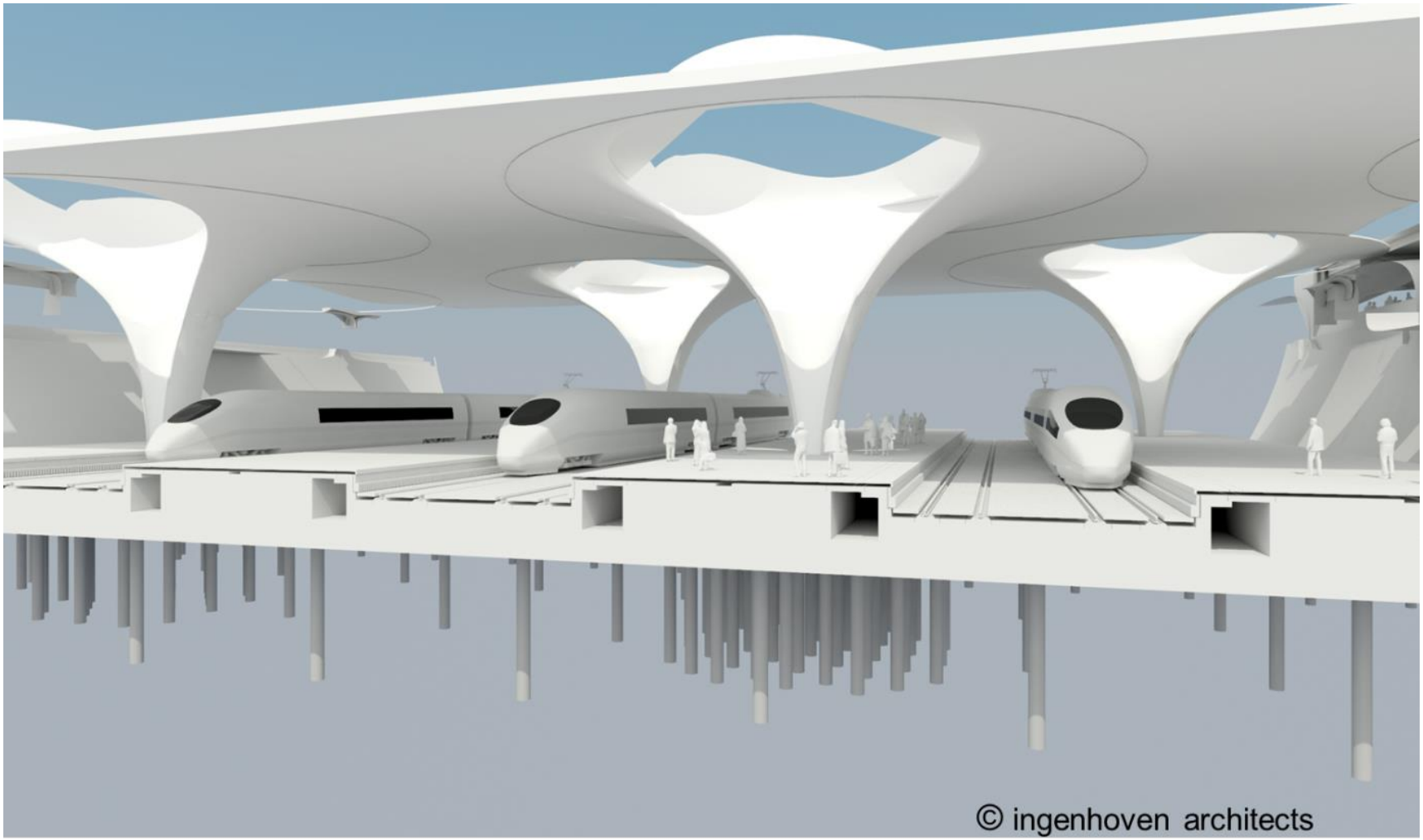
- **Core Project as part of modernisation of railway link between Munich and Paris**
- **450m long, 80m wide underground station**
- **Base plate 12m below ground**

Main Station Stuttgart S21

- **Special characteristic: Doubly Curved Roof with Chalice Columns**
  - Designed by Ingenhoven Architects with contributions of Frei Paul Otto
  - Complex double curved geometry of the roof with constantly varying thickness
  - Filigree roof structure narrows down into single columns connecting the roof with the ground plate
  - White Exposed Concrete C50/60

- **Boudary Conditions**
  - Varying subsoil stratification
  - Structure sensitivity to settlements
  - High concentrated loads
  - Difficult Site constraints
  - Crossing of underground line
  - Construction divided into twenty construction sections

Main Station Stuttgart S21



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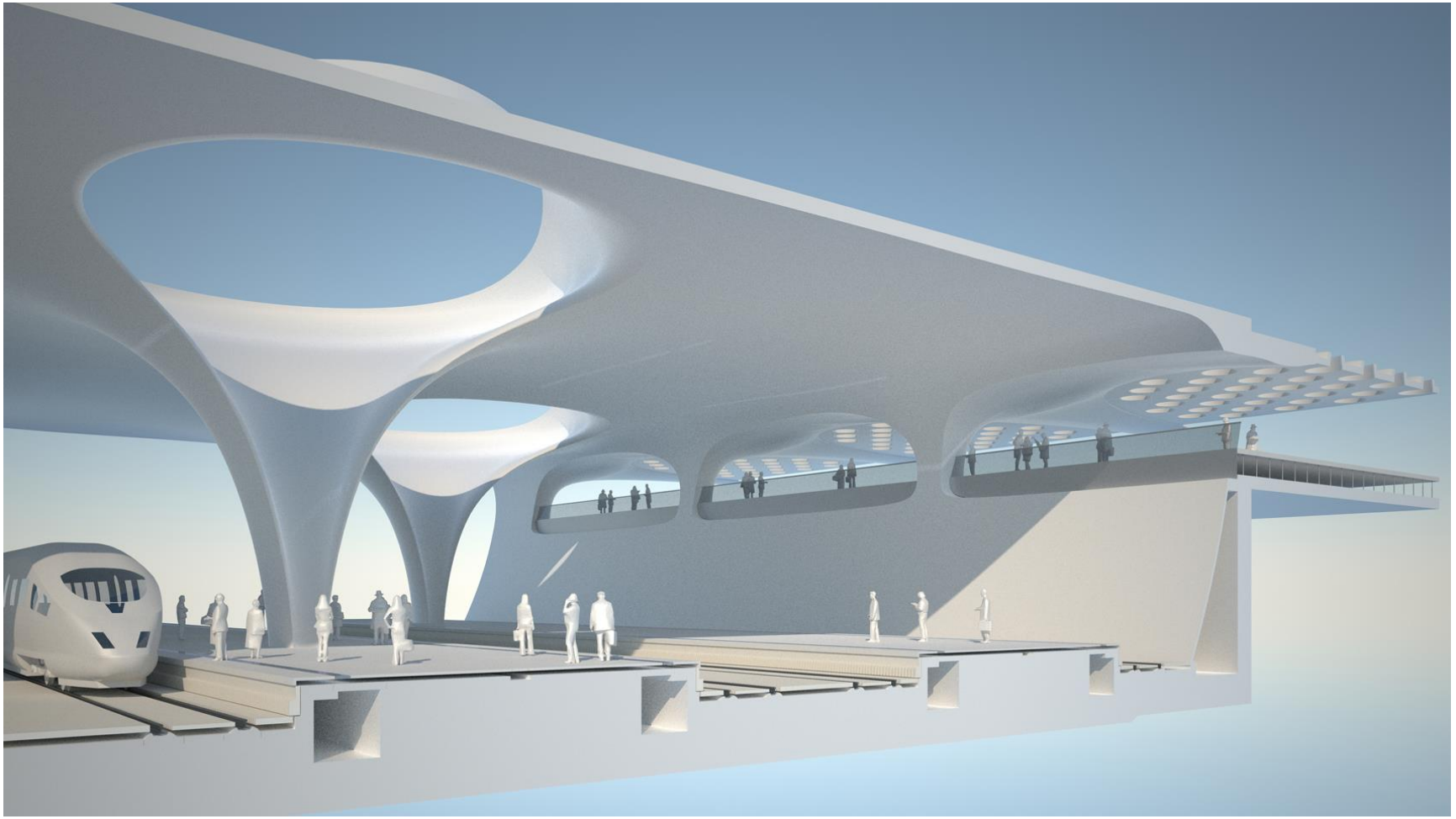

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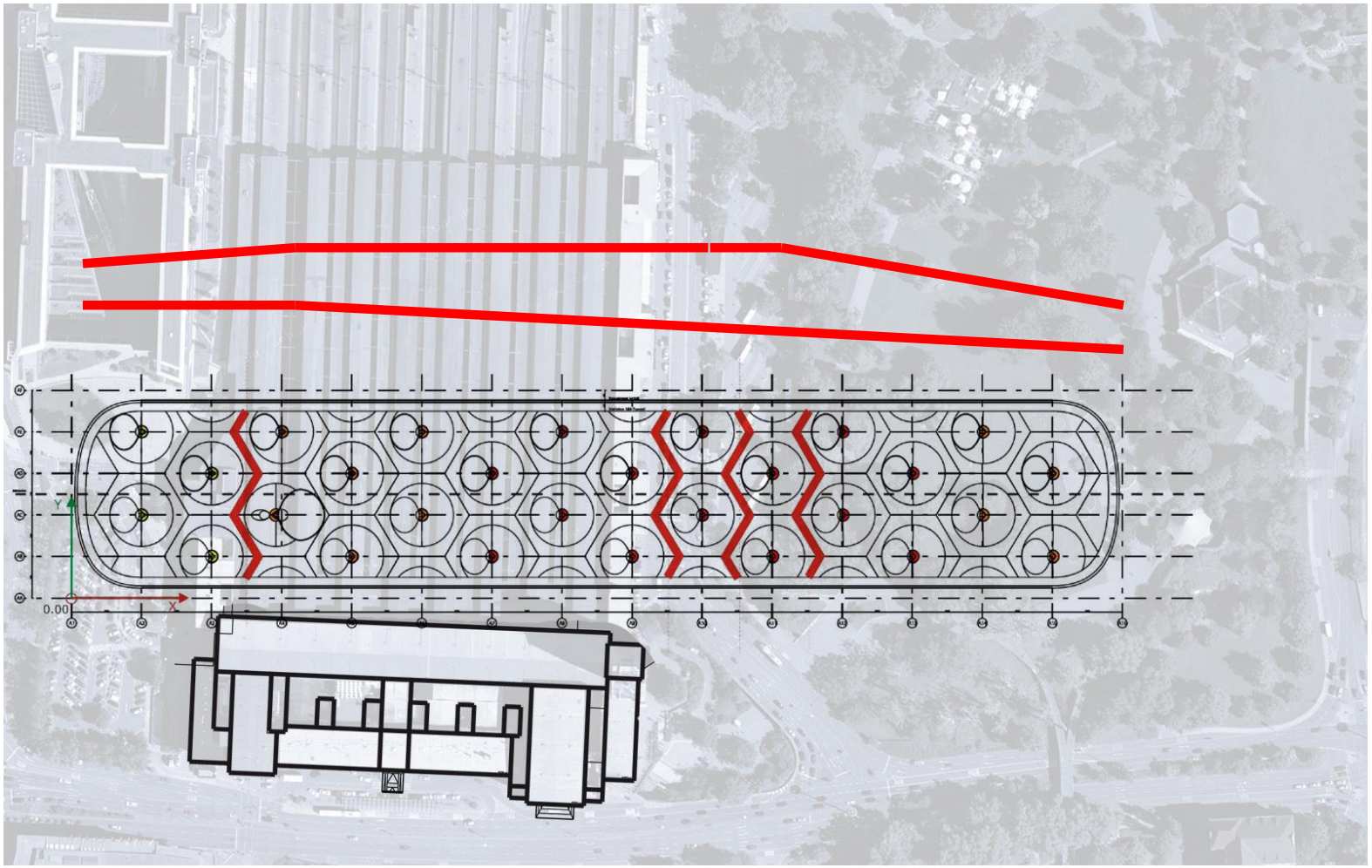

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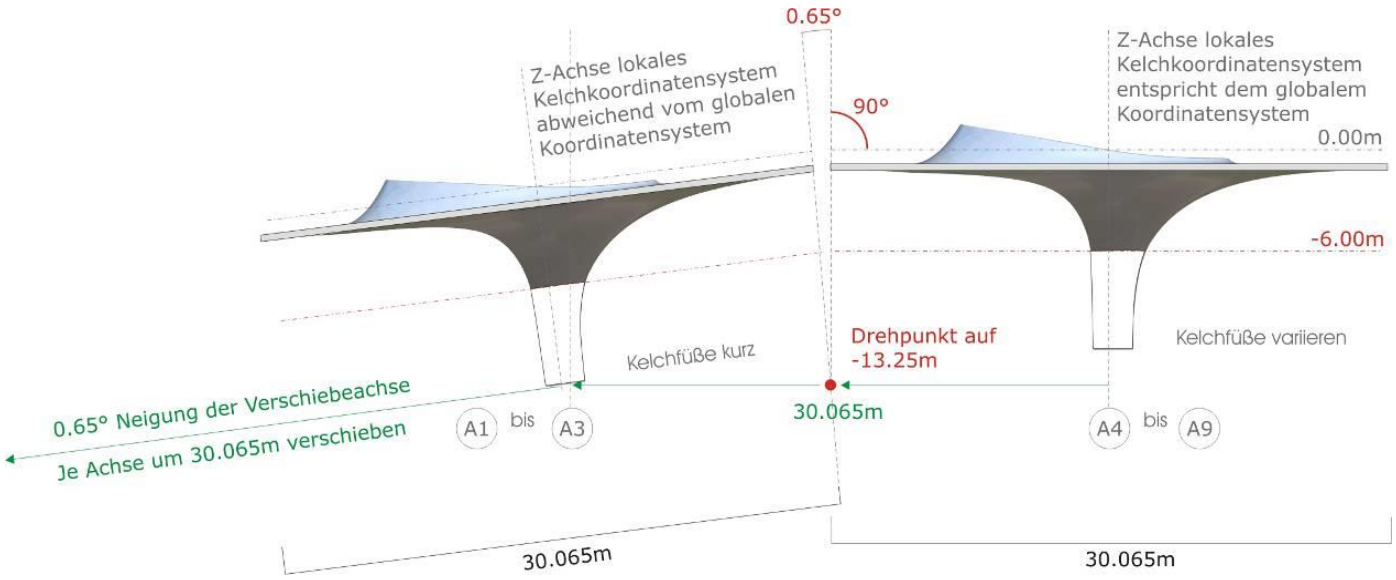
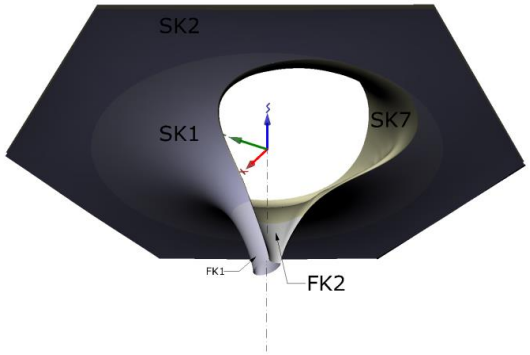

0.65°
Z-Achse lokales Kelchkoordinatensystem abweichend vom globalen Koordinatensystem
90°
Z-Achse lokales Kelchkoordinatensystem entspricht dem globalem Koordinatensystem
0.00m
-6.00m
Kelchfüße kurz
Drehpunkt auf -13.25m
Kelchfüße variieren
0.65° Neigung der Verschiebeachse
Je Achse um 30.065m verschieben
A1
bis
A3
30.065m
A4
bis
A9
30.065m
30.065m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SK1
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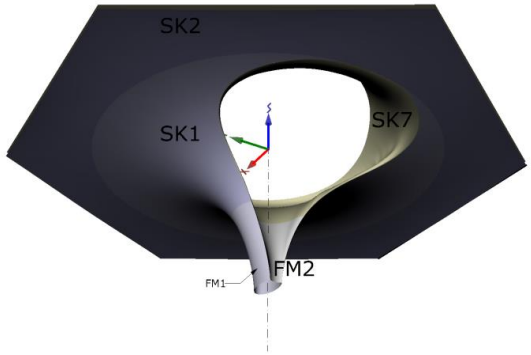
FK1
FK2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SK1
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FM1
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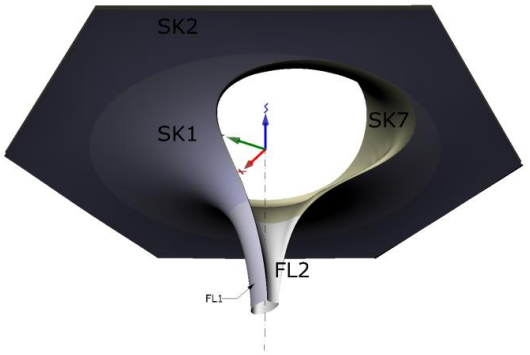
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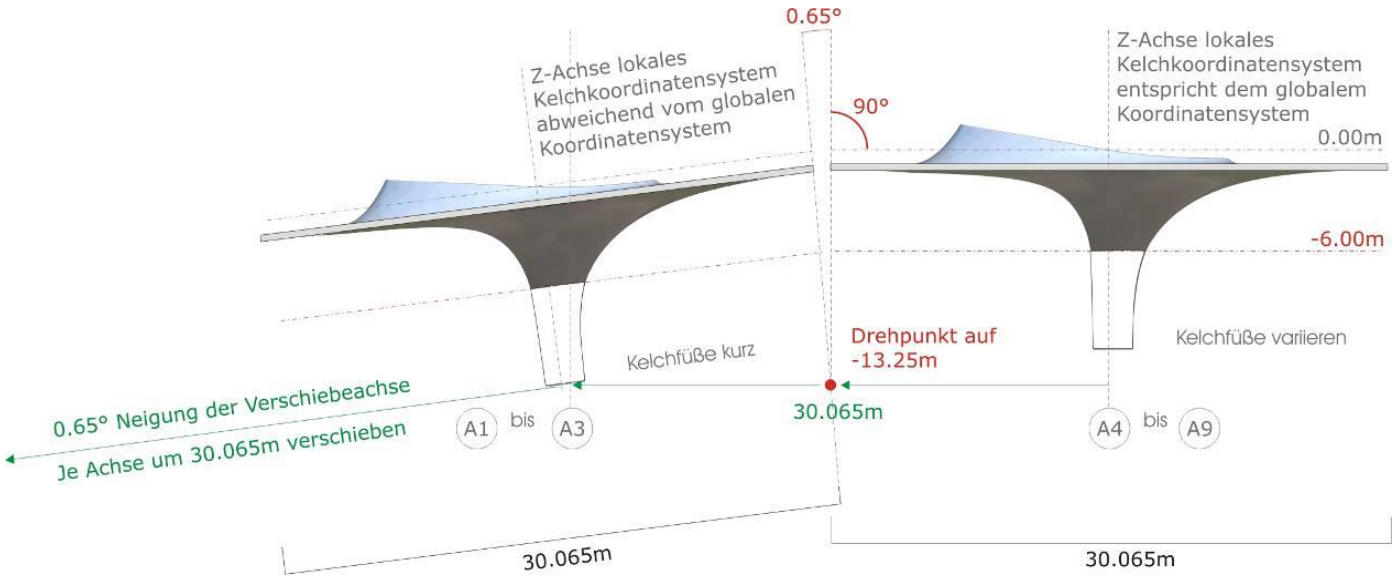
FL2

Geometry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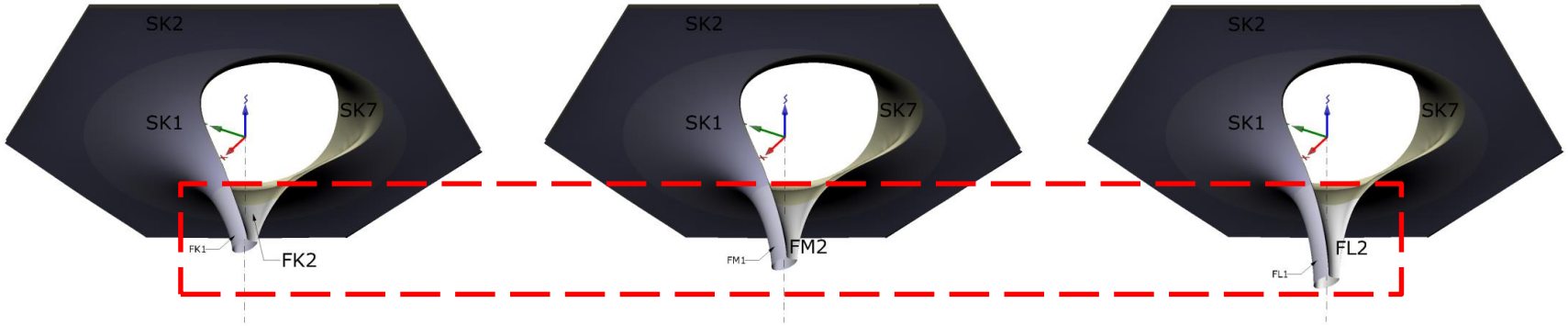
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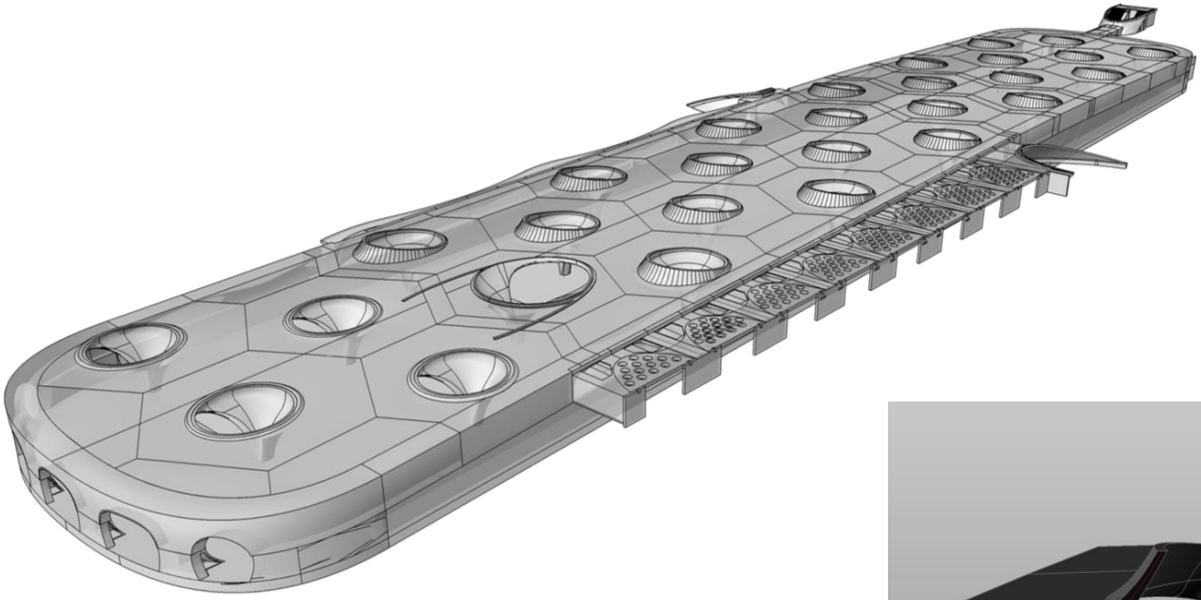

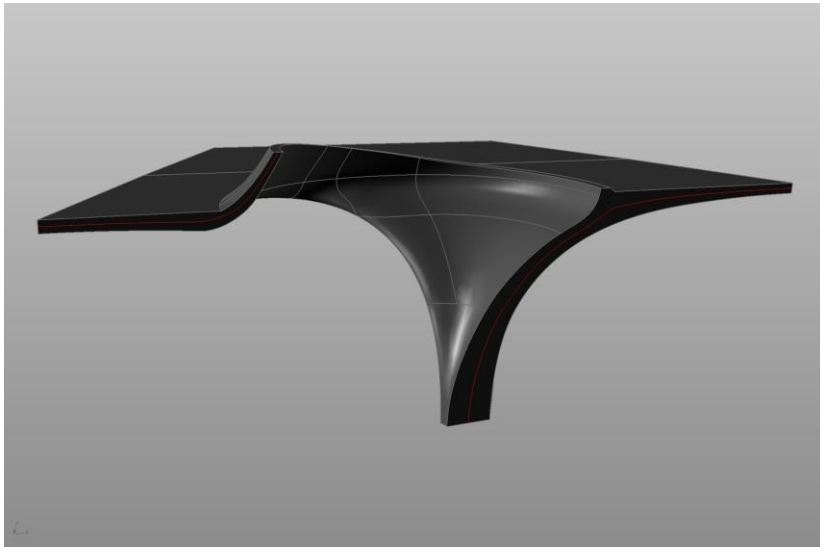

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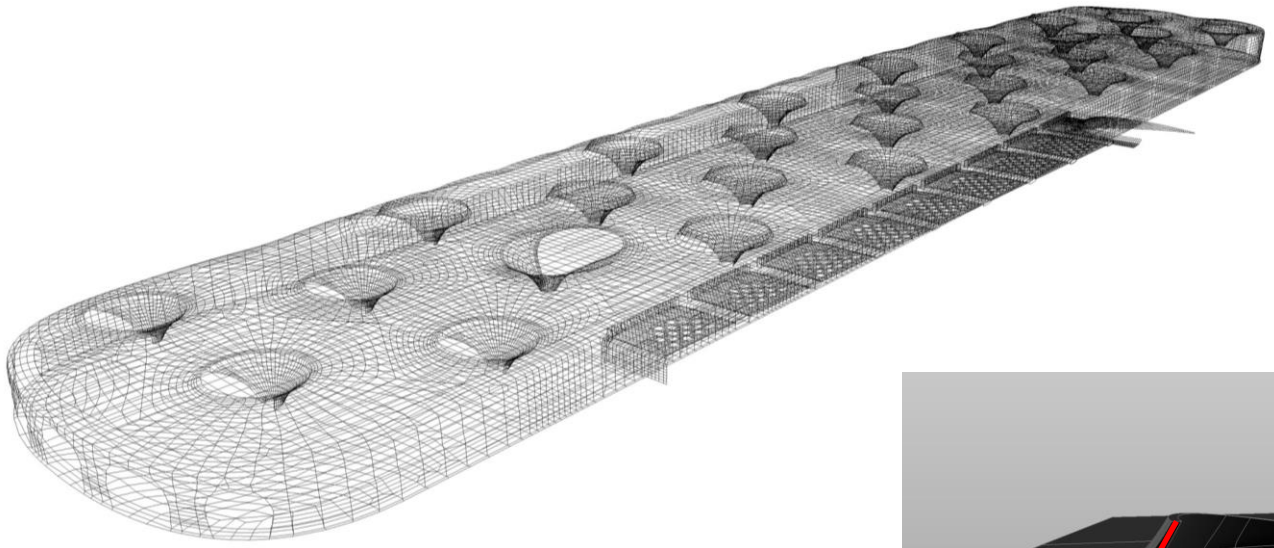

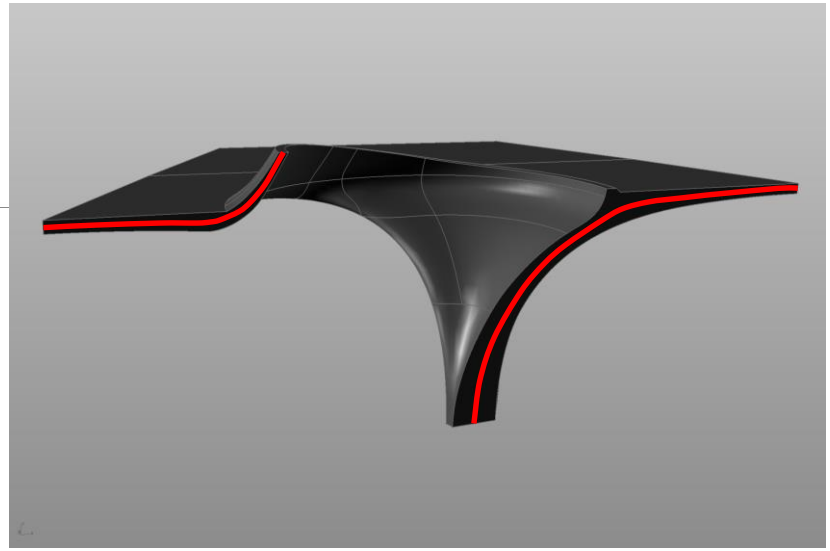

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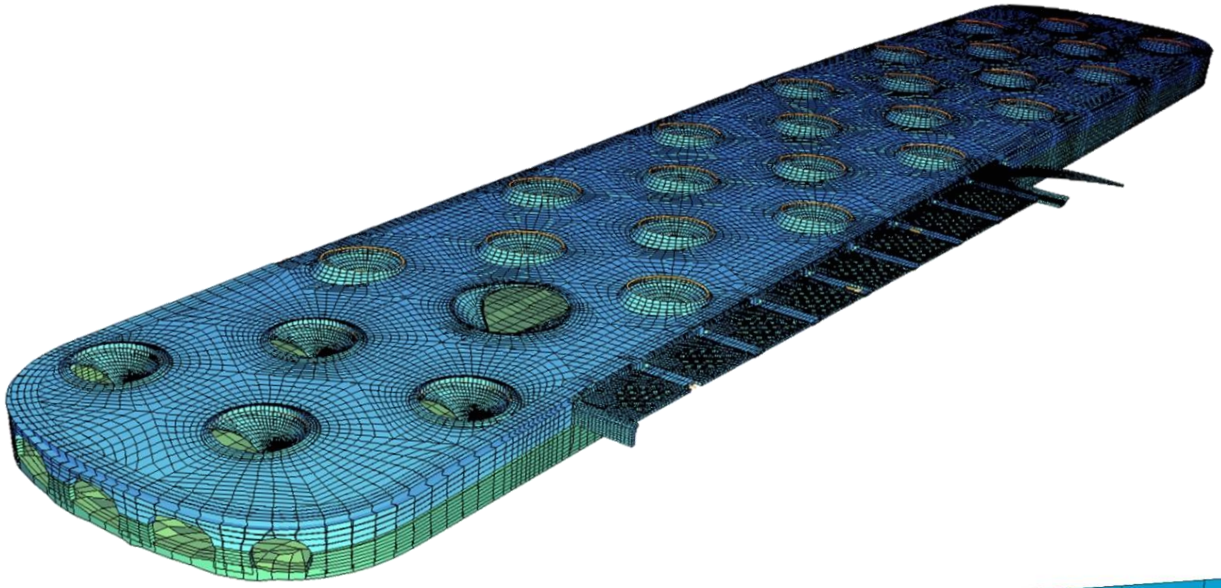
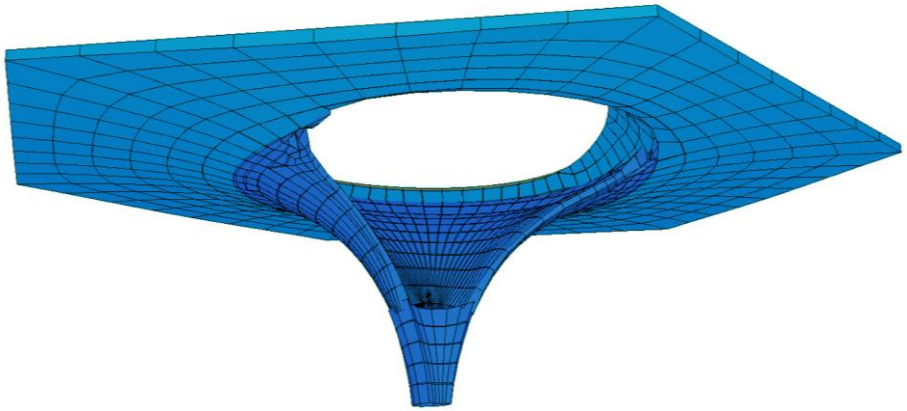
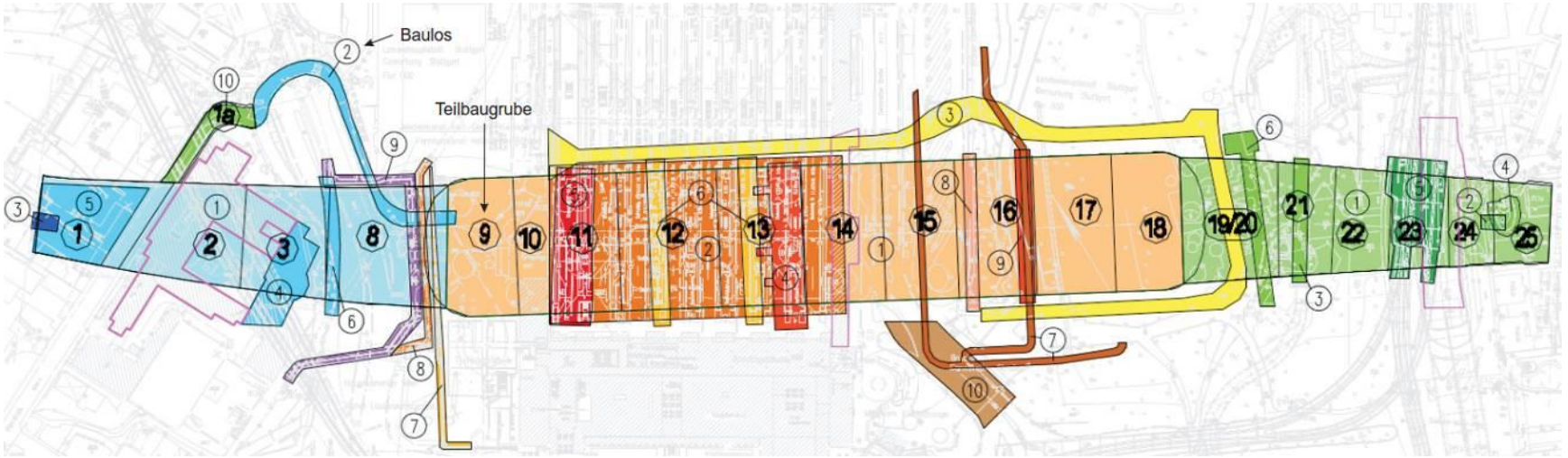
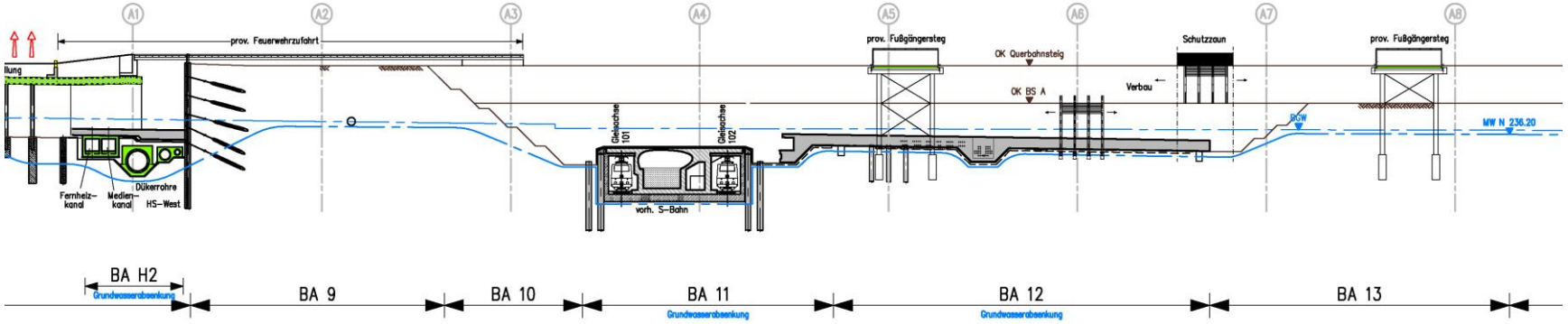




Main Station Stuttgart S21

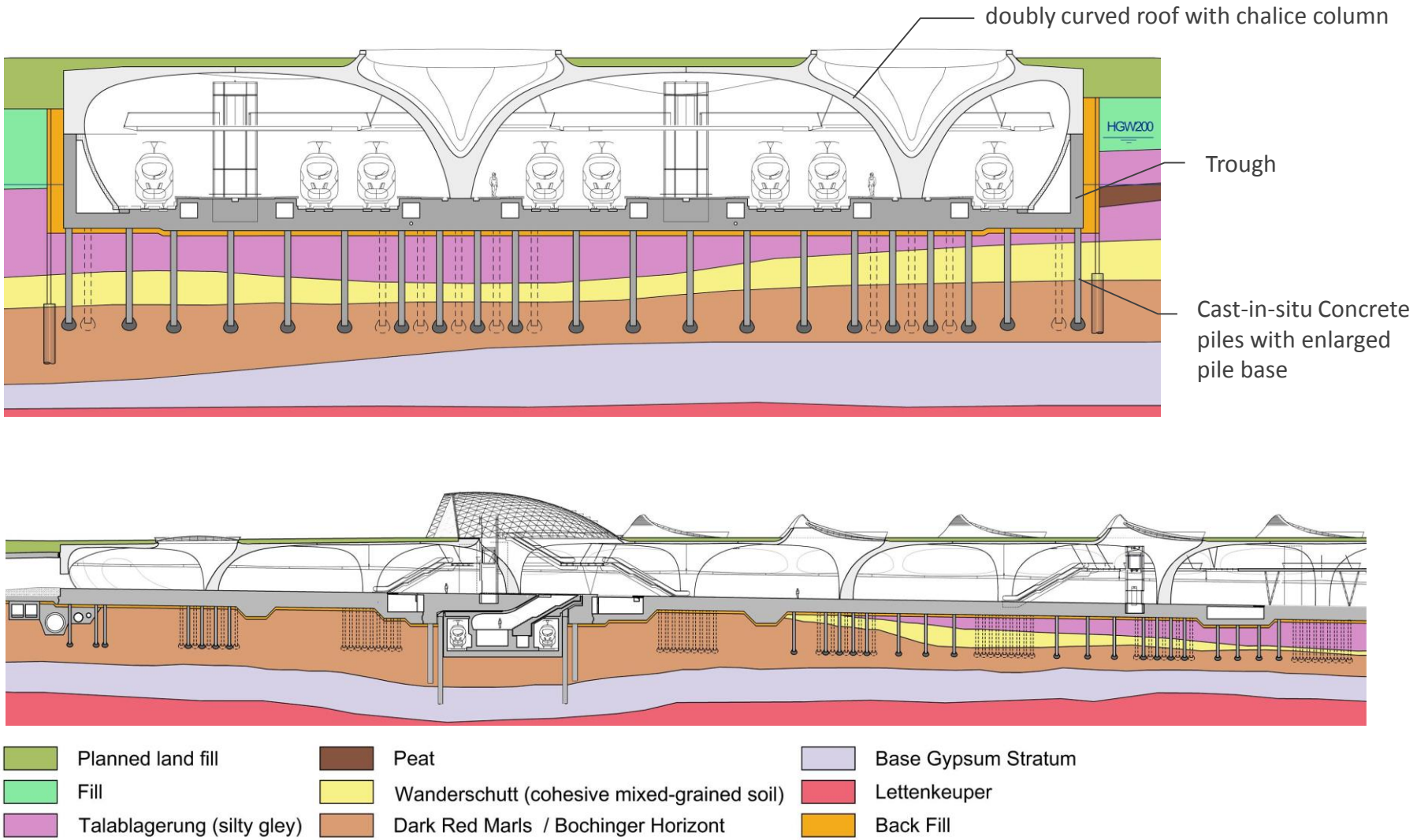


Construction sections in the new central train station

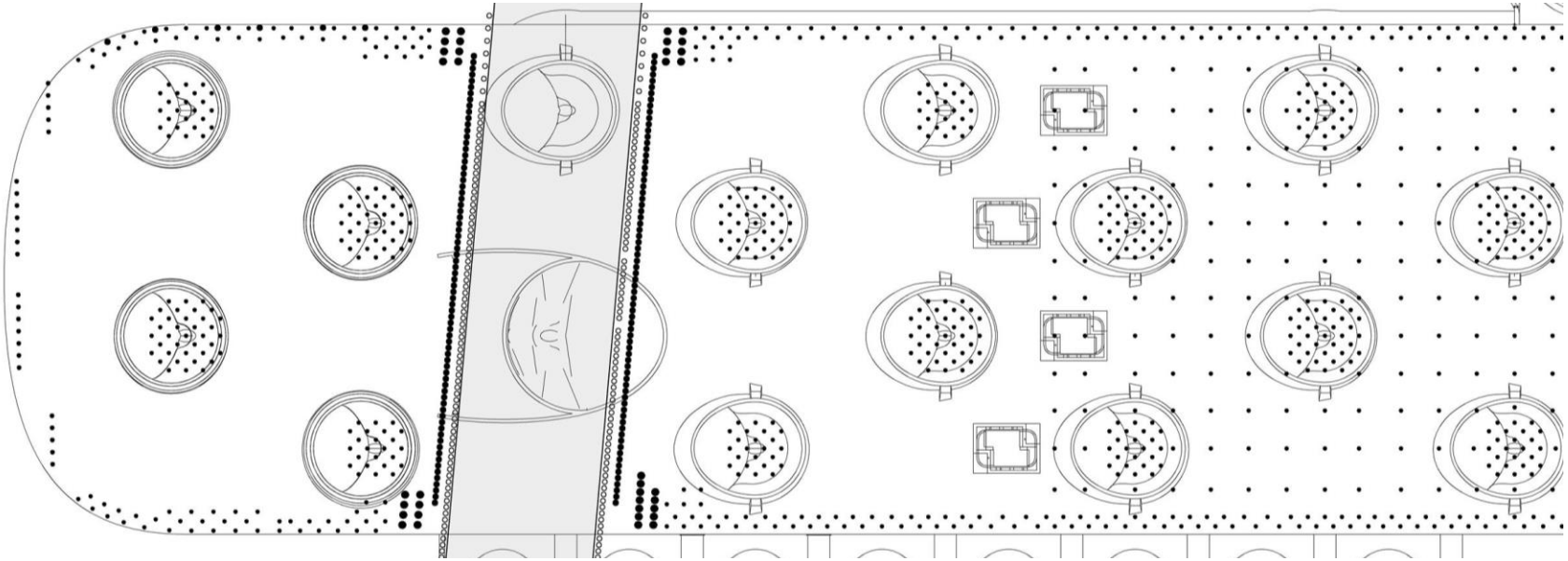


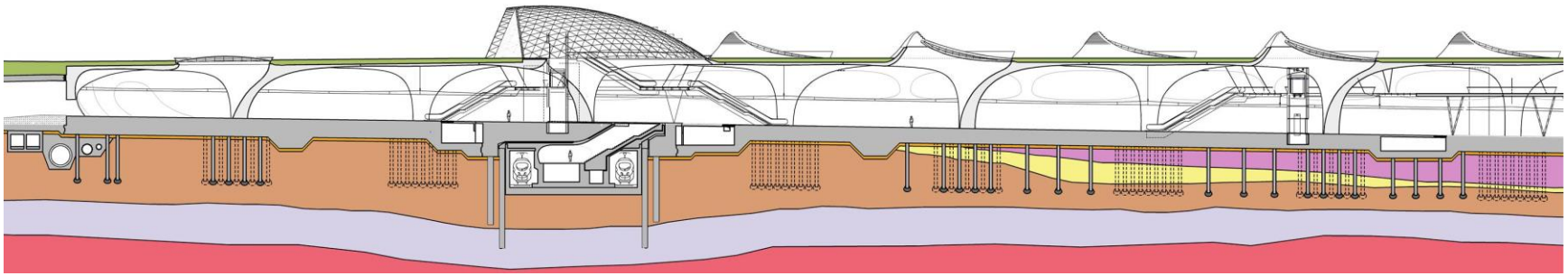
Section showing one construction section (area of BA 8 to BA14)

Building Structure with foundation and soil strata



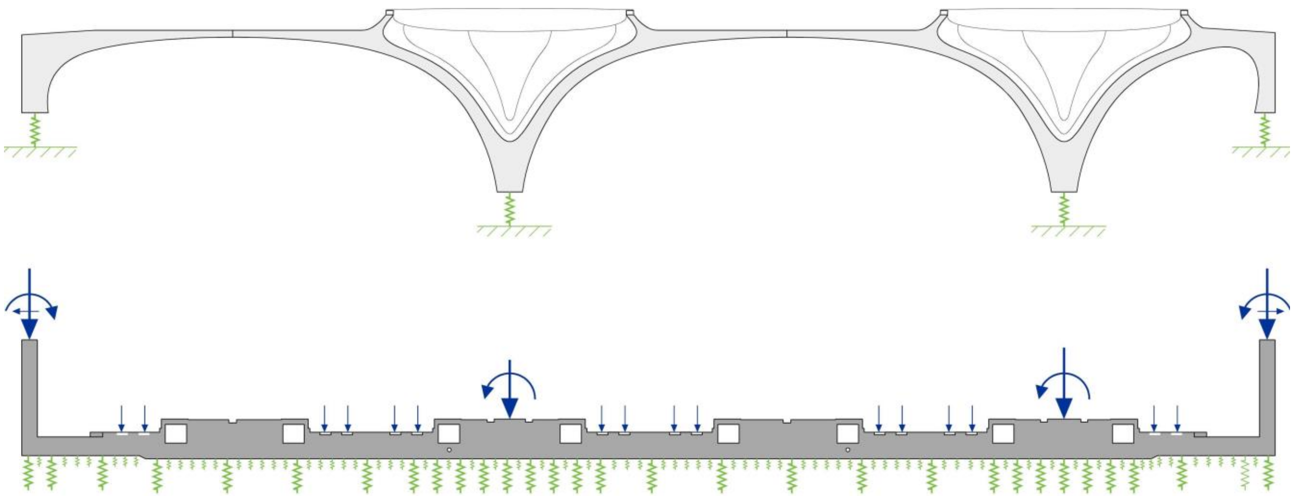
Building Structure with foundation and soil strata





Planned land fill	Peat	Base Gypsum Stratum
Fill	Wanderschutt (cohesive mixed-grained soil)	Lettenkeuper
Talablagerung (silty gley)	Dark Red Marls / Bochinger Horizont	Back Fill

Interconnecting geotechnical and structural design



- **S-Model of Shell Structure**

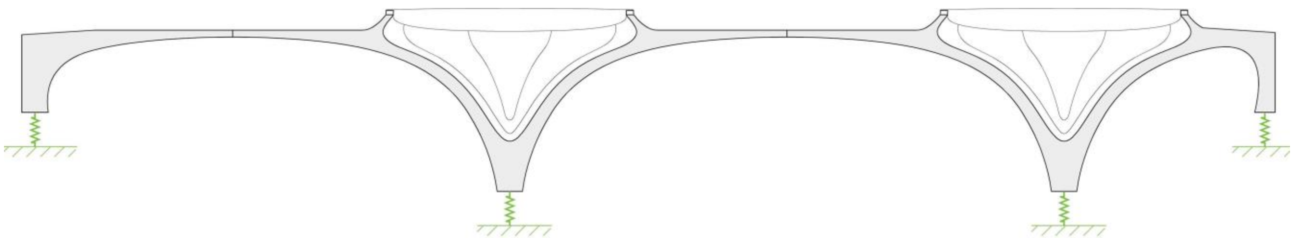
  Support conditions from trough by springs

- **S-Modell of Trough**

  Support conditions from foundation by springs

  Loads applied from shell structure

Interconnecting geotechnical and structural design



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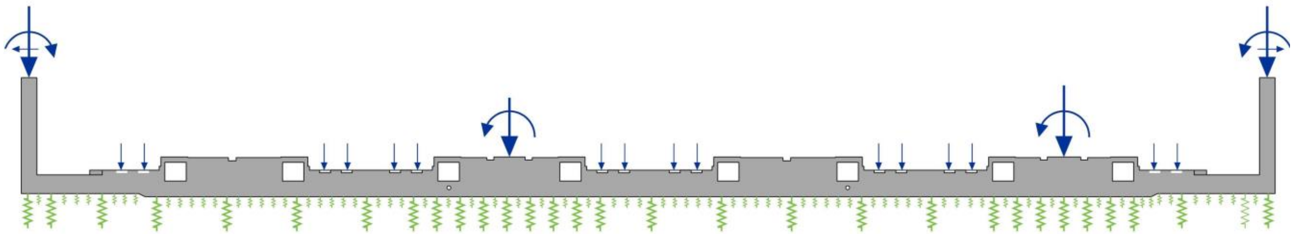

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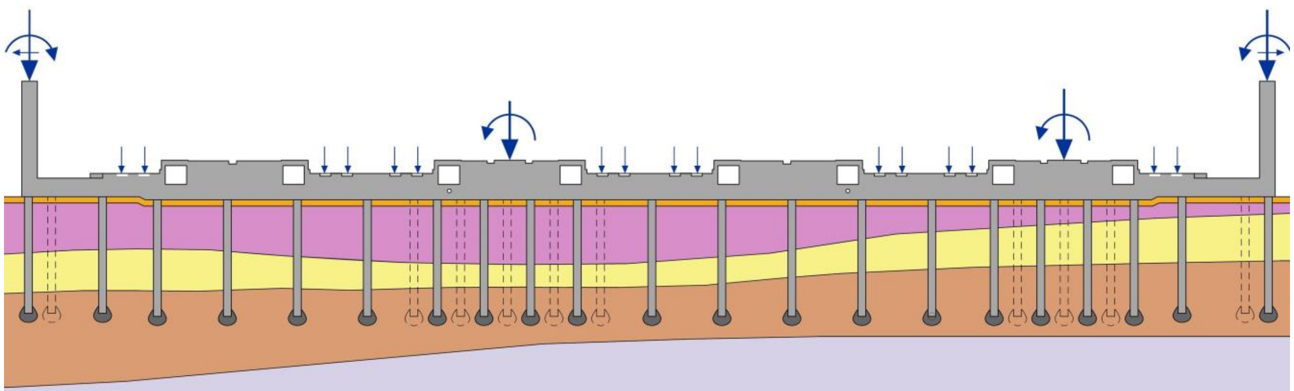
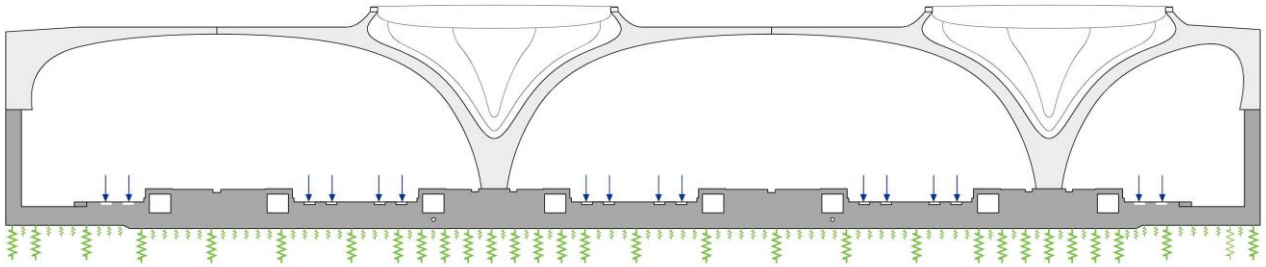


- **G-Modell of Trough and Foundation**

  Determination of support condition

  Loads applied from shell structure

Interconnecting geotechnical and structural design



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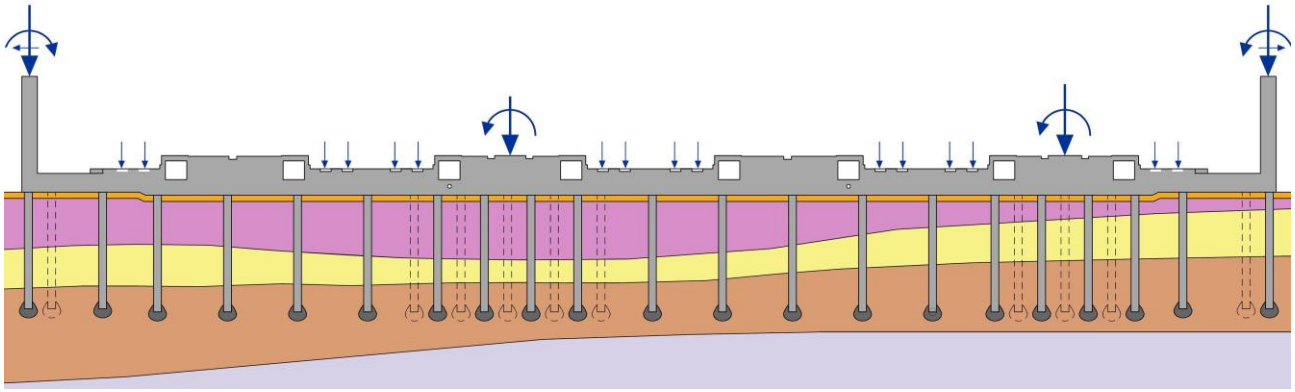
  Support conditions from foundation by springs



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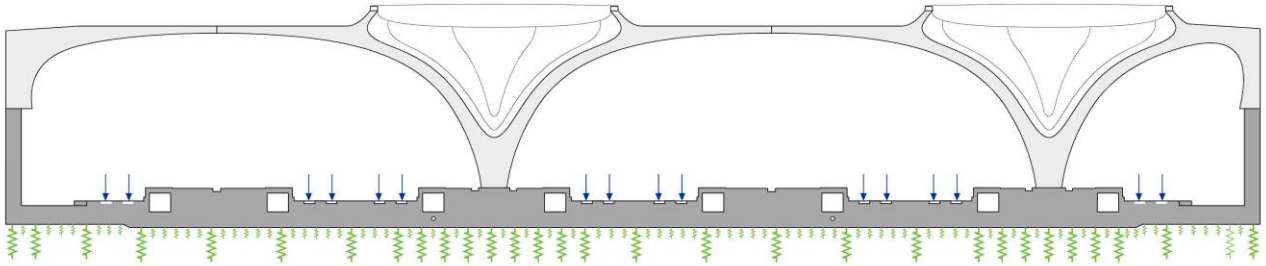

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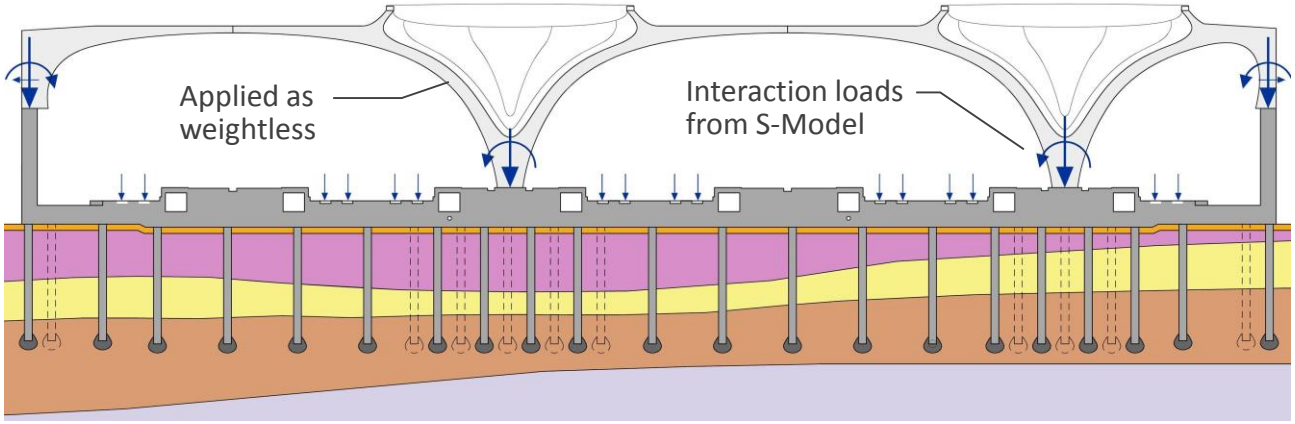

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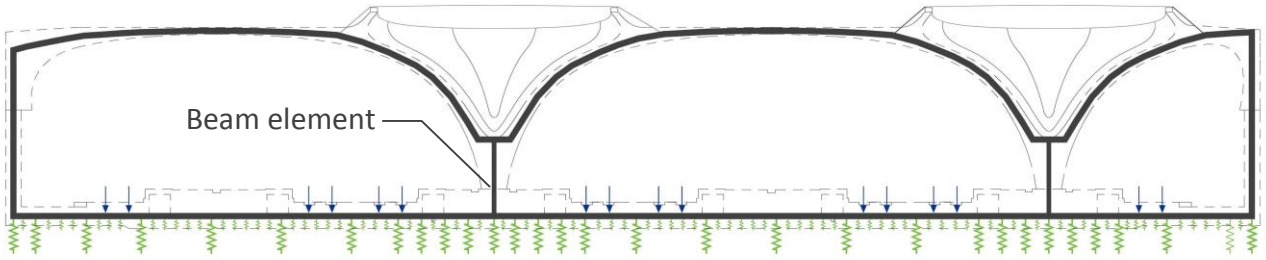
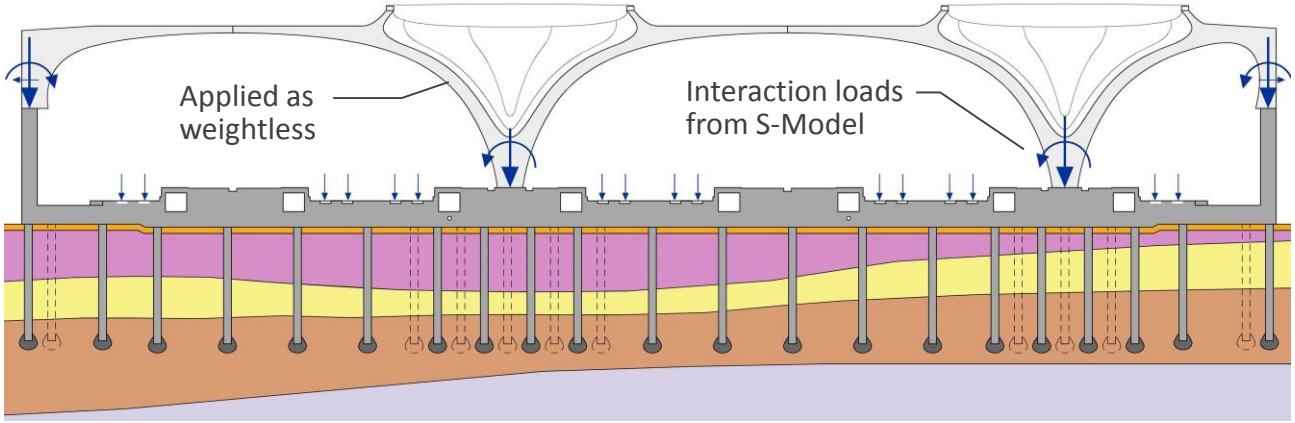


- Shell Structure and Trough modelled as Finite Shell Elements
- Chalice Columns in connection to base plate modelled as Beam Element

S-Model of Shell Structure and Trough

Support conditions from foundation by springs

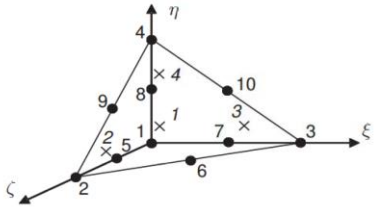


- Soil and structure are discretized with 10-node tetrahedral elements

G-Modell of Trough and Foundation

Determination of support condition

Loads applied from shell structure



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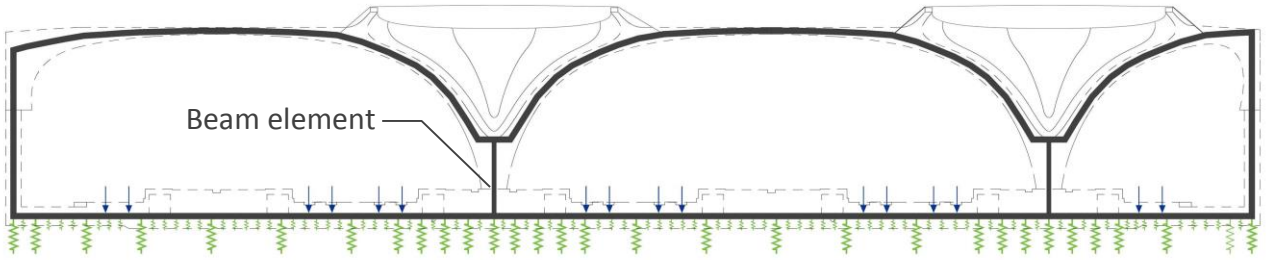
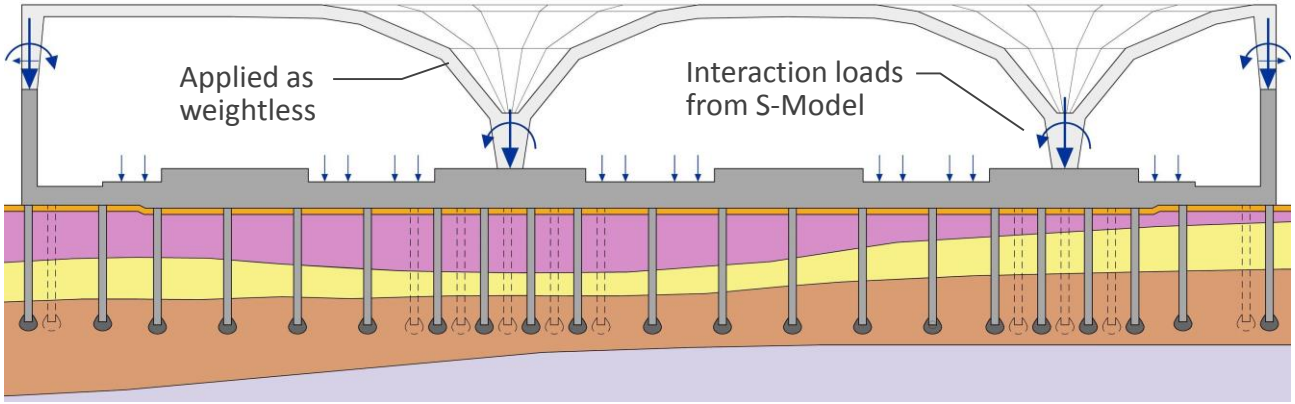


- Shell Structure and Trough modelled as Finite Shell Elements
- Chalice Columns in connection to base plate modelled as Beam Element

S-Model of Shell Structure and Trough

Support conditions from foundation by springs

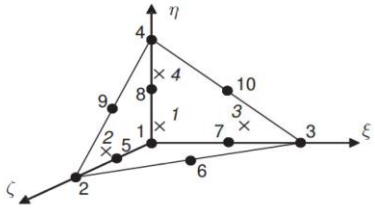


- Soil and structure are discretized with 10-node tetrahedral elements
- Shell Structure and chalice columns simplified

G-Modell of Trough and Foundation

Determination of support condition

Loads applied from shell structure



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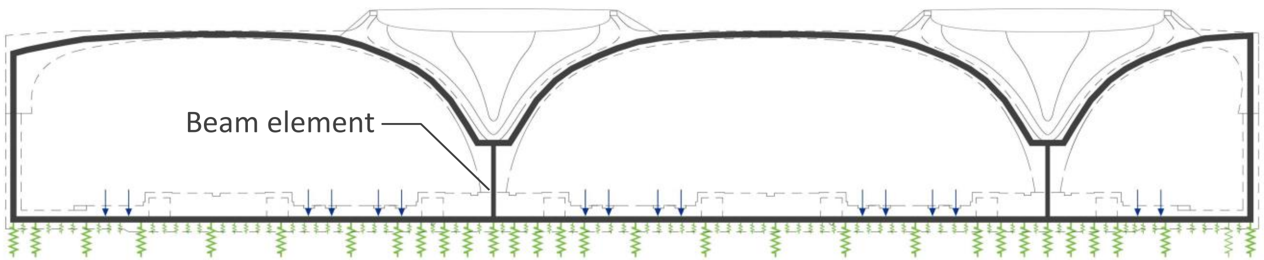
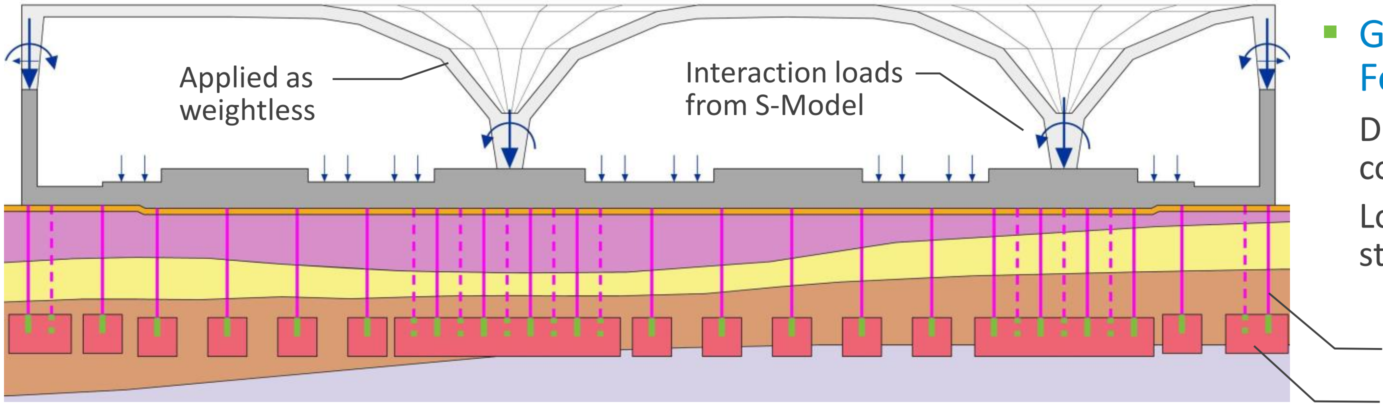


- S-Model of Shell Structure and Trough

  Support conditions from foundation by springs

❖ Shell Structure and Trough modelled as Finite Shell Elements
❖ Chalice Columns in connection to base plate modelled as Beam Element



- G-Modell of Trough and Foundation

  Determination of support condition

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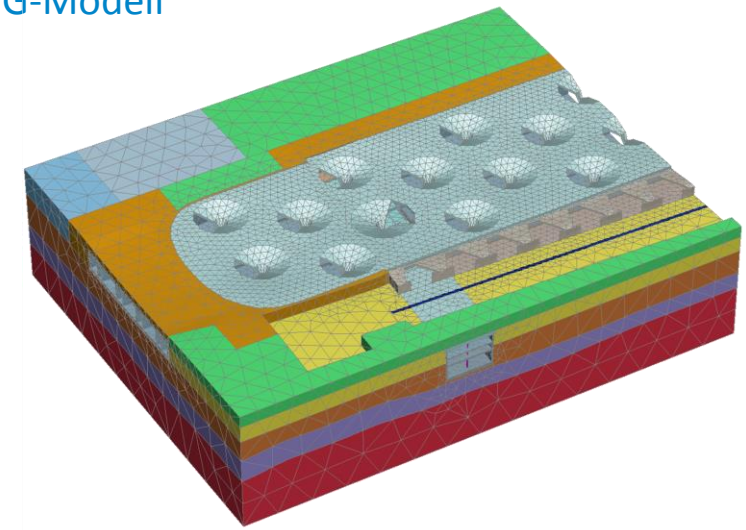
❖ Soil and structure are discretized with 10-node tetrahedral elements
❖ Shell Structure and chalice columns simplified
❖ Piles are modeled with empedded beam elements (Empedded Pile)

Interconnecting geotechnical and structural design

- G-Modell



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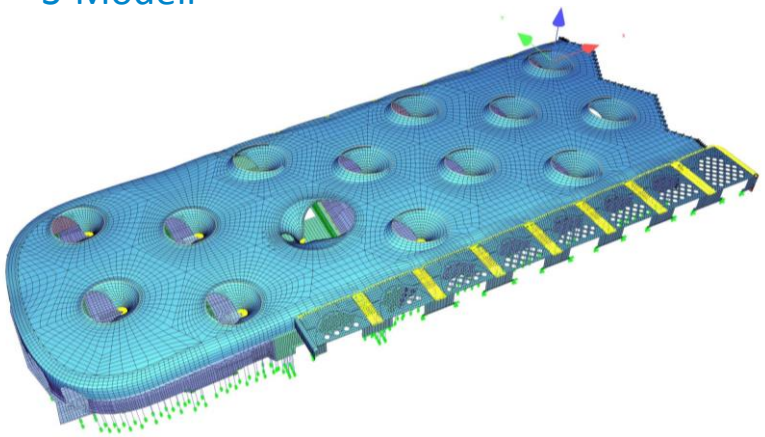
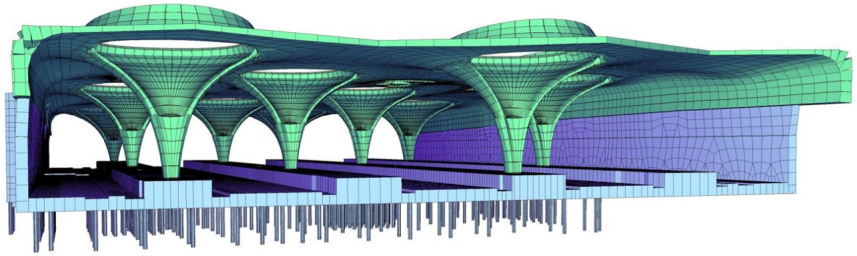


- Determination of subgrade reaction modulus for the base plate and spring stiffness for the piles
- Design for load-bearing capacity of the soil around the piles (‘external’ capacity in ULS)
- Analysis of bearing capacity of the ground while neglecting the piles (ULS)
- Serviceability analyses of the foundation in regard to compliance with the requirements on limitation of deformation

- Design of Structure in ULS and SLS
- Design for ‘inner‘ capacity of piles in ULS and SLS



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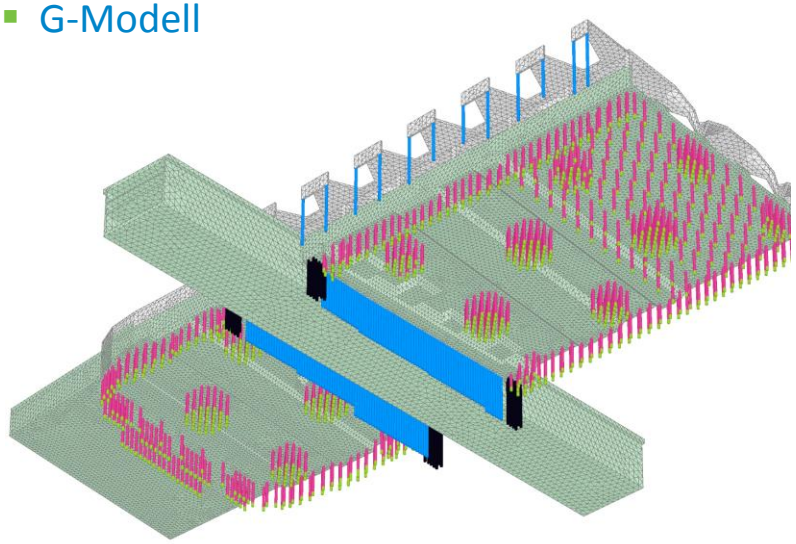

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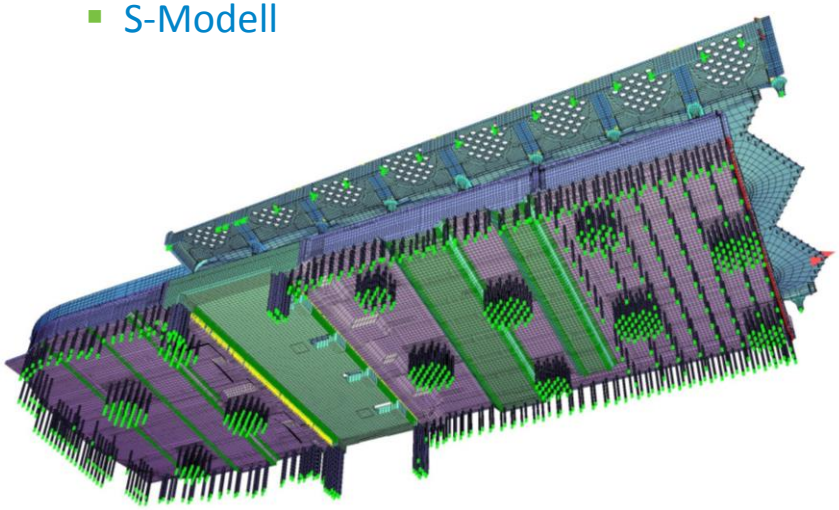
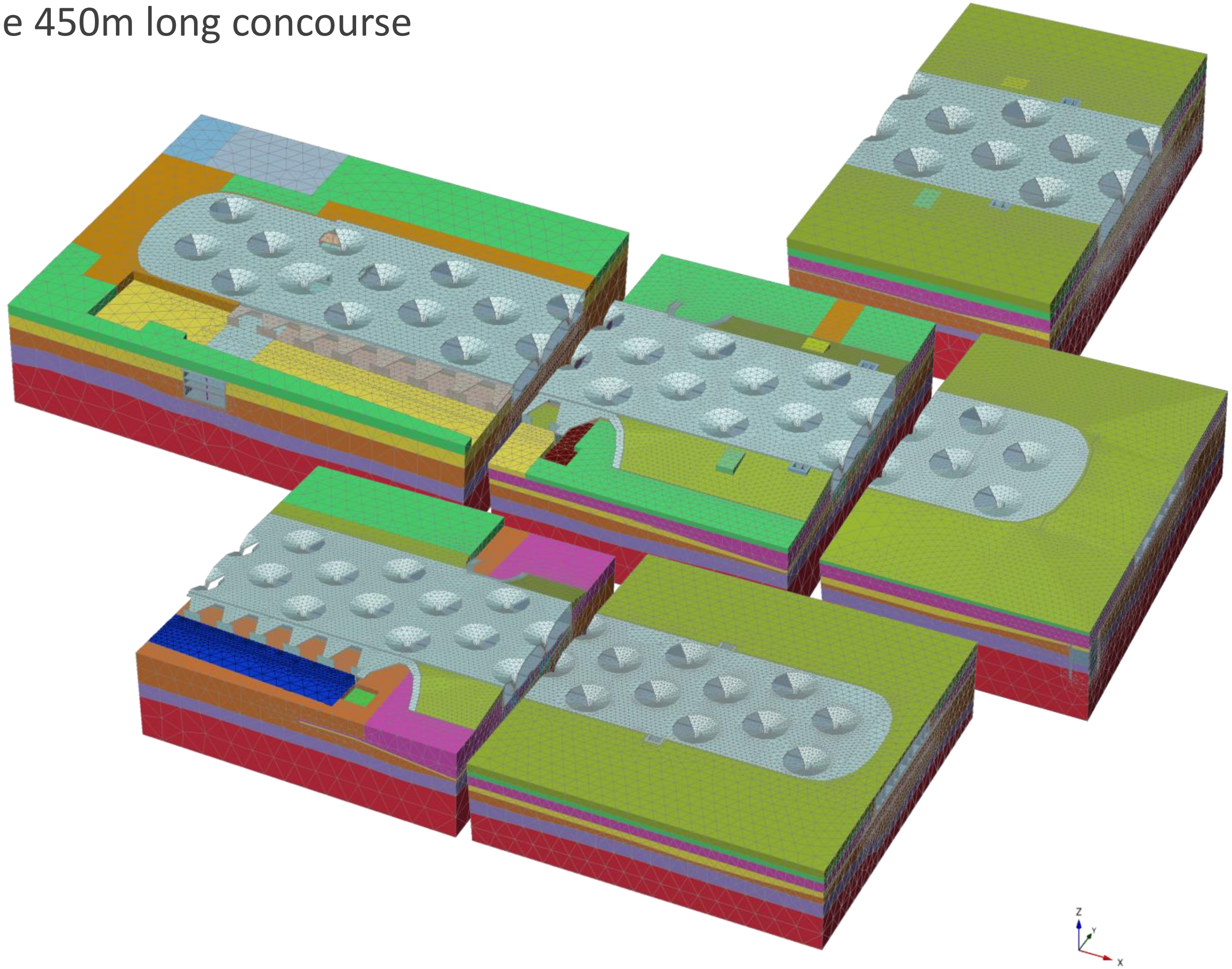


Iterative adaption of geological and structural model:

- Support reaction and deformation are calibrated in an iterative approach
- Calculated settlements and pile reactions should not differ more than a maximum of 10% under a specified load combination
- Resulting deformations must be comparable

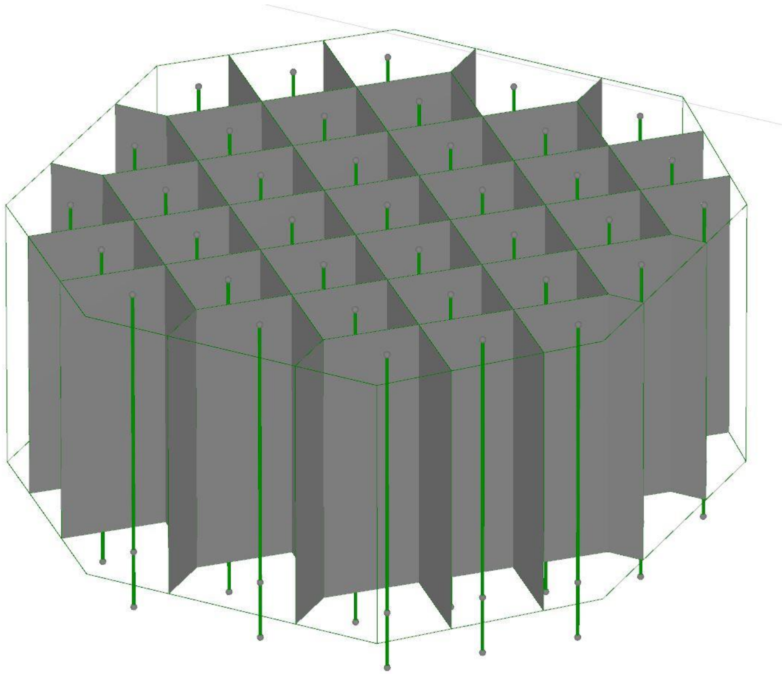
Geotechnical Model

- Subdeviding the 450m long concourse

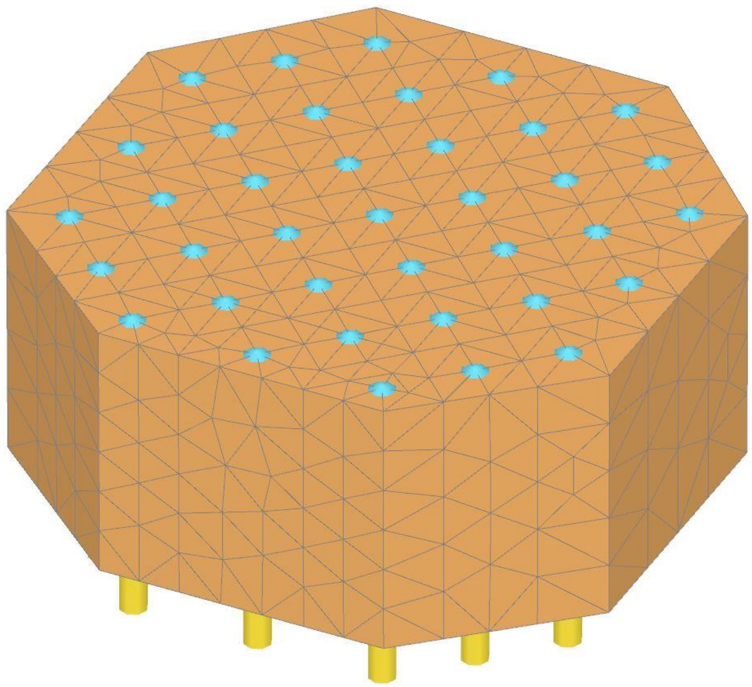


Geotechnical Model

- FE-mesh around pile groups



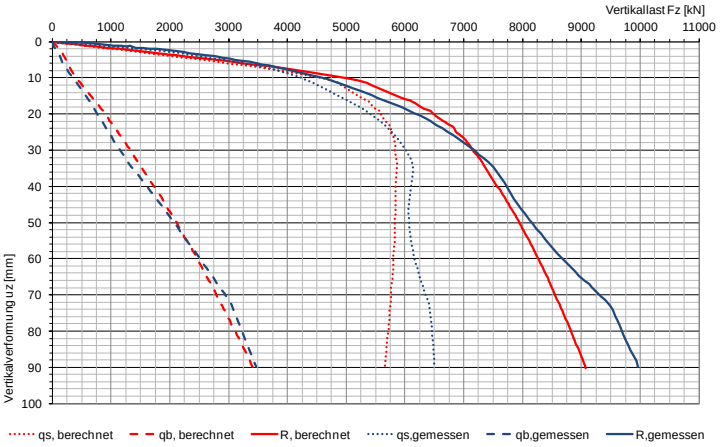
Limiting surfaces for discretising the FE mesh around pile groups

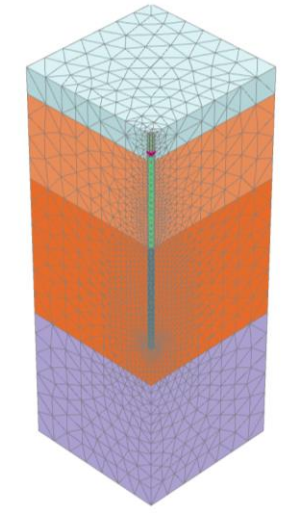


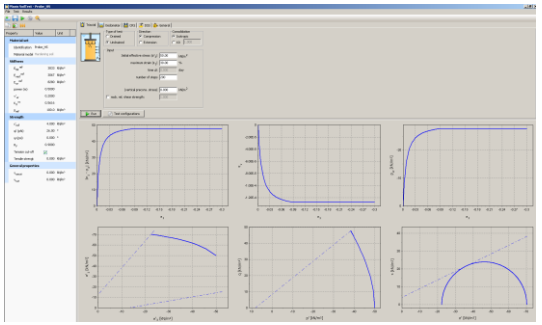
FE mesh around pile groups

Geotechnical Model

- 3D FE model PLAXIS
- Drained analyses based on effective stress as well as effective stiffness and shear strength parameters
- Mathematical modelling for groundwater flow in response to excavation and simultaneous drainage is based on Darcy's law (coupled analysis)
- Soils modelled using the Hardening Soil Model with small strain stiffness
  - parameters were determined using results from field and laboratory tests and recognised correlations







WECHSEL WIRKUNG Numerische Geotechnik

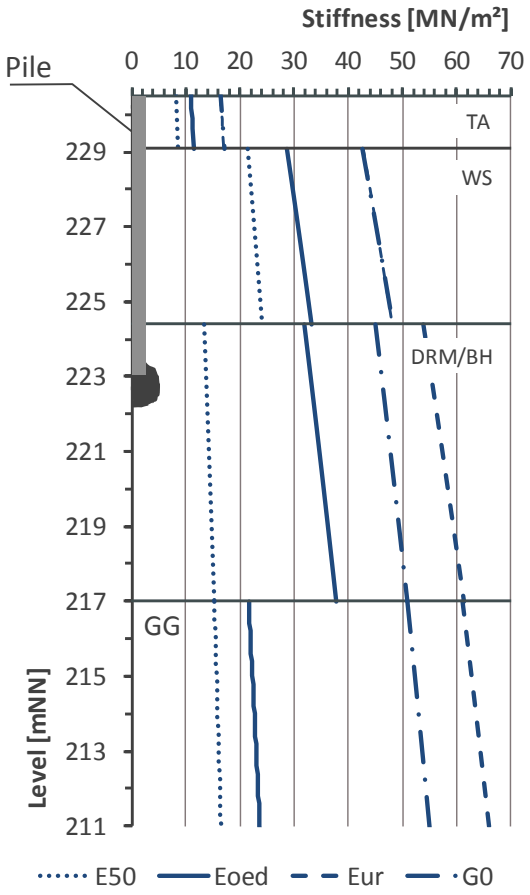
CDM Smith

S&P

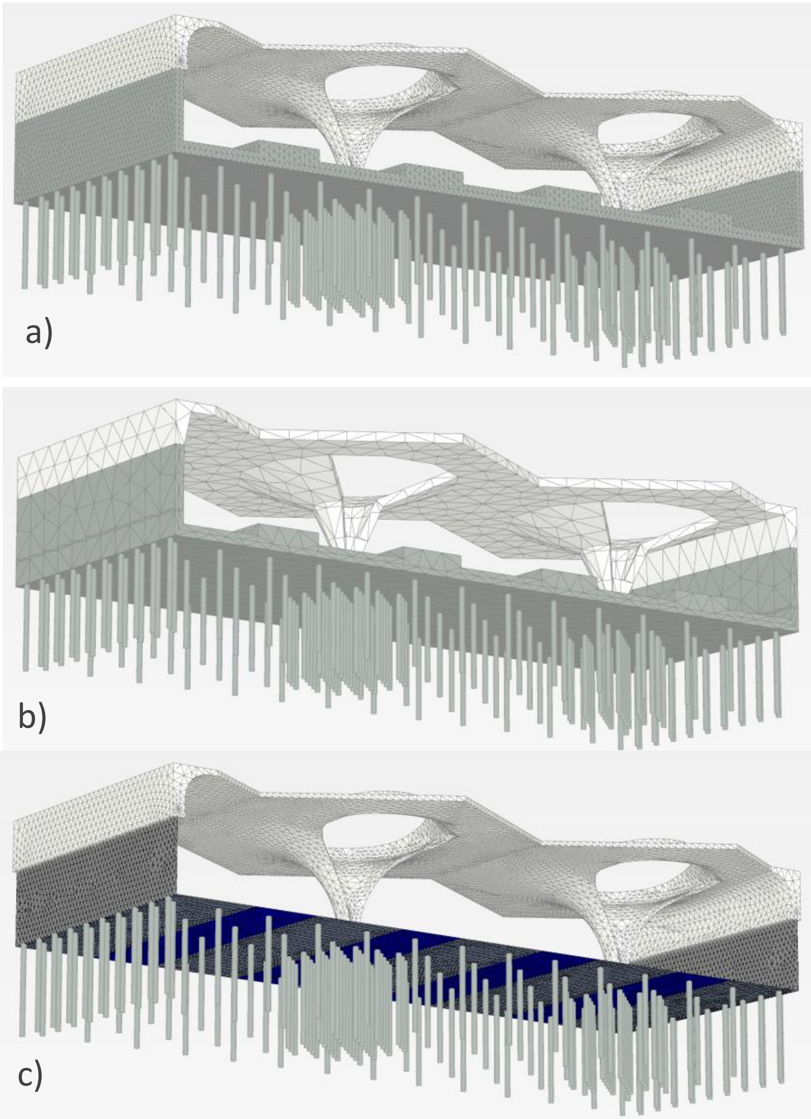
Geotechnical Model

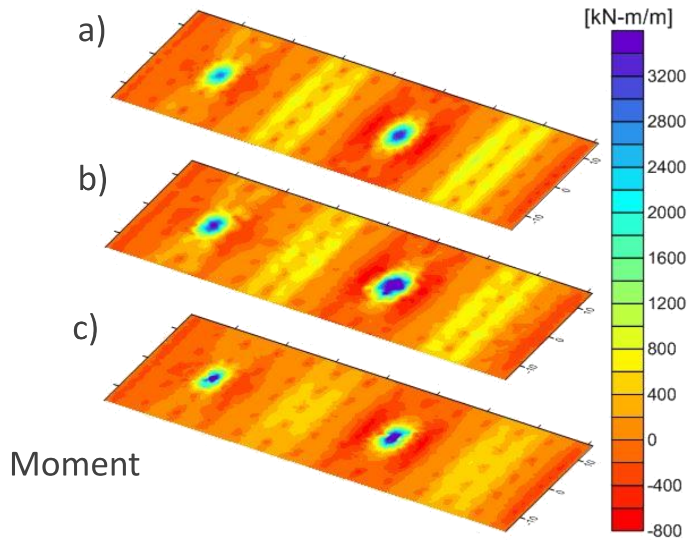
- Soils modelled using the Hardening Soil Model with small strain stiffness
  - parameters were determined using results from field and laboratory tests and recognised correlations

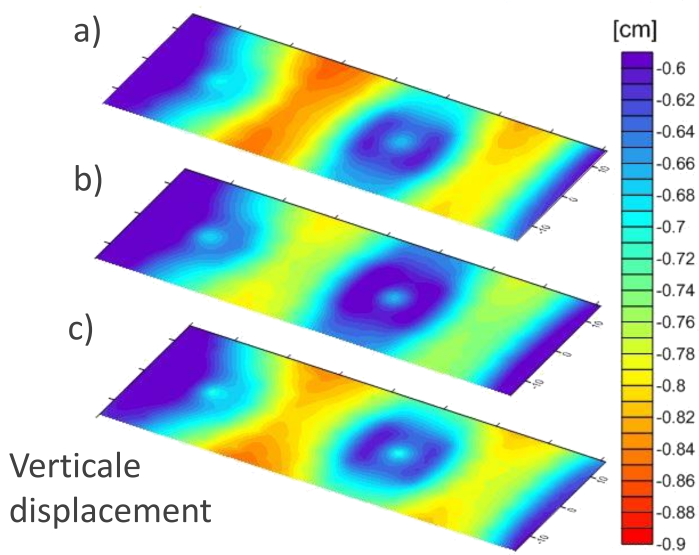
Parameters	Material Colour / Soil Model		TA HSS	WS HSS	DRM/BH HSS	GG HSS
Unit weights	γ_{unsat} / γ_{sat}	[kN/m³]	19	20	21	21
Cohesion	c'	[kN/m²]	22,5	27,5	22,5	25
Internal friction	φ'	[°]	20	20	25	25
K_0-value for normal consolidation	K_0^{nc}	[-]	0,617	0,538	0,617	0,577
Power for stress-level dependency of stiffness	m	[-]	0,6	0,6	0,6	0,5
Poisson's ratio for unloading-reloading	ν_{ur}	[-]	0,2	0,2	0,2	0,2
Reference stress for stiffness	p_{ref}	[kN/m²]	100	100	100	100
Tangent stiffness	E_{oed}^{ref}	[MN/m²]	10	25	25	15
Secant stiffness	E_{50}^{ref}	[MN/m²]	10	25	15	15
Unloading-reloading stiffness	E_{ur}^{ref}	[MN/m²]	20	50	60	60
Shear modulus at very small strains	G_0^{ref}	[MN/m²]	20	21,9	50	50
Shear strain at which is $G_s = 0{,}722G_0$	$\gamma_{0,7}$	[-]	1,0E-4	1,0E-4	3,0E-4	3,0E-4



Supporting studies while preparing the geotechnical model





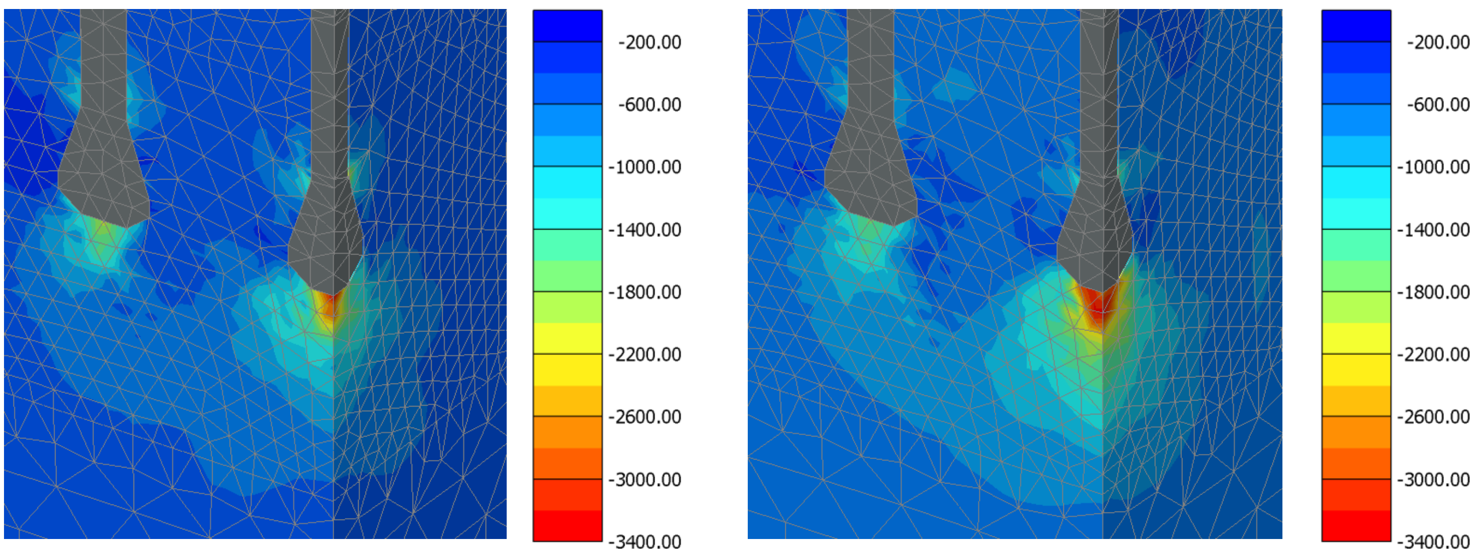


Calibration load bearing behavior of Piles on Pile Load Test

Model of sample load on a driven pile in a pile group (TM1)

<u>Using volume piles (TM1 VP)</u>

- Simulation of foundation soil stress around the pile base by expanding a droplet-shaped cluster volume of a base 5% horizontally und 25% vertically - separately for each pile.
- Pile base was held vertically in a permanent position during volume extension at the upper side where it transitions into the pile shaft



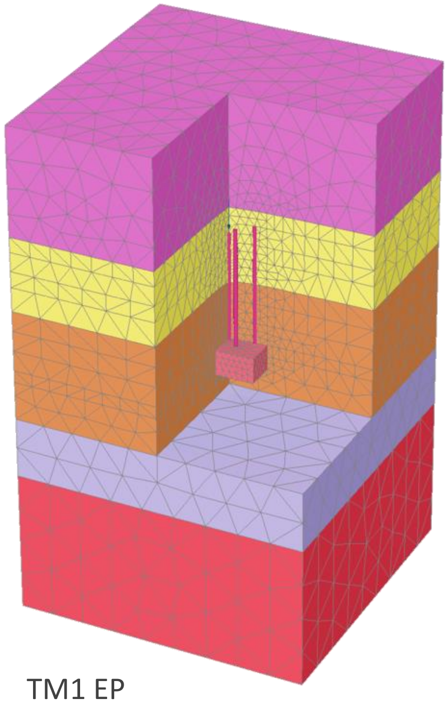
TM1 VP – initial stress generated by volume expansion [kN/m²], left σ1, right σ3, 3D FE model, isometric view

Calibration load bearing behavior of Piles on Pile Load Test

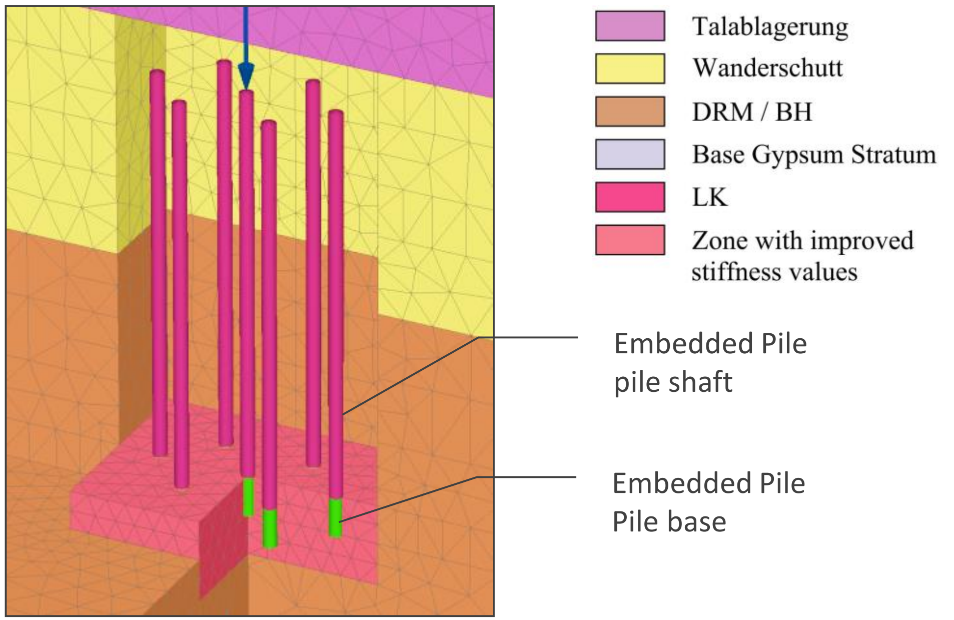
Model of sample load on a driven pile in a pile group (TM1)

<u>Using embedded piles (TM1 EP)</u>

- Implementing zone with improved stiffness values (factor of 4; refer Gabers et al. 2014) around an embedded pile with a diameter of 2 meters for the enlarged pile base
- Increased pile shaft diameter to adjust stiffness of shaft friction in reference to test result



TM1 EP

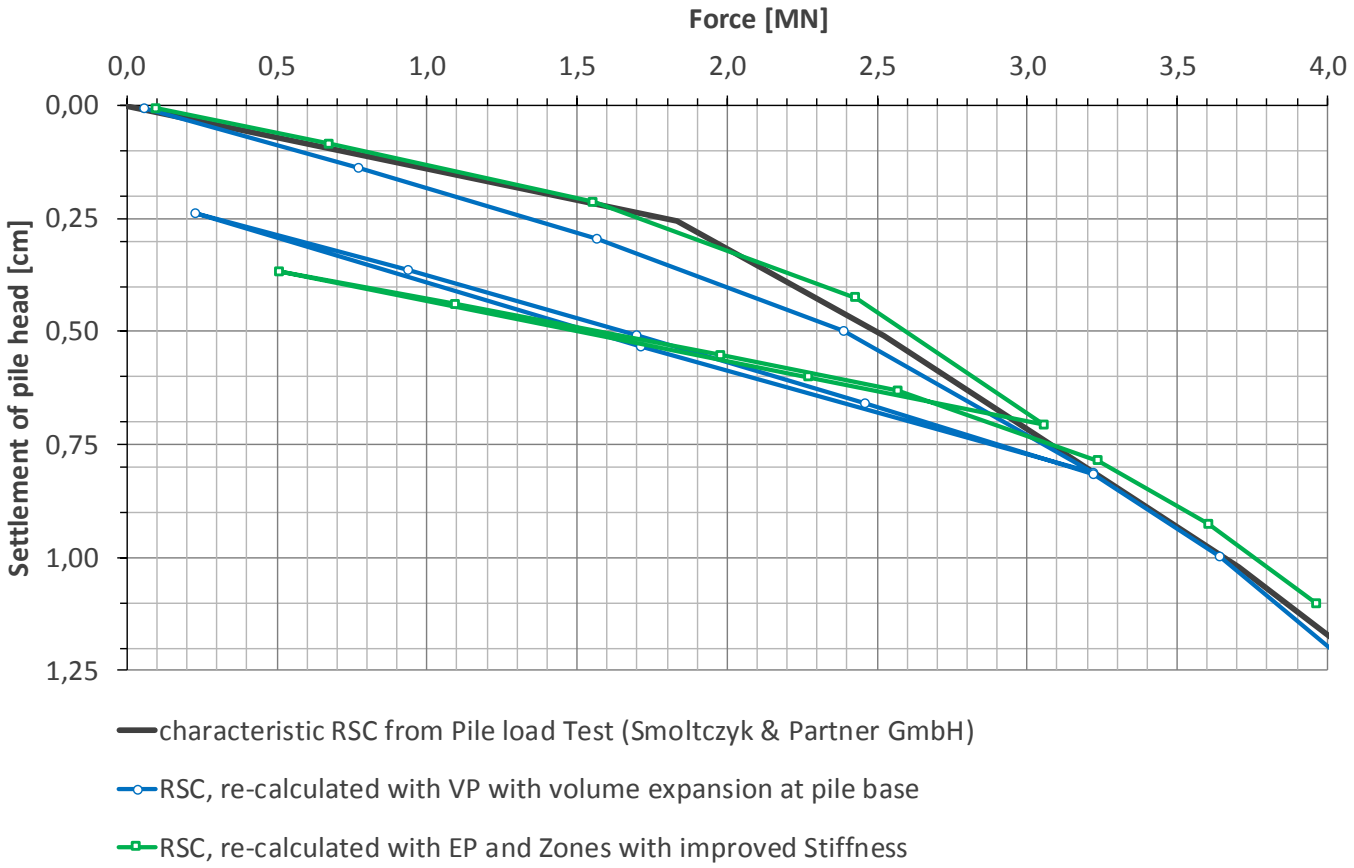


TM1 EP – pile group in the model

Calibration load bearing behavior of Piles on Pile Load Test

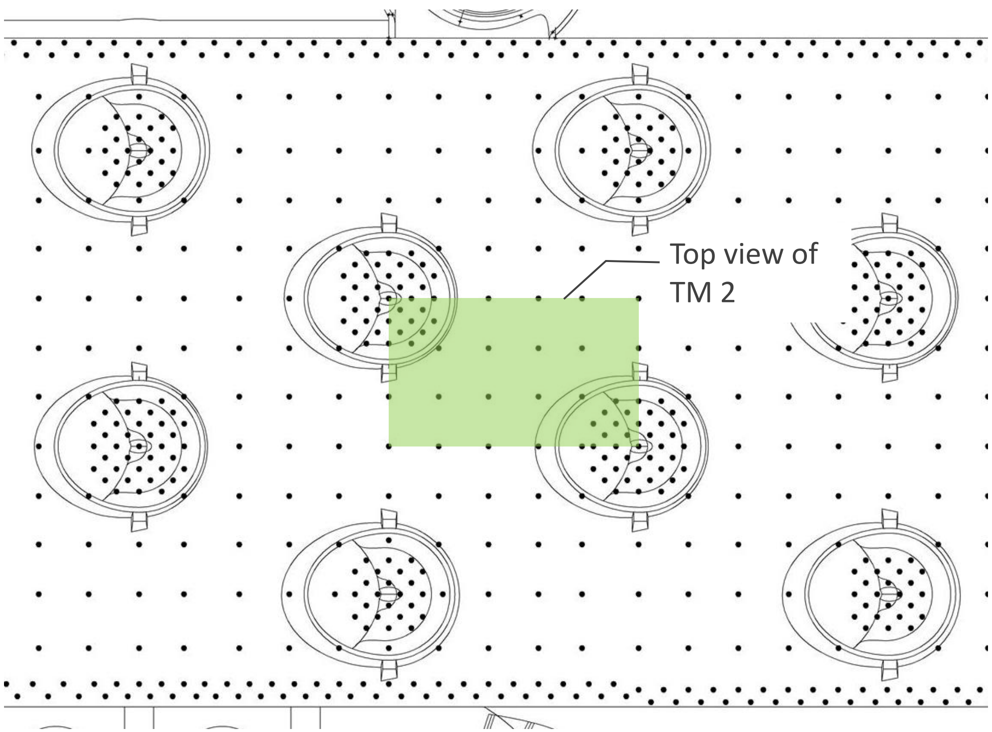
Model of sample load on a driven pile in a pile group (TM1)

Comparison between the RSC from sample load against RSC from recalculations



Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

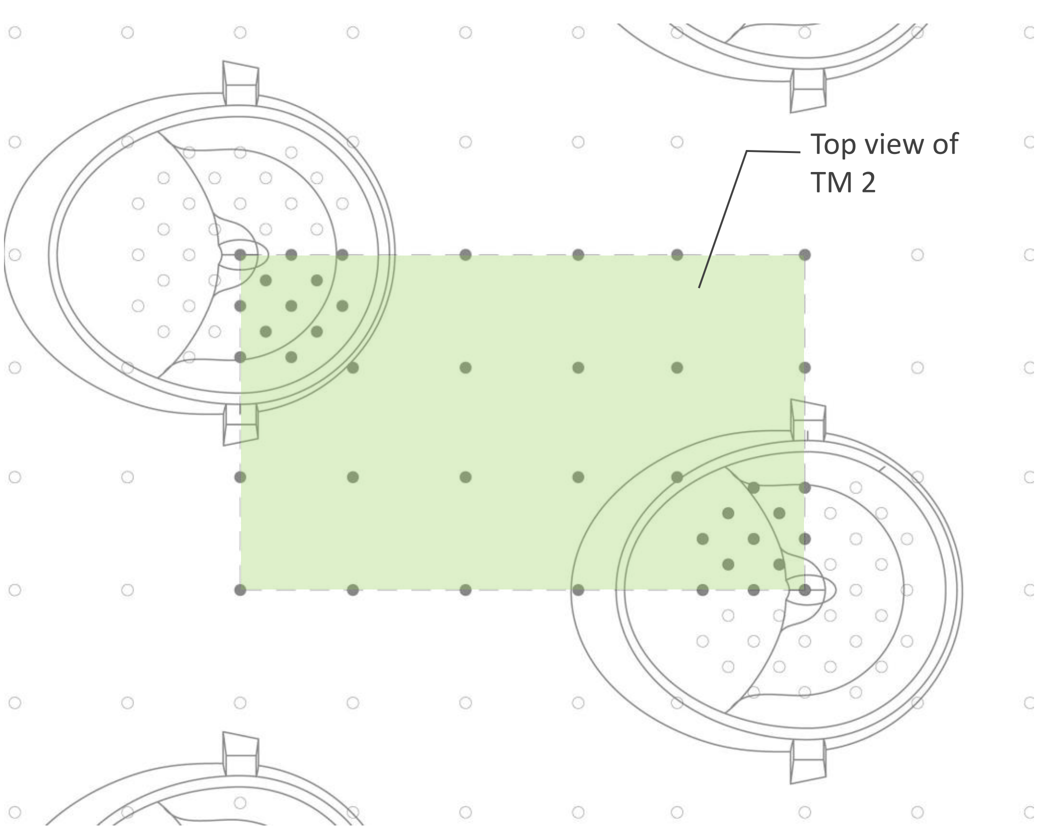
Using same configuration of volume piles and empedded piles



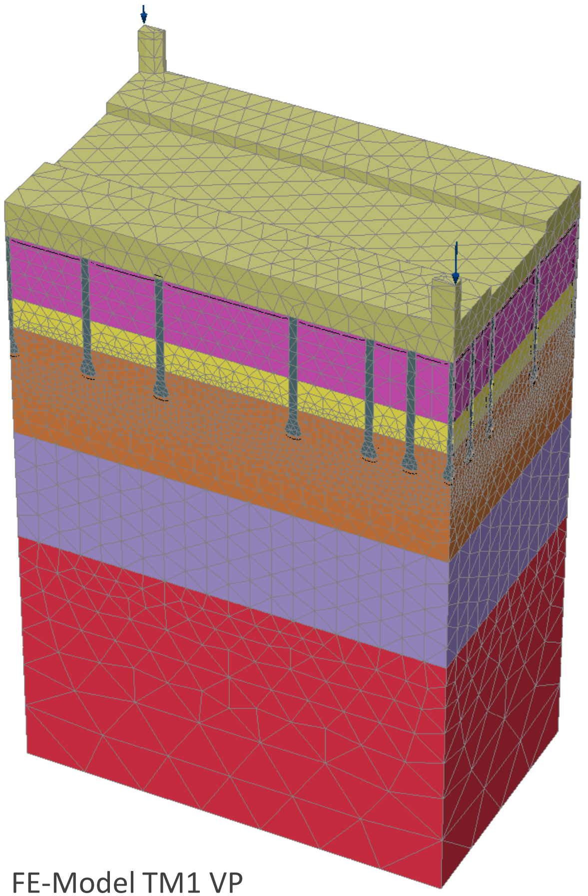
Ground floor plan of the piles foundation in TM 2

Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Using same configuration of volume piles and empedded piles



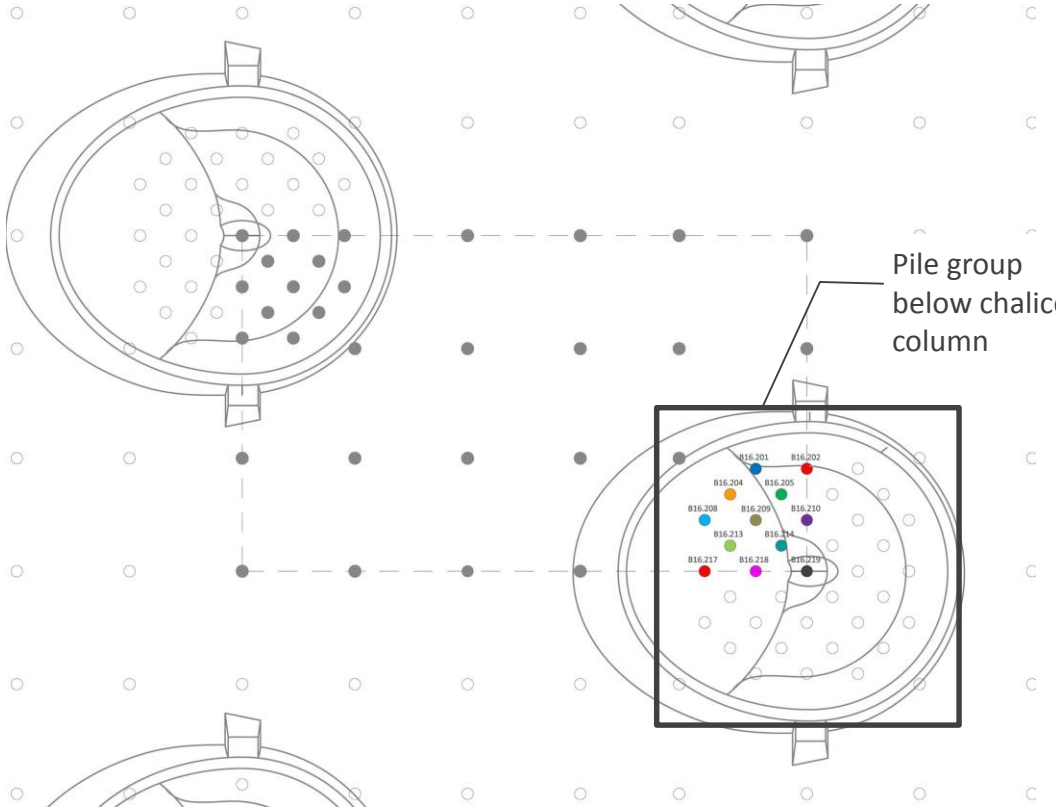
Ground floor plan of the piles foundation in TM 2



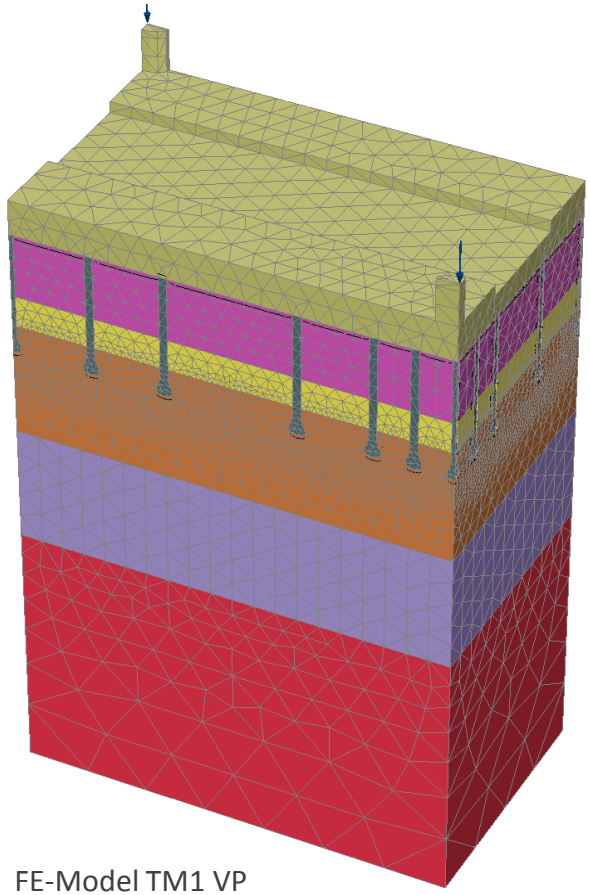
FE-Model TM1 VP

Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Using same configuration of volume piles and empedded piles



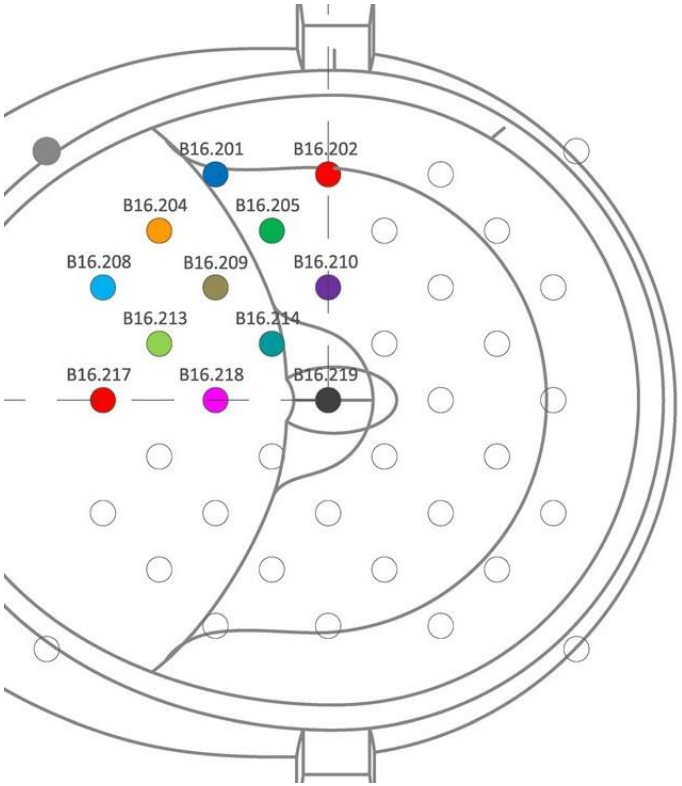
Ground floor plan of the piles foundation in TM 2



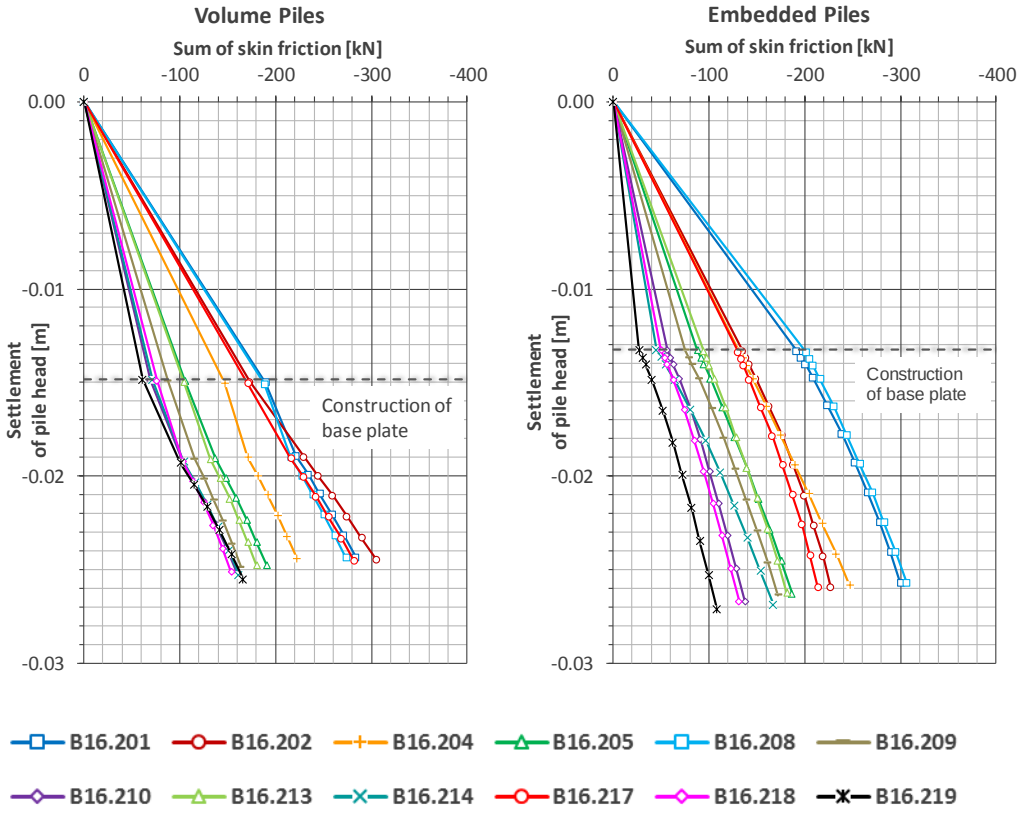
FE-Model TM1 VP

Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Comparison of resistance-settlement curve of the piles – resistance due to skin friction

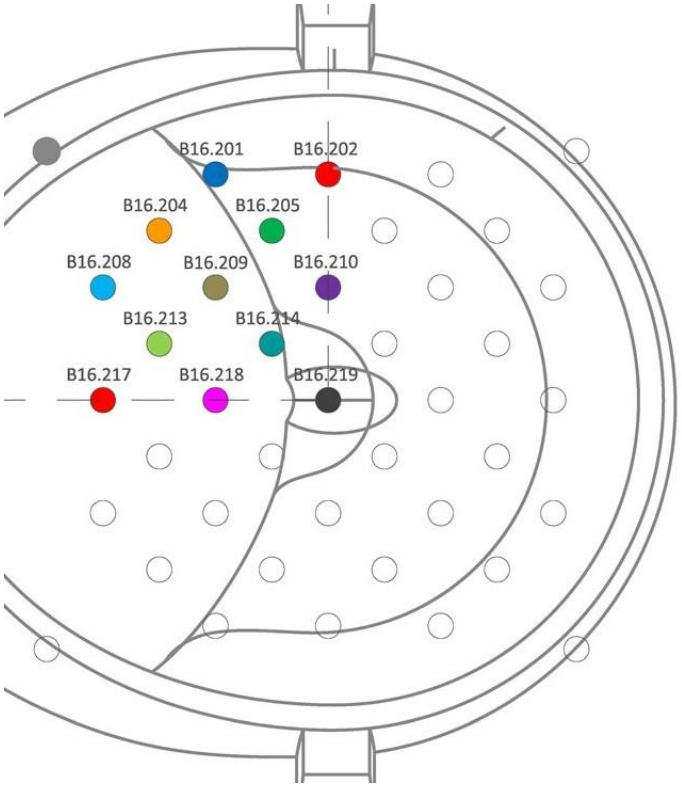


Pile group below chalice column

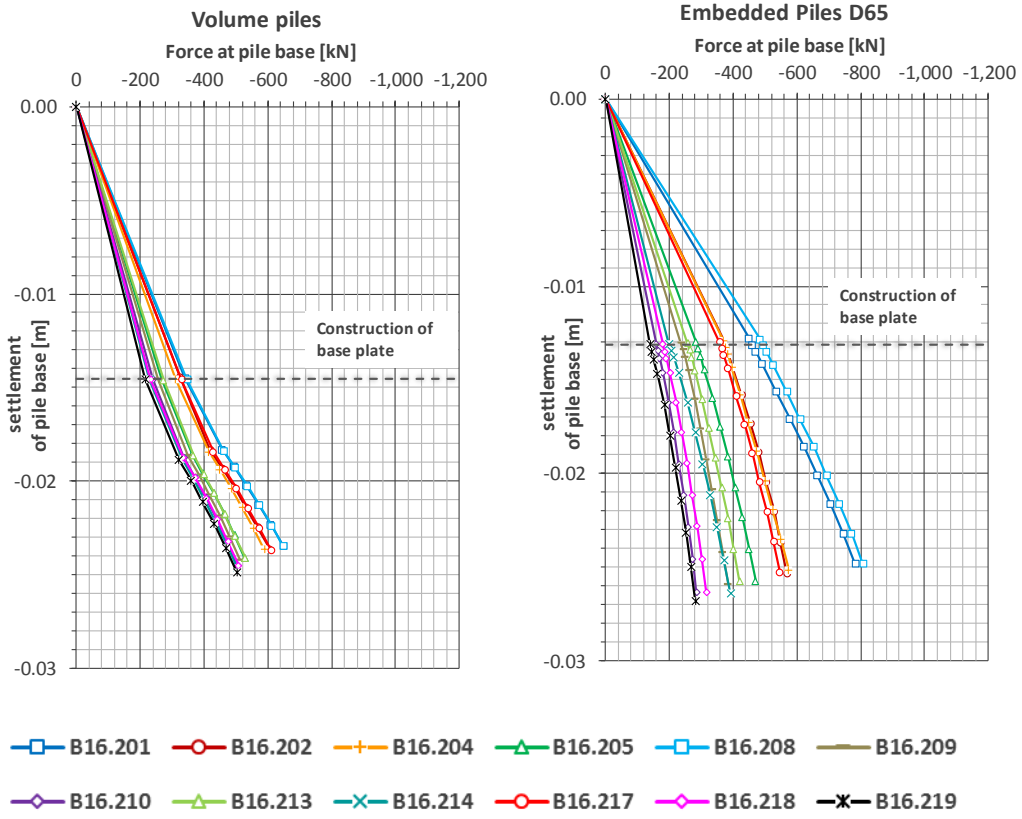


Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Comparison of resistance-settlement curve of the piles – pile base resistance

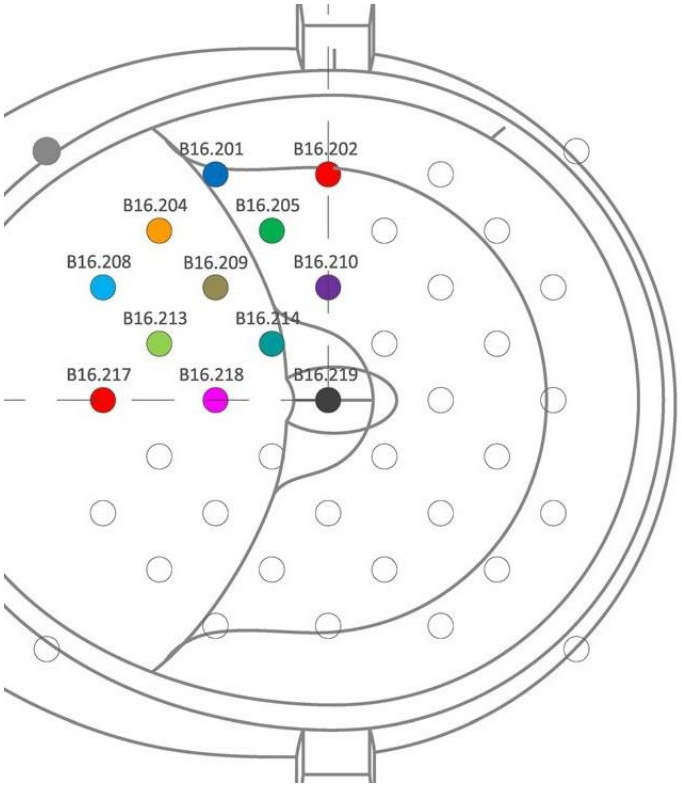


Pile group below chalice column

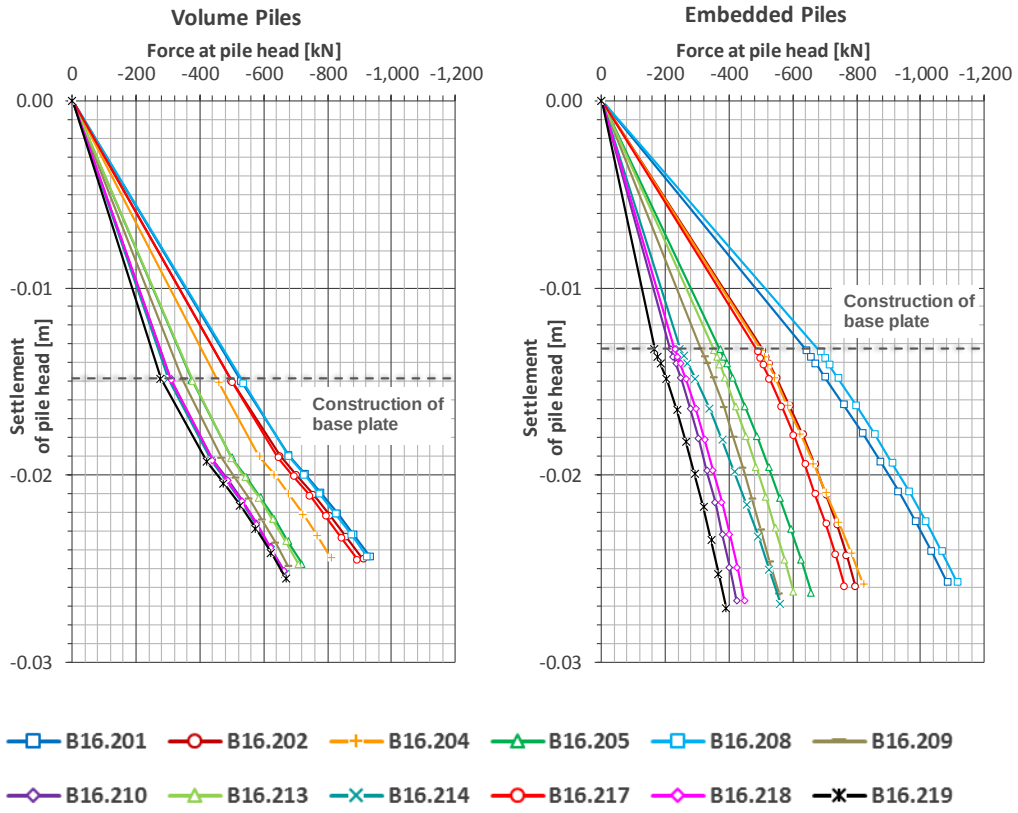


Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Comparison of resistance-settlement curve of the piles – pile resistance

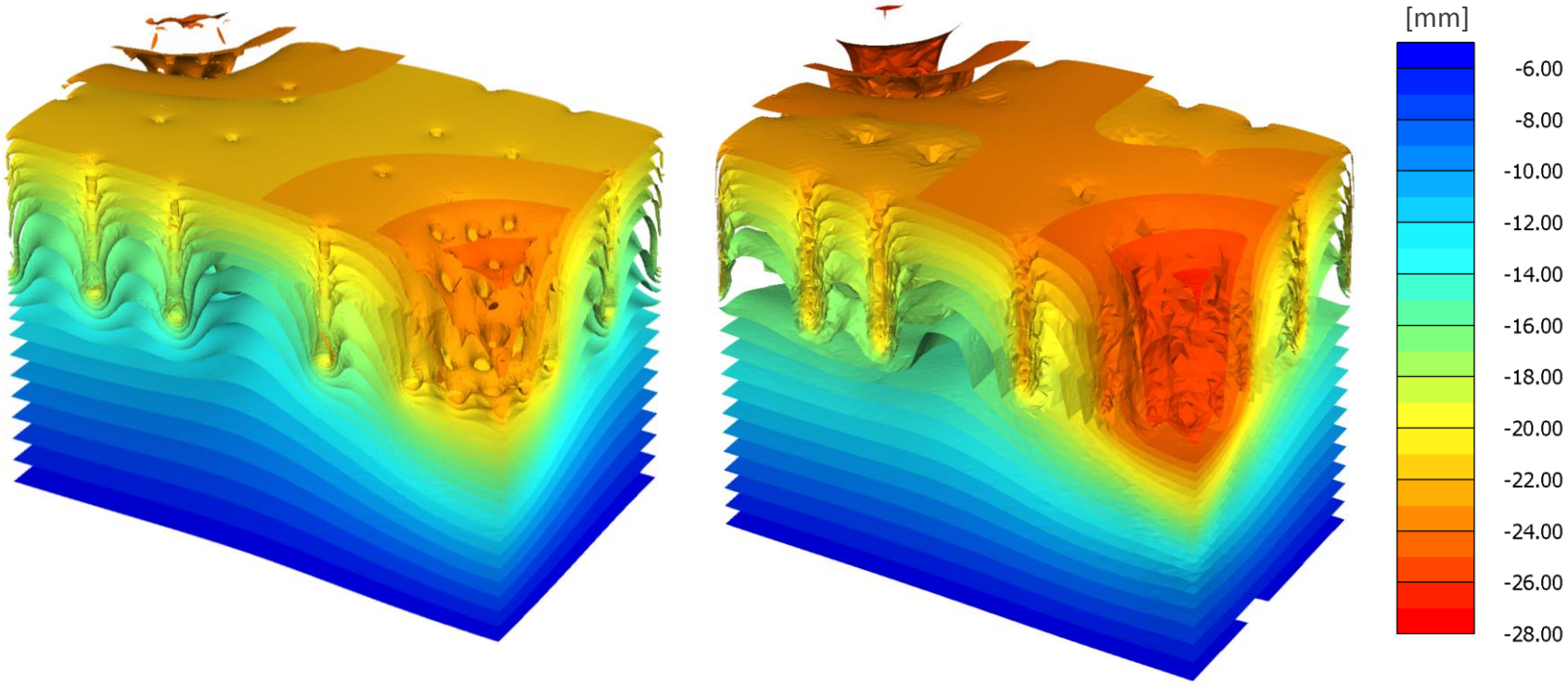


Pile group below chalice column



Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Comparison of vertical displacements



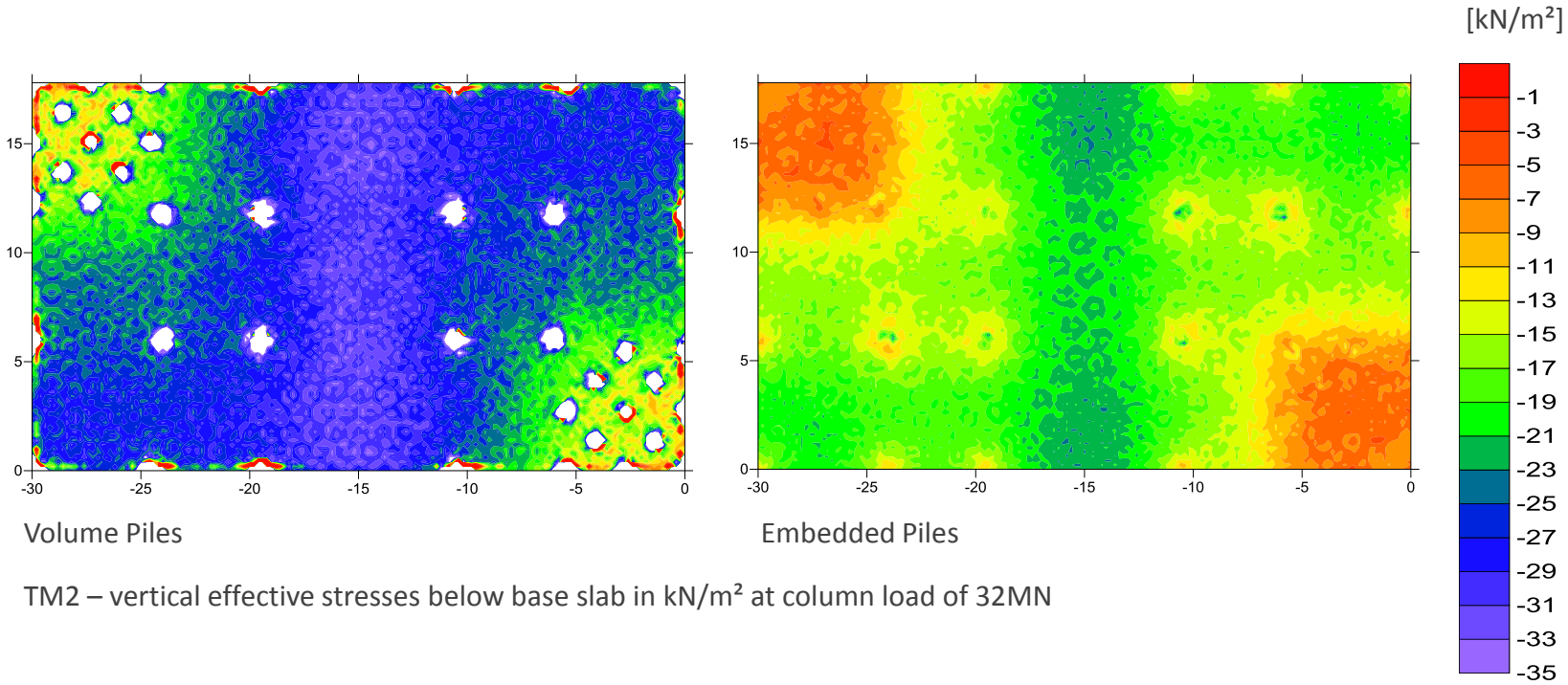
Volume Piles

Embedded Piles

TM2 – Iso surfaces of vertical displacements in mm at colunm load of 32MN

Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Comparison of vertical stresses at soil below base slab



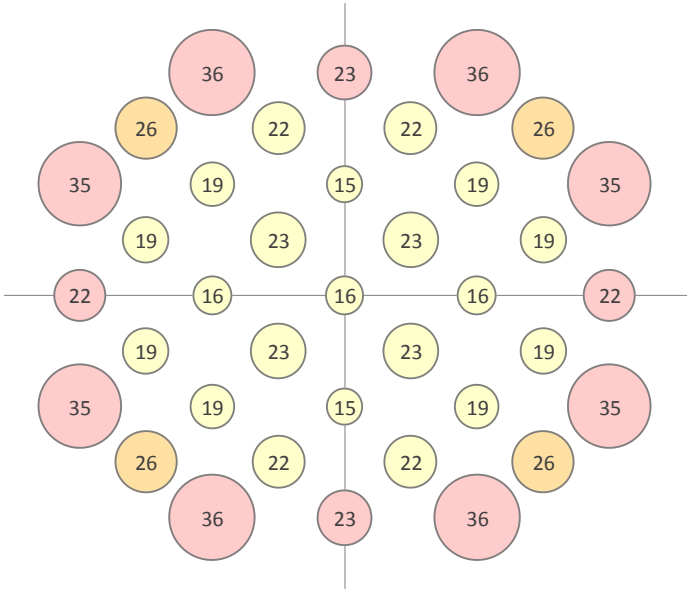
Volume Piles

Embedded Piles

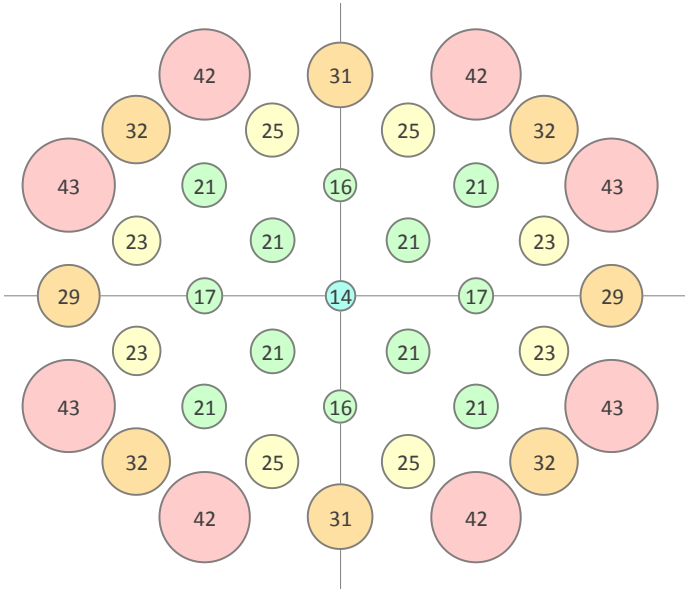
TM2 – vertical effective stresses below base slab in kN/m² at column load of 32MN

Study of load bearing behavior of volume piles and embedded piles while combined with the bas slab - (TM2)

Comparison of axial pile spring stiffness



Volumen Piles

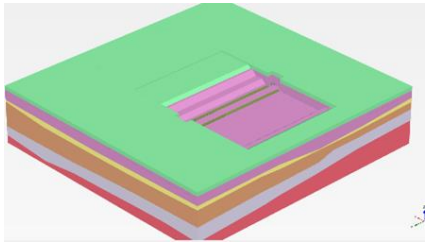


Embedded Piles

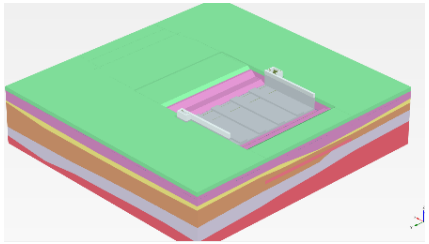
TM2 – axial pile spring stiffness in MN/m, Pile group below chalice column at column load of 32MN

Consideration of construction phase

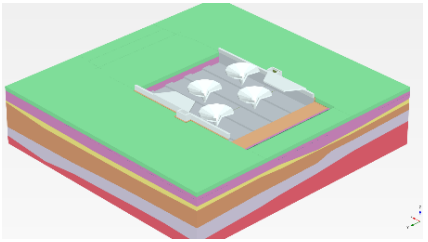
G-Modell with calculation phase



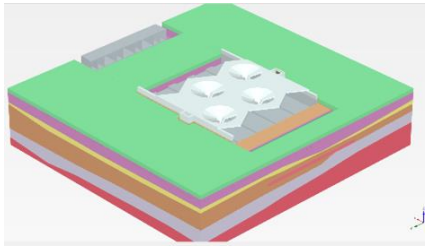
Floor excavation BA16



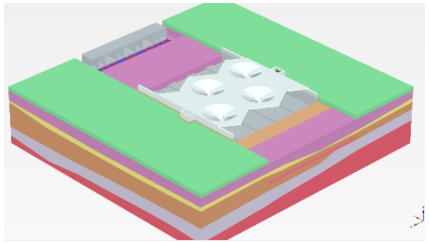
Trough BA16



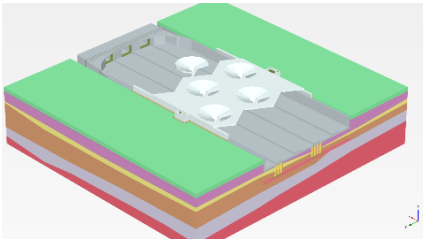
Trough with chalice supports BA16 & 17



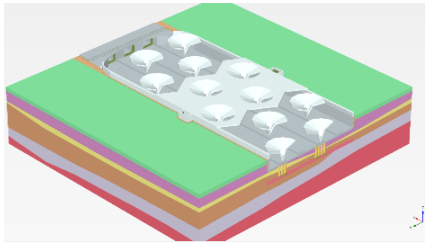
Shell roof BA16 &17, BW BA19



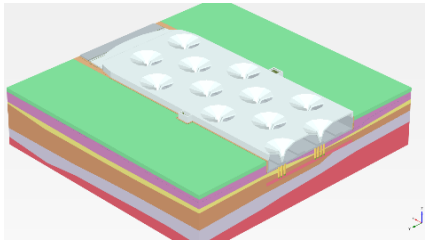
Final excavation BA18 & BA15



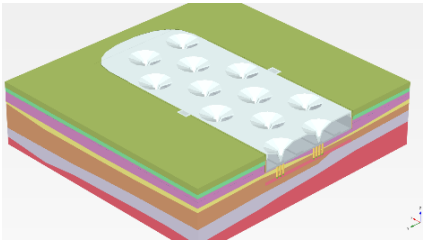
Trough BA18 & BA15



Chalice supports BA18 & BA15



Closing the shell roof

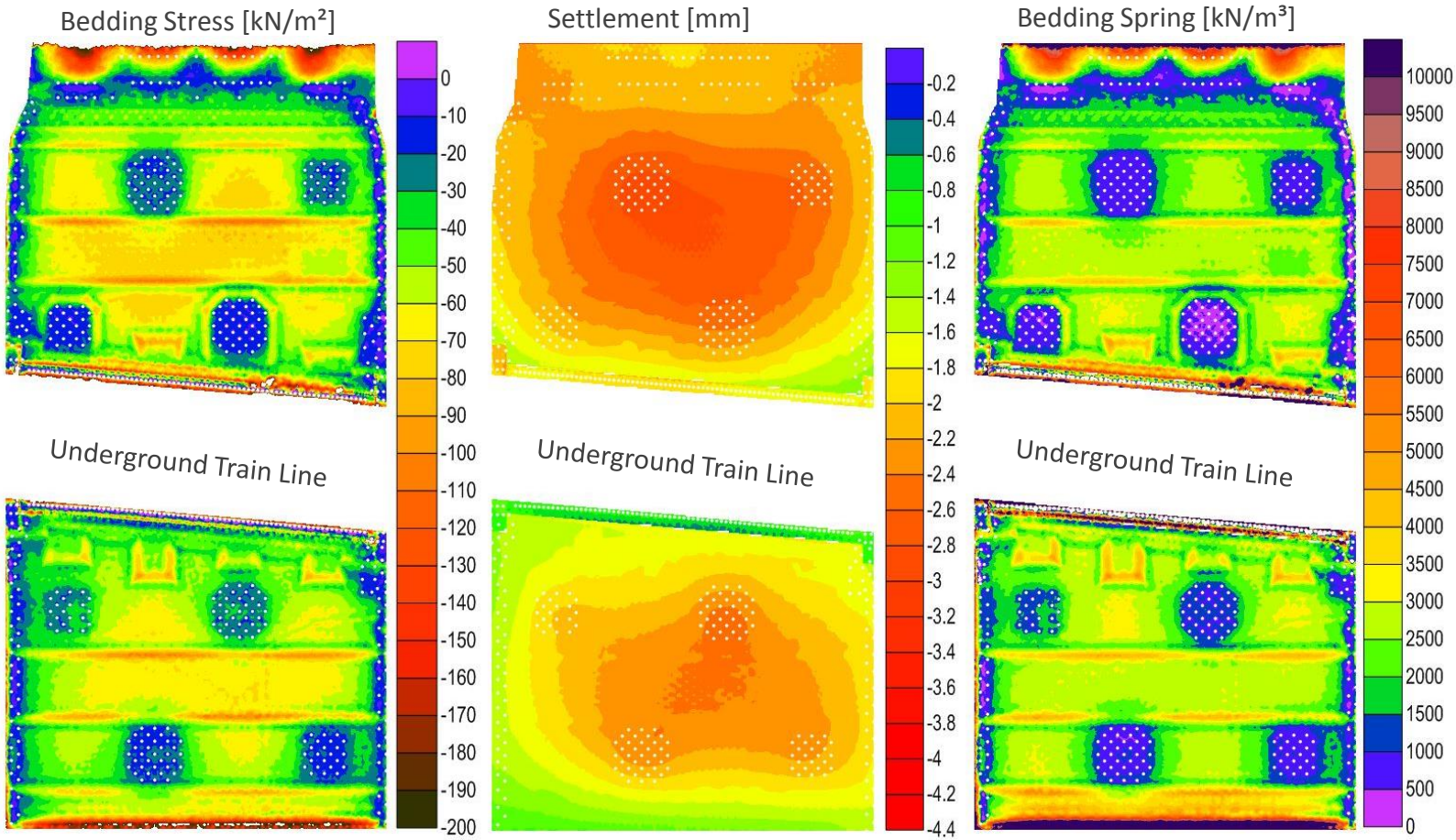


Backfill and landfill

Figure 1: Geotechnical model in selected phases of calculation (examples)

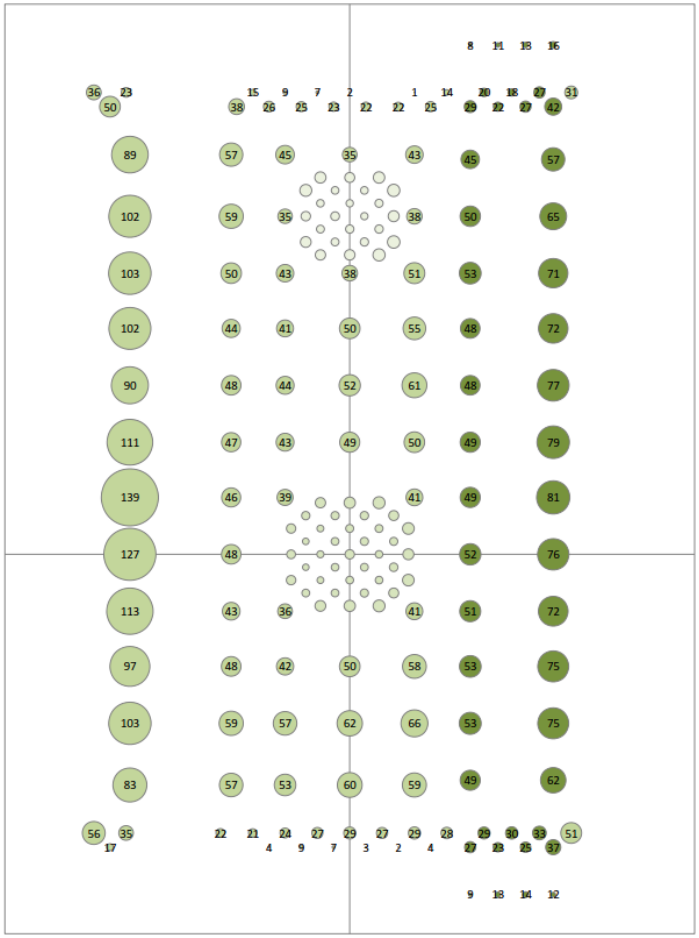
Calibration of Geotechnical and Structural Model

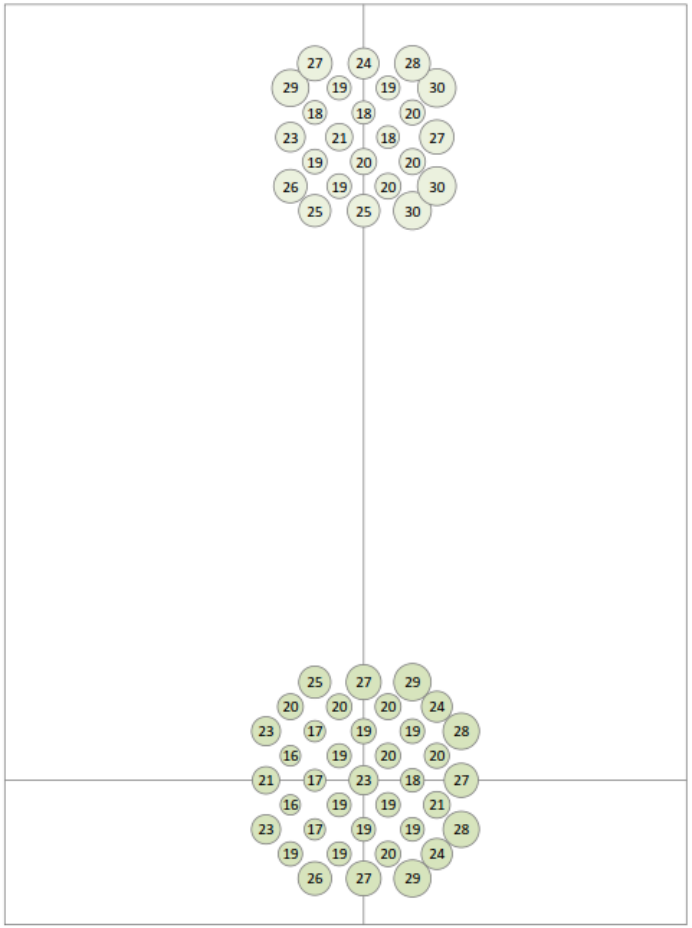
Base reactions from G-Model (Phase 26 - DL+ 1/3LL)



Calibration of Geotechnical and Structural Model

Example of pile springs from G-Model [MN/m²]

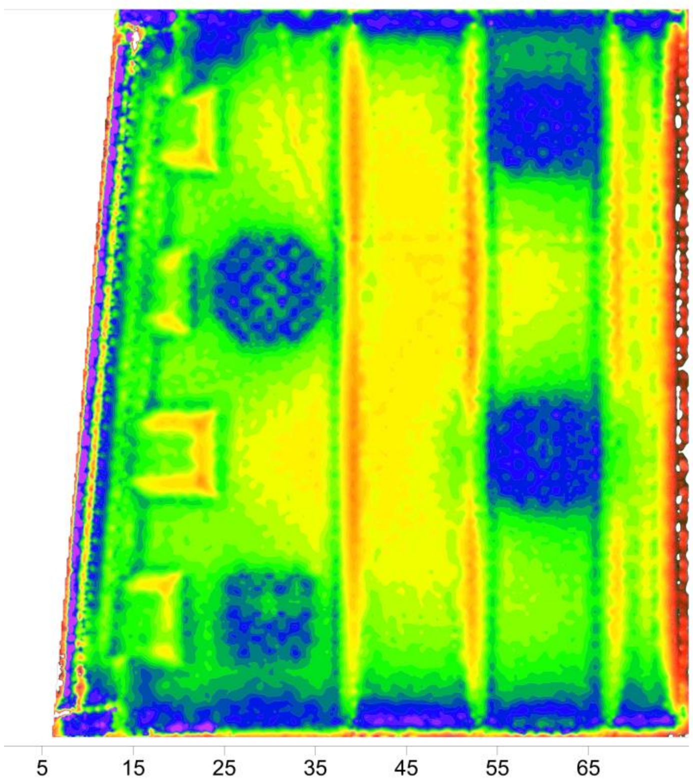




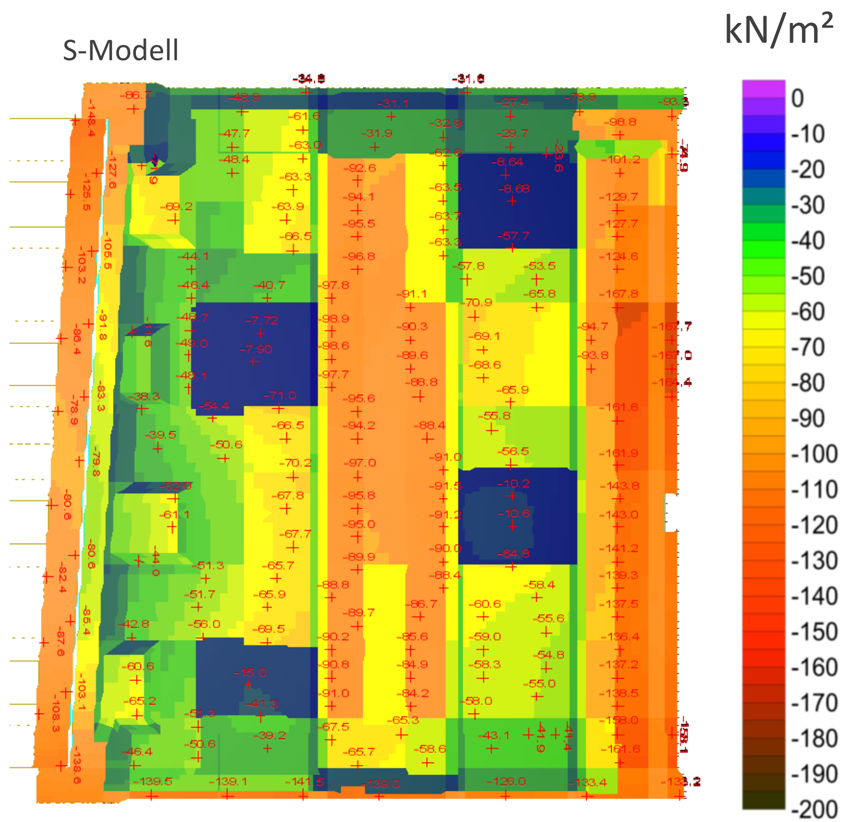
Calibration of Geotechnical and Structural Model

Comparison of bedding stress

G-Modell

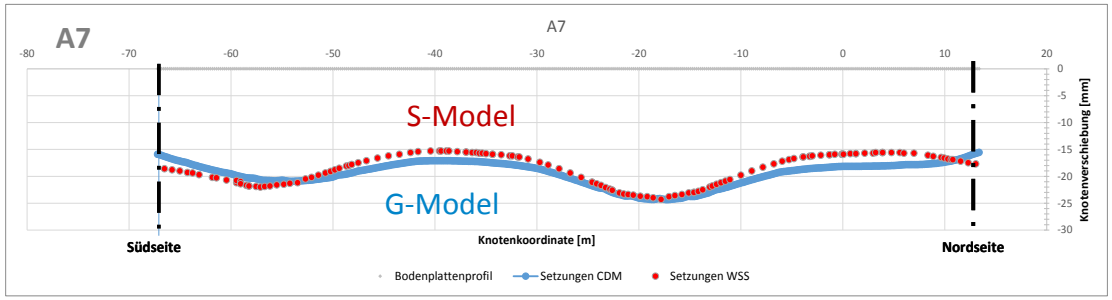


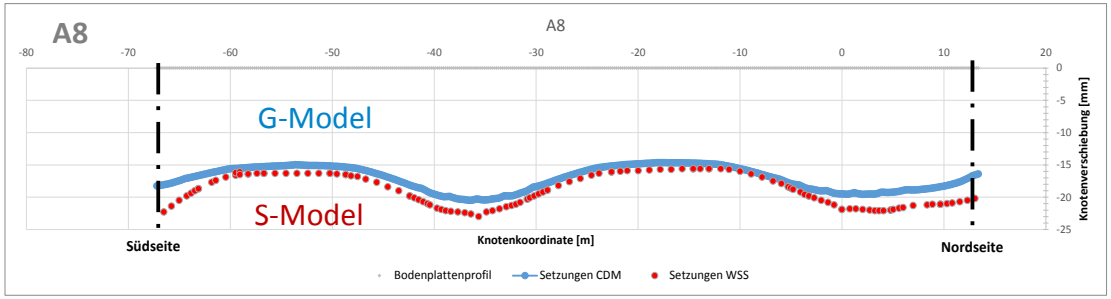
S-Modell

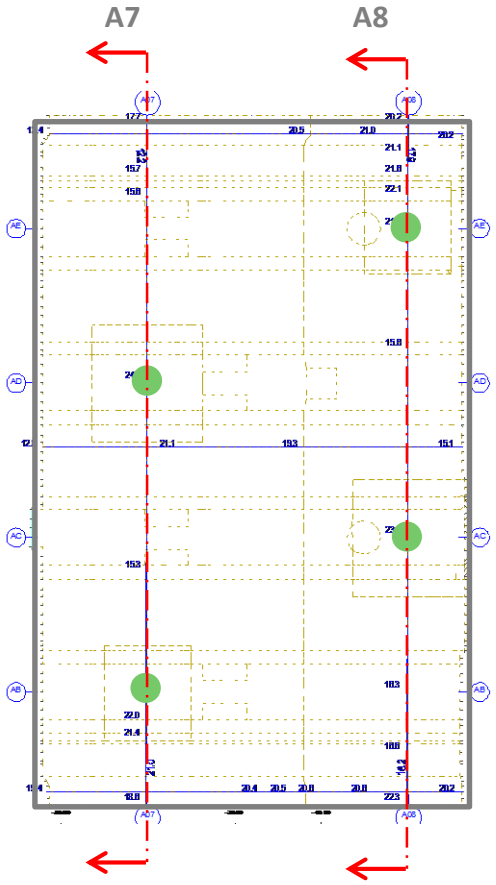


Calibration of Geotechnical and Structural Model

Comparison of settlements – cross sections

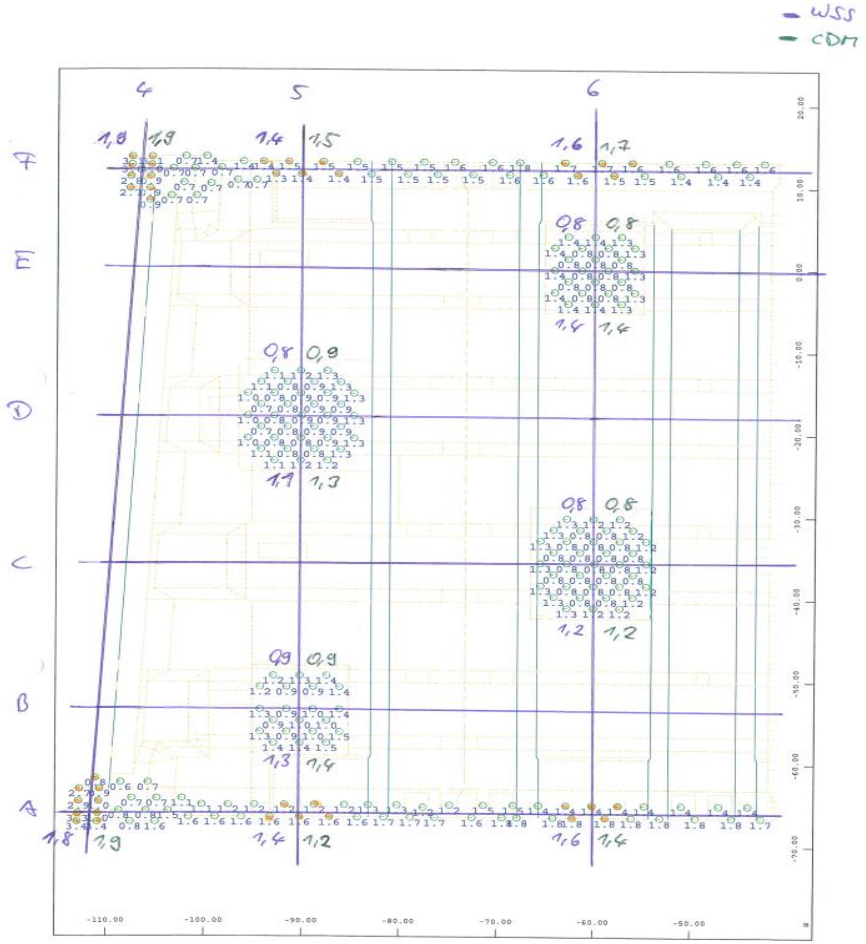






Calibration of Geotechnical and Structural Model

Comparison of pile reactions



Pfahlkräfte [MN]

Stelle	G-Modell (CDM)	T-Modell (WSS)	Abweichung	Abweichung %
A4	1,9	1,8	0,1	5%
A5	1,2	1,4	0,2	14%
A6	1,4	1,6	0,2	13%
B5a	0,9	0,9	0,0	0%
B5b	1,4	1,3	0,1	7%
C6a	0,8	0,8	0,0	0%
C6b	1,2	1,2	0,0	0%
D5a	0,9	0,8	0,1	11%
D5b	1,3	1,1	0,2	15%
E6a	0,8	0,8	0,0	0%
E6b	1,4	1,4	0,0	0%
F4	1,9	1,9	0,0	0%
F5	1,5	1,4	0,1	7%
F6	1,7	1,6	0,1	6%

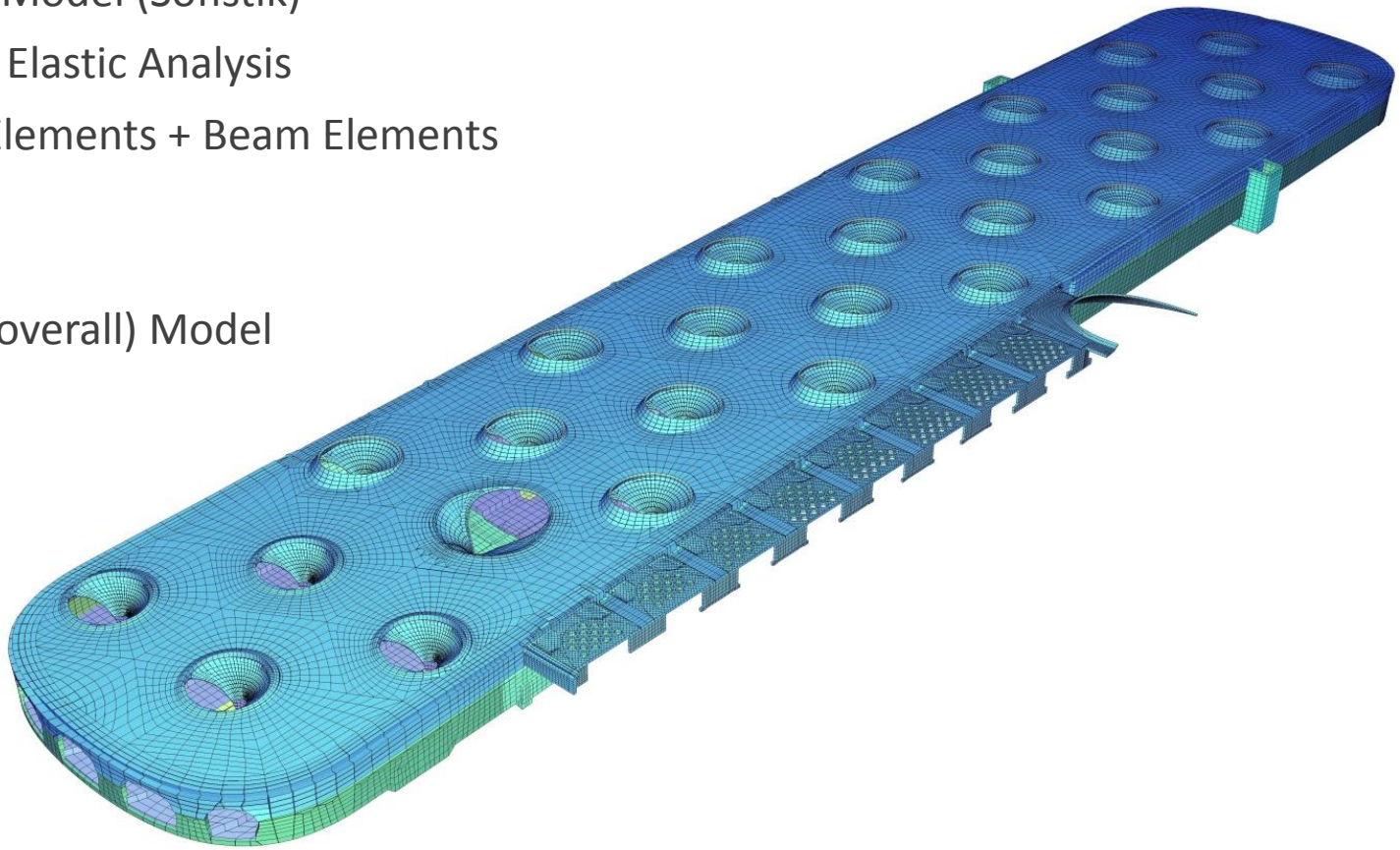
Verformung [mm]

Stelle	G-Modell (CDM)	T-Modell (WSS)	Abweichung	Abweichung %
A4	13	16	3	19%
A5	14	17	3	18%
A6	15	17	2	12%
B5	20	19	1	5%
C6	22	21	1	5%
D5	24	21	3	13%
E6	22	21	1	5%
F4	13	15	2	13%
F5	18	16	2	11%
F6	18	16	2	11%

Structural Models

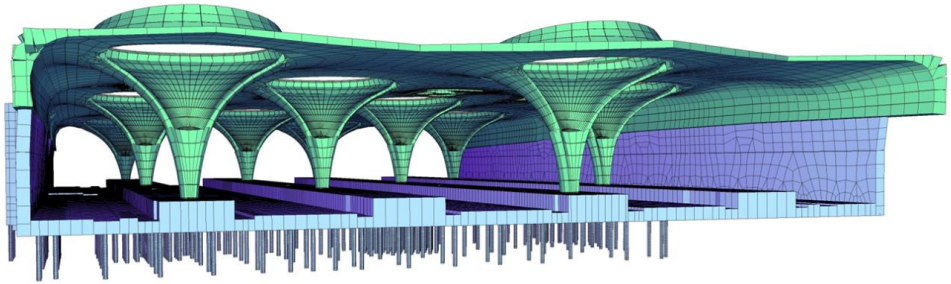
- 3D FE-Model (Sofistik)
- Linear Elastic Analysis
- Shell Elements + Beam Elements

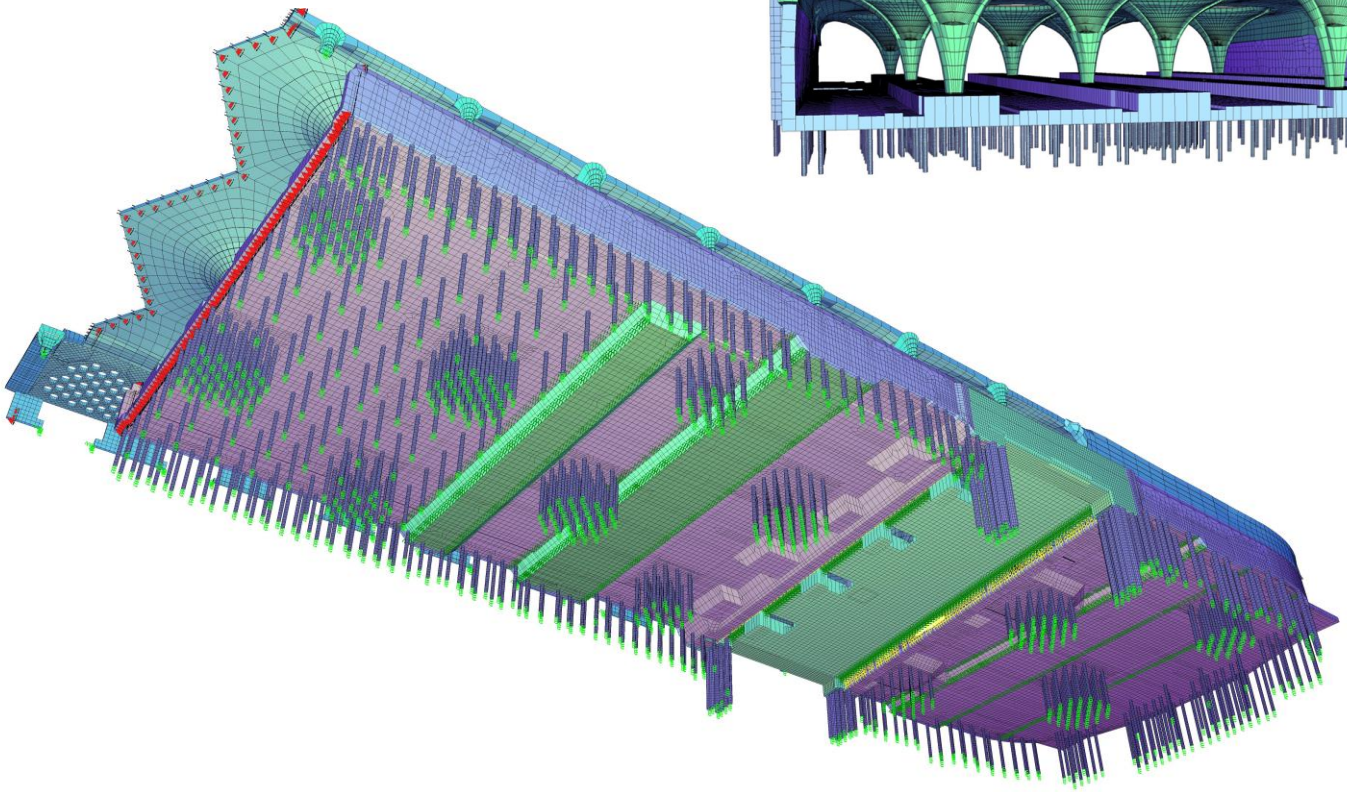
Main (overall) Model



Structural Models

- Partial Models

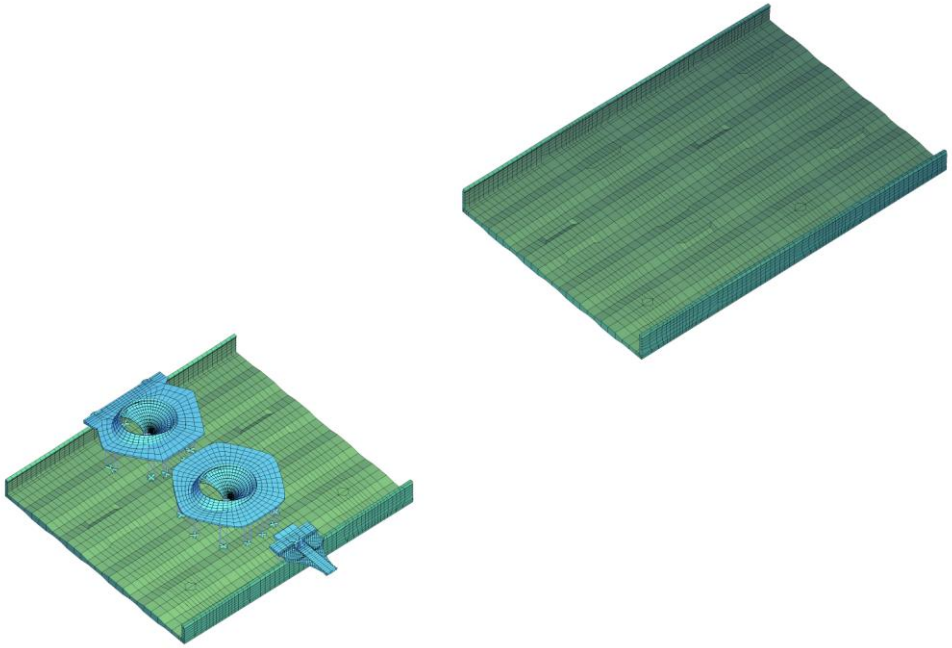




Structural Models

- Construction Phase Model

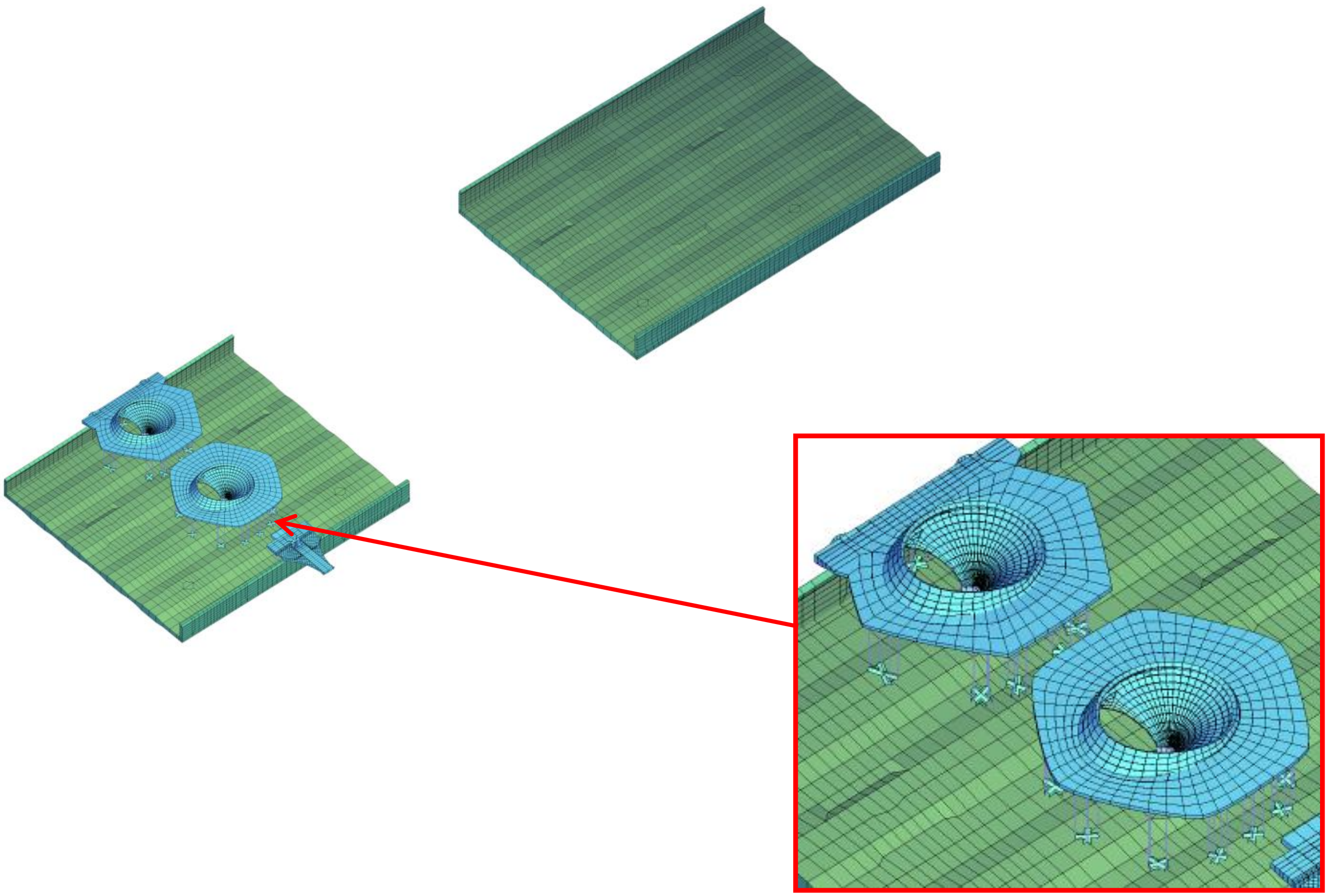
  Phase 5



Structural Models

- Construction Phase Model

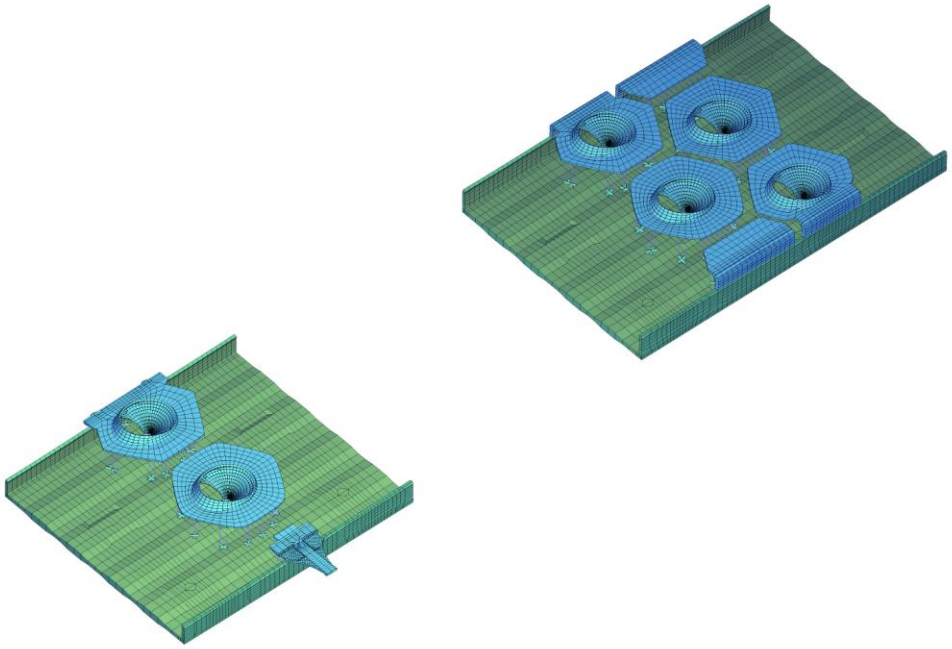
  Phase 5



Structural Models

- Construction Phase Model

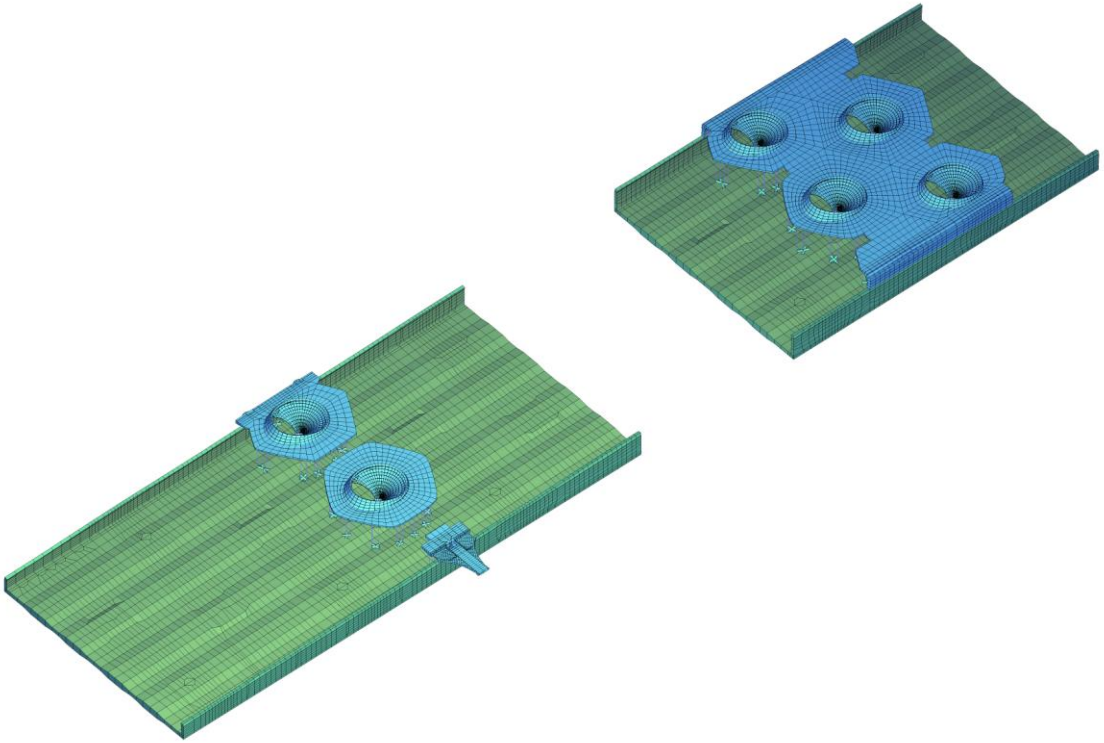
  Phase 6



Structural Models

- Construction Phase Model

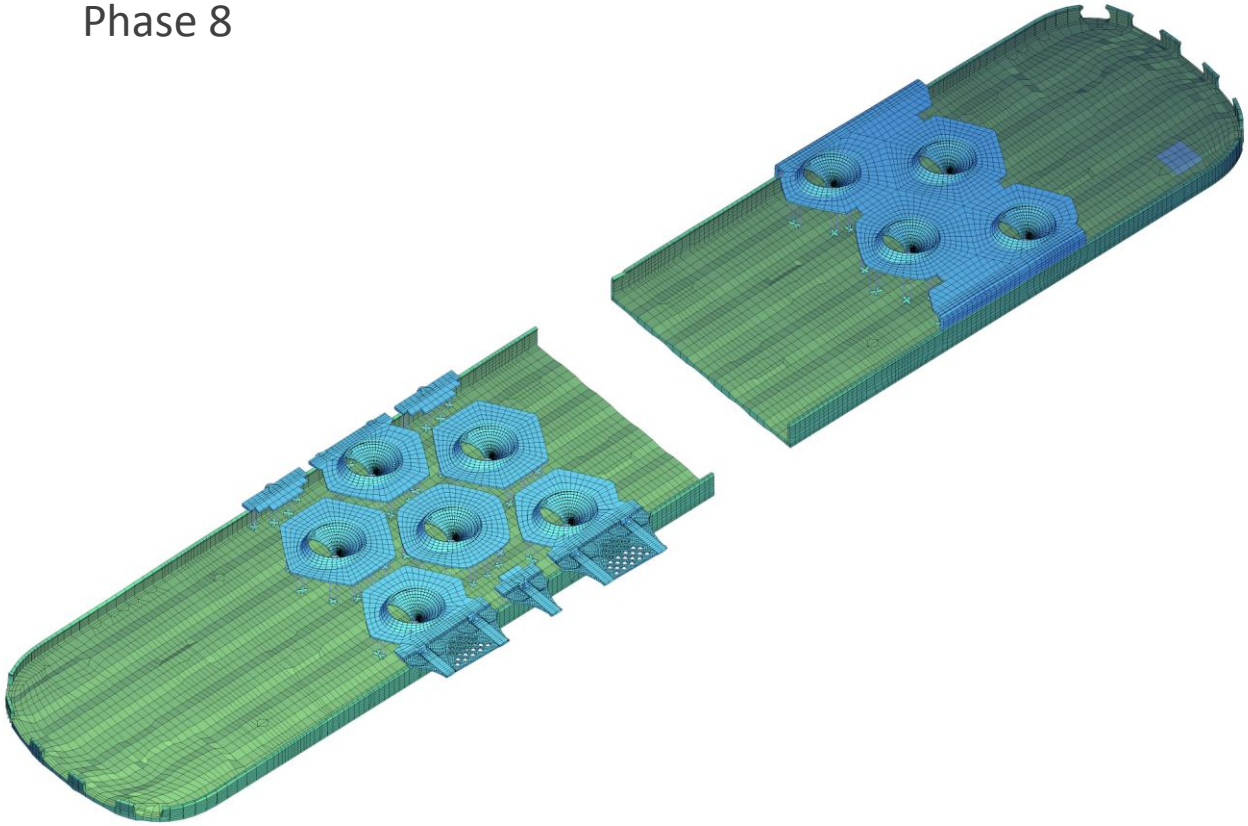
  Phase 7



Structural Models

- Construction Phase Model

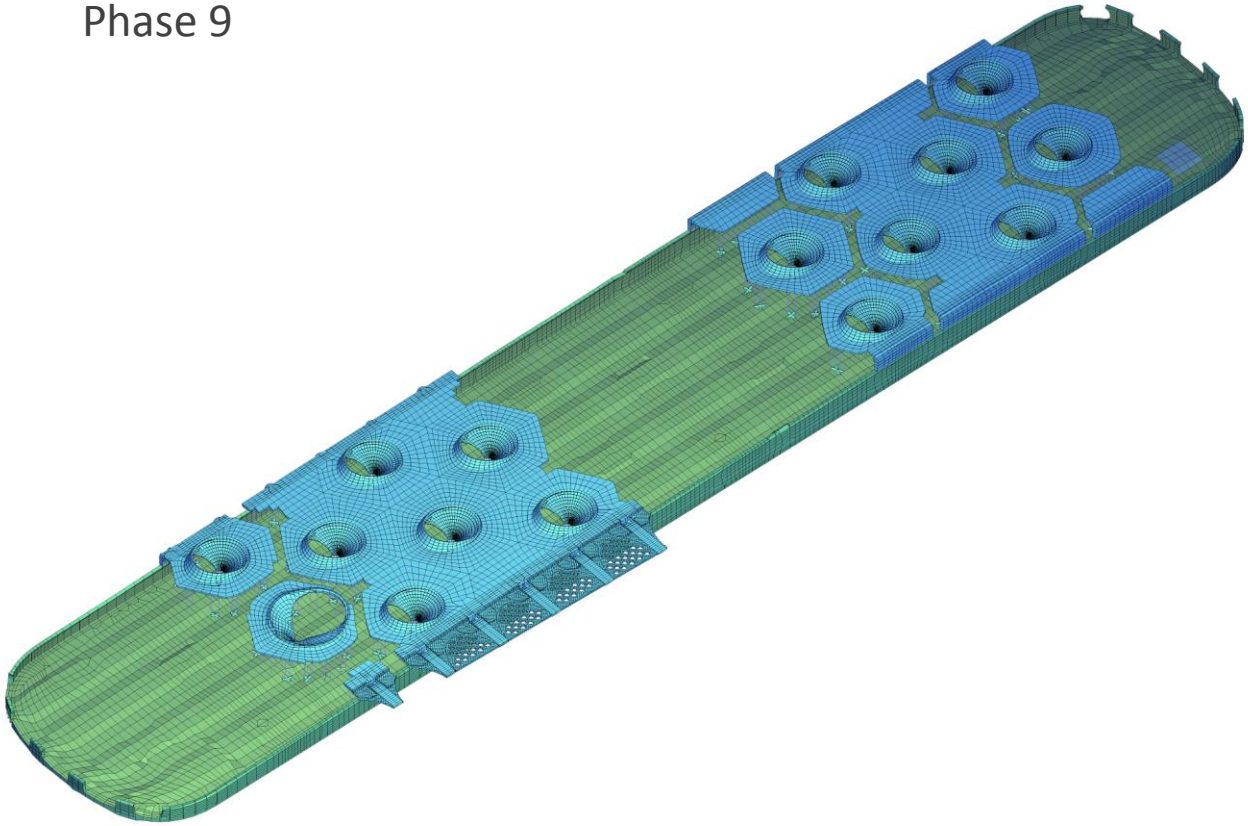
  Phase 8



Structural Models

- Construction Phase Model

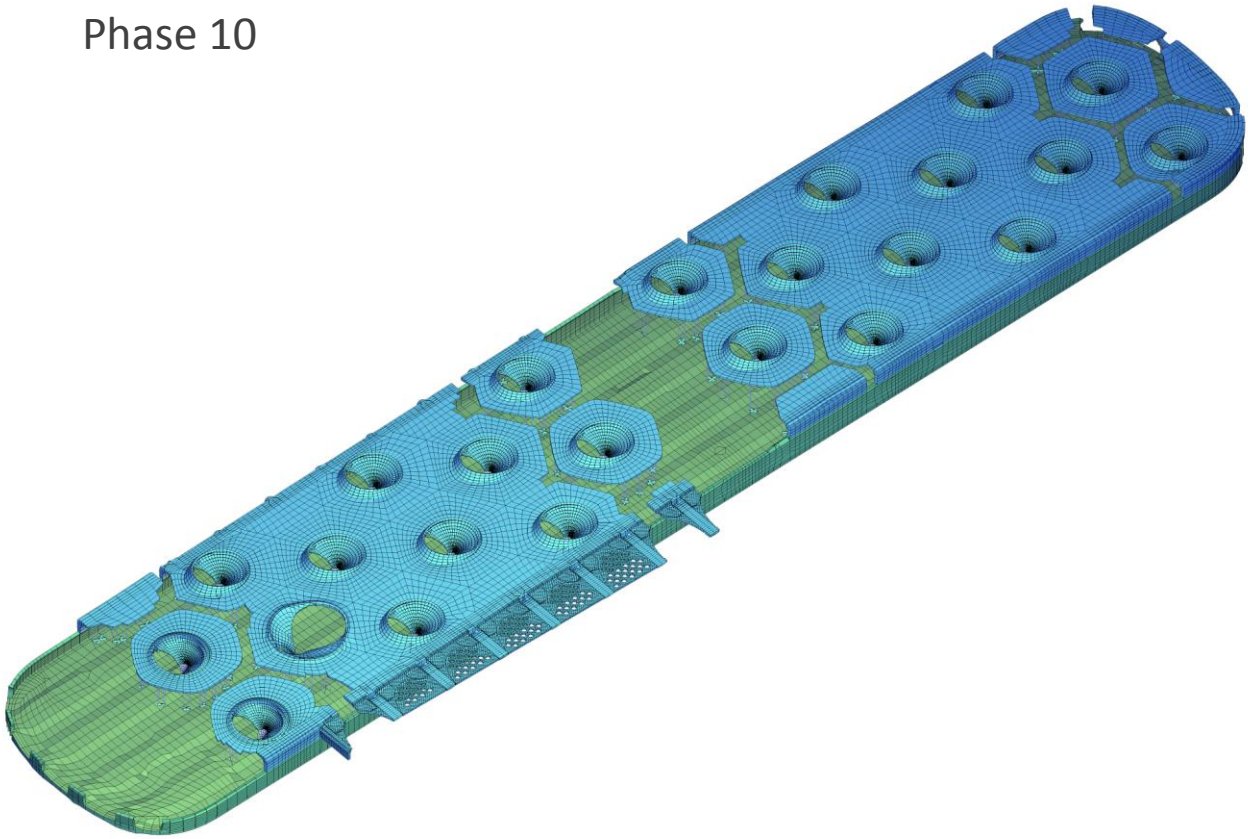
  Phase 9



Structural Models

- Construction Phase Model

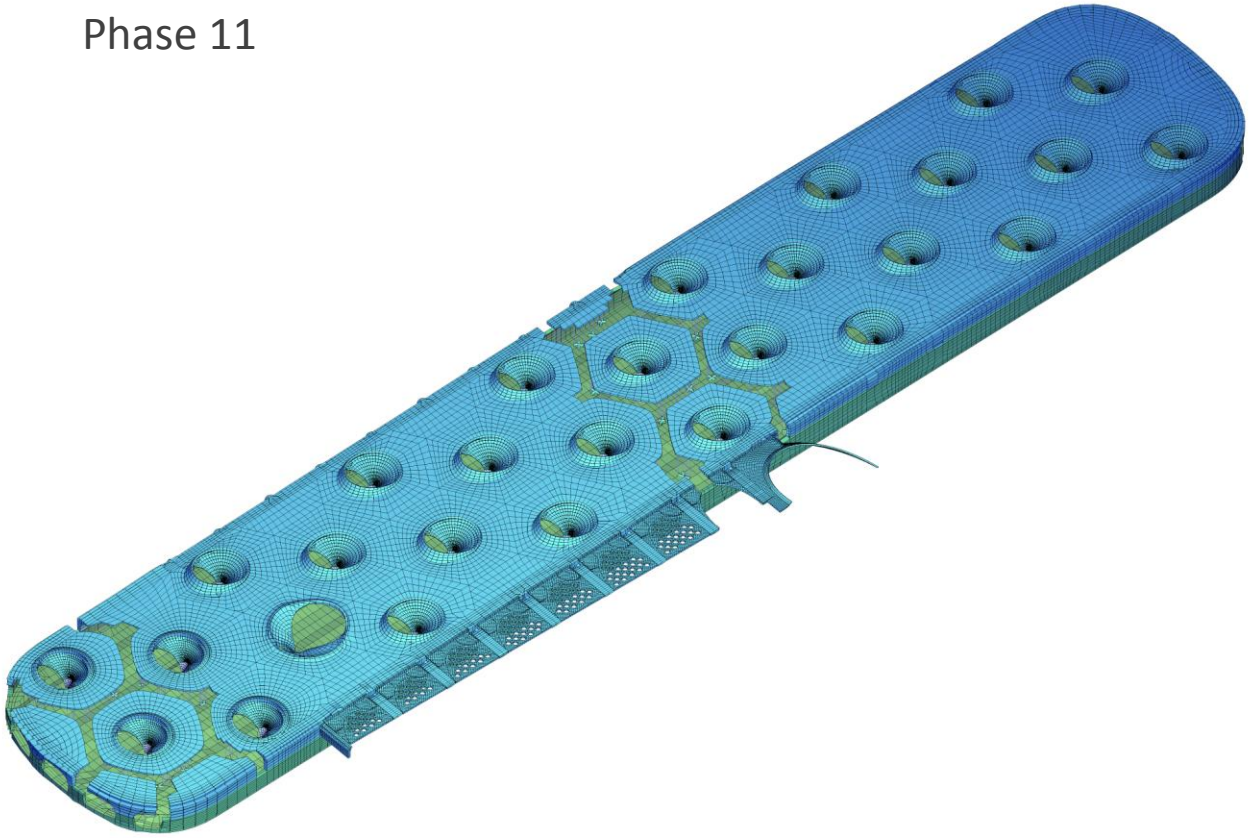
  Phase 10



Structural Models

- Construction Phase Model

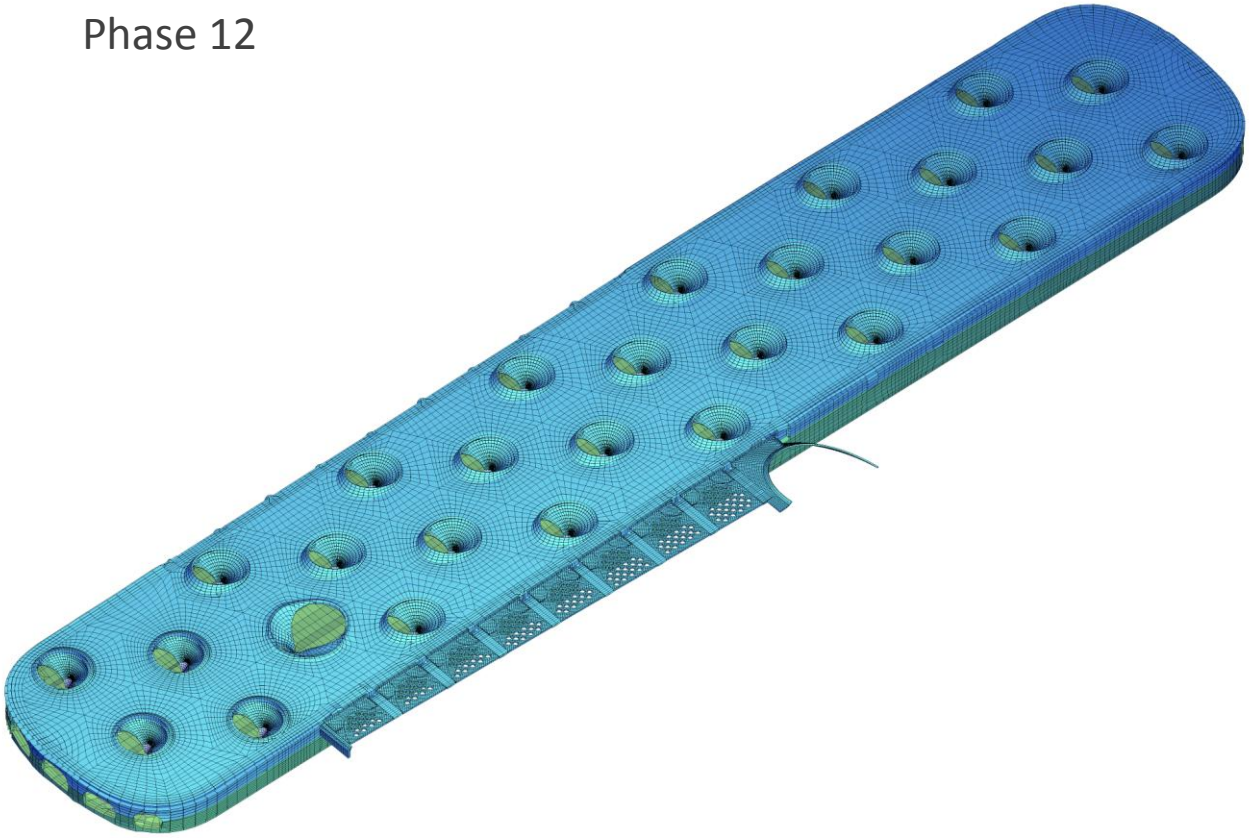
  Phase 11



Structural Models

- Construction Phase Model

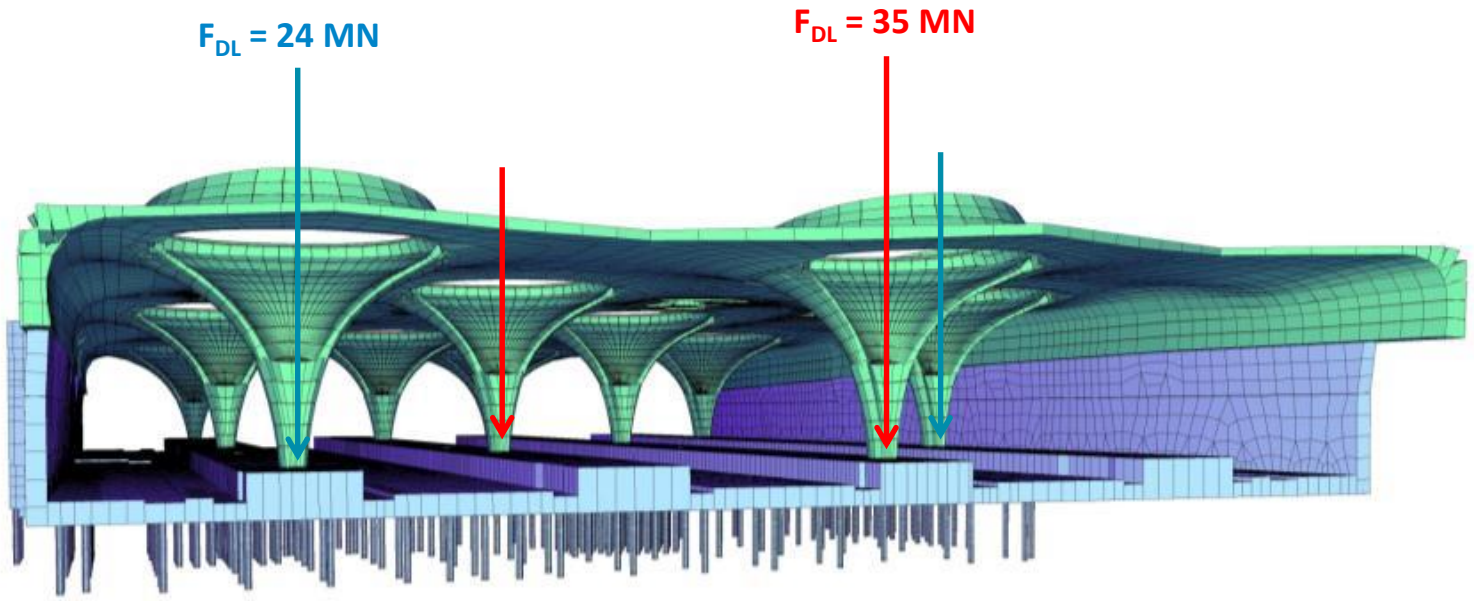
  Phase 12



Structural Design

- Main Loadings

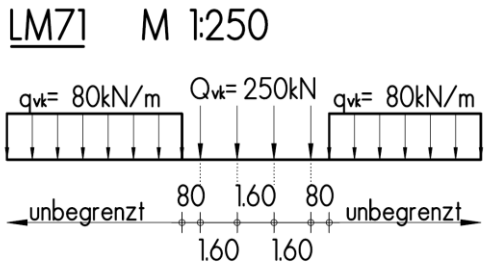
- **Dead Loads**
- Earth pressure and ground water pressure
- Train traffic loading
- Temperature and shrinkage
- Eathquake

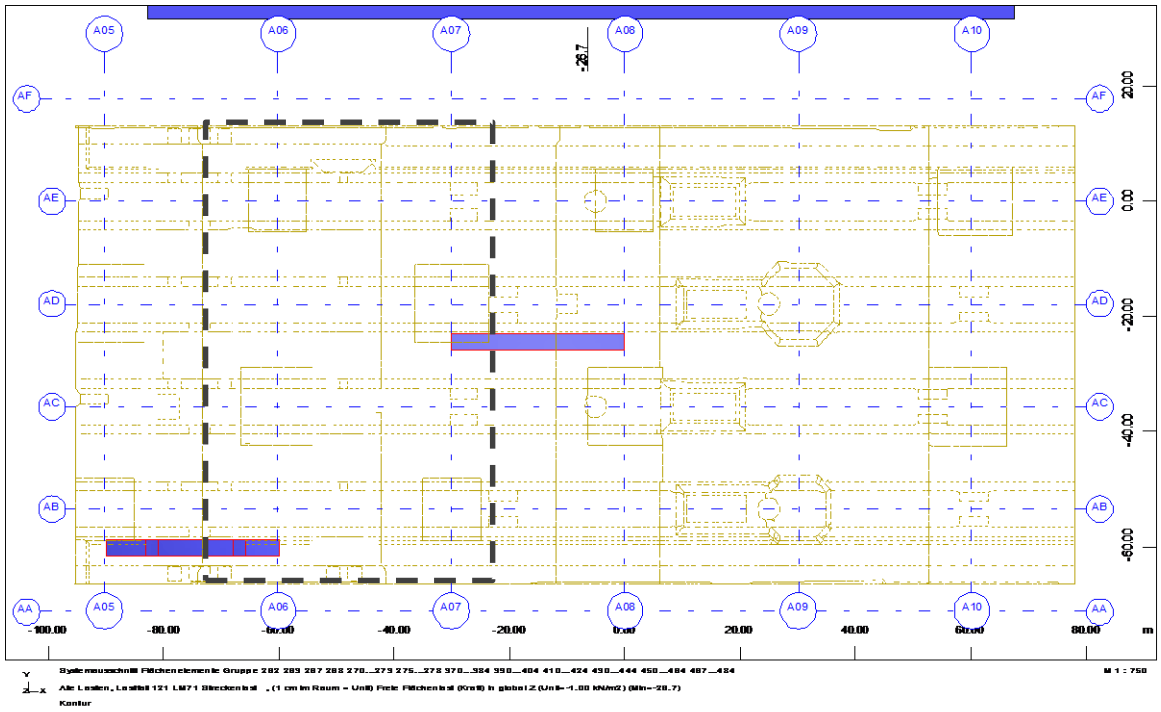


Structural Design

- Main Loadings

- Dead Loads
- Earth pressure and ground water pressure
- **Train traffic loading**
- Temperature and shrinkage
- Eathquake





Structural Design

- Main Loadings

- Dead Loads
- Earth pressure and ground water pressure
- **Train traffic loading**
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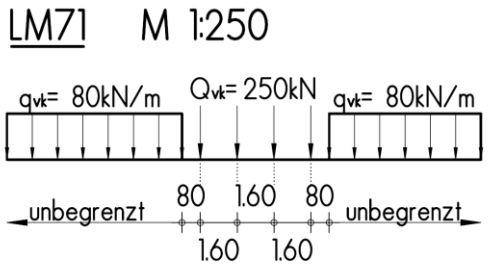

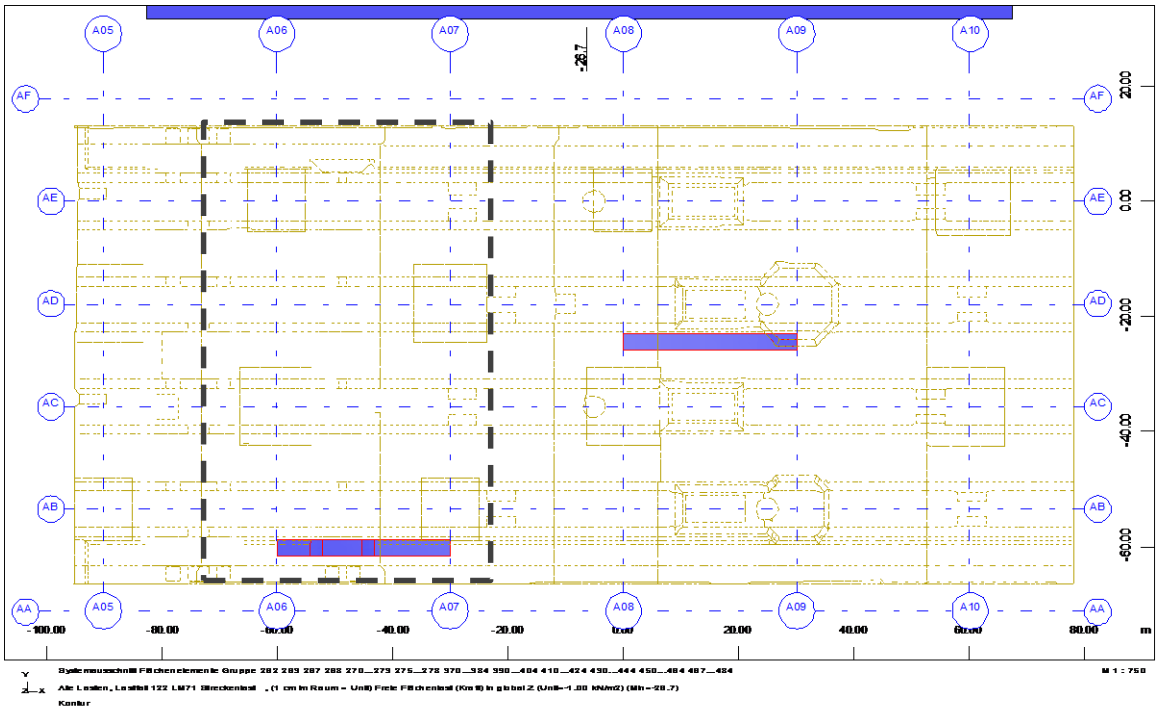

Structural Design

- Main Loadings

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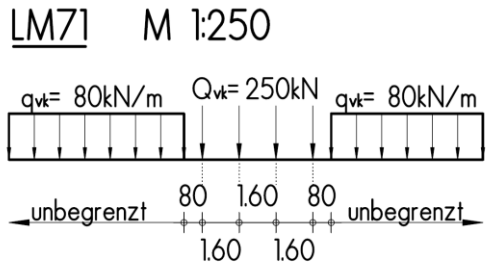

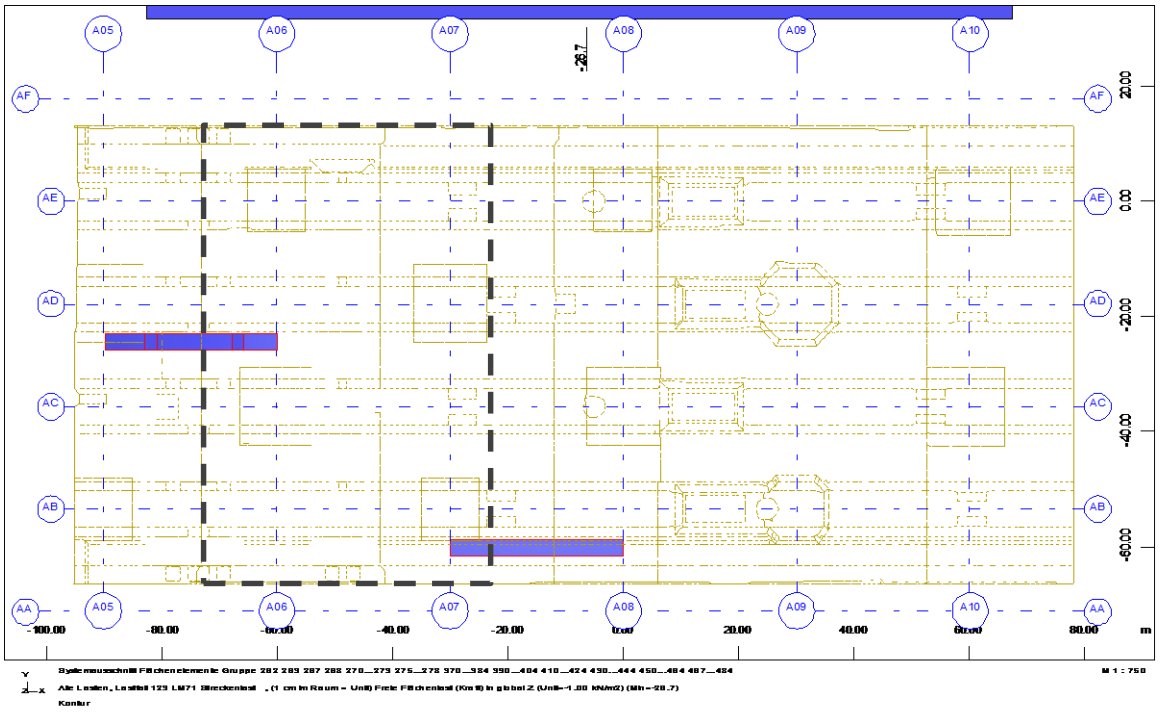

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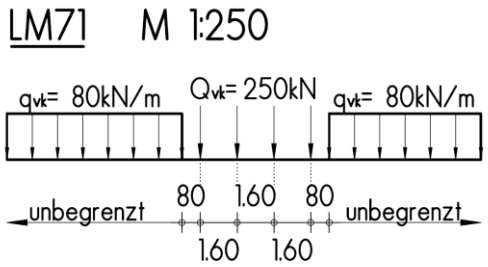

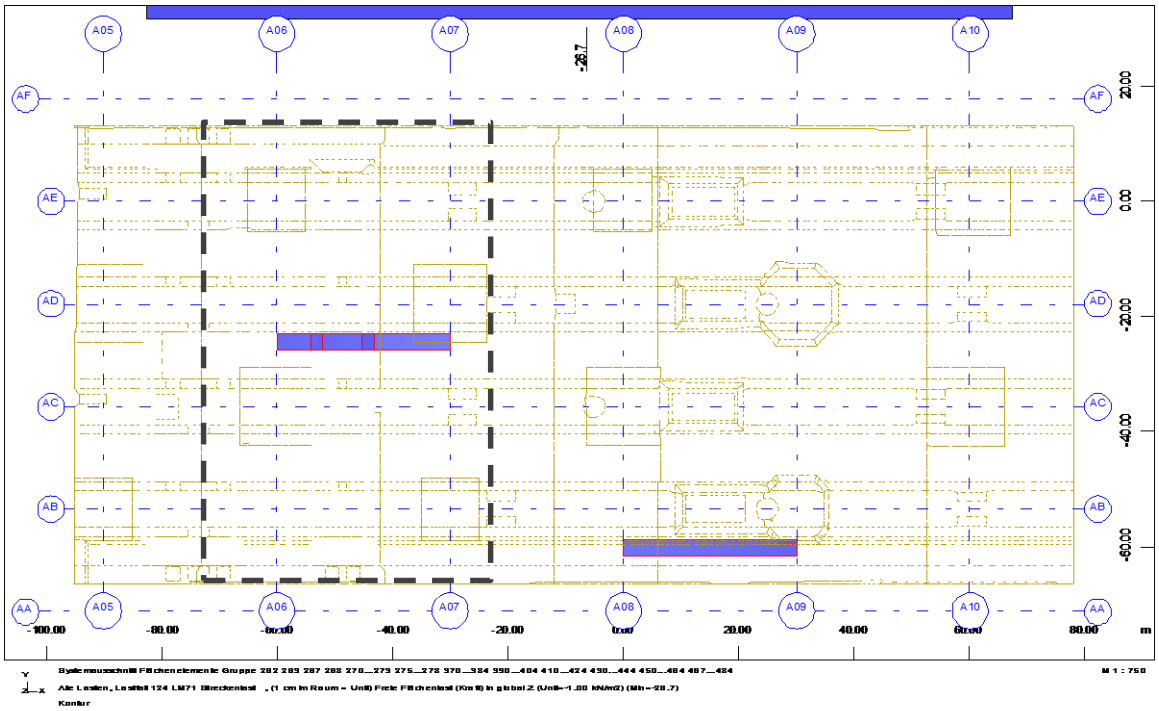

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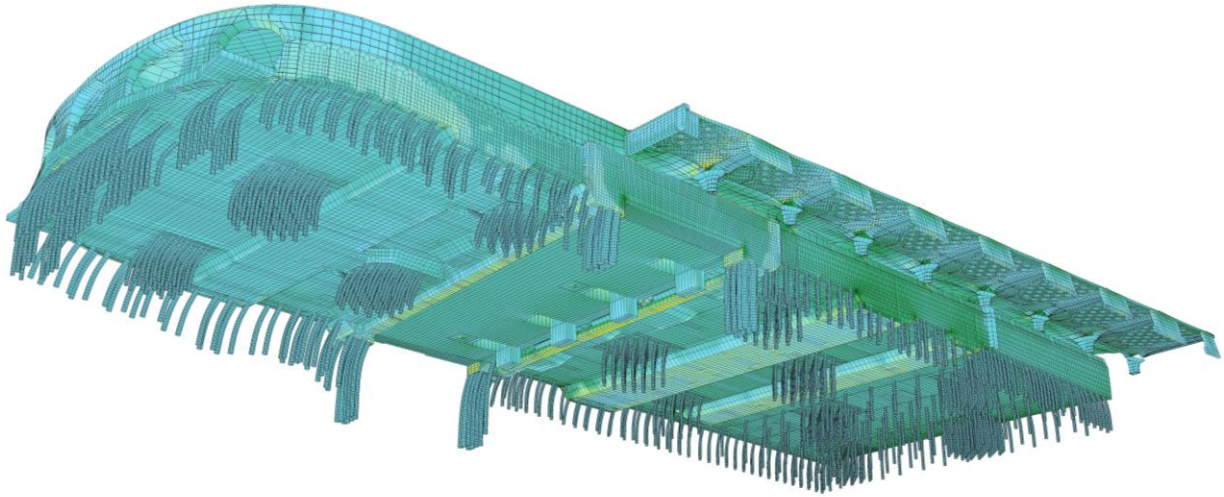

Structural Design

- Main Loadings

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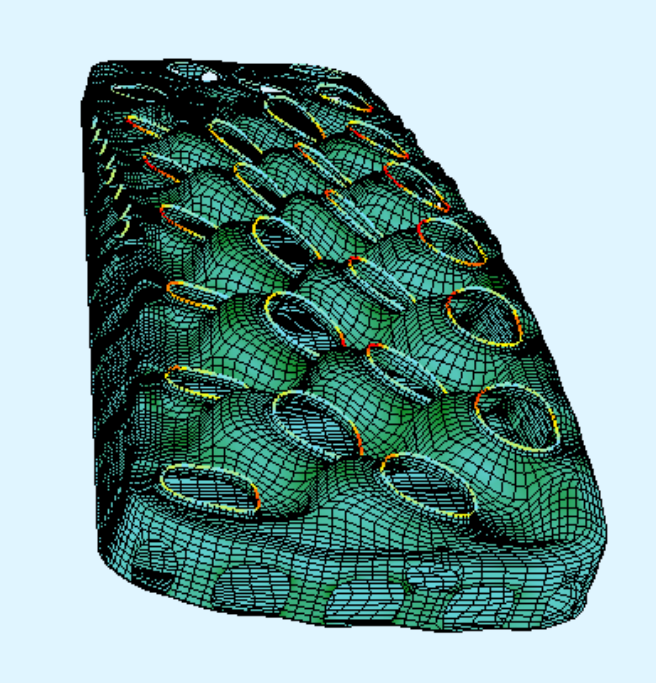


Structural Design

Main Loadings

- Up to 240 single loadcases for one partial model
- 7 different design combinations
- Additional sub-combinations

LF	Bezeichnung	Gruppe
1	Eigengewicht	G1
2	Ausbaulast Dach	G1
3	Eigengewicht Lichtaugen	G1
5	Ausbaulast Bodenplatte	G1
7	Ausbaulast Fertigteile Bodenplatte	G1
8	Eigengewicht + Ausbaulast Rolltreppen	G1
9	Eigengewicht + Ausbaulast Festtreppen	G1
10	Eigengewicht + Ausbaulast Aufzüge	G1
11	Eigengewicht + Ausbaulast Verteilersteg A,B	G1
12	Eigengewicht + Ausbaulast Rucksack	G1
13	Eigengewicht + Ausbau KGK-Schale	G1
21	Eigengewicht Dach gewichtslos	G1
15	Schnee auf Dach	S1
16	Schnee auf Lichtaugen	S1
17	Schnee KGK-Schale I	S2
18	Schnee KGK-Schale II	S2
19	Schnee KGK-Schale III	S2
30	Schwinden -10K	Q1
31	Schwinden Bodenplatte -15.6 K Dach -16.7 K	Q1
32	Schwinden Bodenplatte -15.6 K Dach -16.7 K	Q1
33	Wind KGK-Schale I	W
34	Wind KGK-Schale I	W
35	Wind KGK-Schale I	W
36	Wind KGK-Schale I	W
37	Wind KGK-Schale I	W
41	Erddruck ständig mF	G1
42	Erddruck veränderlich I Nord	Q2
43	Erddruck veränderlich I Süd	Q2
44	Erddruck veränderlich II Nord	Q2
45	Erddruck veränderlich II Süd	Q2
51	Erddruck ständig oF	Q2
52	Erddruck veränderlich I Nord	Q2
53	Erddruck veränderlich I Süd	Q2
54	Erddruck veränderlich II Nord	Q2
55	Erddruck veränderlich II Süd	Q2
56	Wasserdruck HGW200 abzgl. Mindestwasserdruck	Q3
57	Wasserdruck HGW200	Q3
58	Mindestwasserdruck	Q3
61	Anprall Stütze Achse 5-AB	A
62	Anprall Stütze Achse 5-AB	A
63	Anprall Stütze Achse 5-AB	A
64	Anprall Stütze Achse 5-AB	A
65	Anprall Stütze Achse 5-AD	A
66	Anprall Stütze Achse 5-AD	A
67	Anprall Stütze Achse 5-AD	A
68	Anprall Stütze Achse 5-AD	A
69	Anprall Stütze Achse 6-AC	A
70	Anprall Stütze Achse 6-AC	A
71	Anprall Stütze Achse 6-AC	A
72	Anprall Stütze Achse 6-AC	A
73	Anprall Stütze Achse 6-AE	A
74	Anprall Stütze Achse 6-AE	A
75	Anprall Stütze Achse 6-AE	A
76	Anprall Stütze Achse 6-AE	A

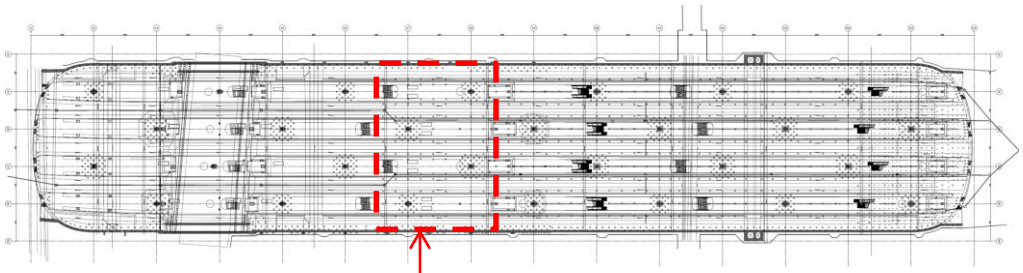
LF	Bezeichnung	Gruppe
81	Anbindebauwerk BA9 - Ständige Lasten	G1
82	Nutz-/Verkehrslasten	G1
101	Verkehrslast Schalendach	Q4
102	Verkehrslast auf Lichtaugen	Q4
104	Verkehrslast Verteilersteg	Q4
105	Verkehrslast Rucksack	Q4
111	Pratzenlast 1a	Q8
112	Pratzenlast 1b	Q8
113	Pratzenlast 2a	Q8
114	Pratzenlast 2b	Q8
115	Müllfahrzeug 1	Q9
116	Müllfahrzeug 2	Q9
117	Müllfahrzeug 3	Q9
121 - 124	LM71 Streckenlast	Q6
125 - 128	LM71 Streckenlast	Q6
129 - 132	LM71 Streckenlast	Q6
133 - 136	LM71 Streckenlast	Q6
141 - 154	LM71 Achsüberlast	Q6
155 - 168	LM71 Achsüberlast	Q6
169 - 182	LM71 Achsüberlast	Q6
183 - 196	LM71 Achsüberlast	Q6
201 - 207	SW/2	Q6
208 - 214	SW/2	Q6
215 - 221	SW/2	Q6
222 - 228	SW/2	Q6
231	Zugverkehr Horizontal +	Q7
232	Zugverkehr Horizontal -	Q7
241 - 244	Verkehrslast Bahnsteig	Q5
245 - 248	Verkehrslast Bahnsteig	Q5
252	Verkehrslast Technikkanal Rand	Q5
253	Verkehrslast Technikräume	Q5
254	Verkehrslast Rolltreppen	Q5
255	Verkehrslast Festtreppen	Q5
256	Verkehrslast Aufzüge	Q5

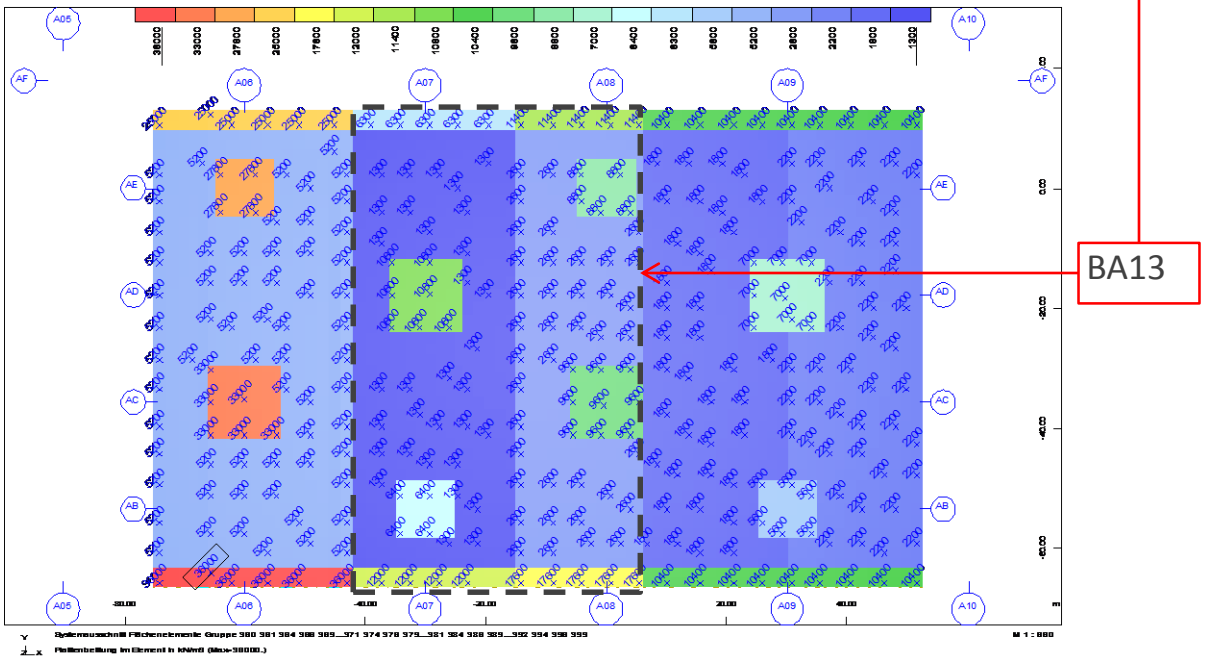
LF	Bezeichnung	Gruppe
321	Temperatur +15K End	T1
322	Temperatur -10K End	T1
323	Temp-Unterschied End Sommer I	T1
324	Temp-Unterschied End Sommer II	T1
325	Temp-Unterschied End Winter I	T1
326	Temp-Unterschied End Winter II	T1
331	Temperatur +15K Bau	T3
332	Temperatur -10K Bau	T3
333	Temp-Unterschied Bau Sommer I	T3
334	Temp-Unterschied Bau Sommer II	T3
335	Temp-Unterschied Bau Winter I	T3
336	Temp-Unterschied Bau Winter II	T3
	Temperatur Überlagerung	
341	Temp End Sommer 1 (LF321 + 0.75*LF323)	T1
342	Temp End Sommer 2 (LF323 + 0.35*LF321)	T1
343	Temp End Sommer 3 (LF321 + 0.75*LF324)	T1
344	Temp End Sommer 4 (LF324 + 0.35*LF321)	T1
345	Temp End Winter 1 (LF322 + 0.75*LF325)	T1
346	Temp End Winter 2 (LF325 + 0.35*LF322)	T1
347	Temp End Winter 3 (LF322 + 0.75*LF326)	T1
348	Temp End Winter 4 (LF326 + 0.35*LF322)	T1
351	Temp End Sommer 1 (LF331 + 0.75*LF333)	T3
352	Temp End Sommer 2 (LF333 + 0.35*LF331)	T3
353	Temp End Sommer 3 (LF331 + 0.75*LF334)	T3
354	Temp End Sommer 4 (LF334 + 0.35*LF331)	T3
355	Temp End Winter 1 (LF332 + 0.75*LF335)	T3
356	Temp End Winter 2 (LF335 + 0.35*LF332)	T3
357	Temp End Winter 3 (LF332 + 0.75*LF336)	T3
358	Temp End Winter 4 (LF336 + 0.35*LF332)	T3
	Temperatur Pfahlbemessung	
361	Temperatur +15K End	T1
362	Temperatur -10K End	T1
363	Temp-Unterschied End Sommer I	T1
364	Temp-Unterschied End Sommer II	T1
365	Temp-Unterschied End Winter I	T1
366	Temp-Unterschied End Winter II	T1
371	Temperatur +15K Bau	T3
376	Temperatur -10K Bau	T3
373	Temp-Unterschied Bau Sommer I	T3
374	Temp-Unterschied Bau Sommer II	T3
375	Temp-Unterschied Bau Winter I	T3
376	Temp-Unterschied Bau Winter II	T3
	Temperatur Überlagerung	
381	Temp End Sommer 1 (LF361 + 0.75*LF363)	T1
382	Temp End Sommer 2 (LF363 + 0.35*LF361)	T1
383	Temp End Sommer 3 (LF361 + 0.75*LF364)	T1
384	Temp End Sommer 4 (LF364 + 0.35*LF361)	T1
385	Temp End Winter 1 (LF362 + 0.75*LF365)	T1
386	Temp End Winter 2 (LF365 + 0.35*LF362)	T1
387	Temp End Winter 3 (LF362 + 0.75*LF366)	T1
388	Temp End Winter 4 (LF366 + 0.35*LF362)	T1
391	Temp End Sommer 1 (LF371 + 0.75*LF373)	T3
392	Temp End Sommer 2 (LF373 + 0.35*LF371)	T3
393	Temp End Sommer 3 (LF371 + 0.75*LF374)	T3
394	Temp End Sommer 4 (LF374 + 0.35*LF371)	T3
395	Temp End Winter 1 (LF372 + 0.75*LF375)	T3
396	Temp End Winter 2 (LF375 + 0.35*LF372)	T3
397	Temp End Winter 3 (LF372 + 0.75*LF376)	T3
398	Temp End Winter 4 (LF376 + 0.35*LF372)	T3

Structural Design

- Variation of ground stiffness

  - Variation of +/- 20% of spring stiffness locally and globally
  - Leads up to 37 different bedding scenario for one building section



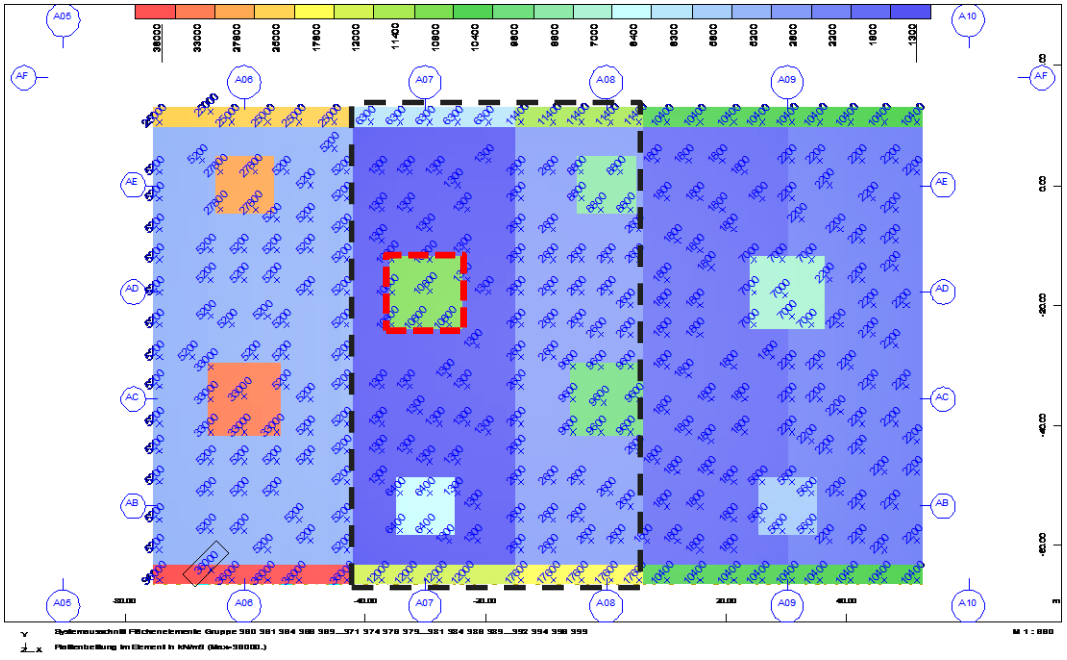


BA13

Structural Design

- Variation of ground stiffness

- Variation of +/- 20% of spring stiffness locally and globally
- Leads up to 37 different bedding scenario for one building section

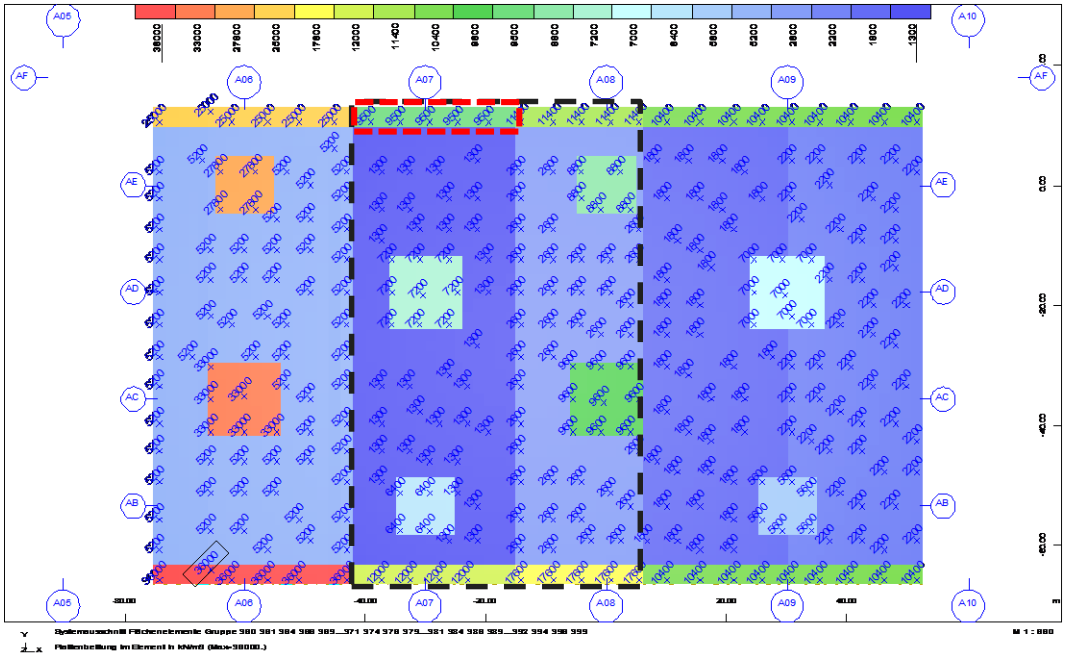


Iteration	Generelle Bettungssi-tuation	Abweichung von mittlerer Bettung		Bereich
		Gruppe	Abweichung	
1	MAX	Trogwand Nord Rechts	ca. -20%	BA12
2	MAX	Trogwand Sued Rechts	ca. -20%	BA12
3	MAX	Mittelstuetze Achse 6	ca. -20%	BA12
4	MAX	Randstuetze Achse 6	ca. -20%	BA12
5	MAX	Trogwand Nord Links	ca. -20%	BA13
6	MAX	Trogwand Nord Rechts	ca. -20%	BA13
7	MAX	Trogwand Sued Links	ca. -20%	BA13
8	MAX	Trogwand Sued Rechts	ca. -20%	BA13
9	MAX	Mittelstuetze Achse 7	ca. -20%	BA13
10	MAX	Mittelstuetze Achse 8	ca. -20%	BA13
11	MAX	Randstuetze Achse 7	ca. -20%	BA13
12	MAX	Randstuetze Achse 8	ca. -20%	BA13
13	MAX	Trogwand Nord	ca. -20%	BA14
14	MAX	Trogwand Sued	ca. -20%	BA14
15	MAX	Mittelstuetze Achse 9	ca. -20%	BA14
16	MAX	Randstuetze Achse 9	ca. -20%	BA14
17	MIN	Trogwand Nord Rechts	ca. +20%	BA12
18	MIN	Trogwand Sued Rechts	ca. +20%	BA12
19	MIN	Mittelstuetze Achse 6	ca. +20%	BA12
20	MIN	Randstuetze Achse 6	ca. +20%	BA12
21	MIN	Trogwand Nord Links	ca. +20%	BA13
22	MIN	Trogwand Nord Rechts	ca. +20%	BA13
23	MIN	Trogwand Sued Links	ca. +20%	BA13
24	MIN	Trogwand Sued Rechts	ca. +20%	BA13
25	MIN	Mittelstuetze Achse 7	ca. +20%	BA13
26	MIN	Mittelstuetze Achse 8	ca. +20%	BA13
27	MIN	Randstuetze Achse 7	ca. +20%	BA13
28	MIN	Randstuetze Achse 8	ca. +20%	BA13
29	MIN	Trogwand Nord	ca. +20%	BA14
30	MIN	Trogwand Sued	ca. +20%	BA14
31	MIN	Mittelstuetze Achse 9	ca. +20%	BA14
32	MIN	Randstuetze Achse 9	ca. +20%	BA14
33	MID	BA13	ca. -20%	BA13
34	MID	BA13	ca. +20%	BA13
35	MID	Loungepfähle	ca. -20%	Alle
36	MID	Loungepfähle	ca. +20%	Alle
37	MID	Alle	-	Alle

Structural Design

- Variation of ground stiffness

  - Variation of +/- 20% of spring stiffness locally and globally
  - Leads up to 37 different bedding scenario for one building section



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4	MAX	Randstuetze Achse 6	ca. -20%	BA12
5	MAX	Trogwand Nord Links	ca. -20%	BA13
6	MAX	Trogwand Nord Rechts	ca. -20%	BA13
7	MAX	Trogwand Sued Links	ca. -20%	BA13
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26	MIN	Mittelstuetze Achse 8	ca. +20%	BA13
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34	MID	BA13	ca. +20%	BA13
35	MID	Loungepfähle	ca. -20%	Alle
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37	MID	Alle	-	Alle

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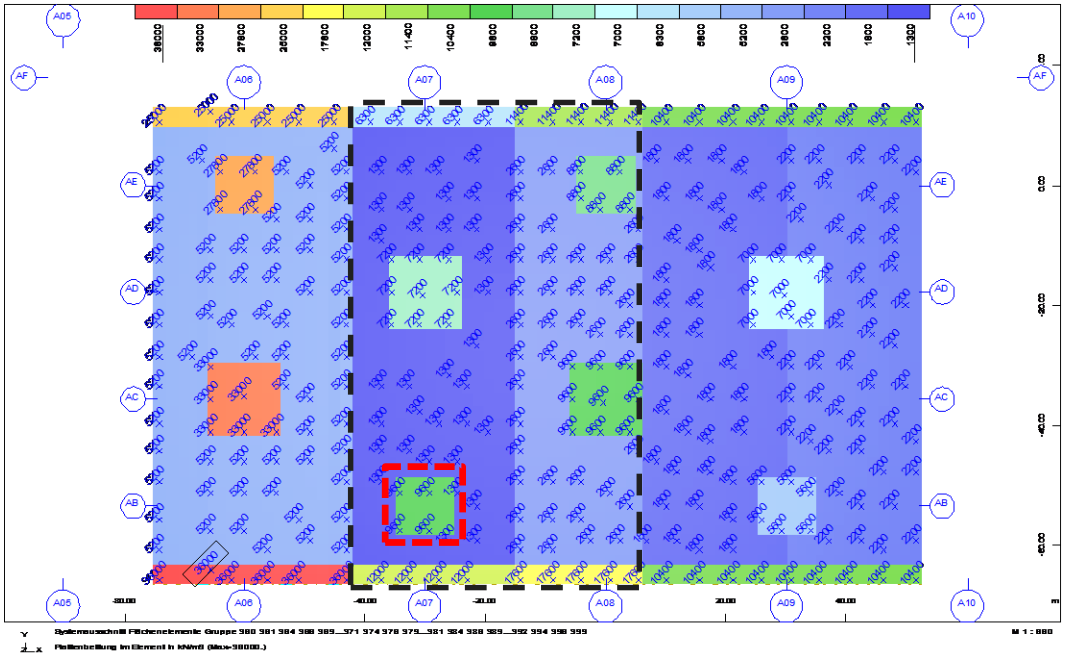

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18	MIN	Trogwand Sued Rechts	ca. +20%	BA12
19	MIN	Mittelstuetze Achse 6	ca. +20%	BA12
20	MIN	Randstuetze Achse 6	ca. +20%	BA12
21	MIN	Trogwand Nord Links	ca. +20%	BA13
22	MIN	Trogwand Nord Rechts	ca. +20%	BA13
23	MIN	Trogwand Sued Links	ca. +20%	BA13
24	MIN	Trogwand Sued Rechts	ca. +20%	BA13
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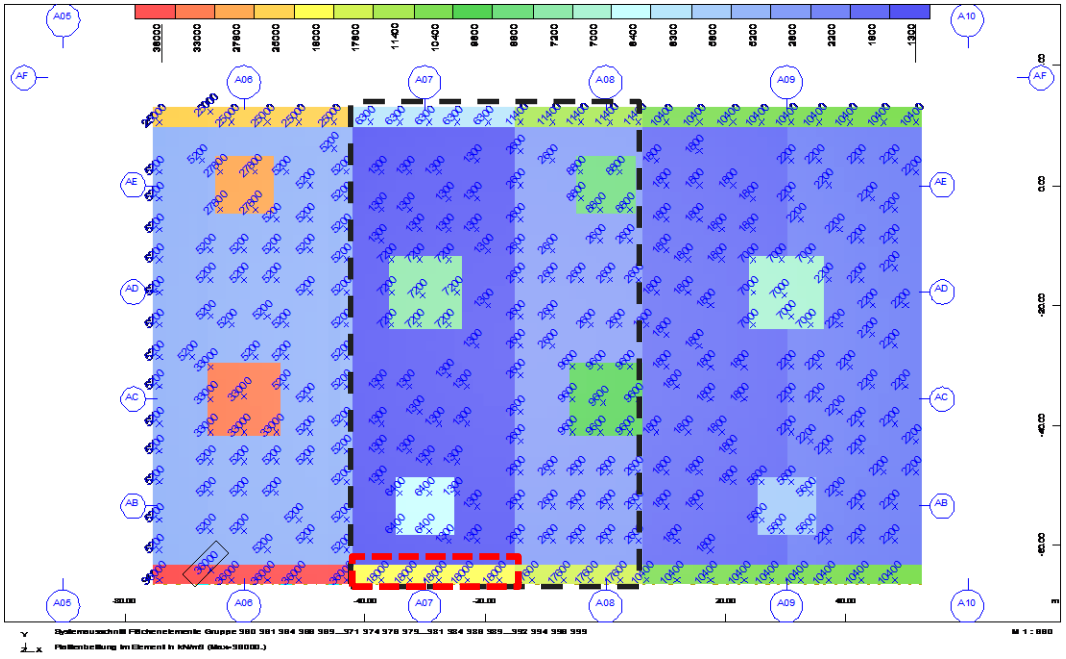
28	MIN	Randstuetze Achse 8	ca. +20%	BA13
29	MIN	Trogwand Nord	ca. +20%	BA14
30	MIN	Trogwand Sued	ca. +20%	BA14
31	MIN	Mittelstuetze Achse 9	ca. +20%	BA14
32	MIN	Randstuetze Achse 9	ca. +20%	BA14
33	MID	BA13	ca. -20%	BA13
34	MID	BA13	ca. +20%	BA13
35	MID	Loungepfähle	ca. -20%	Alle
36	MID	Loungepfähle	ca. +20%	Alle
37	MID	Alle	-	Alle

Structural Design

- Variation of ground stiffness

  - Variation of +/- 20% of spring stiffness locally and globally
  - Leads up to 37 different bedding scenario for one building section



Iteration	Generelle Bettungssi-tuation	Abweichung von mittlerer Bettung		Bereich
		Gruppe	Abweichung	
1	MAX	Trogwand Nord Rechts	ca. -20%	BA12
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8	MAX	Trogwand Sued Rechts	ca. -20%	BA13
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11	MAX	Randstuetze Achse 7	ca. -20%	BA13
12	MAX	Randstuetze Achse 8	ca. -20%	BA13
13	MAX	Trogwand Nord	ca. -20%	BA14
14	MAX	Trogwand Sued	ca. -20%	BA14
15	MAX	Mittelstuetze Achse 9	ca. -20%	BA14
16	MAX	Randstuetze Achse 9	ca. -20%	BA14
17	MIN	Trogwand Nord Rechts	ca. +20%	BA12
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19	MIN	Mittelstuetze Achse 6	ca. +20%	BA12
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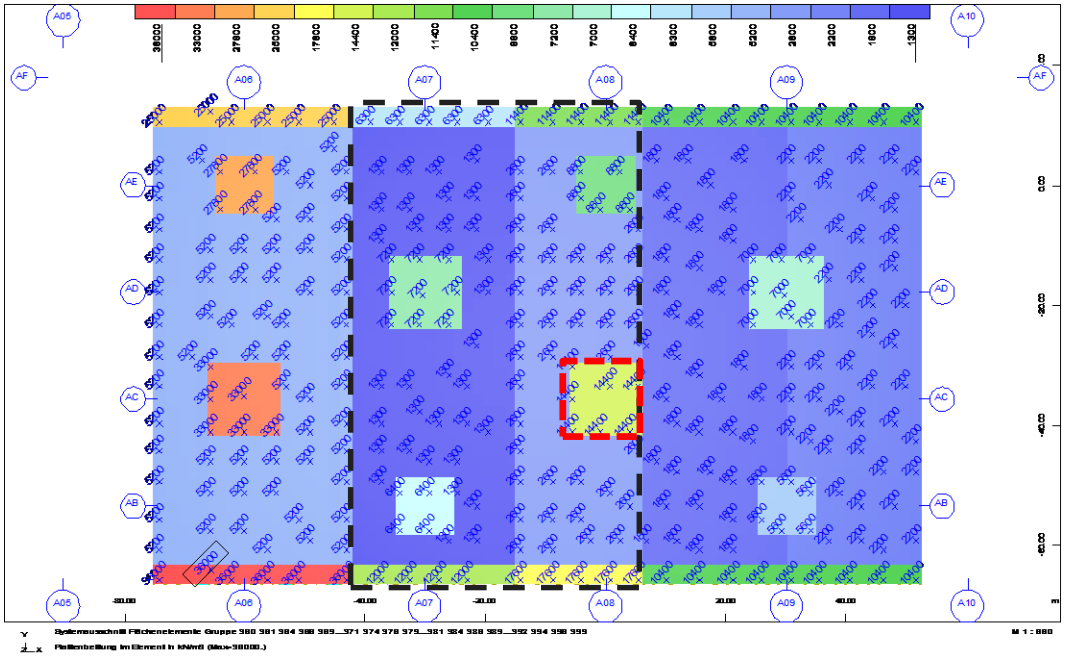

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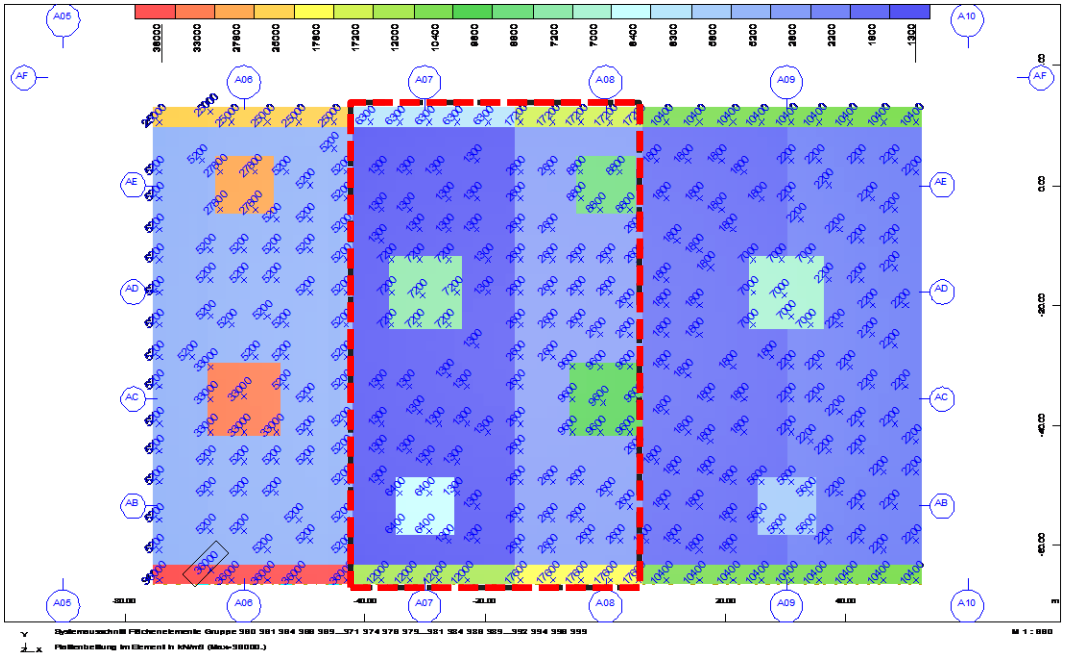

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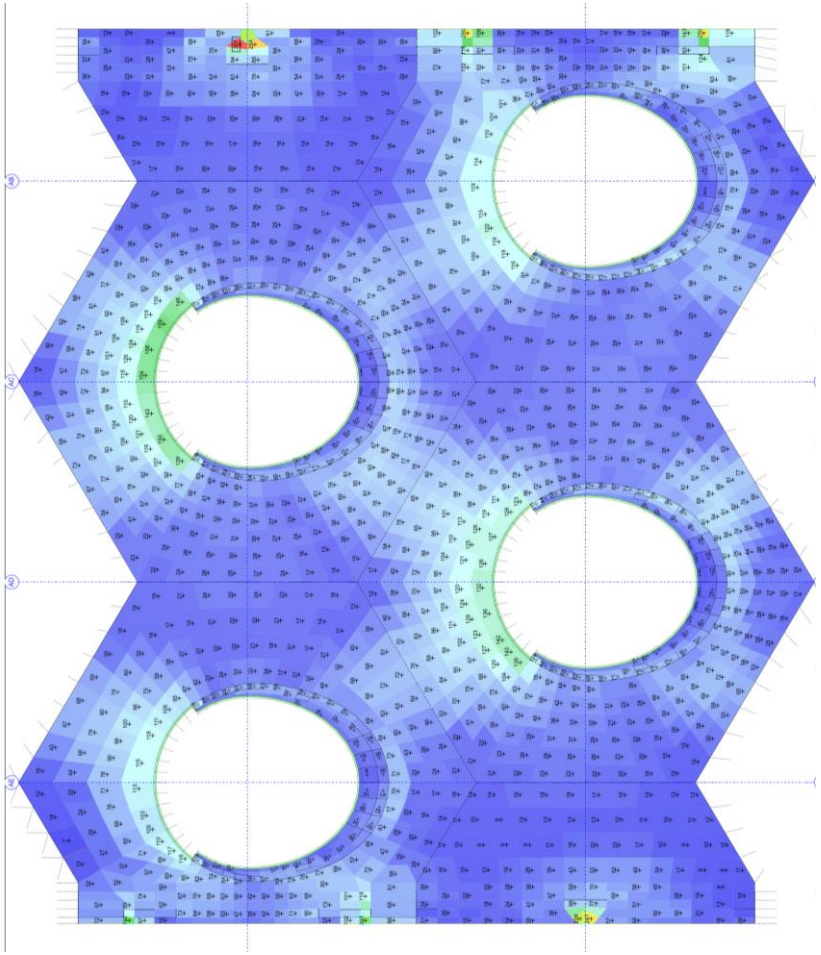
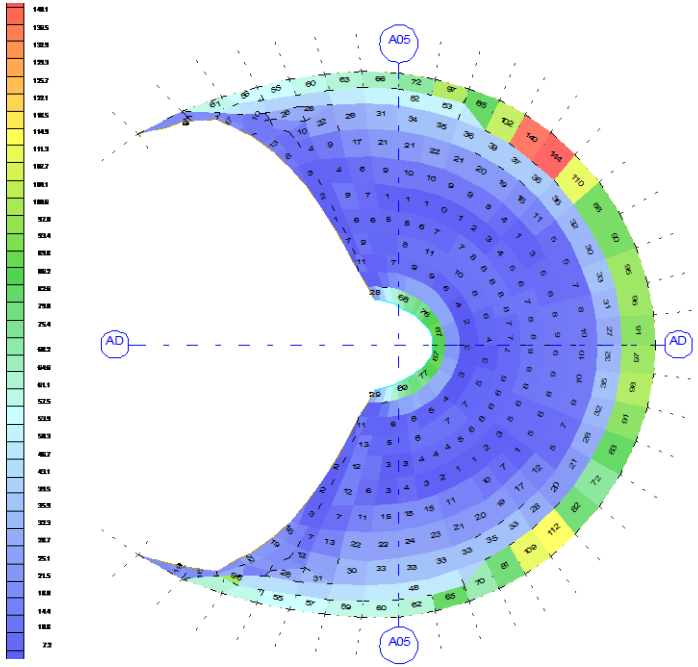
Construction Information

- Generating reinforcement drawings





Construction Information

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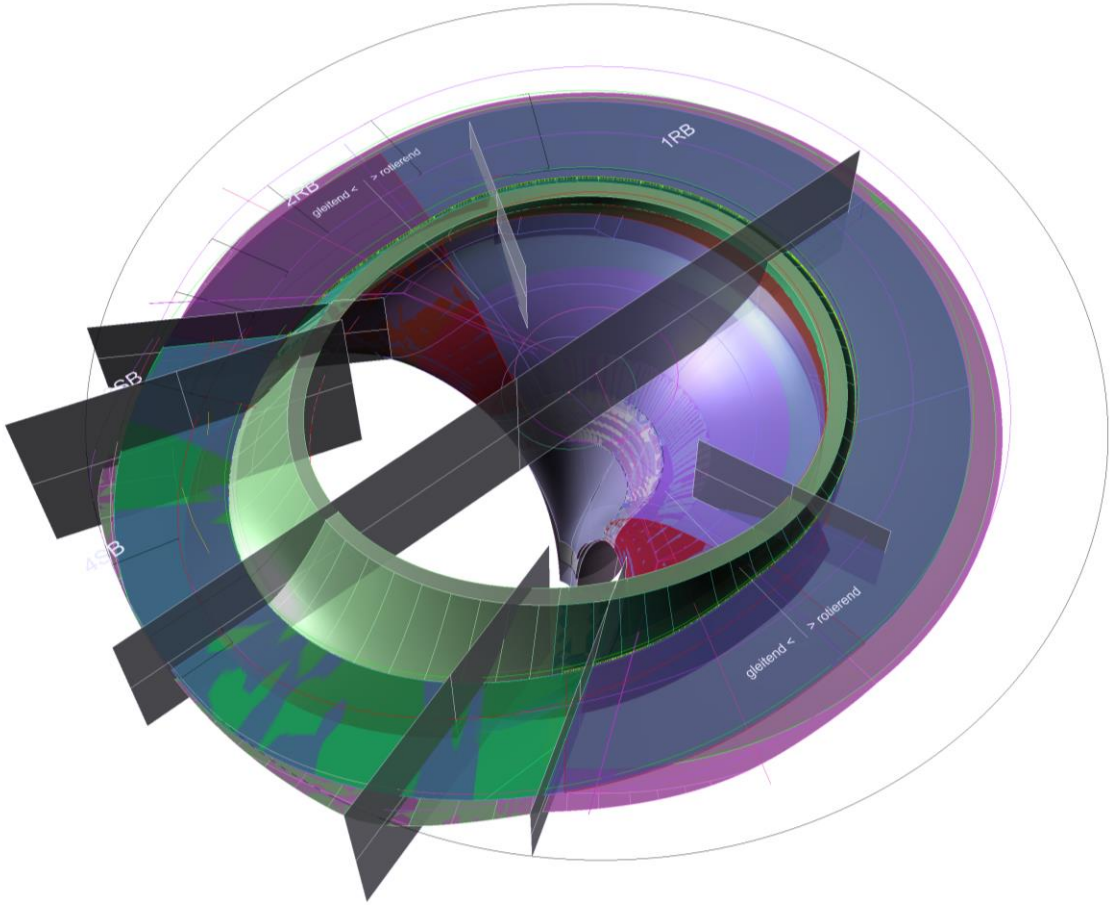

Construction Information

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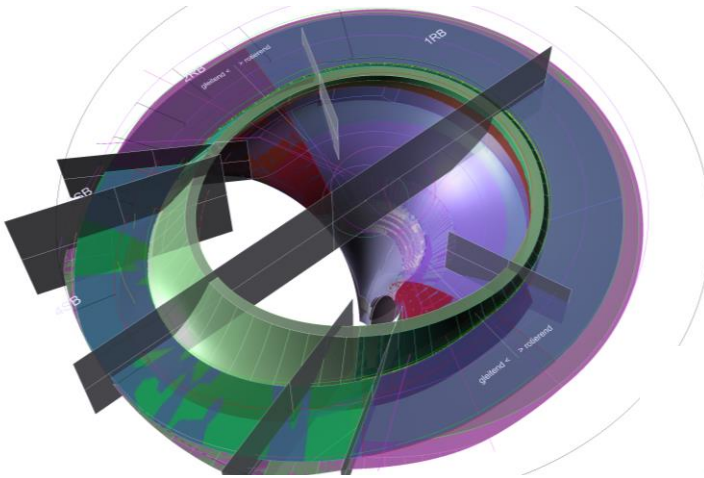

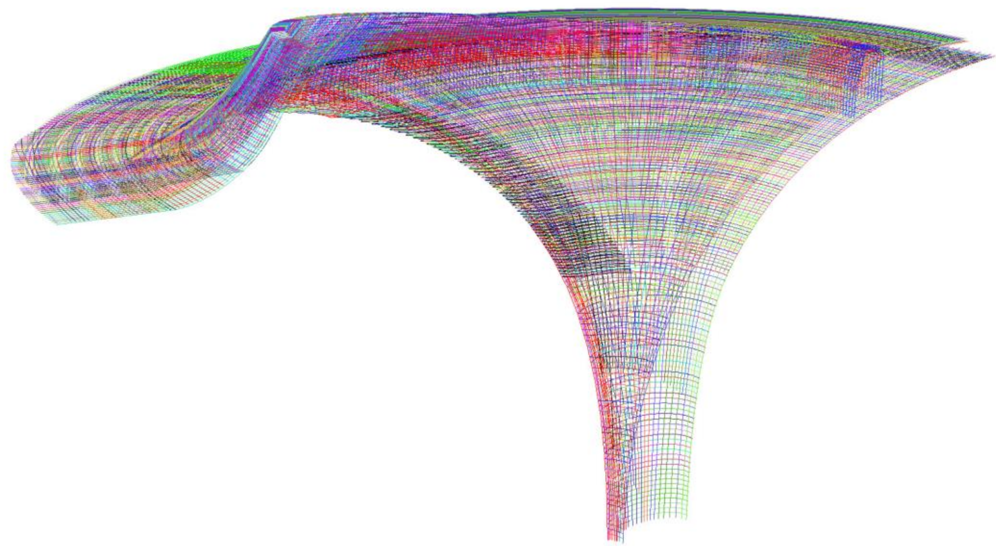

Construction Information

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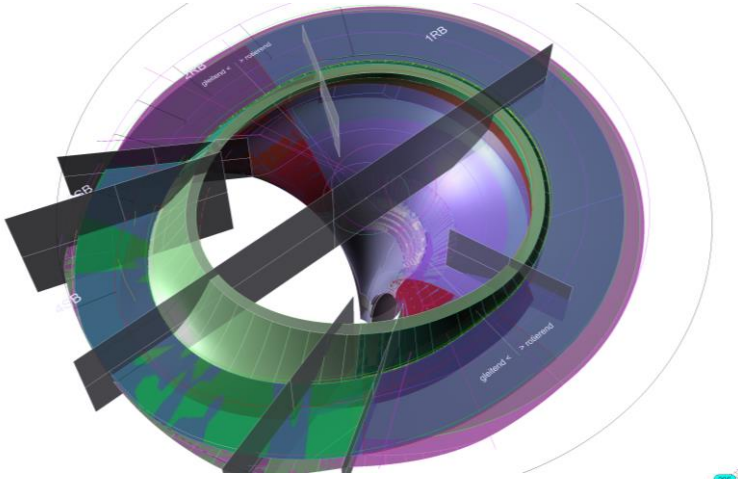

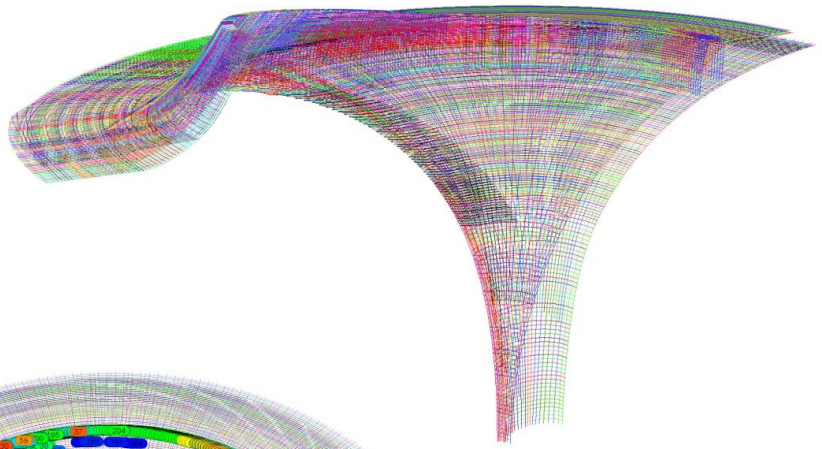

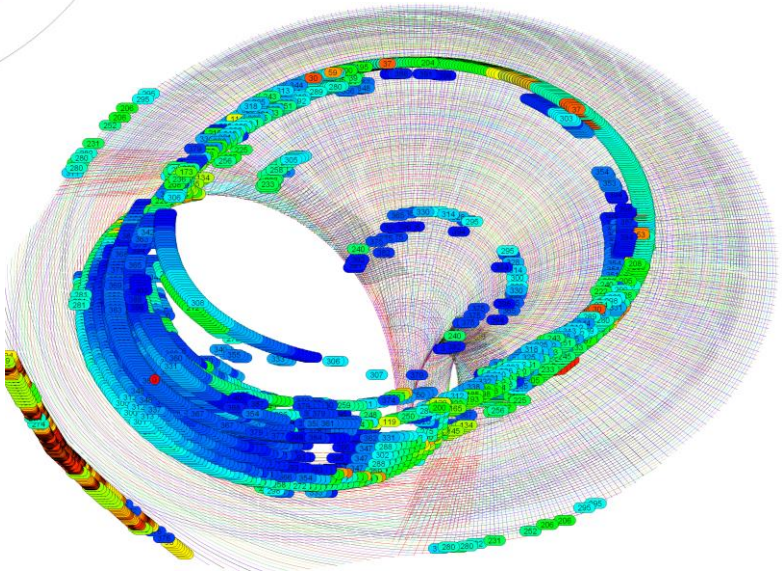

Construction Information

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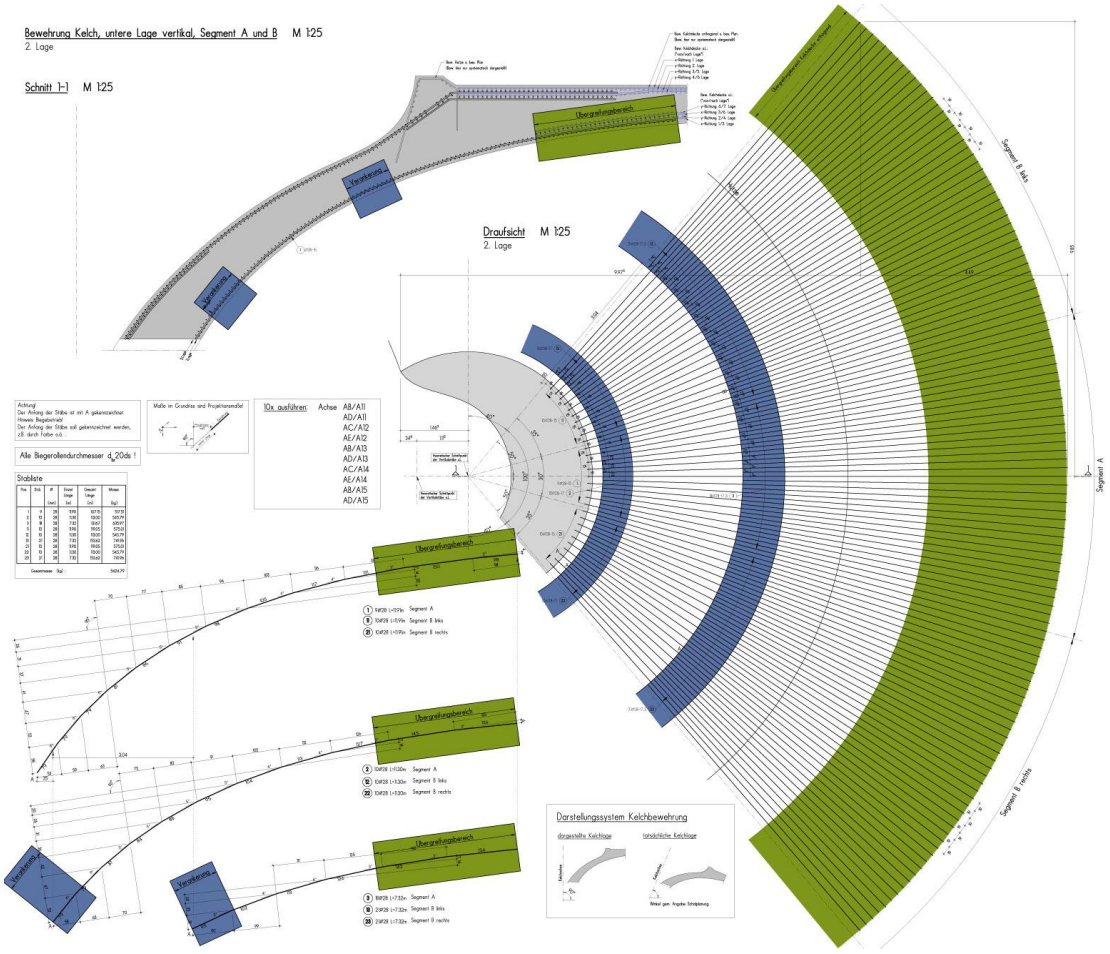
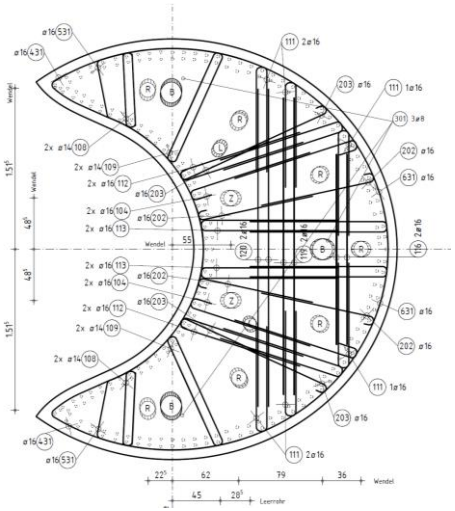
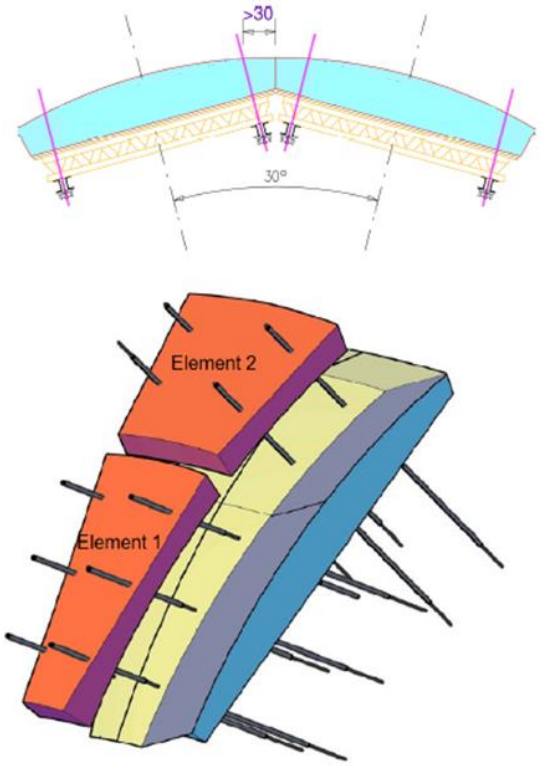
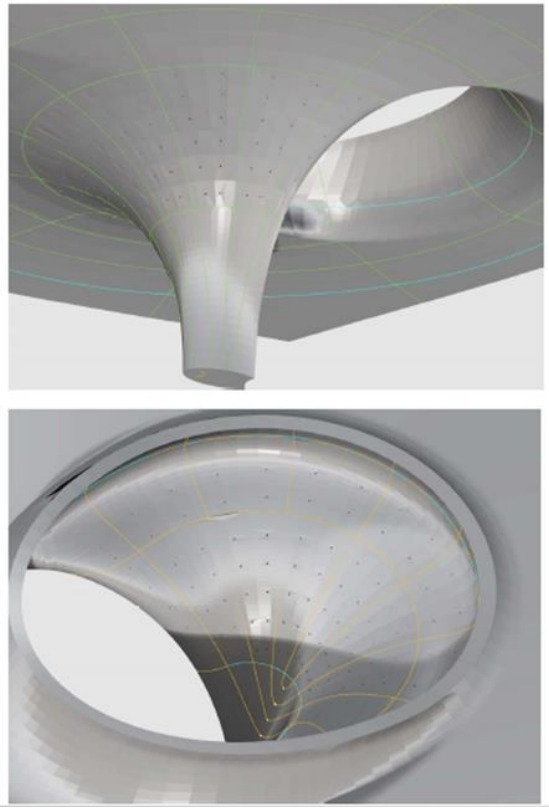


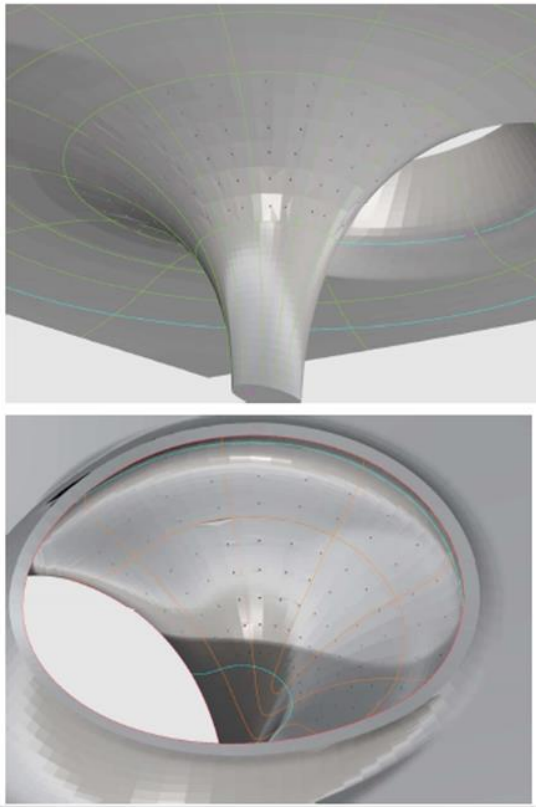


Construction Information

- Positive and negative formwork







Site Photos

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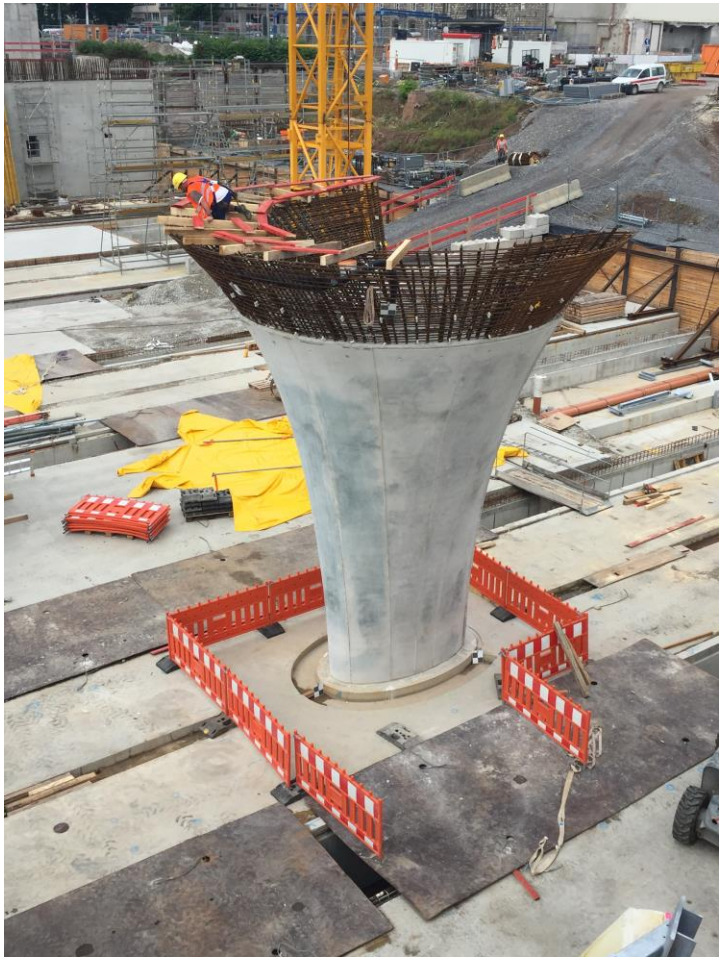

Monitoring

- Load bearing behaviour of the foundation is monitored in selected areas of the building during construction
- Reason:
  - Verification verify the geotechnical model and calculation methods
  - Early detection of possible critical conditions
  - Review of settlement compared to the final settlement predicted and in the construction phase
  - Quality assurance and preservation of evidence

Vielen Dank!