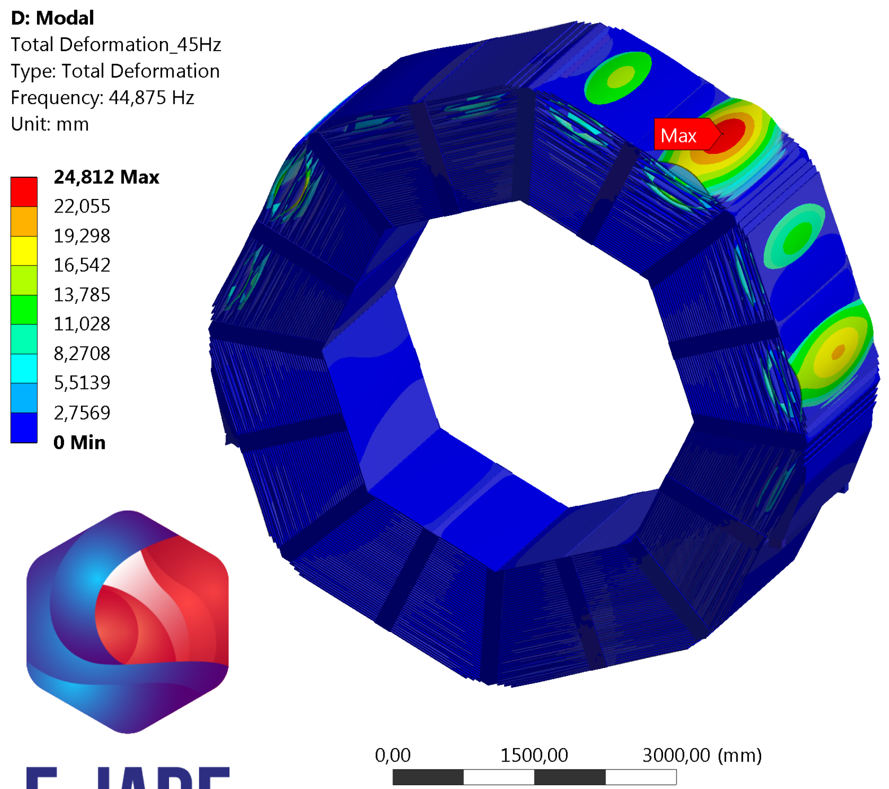
FEM-Study ILD-AHCAL

Seismic simulation



K. Gadow, **M. Lemke**, F. Sefkow
Hamburg, 11.03.2016

E-JADE

HELMHOLTZ GEMEINSCHAFT

LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

DESY

Overview

> Reminder of earlier studies

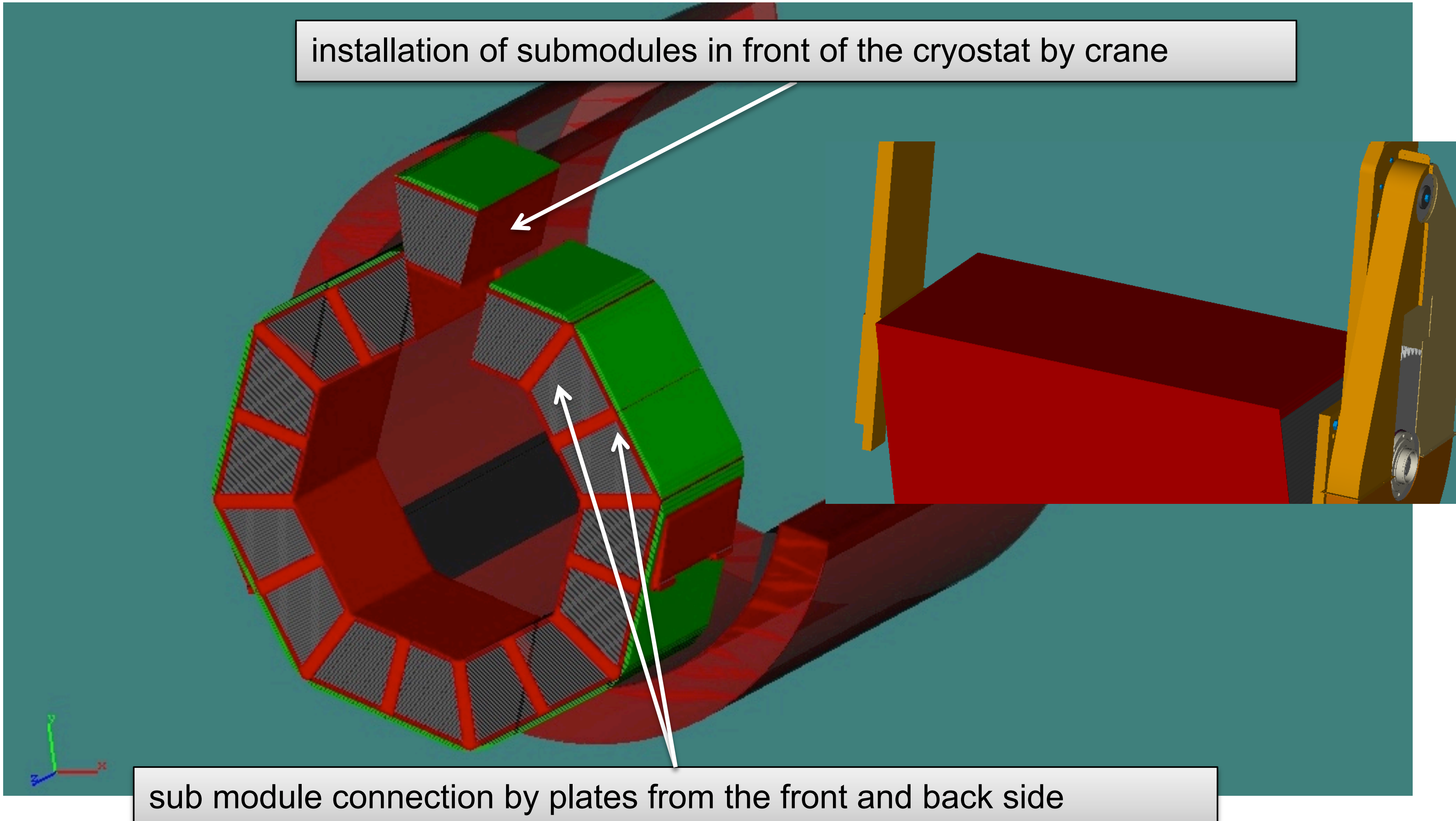
> Sub-structuring method

> First results

> Outlook

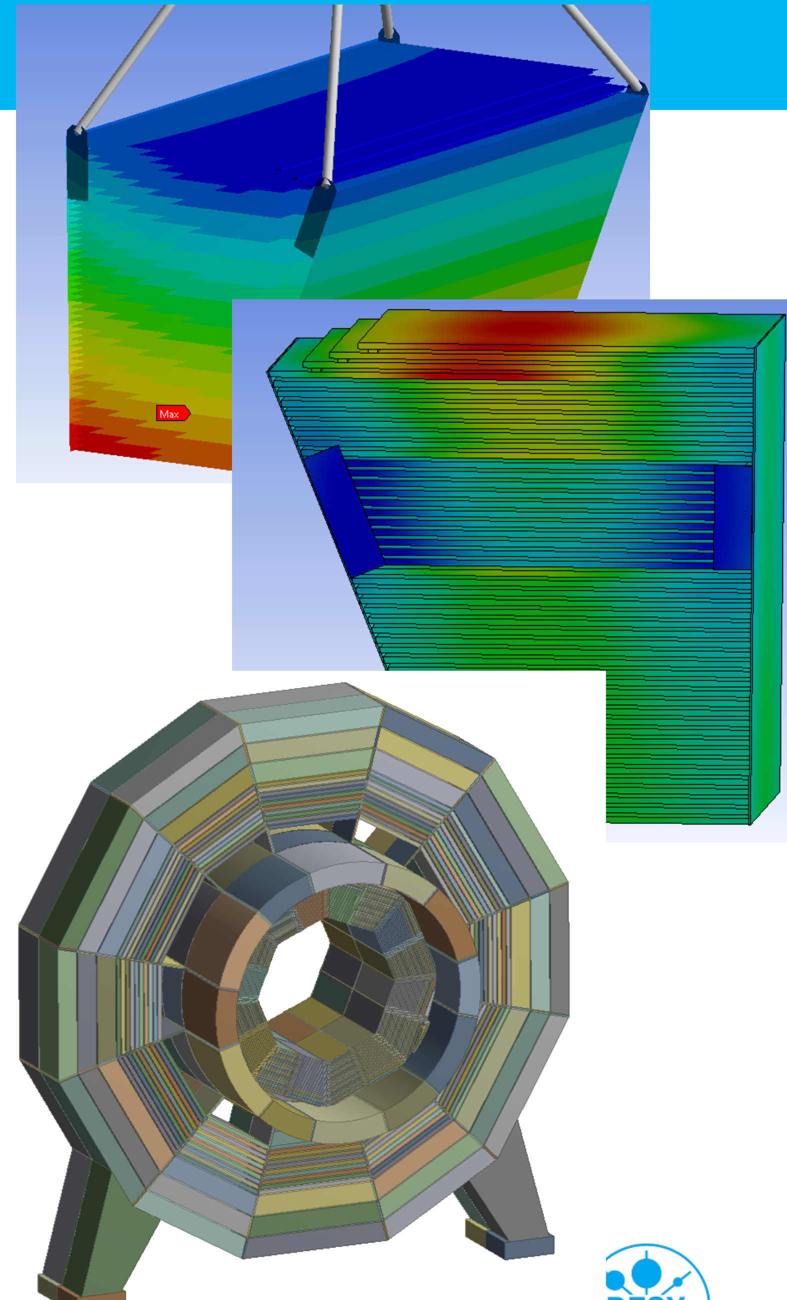
AHCAL submodule

case 2 submodule installation



Earlier studies

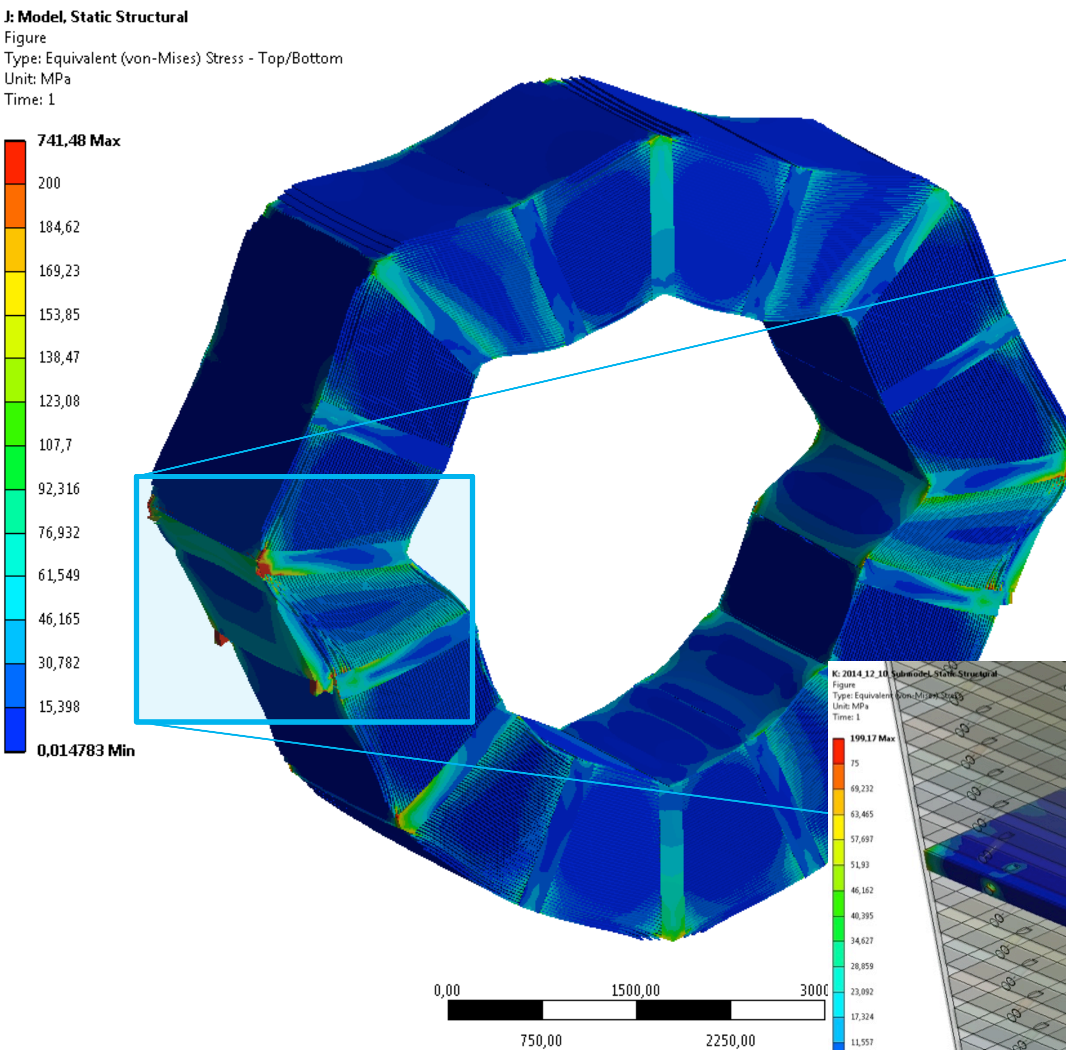
- Static calculations of absorber structure deformation and stress
  - Including configurations during assembly
  - Design validated
- Data from 2011 earthquake pre-processed for dynamical analysis
- First step: modal analysis: determine eigen modes and frequencies of system
- Combination of large dimensions and small details very challenging
  - Full model impractical, slow convergence
  - For the study of the complete configuration a different approach is needed

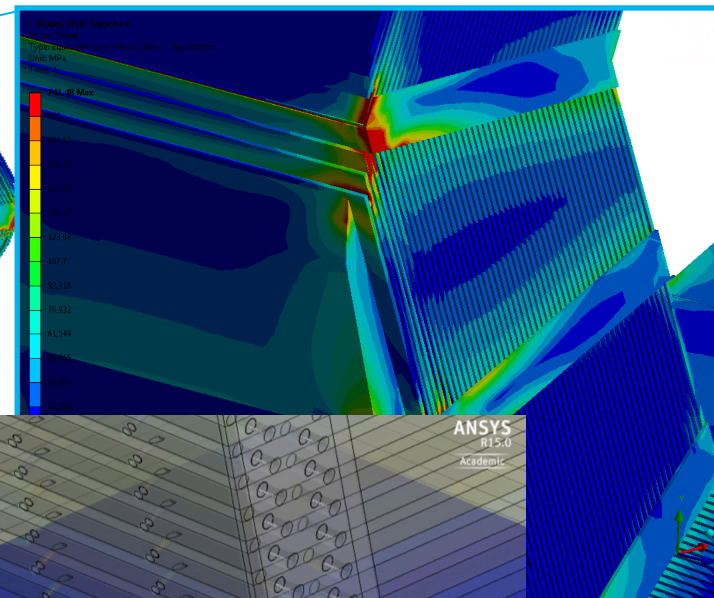


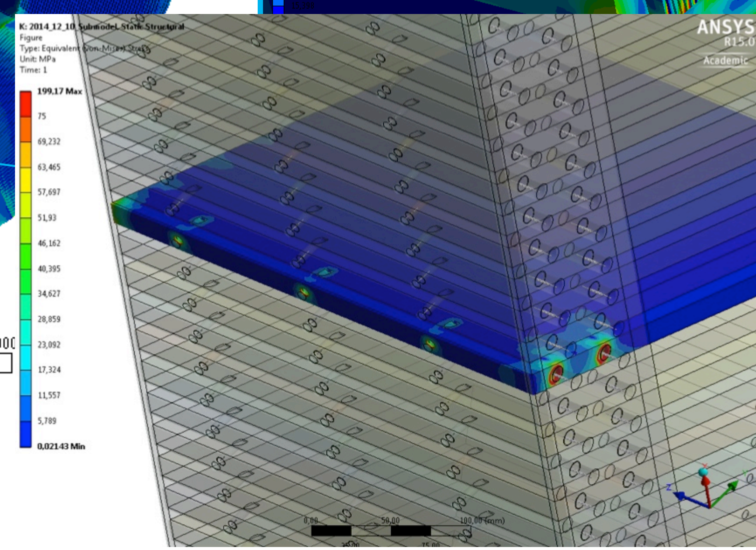
AHCAL Mechanics

absorber structure validation (static)

- ~360 N/mm² maximum tension
- 50 times exaltation graphic

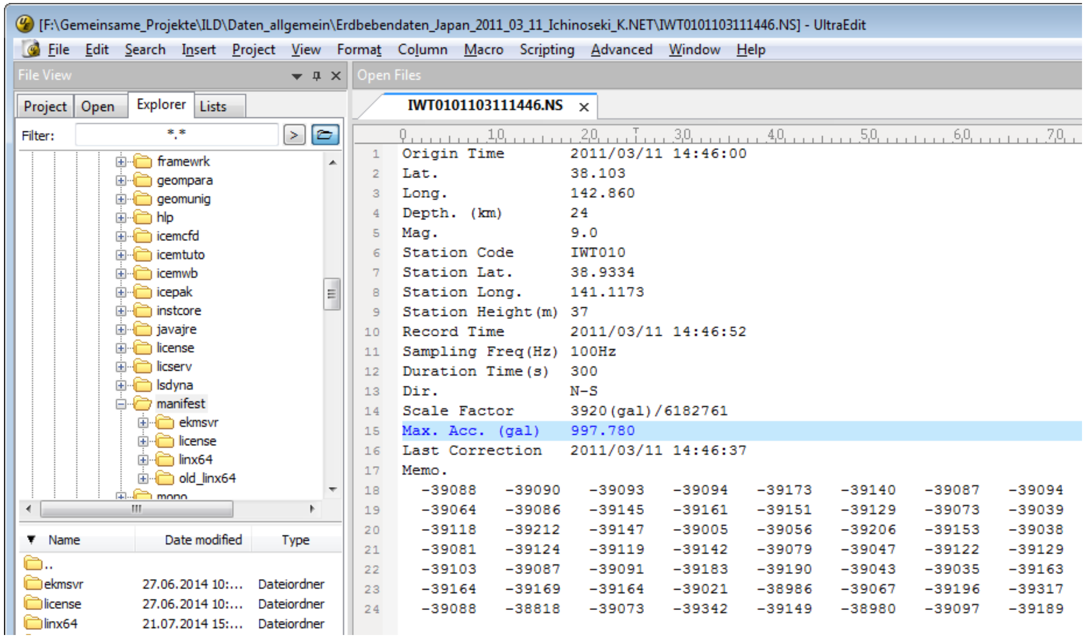






Use realistic earthquake data

- From 11.3.2013
- Max accel ~ 1g
- Typical excitation pulse
- Data processed for transient analysis in ANSYS
  - Initital state with 1 g static force, prism support in cryostat
- Modal analysi:
  - eigen modes



ISO 3010:2001(E)

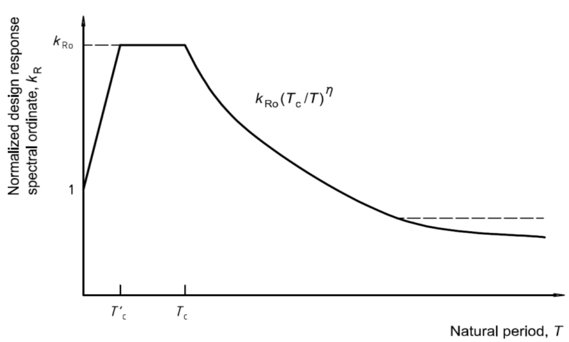
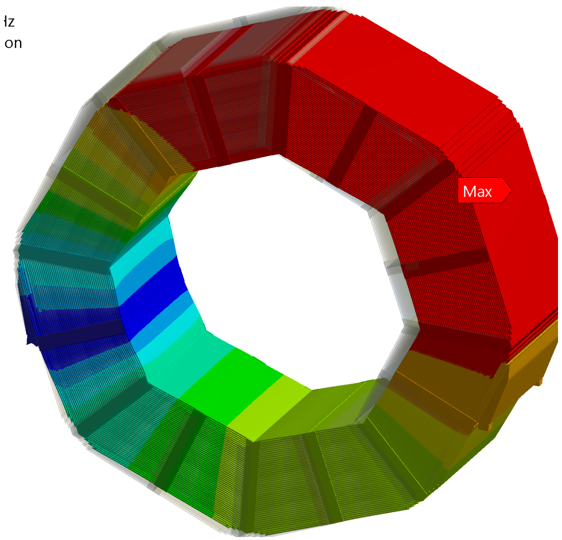
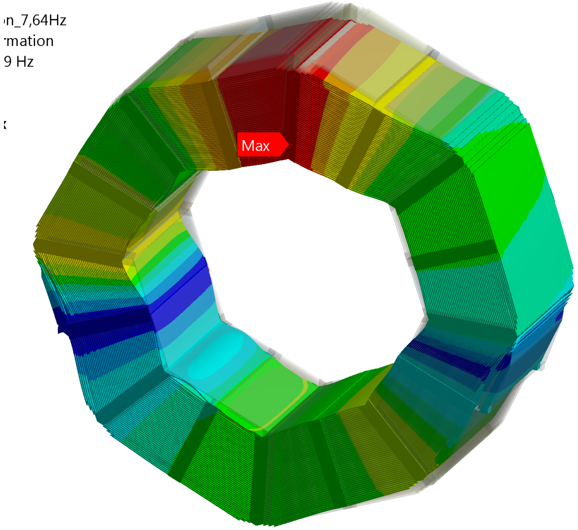


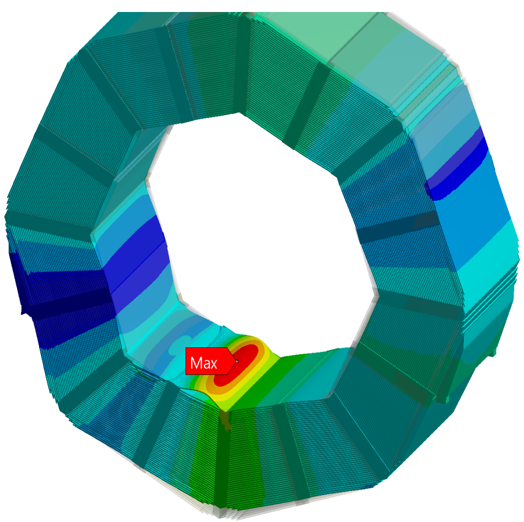
Figure C.1 — Normalized design response spectrum

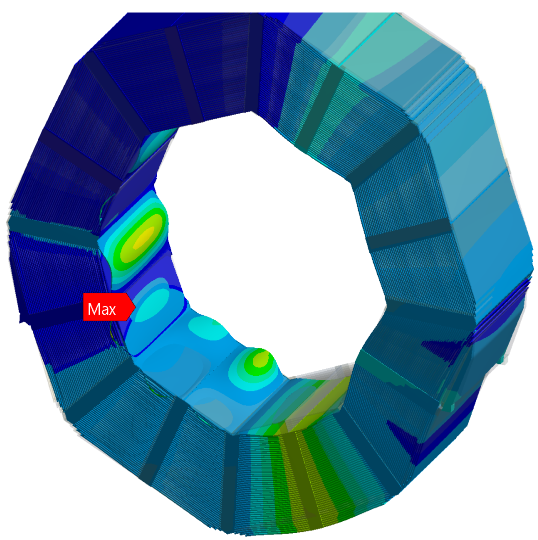
Eigen modes

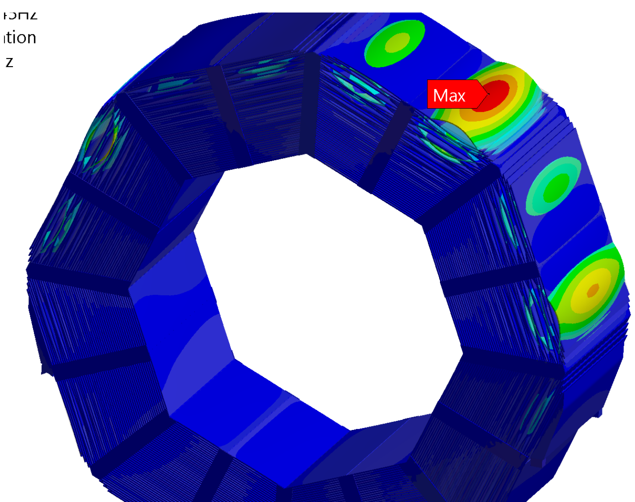
- Swinging barrel: 3Hz
- Swinging module: 8Hz
- Swinging plate: 6Hz
- Higher modes: 15 Hz
- Several plates: 45 Hz











Appropiate calculation method for complex structures

- First tests with a substitution method for the complex AHCAL-Segments with effective material parameters (effective elastic modules and sheer modules, as well as effective Poisson's ratio) in combination with a homogeneous body as a replacement for the detailed AHCAL-Segment => unfortunately no real breakthrough
- Another way to calculate such a complex model like the AHCAL-Structure had to be found …
- The chosen calculation method is the *Substructuring Method* and hereby especially the *Component Mode Synthesis (CMS)* as a form of substructure coupling analysis in ANSYS used in structural dynamics
- Built up test cases in ANSYS to develop the APDL-Command-Snippets (handling geometry/model, combine result-files)

Substructuring – A short explanation

- *Substructuring is a procedure that condenses a group of finite elements into one element represented as a matrix. The single-matrix element is called a superelement. (Source: ANSYS Help V17.0)*
- Three steps to use this method:
  - Generation Pass to calculate the superelement matrices (mass, stiffness, damping) and to define the Master DOFs
  - Use Pass to integrate the superelments into the Finite Element Model, the Master DOFs are used to define the boundary conditions (supports, loads, contacts)
  - Expansion Pass to assign the results of the superlements to the original geometries

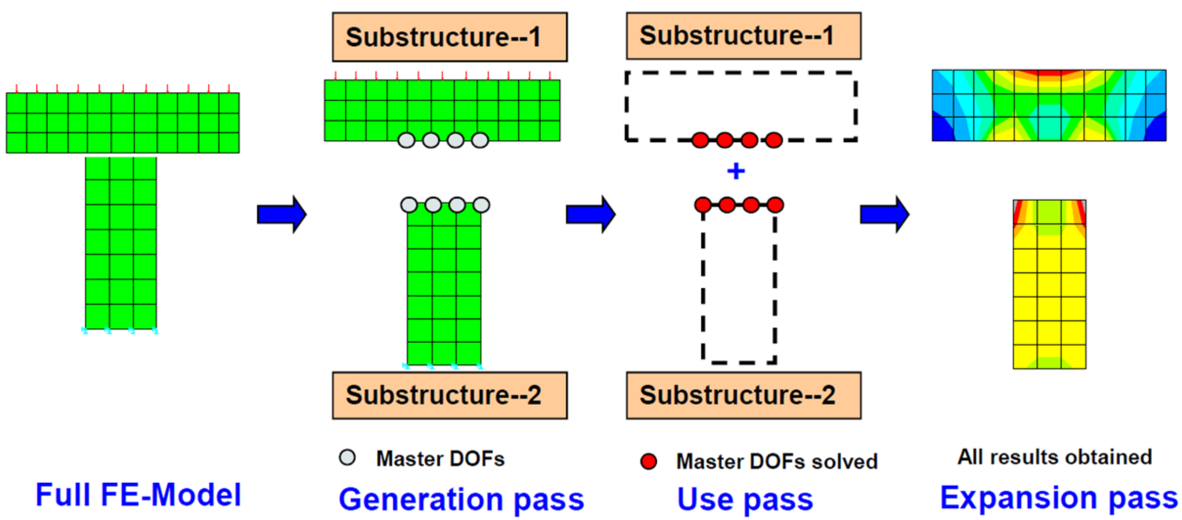


Figure-Source: CADFEM GmbH/Germany

Substruturing – Pros and Cons

> Pro:

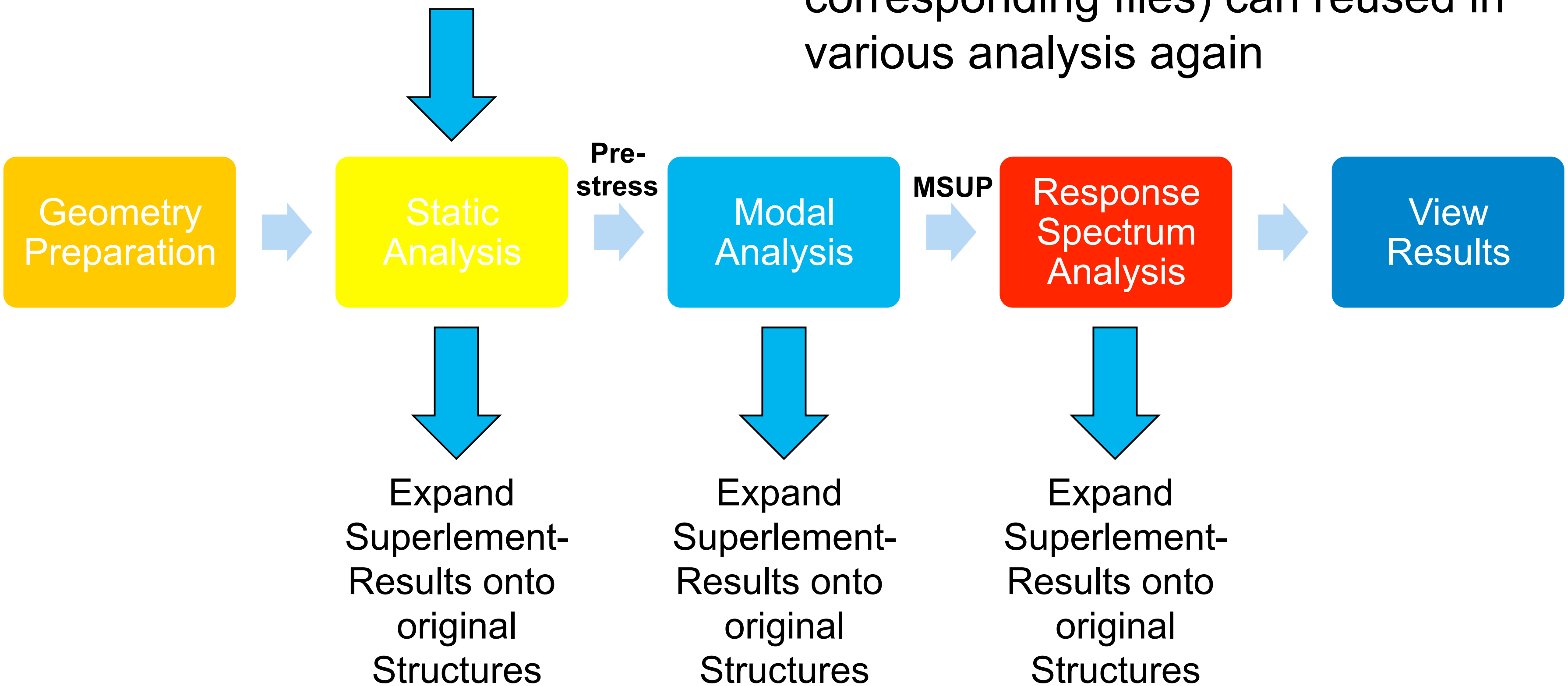
- Complex models can be calculated, n-Elements describing the complex FE-model can be simplified with the CMS-method to one! single element
- For same geometry/mesh, the created files for super-elements can be saved/reused (huge time saving potential)
- Very good performance (with reusing super-element-Files) in dynamic analysis
- Less relevant eigen modes can be sorted out by filtering the calculated modes with APDL-Commands

> Contra:

- Long time to simplify geometry / to prepare the Finite Element Model
- Long preparation/calculation time in Generation Pass and Expansion Pass (these are additional calculations to the real model/analysis) => BUT: very effective in complex models with several analysis steps
- APDL (ANSYS Parametric Design Language) and FE-models around APDL-commands (sometimes) sensitive to handle ;-)
- …

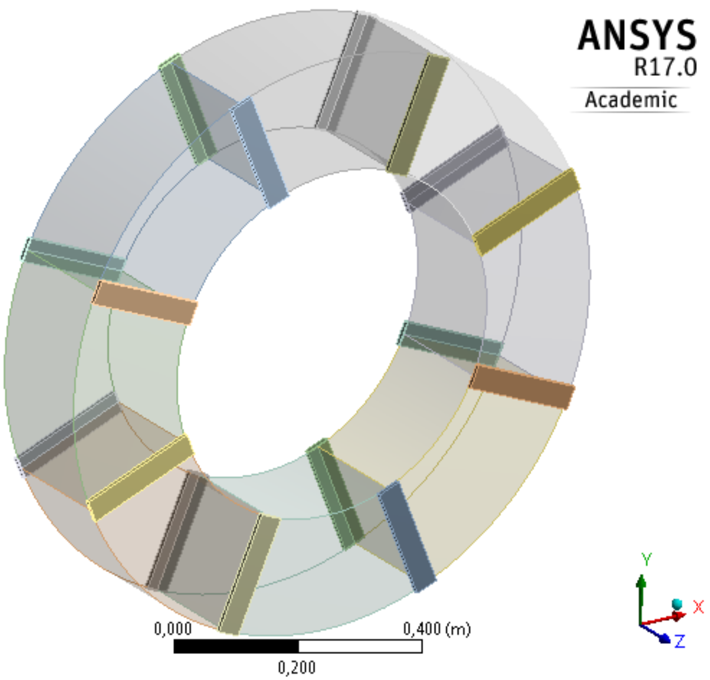
Scheme for dynamic analysis-run with CMS-Method

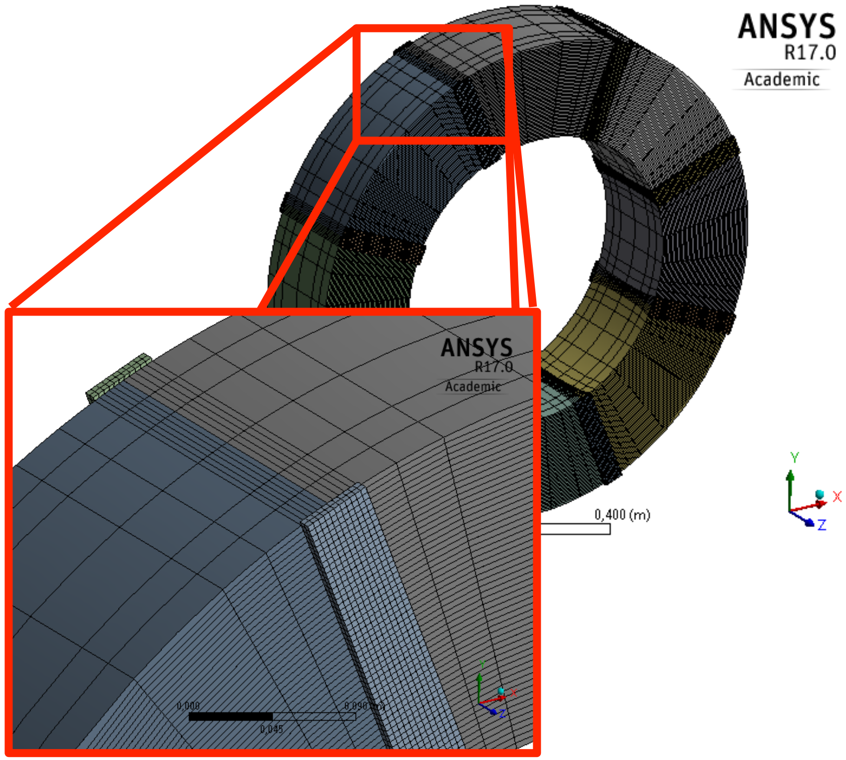
> Generation Pass only calculated for the first run, with same model, the generated Superelements (and the corresponding files) can reused in various analysis again



Tests to develop the substructuring process for AHCAL

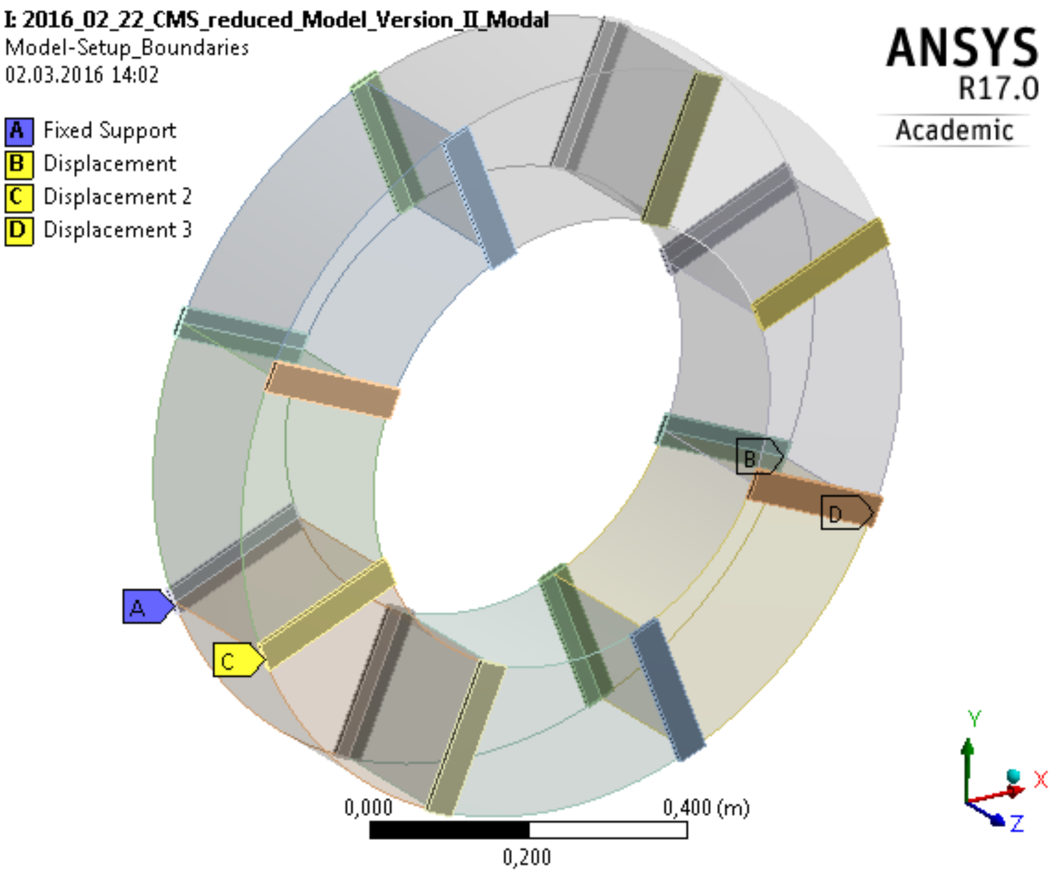
- Simple model, only 8 segments connected by front plates => geometrically identical to detailed AHCAL geometry
- Geometry and mesh for 3D-Full-Model and CMS-Model identical





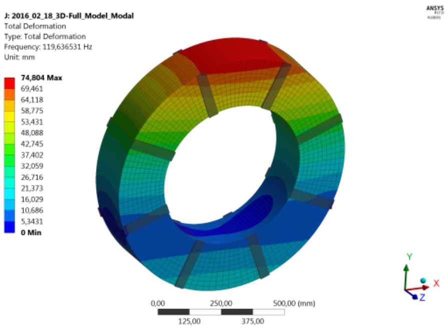
Tests to develop the substructuring process for AHCAL

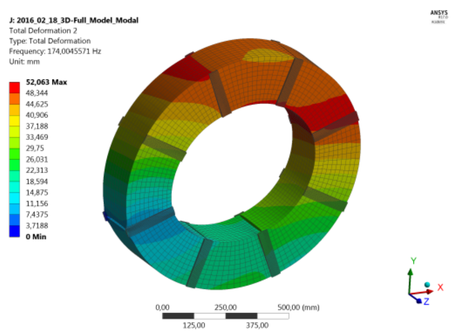
- Boundary conditions comparable to AHCAL-boundary conditions (prism-supported side and loose side, free in x-direction) identically as well

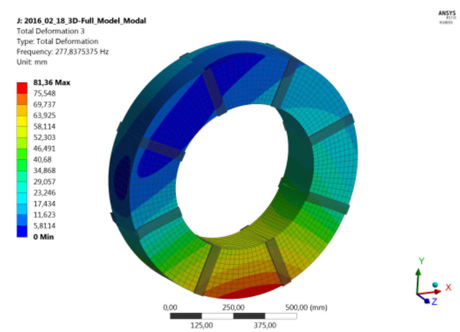


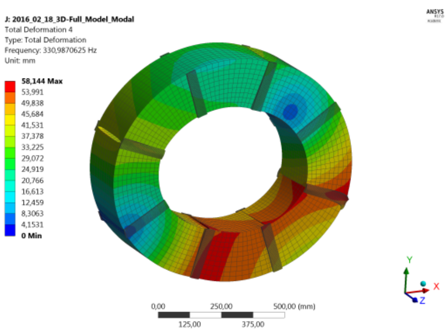
Tests to develop the substructuring process for AHCAL

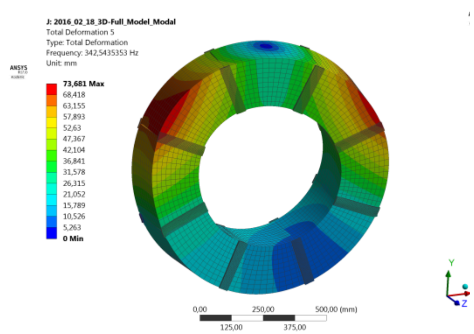
- Modal results of 3D full model

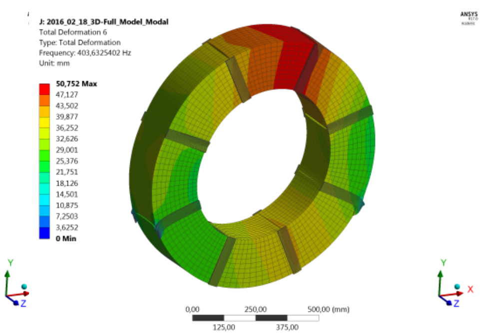










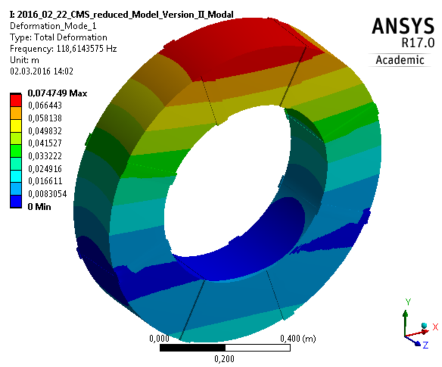


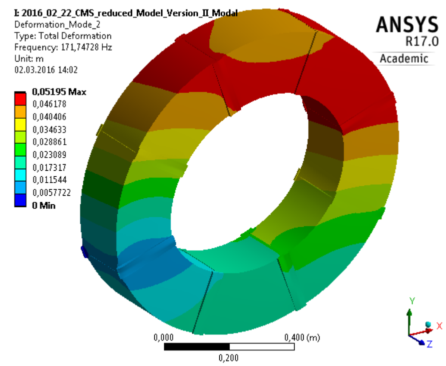
Mode	f [in Hz]
1	119,64
2	174,00
3	277,84
4	331,00
5	342,54
6	403,63

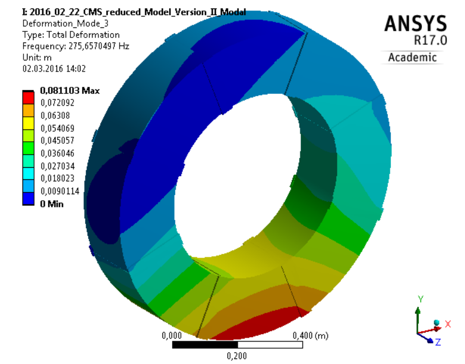
Tests to develop the substructuring process for AHCAL

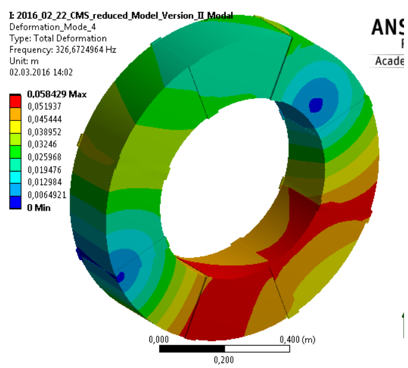
> Modal Results of CMS-Model

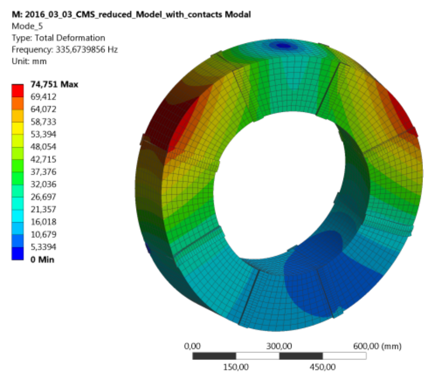
Mode	f [in Hz]
1	118,61
2	171,75
3	275,66
4	326,67
5	335,67
6	384,89

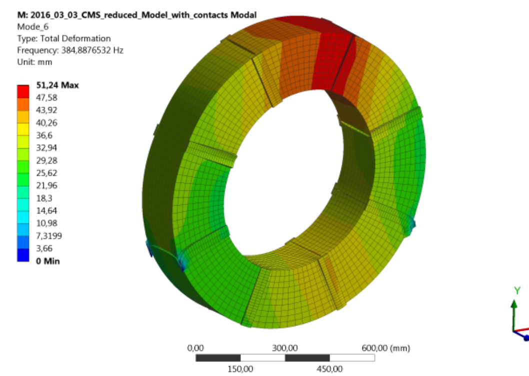






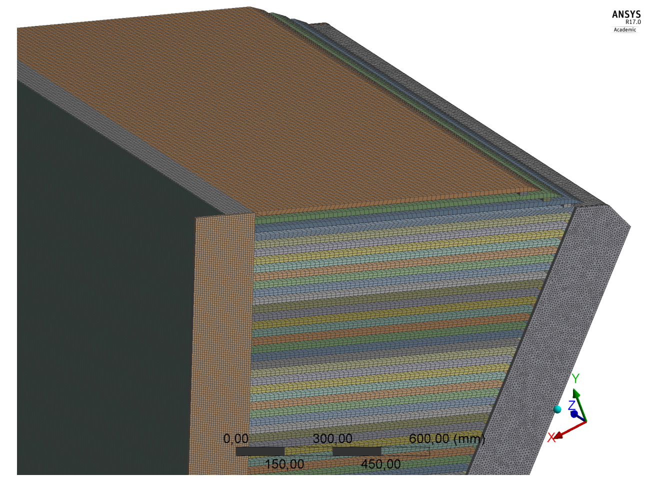


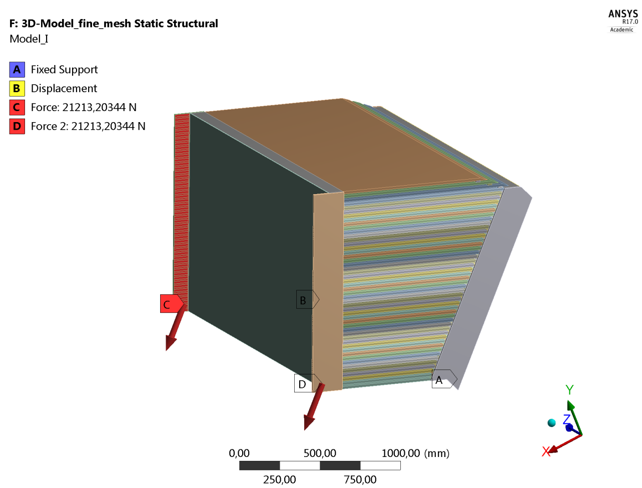


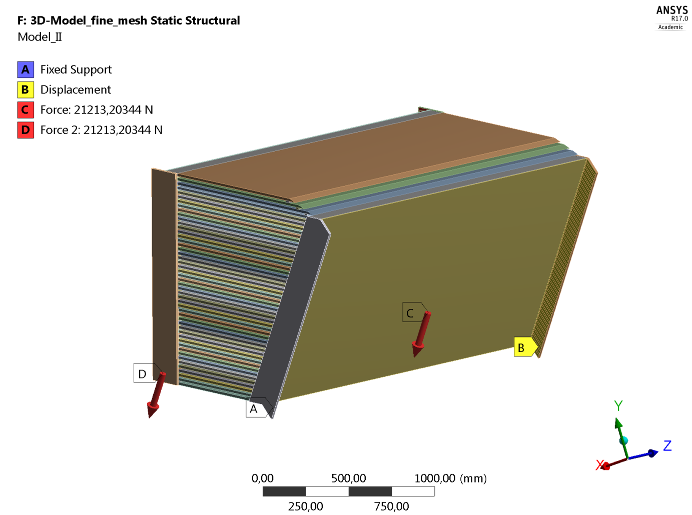


Tests to develop the substructuring process for AHCAL

- Single static-mechanical and modal analyses performed to check the calculation accuracy of FE models using the CMS-method
- Fixed support and two forces
- 6,4 Mio. elements in both analyses (3D-/CMS-FE model)

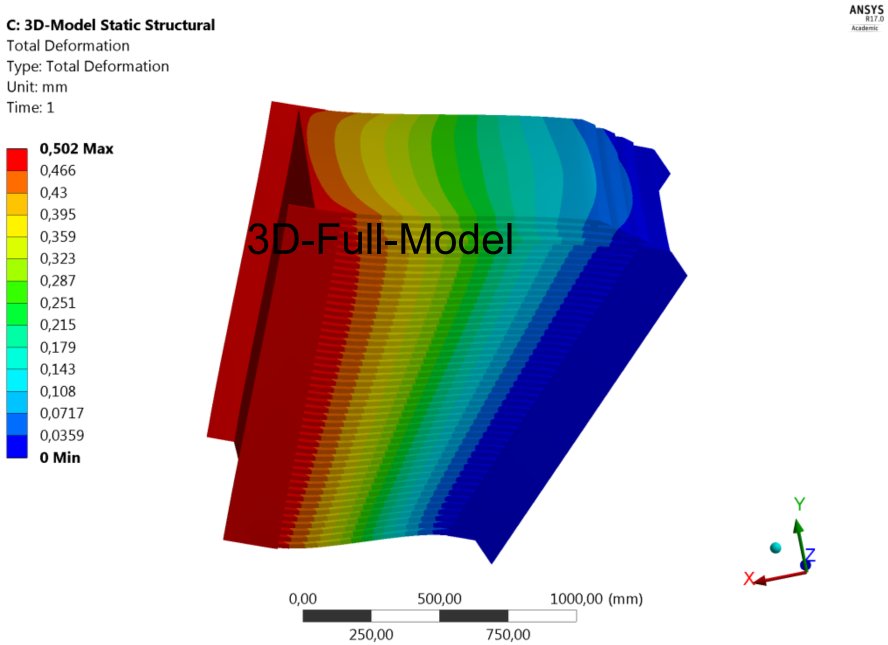


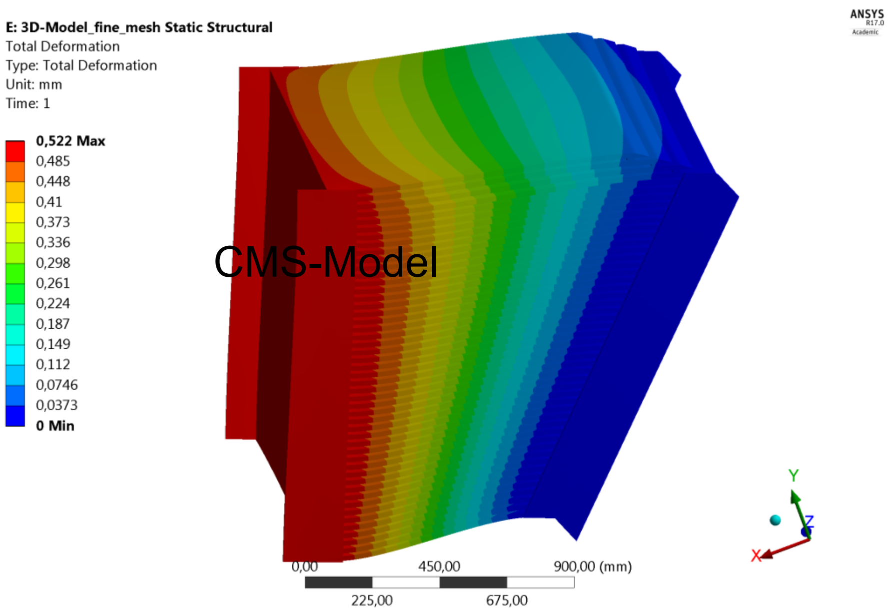




Tests to develop the sub-structuring process for AHCAL

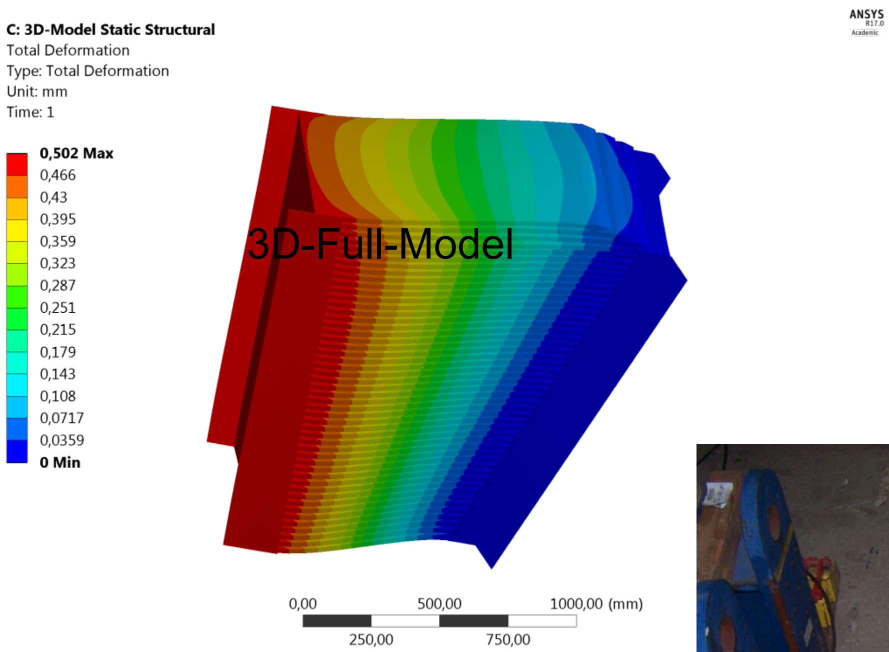
> Accurate results with CMS method

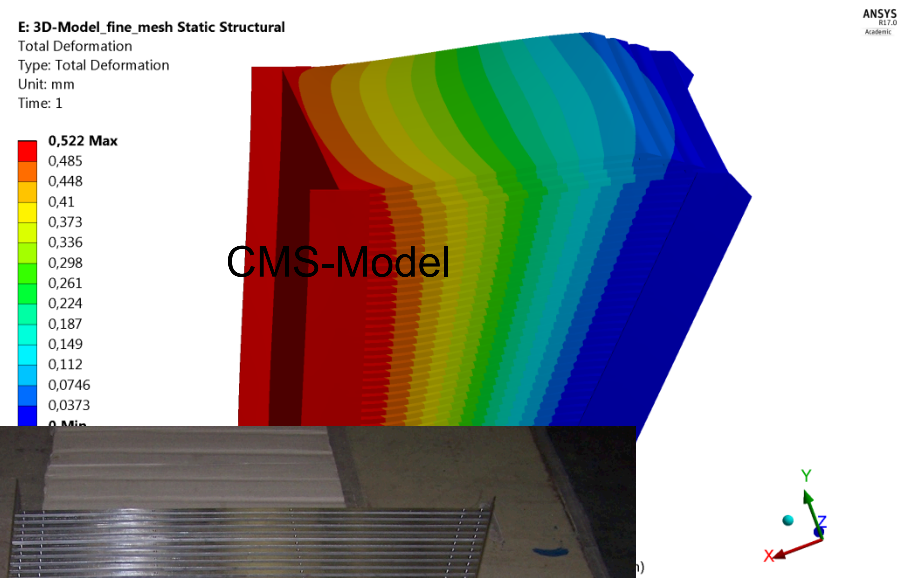




Tests to develop the sub-structuring process for AHCAL

- Accurate results with CMS method

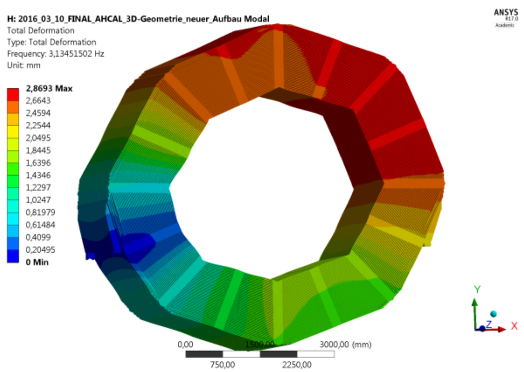


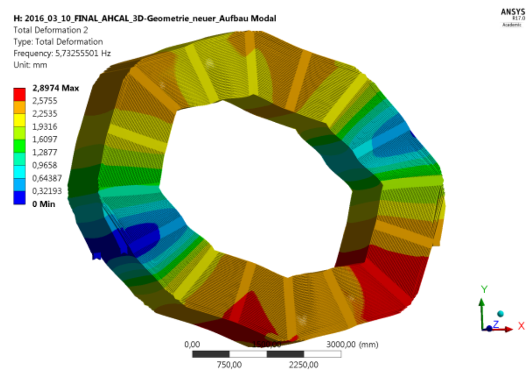


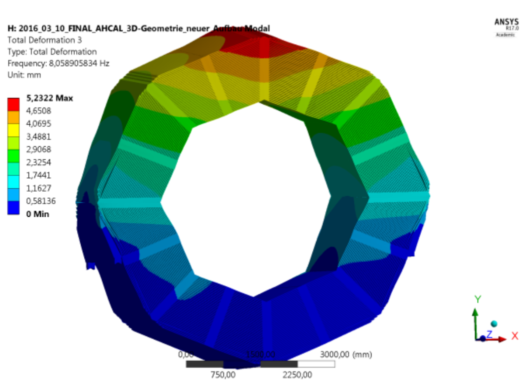
- Should be verified by measurement

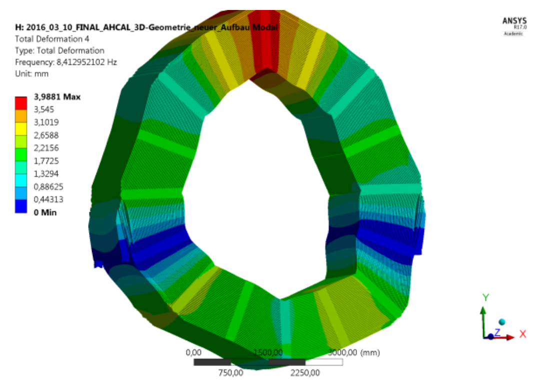
General AHCAL-Model

> Results CMS-Model:





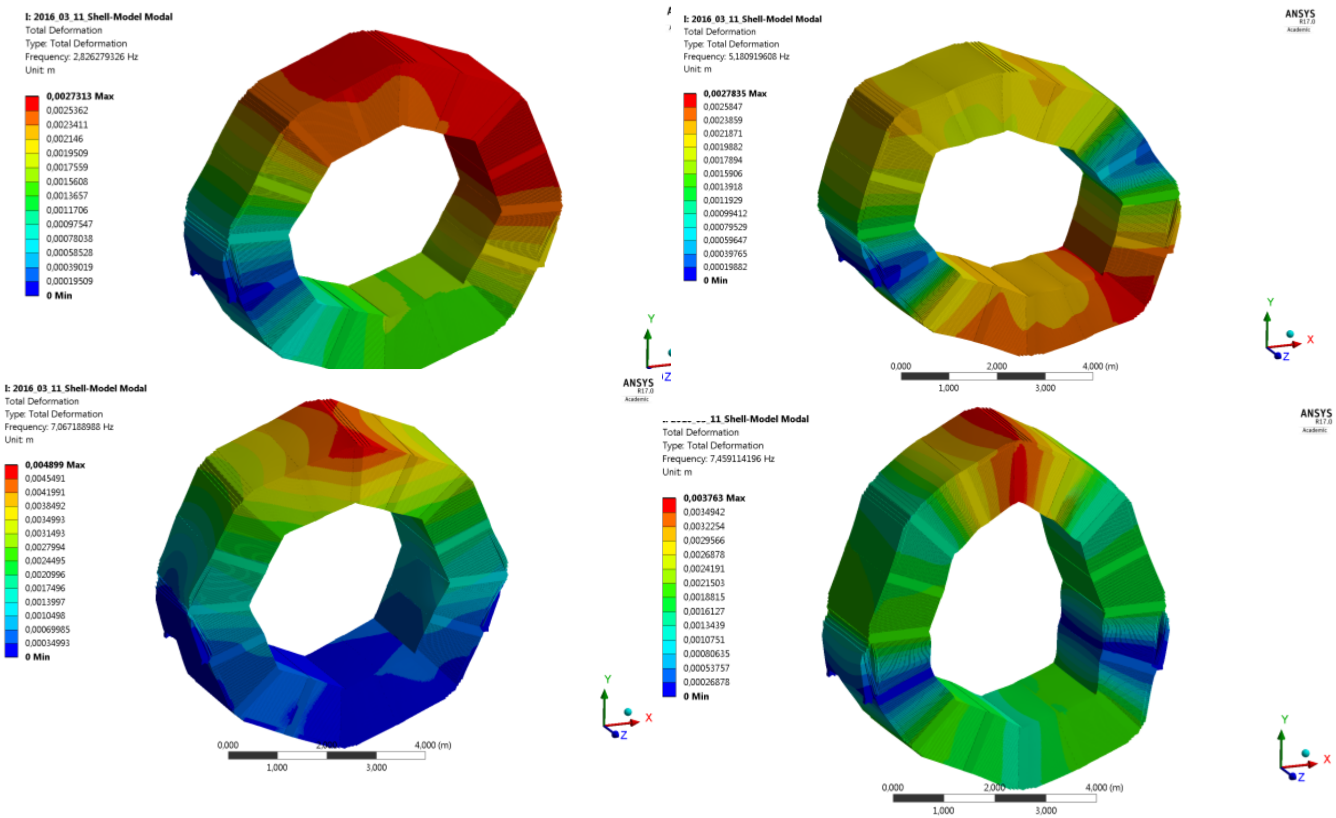




Shell-Model (prestressed)		Shell-Model (free)		CMS-Model (free)	
Nr.	f [in Hz]	Nr.	f [in Hz]	Nr.	f [in Hz]
1	2,97	1	2,83	1	3,13
2	5,27	2	5,18	2	5,73
3	6,11	3	7,07	3	8,06
4	7,65	4	7,46	4	8,41
5	9,16	5	9,94	5	10,84
6	9,85	6	11,60	6	12,91
7	11,68	7	13,65	7	15,02
8	13,32	8	14,70	8	16,47
9	14,65	9	15,37	9	16,83
10	14,67	10	17,18	10	18,07
11	15,76	11	18,75	11	20,38
12	17,37	12	19,29	12	21,14
13	18,32	13	20,21	13	22,44
14	19,37	14	21,46	14	23,34
15	20,29	15	22,48	15	24,44
16	21,99	16	23,63	16	26,12
17	22,83	17	25,52	17	27,06
18	24,05	18	31,37	18	32,28
19	24,49	19	33,39	19	38,16
20	25,23	20	35,12	20	39,50
21	31,22	21	41,07	21	41,03
22	35,29	22	42,68	22	41,03
23	38,82	23	42,68	23	41,03
24	39,76	24	42,72	24	41,03
25	40,52	25	42,72	25	41,03
26	40,55	26	42,72	26	41,03
27	41,00	27	42,72	27	41,03
28	41,27	28	42,72	28	41,04
29	42,32	29	42,81	29	41,04
30	43,78	30	43,33	30	41,04

General AHCAL-Model

> Results 3D-Model:



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11	15,76	11	18,75	11	20,38
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17	22,83	17	25,52	17	27,06
18	24,05	18	31,37	18	32,28
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25	40,52	25	42,72	25	41,03
26	40,55	26	42,72	26	41,03
27	41,00	27	42,72	27	41,03
28	41,27	28	42,72	28	41,04
29	42,32	29	42,81	29	41,04
30	43,78	30	43,33	30	41,04

Nice option: The Modal Participation Factor

- Modal Participation Factor to sort out irrelevant eigenmodes; especially the AHCAL-Structure produces a lot of eigenmodes caused by large amount of single plates in each of 16 segments
- This method saves disc space and reduces calculation time
- Only interesting modes used for following dynamic analysis with MSUP-Method

***** PARTICIPATION FACTOR CALCULATION *****ROTY DIRECTION

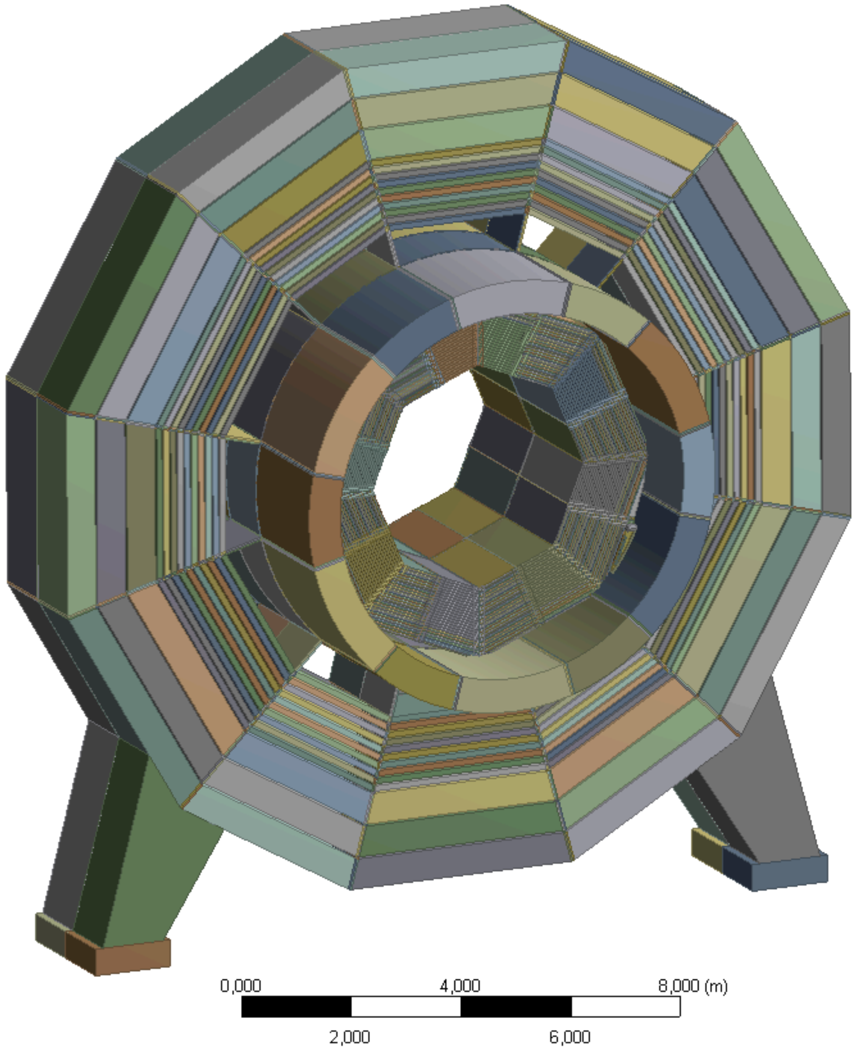
MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
1	2.97162	0.33652	520.02	0.641397	270419.	0.180528	0.180302
2	5.27491	0.18958	83.665	0.103194	6999.91	0.185201	0.466719E-02
3	6.11162	0.16362	-125.79	0.155153	15823.6	0.195765	0.105504E-01
4	7.65056	0.13071	-137.90	0.170092	19017.4	0.208461	0.126799E-01
5	9.15632	0.10921	7.1844	0.008861	51.6155	0.208495	0.344146E-04
6	9.85323	0.10149	21.563	0.026596	464.951	0.208806	0.310006E-03
7	11.6803	0.85615E-01	-92.694	0.114330	8592.23	0.214542	0.572887E-02
8	13.3242	0.75052E-01	-14.826	0.018287	219.821	0.214688	0.146565E-03
9	14.6512	0.68254E-01	-28.183	0.034761	794.260	0.215219	0.529572E-03
10	14.6706	0.68164E-01	-163.66	0.201864	26785.7	0.233100	0.178593E-01
11	15.7643	0.63435E-01	3.5688	0.004402	12.7361	0.233109	0.849182E-05
12	17.3655	0.57585E-01	92.957	0.114655	8641.04	0.238878	0.576141E-02

To Do: General tasks (short term schedule)

- Build up the prestressed modal analysis with CMS-Testmodel (actually working)
- Response spectrum analyses with earthquake data generalised with ISO 3010 and Eurocode 8
- Handover the modal-results to a response spectrum analysis with Earthquake data from Japan/Ichinoseki (Source:NIED K-NET IWT010 2011/03/11) has to be implemented in the Testmodel, max. amplitudes:
  - East-West 852,134 gal (alternatively 8,52 m/sec² => 0,36 g)
  - North-South: 997,780 gal (alternatively 9,98 m/sec² => 1,02 g)
  - Vertical: 352,666 gal (alternatively 3,53 m/sec² => 0,36 g)
- Mandatory: regular adjustments in models (Commands, geometry, …)
- … (next slide)

To Do: Towards the whole barrel-Setup (long(er) term schedule)

- To get real amplitudes, the whole support-structure for the AHCAL has to be calculated
- Thereby the CMS-Method is the key …?! In my opinion:YES!!! => a possible path:
  - In the first step, the barrel yoke with feet and cryostat, and mass points for AHCAL+ECAL+… will be calculated
  - Second: the system response at the AHCAL guide rails will be analysed and saved
  - Third: with these detailed excitations at AHCAL guide rails a second „analysis turn“ will be done for the AHCAL (again with CMS-Method)



Summary, outlook and remarks

- Seismic study is progressing
- Successful change to sub-structure method which will allow integration into cryostat and yoke whilst retaining all details
- Getting ready to simulate with real earthquake data
- Will also address rotated case (by 22^{o} as preferred by ECAL) and ECAL support details

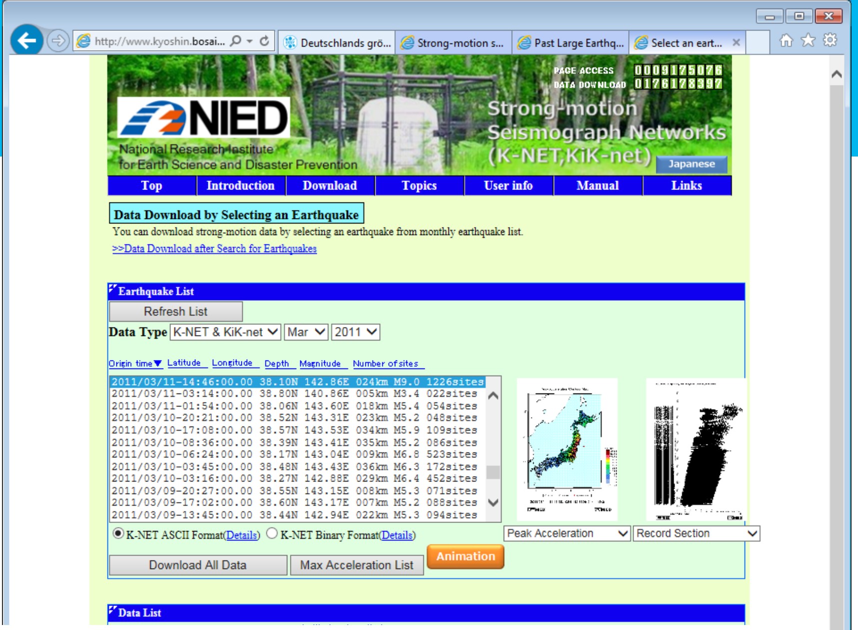
- Results are conservative with respect to
  - Thicker absorber (fewer layers for cost resuction)
  - Smaller inner radius
  - Adaption to SiD

Glossar

- APDL => ANSYS Parametric Design Language (ANSYS scripting/ programming language to expand the capabilities in ANSYS Workbench)
- Master DOF => a previously defined set of nodes, which are excluded from substitution with the superelement and to define boundary conditions and contacts to other bodies/parts/superelements
- CMS => Componenent Mode Synthesis
- MSUP => Modal Superposition Method
- Modal Participation Factor => Each mode of a structure has an effective mass representing the share in the relevance for structural dynamic investigations, for this reason a modal participation factor less then a defined value will have no relevant impact on following dynamic analsis reusing the modal results for the MSUP-Method

Backup-slide

- Bei Bauwerken muss nach Norm (ISO 3010 und Eurocode 8) die Standsicherheit nachgewiesen werden
- Eingangsleistungsspektrum aus ISO 3010/Eurocode 8 für die FE-Analyse aufbereiten (Faktoren für Aufstellort/-Erdregion) bestimmen und globales, dynamisches Modell aufsetzen
- Globales, dynamisches Modell mit Erdbebendaten Ichinoseki (NIED K-NET IWT010 2011/03/11) durchführen und Detailmodelle prüfen



ISO 3010:2001(E)

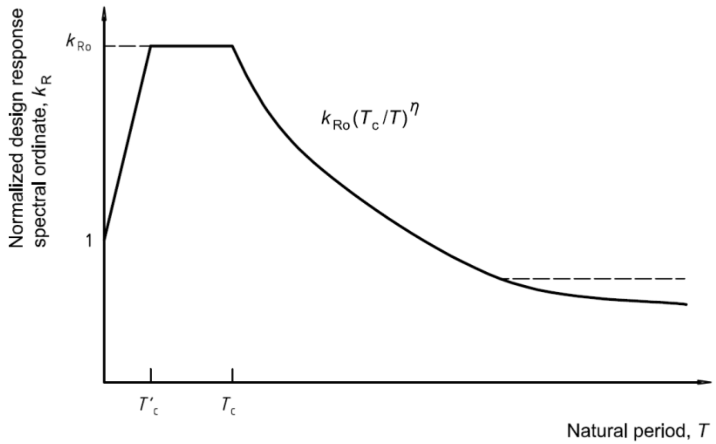


Figure C.1 — Normalized design response spectrum

Some facts …

- Direct comparison between 3D-FE-model and FE-model with CMS method is not necessary, because the CMS method rests upon a 3D-FE-Mesh
- A selected substructure, which has to be reduced to a super-element (CMS-Method), is replaced by **one!** single super-element with all mechanical characteristics of the original 3D-Model saved in Mass, Stiffness (and if needed) the damping matrix

Modell	#Nodes		Calc.-Time [in Min.]	Mode 1 [in Hz]	Delta to Full [in %]	Mode 2 [in Hz]	Delta to Full [in %]	Mode 3 [in Hz]	Delta to Full [in %]	Mode 4 [in Hz]	Delta to Full [in %]
Full 3D	396.111		4,80	119,64		174,00		277,84		330,99	
CMS-Model Fine Mesh	299.296		92,40	118,61	-0,86	171,75	-1,29	275,66	-0,78	326,67	-1,31
CMS-Model Medium Mesh	79.400		14,42	120,31	0,56	174,42	0,24	280,33	0,90	331,78	0,24
CMS-Model Coarse Mesh	377.930		1,50	123,32	3,08	174,60	0,34	285,96	2,92	332,71	0,52
									M. Lemke	Date:	02.03.2016