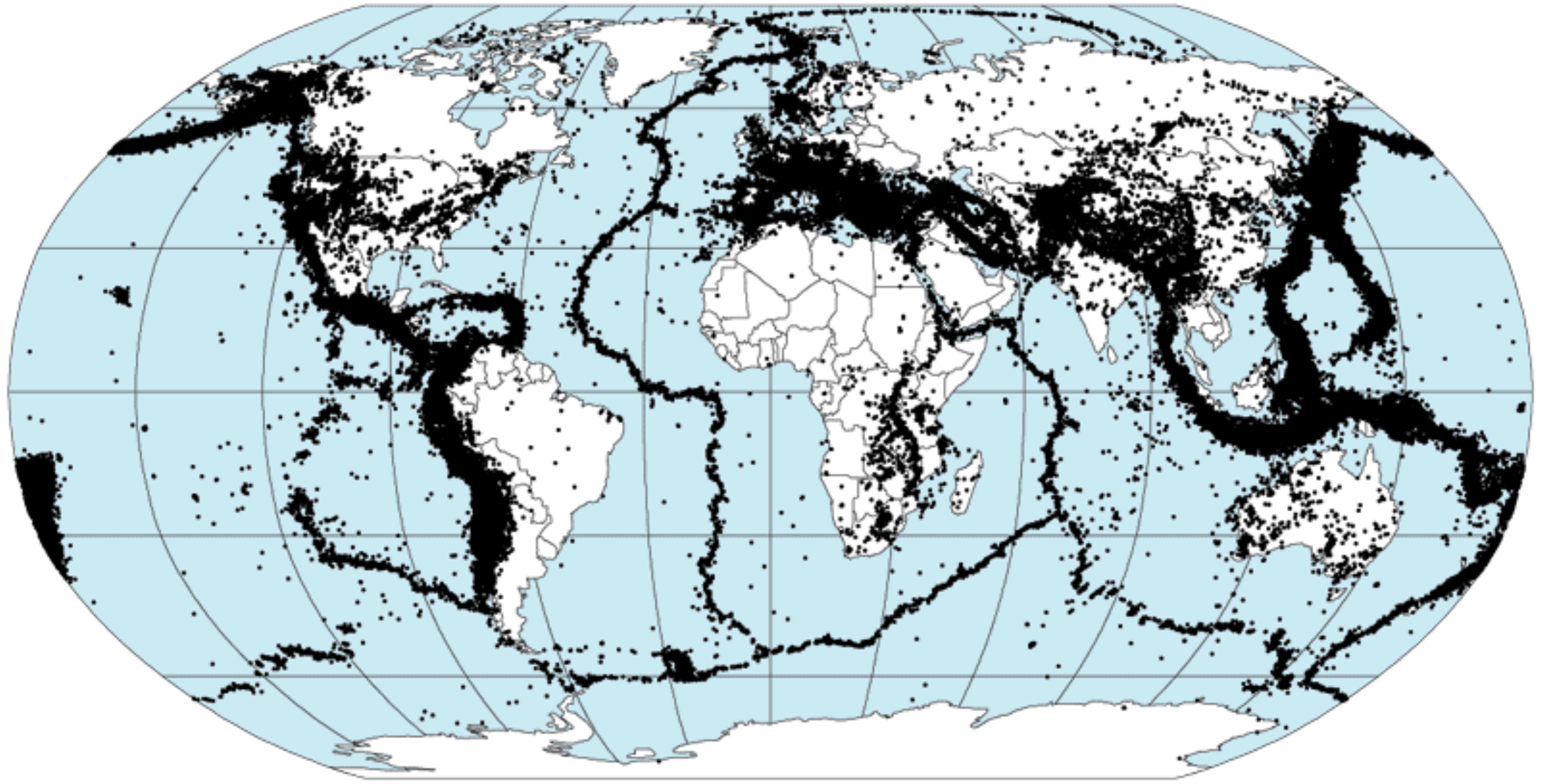
Detectors and Earthquakes

Karsten Buesser
ALCW2018 Fukuoka
29.05.2018

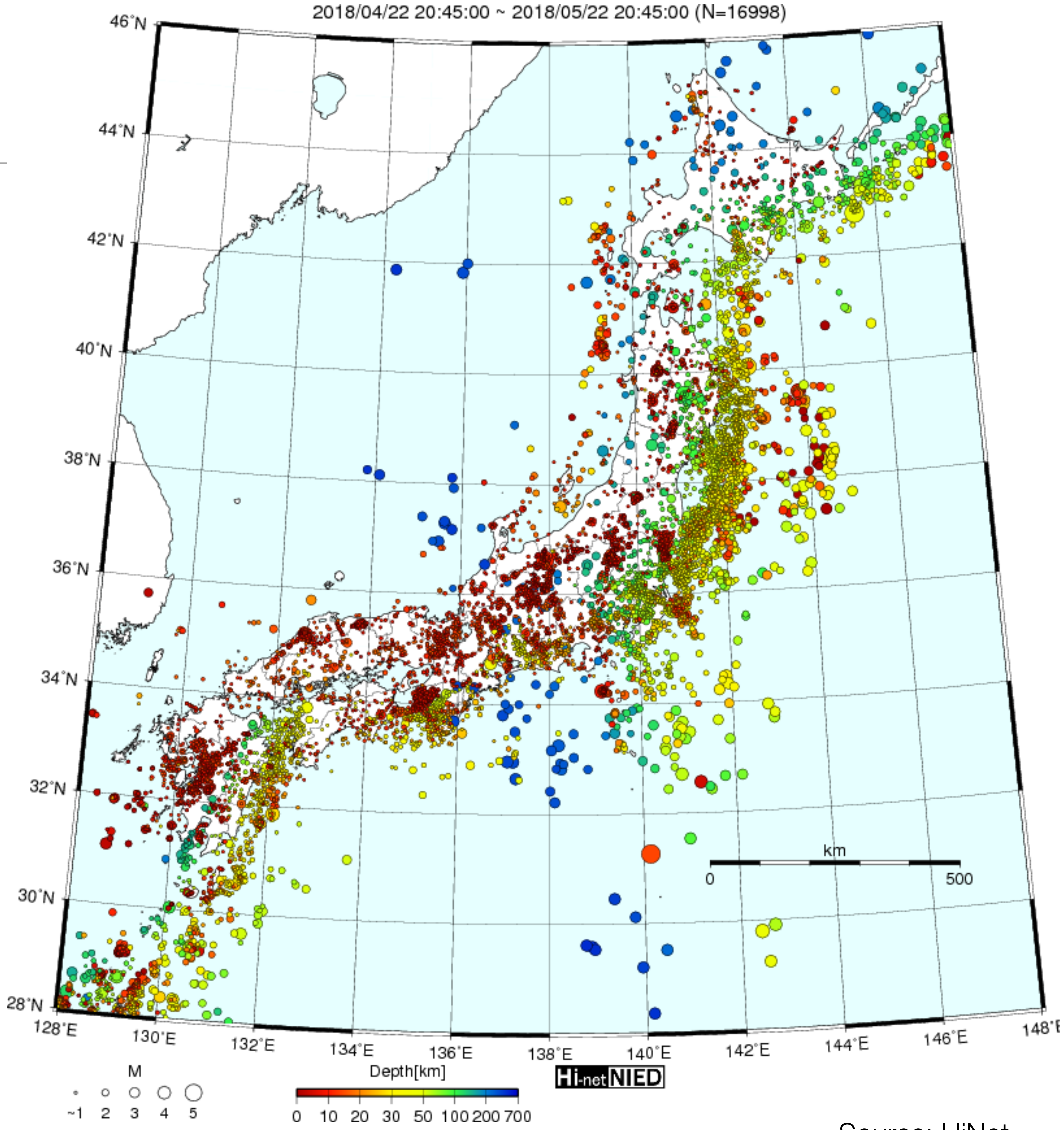
Seismic Activity in Japan

- Japan is in a very busy seismic region of the world
- ~17,000 earthquakes in 30 days (April 22 to May 22, right)

Preliminary Determination of Epicenters
358,214 Events, 1963 - 1998



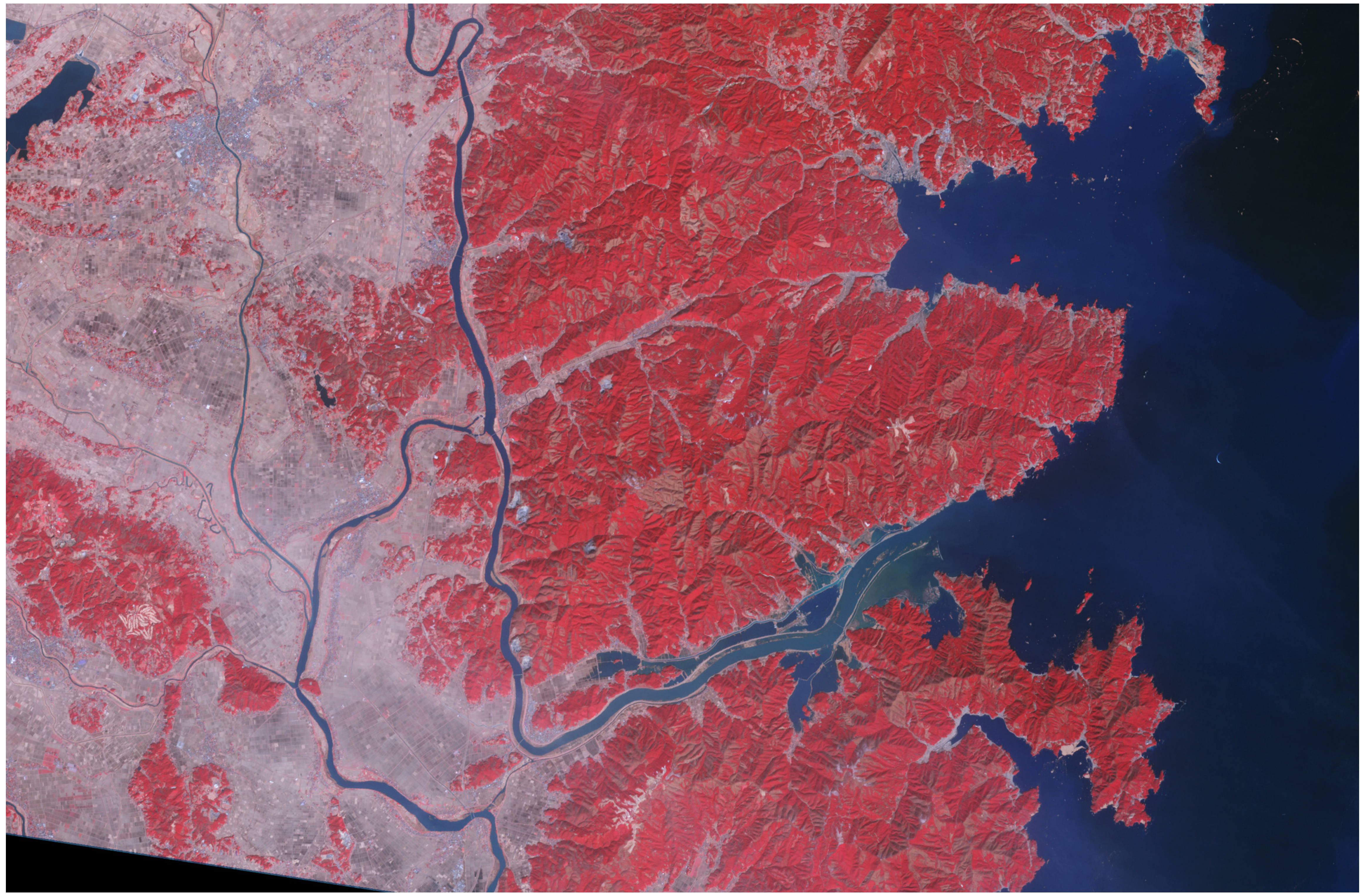
Source: Wikipedia



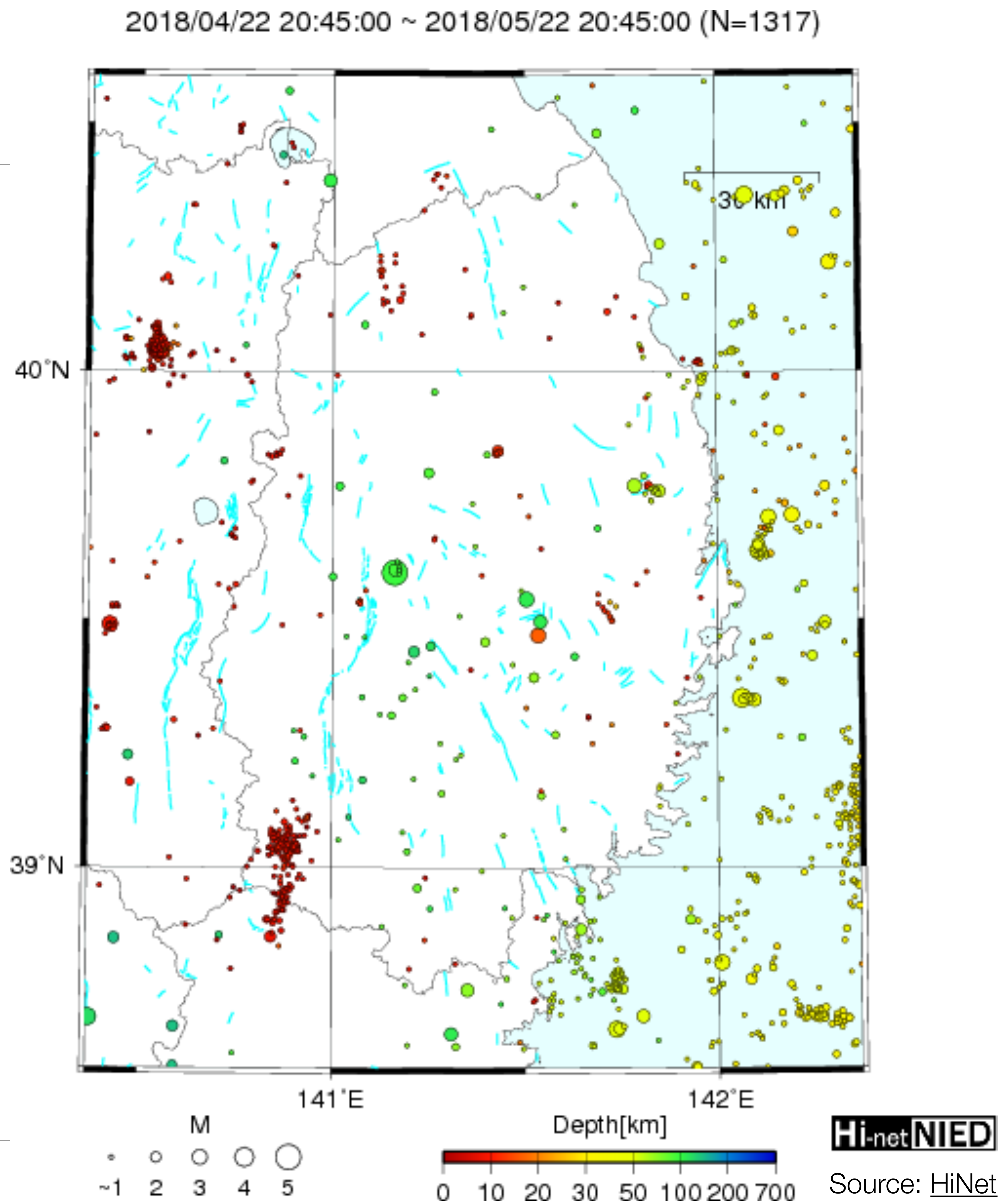
Source: HiNet

Seismic Activity and the ILC

- The Kitakami region is relatively quiet (for Japan)
  - even though 3/11 earthquake happened close by



Source: NASA



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Seismic Activity and the ILC

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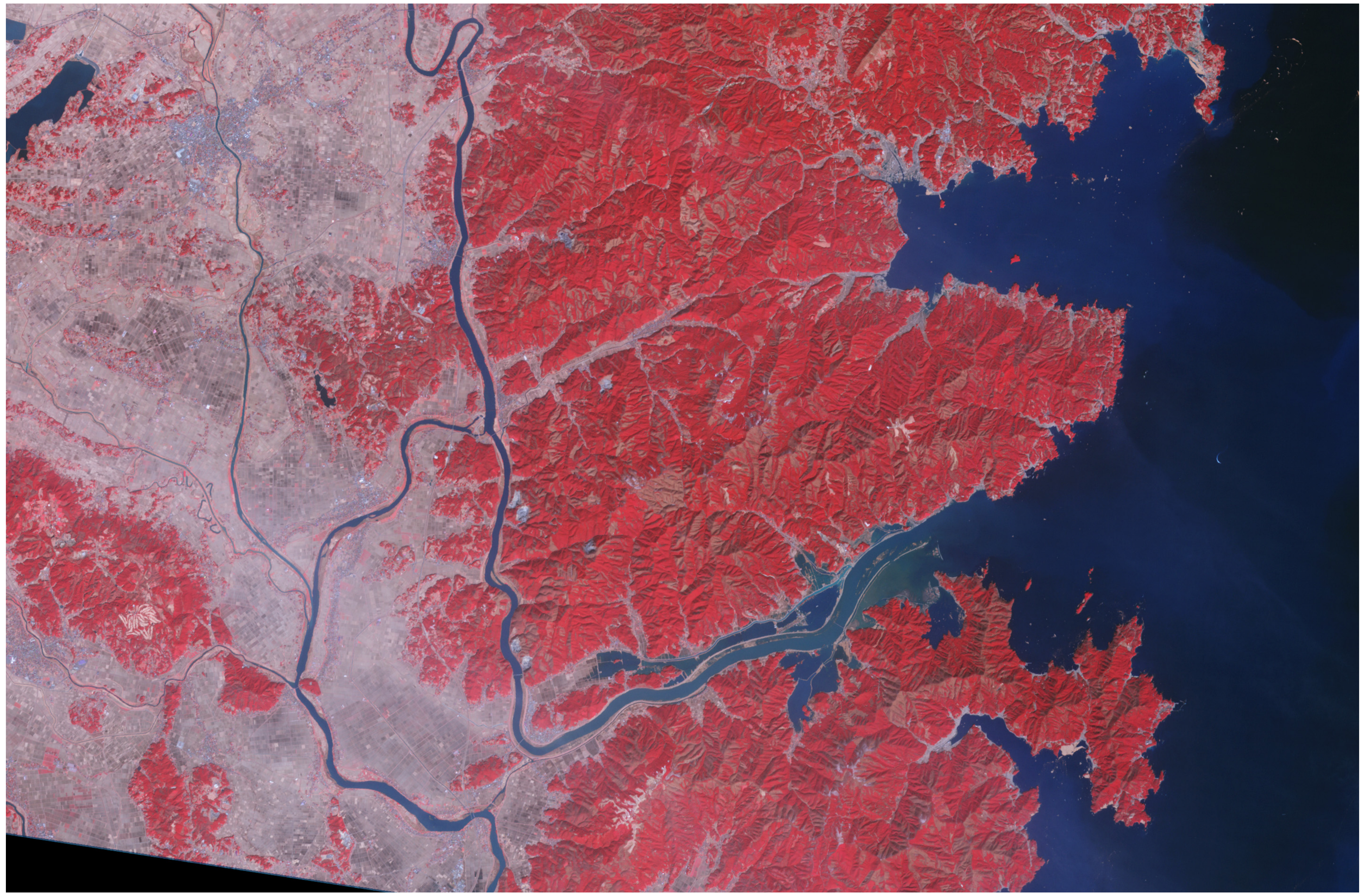

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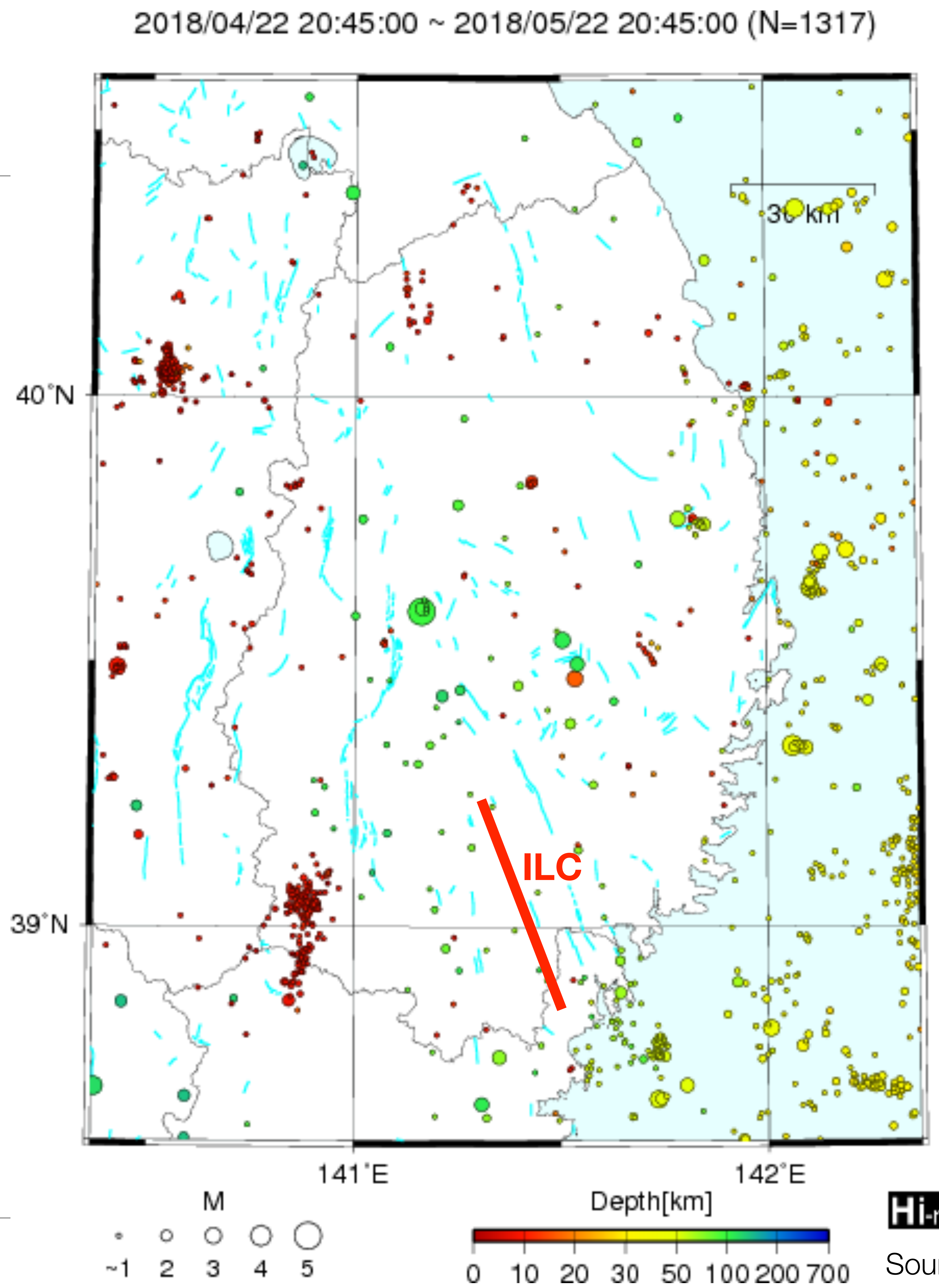


Hi-net NIED

Source: HiNet

Standards

- ISO 3010 „Bases for design standards - Seismic actions on structures"
- My translation:
  - Be prepared for seismic events to happen
  - Ultimate Limit State: Structures should not collapse and people must not be injured in case of severe earthquakes
  - Serviceability Limit State: Structures have to withstand moderate earthquakes and might get damaged within accepted limits in exceptional cases during their lifetime

ISO 3010:

The basic philosophy of seismic design of structures is, in the event of earthquakes

— to prevent human casualties,

— to ensure continuity of vital services, and

— to reduce damage to property.

In addition to these, societal goals for the environment should be considered.

It is recognized that to give complete protection against all earthquakes is not economically feasible for most types of structures. This document states the following basic principles.

a) The structure should not collapse nor experience other similar forms of structural failure due to severe earthquake ground motions that could occur at the site [ultimate limit state (ULS)]. Higher reliability for this limit state should be provided for structures with high consequence of failure.

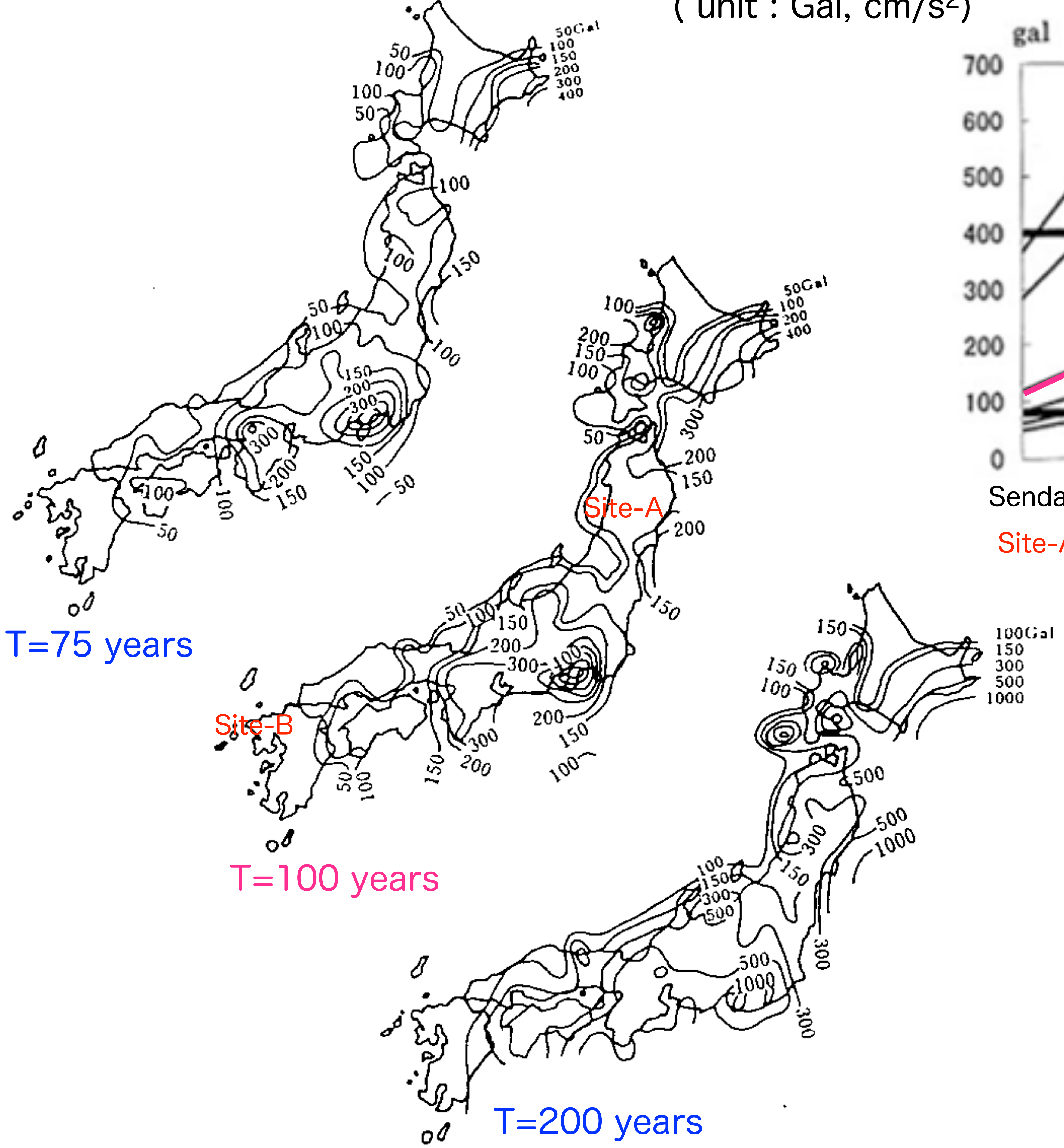
b) The structure should withstand moderate earthquake ground motions which may be expected to occur at the site during the service life of the structure with damage within accepted limits [serviceability limit state (SLS)].

Seismic Hazard Map in Japan : Maximum acceleration (gal) in recurrence intervals (T) of earthquake

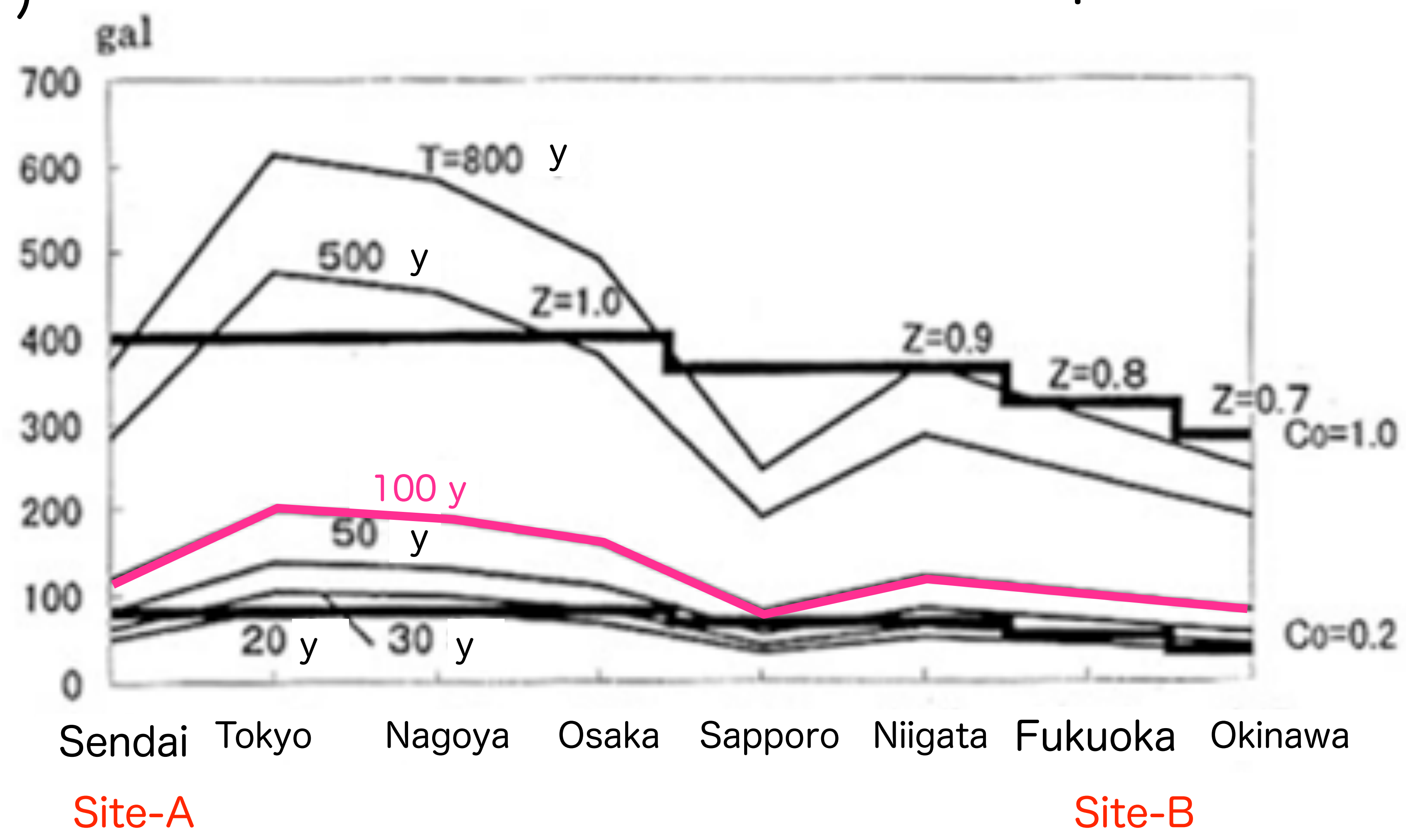
- Expected accelerations for earthquakes in recurrence intervals in Japan:

Kawasumi map : based on earthquakes from 679 to 1,948 in Japan

(unit : Gal, cm/s^2)



Max. acceleration in cities, Japan

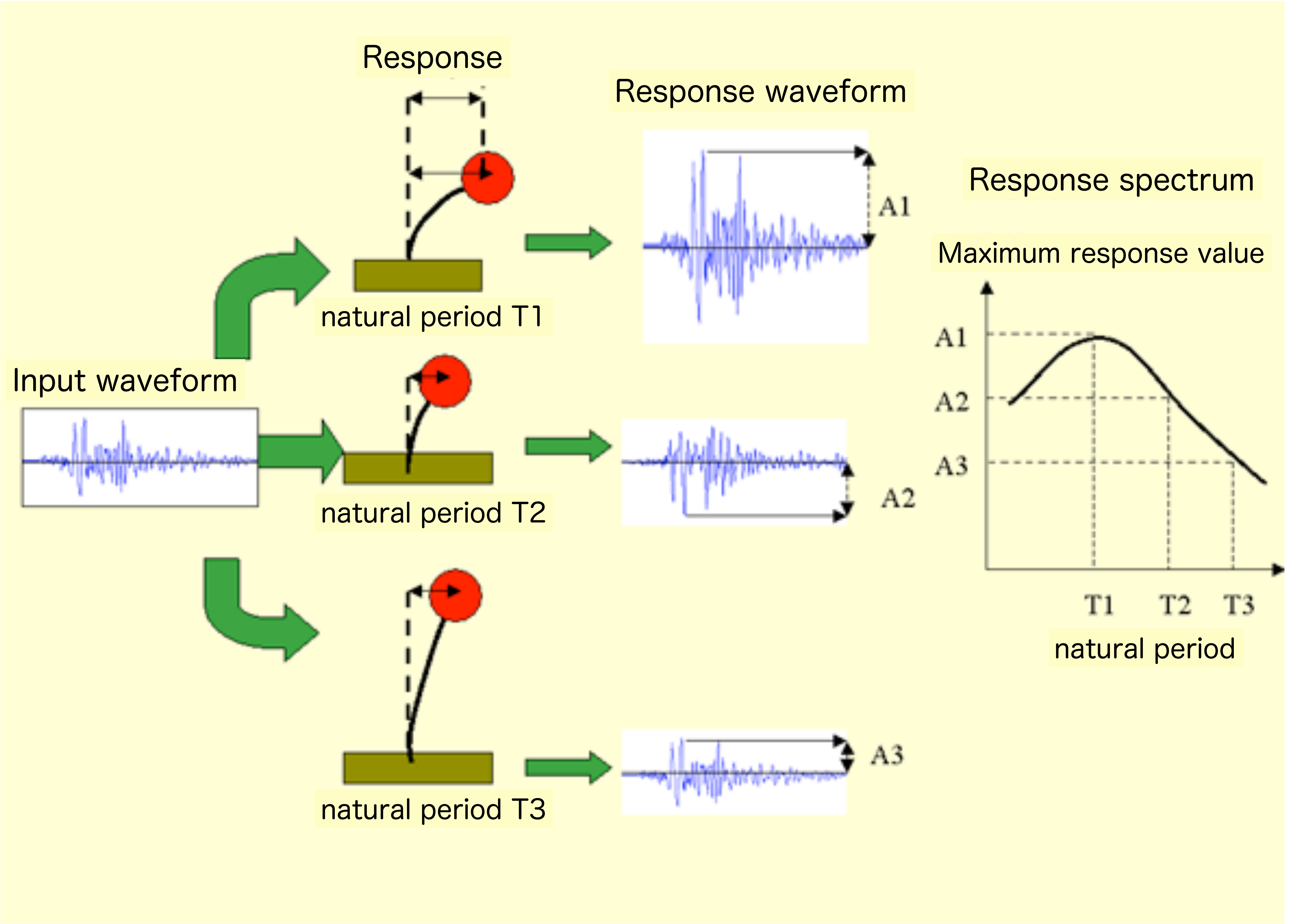


T. Tauchi

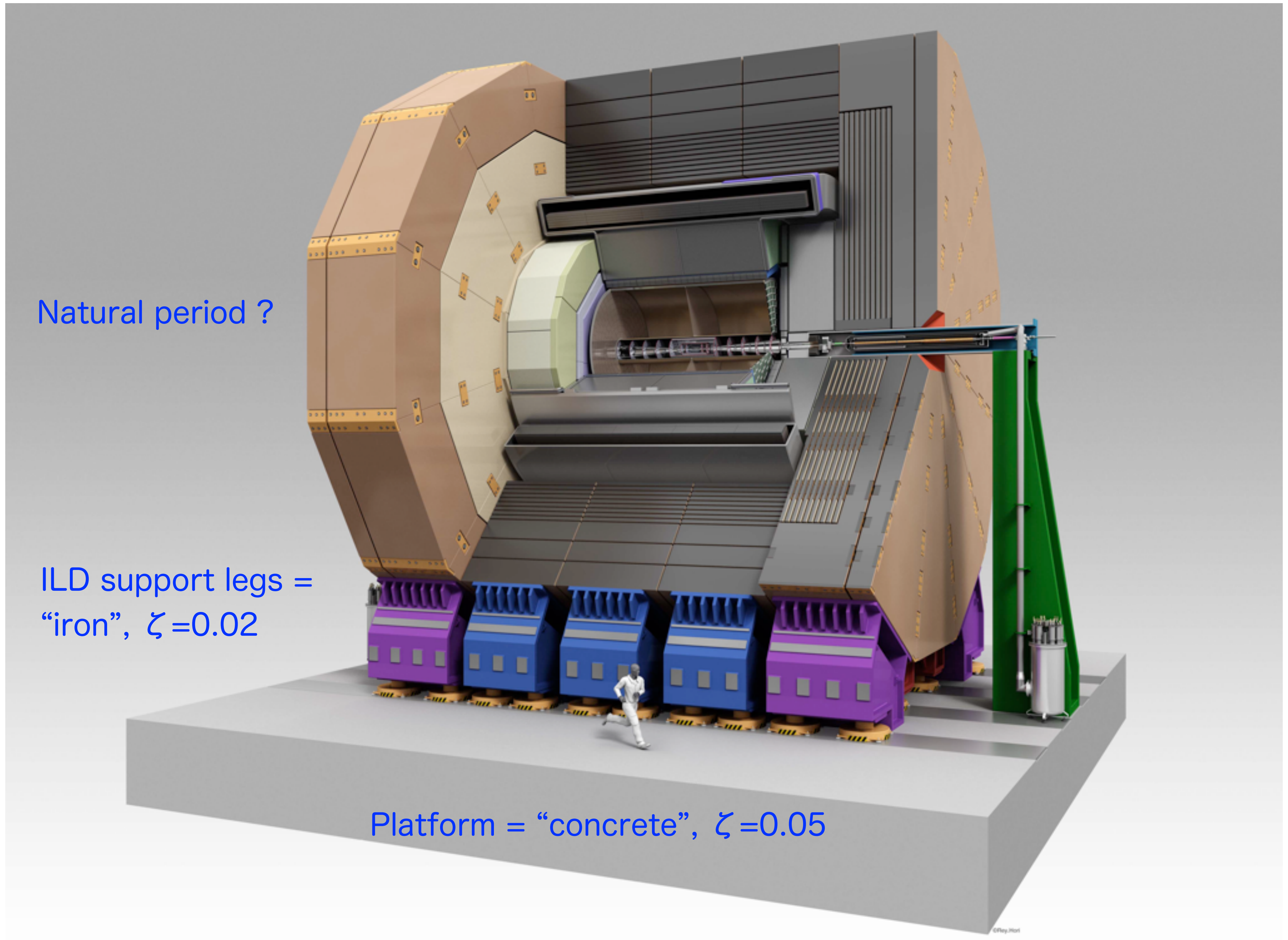
Response Spectrum and Detectors

Response Spectrum of Earthquake

for dynamic ground motion analysis of the structure



T. Tauchi

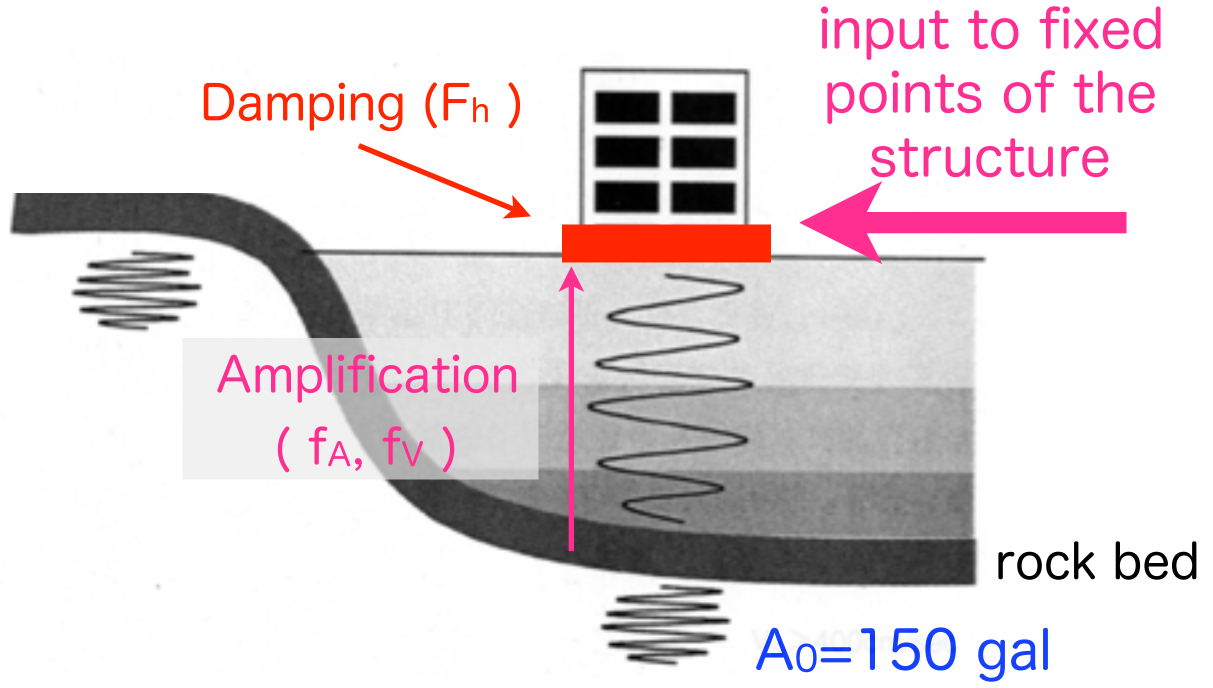


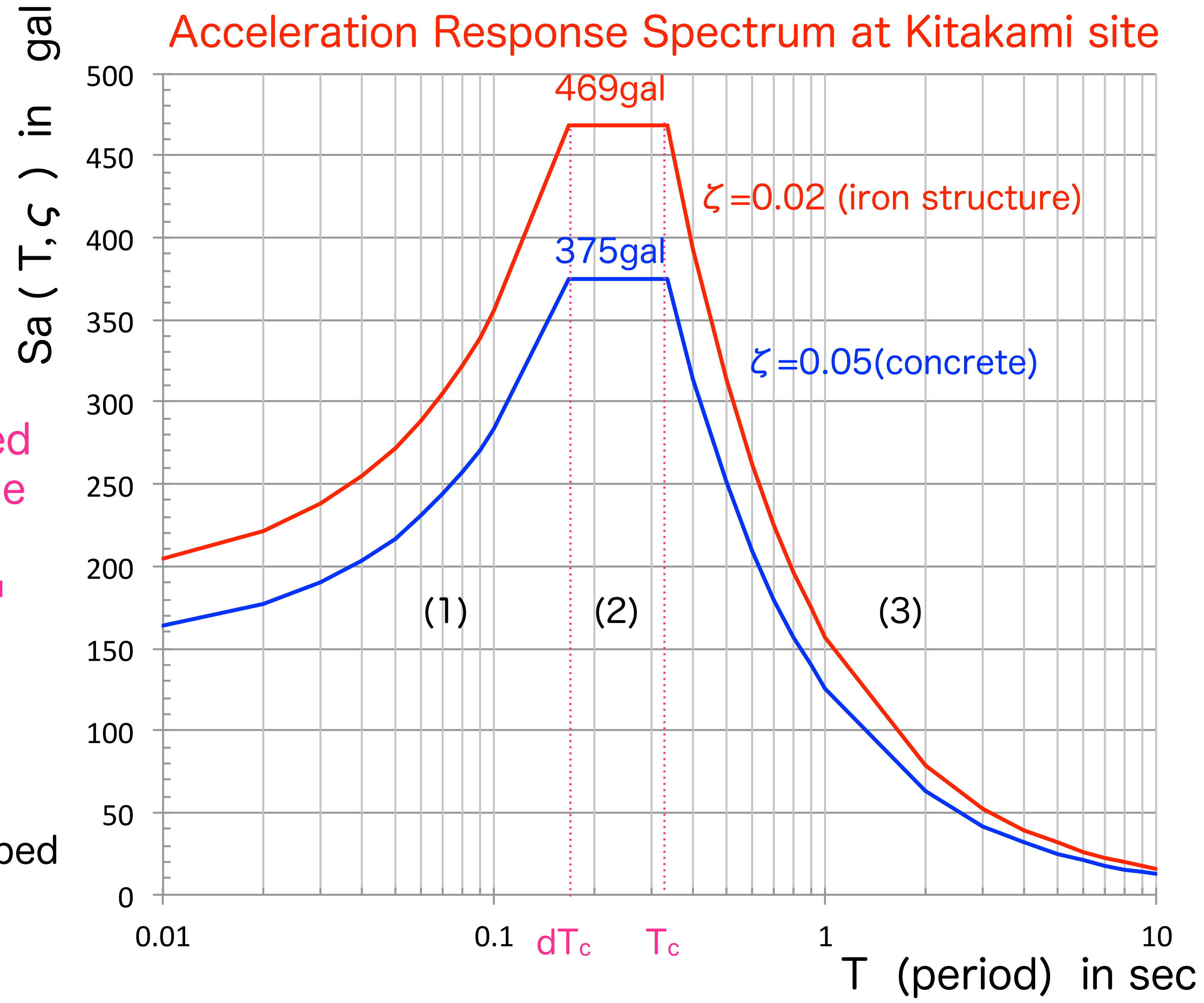
Standard Response Spectrum for Simulations

Seismic Analysis with the class-1 geology (hard soil)

following the guideline of construction loads by Architectural Institute of Japan, also ISO3010

Kitakami is a site with hard soil.





$$(1)\ 0 \le T \le dT_c \quad : \quad S_a = \left(1 + \frac{f_A - 1}{d}\frac{T}{T_c}\right) F_h G_A R_A A_0$$

$$(2)\ dT_c \le T \le T_c \quad : \quad S_a = f_A F_h G_A R_A A_0$$

$$(3)\ T_c \le T \quad : \quad S_a = \frac{2\pi f_V F_h G_V R_V V_0}{T}$$

(constant velocity spectrum)

$$T_c = \frac{2\pi f_V G_V R_V V_0}{f_A G_A R_A A_0} = 0.33\text{sec}$$

$$dT_c = 0.17\text{sec for } d = 0.5$$

$$\text{Frequency:} f = \frac{1}{T} \quad \text{Displacement:} x(f,\zeta) = \frac{S_a(T,\zeta)}{(2\pi f)^2}$$

Site-dependent parameters in seismic analysis for hard soil

A_0 (150 at Kitakami site): Basic maximum acceleration of ground motion
V_0 (A_0/15 hard) : Basic maximum velocity of ground motion
R_A (1.0 hard): conversion coefficient of recurrence intervals (std:100y) of the maximum acceleration
R_v (1.0 hard) : conversion coefficient of recurrence intervals (std:100y) of the maximum velocity
G_A (1.0 hard): site-dependent (ground type) correction factor of the maximum acceleration
G_v (1.0 hard): site-dependent (ground type) correction factor of the maximum velocity
F_h (1.25/1.0 hard): Correction factor by damping,1.5/(1+10ς) with ς=0.02/0.05 for steel/concrete
f_A (2.5 hard): ratio of $G_A R_A A_0$ of S_a(T, ς) in dT_c<T<T_c , amplification factor
f_v (2.0 hard): ratio of $G_v R_v V_0$ of the velocity spectrum S_v(T, ς)= S_a(T, ς)T/2π in T_c<T, amplification factor
d (0.5 hard): dT_c/T_c, ratio of lower bound of period (dT_c) relative to the upper one (T_c=0.33sec hard) in the constant S_a(T, ς)

Natural vibration analysis of structures

Calculation of natural frequencies, own natural periods, natural angular frequencies, natural vibration modes, impulse constants, effective masses then,

Estimation of maximum displacement, maximum response acceleration, and maximum stress to be reviewed if it is less than the allowable stress.

T. Tauchi

ILD ECAL: Eigenmode Analysis

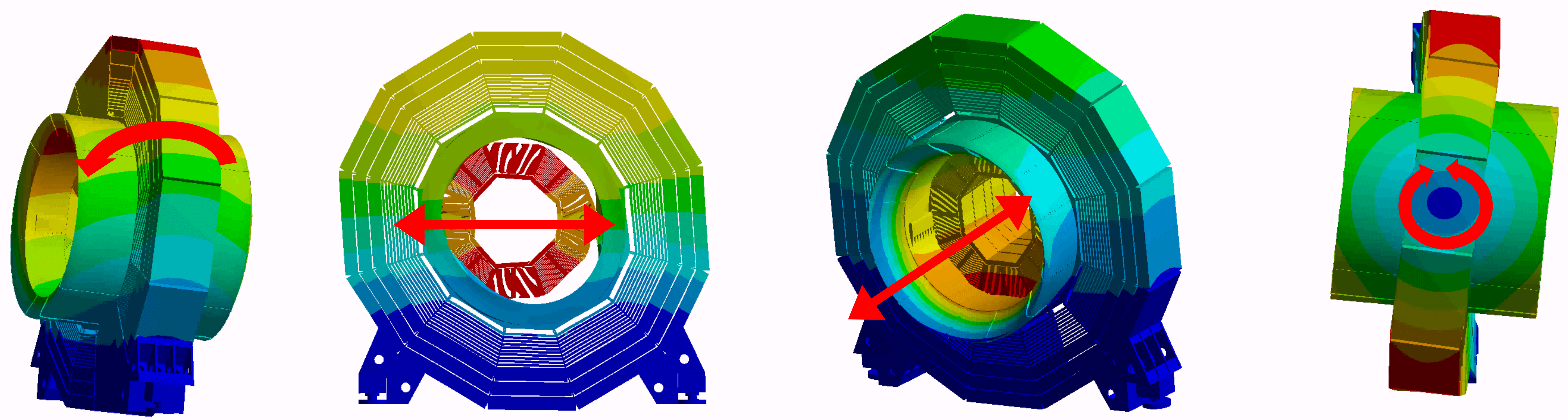
Marc Anduze, Thomas Pierre Emile – LLR

CALICE Collaboration Meeting @Tokyo September 25-27th 2017

H. Videau

Preliminary Analysis Results: **Eigen Modes** (states of excitation/vibration under specified fixed frequencies called resonant frequencies)

Mode 1 @ 2,3Hz | Mode 2 @ 3,05Hz | Mode 3 @ 3,8Hz | Mode 6 @ 7Hz



Due to the very heavy structure, 6 global modes are included into the range of earthquake peak 2-6 Hz

The modes 4 and 5 engage a fraction of the mass too small to be considered

22/02/2018 Henri Videau LLR. February 2018 CFS meeting KEK 5

ILD ECAL Response Spectrum - Beam Direction

Marc Anduze, Thomas Pierre Emile – LLR

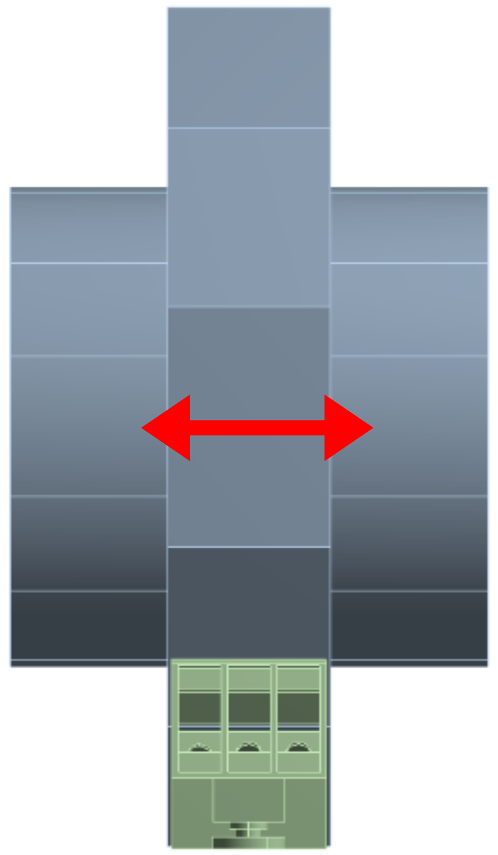
CALICE Collaboration Meeting @Tokyo September 25-27th 2017

H. Videau

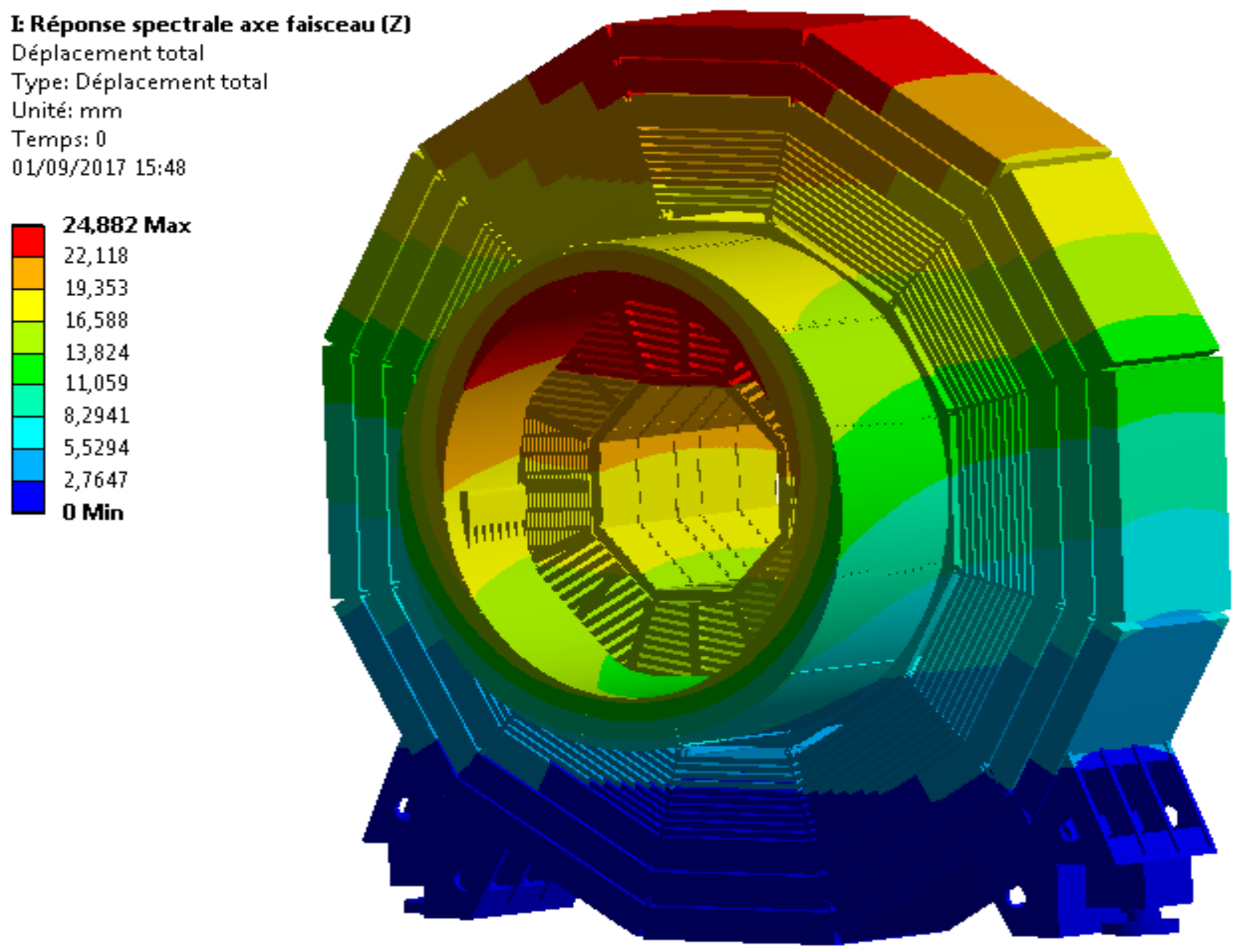
Preliminary Analysis Results: **Response spectrum - detector axis (Z) only**

With the acceleration response spectrum applied along Z axis, the fundamental mode of the structure dominates: back and forth motion of the yoke ring, followed by the mode 3 linked to a distortion of the cryostat flanges

But all the modes having a component along z are taken into account



Central ring only



Maximum displacement: **24,9 mm**

Smallest gap between ECAL rings along z: **0,98 mm**

Nominal 1mm

Smallest gap between ECAL module along phi: **2,29mm**

Nominal 2.5mm

TPC oscillations!
If ISS tied to TPC
poor beamtube!!

- No relative motion along Z between ECAL modules.
  The barrel follows the global motion of the YOKE+HCAL
- Fastening the 3 rings together is probably the way to increase the overall stiffness and reduce the peak displacement linked to mode 1
- thickening the cryostat flanges would help reduce the influence of mode 3.

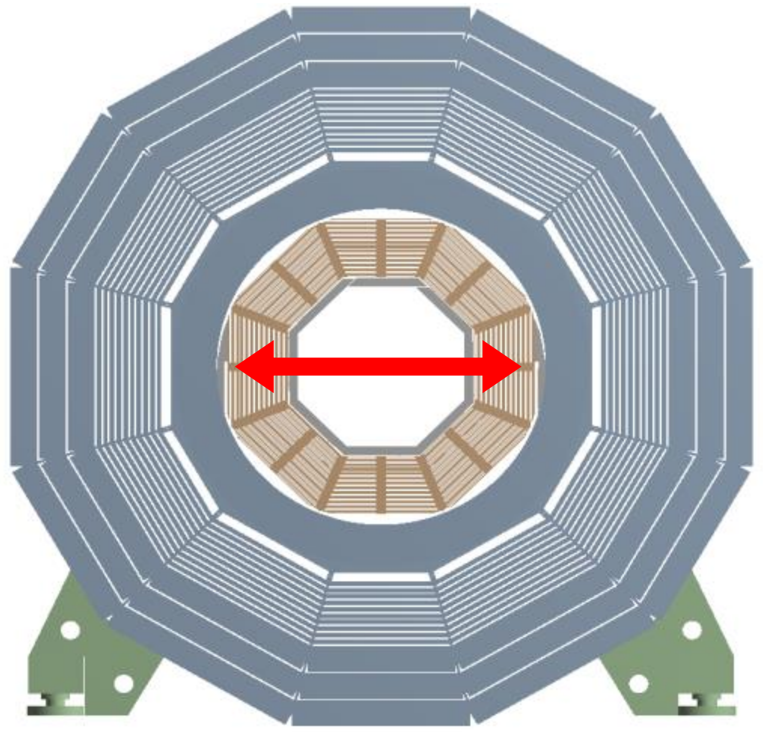
ILD ECAL Response Spectrum - Lateral Direction

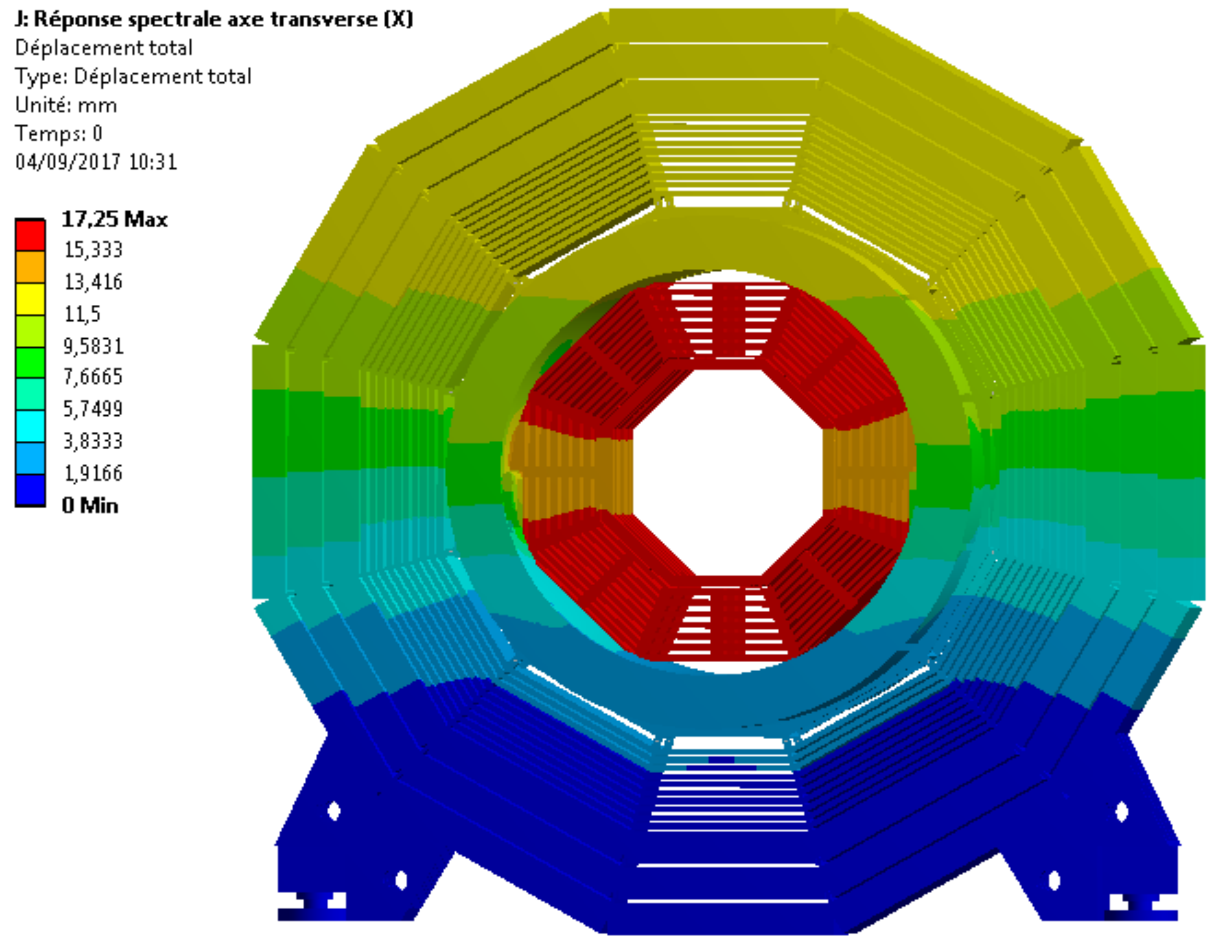
Marc Anduze, Thomas Pierre Emile – LLR
CALICE Collaboration Meeting @Tokyo September 25-27th 2017

H. Videau

Preliminary Analysis Results: **Response spectrum – Lateral only**

With the acceleration response spectrum applied along lateral axis, the mode 2 of the structure dominates: the displacement is lower





Maximum displacement: **17,3 mm**

Smallest gap between ECAL rings along z: **0,98 mm**

Smallest gap between ECAL module along phi: **1,89mm**

Strong effort on the fixing rail

- No significant Z relative motion between ECAL modules because complete barrel moves from left to right

ILD ECAL Response Spectrum - Vertical Direction

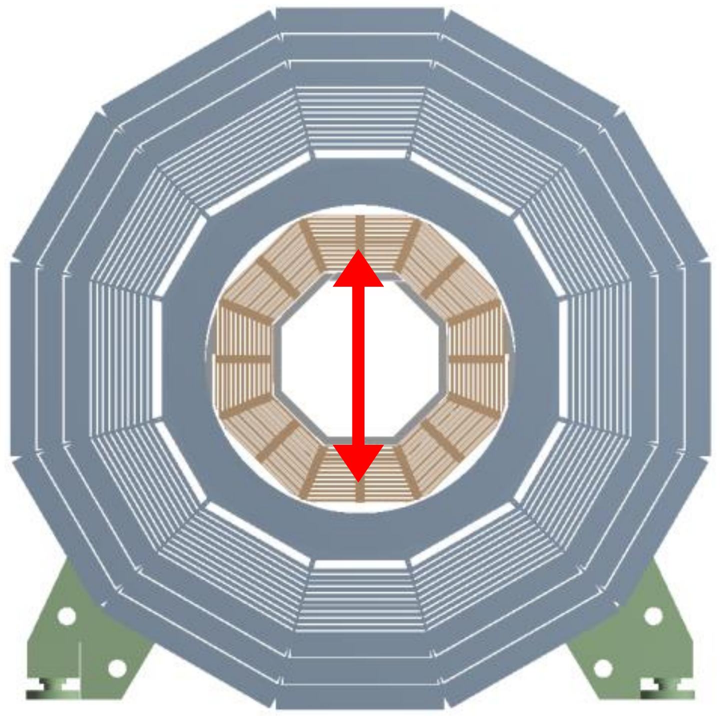
E-JADE

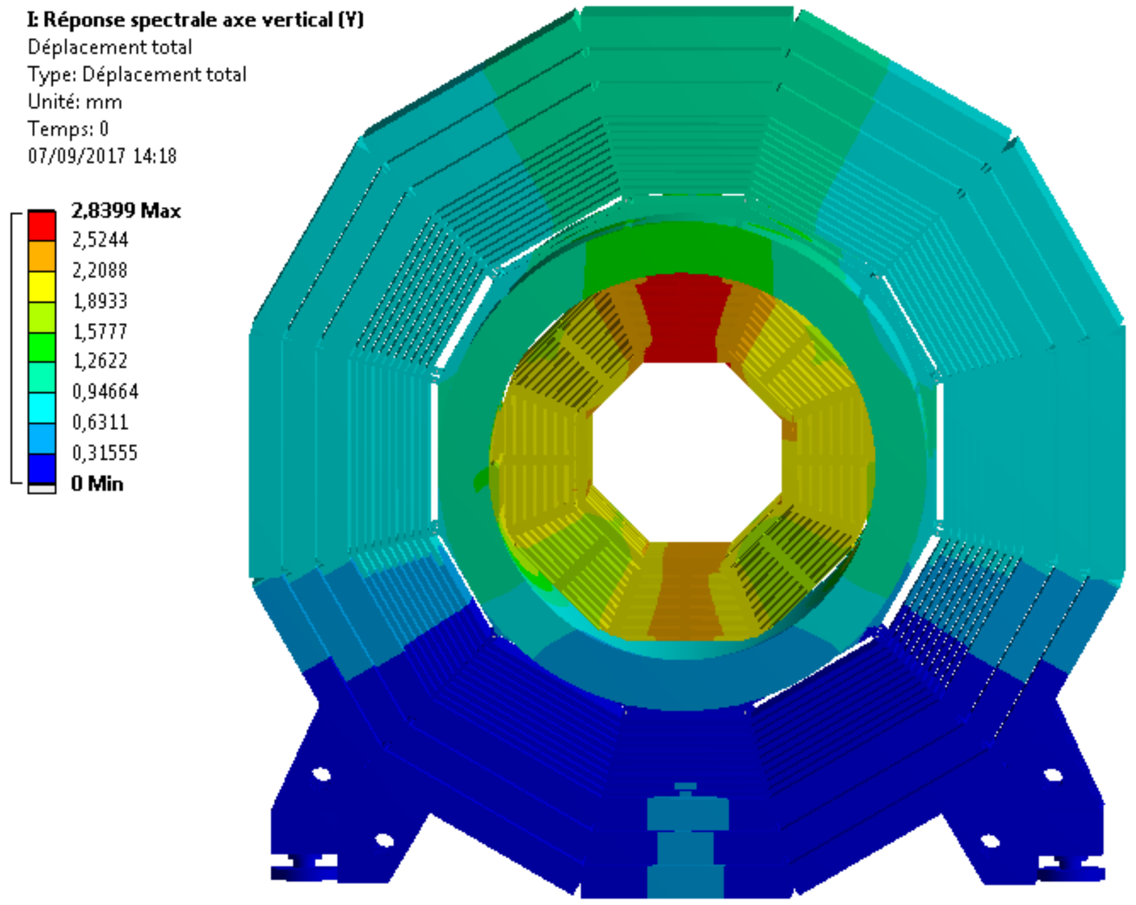
Marc Anduze, Thomas Pierre Emile – LLR
CALICE Collaboration Meeting @Tokyo September 25-27th 2017

H. Videau

Preliminary Analysis Results: **Response spectrum - Up and down only**

With the acceleration response spectrum applied along third axis, the displacement is significantly lower (less than 3 mm).





Maximum displacement: **2,9 mm**

Smallest gap between ECAL rings along z: **0,98 mm**

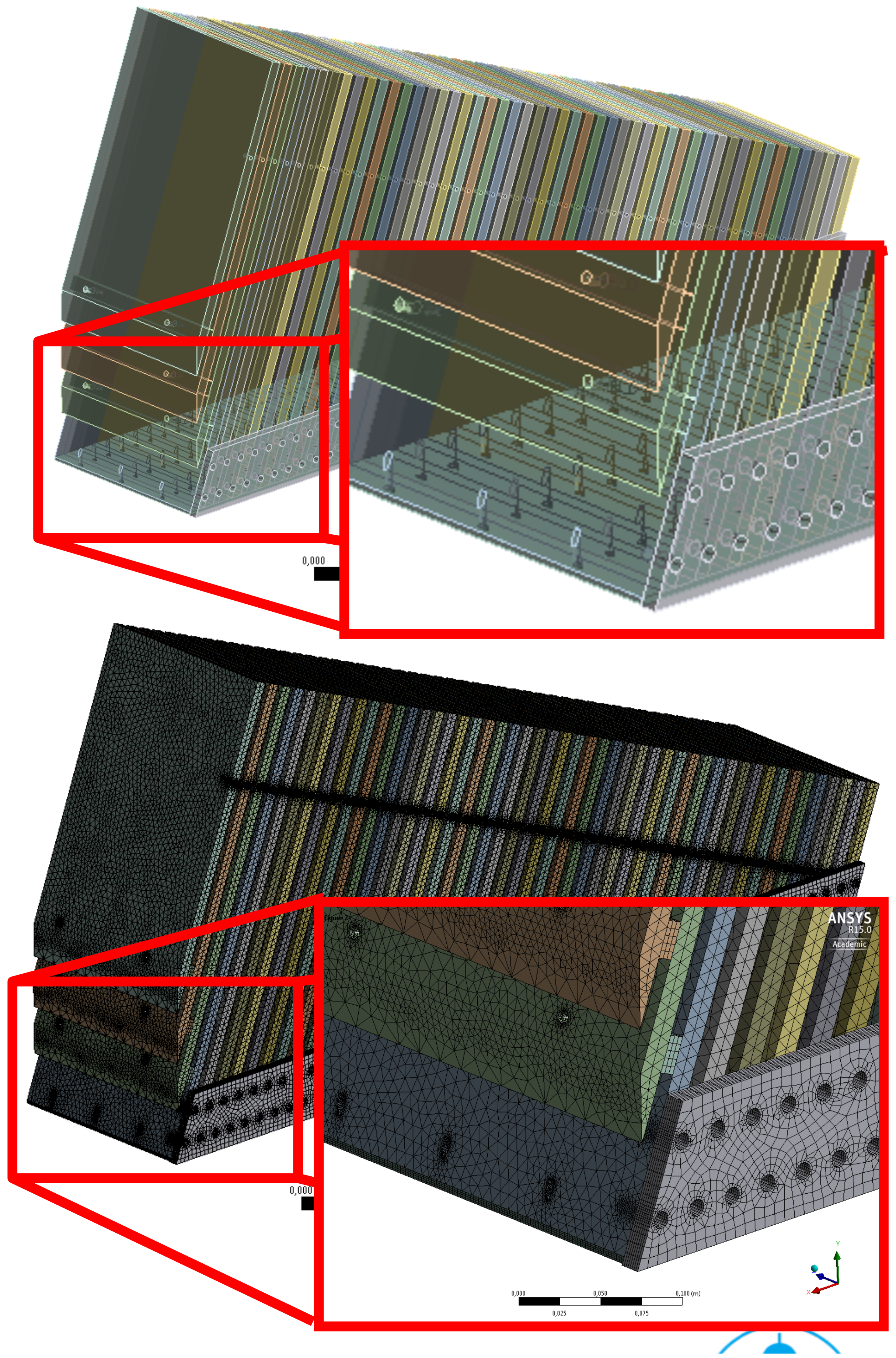
Smallest gap between ECAL module along phi: **2,05 mm**

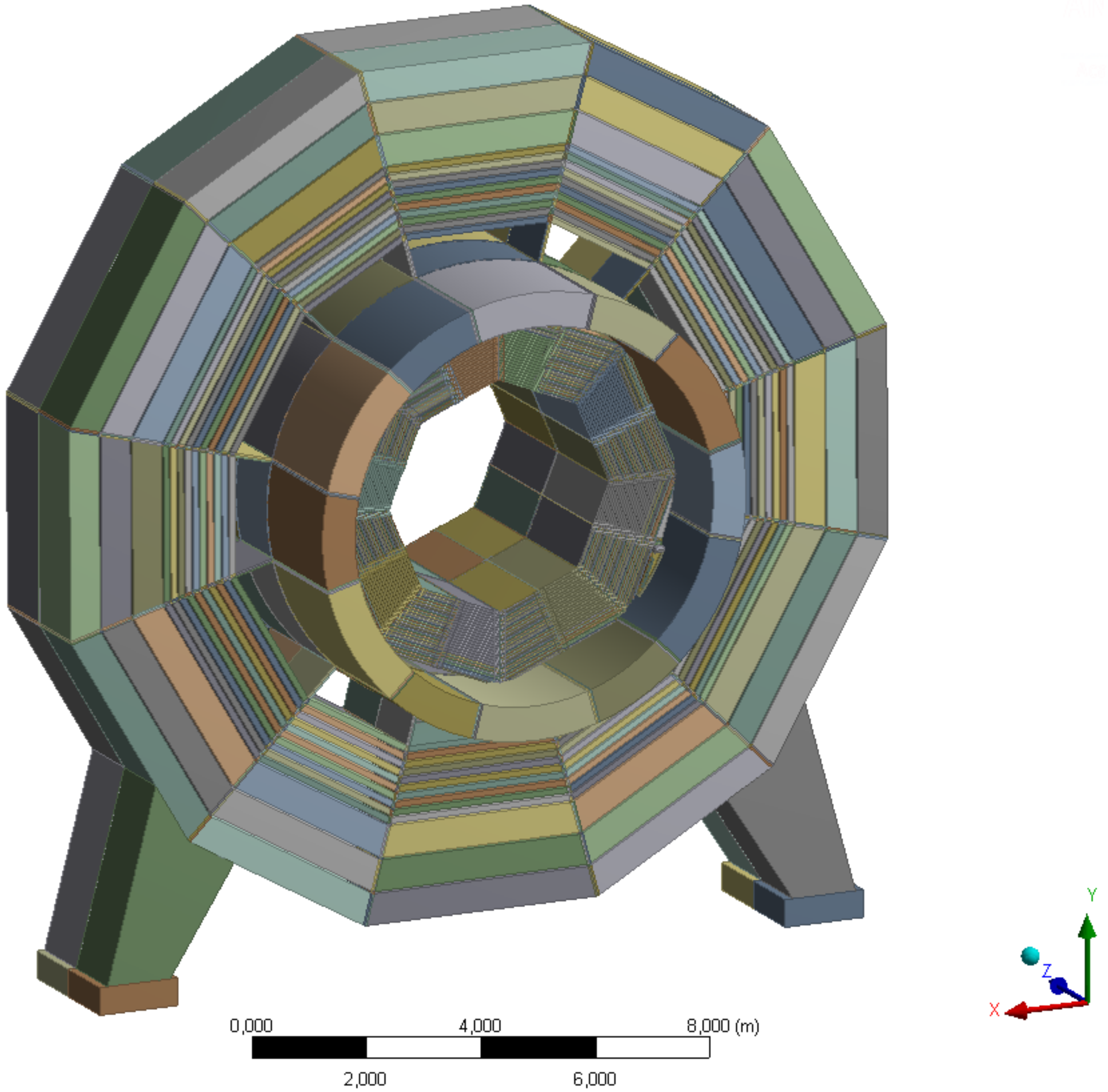
The yoke ring offers a good resistance to side loading
No Z relative motion between ECAL modules too
(same complete barrel behaviour)

Simulation Example: ILD AHCAL

- Analogue HCAL barrel is supported by coil cryostat inside central yoke ring
- First tries with standard FEM methods
- Standard problem: simplification of models to reduce degrees of freedom (CPU and memory)
  - exploit symmetries
  - simplify geometries
  - reduce 3d to 2d where possible

F. Sefkow

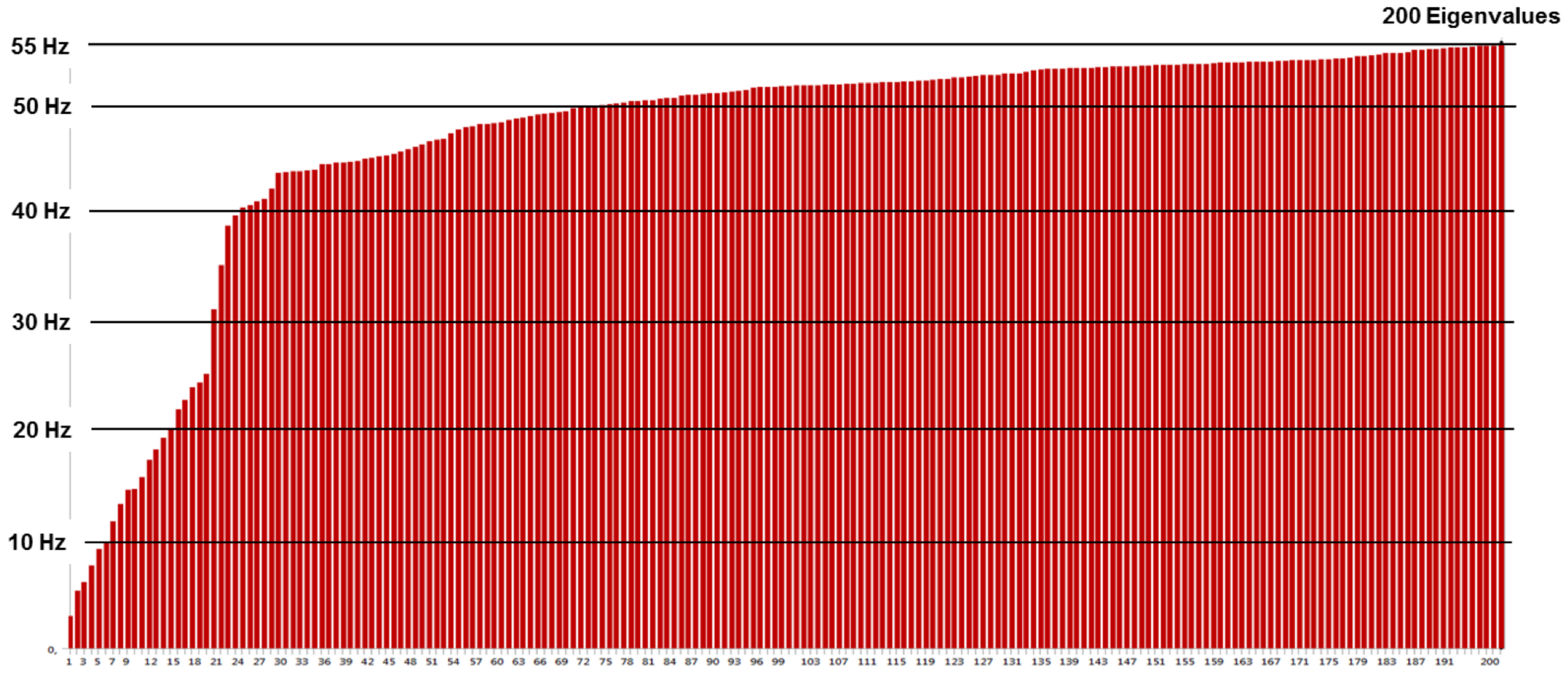


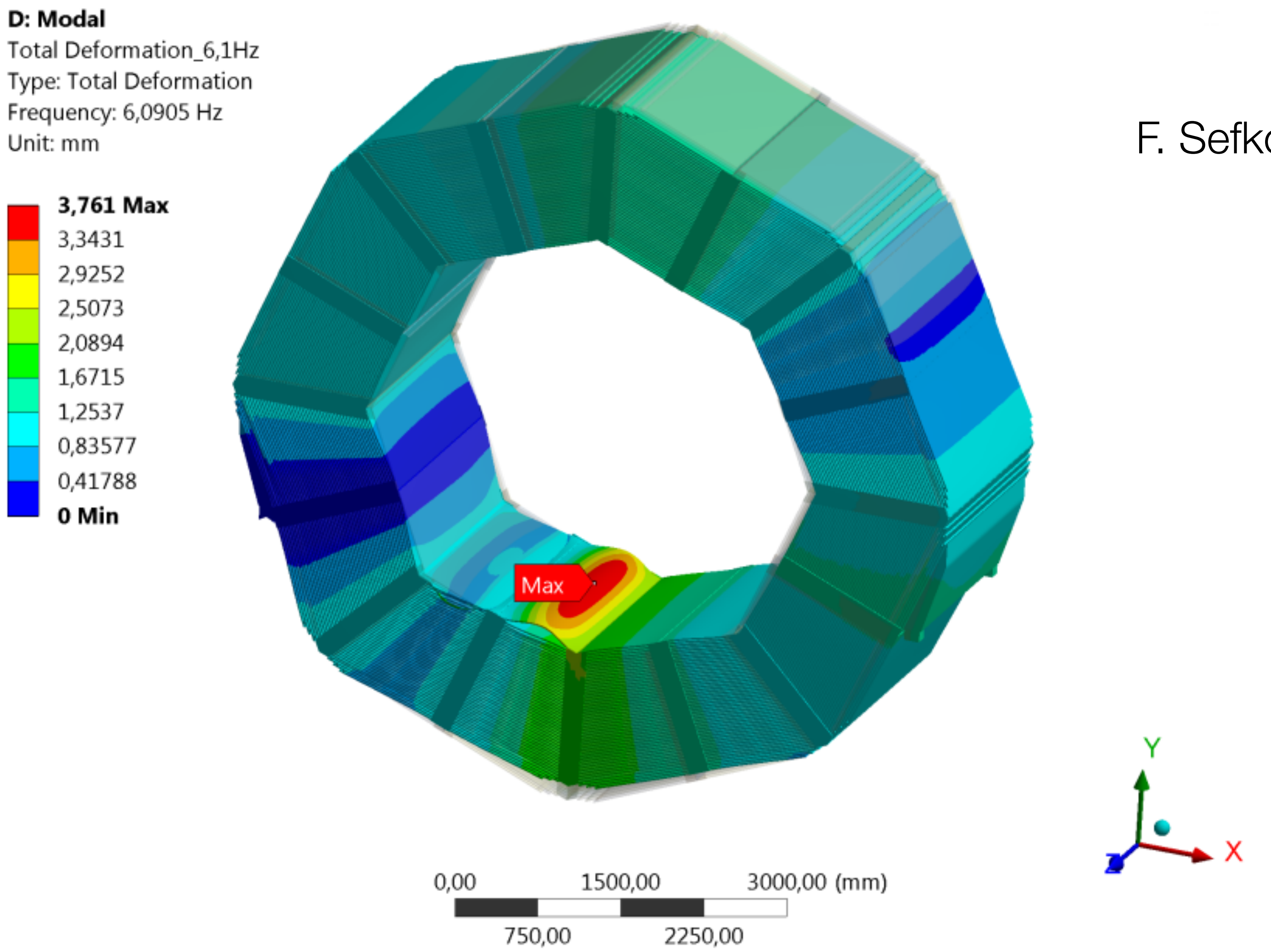


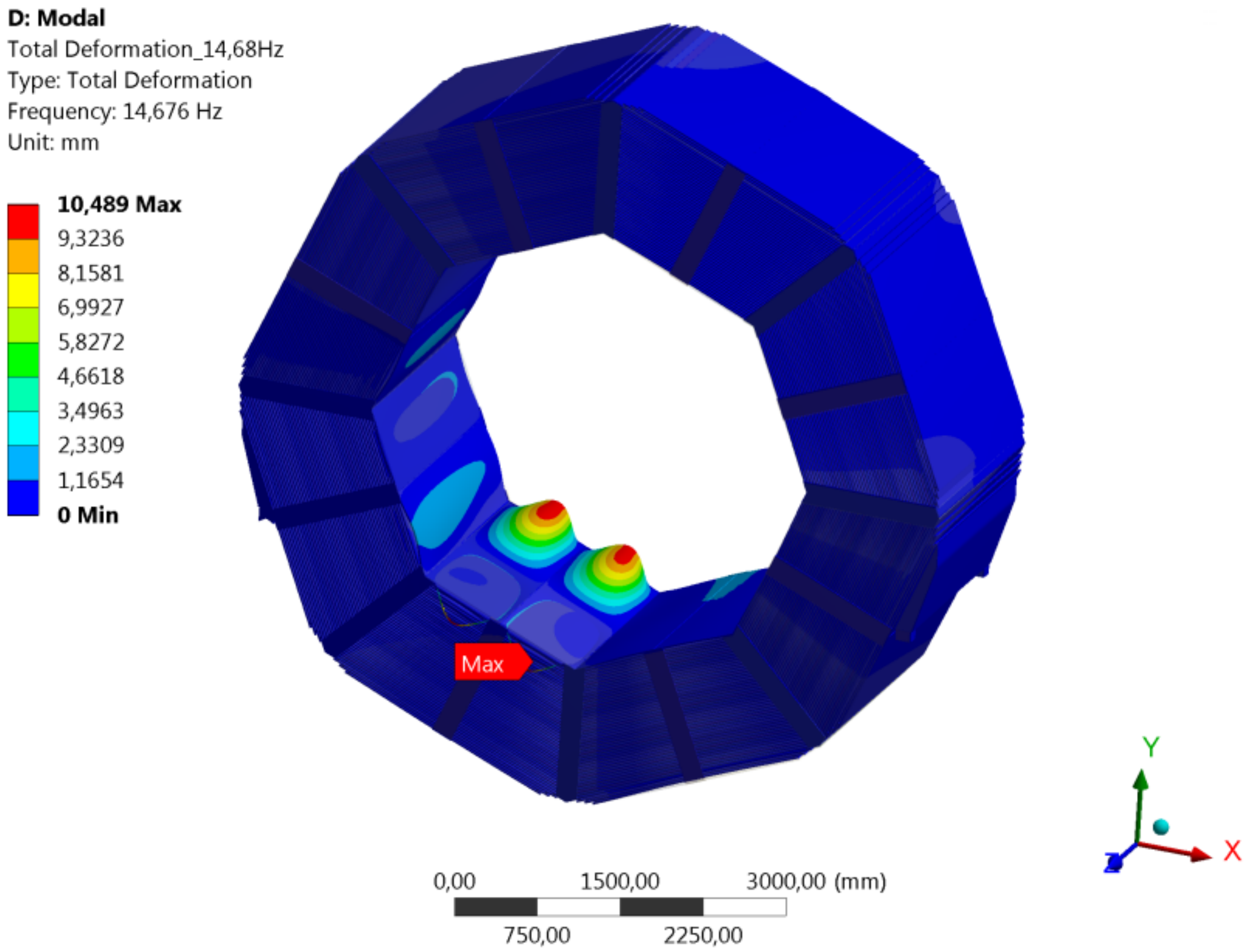
Dynamic AHCAL Simulations

F. Sefkow

- Modal Superposition Method
- AHCAL model built up with shell elements and ~800k nodes
- Problem: many eigenfrequencies due to geometric setup
- Run into solver problems (CPU, storage, …)



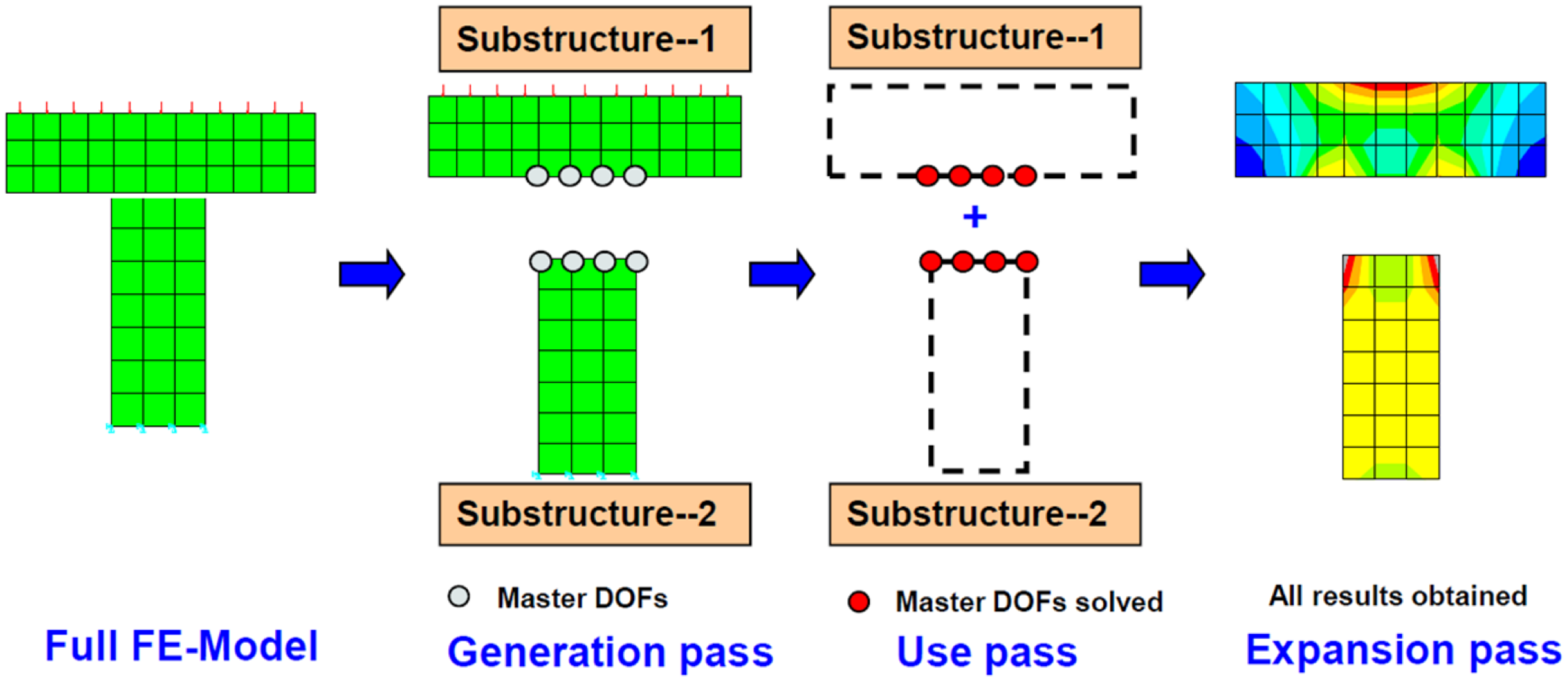




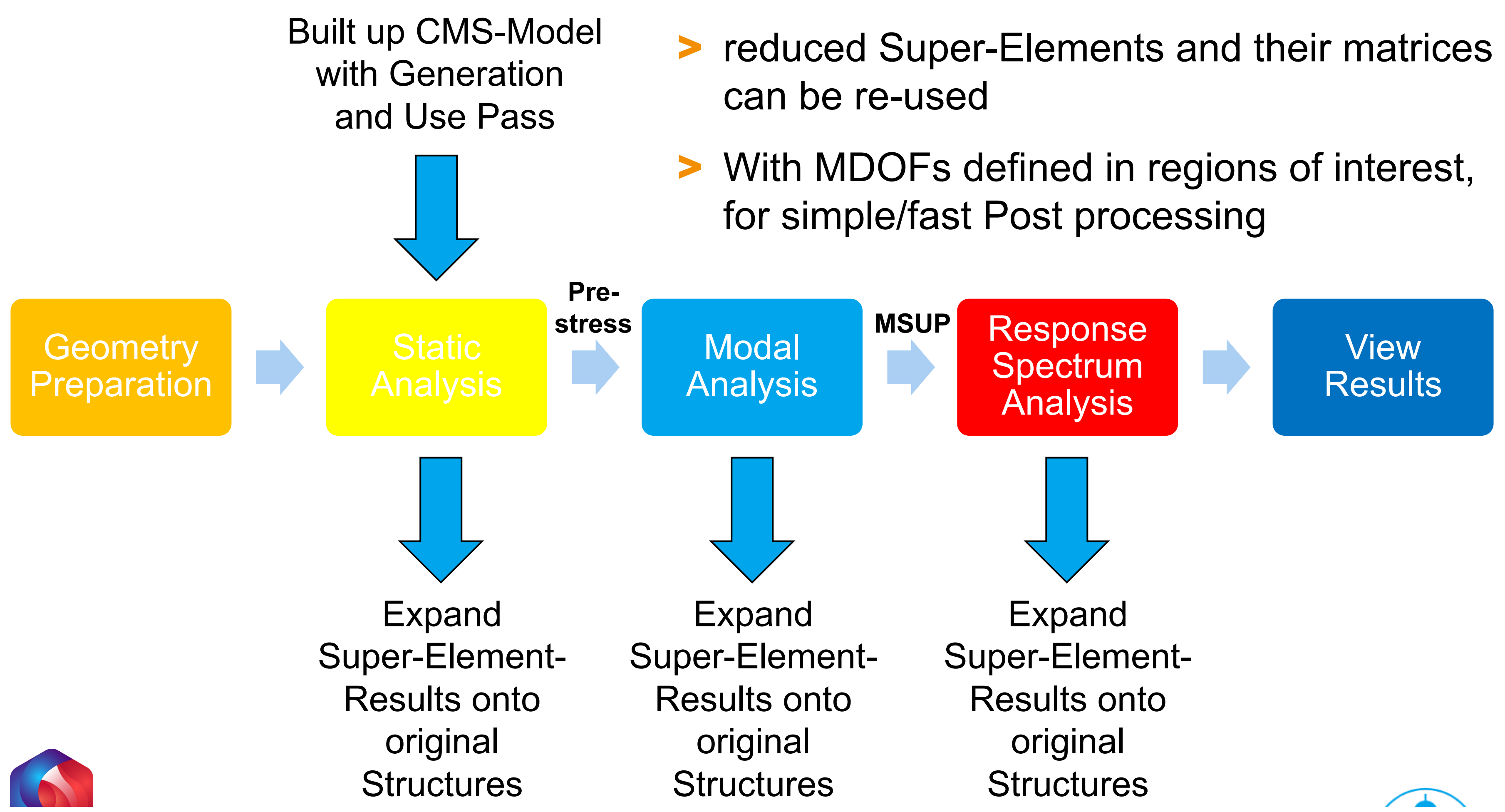
Alternative Approach - Component Mode Synthesis

- Complex models can be calculated, n-Elements describing the complex FE-model can be simplified with the CMS-method to one! single element
- The mechanical properties of the reduced structure is described in mass, stiffness and damping matrices

F. Sefkow



- Adapt the Substructuring Method to the AHCAL-FE-Model
  - Generation Pass must be done only once
  - reduced Super-Elements and their matrices can be re-used
  - With MDOFs defined in regions of interest, for simple/fast Post processing



The Power of CMS

F. Sefkow

- Fine meshed 3D-FE-Model requires a lot of computeral hardware ressources
  => no realistic chance to solve such
  a complex 3D-Model of the AHCAL
- Comparision of some solution data (CPU, GB, RAM, …)

Pos.	General Meshing	Type (3D/CMS)	Mesh-Nodes	Total-CPU-Time [in sec]	Used RAM [in MB]	Result-File size [in MB]	Max. Deformation [in m]
1	very coarse mesh	3D	13.328	566	250	3.670,00	4,847E-03
2	coarse mesh	3D	31.821	1.232	590	11.261,11	4,838E-03
3	standard mesh	3D	186.370	3.640	4.874	60.526,67	4,882E-03
4	fine mesh	3D	315.817	10.200	11.016	93.694,34	
5	very coarse mesh	CMS	11.730	1.703	162	125,69	4,739E-03
6	coarse mesh	CMS	31.766	22.620	232	181,50	4,807E-03
7	standard mesh	CMS	238.900	15.840	1.233	421,63	4,860E-03
8	fine mesh	CMS	369.796	24.540	1.758	595,00	4,647E-03

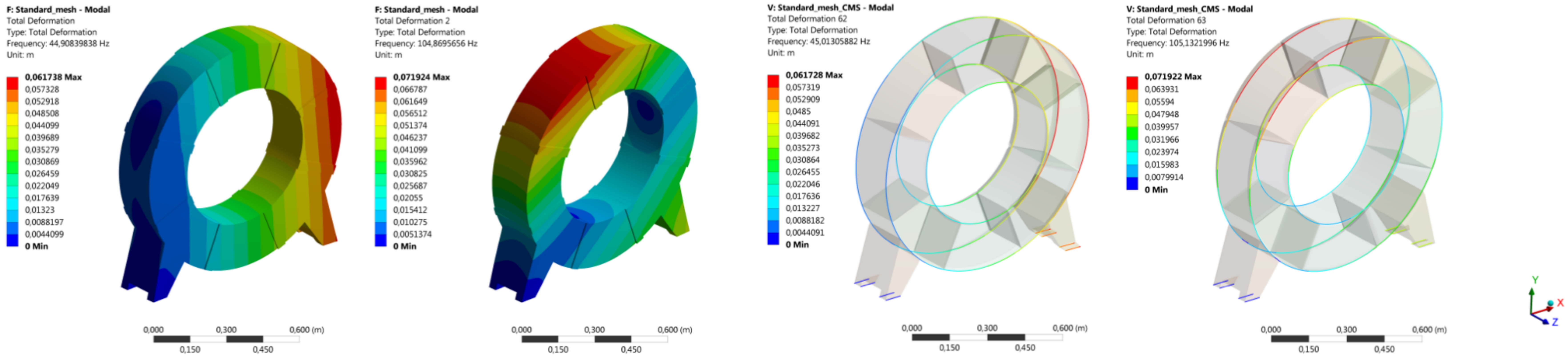
Application of CMS Method

E-JADE

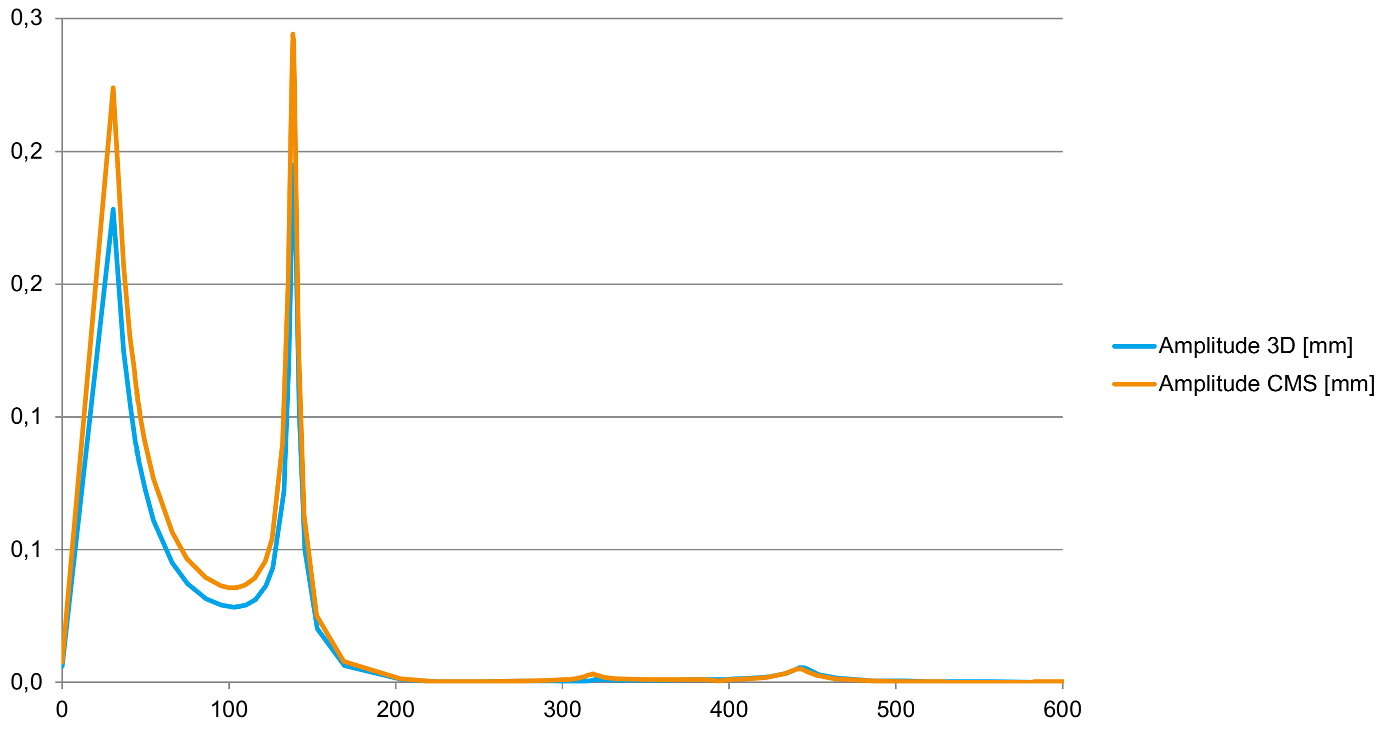
- Test on simplified AHCAL model
- Agreement is ok
- Work in progress!

> Left 3D (Mode1, Mode2), Right CMS (Mode1, Mode2)

F. Sefkow



> Deformation in x-Direction



Pos.	general Meshing	Type (3D/CMS)	Mesh-Nodes	Total-CPU-time [in sec]	Used RAM [in MB]	Result-File size [in MB]	Eigenmode 1 at f [in Hz]	Eigenmode 2 at f [in Hz]	Eigenmode 3 at f [in Hz]	Eigenmode 4 at f [in Hz]
1	very coarse mesh	3D	13.328	64	427	284,25	45,08	105,12	136,72	307,56
2	coarse mesh	3D	31.821	116	1.064	826,06	45,11	105,20	139,41	309,64
3	standard mesh	3D	186.370	74	8.144	3.939,51	44,91	104,87	138,56	308,07
4	fine mesh	3D	315.817	890	17.231	5.778,50	44,87	104,73	138,01	307,38
5	very coarse mesh	CMS	11.730	120	162	7,38	45,57	106,86	144,21	317,34
6	coarse mesh	CMS	31.766	166	270	10,38	45,25	105,89	141,38	312,64
7	standard mesh	CMS	238.900	1.885	1.308	23,63	45,01	105,13	139,10	309,03
8	fine mesh	CMS	369.796	1.215	1.772	33,00	46,06	106,15	139,47	308,53

AHCAL Simulations Outlook

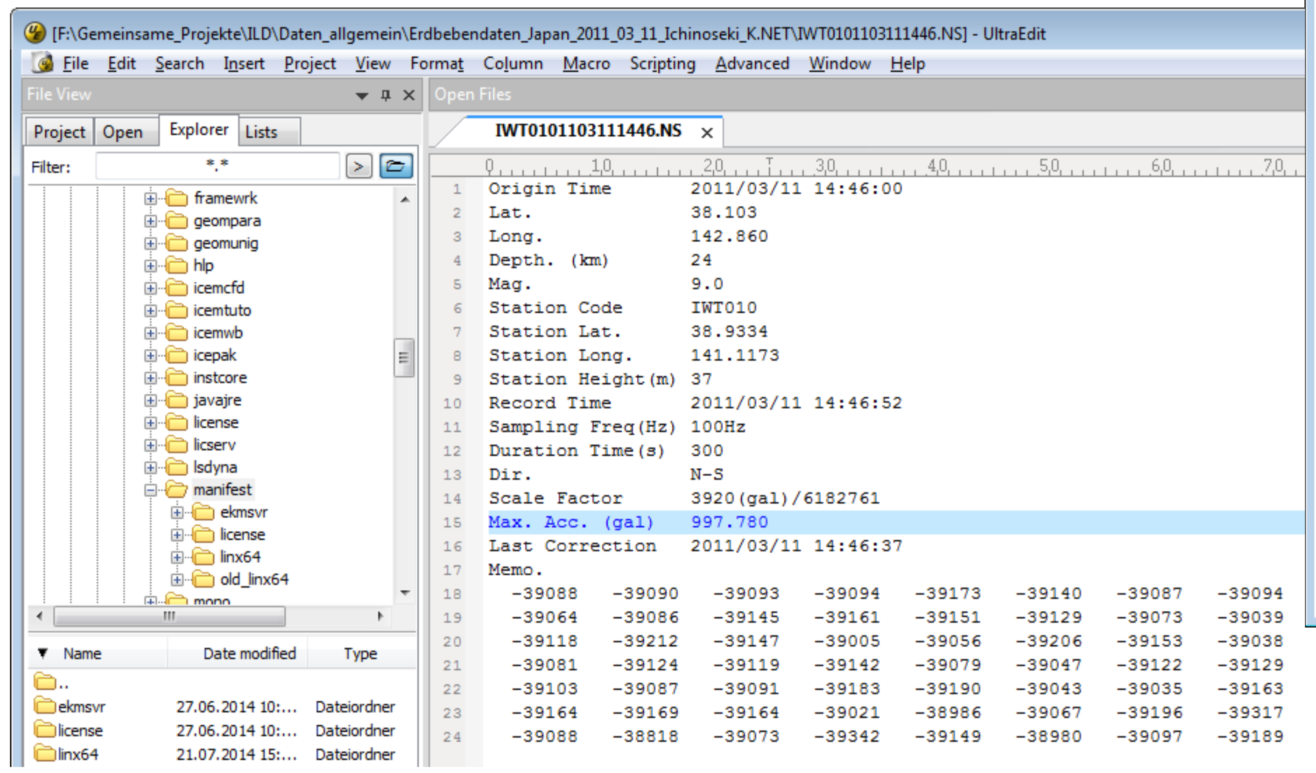
F. Sefkow

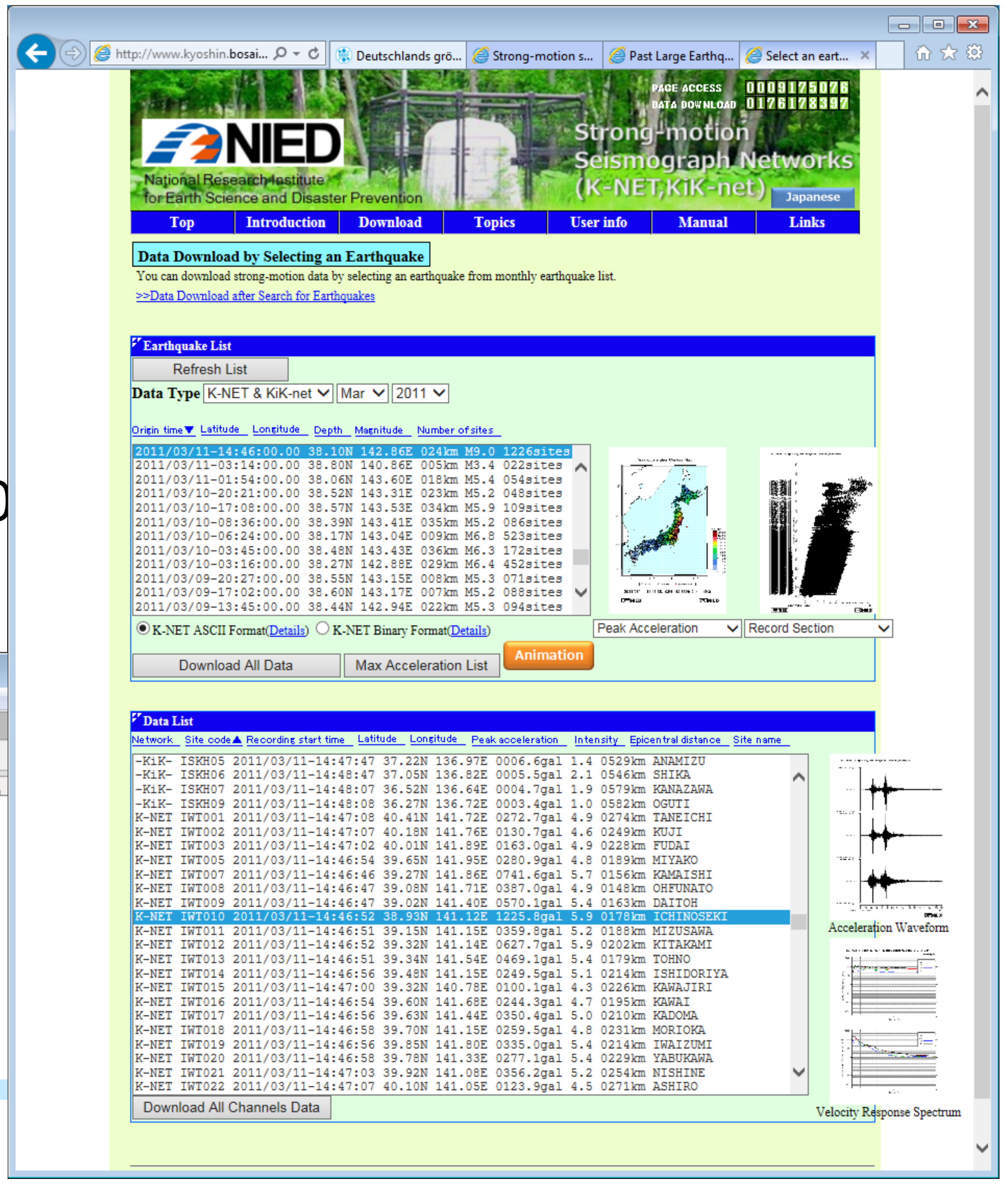
- Confirm CMS modelling is valid
- Use real earthquake data from Kitakami for dynamic simulations

> Earthquake-Data of Ichinoseki from NIED-Institute (National Research Institute for Earth Science and Disaster Resilience)

> Full Access to data after registration

> Complete data set (NIED K-NET IWT010 2011/03/11) downloaded

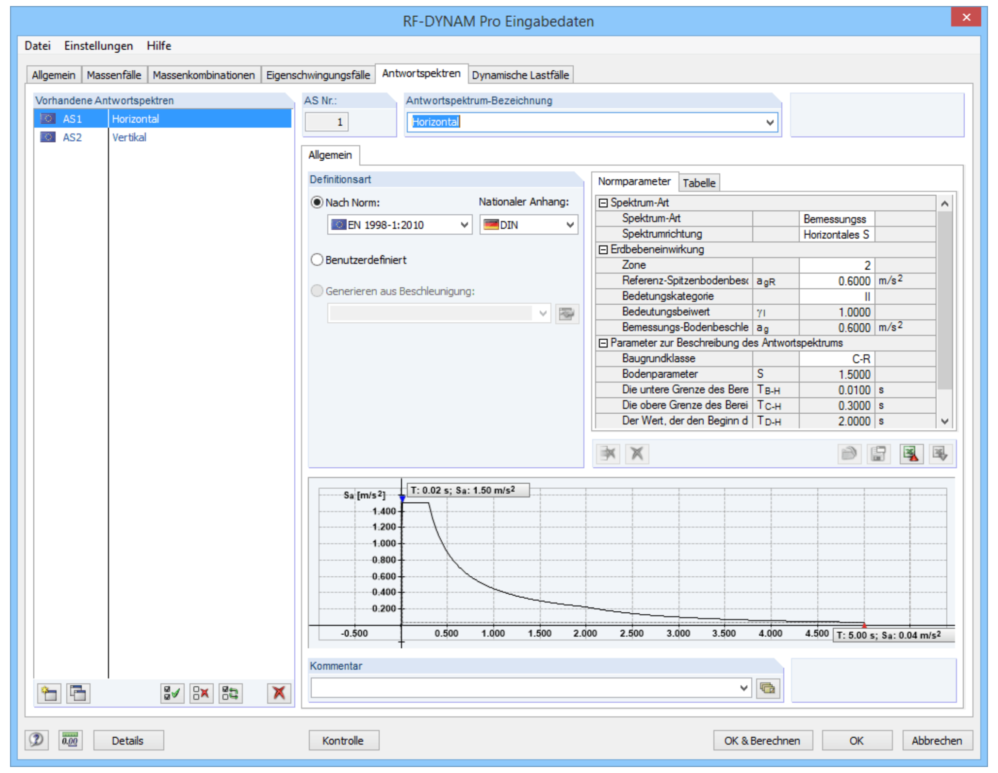


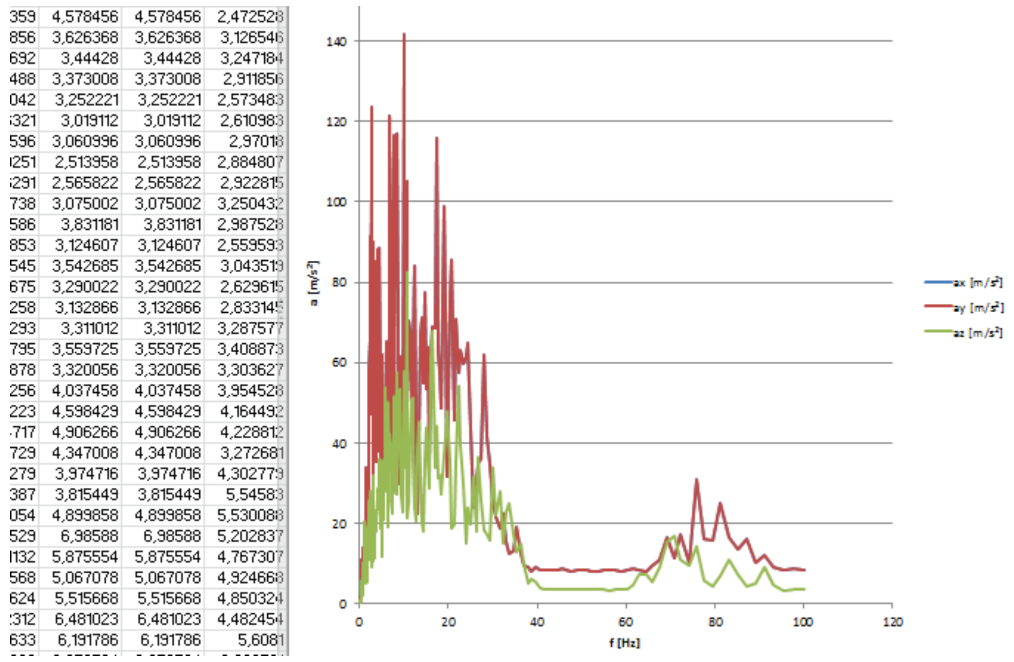


> The commercial structural frame analysis program RSTAB (link: https://www.dlubal.com) is suitable to import and convert the Japanese earthqake-data up to 100 Hz

> Possible output:

- Standardized curvatures to evidence the staiblity of buildings/large structures according to EUROCODE 8/ISO 3010
- Convert the real earthquake data (time-domain) to a spectrum-data-set (frequency-domain) as an input for a Response Spectrum Analysis in ANSYS





Seismic Isolation Strategies

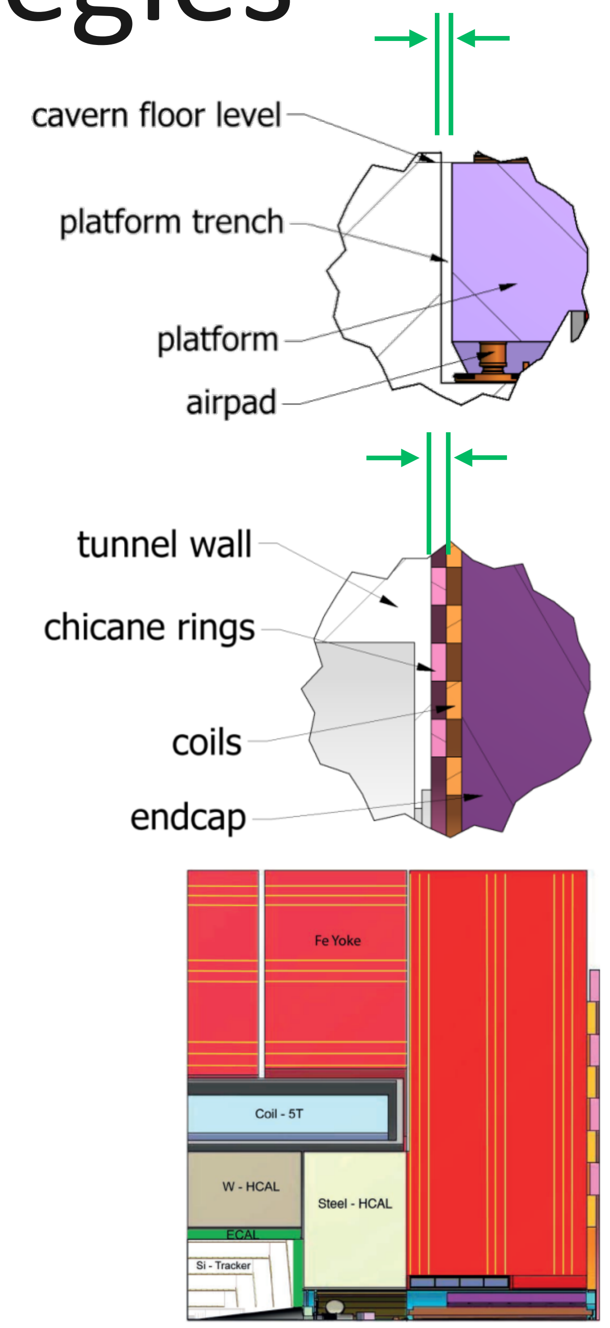
- Studied for CLIC detector in 2012 (F. D. Ramos):

F.D. Ramos

Seismic isolation strategies

- Rigid detector support;
  - Isolation under platform;
    - Using airpads;
    - Using friction pendulum isolators;
  - Isolation above platform;

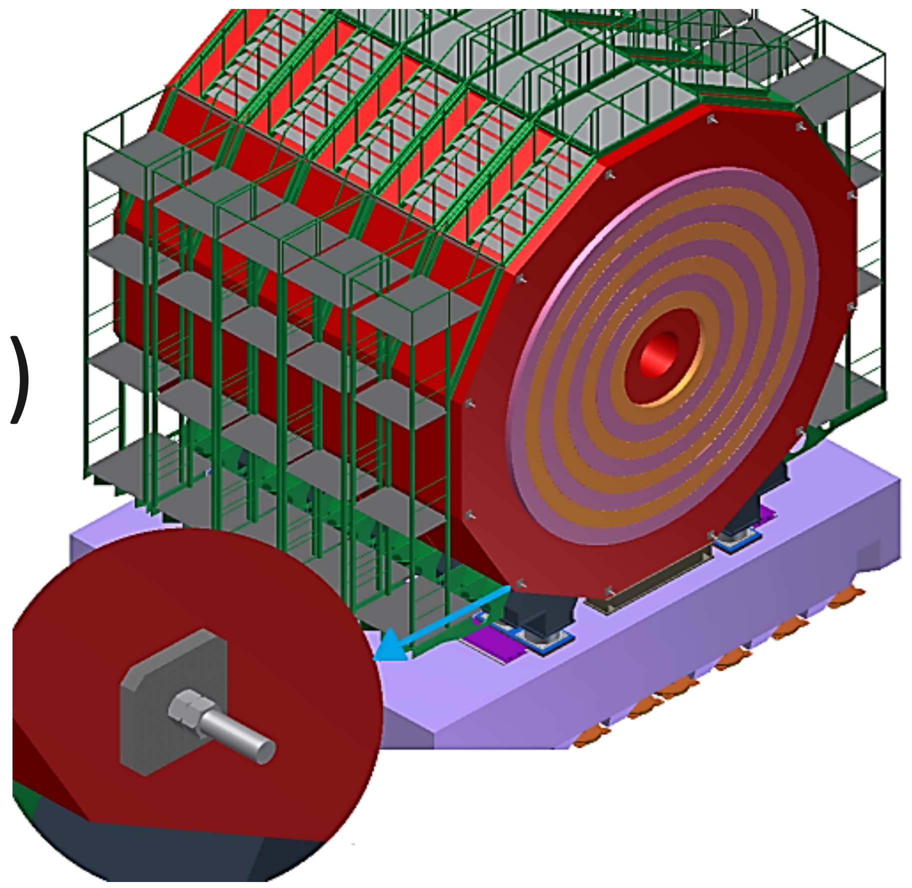
Pros	• Most straightforward to implement; • No impacts with trenches or cavern walls;
Cons	• Design detector to withstand loads;
Feasibility	✓



Earthquake protection for Linear Collider detectors – LCWS12, Arlington, USA | 8

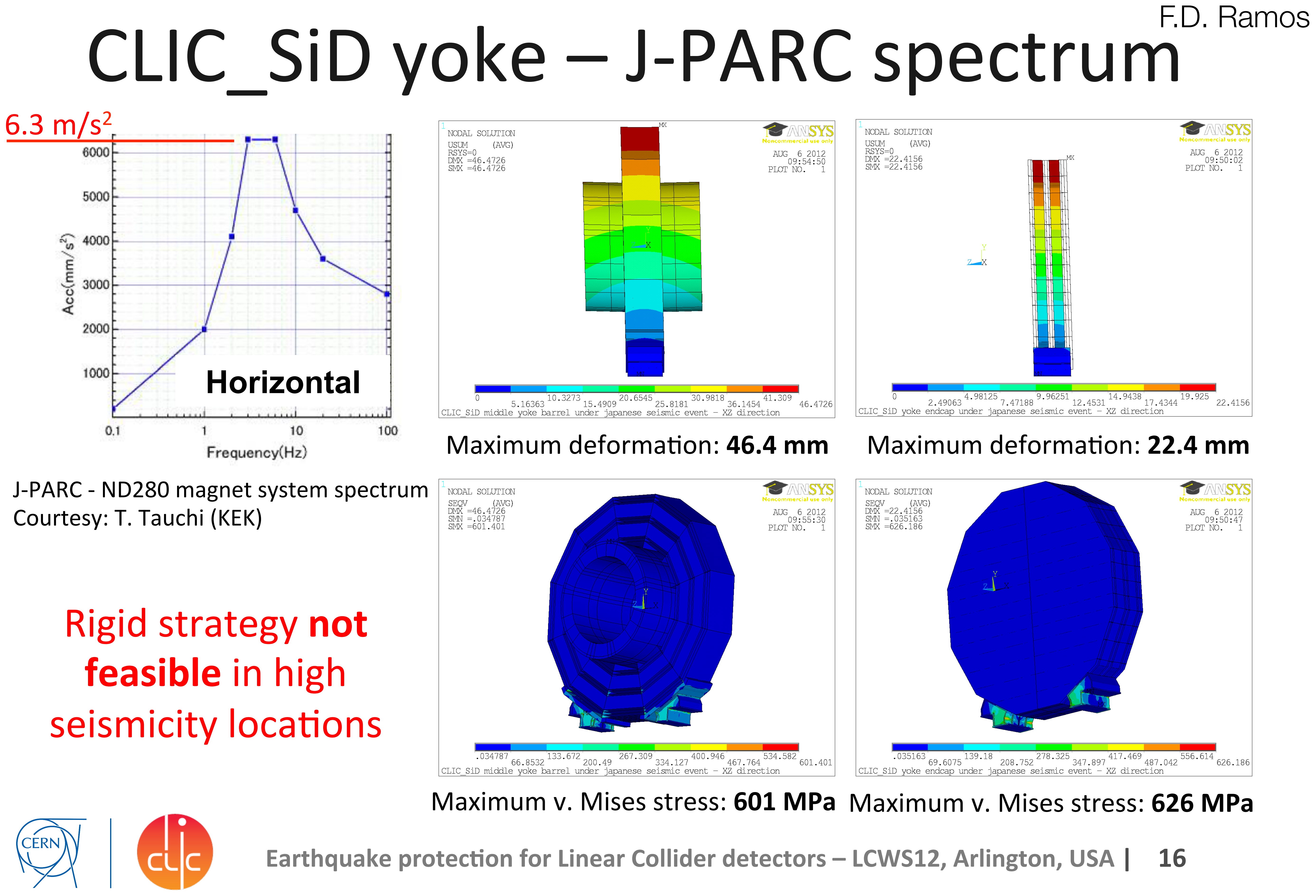
Rigid detector support

- Detector must withstand moderate seismic events;
- Tie-rods and magnetic forces maintain detector closed when in data-taking position;
- Integrity of all detector components must be maintained in garage (opened) and data-taking (closed) position;



Rigid Detector Support

- Simulations with spectra taken at J-PARC result it too large deformations and stresses
- Rigid support strategy would work elsewhere, but not in Japan



Above Platform Isolation

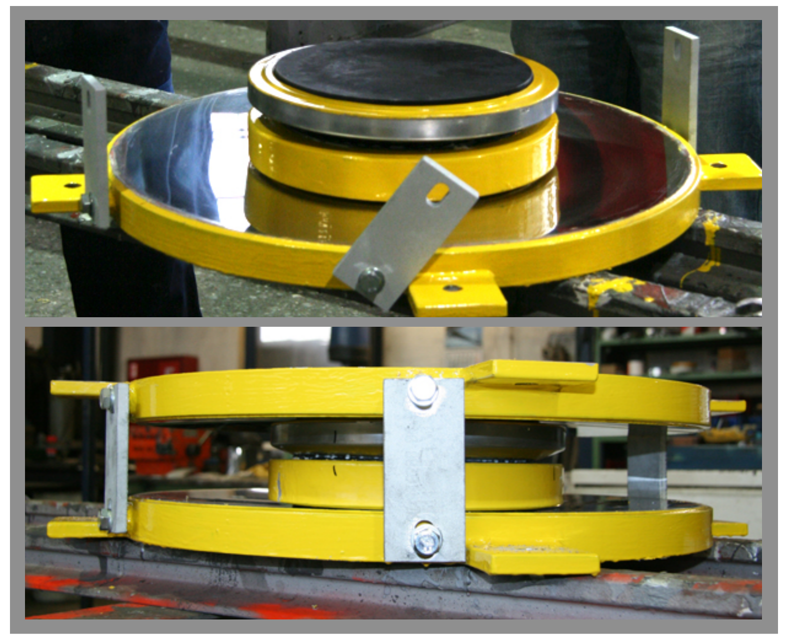
- Friction pendulum isolators might be a good idea

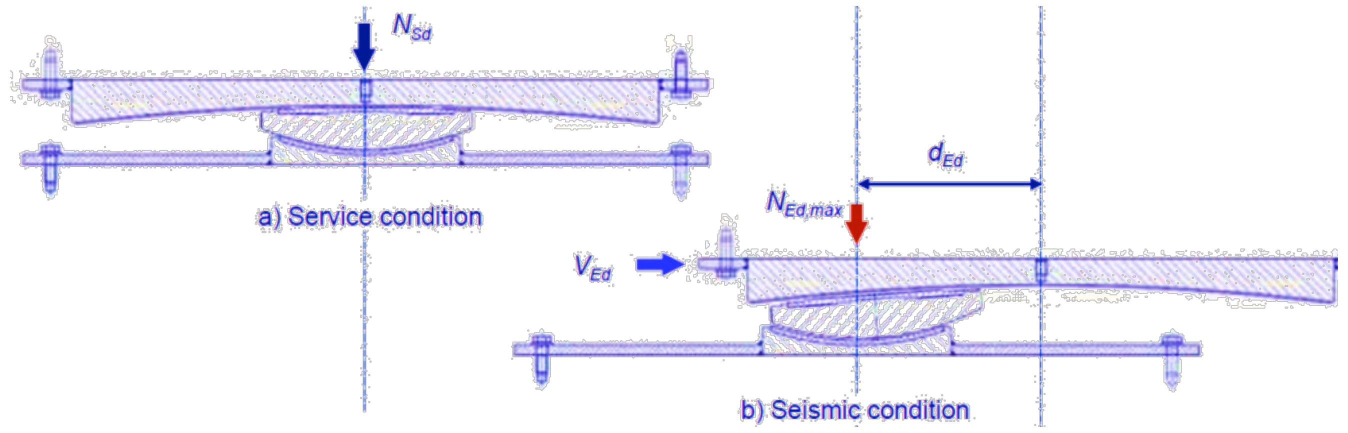
F.D. Ramos

Above platform isolation

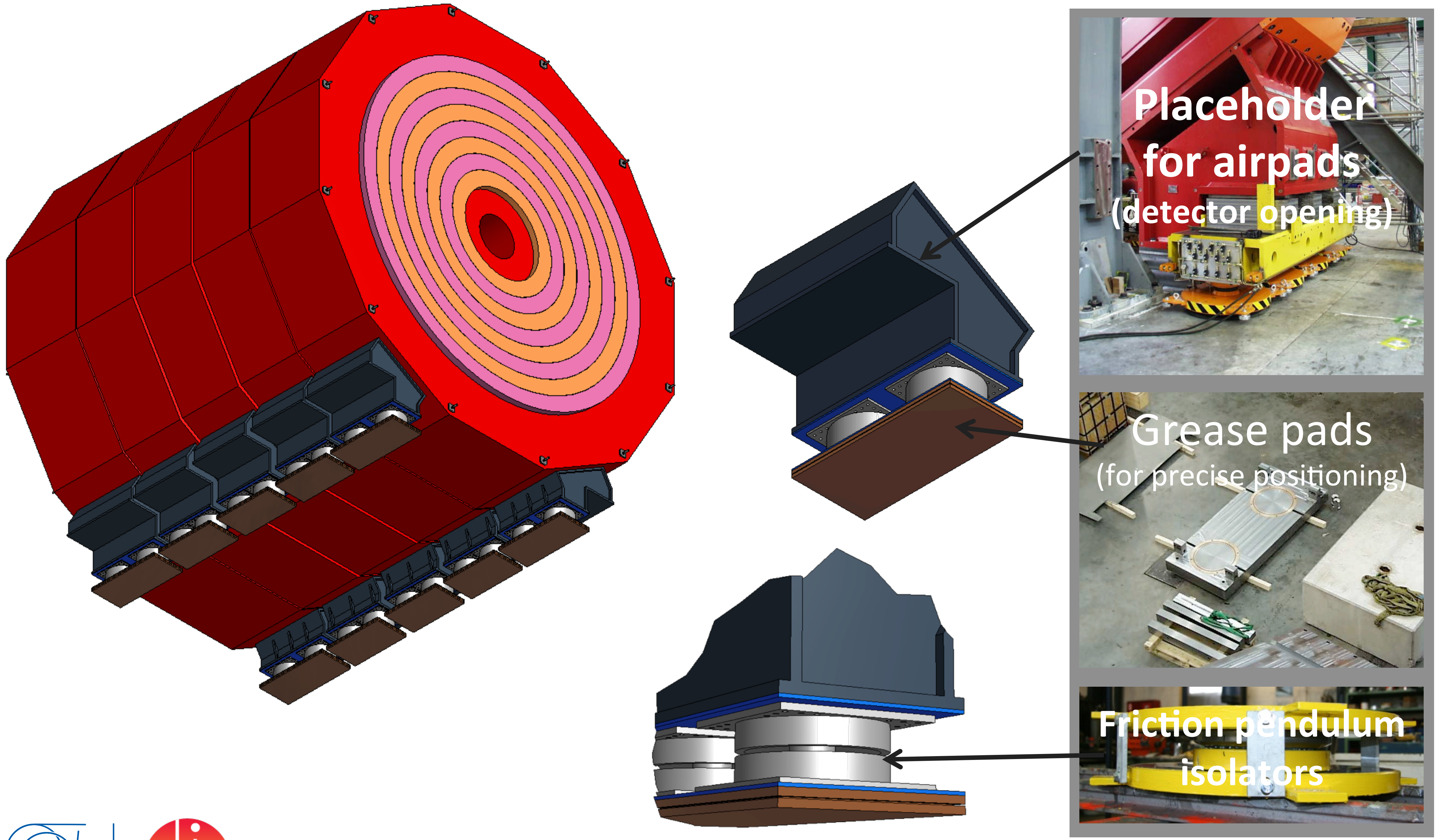
- Friction pendulum isolators beneath the detector feet;
- Reliable technology;
- No high compliance elements (e.g. rubber) improves the positioning of the detector;

Pendulum isolators





Above platform isolation



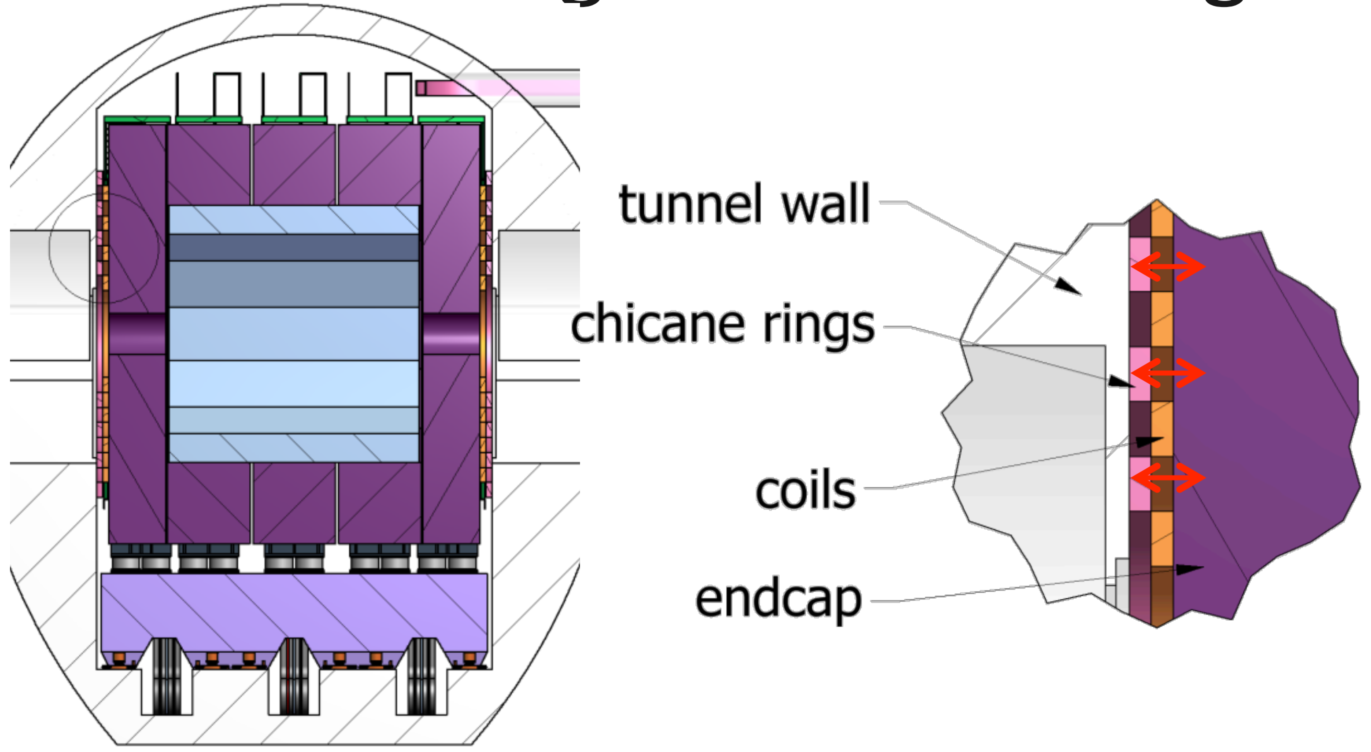
Constraints

- Energy has to go somewhere…

F.D. Ramos

IP area constraints

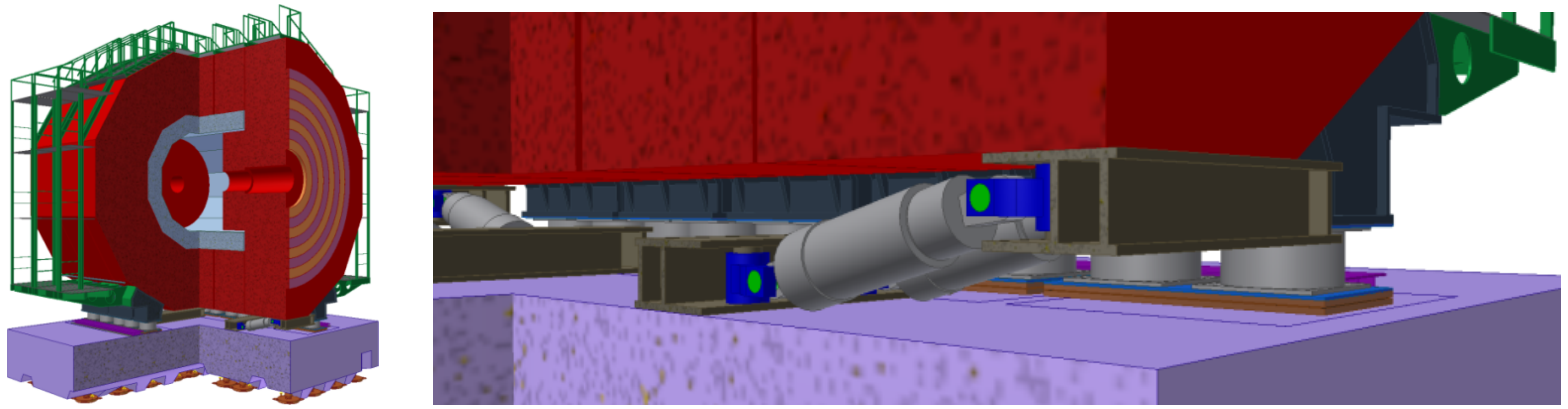
- Movement of detector restricted by cavern walls;
- Viscous dampers can be used to limit oscillation amplitudes along the beam direction;
- Chicane rings will allow longitudinal movement;



Earthquake protection for Linear Collider detectors – LCWS12, Arlington, USA | 19

Energy dissipation

- 8 dampers connect the closed detector to the platform;
- Mechanical “fuse” provides rigidity under normal operating conditions;
- Removal upon opening of detector;



Earthquake protection for Linear Collider detectors – LCWS12, Arlington, USA | 20

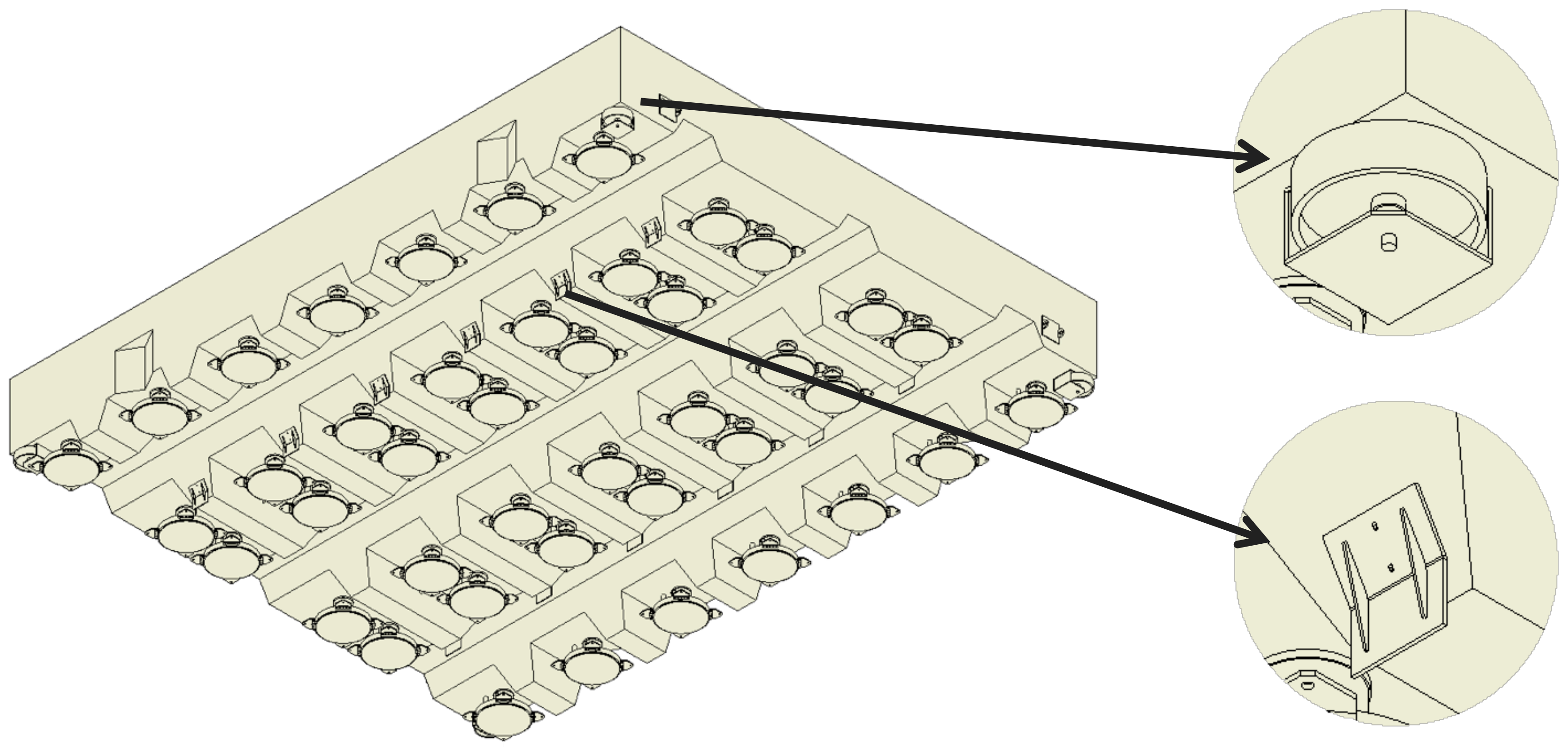
Profit from Airpads?

- Platform would be operated on airpads
- When airpads are inflated, they provide good isolation
- But: is there an earthquake warning system that gives a warning early enough to inflate the airpads?
- And what if the detector is not on the platform?
  - during assembly and construction
  - in the garage

F.D. Ramos

Earthquake during Push-Pull

- Isolation provided by inflated airpads;
- Guidance elements prevent colisions of the platform with the trenches;



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Summary

E-JADE

- Seismic situation in Japan is an issue for the detectors
- Though Kitakami is a quite region, there will be earthquakes from time to time
- Structural design has to follow regulations, e.g. ISO 3010
  - no catastrophic failures, never
  - ok to have some damage, sometimes
- Detector groups have started programme of dynamic mechanical simulations
  - The devil is in the details…
  - Common input spectra for Kitakami conditions exist
- Need to think about seismic isolation strategies
  - e.g. friction pendulum systems
  - but: need to understand consequences on geometries
    - space around platform, etc.