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CONTRIBUTION TO THE IAEA SOIL-STRUCTURE INTERACTION KARISMA BENCHMARK

Presented by
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CLUB CAST3M 2013
28/11/2013

OUTLINE

2007 NCOE (Niigataken-Chuetsu-Oki, Japon) EARTHQUAKE

Kashiwazaki-Kariwa Nuclear Power Plant, located just 16 km from the epicenter

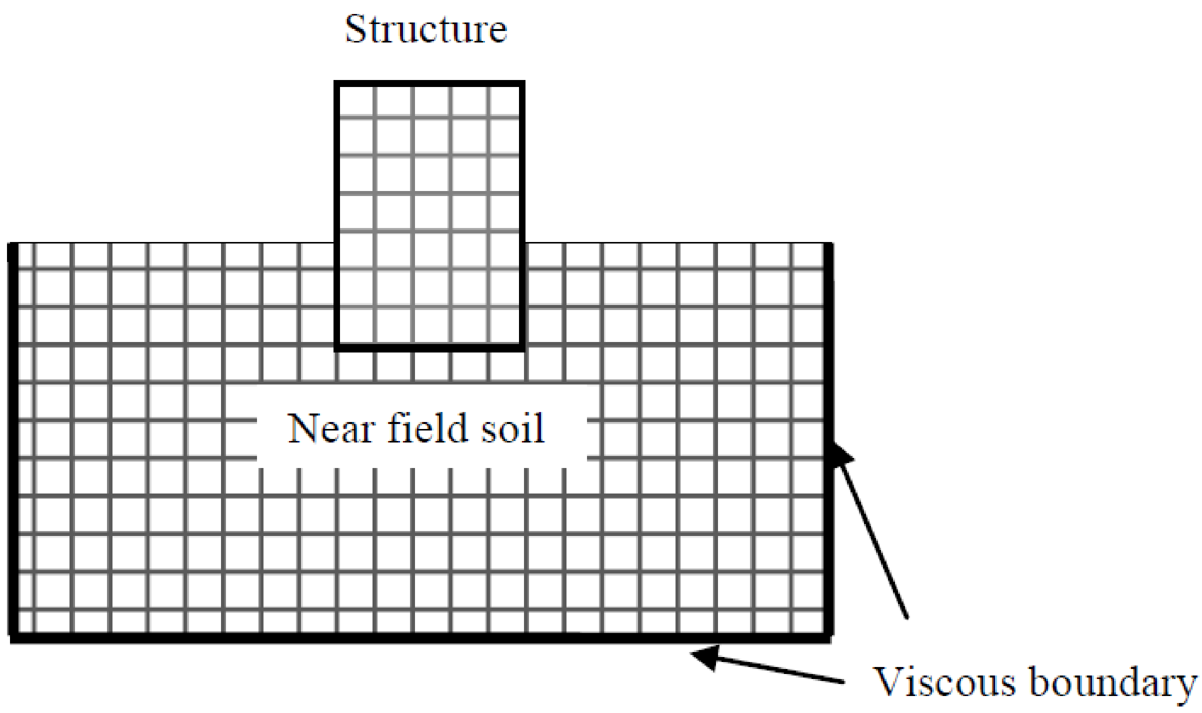
KARISMA BENCHMARK

- Benchmark organization:
  - Following the July 2007 NCOE earthquake (magnitude 6.6, distance16 km) which affected severely the Kashiwazaki-Kariwa Power Plant,
  - Organized by IAEA in the framework of the ExtraBudgetary Project, with the help TEPCO, the owner of the NPP, which provided the necessary data
  - About twenty teams from different countries participated to the Benchmark

- Objectives:
  - To analyze the seismic response of the soil and the structure of the Unit 7 reactor building,
  - To compare current SSI simulation methodologies used by different countries,
  - To evaluate the seismic margin of the structure and equipments.

- 3 Phases (2009 – 2012):
  - Phase I: Modeling, static and modal analyses, soil column analyses,
  - Phase II: Response of the structure and equipments during the earthquake,
  - Phase III: Assessment of the seismic margin by multiplying the seismic level.

SSI ANALYSIS USING FINITE ELEMENT METHOD : CODE CAST3M

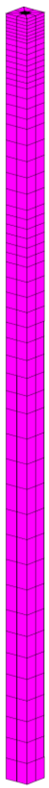


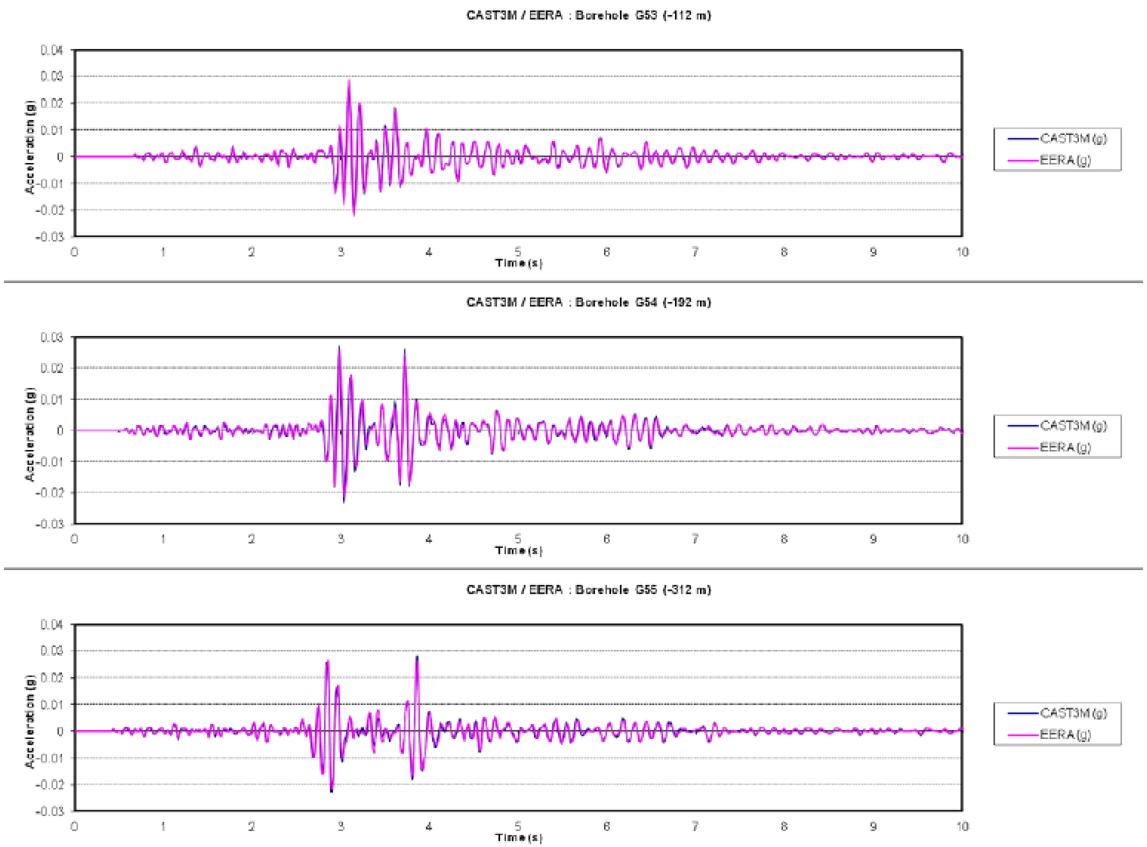
IMPLEMENTATION OF A SSI PROCEDURE IN CAST3M

- Seismic loading:
  - In the form of nodal forces on the boundaries of the near-field soil model
  - Calculated from the acceleration signal on the free surface of the ground by deconvolution on a soil column :
    - Horizontally stratified soil,
    - Vertical propagation of the P and S waves.

- Time domain integration of the coupled soil-structure system:
  - Linear analysis if the structure remains elastic, soil non linearity can be treated by the usual equivalent linear method,
  - Nonlinear analysis if the structure exhibits nonlinear behaviors such as concrete cracking, steel yielding or foundation uplift.

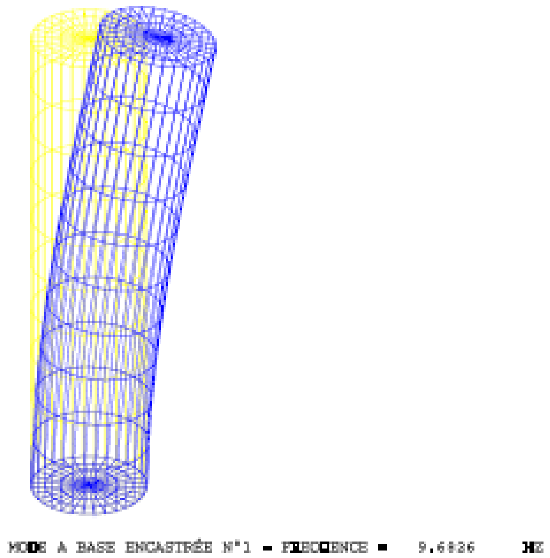
SSI PROCEDURE VALIDATION : DECONVOLUTION



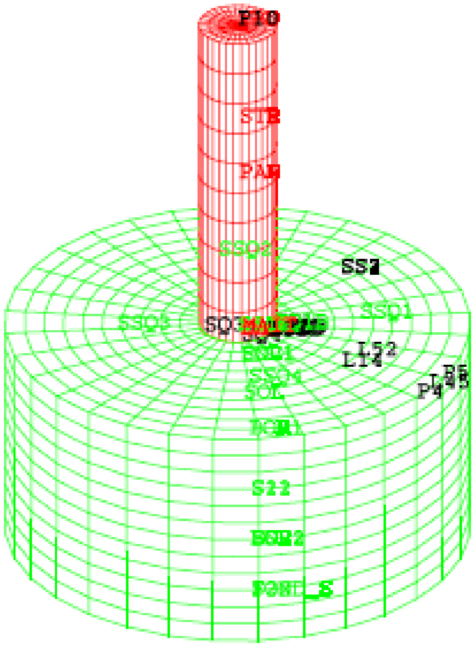


CAST3M / EERA : NCOE Aftershock

SSI PROCEDURE VALIDATION : RESPONSE OF A SIMPLE STRUCTURE

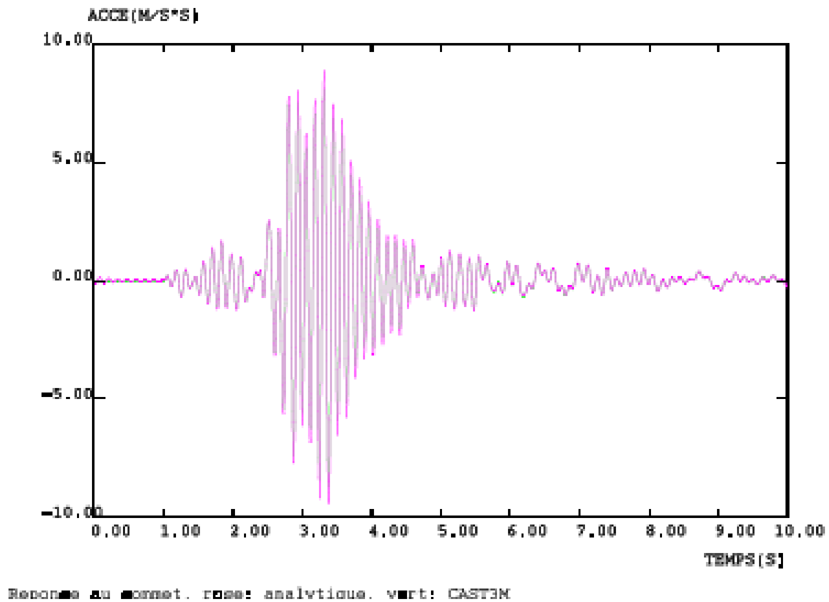


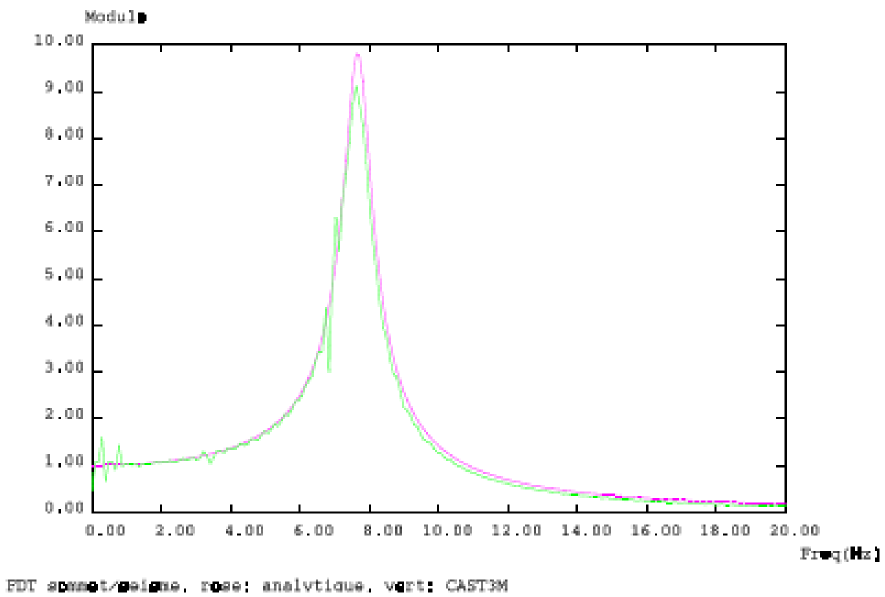
Cylindrical structure



Coupled soil-structure system

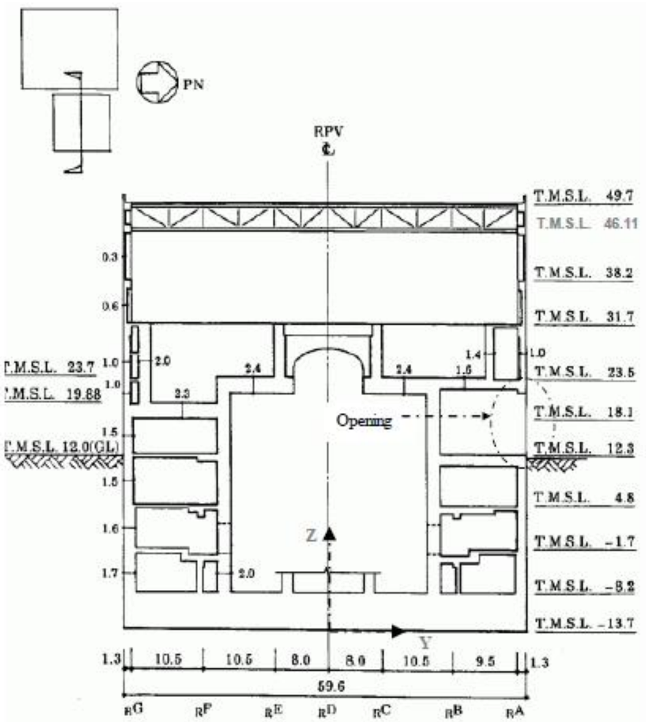
SSI PROCEDURE VALIDATION : RESPONSE / ANALYTICAL SOLUTION
(Top of the structure)



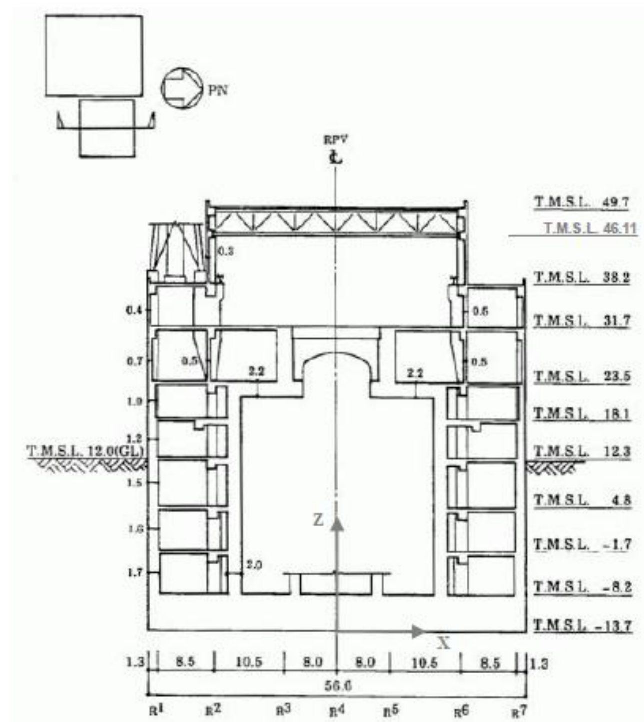


Time-history response

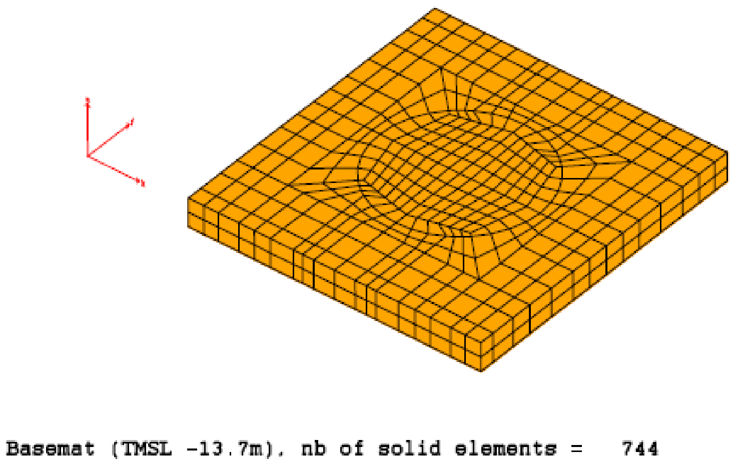
Transfer function: Top / surface motion



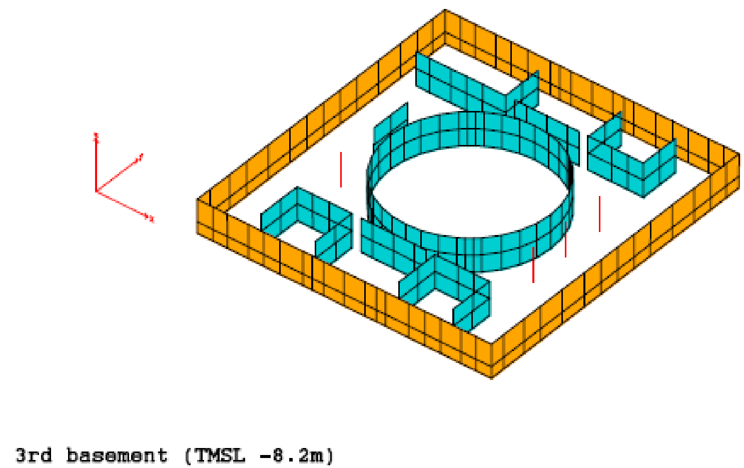
(a) YZ section



(b) XZ section

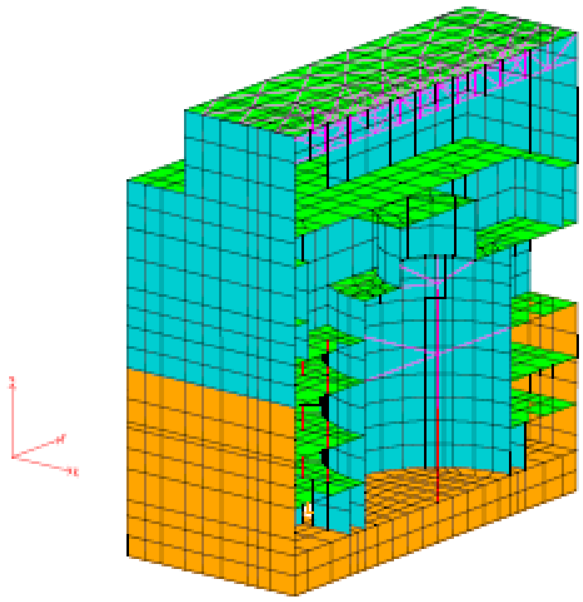

Basemat (TMSL -13.7m), nb of solid elements = 744

(a)

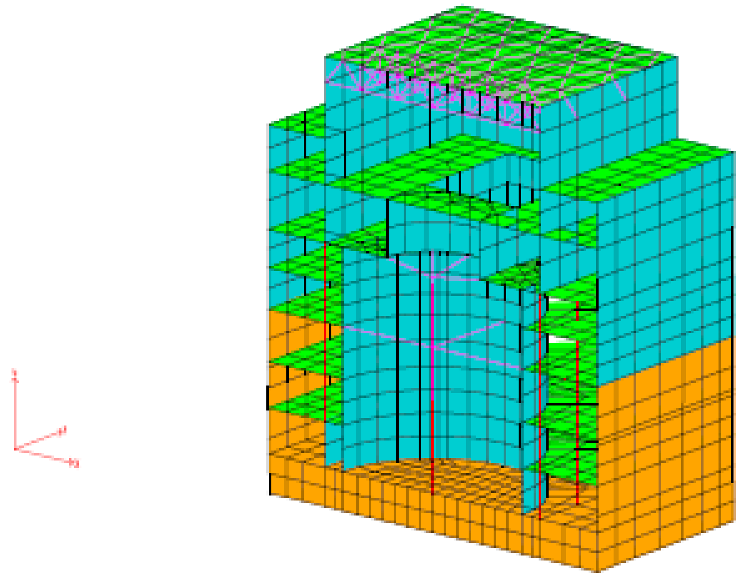

3rd basement (TMSL -8.2m)

(b)

BENCHMARK PHASE I : STRUCTURE MODEL



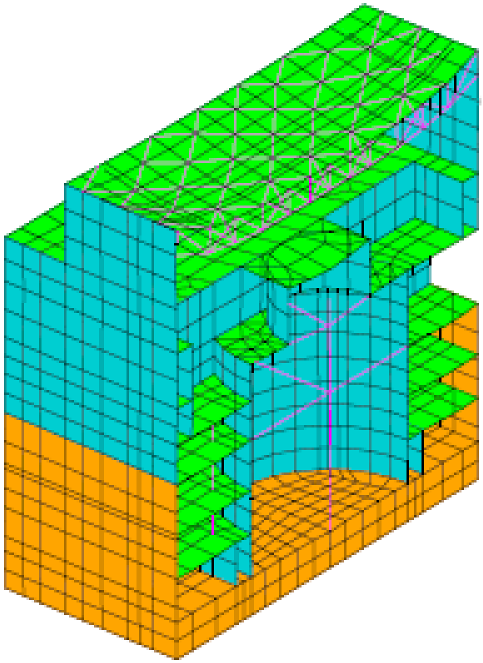
CROSS SECTION YZ, RB7



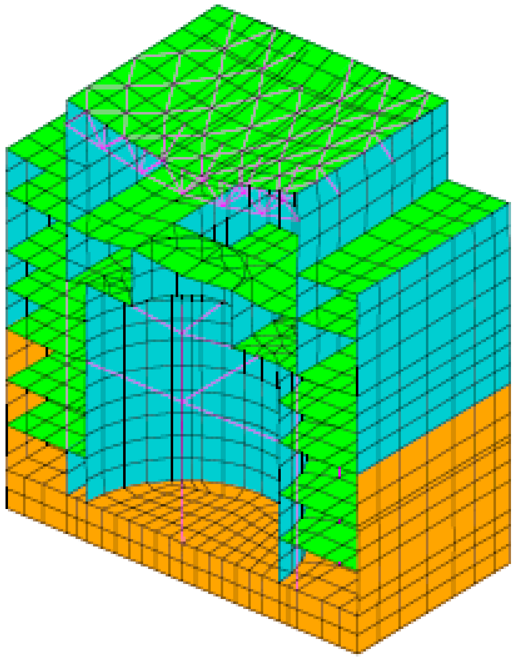
CROSS SECTION XZ, RB7

Element mesh: Unit 7 Reactor Building

BENCHMARK PHASE I : STATIC ANALYSIS



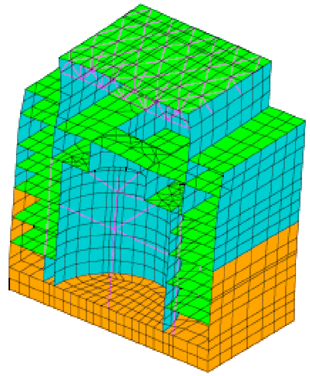
Vertical load (-1g)



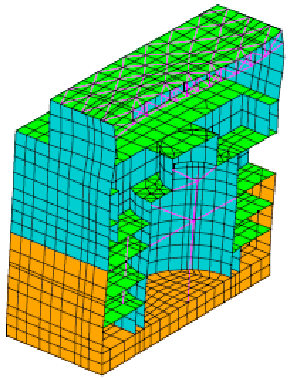
Vertical load (-1g)

Structure deformation under gravity load

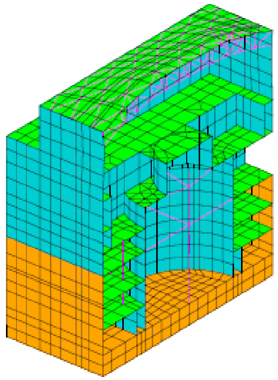
BENCHMARK PHASE I : MODAL ANALYSIS



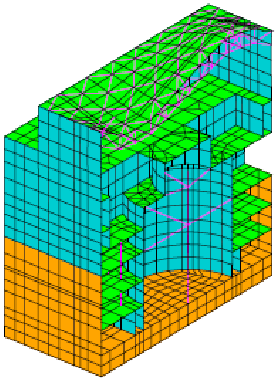
FIXED BASE MODE NO. 1 . FREQUENCY = 4.0374 HZ



FIXED BASE MODE NO. 2 . FREQUENCY = 4.4264 H



FIXED BASE MODE NO. 3 . FREQUENCY = 4.8903

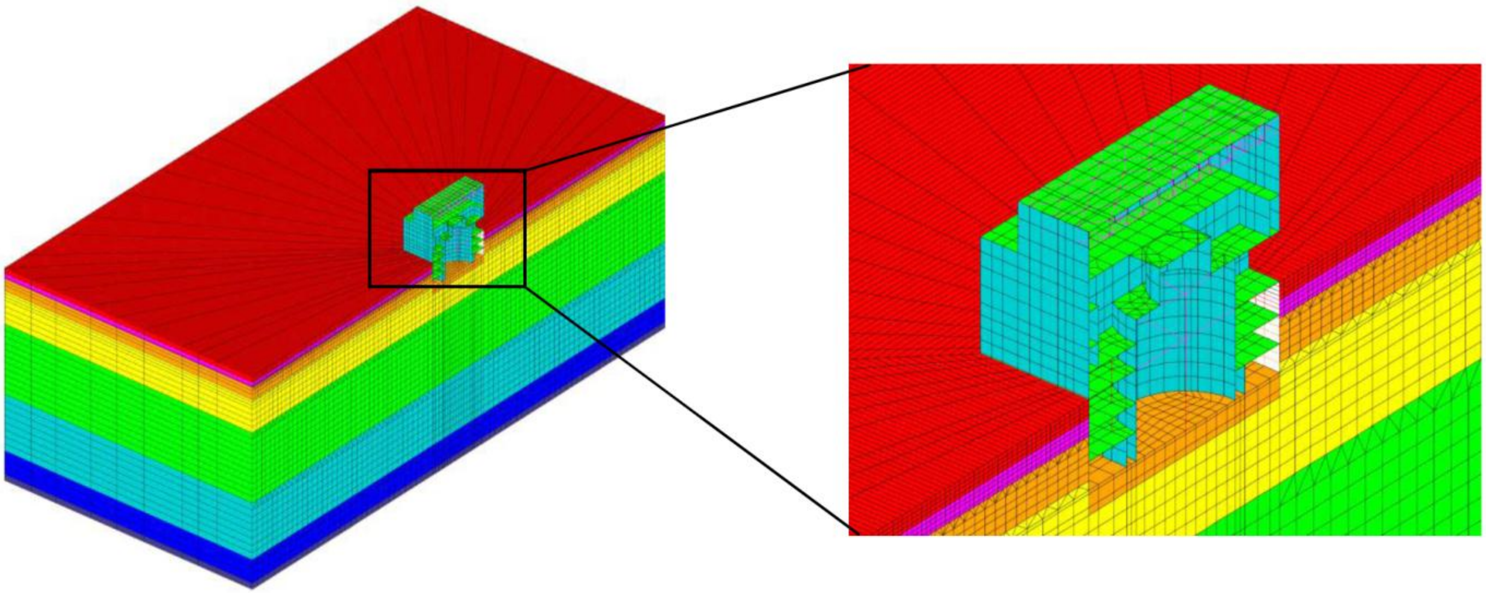


FIXED BASE MODE NO. 4 . FREQUENCY = 5.8141

BENCHMARK PHASE I : MODAL ANALYSIS
(379 modes from 0 to 35 Hz)

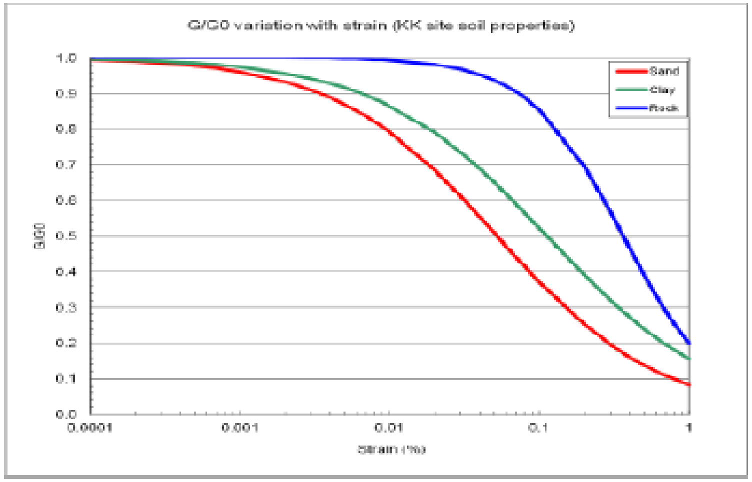
Mode	Frequency (Hz)	Damping Ratio %	Modal participating mass ratios (%)			Modal participating mass ratios (%)		
			UX	UY	UZ	SumUX	SumUY	SumUZ
1	4.0374		70.405	0.00195665	1.24872E-05	70.405	0.00195665	1.24872E-05
2	4.4264		0.0034241	76.739	0.00920882	70.408	76.741	0.00922131
3	4.8903		0.0120503	0.00107754	0.95869	70.42	76.742	0.96791
4	5.8141		0.000721424	0.19234	0.0019503	70.421	76.934	0.96986
5	7.0856		0.4419	0.00323144	0.00144376	70.863	76.938	0.9713
6	7.4334		4.0124	0.0281005	0.50029	74.875	76.966	1.4716
7	7.4887		0.61506	0.0124235	0.0376366	75.49	76.978	1.5092
8	8.3131		0.44845	0.86342	15.192	75.939	77.841	16.701
9	8.5342		0.0467572	1.7375	9.0679	75.986	79.579	25.769
10	8.6407		2.7448	0.14746	0.55064	78.73	79.726	26.32
11	8.997		0.0860444	0.0392096	10.158	78.816	79.766	36.477
12	9.0271		0.56077	0.000229751	1.9744	79.377	79.766	38.452
13	9.1868		0.14756	0.0121986	0.19233	79.525	79.778	38.644
14	9.2058		0.23376	0.00132489	0.00242589	79.759	79.779	38.646
15	9.3837		0.60297	0.00129236	0.1344	80.362	79.781	38.781
16	9.561		0.00175563	0.00427782	3.6937	80.363	79.785	42.474
17	9.7158		0.0253597	0.43163	0.0220287	80.389	80.217	42.496
18	10.157		0.19707	0.00959971	0.000724709	80.586	80.226	42.497
19	10.302		0.00493117	0.40067	0.00227947	80.591	80.627	42.499
20	10.579		0.12819	0.16397	0.00087736	80.719	80.791	42.5
21	10.646		0.7151	0.0446879	0.0569805	81.434	80.836	42.557
22	10.884		0.0577857	0.00494913	0.29409	81.492	80.84	42.851
23	10.912		0.14691	0.000217922	0.00879153	81.639	80.841	42.86
24	11.033		0.16151	0.00601277	0.0164842	81.8	80.847	42.877
25	11.151		0.91135	0.0060289	0.17848	82.711	80.853	43.055
26	11.496		0.046392	0.0921019	0.81439	82.758	80.945	43.87

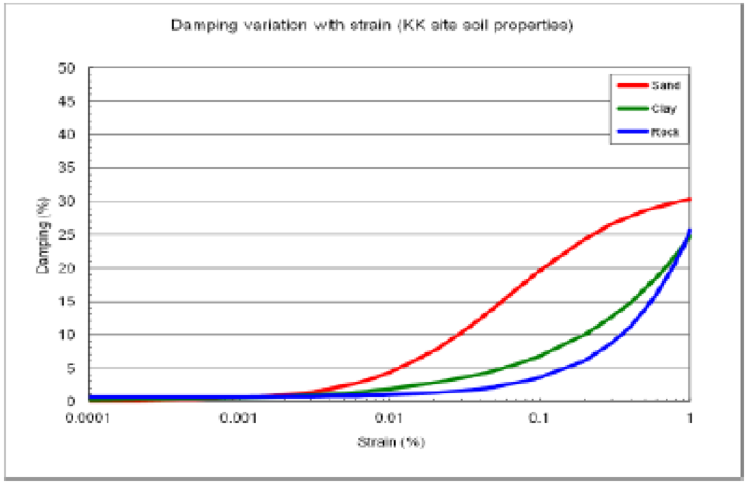
BENCHMARK PHASE II: SOIL-STRUCTURE MODEL
(about 150,000 elements)



Optimized element mesh (360m x 360m x 172m)
(half of the model plotted here)

Equivalent linear soil model

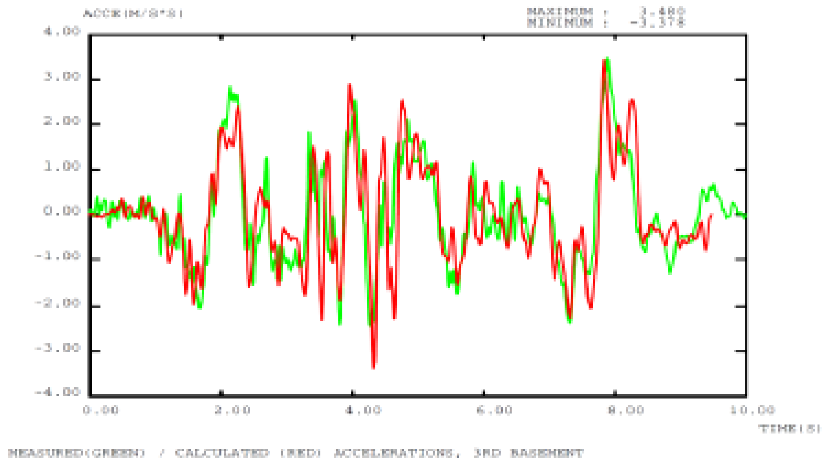


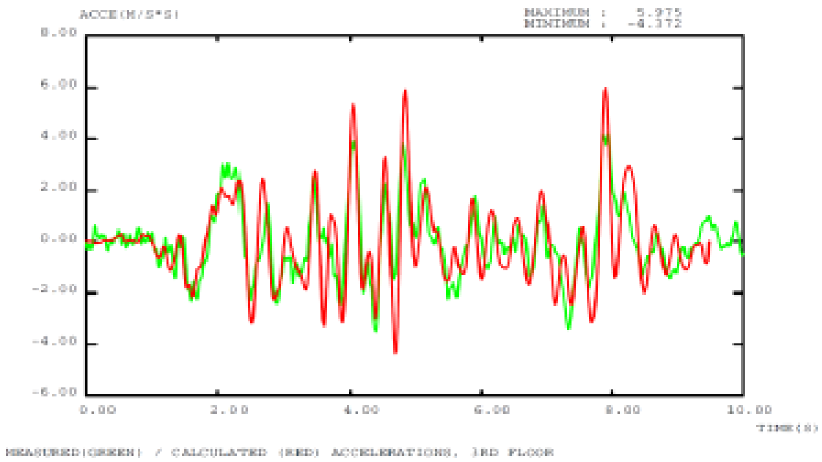


Strain dependent shear modulus and damping ratio.

BENCHMARK PHASE II : STRUCTURE RESPONSE TO THE NCOE

(Y Direction)



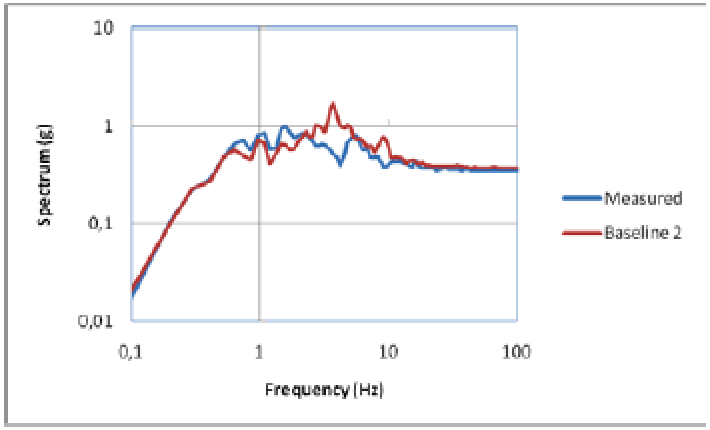


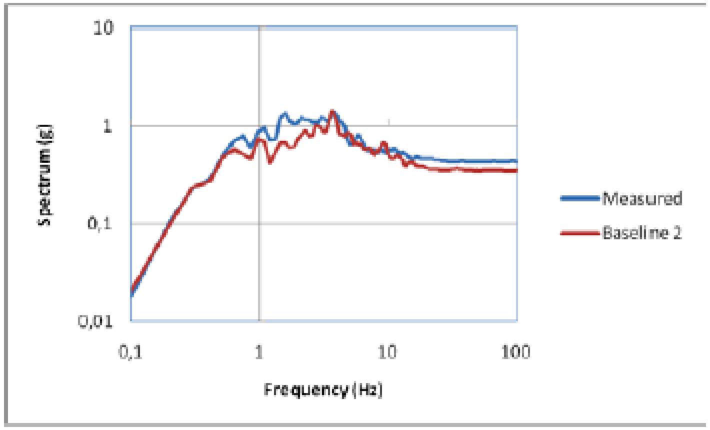
Basemat surface **3rd floor**

Time-history response

(recording= green, calculation= red)

BENCHMARK PHASE II : STRUCTURE RESPONSE TO THE NCOE (Y Direction)

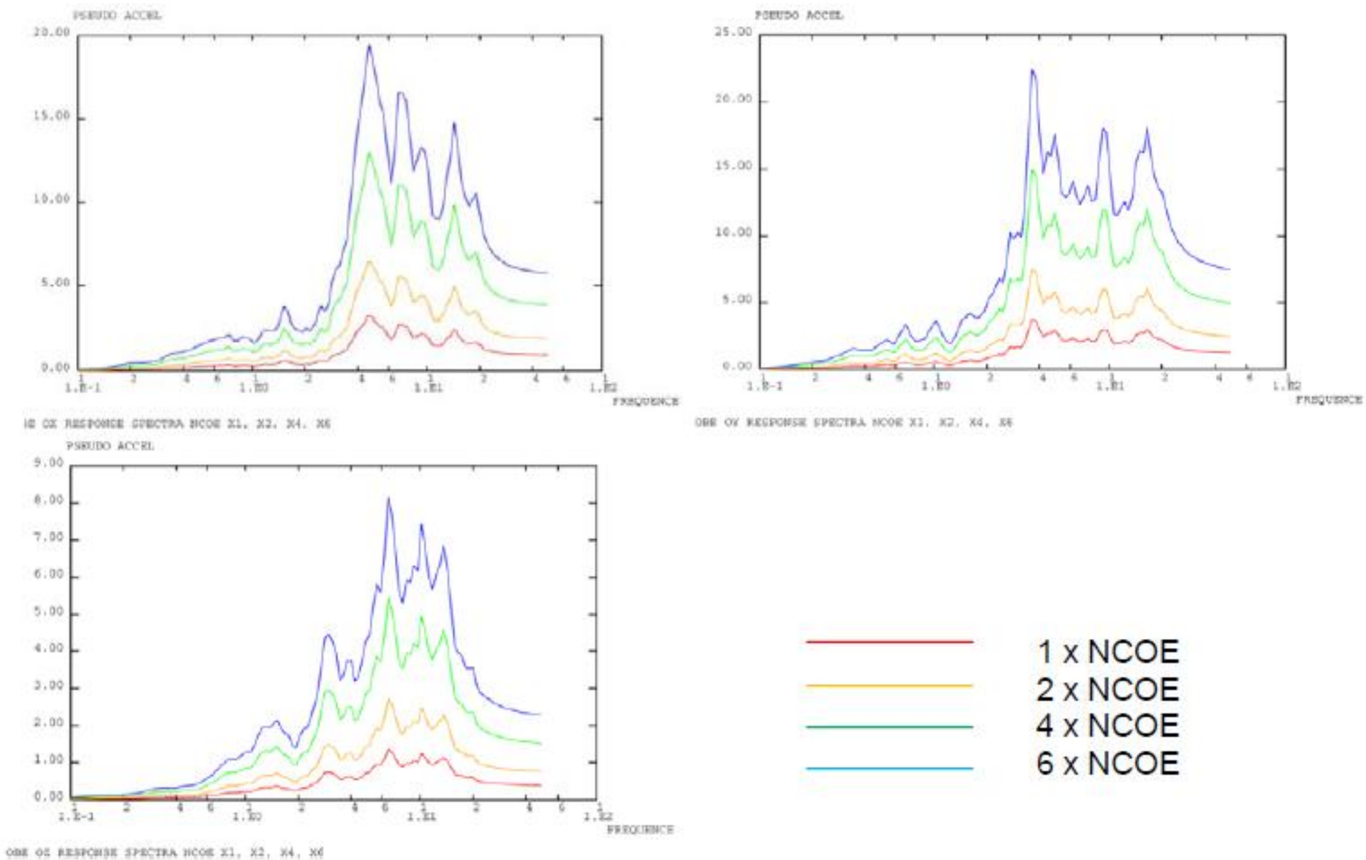




Basemat surface **3rd floor**

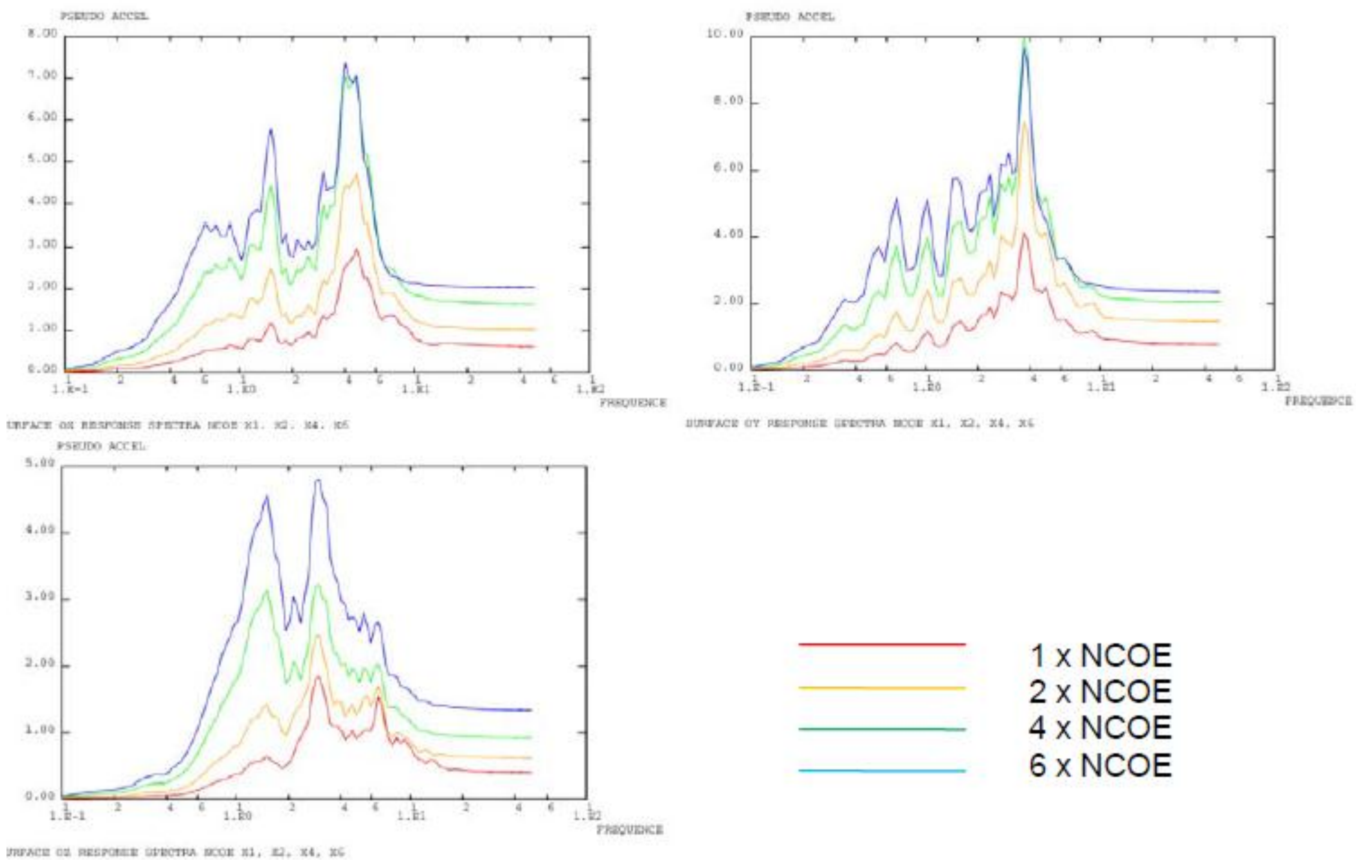
Response spectra (5% damping)
(recording = blue, calculation = red)

BENCHMARK PHASE III : INCREASED SEISMIC LOADINGS



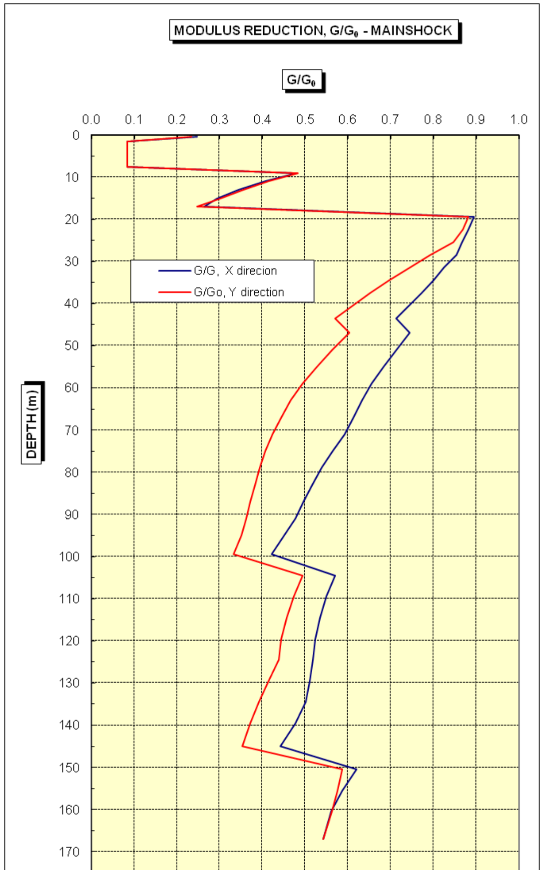
Defined on the bedrock outcrop

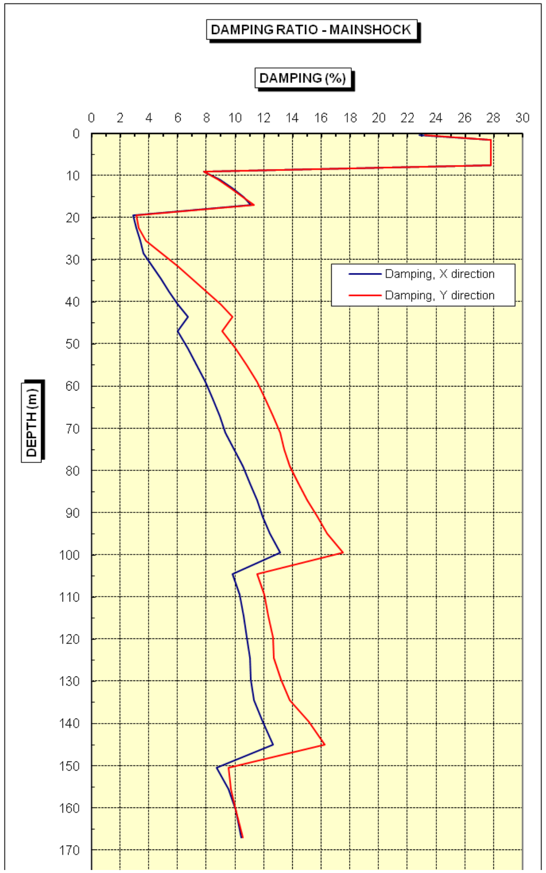
BENCHMARK PHASE III : INCREASED SEISMIC LOADINGS



Surface ground motion obtained by convolution

BENCHMARK PHASE III : EQUIVALENT LINEAR SOIL MODEL





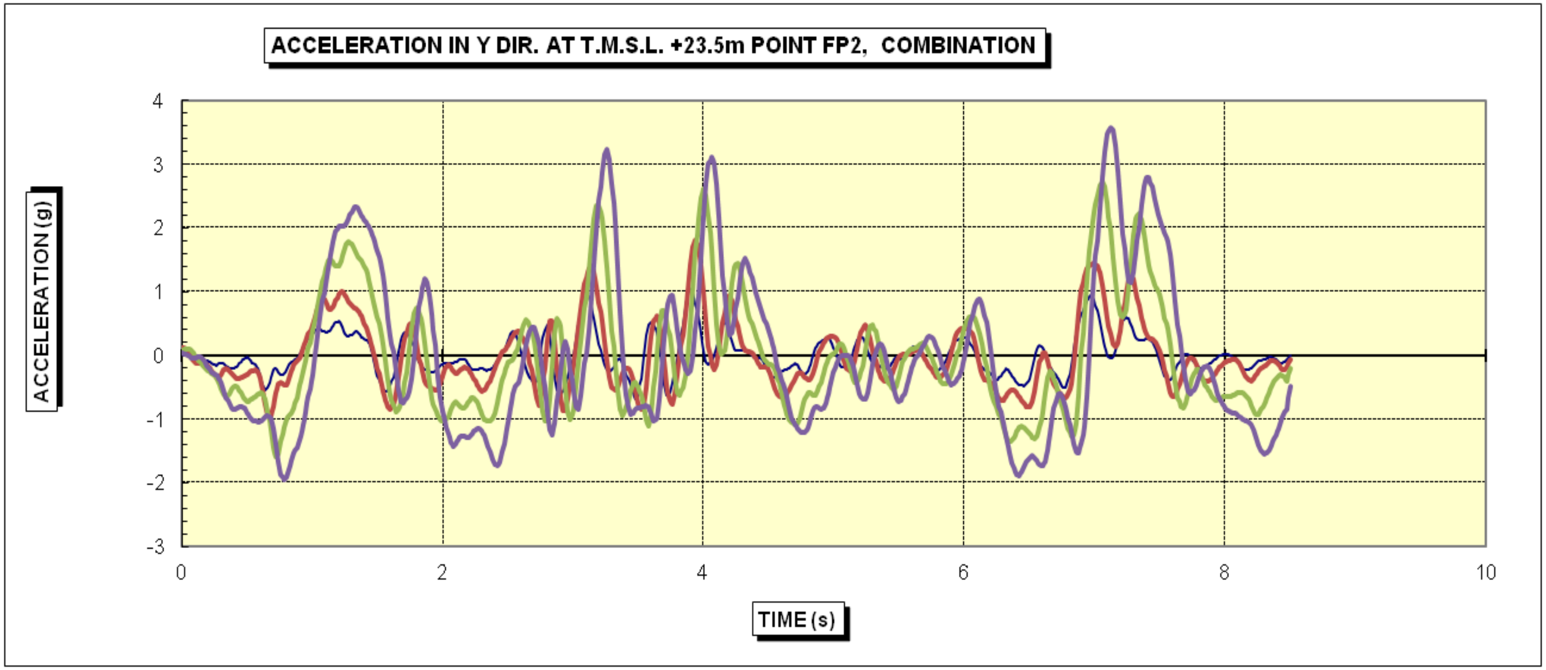
Reference soil model for a fictitious earthquake 6xNCOE

BENCHMARK PHASE III : NONLINEAR STRUCTURE MODEL

- From the phase II elastic model, the main lateral force resisting members, namely the outer walls and the RCCV are replaced by multi-layer shell elements with non linear laws :
  - Concrete : smeared crack model (Ottosen)
  - 5 layers of concrete used for the shell elements of outer walls and the RCCV (for out-of-plan bending)

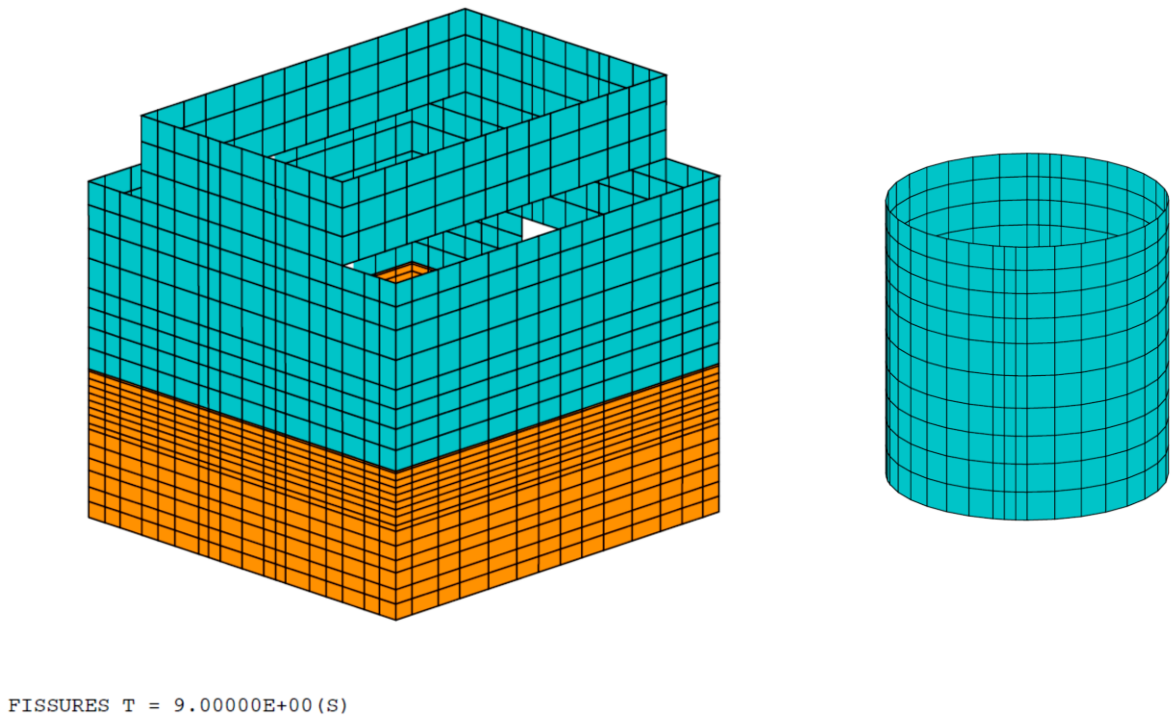
  - Steel reinforcement : unidirectional material with perfect elastic-plastic law,
  - 4 embedded layers are used : for each side of the wall, 1 layer for the horizontal direction and 1 layer for the vertical direction

BENCHMARK PHASE III : STRUCTURE RESPONSE



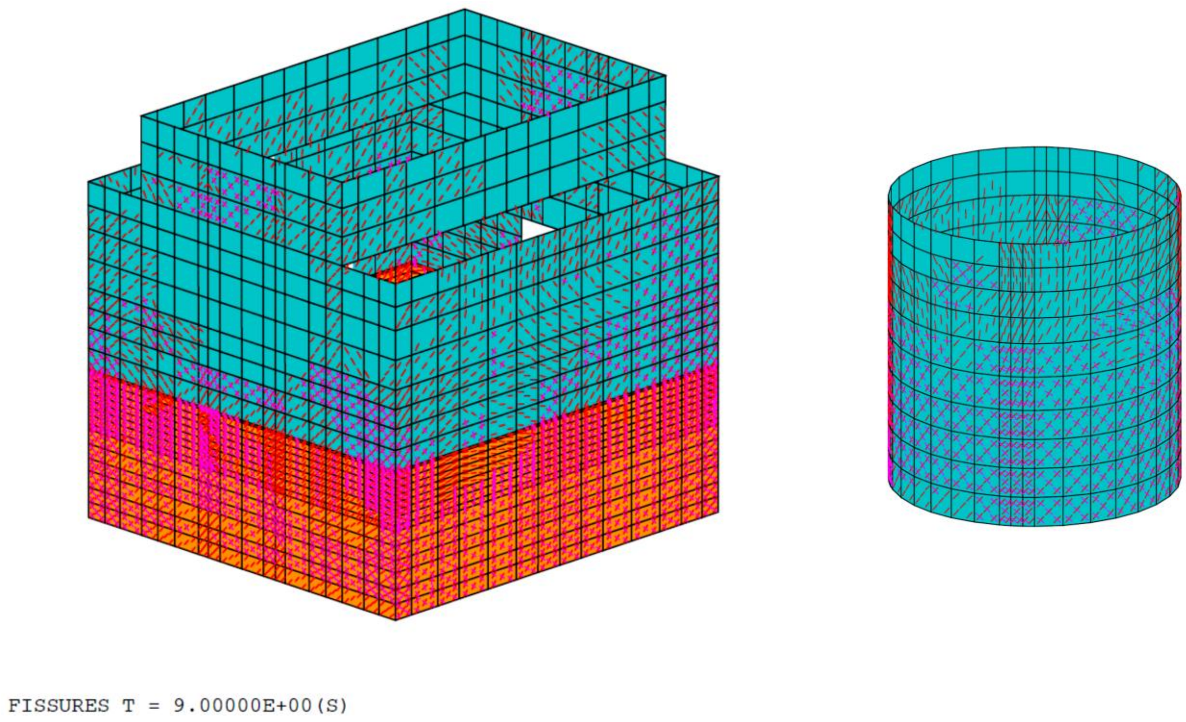
3rd floor response for 1xNCOE, 2xNCOE, 4xNCOE and 6xNCOE

BENCHMARK PHASE III : CONCRETE CRACKING



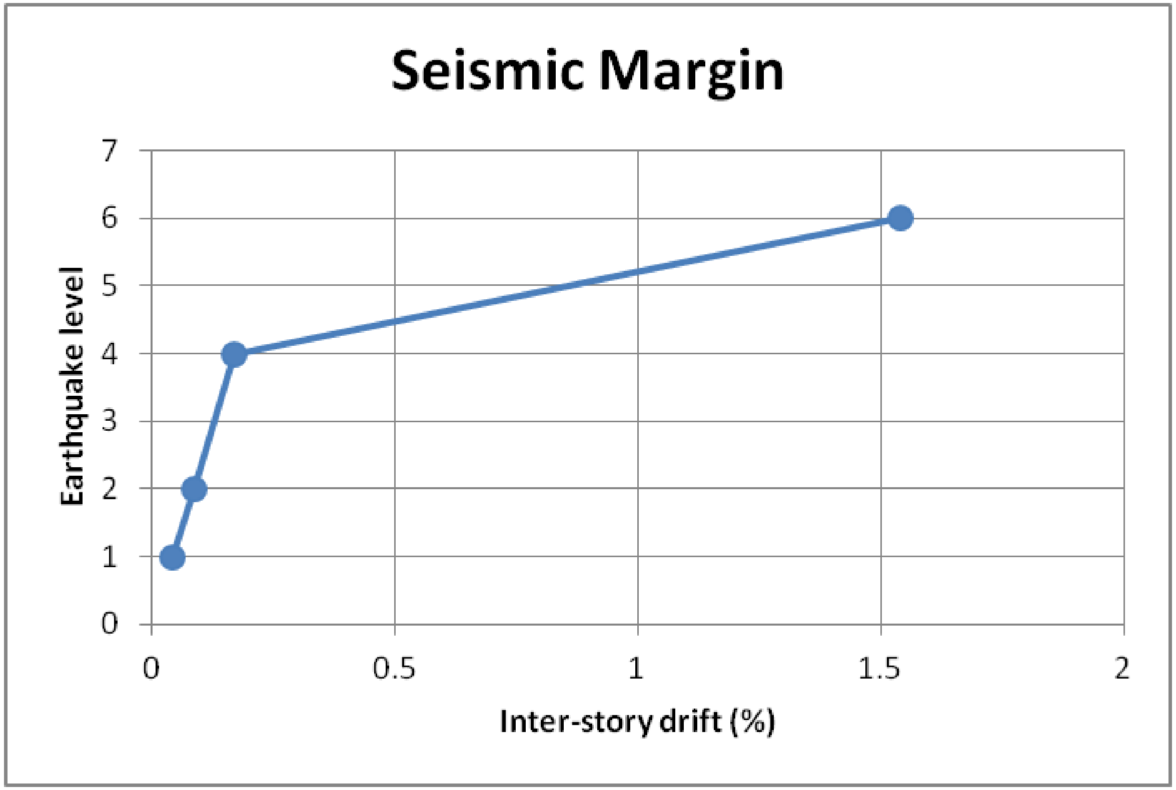
Main shear walls and the RCCV : 1xNCOE

BENCHMARK PHASE III : CONCRETE CRACKING



Main shear walls and the RCCV : 6xNCOE

BENCHMARK PHASE III: MARGIN ASSESEMENT



Seismic margin = at least 4 times NCOE

CONCLUSIONS AND PERSPECTIVES

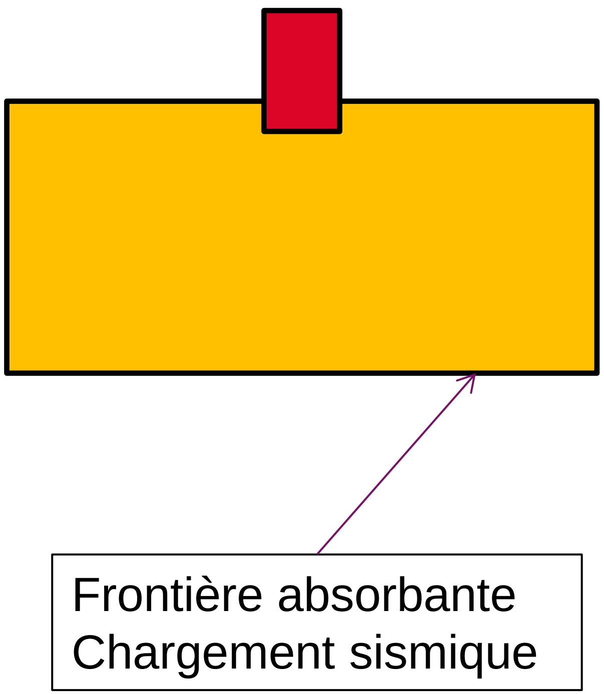
- The work is the contribution of the CEA-IRSN team to the KARISMA Benchmark organized by the IAEA .

- The particularities of this study compared to those of the other teams :

  - 3D finite element modeling of the structure and the near-field soil,
  - Far-field soil represented by viscous absorbing boundaries,
  - Time domain integration performed directly on the coupled soil-structure system,
  - Good results obtained for the NCOE earthquake,
  - The procedure developed capable to perform nonlinear SSI analysis,
  - Seismic margin of the reactor building evaluated.

- Perspectives
  - Foundation uplift, nonlinear soil model, base-isolated structures, …

CAST3M



METHODE DE BIELAK