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SEISMIC VALIDATION FOR FIBER REINFORCED CUBIK HOMEs

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Date	Description Modifications	by	supervised	Indice
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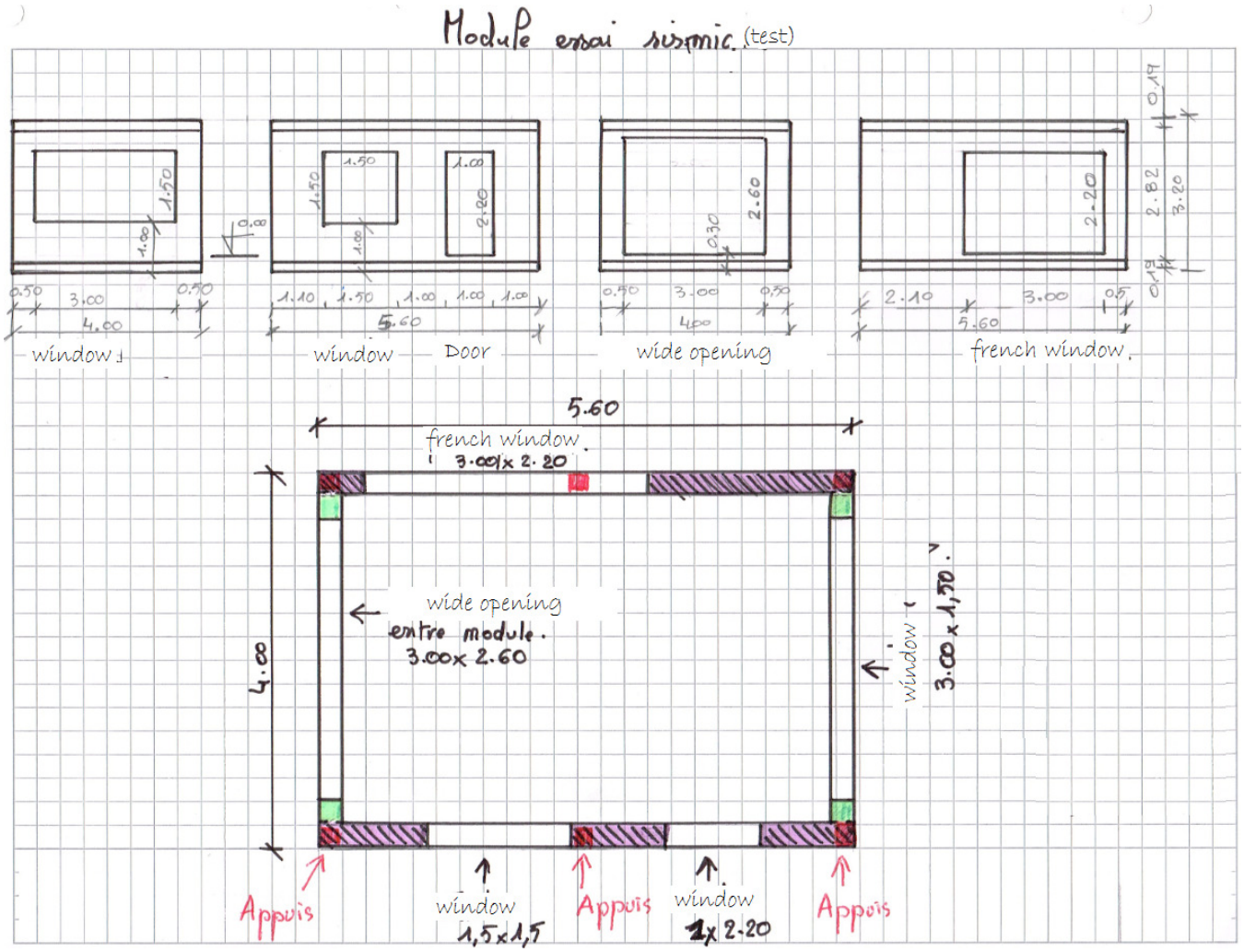
CONTENT

I/ AIM of the design

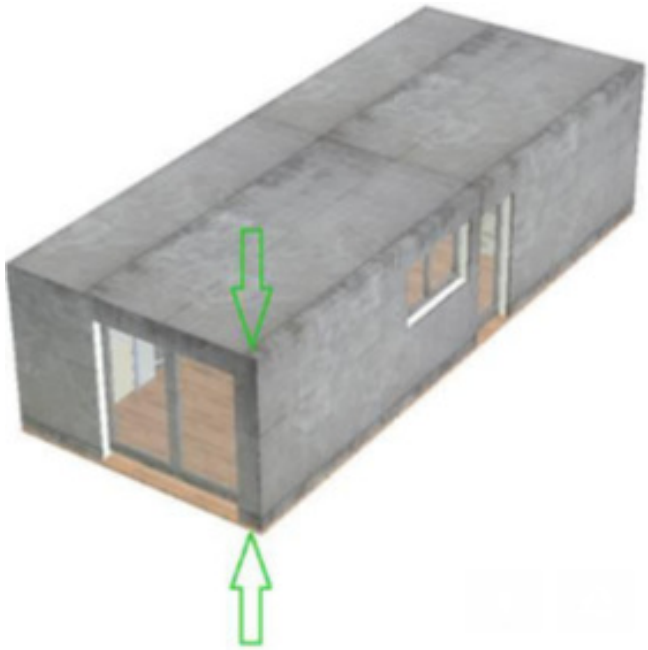
In this design, the seismic security of the modular housing CUBIK HOME is first checked for a standard one-level module, then for a 2-floor one. The slabs and walls are done with high performance concrete including metallic fibers. The numerical simulations are based on Eurocode 8 and the geometrical datas delivered to check the resistance to seismic loadcases. We consider à zone5 with high sismicity where seismic risks and hazard are the highest according to Eurocode 8. Simulations are done with the software Graitec Advance Design.

II/ GEOMETRICAL DATAS

MODULE to be tested



Example of a 3D modele (maximum size 10m x 4m)



NB : some specificities of the building are under patent, sot hey are not shown in this document, but taken in account in the calculations (non-contractual pictures)

III/ GEOGRAPHIC DATAS

For this design, we consider a level 5 seismic zone on a scale of 5 according to Eurocode 8 (Example of Guadeloupe island –French Carribean-). The ground class is E based on the worst hypothesis and importance category of CUBIK HOME is in catégory II.

Commune : Baie-Mahault (971 Guadeloupe)
Canton : Baie-Mahault
Altitude : 0,0 m
Distance à la mer : 0,0 km

Construction parasismique
Zone de sismicité : 5
Catégories de bâtiment : II, III ou IV
Norme NF EN 1998-1:2005
Accélération maximale de référence (sol de classe A) :
- bâtiment neuf : 3,0 m/s²
- bâtiment existant : 1,8 m/s²

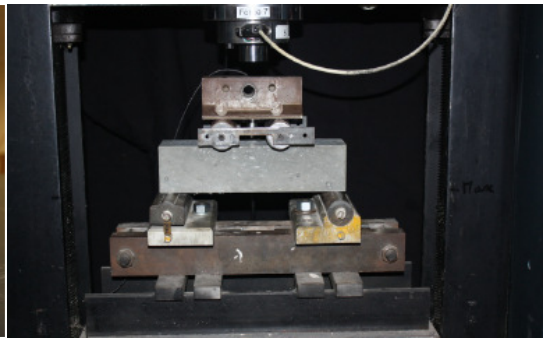
Paramètre de sol S :
- sol de classe A : 1,00
- sol de classe B : 1,20
- sol de classe C : 1,15
- sol de classe D : 1,35
- sol de classe E : 1,40

IV/ MATERIAL CHARACTERISTICS

Tests have been done at the INSA university of Lyon in order to characterize the fiber concrete of a similar modular house (tests done in 2014,).

The used fibers are DRAMIX 3D-65/35-BG with 1100 MPa traction resistance, included in a concrete of compression strength over 70 MPa (>10000psi) . their length is 35 mm (1.5in). to have a post hardening behavior, the fibre dosage has to be minimum 80kg/m^3 of concrete (purely plastic) to 100kg/m^3 (hardening). Cylindric samples 11cm×22cm were used for compression, and traction by splitting, and prismatic samples 7cm×7cm×28cm were used for the 4 point flexion-traction characterization.





prismatic samples (7×7×28)cm	F_{t28} (28 days) [MPa]	mean values [MPa]	standard deviation	caractéristic values [MPa]
N°1	14.35	11.0	2.3	7.3
N°2	12.05	11.0	2.3	7.3
N°3	9.16	11.0	2.3	7.3
N°4	8.87	11.0	2.3	7.3
N°5	10.74	11.0	2.3	7.3
cylindric samples (11×22)cm	F_{c28} (à 28days) [MPa]	mean values [MPa]	caractéristic values [MPa]	Young Modulus [MPa]
N°1	89	86	70	32366
N°2	85	86	70	33227
N°3	86	86	70	

V/ SEISMIC DESIGN HYPOTHESIS

V.1/ ITS MODELISATION

The spectral method will be used, based on a modal analysis linked to an elastic spectral response spécified in the construction norms. We assume that in this design, the behavior of the CUBIK HOME is linear.

For a complete modal simulation, the sum of the modal weights has to be equal to the total active weights in the studied direction. By checking if this sum is over 90% of the total weight, we prevent from forgetting an important mode. We decide to emphasize this level to 100% and thus, will include as many modes as necessary to guaranty this accuracy.

$$\sum_n m_{mod,n} = \sum_n m_n$$

$$m_{mod,n} = \left(\frac{r_n}{m_n}\right)^2 \times m_n = \frac{\left(\sum_j A_{jn} m_j\right)^2}{\sum_j A_{jn}{}^2 m_j}$$

In the modal analysis, you get the global response by adding the responses of all the different modes. Though to avoid adding the maximums to the maximums, because they don't occur at the same time, we use one of the most current superpositioning rule like : SRSS : (Square Root of the Sum of the Squares) or CQC : (Complete Quadratic Combinaison), We'll use the CQC in our design.

analysis type	module behavior	sum of modal weights	superpositioning rule
Spectral	Linéar-Elastic	100%M_t	CQC

V.2/ SPECTRAL ELASTIC RESPONSES

The one used in our design is the Eurocode 8's one. For the accélération response, différent domains are used : between périods T_B and T_C, the ground accéleration (a_{gd}) is amplified by 3 coefficients : a 2.5 constant one,
One depending on the ground charactéristics (S) and
A correcting one (η) because of the damping.
The formulas for an horizontal spectral élastic response are :

$$S_e = a_{gd} S\left[1 + \frac{(2.5\eta - 1)T}{T_B}\right] \qquad 0 \le T \le T_B$$

$$S_e = 2.5 a_{gd} S\eta \qquad T_B \le T \le T_C$$

$$S_e = 2.5 a_{gd} S\eta \frac{T_C}{T} \qquad T_C \le T \le T_D$$

$$S_e = 2.5 a_{gd} S\eta \frac{T_C T_D}{T^2} \qquad T_D \le T \le 4s$$

$$\eta = \sqrt{\frac{1}{0.5 + 10\xi}} \ge 0.55$$

The spectral values of displacement ($S_{u,n} = S_e, n/\omega_n{}^2$) give the maximal modal response $z_{n,max}$ and thus the maximum displacements of each mode.

$$z_{n,max} = \frac{|r_n|}{m_n} S_{u,n}(\omega_n, \zeta) = \frac{|r_n|}{{\omega_n}^2 m_n} S_{e,n}(\omega_n, \zeta)$$

$$\underline{x}_{n,max} = \underline{A}_n \, z_{n,max}$$

seismic Zone	ground Class	importance category	ground acceleration a_{gr} [m/s²]	soil coefficient S	T_B [s]	Tc [s]	TD [s]
5	E	II	3.0	1.40	0.15	0.5	2.0

The formulas of the vertical spectral elastic response are.

$$S_e = a_{vg} S \left[1 + \frac{(3\eta - 1)T}{T_B}\right] \qquad 0 \le T \le T_B$$

$$S_e = 3.0 a_{vg} \eta \qquad T_B \le T \le T_C$$

$$S_e = 3.0 a_{vg} \eta \frac{T_C}{T} \; T_C \le T \le T_D$$

$$S_e = 2.5 a_{gd} S \eta \frac{T_C T_D}{T^2} \; T_D \le T \le 4s$$

sismic zone	a_{vg}/a_g	T_B [s]	Tc [s]	TD [s]
5	0.9	0.15	0.4	2.0

L'Eurocode 8 allows to take long vibration structures in account. The seismic solicitation can thus follow a displacement rpectral response, $S_{De}(T)$ given :

$$S_{De} = 0.025 a_g S T_C T_D \left[2.5\eta + \frac{(T - T_E)}{(T_F - T_E)}(1 - 2.5\eta)\right] \; T_E \le T \le T_F$$

$$S_{De} = d_g \quad T \ge T_F$$

$$d_g = 0.025 a_g S T_C T_D$$

$$S_{De} = S_e \left[\frac{T}{2\pi}\right]^2$$

For a ground class : E : $T_E = 6.0s$; $T_F = 10.0s$

V.3/ MODAL DAMPING VALUE

A constant damping coefficient is directly given for all modes (different from the Rayleigh damping, to guaranty a classical damping). We'll take a flat-rate value of $\zeta = 5\%$ in our design. This damping is a viscous type one.

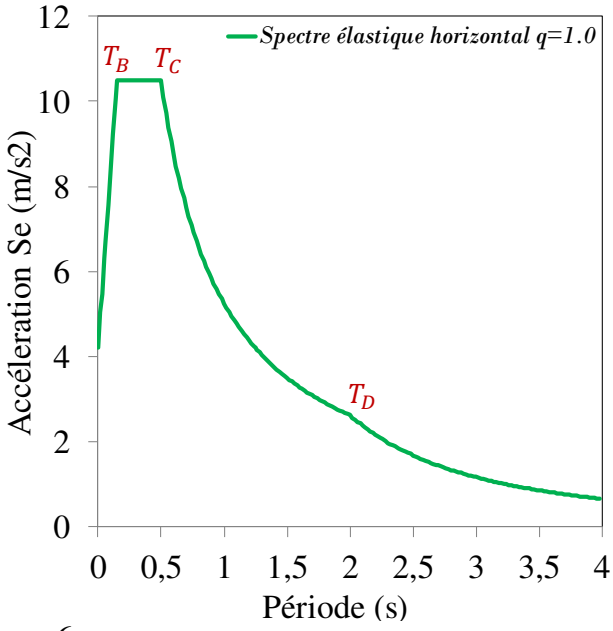
V.4/ BEHAVIORAL COEFFICIENT– SIMPLIFIED PLASTIC ASSUMPTION

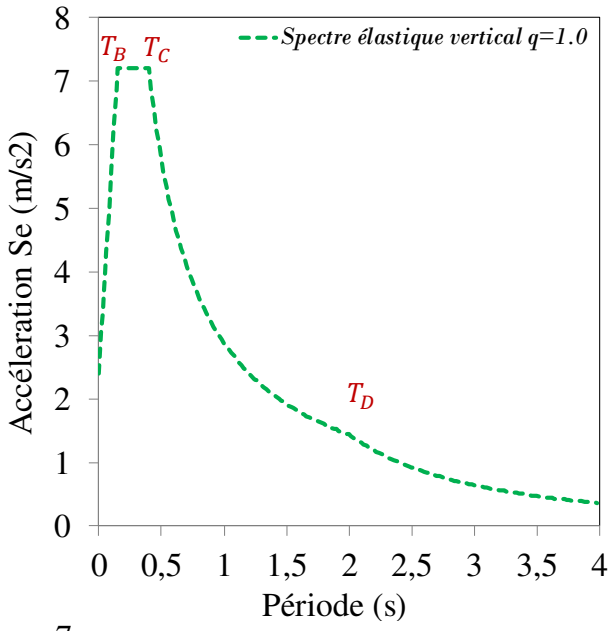
Spectral design , means a linear behavior of the structure (except purely dynamic analysis). But for high eartquakes, the structural behaviors will not stay in a linear mode.

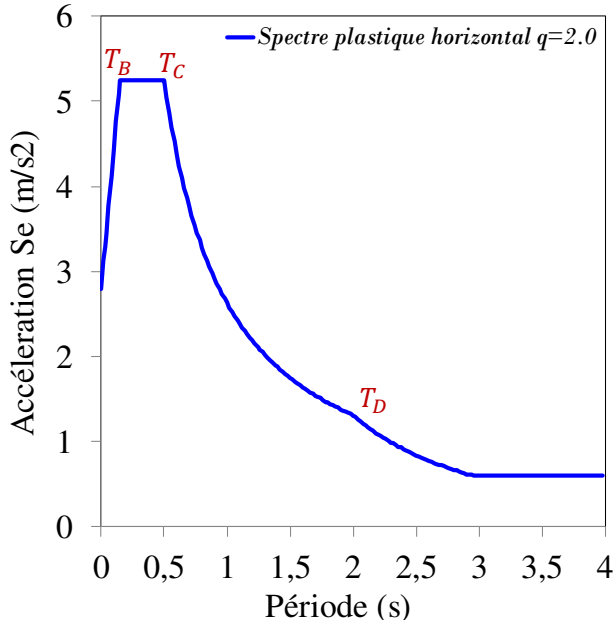
We agree that real strain (non linear behavior, supposed to be elastic, perfectly plastic) are very similar to those we calculate on a linear model based on the initial state (non cracked) of the structure. Thus the related elasto-plastic stressis equal to the calculated stress of an elastic model divided by the ductility coefficient. We agree that the real stresses in a structure can result from calculated stresses on a linear model corresponding to the non cracked state, divided by the behavior coefficient q.

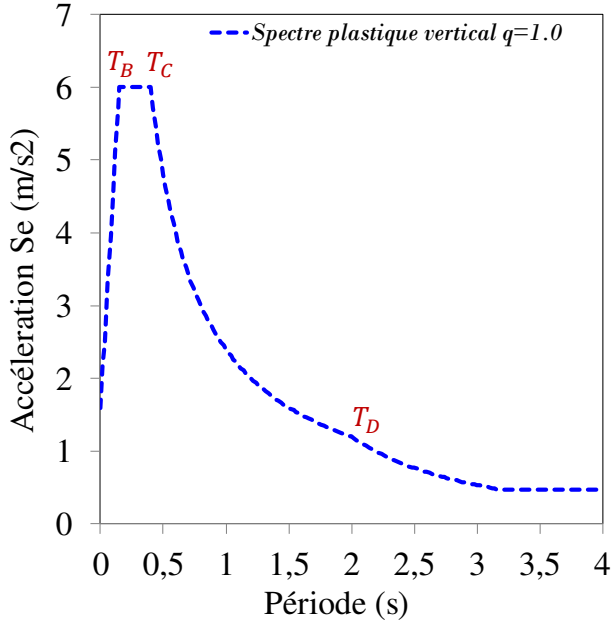
Elastic behavior	simplified plastic behavior	
$q = 1.00$	$q_H = 2.00$	$q_V = 1.00$

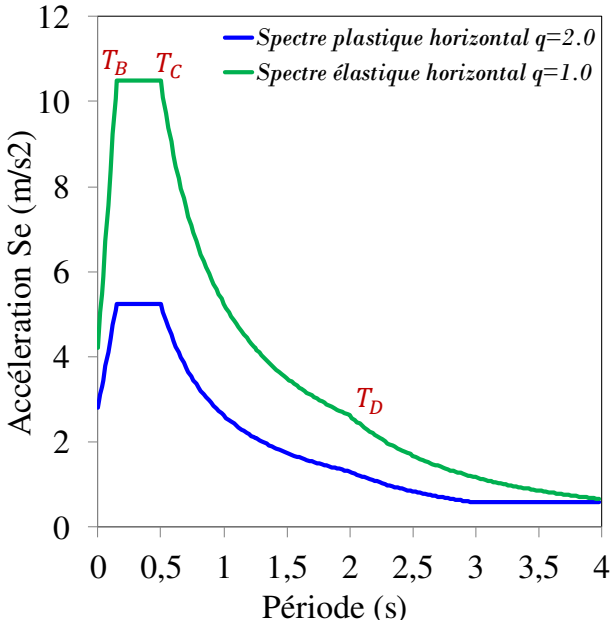
Q is chosen from the recommandations for buildings with height $H \leq 28m$ explicitely given in : [Davidovici, Victor. La construction en zone sismique: approche réglementaire, modèles d'analyse des structures, diagnostic des bâtiments existants, exemple de calculs. Le Moniteur, 1999] for the french parasismic rules PS92. (similar values to the new regulation Eurocode 8). In our design, for the vertical direction, since ductlity is lower, the behavior coefficient is reduced.

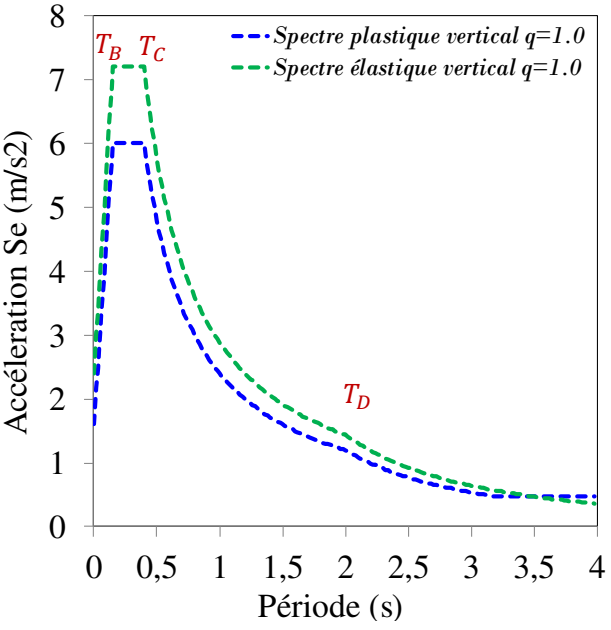

Spectre élastique horizontal q=1.0
T_B T_C T_D
Accélération Se (m/s2)
Période (s)


Spectre élastique vertical q=1.0
T_B T_C T_D
Accélération Se (m/s2)
Période (s)


Spectre plastique horizontal q=2.0
T_B T_C T_D
Accélération Se (m/s2)
Période (s)


Spectre plastique vertical q=1.0
T_B T_C T_D
Accélération Se (m/s2)
Période (s)


Spectre plastique horizontal q=2.0
Spectre élastique horizontal q=1.0
T_B T_C T_D
Accélération Se (m/s2)
Période (s)

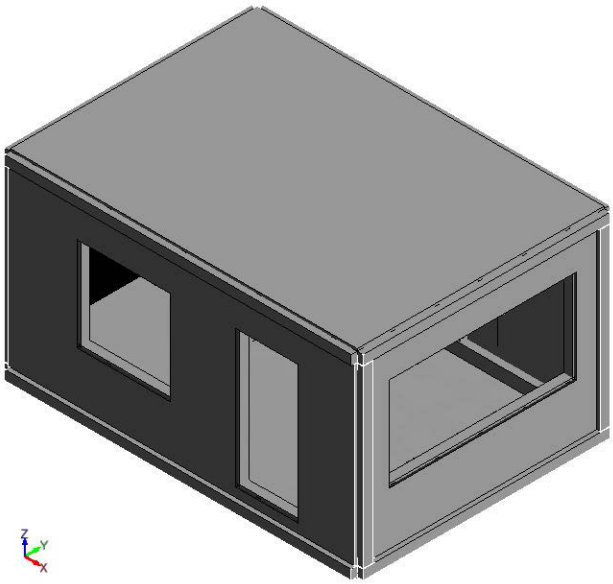

Spectre plastique vertical q=1.0
Spectre élastique vertical q=1.0
T_B T_C T_D
Accélération Se (m/s2)
Période (s)

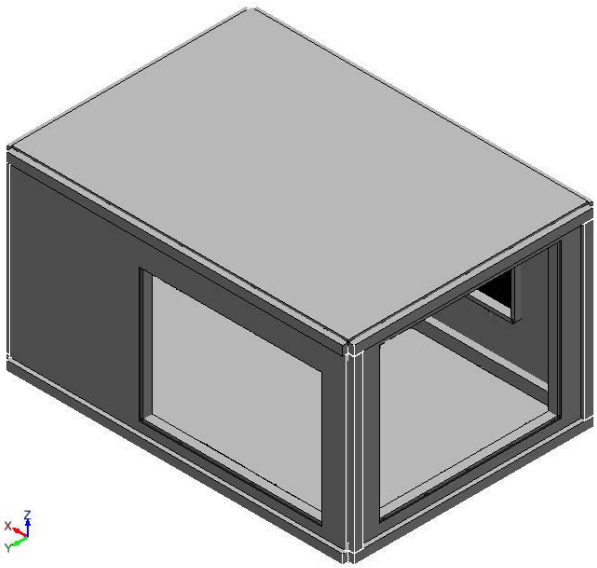
VI/ STRUCTURAL MODELE DESCRIPTION

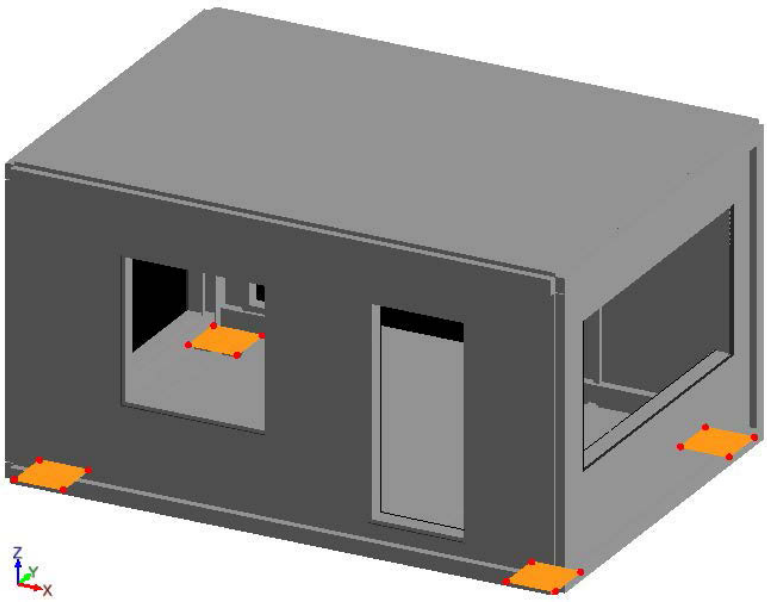
In our design, the numerical simulations have been done based on a continuous Finite Eléments structure.

- For walls, slabs and roofs we used 2D elements. Homogenious rigidity has been chosen for the iron/concrete material with a value of 37GPa.
- The finite élément (FE) discretization for the concrete has been uses parallélépipédic elements and linear triangular interpolation.
- The FE-mesh distance is 0.2 m and gives a high result accuracy.
- For the limit conditions, we studied several cases as to verify their seismic behavioral effects on the module :

  - 4 elastic supports 50cm×50cm with no horizontal rigidity (the module is simply laying, horizontal displacement allowed) in the 4 corners,
  - A single elastic surfacic support with no horizontal rigidity under the entire module, and
  - 4 elastic supports 50cm×50cm *with* horizontal rigidity (hinged, no horizontal displacements).







VII/ RESULTS : ZONE 5 EARTHQUAKE

VII.1/ STANDARD MODULE 1 LEVEL

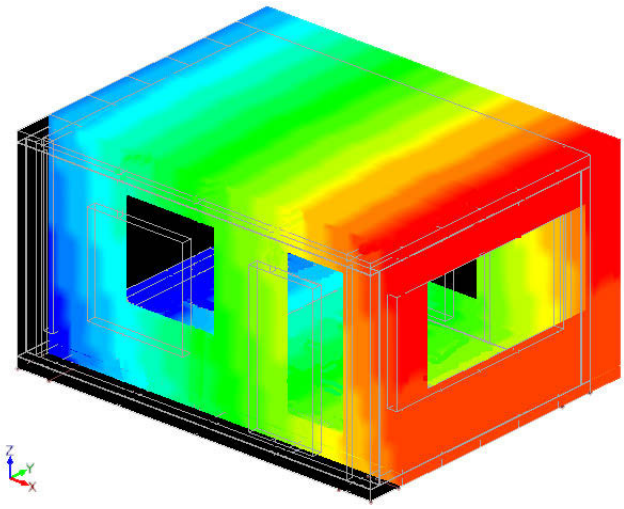
- CASE 1 : 4 ELASTIC SURFACIC SUPPORT WITHOUT HORIZONTAL RIGIDITY

The supports are 50cm×50cm the module is just set on top of them. This limit condition is like the real support système.

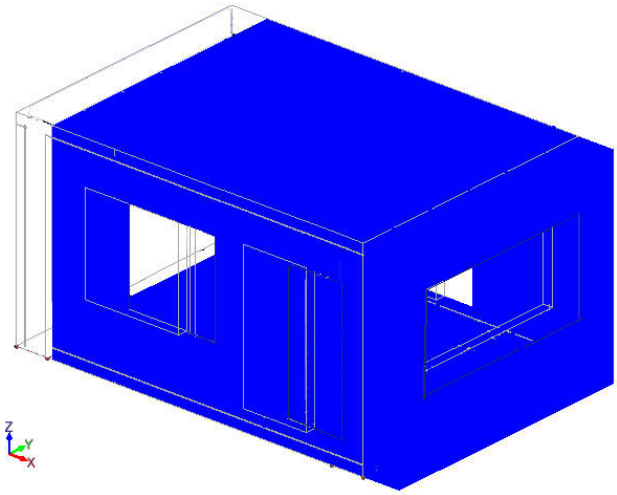
In order to obtain the sum of the modal weights equal to 100% of the total weight in every direction, we considered 6 frequency modes equal to 7.07Hz.
The array below shows the most important modes :
We used the spectral elastic response adapted to the long vibrating periods (>4s).
The maximum seismic displacements in the 3 main directions are given further.

Mode N°	Pulsation (Rad/s)	Period (s)	Frequency (Hz)	modal weights			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
1	0.21	29.72	0.03	0.00 (0.00)	22.49 (100.00)	0.00 (0.00)	5.00
2	0.21	29.51	0.03	22.49 (100.00)	0.00 (0.00)	0.00 (0.00)	5.00
3	3.39	1.85	0.54	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
4	35.42	0.18	5.64	0.00 (0.00)	0.00 (0.00)	0.08 (0.34)	5.00
5	40.79	0.15	6.49	0.00 (0.00)	0.00 (0.00)	21.47 (95.45)	5.00
6	44.39	0.14	7.07	0.00 (0.00)	0.00 (0.00)	0.79 (3.50)	5.00
Total				**22.49 (100.00)**	**22.49 (100.00)**	**22.33 (99.29)**	

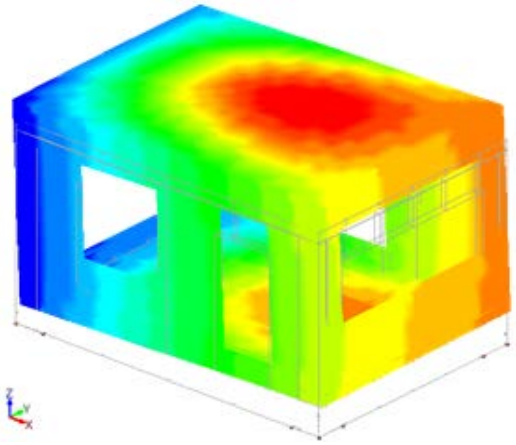
MODE 1



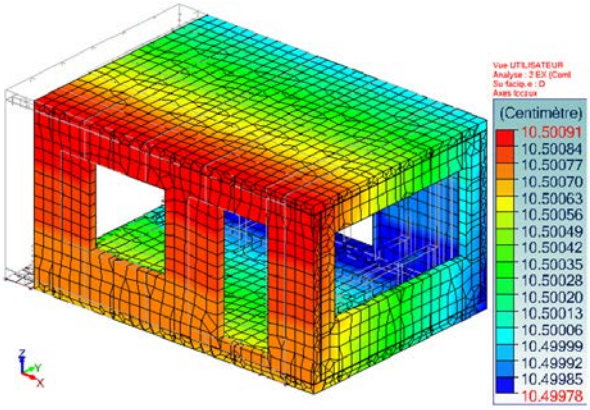
MODE 2



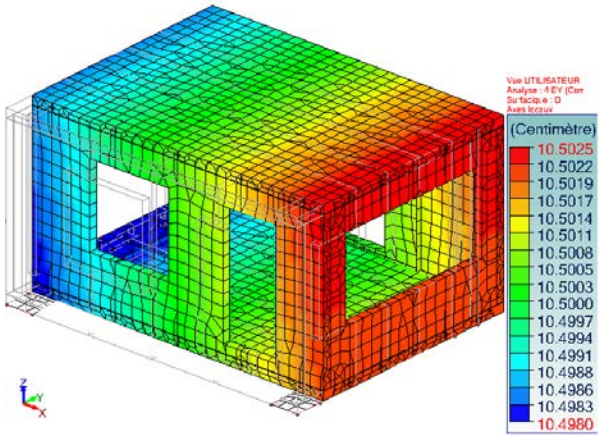
MODE 5



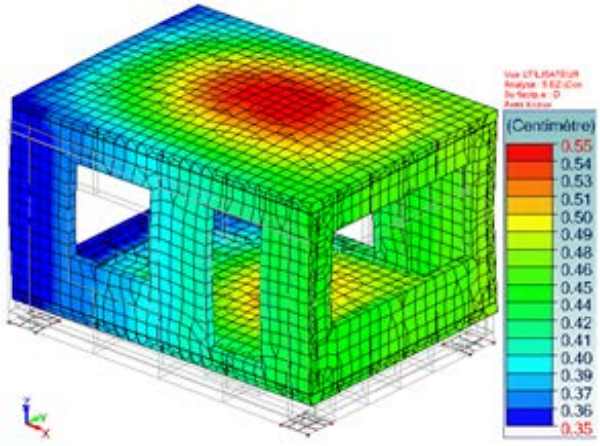
QUAKE *DIRECTION X*



QUAKE *DIRECTION Y*



QUAKE *DIRECTION Z*

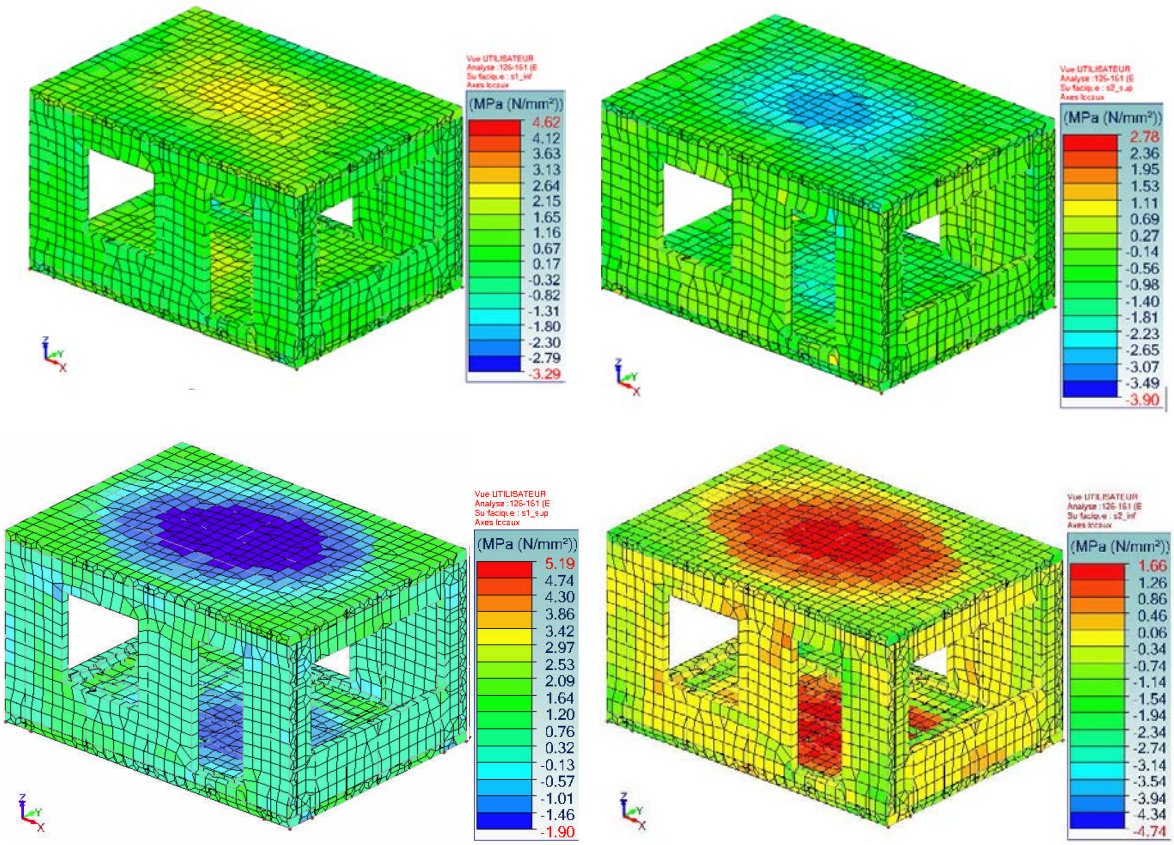


CONCLUSION DISPLACEMENT - CASE 1 :

DIRECTIONS X (10.5 CM) - Y (10.5 CM) - Z (0.55 CM).

DMAX=10.5CM

NO DAMAGE LIMITATIONS REQUESTED



STRESS CONCLUSION - CASE 1 : MAXIMUM VALUE IS 5.19MPA (VERY LOCAL). THIS VALUE IS LOWER THAN THE TRACTION RESISTANCE OF THE FIBER CONCRETE WHICH IS 11.0 MPA (EXPERIMENTAL VALUE). NO CRACKING OF THE MODULE

- **CASE 2 : ENTIRE GENERAL SUPPORT: NO HORIZONTAL RIGIDITY**

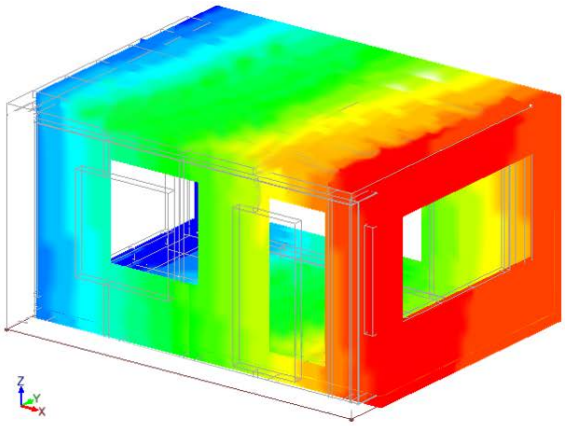
The module is simply laying on the ground, on its entire surface. Horizontal displacements allowed.

In order to obtain the sum of the modal weights equal to 100% of the total weight in every direction, we used 40 modes with a maximal fréquence of 99.75Hz . The most important modes are shown in the array below:
We used the spectral elastic response adapted to the long vibrating periods (>4s).
The maximum seismic displacements in the 3 main directions are given further.

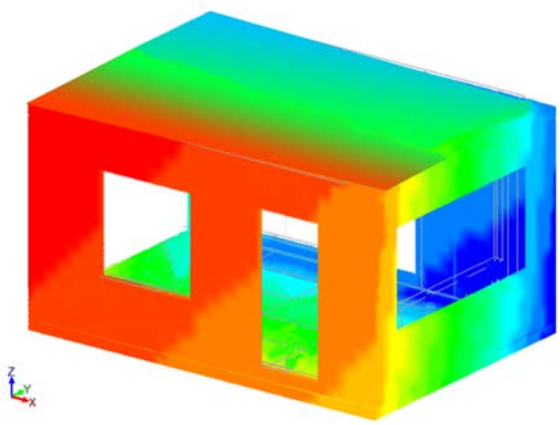
Mode N°	Pulsation (Rad/s)	Period (s)	Frequency (Hz)	modal weight			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
1	0.99	6.36	0.16	0.36 (1.60)	22.13 (98.40)	0.00 (0.00)	5.00
2	0.99	6.36	0.16	22.13 (98.40)	0.36 (1.60)	0.00 (0.00)	5.00
3	3.47	1.81	0.55	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
4	74.29	0.08	11.82	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
5	85.96	0.07	13.68	0.00 (0.00)	0.00 (0.00)	9.06 (40.31)	5.00
6	92.89	0.07	14.78	0.00 (0.00)	0.00 (0.00)	0.69 (3.08)	5.00
7	138.14	0.05	21.99	0.00 (0.00)	0.00 (0.00)	9.62 (42.78)	5.00
8	156.94	0.04	24.98	0.00 (0.00)	0.00 (0.00)	0.03 (0.15)	5.00
9	192.89	0.03	30.70	0.00 (0.00)	0.00 (0.00)	0.01 (0.05)	5.00
10	214.87	0.03	34.20	0.00 (0.00)	0.00 (0.00)	0.05 (0.20)	5.00
11	227.58	0.03	36.22	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
12	231.02	0.03	36.77	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
13	271.87	0.02	43.27	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
14	288.18	0.02	45.87	0.00 (0.00)	0.00 (0.00)	0.02 (0.08)	5.00
15	290.35	0.02	46.21	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
16	323.50	0.02	51.49	0.00 (0.00)	0.00 (0.00)	0.05 (0.21)	5.00
17	338.99	0.02	53.95	0.00 (0.00)	0.00 (0.00)	0.02 (0.10)	5.00
18	365.52	0.02	58.17	0.00 (0.00)	0.00 (0.00)	0.01 (0.03)	5.00
19	397.53	0.02	63.27	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
20	405.83	0.02	64.59	0.00 (0.00)	0.00 (0.00)	0.01 (0.06)	5.00
21	420.01	0.01	66.85	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
22	430.03	0.01	68.44	0.00 (0.00)	0.00 (0.00)	0.10 (0.45)	5.00
23	445.67	0.01	70.93	0.00 (0.00)	0.00 (0.00)	2.62 (11.63)	5.00
24	467.20	0.01	74.36	0.00 (0.00)	0.00 (0.00)	0.00 (0.02)	5.00
25	471.23	0.01	75.00	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
26	479.08	0.01	76.25	0.00 (0.00)	0.00 (0.00)	0.04 (0.17)	5.00
27	481.56	0.01	76.64	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
28	490.98	0.01	78.14	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
29	505.07	0.01	80.38	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
30	510.78	0.01	81.29	0.00 (0.00)	0.00 (0.00)	0.00 (0.02)	5.00
31	520.46	0.01	82.83	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
32	529.11	0.01	84.21	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
33	546.11	0.01	86.92	0.00 (0.00)	0.00 (0.00)	0.01 (0.06)	5.00
34	557.45	0.01	88.72	0.00 (0.00)	0.00 (0.00)	0.01 (0.04)	5.00
35	571.91	0.01	91.02	0.00 (0.00)	0.00 (0.00)	0.05 (0.22)	5.00
36	575.64	0.01	91.62	0.00 (0.00)	0.00 (0.00)	0.02 (0.08)	5.00
37	579.20	0.01	92.18	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
38	600.48	0.01	95.57	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
39	605.25	0.01	96.33	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
40	626.75	0.01	99.75	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00

Mode N°	Pulsation (Rad/s)	Period (s)	Frequency (Hz)	modal weight			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
Total				**22.49 (100.00)**	**22.49 (100.00)**	**22.45 (99.84)**	

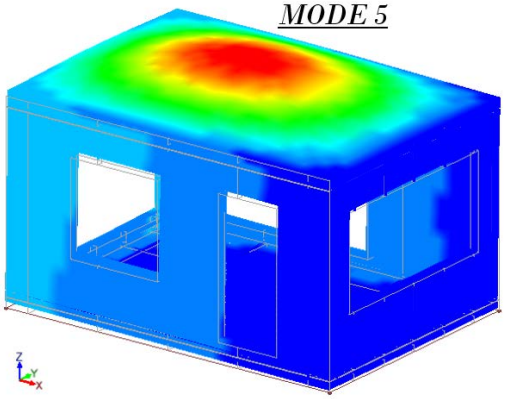
MODE 1



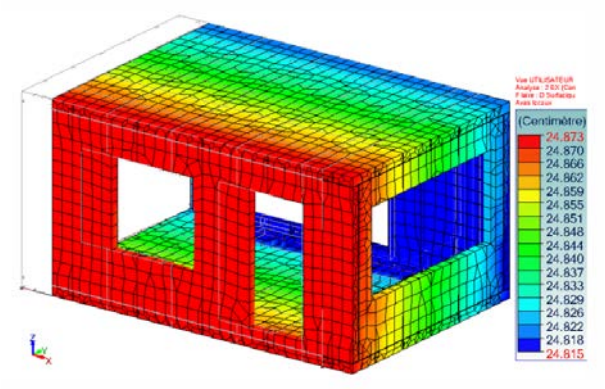
MODE 2



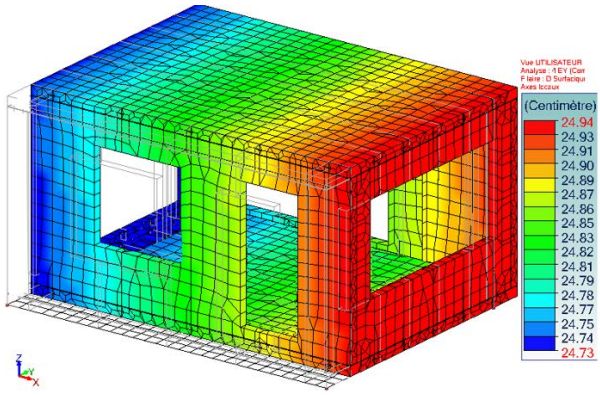
MODE 5



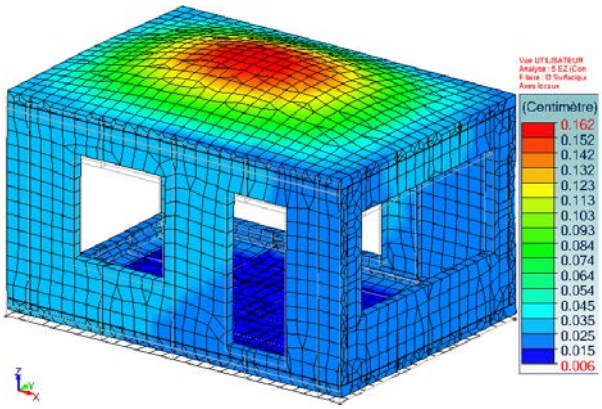
QUAKE *DIRECTION X*



QUAKE *DIRECTION Y*



QUAKE *DIRECTION Z*



DISPLACEMENT CONCLUSION - CASE 2 : THE DISPLACEMENTS OBTAINED ARE LIGHTLY HIGHER : X (24.9 CM) - Y (24.9 CM) - Z (0.16 CM).

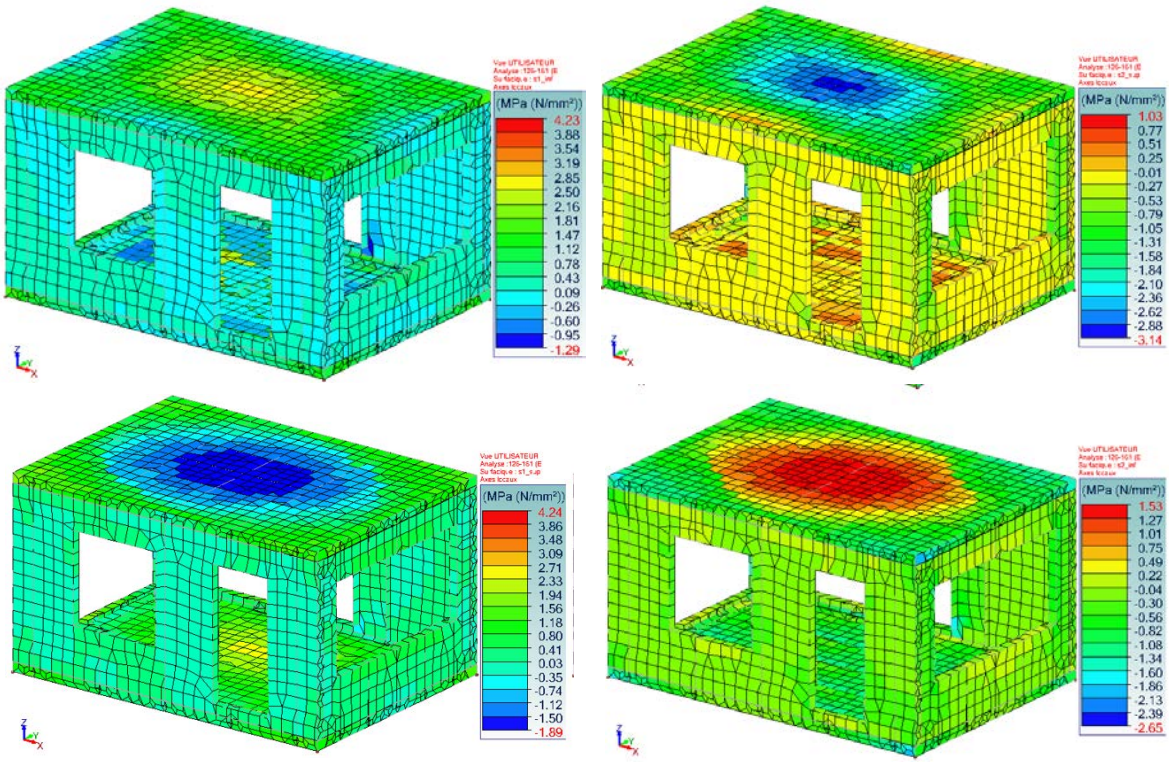
DMAX=24.9CM.

NO DAMAGE LIMITATIONS REQUESTED

. THIS 2ND CASE DOESN'T IMPROVE THE EARTHQUAKE BEHAVIOR.

IT LOOKS SAFER TO LIMIT THE DIRECTIONS X AND Y IN ORDER TO REDUCE THE HORIZONTAL DISPLACEMENTS.

STRESS VERIFICATIONS

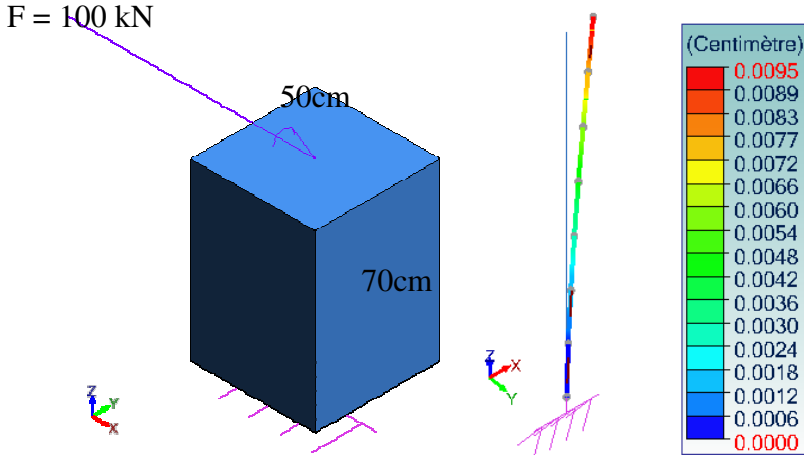


STRESS CONCLUSION - CASE 2 : ETHE MAXIMUM TRACTION VALUE IS 4.24MPA (LOCALLY).

THIS VALUE IS LOWER THAN THE TRACTION RESISTANCE OF THE FIBER CONCRETE WHICH IS 11.0 MPA (EXPERIMENTALY). NO CRACK IN THE MODULE

- CASE 3 : 4 ELASTIC SURFACIC SUPPORTS WITH HORIZONTAL STIFFNESS

The structure is attached horizontally directions X et Y.
The 4 elastic surfacic supports 50cm×50cm are situated in the 4 corners. To define the horizontal stiffness, the foundation is considered 70cm (27in) high. There is no sliding between the foundation and the module. The fondation is considered embedded in the ground. The obtained stiffness value is 1.05×10^6 kN/m which is 4.0×10^6 kN/m/m^2.



80 frequency modes from 12.64Hz to 170.6Hz were used (with Periods from 0.08s to 0.01s). The sum of the modal weights is 98% of the total weight in every direction (acceptable pourcentage).

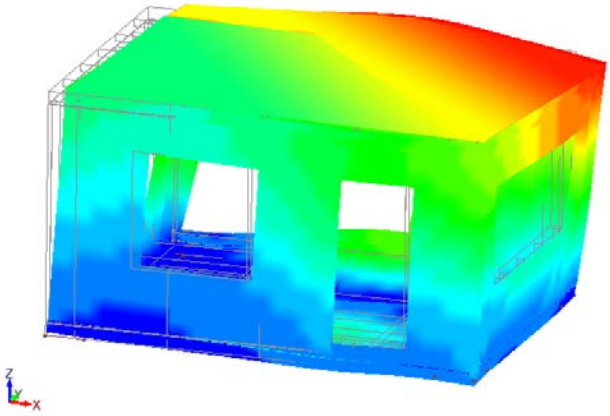
We used the spectral elastic response adapted to the long vibrating periods (>4s).
The maximum seismic displacements in the 3 main directions are given further.

Mode N°	Pulsation (Rad/s)	Period (s)	Frequency (Hz)	modal weight			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
1	79.42	0.08	12.64	0.25 (1.09)	11.62 (51.66)	0.15 (0.65)	5.00
2	94.07	0.07	14.97	0.07 (0.29)	0.22 (0.96)	3.34 (14.84)	5.00
3	103.12	0.06	16.41	0.14 (0.62)	0.10 (0.43)	2.73 (12.13)	5.00
4	126.56	0.05	20.14	9.14 (40.65)	0.74 (3.31)	0.01 (0.05)	5.00
5	183.42	0.03	29.19	1.77 (7.89)	0.31 (1.40)	0.03 (0.12)	5.00
6	194.94	0.03	31.03	2.71 (12.06)	0.23 (1.01)	0.03 (0.14)	5.00
7	207.24	0.03	32.98	0.04 (0.18)	0.00 (0.01)	0.00 (0.01)	5.00
8	212.36	0.03	33.80	0.00 (0.02)	0.18 (0.82)	0.00 (0.01)	5.00
9	226.30	0.03	36.02	0.16 (0.69)	0.15 (0.66)	0.01 (0.04)	5.00
10	254.69	0.02	40.54	0.24 (1.06)	0.12 (0.54)	0.03 (0.14)	5.00
11	270.92	0.02	43.12	0.02 (0.08)	0.00 (0.02)	0.01 (0.03)	5.00
12	283.37	0.02	45.10	0.18 (0.82)	0.00 (0.00)	0.00 (0.02)	5.00
13	300.42	0.02	47.81	0.01 (0.06)	0.01 (0.04)	7.42 (33.01)	5.00
14	323.04	0.02	51.41	0.03 (0.12)	0.08 (0.36)	1.70 (7.58)	5.00
15	344.92	0.02	54.90	0.03 (0.14)	0.02 (0.09)	4.37 (19.44)	5.00
16	348.51	0.02	55.47	0.01 (0.03)	0.00 (0.02)	0.02 (0.09)	5.00
17	360.32	0.02	57.35	0.03 (0.12)	0.01 (0.06)	0.25 (1.09)	5.00
18	368.04	0.02	58.58	0.11 (0.51)	0.02 (0.10)	0.02 (0.10)	5.00
19	384.93	0.02	61.26	0.01 (0.03)	0.06 (0.27)	0.12 (0.54)	5.00
20	397.36	0.02	63.24	0.08 (0.36)	0.22 (0.99)	0.07 (0.30)	5.00
21	403.00	0.02	64.14	0.34 (1.52)	0.01 (0.03)	0.01 (0.03)	5.00
22	420.51	0.01	66.93	0.16 (0.72)	0.03 (0.12)	0.22 (0.98)	5.00
23	433.73	0.01	69.03	0.10 (0.45)	0.09 (0.40)	0.00 (0.00)	5.00

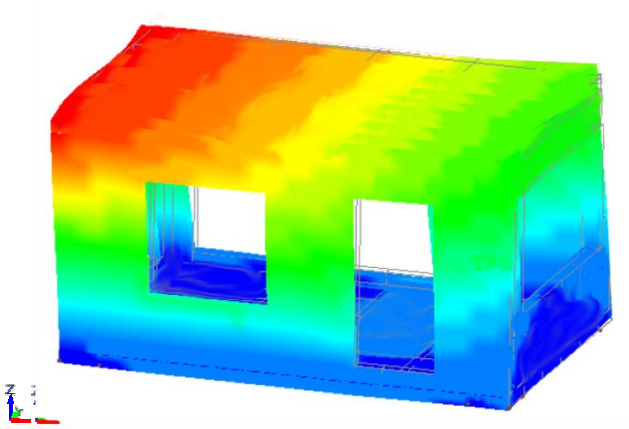
Mode N°	Pulsation (Rad/s)	Period (s)	Frequency (Hz)	modal weight			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
24	455.49	0.01	72.49	0.07 (0.31)	0.02 (0.10)	0.05 (0.21)	5.00
25	472.53	0.01	75.21	0.01 (0.03)	0.02 (0.11)	0.01 (0.03)	5.00
26	477.17	0.01	75.94	0.00 (0.00)	0.73 (3.26)	0.07 (0.33)	5.00
27	491.25	0.01	78.18	0.06 (0.28)	0.00 (0.00)	0.00 (0.01)	5.00
28	501.79	0.01	79.86	0.27 (1.22)	2.93 (13.03)	0.11 (0.50)	5.00
29	509.39	0.01	81.07	0.02 (0.10)	0.11 (0.50)	0.00 (0.01)	5.00
30	514.60	0.01	81.90	1.26 (5.58)	0.49 (2.17)	0.15 (0.68)	5.00
31	522.62	0.01	83.18	0.51 (2.25)	0.09 (0.38)	0.04 (0.18)	5.00
32	533.43	0.01	84.90	0.07 (0.33)	0.01 (0.03)	0.06 (0.26)	5.00
33	549.17	0.01	87.40	0.06 (0.25)	0.84 (3.73)	0.03 (0.11)	5.00
34	561.19	0.01	89.32	0.06 (0.29)	0.23 (1.01)	0.01 (0.03)	5.00
35	566.89	0.01	90.22	0.17 (0.74)	0.01 (0.02)	0.00 (0.00)	5.00
36	572.42	0.01	91.10	0.83 (3.71)	0.89 (3.96)	0.07 (0.29)	5.00
37	583.84	0.01	92.92	0.02 (0.11)	0.05 (0.22)	0.01 (0.05)	5.00
38	598.38	0.01	95.24	1.34 (5.96)	0.52 (2.31)	0.00 (0.02)	5.00
39	606.56	0.01	96.54	0.15 (0.68)	0.20 (0.91)	0.12 (0.55)	5.00
40	611.48	0.01	97.32	0.06 (0.27)	0.13 (0.59)	0.00 (0.01)	5.00
41	626.67	0.01	99.74	0.93 (4.12)	0.01 (0.03)	0.04 (0.18)	5.00
42	638.95	0.01	101.69	0.13 (0.60)	0.01 (0.04)	0.05 (0.21)	5.00
43	645.56	0.01	102.74	0.00 (0.02)	0.09 (0.38)	0.00 (0.02)	5.00
44	666.24	0.01	106.04	0.01 (0.05)	0.00 (0.00)	0.06 (0.27)	5.00
45	667.15	0.01	106.18	0.00 (0.00)	0.26 (1.17)	0.03 (0.13)	5.00
46	681.22	0.01	108.42	0.06 (0.25)	0.03 (0.16)	0.09 (0.38)	5.00
47	699.19	0.01	111.28	0.00 (0.00)	0.01 (0.06)	0.00 (0.01)	5.00
48	712.99	0.01	113.48	0.02 (0.07)	0.01 (0.03)	0.01 (0.03)	5.00
49	735.43	0.01	117.05	0.06 (0.24)	0.00 (0.02)	0.09 (0.41)	5.00
50	744.27	0.01	118.45	0.00 (0.00)	0.00 (0.01)	0.07 (0.33)	5.00
51	754.83	0.01	120.14	0.22 (1.00)	0.00 (0.00)	0.09 (0.41)	5.00
52	771.88	0.01	122.85	0.02 (0.11)	0.00 (0.00)	0.00 (0.01)	5.00
53	783.92	0.01	124.77	0.01 (0.04)	0.00 (0.00)	0.00 (0.00)	5.00
54	799.06	0.01	127.17	0.01 (0.05)	0.00 (0.00)	0.08 (0.35)	5.00
55	810.55	0.01	129.00	0.00 (0.01)	0.01 (0.04)	0.02 (0.08)	5.00
56	823.98	0.01	131.14	0.07 (0.30)	0.00 (0.00)	0.00 (0.01)	5.00
57	826.28	0.01	131.51	0.04 (0.18)	0.00 (0.01)	0.04 (0.19)	5.00
58	837.07	0.01	133.22	0.05 (0.21)	0.03 (0.14)	0.00 (0.01)	5.00
59	841.11	0.01	133.87	0.01 (0.05)	0.02 (0.07)	0.02 (0.10)	5.00
60	845.57	0.01	134.58	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
61	856.34	0.01	136.29	0.01 (0.02)	0.00 (0.00)	0.01 (0.06)	5.00
62	868.02	0.01	138.15	0.00 (0.01)	0.01 (0.03)	0.01 (0.05)	5.00
63	875.90	0.01	139.40	0.00 (0.01)	0.07 (0.32)	0.04 (0.20)	5.00
64	886.84	0.01	141.15	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	5.00
65	898.10	0.01	142.94	0.00 (0.00)	0.00 (0.00)	0.04 (0.17)	5.00
66	911.37	0.01	145.05	0.01 (0.03)	0.08 (0.36)	0.01 (0.02)	5.00
67	932.07	0.01	148.34	0.01 (0.03)	0.01 (0.06)	0.08 (0.35)	5.00
68	940.32	0.01	149.66	0.00 (0.01)	0.00 (0.00)	0.00 (0.02)	5.00
69	954.84	0.01	151.97	0.00 (0.01)	0.01 (0.03)	0.01 (0.06)	5.00
70	972.78	0.01	154.82	0.00 (0.00)	0.01 (0.03)	0.00 (0.00)	5.00
71	986.23	0.01	156.96	0.00 (0.00)	0.00 (0.01)	0.01 (0.03)	5.00
72	989.21	0.01	157.44	0.00 (0.01)	0.01 (0.03)	0.00 (0.01)	5.00
73	999.76	0.01	159.12	0.00 (0.00)	0.01 (0.05)	0.00 (0.00)	5.00
74	1001.50	0.01	159.39	0.00 (0.00)	0.00 (0.00)	0.01 (0.03)	5.00
75	1011.48	0.01	160.98	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	5.00
76	1016.98	0.01	161.86	0.00 (0.00)	0.00 (0.00)	0.01 (0.03)	5.00
77	1046.79	0.01	166.60	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
78	1050.82	0.01	167.24	0.00 (0.00)	0.02 (0.08)	0.00 (0.00)	5.00
79	1057.15	0.01	168.25	0.00 (0.01)	0.00 (0.00)	0.01 (0.04)	5.00

Mode N°	Pulsation (Rad/s)	Period (s)	Frequency (Hz)	modal weight			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
80	1071.88	0.01	170.60	0.01 (0.03)	0.01 (0.06)	0.01 (0.02)	5.00
Total				**22.30 (99.14)**	**22.24 (98.90)**	**22.23 (98.87)**	

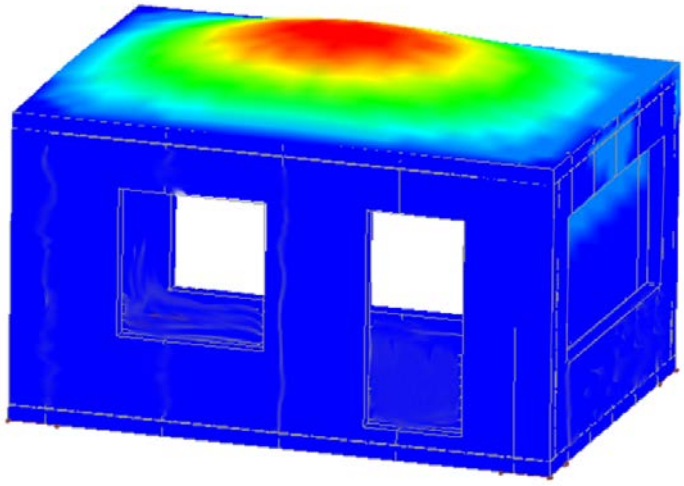
MODE 4



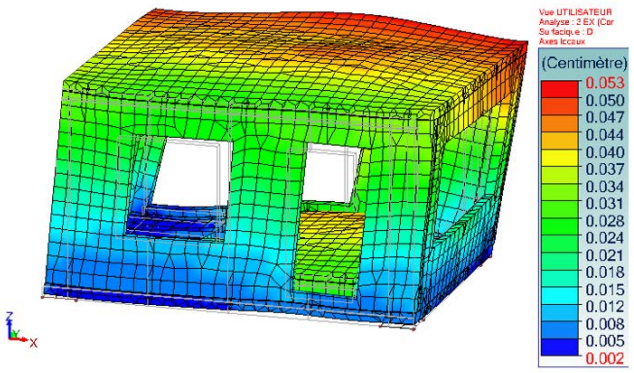
MODE 1



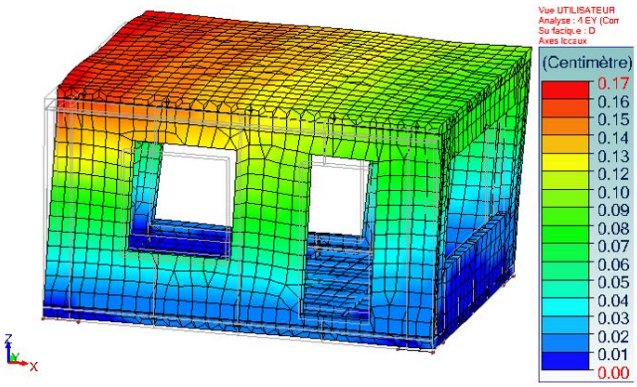
MODE 2



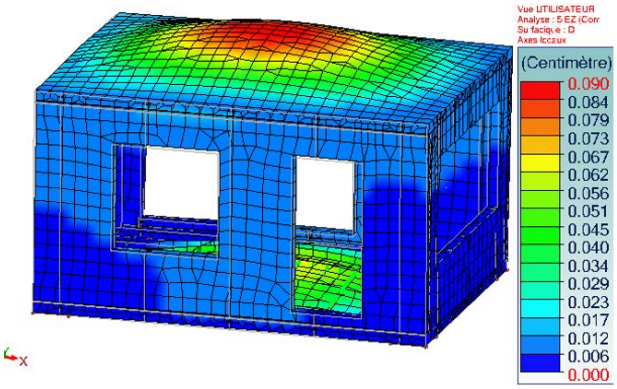
QUAKE DIRECTION X



QUAKE *DIRECTION Y*



QUAKE *DIRECTION Z*



DISPLACEMENT CONCLUSION - CASE 3 : THE DISPLACEMENTS IN THIS CASE ARE :

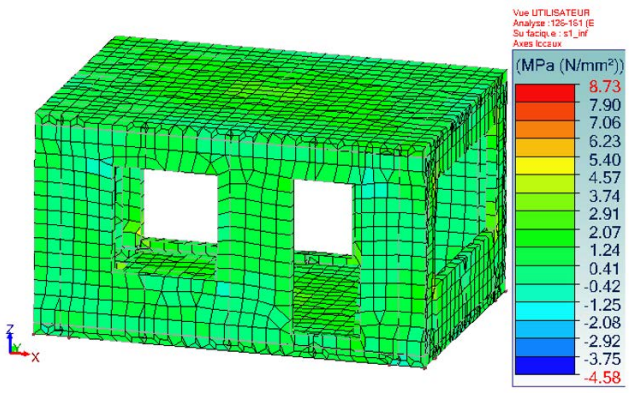
X (0.05 CM), Y (0.17 CM), Z (0.09 CM) GREW MUCH DIMER.

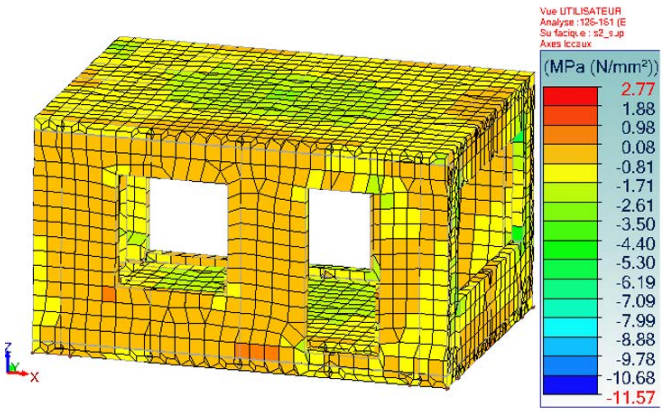
DMAX=0.17CM.

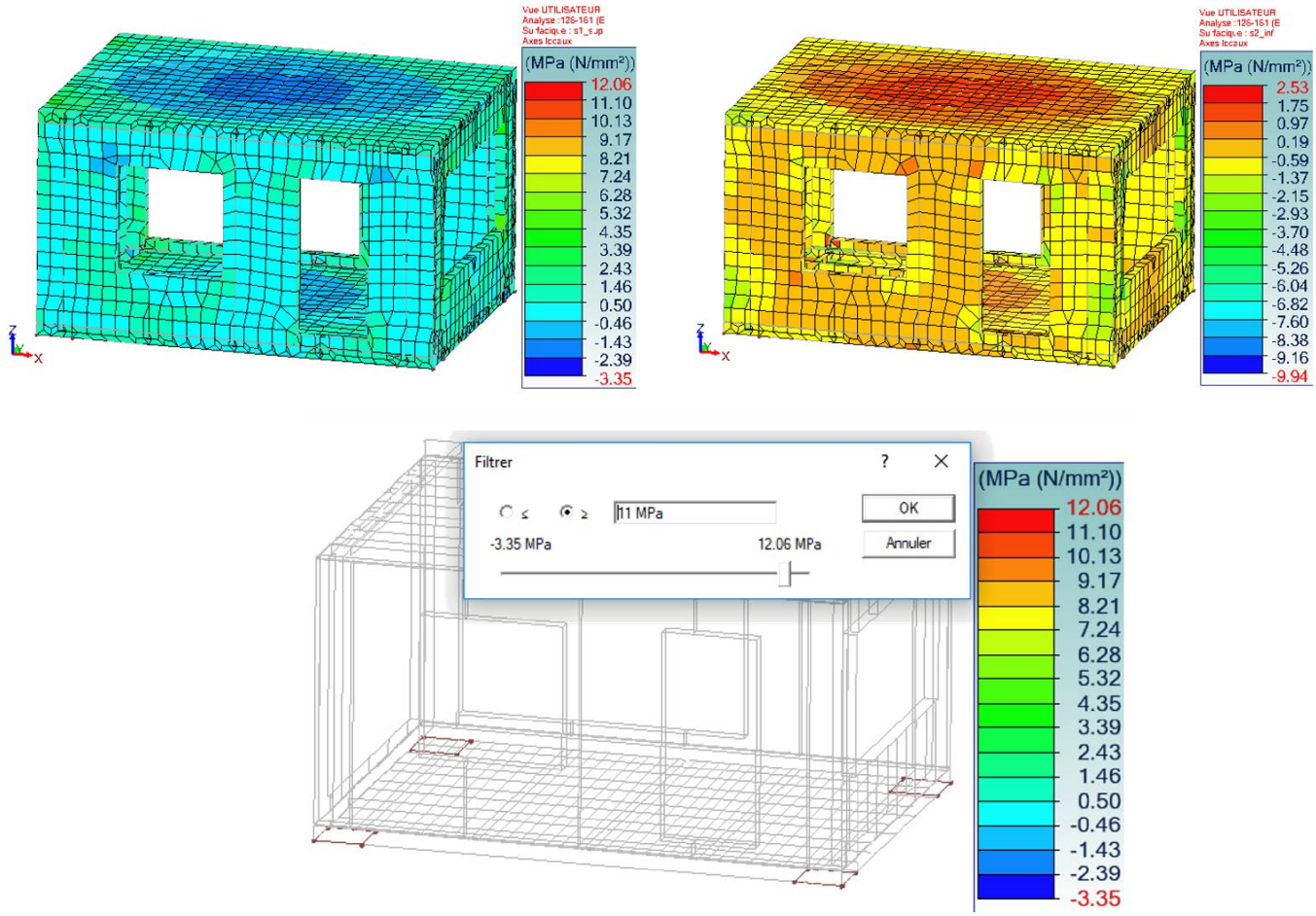
DAMAGE LIMITATION REQUESTS : DMAX≤ 0.005H/0.4 ? : VERIFIED (EC8-1 § 4.4.3).

THE CUBIK-HOME MODULE SHOULD BE FIXED TO THE FOUNDATION. TO SATISFY THE MAXIMUM HORIZONTAL STRESS ON THE SUPPORT, A M16 ROD PER CORNER (4 RODS IN TOTAL) SHOULD BE SUFFICIENT.

STRESS VERIFICATIONS





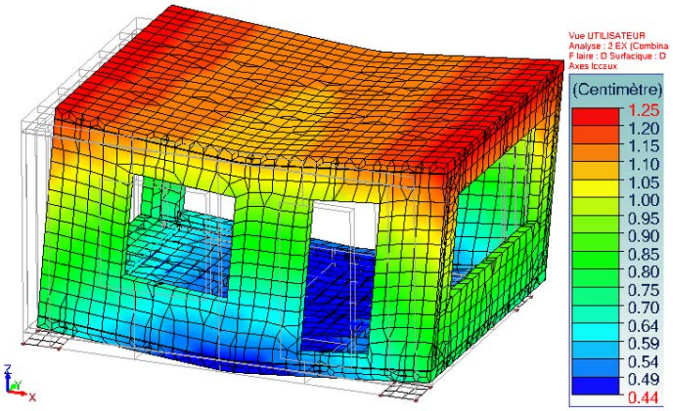


STRESS CONCLUSION - CASE 3: THE MAXIMUM TRACTION VALUE IS 12.06MPA. IT IS VERY LOCALISED. GLOBALLY THE STRESS IN THE WALLS ANS SLABS IS LESS THAN 11.0MPA (LAST SKETCH), THUS BELOW THE RESISTANCE OF THE FIBRE CONCRETE : NO CRACK IN THE MODULE.

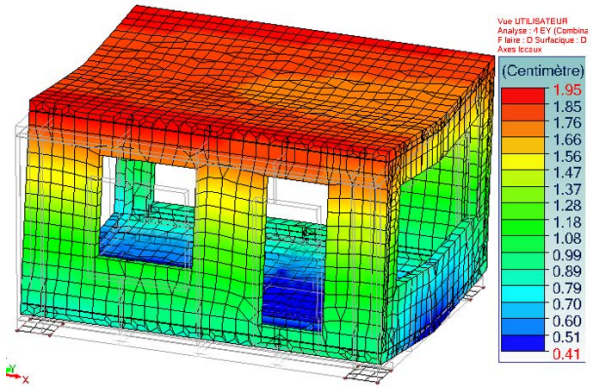
- CASE 4 : WITH A LOW STIFFNESS

Instead of a stiffness of 4.0×10^6 kN/m/m^2 in case of rin case of a total embedded foundation, we take a lower value of 4.0×10^4 kN/m/m^2 (equals 40MPa/m) in order to evaluate the effects on the results, which are given below.

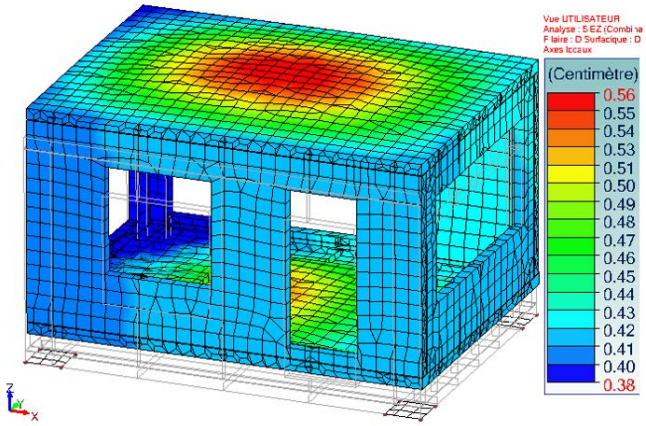
QUAKE DIRECTION X



QUAKE *DIRECTION Y*



QUAKE *DIRECTION Z*

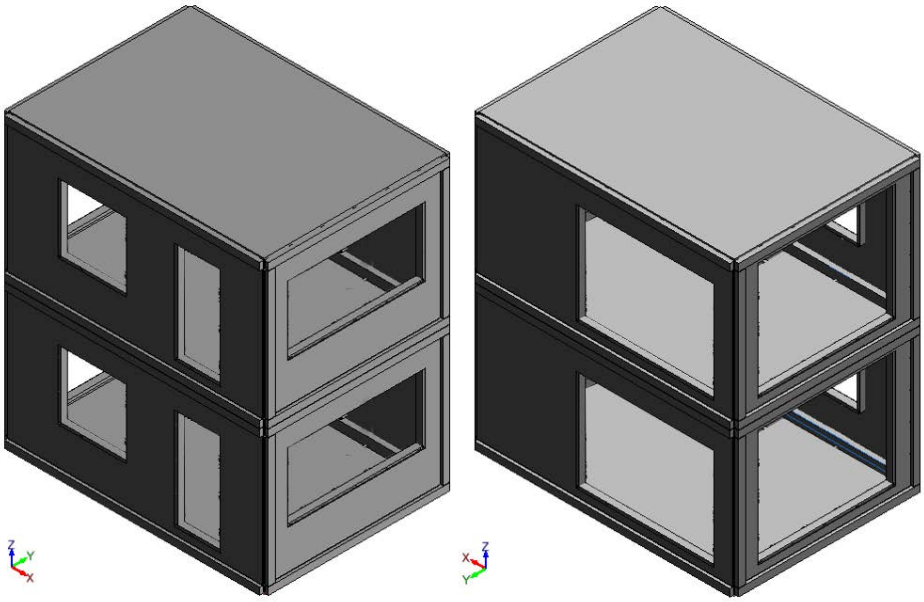


CONCLUSION : THOSE DISPLACEMENTS IN DIRECTIONS X (1.25 CM), Y (1.95 CM), Z (0.56 CM) INCREASED ONLY LIGHTLY COMPARED TO A FULLY EMBEDDED SOLUTION.

DMAX=1.95CM :

NO SECURITY RISKS. WHICH MEANS THAT EVEN WITH A LOW STIFFNESS, THE CUBIK-HOME SAFETY IS NOT AT STAKE.

VII.2/ 2 LEVEL MODULE



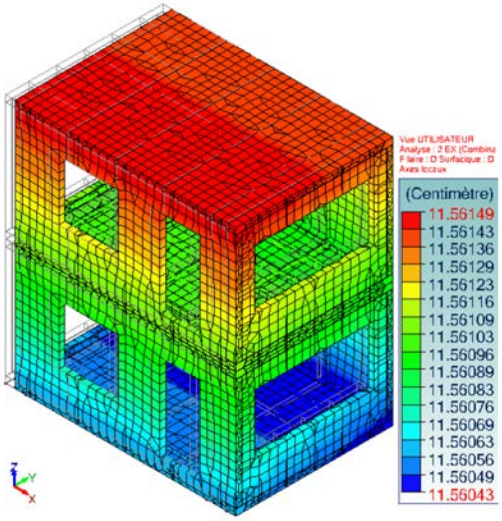
- CASE 1 : MODULE SIMPLY LAYING ON THE GROUND

In order to obtain a sum of the modal weights of 100% of the total weight in each direction, we used 6 modes with maximal frequency equal to 4.63Hz.

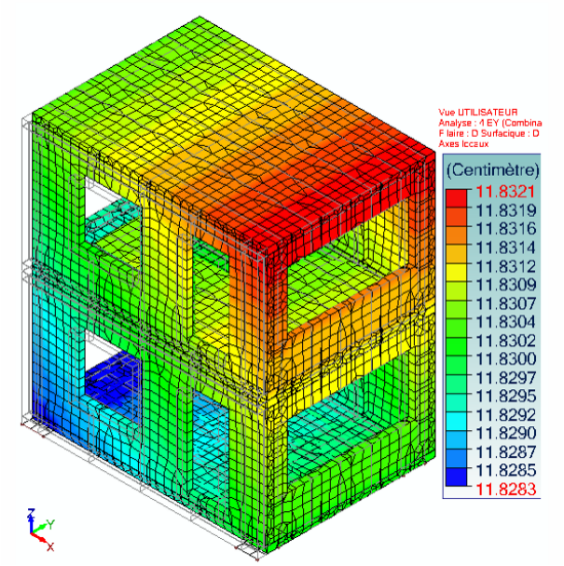
We used the spectral elastic response adapted to the long vibrating periods (>4s).
The maximum seismic displacements in the 3 main directions are given further

Mode N°	Pulsation (Rad/s)	Période (s)	Frequency (Hz)	modal weights			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
1	0.15	42.46	0.02	0.00 (0.00)	45.57 (100.00)	0.00 (0.00)	5.00
2	0.15	41.97	0.02	45.57 (100.00)	0.00 (0.00)	0.00 (0.00)	5.00
3	3.37	1.86	0.54	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00
4	19.98	0.31	3.18	0.00 (0.00)	0.00 (0.00)	0.02 (0.05)	5.00
5	26.08	0.24	4.15	0.00 (0.00)	0.00 (0.00)	1.07 (2.35)	5.00
6	29.10	0.22	4.63	0.00 (0.00)	0.00 (0.00)	44.39 (97.40)	5.00
Total				**45.57 (100.00)**	**45.57 (100.00)**	**45.48 (99.81)**	

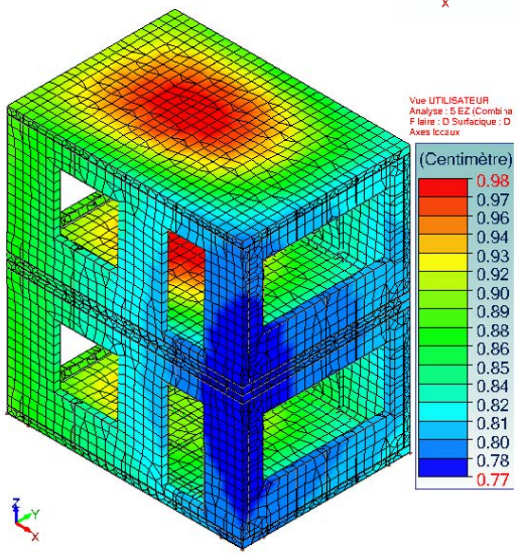
QUAKE DIRECTION X



QUAKE DIRECTION Y



QUAKE DIRECTION Z



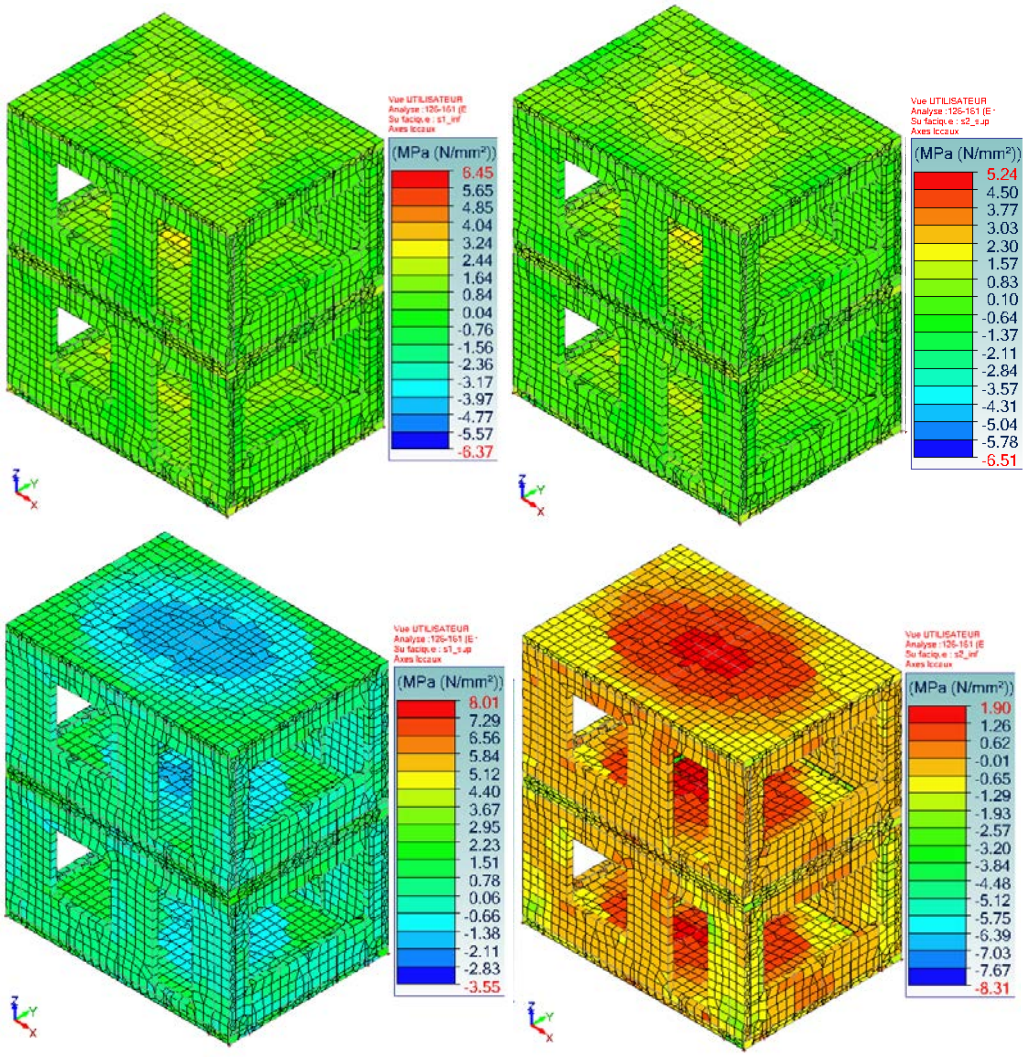
CONCLUSION DISPLACEMENT - CASE 1 : PER DIRECTIONS, THE VALUES ARE :

X (11.56 CM) - Y (11.83 CM) - Z (0.98).

DMAX=11.83CM

AS THE STRUCTURE IS NOT CONNECTED TO THE GROUND, , THERE ARE NO LIMITATION REQUESTS FOR DAMAGES

STRESSES VERIFICATION



STRESS CONCLUSIONS - CASE 1 :BY STUDYING THE MAXIMUM VALUES, WE DEDUCTE THAT NO NO CRACKS APPEAR. THE MAXIMUM VALUE IS 8.01MPA (VERY LOCALLY). WHICH IS BELOW THE TRACTION RESISTANCE OF THE FIBRE CONCRETE (11.0 MPA EXPERIMENTALY).

CASE 3 : HORIZONTALLY ATTACHED MODULES

100 frequency modes from 3.50Hz to 100.92Hz were used (Periods from 0.29s to 0.01s). the sum of the modal weights is minimum 90% of the total weight in each direction (acceptable pourcentage).

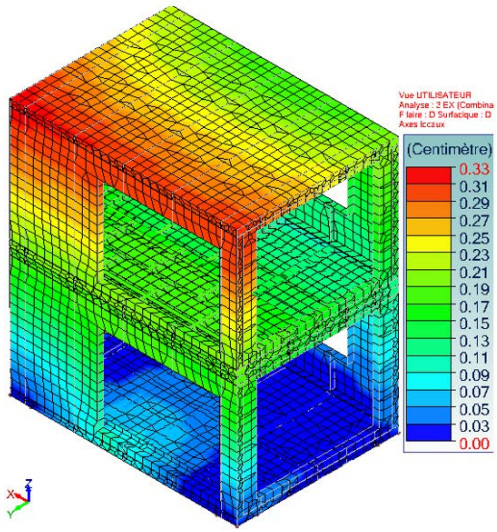
We used the spectral elastic response adapted to the long vibrating periods (>4s).
The maximum seismic displacements in the 3 main directions are given further

Mode N°	Pulsation (Rad/s)	Period (s)	Fréquency (Hz)	modal weights			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
1	39.50	0.16	6.29	0.26 (0.57)	30.94 (67.90)	0.02 (0.04)	5.00
2	64.41	0.10	10.25	25.99 (57.04)	1.04 (2.28)	0.44 (0.97)	5.00
3	90.26	0.07	14.36	1.94 (4.25)	0.10 (0.22)	10.60 (23.25)	5.00
4	94.01	0.07	14.96	1.69 (3.70)	0.33 (0.72)	0.20 (0.44)	5.00
5	95.35	0.07	15.18	3.33 (7.31)	0.84 (1.83)	1.13 (2.49)	5.00
6	103.88	0.06	16.53	0.01 (0.02)	0.02 (0.04)	3.16 (6.94)	5.00
7	125.04	0.05	19.90	0.01 (0.02)	2.81 (6.16)	0.01 (0.01)	5.00
8	179.52	0.04	28.57	0.41 (0.91)	0.00 (0.00)	0.01 (0.02)	5.00
9	187.88	0.03	29.90	0.14 (0.31)	0.00 (0.00)	0.01 (0.02)	5.00
10	206.36	0.03	32.84	0.01 (0.02)	0.09 (0.19)	0.00 (0.00)	5.00
11	208.12	0.03	33.12	0.00 (0.01)	0.18 (0.39)	0.00 (0.01)	5.00
12	215.32	0.03	34.27	0.02 (0.04)	0.01 (0.02)	0.23 (0.50)	5.00
13	217.80	0.03	34.66	0.08 (0.18)	0.07 (0.16)	2.66 (5.83)	5.00
14	221.20	0.03	35.20	0.38 (0.83)	0.17 (0.38)	8.37 (18.36)	5.00
15	225.97	0.03	35.96	0.04 (0.09)	0.18 (0.39)	14.16 (31.07)	5.00
16	229.65	0.03	36.55	0.02 (0.04)	0.00 (0.00)	0.00 (0.00)	5.00
17	242.68	0.03	38.62	3.65 (8.01)	0.00 (0.01)	1.53 (3.35)	5.00
18	264.05	0.02	42.02	0.16 (0.35)	0.01 (0.01)	0.01 (0.01)	5.00
19	269.59	0.02	42.91	0.32 (0.71)	0.01 (0.03)	0.00 (0.01)	5.00
20	281.11	0.02	44.74	0.08 (0.18)	0.00 (0.01)	0.10 (0.22)	5.00
21	287.34	0.02	45.73	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	5.00
22	291.02	0.02	46.32	0.03 (0.07)	0.00 (0.00)	0.01 (0.02)	5.00
23	306.99	0.02	48.86	0.13 (0.28)	0.00 (0.01)	0.01 (0.02)	5.00
24	311.82	0.02	49.63	0.00 (0.00)	0.00 (0.00)	0.01 (0.03)	5.00
25	315.36	0.02	50.19	0.13 (0.28)	0.00 (0.01)	0.00 (0.00)	5.00
26	330.29	0.02	52.57	0.02 (0.05)	0.04 (0.08)	0.04 (0.09)	5.00
27	334.06	0.02	53.17	0.02 (0.03)	0.03 (0.07)	0.20 (0.43)	5.00
28	343.17	0.02	54.62	0.00 (0.00)	0.00 (0.00)	0.43 (0.95)	5.00
29	350.09	0.02	55.72	0.00 (0.00)	0.01 (0.03)	0.63 (1.38)	5.00
30	359.84	0.02	57.27	0.00 (0.00)	0.00 (0.00)	0.14 (0.31)	5.00
31	363.32	0.02	57.82	0.00 (0.01)	0.00 (0.01)	0.00 (0.00)	5.00
32	381.66	0.02	60.74	0.00 (0.00)	0.07 (0.15)	0.00 (0.00)	5.00
33	390.68	0.02	62.18	0.00 (0.01)	0.18 (0.39)	0.00 (0.00)	5.00
34	399.52	0.02	63.59	0.02 (0.04)	0.05 (0.10)	0.00 (0.00)	5.00
35	401.18	0.02	63.85	0.04 (0.10)	0.01 (0.02)	0.01 (0.02)	5.00
36	415.39	0.02	66.11	0.01 (0.03)	0.00 (0.01)	0.02 (0.04)	5.00
37	425.94	0.01	67.79	0.00 (0.01)	0.04 (0.08)	0.00 (0.01)	5.00
38	432.02	0.01	68.76	0.02 (0.03)	0.00 (0.01)	0.18 (0.39)	5.00
39	437.56	0.01	69.64	0.01 (0.02)	0.21 (0.46)	0.01 (0.03)	5.00
40	450.23	0.01	71.66	0.15 (0.33)	0.04 (0.08)	0.03 (0.06)	5.00

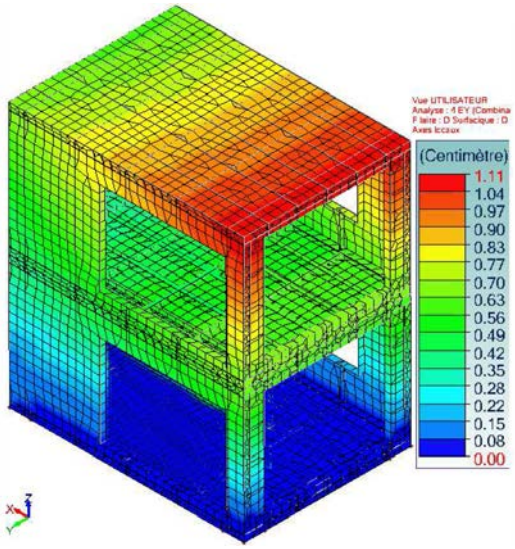
Mode N°	Pulsation (Rad/s)	Period (s)	Fréquency (Hz)	modal weights			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
41	460.33	0.01	73.26	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	5.00
42	467.91	0.01	74.47	0.00 (0.01)	0.08 (0.18)	0.00 (0.00)	5.00
43	470.20	0.01	74.84	0.00 (0.01)	0.10 (0.23)	0.01 (0.03)	5.00
44	476.44	0.01	75.83	0.01 (0.01)	0.05 (0.11)	0.00 (0.00)	5.00
45	479.14	0.01	76.26	0.00 (0.01)	0.02 (0.04)	0.03 (0.07)	5.00
46	483.98	0.01	77.03	0.04 (0.08)	0.91 (2.01)	0.00 (0.00)	5.00
47	491.40	0.01	78.21	0.01 (0.02)	0.00 (0.00)	0.00 (0.01)	5.00
48	501.69	0.01	79.85	0.01 (0.02)	0.01 (0.03)	0.00 (0.00)	5.00
49	504.68	0.01	80.32	0.00 (0.00)	2.52 (5.52)	0.00 (0.00)	5.00
50	508.21	0.01	80.88	0.01 (0.02)	0.17 (0.37)	0.00 (0.00)	5.00
51	517.90	0.01	82.43	0.33 (0.72)	0.17 (0.37)	0.02 (0.04)	5.00
52	520.98	0.01	82.92	0.02 (0.05)	0.03 (0.06)	0.00 (0.01)	5.00
53	523.80	0.01	83.36	0.36 (0.79)	0.07 (0.15)	0.01 (0.02)	5.00
54	528.53	0.01	84.12	0.15 (0.33)	0.22 (0.48)	0.00 (0.00)	5.00
55	538.40	0.01	85.69	0.12 (0.27)	0.61 (1.34)	0.00 (0.00)	5.00
56	554.61	0.01	88.27	1.40 (3.06)	0.07 (0.15)	0.02 (0.05)	5.00
57	556.22	0.01	88.53	0.03 (0.06)	0.03 (0.05)	0.04 (0.09)	5.00
58	561.75	0.01	89.40	0.12 (0.26)	0.21 (0.45)	0.00 (0.00)	5.00
59	565.14	0.01	89.95	0.00 (0.01)	0.01 (0.02)	0.01 (0.02)	5.00
60	566.13	0.01	90.10	0.08 (0.17)	0.02 (0.04)	0.01 (0.02)	5.00
61	575.57	0.01	91.60	0.03 (0.06)	0.77 (1.69)	0.00 (0.00)	5.00
62	580.84	0.01	92.44	0.24 (0.54)	0.22 (0.48)	0.01 (0.02)	5.00
63	586.97	0.01	93.42	0.45 (0.98)	0.20 (0.44)	0.00 (0.00)	5.00
64	594.50	0.01	94.62	0.31 (0.68)	0.04 (0.09)	0.05 (0.11)	5.00
65	604.84	0.01	96.26	0.22 (0.48)	0.08 (0.17)	0.01 (0.01)	5.00
66	609.10	0.01	96.94	0.01 (0.03)	0.01 (0.02)	0.01 (0.02)	5.00
67	610.03	0.01	97.09	0.16 (0.35)	0.31 (0.68)	0.02 (0.03)	5.00
68	619.04	0.01	98.52	0.00 (0.01)	0.07 (0.14)	0.01 (0.02)	5.00
69	626.21	0.01	99.66	0.75 (1.65)	0.01 (0.03)	0.03 (0.07)	5.00
70	638.55	0.01	101.63	0.02 (0.04)	0.07 (0.15)	0.01 (0.01)	5.00
71	639.99	0.01	101.86	0.26 (0.57)	0.14 (0.30)	0.00 (0.00)	5.00
72	644.60	0.01	102.59	0.07 (0.15)	0.00 (0.01)	0.01 (0.01)	5.00
73	655.49	0.01	104.32	0.05 (0.11)	0.01 (0.02)	0.02 (0.04)	5.00
74	662.06	0.01	105.37	0.01 (0.03)	0.02 (0.04)	0.01 (0.02)	5.00
75	667.15	0.01	106.18	0.02 (0.04)	0.24 (0.52)	0.00 (0.00)	5.00
76	677.61	0.01	107.85	0.30 (0.65)	0.00 (0.00)	0.02 (0.05)	5.00
77	682.06	0.01	108.55	0.01 (0.01)	0.00 (0.00)	0.06 (0.13)	5.00
78	686.18	0.01	109.21	0.02 (0.05)	0.01 (0.01)	0.03 (0.07)	5.00
79	695.29	0.01	110.66	0.00 (0.00)	0.04 (0.08)	0.01 (0.02)	5.00
80	701.55	0.01	111.66	0.06 (0.13)	0.00 (0.00)	0.01 (0.02)	5.00
81	702.32	0.01	111.78	0.00 (0.01)	0.01 (0.02)	0.07 (0.16)	5.00
82	720.37	0.01	114.65	0.00 (0.01)	0.00 (0.00)	0.01 (0.02)	5.00
83	723.63	0.01	115.17	0.01 (0.02)	0.00 (0.01)	0.01 (0.01)	5.00
84	733.52	0.01	116.74	0.05 (0.12)	0.00 (0.00)	0.00 (0.00)	5.00
85	737.55	0.01	117.38	0.00 (0.01)	0.01 (0.01)	0.01 (0.03)	5.00
86	743.19	0.01	118.28	0.04 (0.08)	0.00 (0.00)	0.00 (0.00)	5.00
87	750.17	0.01	119.39	0.24 (0.52)	0.00 (0.00)	0.01 (0.02)	5.00
88	772.30	0.01	122.92	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	5.00
89	776.46	0.01	123.58	0.01 (0.03)	0.00 (0.00)	0.00 (0.00)	5.00
90	785.80	0.01	125.06	0.00 (0.00)	0.00 (0.00)	0.03 (0.07)	5.00

Mode N°	Pulsation (Rad/s)	Period (s)	Fréquency (Hz)	modal weights			Damping (%)
				X T (%)	Y T (%)	Z T (%)	
91	788.56	0.01	125.50	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	5.00
92	801.39	0.01	127.55	0.01 (0.02)	0.00 (0.01)	0.00 (0.00)	5.00
93	806.46	0.01	128.35	0.00 (0.01)	0.00 (0.01)	0.03 (0.06)	5.00
94	815.62	0.01	129.81	0.02 (0.05)	0.00 (0.00)	0.01 (0.01)	5.00
95	819.75	0.01	130.47	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
96	822.24	0.01	130.86	0.01 (0.03)	0.00 (0.00)	0.00 (0.00)	5.00
97	829.22	0.01	131.98	0.00 (0.01)	0.00 (0.00)	0.01 (0.01)	5.00
98	835.32	0.01	132.94	0.04 (0.09)	0.04 (0.09)	0.02 (0.04)	5.00
99	837.44	0.01	133.28	0.01 (0.02)	0.00 (0.00)	0.04 (0.08)	5.00
100	838.21	0.01	133.41	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	5.00
Total				**45.31 (99.42)**	**45.08 (98.92)**	**45.08 (98.91)**	

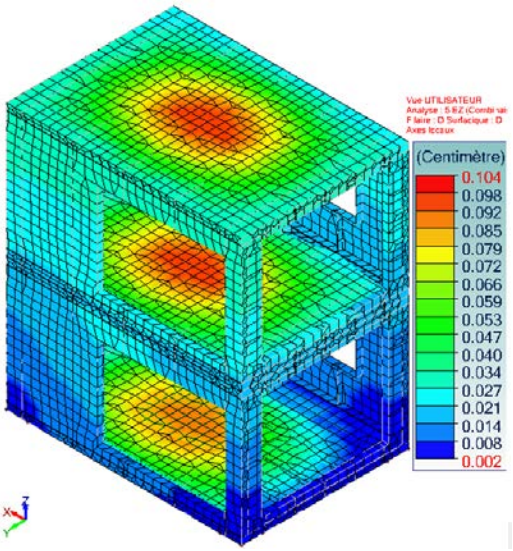
QUAKE DIRECTION X



QUAKE DIRECTION Y



QUAKE DIRECTION Z

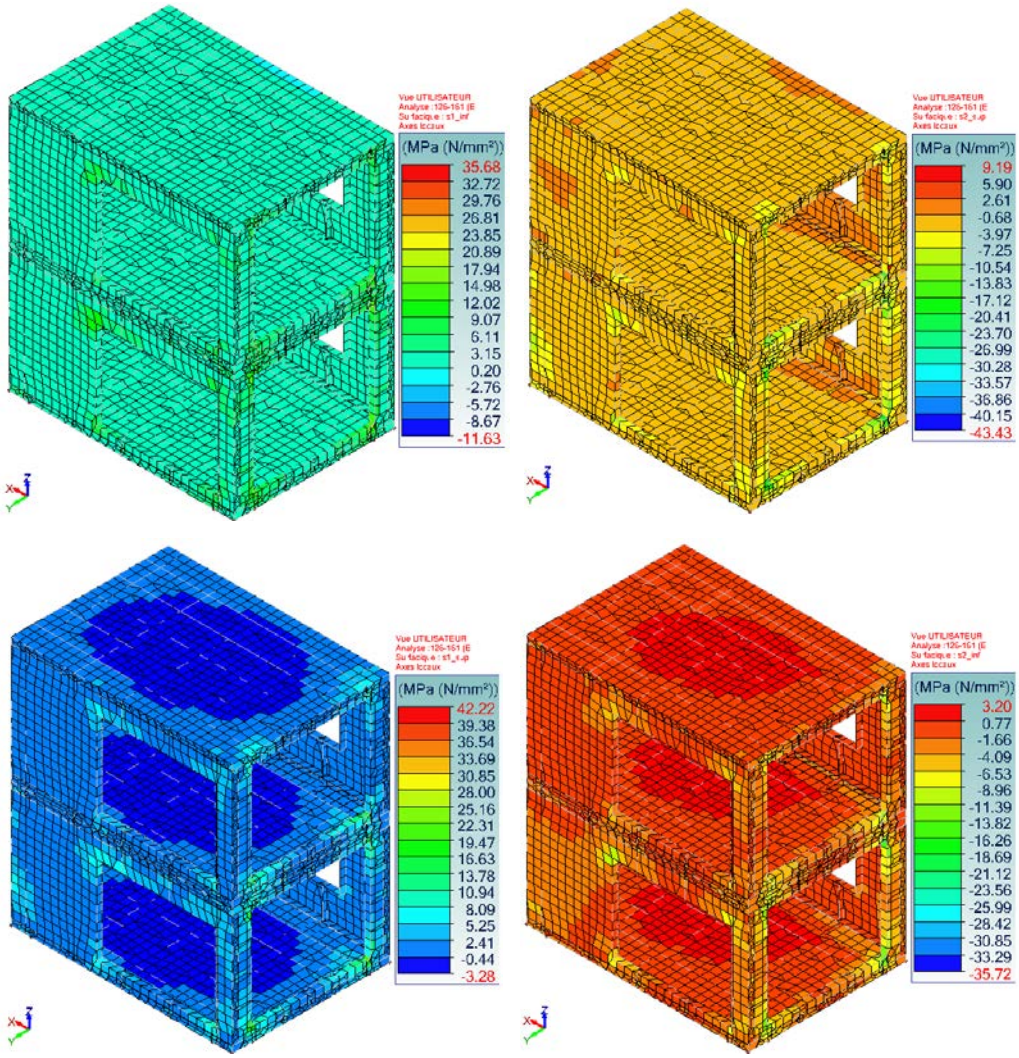


DISPLACEMENT CONCLUSIONS - CASE 3 : QUAKE DISPLACEMENTS IN DIRECTIONS X (0.33 CM), Y (1.11 CM), Z (0.104 CM) HAVE GROWN DIM.

DMAX=1.11CM.

DAMAGE LIMITATION REQUEST : DMAX ≤ 0.005H/0.4 ? : VERIFIED (EC8-1 § 4.4.3)

VERIFICATION DES CONTRAINTES



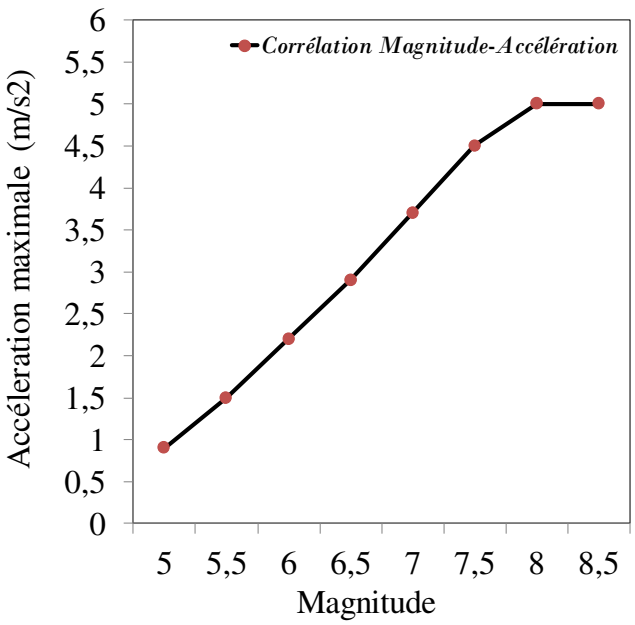
STRESSES CONCLUSION - CASE 3 : THE MAXIMAL TRACTION IS 42.22MPA (VERY LOCAL). THIS STRESS IS REALLY LOCAL IN SOME SPECIFIC PLACES MAINLY NEARBY THE SINGULARITIES. THE MEAN STRESS ON MOST OF THE FACES OF THE MODULE IS LOWER THAN 11.0MPA (LAST SKETCH), THUS BELOW THE TRACTION RESISTANCE OF THE FIBRE CONCRETE: **LITTLE CRACKINGS VERY LOCAL, NEAR THE SINGULARITIES.**

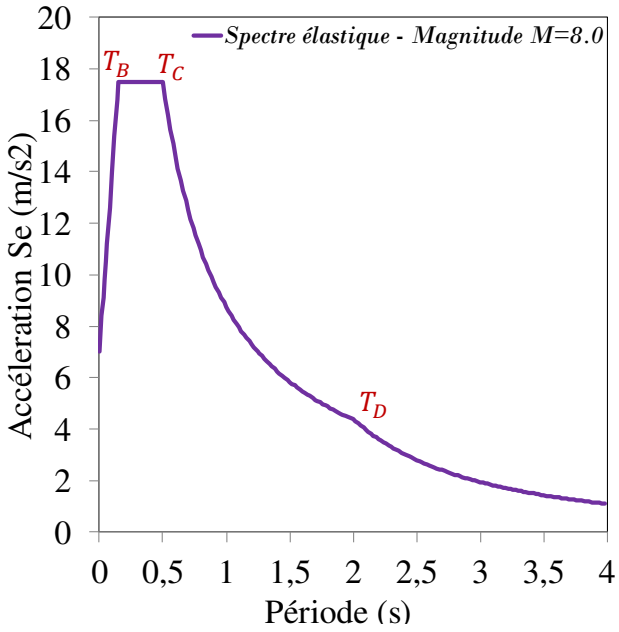
VIII/ NUMERICAL RESULTS: EARTHQUAKE MAGNITUDE M=8.0 8.5

Both Magnitude M>8 according to Richter scale have the same maximum soil acceleration -see below- [Journée technique parasismique, 2013]. We will take a soil accélération of 5.0 m/s^2. The spectral elastic response used is adapted to vibration périods that can be long
For the limit conditions, we take 2 cases résults:

- Just laying modules (horizontal displacements allowed), et
- Horizontally attached modules (X+Y) (horizontal stiffness of 4.10^6 kN/m/m^2).

Magnitude	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5
Accélération maximale [m/s^2]	0.9	1.5	2.2	2.9	3.7	4.5	5.0	5.0

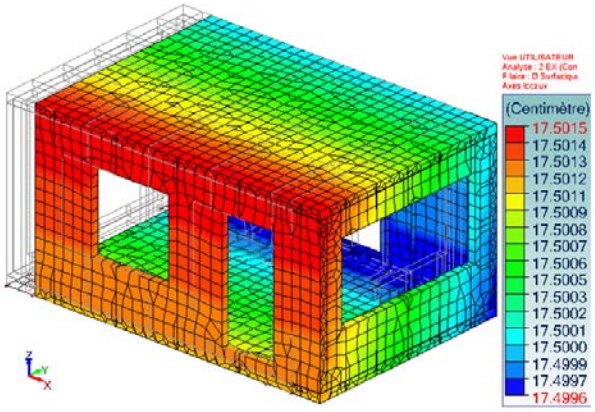




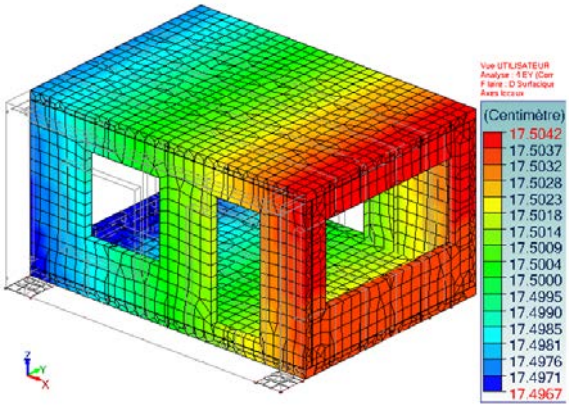
VIII.1/ 1 LEVEL MODULE

- CASE 1 : JUST LAYING MODULES

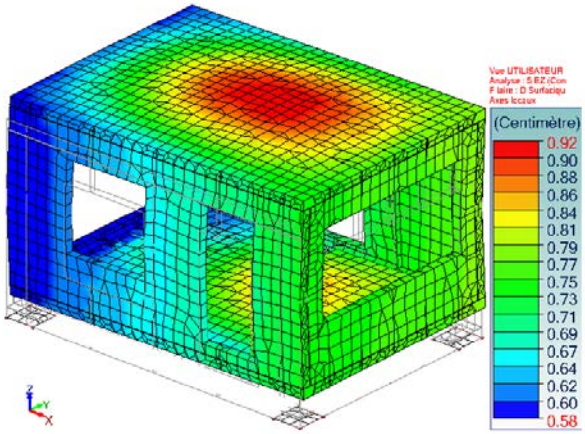
QUAKE DIRECTION X



QUAKE DIRECTION Y

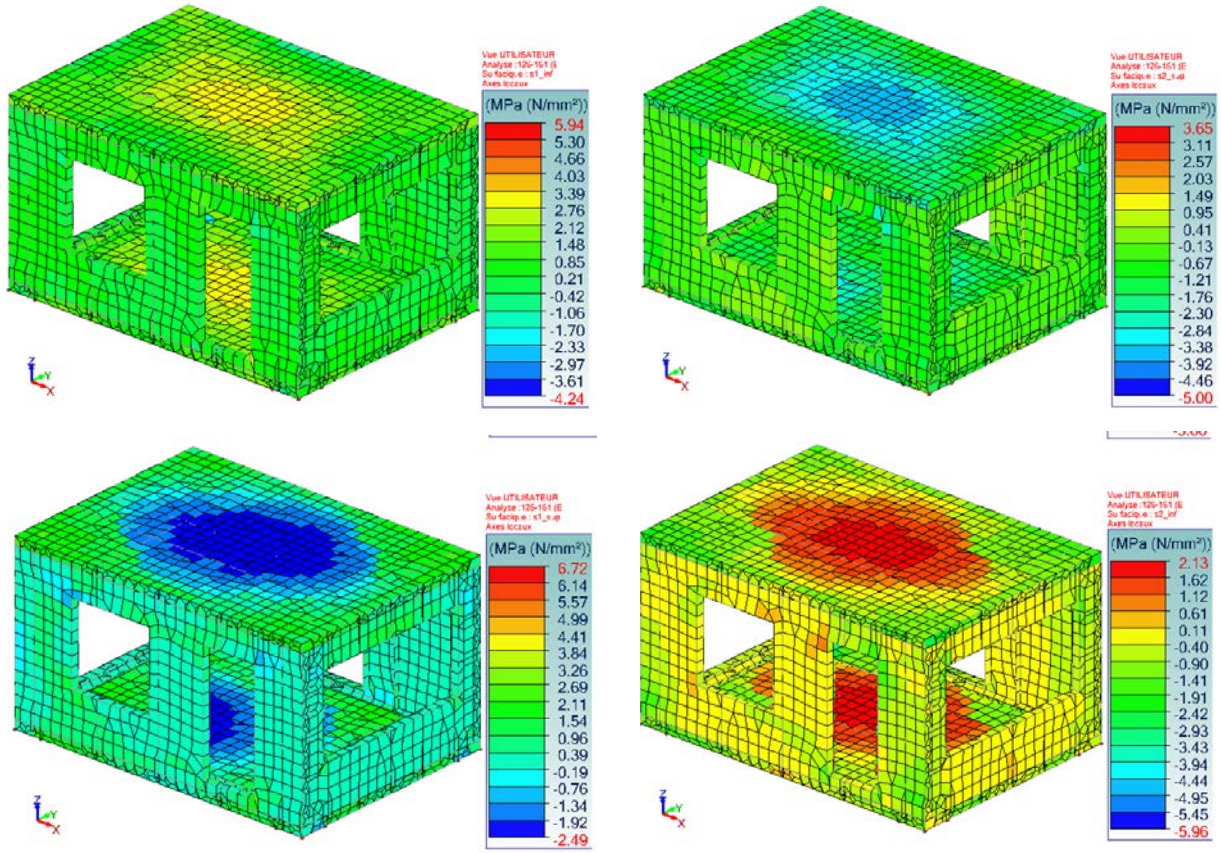


QUAKE DIRECTION Z



DISPLACEMENT CONCLUSION - CASE 1 : DISPLACEMENTS IN DIRECTIONS X (17.5 CM) - Y (17.5 CM) - Z (0.92 CM) ARE HIGHER THAN IN ZONE 5 EARTHQUAKE.
DMAX=17.5CM. AS THE STRUCTURE IS NOT LINKED TO THE GROUND : NO DAMAGE LIMITATION REQUESTED

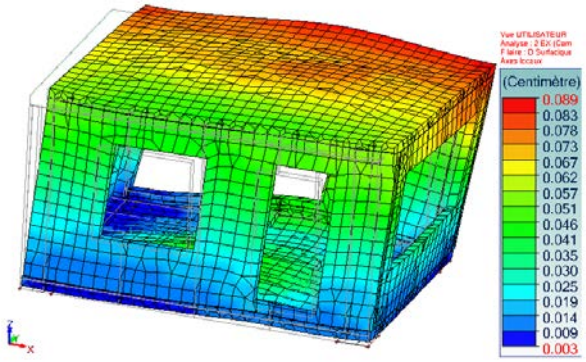
STRESSES VERIFICATION



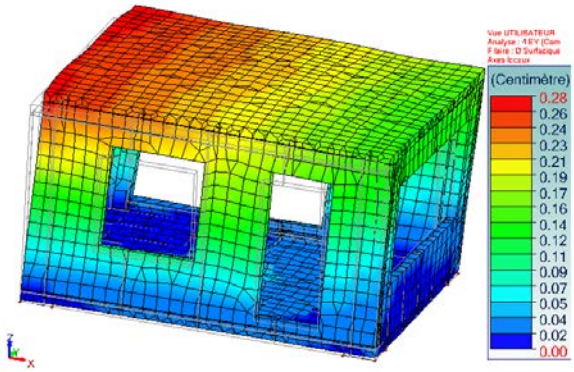
STRESS CONCLUSION - CASE 1 : BASED ON THE MAXIMUM STRESS VALUES, NO CRACKS APPEAR. THE MAXIMAL VALUE IS 6.72MPA (VERY LOCAL). THIS VALUE IS LOWER THAN THE TRACTION RESISTANCE OF THE FIBRE CONCRETE WHICH IS 11.0 MPA (EXPERIMENTALLY).

- CAS 3 : HORIZONTALLY ATTACHED MODULE

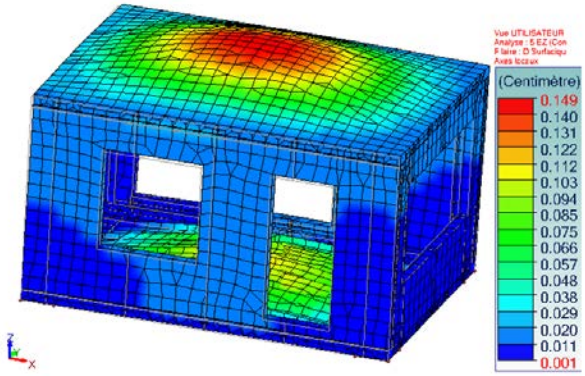
QUAKE DIRECTION X



QUAKE DIRECTION Y



QUAKE DIRECTION Z

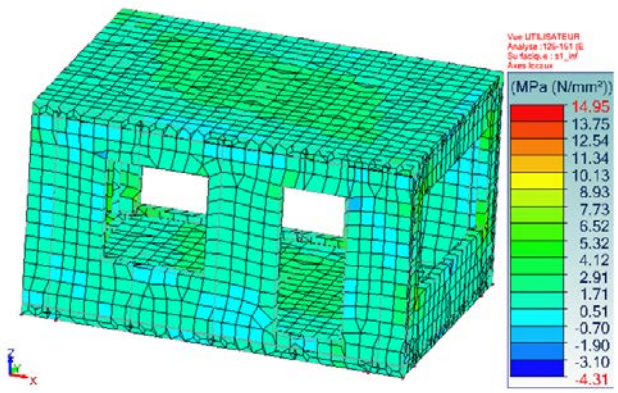


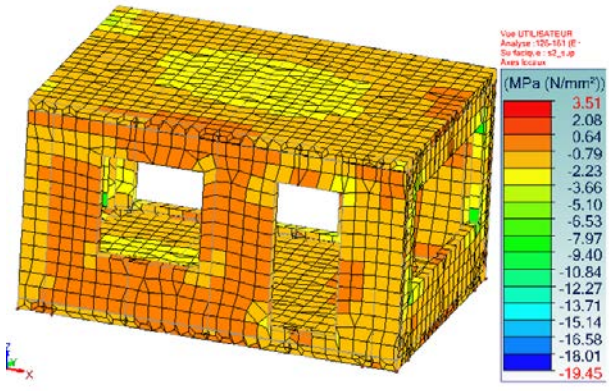
DISPLACEMENT CONCLUSION - CASE 3 : DISPLACEMENTS IN DIRECTIONS X (0.09 CM), Y (0.28 CM), Z (0.15 CM) ARE HIGHER THAN IN A ZONE 5 EARTHQUAKE.

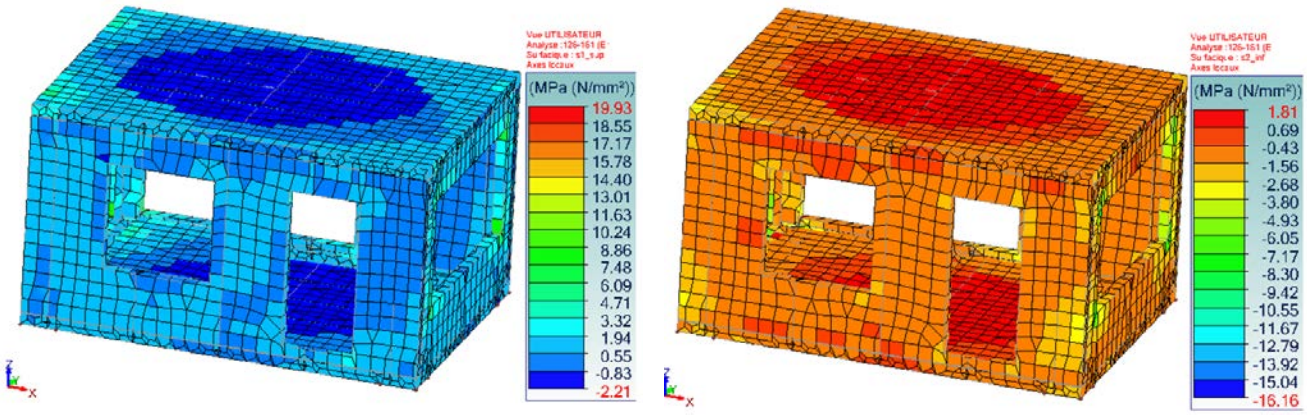
D_{MAX}=0.28CM.

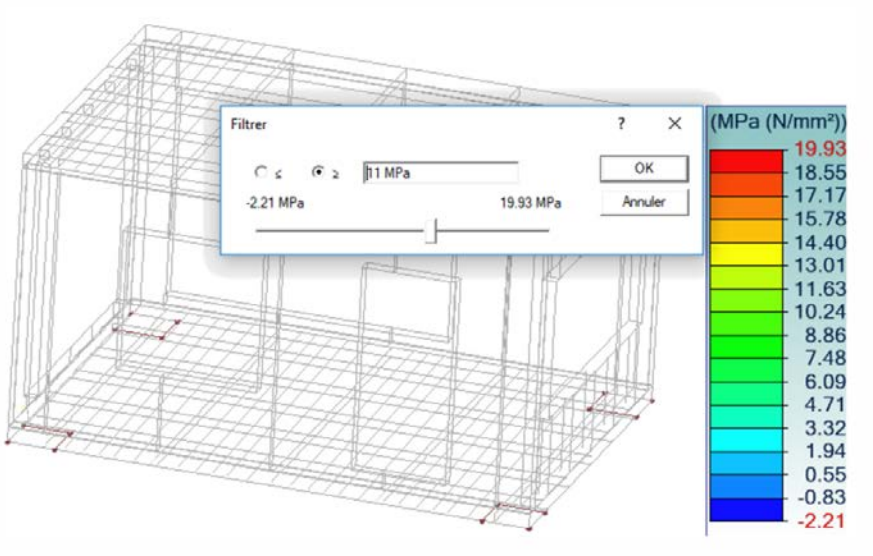
DAMAGES LIMITATION REQUEST : $D_{MAX} \leq 0.005H/0.4$? VERIFIED (EC8-1 § 4.4.3)

STRESSES VERIFICATION







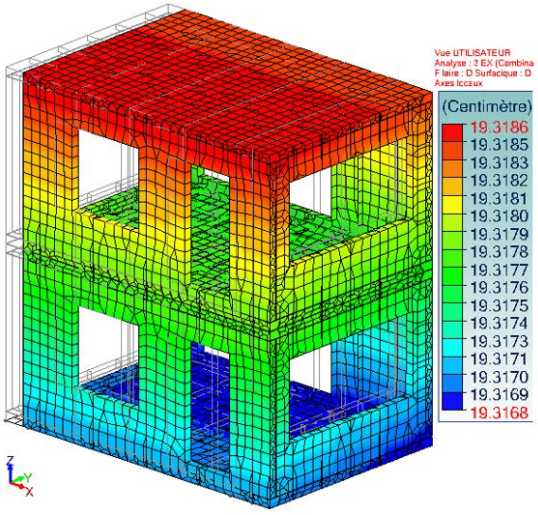


STRESSES CONCLUSION - CASE 3: MAXIMAL TRACTION STRESS IS 19.93MPA. IT IS VERY LOCAL. THE MEAN VALUE ON THE FACES OF THE MODULE IS BELOW 11.0MPA (LAST SKETCH), THUS BELOW THE TRACTION RESISTANCE OF THE FIBRE CONCRETE : NO CRACKS IN THE MODULE

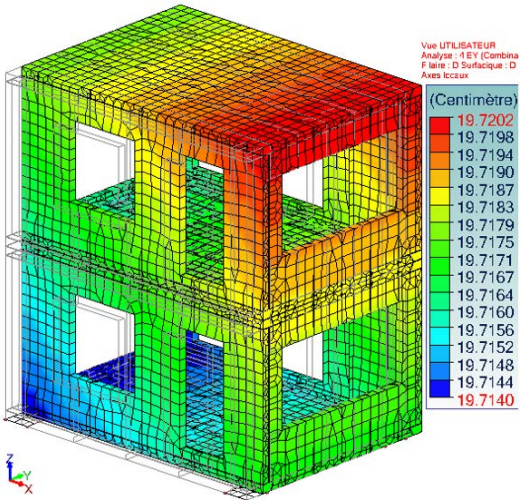
VIII.2/ 2 LEVEL MODULE

- CAS 1 : MODULES SIMPLY LAYING ON THE GROUND

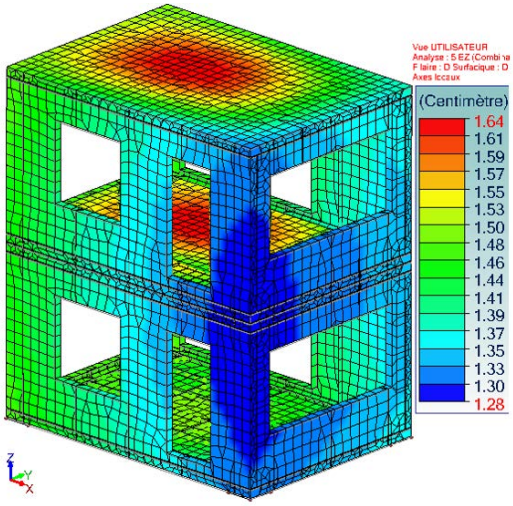
QUAKE DIRECTION X



QUAKE DIRECTION Y

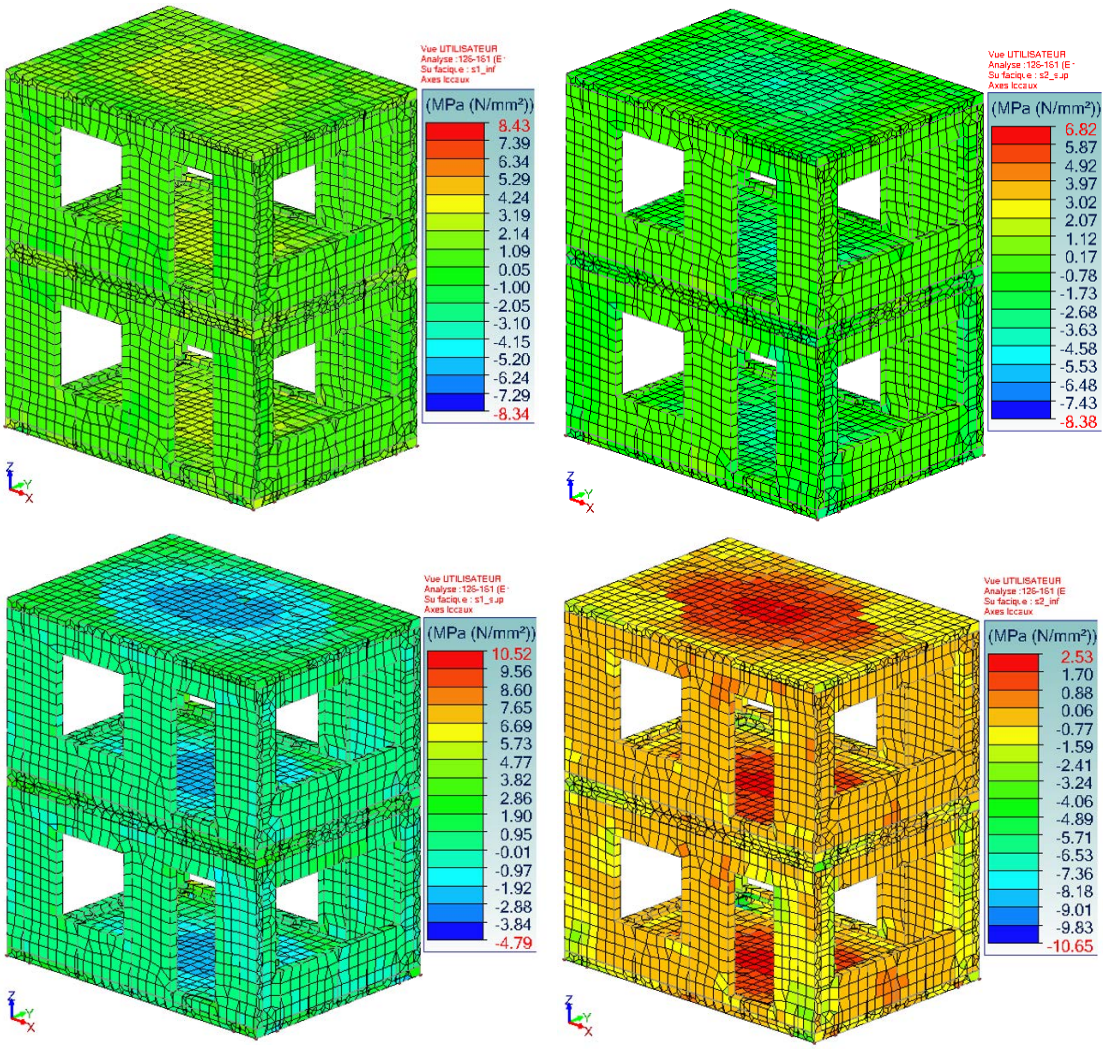


QUAKE DIRECTION Z



DISPLACEMENT CONCLUSION - CASE 1 : DISPLACEMENTS IN DIRECTIONS X (19.32 CM) - Y (19.72 CM) - Z (1.64 CM) ARE HIGHER THAN FOR ZONE 5 EARTHQUAKE.
DMAX=19.72CM.
AS THE STRUCTURE IS NOT ATTACHED TO THE GROUND : NO DAMAGE LIMITATION REQUESTED

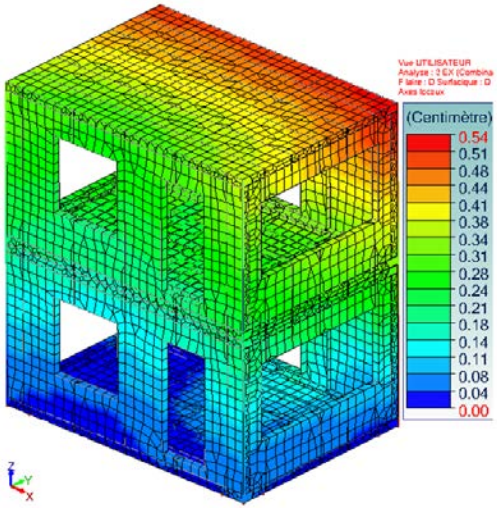
STRESS VERIFICATION



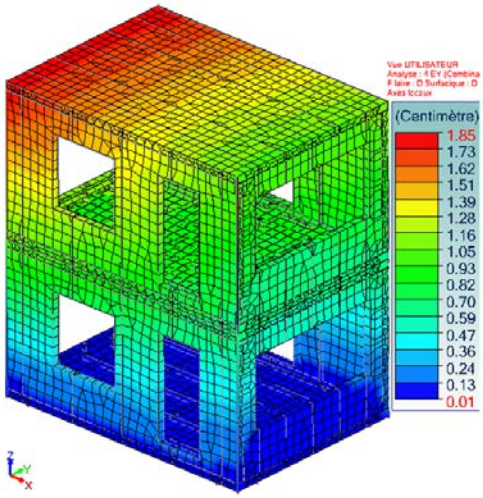
STRESS CONCLUSION - CASE 1: BASED ON THE MAXIMUM TRACTION STRESS VALUES, IT SHOWS THAT NO CRACKING APPEARS IN THE MODULE. THE MAXIMAL VALUE IS 10.52 MPA (VERY LOCAL). THIS VALUE IS LOWER THAN THE TRACTION RESISTANCE OF THE FIBRE CONCRETE WHICH IS 11.0 MPA (EXPERIMENTALLY).

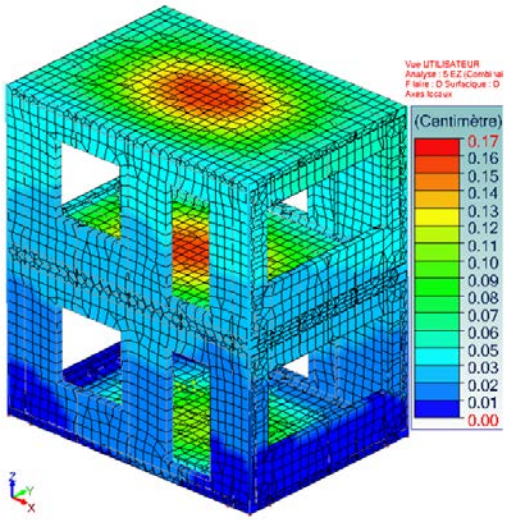
- CAS 3 : HORIZONTALLY ATTACHED MODULES

QUAKE DIRECTION X



QUAKE DIRECTION Y



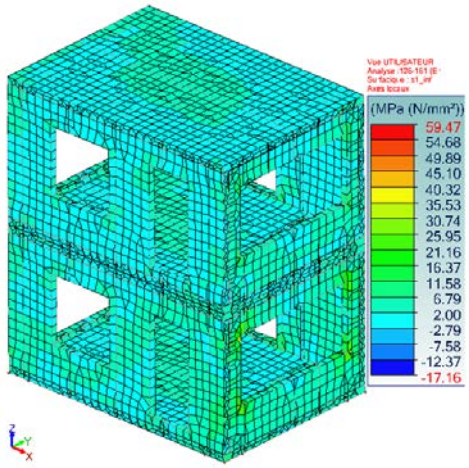


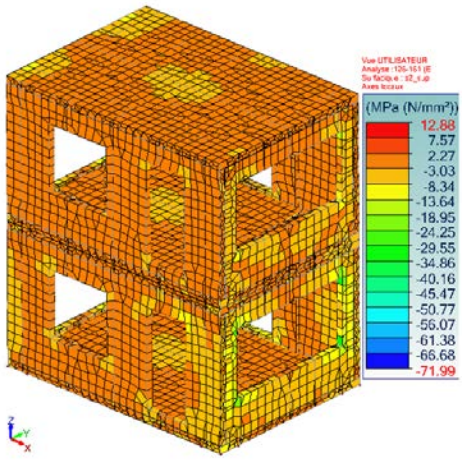
QUAKE DIRECTION Z

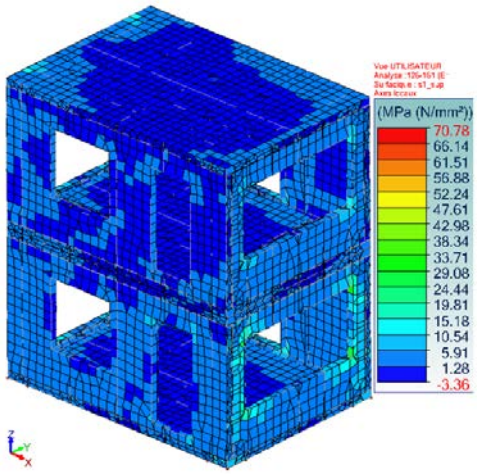
DISPLACEMENT CONCLUSION - CASE 3 : DISPLACEMENTS IN DIRECTIONS X (0.54 CM), Y (1.85 CM), Z (0.17 CM) ARE HIGHER THAN FOR ZONE 5 EARTHQUAKE.

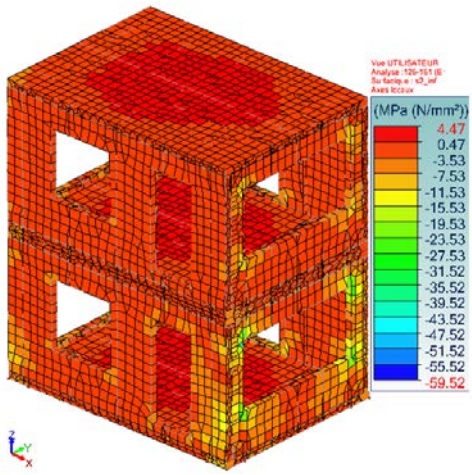
DMAX=1.85CM.

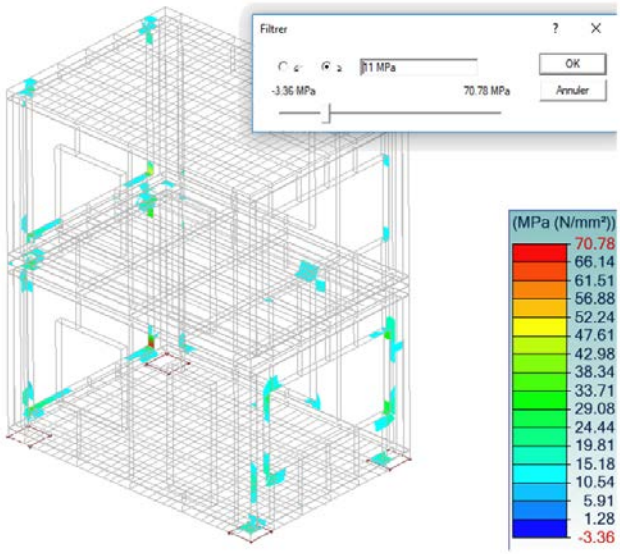
DAMAGE LIMITATION REQUEST : DMAX ≤ 0.005H/0.4 ? : VERIFIED (EC8-1 § 4.4.3)











CONCLUSION : THE MAXIMALE TRACTION IS 70.78 MPA (VERY LOCAL). THIS STRESS IS VERY LOCAL AND JUST A FEW 15 MPA ARE SET NEAR SOME SINGULARITIES. MOST OF THE STRESS ON THE FACES OF THE MODULES IS BELOW 11.0MPA (LAST SKETCH), THUS BELOW THE TRACTION RESISTANCE OF THIS FIBRE CONCRETE: ONLY A FEW LOCALIZED CRACKS NEAR THE SINGULARITIES.

IX/ DESIGN SUMMARIZED CONCLUSIONS

1 LEVEL MODULE

EARTHQUAKE	JUST LAYING			HORIZONTALLY ATTACHED		
	Displacement max [cm]	Displacement request EC8	Acceptable cracking	Displacement max [cm]	Displacement request EC8	Acceptable cracking
ZONE 5	10.5	-	☑	0.2	☑	☑
M = 8/8.5	17.5	-	☑	0.3	☑	☑

2 LEVEL MODULE

EARTHQUAKE	JUST LAYING			HORIZONTALLY ATTACHED		
	Displacement max [cm]	Displacement request EC8	Acceptable cracking	Displacement max [cm]	Displacement request EC8	Acceptable cracking
ZONE 5	11.8	-	☑	1.1	☑	☑
M = 8/8.5	19.7	-	☑	1.9	☑	☑

NB1 : The given results consider that the CUBIK-HOME modules stay in an elastic behavior. The ductility coefficient q given by Eurocode 8 needed to near a plastic behavior haven't been used, because the displacements based on élastisc analysis (spectral méthode) for an horizontally attached module, are already moderated and thus fulfill the security/safety requests. A spectral analysis with ductility coefficient q or a purely non-linear dynamic analysis (for instance, élasto-plastique model) would even more reduce the final displacements, which would be even more in safety.

NB2 : About the limit conditions CASE 1, where the CUBIK-HOME module is just laying on the ground, the main deformation modes are translation mode of the entire module(s). The displacements in directions horizontal X, Y and vertical Z are globally acceptable because they can be controlled by a support systèm to be studied (élastomère system or sliding System…).

X/ REFERENCE DOCUMENTS

[1] Norme EN 1998

Translated by Gilles EXEL, French INSA civil Engineer