SDLL149 – Seismic computation of pipework BM3 (test NRC)

Summarized:
This test mainly makes it possible to validate the implementation of method GUPTA (correlation between periodicals part and rigid of a modal response) on a seismic computation by spectral method applied to part of pipework (COMB_SISM_MODAL) .

Other methods are also evaluated on the same configuration :

- SRSS,
- CQC,
- CQC with pseudo-mode.

This test was proposed by NRC to validate the seismic design of nuclear installations.

1 Problematic problem of

1.1 reference

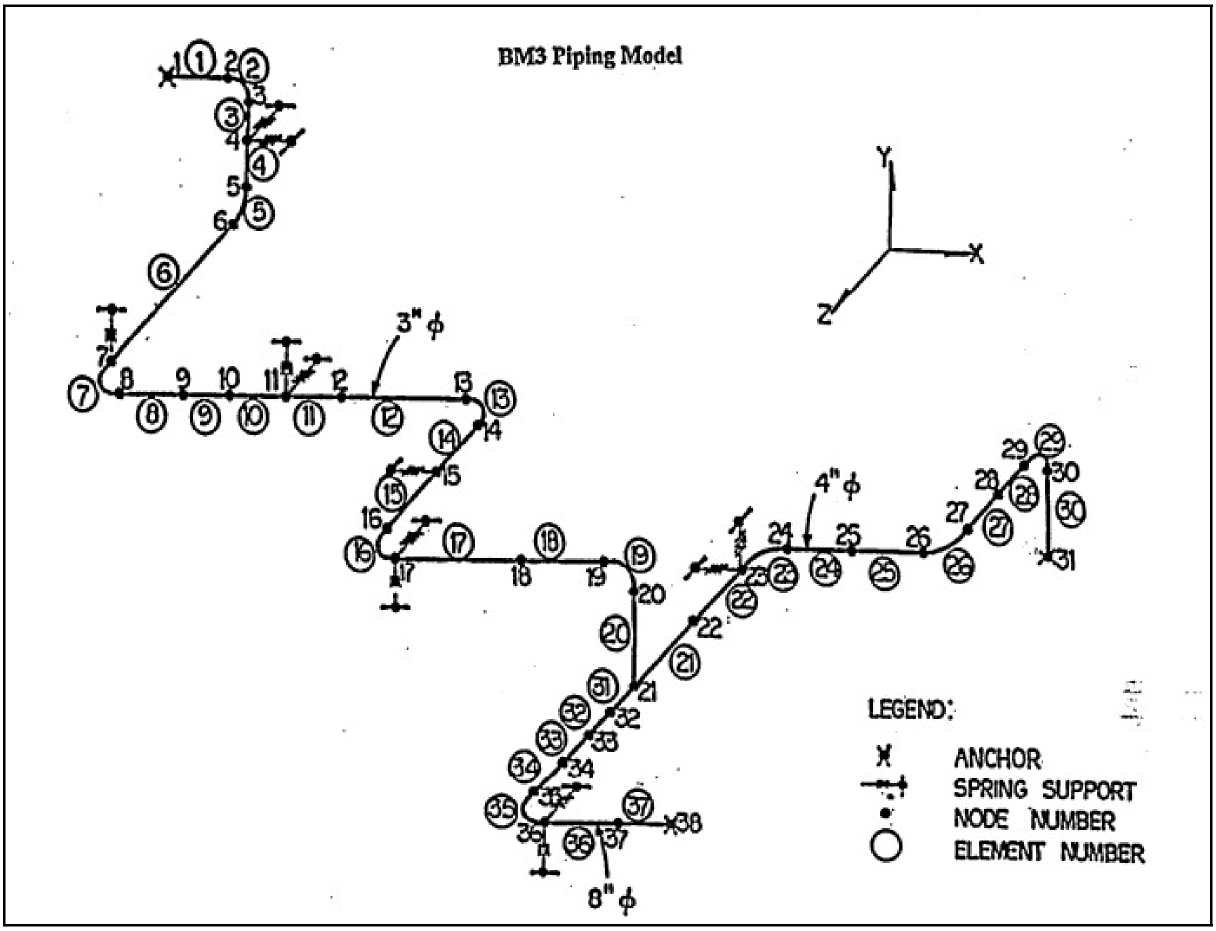
This test consists in carrying out a spectral analysis of the network of drains BM3 used in a nuclear power plant. It makes it possible to validate the various methods of combination used, in other the method of Gupta. To carry out this validation, the results of an equivalent modelization carried out with ANSYS are extracted from the two following documents:

[1] Revaluation of Modal Regulatory Guidance one Response Combination Methods for Seismic Response Spectrum Analysis, NUREG/CR-6645, BNL-NUREG-52576, 1999.

[2] ANSYS Mechanical APDL Technology Demonstration Guides, 2010, Chapter 12: Dynamic Simulation of has Nuclear Piping System Using RSA Methods.

1.2 Geometry

the geometry is telegraphic. The following figure, extracted the document [1], presents this geometry:



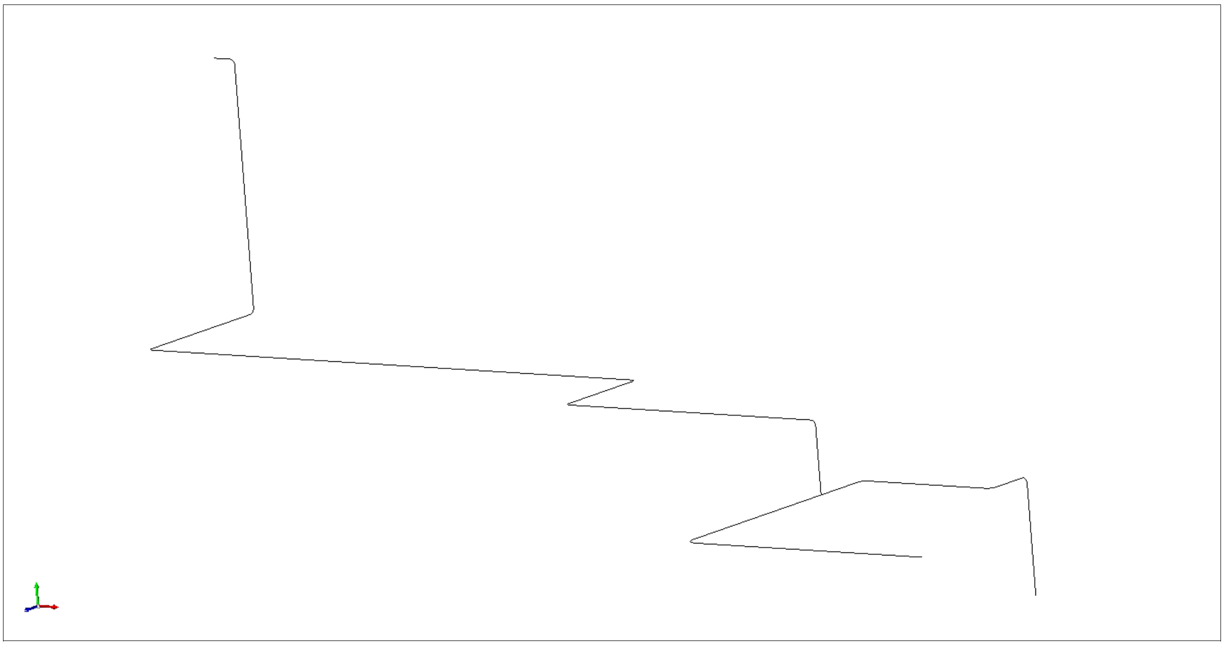
In order to compare itself correctly with the American studies [1] and [2], the selected units are the imperial units.

The structure is made up of three parts with different sections. The following table shows the characteristics of the sections:

	Radius (inch)	Thickness (inch)
section 1	1.75	0,216
section 2	2.25	0,237
section 3	4.31	0,322

1.3 Mesh

The mesh of structure linear and is composed of 37 elements SEG2 for 38 nodes.
The following figure presents the mesh under SALOME-MECA-2012.1:



The following table presents the coordinates of the nodes of mesh:

	Coordinates (inch)		
Nodes	X	Y	Z
1	0	0	0
2	15	0	0
3	19,5	-4,5	0
4	19,5	-180	0
5	19,5	-199,5	0
6	19,5	-204	4,5
7	19,5	-204	139,5
8	24	-204	144
9	96	-204	144
10.254		-204	144
11.333		-204	144

12.411		-204	144
13.483		-204	144
14	487,5	-204	148,5
15	487,5	-204	192
16	487,5	-204	235,5
17.492		-204	240
18.575		-204	240
19.723		-204	240
20	727,5	-208,5	240
21	727,5	-264	240
22	727,5	-264	205
23	727,5	-264	190
24	733,5	-264	184
25	753,5	-264	184
26	845,5	-264	184
27	851,5	-264	178
28	851,5	-264	160
29	851,5	-264	142
30	851,5	-270	136
31	851,5	-360	136
32	727,5	-264	255
33	727,5	-264	270
34	727,5	-264	306
35	727,5	-264	414
36	739,5	-264	426
37	847,5	-264	426
38	955,5	-264	426

bearings of this structure are modelled by stiffness. To be able to recover the nodal reactions to the bearings, an additional node “duplicate”, is created for each bearing. It is shifted of $1{,}\mathrm{E}\text{-}3\,inch$ (tolerance of Code_Aster) along the axis X compared to the something to lean on. All its degrees of freedom are blocked and an element SEG2 is created between the node of the bearing and “duplicate”. It is on this element that the values of stiffness of the bearings will be applied. Thus, the nodal reactions will be raised with the nodes “duplicates”.

1.4 Materials

The materials' properties of structure are the following ones:

$$E=2{,}9\mathrm{E}{+}7\ pound/inch^2$$
$$\nu=0{,}3$$

The densities of structure are the following ones:

	Radius (inch)	Thickness (inch)	Section (inch ²)	linear Density (pound/inch)	Density (pound/inch3)
section 1	1.7500	0,216	2.2273	2.3240E-003	**1.0434E-003**
section 2	2.2500	0,237	3.1724	3.5145E-003	**1.1078E-003**
section 3	4.3125	0,322	8.3950	1.0836E-002	**1.2908E-003**

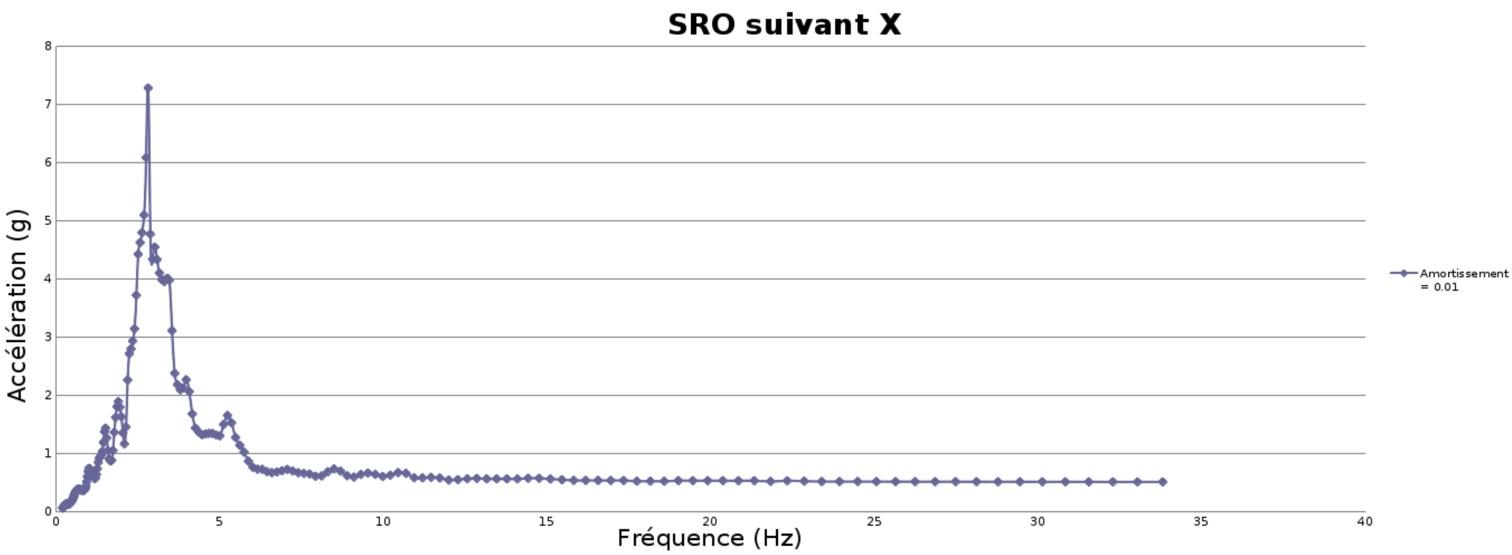
Note:: In the document [2] of 2010, the density of section 3 is of $1.253\mathrm{E}-3\ pound/inch^3$. In order to keep coherence in all the modelizations, it is the value of the document [1] of 1999 which is used.

1.5 Boundary conditions and loadings

the boundary conditions correspond to the bearings of structure. They are modelled by stiffness with the corresponding nodes of the mesh. The stiffness is the following ones:

Nodes	Stiffness UX (pound/inch)	Stiffness UY (pound/inch)	Stiffness UZ (pound/inch)	Stiffness RX (pound/inch)	Stiffness RY (pound/inch)	Stiffness RZ (pound/inches)
1	1.00E+011	1.00E+011	1.00E+011	1.00E+020	1.00E+020	1.00E+020
4	1.00E+008	0.00E+000	1.00E+008	0.00E+000	0.00E+000	0.00E+000
7	0.00E+000	1.00E+008	0.00E+000	0.00E+000	0.00E+000	0.00E+000
11	0.00E+000	1.00E+008	1.00E+005	0.00E+000	0.00E+000	0.00E+000
15	1.00E+005	0.00E+000	0.00E+000	0.00E+000	0.00E+000	0.00E+000
17	0.00E+000	1.00E+008	1.00E+005	0.00E+000	0.00E+000	0.00E+000
23	1.00E+005	1.00E+008	0.00E+000	0.00E+000	0.00E+000	0.00E+000
31	1.00E+011	1.00E+011	1.00E+011	1.00E+020	1.00E+020	1.00E+020
36	0.00E+000	1.00E+008	1.00E+005	0.00E+000	0.00E+000	0,0E+0
38	1.00E+011	1.00E+011	1.00E+011	1.00E+020	1.00E+020	1.00E+020

the loading of the spectral analysis corresponds to a Response sprectrum of Oscillator applied in the direction X. The spectrum is presented in the following graph:



1.6 Modelization

Element POUTRE (3 modelizations):

- modelization POU_D_T for the cross-sections
- modelization POU_C_T for the curved sections
- modelization DIS_TR for the bearings

2 Modelization A

2.1 Characteristic of the modelization

This modelization seeks to approach the document [2] of 2010. For that, the calculated mass matrix is full.

The modal analysis raises the first 14 modes and five spectral analyzes are carried out:

1) Combination SRSS
2) Combination CQC
3) Combination CQC with static correction
4) Combination of the Gupta type with $f1=2,80\,Hz$ and $f2=11,90\,Hz$ static correction
5) Combination of the Gupta type with $f1=2,80\,Hz$ and $f2=6\text{Hz}$ static correction

2.2 Quantities tested and results

the quantities tested are the eigenfrequencies of the first 14 modes and the reactions to the bearings of structure. The tests use as references the values resulting from ANSYS. They are doubled tests of NON-regression with a tolerance of $1{,}\text{E-}6$.

Mode clean	Reference Frequencies (Hz)	Tolerance Code_Aster (%)
1	2.91	1
2	4.44	2
3	4.86	1
4	5.02	1
5	6.95	1
6	7.58	2
7	7.82	1
8	10.94	2
9	11.65	3
10	11.78	2
11	12.8	2
12	14.32	3
13	15.17	8
14	15.79	6

Nodes	Forces	Reference computation 1 (F: lbs, M: lbs-inch)	Tolerance Code_Aster computation 1 (%)	Reference computation 2 (F: lbs, M: lbs-inch)	Tolerance Code_Aster computation 2 (%)	Reference computation 3 (F: lbs, M: lbs-inch)	Tolerance Code_Aster computation 3 (%)
1	FX	30,69	12	30.81	12	43.85	3
1	FY	15.34	10	12.59	9	15.21	8
1	FZ	49.04	9	24.91	5	24.91	5
1	MX	1515.03	6	764.29	7	766.72	7

1	MY	1219.62	6	932.32	0.1	934.03	1
1	MZ	1100.66	12	1096.58	12	1108.78	11
4	FX	45.19	5	45.02	5	77.36	3
4	FZ	82.15	2	55.61	1	56.12	1
7	FY	27.87	2	15.78	11	15.99	9
11	FY	21.54	20	19.57	20	19.59	20
11	FZ	42.91	4	42.35	2	43.43	3
15	FX	368.83	2	388.99	3	389.64	3
17	FY	44.28	0.2	45.83	2	45.95	2
17	FZ	53.12	2	55.06	1	55.31	0.1
36	FY	162.84	3	169.14	1	171.57	3
36	FZ	80.96	8	81.34	6	90.69	10
38	FX	116.92	4	135.99	5	566.65	12
38	FY	52.46	2	54.26	1	54.29	1
38	FZ	39.12	7	44.55	6	50.45	5
38	MX	2543.44	1	2606.69	3	2606.69	3
38	MY	2533.41	6	2894.27	5	3142.75	4
38	MZ	3650.45	2	3763.01	1	3764.97	1
23	FX	177.23	5	193.92	5	245.05	4
23	FY	145.37	4	151.53	1	151.99	1
31	FX	9.41	2	11.09	2	54.42	6
31	FY	22.08	6	24.77	5	27.73	4
31	FZ	31.36	8	32.11	7	32.26	7
31	MX	1971.58	16	2068	14	2072.03	14
31	MY	267.63	23	304.18	23	567.6	28
31	MZ	603.06	6	706.86	3	1912.58	4

Nodes	Forces	Reference computation 4 (F: lbs, M: lbs-inch)	Tolerance computation 4 (%)	Reference computation 5 (F: lbs, M: lbs-inch)	Tolerance computation 5 (%)
1	FX	54.42	1	52.05	1
1	FY	3.43	8	2.73	16
1	FZ	6.61	4	4.93	25
1	MX	190.18	13	135.39	11
1	MY	858.44	2	877.81	4
1	MZ	966.87	3	864.96	2

4	FX	105.14	1	114.06	1
4	FZ	42.48	6	34.9	6
7	FY	8.77	21	6.77	39
11	FY	16.71	33	12.44	37
11	FZ	49.19	2	61.99	3
15	FX	547.38	2	641.84	1
17	FY	35.92	1	26.39	2
17	FZ	56.34	2	46.86	3
36	FY	81.01	5	61.16	21
36	FZ	60.87	3	42.38	20
38	FX	750.45	10	739.29	10
38	FY	46.02	2	42.92	1
38	FZ	45.53	8	41.67	6
38	MX	914.22	9	369.64	3
38	MY	3191.39	7	2909.01	6
38	MZ	3248.59	2	3036.62	1
23	FX	347.2	4	304.8	5
23	FY	49.61	11	16.75	12
31	FX	63.82	3	61.95	3
31	FY	16.89	4	13.34	6
31	FZ	19.53	11	12.96	4
31	MX	1235.04	19	695.41	19
31	MY	818.08	31	757.2	32
31	MZ	2460.9	2	2319.49	3

3 Modelization B

3.1 Characteristic of the modelization

This modelization to seek to approach the document [1] to 1999. For that, the calculated mass matrix is diagonalized.

The modal analysis raises the first 14 modes and three spectral analyzes are carried out:

6) 1. Combination SRSS
7) 2. Combination CQC
8) 3. Combination of the Gupta type with $f1=2,80\ Hz$ and $f2=11,90\ Hz$

3.2 Quantities tested and results

the quantities tested are the eigenfrequencies of the first 14 modes the reactions to the bearings of structure. The tests use as references the values resulting from ANSYS. They are doubled tests of NON-regression with a tolerance of $1,E\text{-}6$.

Mode clean	Reference Frequencies (Hz)	Tolerance Code_Aster (%)
1	2.91	0.1
2	4.39	0.1
3	5.52	0.1
4	5.7	0.1
5	6.98	0.1
6	7.34	0.1
7	7.88	0.1
8	10.3	0.1
9	11.06	0.1
10	11.23	0.1
11	11.5	0.2
12	12.43	0.2
13	13.88	0.3
14	16.12	0.4

Nodes	Forces	Reference computation 1 (F: lbs, M: lbs-inch)	Tolerance computation 1 (%)	Reference computation 2 (F: lbs, M: lbs-inch)	Tolerance computation 2 (%)	Reference computation 3 (F: lbs, M: lbs-inch)	Tolerance computation 3 (%)
1	FX	3.13	2	3.13	1	3.25	2
1	FY	5.44	2	5.05	2	3.4	7
1	FZ	7.48	1	6.76	1	2.47	7
1	MX	275.37	1	246.84	1	64.41	15
1	MY	690.81	1	682.86	1	690.81	0.3

1	MZ	209.33	2	202.85	1	185.59	3
4	FX	24.27	1	23.98	2	23.98	0.2
4	FZ	75.18	2	67.72	2	25.43	6
7	FY	15.53	4	15.26	5	14.42	5
11	FY	19.61	1	19.08	1	15.63	2
11	FZ	79.99	1	77.2	2	74.41	2
15	FX	437.58	2	437.85	1	550.84	1
17	FY	48.82	1	48.05	1	39.11	1
17	FZ	79.11	2	79.73	2	62.91	1
36	FY	90.5	2	90.03	2	59.08	2
36	FZ	78.39	3	79.08	3	75.67	4
38	FX	119.47	4	121.91	2	163.36	4
38	FY	52.78	1	52.78	1	48.38	2
38	FZ	38.38	4	40.09	4	56.3	4
38	MX	1404.67	2	1397.54	2	762.94	4
38	MY	2588.19	4	2699.51	4	3701.39	4
38	MZ	3710.18	1	3710.18	1	3429.58	1
23	FX	214.93	2	219.71	2	238.81	3
23	FY	105.28	3	104.16	3	40.04	6
31	FX	10.13	4	10.2	3	9.86	3
31	FY	24.83	2	24.97	1	17.72	1
31	FZ	31.62	3	30.69	3	23.56	2
31	MX	2436.08	4	2358.92	4	1763.68	3
31	MY	282.8	4	287.99	4	306.15	3
31	MZ	796.48	4	802.56	4	772.16	3

4 Modelization C

4.1 Characteristic of the modelization

This modelization validates the use of the dynamic substructuring for spectral seismic computation. It compares a computation by dynamic substructuring with a “direct” computation (without dynamic substructuring).

4.2 Quantities tested and Modal computation

4.2.1 results: frequencies of line of pipework

One tests the first 14 eigenfrequencies of the pipework and one compares the results of computation by dynamic substructuring with those of the reference [1].

Mode clean	Reference Frequencies (Hz)	Tolerance Code_Aster (%)
1	2.91	1
2	4.44	2
3	4.86	1
4	5.02	1
5	6.95	1
6	7.58	2
7	7.82	1
8	10.94	1
9	11.65	2
10	11.78	2
11	12,80	2
12	14.32	2
13	15.17	6
14	15.79	4

4.2.2 seismic Response by spectral computation

One compares displacements according to the direction DX with the nodes $N10$ of coordinates $(254.0,-204.0,144.0)$, $N20$ coordinates $(727.5,-208.5,240.0)$ and $N30$ coordinates $(851.5,-270.0,136.0)$ the computation of spectral seismic response with the base resulting from the substructuring with those calculated with the base resulting from “direct” computation.

Node	Displacement max in DX (“direct” computation)	Tolerance (%)
$N10$	0,274320 inches	0,2
$N20$	0,179173 inches	0,2
$N30$	0,00825 inches	5,0

One creates the same table for absolute accelerations:

Node	Absolute acceleration max in DX ("direct" computation)	Tolerance (%)
$N10$	227,616 inches/s ²	0,2
$N20$	285,906 inches/s ²	3,0
$N30$	177,284 inches/s ²	4,0

5 Summary of the results

the got results are overall satisfactory. That it is with a complete mass matrix or a diagonal mass matrix, the frequencies of the publications are found.

The results on the nodal reactions resulting from computation by spectral seismic method are for the majority close relations of the results of reference to less than 5%. However, it is noticed that on some something to lean on the variations on the nodal reactions between *Code_Aster* and ANSYS rise with more than 30% (modelization A). They are explained by differences on the modal deformed shapes calculated by the two software (up to 2% on the modelization B), just as on the reactions to the bearings of the modes (up to 5% of variation in the modelization B). One can make go up these differences with implementations distinct on the finite elements from beam enter the two codes. In particular for the modelization A, ANSYS employs an interpolation “finite elements” for the beam elements whereas *Code_Aster* uses an “exact” integration [R3.08.01 – “exact” elements of beam].

It is noted nevertheless that they remain largely in on this side as of differences resulting from the choice of the method or the effect of “missing mass” (effect of the modes high frequency).

With regard to the method known as of Gupta, it appears validated well by this external reference.

The modelization a.c. for interest to validate employment for a spectral seismic response of a modal base resulting from a computation by dynamic substructuring.