ILC Cryomodule Earthquake response simulation

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LCWS13 AWG7-SCRF

(1)Creation of FEM model

(2)Static analysis

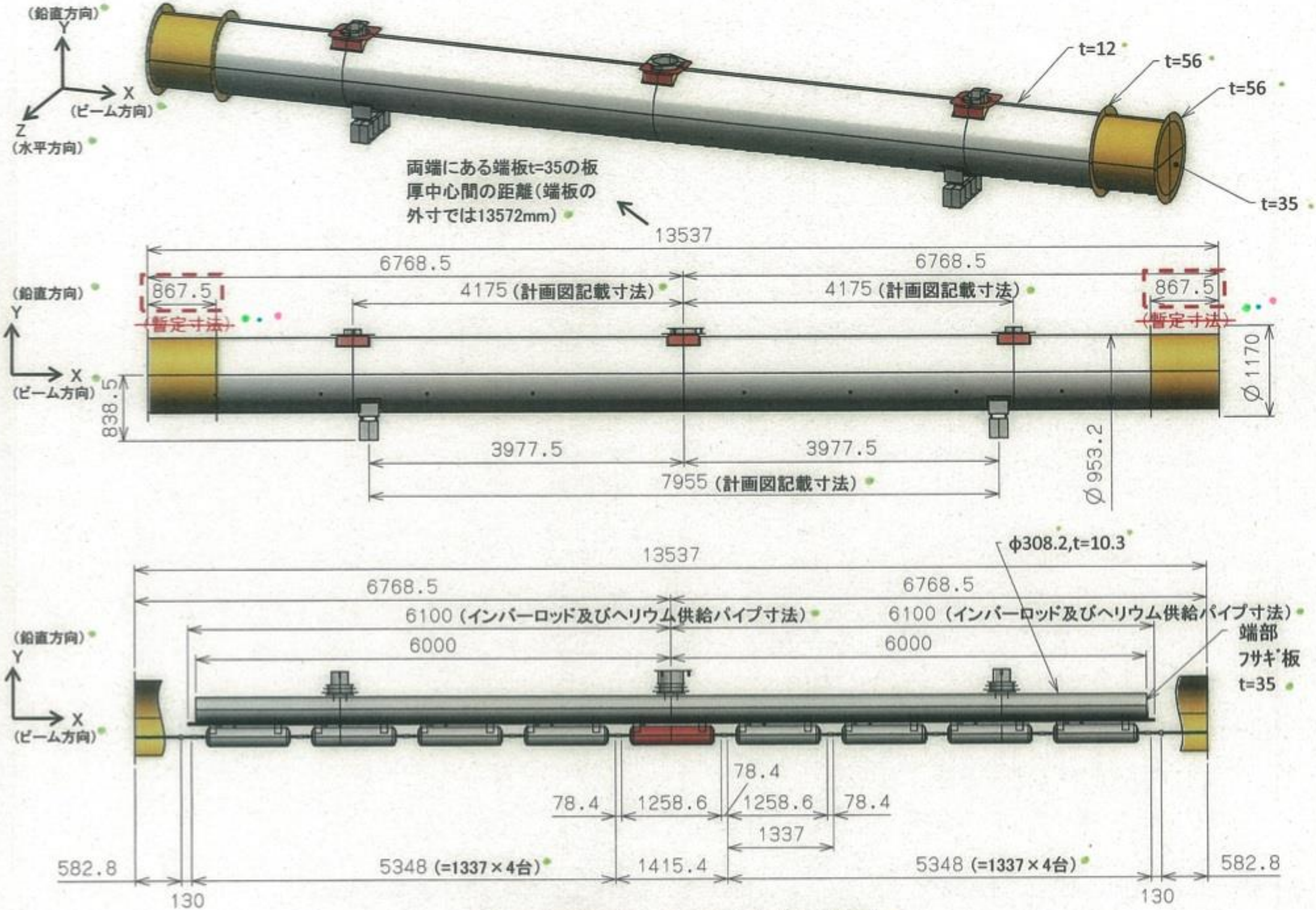
(3)Eigen-mode analysis

(4)Earthquake Response analysis by ISO3010

Analysis by ANSYS ver14.0,

FEM model creation

Modeling of one cryomodule with both end-plate
(connected cryomodule will be done later.)



Basement: FNAL T4CM, Quadrupole magnet in the center

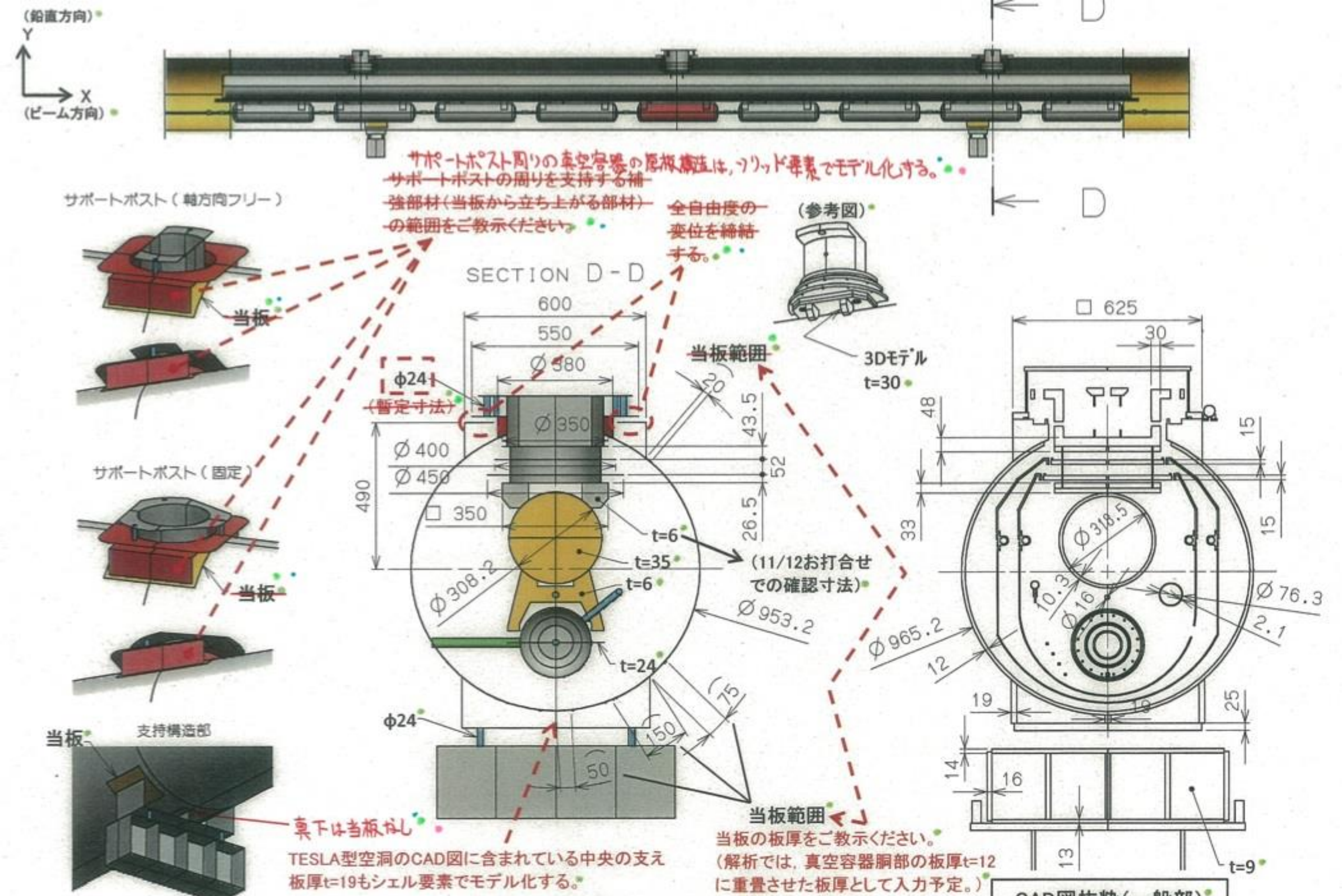
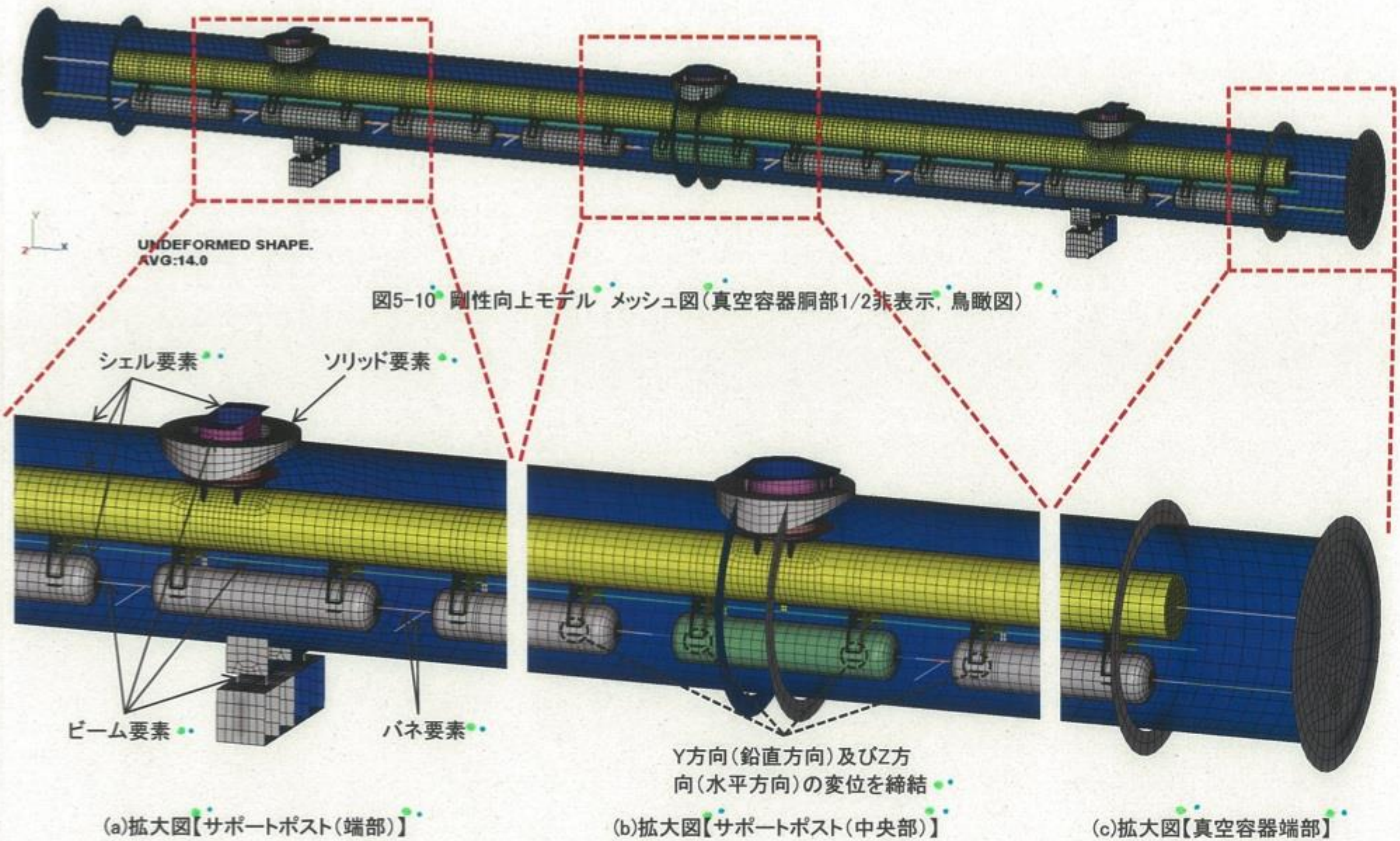


図5 ILCクライオモジュール モデル化(案) 寸法図4

Basement: FNAL T4CM, Quadrupole magnet in the center



Generated Mesh

Vessel, GRP, cavities, magnet : represented by shell element
Screw bolts : represented by beam element
Beam pipes, coupler, GRP-end : represented by spring element

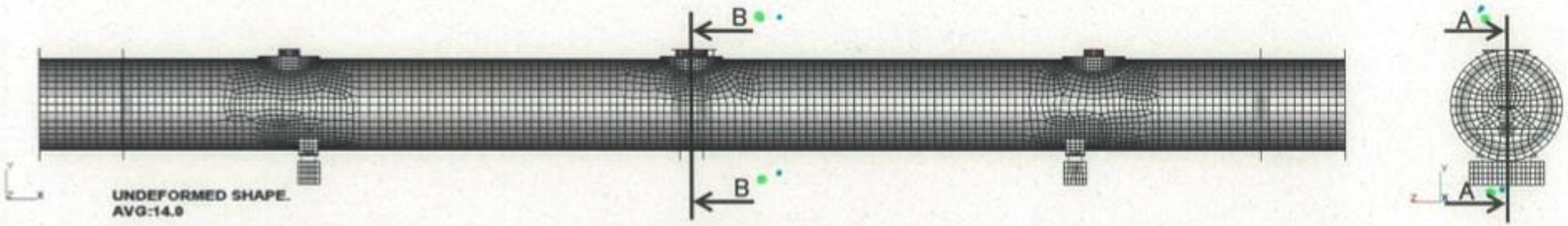
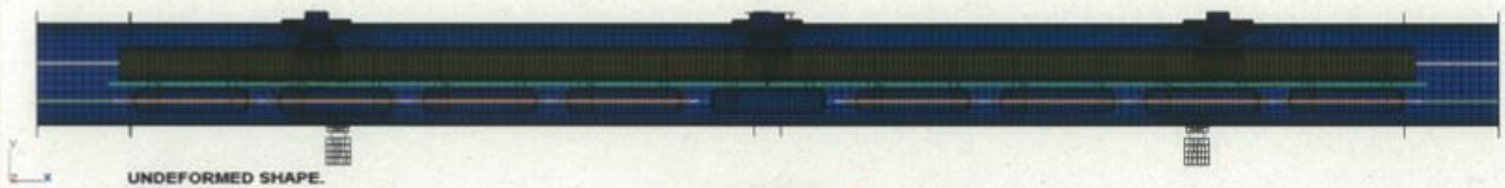
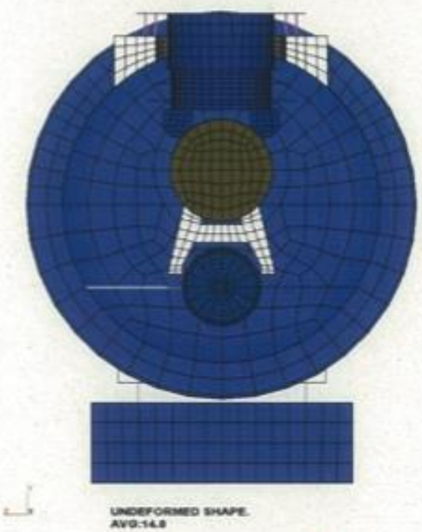


図5-11 剛性向上モデル メッシュ図(外観図)



A-A断面図



B-B断面図

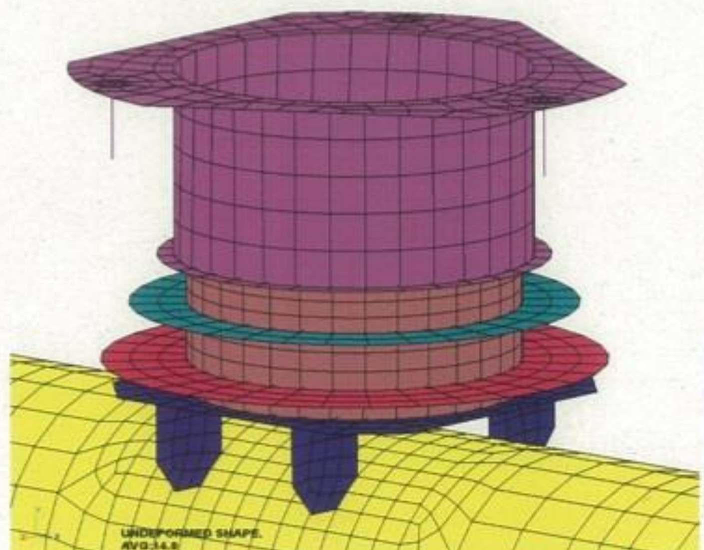


図5-12 サポートポスト(中央部)拡大図

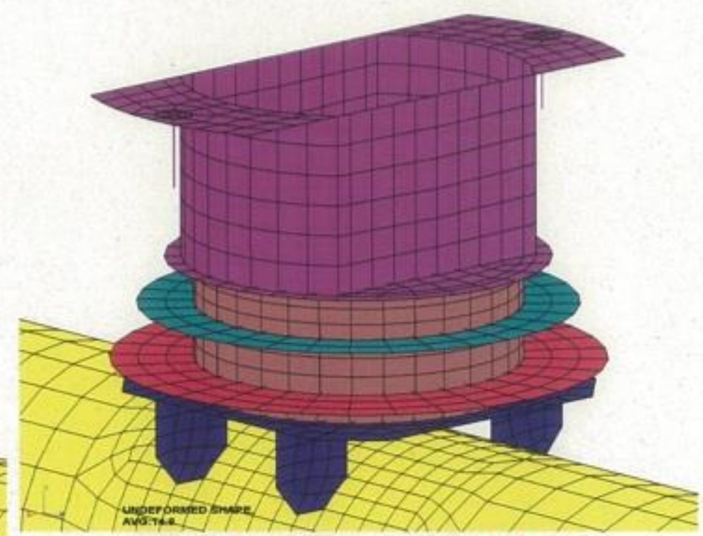


図5-13 サポートポスト(端部)拡大図

Generated Mesh in detail-01

Double shields are represented
by the weight around support post

2重シールド板:286.3kg×
サポートポスト3ヶ所

Gate valves are represented
by the weight at GRP ends

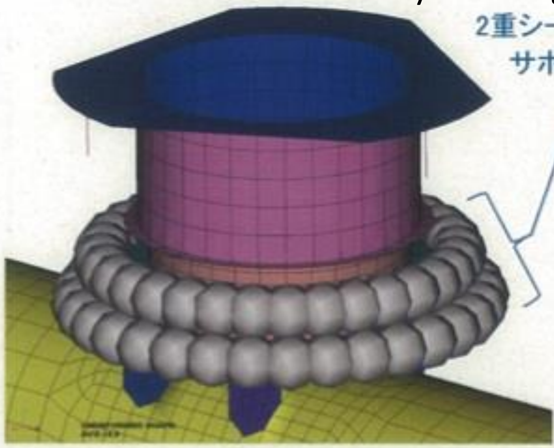


図5-14 サポートポスト(中央部) 節点質量表示

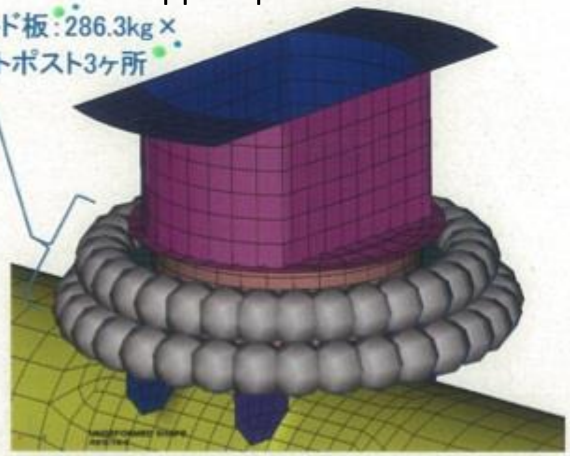


図5-15 サポートポスト(端部) 節点質量表示

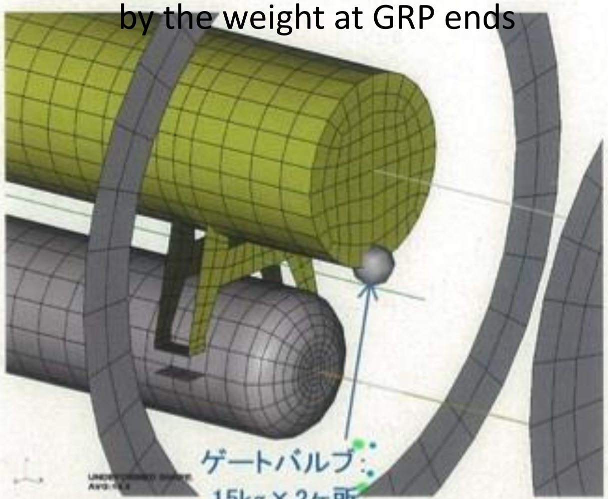


図5-16 ガスリターンパイプ 節点質量表示

Base surface of the mount
Is fixed to the floor

6自由度拘束

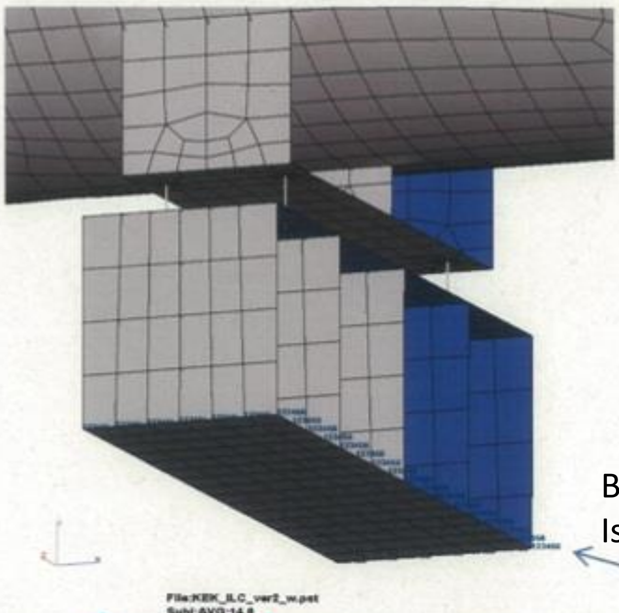


図5-17 -X側支持脚 境界条件表示(底面完全拘束)

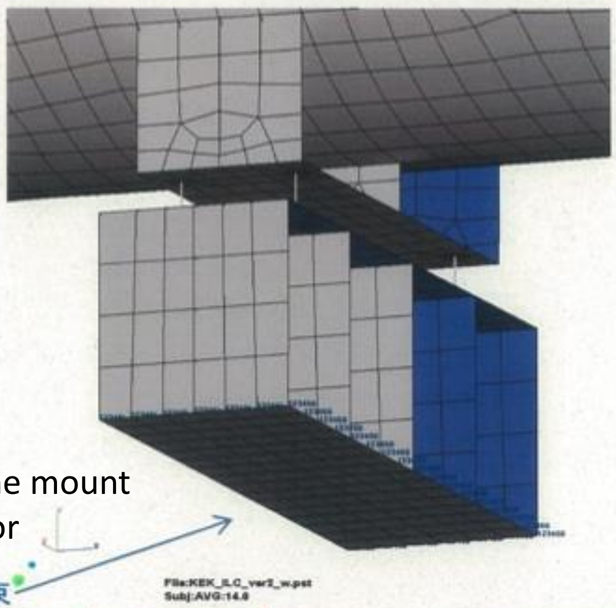


図5-18 +X側支持脚 境界条件表示(底面完全拘束)

Generated Mesh in detail-02

The list of components: material, young-coefficient, poisson ratio, density

表6-1 物性値

No.	部位	材質	ヤング率[*1] (GPa)	ポアソン比 (-)	密度 (kg/mm^3)	備考
1	真空容器及び脚部	鉄材	203[*2]	0.3	7.86E-6[*4]	SS400相当，H鋼上部固定ボルト含む
2	ガスリターンパイプ	SUS材	195[*2]	0.3	7.92E-6[*4]	SUS304相当，超伝導空洞吊り下げ金具含む
3	インバーロッド	スーパーインバー	137	0.29	8.15E-6	32Ni-5Co-Fe[*6]
4	ビームパイプ端部	SUS材	195[*2]	0.3	7.92E-6[*4]	SUS304相当
5	サポートポスト(R.T.)	SUS304	195[*2]	0.3	7.92E-6[*4]	可動部及び固定部共通，サポートポストSUSボルト含む
6	サポートポスト(80K)	A6061-T6	68.6[*3]	0.33	2.70E-6[*4]	
7	サポートポスト(5K)	A6061-T6	68.6[*3]	0.33	2.70E-6[*4]	
8	サポートポスト(2K)	SUS304	195[*2]	0.3	7.92E-6[*4]	ガスリターンパイプ吊り下げ金具含む
9	サポートポストFRP部	GFRP	13.79	0.12	1.88E-6	G10相当
10	ビームパイプ	Nb	102.9	0.38	8.57E-6[*4,*5]	空洞部含む
11	ヘリウムジャケット	Ti	107	0.321	4.51E-6[*4,*5]	

注記

*1：固有振動数の20Hzでの剛柔判定において，安全側の評価とするために，ヤング率が低い値となる常温(300K程度)でのヤング率を採用する。

*2：発電用原子力設備規格　設計・建設規格(2005年版)／日本機械学会

*3：アルミニウムハンドブック(第3版)／昭和アルミニウム(株)

*4：伝熱工学資料　改訂第5版／日本機械学会

*5：No.10，11の密度比を維持したまま，目標質量まで密度を調整する。目標質量は，超伝導空洞75kg/台，超伝導4極マグネット285kgとする。

*6：東北特殊鋼(株)ホームページより抜粋

The list of components: material, volume, density, weight

表6-3 剛性向上モデルの総質量

No.	部位	材質	体積 (mm^3)	密度 (kg/mm^3)	質量 (kg)	備考
1	真空容器及び脚部	鉄材	7.286E+08	7.86E-6	5.73E+3	8ヶ所のフランジ体積含む
2	ガスリターンパイプ	SUS材	1.320E+08	7.92E-6	1.05E+3	
3	インバーロッド	スーパーインバー	2.453E+06	8.15E-6	2.00E+1	
4	ビームパイプ端部	SUS材	4.349E+05	7.92E-6	3.44E+0	
5	サポートポスト(R.T.)	SUS304	3.126E+07	7.92E-6	2.48E+2	中央＋両端の計3ヶ所の体積，サポートポストSUSボルト含む
6	サポートポスト(80K)	A6061-T6	5.562E+06	2.70E-6	1.50E+1	中央＋両端の計3ヶ所の体積
7	サポートポスト(5K)	A6061-T6	7.064E+06	2.70E-6	1.91E+1	中央＋両端の計3ヶ所の体積
8	サポートポスト(2K)	SUS304	1.184E+07	7.92E-6	9.38E+1	中央＋両端の計3ヶ所の体積
9	サポートポストFRP部	GFRP	8.645E+05	1.88E-6	1.63E+0	中央＋両端の計3ヶ所の体積
10	ビームパイプ	Nb	—	—	6.51E+2	超伝導空洞質量(75kg×8台，チューナー込み)＋ヘリウム供給パイプ(50.6kg)
11	ヘリウムジャケット	Ti	—	—		
12	超電導4極マグネット	—	—	—	2.85E+2	超伝導4極マグネット質量(285kg×1台)
13	シールド板(80K)	アルミ	1.699E+08	2.70E-6	4.59E+2	節点質量での入力
14	シールド板(5K)	アルミ	1.480E+08	2.70E-6	4.00E+2	節点質量での入力
15	ゲートバルブ	—	—	—	3.00E+1	ゲートバルブ(15kg×2台)，節点質量での入力
				剛性向上モデルの総質量	9.00E+3	

Total model weight is 9.00t

Eigen-mode Analysis

X: beam axis

Y: vertical axis

Z: horizontal axis

The list of eigen-mode

次数	振動数 (Hz)	周期 (s)	有効質量比 X方向	Y方向	Z方向
1	6.67	0.1500	0.0000	0.0000	0.7776
2	10.76	0.0929	0.3889	0.0001	0.0000
3	13.84	0.0723	0.0000	0.0000	0.0003
4	15.05	0.0665	0.0000	0.0000	0.0000
5	16.95	0.0590	0.0000	0.0000	0.0004
6	18.13	0.0551	0.0037	0.0000	0.0000
7	19.75	0.0506	0.0000	0.6714	0.0000
8	20.03	0.0499	0.0001	0.0894	0.0000
9	23.65	0.0423	0.0164	0.0000	0.0000
10	23.86	0.0419	0.0000	0.0000	0.0000
11	25.23	0.0396	0.0000	0.0000	0.0102
12	25.62	0.0390	0.0052	0.0042	0.0000
13	27.78	0.0360	0.0107	0.0111	0.0000
14	27.79	0.0360	0.0000	0.0000	0.0000
15	28.52	0.0351	0.0014	0.0518	0.0000
16	30.29	0.0330	0.0000	0.0000	0.0000
17	31.13	0.0321	0.0000	0.0000	0.0000
18	31.14	0.0321	0.0000	0.0000	0.0000
19	31.14	0.0321	0.0000	0.0000	0.0000
20	31.14	0.0321	0.0000	0.0000	0.0000
21	31.14	0.0321	0.0000	0.0000	0.0000
22	31.14	0.0321	0.0000	0.0000	0.0000
23	31.14	0.0321	0.0000	0.0000	0.0000
24	31.15	0.0321	0.0000	0.0000	0.0000
25	35.03	0.0285	0.0000	0.0000	0.0000
26	36.20	0.0276	0.0271	0.0000	0.0000
27	37.94	0.0264	0.0001	0.0028	0.0000
28	38.29	0.0261	0.2494	0.0000	0.0000
29	41.04	0.0244	0.0000	0.0000	0.0035
30	43.27	0.0231	0.2633	0.0000	0.0000
31	52.16	0.0192	0.0058	0.0000	0.0000
32	52.79	0.0189	0.0000	0.0000	0.0000
33	53.54	0.0187	0.0001	0.0035	0.0000
34	55.17	0.0181	0.0000	0.0000	0.0103
35	56.29	0.0178	0.0002	0.0001	0.0000
36	57.46	0.0174	0.0001	0.0003	0.0000
37	58.60	0.0171	0.0009	0.0019	0.0000
38	60.10	0.0166	0.0000	0.0000	0.0006
39	60.29	0.0166	0.0000	0.0433	0.0000
40	61.05	0.0164	0.0000	0.0000	0.0182
41	61.44	0.0163	0.0000	0.0000	0.1070
42	61.95	0.0161	0.0000	0.0000	0.0060
43	62.47	0.0160	0.0000	0.0000	0.0018
44	64.72	0.0155	0.0000	0.0000	0.0001
45	64.77	0.0154	0.0000	0.0003	0.0000
46	65.84	0.0152	0.0001	0.0057	0.0000
47	66.40	0.0151	0.0003	0.0035	0.0000
48	66.98	0.0149	0.0000	0.0000	0.0085
49	68.37	0.0146	0.0000	0.0000	0.0133
50	69.31	0.0144	0.0001	0.0006	0.0000

次数	振動数 (Hz)	周期 (s)	有効質量比 X方向	Y方向	Z方向
51	69.38	0.0144	0.0002	0.0041	0.0000
52	70.14	0.0143	0.0000	0.0271	0.0000
53	71.20	0.0140	0.0035	0.0000	0.0000
54	72.00	0.0139	0.0000	0.0000	0.0000
55	72.88	0.0137	0.0001	0.0001	0.0000
56	73.17	0.0137	0.0000	0.0000	0.0001
57	78.36	0.0128	0.0000	0.0000	0.0000
58	79.86	0.0125	0.0000	0.0000	0.0000
59	80.96	0.0124	0.0002	0.0001	0.0000
60	81.94	0.0122	0.0000	0.0003	0.0000
61	84.50	0.0118	0.0000	0.0000	0.0005
62	86.66	0.0115	0.0003	0.0004	0.0000
63	88.17	0.0113	0.0000	0.0006	0.0000
64	88.89	0.0112	0.0014	0.0000	0.0000
65	90.77	0.0110	0.0000	0.0000	0.0033
66	91.11	0.0110	0.0000	0.0000	0.0001
67	94.75	0.0106	0.0000	0.0000	0.0012
68	95.68	0.0105	0.0000	0.0000	0.0000
69	97.50	0.0103	0.0000	0.0000	0.0001
70	100.31	0.0100		0.0013	
71	100.42	0.0100		0.0001	
72	102.97	0.0097		0.0000	
73	103.71	0.0096		0.0000	
74	104.20	0.0096		0.0000	
75	104.54	0.0096		0.0011	
76	104.70	0.0096		0.0000	
77	104.84	0.0095		0.0000	
78	105.27	0.0095		0.0000	
79	105.52	0.0095		0.0000	
80	106.17	0.0094		0.0000	
81	106.19	0.0094		0.0000	
82	106.28	0.0094		0.0000	
83	106.51	0.0094		0.0000	
84	106.52	0.0094		0.0000	
85	106.58	0.0094		0.0000	
86	108.98	0.0092		0.0001	
87	109.61	0.0091		0.0000	
88	110.03	0.0091		0.0000	
89	110.26	0.0091		0.0000	
90	110.29	0.0091		0.0000	
91	110.41	0.0091		0.0000	
92	110.56	0.0090		0.0000	
93	110.60	0.0090		0.0000	
94	110.61	0.0090		0.0000	
95	110.69	0.0090		0.0000	
96	110.74	0.0090		0.0000	
97	110.77	0.0090		0.0000	
98	110.79	0.0090		0.0000	
99	110.85	0.0090		0.0000	
100	110.91	0.0090		0.0000	

次数	振動数 (Hz)	周期 (s)	有効質量比 X方向	Y方向	Z方向
101	110.96	0.0090		0.0000	
102	111.01	0.0090		0.0000	
103	111.06	0.0090		0.0000	
104	111.57	0.0090		0.0000	
105	111.63	0.0090		0.0000	
106	112.44	0.0089		0.0000	
107	115.55	0.0087		0.0000	
108	115.91	0.0086		0.0000	
109	116.80	0.0086		0.0000	
110	119.16	0.0084		0.0000	
111	119.66	0.0084		0.0000	
112	119.82	0.0083		0.0000	
113	120.12	0.0083		0.0000	
114	120.13	0.0083		0.0000	
115	120.28	0.0083		0.0009	
116	120.32	0.0083		0.0000	
117	120.58	0.0083		0.0097	
118	121.30	0.0082		0.0000	
119	121.30	0.0082		0.0000	
120	121.48	0.0082		0.0000	
121	122.44	0.0082		0.0009	
122	123.04	0.0081		0.0000	
123	123.31	0.0081		0.0000	
124	126.11	0.0079		0.0000	
125	126.60	0.0079		0.0000	
126	127.10	0.0079		0.0000	
127	127.14	0.0079		0.0000	
128	127.22	0.0079		0.0000	
129	128.52	0.0078		0.0000	
130	128.68	0.0078		0.0000	
131	129.33	0.0077		0.0000	
132	132.30	0.0076		0.0001	
133	132.40	0.0076		0.0000	
134	132.96	0.0075		0.0000	
135	132.96	0.0075		0.0000	
136	133.84	0.0075		0.0000	
137	134.07	0.0075		0.0000	
138	135.86	0.0074		0.0000	
139	136.50	0.0073		0.0000	
140	137.91	0.0073		0.0000	
141	138.61	0.0072		0.0000	
142	139.22	0.0072		0.0000	
143	139.33	0.0072		0.0011	
144	141.20	0.0071		0.0006	
145	142.24	0.0070		0.0000	
146	142.52	0.0070		0.0000	
147	142.79	0.0070		0.0000	
148	145.55	0.0069		0.0008	
149	145.79	0.0069		0.0000	
150	145.79	0.0069		0.0000	

次数	振動数 (Hz)	周期 (s)	有効質量比 X方向	Y方向	Z方向
151	145.84	0.0069		0.0000	
152	145.91	0.0069		0.0000	
153	145.92	0.0069		0.0000	
154	145.99	0.0068		0.0000	
155	146.70	0.0068		0.0000	
156	148.56	0.0067		0.0013	
157	149.49	0.0067		0.0000	
158	149.93	0.0067		0.0057	
159	152.36	0.0066		0.0000	
160	152.72	0.0065		0.0000	
161	156.05	0.0064		0.0000	
162	157.55	0.0063		0.0000	
163	158.99	0.0063		0.0000	
164	159.02	0.0063		0.0178	
165	159.79	0.0063		0.0002	
166	160.31	0.0062		0.0000	
167	160.32	0.0062		0.0000	
168	160.33	0.0062		0.0000	
169	160.41	0.0062		0.0008	
170	161.00	0.0062		0.0000	
171	161.13	0.0062		0.0000	
172	161.30	0.0062		0.0000	
173	161.31	0.0062		0.0000	
174	161.74	0.0062		0.0000	
175	163.21	0.0061		0.0000	
176	163.65	0.0061		0.0005	
177	163.85	0.0061		0.0000	
178	165.08	0.0061		0.0001	
179	167.17	0.0060		0.0000	
180	167.23	0.0060		0.0000	
181	167.92	0.0060		0.0000	
182	168.29	0.0059		0.0000	
183	171.00	0.0058		0.0000	
184	171.93	0.0058		0.0000	
185	175.75	0.0057		0.0000	
186	177.09	0.0056		0.0000	
187	177.81	0.0056		0.0000	
188	177.85	0.0056		0.0000	
189	177.91	0.0056		0.0000	
190	178.15	0.0056		0.0000	
191	178.22	0.0056		0.0000	
192	178.24	0.0056		0.0000	
193	178.28	0.0056		0.0000	
194	178.28	0.0056		0.0000	
195	178.31	0.0056		0.0000	
196	178.32	0.0056		0.0000	
197	178.34	0.0056		0.0000	
198	178.34	0.0056		0.0000	
199	178.38	0.0056		0.0000	
200	178.66	0.0056		0.0000	

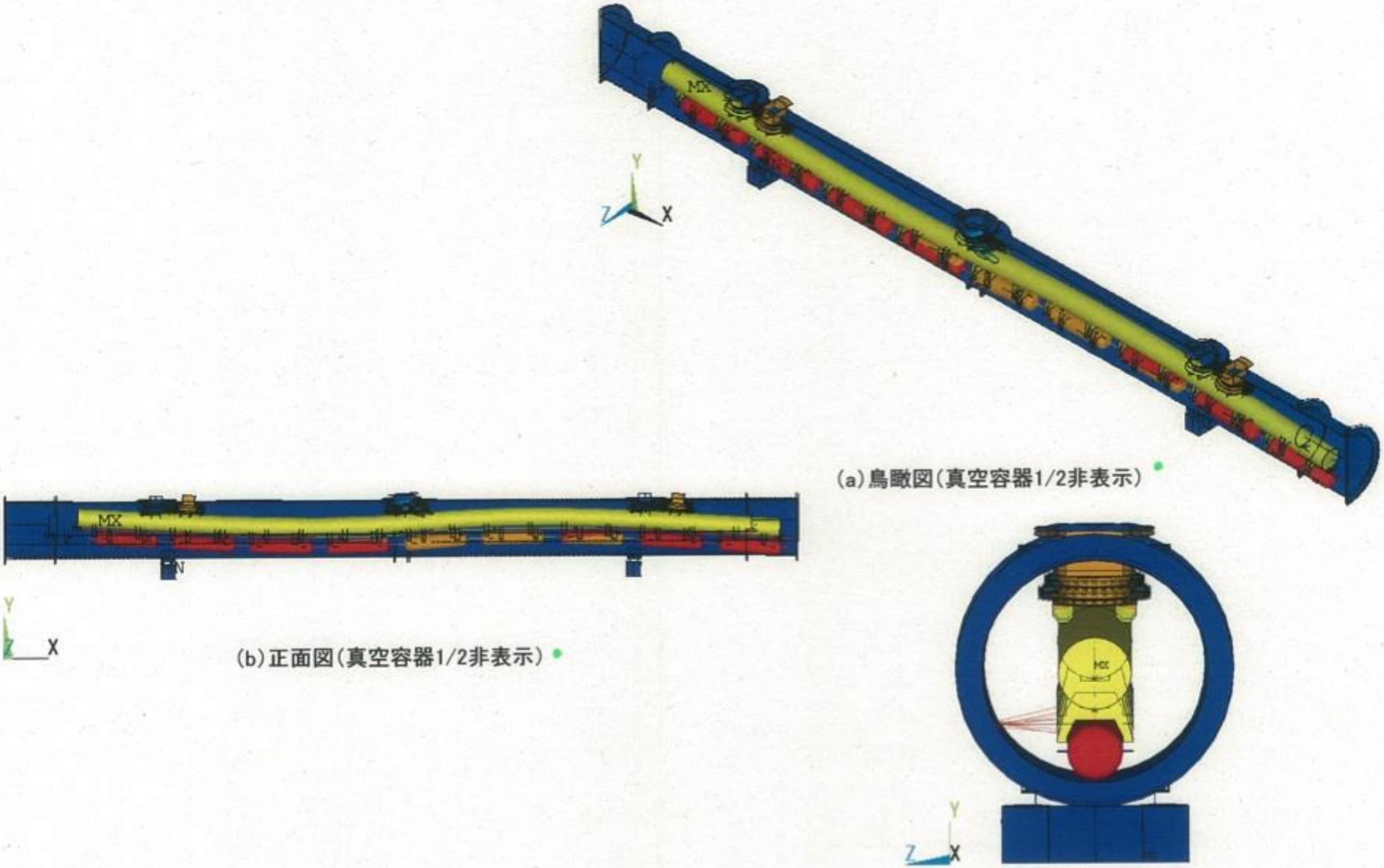
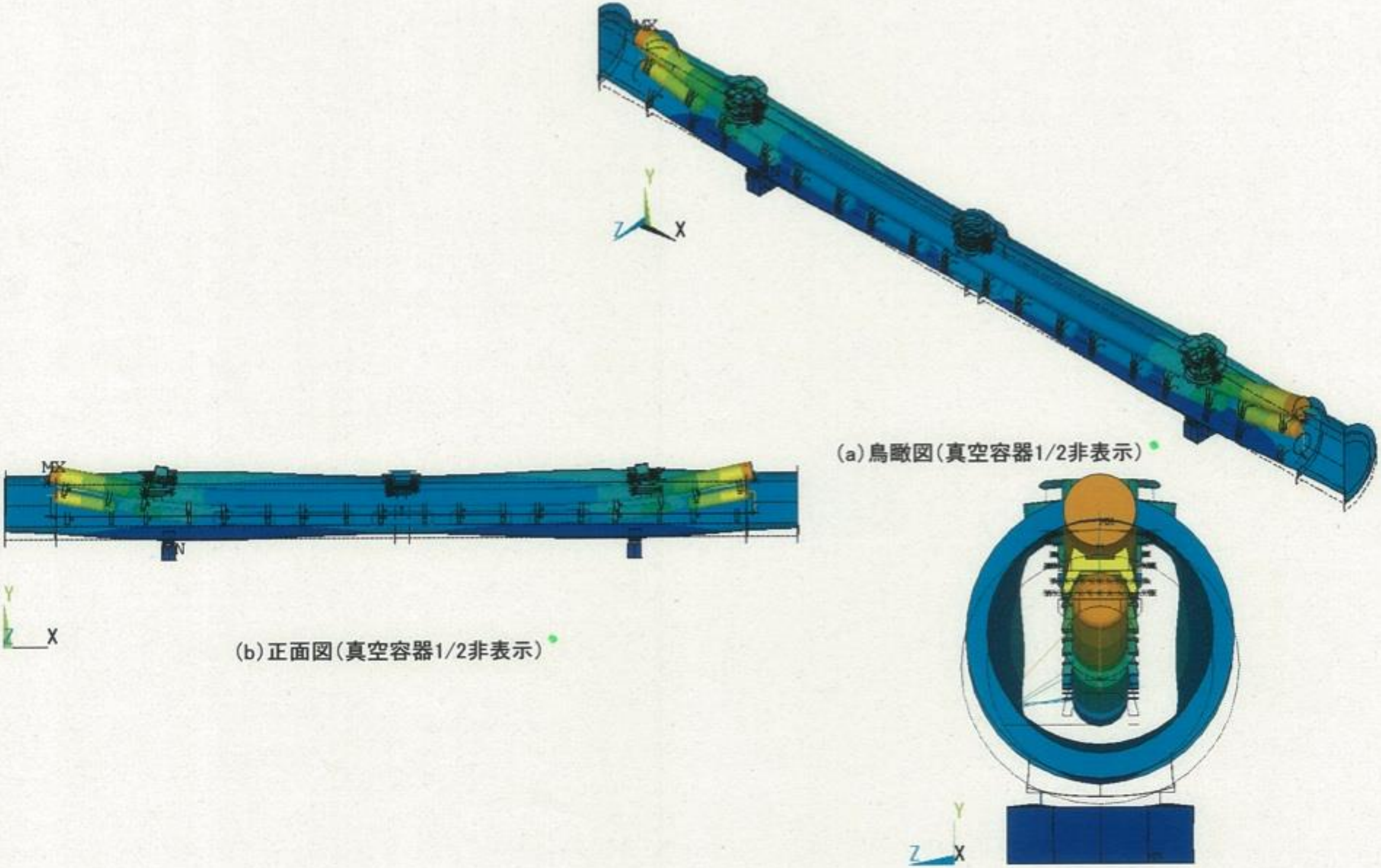


図3-1 固有値解析 ビーム方向(モデルX方向)卓越モード 固有モード図(2次:10.76Hz)

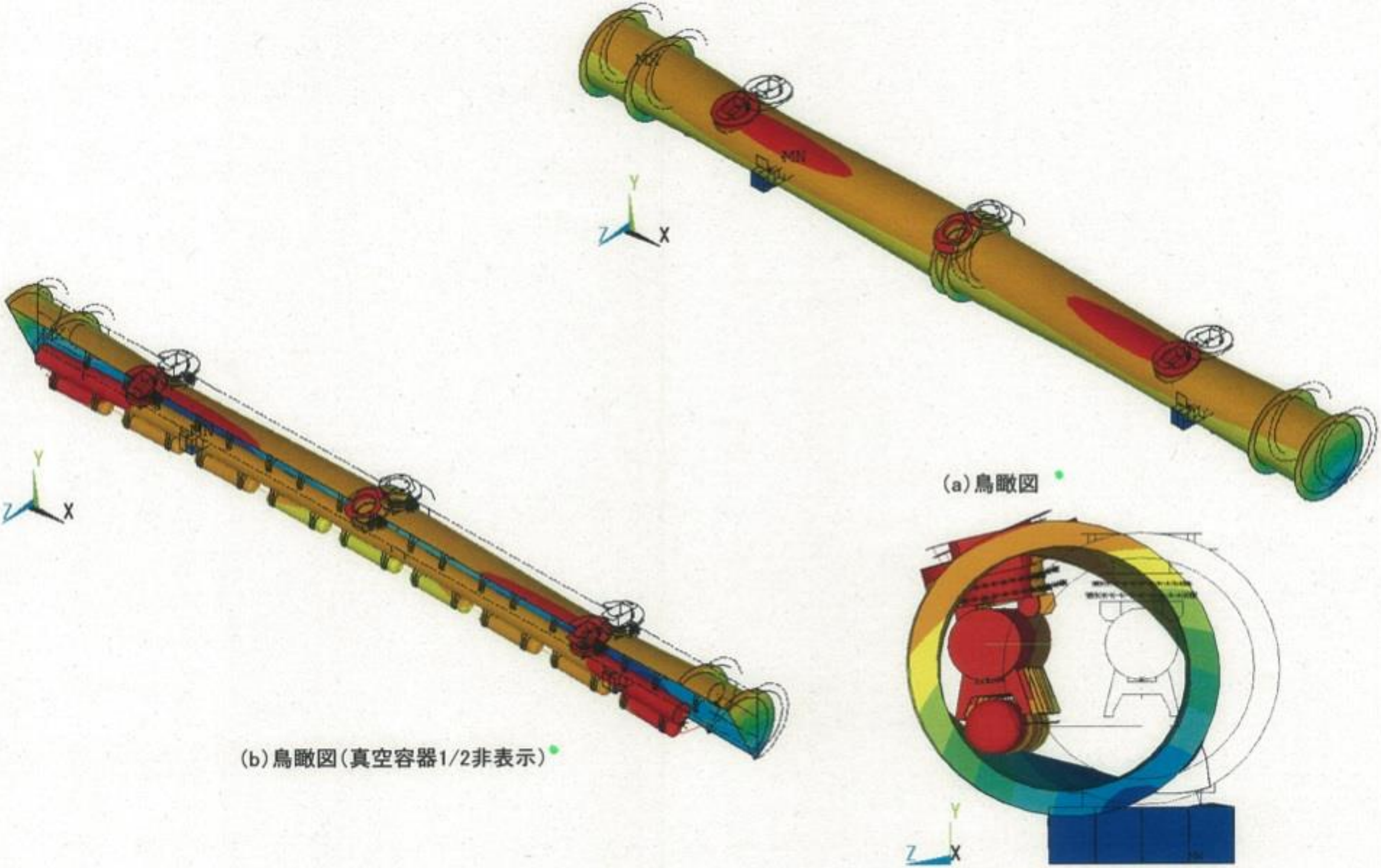
Main mode of X-direction (beam axis) : 10.76Hz



(c)側面図(真空容器端板非表示)

図3-2 固有値解析 鉛直方向(モデルY方向)卓越モード 固有モード図(7次:19.75Hz)

Main mode of Y-direction (vertical axis) : 19.75Hz



(a)鳥瞰図

(b)鳥瞰図(真空容器1/2非表示)

(c)側面図(真空容器端板非表示)

図3-3 固有値解析 水平方向(モデルZ方向)卓越モード 固有モード図(1次:6.67Hz)

Main mode of Z-direction (horizontal axis) : 6.67Hz

Static analysis

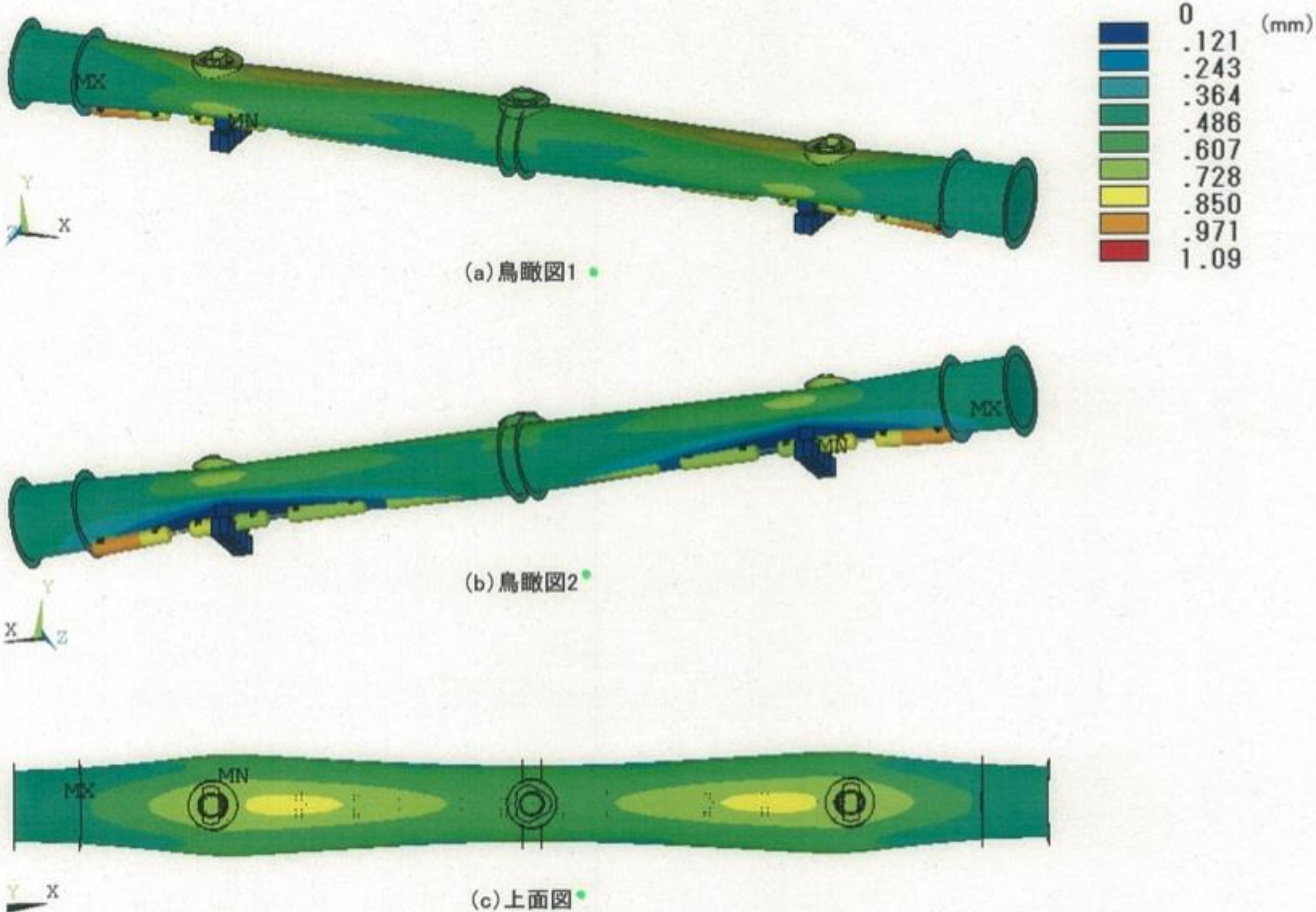


図2-1 自重解析 合成変位分布図

Static: Vacuum Vessel displacement

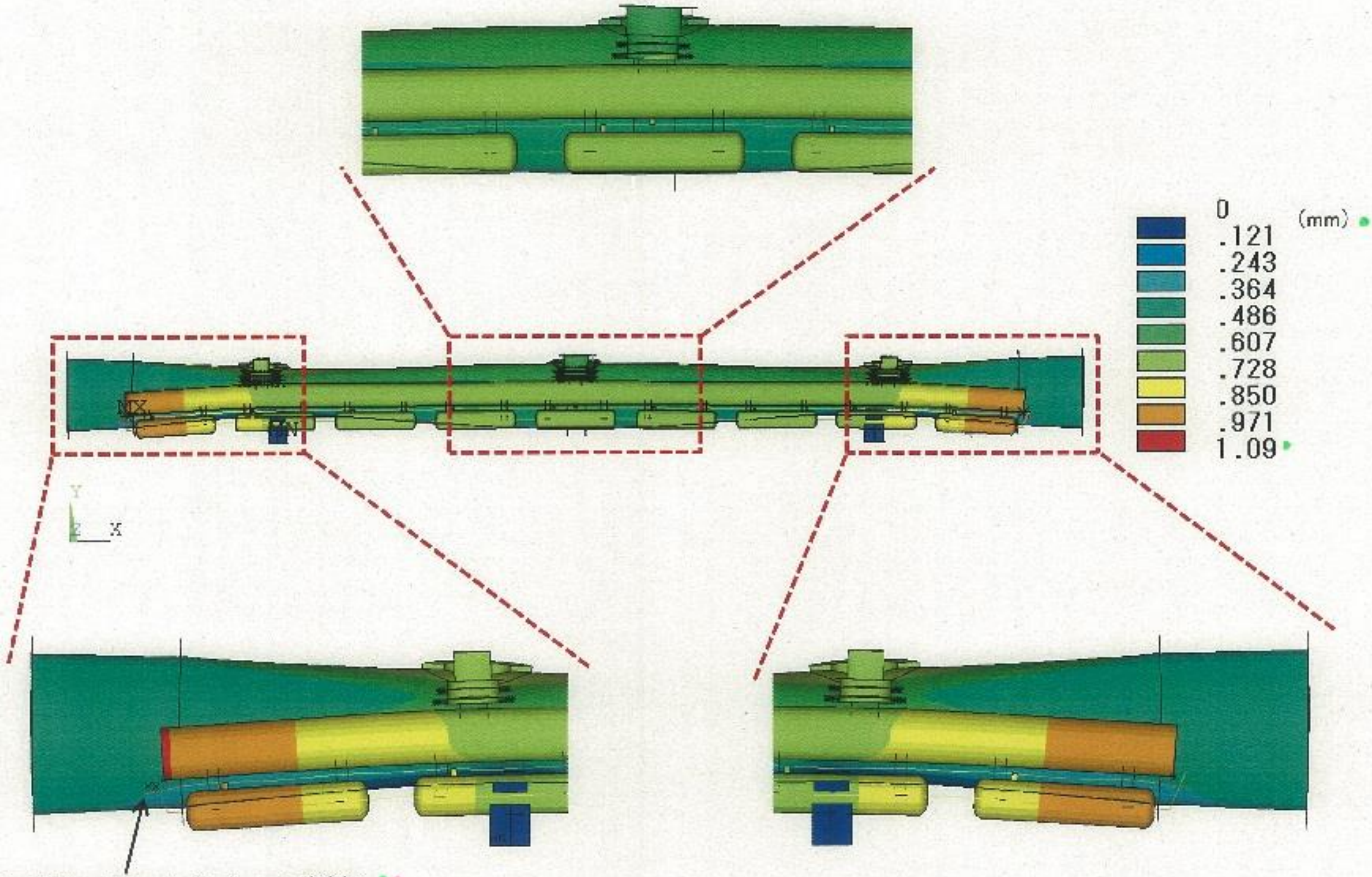


図2-2 自重解析 合成変位分布図（真空容器1/2非表示）

Static: GRP and Cavities displacement

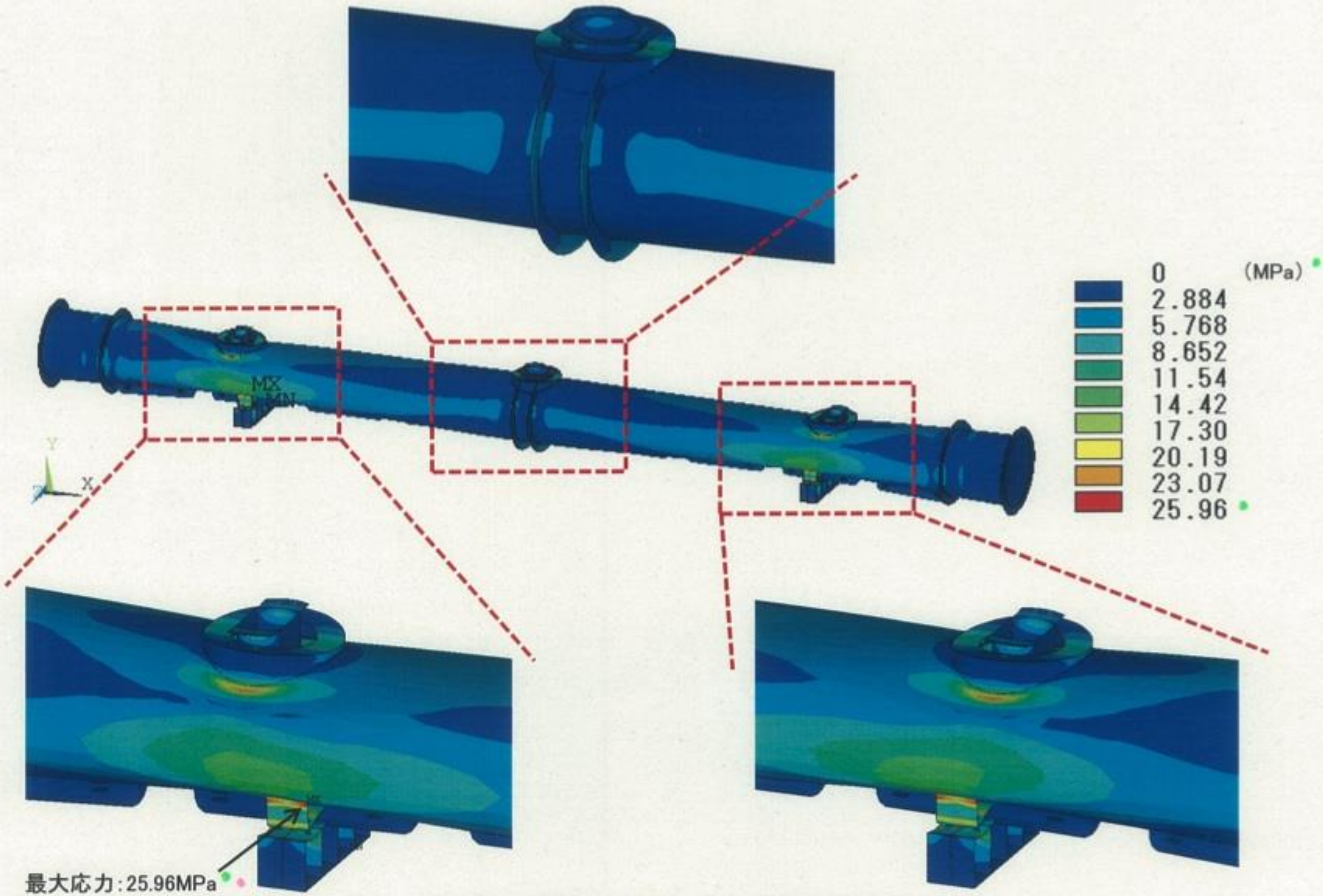


図2-3 自重解析　組合せ応力分布図(シェル要素TOP側)

Static: Vacuum Vessel Stress

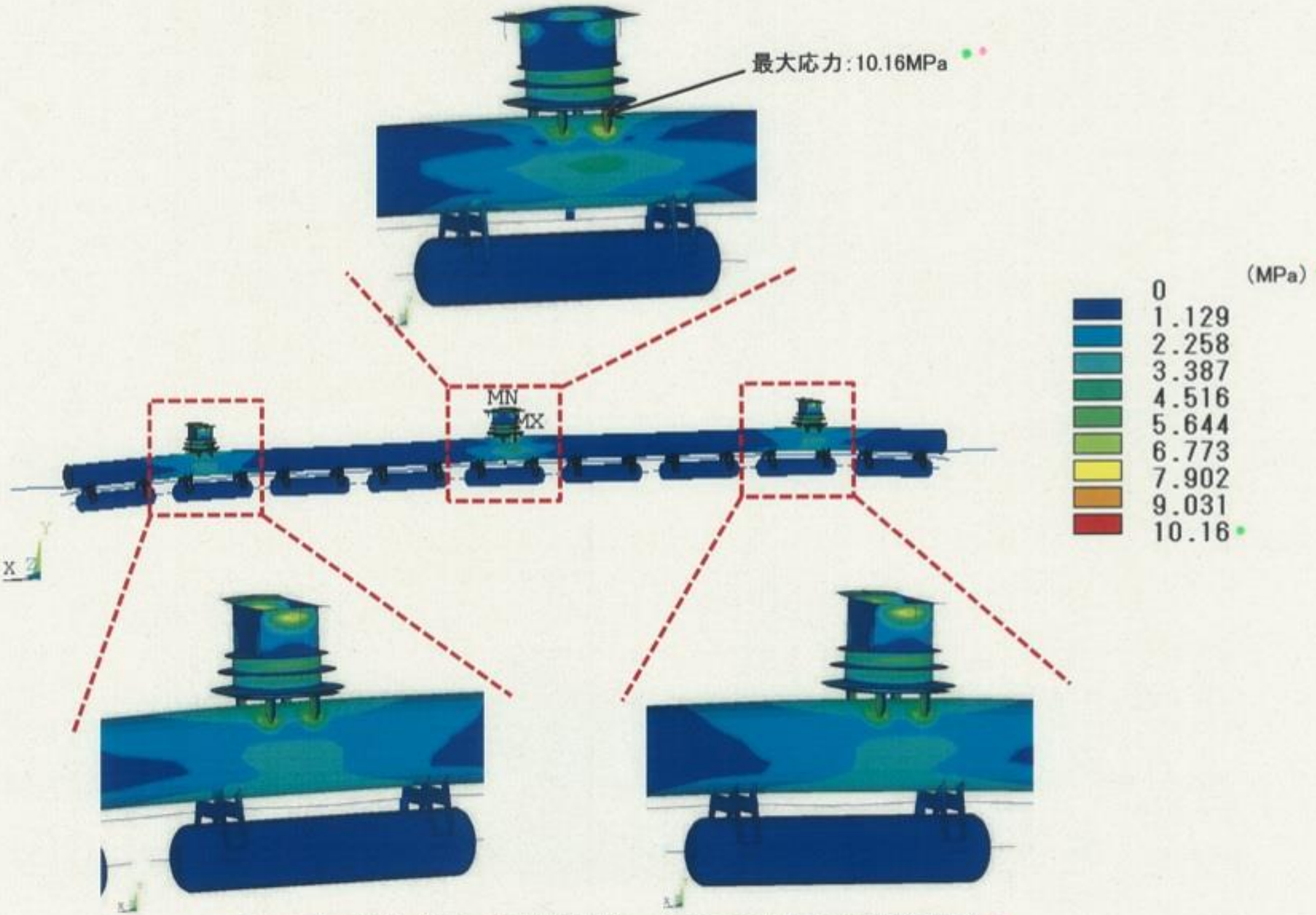


図2-5 自重解析　組合せ応力分布図(シェル要素TOP側, 真空容器非表示)

Static: GRP Stress

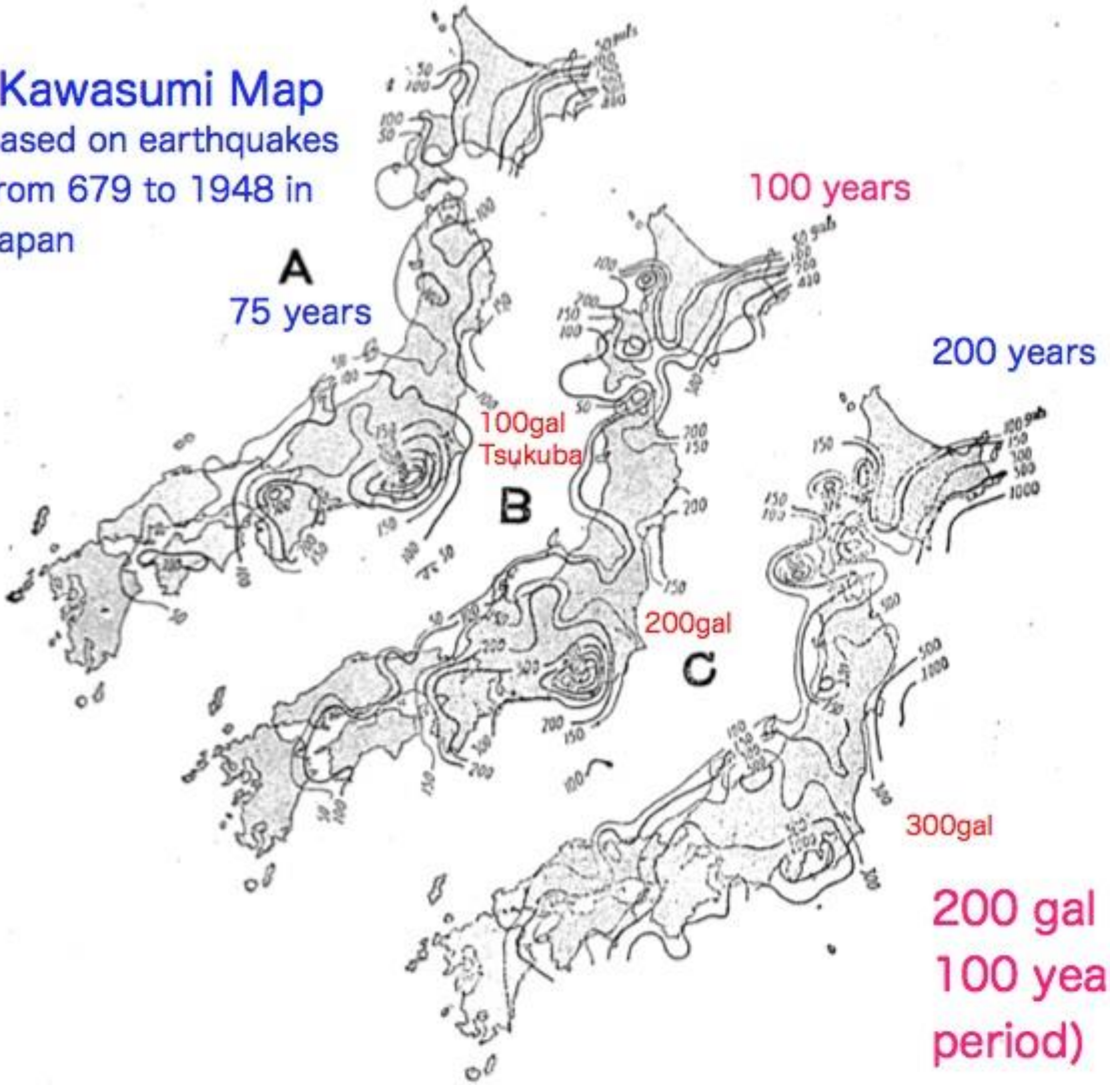
Earthquake Response analysis by ISO-3010

Hazard map in Japan

H. Yamaoka and T. Tauchi

Maximum acceleration (gal) in the 100 years of recurrence intervals of earthquake

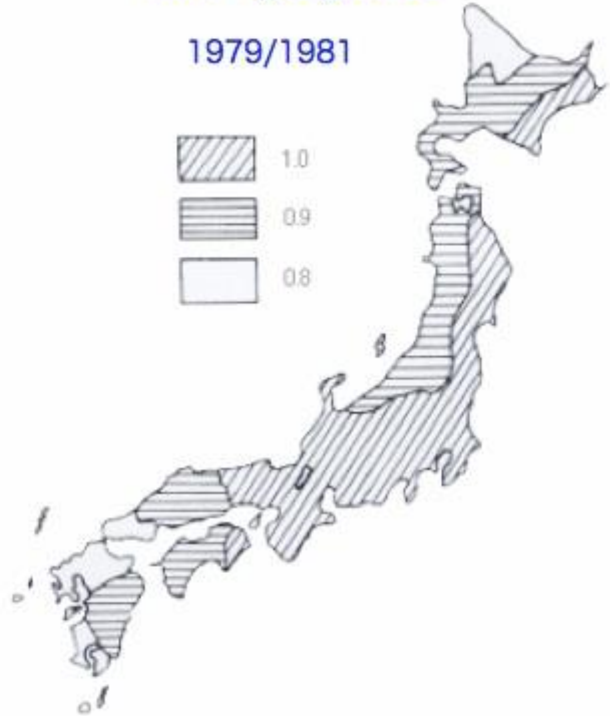
Kawasumi Map
based on earthquakes from 679 to 1948 in Japan



Regional constants of earthquake ground motions

small number means more rigid ground

1979/1981



200 gal in Tsukuba for the 100 years endurance(return period)

150 gal in Kitakami

H. Yamaoka and T. Tauchi

JMA (Japan Meteorological Agency) http://www.jma.go.jp/jma/kishou/know/shindo/explane.html

Scale(m)	JMA gal lower end	Acc(cm/s^2) $0.45 \times 10^{m/2}$	People	Indoor Situations	Outdoor Situations
0			Imperceptible to people.		
1	0.8	1.4	Felt by only some people in the building.		
2	2.5	4.5	Felt by most people in the building. Some people awake.	Hanging objects such as lamps swing slightly.	
3	8	14	Felt by most people in the building. Some people are frightened.	Dishes in a cupboard rattle occasionally.	Electric wires swing slightly.
2012.12.7 (M7.3)@Tsukuba 4	25	45	Many people are frightened. Some people try to escape from danger. Most sleeping people awake.	Hanging objects swing considerably and dishes in a cupboard rattle. Unstable ornaments fall occasionally.	Electric wires swing considerably. People walking on a street and some people driving automobiles notice the tremor.
5-Lower	80	142	Most people try to escape from a danger. Some people find it difficult to move.	Hanging objects swing violently. Most Unstable ornaments fall. Occasionally, dishes in a cupboard and books on a bookshelf fall and furniture moves.	People notice electric-light poles swing. occasionally, windowpanes are broken and fall, un-reinforced concrete-block walls collapse, and roads suffer damage.
5-Upper		253	Many people are considerably frightened and find it difficult to move.	Most dishes in a cupboard and most books on a bookshelf fall. Occasionally, a TV set on a rack falls, heavy furniture such as a chest of drawers falls, sliding doors slip out of their groove and the deformation of a door frame makes it impossible to open the door.	In many cases , un-reinforced concrete-block walls collapse and tombstones overturn. Many automobiles stop because it becomes difficult to drive. Occasionally, poorly-installed vending machines fall.
2011.3.11 (M9.0)@Tsukuba 6-Lower	250	450	Difficult to keep standing.	A lot of heavy and unfixed furniture moves and falls. It is impossible to open the door in many cases.	In some buildings, wall tiles and windowpanes are damaged and fall.
6-Upper		800	Impossible to keep standing and to move without crawling.	Most heavy and unfixed furniture moves and falls. Occasionally, sliding doors are thrown from their groove.	In many buildings, wall tiles and windowpanes are damaged and fall. Most un-reinforced concrete-block walls collapse.
7	400	1423	Thrown by the shaking and impossible to move at will.	Most furniture moves to a large extent and some jumps up.	In most buildings, wall tiles and windowpanes are damaged and fall. In some cases, reinforced concrete-block walls collapse.

H. Yamaoka, "Magnet seismic analysis", 10 July, 2007, KEK

H. Yamaoka and T. Tauchi

International Standard
Based for Design of Structures - Seismic Actions on Structures

2001

International Organization for Standardization

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).

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).

Normalized design response spectrum

The normalized design response spectrum can be interpreted as an acceleration response spectrum normalized by the maximum ground acceleration for design purpose.

It may be of the form

$k_R = 1$ for $T = 0$ (C.1)

Linear interpolation for $0 < T \leqslant T_c'$ (C.2)

$k_R = k_{R0}$ for $T_c' < T \leqslant T_c$ (C.3)

$$k_R = k_{R0}\left(\frac{T_c}{T}\right)^{\eta} \text{ for } T > T_c \quad \text{(C.4)}$$

where

- k_R is the ordinate of the normalized design response spectrum;
- k_{R0} is a factor dependent on the soil profile and the characteristics of the structure, e.g. the damping of the structure; for a structure with a damping ratio of 0,05 resting on the average quality soil, k_{R0} may be taken as 2 to 3;
- T is the fundamental natural period of the structure;
- T_c and T_c' are the corner periods as related to the soil condition, as illustrated in Figure C.1;
- η is an exponent that can vary between 1/3 and 1; when $\eta = 1$, the response velocity becomes constant as $\left(\frac{g}{2\pi} k_{R0} T_c\right)$ for $T > T_c$, therefore, T_c is closely related to the response velocity;

T_c, T_c' and η are dependent on tectonic and geological conditions; T_c' may be taken as (1/5) to (1/2) of T_c.

For example, for horizontal motions T_c can be taken as

- 0,3 s to 0,5 s for stiff and hard soil conditions,
- 0,5 s to 0,8 s for intermediate soil conditions, and
- 0,8 s to 1,2 s for loose and soft soil conditions.

For the classification of soil conditions, the thickness of the soil layers should be taken into account.

The fundamental natural period, T, can be calculated from calibrated empirical formulae, from Rayleigh's approximation, or from an eigenvalue formulation. For the estimation of T, the reduction of stiffness of concrete elements due to cracking should be taken into account.

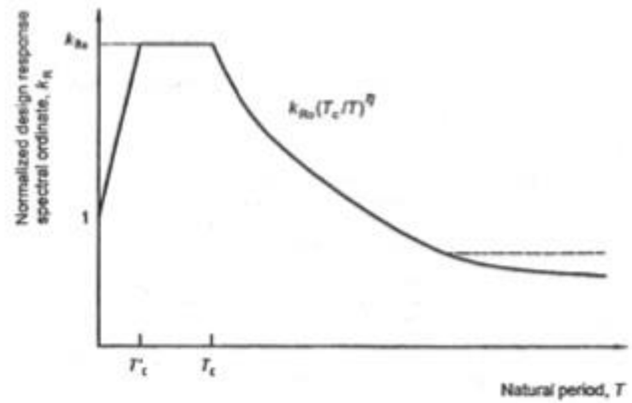


Figure C.1 — Normalized design response spectrum

Figure C.1 indicates that k_R is unity at $T = 0$ and linearly increases to k_{R0} at $T = T_c'$. It is recommended, however, to use $k_R = k_{R0}$ for $0 < T \leqslant T_c'$, as the dotted line of Figure C.1, because of the following reasons:

- uncertainty of ground motion characteristics in this range;
- low sensitivity of strong motion accelerometers in this range, and therefore a possibility of a higher value of k_R than the apparent one;
- possibility of an unconservative estimate of the structural factor k_D for short period structures.

For determination of forces at longer periods, it is recommended that a lower limit be considered as indicated by the dashed line in Figure C.1. The value of this level may be taken as 1/3 to 1/5 of k_{R0}.

For determination of the displacements at longer periods, Figure C.1 becomes too conservative. For long periods, the response displacement becomes a function of the maximum displacement of earthquake ground motions. There is uncertainty about the ground displacement close to faults in very large magnitude earthquakes, therefore extrapolation of data from smaller earthquakes should be made with care.

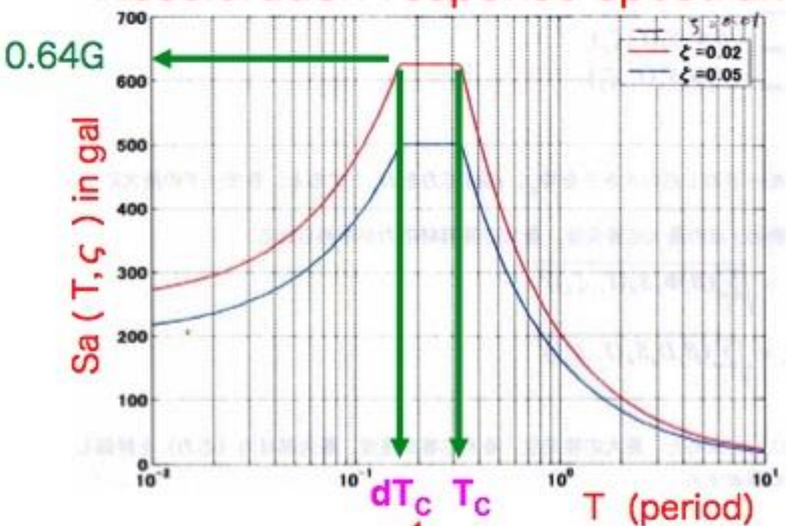
An equivalent linearization approach may also be used for estimating the maximum deformations of structural systems. In this approach, a system involving hysteretic behaviour is replaced with a linear system having an equivalent natural period and an equivalent viscous damping ratio. The maximum deformation of the hysteretic system is estimated as that of the equivalent linear system. A number of proposals are available for determining the equivalent natural period and viscous damping ratio, which are primarily specified as a function of the expected ductility factor. In recent years, design concepts based upon displacement analysis have been advanced, and the equivalent linearization approach is often used for determining the required strength for a given maximum deformation.

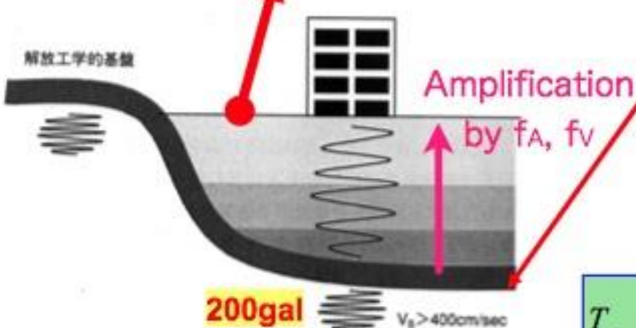
H. Yamaoka and T. Tauchi

ISO3010, geology (class-1, rigid), on the surface

Seismic analysis

Acceleration response spectrum





Steel structure : $\varsigma=0.02$

$0 \le T \le dT_C$

$$S_a = \left(1 - \frac{f_A - 1}{d} \cdot \frac{T}{T_C}\right) \cdot F_h \cdot G_A \cdot R_A \cdot A_0$$

$dT_C \le T \le T_C$

$$S_a = f_A F_h \cdot G_A \cdot R_A \cdot A_0$$

$T_C \le T$: Velo = const.

$$S_a = \frac{2\pi \cdot f_V \cdot F_h \cdot G_V \cdot R_V \cdot V_0}{T}$$

rigid $A_0 = 15 V_0$

A_0=200gal: *representative value of earthquake*

In case of *hard soil*, rigid

f_A=2.5, f_V=2.0, d=0.5, R_A=1.0, R_V=1.0, G_A=1.0, G_V=1.0, T_C=0.33

$$F_h = \frac{1.5}{1 + 10\varsigma}$$

ζ(Damping ratio) =0.02 → F_h=1.25

$$T_c = \frac{2\pi f_V \cdot G_V \cdot R_V \cdot V_0}{f_A \cdot G_A \cdot R_A \cdot A_0} = \frac{2\pi \cdot 2 \cdot 1 \cdot 1 \cdot A_0/15}{2.5 \cdot 1 \cdot 1 \cdot A_0} = 0.33 \text{ sec}$$

$dT_C \le T \le T_C$

$$S_a = f_A F_h \cdot G_A \cdot R_A \cdot A_0 = 2.5 \cdot 1.25 \cdot 1.0 \cdot 1.0 \cdot 200 \; . = 625 \; (gal)$$

T_c=0.33sec= *3Hz*

dT_c=0.16sec= *6.3Hz*

H. Yamaoka, “Magnet seismic analysis”, 10 July, 2007, KEK

f_A : ratio of $G_A R_A A_0$ of $S_a(T,0.05)$ in $dT_c<T<T_c$, amplification factor

f_v : ratio of $G_v R_v V_0$ of $S_v(T,0.05)= S_a(T,0.05)T/2\pi$ in $T_c<T$, amplification factor

d : dT_c/T_c, ratio of lower bound of period (dT_c) relative to the upper one (T_c) in the constant $S_a(T,\varsigma)$

F_h : Correction factor of damping constant, $1.5/(1+10\varsigma)$

A_0 : Basic maximum acceleration of ground motion

V_0 : Basic maximum velocity of ground motion

R_A : conversion coefficient of recurrence intervals of the maximum acceleration

R_v : conversion coefficient of recurrence intervals of the maximum velocity

G_A : site-dependen correction factor of the maximum acceleration

G_v : site-dependen correction factor of the maximum velocity

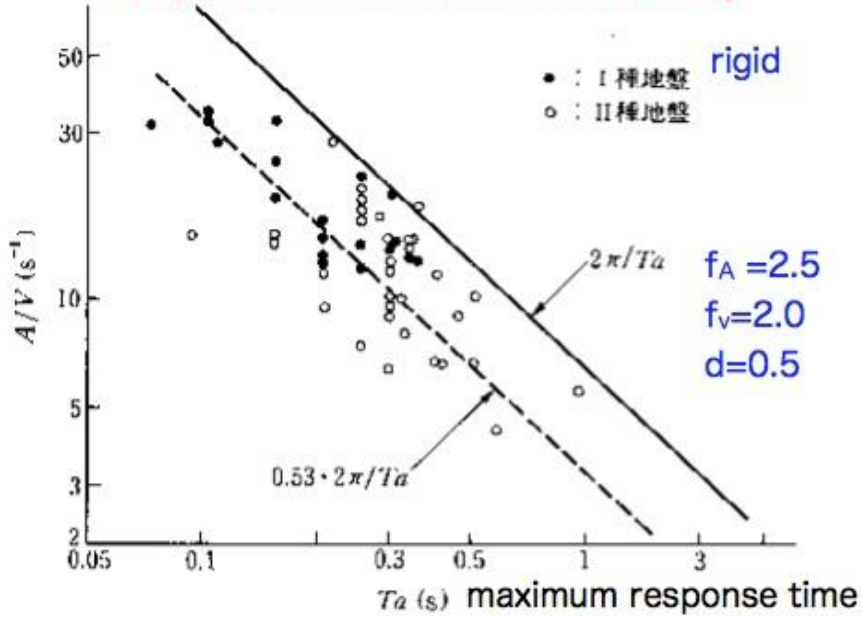
Natural vibration analysis of structures

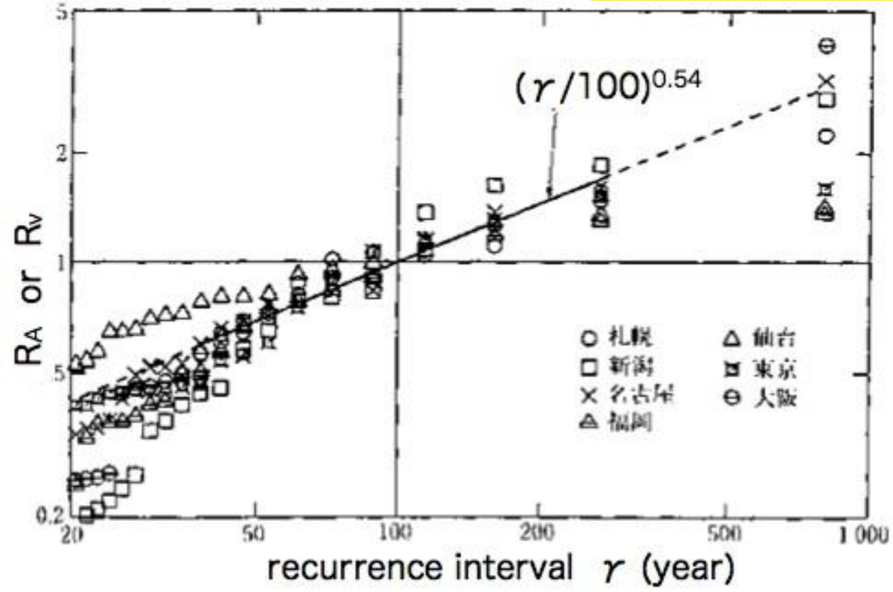
Calculation of eigen frequencies, own natural periods, eigen angular frequencies, natural vibration modes, impulse constants, effective masses then,

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

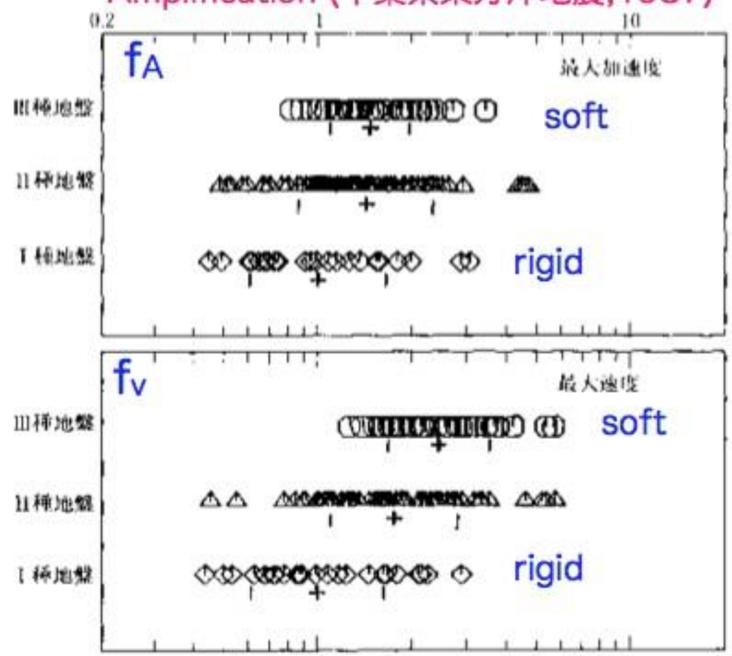
H. Yamaoka and T. Tauchi

Response time of acceleration/velocity



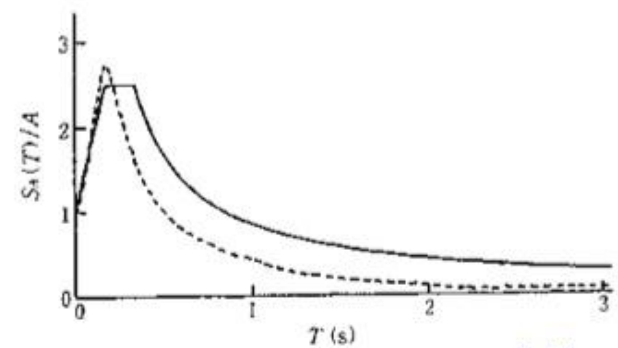


Amplification (千葉県東方沖地震,1987)



荷重指針で推奨する地盤種別ごとの G_A, G_V および T_c

	地盤種別	G_A	G_V	T_c (s)
rigid	第Ⅰ種：標準地盤（堅固な地盤）	1.0	1.0	0.33
	第Ⅱ種：緩い洪積地盤または締った沖積地盤	1.2	2.0	0.56
soft	第Ⅲ種：軟弱地盤	1.2	3.0	0.84



(a) 第Ⅰ種地盤（破線は1種） rigid

表4-1 各種地盤での応答スペクトル算出用のパラメータ

パラメータ	第Ⅰ種地盤	第Ⅱ種地盤	第Ⅲ種地盤	備考
f_A	2.5	3.0	3.0	最大加速度の分布より
f_V	2.0	3.4	3.4	最大速度の分布より
d	0.5	0.35	0.35	T_C'とT_Cの比
R_A	1.0	1.0	1.0	発生間隔(100年)より
R_V	1.0	1.0	1.0	発生間隔(100年)より
G_A	1.0	1.2	1.2	山岡先生の資料より
G_V	1.0	2.0	3.0	山岡先生の資料より
T_C(s)	0.33	0.8	1.2	山岡先生の資料より
T_C'(s)	0.16	0.28	0.42	T_C'はTCの1/5～1/2
F_h	1.25	1.25	1.25	$F_h=1.5/(1+10\cdot\zeta)$より, $\zeta=0.02$
A_0(gal)	200	200	200	つくば地盤の加速度より

応答スペクトル算出式

$0 \leqq T \leqq T_C'$ $\quad S_a=(1+((f_A-1)/d)\cdot(T/T_C))\cdot F_h\cdot G_A\cdot R_A\cdot A_0$ ・・・・・(1)

$T_C' \leqq T \leqq T_C$ $\quad S_a=f_A\cdot F_h\cdot G_A\cdot R_A\cdot A_0$ ・・・・・(2)

$T_C \leqq T$ $\quad S_a=2\cdot\pi\cdot f_V\cdot F_h\cdot G_V\cdot R_V\cdot V_0/T$ ・・・・・(3)
(ここで$A_0=15\cdot V_0$)

ISO-3010 Earthquake Spectrum

Assumed spectrum;
100 years endurance,
at Tsukuba surface (medium rigidity)
(and at Kitakami-site surface)

200 gals is representative earthquake,
peak acceleration is 900 gals
at 0.28 – 0.8 sec period
(1.25Hz - 3.57Hz)

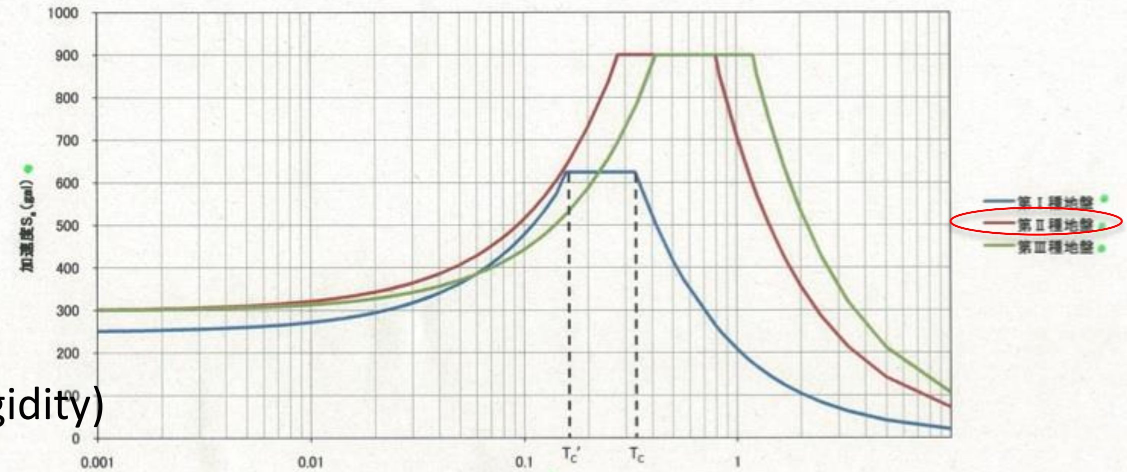


図4-1 応答スペクトル(横軸:周期)

Three main Eigen-modes

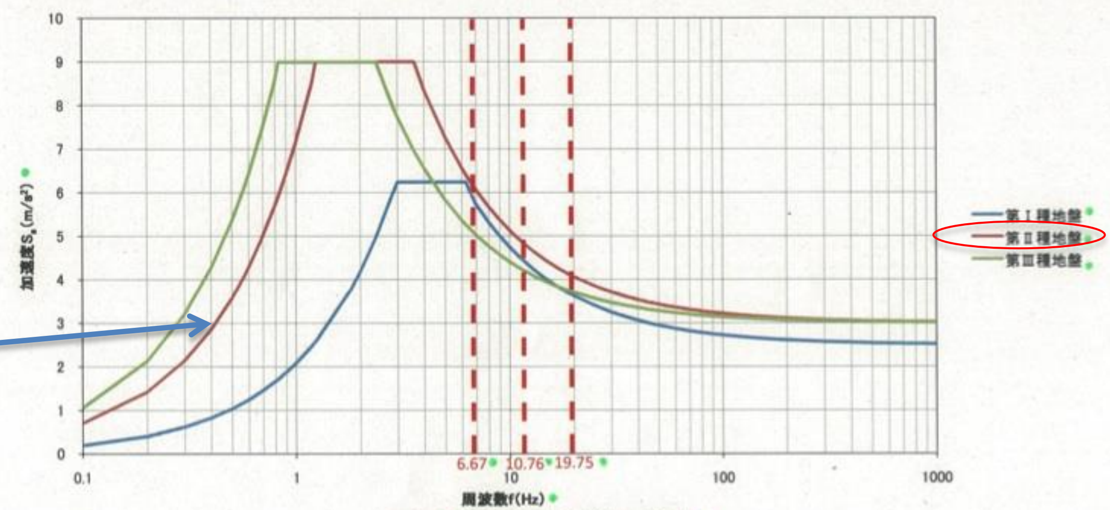


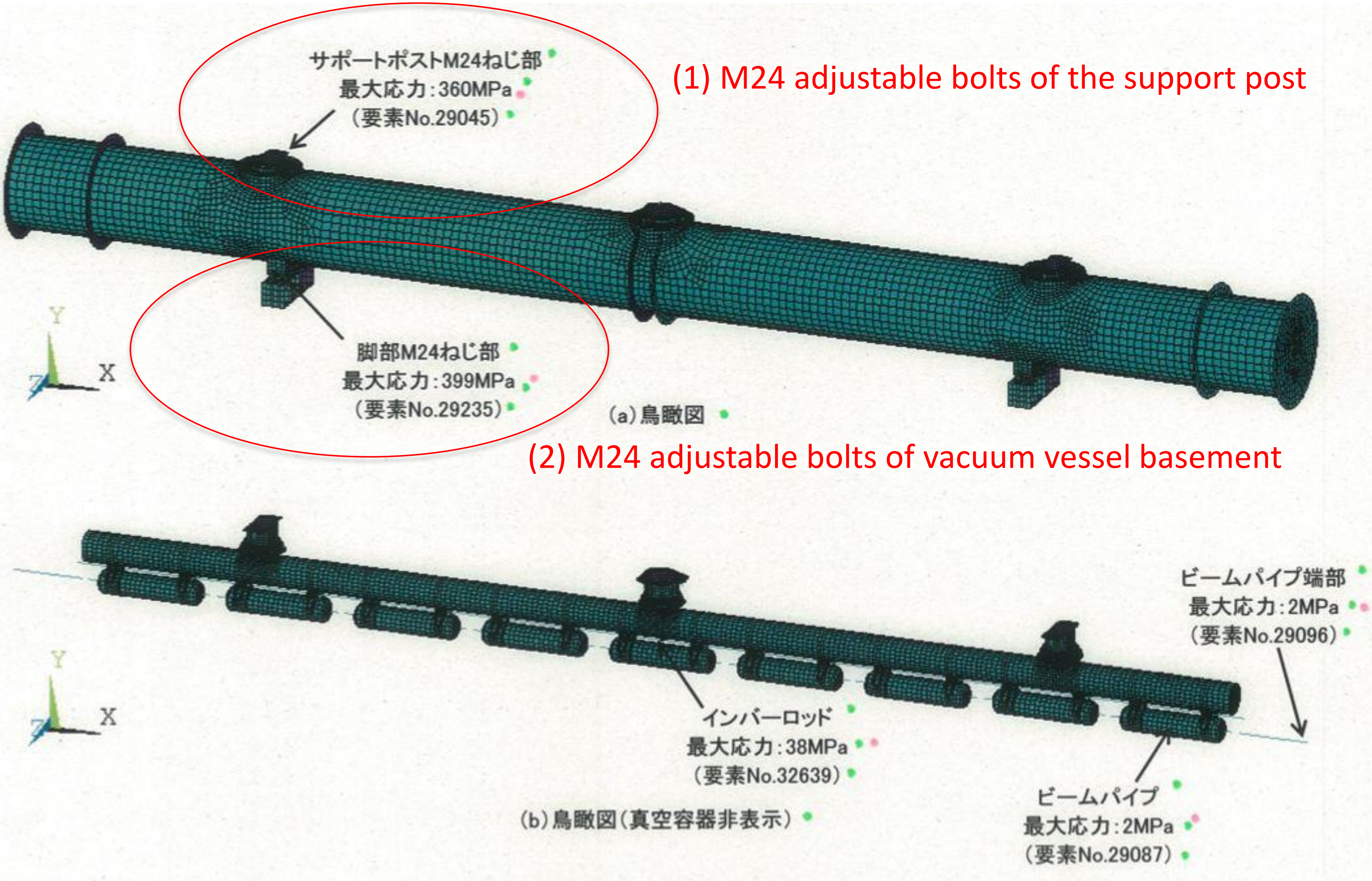
図4-2 応答スペクトル(横軸:周波数)

Assumed spectrum
(red line)

Stress Analysis applying earthquake spectrum

Components excessing max. allowable stress are;

Max. allowable stress of steel and stainless-steel is 200MPa



Max. stress for beam-elements by static + Earthquake

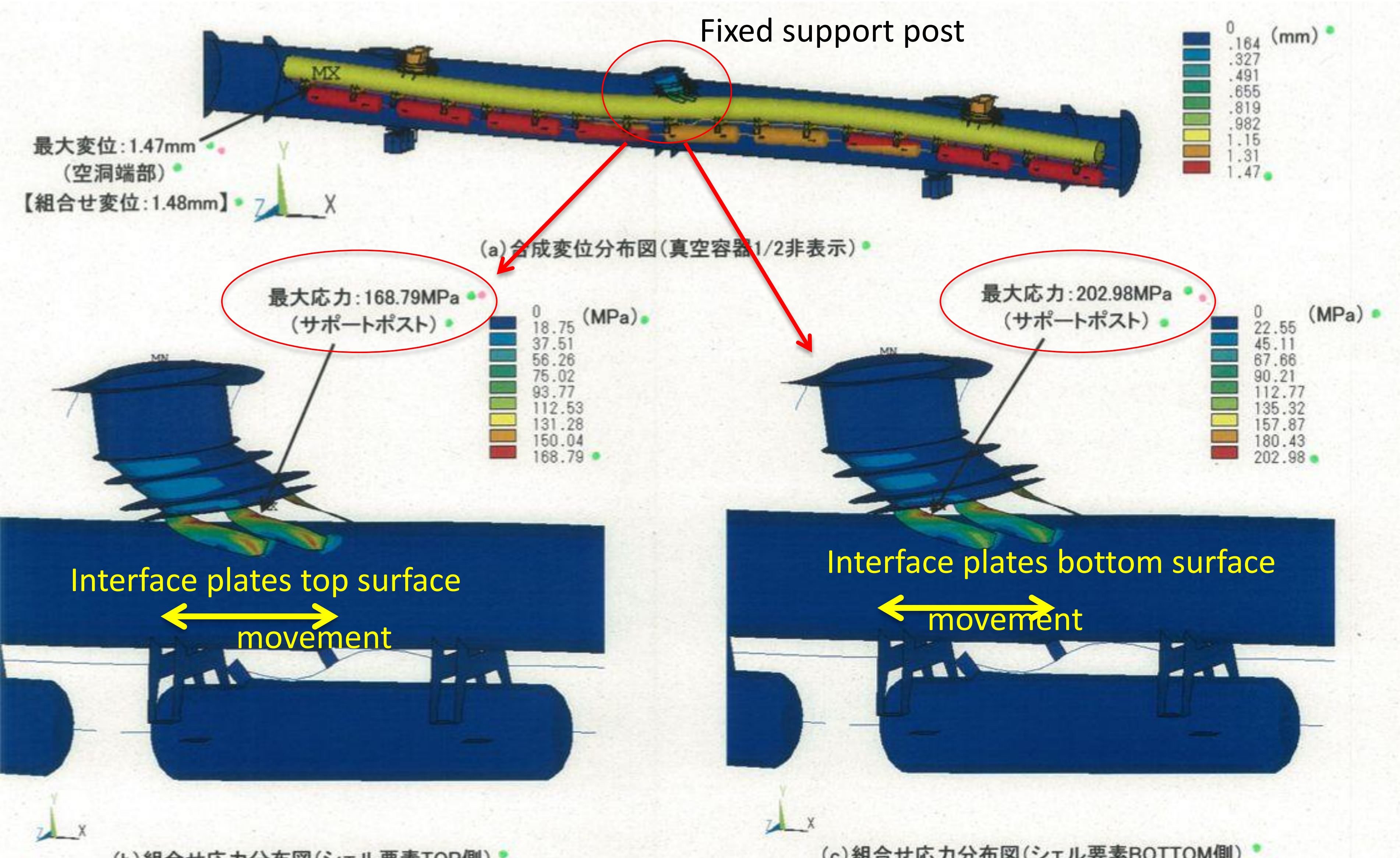
Components excessing max. allowable stress are;

Max. allowable stress of steel and stainless-steel is 200MPa

(3) Interface plates between GRP and support post

Max. stress for shell-elements by static + Earthquake

More detail explanation of max stress: (3) Interface plates between GRP and support post



Max. stress for shell-elements by 10.76Hz Eigen-mode (beam axis direction mode)

Summary of Analysis

ILC cryomodule based on T4CM(FNAL) was modeled for FEM analysis.
The Eigen-modes are;

10.76 Hz for X axis (electron beam direction)
19.75 Hz for Y axis (vertical direction)
6.67 Hz for Z axis (horizontal direction)

Earthquake spectrum based on ISO-3010 was assumed for;
100 years recurrence, 200 gal acceleration at Tsukuba area rigidity.
(It corresponds to 150 gal at Kitakami area, smaller than Tsukuba)

Components excessing max. allowable stress (200MPa) are;

(1) M24 adjustable bolts of the support post (360MPa)
(2) M24 adjustable bolts of vacuum vessel basement (399MPa)
(3) Interface plates between GRP and support post (318MPa)

Need size-up of M24 bolts, additional support for the GRP-support post interface plate.
Their cost-up will not be so much.