2023 KEPIC-Week, E1 - 기기검증 I

대형기기 내진 검증 시 IERS 활용 사례

Cases of using IERS in seismic Qualification of large equipment

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1. 대형기기의 내진검증 방법 소개

기기의 안전성능에 따른 분류
- 안전성 기기 (Safety Related Equipment)
- 비안전성 기기 (Non Safety Related Equipment)

기기의 동작에 따른 분류
- 능동기기 (Active Equipment)
- 수동기기 (Passive Equipment)

기기의 강성에 따른 분류
- 강성기기 (Rigid Equipment)
- 연성기기 (Flexible Equipment)

기기의 크기에 따른 분류
- 대형기기 (Large Equipment)
- 소형기기 (Small Equipment)

1. 대형기기의 내진검증 방법 소개

$$m\ddot{x}_{(t)} + c\dot{x}_{(t)} + kx_{(t)} = F_{(t)}\,(mg, f_1, f_2\ \ldots)$$

시스템의 내적 요인

1. 질량
2. 감쇠
3. 강성

시스템의 외적 요인

1. 지진
2. 운전 하중
3. 노즐 하중
4. 기타 하중

1. 대형기기의 내진검증 방법 소개

내진검증의 정의

- 시스템의 외적 요인으로부터 영향 받는 동적 특성을 통해 시스템의 성능 건전성을 입증하는 행위

$$m\ddot{x}_{(t)} + c\dot{x}_{(t)} + \mathrm{k}x_{(t)} = 0$$

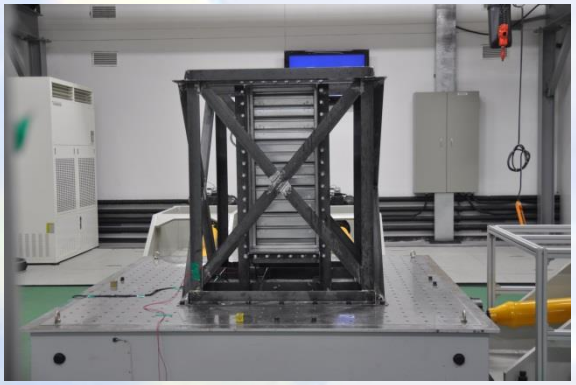
$$\omega_n = \sqrt{\frac{k}{m}} \qquad \zeta = \frac{c}{2m\omega_n}$$

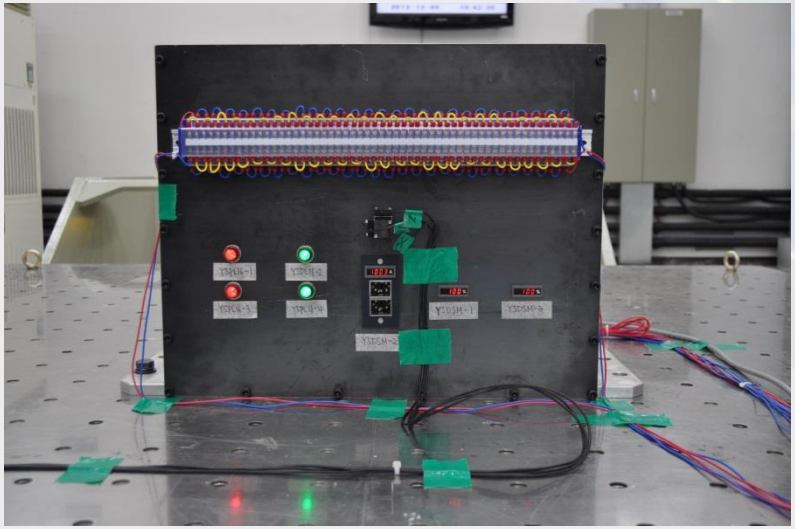
$$\omega_d = \omega_n\sqrt{1-\zeta^2} \qquad \zeta = 0.03\ (SSE\ Condition)$$

$$\omega_d \cong \omega_n = \sqrt{k/m}$$

1. 대형기기의 내진검증 방법 소개

KONEQ

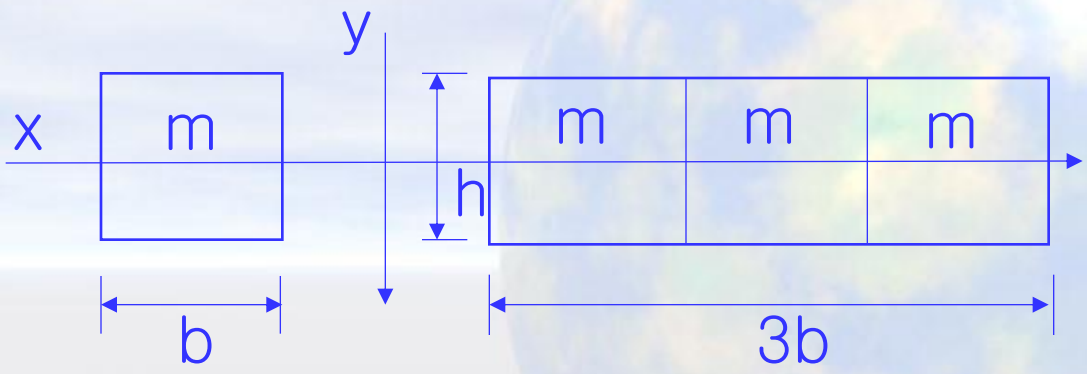




1. 대형기기의 내진검증 방법 소개

KONEQ

$$\omega_d \cong \omega_n = \sqrt{k/m} \qquad k \propto I$$



$$I_x = \frac{bh^3}{12} \qquad I_y = \frac{hb^3}{12}$$

1. 대형기기의 내진검증 방법 소개

KONEQ

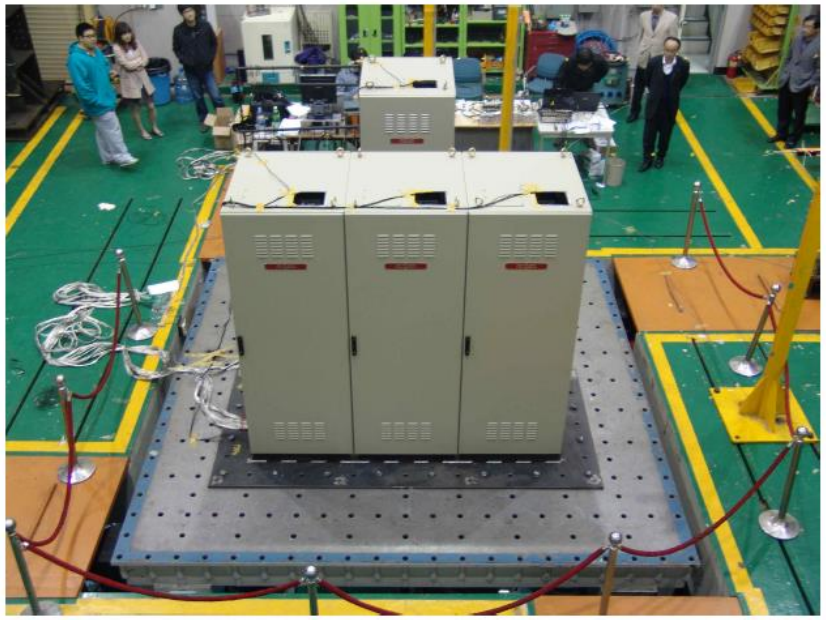


Table C.1: The lowest natural frequencies identified in X direction

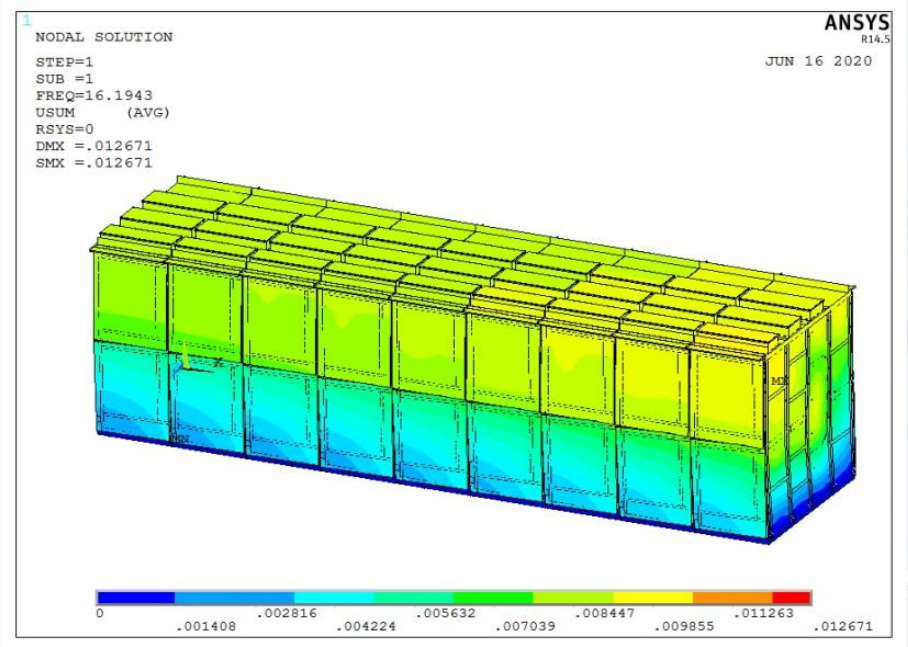
Location		Frequency (Hz)		
No.	Name	Before OBE (RES1)	After OBE (RES2)	After SSE (RES3)
1	Right Front Top Outside (LX)	12.12	11.52	10.15
7	Right Front Top Outside (GX)	15.93	14.92	14.32

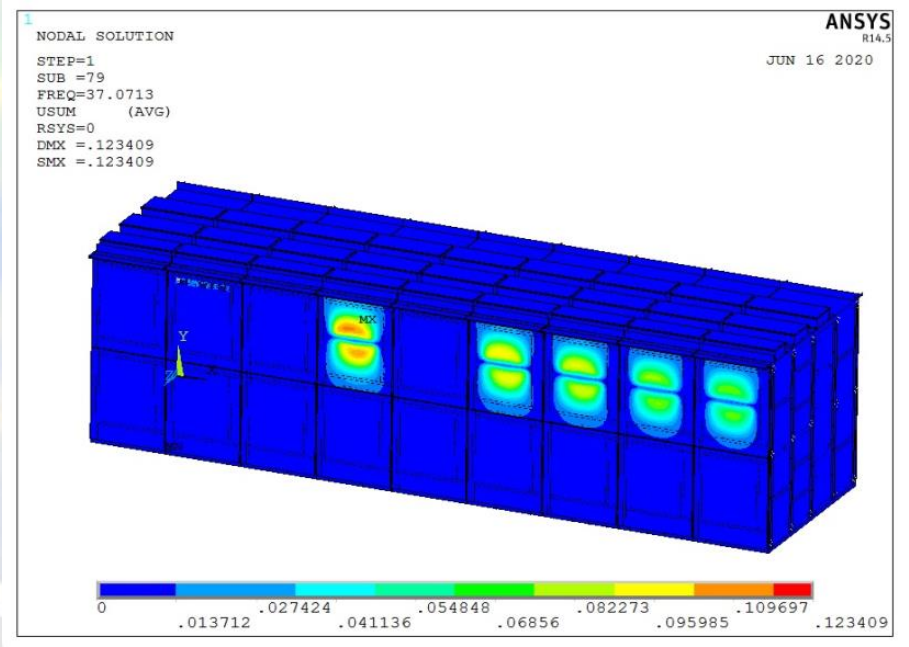
Table C.2: The lowest natural frequencies identified in Y direction

Location		Frequency (Hz)		
No.	Name	Before OBE (RES1)	After OBE (RES2)	After SSE (RES3)
1	Right Front Top Outside (LX)	27.92	27.71	25.44
7	Right Front Top Outside (GX)	28.53	28.53	28.04

1. 대형기기의 내진검증 방법 소개

KONEQ





1. 대형기기의 내진검증 방법 소개

KONEQ

******* PARTICIPATION FACTOR CALCULATION ***** X DIRECTION**

MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	MASS FRACTION	CUMULATIVE RATIO TO TOTAL EFF.MASS
1	11.2894	0.88579E-01	-98.638	1.000000	9729.45	0.781683	0.650227
2	18.4824	0.54105E-01	-0.25803	0.002616	0.665811E-01	0.781688	0.444967E-05
3	19.4363	0.51450E-01	0.24762	0.002510	0.613181E-01	0.781693	0.409794E-05
4	19.4425	0.51434E-01	-0.23468E-01	0.000238	0.550726E-03	0.781693	0.368055E-07
5	19.4636	0.51404E-01	0.19954	0.002023	0.398174E-01	0.781696	0.266103E-05
6	19.4857	0.51293E-01	-0.17512	0.001775	0.306661E-01	0.781699	0.204944E-05
7	20.2355	0.49418E-01	-0.18344	0.001860	0.336506E-01	0.781701	0.224889E-05
8	20.3008	0.49259E-01	-0.17265	0.001750	0.298084E-01	0.781704	0.199212E-05
9	23.5283	0.42502E-01	-11.236	0.113908	126.239	0.791846	0.843666E-02
10	26.1967	0.38173E-01	-0.13999	0.001419	0.195964E-01	0.791848	0.130964E-05
11	26.4309	0.37834E-01	-0.20549	0.002083	0.422242E-01	0.791851	0.282188E-05
12	27.0357	0.36998E-01	0.89828	0.009107	0.806904	0.791916	0.539260E-04
13	27.0457	0.36975E-01	1.1548	0.011708	1.33367	0.792023	0.891304E-04
14	27.0470	0.36973E-01	-0.20823E-01	0.000211	0.433608E-03	0.792023	0.289780E-07
15	28.7233	0.34815E-01	0.30554	0.003098	0.933558E-01	0.792030	0.623904E-05
16	28.9908	0.34484E-01	-0.31778	0.003222	0.100981	0.792039	0.674864E-05
17	29.0422	0.34433E-01	-0.10110	0.001025	0.102208E-01	0.792039	0.683065E-06
18	29.4547	0.33950E-01	3.2962	0.033417	10.8649	0.792912	0.726107E-03
19	29.5534	0.33837E-01	-0.74158E-01	0.000752	0.549944E-02	0.792913	0.367532E-06
20	29.9735	0.33363E-01	0.19929	0.002020	0.397171E-01	0.792916	0.265432E-05
21	30.4222	0.32871E-01	1.0995	0.011147	1.20899	0.793013	0.807975E-04
22	31.9164	0.31332E-01	-0.46957	0.004760	0.220492	0.793031	0.147367E-04
23	31.9975	0.31252E-01	0.43914	0.004452	0.192847	0.793046	0.128881E-04
24	32.1136	0.31139E-01	0.63387	0.006426	0.401788	0.793079	0.268518E-04
25	32.2861	0.30973E-01	-0.62574E-01	0.000634	0.391554E-02	0.793079	0.261678E-06
26	32.3384	0.30923E-01	-0.28075	0.002846	0.788213E-01	0.793085	0.526769E-05
27	32.3597	0.30903E-01	0.14998	0.001520	0.224935E-01	0.793087	0.150326E-05
28	32.3645	0.30898E-01	-0.63242E-03	0.000006	0.399952E-06	0.793087	0.267291E-10
29	32.3726	0.30890E-01	0.69792E-01	0.000708	0.487088E-02	0.793087	0.325525E-06
30	32.4063	0.30859E-01	0.15024	0.001523	0.225731E-01	0.793089	0.150858E-05
31	33.8121	0.29575E-01	0.61808	0.006266	0.382024	0.793120	0.255309E-04
32	34.0747	0.29347E-01	0.44924	0.004554	0.201821	0.793136	0.134878E-04
33	34.0803	0.29342E-01	0.28612	0.002901	0.818668E-01	0.793143	0.547123E-05
34	34.0878	0.29336E-01	0.74668E-02	0.000076	0.557531E-04	0.793143	0.372603E-08
35	34.1109	0.29316E-01	0.86145	0.008733	0.742089	0.793202	0.495944E-04
36	34.2207	0.29222E-01	-3.2586	0.033035	10.6182	0.794055	0.709622E-03
37	34.2995	0.29155E-01	-1.3202	0.013384	1.74298	0.794195	0.116481E-03
38	34.3269	0.29132E-01	-0.84219	0.008538	0.709282	0.794252	0.474019E-04
39	34.3525	0.29110E-01	-2.1043	0.021333	4.42794	0.794608	0.295923E-03
40	34.3720	0.29093E-01	-1.7304	0.017543	2.99438	0.794849	0.200117E-03
41	34.3873	0.29080E-01	-1.4546	0.014745	2.11544	0.795019	0.141377E-03
42	34.4027	0.29067E-01	-2.0036	0.020312	4.01433	0.795341	0.268281E-03
43	34.5303	0.28960E-01	-0.62335	0.006320	0.388560	0.795372	0.259678E-04
44	34.5786	0.28920E-01	-0.13271E-01	0.000135	0.176113E-03	0.795372	0.117698E-07
45	34.5835	0.28915E-01	-0.32905E-01	0.000334	0.108277E-02	0.795373	0.723621E-07
46	34.5836	0.28915E-01	0.21078E-01	0.000214	0.444272E-03	0.795373	0.296911E-07
47	34.5836	0.28915E-01	0.14546E-02	0.000015	0.211579E-05	0.795373	0.141400E-09
48	35.4700	0.28193E-01	-8.2360	0.083497	67.8309	0.800822	0.453319E-02
49	36.4264	0.27453E-01	-2.2683	0.022996	5.14525	0.801236	0.343861E-03
50	36.7566	0.27206E-01	-0.40824	0.004139	0.166658	0.801249	0.111379E-04
51	37.4013	0.26737E-01	0.85066	0.008624	0.723615	0.801307	0.483598E-04
52	37.4151	0.26727E-01	5.9940	0.060767	35.9276	0.804194	0.240107E-02
53	37.4798	0.26681E-01	-26.893	0.272641	723.221	0.862299	0.483336E-01
54	37.5518	0.26630E-01	2.8389	0.028781	8.05939	0.862946	0.538615E-03
55	37.9010	0.26385E-01	-0.29567E-01	0.000300	0.874210E-03	0.862946	0.584242E-07
56	39.1570	0.25538E-01	-23.998	0.243291	575.893	0.909215	0.384874E-01
57	39.6861	0.25198E-01	10.735	0.108831	115.236	0.918473	0.770135E-02
58	40.3734	0.24769E-01	-15.407	0.156196	237.371	0.937544	0.158637E-01
59	41.0602	0.24354E-01	5.2908	0.053639	27.9927	0.939793	0.187077E-02
60	41.2881	0.24220E-01	-4.0989	0.041555	16.8009	0.941142	0.112282E-02
61	41.3901	0.24160E-01	3.8025	0.038551	14.4594	0.942304	0.966331E-03
62	41.5779	0.24051E-01	-1.1810	0.011973	1.39473	0.942416	0.932112E-04
63	41.7668	0.23942E-01	2.4709	0.025050	6.10521	0.942907	0.408016E-03
64	41.8119	0.23917E-01	-0.48688E-01	0.000494	0.237052E-02	0.942907	0.158424E-06
65	42.3566	0.23609E-01	-8.9819	0.091060	80.6753	0.949389	0.539159E-02
66	42.3956	0.23587E-01	-6.3113	0.063984	39.8323	0.952589	0.266202E-02
67	42.6138	0.23467E-01	-13.009	0.131887	169.236	0.966185	0.113102E-01
68	43.3748	0.23055E-01	-0.43452	0.004405	0.188808	0.966201	0.126182E-04
69	43.4247	0.23028E-01	0.24205	0.002454	0.585885E-01	0.966205	0.391552E-05
70	43.5302	0.22973E-01	-1.2375	0.012546	1.53137	0.966328	0.102343E-03
71	43.5512	0.22961E-01	-0.37083	0.003760	0.137517	0.966339	0.919034E-05
72	43.8819	0.22788E-01	-12.708	0.128838	161.502	0.978315	0.107933E-01
73	43.9695	0.22743E-01	-11.243	0.113981	126.401	0.989470	0.844749E-02
74	44.0359	0.22709E-01	8.2439	0.083578	67.9624	0.994930	0.454198E-02
75	44.2757	0.22586E-01	3.2877	0.033330	10.8087	0.995799	0.722361E-03
76	44.5109	0.22466E-01	1.6321	0.016546	2.66361	0.996013	0.178011E-03
77	44.6055	0.22419E-01	0.87325E-01	0.000885	0.762560E-02	0.996013	0.509625E-06
78	44.6170	0.22413E-01	0.92843	0.009412	0.861982	0.996083	0.576089E-04
79	44.6175	0.22413E-01	-0.20008	0.002028	0.400330E-01	0.996086	0.267544E-05
80	44.6247	0.22409E-01	-0.47031	0.004768	0.221189	0.996104	0.147822E-04
81	44.6269	0.22408E-01	-0.20417	0.002070	0.416858E-01	0.996107	0.278590E-05
82	44.6605	0.22391E-01	1.0039	0.010178	1.00781	0.996188	0.673525E-04
83	44.6647	0.22389E-01	0.97331E-01	0.000987	0.947340E-02	0.996189	0.633115E-06
84	44.6747	0.22384E-01	0.62185E-02	0.000063	0.386891E-04	0.996189	0.258429E-08
85	44.6749	0.22384E-01	-0.77590E-01	0.000787	0.602018E-02	0.996189	0.402334E-06
86	44.6749	0.22384E-01	0.22618	0.002293	0.511566E-01	0.996193	0.341884E-05
87	44.7766	0.22333E-01	-2.6037	0.026396	6.77903	0.996738	0.453048E-03
88	45.6848	0.21889E-01	-0.37995	0.003852	0.144365	0.996750	0.964802E-05
89	45.9595	0.21758E-01	0.57472	0.005827	0.330305	0.996776	0.220745E-04
90	46.4749	0.21517E-01	-0.75693	0.007674	0.572945	0.996822	0.382904E-04
91	46.5091	0.21501E-01	-0.50089	0.005078	0.250895	0.996842	0.167675E-04
92	46.5535	0.21476E-01	0.32509E-01	0.000330	0.105684E-02	0.996842	0.706294E-07
93	46.6027	0.21458E-01	-1.7796	0.018042	3.16697	0.997097	0.211651E-03
94	46.7864	0.21374E-01	-0.58829	0.005964	0.346088	0.997125	0.231293E-04
95	46.9414	0.21303E-01	0.63284	0.006416	0.400482	0.997157	0.267646E-04
96	47.8170	0.20913E-01	-5.4092	0.054839	29.2594	0.999508	0.195543E-02
97	48.6026	0.20575E-01	0.68964	0.006992	0.475699	0.999546	0.317847E-04
98	48.9230	0.20440E-01	-2.3778	0.024107	5.65406	1.00000	0.377865E-03
sum					12446.8		0.831830

1. 대형기기의 내진검증 방법 소개

KONEQ

1. 대형기기의 내진검증 방법 소개

5/6-823-E-SW01A	2-PT T X VCB	B Z VCB B Z VCB	T Z VCB T Z VCB	B Z VCB B Z VCB	T Z VCB T X VCB	T Z VCB T Z VCB	2-PT T X VCB	2-PT T X VCB	
Ampere Size	2000A	1200A	1200A	1200A	1200A 2000A	1200A	2000A	2000A	
5/6-823-E-SW01B	2-PT T X VCB	2-PT T X VCB	T Z VCB T Z VCB	T Z VCB T X VCB	B Z VCB B Z VCB	T Z VCB T Z VCB	B Z VCB B Z VCB	2-PT T X VCB	
Ampere Size	2000A	2000A	1200A	1200A 2000A	1200A	1200A	1200A	2000A	
5/6-823-E-SW02A	PT+O T X VCB	O+PT B X VCB	2-PT T X VCB	B Z VCB B Z VCB	2-PT T X VCB	T Z VCB T X VCB	B Z VCB B Z VCB	T Z VCB B Z VCB	T Z VCB B Z VCB
Ampere Size	2000A	1200A	2000A	1200A	2000A	1200A 2000A	1200A	1200A	1200A
5/6-823-E-SW02B	T Z VCB B Z VCB	T Z VCB B Z VCB	B Z VCB B Z VCB	T Z VCB T Z VCB	2-PT T Z VCB	B Z VCB B Z VCB	2-PT T X VCB	O+PT B X VCB	PT+O T X VCB
Ampere Size	1200A	1200A	1200A	1200A 2000A	2000A	1200A	2000A	1200A	2000A

Prototype Switchgear	PT+0 T X VCB	2 PT T X VCB	T Z VCB T Z VCB	B Z VCB B Z VCB
Ampere Size	2000A	2000A	1200A	1200A 2000A

1. 대형기기의 내진검증 방법 소개

1. 대형기기의 동특성 파악(해석)
2. 대형기기의 Local Mode를 모두 야기시킬 수 있는 Proto-type 제작
3. Proto-type의 동특성 파악(시험)
4. 대형기기의 IERS 도출
5. IERS로 New RRS 작성
6. New RRS로 Proto-type 내진 시험
7. 6번의 TRS와 5번의 IERS를 비교하여 대형기기의 내진 건전성 입증

추가적으로 1번 해석의 결과의 정당성을 위해 Proto-type을 해석하여 3번의 결과와 비교하여 해석의 정당성을 입증

2. IERS (In-Equipment Response Spectrum)

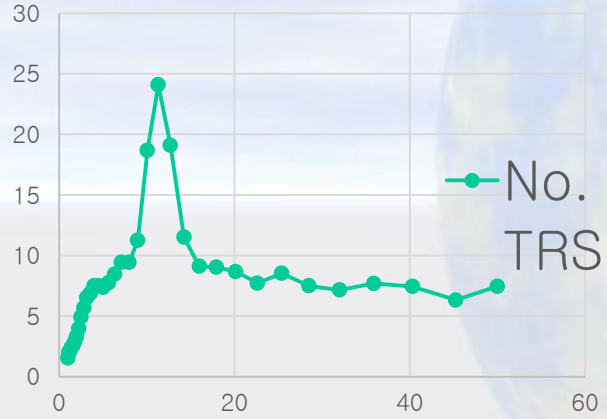
유한요소해석(FEM)에서의 동적 구조해석 종류

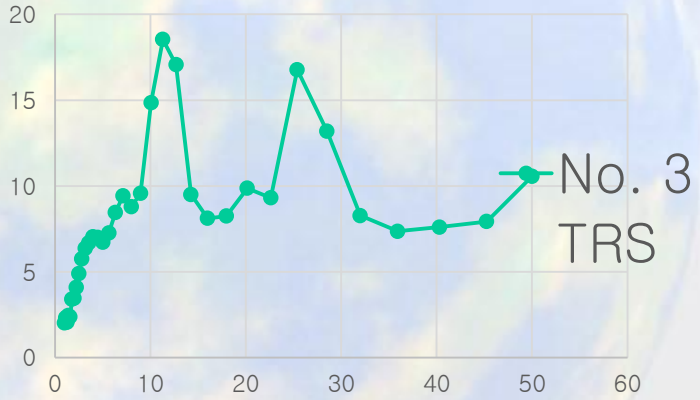
1. Mode Analysis
2. Static Coefficient Analysis
3. Response Spectrum Analysis (Single, Multi)
4. Transient Response (Full, Mode Superposition)
5. Harmonic Response (Full, Mode Superposition)

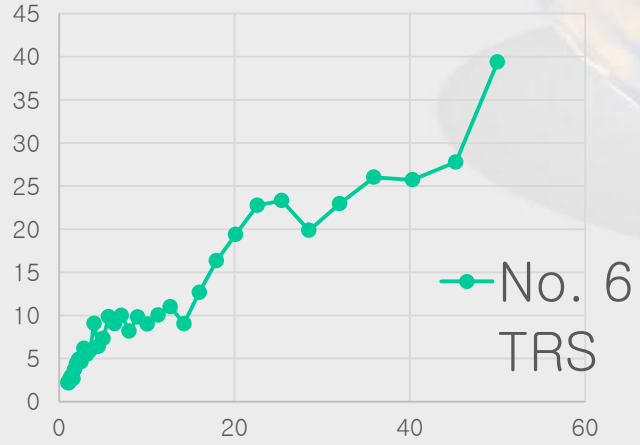
Time History Verification
Damping ?

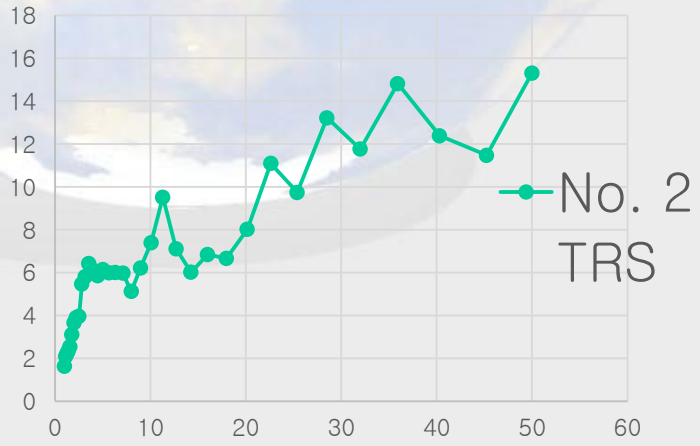
2. IERS (In-Equipment Response Spectrum)

Global Mode와 Local Mode의 관점에서 IERS



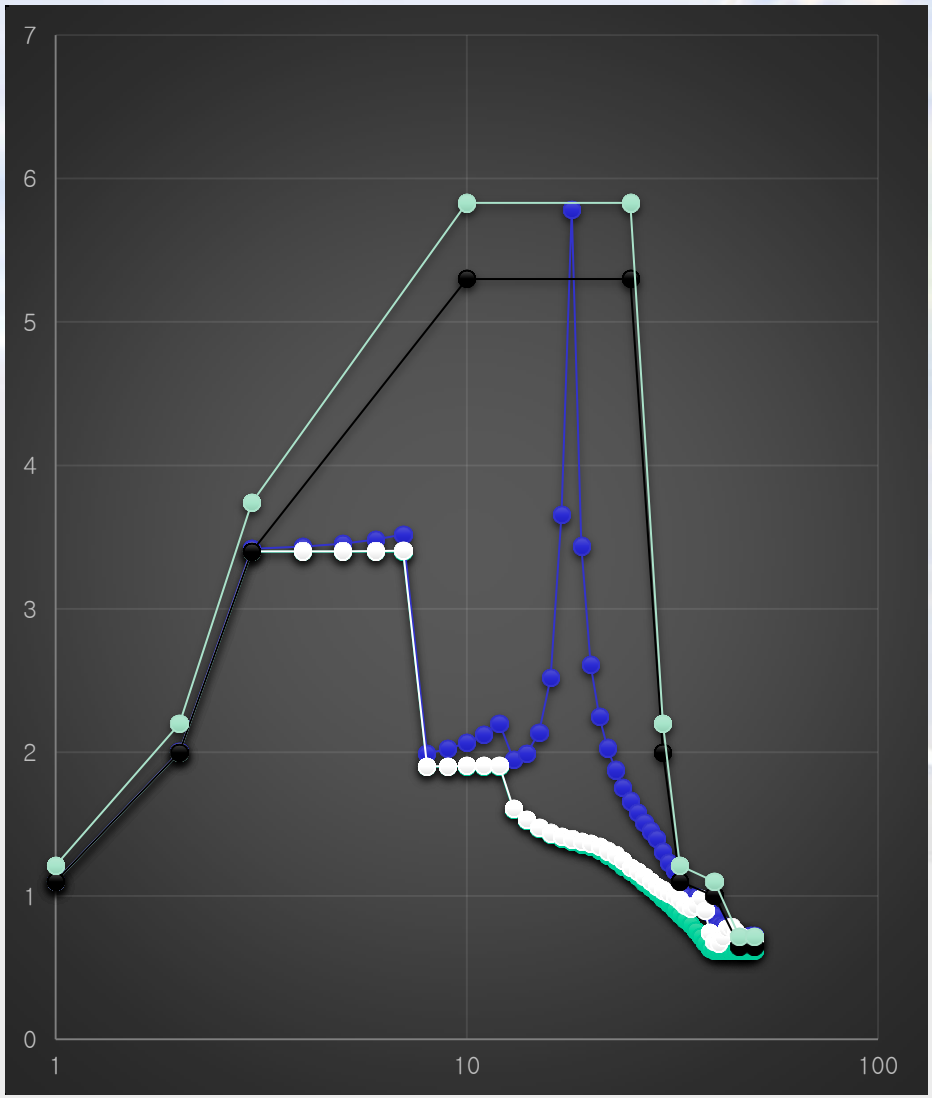


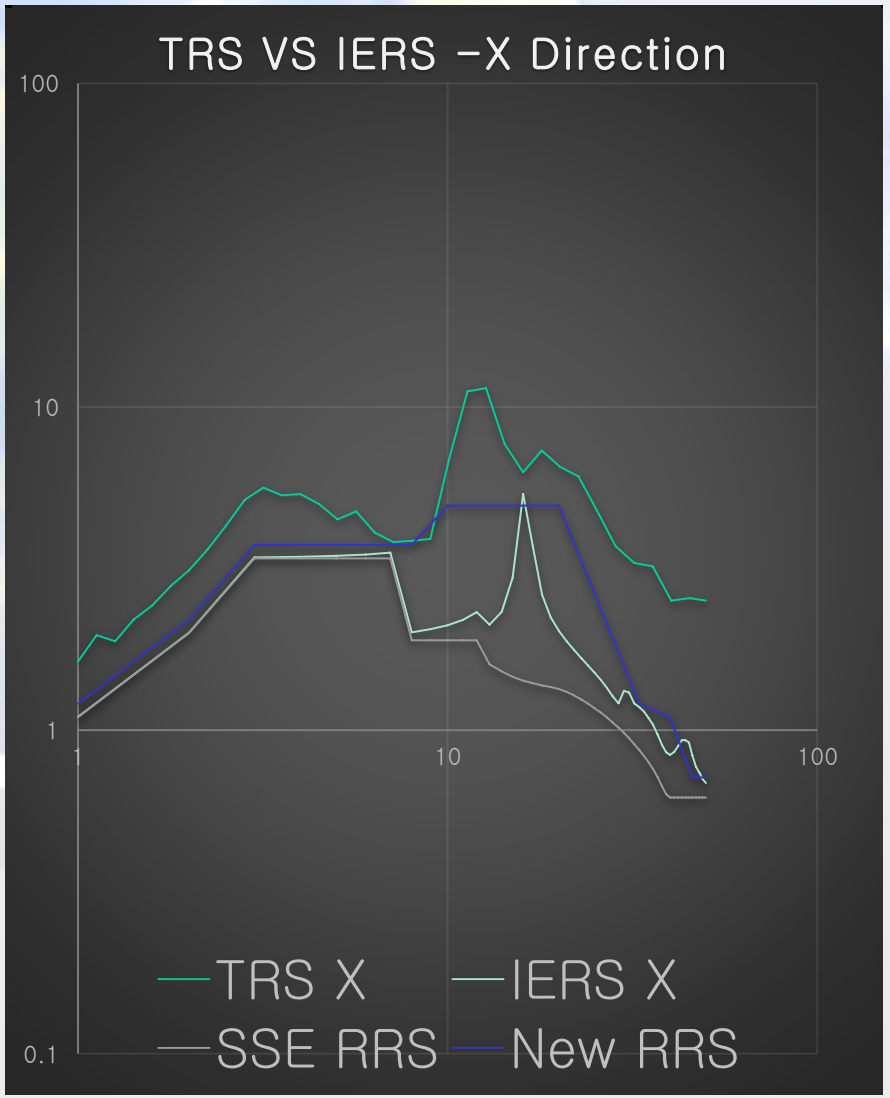




3. 검증 단계에서 IERS 활용

KONEQ





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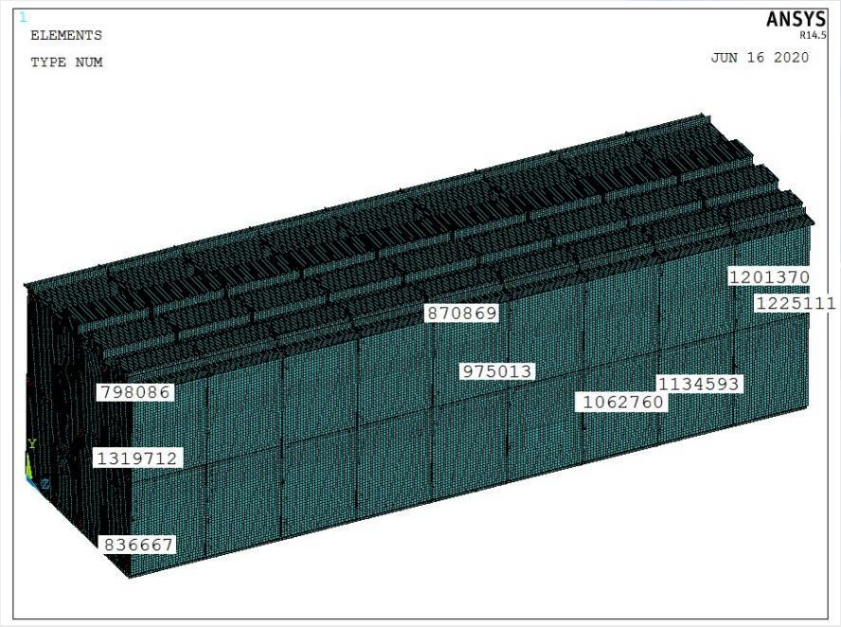

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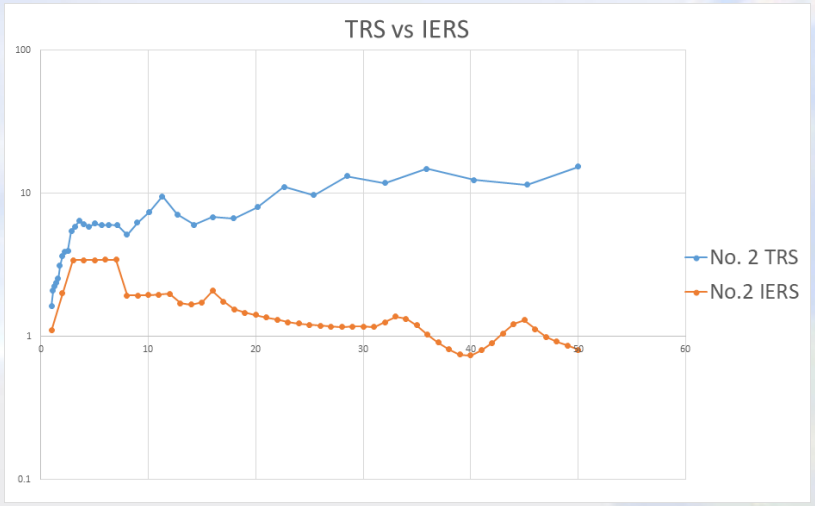
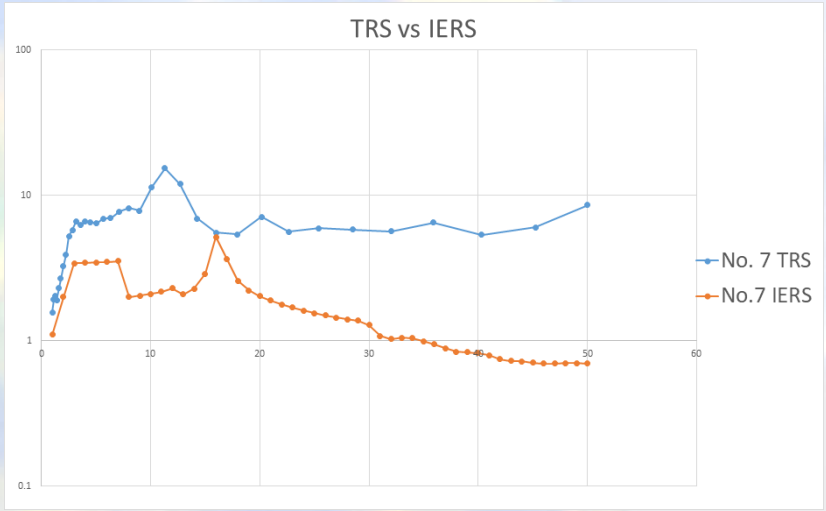
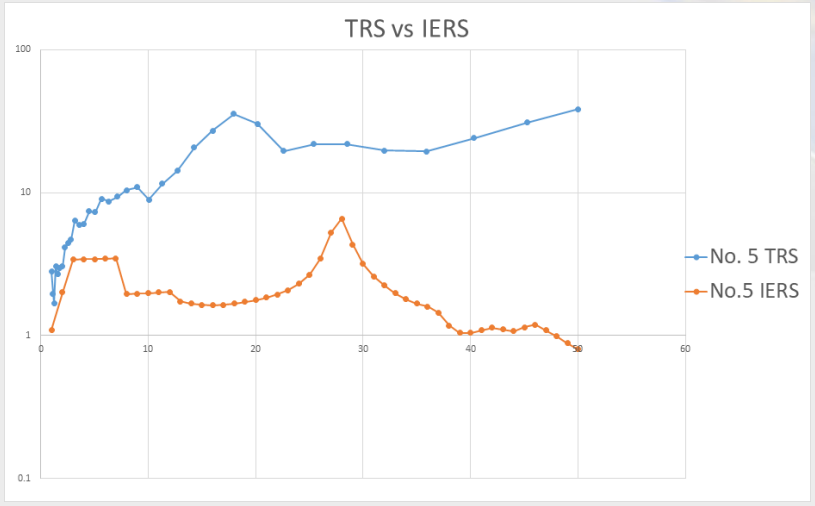
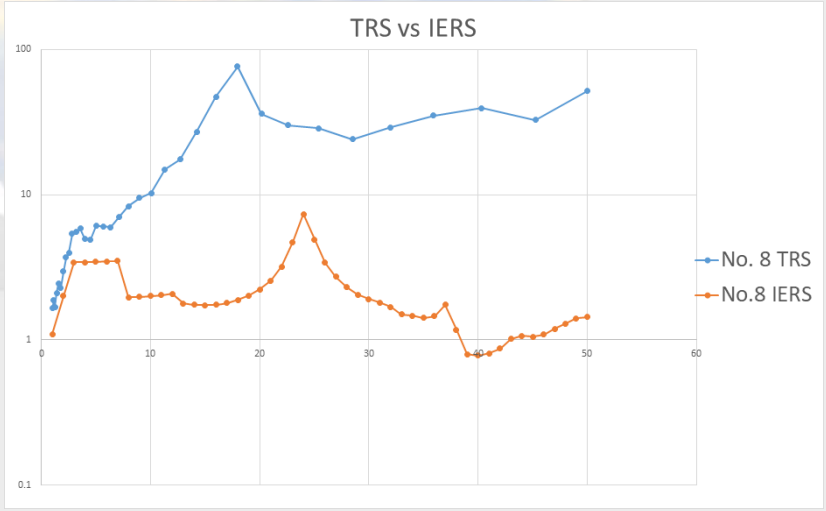
KONEQ

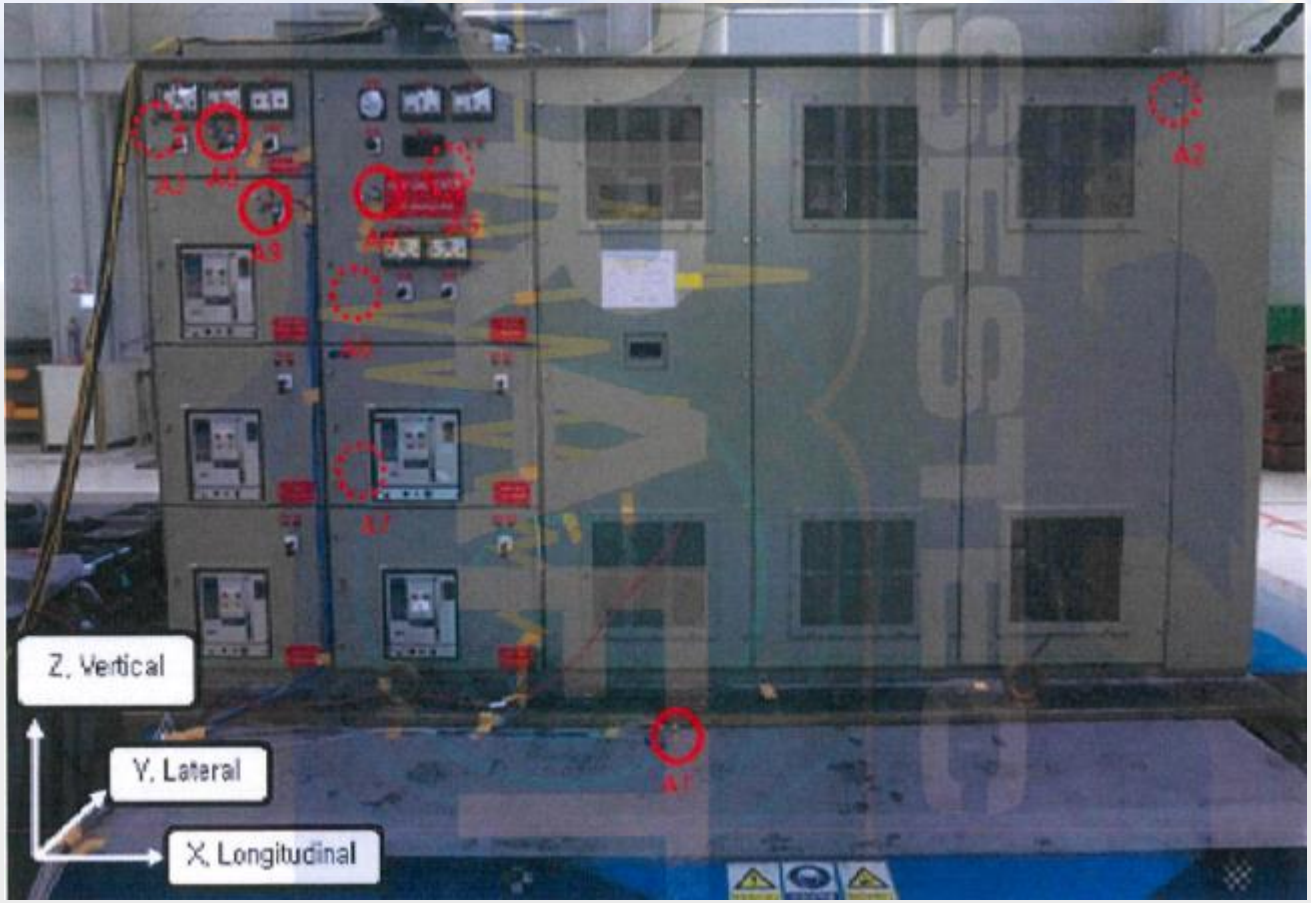








3. 검증 단계에서 IERS 활용



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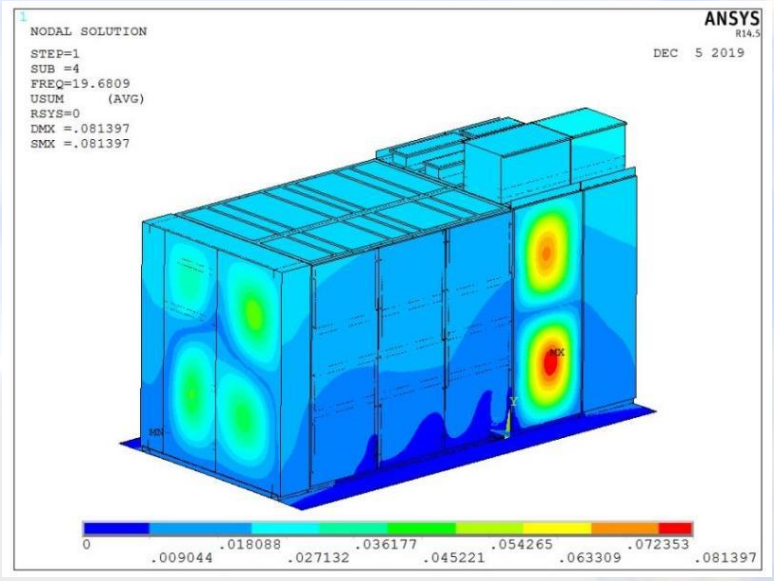
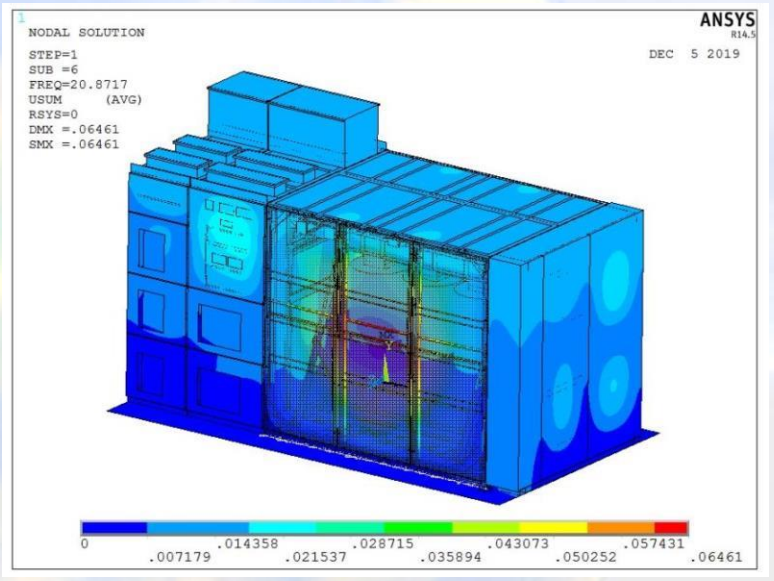
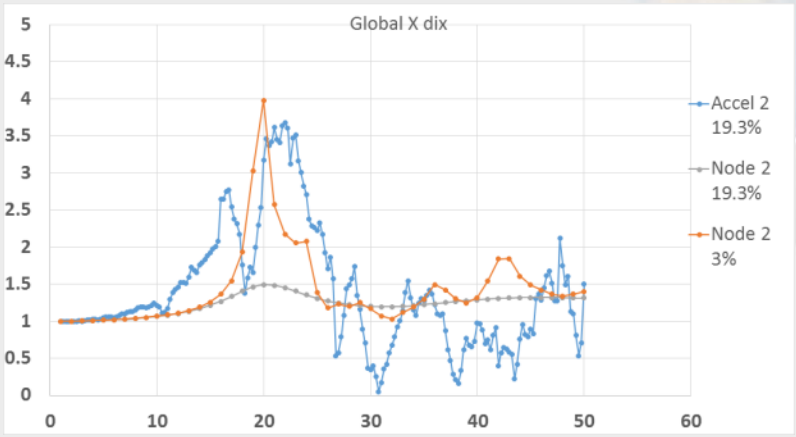
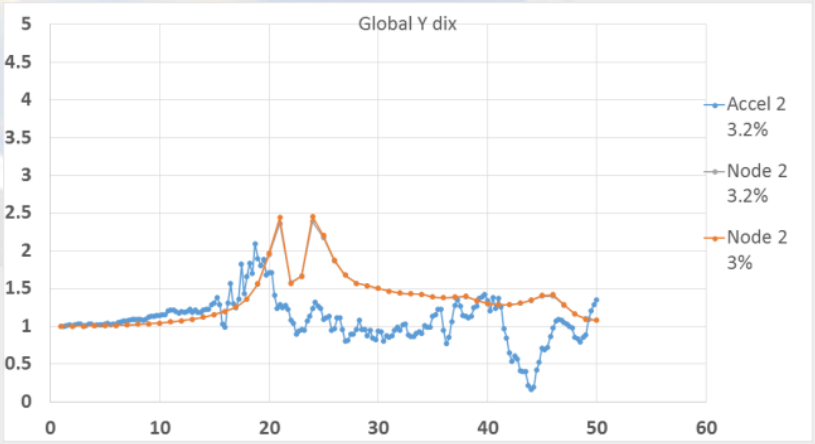
KONEQ









3. 검증 단계에서 IERS 활용

KONEQ

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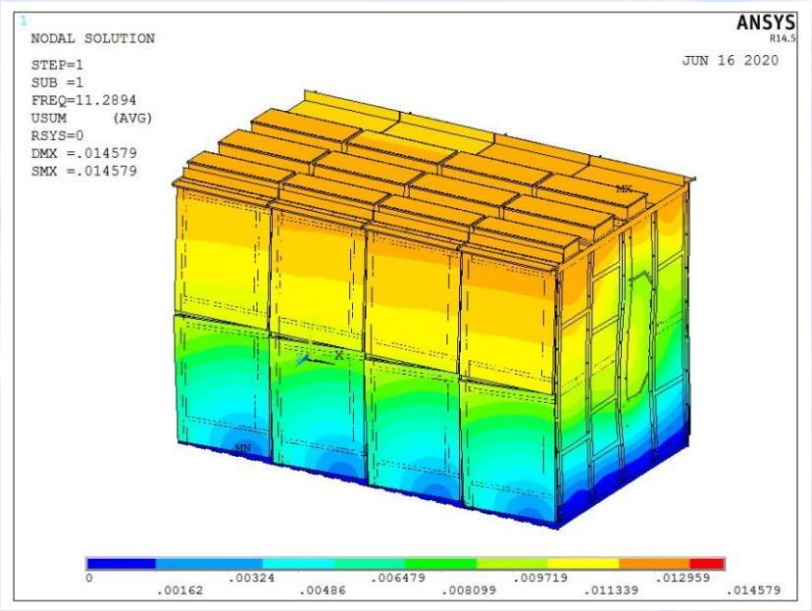

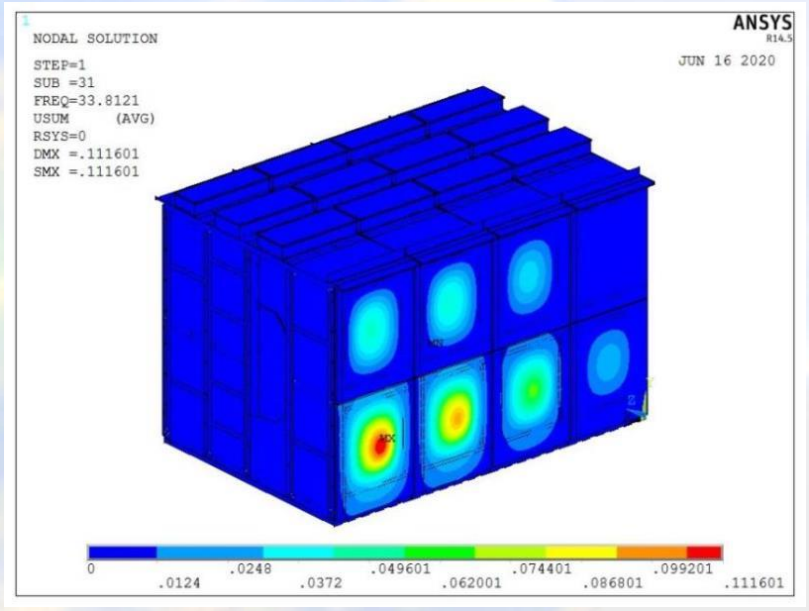

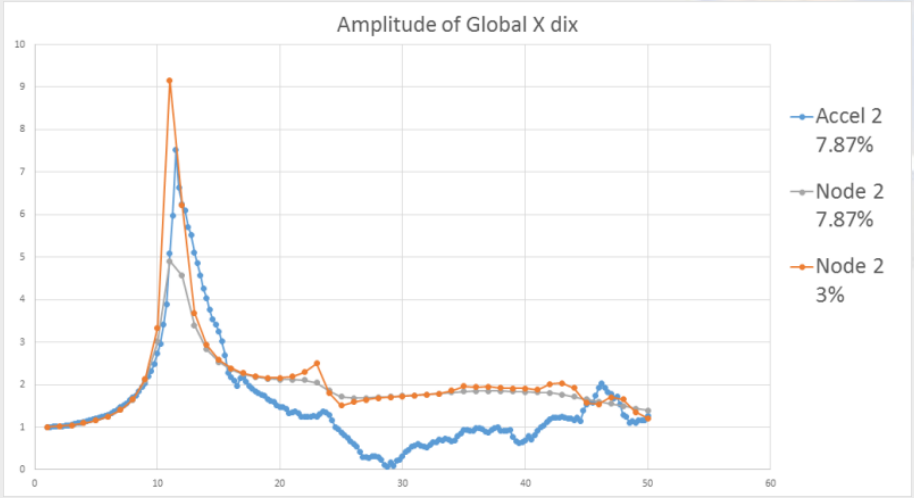

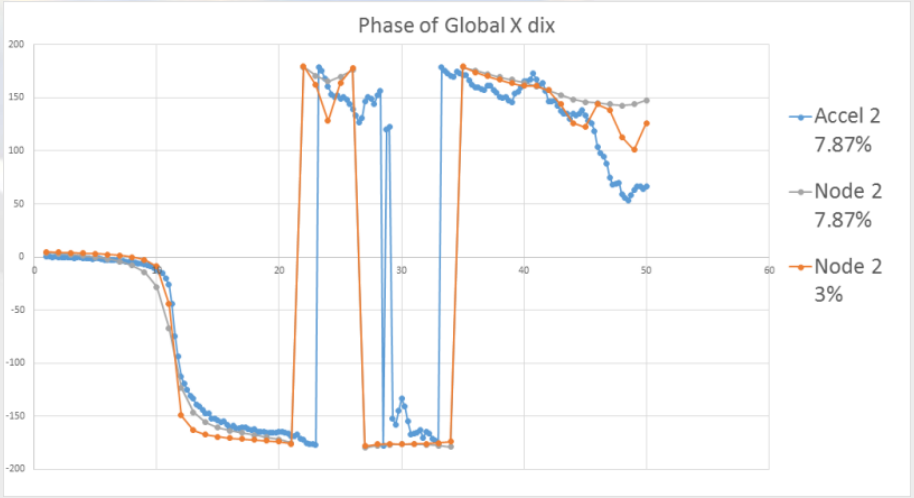

4. 맺는말

Q & A

감사합니다.