Title: Seismic Resistance of WWER Equipment (Sistematization and Generalization)

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SEISMIC RESISTANCE OF WWER EQUIPMENT
(SISTEMATIZATION AND GENERALIZATION).

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1. INTRODUCTION.

During 4 years VNIIAM carried out the calculational-experimental examination of equipment seismic resistance at Kozloduy (Units 5/6) and Paks NPPs in accordance with Research Contract No.7449/EN between International Atomic Energy Agency and VNIIAM. Before, starting with 1979, VNIIAM systematically conducted inspection of different NPPs with WWER-type reactors in Armenia, Bulgaria, Russia, Slovakia, and Ukraine. The large volume of works was carried out at 21 starting and operating units of following NPPs:

Kozloduy (Bulgaria) – 4 Units WWER-440, 2 Units WWER-1000;

Zaporozhskaya (Ukraine) – 2 Units WWER-1000;

Metsamor (Armenia) – 2 Units WWER-440;

Bohunice (Slovakia) – 4 Units WWER-440;

Rostovskaya (Russia) – 1 Units WWER-1000;

Paks (Hungary) – 4 Units WWER-440.

Beginning from 1985 VNIIAM carries out the works at NPPs jointly with KBGU.

In results of fulfilled works the following types of equipment were inspected:

- technological heat exchangers of different construction, configuration, and purpose;
- pressurizers;
- deaerators;
- filters of systems of water treatment, gas cleaning, oil cleaning;
- different tanks, reservoirs, containers;
- ventilators;
- pumps;
- cooling down reduction installations;
- numerous water and steam valves from small electric drive special valves of boron systems (D=10-50 mm) up to main shut off gate valves (D=500-800 mm);
- air valves for the recirculation and vacuum systems;
- conditioners;
- electrotechnical, checking and measuring equipment and assemblies (transformators, cabinet, control and adjustment panels, et al.);
- elements of loading-unloading machines, cranes;
- water and steam pipelines.

Total number of inspected units of equipment is more than 1000. This volume of inspected equipment was supplemented with results of participation of VNIIAM (S. Kaznovsky and I. Ostretsov) in plant walkdowns of Paks and Kozloduy NPPs during IAEA RCMs in frame of "Benchmark" Programme as well during participation of S. Kaznovsky in mission of IAEA experts at Kozloduy NPP in 1991.

For all seismic unsatisfactory terms the concrete technical recommendations for ensuring of the seismic resistance were worked out.

Accumulated extensive material permitted us to carry out the systematisation and generalization of results with the purpose of working out general recommendations allowing in case of need to evaluate the seismic capacity of equipment and to choose the technical means of its upgrading without laborious investigations and inspections. One can regard present report as reference book of recommendational character.

2. CALCULATIONAL-EXPERIMENTAL METHOD OF EXAMINATION OF EQUIPMENT SEISMIC RESISTANCE AT NPPs DIRECTLY.

As it is known the seismic influence on structures and equipment has a resonance nature. Ground and floor response spectra have the peaks in range of natural frequencies from 1-2 to 6-10 Hz. Therefore the natural dynamic characteristics (frequencies, decrements and modes of vibrations) exert decisive influence on equipment and pipelines seismic resistance. It is obvious that natural dynamic characteristics of any concrete unit depend on its construction and materials as well as on dynamic properties, space configuration, and masses of all jointed elements (supports, pipelines, isolation, etc.). Any concrete unit can not be seismically resistant by itself, separately from all mechanically jointed units. Disregard of this fact can lead to serious troubles. Unfortunately the best mathematical programmes and computers are not able to reproduce dynamic correlation between all elements of NPP and even of separate complex technological system. The same problem exists for vibration tests on special shake tables because their sizes and bearing capacity do not permit to test the real technological systems of NPP [1,2]. The tests of decreased models do not solve this problem too [3,4]. Therefore VNIIAM, widely using the traditional methods [1,2,5], simultaneously organized intense examinations of equipment and pipelines seismic resistance at NPPs directly [1,2,6,7].

Developed by VNIIAM calculational-experimental method consists of the following [2,7].

With help of external power influence the vibrations of examinated unit are excited and at the same time registration of vibrations are carried out. Analysis of experimental data permits to receive the values of the natural dynamic characteristics (first of all frequencies and decrements) of units in their real joint with other elements of NPP. Experimental data then are used for seismic resistance calculations with application of appropriate mathematical programmes and floor response spectra.

For excitation of the oscillations at the early stages we used the shock method with analysis of the damped vibrations. Subsequently VNIIAM jointly with Kabardin-Balkar State University (KBGU) worked out and mastered special small-sized automated connectable electromechanical vibrators of directed action and systems of control and measurements. These vibrators operate in frequency range from 1-2 to 50 Hz in the regimes of smooth of step change with regulated velocity. Using of vibrators essentially broadened the possibilities of the method and raised the reliability of results of dynamic tests [8,9,10]. At present we use the shock method for dynamic tests at NPPs only in cases of hard access to equipment or dangerous radioactivity in rooms.

Calculational-experimental method includes the following stages [2,7]:

- preparing and agreement of list of equipment which must be checked-up,
- detailed study of design documentation,
- visual and instrumental inspection of equipment at NPP for checking up of the correspondence of equipment and its mounting to technical documentation,
- carrying out of dynamic testing with using of shock or resonance method,
- analysis of test results for receiving of experimental values of natural dynamic characteristics,
- calculational check-up of equipment seismic resistance, using experimental values of natural dynamic characteristics and floor response spectra for examinated concrete NPP, Unit, building,
- development of technical procedures for ensuring of seismic resistance, when it is not confirmed.

Analysis of seismic capacity is carried out in accordance with Russia and International Standards [11,12].

Thus above-mentioned method actually unites three independent methods: walkdown of NPP; dynamic testing at NPP; traditional calculations of dynamic strength.

3. CLASSIFICATION OF REASONS OF DIFFERENT EQUIPMENT SEISMIC INSTABILITY. GENERALIZED RECOMMENDATIONS.

Detailed list of inspected equipment and pipelines are presented in tables: Table 1 – list of seismic resistant equipment, Table 2 – list of seismic instable equipment, Table 3 – list of checked pipelines.

Farther for different types equipment, grouped by signs of functional destination and spatial configuration, the main reasons of seismic instability and necessary measures for ensuring of seismic resistance are stated.

The final classification of seismic instable equipment is proposed in the end of report. Numbers of proposed classificational groups are included in Table 2.

Separate results of works of VNIIAM at NPPs were published in scientific press [2,7,9,10,13-17]. The most part of data was presented only in Technical Reports of VNIIAM for customers (NPPs) that is hitherto was not available to the broad masses of specialists.

Table 1. List of seismic resistant equipment.

Nos.	NPP, type, Unit	Period	Name of equipment	Natural frequencies, Hz		
				X	Y	Z
1	2	3	4	5		
1	Kozloduy NPP, V-440, Units 1-4	1980-1986	Damping tanks of making-up pumps	13.5	5.8	12.5
2			Heat exchanger for emergency cooling			
3			Cooler of enduring pool	10.0	15.0	
4			Intermediate heat exchanger of main circulation pump	6.5	11.8	
5			Air valves for recirculation and vacuum systems (D300, 600, 1400 mm)			
6			Steam and water pipelines valves-gate, steam generator, quick acting, impulse valves (14 types)	11-35 But pipelines 1.5-9.0, seismic resistance is questionable		
7	Units Nos. 2, 3, 4		Pumps of emergency making up type CN-65-130	>10	>10	>20
8	"Yuznoukrainskaya" NPP V-1000, Unit 1	1983-1984	Heat exchanger for emergency cooling	>30	>30	
9			Heat exchanger of gas-cleaning system		23.5	
10			Cooler of feeding water		8.5	
11			Ventilators VDNA-15, VMA-15	Body: >50 Work elements: 15-20		
12			Filter self-cleaning	22		
13			Reverse valve	48	42	
14			Throttle valve	32	23.5	
15			Regulating valve	42	23	
16			Slide-valve D 400 mm	40	20	
17			Slide-valve D 150 mm	51	20	
18			Slide-valve D 100 mm	25	20	

1	2	3	4	5		
19			Shut off gate throttle valve	17.5		
20			Main shut off gate valve	42	30	
21	"Zaporozhskaya" NPP, V-1000, Units 1,2	1985	Heat exchanger of intermediate contour	40	40	70
22			Heat exchanger for emergency cooling	>20	>20	
23			Cooler of making up water	42	40	65
24			Supercooler of making up water	50	30	60
25			Cooler of hydroabutment of making up pumps	45	32	65
26			Cooler of enduring pool	35	30	60
27			Organized leaks cooler	40		
28	Kozloduy NPP, V-1000, Unit 5	1986-1988	Regenerative blowing off heat exchanger of the primary contour	14	14	29
29			Supercooler of the primary blowing off	21	25	37
30			Heat exchanger for emergency cooling	27		18
31			Cooler of enduring pool	34		22
32			Cooler of hydroabutment of making up pumps	25		
33			Heat exchanger of intermediate contour	22		20
34			Supercooler of feeding water of making up deaerator	27		
35			Cooler of make up water	30	38	
36			Organized leaks cooler	10	12	22
37			Heat exchanger of sampling system	5	6	20
38			Heat exchanger from stainless steel (STO)	21	24	18
39			High temperature mechanical filter AFMVT	13	14.5	
40			Filter-trap AFLVT	7.5	8	
41			Filter-container SVO-1	8		

1	2	3	4	5	
42			Self-cleaning filter	23	35
43			Zeolite filter	10	17
44			Ion=change filter	7.5	8
45			Iodine filter ASU	16	18
46			Aerosol filter "FARTOS-C-500"	12	
47			Trap of granular materials		
48			Filter-adsorber		
49			Filter FVB		
50			Pump of enduring pool cooling	35	
51			Pumping aggregate of intermediate contour	>30	>30
52			Pump of emergency cooling system	>30	>30
53			Pumping aggregate of organized leaks	>30	
54			Stream pump	>30	
55			Aggregate of distilled water feeding	>40	
56			Electro-pumping aggregate NCS-3	>20	
57			Ventilator VDNA-NZh-15s	18	20
58			Ventilator VC 4-74-6.3		
59			Ventilator VC 14-46-5.0		
60			Ventilator 63/40-CSU-14		
61			Ventilator 63/40-CSU-11		
62			Ventilator 63/40-CSU-44V		
63			Gear compressor		
64			Compressor for supply of pneumatic cut off valves by compressed air		
65			Electro-radiator SFO-40/1		
66			Radiator KVB-11P		
67			Radiator KVB-10P		

1	2	3	4	5	
68			Reducing installation of steam discharge into atmosphere (BRU-A)	14	15
69			Safety-valve	16	37
70			Impulse valve	13	23
71			Shut off gate valve D 400 mm	22	32
72			Shut off gate valve D 300 mm	14	
73			Shut off gate wedge valve	18	20
74			Regulating valve D 100 mm	14	22
75			Regulating valve D 250 mm		
76			Nitrogen receiver 15 m^3	13	13
77			Air storage tank 15 m^3	12.5	13.0
78			Vessel 10 m^3 D 1000 mm AFM-2.0-1.0	11.5	11.5
79			Tank-hydrogate	6	18
80			Tank of emergency stock of boric solution 15 m^3		
81			Tank of sprinkler system 6 m^3		
82			Tank of desalted water 500 m^3		
83			Tank of organized leaks 14 m^3		
84			Tank of technical water stock 80 m^3		
85			Tank of boiler residue 200 m^3		
86			Tank of filtering materials		
87			Complete transformer substation for own needs KTP-SN		
88			Direct current panels PDE		
89			Emergency supply panels		
90			Stabiliser of voltage 100 kVA STS-2MS		
91			Switchboard PR-11		
92			Switch center PR-22		

1	2	3	4	5		
93			Assemblings RTZO			
94			Booster charge equipment ZPU-2			
95			Electrical equipment of control and safeguard SUZ (system of neutron absorbing rods)			
96			Measuring converters "SAPPHIRE"			
97			Normalizing converters I, II			
98			Feed panels 48V			
99	Armenian NPP, V-440, Units 1,2	1988	Pressurizer (after additional fastening)	44 (11 without fastening)	44	
100	Unit 2		Make up deaerator (vertical)	9,5	9,5	
101			Main shut off gate valve GZZ-500	11		
102			Quick-acting installation of steam discharge into condensation (BRU-K)	22	22	
103			Regulator of steam generator feed	8		
104			Gate valve D 250 mm	8		
105			Reverse valve D 250 mm	8		
106			Gate valve D 450 mm	16		
107			Gate valve D 400 mm	12		
108	Bohunice NPP, V-440 Units V1, V2.	1989	Main circulation pump GZN-310	23.5	8.5	
109			Cooler of enduring pool	23	15	
110			Main heat exchanger for emergency cooling		5.8	19.5
111			Quick-acting installation of steam discharge into condensation (BRU-K)	6.8	18	24.5
112			Heat exchanger of contour of control and safeguard system SUZ		8	18.6
113			Cooler of sprinkler water	8.2	15.5	14.3
114			Main shut off gate valve	10	11	20

1	2	3	4	5		
115			Make up deaerator	15	10.5	32
116			Organized leaks cooler	13	21	10
117			Intermediate heat exchanger of emergency cooling system SAOZ	24	36	50
118			Reverse shut off valve D 500 mm	>50		
119	"Rostovskaya" NPP, V-1000, Unit 1	1992-1993	Emergency cooling heat exchanger of SAOZ system	18.2	24.6	26.6
120			Ventilator of drawing out centre VDN	19.7	27.4	43.3
121			Centrifugal pumping aggregate of SAOZ system	22.8	14.5	27.8
122	Paks NPP, V-440, Units 1-4	1994	Intermediate heat exchanger of emergency cooling system SAOZ-II	4.2	24	
123	Armenian NPP, V-440, Unit 2	1994-1995	Pump of enduring pool cooling		46	
124			Boron sprinkler pump		50	
125			Emergency make up pump of boric unit		63	70
126			Emergency condensation pump of boric unit		54	
127			Pump ASN of boric unit		41	
128			Diesel engine 15D1000		1.6	
129			Generator of diesel engine SDGS		1.7	
130			Electric compressor of DGS			
131			Water cooler of DGS	25	20	
132			Technical water valve of DGS			
133			Spume pump of fire-prevention system (FPS)		51	
134			Technical water pump of FPS		>50	
135			Technical water valve of FPS			
136	Kozloduy NPP, V-1000, Units 5,6	1995	Tank of technical water stock 60 m³ of FPS	5.8	9.9	
137			Make up water pump of FPS		60	
138			Shut off gate of pump of FPS		30	

1	2	3	4	5		
139			Gate valve of FPS		17.5	
140			Water cooler of DGS		18	
141			Oil cooler of DGS		10	
142	Paks NPP, V-440, Units 1-4	1997	Axial ventilator UG05D002 (Main Building, gallery of electric equipment)	11	10	24
143			Heat exchanger 30 QJ05W001 (DGS)	7	9.7	
144			Jalousie QA20G001 (DGS)	28.5	50	

Table 2. List of seismic instable equipment.

Nos.	NPP, Type, Unit	Period	Name of equipment	Natural frequencies, Hz			Decrements, % of critical			Nos. Classification groups
				X	Y	Z	X	Y	Z	
1	2	3	4	5			6			7
1	Kozloduy NPP, V-440, Units 1-4	1980-1986	Ion-exchange filters SVO-1							2
2			Pressurizer	5.5	5.5					
3			Deaerator tank with columns DSP-1000							1d, 2
4			Process condenser with cooler							1b
5			Make up deaerator with hydrogate	3						1a, 2
6			Cooling down reduction installation							3, 4
7			Blow down regenerator and cooler of special water treatment installation SVO-1							3
8			Organized leaks cooler	5.5	7.6					1a, 1b

1	2	3	4	5	6	7
9-16			Special electrically driven sylphone valves, 8 types (D15-400 mm)	2-10		1d
17-30			Steam and water pipeline valves, 14 types (gate, steam generator, quick acting, impulse valves). Valves are seismic resistant, but pipelines can be seismic instable	Valves: 11-35 Pipelines: 1.5-9.0		1b, 1d
31	Unit 1		Pump of emergency making up EP-50	Bodies: >10 Connecting pipes, muff: 1-3		3
32			Protective explosive valves of steam generator room			3, 4
33			Paired storage batteries SK-16×2			3
34	"Yuzhnoukrains-kaya" NPP, V-1000, Unit 1		Blow down of primary contour regenerative heat exchanger	3.6 2.8		1b, 3
35			Blow down subcooler	3		1b, 3
36			Make up water cooler	2.3		1b, 3
37			Cooler of enduring pool	5.6		1b
38			Heat exchanger of intermediate contour	5		1b
39			Zeolite filter of gas cleaning system	3.5 10		1b
40			Ion-exchange filter of mixed action			1d
41			Safety valve with reserve impulse inertial valve	21.5		3, 4

1	2	3	4	5			6	7
42			Heat exchanger of main circulation pump intermediate contour					2
43	"Zaporozhskaya" NPP, V-1000, Units 1, 2	1985	Gate valve D 300 mm	6	8	27		1c, 2
44	Unit 2		Heat exchanger for emergency cooling	10	12	27		1a, 2
45			Blow down of primary contour regenerative heat exchanger	7	7	13		1a, 1d
46	Unit 1		Blow down subcooler	11	11	17		1a, 1d
47			High temperature mechanical filters and traps (unit No.3)	11	11.5	65		2
48			Ventilator VDNA-15	11	16	67		3
49			Ventilator VMA-15	10	15	65		3
50			Ionic filter SVO-2 (unit No.3)	6.8	7.8	30		2
51			Ionic filter SVO-2 (unit No.5)	9.5	12.6	9.0		2
52	Kozloduy NPP, V-1000, Unit 5	1986-1988	Pumping aggregate of primary contour making up					4
53			Emergency feeding pump					4
54			Pump of boron emergency injecting					4
55			Pump of supply of high pressure boric solution					4
56			Sprinkler pump CISA-700-140					4
57			Pump of responsible users (DGS)					4
58			Block of air cleaning (DGS)	6				1d

1	2	3	4	5		6	7
59			Air-conditioner KTA-1-4	10			1d
60			Air-conditioner KTA-1-10	9			1d
61			Centrifugal air-conditioner (DGS)				1d
62			Shut off valve D 25 mm	13	25		2
63			Shut off valve D 32 mm	12			2
64			Emergency cooling heat exchanger				2
65			High temperature mechanical filter				2
66			Filter-container				1a, 1b, 2
67			Ion-exchange filter				1a, 1b, 2
68			4-sectional coal filter	3.5	4		1a, 1b, 2
69			Compressed air compressor				1c, 1d
70			Wedge slide-valve D 600 mm				1b, 1d
71			Slide-valve D 300 mm				1d
72			Uninterrupted feed aggregate				1d
73			Normalizing converters HX (room AE 403/3)				1d
74			Apparatus of neutron flow control (rooms AE 438/1-3)				1d
75			Panel HY.05 (room AE 340)				1d
76			Panel HY.25 (room AE 341)				1d

1	2	3	4	5	6	7
77-90			Panels HY.27-33, 37-43 (room AE 341)			2
91-95			Panels of fire putting off HZ.12-16 (room AE 341)			1d
96-103			Panels of feeding assembling HG.42-49 (rooms AE 340, AE 341)			1d
104-119			Panels of control and automation instruments HV.01-13,15,16,123 (rooms AE-408/1, AE-434/1)			1d
120			Local panel of ventilation UT.21 (room AE 414/2A)			2
121-123			Panels of fire putting off HK.97-99 (rooms AE 609/1,2,3)			1d
124-125			Transformers TSZA-1000/10 CP.1,2			1d
126	Armenian NPP, V-440, Units 1,2	1988	Pressurizer (before antiseismic fastening)	11 11		1b
127	Unit 1		Make up deaerator (horisontal)	7		2
128			Tank of stock of boric solution 30t	0.6		1d
129			Tank of stock of desalinized water 500t	0.3		1d
130			Ion-change filter SVO-1			1b, 2
131			Blow down regenerative heat exchanger and subcooler	6 5 30		1b, 3
132			Emergency condenser	11 6 35		1a, 1b, 1c

1	2	3	4	5			6			7
133			Dilator of steam generator blow down	4	4	32				1b
134			Cooler of steam generator blow down	20	16	34				1a, 1c
135			Mechanical filter SVO-4	6	6	30				1b
136			Ion-change filter SVO-4	8	11	32				1b
137			Cooler of enduring pool	16	25	29				1c
138			Heat exchanger of sprinkler installation	10	8	11				1a, 1c
139			Process condenser with cooler	7	16	35				1b
140			Safety valve of pressurizer	4	5					1d
141			Quick acting reducing installation BRU-A	7	8					1d
142			Pressure regulator of cooling down installation	7	6					3, 4
143			Safety valve of cooling down reducing installation with reserve impulse inertial valve							3, 4
144	Bohunice NPP, V-440, Units V1, V2	1989	Cooler of making up water of primary contour	16	5.5	18	6.2	9.1		1b, 3
145			Heat exchanger of intermediate contour of main circulation pump	8	9	11	7.0	5.3	6.8	1b
146			Heat exchanger of hydrogen burning out system		9.5			14.2		1b
147			Heat exchanger of gas cleaning system		8			5.9		1b, 3
148			Regenerative heat exchanger of primary contour bypass cleaning	9.5	4	26	2.5	11.8	8.6	1b, 3

1	2	3	4	5	6	7
149			Regenerator and subcooler of water treatment installation SVO-1	8.5 7 13.5	2.7 1.6 1.1	1b, 3
150	Paks NPP, V-440, Units 1-4	1994	Pump of low pressure of emergency cooling system SAOZ-II	8.3		1c
151			Valve of low pressure pump of SAOZ-II	2-10		1d
152	Armenian NPP, V-440, Unit 2	1994-1995	Intermediate heat exchanger of main circulation pump	5 6.2	3.9 3.5	1a, 1c
153			Cooler of organized leaks	6.4 7.9	4.7 4.8	1a
154			Barboter (tank for gurgling of vapour and gas bubbles) 15 m^3	9.5 4.3	4.9 4.0	1a, 1b, 1c, 1d
155			Drainage pump of boric system	4 5.5		2
156			Oil cooler (DGS)	6.5 6.0	4.0 3.5	1d
157			Oil pump of forestart feeding (DGS)	4 7		1a, 1d
158			Oil pump of hot reserve (DGS)	5 7.5		1a, 1d
159			Oil reserve tank (DGS)	10.5	3.0	1c, 1d
160			Air storage tank of fire putting off system	13 14.5	2.3 2.7	1b, 1c
161			Hermetic doors of reactor building	3-5		1d
162	Kozloduy NPP, V-1000, Units 5, 6	1995	Compressed air tank (DGS)	12 12	2.9 2.9	1a, 1b
163			Oil reserve tank (DGS)	17 16.9		1a, 1b
164			Two-chamber filters for oil cleaning (DGS)	9.2 6.2	5.8 1.7	1a, 1b, 1c, 1d

1	2	3	4	5	6	7
165			Automation of safety system UKTS (panels)			1d

Table 3. List of inspected pipelines.

Nos.	NPP, Type, Unit	Period	Name of pipelines	Natural frequencies (1^{st},2^{nd},3^{rd} modes), Hz	Decrements (1^{st},2^{nd},3^{rd} modes), % of critical	Nos. Classification groups
1	2	3	4	5	6	7
1	Armenian NPP, V-440, Units 1, 2	1988	Pipelines of steam generator blowing off and return of blowing off			1d
2			Pipelines of feed water			1d
3			High pressure steam pipes			1d
4	Kozloduy NPP, V-440, Units 3, 4	1989-1990	High pressure feed water pipelines (within the limits of turbine hall up to deaerator rack) Section between supports No.84 and No.87:	5.5 9.0	2.0 3.6	1d
5			High pressure steam pipes (within the limits of the turbine hall up to main steam gate valve) Section between supports No.33 and No.37:	4.5 11.0 17.0	0.5 0.4 0.6	1d
6			Suction pipelines of the feed water and emergency feed water pumps Section No.1: Section No.2:	 6.3 8.5 15.0 5.5 7.5 15.0	 1.7 1.9 2.5 0.6 1.4 5.5	1d

1	2	3	4	5	6	7
			Section No.3:	7.2	0.8	
7			Recirculation pipelines of feed and emergency feed electric pumps			1d
8			Main condensate pipelines from the low pressure heater up to the deaerator			1d
9			The balancing water pipeline between the deaerators			1d
10			Pipelines for the discharge from the deaerators			1d
11			Steam pipes to the process condenser			1d
12			Condensate pipelines from the process condenser to the deaerator			1d
13			Cooling pump suction pipelines (from the deaerator)			1d

The general views (simplified forms) of different types of the seismic instable equipment are presented in Figure 1.

In Fig. 1-1 the emergency condenser of Armenian NPP is depicted (position 132 of Table 2). The outfits named in positions 94, 152, 153, 162 have the similar constructions and the same reasons of seismic instability.

In Fig. 1-2 the make up deaerator of Kozloduy NPP, Units 1-4, is depicted (position 5 of Table 2). The outfits named in positions 44, 66, 67, 134, 154, 157, 158 have the similar constructions and the same reasons of seismic instability.

In Fig. 1-3, 1-4, 1-5 the pressurizer of Kozloduy NPP, Units 1-4 (position 2 of Table 2), the cooler of organized leaks of Kozloduy NPP, Units 1-4 (position 8 of Table 2), the heat exchanger of hydrogen burning out system of Bohunice NPP (position 146 of Table 2) are depicted. The outfits named in positions 4, 37-39, 66, 130, 132, 133, 135, 136, 139, 145, 154, 160, 162-164 have the similar constructions and the same reasons of seismic instability.

In Fig. 1-6 the quick acting reducing installation of Armenian NPP (position 141 of Table 2) is depicted. The outfits named in positions 17-30, 70, 71 have the similar constructions and the same reasons of seismic instability (high pliability of jointed bearing pipelines as well as of hoops placed between valve body and reducer with electric motor).

In Fig. 1-7 the carriage with DGS oil cooler, oil pumps (positions 156, 157, 158 of Table 2), and water cooler (position 131 of Table 1) are depicted. In contrast to oil cooler and oil pumps, water cooler is seismic resistance outfit, because it is placed on the lower level ("ground floor") of the carriage, that is in zone of more big rigidity. The outfits named in positions 3, 45, 46, 68, 69 have the same reasons of the seismic instability (not sufficient rigidity of the support carriage).

In Fig. 1-8 the ion-exchange filter of mixed action of "Yuzhnoukrainskaya" NPP (position 40 of Table 2) is depicted. The outfits named in positions 1, 47, 50, 51, 66-68 have the similar construction and the same reasons of the seismic instability.

In Fig. 1-9 the valve of low pressure pump of Paks NPP (position 151 of Table 2) is depicted. The reason of the seismic instability is the same as in previous case presented in Fig. 1-8, namely: a lack of mechanical binding of equipment to support (support is using only as a prop) can lead to inadmissible horisontal shift and to jumping up of equipment with following its shocks about support. The concrete valve is picked out by reason of redoubling availability of lengthy pliable hoop with cantileverly mounted electric driver. Besides that at Paks NPP the floor response spectra for this valve location has a big accelerations in field of low frequencies (up to 2-3 g in horisontal directions and up to 1.5-2.5 g in vertical direction).

In Fig. 1-10 a typical panel without fastening to foundation and/or to walls is depicted. Similar outfits (positions 74-123, 165) have a possibility of horisontal shift (sliding) and overturning during earthquake.

In Fig. 1-11 a typical big tank without fastening to foundation or limiter of horisontal shifts is depicted. Similar outfits (positions 128, 129 of Table 2), as well as transformers (positions 124, 125) and other equipment (positions 72, 73) will scarcely can overturn (horisontal dimensions are commensurable with height) but the horisontal shifts (sliding) are possible.

In Fig. 1-12 the impulse inertial valve (weight pressure regulator) of different installations (positions 6, 41, 142, 143) is depicted. Using of similar constructions can lead to false opening or shutting of valve during earthquake.

In Fig. 1-13 the multisectional on vertical lines horisontal heat exchanger (type of many-tier book stands or many-storied building) is depicted (positions 7, 34-36, 131, 144, 147-149 of Table 2). Such constructions in a number of cases include 6-10 sections without intermediate horisontal fastening.

In Fig. 1-14 the pump of emergency making up EP-50 of Unit 1 of Kozloduy NPP is depicted (position 31 of Table 2). Main aggregates (bodies of pump) and electric motor have the shifted axes and mounted on independent carriages. Similar arranging was used in the early constructions of the big ventilator (blast-engines) projected by VNIIAM without taking into account of seismic loads.

Detailed analysis of the results of seismic resistance checking up for different types of equipment allowed to propose the following classification of seismic instability reasons with generalized recommendation for ensuring of seismic resistance.

<u>Group 1.</u> Projecting mistakes in methods fastening and construction of supports.

As it is evident from tables 2 and 3, it is the most widespread reason of equipment seismic instability (69% from total number of the events). For more detailed and concrete analysis of reasons of seismic instability and choice of the optimum measures for seismic resistance ensuring it is convenient for users to divide the group 1 unto following 4 subgroups.

<u>Subgroup 1a.</u> Insufficient rigidity of the profile supports (supports claws of vertical vessels in intermediate sections, Fig. 1-1; channel bar supports under lower part of vertical and horisontal vessels, Fig. 1-2). 20 events were fixed (heat exchangers, filters, tanks, positions 5, 8, 44-46, 66-68, 132, 134, 138, 152-154, 157-159, 162-164 of Table 2).

Recommended measures:

- welding of additional horisontal or inclined plates transmuting the open profile into box section, as it is shown in Fig. 2,

- welding of additional vertical ribs of rigidity, as it is shown in Fig. 3.

<u>Subgroup 1b.</u> Inadmissible amplitudes of horisontal vibrations of vertical extensive aggregates fastened only in the bottom zone (mounted on tube or profile legs, on "skirtal" supports, et al.) or in the intermediate section far from flatness of centre of mass (Figs. 1-3, 1-4, 1-5, 1-6). 44 events were fixed (pressurisers, heat exchangers, filters, hoop type valves with cantilever fastening of reducer and electric drive, positions 4, 8, 17-30, 34-39, 66-68, 70 126, 130-133, 135, 136, 139, 144-149, 154, 160, 162-164 of Table 2).

Recommended measures:

- mounting not far from equipment free end (that is in upper or lower part of equipment – depending on place of designed fastening) of additional supports or shift limiters fastened with equipment through intermediate joints, elastic washers, slipping clamps, as it is shown in Fig. 4,

- using of snubbers mounted also not far from equipment free end.

<u>Subgroup 1c.</u> Insufficient strength or inadmissible pliability of anchor bolts, bolts joints between equipment and support structures, threaded joints of equipment elements, etc. 12 events were fixed (pumps, valves, heat exchangers, tanks).

Recommended measures:

- substitution of bolts on more strong ones (positions 132, 134, 137, 138, 152, 164 of Table 2),

- mounting of additional bolt joints (positions 69, 154, 159, 160 of Table 2),

- in certain cases – strengthening of bolts tightening (positions 43, 150 of Table 2).

<u>Subgroup 1d.</u> In this subgroup the all other cases are included, namely:

- support frames (carriages) have not sufficient rigidity (Fig. 1-7),

- jointed pipes have not sufficient own fastening,

- natural frequencies of equipment are low, that is they are in diapason of earthquake resonance frequencies (this case requires a particular attention when the acceleration peaks of floor response spectra are sufficiently big – 1.5-2.0 g and more),

- supports are not fastened to equipment, they are not prevent from sliding out, jumping, dropping of equipment (Figs. 1-8, 1-9),

- the some kind of projecting fastenings of equipment to bearing structures staving off shifts and overturning of equipment are absent (Figs. 1-10, 1-11).

103 events were fixed (heat exchangers, filters, valves, conditioners, tanks, transformators, compressors, control and adjustment panels, cabinets, all inspected pipeline systems).

Recommended measures:

- fastening of the equipment with supports by welding, bolts, clamps (positions 3, 40, 70, 71, 151, 159 of Table 2),

- raising of the rigidity of support frames by way of mounting (welding) of additional links or using of more high-capacity section steel (shaped bars) (positions 45, 59-61, 69, 140, 156-158 of Table 2),

- fastening of jointed pipes for ensuring of raising of natural frequencies and lowering of loads on nozzles (positions 9-30, 58, 141, 154 of Table 2),

- fastening to foundation or walls of the articles (big tanks, transformators, panels), which have not whatever project fixation and can shift or overturn during earthquake (positions 72-76, 91-119, 121-125, 128, 129, 165 of Table 2),

- additional fastening of pipeline systems: the replacement of the existing supports and spring suspension brackets by the new ones with more high rigidity and strength, mounting of additional supports and suspension brackets, using of the snubbers (all positions of Table 3).

Group 2. Blunders in process of equipment mounting (breach of demands stated on technical documentation).

35 events, or 20% from total number, were fixed (deaerators, valves, heat exchangers, filters, pumps, transformators, electrical and control panels and assemblies).

The most widespreaded blunders are the next:

- the lack of welded or bolt joints in supports (positions 2, 3, 43, 77-90, 120, 130, 155 of Table 2),

- the lack of concreting of supports to foundation (positions 44, 64, 65 of Table 2),

- incorrect mounting of sliding supports of horisontal heat exchangers (positions 5, 127 of Table 2),

- the lack of part of pipeline hanger brackets and arbitrary change of pipelines tracing (positions 47, 50, 51, 62, 63 of Table 2),

- arbitrary replacement of project section steel (shaped bars) in supports on the low resistant models (position 42 of Table 2).

Recommendations are obvious: it is necessary to keep strictly the all demands stated on technical documentation.

<u>Group 3.</u> Discrepancy of construction of equipment (or their main elements) to demands of seismic resistance of principle.

18 events, or 10% from total number, were fixed.

The following technical decisions concern to this category.

- Using of weight pressure regulators in reducing installations (Fig. 1-12, positions 6, 41, 142, 143 of Table 2). The false snapping into action is possible during earthquake. Only spring mechanisms must be used.

- Application of multisectional on vertical lines horisontal heat exchangers (type of many-tier book-stands, or many-storied buildings, Fig. 1-13, positions 7, 34-36, 131, 144, 147-149 of Table 2).

For installed at NPPs similar heat exchangers the different types of additional horisontal fastening was recommended. For all over designed NPPs we recommend to avoid the application of similar constructions, as a last resort to use the like heat exchanger with number of storeyes (sections) not more than 3.

- Using of long vertical transmission bars without intermediate guide devices protecting from jam in cases of warps, faults, deformations (position 32 of Table 2). It was recommended either to change the construction of transmission mechanisms or to install reliable guide devices.

- Using of pumps and ventilators with displaced axes of main aggregates and electric motor often mounted moreover on independent carriages (Fig. 1-14, positions 31, 48, 49 of Table 2). The changes of equipment on special seismic resistant types were recommended.

- Using of seismic instable paired storage batteries S_k-16×2 (position 33 of Table 2). The using of special seismic resistant batteries S_p-385 was recommended.

<u>Group 4.</u> Doubt of capacity for work during earthquakes of mechanism having elements of rotation and reversible forward motion.

In the first place such doubts have to do with pumps, fast-acting valves, driving mechanisms of neutron absorbing rods, snubbers, elements of loading-unloading machines and cranes. Capacity for work of equipment can be checked up practically only by way of full-scale tests on shake tables or at special blast polygons. In particular VNIIAM carried out the tests of different valves, ventilators, and snubbers on vibrostands, on blast stand of military polygon near Viborg, at blast polygon in Armenia. Complex of tests of valves, electrical and control panels was carried out at vibrostands by Institute "Atomenergo-project". Tests of driving mechanisms of control rods were carried out by CKTI on special vibrostand.

In result of afore-mentioned tests either capacity for work of equipment was confirmed or necessary improvements of constructions were worked out.

It is necessary to pay attention to column 7 of Table 2. For majority of positions the several classification indications (that is reasons of seismic instability) were revealed simultaneously. In such cases the technical measures for ensuring of seismic resistance must be selected with particular care. In certain cases the main reason of seismic instability and appropriate measure can be defined, in other cases the complex of technical measures is required. At last sometimes the inspector can choose the most convenient solution from several possible ones.

For example for two-chamber filter for oil cleaning of DGS at Kozloduy NPP (position 164 of Table 2) either additional fastening of upper part with help of clamp and bearing rods or change of supporting tubes D20×5 mm on D80×8 mm and foundation bolts M14 on M18 may be used. Certainly the optimum solution will depend on intuition and experience of the inspectors.

CONCLUSION.

On the base of generalisation of extensive real data accumulated during inspection of equipment seismic resistance at different VVER-type NPPs the classification of seismic instability reasons and working out of generalised recommendations were carried out. It gives the possibility to specialists in many cases to expose the seismic insufficiency of equipment and to choose the suitable measures without laborious experimental investigations, tests, and calculations.

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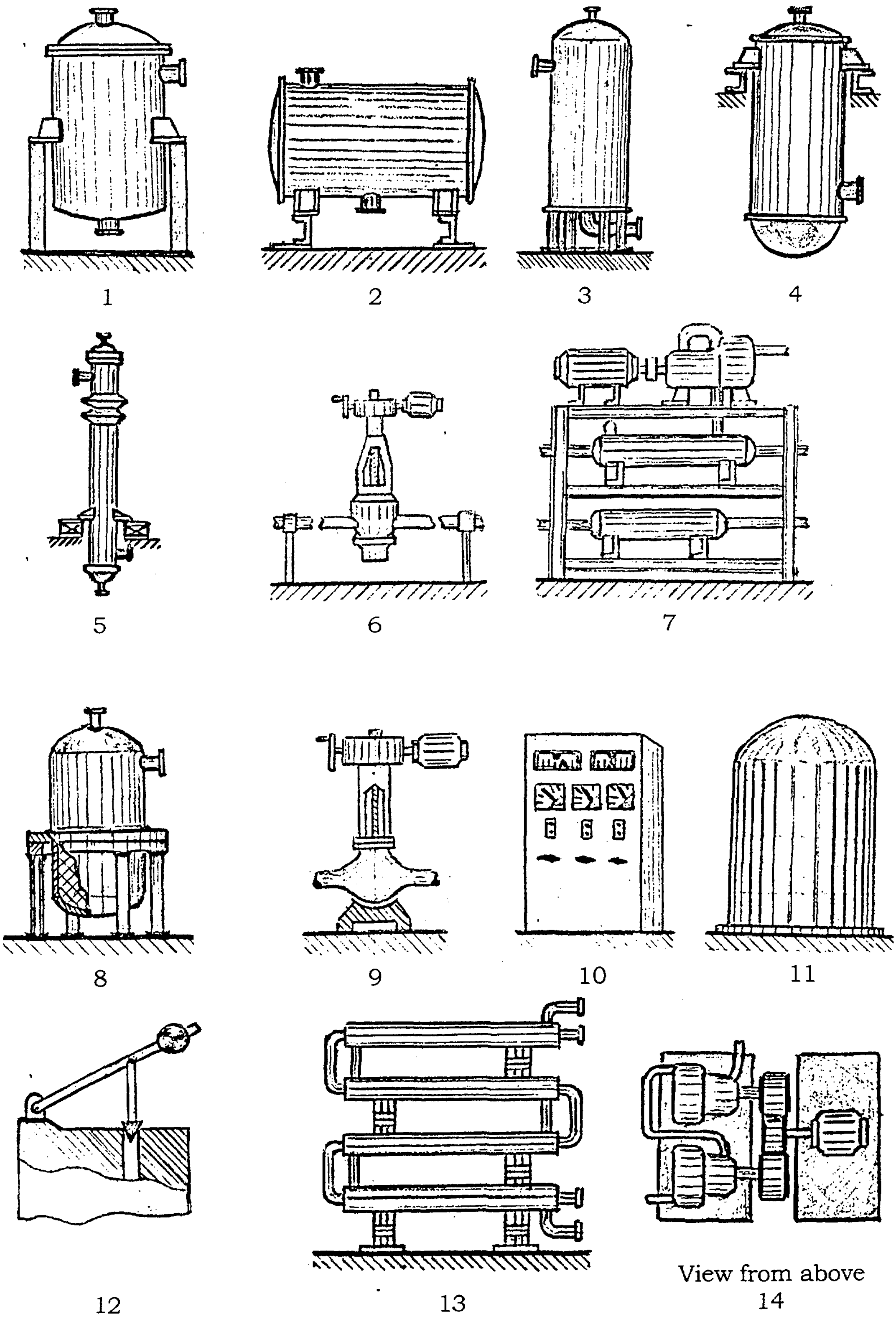
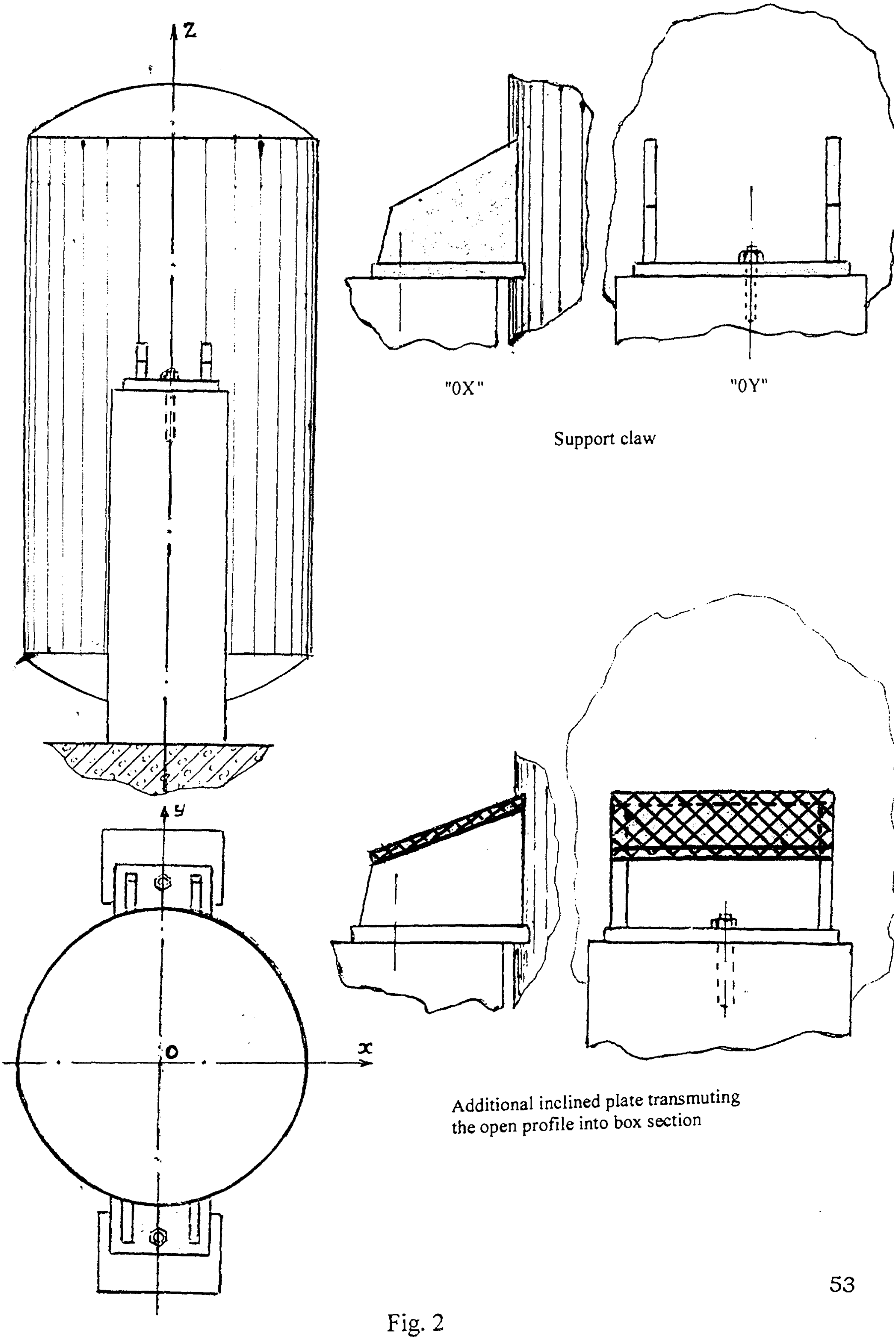


Fig. 1. Simplified forms of different types of seismic instable equipment.


z
"0X"
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Support claw
y
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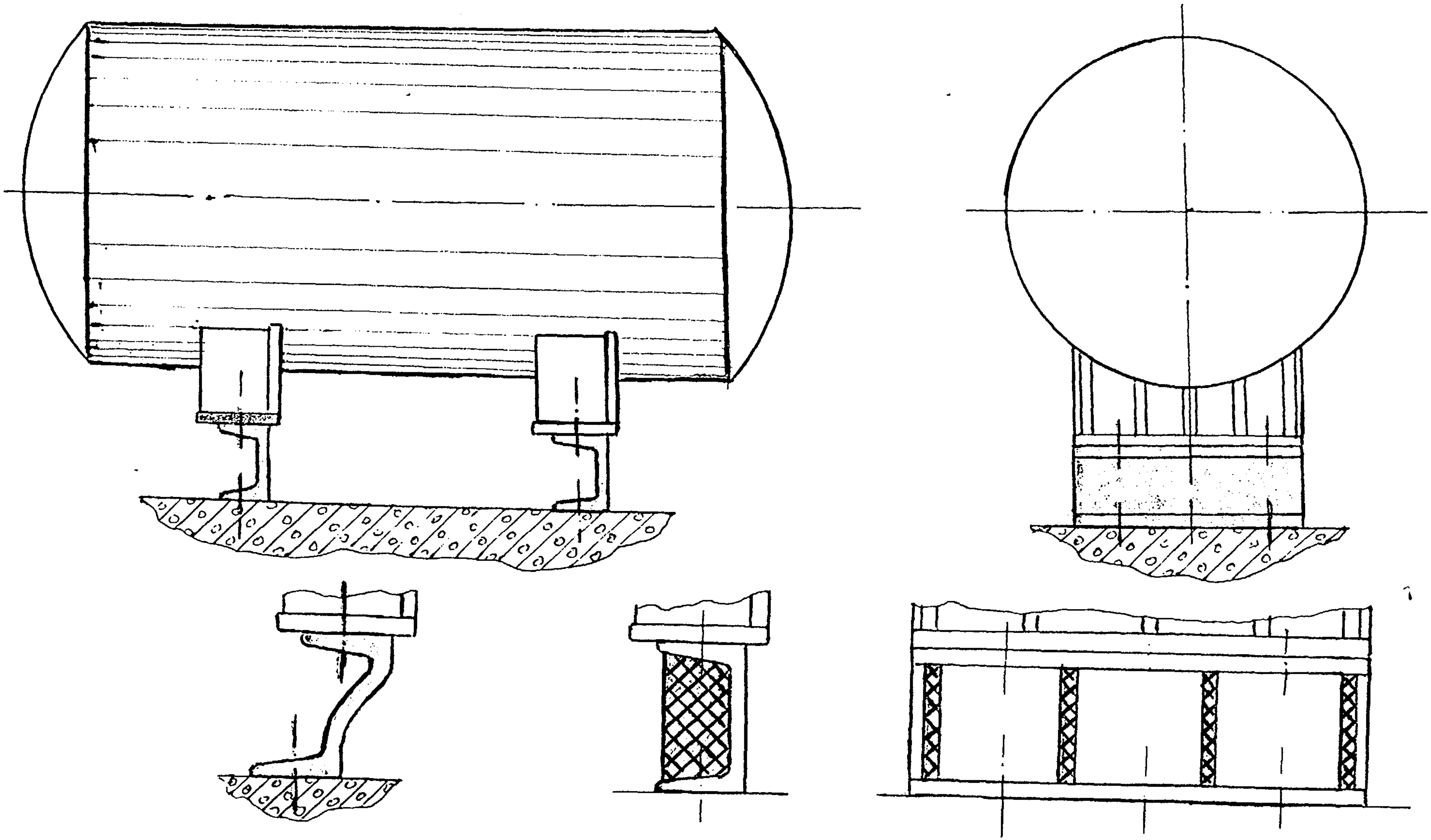
Additional inclined plate transmuting
the open profile into box section

Fig. 2



Deformation from seismic load

Ribs of rigiditi

Fig. 3

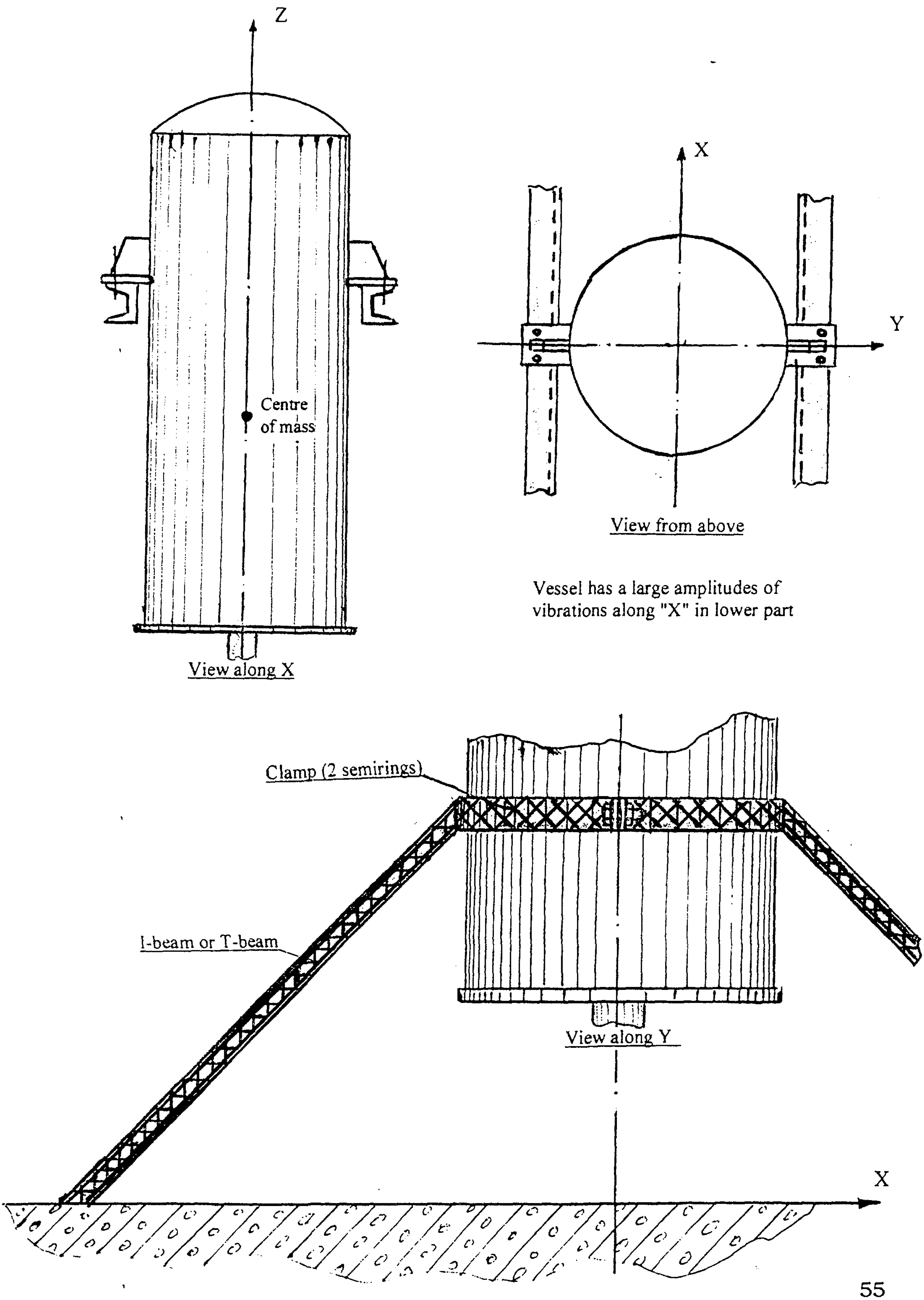

Z
Centre
of mass
View along X
X
Y
View from above
Vessel has a large amplitudes of
vibrations along "X" in lower part
Clamp (2 semirings)
I-beam or T-beam
View along Y
X

Fig. 4