Seismic Precalculation for Mechanical Equipment

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Abstract

The dynamic experiments in the decommissioned nuclear power plant HDR (Heißdampfreaktor) are a special kind of the few possibilities to check dynamic calculations of mechanical equipment.
While extension and kind of the experiments are described before (Reports K14/1-3), this paper concentrates on precalculations of the experiments and some choiced comparisons between experimental and calculational data.

The analysed structures were the coupled and noncoupled models of the RPV (reactor pressure vessel), PDL (steam line), URL (recirculation line) and FWB (flooding water tank). Parameter variation was done for cold/hot conditions, excitation level and direction and methods of computation (linear-nonlinear, beam- and shell model).

Special investigations were done for fluid-structure interaction in the RPV and FWB, interaction between RPV and core shroud and nonlinear boundary conditions for the piping system.

The analysis were performed with the computer programs ADINA, ASKA, KWHUROHR, SAP IV and STARDYNE. The dynamic analysis were performed using time history direct integration (THDI), time history modal superposition (THMS) and response spectrum modal superposition (RSMS) technique.

Because the outlined extension cannot be condensed into a few pages, this report will concentrate on the main important facts of influence, illustrated by some experimental data.

The report describes some precalculational dynamic analyses of the investigated structures PDL, URL and FWB, done by the institutions GRS, KWU, SDF and TÜV. An overview of the whole experimental and analytical research project has been presented already in preceeding lectures K14/1-3. All here described methods and models concentrate on the chosen part of analysis, the full part will content more details /1, 2, 3/.

After presenting the analysis methods used, the modelling of the investigated structures will be described. This will be followed by a discussion of some examplary results.

Method of Analysis

The piping systems were analysed with the computer programs shown in Table 1 /4, 5, 6, 7, 8/. These are finite-element programs exclusively. There is shown too the dynamic analytical methods used, finite element-types and degrees of freedom per model. The defined model name is consistent with the use in the mentioned lectures before and with the abbreviations of the institutions and gives the dependency with the programs.

Modelling of the Structures

Figures 1 and 3 show simplified pictures of PDL and URL. All institutions used beam elements with lumped masses and mass-less springs for the piping systems. The fix point modelling is shown in Table 2. Three points should be of special interest:

- model SDF-4 allowed free rotation round the axis of the steam collector of PDL
- TÜV used two models for this point, one with a lowered stiffness for the mentioned rotation (TÜV 4/1) and one with a rigid fix point for all directions (TÜV 4/1a)
- the constant hangers for URL were fixed in vertical direction by model SDF-3a. This introduces clamping effects of the hangers.

The results of these differences in modelling will be discussed.

The FWB modelling was done with beam and shell elements as shown in Table 1.
The only connection of the FWB with the building is the frame's legs at the bottom, treated as rigid fix points for all models.

For the dynamic response of the FWB (see Fig. 11) the stiffness of the substructure frame/bumped boiler end is of highest importance. For the GRS 5 model (see Figure 12) this was considered by engineering judgement.

For the models KWU 5/1 and KWU 5/2 (see Fig. 13) the character of the mentioned structures were incorporated through more detailed stiffness calculations.

The water in the FWB was idealized differently for the horizontal and vertical direction for all three models. In horizontal direction the water body was divided up into a dead part and a sloshing water part.
The second part considers the motion of the free surface. The water masses are added in horizontal direction to the nodes at the respective levels. In vertical direction the total mass was added to the mode representing the bottom of the FWB.

Results of Modal Analysis

Table 3 shows the eigenfrequencies of the PDL and URL, Figures 2 and 4 the base mode shape. In general good agreement between analysis and measurements can be observed. Therefore, only the measured mode shapes are shown. The remaining differences give the following impressions: All eigenfrequencies are lower than the measured data indicates.
KWU-4 and TÜV 4/1-a gave the best results for the PDL, the differences between the both TÜV-models show the influence of the rotational boundary condition at the steam collector (lower frequencies by using an elastical torsion spring for all rotations). The result of model SDF-4 shows a consistent tendency; absolut free rotation lowered the frequencies clearly.
The results fo the URL show no uniform response. KWU 3 and TÜV 3/2 alternate with the best approximation near the measured data. A parametervariation done with ASKA (model SDF-3a), the constant hangers were fixed in vertical direction, shows the possibility of clipping constant hangers instead of ideal behavior.

The generally higher values of model TÜV 3/2 compared with KWU-3 results can probably be traced to the different elasticity constants of hangers and fix points. In the summary it can be started that for PDL and URL the modelling of fixed points and the nonlinear behavior of the hangers (gaps, hysteresis, curved characteristics, clamping effects etc.) are the main reasons for the discrepancies. A detailed incorporation of these phenomena is far beyond design calculations of piping systems.
For that reason only general ways for considering these effects must be found.

For the FWB the models GRS 5 and KWU 5/1 in general get the same bending mode shapes for the three lowest modes (see Fig. 14). The related eigenfrequencies of the models KWU 5/1 and KWU 5/2 agree (see Table 3).
The model KWU 5/2 also gives the typical shell vibration modes of this thin shell cylindrical container (see Fig. 15). However, only the uneven harmonics give some small contributions from the seismic excitation.

Taking in account the unknown boundary conditions at the bottom, the results are in good agreement with the experimental data. The remaining differences are probably reasoned by less knowledge about the realistic structures, i. e. coupling mechanism between the neighbouring FWB's.

Results from Excitation

Figures 5 to 10 show the results of one snap back test for the each PDL and URL. Each figure shows the measured and the calculated acceleration time history. The agreement is good in all cases: Less phase difference at starting, damping estimates, measuring sign and the known frequency differences from eigenvalue analysis for the dominant modes.

Figures 16 to 18 show acceleration time histories resulting from an explosive test for the FWB. The agreement is good, the interpretation of phase and frequency differences is the same as above.

Differences are generally small, a few are large. They will be further discussed and then additional calculations will follow.

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Table 1 Models and analytical methods
(The model names correspond with the institutions)

Structure	Model-Name	FEM-Program	Analytical Methods	Element-Typ	Degrees of Freedom
PDL	SDF 4	ASKA		BEAM	150/50*
	KWU 4	KWUROHR		PIPE	252
	TÜV 4/1	SAP IV	THDI/ THMS	PIPE	285
URL	SDF 3	ASKA		BEAM	670/170*
	KWU 3	KWUROHR		PIPE	510
	TÜV 3/2	SAP IV		PIPE	972
FWB	GRS 5	ADINA	THDI	BEAM	105
	KWU 5/1	STARDYNE	THMS	BEAM	124
	KWU 5/2	STARDYNE	RSMS	SHELL	1976

* = reduces for the coupled model

Table 3 Eigenfrequencies (Hertz)

Structure	Precalculational Model Name				Experiment
PDL	SDF 4	KWU 4	TÜV 4/1	TÜV 4/1a	
	2.25	3.11	2.59	3.12	3.1 - 4.0
	6.13	7.11	7.05	7.25	8.8 - 9.1
	7.55	8.55	7.76	8.41	8.0 - 8.6
	8.11	9.04	8.83	9.02	9.6 - 10.6
	9.59	11.42	11.57	12.04	13.3 - 15.0
URL	SDF 3	SDF 3a	KWU 3	TÜV 3/2	
	1.79	2.08	1.39	1.67	2.40
	3.15	2.85	2.74	3.07	2.73 - 2.95
	4.78	5.29	5.09	5.63	5.75 - 6.12
	5.80	-	5.85	6.68	5.86 - 6.20
	6.39	7.27	6.39	7.44	6.90 - 7.23
FWB	GRS 5	KWU 5/1	KWU 5/2		
	2.32	2.99	2.93		2.40 - 2.55
	34.46	25.27	24.67		19.60
	74.36	62.79	-		

Table 2 Fix Point Conditions

Model Name	PDL F.P. RPV	PDL F.P. S.C.	URL F.P. (all)	URL Constant Hangers
SDF 4	rigid	rigid, but free rotation free round horizontal steam collector axis		
KWU 4	elastic spring	elastic spring		
TÜV 4/1	rigid	rigid, but rot. with elastic springs		
TÜV 4/1a	rigid	rigid		
SDF 3			rigid	free
SDF 3a			rigid	free, but rigid in vertical direction
KWU 3			elastic spring	free
TÜV 3/2			rigid, but elastic springs at B.N.	free

Abbr.: F.P. fix point
S.C. steam collector
B.N. burst nozzle for blow down experiments

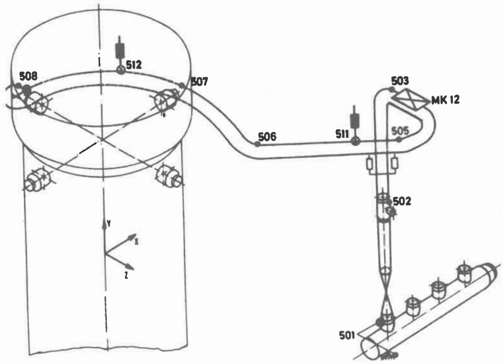


Fig. 1: Structure PDL

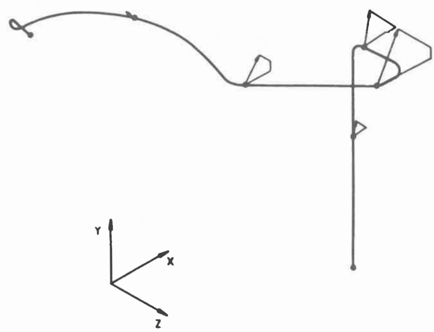


Fig. 2: PDL - Base Mode
3.1 - 4.0 Hertz
Horizontal Movement

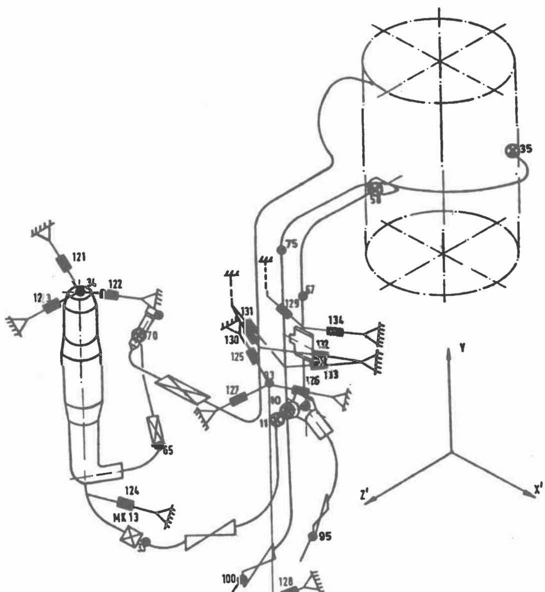


Fig. 3: Structure URL

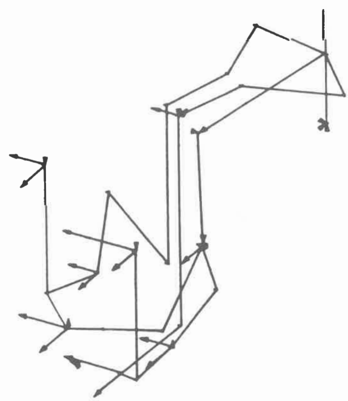


Fig. 4: URL - Base Mode
2.40 Hertz
Two Loops Moving
in Phase

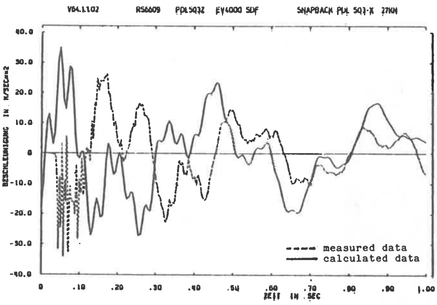
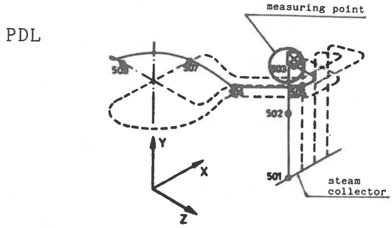


Fig. 5: Model SDF 4 Acceleration Time History



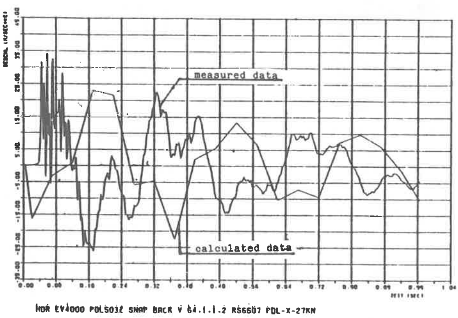


Fig. 6: Model KWU 4 Acceleration Time History

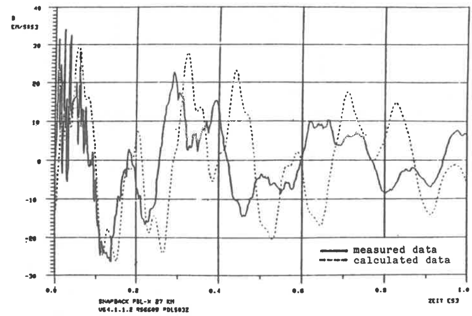


Fig. 7: Model TÜV 4/1 Acceleration Time History

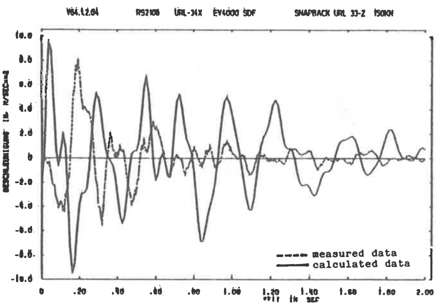
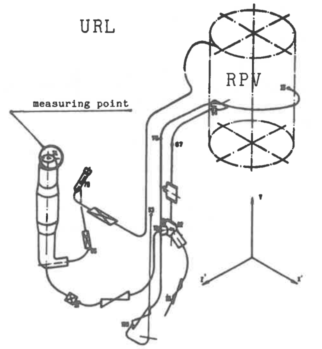


Fig. 8: Model SDF 3 Acceleration Time History



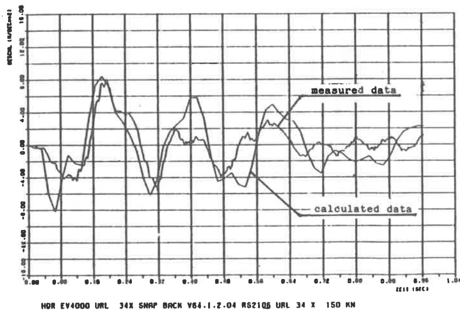


Fig. 9: Model KWU 3 Acceleration Time History

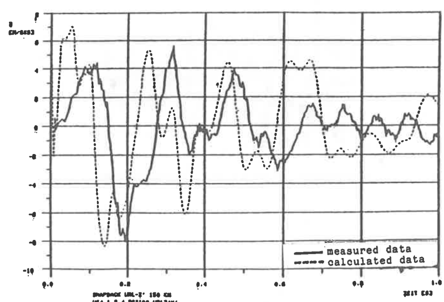


Fig. 10: Model TÜV 3/2 Acceleration Time History

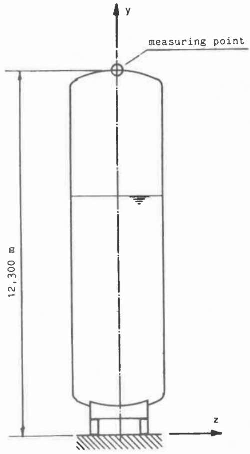


Fig. 11: Flooding Water Tank (FWB)

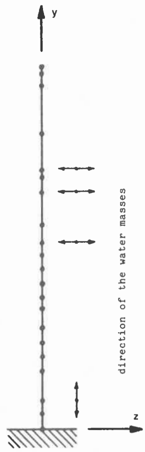


Fig. 12: Modell GRS5

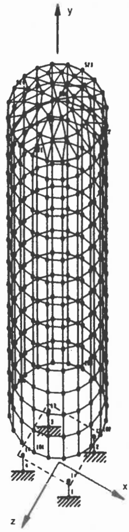


Fig. 13: Modell KWU5/2

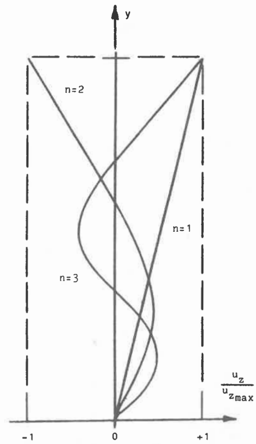


Fig. 14: Modell GRS5 Bending Modes

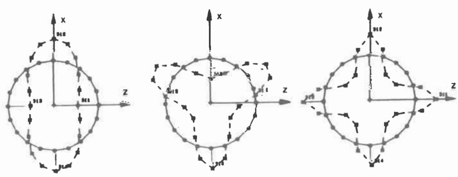


Fig. 15: Modell KWU5/2 Shell Modes

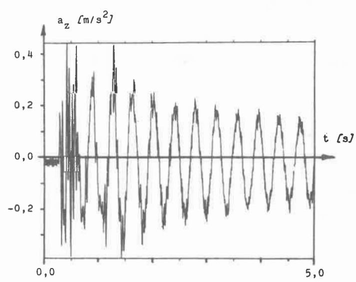


Fig. 16: Measured Acceleration Time History

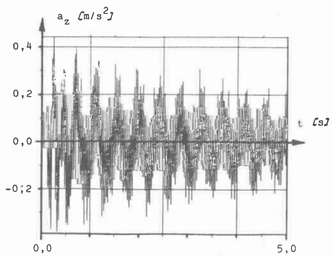


Fig. 17: Modell GRS5 Acceleration Time History

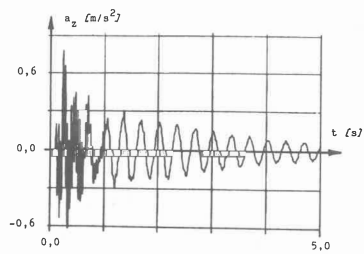


Fig. 18: Modell KWU5/1 Acceleration Time History