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SOME PRACTICAL ASPECTS OF THE SEISMIC REQUALIFICATION OF A STEEL SUPPORTING STRUCTURE OF A PIPE SYSTEM

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1. INTRODUCTION

The main steam and feed water piping systems located outside the reactor building at the Beznau nuclear power plant have had to be requalified for seismic action. The pipes pass from the reactor building via the operation building to the machine building. They are supported by a steel structure using different types of suspenders. As shown schematically in Fig. 1 the steel structure rests on the roof of the operation building. The steel structure also supports a sound absorber. As a requirement for the earthquake safety of the piping systems both the building and the steel structure have to shown to have adequate earthquake resistance. The seismic requalification of the operation building has been dealt with in reference [1].

For the steel structure first an experimental investigation was carried out. This was followed by a numerical analysis in which several iteration steps were necessary. Based on the results of numerical analysis the steel structure was strengthened and new supports for the piping systems installed. The work on requalification of the piping systems is still underway.

This contribution treats practical aspects in the requalification of the steel structure and passes on the experiences gained. This information could be useful in the requalification of similar interconnecting structures.

2. CONSTRUCTIONAL ASPECTS

The operation building lies between the reactor building and the machine building. The building has two floors, having a length of 47 m, width of 14.5 m and height of 7.0 m. As shown in Fig. 1 two structures have been placed on its roof.

The steel structure is a space frame with the dimensions 21x13.3x7.0 m (length x height x width): see Fig. 2b. The structural system in the transverse direction consists of 4 bolted frames stiffened and fixed at their corners. The longitudinal beams have hinge connections to the frames. The main steel types are European beams of HEB and HEM sections, of height from 100 to 400 mm. The whole structure has been stiffened with L-sectioned diagonals both in the horizontal and vertical planes. The columns of the steel structure are fastened to the building using anchor bolts. The different suspender types - constant hanger, spring hanger - carry the piping systems and transmit the loads to the steel structure. The masses of the buildings amount to 6,712 t, of the steel structure and sound absorber to 172 t, the main steam subsystem to 108 t, and the feed water subsystem to 52 t.

It is evident from the mass ratios of the various parts that the main coupling effect will be between the steel structure and the piping systems. For this reason the dynamic behavior of the steam blow out station was first investigated experimentally.

3. EXPERIMENTAL INVESTIGATIONS

The aim of the experimental investigation was to examine the dynamic behavior of the steel structure by determining the eigenfrequencies, modal damping values and the mode shapes from the data obtained by the dynamic measurements. The experimental investigation was carried out by the Fraunhofer Institute (LBF), Darmstadt, and documented in reference [2]. The dynamic measurements were obtained during normal operation of the plant, making use of the excitation produced mainly by the steam flow in the piping system.

The following items of equipment were employed in the experimental investigation:

7 acceleration transducers (SETRA) including the amplifiers
range of acceleration 0_±15g.
1 tape recorder (8 channels)
1 4-channel chart recorder
1 HP Fourier analyzer

The measuring positions on the structure are shown in Fig. 1. The additional measuring positions were on the supports, on the pipes or on the valves.

The experimental investigation of the live steam station under normal operating conditions had shown that in the frequency range up to about 15 Hz modal parameters could be found independently using the response measurements without a knowledge of loading quantities. The identified eigenfrequencies and mode shapes are summarized in Table 1.

The results of the dynamic measurements were used by the engineers of the Swiss Authorities for plausibility checks.

Table 1 Results of the experimental investigations

Frequency Hz	Direction	Damping values %	Steel structure / component	Remarks
3.0	x	4.6	Structure + pipes	The whole structure vibrates including the piping system
3.4	x	5.8	Structure +feed water pipe	The front of the structure is at rest, the U-shape part vibrates in opposite phase
4.0	y	3.2	Structure + pipes	The whole structure vibrates including the piping system
5.1	x	2.9	Structure + pipes	The front of the structure vibrates in opposite phase to the U-shape part: the pipes exhibit in part high response and thus strong coupling
8.8	y	2.2	Feed water pipe	The part of feed water pipe on reactor side vibrates in uncoupled mode
10.2	x	1.8	Feed water pipe	The part of feed water pipe on turbine side vibrates in uncoupled mode
11.0	y	1.8	Structure + pipes	The middle part of the structure vibrates in opposite phase to the part on the reactor and turbine sides of structure

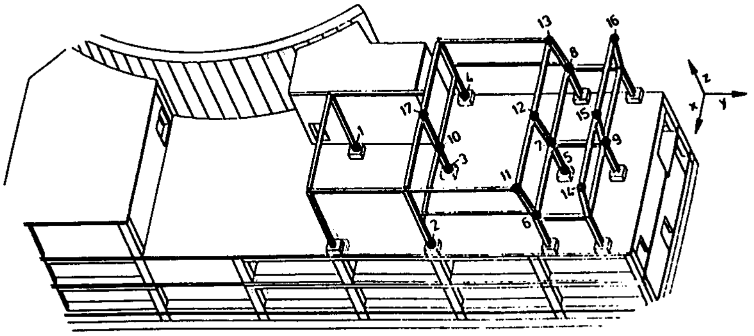

Figure 1. Steel structure (schematically) on the roof of the operation building with the measuring points

4. PROCEDURE ADOPTED IN THE REQUALIFICATION

4.1 Developing the computational model

Since the experimental investigation showed that coupling effects were present a complete model consisting of the following sub-models was developed:

Building and ground
Steel structure
Steam and feed water piping systems

The sub-models are shown in Fig. 2, from which it may be seen that the building was simulated by a 3-D lumped mass model, the ground by springs and dampers. The steel structure was modeled by a space frame [4]. In this model practically every steel member is modeled with its geometry and cross-section. The 3-D models for the piping systems were based on the model produced by the firm Westinghouse [5]. The steel structure model was connected rigidly to the building model. The piping systems were connected to the steel structure model with spring elements having the same stiffnesses as those of the suspenders and supports. The fixed points of the pipes, which are located outside the operation building, were connected to the mass points of the first floor of the operation building. The complete model comprises 1711 elements and 1791 nodes. For the dynamic analysis 600 degrees of freedom were considered.

4.2 Solution methods

The dynamic analysis was carried out with the method of response spectra using the program ANSYS [6]. The excitation for the load case SSE was taken from the free field design spectra valid for NPPs. They were scaled to a maximum acceleration of 0.21g (horizontal x), 0.20g (horizontal y), and 0.15g (vertical z). The main x,y and z directions were excited separately. The first 200 modes up to 33Hz as well as the main directions were superimposed according to the SRSS method.

4.3 Results

The main results were the stresses in the steel members due to the SSE excitation. These stresses were superimposed with those of the static analysis and evaluated according to the Swiss SIA Standard [7]. The seismic loading on the pipes as well as accelerations and displacements at selected positions for the requlalification of the pipes and the suspenders were passed on to the design engineers. The pipes are also supported in the neighboring buildings. The seismic motions of these buildings relative to those of the operation building were taken into account by means of additional static analyses. The results of these analyses were also passed on to the pipe design engineers.

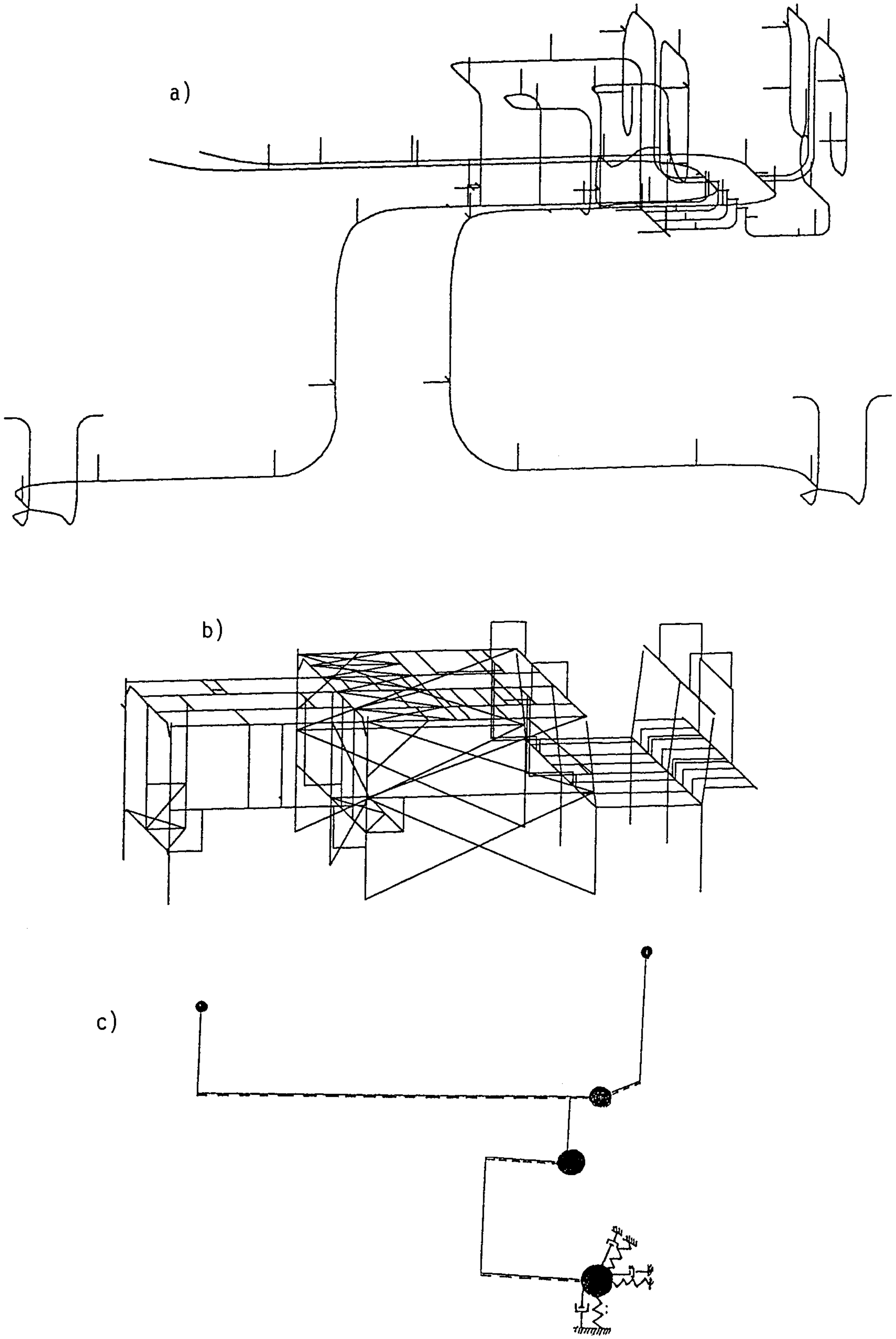

Figure 2 . Computational model a) Piping (only LDF) b) Steel structure c) Building and ground

5. ITERATIONS IN THE ANALYSIS

The requalification was executed in three steps. Table 2 shows the individual steps of the requalification.

Table 2

Calculation iteration	Results	Constructional change
1. Step Analysis with fixed supports	Supports could not resist loads; local structural safeties of concrete members could not be verified	Construction of hinges at supports
2. Step Analysis with hinged supports	Steel structure overstressed at some locations, local load capacity checks okay	Steel structure is stiffened (additional stiffeners and strengthening of cross-sections
		Additional suspenders in the piping systems
3. Step Analysis with stiffened steel structure: "as built state"	Stresses in steel structure okay; local load capacity checks in concrete okay	None
	Passing on results for requalification of piping systems	

The influence of constructional changes on the dynamic behavior of the steel structure and thus on the seismic loading is quantified in Tables 3 and 4. In Table 3 the eigenfrequencies of the first 15 modes are presented. As an example in Table 4 the reactions in a column of the steel structure are compared.

Table 3 Comparison of eigenfrequencies and effective masses

Mode	**Model:fixed**				**Model:hinged**				**Model:stiffened**			
		Effective mass				**Effective mass**				**Effective mass**		
	Freq	x	y	z	**Freq**	x	y	z	**Freq**	x	y	z
1	**1,41**	12,870	12,790	0,170	**1,41**	17,977	11,521	0,171	**1,66**	203,651	0,057	0,017
2	**1,48**	4,036	28,823	0,062	**1,46**	58,250	26,291	0,027	**1,74**	1,055	0,180	3,601
3	**1,73**	12,661	4,849	1,252	**1,57**	159,070	3,713	0,073	**1,84**	5,013	0,183	3,516
4	**1,81**	0,001	1,944	5,609	**1,74**	0,617	5,607	1,575	**1,96**	0,070	0,055	0,379
5	**1,92**	0,003	0,425	0,089	**1,81**	3,691	2,895	5,288	**2,30**	4,185	0,044	0,027
6	**2,02**	31,543	18,671	0,061	**1,92**	0,200	0,576	0,100	**2,41**	0,018	113,49	0,478
7	**2,12**	110,064	1,224	0,967	**2,03**	0,506	17,686	0,020	**2,55**	8,104	8,845	0,084
8	**2,23**	2,259	1,734	2,143	**2,13**	0,670	0,855	0,475	**2,94**	0,454	3,408	0,603
9	**2,24**	13,086	0,155	3,018	**2,23**	0,010	1,545	0,610	**3,03**	46,087	7,627	0,163
10	**2,31**	0,018	79,000	0,339	**2,24**	0,020	0,020	5,223	**3,24**	5,036	25,381	6,667
11	**2,36**	0,580	0,788	1,941	**2,29**	28,075	1,004	0,239	**3,33**	9,170	1,982	0,177
12	**2,39**	16,443	5,007	0,769	**2,36**	0,060	12,542	0,818	**3,35**	5,006	0,005	2,375
13	**2,45**	47,424	0,005	0,524	**2,39**	0,382	69,569	0,116	**3,42**	1,306	5,442	0,228
14	**2,49**	33,089	1,734	0,161	**2,41**	0,054	15,386	1,987	**3,51**	0.372	0,078	1,448
15	**2,79**	0,042	0,661	0,090	**2,48**	0,390	0,507	0,348	**3,70**	0.920	33,840	0,152

Table 4. Comparisons of reactions due to SSE loading for a column of steel structure

	Horizontal	Vertical	Moment-X	Moment-Y
	kN	kN	kNm	kNm
Model: fixed	95.	±216.	128.7	91.9
Model: hinged	53.	±322.	-	-
Model: stiffened	49.	±365.	-	-

6. CONCLUSIONS

The advantage of this procedure is that the stresses are determined both for the steel structure including column supports and for the piping systems in one computational model. This model is indeed complicated, but compared to the procedure with the sub-models (whereby the output from the building model serves as input for the calculation of the piping systems) the conservativeness of the approach is reduced and compatible results are guaranteed.

7. REFERENCES

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