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Recording and Assessment of Structural Vibrations Recent Case Studies in Beznau NPP

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ABSTRACT

The two presented case studies illustrate recent experience with the experimental approach to solve structural dynamic problems at the Beznau nuclear power plant.

The experimental assessment of operational floor vibrations investigates the transfer path of the structural vibrations caused by the main steam line MSL and the feedwater line FWL. The measurements provide a data basis to assess equipment failures and to specify vibration requirements for new installations.

The evaluation of the seismic strong motion instrumentation presents criteria for an upgrade of the existing system in order to collect the data at representative locations and to process them rapidly. The generated information shall efficiently support the decision about plant shutdown, inspection or ongoing operation in case of a seismic event.

1. THE BEZNAU NUCLEAR POWER PLANT KKB

1.1 Plant features and milestones

The Beznau Nuclear Power Plant (Kernkraftwerk Beznau, KKB) is owned and operated by Nordostschweizerische Kraftwerke AG (NOK), Switzerland. KKB consists of two units, each of which has a rated output of 365 MWe. With Unit 1, one of the first generation NPP erected in continental Europe on a purely commercial basis. NOK made the change to power generation by nuclear technology in Switzerland. The nuclear units 1 and 2 came on line on July 17, 1969 and October 23, 1971 respectively.

The nuclear steam supply system of each of the units consists of a Westinghouse pressurized water reactor with two loops enclosed in a steel and concrete double containment. Each unit has its own control room and an external spent fuel pool. The turbine hall with two turbine-generator sets per reactor is common to both units. In addition to generating electricity, Beznau supplies hot water to a district heating network from a heat exchanger supplied with steam tapped off between the high and low pressure turbines. The capacity is in the range of 70 MWth.

In 1992, a Bunkered Emergency Heat Removal System (NANO, Notstand System) was commissioned in Unit 2. In 1993, Notstand System was commissioned and the two steam generators were replaced in Unit 1. The replacement of the two steam generators enabled an increase in electrical output of 2% without an increase of reactor power.

The prinicipal objectives of the Notstand System are:

- to increase the degree of protection against external events such as earthquakes, airplane crash, river flood, lightning strikes and third-party intervention
- to improve the spatial separation of emergency core cooling and decay heat removal equipment
- to provide a redundant on-site emergency power supply
  The equipment provisions for primary system cooling include
- a high pressure pump used to inject water into the primary loop
- the emergency seal cooling pump, which injects borated water into the seals of the reactor coolant pumps to assure their functional integrity
- the borated water storage tank
- the external recirculation pump with ejector installed in the containment sump
- the water cooled external heat exchanger, which acts as an ultimate heat sink.
  The instrumentation and control systems have been designed to provide full independance of the Notstand System from the existing unit I&C System.

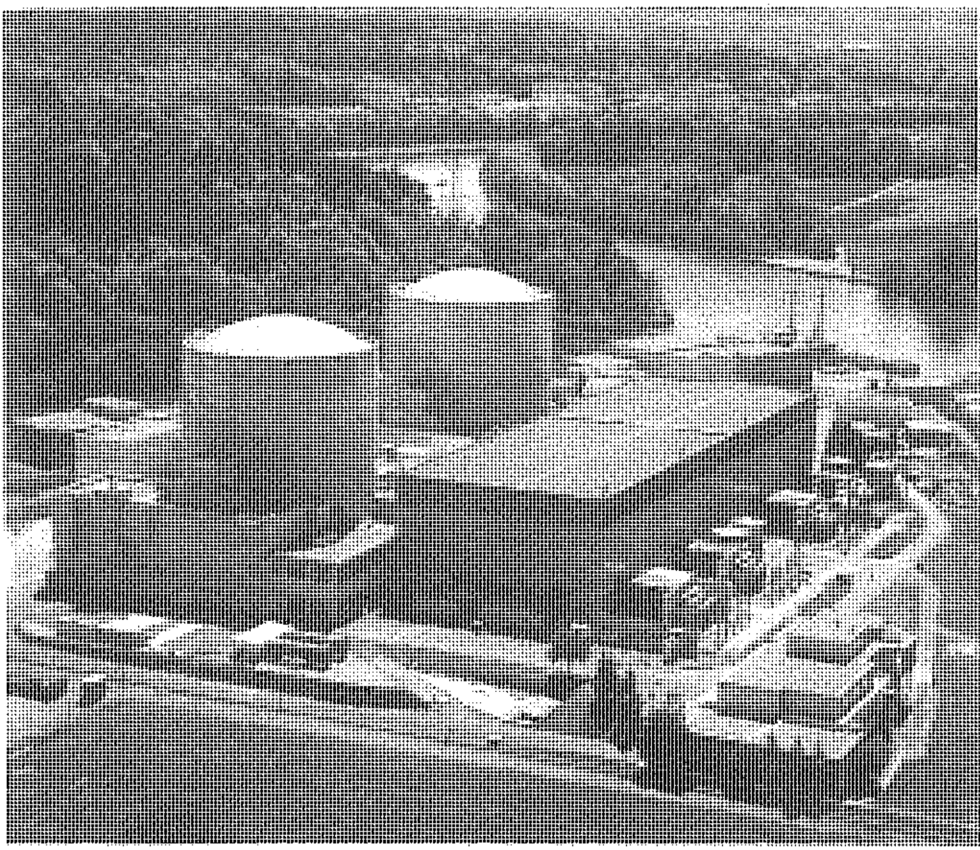


Figure 1 View of the Beznau NPP

1.2 Seismic Hazard and Regulatory Requirements

Seismicity in most parts of Switzerland is moderate. For the KKB site the Safe Shutdown Earthquake SSE with the annual event frequency of 10^{-4} is specified with a horizontal peak ground acceleration of 0.15 g at the underlying rock base.

Within the variety of dynamic load cases the seismic qualification requires the most attention and effort. According to the regulatory guidelines all safety related structures and systems belonging to safety clases 1 to 3 must be qualified for SSE and OBE level.

In the early 1980ies the original seismic qualification was re-evaluated. Based on the updated seismic data the regulatory agency requested a complete and systematic reassessment and requalification. The current systems are compatible with state-of-the-art technology, based on the following completed main tasks:

- seismic reassessment and requalification of class 1 and some of the class 2 structures, systems and components
- backfitting projects, such as the Notstand Systems and buildings with rigorous seismic qualification
- analysis for new systems, complementary safety systems and new buildings
- seismic upgrade of selected systems and structures

2. STRUCTURAL DESIGN PROCEDURES AT KKB

Figure 2 shows the utilities tasks in the area of structural dynamics. These problems have been solved analytically, experimentally or with a combined approach.

In general the structural dynamic problems are solved with analytical methods. In addition and for special cases full-scale tests and experimental vibration assessments are used, in order to validate the analysis methods and models. As a permanent monitoring system the seismic strong motion instrumentation provides not only data to decide about plant-intervention but also event-specific feedback data for the dynamic behaviour of soil and structures.

The following chapters present two recent case studies with experimental assessments of structural vibrations.

3. EXPERIMENTAL ASSESSMENT OF OPERATIONAL VIBRATIONS

3.1 Problem and Objectives

The pipes of the main steam line MSL and feedwater line FWL pass from the reactor building to the turbine building. The piping section between the two buildings is supported by a steel structure anchored on the top of the intermediate building, as indicated in figure 3. Hence the flow induced vibrations are transmitted from the piping through the support structure to the roof of the intermediate building and finally to the electrical equipment located in the lower level rooms.

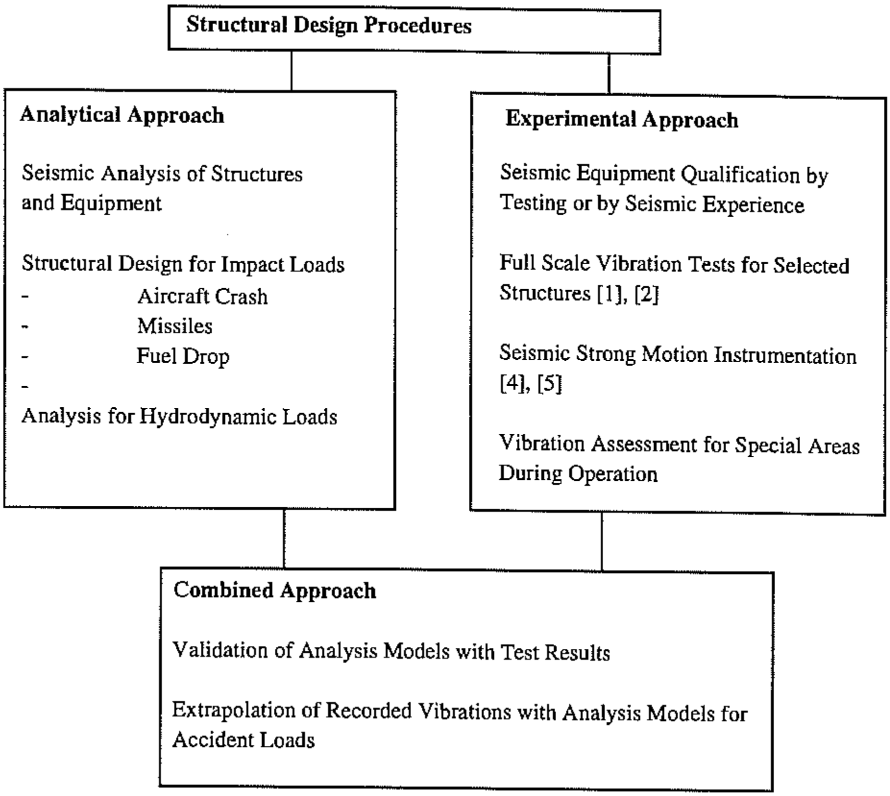


Figure 2 Analytical and Experimental Approach for Structural Dynamic Problems

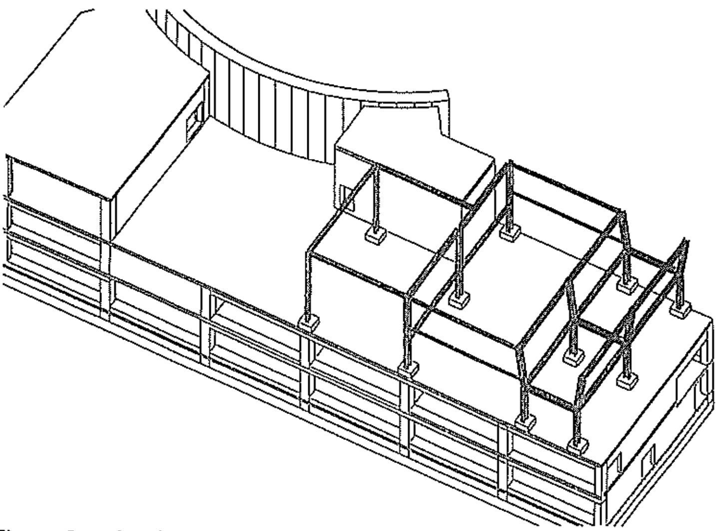


Figure 3 Steel structure on the intermediate building, supporting the MSL and FWL piping

The intermediate building is situated between the reactor building and the turbine building. Occasionally some electrical components on the first floor level of the intermediate building of unit KKB II were damaged. Their function failed and parts had to be replaced. One potential cause for these failures was assumed to be the flow induced vibrations of the MSL and the FWL, caused by the support modifications in conjunction with the seismic requalification. Because the discussion about the cause was controversial, KKB decided to measure the structural vibrations in order to find out if there is any correlation between the mechanical failures of the electrical equipment and the flow induced piping vibration.

The objectives of the in-situ measurements are

- to collect data about the vibrations due to various excitation sources
- to assess whether the recorded vibration levels are acceptable (not damaging)
- to supply data to facilitate decision making in connection with restoration measures and
- to establish a data base for the validation of analytical models for dynamic analyses.

3.2 Vibration Recording Concept

The vibrations were measured with the recording system MR2002 from Syscom Instruments. The sensors record the three spatial components of the velocity-time-functions in the range of 0.005 to 100 mm/s for frequencies between 1 and 160 Hz. The signals were collected with the mobile data acquisition system and processed with the Software VIEW2002 on the desktop-PC.

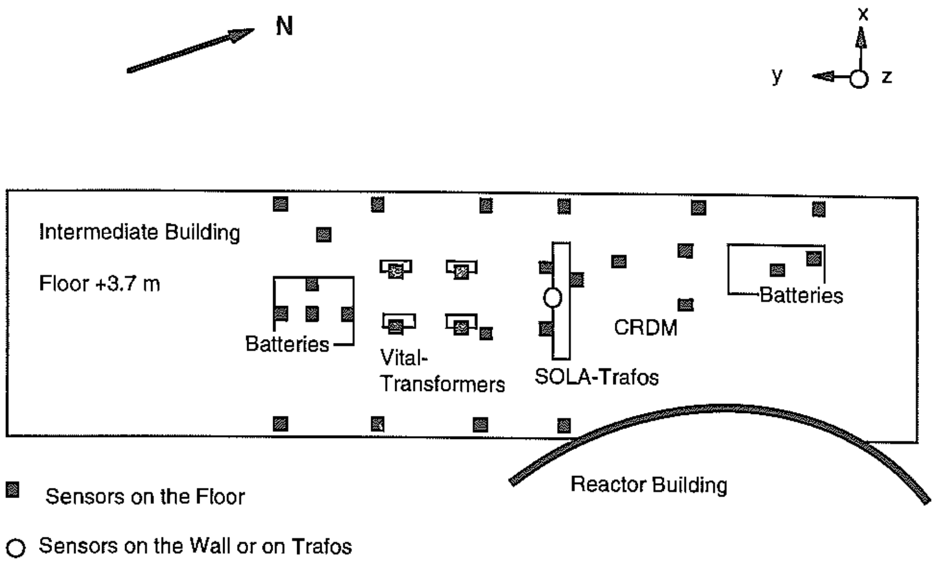
The signals were recorded subsequently at 46 different structural locations on the pipes, on equipment components, on the pipe supports and mainly on the two floor levels. The sensor locations are summarized in figure 4. Since the operation condition was normal plant operation, the vibrations reflect stationary signals. The recording-time span was varied in the range of 3 to 10 seconds.

3.3 Results

Figure 5 gives a typical example for the recorded and processed data. The vertical component of the velocity-time-function was dominating on the structural floors. This location on the floor below the vital-transformers shows peak velocity amplitudes of 0.6 mm/s. The corresponding Fourieramplitude-spectrum has a first significant peak at the frequency of 21 Hz, which is found to be the first eigenfrequency of the floor plate in this area. Further frequency peaks are obvious in the frequency range up to 40 Hz, excited by the piping above and transmitted through the concrete structure to this location.

A completely different source for structural vibrations was identified with the measurements near the Control Rod Drive Mechanism (CRDM-motor-generating set), as illustrated with figure 6. The generators operate with 1500 cycles/minute, which is equivalent to 25 Hz. This frequency is again amplified by the first mode of the structural floor plate. In addition to this the 2nd, 3rd and 4th harmonics of this forced vibration are identified obviously with the peakks at 50, 75 and 100 Hz.

As an overview, the table 1 shows a summary of the recorded vibrations. The measurements are thorougly evaluated. The vibrations are generally on a low level. Transfers can be demonstrated from the pipes to the lower building levels but also from other vibration sources such as the electromechanic generators.



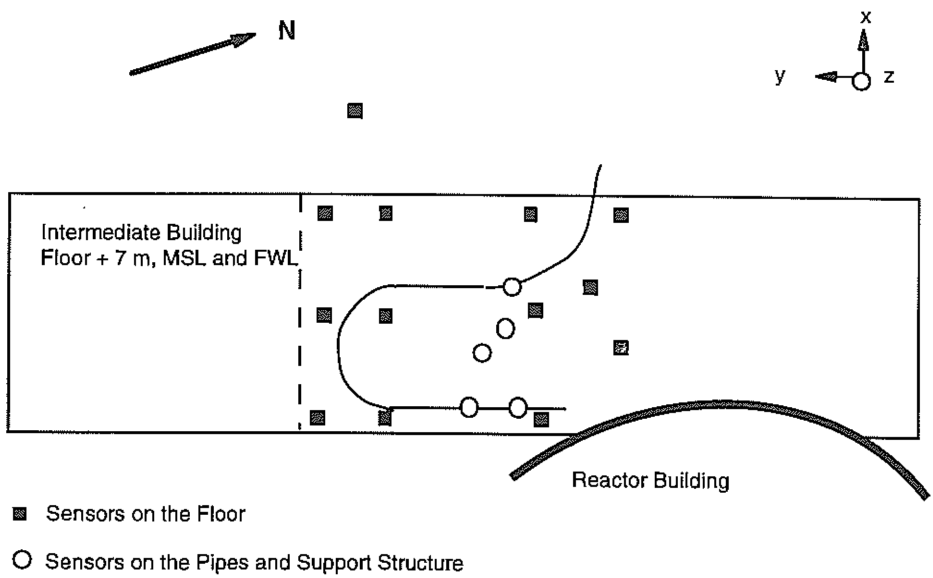


Figure 4 General Layout and Sensor Location for the Halon-Zone (level + 3.7 m) and the Above Piping Level (+ 7 m)

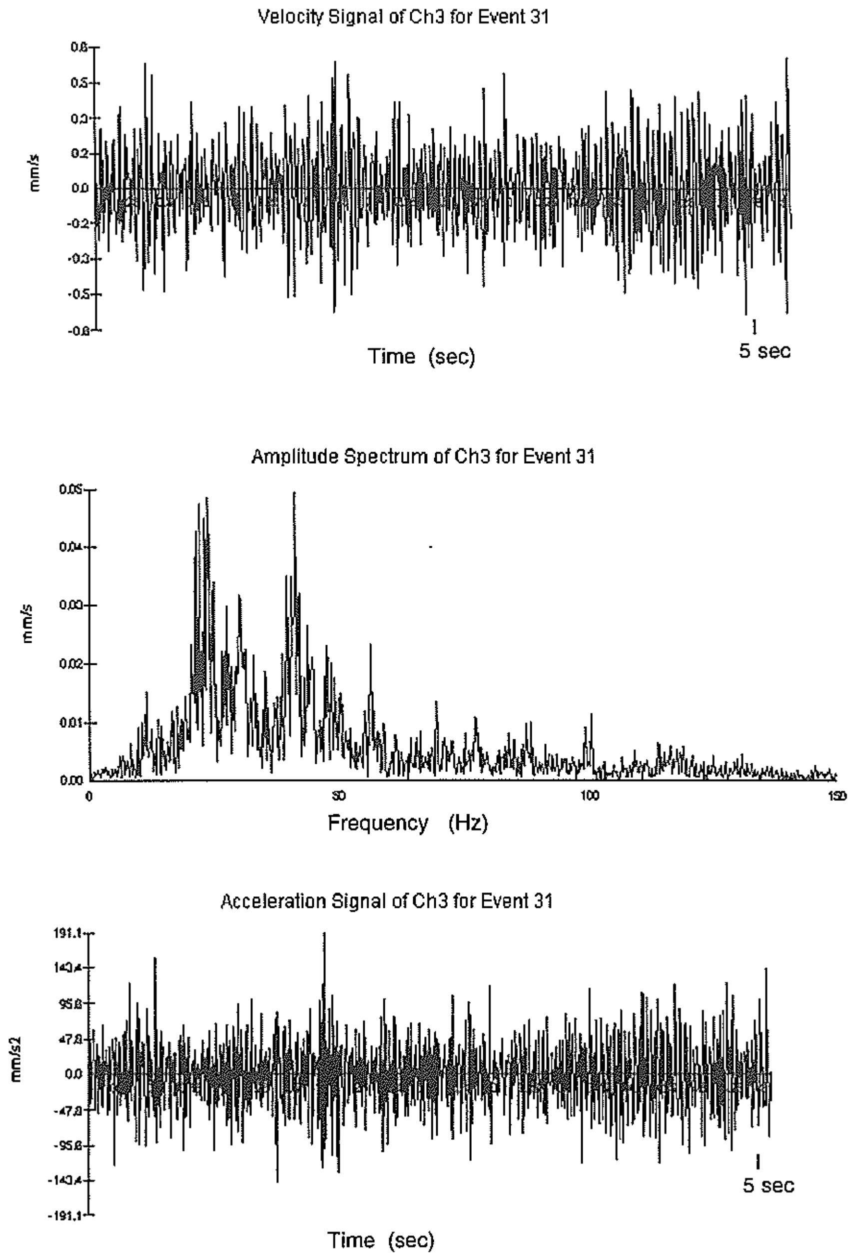


Figure 5 Typical Example for the Recorded and Processed Data: Vertical Component of the Velocity-Time-Function and the Corresponding Fourieramplitude-Spectrum at the Floor Below the Vital-Transformers, Derivated Acceleration-Time Function

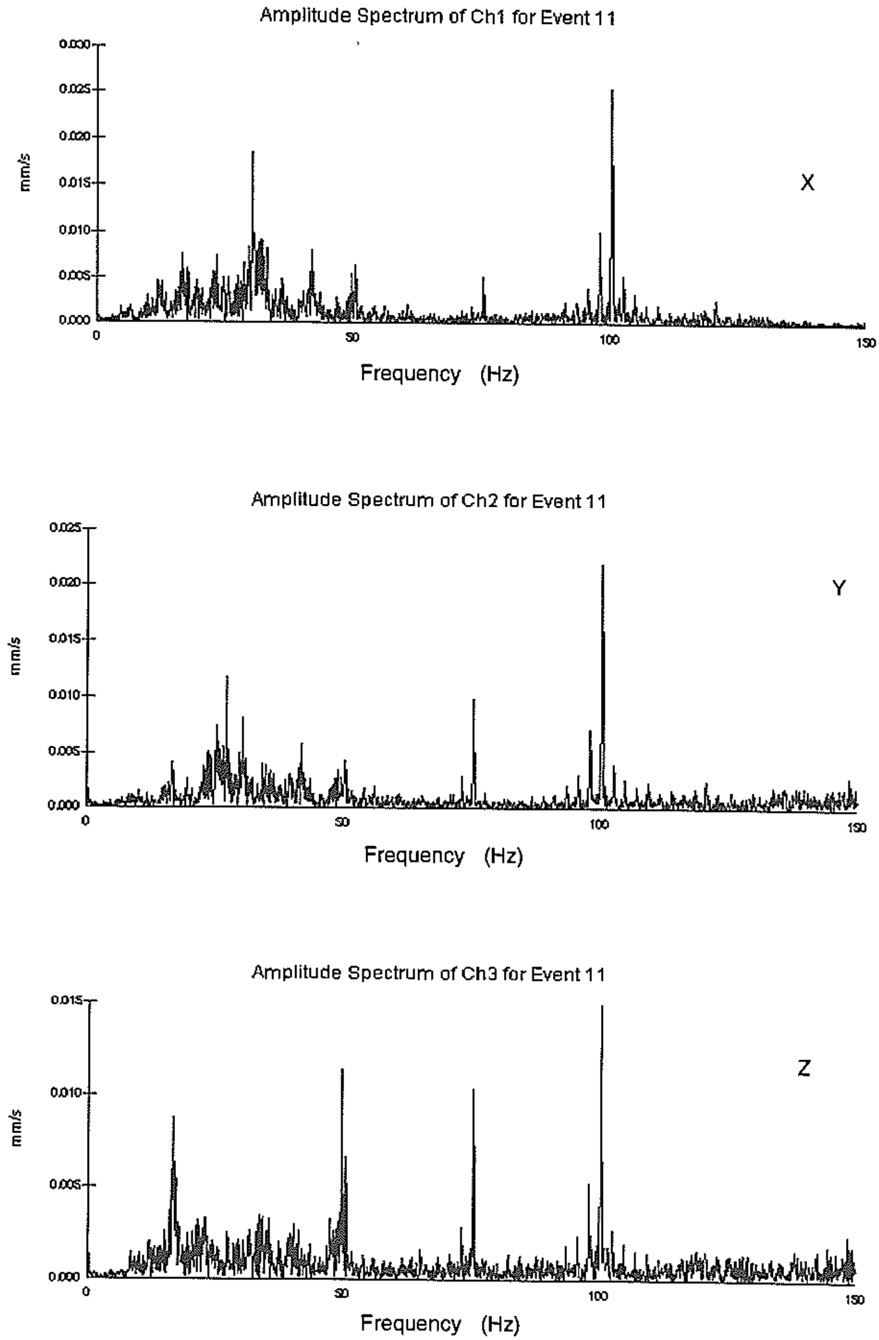


Figure 6 Typical Example for the Recorded and Processed Data: Three Spatial Components of the Fourieramplitude-Spectrum at the Floor Near the CRDM-motor-generating set

Table 1 Summary of Recorded and Processed Data

Peak Velocity	**Vibration Sources, Frequencies, Vibration Contributions** <------ MSL and FWL piping ----- >						Eigen-fre-quency
	CRDM-motor 5-25 Hz	30 Hz	41 Hz	61 Hz	90 Hz	CRDM-motor 100Hz	
on the pipes, total up to **25 mm/s** x	2.3 mm/s x, z	0.7 mm/s x, z	0.4 mm/s z	0.2 mm/s x	not recor-ded	---	
on the steel structure, total up to **7 mm/s** z	0.7 mm/s z	0.2 mm/s z	0.1 mm/s z	0.1 mm/s z	---	---	
on floor 334 m, total up to **1 mm/s** x, y, z	0.06 mm/s x, y, z	0.03 mm/s x, y, z	0.03 mm/s x, y, z	0.02 mm/s x, y, z	0.02 mm/s x, y, z	0.018 mm/s x, y, z	25 Hz 35 Hz
on floor 330.7 m, total up to **1.5 mm/s** z	0.2 mm/s z	0.04 mm/s x, z	0.05 mm/s z	0.01 mm/s z	---	0.14 mm/s z	25 Hz 50 Hz 63 Hz

3.4 Lessons Learned from the Recorded Vibrations

The recorded vibrations provide a substantial basis for further decisions.

a. The transfer path from two identified vibration sources to the questionable electrical equipment positions is evident. The excitation and transmission from the MSL and FWL piping is proved by the measurements. There is also an effect caused by the CRDM-motors located on the same floor level.

b. The recorded structural velocities are compared with generally available acceptance criteria. The measured floor vibrations are found to be far below acceptable values recommended in guideline DIN 4150 for industrial buildings [3], which are defined to be 20 mm/s and more (threshold for structural damage).

c. If specific electrical components continue to be sensitive to vibrations, the recorded data may be used for a more detailed assessment. For such cases, the acceptable level of vibrations are to be defined individually for the specific components based on the equipment specifications.

d. The recorded vibration data provide a basis to assess potential equipment failures. They will also be used to specify vibration requirements for new installations.

4. SEISMIC STRONG MOTION INSTRUMENTATION

The existing strong motion instrumentation has been operable for more than 20 years since 1977. Encouraged by recent maintenance experience and by a successful upgrading in the comparable plant Mühleberg NPP, the utility KKB decided to evaluate the current state-of-the-art of instrumentation technology as a basis to decide about upgrading the system.

4.1 Existing Instrumentation and Experience KKB

The existing system collects the data from 5 sensors, placed in the free-field, the reactor building and the fuel building. The system has worked satisfactorily so far. The two seismic events during the operation period were recorded successfully and reported in [4] and [5]. The system is compatible with the currently valid guidelines of the Federal Nuclear Safety Inspectorate in Switzerland.

However the operation and maintenance experience reveal some shortcomings which could impede the correct and timely acquisition and processing of data from future seismic events:

- The data processing unit is not part of the system in the plant. data are transferred to the utilities' external computer system. Therefore the processing is more time-consuming than in modern systems. The time-period required for response spectra generated is estimated to be about one day.
- Spare parts for obsolete eqipment components are no longer guaranted, because the provider of the original system retired from business.
- Two sensors are sensitive to failfunctions: the free field sensor is surrounded by groundwater. The sensor on the steam generator is sensitive to non-seismically induced operational vibrations.

4.2 Recent Developments of Guidelines and Equipment

The current state-of-the-art is defined by the recent US-NRC-guidelines [6]. It is directed towards the main goal to evaluate the recorded seismic data rapidly. The response spectra shall be available within 4 hours and a first comparison of recorded spectra with OBE-design spectra is available at this time. The question of OBE-exceedance shall be answered immediately, based on this information.

The guidelines require to record the seismic events with 6 tri-axial accelerometers. One of them shall be placed in the free field near ground surface level.

Many equipment providers offer instrumentation systems which are qualified to fulfill the latest NRC-guidelines. The data processing software is easy to handle and directly available at the site. The software is integrated in the central processing unit or it can be connected to it from a personal computer at a data interface. The latest developments of four different producers were included in this evaluation.

4.3 Upgrade Recommendation

The evaluation concludes with the pronounced recommendation to upgrade the existing instrumentation by replacement. It specifies the profile of the new system, with the objective to collect the data at representative locations and to process them rapidly to support the decision about plant shutdown, inspection or ongoing operation in case of a seismic event.

Recommendations and criteria are developped for optimal sensor locations, see figure 7, and for a rapid and efficient data processing.

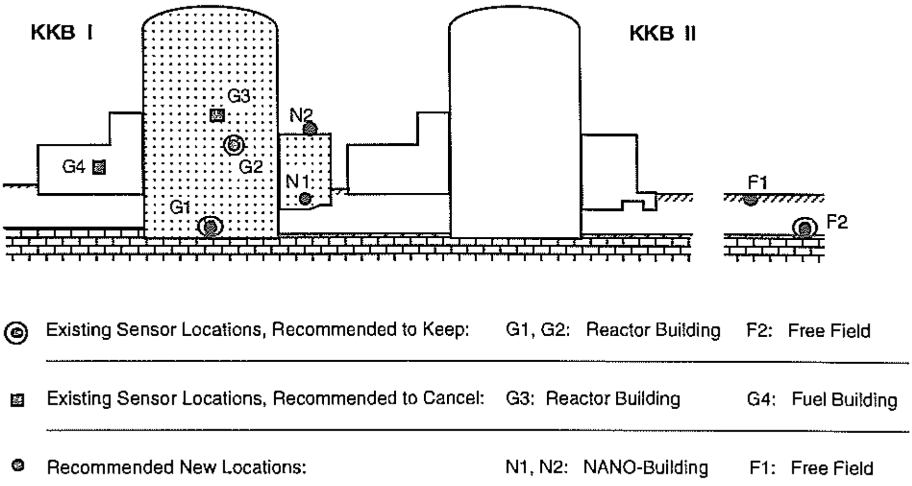


Figure 7 Recommended Sensor Locations; G1: reference sensor for the first rapid evaluation

5. CONCLUSIONS

The two presented case studies illustrate recent experience with the experimental approach to solve structural dynamic problems at the Beznau nuclear power plant.

The recorded vibration data provide a basis to assess equipment vulnerabilities and to specify vibration requirements for new installations.

The evaluation of the strong motion instrumentation system concludes with the recommendation to upgrade by replacing the system. It specifies the requirements for a modernized system able to generate information about future seismic events within acceptable processing time.

6. REFERENCES

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