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ROBUSTNESS OF AN ORIGINALLY NON-SEISMIC DESIGNED PIPING SYSTEM

Dr. Björn Elsche[1], Ertugrul Karabaki [1],
Christian Blaß[2], Dr. Ing. Fritz-Otto Henkel[2], Willi Messerer[2]

[1] E.ON Kernkraft GmbH, Tresckowstrasse 5, 30457 Hannover, Germany
(bjoern.elsche@eon.com, ertugrul.karabaki@eon.com)
[2] Wölfel Beratende Ingenieure GmbH + Co. KG, Max-Planck-Str. 15, 97204 Höchberg, Germany
(blass@woelfel.de, henkel@woelfel.de, messerer@woelfel.de)

ABSTRACT

In the 1990s in German nuclear power plants (NPPs) a system for filtered venting has been designed and upgraded under consideration of operational aspects. This system has not been designed for the earthquake load case. After the Fukushima accident the German Reactor Safety Commission (RSK) drafted recommendations regarding the robustness of the German nuclear power plants. According to this, German NPP-operators have to show that the piping and components of the filtered venting system have a sufficient resistance against earthquake and that the system still has the integrity after earthquake load case.

Germany is characterized by low seismicity. Particularly for the E.ON Kernkraft GmbH (EKK)-operated nuclear power plants, the design intensity for the sites is below the intensity of $I \leq 6.5$. Because of this low intensity the robustness of the system of the filtered venting was assessed by engineering practice. This means the assessment included a combination of assessment criteria for verification by experience based considerations:

- Inspection walk down
- Review of the documentation
- European Macroseismic Scale 98
- Observations of earthquakes in Germany
- International experiences regarding originally non-seismic designed piping systems under seismic action
- Comparison of originally non-seismic designed system-areas with the originally seismic-designed system-areas of the same nuclear power plant
- Comparison of the structure with the application guidelines PAR
- Reviewing the design calculation of the system for operating loads (positive reviewed by the authorities)

By considering all the above listed criteria it can be assumed that the piping and components of the filtered venting system in EKK owned NPPs resist the design earthquake and are still integer after the earthquake.

INTRODUCTION

After Fukushima accident, operators of nuclear power plants worldwide have an additional interest regarding the design and implementation of a venting system in NPPs. This system has already been implemented in German NPPs since 90s and was designed for operating loads only. Due to the recommendations of German Reactor Safety Commission (RSK) /7/, via above listed methods an engineering judgment has been performed to show that the system can also resist design earthquake.
This paper explains in detail how these criteria been considered and practically applied for this purpose.

In case of a beyond design load case, venting system is used to decrease the pressure inside the containment by transferring the filtered medium from containment to the chimney of the NPP.
Venting system is a Standby-System which is mechanically connected with the H_2-Degradation system. H_2-Degradation system has already been designed for the load case earthquake. In different EKK operated NPPs, there are slight changes regarding the design of the venting system. The investigation has been performed for the following NPPs: Grohnde, Brokdorf, Grafenrheinfeld and Isar 2. There is an aerosol filter existing in all the plant designs. In two of these NPPs piping system includes additionally a venture scrubber before the aerosol filter. In the containment of NPP, before the containment penetration there is a bursting disc implemented in the pipe. Starting from this fixed support of the containment penetration, the piping reaches to annular space. After that the piping continues inside auxiliary building and then connects with the aerosol filter via bellows. Out-surge pipes from the aerosol filter ends inside the chimney where the filtered medium leaves the nuclear power plant.

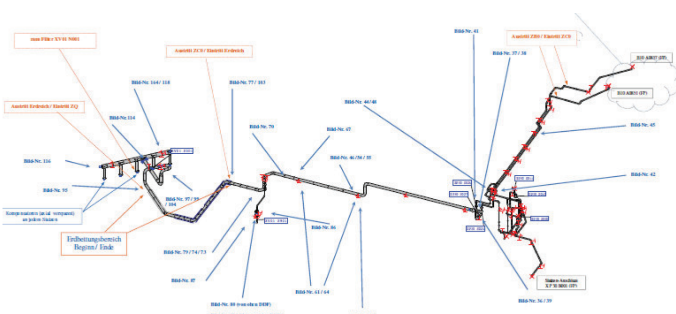


figure 1 – Venting system from containment to aerosol filter (exemplary for one NPP)

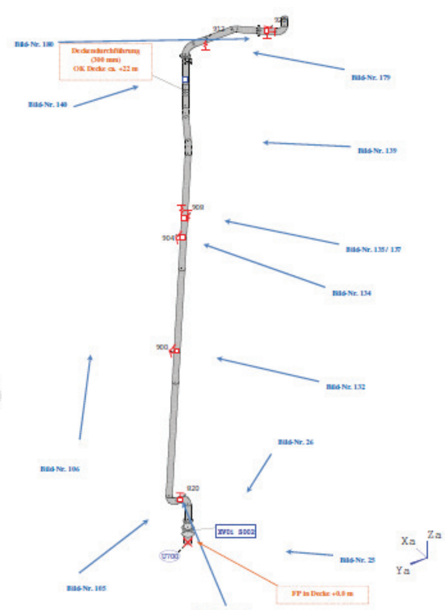


figure 2 – Venting system from aerosol filter to chimney

INSPECTION WALK-DOWN & REVIEW OF DOCUMENTATION

Walk-down of the venting system has been performed during the normal operation of the power plant. All the necessities regarding the walk-down and organization had to be clearly defined at the beginning. Limitation of radiation dose and time were the uttermost important criteria. Engineers of EKK and Wölfel have reviewed the documentation of the system and determined a walk-down methodology. This consists the following criteria:

- Gathering of floor plans, isometrics, calculation notes, drawings
- Listing of the piping, supports and components according to the room numbers
- Pre-evaluation of the existing calculation notes regarding the critical locations
- Pre-evaluation of H_2-Degradation system with which the venting system is mechanically connected to
- Inclusion of an experienced power plant personnel into every decision step
- Summation of information regarding the earthquake loads at every location
- Preparation of photographical documentation
- Limitation of the number of members of walk-down team

Having completed all the prerequisites, walk-downs of the venting system in all designated NPPs have been performed in a relatively short time with a high efficiency. Right at the end of the walk-down, all the steps, reached agreements and conclusions have been discussed extensively. Some of the open points have been left for the decision after the responsible engineer accomplished his/her judgments via calculations. Engineers agreed on the fact that there was a need for some supplementary documents from archive of the NPP. Together with an experienced engineer from the NPP, those were made available for further steps. Open points have been listed and after having had more knowledge, these points were handled upon common agreement. Photographical documentation with measurements on-site has helped the engineers in many ways; there have been no ageing phenomena noticed, clearances at penetrations were considered, collision probabilities have been checked, stiffness of some supports and components together with possible deficiencies regarding installation were verified.

EUROPEAN MACROSEISMIC SCALE 98

The effects of an earthquake can be described by its intensity. In the European Macroseismic Scale 98 (EMS 98) the observed effects on human, objects, nature and buildings are defined. All EKK sites have an Intensity lower than 6.5. Due to this fact hereafter the effects for intensity VI and VII are described to understand, which effects can be expected.

All buildings, in which the venting system is implemented, are concrete buildings and consist of walls and floors. Most of the buildings are not designed against earthquake (Class C), earthquake resistant designed buildings are Class D or E.

The damage grades are described in the table below.

Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction (very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

table 1 - classification of damage to buildings of reinforced concrete

The definition for the intensities VI and VII are in the EMS 98 given as followed:

VI. Slightly damaging

a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
c) Damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1 (no structural damage).

VII. Damaging

a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.

b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class C sustain damage of grade 2 (slight structural damage).
A few buildings of vulnerability class D sustain damage of grade 1.

OBSERVATIONS OF EARTHQUAKES

In the last decades two earthquakes with damage-effects in Germany have occurred (see /4/).

date			coordinates		depth	magnitude			location
year	month	day	latitude N	Longitude E	km	ML	Intensity MSK-64	R km	City
1978	9	3	48°17’	9°02’	6	5.7	VII-VIII	330	Albstadt
1992	4	13	51°09’	5°56’	17	5.9	VII	440	Roermond (Netherlands)

table 2 – chronological list of relevant earthquakes for Germany

Albstadt

On the third of September 1978 an earthquake occurred at the Schwäbische Alb /6/. The epicentre-intensity (MSK 64, which is comparable to the EMS 98 /5/) was between VII and VIII. The epicentre was located at Albstadt. The acceleration-correlations over time and frequency are shown in figure 3.

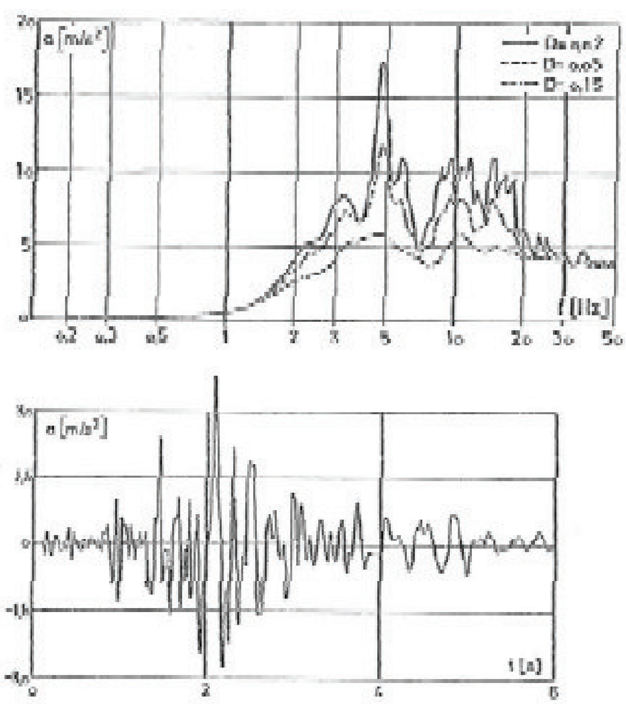


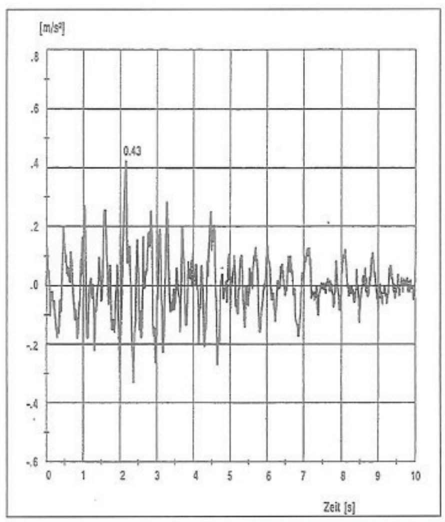
figure 3 - registration Schwäbische Alb 3.9.78

Many damages were found after the earthquake but most of the damages were found at masonry building and structures which have a no earthquake adequate construction.
The descriptions of the effects of the earthquake show that in reinforced building normally no damages occurred. For machines it is explained, that only effects were observed, if they were not connect with the structure.

Roermond

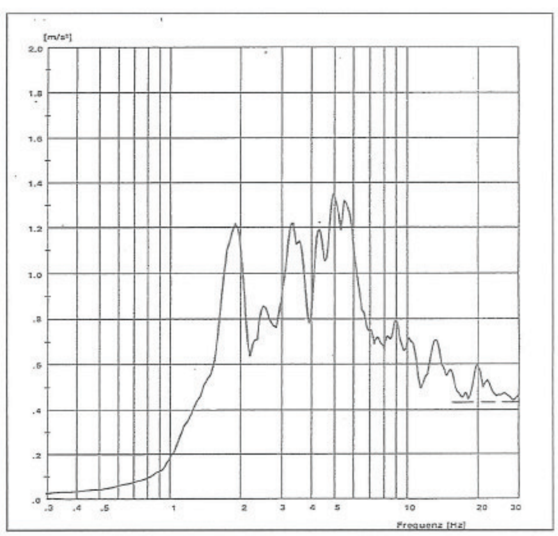
On the thirteenth of April 1992 the strongest earthquake since 1756 occurred in the Lower Rhine embayment. For the periphery with a circle of 10 km to 20 km around the epicentre the intensity is VII.

The seen effects of the earthquake are similar to the Albstadt-earthquake. It is to be noticed that in a distance of 150 km the nuclear power plant Mülheim-Kärlich is located. Here were the accelerations measured. The time history correlation is shown in figure below



Zeitverlauf

figure 4 - nuclear power plant Mülheim Kärlich, acceleration time histories - free field -



Antwortspektrum D = 0,04

figure 5 - nuclear power plant Mülheim Kärlich, response spectra -free field -

At the nuclear power plant no damages were found.

For the observed earthquake in Germany it can be summed up, that for these earthquakes with low intensities no damages were found at earthquake resistant buildings and the components inside these buildings.

INTERNATIONAL EXPERIENCES REGARDING ORIGINALLY NON-SEISMIC DESIGNED PIPING SYSTEMS UNDER SEISMIC ACTION

Experiences earned until now have shown the fact that the piping systems of industrial power plants which were not even designed for earthquake load case can resist the vibrations caused by earthquake via supporting structures (Ref. /1/ and /2/). Additionally, a partial failure of a piping system does not necessarily cause a total break-down of the whole piping system. Induced mass forces can be carried by piping systems with the help of their high ductility. Very few observed examples of damages can be traced back to restraints of the differential translations due to "not flexible enough" design of piping systems. In Ref. /2/, it has been postulated that the piping systems can resist earthquake loads with free field acceleration of 0,5pga. At locations of all four investigated NPPs, free field acceleration value is lower than 0,5gpa which means that even without an earthquake based design the piping system is not vulnerable due to the existing international experience.

Furthermore, in some other EKK owned NPPs, there has been upgrade projects performed regarding new seismic design of an existing piping system which was originally non-seismic designed. It has been observed that pipes are mainly not the critical parts of such an upgrade project and that they are mostly unaffected of new earthquake loads as long as they have originally been designed properly for other load cases with a reasonable stiffness at support systems.

COMPARISON OF ORIGINALLY NON-SEISMIC DESIGNED SYSTEM AREAS WITH THE ORIGINALLY SEISMIC DESIGNED SYSTEM AREAS OF THE SAME NUCLEAR POWER PLANT

During the walk-down and after consideration of the photographical documentation, careful attention has been given to the comparison of the piping systems which do have an earthquake load design and venting system which does not have. Mainly H_2-Degradation system and venting system have been compared. This gives an engineer a pragmatical perspective in his/her judgment. Following have been compared:

- Types of supports and stiffeners
- Span between two supports
- Amount of bends in the piping
- Supports and assembly of the components
- Translational displacement of spring hangers
- Distance between the pipes and to other components

This comparison has shown no significant differences between these two different piping systems in all four NPPs.

COMPARISON OF THE STRUCTURE WITH THE APPLICATION GUIDELINES “PAR”

In Germany, plant manufacturer KWU (Kraftwerk Union) has created a specification called “PAR-Planungs- und Abnahmerichtlinie” (Ref. /3/) which can be translated as “Planing and acceptance/approval guideline”. This specification gives information about design of piping systems $50 < DN \leq 400$ for normal operation and earthquake load cases (besides other externally initiated load cases).

In this specification, there are tables for the piping design engineer regarding the minimum distances between supports and support types under consideration of piping dimensions (see table 3). Besides these values, PAR gives the limiting loads for supports depending on the load case, as well.

Richtstützweiten (über Führungslager bzw. Festpunkte zu realisieren)			horizontale Stützweite [m]	vertikale Stützweite [m]	axiale Stützweite [m]	horizontale Stützweite [m]	vertikale Stützweite [m]	axiale Stützweite [m]	Richtwerte konvetioneller Anlagenbau [m] 1) L_{max} -ohne EVA-			
-			Richtwerte			Istwerte			nicht isoliert		isoliert, T≤ 300 °C	
Nennweite	Abmessungen	Systembereich	$L_h = L_{max}$	$L_v \leq 3 \cdot L_h$	$L_a \leq 3 \cdot L_h$	L_h	$L_v \leq L_h/3$	$L_a = L_h$	"Wasser / Öl"	"Gas / Dampf"	"Wasser / Öl"	"Gas / Dampf"
DN80	88.9 x 3.2	Abschnitt 1 / 2	3.5	10.4	10.4	≈ 2.0	- entfällt -	nicht beachtet	5.1	6.8	3.5	3.6
DN200	219.1 x 8.0		6.0	18.1	18.1	≈ 5.5	- entfällt -	nicht beachtet	7.5	10.9	6.1	7.4
DN250	273.0 x 8.8	Abschnitt 3	6.7	20.1	20.1	- entfällt -	≈ 12	≈ 24	8	12.1	6.6	8.4

table 3 – example from PAR

Regarding the support loads, engineers have considered the already calculated normal operation loads from the existing piping calculation and checked the given limiting loads by PAR. By this way, there was a possibility to understand how much earthquake load margin was available at the supports.

In our study, this guideline has helped our conclusions extensively. Most parts of the venting system complied with the values the given by PAR. For the cases where between two supports the distance was relatively big, hand calculations and engineering judgments have been performed.

JUDGMENTS BASED ON THE EXISTING DESIGN CALCULATION FOR OPERATING LOADS

Due to the fact that the venting system was designed only for operating loads and not for earthquake loads, existing piping calculation has delivered a well-defined basis for the engineering judgment.

Calculated load cases were “dead-weight” and “thermal expansion”. It was possible to understand the stress level in those load cases for pipes, supports and components. Engineers were able to calculate and estimate the overall earthquake loads at relevant locations based on the load reports. On the basis of the operational loads and the estimated earthquake loads an “educated guess” was performed, whether the system can fulfill the stress limits for piping and supports.
In some cases, some of the input files of the calculation could be reactivated. This also showed the importance of good archive and documentation processing for reports which are partially more than 25 years old.

Summary

Germany is characterized by low seismicity. Particularly for the E.ON Kernkraft GmbH (EKK)-operated nuclear power plants, the design intensity for the sites is below the intensity of I ≤ 6.5. Because of this low intensity the robustness of the system of the filtered venting was assessed by engineering practice. This means the assessment included a combination of assessment criteria for verification by plausibility considerations:

- The inspection walk downs showed only a few facts which required further analyses.
  All further analyses confirmed the robustness of the system.
- The observations of German earthquakes (comparable intensity) do not expect for the investigated power plants damages which impact negatively the venting system.
- The effects of earthquakes with an intensity of lower 7 (EMS 98) do not expect for the investigated power plants damages which impact negatively the venting system.
- International experiences regarding originally non-seismic designed piping systems under seismic action confirm the robustness of piping systems.
- Comparisons of originally non-seismic designed system-areas with the originally seismic-designed system-areas of the same nuclear power plant show similarities for the construction and support concept.
- Comparisons of the piping structure with the application guidelines PAR show as far as possible accordance in a wide range.
- Reviewing the design calculations of the systems for operating loads (positively reviewed by the authorities) show sufficient margins.

By considering all the above listed criteria it can be assumed, that the piping and components of the filtered venting system in EKK owned NPPs, resist the design earthquake and are still integer after the earthquake.

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