2019 SECED Conference
Earthquake risk and engineering towards a resilient world
9-10 September 2019, Greenwich, London

INCREASE OF SEISMIC RESISTANCE BY OPTIMIZATION OF THE SUPPORT CONCEPT

Stefan Riedelmeier[1], Holger Senechal[2], Dieter Kollmann[3] & Michael Heyder[4]

Abstract: *Due to the Fukushima earthquake event in 2011, stress tests for all nuclear power plants were and are still carried out. The result of these tests showed, that a lot of nuclear power plants have to reassess safety-relevant buildings, components and piping systems with respect to earthquake. The first step represents the calculation of new floor response spectra with increased ground acceleration. The seismic proof of the buildings is mostly successful, but the new spectra lead to inadmissible loads on pipe supports and connections to components. For most supports a simple reinforcement, using anchors with a larger diameter, is not possible. The 20 to 30 years old support and anchor concepts do not meet the current codes or the state of the art. Therefor in most cases changes in the hardware, such as anchors and supports were installed. It has to be noticed that the old support concepts were much too rigid due to too many supports. In the progress of analyzing a lot of piping systems, the authors established that computational optimized support concepts require 60 to 70 percent less supports than the original design. Furthermore, the resulting loads on the supports and the building decreases. The new support constructions are lighter and simpler. All in all, the effort and costs are reduced. The success of the optimization concept will be demonstrated using real safety-relevant piping systems of nuclear power plants.*

1. Soil-Structure Interaction

The classical approach of doing seismic analyses of piping systems is a coupled calculation of a soil model and a model of the building structure (see Figure 1 and Figure 2)..

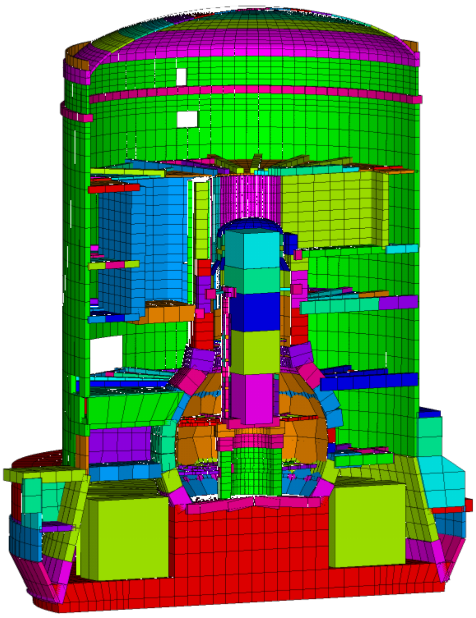

Figure 1: Model of a reactor building

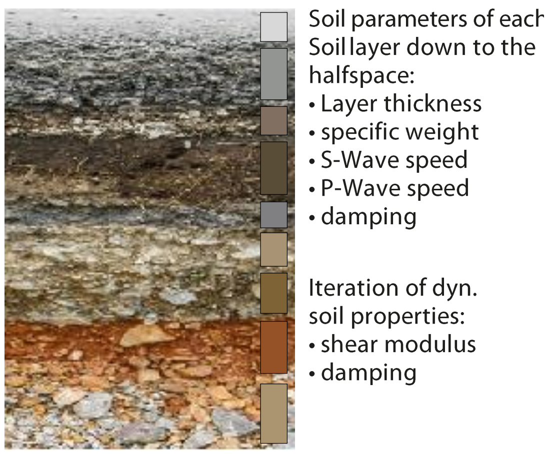

Figure 2: Modelling of soil layers

For this, covering characteristic acceleration time histories are initiated into the soil which propagate in the soil via compression and shear waves to stimulate the eigenmodes of the

---

[1] Dr.-Ing., KAE GmbH, Hausen, Germany, riedelmeier@kae-gmbh.de
[2] Dipl.-Ing. (FH), KAE GmbH, Hausen, Germany
[3] Dipl.-Ing., KAE GmbH, Hausen, Germany
[4] Prof. Dr.-Ing., TH Nürnberg Georg-Simon-Ohm, Nürnberg, Germany

structure through interaction between the building and the soil. This leads to acceleration time histories on floors and walls of the building on which components or piping systems are fixed by supports. Out of the acceleration time histories response spectra are determined which are basis of a separate modal piping calculation. This calculation provides then stresses in the pipes, cutting loads of components (like pumps, vessels, valves etc.) and mounting loads which have to be approved on the basis of a technical standards.

Another approach of doing seismic analyses of piping systems is to model the building structure in a more detailed way and include the main safety-related piping systems such as the primary coolant lines of a pressurised-water reactor. Doing the soil-structure interaction calculation with this method leads directly to the stresses in the piping, the cutting loads und the support loads. However, this method is very time-consuming, therefore it is used only for very sensitive piping regions.

Seismic reassessment of nuclear power plants with new increased seismic hazard assumptions has shown that the building structure can usually be approved, whereas the piping systems in particular the supports are making problems. Therefore, in most cases it is necessary to do a partial reconstruction including changes in the support concept and building new pipe supports.

Seismic reassessment of many piping systems has shown, that the former support concepts are much too rigid and optimized support concepts get by with only 60 to 70% of the original number of supports. With this knowledge it is possible to achieve a positive proof of the piping system according to the state of the art within the seismic reassessment in combination with omitting of supports and spotted new construction or renovation of individual supports. For this, a special know how regarding optimization of support concepts is absolutely necessary.

2. Optimization of pipe support concepts

All piping systems need supports to protect the piping from loads resulting from dead weight or dynamical excitation (like pressure waves, earthquake or airplane crash). Thereby the supports must not hinder the thermal expansion, so that besides dead weight or internal pressure no additional loads for the piping itself but mainly for the piping components are caused. Based on the task the supports can be classified into three types:

- Supports with motion depending function. That means the thermal motion of the piping is balanced and allowed respectively (e.g. spring hanger, constant hanger, snubber)
- Rigid supports which secures the position of the piping (e.g. rigid struts, connecting rods, fixed points)
- Supports which allow a defined way of the piping. That means in the installed condition a play between piping and support is considered. Thus, it is possible for the piping to expand well-defined by temperature or to allow a defined oscillation range for the piping by dynamic excitation (e.g. pipe-whip restraints)

The position of a support is just as important as the selection of its function. Thereby the piping components deserve special attention because they react more sensitive to loads than the piping itself. Depending on whether a piping component is located at the edge or in the middle of the piping system we distinguish between:

- Connecting components like valves, pumps, strainers, tees and collectors
- Edge components that either form the end of the piping or which can be regarded as fixed point because of their size and mass. This includes e.g. turbines, pumps, vessels and pools.

Connecting components such as valves and pumps often represent a mass concentration which strongly influences the defelction of the piping in the load case dead weight or which tend to oscillate under dynamic excitation. The edge components are often sensitive elements which must be protected from external mechanical loads of the piping.

Each support concept must take these requirements into account in order to ultimately ensure safe and trouble-free operation of the system. At safety relevant piping systems, the safe operation after an accident (e.g. earthquake) is additionally required. Irrespective of this, an optimal support concept must fulfil the following additional requirements:

- As few supports as necessary
- Prevention of load peaks
- As few supports with motion dependent function as possible

Such support concepts can only be created through the use of specific computer programs. The piping programs available today make it possible in principle to obtain an optimum support concept by varying all conceivable possibilities. But, since the number of arbitrary parameters is very huge a complete combination of these parameters leads to an infinite number of iteration steps. In order to keep these iteration steps to a minimum, KAE has developed an algorithm with which it is possible to accurately determine the optimum support concept for any piping system. The following boundary conditions are considered:

- Arbitrarily load case combinations
- Compliance with provided technical regulations
- Structural conditions, immovable positions of supports

For existing piping systems which must be revaluated due to load case changes or geometrical changes we use this algorithm to get the support concept with the least effort of reconstruction.

3. Philosophy of the optimization

Optimizing the support concept of the considered system, the static und dynamic load cases should be linked with each other to better use the multifunctionality of rigid supports in contrast to earlier approaches. So, spring hangers, which are only relevant for the load case dead weight and snubbers which are activated only in dynamic load cases are waived as far as possible. These two support types are mechanical supports which must be periodically tested and maintained with high costs. It is therefore in the general interest of all power plant operators to do without these support types as far as possible. Instead of soft mechanical supports the optimized support concept shall consist of almost only rigid supports consisting of standard parts as rigid struts, pipe clamps and weld-on brackets.

To optimally use the multifunctionality of rigid supports, each support must be placed at the correct position to adsorb the load of dead weight effectively to prevent the pipe from swinging up due to dynamic excitation (pressure waves, earthquake) and not to hinder its thermal expansion at the same time. Furthermore, attention must be payed in getting a uniform utilisation of allowable loads for all parts (component connectors, pipes and supports) by distribution of the supports over the entire system. This limits the number of supports required.

In the cases where a pressure wave load case must be considered, this often also determines the dimensioning of the support concept. The first graph (Figure 3) shows a typical pressure wave-time-history and the graph below (Figure 4) shows the corresponding frequency dependent dynamic load factor (DLF). These DLF indicates the ratio between the maximum amplitude of the response function and the maximal amplitude of the excitation function of a single degree of freedom system (SDOF) with 4% critical damping for any frequency. From this it can be seen that the characteristics of the fluid dynamic excitation functions are such that the lower its natural frequency, the smaller the maximum dynamic response of the vibrating pipe system is. It follows that the lowest support loads due to pressure waves can be achieved by a low-frequency soft support concept with the fewest possible number of supports.

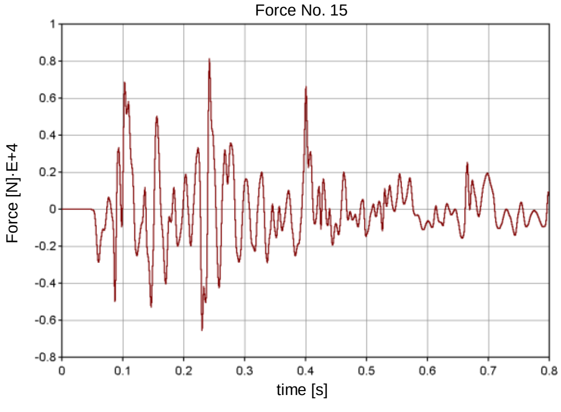

Figure 3: typical water hammer time history

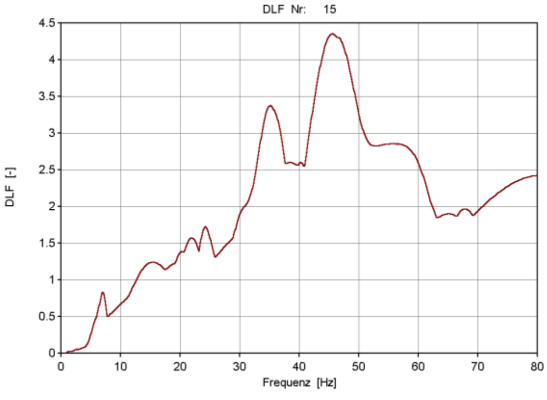

Figure 4: typical DLF (dynamic load factor)

Taking into account the fluid-structure interaction, which is always present in reality, a soft and flexible support concept has additional positive effects on the support loads.

In load cases (earthquake, airplan crash etc.) initiated by building vibration where the loads are transferred from the building to the piping system via the supports, a soft support concept has also only advantages:

1. The less supports exist the lesser is the load which is transferred from the building via the remaining supports in the piping system.
2. In a soft piping system loads resulting from building vibrations are first converted into kinetic energy (vibration energy) of the piping. Due to the damping and friction mechanisms in each piping system the vibration energy is reduced, so that the piping supports must only partly bear this energy.

However, a soft support concept leads to greater oscillation amplitudes in the piping with increasing stresses in fittings such as bends, tees etc. This results in an optimal number of supports which, while still representing a soft support concept, at the same time ensures the compliance with the allowable stresses in the piping and the component connections.

4. Examples from practical experience

The first example shows, how much supports can be saved when using a consistent optimization compared to the original concept (see Figure 5 and Figure 6).

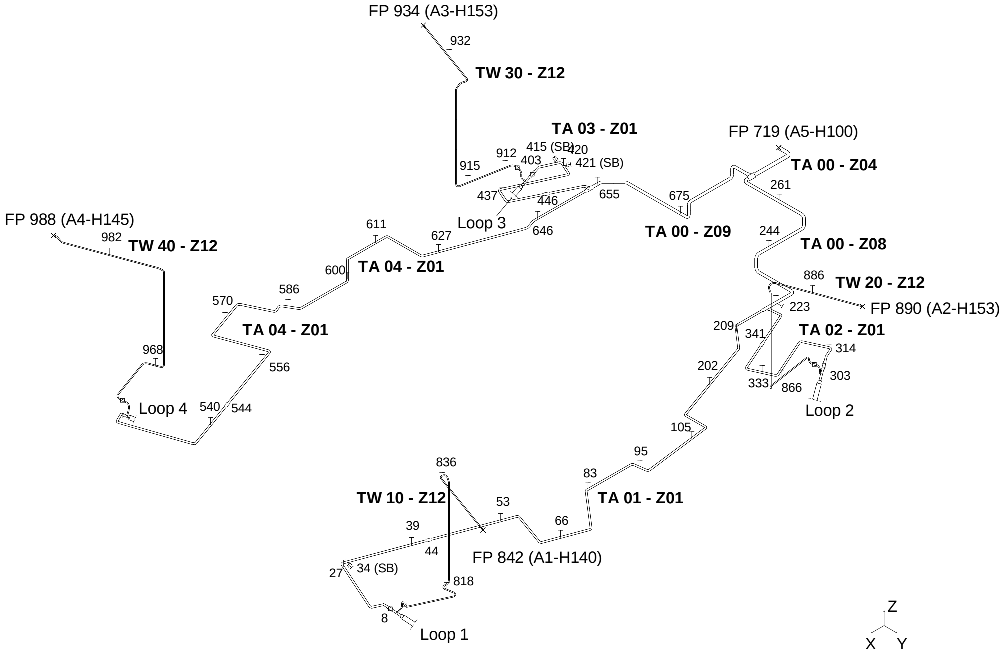

Figure 5: Example 1 - TA System of a PWR

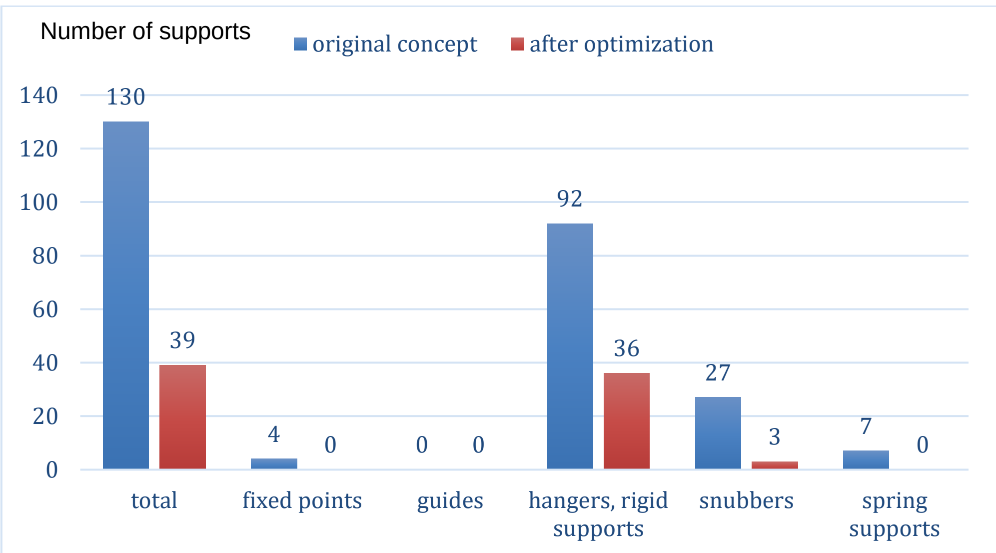

Figure 6: savings of support for Example 1

Considering examples 2 to 4, the aim was not a classical optimization of the support concept, but, in the context of a reassessment of the piping systems, the determination of the minimal effort for redevelopment. In the first step, the load-bearing capacity of the supports was evaluated in order to indentify the most stable support constructions. On the basis of this evaluation, the optimal support concept is created (see Figure 7 to Figure 10).

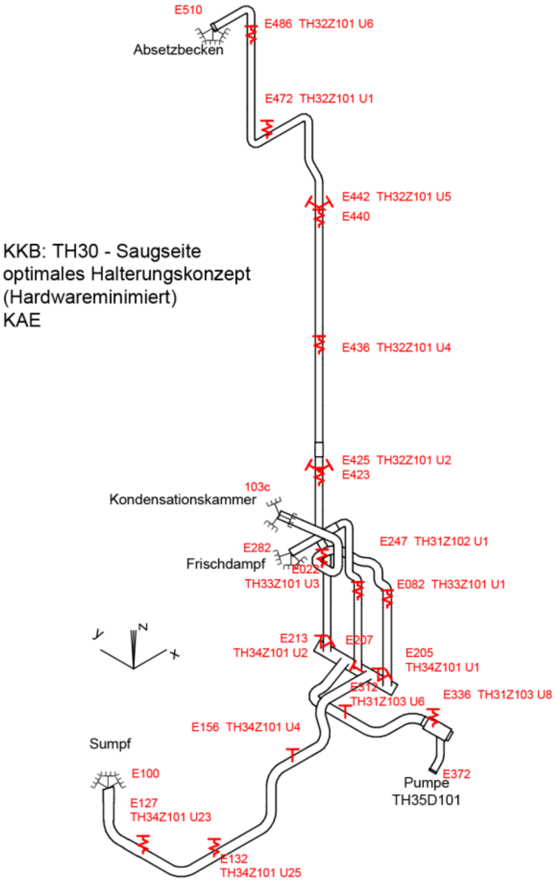

Figure 7: Example 2 - TH System of a BWR

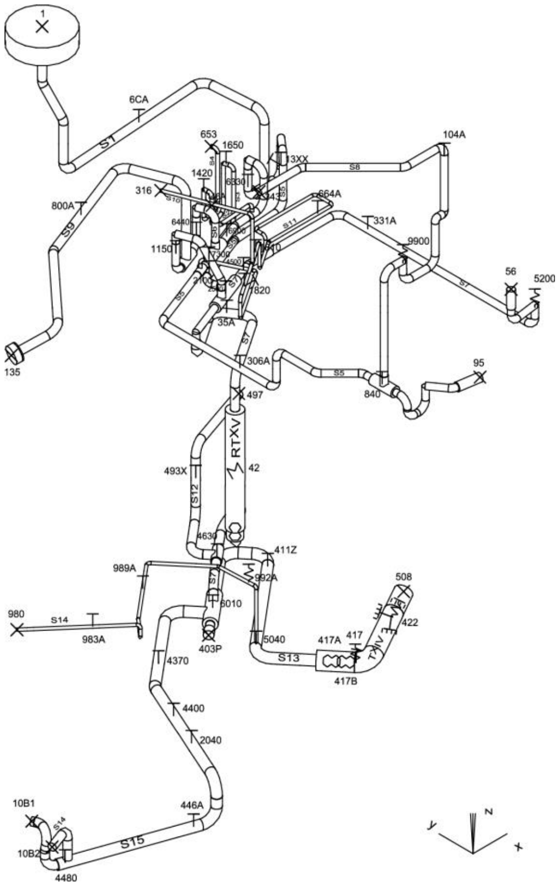

Figure 9: Example 3 - TH System of a PWR

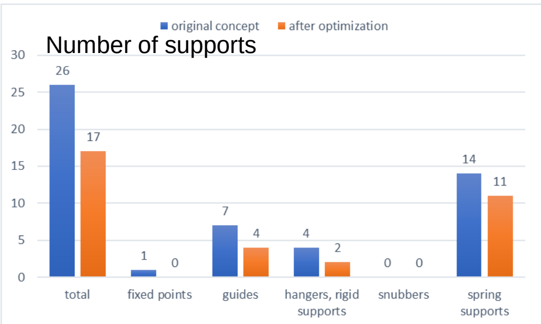

Figure 8: savings of supports for Example 2

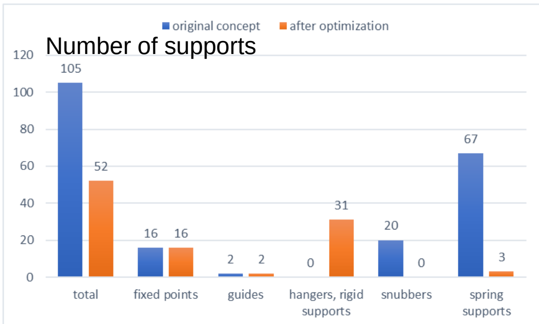

Figure 10: savings of supports for Example 3

5. Conclusion

The main idea behind the performed optimization of support concepts is a reduction of the number of supports in order to make the system less stiff for load cases as thermal expansion or dynamic oscillations and the usage of multifunctional rigid supports positioned at the right place.

This procedure is not strictly limited to any nominal diameter of the pipe or nuclear facilities. Decisive for the realization of an optimized support concept is primarily the existence of static and dynamic loads, as also present in conventional power plants, supply facilities or facilities (e.g. pump start or stutdown, valve closure or opening).

In the case of example 1, the optimization of the support concept of the TA-feedwater line led to a reduction of the number of supports of circa 70 per cent. The springs and the fixed points were deleted and the number of snubbers decreased from 27 to 3. Considering the rest of the supports inside the piping system, the loads were reduced. At the fixed points of the system boundaries, the loads partly increased slightly. But due to the flexible support concept, the total integral load decreased about 25 per cent, which relieves the building structure. The optimization of the support concept caused a severe reduction of the pipe stresses for load case *operation* and no inadmissible stresses for the incident load cases.

The other examples show a similar trend, although the aim was not a classical optimization of the support concept, but a minimization of the effort for redevelopment of the piping system. This was realized successfully, because reducing the effort for redevelopment not only means saving money and time, but also a reduced radiation load for the staff considering piping systems in the reactor building.

6. References

Wylie B and Streeter V (1978), Fluid Transients, MacGraw-Hill New York, USA

Lahey Jr. RT and Moody FJ (1977), The Thermal Hydraulics of a Boiling Water Nuclear Reactor, ANS Publications

ASME Boiler Pressure vessel code, Section III, Subsection NC, Class 2, New York, USA

Pestel E and Leckie F (1963), Matrix Methods in Elastomechanics, McGraw-Hill, New York, USA

Bathe KJ (1982), Finite Element Procedures in Engineering Analysis, PHI London, United Kindom

KAE GmbH (2009), DRAKO® programme v3.25, Pressure Wave Calculation in Pipe Systems with General Components, User manual, Hausen, Germany

Sigma Ingenieurgesellschaft mbH (2017), ROHR2 programme v32.1, programme system for static and dynamic analysis of complex piping and skeletal structures, Dortmund, Germany