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Piping system subjected to seismic hard rock high frequencies

Cecilia Rydell[a,b,*,1], Richard Malm[a], Anders Ansell[a]

[a] KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
[b] Vattenfall AB, SE-169 92 Stockholm, Sweden

HIGHLIGHTS

- A study of the influence of support gaps in the analysis of a piping system.
- Piping system located within a nuclear power plant reactor containment building.
- Piping system subjected to a seismic hard rock high-frequency load.
- Comparison of low- and high-frequency seismic loads.
- The influence on the stress response of piping and acceleration response of valves.

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ABSTRACT

This paper addresses the influence of support gaps in the analyses of a piping system when subjected to a seismic hard rock high-frequency load. The system is located within the reactor containment building of a nuclear power plant and is assessed to be susceptible to high-frequency loads. The stress response of the pipe and the acceleration response of the valves are evaluated for different support gap sizes. It is shown that the inclusion of the support gaps in the analyses reduces the stress response for almost all pipe elements. On the other hand, the acceleration response of the valves is not necessarily reduced by the consideration of the gaps.

1. Introduction

Piping systems of nuclear power plants have to be designed to withstand earthquake induced loads. Generally, linear elastic modal response spectra analysis is used and inherent small gaps in pipe supports are neglected. The inherent gaps might be gaps in pin connections or gaps between the support and the pipe. The question of what effect the gaps have on the piping response was actualized with the release of the new seismic source characterization model for Central and Eastern United States (CEUS) for nuclear facilities (EPRI, 2012). For CEUS hard rock sites, the new seismic source characterization model, together with the ground motion predictive equations (EPRI, 2004, 2006), results in ground motion response spectra showing high amplification in the high frequency range, compared to spectral shapes traditionally used.

The influence of high-frequency content loads on piping response have been studied by for example Vayda (1981), Lockau et al. (1984), Steinwender et al. (1984) and Youtsos (1989a,b). Vayda (1981) has studied the effect of snubber gaps on piping system response when subjected to sinusoidal support motions with varied frequency and amplitude. In the study it was concluded that; (1) for high-frequency dynamic events (forcing frequency higher than eigenfrequency of system with closed gaps), a small non-zero gap size gives the lowest pipe stresses and lowest snubber forces and (2) for low-frequency dynamic events (forcing frequency lower than eigenfrequency of system with open gaps), any non-zero gap size yields higher stresses than zero gap size. Lockau et al. (1984) have performed several full-scale experiments on piping systems and supports subjected to short duration high-frequency events. In none of the tests could failure of pipes or supports be observed. It was concluded that short duration high-frequency events, e.g. pipe break or air plane crash, does not have sufficient energy to

* Corresponding author at: KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden. Tel.: +46 730 512850.
E-mail addresses: cecilia.rydell@byv.kth.se, cecilia.rydell@vattenfall.com (C. Rydell).
[1] Part of the work was conducted while the first author was visiting Westinghouse Electric Company, 1000 Westinghouse Drive, Cranberry Twp., PA 16066, USA.

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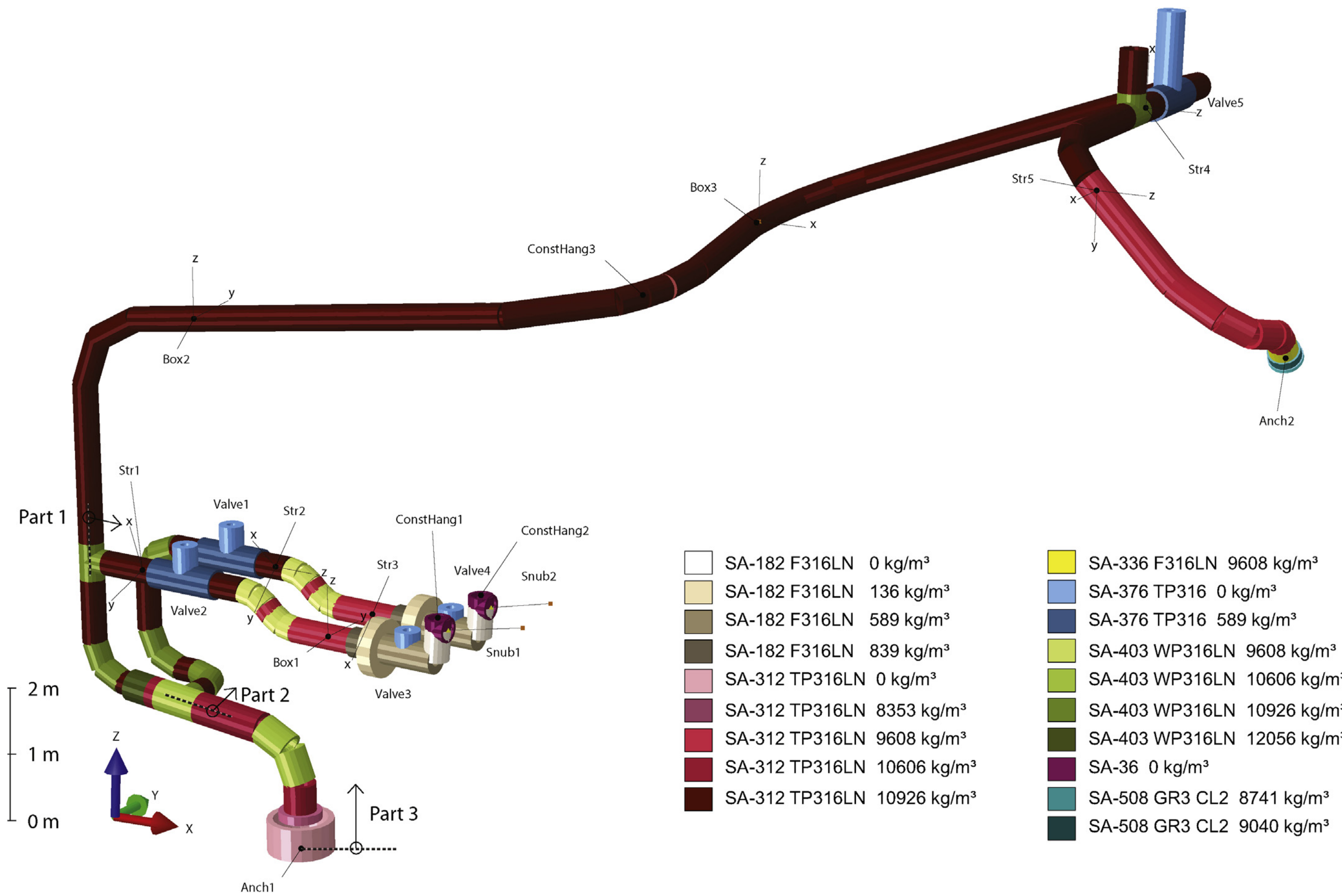

Fig. 1. Piping system computational model. The supports are labeled as follows: box supports Box1, -2, -3, strut supports Str1–Str5, anchor supports Anch1, -2, constant hanger supports ConstHang1, -2, -3 and snubbers Snub1, -2. The color coding indicates material and weight properties.

damage the structures. Nonlinearities such as gaps, friction and local plastic deformation were thought to be the reason for this. Steinwender et al. (1984) have studied the load transfer behavior of piping supports under short duration high-frequency excitation by performing shake table tests. The test set-up consisted of a straight pipe and two supports. Gaps in the supports and frictional contact forces at the bearing surfaces of the supports constituted the geometric nonlinearities in the system. When plastic deformation of the supports occurred, still no local effects were observed on the pipes and clamps. Youtsos (1989a) has investigated the impact of supporting structural steel flexibility and snubber gaps on piping response when subjected to combined high and low frequency content loads (earthquake, safety relief valve and vent chugging loads) in one and three directions, respectively. Different models of a piping system representative of a nuclear power plant were analyzed. The responses from nonlinear models, with varied snubber gap size and stiffness and with supporting flexible steel structure included, were compared to the response from a conventional linear model (rigidly supported and without snubber gaps, analyzed using the response spectrum method). It was shown that for three dimensional seismic loading (considered a low-frequency content load), the maximum piping stress is smaller for models including snubber gaps, compared to the linear model, as long as the gaps remain within a certain size. Apart from being dependent on gap size the response was highly dependent on the snubber stiffness. It was also concluded that as long as the gap size is kept within a certain size, the response spectrum analysis procedure where snubber gaps and supporting structural steel flexibility are neglected, is adequate in assessing the maximum piping stress and restraint load under combined high and low frequency content loads. Youtsos (1989b) also studied the response of piping systems subjected to high-frequency content loads in order to establish a cut-off frequency rule. The influence of supporting structural steel flexibility and snubber gaps was investigated. It was shown that the high-frequency content response is small as long as the gaps of the snubbers are accounted for. The above studies mainly deal with loads of short duration and with high-frequency content much higher than could be expected from an earthquake and the results might not be representative for high-frequency seismic loads. Empirical studies showing that high frequency, high amplitude and low energy seismic events are non-damaging to nuclear power plant structures and equipment although exceedances in the greater than 10 Hz region compared to the design spectra, are presented by Chen et al. (1988), Bernero et al. (1988) and Whorton (1988).

In the present paper, the influence of support gaps on the response of a piping system when subjected to a seismic high-frequency load is investigated through the study of a representative piping configuration located inside the containment building of the AP1000[2] nuclear power plant. The piping system is potentially susceptible to high-frequency content excitation, having modes and natural frequencies in the high frequency range and being located

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