Evaluation of Damping Values of on In-Situ Piping System at and above SSE Load Levels

D. SCHRAMMEL
Kernforschungszentrum Karlsruhe, Karlsruhe, FRG
H. STEINHILBER
Fraunhofer-Institut für Betriebsfestigkeit, Darmstadt, FRG

ABSTRACT

An in-situ piping system was subjected to seismic-like loads during the SHAM test series at the HDR test facility in Kahl, FRG. Tests were run using random excitation to identify natural frequencies, mode shapes and damping values for different support configurations with MDOF system identification methods. For one support configuration, tests with earthquake-like excitation were evaluated by fitted parameter calculations for different load levels. Both sets of evaluations cover the spectrum of support configurations used in practice, and trace the effects of load increase.

1 INTRODUCTION

The damping values for pipes used in current design practice in Germany are thought to be on the conservative side. They allow higher damping values to be used for pipes of larger diameters (> 300 mm) than for those of smaller diameters (2% as compared to 1%) for the operating basis earthquake and again 1% higher damping values in the safe shutdown earthquake load case. These values have repeatedly been the subject of discussions because, much higher damping values have been observed in many vibration studies of piping systems. However, most of these experimental findings vary considerably, and in nearly all cases strongly damped vibrations as well as weakly damped vibrations were observed in the same piping system [1]. This explains why attempts are being made to extract, from the existing extensive data base, by means of averaging and regression analyses, values and findings which have a sounder statistical basis [e.g. 2].

In the new KTA 2201.4 draft regulatory code [3] a standard level of 4% damping is assumed for pipes of any diameter (the distinction between OBE and SSE is eliminated in favor of the design basis earthquake concept). The reason given is, that conservative damping assumptions in the earthquake load case result in a stiff systems design which, in turn, will entail disadvantages in normal operation. It is also known from observations and analyses of plants affected by earthquakes that so far flexible pipe systems have never been damaged by seismic vibrations. Finally the SHAM tests conducted on the HDR [4] provided an impressive demonstration that a flexible pipe system was able to sustain eight times the design basis load without being damaged. This experience lead to the conclusion that the introduction of a mean value concept for damping in the earthquake load case will not impair the overall safety of a pipe system.

Against the background of this ongoing discussion it seemed important, when evaluating the SHAM tests, to pay particular attention to the assessment of damping values. For this reason, the SHAM tests differ from previous vibration studies of pipes in several respects:

Excitation was similar to that produced by an earthquake. Loads were increased stepwise far beyond the yield point. The pipe was investigated with different number of restraints and is sufficiently prototypical (branchings, vessel connections, diameters).

In addition, the employed methods of evaluation which included parameter identification with simultaneous curve fitting over all natural frequencies and measuring points, as well as parameter variation calculation with individual fitting of modal damping values at various load levels, by far exceed the standard and are quite capable of providing reliable information.

2 TESTS PERFORMED

The test object of the SHAM tests was the VKL piping system (Fig.1), a multibranched piping system with nominal pipe diameters between 100 and 300 mm, which could be excited simultaneously at two points by means of servohydraulic actuators. This piping system was restrained in various ways resulting in six different support configurations. Fig. 2 shows an overview of all support configurations with the location and type of dynamic support clearly indicated. Three configurations tested were part of this damping investigation. In the HDR configuration (1) two rigid struts limited the transverse movement for the excitation systems. The flexible KWU configuration (2) contained three additional rigid struts. A bounding case of a stiff restraint concept was the NRC configuration (3) in which four additional rigid struts and six snubbers (mechanically acting shock absorbers) were used.

For these three configurations the random tests performed were evaluated by a system identification program. For the flexible configuration (2), the earthquake tests performed were evaluated by fitted parameter calculations for the four loading levels between 100% and 400% SSE.

These sets of evaluations cover the range of configuration used in practice and trace the effects of increasing load.

3 RANDOM TESTS, EXPERIMENTAL MODAL ANALYSIS

The random displacement signal used in these tests had a duration of 120 seconds. The signal consists of broadband noise linearly decreasing in intensity over the 2-40 Hz frequency range. Two tests were run with random excitation for all configurations, in each of which one actuator was immobilized.

The database was comprised of 30 acceleration measurement points. From their transfer functions (50 averages; Fourier length 4096 points; Hanning window) impulse responses were calculated by an inverse Fourier transform. The impulse response, weighted by an exponential window, was discretized, by means of a complex exponential technique in the time domain, into a number of independent free vibration processes, which directly contain the required systems parameters. From the natural frequencies and dampings identified in this way, a fixed set of modal parameters was assembled for best fit to all transfer functions of both tests with different excitation locations. In this manner it became possible, despite occasionally bad coherence due to non-linearities inherent in the system, to identify reliable modal parameters [5].

For all measurement points and both tests of each configuration, the agreement between the transfer functions and their counterparts reconstructed from the identified modal parameters is good.

Fig. 3 shows the evaluated damping values as a function of frequency. The mean values of damping in the frequency range up to approx. 10 Hz of 3.28%, 3.92%, and 4.14% for the three configurations are in line with expectations based on experience from earlier pipe studies, as is the occurrence of individual very strongly or very weakly damped modes.

Plotting the mean values of damping for the three configurations studied versus the number of dynamically effective restraints as shown in Fig. 4, indicates an apparently unequivocal trend towards stronger damping with increasing numbers of restraints. However, because of the large variance in individual findings, this statement would not pass a statistical significance test. Instead, it must be remembered that the mean values of damping differ very little for the stiff system (3) and the flexible system (2), and that for random excitation both values of approx. 4% correspond to the level proposed in the draft KTA code [3].

4 EARTHQUAKE TESTS, PARAMETER CALCULATIONS

The generated time history used in the earthquake tests had a duration of 15 s and a peak acceleration of 6 m/s^2 (=100%-SSE). The increases in load were achieved by linear amplification. Because the duration of excitation is relatively short and the system was excited simultaneously at two points it is not possible to determine damping values by a direct system identification process. Therefore, parameter calculations using a modal superposition time history analysis method were performed [6]. In this way, it was possible to use different damping values for different eigenmodes. In a first step, small damping was chosen for all eigenmodes. The damping values were changed until optimum agreement was achieved in the acceleration response spectra obtained from measurements and calculations, respectively. In addition, some natural frequencies had to be matched to those of the measurements for the different loading levels.

As a rule, the response spectra for each individual eigenmode could not be perfectly fitted at all measurement points. Consequently, fitting was performed in such a way that the measurement points with high accelerations in the considered vibration mode were given more weight.

Fig. 5 shows the damping values determined in this manner for the various loading levels plotted versus frequency. The connected points represent damping values changing with the loading levels.

Evaluation by parameter variation calculations allows the stress in the piping to be determined for each individual vibration mode and to be compared with the associated modal damping value. The large variance of modal damping values is found in the region of low modal stresses. In particular, all damping values identified at 1% or less can be assigned to vibration modes which generated stresses of not more than 25 MPa.

The results of the evaluation of the relationship between modal damping and maximum modal stress are shown in Fig. 6 for six modes. The permissible stresses (dynamic part) in this austenitic material would be approx. 300 MPa for level C and approx. 400 MPa for level D allowables. This figure does not exactly show the expected result. While five modes show an increase in damping when the load is raised from 300 to 400% SSE, damping does not yet increase for mode 2, despite a maximum modal stress in excess of 500 MPa and well above yield in 4 other regions of the pipe.

The average damping of the six relevant modes decreases (from 3.2 to 3%) as the load increases from 100 to 200%, remains unchanged as the load increases from 200 to 300%, and grows more strongly (to 3.7%) as the load is raised to 400%. This behavior is well known from many experimental investigations [1]; it is due to the fact that damping caused by mechanisms in which the damping force is independent of the vibration amplitude (such as friction forces) decreases proportional to the increase in amplitude, while the effect of other damping mechanisms (such as material damping) comes into play only at larger amplitudes. The fact that this effect began to be felt, in the experiments with earthquake-like excitation only under loads at which the stress limits of level D were exceeded at multiple locations is an unexpected finding.

Fig. 6 also shows the damping values as given by regulatory codes, together with the applicable stress limits in the respective ranges of applicability. The damping values used to date in accordance with KTA Rule 2201.4 are seen to be conservative lower bound estimates of damping for the response related modes in the SHAM experiments. The damping value of 5% in the frequency range up to 10 Hz proposed by the PVRC [7] is clearly higher than the mean damping values determined in the SHAM tests. In a study by Hadjian et al. [2] referred to above, even higher damping values of up to 7.5% (for DN 200) are proposed for introduction into the US licensing procedure. These are based on regression analyses of experimental data. The database of those analyses stems from various experiments in which the maximum stresses exceeded half the yield point in only a few exceptional cases. Consequently, an extrapolation to approximately five times the loading was made from the existing data. The values derived in this way are not confirmed by the SHAM tests.

The uniform value of 4% for all pipes as foreseen in the new German draft code [3] can be considered to be reasonable in the light of the SHAM test results.

5 CONCLUSIONS

Evaluation of the random tests by means of an advanced method of experimental parameter identification did not, on the average, result in major differences between the damping characteristics of the piping in the flexible configuration (2) and in the stiff configuration (3). The mean values of modal damping of the 15 modes identified in the frequency range of up to approx. 10 Hz are 3.92 and 4.15%, respectively, thus confirming the 4% damping value for piping systems given in the new draft regulatory code of KTA 2201.4.

Evaluation by parameter variation calculations of the earthquake tests for the flexible configuration permitted an assessment of the vibration modes of the pipe as to their significance to the response. In particular, vibration modes with modal damping of 1% and less were insignificant with respect to the stress exerted on the pipe.

The basic idea underlaying the concept, in the new draft regulatory code [3], namely to allow more flexible restraint systems to be installed and make better use of the capacity of piping in the rarely expected earthquake event without impairing overall safety, can be confirmed in the light of the SHAM tests results.

6 REFERENCES

[1] H. Steinhilber, K. Michelmann, Ermittlung der Dämpfung für Reaktorgebäude und maschinentechnische Anlagen des HDR, PHDR TFB 32-82, Feb. 1983

[2] A.H. Hadjian, H.T. Tang, Piping System Damping Evaluation, 2nd Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping, Orlando, Florida, Dec. 1988.

[3] KTA 2201.4 (draft), Auslegung von Kernkraftwerken gegen seismische Einwirkungen, Teil 4: Anforderungen an Verfahren zum Nachweis der Erdbebensicherheit für maschinen- und elektrotechnische Anlagenteile, Fassung 6/89.

[4] D. Schrammel, H. Steinhilber, High Level Easthquake Experiments at a Piping System with Different Support Configurations, PHDR TFB 96-90, Sept. 1990.

[5] D. Flade, H. Steinhilber, Experimentelle Modalanalyse der VKL-Rohrleitung mit HDR-, KWU- und NRC-Hängerkonfiguration, LBF- Berichte No. 6656/1, 6656/3, 1989

[6] K. Waldner, Parameterrechnungen zur Bestimmung der Dämpfung der Rohrleitungen des HDR-Versuchskreislaufs in Abhängigkeit von der Anregungshöhe, Sept. 1989, PHDR No. 4.368/89.

[7] Pressure Vessel Research Committee (PVRC), Damping Values-Piping Systems, Technical Position and Justification, 1987.

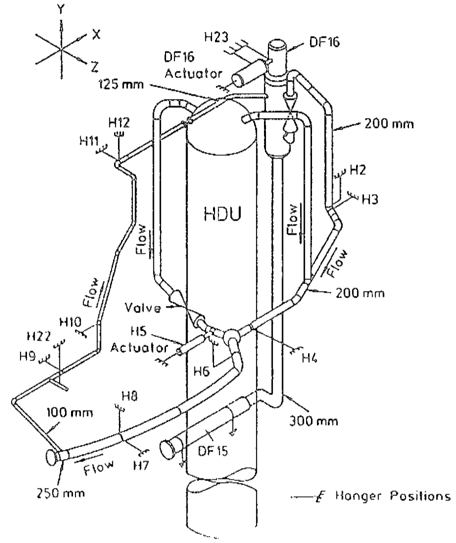

Fig.1: VKL Piping with Positions of Dynamic Supports

Han-ger-No.	Support Configurations 1 HDR	2 KWU	3 NRC	4 EPRI/EA	5 EPRI/SS	6 CEGB
2	—	—	Snubber PSA1	—	Seismic stop	—
3	—	—	Strut Size B			—
4	Strut Size 20					
6	—	—	Snubber PSA1/2	—	Seismic stop	—
7	—	—	Snubber A/D 150	Energy Absorber	Seismic stop	Strut RS-15
8	—	—	Snubber A/D 70	Energy Absorber	Seismic stop	Strut RS-7
9	—	Strut Size B	Strut Size A			Strut RS-7
10	—	Strut Size B	Strut Size A			—
11	—	Strut Size B	Strut Size A			—
12	—	—	Snubber A/D 40	—	Seismic stop	Strut RS-15
22	—	—	Snubber PSA 1/4	Energy Absorber	Seismic stop	—
23	Two Struts 2 x Size 20					

Fig.2: Arrangement of Dynamic Supports to Different Configurations

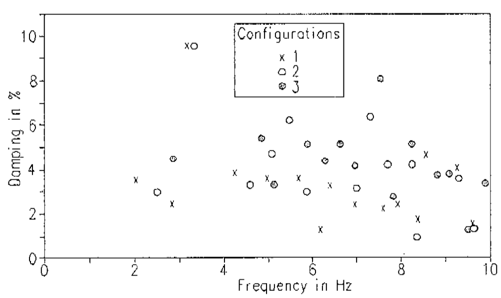

Fig.3: Evaluated Damping Values from Random Tests for Different Configurations

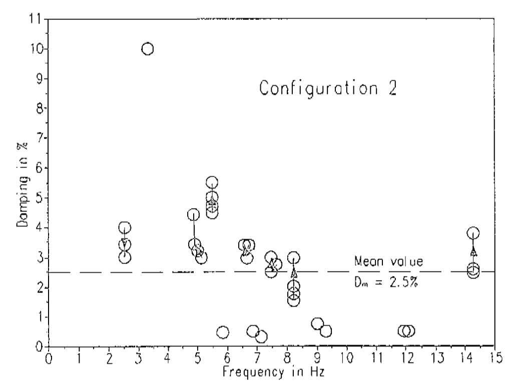

Fig.4: Evaluated Damping Values from Earthquake Tests for Different Load Levels

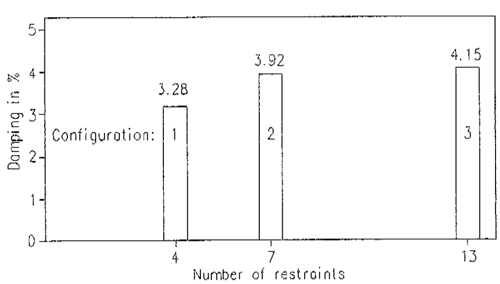

Fig.5: Dependence of Average Damping on the Number of Dynamically Active Restrains

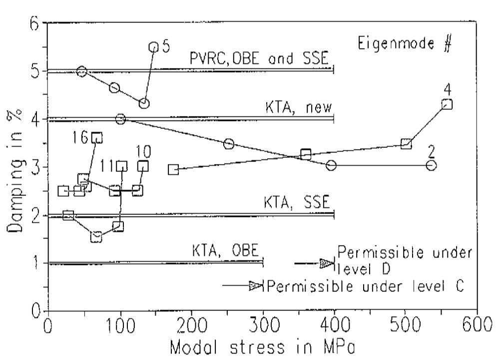

Fig.6: Dependence of Damping on the Modal Stress under Load Increase Conditions, and Comparison with Damping Values in Codes