Transactions of the 13th International Conference on Structural Mechanics in Reactor Technology (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul,
Porto Alegre, Brazil, August 13-18, 1995

Seismic upgrading of piping supports in VVER 1000MW

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ABSTRACT: Russian VVER type nuclear power plants were initially designed for a horizontal earthquake peak acceleration of 0.1g. Since a level up to 0.2g is now considered more realistic, a reassessment of the seismic capacity of safety relevant piping systems and supports is of great importance. An improved behaviour can be obtained by adding more or better support devices. In the current paper, two types of inexpensive and easily implementable motion limiting devices are compared.

1 INTRODUCTION

The improvement of the support configuration for an existing piping system requires an optimal choice of the number, position and type of additional support devices. In the current work, two easily implementable motion limiting devices are examined and compared: viscous dampers and gaps. An important issue is the tradeoff between stresses in pipings and support loads.

2 MOTION REDUCTION BY GAPS

The introduction of gaps is an inexpensive and effective method to reduce seismically induced large amplitude motion while allowing free thermal expansion and free low-amplitude vibrations. The energy accumulation of a resonant mode is limited mainly by perturbing the phase lag between excitation and response such that a resonant behaviour is not possible (Messmer, 1993).

A sample piping system has been used to numerically investigate the behaviour of a piping subsystem with motion reducing gaps. The system shown in figure 1 consists of a straight pipe of 10m length, simply supported at both ends. The cross sectional properties and overall dimensions correspond approximately to segments of the emergency feedwater system of VVER 1000MW reactors.

In a first step, the system was excited by a sine ground acceleration input with 0.5g amplitude and a frequency near the resonant frequency of the pipe without gap support. The response has been analyzed during 15 seconds starting from a motionless initial state.

Without gap, a maximum amplitude of 559mm is reached. In the following, this amplitude was limited by introducing a symmetrical 20mm gap with a finite stiffness. The non-linear support stiffness is shown in figure 2. Several choices of the gap stiffness have been tested. In figure 3, the maximum stress in the piping system and the maximum gap reaction and displacement are plotted against the relative gap stiffness for a 20mm symmetrical gap.

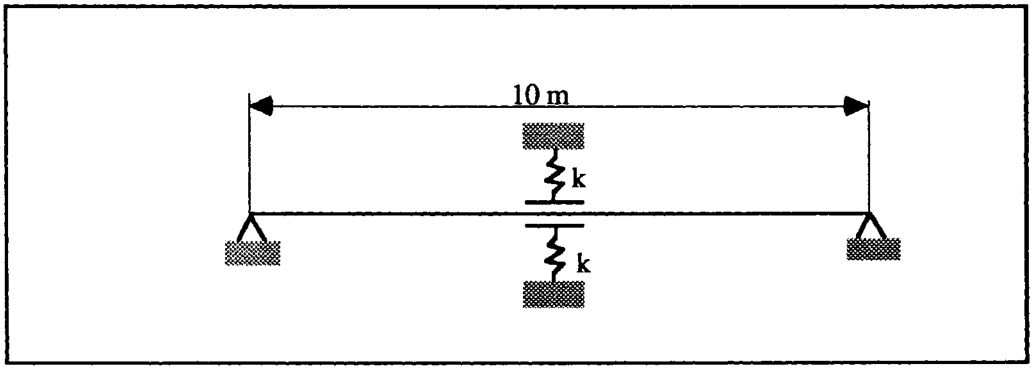
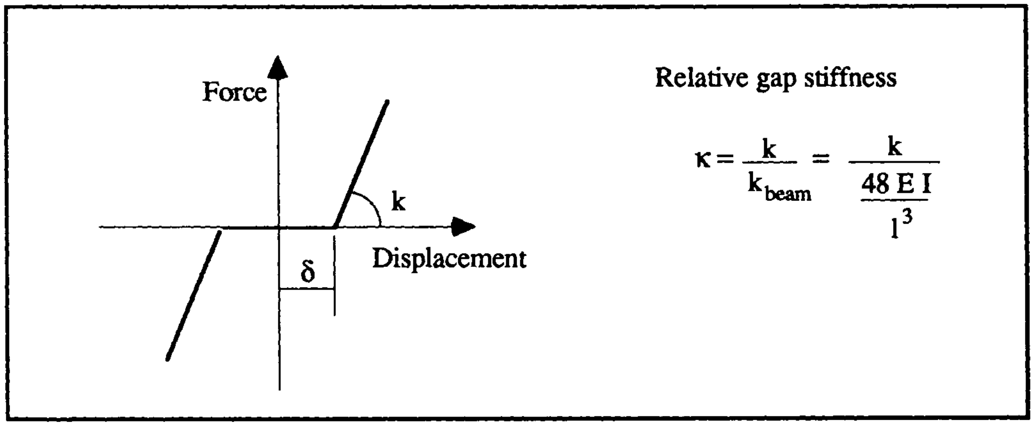


Figure 1 - Sample piping subsystem with gap support



$$\kappa = \frac{k}{k_{beam}} = \frac{k}{\frac{48\,E\,I}{l^3}}$$

Figure 2 - Non-linear stiffness of the gap element

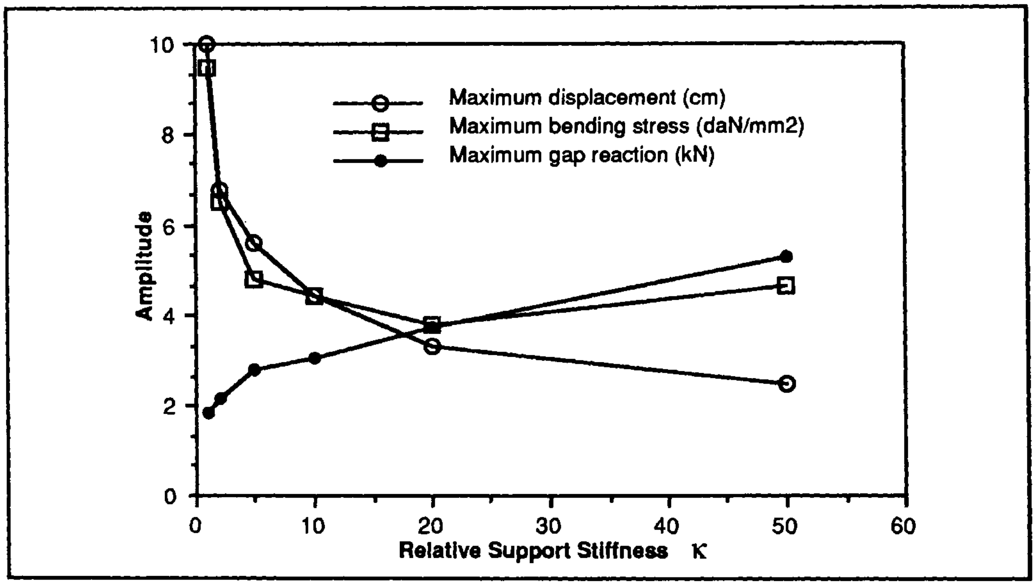


Figure 3 -Maximum gap reaction and maximum stress in pipe as a function of the relative stiffness κ

From figure 3, it can be seen that the stress in the pipes decreases for increasing support stiffness up to a relative stiffness of about 20 and then increases again. This is due to the apparition of high frequency motion with very hard spring characteristics. For a relative support stiffness between 5 and 50, the variation of the maximum stress in the piping system varies little. Since low values for the gap stiffness lead to lower gap support reactions, a value of 5 for the relative stiffness parameter would be a good choice in the present example.

3 APPLICATION OF REALISTIC EATH-QUAKE MOTION TO GAP AND VISCOUS DAMPER SUPPORTS

A typical earth-quake motion in a horizontal axis at building level 30m of the Kozloduy 1000MW reactors has been applied to the sample system described in section 2. The acceleration input is shown in figure 4.

The system response has been obtained for the system without support, with a gap of 20mm and a stiffness of 200'000 N/m (relative stiffness 8.7) and with an idealized viscous damper of 1500 kg/s. The characteristic results are reported in table 5. The displacement of the beam central section is shown in figures 6 to 8 for each of the three configurations.

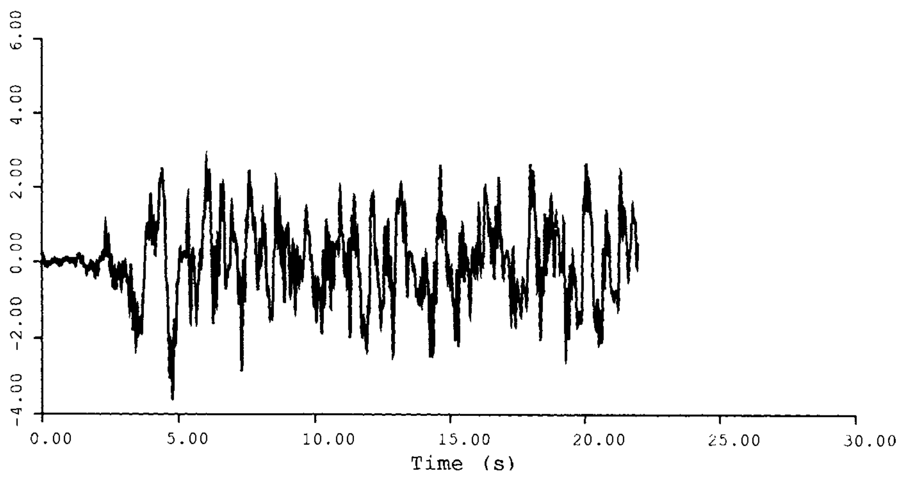


Figure 4 - Acceleration input at level 30m

Configuration	Maximum stress in pipe (N/mm^2)	Stress reduction factor	Maximum displacement (mm)	Maximum reaction force (N)
Without support	52	1	54.4	--
Gap k=200'000 N/m	27	0.52	26.3	1251
Viscous damper c=1500 kg/s	22	0.42	21.5	268

Table 5 - Characteristic response values

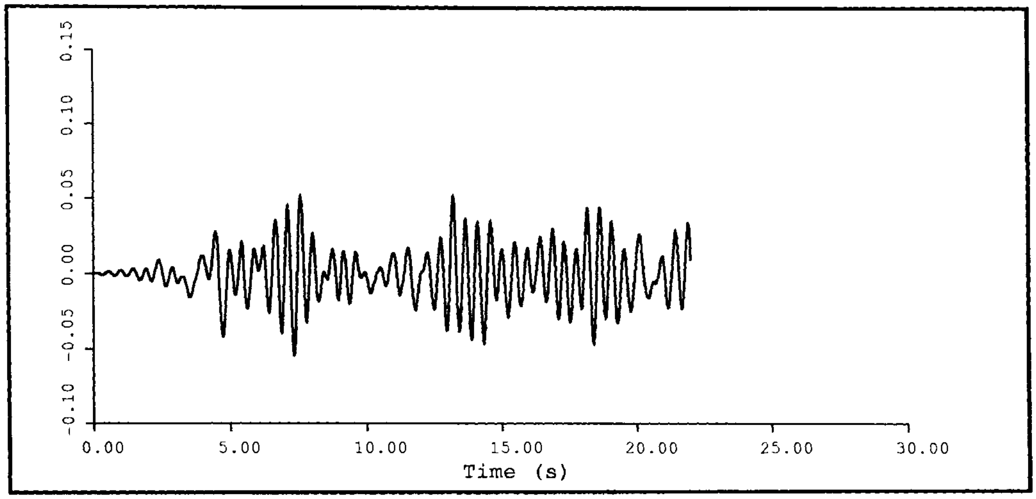


Figure 6 - System without additional support - Displacement at central section (in m)

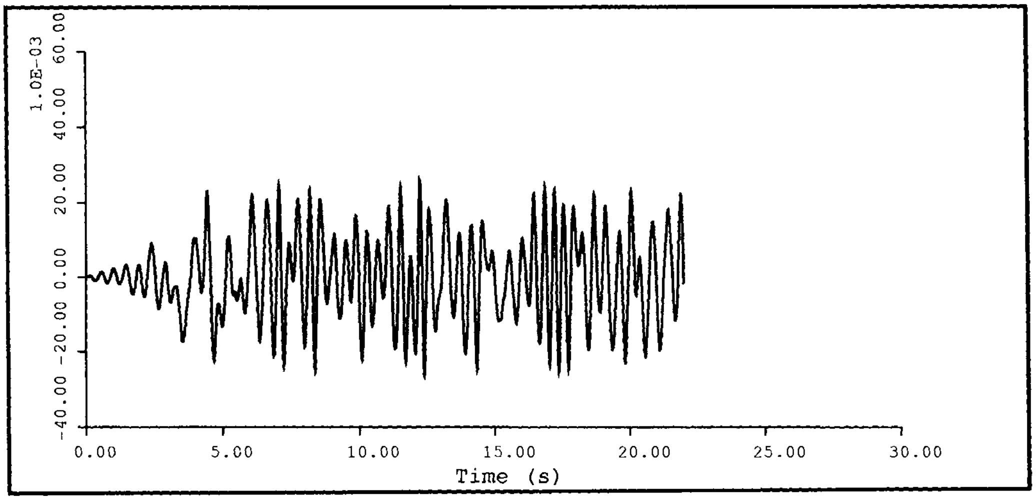


Figure 7 - System with gap - Displacement at central section (in m)

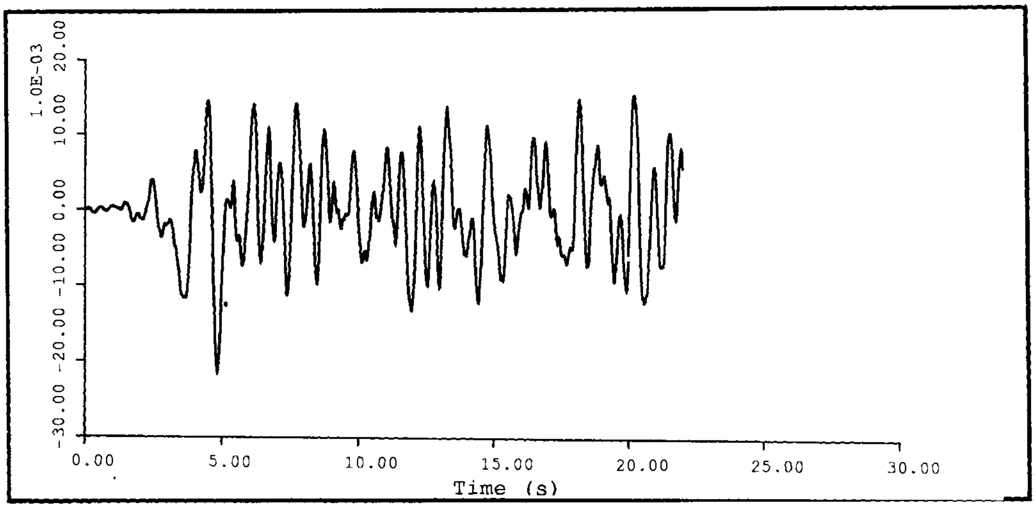


Figure 8 - System with viscous damper - Displacement at central section (in m)

From the results presented above, the following conclusions can be drawn:

- Both gaps and viscous dampers allow an efficient reduction of the stress in pipes
- Viscous dampers lead to lower support reactions for a comparable reduction of the pipe stresses. Energy accumulation is reduced by an increased modal damping factor. From figures 7 and 8, it is evident that the average vibration amplitude is much lower for the system with viscous damper although the peaks are of comparable magnitude.

The main advantage of the gap solution is the very low cost. In fact, a stiffness such as the one used above can be realized easily by a typical steel construction of the support (cantilever beam, beam frame, etc.). As general guideline, gap motion reduction is appropriate for light structures (low reaction forces, high bending stresses) whereas viscous dampers are useful in systems where high reaction forces are the dominant problem.

4 PRACTICAL CONSIDERATIONS FOR VVER 1000MW REACTORS

Actual calculations on the 1000MW VVER plants are currently just starting such that only few results are available. Preliminary results indicate that most of the safety relevant piping subsystems (systems required for the safe shutdown of the reactor after an earthquake) receive rather low seismic stresses. This is due to the fact, that the piping subsystems are rather short and have large cross-sections.

For the VVER primary sytem under study, upgrades, if any, will most probably be oriented toward reduction of the reaction forces at supports or strengthening of the support structures. Considering the results of section 3, an application of viscous dampers could be of interest if large amplitude resonant motion occurs.

5 CONCLUSIONS

Motion reduction by gaps and viscous dampers in seismically excited piping systems has been studied by numerical examples. Both devices allow an efficient reduction of pipe stresses and both are inexpensive and easy to implement. Gaps are probably the most efficient means for the motion reduction of smaller diameter piping subsystems.

Though the implementation of gaps or viscous damper elements is straightforward, their analysis needs some additional consideration. In fact gaps are highly non-linear elements, and localized viscous dampers result in complex mode shapes. In the current study, calculations were performed by direct time integration. If modal superposition or response spectrum analysis are to be used, linearization procedures can be applied (see for example zum Felde & Haas or Tang, Jaquay & Larson).

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