Experimental Investigation of the Load Transfer Behaviour of Piping Supports Under High-Frequency Excitation

F. Steinwender, J. Lockau, J. Rudolph

Kraftwerk Union AG, Abteilung R622, Berliner Str. 295-299, D-6050 Offenbach, Germany

Summary

This paper deals with the results of dynamic experiments performed on two typical supports with water filled pipes of nominal size 4 and 12 inches subjected to an internal pressure of 10 bars. Each pipe was provided with a guide and a fixed support doweled to the concrete using conical split sleeves. The set-up was excited in the two vertical planes. The required excitation was generated from the specified spectra and was applied to the concrete slabs simultaneously for both excitation planes by means of 6 hydropulse cylinders. Each series of experiments was started by applying 50 % of the specified load and was increased step by step until four times the specified load was reached.

The results were as follows:

- a) Even at four times the specified load and having the test specimen underdesigned from the calculational point of view no break occurred. Plastic deformation in the pipe support did not occur until three times the specified load was reached and still did not affect structural integrity.
- b) The actual load on the dowel approved for nuclear power plants was well above the permissible load. The calculated loads were considerably higher than the loads measured and therefore the calculation is fairly conservative.
- c) No obvious local effects were recorded on the pipes and clamps.

1 Introduction

Safety-related piping systems in nuclear power plants are designed to withstand the effects of external impacts (e. g. earthquake, aircraft crash and gas cloud explosion) and of internal loads (e. g. shock waves caused by turbine trip). The increasing stringency of requirements related to the vibrational safety of nuclear power plants resulted in more rigid piping systems and consequently shifted the dominant eigenfrequencies into a higher frequency range. Consideration of the high-frequency, short duration load caused by an aircraft crash gave rise to additional problems in piping design. Experimental investigations were necessary to check the conservative assumption made in the analytic design of piping systems and pipe supports.

2 Experiments

Dynamic experiments were performed together with the LBF Darmstadt in West Germany on pipe supports bearing pipes of two different diameters (4 and 12 inches, corresponding approx. to DN 100 and DN 300 mm resp.). The tested pipe supports are typical for nuclear power plants. A test set-up consisting of a ten meter length of pipe, a specially constructed seismic table and a guide and fixed support with an effective span of 5 meters was used in the experiments (see Fig. 1). The pipe supports are secured on the concrete slabs of the seismic table by means of safety dowels (conical split sleeves). Six hydropulse cylinders apply the required excitation to the two concrete slabs which are rigidly connected via a steel frame.

The pipes were filled with water to an internal pressure of 10 bar. The overall weight of the test set-up was 50 kN. The geometric nonlinearities of the guide support were caused by the gaps in the supports and the resulting frictional contact force at the bearing surfaces of the support. The maximum clearance of 4 mm for movement of the pipe cross-section in the guide was the same for both directions of movement. The two planes of excitation were on the one hand horizontal along the pipe longitudinal axis and vertical, and on the other horizontal transverse to the pipe axis and vertical. Fifty-five measuring devices were arranged on the pipe sections for the hundred different experiments in order to determine load transfer, load-carrying capacity and the available reserves of strength.

3 Experiment Parameters

In the scope of this study the anchoring point DOWEL-ANCHOR PLATE-POST of the fixed support was tested under load from a DN 300 pipe by varying the stiffness of its components from soft to hard (see table I). In addition tests were performed with 2 x M10 tie rods and with a DN 100 pipe. In accordance with the design calculations this fixed support comprised 4 x M12 conical split sleeves. The load stages 50 %, 100 %, 200 %, 300 % and 400 % (500 %) are achieved through multiplication of the specified load (= 100 %) for the aircraft crash load condition.

4 Load Conditions

The excitation functions were taken from the load resulting from a Phantom aircraft crash on the reactor building according to German regulations. The resulting horizontal acceleration time histories used for support excitation of the pipe section reached their maximum amplitudes of 1 g after 0.15 s. In the vertical direction the absolute maximum of 0.5 g was reached after 0.07 s (see Figs. 2 and 3).

5 Results

In the experiments using DN 300 pipe, plastic deformation of the fixed support occurred only at loads of 300 % of the specified load and higher, and this still did not affect structural integrity. At 400 % of the specified load and using the weakest anchoring arrangement 2 x M6 (design 6 x M16) dowel slip of 1.3 mm occurred.

Variation of the fixed support design did not cause any significant changes at the guide. Despite the gaps, no plastic deformation was measured in the frame. A small degree of plastic deformation (strain = less than 0.2 ‰) occurred in the material at the base of the guide support during two measurements at 300 % and 400 % of the specified load. Local effects and stresses in the pipe were very low (the strain measured was less than 0.25 ‰). At the fixed support of the DN 100 pipe set-up the greatest strain of 1.7 ‰ at the anchor point was registered at 400 % of the specified load with the excitation horizontal to the pipe longitudinal axis and vertical, leaving a permanent set of 0.2 ‰. Maximum displacements of 0.03 mm occurred between concrete and anchor plate under the maximum load. Otherwise the strain measured was below 0.2 ‰ and slipping in the guide was observed only at 200 % of the specified load and higher.

6 Comparison of the Results of the Experimental Investigation with the Values obtained in the Design Calculation

Following the standard computation method for dynamic stress analysis and predesign, the pipe section with the various fixed support configurations was represented as a linear FE model. The resultant and the support reaction force were calculated using the response spectrum modal analysis for both excitation planes without allowance for flexibility at the anchor point.

Comparison of the calculated and measured maximum loads of the dowel shows that the loads calculated to act on the dowels and the loads used as the basis for the dowels include considerable safety reserves (see Figure 4). If in the design calculation the supports are assumed to be rigid, every reduction in the number of dowels or in the cross-sections of the dowels causes in general a higher load per dowel. The measured and calculated dowel loads, however, show an opposite trend. The softest dowel configuration (Figure 4) exceeds by far the admissible dowel loads without failure. The reason for the reduction in dynamic loads on the dowels is the reduction in overall stiffness as a result of weakening of the dowels. This change of the system properties from hard to soft reduces the load transfer behavior from concrete slab to the pipe via the support due to the dissipation of the energy input (slipping of the dowel and anchor plate, material behavior). A change of the system characteristics also causes a reduced dynamic reaction of the piping. The weakest element (dowel-plate-post) of the pipe support is decisive for the dynamic load transfer behavior due to the highest energy dissipation. Finally the comparison of the results of the experimental investigation with the values obtained in the design calculation has confirmed the conservative assumption of the analytic design of the piping systems. Every calculated dowel load is clearly higher than the measured dowel load.

7 Conclusion

Plastic deformation only occurred at unrealistic load levels of 300 % and higher and did not adversely affect the structural integrity of the pipe support. The loads calculated for the dowels were considerably higher than the loads measured, which, in turn, were above the specified permissible loads.

Figure 4: RELATION BETWEEN EXPERIMENTALLY DETERMINED (F_{De}), CALCULATED (F_{Dc}), AND ADMISSIBLE (S_o) DOWEL LOADS FOR EXCITATION OF PIPE DN 300 IN Y-Z-PLANE AND IN X-Z-PLANE

Table I: PARAMETRIC STUDY OF A DN 300 PIPE (DN 300 $\hat{=}$ INCH NOMINAL SIZE 12)

POST-PROPERTIES	VARIATIONS OF FIXED SUPPORT: DOWEL-PLATE-POST						
	H H H	H H S	H H VS	H S H	H S S	S H H	VS H H
A [m ²]	.65 · 10 ⁻²	.26 · 10 ⁻²	.88 · 10 ⁻³	.65 · 10 ⁻²	.26 · 10 ⁻²	.65 · 10 ⁻²	.65 · 10 ⁻²
J [m ⁴]	.46 · 10 ⁻⁴	.74 · 10 ⁻⁷	.71 · 10 ⁻⁶	.46 · 10 ⁻⁴	.74 · 10 ⁻⁷	.46 · 10 ⁻⁴	.46 · 10 ⁻⁴
I ₂ [m ⁴]	.27 · 10 ⁻⁴	.45 · 10 ⁻⁵	.46 · 10 ⁻⁶	.27 · 10 ⁻⁴	.45 · 10 ⁻⁵	.27 · 10 ⁻⁴	.27 · 10 ⁻⁴
I ₃ [m ³]	.27 · 10 ⁻⁴	.17 · 10 ⁻⁵	.46 · 10 ⁻⁶	.27 · 10 ⁻⁴	.17 · 10 ⁻⁵	.27 · 10 ⁻⁴	.27 · 10 ⁻⁴
POST TYPE	160 × 160 × 15mm	IPB 100	60 × 60 × 4mm	160 × 160 × 15mm	IPB 100	160 × 160 × 15mm	160 × 160 × 15mm
DOWELED ANCHOR	6 × M16	6 × M16	6 × M16	6 × M16	6 × M16	2 × M10	2 × M6