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Strong Cyclic Loading of an Industrial Piping System

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1 INTRODUCTION

Typically, a piping system consists of straight pipes, elbows and tee junctions. In the case of severe seismic action, piping systems may be loaded well into the plastic range under large amplitude reversible cyclic loading. In particular, piping components deform into the inelastic range and fatigue-ratcheting may occur, causing failure of pressurized piping system. In recent years, significant research has been published aimed at improving the seismic design of the piping system, mainly motivated by the safety requirements of the nuclear industry. Towards this purpose, a series of experimental programs has been reported on the assessment of the piping system under severe static or dynamic loadings that simulates the earthquake loading conditions [Suzuki *et* al. 2003; Ravi Kiran *et al*. 2009; Varelis *et al*., 2013].
In the present work, an experimental study is presented which examines the response of a pressurized piping system subjected to reverse cyclic loading and the experimental investigation is supported by numerical simulations.

2 OUTLINE OF FULL-SCALE OF EXPERIMENTAL TESTING

The experimental work refers to an 8-inch-diameter piping system with nominal thickness equal to 6.35 mm (SCH20), containing three long-radius elbows and straight parts. The piping system pressurized first with internal pressure equal to 30 bar and afterwards it is subjected to severe cyclic displacement-controlled loading in a quasi-static manner. The amplitude of the displacement is equal to 250mm. Figure 1 presents the experimental set-up, Elbow 1 and Elbow 3 are subjected to in-plane bending, while Elbow 2 is mainly subjected to out-of-plane bending. Strain gauges have been located at the elbows in order to record the value of plastic strain at critical location and theirs accumulation over the cyclic loading. Moreover, three special-purpose devices with LVDT's have also been used in order to measure the development of cross-sectional ovalization at the elbows. Figure 2 demonstrates the experimental instrumentations at Elbow 3. The piping system have failed at Elbow 3 at flank region as shown in Figure 2 after 129 cycles. In Figure 3 the force-displacement diagram of the piping system and the evolution of hoop strain at flank location with respect to the number of cycles for the Elbow 3 are depicted.

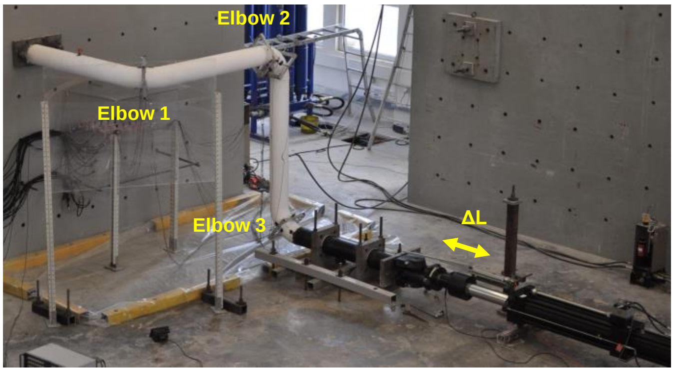

Figure 1*: Experimental set up for the 8-inch-diameter piping system.*

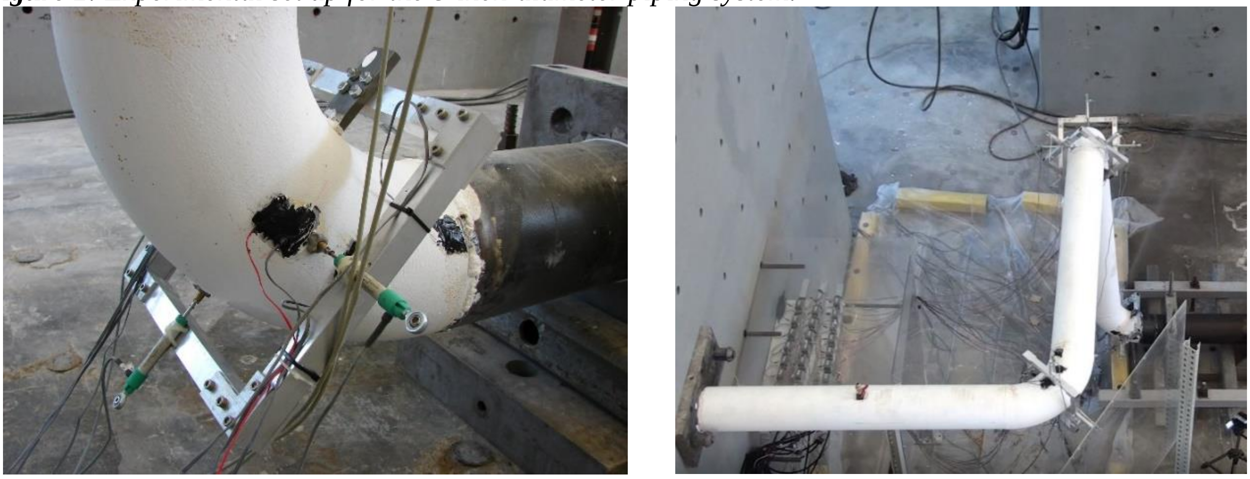

Figure 2*: Experimental instrumentation (left); failure at Elbow 3 (right).*

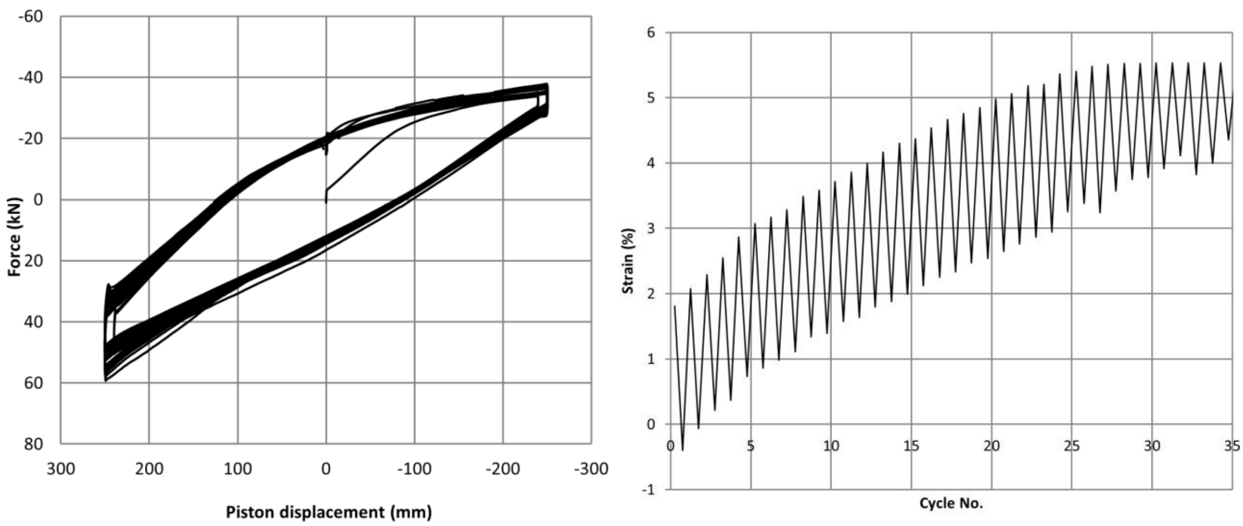

Figure 3*: Force displacement diagram (left); hoop strain with respect of the number of cycles (right).*

3 NUMERICAL SIMULATION OF PIPINING SYSTEM

The second part of the work refers to the numerical simulation of the piping system response, for the purpose of elucidating some special issues, complementing the experimental work. A finite element model (Figure 4) has been developed, using general-purpose software ABAQUS. The model employs the geometry of the specimens based on measurements conducted prior the execution of the experiment. The support conditions have been imposed in the numerical model exactly as in the experimental set-up, using appropriate kinematic constraints at the two ends of the straight parts. The pipes and the elbows are discretized with shell elements (S4). Material tests have been performed in order to describe accurately the material behavior of the components of the piping system. A built-in constitutive model, proposed by Chaboche (1986) is employed.

Figure 5 shows the mesh of finite elements in the elbow area, and in Figure 6 the hoop strains at maximum loading at the three elbows are shown.

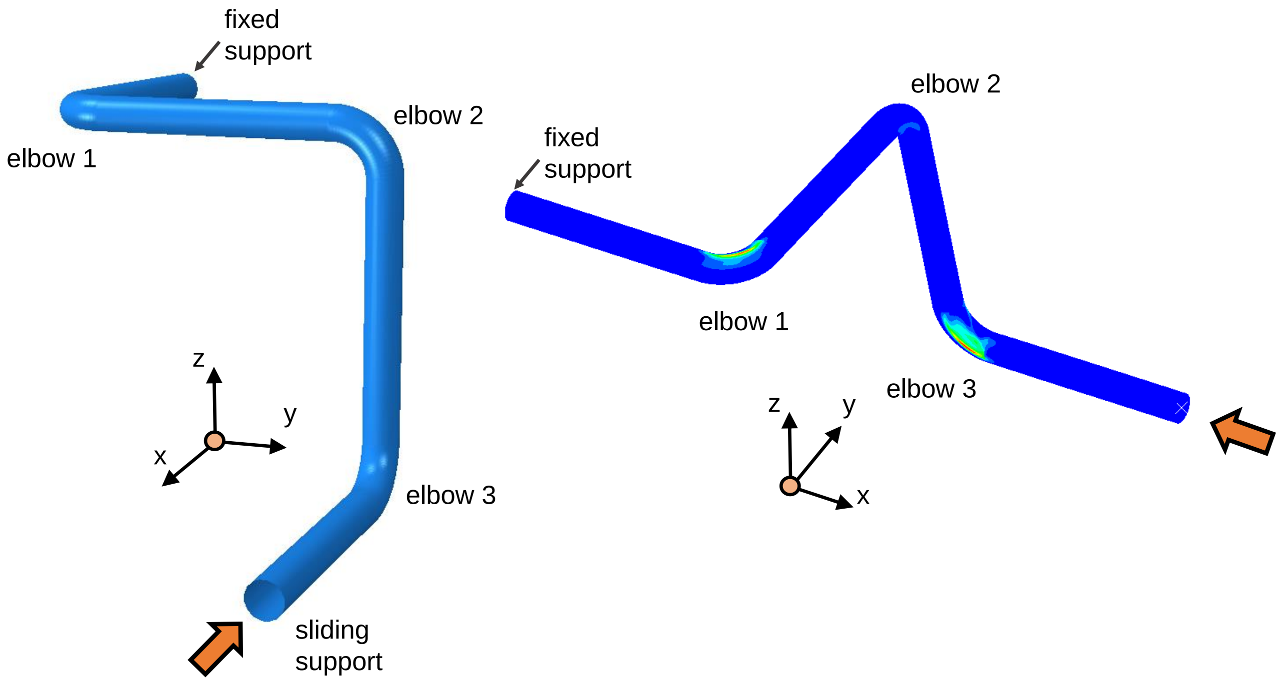

Figure 4*: Finite element model.*

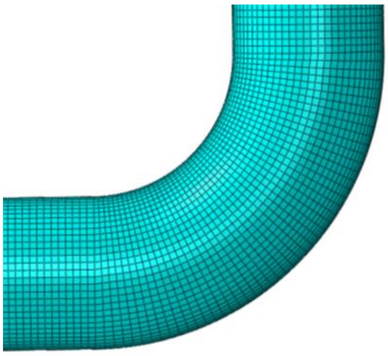

Figure 5*: Elbow meshing detail.*

4 RESEARCH RESULTS AND CONCLUSIONS

The piping system has failed due to low-cyclic fatigue after 129 cycles, a crack was developed at the flank region at Elbow 3. Strain gauges and special-purpose devices with LVDT's have been located at the elbows in order to examine the behavior of piping system under strong cyclic loading, both globally and locally (development and evolution of strains at critical locations). The experiment has been simulated numerically, using the exact boundary conditions of the test, appropriate thickness and diameter measurements, and material data from cyclic test on strip specimens extracted from elbows of the same heat.

The load-displacement response and the values of local strains at critical locations are in fairly good agreement with the test data. In conclusion, the finite element model seems to be capable of predicting the mechanical response of the elbows, offering a powerful tool for structural assessment of piping systems under severe loading.

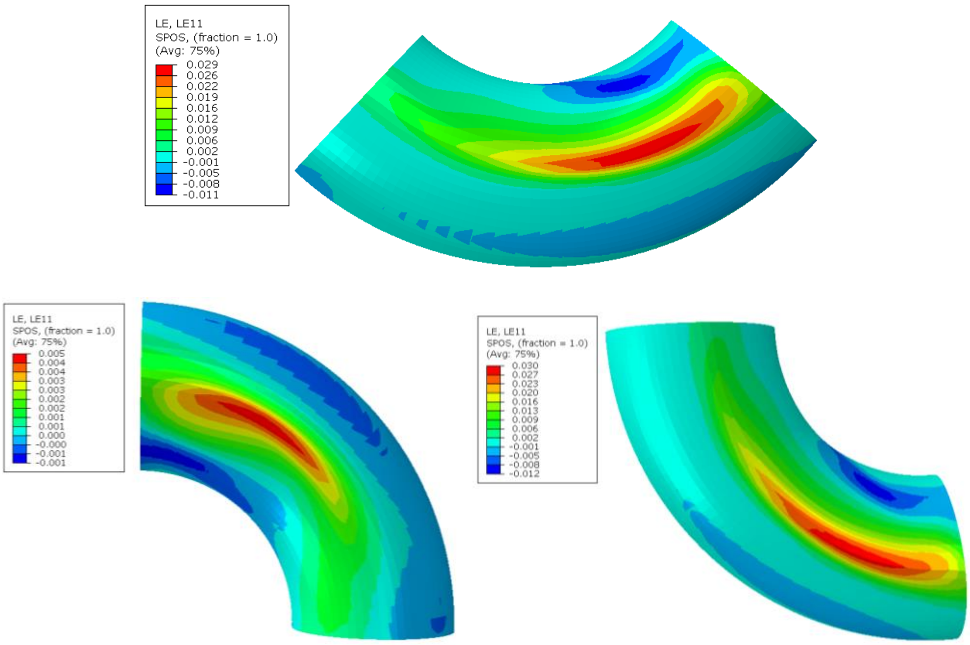

Figure 6: *Distribution of hoop strain for Elbow1 (Up) Elbow2 (left), Elbow 3 (right).*

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