14.6 FATIGUE-RATCHETING INVESTIGATIONS ON PRESSURISED PIPES, ELBOWS AND PIPING LOOP

The Nuclear Power Plant (NPP) piping components, which are under high pressure, are subjected to large amplitude reversible cyclic loading during the earthquake event. During this event the stresses may exceed the elastic limit of piping material. In this situation there is a strong possibility of accumulation of plastic strain by ratcheting in addition to the low cycle fatigue damage. Ratcheting can substantially reduce the fatigue life and lead to failure due to excessive plastic strain accumulation.

To understand the failure phenomena, 3 fatigue-ratcheting experiments were conducted at IIT, Madras. The phenomenon of ratcheting was clearly observed. The pipe bulged under the application of constant internal pressure and cyclic bending moment applied through actuators. The circumferential strain increased with number of cycles before the final rupture at bulged portion.

Similar studies were carried out on 90° elbows at IIT, Bombay. These tests have been carried out under constant internal pressure (0.3\(\sigma_{ys} - 0.7\sigma_{ys}\) hoop stress) and large amplitude (approximately 3-4Sm) cyclic displacement controlled loading. In all the tests, the elbows have failed at crown location (axial through wall crack formed at crown location), in limited number of cycles (100-400 cycles).
Significant ballooning (8-12%) has taken place with simultaneous fatigue damage, which is followed by crack initiation and growth till it becomes through wall thickness. Figures show the accumulation of local hoop strain at crown and gross hoop strain i.e. dilation/ballooning of the elbow cross section (increase in crown-crown and extrados-intrados diameter). For detecting the crack initiation, various techniques such as Acoustic Emission Technique (AET), Ultrasound Technique (UT) and Magnetic Barkhausen Noise Technique (MBT) have been used and consistent readings obtained.

After performing the above component tests, a piping loop was subjected to ratcheting test on a shake table, thus simulating the earthquake loading. Again there was strain accumulation followed by failure due to fatigue-ratchetting.

On the analytical front, biaxial ratcheting analysis has been carried out on the pressurized pipe tubes subjected to reversible cyclic axial strain loading. The radial dilation after 5, 10, 20, … load cycles has been evaluated for various combinations of primary and secondary stresses. Based on these the Ratchet Assessment Diagrams (RADS) have been developed for SA333Gr6 carbon steel material. The RADS are the plot of iso-strain (i.e. accumulated plastic strain after 'N' number of cycles) curves on ‘stress amplitude (secondary load)’ and ‘hoop stress (primary load)’ plane and provide a simplified way of ratchetting assessment.

The ballooning in the elbow tests was predicted from these RADS. The comparison of the predicted and experimental values is reasonably good.
Following conclusions can be drawn:

- The phenomenon of ratcheting has been observed in piping components when loaded by actuators as well as when loaded on shaketable.

- In general, the number of cycles required to produce significant ratcheting is quite large. Detailed Ratcheting Assessment can help in reducing the conservatism in the seismic design of piping.

- Further studies are required to formulate design rules to account for this phenomenon.

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