Evaluation of Plastic Collapse Moment of Initially Geometric Imperfect Pipe Bends Under Internal Pressure and Bending Moments

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Abstract

Pipe bends induce higher stresses and strains compared to straight pipes of the same size and material property under identical loading conditions. Therefore, pipe bends are one of the critical components of a pipeline system. For avoiding the failure of pipe bends, it is necessary to have accurate estimation of plastic collapse moment. Pipe bends are manufactured from straight pipes using pipe bending process. The bending process leads to transformation of circular cross-sections into non-circular cross-sections for any bend angle. This change in the cross-section is defined as the initial geometric imperfection. The presence of initial geometric imperfection can affect the plastic collapse moment. Also, the plastic collapse moment values of pipe bends depend on type of applied load like in-plane closing bending moment, in-plane opening bending moment or out-of-plane bending moment with or without application of internal pressure. Moreover, the effect of the pipe bend angle on plastic collapse moment is found significant. Hence, for the accurate estimation of plastic collapse moment of different angled pipe bends under different loading conditions, it is necessary to incorporate initial geometry imperfection into the cross-section of pipe bends.

The objective of this research is to study the effect of initial geometric imperfection for different angled pipe bends and propose empirical equations for determining more accurate plastic collapse moments under bending moments and internal pressure. For achieving the present objectives, extensive nonlinear finite element analyses have been carried out for a diverse geometric spectrum ranging from 30° to 180° pipe bend configurations accounting for the initial geometric deformations of the cross-sections. For modeling the pipe bends with initial imperfection, python scripting is incorporated. The analyses are accounted for material as well as geometry nonlinearities. The investigation has been carried out for two material models, elastic-perfectly plastic and strain-hardening. In present work, pipe bends are loaded to in-plane closing, in-plane opening bending and out-of-plane bending moments

with or without internal pressure. The twice-elastic-slope method is adopted to determine the plastic collapse moment results.

For analyzing the effect of initial imperfection, the collapse moment results for circular and imperfect pipe bends are compared and found that the presence of initial imperfection has significant effect on it. For the unpressurized condition of all three bending moments, it is observed that collapse moments of initially deformed pipe bends are lower as compared to that of circular cross-sectioned pipe bends for all the considered cases. In the case of combined loading of internal pressure and in-plane closing bending, the presence of initial imperfection for normalized internal pressure, $p < 0.25$, has negative effect that is pipe bends with imperfection have lower collapse moment as compared to circular one for both material models. For the $p > 0.25$, the presence of initial imperfection has positive effect that is pipe bends with imperfection have higher collapse moment compared to circular one for both material models. The positive effect of geometric imperfection increases with the increase in bend angle for the pressurized condition. Under the loading condition of internal pressure and in-plane opening bending, at the lower magnitude of applied pressure initial imperfection has adverse effects. At the higher pressure values, the negative effect of initial imperfection decreases with increased pressure for thinner pipe bends and observed maximum 30.73% decrease in collapse moment. In case of internal pressure and out-of-plane bending, the effect of initial imperfection is minimum as compared to other bending moments. The effect of initial imperfection on collapse moment is more pronounced in elastic-perfectly plastic material compared to that of strain-hardening material for all cases of bending moment. The application of internal pressure produces stiffening effect to pipe bends which increases collapse moment up to a certain limit and with further increase in pressure, collapse moment decreases in all bending modes.

The results show that initial geometric imperfection has different effects on collapse moment under different bending modes with internal pressure. Therefore, it is difficult to suggest the critical mode of bending moment under pressurized conditions. Thus, it becomes necessary to determine collapse moment in each case of bending moment. Therefore, using nonlinear regression analysis, empirical equations are formulated to predict the accurate collapse moments of different angled pressurized pipe bends with more realistic cross-sections employing elastic-perfectly plastic and strain-hardening material models for all the considered bending modes.