Investigation of the 20bar Threshold Between High and Moderate Energy Lines

Case study

EDF NNB currently uses a 20 bar threshold to delineate high energy lines (HEL) and moderate energy lines (MEL). The threshold is used as a process for establishing additional analysis to be performed as part of HEL break analysis. The Office of Nuclear Regulation (ONR) has challenged EDF NNB to provide substantiation that the 20 bar threshold used for the differentiation of HEL and MEL is an appropriate value.

It is known that when a pressurised pipe breaks, the escaping fluid exerts a thrust force on the pipe. This thrust results in a bending moment on the pipe which in some instances will exceed the plastic section moment and a plastic hinge develops. The continuing thrust generates a rapidly accelerating rotational displacement of the section on the break side of the plastic hinge, the phenomenon called pipe whip.

The whipping pipe has the potential to damage objects within the hazard zone therefore must be assessed. This requires knowledge of the extent of the hazard zone and the kinetic energy of the whipping pipe. Methods of assessment range from the simplified route R3 Impact Assessment, to computer based large deformation models for simple geometries to full finite element representations of events.

In the study presented here, independent calculations using numerical structural analysis have been undertaken to ascertain, for a range of pipe characteristics, and pressures in the range of 10-50 bar, whether a plastic hinge will occur and whether pipe whip effects will be seen for that case.

Our approach

Following a pipe break the fluid exerts a number of forces on the broken pipe and surrounding structures. These forces include a thrust force due to escaping fluid, jet impingement forces on the surrounding structure, a pressure wave and internal flow forces. These forces have been reviewed in our analysis which concluded that although the internal flow forces are the largest loads, these are remote from the pipe break and at the break the thrust force bounds the pressure wave and jet impingement forces. The analysis also notes that jet impingement on pipe of a smaller bore than the broken pipe could be more onerous than the thrust force or pressure wave and, therefore, each situation should be considered in more detail. Since this study is concerned with pipe whip at the break, only the thrust force has been considered.

The focus of this study is to confirm whether or not a plastic hinge will form under the applied loading and hence whether pipe whip will occur. Also of interest is the location of the plastic hinge, should one occur.

The report also provides some justification for exclusion of a break based on leak-before-break (LBB) arguments. However, as LBB assessment is not within the scope of this work, it is assumed that pipe whipping can occur at low pressures provided a plastic hinge is formed under the influence of the applied thrust acting on the broken pipe end.

The assessment has been undertaken in three phases. The initial phase of this work was to investigate and determine the characteristics of a whipping pipe by firstly performing R3 pipe whip calculations. Then the R3 pipe whip assessment results were compared with the results of a non-linear, elasto-plastic, finite element (FE), pipe whip analysis using pipe/ beam elements.

The basis of the FE analysis undertaken in the first phase is the findings of a numerical elasto-plastic pipe whip analysis with fully coupled fluid-structure interaction. This paper compares simplistic methods of assessing the hydraulic loading, the plastic hinge location and the kinetic energy of a whipping pipe, to a numerical methodology based on a non-linear, fast transient, FE method with the fully coupled fluid-structure interaction (FSI) between the compressible (one or two phase) fluid and the piping structure submitted to large deformations. Reference is made to a previous FE based study.

Given this, it is therefore proposed that as the rate of plastic strain evolution is not the focus of this study, the use of FSI based FE analysis is not computationally efficient. Therefore, the force-time history method has been adopted. The second phase of the study considered the influence of piping layout geometry upon the location of the plastic hinge. The following two layout configurations have been considered:

- straight pipe, 2 in-plane bends (U-shape); and
- straight pipe, 1 in-plane and 1 out-of-plane bend (S-shape).

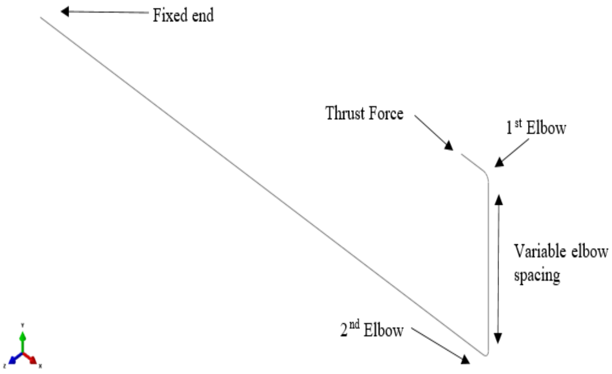

Figure 1 S-shaped FE pipe/ beam element analysis geometry

The results

The report concluded that even in the absence of pipe whip the impact energy imparted by the broken pipe onto adjacent structures, components and equipment is not insignificant. Kinetic energies associated with a 90° rotation of the broken pipe are provided for information and to enable the assessment of the capacity of the adjacent structures, components and equipment to withstand the impact.

Comparison of the pipe/beam models for U- and S-shaped piping shows that

R3 is conservative. For S-shaped pipes where torsional loading becomes significant the use of shell element models is suggested.

By focusing on the problem we were able to use some of the findings from similar work carried out in the past to optimise the analyses and resources for this task. This provided a timely response avoiding any unnecessary assessments and putting into use some of our past experience.

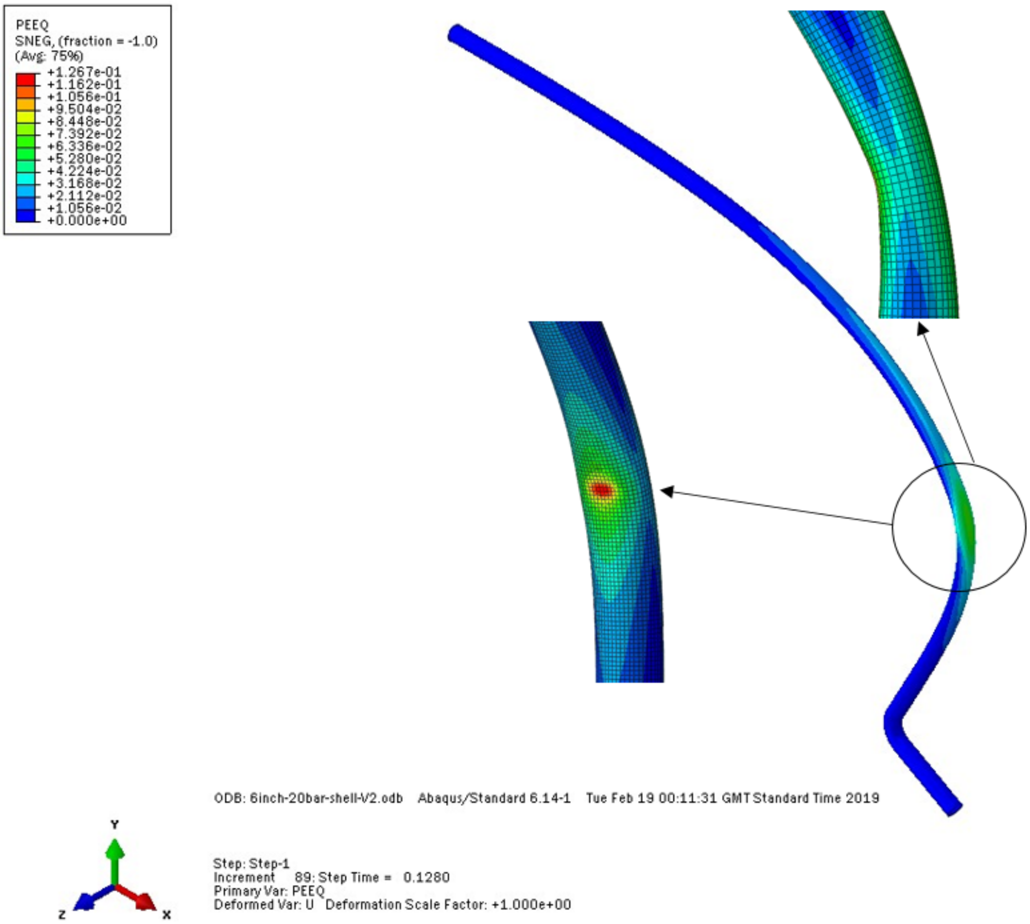

Figure 2 Variation of plastic hinge distance with pipe section at 20bar