International Journal of Pressure Vessels and Piping 88 (2011) 189–197

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

journal homepage: www.elsevier.com/locate/ijpvp

Structural modelling and testing of failed high energy pipe runs: 2D and 3D pipe whip

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ARTICLE INFO

Article history:
Received 15 April 2011
Received in revised form
19 May 2011
Accepted 26 May 2011

Keywords:
Pipe whip
Dynamic structural plasticity
Safety design
Large plastic deformation

ABSTRACT

The sudden rupture of a high energy piping system is a safety-related issue and has been the subject of extensive study and discussed in several industrial reports (e.g. [2–4]). The dynamic plastic response of the deforming pipe segment under the blow-down force of the escaping liquid is termed pipe whip. Because of the potential damage that such an event could cause, various geometric and kinematic features of this phenomenon have been modelled from the point of view of dynamic structural plasticity. After a comprehensive summary of the behaviour of in-plane deformation of pipe runs [9,10] that deform in 2D in a plane, the more complicated case of 3D out-of-plane deformation is discussed. Both experimental studies and modelling using analytical and FE methods have been carried out and they show that, for a good estimate of the "hazard zone" when unconstrained pipe whip motion could occur, a large displacement analysis is essential. The classical, rigid plastic, small deflection analysis (e.g. see [2,8]), is valid for estimating the initial failure mechanisms, however it is insufficient for describing the details and consequences of large deflection behaviour.

1. Introduction

The design and construction of nuclear power plants for 'new build' projects have changed significantly over the years. There is an increased use of and reliance on computer-based plant design management systems that can integrate design, CAD manipulation, structural integrity assessments, manufacture, construction and safety considerations [1].

One of the un-met requirements is to enhance the capability of the plant design management systems to give 'safe by design' capability for high energy piping systems. In a typical nuclear power plant, the sudden rupture of a high energy piping system is a safety-related issue. A sudden rupture results in a force from the escaping fluid (jet impingement or blow-down force) and dynamic motion of the pipe, i.e. pipe whip. Designers have to ensure that any safety-related equipment is either protected or is out of the Hazard Zone where a whipping pipe may strike. In the past, the R3 Impact Assessment Procedure [2,3] developed in the UK nuclear industry and the American code ANSI/ANS 58.2 [4] have been used to assess pipe rupture hazards. Particularly with regard to the structural deformation and motion of the pipe, which are responsible for some of the potential damage (note: the variations in the flow, fluid–structure interaction and jet loading is not an issue to be dealt with here), these procedures now need to be updated. More recent pipe whip mechanics research, and its application needs to be added to the capability in the commercial codes, such as PDMS [1], being used by designers.

As far as structural modelling is concerned, many of the published models [e.g. 5–7] are based on small-deflection, rigid, perfectly-plastic approaches [2,8], focusing on the initial failure mechanisms identifying both the number and the location of the plastic hinges. The consequent results are valid when the motion of the pipe segment is limited. They provide good guidance for the design and positioning of pipe-run supports and restraints. However, for unconstrained pipes, where both the deformation and deflection can be large following a rupture, the dynamic response of the whipping pipe is potentially a more serious safety concern. Such events need to be predicted by an improved modelling capacity, tested for verification, and, eventually, be made available through a 3D virtual model of the plant, to help safeguard the workplace and any safety critical equipment.

In this paper, first an experimental study of 2D in-plane and 3D out-of-plane of high energy pipe runs performed in UMIST in 1996–2000 is outlined. Next, the 2D bending-dominated behaviour of pipe segments undergoing motion in a plane is discussed. This includes an account of modelling developments using finite element analysis and other techniques showing predictions of the

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doi:10.1016/j.ijpvp.2011.05.006