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DIAPRS — A COMPUTER PROGRAM·FOR DYNAMIC INELASTIC ANALYSIS OF RUPTURED PIPING

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SUMMARY

Design of energy absorbing restraints for a whipping piping system following postulated rupture in a loss of coolant accident requires a dynamic, inelastic analysis for jet forces generated by the discharge of internal fluid. The purpose of this paper is to describe features and capabilities implemented in a special purpose program for pipe whip analysis. The salient features and capabilities of the program include: a variety of inelastic and restraint elements, a generalized solution strategy, analysis restart capability, and output reorganization of response results.

1. Introduction

The loss of coolant accident, wherein a pipe rupture is postulated resulting in a discharge of high pressure fluid is a hypothetical accident that has been used as one of the many sensitive considerations for design of nuclear power piping. From a cost effective standpoint, it will be necessary to fully utilize piping and restraint strength capabilities by allowing deformations in the plastic regime of the materials. To avoid interference with piping in normal operation, it is customary to design pipe restraints with an initial gap between pipe and restraint. Also, locations of restraints are designed so that the containment and necessary safety systems are out of reach of a whipping piping following postulated ruptures. These considerations require that the design of energy absorbing restraints for a whipping pipe following rupture be performed with a dynamic, inelastic and large displacement analysis of piping-and-restraint system.

Techniques for analysis of nonlinear structural systems discretized by finite elements have been developed by many investigators [1], and several computer programs have been developed. Based on these techniques and computer programs, problem areas of dynamic, inelastic analysis of whipping pipe can be effectively researched and identified.

A general purpose finite element computer code ANSR (Analysis of Nonlinear Structural Response) has been developed for static, dynamic, and earthquake response analysis of nonlinear finite element systems [2]. A special purpose program DIAPRS (Dynamic Inelastic Analysis of Pipe Rupture Systems) has been developed based on the ANSR program. The objective of this paper is to summarize some of the major features and capabilities of the program DIAPRS.

2. Program Features and Capabilities

The main features and capabilities of the program DIAPRS are as follows:

(1) The piping-restraints system can be modelled by any combination of a variety of inelastic pipe elements and restraint elements. The structure of the program has been designed so that new elements can be developed relatively easily.

(2) Any sequence of static and dynamic analyses can be performed.

(3) Using analysis restart capability, any one of several intermediate analysis results saved in previous computer runs may be recalled to use an initial condition for additional analyses. The time step size, iterative solution strategy, points of application of dynamic loading function, etc. can be changed when using this restart analysis option.

(4) A variety of solution schemes such as step-by-step integration, and constant stiffness iteration and Newton-Raphson iteration schemes are built into the DIAPRS program through a single solution strategy. The analyst can select the parameters of the solution strategy to perform the pipe-whip analysis in a cost effective manner.

(5) Both in-core and out-of-core equation solutions are included to solve small and large piping systems.

(6) Nonlinear analysis of general piping systems can also be performed for multi-support in-phase or out-of-phase support excitations.

(7) Response histories of selected nodes and pipe/restraint elements can be output at intervals of time steps as computation progresses, or these histories may be output in a reorganized (summarized) manner for graphical display.

3. Theory

The program DIAPRS uses discrete finite element incremental equations of motion to be integrated numerically to obtain the dynamic response. These equations include such non-linear effects as large displacements, large strains and/or inelastic materials.

The equations of motion are integrated numerically in a step-wise manner using an implicit Newmark operator. One form of this operator, namely "constant average acceleration" operator, has been proven to be unconditionally stable in linear dynamics, and has been successfully used in many nonlinear analysis. Equilibrium iterations can be performed in any time step to obtain accurate and convergent results subject to a specified tolerance. To provide the analyst flexibility in analyzing the pipe-whip problem in a cost-effective way, a general solution strategy with several parameters is included in the program. The parameters specify intervals of time steps to perform equilibrium iterations, type of iteration scheme (constant stiffness, Newton-Raphson simple step-by-step, or a hybrid combination of these), intervals of time steps between tangent stiffness reformulations, coarse and fine convergence tolerances, etc. [3].

4. Inelastic Pipe and Restraint Elements

The piping and restraints can be modelled by the following elements:

(1) A three dimensional pipe/beam-column element which yields through the formation of concentrated plastic hinges at its ends. The inelastic behavior is considered using interaction between axial force and major axis bending moment only, and elastic behavior is assumed for the torsional and minor axis bending moment. A bilinear axial force-elongation relationship and a bilinear major axis bending moment-rotation relationship can be input.

(2) A three dimensional pipe/beam-column element which yields through the formation of generalized plastic hinges at its ends. The yield function is spherical or parabolic with kinematic hardening, and includes interaction of the four principal stress resultants, namely axial force, two bending moments and torsional moment. Approximate large displacement effects (P-Δ type) are included. A multilinear action-deformation relationship for each of the four principal stress resultants can be specified [4,5].

(3) A three dimensional pipe element with point-wise evaluation of stress-strain relationship at a number of locations over the cross sections at each end. The material model consists of a multilinear description of stress-strain curve, with kinematic hardening.

(4) A three dimensional gap element to model gapped pipe supports. A multilinear restraint force-deformation relationship can be specified. The gap element can also be used to model restraints such as brackets.

(5) A three dimensional linear support spring element to model anchors and other flexible supports.

(6) A three dimensional linear straight pipe or elbow element.

5. Future Developments

A number of further developments for the program are planned. These include: (a) improvement of existing piping elements, (b) development of U-bar and special restraint elements, (c) incorporation of an explicit time integration scheme in dynamic analysis, and (d) development of a post processing subprogram to plot time histories of nodal and pipe-restraint response results. It is expected that the program will be continually updated to include state-of-the-art techniques for pipe-whip analysis.

References

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