DEVELOPMENT OF LARGE-DISPLACEMENT, NONLINEAR, ELASTIC-PLASTIC CODE FOR PIPE WHIP ANALYSIS

by

Graham H. Powell
Professor of Structural Engineering
University of California
Berkeley, Ca. 94720

Prepared for Seventh Water Reactor Safety Research
Information Meeting, Gaithersburg, Nov. 5, 1979

1. INTRODUCTION: PROGRAM OBJECTIVES

The objective of the program is to develop a special purpose computer code for pipe whip analysis; to verify the code by comparison with available experimental results; and to perform parameter studies to assist in the development of design guides. The computer code is to be implemented on a minicomputer (32-bit word "super" mini) in interactive mode. The code must be capable of performing pipe-to-pipe and pipe-to-wall impact analyses, as well as analyses of the interaction of piping with pipe whip restraints. Large displacements of the piping system and large distortions of individual piping components are to be considered.

The project began in October 1978, and is scheduled to be completed in three years. Nine graduate students, three post-doctoral researchers and the principal investigator are involved in the project, all working part time.

2. PROGRAM ASPECTS

There are five major aspects of the program, namely (1) computer code design; (2) solution strategy for nonlinear behavior; (3) finite element library; (4) code verification; and (5) parameter studies. These aspects are considered in the following sections.

3. COMPUTER CODE DESIGN

Most structural analysis codes have been developed for large mainframe computers. They have also been developed using coding techniques which are becoming outdated, particularly with regard to data management. The code being developed uses a special purpose Data Base Manager for all data storage and recovery. This leads to a much more modular code, and makes it much easier to add new features. The code is an extension of the FACTS code (Finite Element Analysis of Complex Three-dimensional Systems), developed by SSD, Inc., Berkeley, California. The code has been designed with minicomputer implementation in mind, and incorporates a flexible substructuring scheme. The FACTS code is first being extended to perform nonlinear dynamic analyses in batch mode. Interactive I/O modules will then be added.

As of 10/1/79, extension of FACTS to perform nonlinear analyses is nearing completion, with approximately two months more effort required. Work has begun on implementing the program on a DEC-VAX computer, and on development of interactive input routines.

4. SOLUTION STRATEGY

A tangent stiffness strategy with implicit step-by-step integration scheme is being used. The strategies for stiffness reformulation and equation solving are those developed for the general purpose ANSR code (Analysis of Nonlinear Structural Response). Modifications are being studied to account for velocity discontinuities on impact, following schemes developed elsewhere. A modification is being sought to allow automatic variation of the integration time step.

5. FINITE ELEMENT LIBRARY

The procedures developed for ANSR are being used for developing nonlinear elements. Work is being carried out on several inelastic elements. Currently straight pipe, elbow, restraint, and arbitrary shell elements are being developed. Two straight pipe elements, two restraining elements and an elastic elbow are complete. An inelastic elbow and an arbitrary inelastic shell element are nearing completion.

The elements are being tested using ANSR, and will then be transferred to FACTS. The computer code is designed to allow expansion of the element library. Because new elements can be added relatively easily to the code, it will be possible to incorporate elements developed for other codes.

6. CODE VERIFICATION

A major difficulty for code verification is that few well documented sets of test results are available. We have devoted some effort to locating suitable results, but with little success. We intend to be more aggressive in the forthcoming year.

7. PARAMETER STUDIES

A parameter study has been completed on straight cantilever configurations with single yielding restraints. The main purpose of the study has been to compare the restraint deformations computed using simple energy balance calculations (by hand) with those computed using step-by-step inelastic dynamic analysis (by ANSR). The results show that the energy balance procedure produces fairly accurate and conservative results.

COMPUTER CODE DEVELOPMENT FOR PIPE WHIP ANALYSIS

BY

GRAHAM POWELL
UNIVERSITY OF CALIFORNIA
BERKELEY

SEVENTH WATER REACTOR SAFETY RESEARCH INFORMATION MEETING

NOVEMBER, 1979

FEATURES OF COMPUTER CODE

*DESIGNED FOR MINICOMPUTER IMPLEMENTATION (32-BIT "SUPER" MINI. E.G. VAX, PRIME)

*DYNAMIC, INELASTIC, LARGE DISPLACEMENT ANALYSIS OF PIPING SYSTEMS MODELLED WITH BEAM AND SHELL ELEMENTS.

*ANALYSIS OF PIPE-TO-PIPE AND PIPE-TO-WALL IMPACT

*INTERACTIVE INPUT-OUTPUT

*HIGHLY MODULAR. DEVELOPED AROUND DATA BASE MANAGER FOR MODULARITY AND EASE OF MODIFICATION.

*INCLUDES SUBSTRUCTURING, WITH DETAILED (SHELL) MODELLING OF CRITICAL COMPONENTS WITH SIMPLIFIED (BEAM) MODELLING FOR OTHER COMPONENTS.

ASPECTS OF PROJECT

*COMPUTER CODE DESIGN

*SOLUTION STRATEGY

*ELEMENT LIBRARY

*CODE VERIFICATION

*PARAMETER STUDIES

1602 350

COMPUTER CODE DESIGN

*USES SPECIAL PURPOSE DATA BASE MANAGER. HANDLES ALL DATA STORAGE AND RECOVERY.

*ADVANTAGES FOR:

MODULARITY
EASE OF MODIFICATION
PORTABILITY
INTERACTIVE I/O

*BASED ON FACTS CODE, DEVELOPED BY STRUCTURAL SOFTWARE DEVELOPMENT, INC.

*DESIGNED FOR:

MINICOMPUTER IMPLEMENTATION
SUBSTRUCTURING

BEING EXTENDED FOR:

NONLINEAR DYNAMIC ANALYSIS

SOLUTION STRATEGY

*OVERALL STRATEGY FROM ANSR CODE.

GENERAL PURPOSE
EASY TO DEVELOP NEW ELEMENTS
IMPLICIT STEP-BY-STEP SCHEME

*EXTENSIONS NEEDED FOR

IMPACT DISCONTINUITIES (HUGHES, HIBBIT)
AUTOMATIC TIME STEP SELECTION

ELEMENT LIBRARY

*STRAIGHT PIPES BASED ON:

LUMPED PLASTICITY
DISTRIBUTED PLASTICITY
YIELD BASED ON STRESS RESULTANTS
YIELD BASED ON STRESSES

*ELBOW ELEMENT USING EXTENSION OF VON KARMAN APPROACH.

*RESTRAINT ELEMENTS FOR:

INELASTIC CUSHION
U-BAR

*ARBITRARY 4-NODE SHELL WITH YIELDING AND LARGE DISPLACEMENTS (TAYLOR-WORSAK).