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R5FORCE/MOD3s: A PROGRAM TO COMPUTE FLUID-INDUCED FORCES
USING HYDRODYNAMIC OUTPUT FROM THE RELAP5/MOD3 CODE

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ABSTRACT

This report describes an update of a computer program which operates on hydrodynamic output from the RELAP5/MOD3 program and computes piping hydrodynamic force/time histories for input into various structural analysis codes. This version of the program is compatible with RELAP5/MOD3 and the Micro Vax computing environment whereas an earlier version of the program was compatible with RELAP5/MOD1. The report describes the force calculation theory, showing the development of a general force equation and the solution of this equation within the RELAP5 output structure. To illustrate the calculational method and provide results for discussion, a sample problem is presented. A detailed user manual for the computer program is included as an appendix.

The work was originally performed in support of the NRC Safety/Relief Valve Program for which EG&G Idaho acted as the System Integrator.

SUMMARY

This report describes an update of a computer program that uses hydrodynamic output from the RELAP5/MOD3 program and computes piping hydraulic force/time histories for input into various structural analysis codes. This version of the program is compatible with RELAP5/MOD3 and the Micro Vax computing environment whereas an earlier version of the program was compatible with RELAP5/MOD1. This program is considered an improvement over existing force calculation techniques available at EG&G Idaho because it solves the force equation using the pressure and wall shear force terms instead of the pressure and fluid acceleration terms, eliminating potential instabilities associated with computing the time derivative in the fluid acceleration term; and uses output from the RELAP5/MOD3 program, an advanced one-dimensional computer program which is fast, accurate and easy to use.

A general equation was constructed to describe the force exerted on a container. This general equation is applicable to a wide variety of pipe force situations and serves as the fundamental relationship for the calculation program. Forces are computed for each RELAP5 hydrodynamic control volume, then summed over designated control volumes to obtain the total force.

The computer program R5FORCE/MOD3s is designed to operate on input, output and calculational phases. During the input phase, system geometry data and user input data are read, stored in memory, and then used to set up control arrays. The calculation phase involves a progression through the RELAP5 output data where all required forces are computed and written to an output file. Upon completion of the requested force calculations, the program provides a summary identifying the maximum positive and negative forces encountered for each volume force, subforce and combined force requested, including the time of the maximum force.

A sample problem was considered to illustrate the calculational technique and provide results for discussion. Two sample problems were

used to create results for comparison with existing force calculation techniques available at EG&G Idaho, Inc. The same system was used for both sample problems and consisted of a supply vessel connected by a valve to an accumulator which was then connected to a relief valve through a short length of piping; a section of relief valve discharge piping was also included. The first transient consisted of a system filled relief valve inlet line in which the supply vessel pressure was increased until the relief valve opened. The valve separating the supply vessel and the accumulator was then closed, allowing the accumulator to blowdown until the relief valve closed. The second transient was identical to the first except the loop seal in the relief valve inlet piping was filled with subcooled liquid. Force calculations were performed for each transient and results are presented later in this report.

A detailed user manual for R5FORCE/MOD3s is included as an appendix to this report.

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R5FORCE/MOD3s: A PROGRAM TO COMPUTE FLUID INDUCED
FORCES USING HYDRODYNAMIC OUTPUT FROM THE RELAP5/MOD3 CODE

1. INTRODUCTION

There are currently available a number of computer programs (such as RELAP5^{1,9} and TRAC²) that have the capability of simulating the transient and steady-state flow behavior in piping systems under both single and two-phase flow conditions. In each of these programs, the primary effort was directed towards predicting the flow behavior in the piping system but did not include the calculation of fluid induced forces. For the design and analysis of piping systems (such as relief valve discharge piping, systems undergoing pipe rupture, or abnormal valve or pump operation), fluid forces on the piping are an important portion of the overall structural analysis and must be computed.

This report describes the development of a computer program that operates on hydrodynamic output from the RELAP5/MOD3 program and computes piping hydraulic force/time histories for input into various structural analysis codes, such as NUPIPE,³ SAP⁴, or ADINA⁵. This program is considered an improvement over existing force calculation techniques available at EG&G Idaho (References 6 and 7) because it solves the force equation using the pressure and wall shear force terms instead of the pressure and fluid acceleration terms, eliminating potential instabilities associated with computing the time derivative in the fluid acceleration term; and uses output from the RELAP5/MOD3 program, an advanced one-dimensional computer program that is fast, accurate and easy to use. This version of the program is compatible with RELAP5/MOD3 and the Micro Vax computing environment whereas an earlier version of the program¹⁰ was compatible with RELAP5/MOD1.

Section 2 of this report is a description of the force calculation theory showing the development of a general force equation and how it applies to various system geometries. Section 3 details how these force equations are then solved within the RELAP5 output structure. The

resulting computer program R5FORCE/MOD3s is described in Section 4. To illustrate the calculational method and provide results for discussion, a sample problem is considered in Section 5. In Section 6, this sample problem and a slightly modified form of this problem are used in a comparison study with previously existing calculational techniques available at EG&G Idaho. Section 7 includes several conclusions from this work. A detailed user manual for the R5FORCE/MOD3s program is included as an appendix to this report.

2. FORCE CALCULATION THEORY

2.1 General Equation

It is possible to derive a general equation for the net force exerted on a container based upon the following assumptions:

1. Neglect external fluid velocity and shear force effects
2. One-dimensional uniform cross sectional area control volume
3. Normal stress approximated by the quasi steady change in momentum (the local dynamic pressure plus the fluid momentum)
4. Uniform fluid velocity, density, and pressure over the local cross sectional area and uniform shear over the local control volume surface area.

Based on the cross sectional view of the arbitrary shaped container and the notation specified in Figure 1, this equation can be expressed as

$$F = - (P_{I1} + \rho_I u_I^2) A_{I1} + (P_{I2} + \rho_I u_I^2) A_{I2} + P_{E1} A_{E1} - P_{E2} A_{E2} + \tau A_S \quad (1)$$

where

- A = volume surface area
- P = fluid pressure
- u = fluid velocity
- ρ = fluid density
- τ = shear force per unit area

4

and the subscripts (I) and (E) refer to interior or external conditions, the subscripts (1) and (2) refer to the volume inlet or outlet and the subscript (s) refers to the interior surface area parallel to the flow. The first four terms in this equation represent the forces resulting from the pressure and momentum at Control Surfaces CS1 and CS2. The fifth term represents the force resulting from fluid shear on Control Surface CS3. Starting from basic principles, a detailed development of Equation (1) is included in Appendix A. This equation applies to a wide variety of pipe force situations and serves as the fundamental relationship for the calculation program described herein.

A dynamic structural analysis of a piping system requires that forces be applied, in terms of time histories, at various points or node locations in the piping model. These nodes are generally located near components that result in either a change in flow direction or flow area (such as elbows or bends, reducers, valves or an open pipe end). Since the application of Equation (1) makes it possible to compute a net force for each volume in the hydrodynamic analysis, the total force at any particular node location can be considered to be the sum of the individual forces of each hydrodynamic volume within the control volume defining the nodal force.

Equation (1) is made up of five terms. Two of these terms represent forces associated with the volume inlet junction, two with the volume outlet junction and one with the volume itself. The application of Equation (1) will differ depending on the type of volume end geometry. In particular, a volume can be connected to an adjoining volume in one of four ways:

1. Continued--Adjacent volumes are at the same angle, such as Volumes CV2 and CV3 in Figure 2
2. Bounded--Adjacent volumes are at different angles, such as Volumes CV3 and CV4 in Figure 2

Figure 2. Typical piping/control volume system.

3. Open--A volume represents the end of a pipe, although continued to an adjacent volume in the RELAP5 model, such as Volume CV4 in Figure 2
4. Special--Mechanistic junction models, such as the relief valve between Volumes CV1 and CV2 in Figure 2.

These geometries can also contain area changes between adjacent volumes and a constant or variable throat ratio, simulating an orifice or a valve. Each of these geometries will be discussed in greater detail below.

2.2 Continued Junction

From the previous discussion, the junction connecting Volumes CV2 and CV3 in Figure 2 can be considered to be continued since there is no change in direction between the adjacent volumes. Applying the applicable portions of Equation (1) to the inlet and outlet junctions of a general hydrodynamic control volume results in:

$$F_1 = -(P_{I1} + \rho_I u_I^2) A_{I1} + P_{E1} A_{E1}$$

$$F_2 = (P_{I2} + \rho_I u_I^2) A_{I2} - P_{E2} A_{E2}$$

where

P = fluid pressure

ρ = fluid density

u = fluid velocity

A = area

and the subscripts (I) and (E) refer to internal and external conditions, and the subscripts (1) and (2) refer to the inlet and outlet junctions of a control volume, respectively. Thus, there are four internal parameters (P , ρ , u , A) and two external parameters (P , A) that must be determined for the inlet and outlet junction of each control volume.

The external pressure at the inlet and outlet junction are available from the input data to R5FORCE. The internal change in momentum and area at the inlet and outlet junction are not available directly in RELAP5, however, they can be computed as discussed in Appendix B.

2.3 Bounded Junction

The junction connecting Volumes CV3 and CV4 in Figure 2 can be considered to be bounded since there is a change in direction between adjacent volumes. Applying the applicable portions of Equation (1) to the inlet and outlet junctions of a general hydrodynamic control volume results in:

$$F_1 = -(P_{I1} + \rho_I u_I^2) A_{I1} + P_{E1} A_{E1}$$

$$F_2 = (P_{I2} + \rho_I u_I^2) A_{I2} - P_{E2} A_{E2}$$

Note: When the $(P + \rho u_I^2)(A)$ term was evaluated for a continued type of junction, the $(P + \rho u_I^2)$ term corresponded to the pressure and momentum approximated from volume conditions impinging on a flow area restriction. For a bounded type of junction, this force will still exist in addition to the force resulting from the pressure and momentum at the junction acting on the pipe during the bend. Expanding the above expressions to account for these force developing areas results in:

$$F_1 = -(P_{I1} + \rho_I u_I^2) A_{I1} - (P_{IJ1} + \rho_{IJ1} u_{IJ1}^2) A_{IJ1} + P_{E1} A_{E1}$$

$$F_2 = (P_{I2} + \rho_I u_I^2) A_{I2} + (P_{IJ2} + \rho_{IJ2} u_{IJ2}^2) A_{IJ2} - P_{E2} A_{E2}$$

where the subscript (J) refers to junction conditions.

Note: Since the force on each hydrodynamic control volume is computed, then summed over one or more control volumes with the same elevational angle, the results will be independent of the geometric relationship of the volumes on the other side of a bend. Thus, the results are not dependent on any particular bend angle.

2.4 Open Junction

The outlet junction of Volume CV4 in Figure 2 can be considered to be open, representative of the end of a pipe. Since an open pipe is at the outlet of a piping system, only the outlet junction of a volume will be considered to be open. Applying the applicable portions of Equation (1) to the outlet junction of a general hydrodynamic control volume results in:

$$F_2 = (P_{I2} + \rho_I u_I^2) A_{I2} - P_{E2} A_{E2}$$

2.5 Special Junction

Because of the physical differences between an actual relief valve and the RELAP5 model of a relief valve, the junction connecting Volumes CV1 and CV2 in Figure 2 must be treated with a special mechanistic model. Two special mechanistic models currently exist in the code, one of which is a relief valve model with the orifice on the inlet and the other is a relief valve with the orifice on the outlet. Both of these mechanistic models assume the control volumes connected to the relief valve inlet and outlet are at an angle to each other. Applying the applicable portions of

Equation (1) to the valve inlet (outlet junction of the preceding control volume) and outlet (inlet junction of the following control volume) where the orifice is on the valve outlet results in:

$$F_1 = -(P_{I1} + \rho_I u_I^2) A_{I1} - (P_{IJ1} + \rho_{IJ1} u_{IJ1}^2) A_{IJ1} + P_{E1} A_{E1}$$

$$F_2 = (P_{I2} + \rho_I u_I^2) A_{I2} - P_{E2} A_{E2}$$

where the valve outlet force (F_1) is defined as though it were a bounded junction and the valve inlet force (F_2) is defined as though it were a continued junction, except that area A_{I2} is the full area of the pipe. For the case of the relief valve orifice being on the valve inlet, the above equations would be reversed.

3. COUPLING TO RELAP5

The numerical solution of the two-phase flow equations in RELAP5 is accomplished through the use of a spatial mesh of hydrodynamic control volumes connected by junctions. Fluid properties are defined at the center of each control volume (such as pressure, density and velocity) and at each junction (such as density and velocity). The application of Equation (1) makes it possible to compute a net force for each hydrodynamic control volume in the RELAP5 analysis. In general, each force control volume includes one or more control volumes. Moreover, the force acting on each control volume can be computed, then summed over an entire force control volume.

Examining Equation (1) yields several flow quantities that must be obtained from RELAP5 in order to evaluate the forces acting on a control volume.

These include the following:

1. Control volume pressure
2. Control volume shear force
3. Control volume momentum
4. Junction throat ratio
5. Indication of choking at a junction.

The control volume pressure is readily available as is the momentum term and the indication of junction choking. However, the control volume momentum must be modified for a two-phase flow situation as:

$$\rho u^2 = \alpha_g \rho_g u_g^2 + (1-\alpha_g) \rho_f u_f^2$$

where α is the void fraction and the subscripts (g) and (f) refer to the gas and fluid phases, respectively.

The control volume shear force term is not available directly in RELAP5, however, it can be computed as discussed in Appendix C. To correctly compute the fluid shear however, system components resulting in a frictional loss, such as elbows, must be modeled by modifying the volume roughness rather than by adding an energy loss coefficient at a junction. Modification of the volume roughness is also contained in Appendix C.

Using the internally computed properties, the following quantities are written to the RELAP5 output tape at every successful time step.

1. For each volume:
  - a. Control volume pressure
  - b. Total wall shear
  - c. Control volume momentum
2. For each junction:
  - a. Junction throat ratio
  - b. Indication of junction choking

This information can then be used to compute the force on any RELAP5 control volume then summed over designated control volumes to obtain the total force.

4. THE COMPUTER PROGRAM

The computer program that solves the force equations and creates a force/time history is entitled R5FORCE. The program uses output data from RELAP5 in the format described in Appendix C; the code updates used to create this data file are also included in this appendix.

Figure 3 shows that R5FORCE operates in an input, calculational and output phase. During the input phase, system geometry data (available on the RELAP5 output tape) and user input data are read and stored in memory. This data is then used to set up integer control arrays that contain such information as the force reference numbers, direction indicator flags, and applicable RELAP5 junction and control volume numbers. Once the control arrays are established the calculation phase involves a progression through the RELAP5 output data, where all required forces are computed (at each RELAP5 computational time step) and then written to an output file; forces can also be printed at selected time steps. Upon completion of the requested force calculations, the program provides a summary identifying the maximum positive and negative forces encountered for each volume force, subforce, and combined force requested, including the time of the maximum force. In addition, each computed force can be output in a format suitable for plotting. Pressures at each RELAP5 control volume can also be written to an output file for use as input to structural analysis codes.

In order to be consistent with the basic equations solved in R5FORCE, the following conventions must be followed.

1. The RELAP5 model must be developed in the direction of positive flow.
2. The force direction must be colinear with the pipe axis, in any direction.

Figure 3. R5FORCE flow diagram.

3. System components resulting in a frictional loss, such as elbows, must be modeled by modifying the volume roughness term, not by the addition of an energy loss coefficient. Note: The roughness cannot be larger than half the volume diameter.

R5FORCE/MOD3s has been written using FORTRAN Version 5.

5. SAMPLE PROBLEM

A sample problem is now considered in order to illustrate the application of the methods considered previously, and also to provide results for discussion. Detailed user input instructions for this sample problem are discussed in Appendix F of this report.

The sample problem consisted of a simple relief system as shown in Figure 4. The system involved a pressurized accumulator connected to a relief valve through a short length of piping which served as a loop seal. The relief valve discharge piping terminated as an open pipe segment.

A RELAP5/MOD1 hydrodynamic model of this system was used to generate an input file for force calculations. This model consisted of fluid control volumes connected by junctions and extended through the entire piping system. Each control volume and junction was described in terms of fluid state, geometry, and flow characteristics, with locations selected to ensure adequate representation of the fluid transient.

Upstream from the relief valve, the accumulator and piping initially contained saturated steam at a pressure of 16.55 MPa that was increased linearly to 18.27 MPa in 0.5 s. The discharge piping was assumed to be initially filled with saturated steam at atmospheric pressure; the downstream boundary was maintained at this pressure. The fluid transient considered involved a 40 ms relief valve opening beginning when the relief valve inlet pressure reached 17.24 MPa, which occurred at 0.21 s. Following the valve opening, steady flow in the piping was achieved at approximately 0.5 s, once the supply pressure stopped increasing. The valve separating the supply vessel and the accumulator remained open until 1.0 s, at which time it was closed, allowing the accumulator to blowdown until the relief valve closed at 16.38 MPa at 1.44 s. The problem was terminated at 2.0 s.

Figure 4. Piping system for sample problem.

A description of the various subforce and combined forces selected for discussion is shown in Figure 5. Figure 6 is a force/time history of subforces SF101 and SF103 which act on opposing elbows as shown in Figure 5, and Figure 7 is the force/time history for the combined force CF201. Figures 8 and 9 describe the subforces and combined force on a pipe leg which includes an area change.

Figure 5. Sample piping system showing selected forces.

Figure 6. Subforces SF101 and SF103 for the sample problem.

Figure 7. Combined force CF201 for the sample problem.

Figure 8. Subforces SF102, SF104 and SF106 for the sample problem.

Figure 9. Combined force CF202 for the sample problem.

6. COMPARISON WITH EXISTING TECHNIQUES

At EG&G Idaho, Inc., fluid induced forces have typically been approximated from RELAP5 hydrodynamic output by using only the pressure and momentum force terms applied at various points in the piping; this technique is documented in Reference 6 and will herein be referred to as the old approach. Recently, another technique to approximate the fluid induced forces was generated which utilized the pressure and momentum force terms in addition to a fluid acceleration term; this technique is documented in Reference 7 and will herein be referred to as the modified approach. This section provides a brief comparison between the old and modified approaches and the new approach used in the R5FORCE program. Referring to Figure 5, subforces SF105 and SF108, and the sum of these forces, CF203, will be used for the comparison. Two fluid transients were used, the sample problem discussed in Section 5 and the same sample problem with a liquid slug in the loop seal.

Evaluating the Section 5 sample problem first, Figures 10 and 11 provide time history information for subforces SF105 and SF108, respectively. Note that prior to and during the early stages of valve opening, the force predictions by the old, modified and new methods were very similar; as the fluid velocity became significant however, there were slight differences between the techniques. This was more evident in the time history of combined force CF203 which is shown in Figure 12. The modified and new methods predicted a peak force of approximately 7000 N (occurring immediately after the relief valve opened) which eventually approached zero as steady flow was achieved. The old approach predicted a higher maximum force of approximately 11,000 N which then decreased to a relatively constant value of 4000 N during steady flow. This significant force observed at steady state is not consistent with theory and is the result of neglecting the frictional shear force term. By computing the pressure and momentum forces at two points in a piping system, the momentum change between the two points is not balanced by the shear force, resulting in an unrealistic combined force. This was the only significant difference

Figure 10. Comparison of the old, modified and new approaches for subforce SF105 for the sample problem.

Figure 11. Comparison of the old, modified and new approaches for subforce SF108 for the sample problem.

Figure 12. Comparison of the old, modified and new approaches for combined force CF203 for the sample problem.

observed between the old and the modified and new approaches. Differences between the modified and new method are slight, however, the new method will eliminate instabilities and data spikes previously encountered with the modified method, as shown in the next sample problem.

Evaluating the second sample problem, a liquid slug in the loop seal, Figures 13, 14, and 15 provide time history information for subforces SF105 and SF108 and combined force CF203, respectively. The trends of this evaluation are identical to those noted in the first sample problem, except for data spikes associated with the modified method. The effect of these data spikes is clearly shown in Figure 16 for the modified method versus Figure 17 for the new method; combined force CF203 over the time range of 0.2 to 0.5 seconds. The old approach predicted a maximum force of approximately 47,000 N, decreasing to a relative constant value of 4,000 N during steady flow. The modified and new approaches are effectively identical except for the data spikes associated with the modified method. The new method predicted a peak force of approximately 41,000 N whereas the modified method, because of the data spikes, predicted a higher peak force of approximately 65,000 N. The modified method in this example would have resulted in peak forces approximately 60% higher than the new method, due entirely to data spikes. Other problems run with both methods have resulted in peak modified forces many orders of magnitude higher than the new method. In such situations, the user is required to examine the data in detail to eliminate potential data spikes, if possible.

Figure 13. Comparison of the old, modified and new approaches for subforce SF105 for the second sample problem.

Figure 14. Comparison of the old, modified and new approaches for subforce SF108 for the second sample problem.

Figure 15. Comparison of the old, modified and new approaches for combined force CF203 for the second sample problem.

Figure 16. Modified approach for combined force CF203 for the second sample problem from 0.2 t 0.5 seconds.

Figure 17. New approach for combined force CF 203 for the second sample problem from 0.2 to 0.5 seconds.

7. CONCLUSIONS

An approach has been outlined and a computer program developed for transient and steady state force calculations using hydrodynamic output data from the RELAP5/MOD3 computer code. This program is considered an improvement over existing force calculation techniques available at EG&G Idaho because it solves the force equation using the pressure and wall shear force terms instead of the pressure and fluid acceleration terms, eliminating potential instabilities associated with computing the time derivative in the fluid acceleration term; and uses output from the RELAP5/MOD3 program, an advanced one-dimensional computer program that is fast, accurate and easy to use.

It must be understood that verification studies with R5FORCF/MOD3s program have been very limited and no comparison with experimental data has yet been made.

8. REFERENCES

1. V. H. Ransom, et. al., RELAP5/MOD1 Code Manual, Vols. 1-2, NUREG/CR-1826, November 1980.
2. J. W. Spore, et. al., TRAC-BD1, An Advanced Best-Estimate Computer Program for Boiling Water Reactor Loss-of-Coolant Accident Analysis, Vols. 1-4, NUREG/CR-2178, October 1981.
3. NUPIPE User's Information Manual, Revision F, Nuclear Services Corporation, January 3, 1979.
4. K. J. Bathe, et. al., SAP IV, A Structural Analysis Program for Static and Dynamic Response of Linear Systems, EERC 73-11, June 1973.
5. K. J. Bathe, ADINA, a Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis, MIT Report 82448-1, December 1978.
6. A. G. Ware, Blazer User Manual, RE-A-80-134, December 1980.
7. R. L. Williamson, FORCE1: A Program to Compute Fluid Induced Forces Using Hydrodynamic Output from the RELAP5 Code, EGG-EA-5631, October 1981.
8. J. R. Larson, An Evaluation of the Capabilities of RELAP4/MOD6, RELAP4/MOD7, RELAP5/MOD"0" AND TRAC-P1A to Calculate the Thermal-Hydraulic Behavior of Reactor Safety/Relief Valve Systems, EGG-CAAD-5483, June 1981.
9. V. H. Ransom, et. al., RELAP5/MOD2 Code Manual, Vols. 1-2, EGG-SAAM-6377, April 1984.
10. J. C. Watkins, R5FORCE: A program to compute fluid induced forces using hydrodynamic output from the RELAP5 code, EGG-EA-5920, October 1982.

APPENDIX A

DEVELOPMENT OF THE GENERAL FORCE EQUATION

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DEVELOPMENT OF THE GENERAL FORCE EQUATION

A force can be exerted on a container in only three ways:

1. By means of pressure which acts on the surface of the container
2. By means of a shear force (friction) between a fluid and the surface of the container
3. By means of an interaction between the container and a structural support member.

Consider the cross sectional view of the arbitrary shaped container shown in Figure A-1 where:

S_n = local normal stress

τ = local shear stress

ds = differential surface element

P = local pressure

ρ = local density

u = local fluid velocity

$\bar{n}$ = unit vector normal to a surface

$\bar{n}_T$ = unit vector tangent to a surface

$\bar{L}$ = unit vector in the desired force direction

A = area

Figure A-1. Generalized fluid container.

with the following subscript notation:

I = internal

E = external

1 = control surface 1 (inlet)

2 = control surface 2 (outlet)

3 = control surface 3

The force acting on the control surface in the direction $\vec{L}$ can then be written as the sum of two surface integrals, or

$$F = \iint_S S_n (\vec{n} \cdot \vec{L}) ds + \iint_S \tau (\vec{n}_T \cdot \vec{L}) ds \quad (A-1)$$

For an inviscid treatment, the shear term in Equation (A-1) is not used and the force is obtained utilizing only the normal force term. When viscous losses are considered, the shear force term in Equation (1) is generally difficult to evaluate. Through an application of the law of conservation of momentum, an alternate form of Equation (1) can be derived (footnote)* and written in one-dimensional form as

$$F = - \frac{d}{dt} \iiint \frac{\dot{M}_I}{A_I} dV_I - (P_{I1} + \rho_{I1} U_{I1}^2) A_{I1} + (P_{I2} + \rho_{I2} U_{I2}^2) A_{I2} \quad (A-2)$$

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* R. L. Williamson, FORCE1: A Program to Compute Fluid Induced Forces Using Hydrodynamic Output from the RELAP5 Code, EGG-EA-5631, October 1981.

This technique is used extensively to evaluate fluid forces acting on a container. However, this technique has potential instabilities associated with computing the time derivative in the fluid acceleration term, often requiring various smoothing techniques to make the output useful.

If however, the shear force and pressure distribution are known for a container, Equation (A-1) can be used directly to obtain the fluid force on the container. Expanding Equation (A-1) over the three control surfaces identified in Figure A-1 and neglecting gravitational forces results in the following:

$$\begin{aligned}
 F = & \iint_{CS1} S_{n_{I1}} (\bar{n}_1 \cdot \bar{L}) ds_{CS1} + \iint_{CS2} S_{n_{I2}} (\bar{n}_2 \cdot \bar{L}) ds_{CS2} \\
 & + \iint_{CS3} S_{n_{I3}} (\bar{n}_3 \cdot \bar{L}) ds_{CS3} + \iint_{CS1} \tau_{I1} (\bar{n}_{T1} \cdot \bar{L}) ds_{CS1} \\
 & + \iint_{CS2} \tau_{I2} (\bar{n}_{T2} \cdot \bar{L}) ds_{CS2} + \iint_{CS3} \tau_{I3} (\bar{n}_{T3} \cdot \bar{L}) ds_{CS3} \\
 & - \iint_{CS1} S_{n_{E1}} (\bar{n}_1 \cdot \bar{L}) ds_{CS1} - \iint_{CS2} S_{n_{E2}} (\bar{n}_2 \cdot \bar{L}) ds_{CS2} \\
 & - \iint_{CS3} S_{n_{E3}} (\bar{n}_3 \cdot \bar{L}) ds_{CS3} - \iint_{CS1} \tau_{E1} (\bar{n}_{T1} \cdot \bar{L}) ds_{CS1} \\
 & - \iint_{CS2} \tau_{E2} (\bar{n}_{T2} \cdot \bar{L}) ds_{CS2} - \iint_{CS3} \tau_{E3} (\bar{n}_{T3} \cdot \bar{L}) ds_{CS3} \quad (A-2)
 \end{aligned}$$

Summing forces in the direction of fluid flow ($\bar{L}$) and:

1. Neglecting external shear force effects, and

2. Recognizing that for the one-dimensional uniform cross sectional area control volume assumption in RELAP5:

$$(\bar{n}_3 \cdot \bar{L}) = 0$$

$$(\bar{n}_{T1} \cdot \bar{L}) = 0$$

$$(\bar{n}_{T2} \cdot \bar{L}) = 0$$

Results in

$$\begin{aligned} F = & \iint_{CS1} S_{nI1} (\bar{n}_1 \cdot \bar{L}) ds_{CS1} + \iint_{CS2} S_{nI2} (\bar{n}_2 \cdot \bar{L}) ds_{CS2} \\ & + \iint_{CS3} \tau_{I3} (\bar{n}_{T3} \cdot \bar{L}) ds_{CS3} - \iint_{CS1} S_{nE1} (\bar{n}_1 \cdot \bar{L}) ds_{CS1} \\ & - \iint_{CS2} S_{nE2} (\bar{n}_2 \cdot \bar{L}) ds_{CS2} \end{aligned} \quad (A-3)$$

Since the local static pressure distribution is not known, the normal stress will be defined in terms of the quasi steady change in momentum (the local static pressure plus the fluid momentum). In addition, the external fluid velocity effects will be neglected which is consistent with neglecting the external shear force effects, resulting in

$$\begin{aligned} F = & \iint_{CS1} (P_{I1} + \rho_I u_I^2) (\bar{n}_1 \cdot \bar{L}) ds_{CS1} \\ & + \iint_{CS2} (P_{I2} + \rho_I u_I^2) (\bar{n}_2 \cdot \bar{L}) ds_{CS2} \end{aligned}$$

$$\begin{aligned}
& + \iint_{CS3} \tau_{I3} (\bar{n}_{T3} \cdot \bar{L}) ds_{CS3} - \iint_{CS1} P_{E1} (\bar{n}_1 \cdot \bar{L}) ds_{CS1} \\
& - \iint_{CS2} P_{E2} (\bar{n}_2 \cdot \bar{L}) ds_{CS2}
\end{aligned} \tag{A-4}$$

Now, assuming that the fluid velocity, density and pressure are uniform over the local cross-sectional area and that the shear is uniform over the local control volume surface area, which is consistent with the one-dimensional approximation used in RELAP5, results in the following:

$$\begin{aligned}
F = & (P_{I1} + \rho_I u_I^2)(\bar{n}_1 \cdot \bar{L}) A_{I1} + (P_{I2} + \rho_I u_I^2)(\bar{n}_2 \cdot \bar{L}) A_{I2} \\
& + \tau_{I3} (\bar{n}_{T3} \cdot \bar{L}) A_{I3} - P_{E1} (\bar{n}_1 \cdot \bar{L}) A_{E1} - P_{E2} (\bar{n}_2 \cdot \bar{L}) A_{E2}
\end{aligned} \tag{A-5}$$

For the one-dimensional uniform cross-sectional area control volume assumption in RELAP5, the following unit vectors can be evaluated from Figure A-1:

$$(\bar{n}_1 \cdot \bar{L}) = -1$$

$$(\bar{n}_2 \cdot \bar{L}) = 1$$

$$(\bar{n}_{T3} \cdot \bar{L}) = 1$$

Substituting these expressions into Equation (A-5) yields the following expression for the force acting on a container:

$$F = -(P_{I1} + \rho_I u_I^2)(A_{I1}) + (P_{I2} + \rho_I u_I^2)(A_{I2})$$

$$+ P_{I3} A_{I3} + P_{E1} A_{E1} - P_{E2} A_{E2}$$

(A-6)

APPENDIX B

DEVELOPMENT OF THE JUNCTION PRESSURE AND JUNCTION AREA TERMS

APPENDIX B

DEVELOPMENT OF THE JUNCTION PRESSURE AND JUNCTION AREA TERMS

A general equation for the force exerted on a container has been developed and can be expressed as

$$F = - (P_{I1} + \rho_I u_{I1}^2) A_{I1} + (P_{I2} + \rho_I u_{I2}^2) A_{I2} + P_{E1} A_{E1} - P_{E2} A_{E2} + \tau A_s \quad (B-1)$$

where

- A = volume surface area
- P = fluid pressure
- u = fluid velocity
- ρ = fluid density
- τ = shear force per unit area

and the subscripts (I) and (E) refer to interior or external conditions, the subscripts (1) and (2) refer to the volume inlet or outlet and the subscript (s) refers to the interior surface area parallel to the flow.

Equation (B-1) is made up of five terms. Two of these terms represent forces associated with the volume inlet junction, two with the volume outlet junction and one with the volume itself. The application of Equation (B-1) will differ depending on the type of volume end geometry. In particular, a volume can be connected to an adjoining volume in one of four ways:

1. Continued--Adjacent volumes are at the same angle, such as Volumes CV2 and CV3 in Figure B-1
2. Bounded--Adjacent volumes are at different angles, such as Volumes CV3 and CV4 in Figure B-1
3. Open--A volume represents the end of a pipe, although continued to an adjacent volume in the RELAP5 model, such as Volume CV4 in Figure B-1
4. Special--Mechanistic junction models, such as the relief valve between Volumes CV1 and CV2 in Figure B-1.

These geometries can also contain area changes between adjacent volumes and a constant or variable junction throat ratio, simulating an orifice or a valve. The volume pressure and momentum, shear force and shear force area terms are readily available on the RELAP5 output tape. The internal and external quasi steady change in momentum at the inlet and outlet junction of each computational volume and the areas that the change in momentum acts on must be computed.

1. Development of the Junction Change in Momentum Term

The internal and external change in momentum (pressure plus momentum flux) at the inlet and outlet junction of each computational volume must be determined in order to determine the forces acting on that volume. The external pressure is defined through the input data and defaults to 14.7 psia (0.101 MPa) for all junction types except an open junction. For an open junction, the external pressure is defined as the pressure plus momentum flux in the adjacent downstream volume of the RELAP5 model. This will allow the effects of variable discharge conditions to be included in the analysis.

Figure B-1. Typical piping/control volume system.

The internal change in momentum is defined as the pressure plus momentum flux in a volume. The change in momentum at a junction must be approximated from the volume change in momentum. Only the outlet junction change in momentum will be developed for each junction type, the inlet junction change in momentum development being identical with the exception of the open junction which is not allowed as an inlet junction.

Continued Junction

Figure B-2 shows the location of the desired outlet junction change in momentum term. This quantity will be approximated using a ratio of the adjacent volume quantities and volume lengths as

$$(P + \rho U^2)_J = \frac{(P + \rho U^2)_2 DL_3 + (P + \rho U^2)_3 DL_2}{DL_2 + DL_3} \quad (B-2)$$

This method will provide a reasonable approximation of the outlet junction change in momentum except for the following situations:

1. If the downstream volume (volume 3) is a time dependent volume. then DL_3 will be zero. For this situation, the computational and upstream volumes (volumes 1 and 2) will be used to approximate the outlet junction change in momentum as

$$(P + \rho U^2)_J = (P + \rho U^2)_2 + \frac{DL_2}{DL_1 + DL_2} \left[(P + \rho U^2)_2 - (P + \rho U^2)_1 \right] \quad (B-3)$$

2. If the outlet junction is choked or an area restriction (orifice, valve) exists at the junction, a non-linear decrease in the hydraulic head will occur and the adjacent change in momentum cannot be used to determine the outlet junction change in momentum. For this situation, the computational and upstream volumes (volumes 1 and 2) will be used to approximate the outlet junction change in momentum as discussed in item 1.

Figure B-2. Outlet junction change in momentum approximation method.

3. If either items 1 or 2 exist and if either the upstream volume (volume 1) is a time dependent volume (DL_1 will be zero) or the inlet junction is choked or an area restriction (orifice, valve) exists, the junction change in momentum will be set equal to the volume change in momentum.
4. If a downstream volume does not exist, then the junction change in momentum will be set equal to the volume change in momentum.

Bounded Junction

The internal change in momentum for this type of junction is identical to the continued junction.

Open Junction

The internal change in momentum for an open junction will be determined by methods 2 and 3 for the continued junction. The other techniques are not applicable since there is no physical piping downstream of an open pipe (Volume 3 would not exist).

Special Junction

The internal change in momentum for this type of junction is identical to the continued junction.

2. Development of the Junction Area Term

The areas that the internal and external change in momentum acts on in each computational volume must be determined in order to determine the forces acting on that volume. Only the outlet junction area will be developed for each junction type, the inlet junction area development being identical with the exception of the open junction which is not allowed as an inlet junction. RELAP5 internal and output terminology will be used in the development of the following expressions.

Continued Junction

Figure B-3A shows the geometric configuration of a typical continued junction. The internal area must account for the effects of an area change between adjacent volumes and a junction flow area which could be larger or smaller than the computational volume. The effects of these two geometries are accounted for as

$$A_{IR} = A_{V2} - \text{minimum} \left\{ \begin{array}{l} A_{J2} * TR_{J2} \\ A_{V3} \end{array} \right\} \quad (B-6)$$

A zero or negative result means that there will be no area for the junction change in momentum to act on, thus there will be no force at that location.

The external area must account for the effects of an area change between adjacent volumes. The effect of this geometry is accounted for as

$$A_{ER} = A_{V2} - A_{V3} \quad (B-7)$$

Bounded Junction

Figure B-3B shows the geometric configuration of a typical bounded junction. The internal area must account for the effects of an area change between the volume and the junction (A_{IR1}) as well as the area of the junction (A_{IR2}). The effects of these two geometries are accounted for as

$$A_{IR1} = A_{V1} - A_{J1} * TR_{J1} \quad (B-8)$$

$$A_{IR2} = A_{J1} * TR_{J1} \quad (B-9)$$

Figure B-3A. Continued junction geometric configuration.

Figure B-3B. Bounded junction geometric configuration.

Figure B-3C. Open junction geometric configuration.

Figure B-3D. Special relief valve geometric configuration with the orifice on the valve outlet.

The external area must account for the effects of an area change between the computational volume and the junction as well as the bend. These geometries are accounted for as

$$A_{ER} = A_{V1} \quad (B-10)$$

Open Junction

Figure B-3C shows the geometric configuration of a typical open junction. The internal area must account for the effects of a junction flow area which could be larger or smaller than the computational volume. The effect of this geometry is accounted for as

$$A_{IR} = A_{V2} - A_{J2} * TR_{J2} \quad (B-11)$$

The external area must account for the effects of a junction flow area which could be larger or smaller than the computational volume. The effect of this geometry is accounted for as

$$A_{ER} = A_{V2} - A_{J2} * TR_{J2} \quad (B-12)$$

Special Junction

Figure B-3D shows the geometric configuration of the special relief valve mechanistic model with the orifice on the valve outlet. The mechanistic model with the orifice on the valve inlet can be obtained by interchanging the inlet and outlet junction areas. The internal area must account for the effects of a dead end for one junction and a bounded junction for the other. The effects of these two geometries are accounted for as

$$A_{IR} = A_{V1} \quad (B-13)$$

$$A_{IL1} = A_{V2} - A_{J1} \star TR_{J1} \quad (B-14)$$

$$A_{IL2} = A_{J1} \star TR_{J1} \quad (B-15)$$

The external area must account for the effects of a bend. This geometry is accounted for as

$$A_{ER} = A_{V1} \quad (B-16)$$

$$A_{EL} = A_{V2} \quad (B-17)$$

APPENDIX C

DEVELOPMENT OF THE SHEAR FORCE COMPONENT AND MODIFICATION OF THE RELAP5 ROUGHNESS TERM

APPENDIX C

DEVELOPMENT OF THE SHEAR FORCE COMPONENT AND MODIFICATION OF THE RELAP5 ROUGHNESS TERM

1. DEVELOPMENT OF THE SHEAR FORCE COMPONENT

The force component contribution to shear can be considered to be the sum of the shear forces for the gas and fluid, or

$$F_{\text{shear}} = F_{\text{shear}_g} + F_{\text{shear}_f} \quad (\text{C-1})$$

where the shear force for each phase is equal to the shearing stress, or the wall friction per unit area for the phase times the pipe surface area proportional to the phase, or

$$F_{\text{shear}_g} = \tau_g \alpha_g \pi D L \quad (\text{C-2})$$

$$F_{\text{shear}_f} = \tau_f \alpha_f \pi D L \quad (\text{C-3})$$

Reference (9) defines the wall friction drag coefficient as one eighth of the phasic friction factor times the absolute velocity times the pipe perimeter proportional to the phase times the density of the phase divided by the pipe cross sectional area, or

$$FW_g = \frac{\lambda_g u_g \text{PER}_g \rho_g}{8 A} \quad (\text{C-4})$$

$$FW_f = \frac{\lambda_f u_f \text{PER}_f \rho_f}{8 A} \quad (\text{C-5})$$

The pipe perimeter proportional to the phase can be expressed as the phasic void fraction times the pipe perimeter (4A/D), or

$$PER_g = \alpha_g PER = \frac{4 A \alpha_g}{D} \quad (C-6)$$

$$PER_f = \alpha_f PER = \frac{4 A \alpha_f}{D} \quad (C-7)$$

Substituting the above into Equations (C-4) and (C-5) and solving for λ_f and λ_g yields

$$\lambda_g = \frac{2 D FW_g}{u_g \alpha_g \rho_g} \quad (C-8)$$

$$\lambda_f = \frac{2 D FW_f}{u_f \alpha_f \rho_f} \quad (C-9)$$

The wall friction per unit area is defined as one eighth of the friction factor times the phasic density times the velocity times the absolute velocity, or

$$\tau_g = \frac{1}{8} \lambda_g \rho_g u_g |u_g| \quad (C-10)$$

$$\tau_f = \frac{1}{8} \lambda_f \rho_f u_f |u_f| \quad (C-11)$$

Substituting Equations (C-8) and (C-9) into the above yields

$$\tau_g = \frac{FW_g D u_g}{4 \alpha_g} \quad (C-12)$$

$$\tau_f = \frac{FW_f D u_f}{4 \alpha_f} \quad (C-13)$$

Substituting the above into Equations (C-2) and (C-3) yields

$$F_{shear_g} = \frac{FW_g D^2 u_g \pi L}{4} \quad (C-14)$$

$$F_{shear_f} = \frac{FW_f D^2 u_f \pi L}{4} \quad (C-15)$$

2. MODIFICATION OF THE RELAP5 ROUGHNESS TERM

Due to the solution technique used in R5FORCE/MOD3s, system components which result in a frictional loss, such as elbows, must be modeled by modifying the volume roughness rather than by adding a form loss coefficient at a junction. Form losses, such as orifices and valves, must still be calculated by the addition of an energy loss coefficient or an area change at a junction. This section of the appendix discusses how to modify the volume roughness term to account for frictional losses.

Currently, frictional loss geometries such as elbows are modeled by adding an energy loss coefficient at a junction. This energy loss coefficient is the product of the turbulent friction factor and the L-over-D ratio, or

$$K = f_t (L/D)_L \quad (C-16)$$

where f_t is based on the Colebrook Equation,

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left| \frac{E}{3.7 D} + \frac{2.51}{Re \sqrt{f}} \right| \quad (C-17)$$

Assuming turbulent flow ($Re = \text{large}$), this expression can be simplified to

$$\frac{1}{\sqrt{f_t}} = -2 \log_{10} \frac{E}{3.7 D}$$

or,

$$f_t = \left[\frac{1}{-2 \log_{10} \frac{E}{3.7 D}} \right]^2$$

To modify the volume roughness, an equivalent turbulent friction factor must be determined as the sum of the above $f_t (L/D)_L$ and the $f_t (L/D)_V$ of the volume being modified, or

$$f_e (L/D)_V = f_t (L/D)_V + f_t (L/D)_L$$

or,

$$f_e = f_t \frac{(L/D)_v + (L/D)_L}{(L/D)_v} \quad (C-19)$$

The equivalent turbulent friction factor can now be used to calculate an equivalent volume roughness by rearranging Equation (C-18) as

$$E_e = 3.7 D 10^{\frac{1}{-2\sqrt{f_e}}} \quad (C-20)$$

Using this value [Equation (C-20)] of volume roughness instead of the normal pipe roughness will incorporate the effects of frictional losses into the shear term.

As an example, consider an elbow in a RELAP5 model which has an L-over-D loss of 16 ($K = 16 f_t$). The length and diameter of the volume upstream of the elbow is 1.60 ft and 0.6651 ft ($L/D = 2.406$), and downstream of the elbow is 2.00 ft and 0.6651 ft ($L/D = 3.007$). The pipe roughness (E) is nominally 0.00015 ft.

Half the elbow resistance ($L/D = 8$) will be added to the volume upstream of the elbow and half downstream of the elbow. From Equation (C-18), the turbulent friction factor can be calculated for both volumes as,

$$f_t = \left[\frac{1}{-2 \log_{10} \frac{0.00015}{(3.7)(0.6651)}} \right]^2$$

$$= 0.01407$$

The equivalent turbulent friction factor can now be determined from Equation (C-19) as,

$$f_e \text{ (upstream)} = 0.01407 \frac{2.406 + 8}{2.406}$$

$$= 0.0609$$

$$f_e \text{ (downstream)} = 0.01407 \frac{3.007 + 8}{3.007}$$

$$= 0.0515$$

The equivalent volume roughness can now be calculated using Equation (C-20) as,

$$E_e \text{ (upstream)} = (3.7)(0.6651) 10^{\frac{1}{-2\sqrt{0.0609}}}$$

$$= 0.02317$$

$$E_e \text{ (downstream)} = (3.7)(0.6651) 10^{\frac{1}{-2\sqrt{0.0515}}}$$

$$= 0.01541$$

Using these E_e values for the respective volume roughness terms will simulate the effects of an elbow.

APPENDIX D

RELAP5 CODE UPDATES AND OUTPUT TAPE FORMAT

APPENDIX D

RELAP5 CODE UPDATES AND OUTPUT TAPE FORMAT

1. RELAP5 CODE UPDATES

Add a call to subroutine forces from within subroutine dtstep as follows:

```
      iplt = iecf
      iecf = iand(iecf,iprnt)
*if def,plots,1
*   if (iand(iecf,8).ne.0 .and. filid(15).ne.0.0) call pltrec
      if (iand(iecf,4) .ne. 0) call mirec
      if (iand(iecf,2) .ne. 0) call majout
C
C   *****
C
      call forces
C
C   *****
C
      if (iand(iecf,1) .ne. 0) call rstrec
      ivskip2 = iand(iplt,ishft(iprnt,3))
      if (iand(iplt,8) .ne. 0) then
         if (iand(ivskip2,8).ne.0 .or. iand(iprnt,32).ne.0) then
            call pltwrt
```

Add a new subroutine called forces as follows:

```

subroutine forces
c
  implicit real*8(a-h,o-z)
  include 'genr1.h'
  include 'comctl.h'
  include 'contrl.h'
  include 'fast.h'
  include 'jundat.h'
  include 'voldat.h'
c
c *****
c *** updates to write an r5force stress ***
c *** tape a every successful time step ***
c *** (writes to file 23: r5-r5f) ***
c *** 32 bit vax machine version ***
c *****
c
  data jflag /0/
  if (jflag.eq.0) then
    open (23,file='r5-r5f',status='new',form='unformatted')
    jflag = 1
c
c - write total number of volumes and junctions
c
    write(23) nvols(2,filndx(4)), njuns(2,filndx(5)), ptitle
c
c - compute and write control volume geometry
c
    iv = filndx(4)
    ive = iv + (nvols(2,iv) - 1) * ivskip
    do 83 i = iv, ive, ivskip
      if (dl(i).eq.0.0) then
        dzdl = 3.0
      else
        dzdl = dz(i) / (dl(i) * 4.903325)
      endif
      write(23) volno(2,i), avol(i), dzdl, dl(i)
83    continue
c
c - write connection and control parameters for junctions
c
    ij = filndx(5)
    ije = ij + (njuns(2,ij) - 1) * ijskip
    do 84 i = ij, ije, ijskip
      write(23) junno(2,i), ajun(i), ijlvn(2,i), ij2vn(2,i)
84    continue
  endif

```

```

c
c - write the problem time
c
    write(23) timehy
c
c - loop through volumes, compute average volume shear
c - force and volume pv**2 term, write to tape
c
    do 86 i = iv, ive, ivskip
        frf = fwalf(i) * velf(i) * dl(i) * diamv(i)**2
        frg = fwalg(i) * velg(i) * dl(i) * diamv(i)**2
        frtot = 3.1415927 * 0.25 * (frf + frg)
        pv2v = voidf(i) * rhof(i) * velf(i)**2 +
        &      voidg(i) * rhog(i) * velg(i)**2
        write(23) p(i), frtot, pv2v
    86 continue
c
c - loop through junctions, write to tape
c
    do 87 i = ij, ije, ijskip
        write(23) athrot(i), jc(2,i)
    87 continue
c
    return
end

```


2. OUTPUT TAPE FORMAT

System Geometry (written once).

1. Total Number of Volumes; Total Number of Junctions; RELAP5 Version
2. For each volume, Volume Number; Volume Area; Volume Inclination; Volume Length
3. For each junction, Junction Number; Junction Area: "From" Junction Control Flag; "To" Junction control Flag.

Output Data (written every time step)

1. Time
2. For each volume, Volume Pressure; Average Volume Shear Force; Average Volume Momentum Flux
3. For each junction, Junction Throat Ratio; "To" Junction Control Flag (Contains "To" Junction Choking Flag).

APPENDIX E

R5FORCE/MOD3s PROGRAM LISTING

(MICROFILM)

NOT INCLUDED WITH THIS VERSION OF THE REPORT

APPENDIX F

PROGRAM USERS GUIDE

APPENDIX F

PROGRAM USERS GUIDE

The purpose of this appendix is to provide sufficient information to permit application of the R5FORCE program to a typical piping system. Included are a description of the force modeling strategy, detailed user input instructions, and a sample problem. It is recommended that the main body of this report be read and understood prior to using the program.

1. FORCE MODELING STRATEGY

The RELAP5 code numerically computes the fluid transient response within a piping system by dividing the system into a number of hydrodynamic control volumes connected by junctions. Associated with each control volume and junction is a nine digit integer reference number. This reference number is written to the RELAP5 hydrodynamic output tape and is therefore available for use in the force calculation program. In the R5FORCE input instructions, force control volumes can then be constructed simply by specifying the applicable RELAP5 control volume reference numbers.

2. R5FORCE INPUT AND OUTPUT

This section provides detailed input instructions and a discussion of the various modeling rules and sign conventions used in the R5FORCE program.

2.1 Input Instructions

All input data is in free format input and default information is contained in parenthesis. Input data need not be entered if default values are acceptable.

<u>Card Number</u>	<u>PARAMETER</u>
=	Title Card, with the "=" sign in Column 1
100	<u>Output Units</u> , "BRITISH" or "METRIC" (BRITISH) <u>Input Units</u> , "BRITISH" or "METRIC" (BRITISH)
200	<u>Time Between Printouts</u> , seconds (1.0) <u>Start Time</u> , seconds (0.0) <u>Finish Time</u> , seconds (1.0×10^{12})
300	<u>Ambient Pressure</u> , psia or Pa (14.7 psia or 0.101 MPa)
400	<u>Type of Printed Output</u> : Output contains problem definition and summary output in addition to the following options: "CHECK"--input check only, problem stops at the end of input processing "NONE"--no output at requested printout times "FORCES"--Subforce and combined force output at requested printout times "ALL"--Subforce, combined force and volume force output at requested printout times (FORCES)
500	<u>Maximum Number of Subforces Per Combined Force</u> (5)

600	Junction number of bends when both adjacent volumes are horizontal (more than one junction number can be on a card)
620	Junction number of a special geometry, such as a relief valve, with an orifice at the outlet but not at the inlet. This geometry assumes the adjacent volumes are at angles to each other. (More than one junction number can be on a card)
640	Same as the 620 card except the orifice is at the inlet only, not the outlet.
700	Initial force zeroing "NONZERO"--Do not zero initial forces
1XXX	Subforce input information for all geometries except an open pipe (XXX is the subforce number) <u>Direction of subforce relative to the RELAP5 model.</u> A positive number is in the direction of positive flow in the RELAP5 model and a negative number is in the direction of negative flow in the RELAP5 model. <u>Beginning control volume number of the subforce relative to the RELAP5 model</u> <u>Ending control volume number of the subforce relative to the RELAP5 model.</u> If this control volume number is the same as the beginning control volume number, either a zero may be entered or the control volume number may be repeated. <u>Combined Force Number/Direction relative to subforce direction.</u> A positive number is in the direction of the subforce and a negative number is in the opposite direction of the subforce. Note that a combined force number need not be entered.
2XXX	Subforce input information for an open pipe. Input identical to card 1XXX.

2.2 Force Direction Conventions

In order to be consistent with the basic equations solved in R5FORCE, the following conventions must be followed.

1. The RELAP5 model must be developed in the direction of positive flow.

2. The force direction must be colinear with the pipe axis, in any direction.
3. System components which result in a frictional loss, such as elbows, must be modeled by modifying the volume roughness rather than by adding an energy loss coefficient at a junction.

2.3 Output

The R5FORCE/MOD3s program writes information to both an output file (which is usually printed) and a disk or tape file (for structural input).

The output file contains an echo of all input data, information about input data processing, and then force results at requested printout times. This information is considered self-explanatory and will be shown in a sample problem to be discussed later.

Two disk or tape files are currently written at every time step in the following format:

- (1) TIME, FORCE 1, FORCE 2, ..., FORCE N,
- (2) TIME, PRESSURE 1, PRESSURE 2, ..., PRESSURE M,

where N is the total number of subforces and combined forces and M is the total number of RELAP5 hydrodynamic control volumes. The force file is called tape-f and the pressure file is called tape-p. The last page of input processing (in the previously discussed output file) provides a description of the time/force array. For reference purposes, the total number of time steps on the disk or tape file is also written on the output file following the last time step. Also written out is a summary of the maximum positive and negative volume forces, subforces and combined forces.

3. SAMPLE PROBLEM

A detailed sample problem is now presented to help users become familiar with the use of the R5FORCE program.

The piping system geometry and fluid transient used for the sample problem have been previously described in the main body of this report. Figure F-1 shows the piping system and includes a description of the subforces and combined forces to be computed. Figure F-2 is a RELAP5 nodalization diagram of this system showing the hydrodynamic control volumes and junctions as well as each of the control volumes used for force calculations. Note that in general, a force control volume is made up of several hydrodynamic control volumes. A description of the required R5FORCE input data for this sample problem is listed in Figure F-3.

Prior to performing any calculations the R5FORCE program provides an echo of the input data (Figure F-3), and then processes this data. During processing, the user is provided with a description of the RELAP5 hydrodynamic model, information on each of the component and combined forces, a description of the output format of the force file, the initial forces in the system at time zero and the resultant zeroed forces at time zero. Note that all later force values are in reference to the zeroed force values. Appendix G contains a copy of this input processing description for the sample problem.

Figures F-4, F-5, and F-6 represent sample force results at times 0.1, 0.25, and 0.7 s, respectfully. At 0.1 s, the relief valve is completely closed and the only significant unbalanced force (see the combined forces in Figure F-4) occurs upstream of the relief valve which is undergoing rapid pressurization. At 0.25 s the relief valve is in the process of opening and there exists significant unbalanced forces at all points in the system. At 0.7 s the flow is essentially at steady-state and the unbalanced forces are small.

Figure F-1. Sample piping system showing selected forces.

[illegible]

Figure F-3. R5FORCE input data of sample piping system.

FORCE-TIME HISTORY FROM RELAP5 OUTPUT DATA - VOLUME FORCE DATA

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LCOOP SEAL

10/15/82 12.03.20.

PROBLEM TIME = 1.000E-01 DATA SET NUMBER = 21

VOL. ALM.	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
101010000	0.15092	-3.24208E+05	3.14177E+05	0.	0.	-3.24208E+05
103010000	1.51000E-02	0.	0.	0.	0.	3.14177E+05
201010000	1.91000E-02	0.	0.	0.	0.	1.79955E+05
201020000	3.14330E-02	-4638.4	7998.2	0.	0.	1.79955E+05
201030000	1.49200E-02	-4638.4	4638.4	0.	0.	-4638.4
201040000	1.03440E-02	0.	0.	0.	0.	4638.4
201050000	9.38440E-03	-4641.5	4641.5	0.	0.	-4641.5
201060000	9.17770E-03	-4639.1	4639.1	0.	0.	-4639.1
201070000	3.12330E-04	0.	0.	0.	0.	5.17930E-04
201080000	1.23300E-04	0.	4618.8	0.	0.	4618.8
201090000	1.23300E-04	0.73e35	0.	0.	0.	73300E-04
203010000	-1.23300E-07	0.	0.	0.	0.	-1.23300E-07
203020000	-1.23300E-07	0.	0.	0.	0.	-2.15700E-07
203030000	-2.15700E-07	0.	0.	0.	0.	-2.15700E-07
203040000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203050000	-3.05500E-07	0.73175	0.	0.	0.	-3.05500E-07
203060000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203070000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203080000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203090000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203100000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203110000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203120000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203130000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203140000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203150000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203160000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203170000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203180000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203190000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203200000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203210000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203220000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203230000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203240000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203250000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203260000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203270000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203280000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203290000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203300000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203310000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203320000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203330000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203340000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203350000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203360000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203370000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203380000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203390000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203400000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203410000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
203420000	-3.05500E-07	0.	0.	0.	0.	-3.05500E-07
 

Figure F 4. R5FORCE results at 0.1 s.

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUBFORCE AND COMBINED FORCE DATA

12.C3.2C.

10/15/82

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LCDP SEAL

PROBLEM TIME = 1.000E-01 DATA SET NUMBER = 21

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
SF101	4.30713E-02	-73175	0.	0.	0.	-73175
SF102	6.10227E-07	-73175	-73175	0.	0.	-73175
SF103	-1.02701E-06	0.	0.	0.	0.	-66008
SF104	2.69757E-07	-66008	0.	0.	0.	-66008
SF105	1.36647E-06	-58939	0.	0.	0.	-58939
SF106	-8.5520E-06	0.	0.	0.	0.	-85520
SF107	2.69376E-06	-36318	0.	0.	0.	-36318
SF108	-9.84371E-06	0.	36318	0.	0.	36318
CF201	-1.08000E-06	73175	-73175	0.	0.	0.
CF202	-5.12515E-06	1.3918	-58939	0.	0.	61.9812
CF203	-1.12492E-05	-58939	58939	0.	0.	-22622

Figure F-4 (Contd.). R5FROCE results at 0.1 s.
F-10

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - VOLUME FORCE DATA

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE P/O LCOP SEAL

10/15/82 12.C3.2C.

PROBLEM TIME = .25 DATA SFT NUMBER = 110

VOL. NUM.	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
10101CC00	0.	-6.1C589E+05	0.	0.	0.	-6.1C589E+05
10301CC00	1.57649	0.	0.	0.	0.	1.57649
20101CC00	1.11.31	0.	0.	0.	0.	1.11.31
20102CC00	306.37	0.	0.	0.	0.	306.37
20103CC00	206.49	-1.23216E+04	1.12919E+04	0.	0.	-1.10896E+04
20104CC00	206.49	-1.12919E+04	0.	0.	0.	-1.10896E+04
20105CC00	206.49	0.	0.	0.	0.	206.49
20106CC00	206.49	-9.852.2	9.852.6	0.	0.	-9.852.2
20107CC00	206.49	-9.852.2	9.852.6	0.	0.	-9.852.2
20108CC00	113.82	0.	0.	0.	0.	113.82
20109CC00	113.82	0.	0.	0.	0.	113.82
20301CC00	111.61	-6.34095E+04	0.	0.	0.	-6.32983E+04
20302CC00	357.13	0.	0.	0.	0.	357.13
20303CC00	436.44	0.	0.	0.	0.	436.44
20304CC00	474.26	0.	0.	0.	0.	474.26
20305CC00	1415.2	0.	0.	0.	0.	1415.2
20306CC00	1036.37	-3.94794E+04	0.	0.	0.	-3.84425E+04
20307CC00	1036.37	0.	0.	0.	0.	1036.37
20308CC00	189.78	-2.42766E+04	0.	0.	0.	-2.41065E+04
20309CC00	1235.61	0.	0.	0.	0.	1235.61
20310CC00	259.17	0.	0.	0.	0.	259.17
20311CC00	270.00	0.	0.	0.	0.	270.00
20312CC00	257.54	0.	0.	0.	0.	257.54
20313CC00	257.54	0.	0.	0.	0.	257.54
20314CC00	257.54	0.	0.	0.	0.	257.54
20315CC00	257.54	0.	0.	0.	0.	257.54
20316CC00	257.54	0.	0.	0.	0.	257.54
20317CC00	257.54	0.	0.	0.	0.	257.54
20318CC00	257.54	0.	0.	0.	0.	257.54
20319CC00	257.54	0.	0.	0.	0.	257.54
20320CC00	257.54	0.	0.	0.	0.	257.54
20321CC00	257.54	0.	0.	0.	0.	257.54
20322CC00	257.54	0.	0.	0.	0.	257.54
20323CC00	257.54	0.	0.	0.	0.	257.54
20324CC00	257.54	0.	0.	0.	0.	257.54
20325CC00	257.54	0.	0.	0.	0.	257.54
20326CC00	257.54	0.	0.	0.	0.	257.54
20327CC00	257.54	0.	0.	0.	0.	257.54
20328CC00	257.54	0.	0.	0.	0.	257.54
20329CC00	257.54	0.	0.	0.	0.	257.54
20330CC00	257.54	0.	0.	0.	0.	257.54
20331CC00	257.54	0.	0.	0.	0.	257.54
20332CC00	257.54	0.	0.	0.	0.	257.54
20333CC00	257.54	0.	0.	0.	0.	257.54
20334CC00	257.54	0.	0.	0.	0.	257.54
20335CC00	257.54	0.	0.	0.	0.	257.54
20336CC00	257.54	0.	0.	0.	0.	257.54
20337CC00	257.54	0.	0.	0.	0.	257.54
20338CC00	257.54	0.	0.	0.	0.	257.54
20339CC00	257.54	0.	0.	0.	0.	257.54
20340CC00	257.54	0.	0.	0.	0.	257.54

Figure F-5. R5FORCE results at 0.25 s

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUBFORCE AND COMBINED FORCE DATA

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/C LCOP SEAL

1C/15/82

12.C3.2C.

PROBLEM TIME = .250 DATA SET NUMBER = 11C

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
SF101	-111.61	6.34095E+04	0.	0.	0.	6.32983E+04
SF102	-1357.0	5.94794E+04	0.	0.	0.	5.61215E+04
SF103	-2487.0	0.	5.94794E+04	0.	0.	5.19665E+04
SF104	-165.78	2.42756E+04	0.	0.	0.	2.41069E+04
SF105	-1002.4	3.66907E+04	0.	0.	0.	3.56881E+04
SF106	-3543.3	0.	3.66907E+04	0.	0.	4.02340E+04
SF107	-1115.7	2.75475E+04	0.	0.	0.	2.64324E+04
SF108	-2177.7	0.	2.75475E+04	0.	0.	2.53725E+04
CF201	2558.6	-6.34095E+04	5.94794E+04	0.	0.	-1331.6
CF202	5071.0	-8.37561E+04	3.66907E+04	0.	0.	-4.70654E+04
CF203	3160.2	-3.66907E+04	2.75479E+04	0.	0.	-5562.6

Figure F-5 (Contd.). R5FORCE results at 0.25 s.

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - VOLUME FORCE DATA

10/15/82 12.03.20.

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LOUP SEAL

PROBLEM TYPE = .700 DATA SET NUMBER = 830

VOL. NUM.	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
1001010000	0.	-1.62091E+06	0.	0.	0.	1.62091E+06
1001010000	1.2752	0.	0.	0.	0.	1.2752E+06
1001010000	56.768	0.	0.	0.	0.	56.768E+06
2001010000	126.08	0.	0.	0.	0.	126.08E+06
2001030000	314.61	-2.51492E+04	4.1258E+04	0.	0.	4.1258E+04
2001040000	308.70	-2.48453E+04	2.48453E+04	0.	0.	0.
2001050000	308.45	0.	0.	0.	0.	0.
2001050000	316.12	0.	0.	0.	0.	0.
2001070000	208.28	-2.43725E+04	2.43725E+04	0.	0.	0.
2001080000	117.13	-2.40681E+04	2.40681E+04	0.	0.	0.
2001080000	140.73	0.	0.	0.	0.	0.
2003010000	109.40	-7.40630E+04	4.25310E+04	0.	0.	4.25310E+04
2003010000	347.87	0.	0.	0.	0.	347.87E+06
2003030000	427.82	0.	0.	0.	0.	427.82E+06
2003030000	473.82	0.	0.	0.	0.	473.82E+06
2003050000	1265.25	0.	0.	0.	0.	1265.25E+06
2003060000	1120.33	-7.04152E+04	7.04152E+04	0.	0.	0.
2003060000	321.25	0.	0.	0.	0.	321.25E+06
2003090000	200.25	-3.71006E+04	0.	0.	0.	3.71006E+06
2003110000	243.13	0.	0.	0.	0.	243.13E+06
2003110000	258.05	0.	0.	0.	0.	258.05E+06
2003110000	259.17	0.	0.	0.	0.	259.17E+06
2003130000	272.21	0.	0.	0.	0.	272.21E+06
2003140000	274.84	0.	0.	0.	0.	274.84E+06
2003150000	277.36	0.	0.	0.	0.	277.36E+06
2003150000	279.89	0.	0.	0.	0.	279.89E+06
2003170000	282.48	0.	0.	0.	0.	282.48E+06
2003190000	286.16	0.	0.	0.	0.	286.16E+06
2003200000	1260.14	-6.94259E+04	6.94259E+04	0.	0.	0.
2003200000	1340.43	0.	0.	0.	0.	1340.43E+06
2003210000	357.89	0.	0.	0.	0.	357.89E+06
2003220000	367.89	0.	0.	0.	0.	367.89E+06
2003240000	405.94	0.	0.	0.	0.	405.94E+06
2003250000	416.40	0.	0.	0.	0.	416.40E+06
2003250000	416.40	0.	0.	0.	0.	416.40E+06
2003270000	1628.4	-6.58143E+04	6.58143E+04	0.	0.	0.
2003280000	1675.37	0.	0.	0.	0.	1675.37E+06
2005010000	0.	-671.27	527.44	0.	0.	0.

Figure F-6. R5FORCE results at 0.7 s.

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SURFORCE AND COMBINED FORCE DATA

12.C3.20.

10/15/82

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE P/U LOOP SEAL

PROBLEM TIME = .700 DATA SET NUMBER = 830

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
SF101	-107.50	7.40035E+04	0.	0.	0.	7.39335E+04
SF102	-1482.0	7.04152E+04	0.	0.	0.	6.99332E+04
SF103	2514.0	0.	7.04152E+04	0.	0.	7.29292E+04
SF104	-200.69	3.71000E+04	0.	0.	0.	3.68999E+04
SF105	-1340.5	6.54255E+04	0.	0.	0.	6.40855E+04
SF106	3947.4	0.	6.94259E+04	0.	0.	7.33734E+04
SF107	-2243.8	6.58143E+04	0.	0.	0.	6.35703E+04
SF108	3546.7	0.	6.58143E+04	0.	0.	6.93605E+04
CF201	2623.5	-7.40630E+04	7.04152E+04	0.	0.	-1024.3
CF202	5850.1	-1.07516E+05	6.54259E+04	0.	0.	-3124.97
CF203	4837.1	-6.94259E+04	6.58143E+04	0.	0.	-1275.5

Figure F-6 (Contd.)

R5FORCE results at 0.7 s.
F-14

Upon completion of the requested force calculations, the R5FORCE program provides a summary identifying the maximum positive and negative forces encountered for each volume force, subforce and combined force requested, including the time of the maximum force. Appendix H contains a copy of this output for the sample problem.

APPENDIX G

SAMPLE PROBLEM INPUT PROCESSING DESCRIPTION

FORCE-TIME HISTORY FROM RELAYS OUTPUT DATA - INPUT DESCRIPTION OF SLEEFORCES

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE P/C LCCP SEAL

12-03-20-

10/15/82

SUBFORCE NUM.	DIRECTION	REL. CV. NUM.	END. CV. NUM.	FROM JUN. TYPE	TO JUN. TYPE	FORCE COMB. NUP.
101	-1	203010000	203010000	BOUNDED		-201
102	-1	203020000	203020000	BOUNDED		-202
103	+1	203030000	203030000	BOUNDED		+201
104	-1	203040000	203040000	BOUNDED		-202
105	-1	203050000	203050000	BOUNDED		-203
106	+1	203060000	203060000	BOUNDED		+202
107	-1	203070000	203070000	BOUNDED		-203
108	+1	203080000	203080000	BOUNDED		+203

PERCE-TIME HISTORY FROM RELAPS OUTPUT DATA - DESCRIPTION OF RELAPS HYDRODYNAMIC VOLUMES AND JUNCTIONS

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O COP SEAL

10/15/82

12.03.20.

VOL. NLP.			LENGTH		AREA (SQ. METERS)		FRCP VOL.		TO VOL.		FRCP JUNCTION INFORMATION NUMBER AREA (SQ. METERS)		TC JUNCTION INFORMATION NUMBER AREA (SQ. METERS)		TYPE	
1	101C100C00	00	3	01200	02	94031	103C10000	100C100C00	100C100C00	103C10000	02	94031	120C0C0C0C	02		94031
2	101C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
3	201C100C00	00	4	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
4	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
5	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
6	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
7	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
8	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
9	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
10	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
11	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
12	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
13	201C100C00	00	5	01720	02	94031	201C100C00	100C100C00	100C100C00	201C100C00	02	94031	120C0C0C0C	02		94031
 	

12.C3.2C.

78/51/31

SAMPLE PROBLEM -- PELTIF VALVE DISCHARGE W/O LCCP SEAL

DIFFERENCE COMPONENTS OF A COMBINED FORCE
(+ + + IMPLIES ADDITION; - - - IMPLIES SUBTRACTION)

ARRAY INDEX NUMBER	FORCE NUMBER	FORCE COMPONENTS OF A COPEINED FORCE (IF APPLIES ADDITION; - IF APPLIES SUBTRACTION)
001	SF1C1	
002	SF1C2	
003	SF1C3	
004	SF1C4	
005	SF1C5	
006	SF1C6	
007	SF1C7	
008	SF1C8	
009	SF2C1	+1C1
010	CF2C2	-1C2
011	CF2C3	+1C3
		-1C4
		+1C6

G-3

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - INITIALIZED SURFACE AND COMBINED FORCE DATA

12.03.20.

10/15/82

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LOOP SEAL

TIME ZERO = 0.

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
SF101	0.	3271.1	0.	-3271.1	0.	1.45519E-11
SF102	0.	3271.1	0.	-3271.1	0.	1.45519E-11
SF103	0.	0.	3271.1	0.	-3271.1	1.45519E-11
SF104	0.	0.	0.	-3374.7	0.	1.45519E-11
SF105	0.	6645.8	0.	-6645.8	0.	2.51038E-11
SF106	0.	0.	6645.8	0.	-6645.8	2.51038E-11
SF107	0.	6645.8	0.	-6645.8	0.	5.82077E-11
SF108	0.	0.	6645.8	0.	-6645.8	5.82077E-11
CF201	0.	-3271.1	3271.1	3271.1	-3271.1	0.
CF202	0.	-6645.8	6645.8	6645.8	-6645.8	0.
CF203	0.	-6645.8	6645.8	6645.8	-6645.8	2.51038E-11

LC/15/82

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LOOP SEAL

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PROBLEM TIME = 0.
DATA SET NUMBER = 1

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[illegible]

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUBFORCE AND COMBINED FORCE DATA

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LOOP SEAL

10/15/82

12.03.20.

PROBLEM TYPE = 0. DATA SET NUMBER = 1

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	TOTAL FORCE (NEWTONS)
SF101	0.	0.	0.	0.	0.	0.
SF102	0.	0.	0.	0.	0.	0.
SF103	0.	0.	0.	0.	0.	0.
SF104	0.	0.	0.	0.	0.	0.
SF105	0.	0.	0.	0.	0.	0.
SF106	0.	0.	0.	0.	0.	0.
SF107	0.	0.	0.	0.	0.	0.
SF108	0.	0.	0.	0.	0.	0.
CF101	0.	0.	0.	0.	0.	0.
CF201	0.	0.	0.	0.	0.	0.
CF202	0.	0.	0.	0.	0.	0.

APPENDIX H

SAMPLE PROBLEM OUTPUT SUMMARY

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUMMARY OF MAXIMUM POSITIVE VOLUME FORCES

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LCUP SEAL

12-03-20.

10/15/82

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	MAXIMUM FORCE (NEWTONS)	TIME CF FORCE (SECONDS)
101010000	0.	-1.62089E+06	1.71807E+07	0.	0.	1.55598E+07	1.00
103010000	1.2286	0.	1.59679E+06	0.	0.	1.59679E+06	.510
201010000	67.772	0.	0.	0.	0.	67.772	.257
201020000	127.49	0.	0.	0.	0.	4.14659E+07	.510
201030000	8.6579	-2785.0	4.116364E+04	0.	0.	7315.0	1.44
201040000	974.51	7349.3	5492.0	0.	0.	2.51032E+04	.555
201050000	210.02	0.	2.48932E+04	0.	0.	1.1874.2	1.43
201060000	13.647	-7283.7	9144.2	0.	0.	1.10177E+04	1.44
201070000	2.2667	0.	0.	0.	0.	1.1874.2	.549
201080000	118.66	0.	2.42385E+04	0.	0.	2.42385E+04	.556
201090000	141.43	0.	0.	0.	0.	1.317.2	1.52
203010000	4.13412E-03	1317.2	0.	0.	0.	363.48	1.44
203020000	363.48	0.	0.	0.	0.	441.15	.247
203030000	471.15	0.	0.	0.	0.	476.55	.248
203040000	476.55	0.	0.	0.	0.	7.18146E+04	1.01
203050000	1266.17	1220.6	7.05485E+04	0.	0.	1.220.6	1.52
203060000	362.37	0.	0.	0.	0.	1.233.4	1.51
203070000	272.66	1233.1	0.	0.	0.	264.26	.273
203080000	264.26	0.	0.	0.	0.	294.56	.273
203090000	294.56	0.	0.	0.	0.	311.11	.273
203100000	311.11	0.	0.	0.	0.	320.85	.273
203110000	320.85	0.	0.	0.	0.	326.55	.273
203120000	326.55	0.	0.	0.	0.	329.70	.273
203130000	329.70	0.	0.	0.	0.	329.70	.273
203140000	329.70	0.	0.	0.	0.	329.70	.273
203150000	329.70	0.	0.	0.	0.	329.70	.273
203160000	329.70	0.	0.	0.	0.	329.70	.273
203170000	329.70	0.	0.	0.	0.	329.70	.273
203180000	329.70	0.	0.	0.	0.	329.70	.273
203190000	329.70	0.	0.	0.	0.	329.70	.273
203200000	329.70	0.	0.	0.	0.	329.70	.273
203210000	329.70	0.	0.	0.	0.	329.70	.273
203220000	329.70	0.	0.	0.	0.	329.70	.273
203230000	329.70	0.	0.	0.	0.	329.70	.273
203240000	329.70	0.	0.	0.	0.	329.70	.273
203250000	329.70	0.	0.	0.	0.	329.70	.273
203260000	329.70	0.	0.	0.	0.	329.70	.273
203270000	329.70	0.	0.	0.	0.	329.70	.273
203280000	329.70	0.	0.	0.	0.	329.70	.273
203290000	329.70	0.	0.	0.	0.	329.70	.273
203300000	329.70	0.	0.	0.	0.	329.70	.273
203310000	329.70	0.	0.	0.	0.	329.70	.273
203320000	329.70	0.	0.	0.	0.	329.70	.273
203330000	329.70	0.	0.	0.	0.	329.70	.273
203340000	329.70	0.	0.	0.	0.	329.70	.273
203350000	329.70	0.	0.	0.	0.	329.70	.273
203360000	329.70	0.	0.	0.	0.	329.70	.273
203370000	329.70	0.	0.	0.	0.	329.70	.273
203380000	329.70	0.	0.	0.	0.	329.70	.273
203390000	329.70	0.	0.	0.	0.	329.70	.273
203400000	329.70	0.	0.	0.	0.	329.70	.273
203410000	329.70	0.	0.	0.	0.	329.70	.273
203420000	329.70	0.	0.	0.	0.	329.70	.273
203430000	329.70	0.	0.	0.	0.	329.70	.273
203440000	329.70	0.	0.	0.	0.	329.70	.273
203450000	329.70	0.	0.	0.	0.	329.70	.273
203460000	329.70	0.	0.	0.	0.	329.70	.273
203470000	329.70	0.	0.	0.	0.	329.70	.273
203480000	329.70	0.	0.	0.	0.	329.70	.273
203490000	329.70	0.	0.	0.	0.	329.70	.273
203500000	329.70	0.	0.	0.	0.	329.70	.273
203510000	329.70	0.	0.	0.	0.	329.70	.273
203520000	329.70	0.	0.	0.	0.	329.70	.273
203530000	329.70	0.	0.	0.	0.	329.70	.273
203540000	329.70	0.	0.	0.	0.	329.70	.273
203550000	329.70	0.	0.	0.	0.	329.70	.273
203560000	329.70	0.	0.	0.	0.	329.70	.273
203570000	329.70	0.	0.	0.	0.	329.70	.273
203580000	329.70	0.	0.	0.	0.	329.70	.273
203590000	329.70	0.	0.	0.	0.	329.70	.273
203600000	329.70	0.	0.	0.	0.	329.70	.273
203610000	329.70	0.	0.	0.	0.	329.70	.273
203620000	329.70	0.	0.	0.	0.	329.70	.273
203630000	329.70	0.	0.	0.	0.	329.70	.273
203640000	329.70	0.	0.	0.	0.	329.70	.273
203650000	329.70	0.	0.	0.	0.	329.70	.273
203660000	329.70	0.	0.	0.	0.	329.70	.273
203670000	329.70	0.	0.	0.	0.	329.70	.273
 							

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUMMARY OF MAXIMUM NEGATIVE VOLUME FORCES

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LCCP SEAL

1C/15/82

12.03.2C.

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	CUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	CUTLET EXT. FORCE (NEWTONS)	MAXIMUM FORCE (NEWTONS)	TIME OF FORCE (SECONDS)
101010000	0.	-1.62112E+06	1.57597E+06	0.	0.	-1.62112E+06	5.00
103010000	1.1357	-1.71762E+07	0.	0.	0.	-1.56002E+07	1.00
201010000	-3.1200	0.	0.	0.	0.	-3.1200	1.44
201020000	33290	0.	-8676.9	0.	0.	-8676.9	1.44
201030000	1.1871	5114.0	-7349.3	0.	0.	-2234.1	1.51
201040000	210.21	-2.52530E+04	0.	0.	0.	-2.50428E+04	1.51
201050000	1.2379	0.	-1.01950E+04	0.	0.	-1.01950E+04	1.219
201060000	26.450	-4891.7	3489.0	0.	0.	-1.377.2	1.219
201070000	209.19	-2.46631E+04	0.	0.	0.	-2.44539E+04	1.556
201080000	-38.03	0.	0.	0.	0.	-38203	1.44
201090000	-2.0258	-7.41691E+04	-1.08423E+04	0.	0.	-1.08903E+04	1.44
203010000	105.64	0.	0.	0.	0.	-7.40592E+04	1.559
203020000	126.45	0.	0.	0.	0.	-26045	1.54
203030000	-2.6647	0.	0.	0.	0.	-66047	1.54
203040000	-1.1840	0.	0.	0.	0.	-1.1340	1.52
203050000	1.1977	0.	-1220.6	0.	0.	-1220.6	1.52
203060000	112.11	-7.05405E+04	0.	0.	0.	-6.54274E+04	1.01
203070000	116.19	0.	0.	0.	0.	-1.6197	1.54
203080000	-201.01	-3.71723E+04	0.	0.	0.	-3.65713E+04	1.01
203090000	1.1789	0.	0.	0.	0.	-1.5789	1.54
203100000	-2.0007	0.	0.	0.	0.	-2.0007	1.54
203110000	-2.0355	0.	0.	0.	0.	-2.0355	1.54
203120000	-2.0839	0.	0.	0.	0.	-2.0839	1.54
203130000	-3.3721	0.	0.	0.	0.	-3.3721	1.54
203140000	-3.7512	0.	0.	0.	0.	-3.7512	1.54
203150000	-4.0083	0.	0.	0.	0.	-4.0083	1.54
203160000	-4.2072	0.	0.	0.	0.	-4.2072	1.54
203170000	-4.2950	0.	0.	0.	0.	-4.2950	1.54
203180000	8.1950	0.	0.	0.	0.	-1971.5	1.54
203190000	1341.9	-5.95467E+04	-1979.7	0.	0.	-6.82048E+04	1.02
203200000	5.7854	0.	0.	0.	0.	-5.7854	1.54
203210000	-5.7457	0.	0.	0.	0.	-5.7457	1.54
203220000	-5.6777	0.	0.	0.	0.	-5.6777	1.54
203230000	-5.6737	0.	0.	0.	0.	-5.6737	1.54
203240000	-5.6360	0.	0.	0.	0.	-5.6360	1.54
203250000	12.707	0.	-434.13	0.	0.	-421.42	1.50
203260000	16.867	-1.59022E+04	0.	0.	0.	-6.42335E+04	1.02
203270000	16.867	0.	0.	0.	0.	-4.3492	1.55
203280000	-4.3492	0.	0.	0.	0.	0.	0.
203290000	0.	0.	0.	0.	0.	0.	0.

H-2

FORCE-TIME HISTOY FROM RELAPS OUTPUT DATA - SUMMARY OF MAXIMUM POSITIVE SUBFORCES

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LOCP SEAL

10/15/82

12.03.20.

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	MAXIMUM FORCE (NEWTONS)	TIME OF MAXIMUM FORCE (SECONDS)
101	-109.54	7.41691E+04	C.	0.	C.	7.40592E+04	.559
102	-1482.8	7.05485E+04	C.	0.	C.	6.90258E+04	1.01
103	2516.5	0.	7.05485E+04	0.	C.	7.30641E+04	1.01
104	-201.01	3.71723E+04	C.	0.	C.	3.65713E+04	1.02
105	-1341.5	6.95467E+04	C.	0.	C.	6.82048E+04	1.01
106	3972.9	C.	6.95466E+04	0.	C.	7.35195E+04	1.01
107	-2244.0	6.59022E+04	C.	0.	C.	6.36382E+04	1.02
108	3548.9	C.	6.59022E+04	0.	C.	6.94511E+04	1.02

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUMMARY OF MAXIMUM NEGATIVE SUBFORCES

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LOOP SEAL

10/15/82

12.03.20.

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	MAXIMUM FORCE (NEWTONS)	TIME CF MAXIMUM FORCE (SECONDS)
101	-4.13412E-02	-1317.6	C.	0.	C.	-1317.2	1.52
102	-4.4586	-1220.6	C.	0.	0.	-1221.1	1.52
103	-52066	C.	-1220.6	0.	0.	-1220.1	1.51
104	-27366	-1233.1	C.	0.	C.	-1233.4	1.50
105	-9.5079	-1979.7	C.	0.	0.	-1969.6	1.50
106	18.477	C.	-1479.7	0.	C.	-1961.2	1.50
107	-13.059	-434.13	C.	0.	0.	-447.19	1.50
108	31.658	C.	-434.13	0.	C.	-402.47	1.50

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUMMARY OF MAXIMUM POSITIVE COMBINED FORCES
SAMPLE PROBLEM - RELIEF VALVE DISCHARGE V/O LOOP SEAL

10/15/82 12.03.20.

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	OUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	OUTLET EXT. FORCE (NEWTONS)	MAXIMUM FORCE (NEWTONS)	TIME CF MAXIMUM FORCE (SECONDS)
201	236.74	-5192.1	9197.6	0.	0.	4242.3	1.43
202	647.04	-1.21636E+04	2.11611E+04	0.	0.	9864.6	1.43
203	1019.7	-1.18567E+04	1.71427E+04	0.	0.	6305.7	1.44

FORCE-TIME HISTORY FROM RELAPS OUTPUT DATA - SUMMARY OF MAXIMUM NEGATIVE COMBINED FORCES

SAMPLE PROBLEM - RELIEF VALVE DISCHARGE W/O LCOP SEAL

12.03.20.

10/15/82

FORCE NUMBER	SHEAR FORCE (NEWTONS)	INLET INT. FORCE (NEWTONS)	CUTLET INT. FORCE (NEWTONS)	INLET EXT. FORCE (NEWTONS)	CUTLET EXT. FORCE (NEWTONS)	MAXIMUM FORCE (NEWTONS)	TIME CF MAXIMUM FORCE (SECONDS)
201	153.60	-9424.1	3813.6	0.	0.	-5456.8	1.46
202	4800.3	-8.12292E+04	3.35981E+04	0.	0.	-4.24248E+04	.248
203	2754.6	-3.22165E+04	2.25594E+04	0.	0.	-6902.5	.247

*** 2184 TIME-FORCE RECORDS HAVE BEEN WRITTEN TO THE STRUCTURAL OUTPUT FILE

END

DATE FILMED

02 / 13 / 91