VALIDATION OF A THERMAL HYDRAULIC COMPUTER CODE TO PERFORM TWO-PHASE MULTI-COMPONENT FORCE CALCULATIONS FOR STRUCTURAL EVALUATIONS

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ABSTRACT

This paper presents the results of validation calculations using the thermal hydraulic computer program, RELAP5/M3.3, to perform two-phase multi-component hydraulic calculations in determining the force associated with the fluid flow in piping networks.

RELAP5/M3.3 is a computer code used for the thermal-hydraulic analysis of transients and small-break accidents and transients in light-water nuclear power plants. It uses a one-dimensional, two-fluid model, consisting of steam and water, with the possibility of the vapor phase containing a non-condensable component and the liquid phase containing a nonvolatile solute. The RELAP5/M3.3 code manual indicates that the program has not been validated to provide forcing function for structural evaluations. The evaluations presented in this paper provide the necessary validations to establish RELAP5M3.3 as a computer program that can be used to develop forcing functions for structural evaluations.

Two cases are used to validate RELAP5M3.3 for use in analyzing fluid flow in piping systems and for producing the vector piping loads. The two cases are from the CE 908 test performed at Windsor, Connecticut and from the ALTRAN water hammer testing, which were conducted to determine loads during column closure events using complicated geometries.

The comparison of CE 908 test results are compared to RELAP5/M3.3 calculated results. The RELAP5/M3.3 calculated parameters such as pressure and calculated forcing functions are compared to measured pressure, temperature and forces from the CE 908 test performed in Windsor, Connecticut in 1979 through 1980. This test represents the high-pressure water slug discharge through a safety valve into a downstream piping configuration. The piping configuration represented typical pressurized water reactor (PWR) safety/relief valve (S/RV) configurations.

The ALTRAN water hammer test results are compared to RELAP5/M3.3 calculated results. The ALTRAN water hammer testing program performed a number of tests, covering simple column closure to water hammer in more complicated geometries. A particularly desirable aspect for some of the ALTRAN water hammer testing was that the support reaction loads were measured, which allows not only the RELAP5/M3.3 pressure, velocity and acceleration responses to be validated, but also the force time history generation methodology employed that was used to calculate the reaction loads.

Nomenclature
Introduction

Development of RELAP5/M3.3 (Ref. 5) was started in the 1980s to perform simulation of light water reactor (LWR) loss of coolant accidents (LOCA) simulations. RELAP5/MOD3, which is the version used to perform the analyses presented in this paper, is a "best estimate" system code suitable for the analysis of all transients and postulated accidents in Light Water Reactor (LWR) systems, as well as the full range of operational transients. The one dimensional RELAP5/MOD3 code is based on a non-homogeneous and non-equilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients.

For many years the nuclear community used RELAP5/M3.3 to determine water hammer type loads on piping structures containing a liquid mixture of steam and water with air. In the application of using RELAP5/M3.3 to model piping systems, it was stated in the RELAP5/M3.3 user manual (Ref. 5) that RELAP5/M3.3 was not validated to perform load calculations for piping systems. This document is presented to provide that assessment.

Discussion

The purpose of this paper is to provide calculated comparisons to test data of thermal hydraulic load measurements from ALTRAN testing performed to support the response to GL 96-06 (Ref. 1) and from test data for CE 908, which was a test performed to validate piping restraints in support utility responses to NUREG-0737 (Ref. 3). Comparisons of the measured data to RELAP5/M3.3 calculated pressure and forces are provided for two tests. The ALTRAN Test 2b was used to simulate a low-pressure water hammer event and the CE Test 908 was used to simulate the high-pressure water hammer event. The comparisons are presented in the following paragraphs.

Structural Loading Methodology

The development of the transient force time history information as provided by RELAP5/M3.3 for application to structural analysis models is based on the general force equations for a container. The integration of two fluid force equation in one-dimensional form can be reduced to RELAP5/M3.3 variables as follows.

As related to RELAP5/M3.3 variables, for vapor

\[ W_g = -\text{Deriv}(\sum(\text{Vel}_g \times \text{Void}_g \times \text{Rho}_g \times dL) \times A/g) \]

As related to RELAP5/M3.3 variables, for liquid

\[ W_f = -\text{Deriv}(\sum(\text{Vel}_f \times \text{Void}_f \times \text{Rho}_f \times dL) \times A/g) \]

Force = \( W_g + W_f \)

A command program was written to develop these forces for RELAP5's piping application using the XMGR processor.

RELAP5/M3.3 Validation for Low Pressure Waterhammer Applications

The EPRI program to address GL 96-06 included some laboratory testing to quantify low pressure condensation induced waterhammer as well as to investigate the effects of thermal boundary layers and the presence of noncondensable gases on column closure waterhammer events, as documented in the Technical Basis Report (TBR), Reference 1. This testing was performed by ALTRAN Corporation and the data generated (Ref. 2) provides the opportunity to perform direct assessment of RELAP5/M3.3 capabilities.

Description of ALTRAN Test Facility

The ALTRAN test configuration 2b and test loop are shown in Figures 1 and 2. Detailed description of the test facility is presented in Refs. 1 and 2.

The ALTRAN testing program performed a number of tests, covering simple column closure to more complicated geometries. A particularly desirable aspect of the ALTRAN testing was that support reaction loads were measured, which allows not only the RELAP5/M3.3 pressure response to be validated, but also the force time history generation.
methodology employed to generate piping segment loads. ALTRAN test 240-2-75-2-E was selected for a validation case (Reference 2). It contains the following features.

1) Longer driving length.
2) More complex geometry, with longer horizontal runs in the void collapse region.
3) Support loads were measured and are available.
4) Driving pressure of 70 psig, yielding high void closure velocities on an open system (discussion with ALTRAN personnel indicated that the test data labeled as 240-2-75-2-E was in fact run at 70 psig, with the tank isolation valve V3 open throughout).

Comparison of RELAP5/M3.3 to ALTRAN TEST DATA

A RELAP5/M3.3 model was prepared based on Figures 1 and 2 and information from Refs. 1 and 2. The RELAP5/M3.3 nodal diagram is shown in Figure 3. The RELAP5/M3.3 model was configured to employ the same key modeling features as those utilized in the similar water hammer analysis performed by the utility. Specifically, a small amount of non-condensable was included in the liquid portions of the model (volume property mode=4, q=0.00001 for all volumes, except 104, where q=.000013 was used).
RELAP5/M3.3 Hydraulic Response for ALTRAN

The model as described above was executed to completion. The code predicted waterhammer pressures of approximately 800 psig. Comparisons of the predicted to measured pressure are provided in Figures 4. For the purposes of comparison, the test data was plotted on the same figure as the calculated values, and a time shift was applied to the test data to place it at the proper location. The test data compared in this paper was from the ALTRAN test. It should be noted that the test data is from EPRI proprietary information therefore only approximate values of the data is presented here. The actual data is not presented here for confidentiality reasons. Figure 4 shows that the RELAP5/M3.3 model as configured generated pressure responses that were consistent and conservative with respect to the test data. The same time shift was employed for all the figures, which demonstrates that the overall timing predicted by the model is consistent, and that the model also effectively predicts the propagating behavior.

Structural Response ALTRAN Case

The same methodology discussed earlier was applied to generate piping segment forces for the 2B test configuration. Command files were written in XMGR to calculate the wave and segment end loads. These loads were then compared to the forces measured in the test pipe supports.

The comparison of the support forces requires an understanding of the behavior of the structural system. The water-hammer load is very short duration, as evidenced in the pressure responses at various locations in the test apparatus. As can be seen, however, the support members experience force oscillations associated with structural ringout for a number of cycles following the application of the pressure force. The single horizontal support can be compared directly to the force calculation during the passage of the pressure wave. The two supports that take load on the long axis of the experimental apparatus represent a different story, since the loading of one support involves the other one as well. This is also evidenced in the test data, as the interaction between the supports continues well beyond the application of the waterhammer load.

Due to this behavior, the comparison of experimentally measured support forces to analytically calculated segment loads will be limited to the first cycle in which the support is loaded. The comparison will be made on the single horizontal support, since it is less affected by the complex interactions observed in the longitudinal support pair. Figure 5 provides the force time history calculated for support F1. The forces generated by post processing of the RELAP calculation are compared to the test data in the Table 1.

Ref. 1 contains data for 15 tests in the 2B configuration, with a 240” column, 70 psig driving head test data, and a range of measured air content. The mean of all tests was 738.13 psig, with a median of 751.7 psig and a standard deviation of 59.81 psig. The RELAP model as configured predicts the peak reported pressures within approximately a 1-sigma variation, and on the conservative side.
Table 1
ALTRAN Test Configuration 2B Loads in Horizontal Support F1

<table>
<thead>
<tr>
<th>Support</th>
<th>Measured Force in first loading cycle (pounds)</th>
<th>Force calculated by RELAP5/XMGR (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>-250</td>
<td>-640</td>
</tr>
</tbody>
</table>

As can be seen, the RELAP code and XMGR post processing routine predicts forces that are conservative relative to the measured values. It was believed that the structural response of the system increased the magnitude of the measure response for the ALTRAN case.

Combustion Engineering Test Facility

The Combustion Engineering (CE) test facility was designed for full flow tests of selected safety valves under a wide range of inlet fluid conditions and inlet piping configurations. In this Section, a description of the test facility and valve used will be provided.

The test data compared RELAP5/M3.3 in this paper was from the CE908 test. It should be noted that the test data is EPRI proprietary therefore only approximate values of the data are presented here. The actual data is not presented here for confidentially reasons. The test loop is shown in Figure 6. The piping isometric for CE908 is shown in Figure 7.

Figure 6 CE 980 Test Configuration

Figure 7 CE 980 Test Piping Isometric

The CE908 test used the Crosby 6M6 spring-loaded safety valve and a full-scale loop seal. More detailed information can be found in References 6 and 7.

CE908 Testing Facility Description

The major components of the facility were two large tanks with interconnected piping, a high pressure boiler, a test valve with associated inlet and outlet piping. The boiler is not shown in the Figure 6. By varying the initial fluid conditions in the boiler tank, the opening rate of the valve between the boiler tank and the accumulator tank (shown in Figure 6), as well as the boiler flow, it was possible to simulate the appropriate condition for the prescribed test.

The CE908 Transient

There are several postulated reactor coolant system transients, which may result in the actuation of the pressure relief system. These transients range from normal system transients to postulated accidents such as those analyzed in plant safety analysis reports. Typically, these plant transients result in a pressurization of the steam in the dome of the pressurizer that causes the safety and relief valves to open, thereby mitigating the overpressure transient.
To simulate the high-pressure transient that would actuate the safety valve, the high-pressure boiler provided the high-pressure source of steam to a 6-foot accumulator tank through a test initiation valve, W-6. The pressure rise in the accumulator was regulated by opening speed of the test initiation valve. The inlet to the safety valve was from the top of the accumulator and when the pressure reached the set point of the safety valve. The test results showed that the safety valve began to simmer after the accumulator pressure exceed the safety valve actuation set point of the safety valve at 2,580 psia. The water loop seal that was formed in front of the safety contained approximately 1.18 ft² of water. Although this water seal, during the normal operation of a power plant, was used to protect the inlet of the Crosby safety valve from steam erosion, it provided additional complexities to simulating the event and added significant piping loads to the facility. Simmering of the safety valve occurred during the passage of the water through the safety. Simmering is the rapid up and down motion of the safety valve. Once the water slug passes through the safety valve, the valve pops open to full steam flow at approximately 2700 psia. This causes the water slug that was relocated down stream of the safety valve during the simmering process to accelerate into the down stream piping. This produces significant piping loads on the down stream piping. Load cells are used to measure these forces during the event.

**RELAP5/M3.3 Analysis Used to Simulate CE908**

**RELAP5/M3.3** was used to simulate the CE908 transient. To model the loop seal accurately, the temperature in the loop seal was modeled as shown in Figure 8. The node closest to the steam (Node 1) was the hottest at approximately 652 °F and the water node that was about 2.7 feet from the steam water interface (Node 21) was at approximately 130 °F. Modeling the temperature distribution of the water being driven into the downstream piping was critical in determining the correct piping loads.

The **RELAP5/M3.3** model was constructed to simulate the CE908 test facility. The RELAP5/M3.3 nodal diagram is shown in Figure 9.

The pressures calculated by **RELAP5/M3.3** are presented in Figure 10. As you can from the pressures increase as the water slug moves downstream into the piping.
The pressure at PT11 was measured during the test and a comparison between the measured data and the calculated data is presented in Figure 11.

The forces were measured on the long vertical leg designated as RELAP5 volume 106 and shown in Figure 7. The RELAP5 calculate force is compared to the measured force in Figure 12. The measured data load presented in Figure 12 was modified to account for structural magnification of the original data.

Summary and Conclusions

Test data from ALTRAN Test 2b and from CE 908 was compared to calculations performed by RELAP5. These two test cases represented very complex flow phenomenon at a high pressure (CE 908) and at a low pressure (ALTRAN Test 2b). In all cases, the RELAP5 predictions were conservative to the test data and it can be concluded that RELAP5 can be used to perform piping load calculations.

Acknowledgments

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References


2) Raw Data: Configuration 2b, test 240-2-75-2-E, CCWH Test Program, presented by ALTRAN to Expert Panel Meeting 2/22/99.


5) NUREG/CR-5535/Rev1, RELAP5/MOD3.3 VOLUMES 1 through 8, Prepared by Information Systems Laboratories,
