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EPRI

August 9, 2001

James Tatum
U.S. Nuclear Regulatory Commission
11555 Rockville Pike, M/S O-11A11
Rockville, MD 20852

Attention: Mr. Jim Tatum

SUBJECT: Response to Questions on Generic Letter 96-06

Enclosed are responses to questions raised on the document "Resolution of Generic Letter 96-06 Waterhammer Issues", EPRI Interim Report TR-113594--V1 & V2, December 2000. We have previously transmitted revisions to Section 5.2.2 and 5.2.3 of Volume 1 (User's Manual) and Sections 6 and 8 of Volume 2 (the Technical Basis Report). The other sections of the report are essentially unchanged from the earlier transmittal and will only have editorial changes made prior to final submittal. The attachment to this letter includes responses to specific questions raised by the NRC. This information will be addressed as applicable in the final revision to the Technical Basis Report.

The enclosed document does not contain any proprietary information.

If you have any questions on the enclosed information or the general subject it addresses, please call me at 919-546-7959 or Avtar Singh at 650-855-2384.

Sincerely,

Avtar Singh for

Vaughn Wagoner
Carolina Power & Light Company
Chairman, EPRI Waterhammer Project Utility Advisory Group

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Attachment

Questions from Walt Jensen and Jim Tatum (NRR staff):

1. **The relationship of pressure rise time to impact velocity is given only for test configuration No. 1 which did not include air in the steam void. Please provide a comparison of the pressure rise time relationship with the data from test configuration 2 which did include air.**

   Response:

   The individual rise times for the Configuration 2a and 2b tests have been calculated. This data is provided in Figure 10-8, attached. This figure also includes the Configuration 1 test results. The comparison shows that the rise times for Configuration 2a and 2b tests are similar to the rise times for Configuration 1 when the closure velocities are similar.

2. **Please provide figure 10-9 which was missing from the "Technical Basis Report".**

   Response:

   A copy of Figure 10-9 is attached.

3. **We understand that burst tests have been performed for representative fan cooler tubing and piping which showed failure only at very elevated pressures. Please provide documentation for these tests.**

   Response:

   The burst test data discussed during the January 16, 2001 meeting is industry data that had been previously developed by EPRI. A copy of EPRI report TR-108812, dated December, 1997, describing the burst test program has been provided.

4. **The NRC staff shares the same concerns as the ACRS Subcommittee on T/H's regarding noncondensable gas generation during system draining and steam condensation during column closure. In responding to the ACRS T/H subcommittee on this issue, please also address configuration differences that exist between the test apparatus and the actual plant. For example, the heat exchanger tubes in the FCUs are generally horizontal, while the test apparatus modeled a vertical configuration. It would seem that there could be significant differences in the test results if steam bubbles are rising through a vertical tube (as in the test apparatus) vs. the plant configuration where the steam bubbles form in the tube and must expand to a vertical header that is usually at the high point (but could also be at the low point) of the system. It is not clear how the test results apply to the actual plant configuration.**

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Response:

Additional testing has been performed to determine the amount of air released during the transient. The test results and a modified approach to evaluating air release are documented in the TBR Section 6 and User's Manual (UM) Section 5.2.3, respectively.

Section 6.3.2 of the revised TBR described the test configuration and compared the test configuration and conditions to the prototypical configurations and conditions in nuclear plant applications. Specifically, the additional air release testing utilized a horizontal tube attached to a vertical header. Tests were run both with the header full and with the header empty to simulate a variety of plant conditions. These tests were more prototypical of actual plant geometry and conditions.

Questions from Gary Hammer (NRR staff):

1. **The rigid body model involves defining the waterhammer pulse as a trapezoid function having a recommended rise time. However, the recommended method for choosing rise times does not appear to be conservative when considering the steepest part of the pressure-time data plots. Also, the pulse duration is recommended to be lengthened by a factor to preserve the area under the trapezoid shape. However, this also does not appear to be conservative since it could result in less structural response than for the actually expected duration.**

   Response:

   The characterization of the pressure pulse as a trapezoid was selected to simplify the complexity of the actual pressure pulses that were seen in the tests. The trapezoidal model used to characterize the pressure pulse was developed to reflect fundamental theory, capture the pulse magnitude, rise time, and duration to simplify the transient pressure response into a set of defined pressure time (P-T) points for use in a structural calculation.

   The selection of the pulse was described in Section 9.2 and 9.3 of the TBR. The adequacy of the trapezoidal representation was evaluated and the results were reported in Section 13.5 of the TBR.

   The effectiveness of the trapezoid model was tested by comparing the response of an ANSYS model with loading from the idealized trapezoids and loading with actual pressure-time histories to the measured force response from the tests. Support loads at three locations were measured in the tests. A set of 44 test measured pressure traces from the tests was used as the "actual" pressure-time input. The test traces were accurately input to ANSYS in detail. These pulses were also characterized as trapezoids using the methods recommended in the User's Manual and then used to load the ANSYS model. The results of these two load sets (idealized trapezoid versus the actual pressure history) compared to the support forces measured in the tests is provided below (Figure 13-7 of

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the TBR). Most data fell above the "predicted = measured" line at 45° in the figure. The points that fell below the 45° line were a small percentage of the total and these points were located close to the line.

Figure 13-8 in the TBR, also provided below, showed the results for the trapezoidal characterization of the pulses for all tests analyzed using the same ANSYS model. These force responses are plotted versus the measured force data for all three restraints (F1, F2, and F3). The 45° dashed line (predicted = measured) represents exact matching of the measured response. This plot further demonstrates the accuracy of the trapezoidal modeling technique as a means of predicting real support forces.

These two comparisons show that both the actual pressure trace and the trapezoidal representation provide accurate methods to capture the response of the structure when compared to the test data. Figures 13-7 and 13-8 further show that the "curve fit" for the trapezoidal pulses provide a prediction of a higher support load than the actual pressure pulse. This indicates that on average, the trapezoidal pressure pulse is more conservative. The statistical nature of the testing, particularly for events like waterhammer, does provide a small number of calculated loads that are lower than the test results. The number of calculated points that fall below the test data is considered to be typical of what would be expected for this number of tests for a phenomena that has as much scatter as waterhammer testing.

On average, the analysis with the actual pressure time loading is conservative versus the test data by approximately 15% (percentage calculated at a load of 1,000 pounds) and the analysis with the trapezoidal pressure time loading is conservative versus the test data by approximately 30%. The trends from Figure 13-8 are the same.

The margins that exist in the calculation of the pressure magnitude and in the design and qualification of the supports is considered adequate with this trapezoidal representation to assure that a conservative basis for qualification of supports is provided. The trapezoidal representation gives higher loads than the actual pressure time curve.

The question also asked about the "lengthening" of the pressure pulse. The pulse duration will change as the pressure magnitude is cushioned to satisfy conservation of momentum. This accurately represents how the pressure pulse changes with cushioning. This is discussed in Section 9.2.2 of the Technical Basis Report. Calculation of the pulse duration is provided in the User's Manual, Section 5.3.5. The pressure pulse duration to be used is calculated based on the time of reflection. There is no recommendation to increase pressure pulse duration beyond this value.

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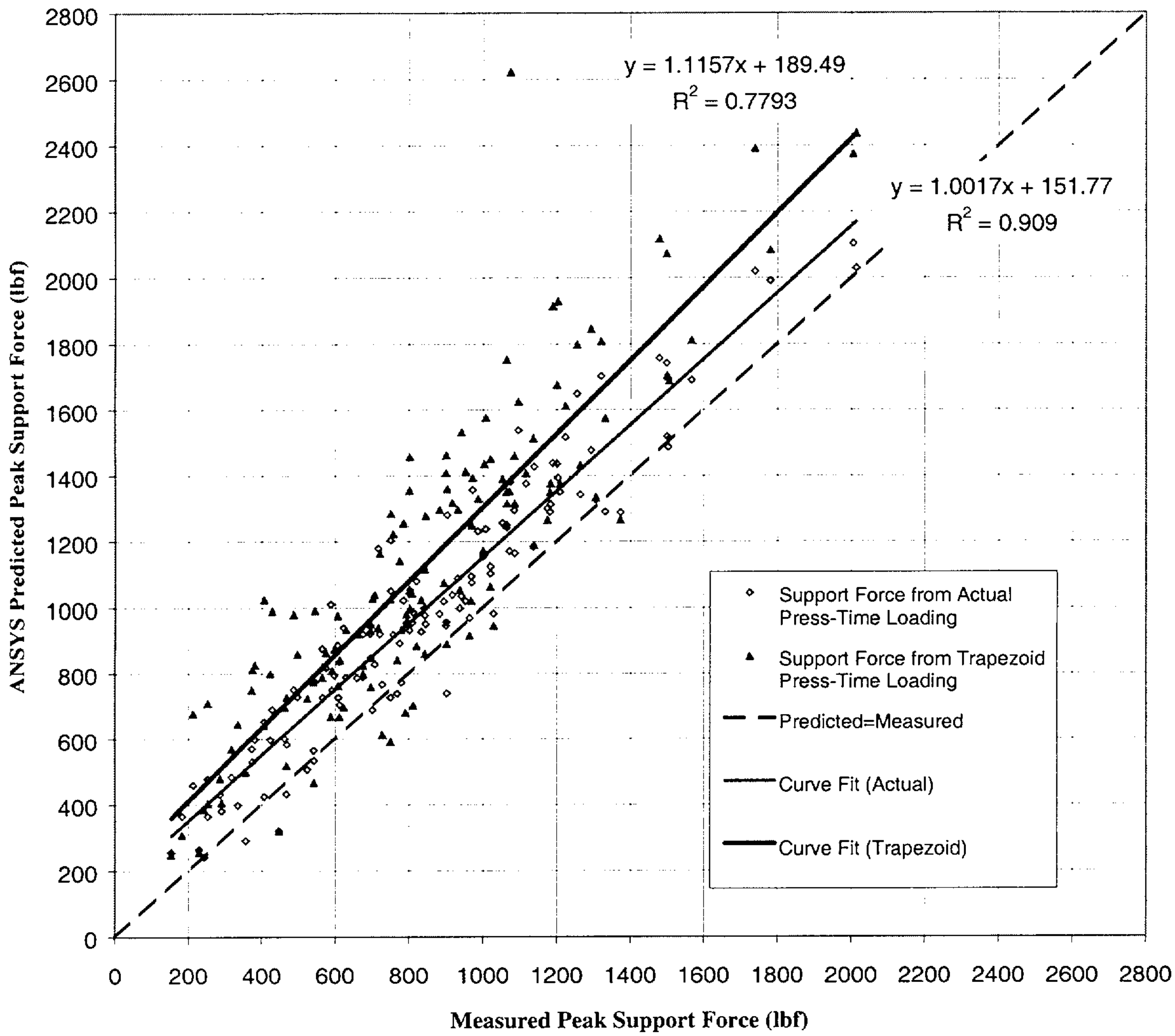

Figure 13-7: Trapezoid Characterization/Actual Data Comparison (44 Tests)

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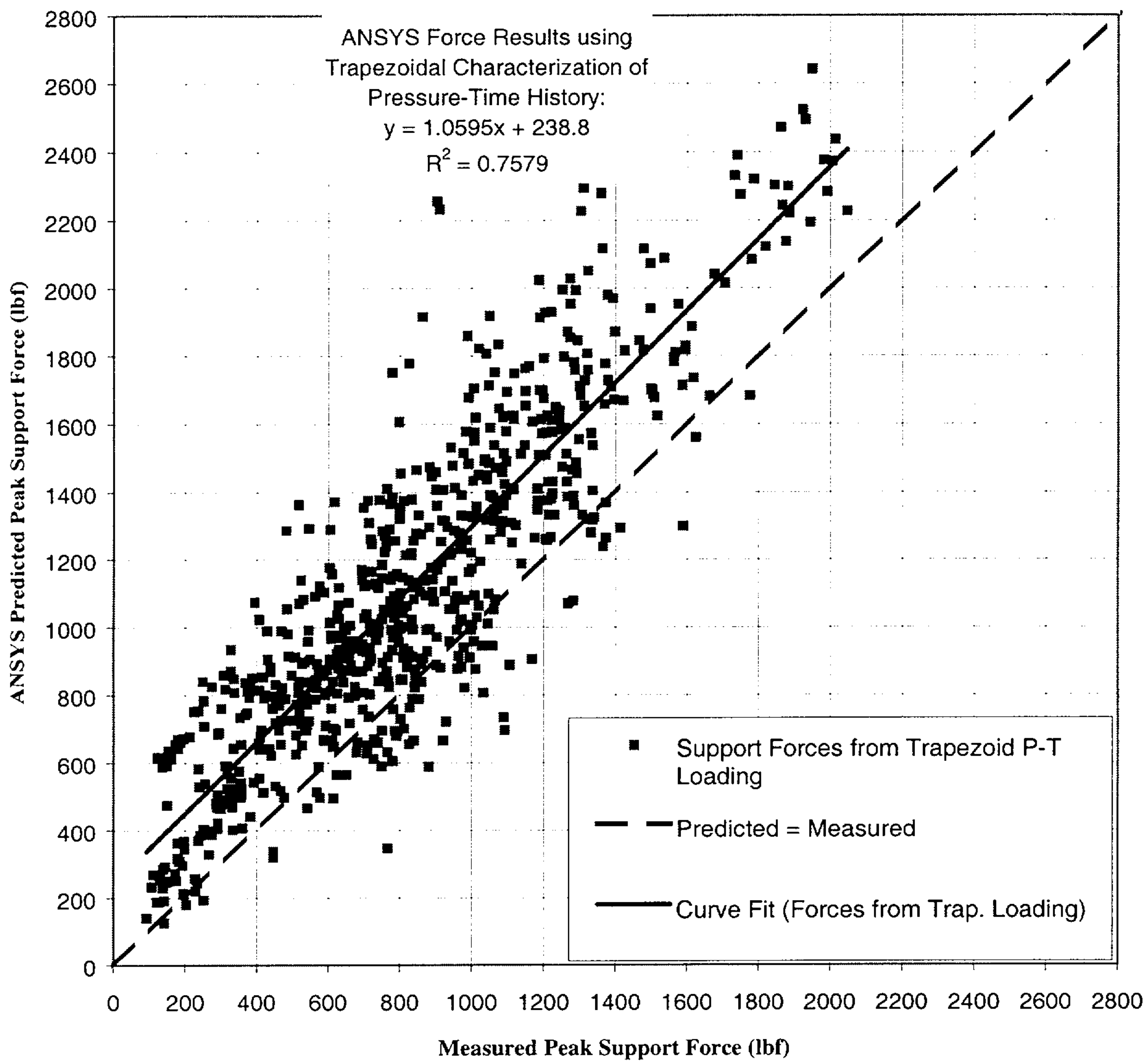

Figure 13-8: Trapezoid Characterization (All Tests)

2. **The report recommends using only one waterhammer pulse in evaluating system piping. However, waterhammer pressure loads are composed of several reversing cyclic pulses (Examples are shown in Figures 5-3 and 7-3). Figure 13-8 indicates that for the test configuration, the use of a single trapezoidal pulse is conservative in most cases evaluated. However, there are a few cases shown where this method is not conservative. Also, the structural and forcing function frequencies for plant piping configurations will differ from the tests. Therefore, a longer pressure history involving several cycles**

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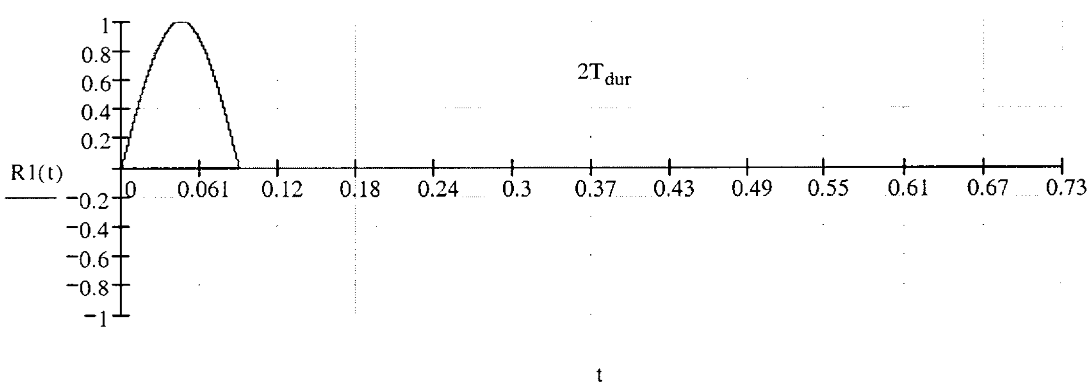
should be included in analysis of plant piping systems since this could result in additional energy being added to the structures.

<u>Response:</u>

The column closure event is essentially a single pulse phenomenon. Any subsequent pressure pulse after the initial pressure rise is caused by reflected waves passing through the system. The reflected waves will be significantly smaller in magnitude than the initial pulse.

To investigate the accuracy of using a single pulse, a single degree of freedom model was selected as typical of a single segment of piping that experiences an axial load caused by a passing pressure wave. This model was loaded with a repeating, decaying pressure pulse that occurs at the <u>precise</u> natural frequency of the structure. This was compared to a single pressure pulse load of the same initial duration. The degree of decay from the first peak to the second peak was approximately 75% as would be expected with a reflected wave and as was seen in Figure 5-3 of the TBR. The two loads are provided in the following figures.

Single Pulse Loading:



Repeated Pulse Loading:

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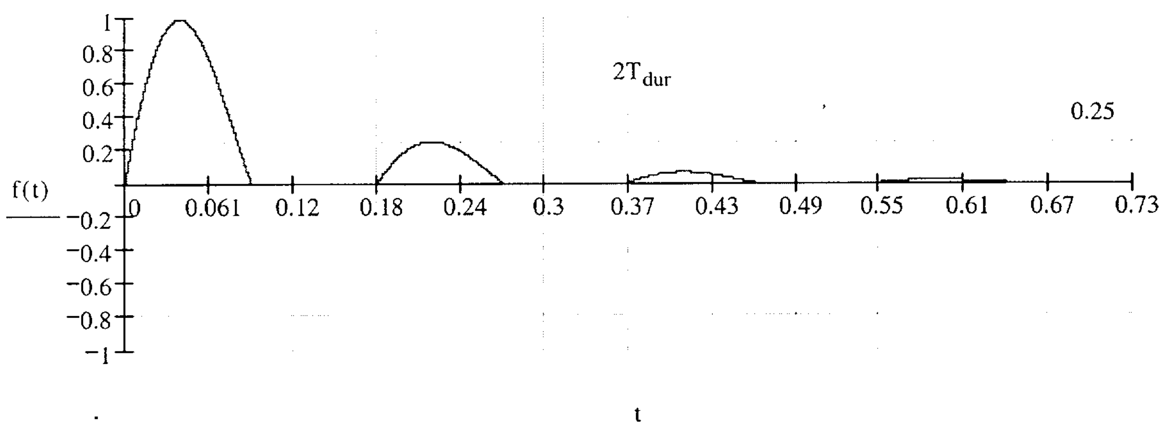

Using 2% damping, the resulting displacements for the multiple loading are within 10% of that produced by a single load. This was for the case where the loading frequency was precisely equal to the natural frequency of the system.

The response of a complex system is dependent not on the response of a single axial segment, but on the combined response of many segments to a passing pressure wave. Further, the load in any individual support is a combination of loads from many parts of a piping system. The likelihood of any individual segment having the precise natural frequency of repeated loading is very low. The likelihood of multiple segments contributing to the loading of a support and having the precise natural frequency as a repeated loading is much lower. Even a small difference between the natural frequency and the driving frequency will dramatically change the response to multiple loading. In other words, the repeated smaller loads do not have the potential to significantly affect the structural response in actual systems.

As shown for the trapezoidal load, the margins that exist in the calculation of the pressure magnitude and in the design and qualification of the supports is considered adequate to allow a single pulse to be used to assure that a conservative basis for qualification of supports is provided.

3. **The report outlines a simple method of incorporating Poisson coupling and junction coupling type fluid-structure interaction based on a study of a very simple configuration. There are significant uncertainties involved in making such predictions, and if fluid-structure interaction is to be considered in attenuating the waterhammer loads, it should be based on a more detailed plant-specific analysis.**

Response:

The analytical evaluation of potential pulse amplification by fluid structural interaction (FSI) is based on the detailed methods defined by Wood as described in reference 33 of the TBR. It was further investigated in references 34 through 38 as described in the TBR.

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The simplified method of attenuation described in TBR Section 12.4 is not provided for generic plant analysis. It is used to show that the attenuation, being cumulative, will quickly surpass any potential amplification due to FSI. This analysis is used as a basis for the recommendation that the potential amplification from FSI can be conservatively ignored.

At the discretion of the individual licensee(s), fluid structure interaction may be used only if both attenuation and amplification are employed. The degree to which attenuation or amplification dominates fluid structure interaction will be a function of the stiffness of a piping system and its supporting elements. These are plant specific elements, and thus should be addressed in the plant specific responses to the generic letter.

4. **The report does not indicate the structural damping value used in the comparison of analyzed loads vs measured loads. This information needs to be provided as part of the basis for the comparison.**

Response:

The damping used in the analysis for comparison to test data was 0.1% of critical damping. Specific damping values to be used would be plant-specific and would be in accordance with the plant's licensing documents.

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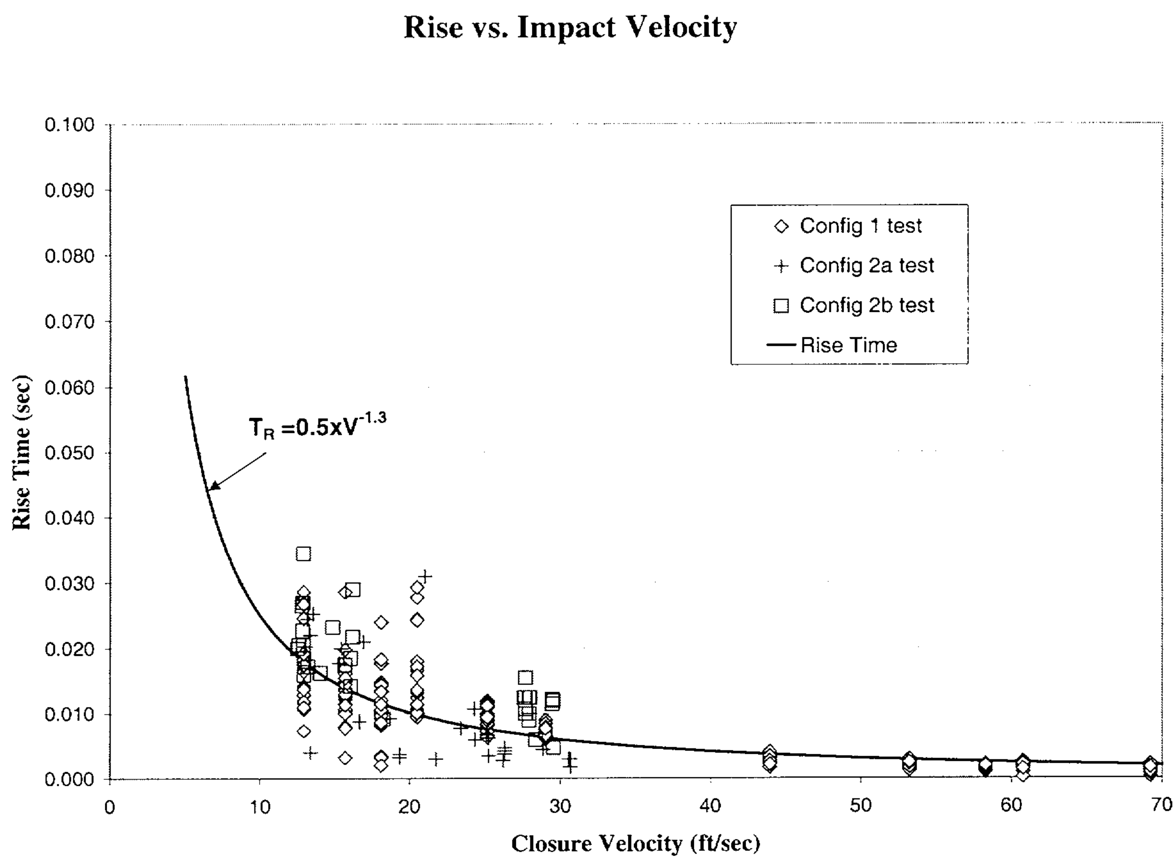

Figure 10-8: Rise Time vs. Impact Velocity – Configuration 1, 2a, and 2b

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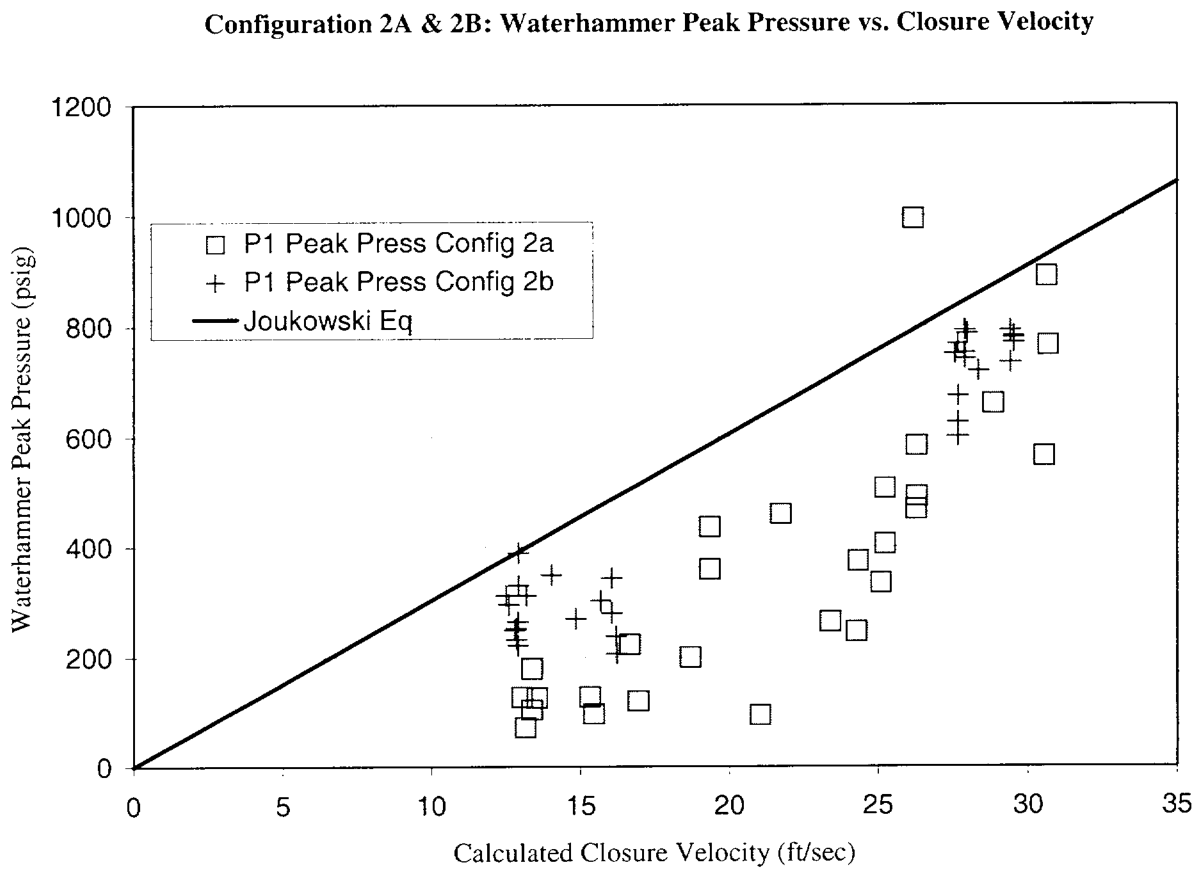

Figure 10-9: Configuration 2a and 2b Peak Pressure vs. Closure Velocity