

# WOLF CREEK

NUCLEAR OPERATING CORPORATION

Richard A. Muench  
Vice President Engineering

FEB 29 2000

ET 00-0010

U. S. Nuclear Regulatory Commission  
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Washington, D. C. 20555

Reference: 1) NRC Generic Letter 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," dated September 30, 1996  
2) WCNOG Letter WM 99-0042, dated June 29, 1999, from O. Maynard, WCNOG, to NRC

Subject: Docket No. 50-482: Supplemental Response to Generic Letter 96-06 (TAC NO. M96887)

Gentlemen:

Reference 2 submitted Wolf Creek Nuclear Operating Corporation's (WCNOG's) response to NRC Generic Letter 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," dated September 30, 1996 (Reference 1). On November 2, 1999, a telecon was held between WCNOG personnel and NRC Staff to discuss and clarify several items noted by the Staff during their review of Reference 2. Following the Staff's review of the discussion from this telecon, a second telecon was held on February 2, 2000. In that telecon WCNOG was requested to provide additional information in a written format. The additional information requested is summarized below. The enclosure contains more detailed information relative to the NRC questions and was provided by the contractor performing the work for WCNOG.

The NRC staff was concerned with three items in Reference 2. First, WCNOG compared the calculated maximum stress due to a waterhammer with the emergency condition allowable stress limit ( $1.8 \times Sh$ ) rather than the faulted condition allowable stress limit ( $2.4 \times Sh$ ). Second, WCNOG used a value of 2300 ft./sec. as the speed of sound (sonic velocity) in water, which was seen as potentially non-conservative. Third, WCNOG did not explicitly consider condensation induced waterhammer in the evaluation.

Due to waterhammers occurring during past testing in the Wolf Creek containment cooling system, WCNOG specifically requested our contractor, Altran Corporation, to compare the calculated stresses caused by waterhammer in the containment cooling system to the emergency condition allowable stress limit. Since the emergency condition allowable stress limit ( $1.8 \times Sh$ ) is significantly lower than the faulted condition allowable stress limit ( $2.4 \times Sh$ ), it would be apparent that if the piping system could meet the emergency condition stress limit, margin would be available to the faulted condition

stress limit. As shown in Table 4 of Altran Technical Report 96227-TR-03, Revision 0, the calculated maximum stress is at or below the emergency condition stress limit. Therefore, there would be a 33% margin to the faulted stress limit. WCNOC has revised our testing methods to eliminate the possibility of causing a waterhammer in the containment cooling piping system in the future.

WCNOC used a sonic velocity of 2300 ft/sec in the calculations based on the best estimates available. However, the NRC staff was concerned that number may be non-conservative and suggested that a sonic velocity of 4600 ft/sec would be a more conservative number to use. Based on the methodology used to calculate the forcing function for the stress created due to the waterhammer, and the relatively short segments of straight pipe in the Wolf Creek containment cooling piping system, there is an insignificant difference between using 2300 ft/sec. and 4600 ft./sec. for the sonic velocity. This is calculated and shown in the enclosure.

Altran Corporation did not explicitly consider condensation-induced waterhammer in the Wolf Creek analysis because of the relatively low pressure in the piping system during system draindown. It was shown in Altran Technical Report 96227-TR-001, Revision 03, on Page 29, that condensation-induced waterhammer is precluded during refill of the piping system. During draindown, the pressure is calculated to reach only 8.2 psia. A test program sponsored by EPRI and witnessed by the NRC has shown that for system pressures less than 15 psig, condensation induced waterhammers are limited in magnitude and duration such that the column closure waterhammer is limiting. The testing has been documented in a draft EPRI Technical Basis Report, TR-113594. Therefore, since the Wolf Creek piping system pressure is significantly less than 15 psig during draindown, it was not necessary to explicitly consider the condensation-induced waterhammer.

As previously noted, more detailed information on the above items is provided in the enclosure. The attachment notes commitments contained in this letter. If you have any questions concerning this matter, please contact me at (316) 364-4034, or Mr. Michael J. Angus at (316) 364-4077.

Very truly yours,



Richard A. Muench

RAM/rlr

Attachment

Enclosure: Altran Corporation Letter 99634B-001, dated December 21, 1999, "Letter Report Assessment of GL 96-06 Waterhammer Analysis Assumptions and Available Margin," from M. Zweigle, Altran Corporation, to W. Selbe, WCNOC

cc: J. N. Donohew (NRC), w/a, w/e  
W. D. Johnson (NRC), w/a, wo/e  
E. W. Merschoff (NRC), w/a, wo/e  
Senior Resident Inspector (NRC), w/a, wo/e

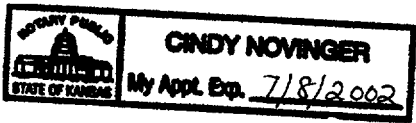
STATE OF KANSAS     )  
                              )   SS  
COUNTY OF COFFEY    )

Richard A. Muench, of lawful age, being first duly sworn upon oath says that he is Vice President Engineering of Wolf Creek Nuclear Operating Corporation; that he has read the foregoing document and knows the content thereof; that he has executed that same for and on behalf of said Corporation with full power and authority to do so; and that the facts therein stated are true and correct to the best of his knowledge, information and belief.

By           *RMuench*            
Richard A. Muench  
Vice President Engineering

SUBSCRIBED and sworn to before me this 29<sup>th</sup> day of February, 2000.

          *Cindy Novinger*            
Notary Public



Expiration Date July 8, 2002

**LIST OF COMMITMENTS**

The following table identifies those actions committed to by Wolf Creek Nuclear Operating Corporation (WCNOC) in this document. Any other statements in this submittal are provided for information purposes and are not considered to be commitments. Please direct questions regarding these commitments to Mr. Michael J. Angus, Manager Licensing and Corrective Action at Wolf Creek Generating Station, (316) 364-4077.

<b>COMMITMENT</b>	<b>Due Date/Event</b>
None	N/A



December 21, 1999  
99634B-001

Mr. William Selbe  
Wolf Creek Nuclear Operating Company  
1550 Oxen Lane N.E.  
Burlington, Kansas 66839-0411

**SUBJECT: Letter Report Assessment of GL96-06 Waterhammer Analysis Assumptions and Available Margin**

Ref.: 1. USNRC Generic Letter 96-06  
2. Altran Technical Report 96227-TR-001, Rev. 3, 3/98  
3. Altran Technical Report 96227-TR-003, Rev. 0, 2/98  
4. EPRI Technical Basis Report (TBR) TR-113594 (Draft)  
5. WCNOC PO 0572706/3

Dear Mr. Selbe:

Altran Corporation has completed an assessment of the evaluation previously performed to address waterhammer issues for USNRC Generic Letter 96-06 for Wolf Creek (Ref. 1). Altran had performed this analysis of the waterhammer issues (Ref. 2) and qualified the piping system for these waterhammer loads as documented in previous analysis. This letter assess two specific issues raised in the review of the analysis and the margin available based on the qualification of the piping system. This work is completed in conformance with the requirements of the referenced purchase order.

The two issues discussed with the NRC in a recent review of the GL96-06 response are as follows: Condensation induced waterhammer (CIWH) was not explicitly considered in the previous evaluation and the sonic velocity used in the previous column closure waterhammer evaluation was believed to be unconservative.

### **Condensation Induced Waterhammer**

Condensation induced waterhammers are expected to occur during the draining phase of the event, when pumps have lost power and heat is being added to boil water at the Fan Coolers. CIWH occur when the system pressure drives slugs of water to collapse trapped steam bubbles. Since the motive force for the acceleration of the water slugs is the system pressure and the system pressure is lowered with the loss of pump pressure, the energy of the CIWH has to be limited.

A testing program was conducted to investigate the effects of both condensation induced and column closure type waterhammers expected to occur due to the combined LOCA/LOOP conditions described in generic letter 96-06. This testing program was performed by an industry consortium and resulted in a draft EPRI Technical Basis Report (TBR), Reference 4. The waterhammers produced in the CIWH portion of the testing program established that these events were of limited energy and are not expected to challenge system piping integrity. As stated in the TBR:

The conclusion can be drawn from the CIWH testing program that the CIWH waterhammers, for low pressure service water systems, are limited in magnitude or duration such that they are not a credible threat to pressure boundary integrity. This conclusion will apply only to systems that meet the following conditions:

- the system steam pressure at the time of the postulated CIWH is less than 15 psig
- the system draining water contains non-condensables
- the piping has been shown by test or analysis to be capable of withstanding a CCWH following LOOP, LOOP/LOCA, or LOOP/MSLB

CIWH does not need to be explicitly evaluated if the bulleted items described above are true. This can be established as follows:

- The pressures calculated to occur in the Service Water System are calculated to reach 8.2 psia per Reference 2, page 25. Therefore, the pressure is less than 15 psig.
- The Service Water System is drawn from the man-made lake. It is therefore aerated to approximately the saturation point for air.
- The piping system is qualified for column closure waterhammer in Reference 3.

Therefore, CIWH does not need explicit analysis since the CCWH is bounding, as established in the EPRI TBR.

### **Sonic Velocity**

The value for sonic velocity (C) is used in two places in the application of waterhammer loading. Based on the model used for Wolf Creek, changes to the sonic velocity in these two places will produce results that act in opposite directions, producing a net change of zero for the piping system loads. This is described below.

First, sonic velocity is used in the equation to determine the magnitude of the waterhammer pressure pulse. This is the classical Joukowski equation:

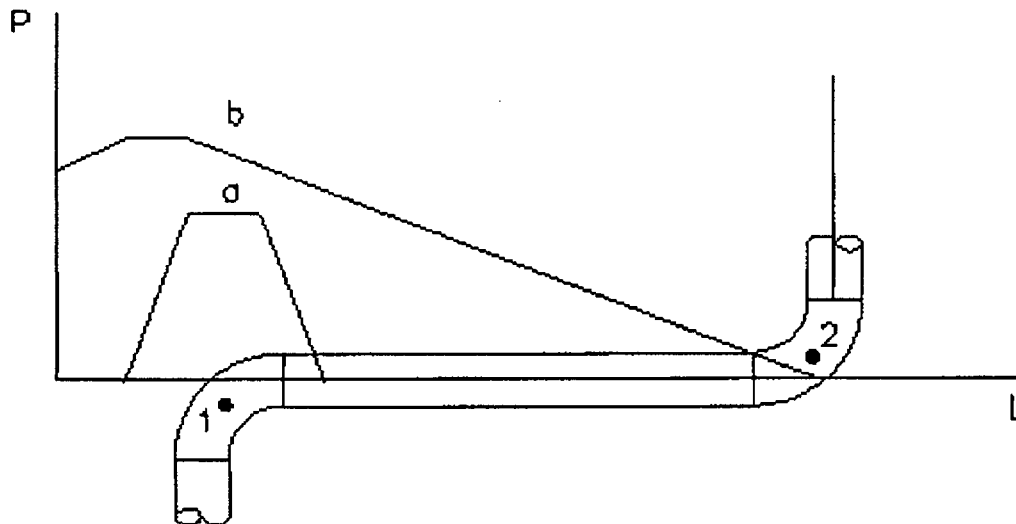
$$\Delta P = k\rho C\Delta V$$

where:

- $\Delta P$  = the waterhammer pressure pulse magnitude
- $k$  = a constant for the impact surface (1/2 or 1)
- $C$  = sonic velocity
- $\Delta V$  = the velocity change at impact

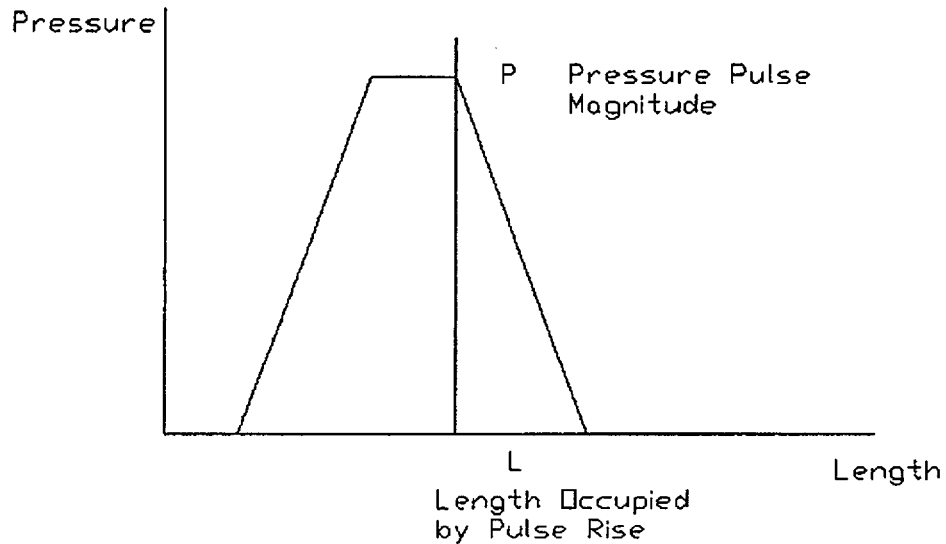
It is obvious that increasing the sonic velocity term in the Joukowski equation will linearly increase the magnitude of the pressure pulse and therefore the piping loads.

The second place that the sonic velocity term is used in the evaluation is in the application of the pressure pulse to load the piping system. The loading applied at Wolf Creek follows the method described in detail in the EPRI TBR document (Reference 5). As a pressure pulse travels through a pipe section, structural loads are produced by the unbalanced pressure forces. A representation of this phenomenon is presented in the figure below for a simplified trapezoidal pressure wave. This figure presents two different trapezoidal pressure waves (denoted "a" and "b") each superimposed on a length of pipe running from point 1 to point 2. A wave enters the pipe from the left and travels across the span at the sonic velocity of the fluid. Based on the length of the piping segment compared to the length and slope of the rising pressure wave, a time-dependent loading of the section will occur. The magnitude of the pipe loading is the differential pressure across the segment times the pipe cross sectional area.



For pipes which are relatively short compared to the length occupied by the rising pressure wave, the slope of the pressure wave rise is the primary variable affecting differential pressure loading.

The rise "length" is the rise time times the sonic velocity ( $L = T_R \times C$ ). It can be seen that increasing the sonic velocity by the same amount in both the determination of pressure peak magnitude and length through which it travels will leave the slope the same. Therefore, for short piping lengths relative to the pulse rise time, the net effect of increasing the sonic velocity is zero, since the magnitude and rise slope act in opposite directions.



The effect of changing the sonic velocity ( $C$ ) can be shown mathematically as follows:

Pressure Pulse from Joukowski

$$P = \Delta P = k\rho C\Delta V$$

Pulse Rise Length

$$L = T_R C \text{ where } T_R = \text{pulse rise time}$$

Force on the Pipe Segment

$$F = dP/dL \times L \times A \text{ where } A = \text{pipe cross sectional area}$$

$$F = d(k\rho C\Delta V)/d(T_R C)$$

Since  $C$  terms exist in both numerator and denominator, the force on the pipe is unchanged with higher sonic velocity. This effect was independently verified using a single degree of freedom model of a piping segment. For information purposes, a copy of this model is included as an attachment to this report.



Mr. William Selbe  
99634B-001  
December 21, 1999  
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To meet the criteria described above, the segments lengths in the piping system must be shown to be short relative to the pressure pulse. Per reference 3, the longest pipe segment in the piping system is 61.93 feet (Segment 11). Since the rise time is 100 milliseconds, the wave will travel  $.1 \text{ sec} \times 4600 \text{ ft/sec}$  or 460 feet during this rise. Since the pipe length occupied by this rise time is much greater than the 61.92 feet of the longest segment, it can be concluded that all of the pipe segments are small relative to the wave rise time.

In conclusion, the increase in pressure pulse will be countered by a decrease in the pipe loading due to the greater pressure wave travel speed. This is true for pipe segments which are short relative to the length occupied by the rising wave, and all the segments in this system meet this criteria. Therefore, there is no net increase in pipe loads due to the differential pressure loading from the waterhammer, and the current analysis remains valid.

Please feel free to contact me with any questions or comments.

Sincerely,

ALTRAN CORPORATION



Gregory Zysk  
*Project Engineer*



*For* Matt Zweigle  
*Project Engineer*

cc: W. Selbe  
M. Eissa  
M. Zweigle

**Introduction:**

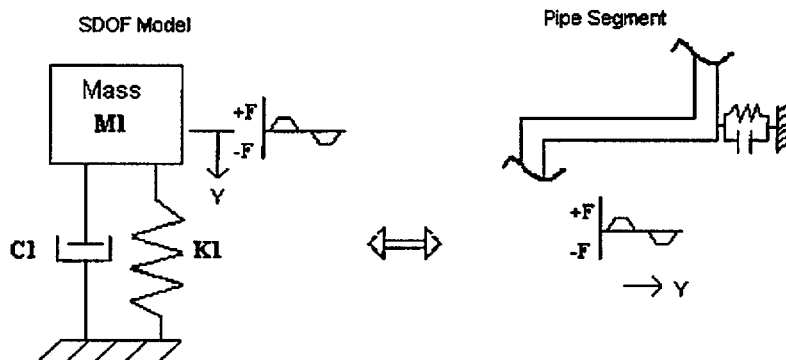
The dynamic effects of the increase in sonic velocity will be to increase the pressure pulse and decrease the pulse travel time. The object of this calculation is to show that the net effect of the sonic velocity increase is zero.

The calculation is based on a single degree of freedom (SDOF) model, used to represent a pipe segment. The solution to the single degree of freedom system (bounded pipe segment) when subjected to a trapezoidal pulse loading at each elbow is shown below. The trapezoidal pulse has been degenerated to a triangular pulse at each elbow. This is done by simply reducing the flat period of the trapezoid to a duration of 1 msec.

The solution of this single degree of freedom (SDOF) problem is the force on the pipe support (spring).

$$M1y'' + C1y' + K1y = \text{Sum}(t,w,y1)$$

SDOF system equivalent to bounded pipe segment.



$$y'' = (-C1/M1) \times y' - (K1/M1) \times y + \text{Sum}(t,w,y1)$$

$$y' = (-C1/M1) \times y_1 - (K1/M1) \times y_0 + \text{Sum}(t,w,y1)$$

**TRAPEZOIDAL FUNCTION**

Create a trapezoidal forcing function representing the pressure wave.

$P_{rise} := 225$  Waterhammer pressure and sonic velocity used to define the pressure pulse (reference 96227-TR-01, Rev3 page 29).

$C := 2300$

$t_{rise} := .1$

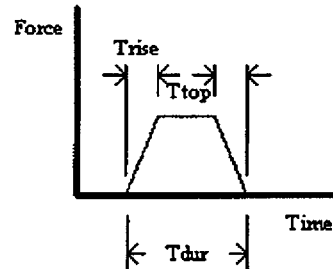
$T_{top} := 0.001$

$w_1 := t_{rise} + T_{top}$

$D_i := 1.939$

$w := t_{rise}$

$Leg := 10$



$T_{dur} := 2 \cdot t_{rise} + T_{top}$

$K1 := .1622 \cdot 10^5$  lbf/ft Note the units.

$T_{dur} = 0.201$

$M1 := 7.435$  This is the mass/G =  $[\text{lbm}/((\text{ft} \times \text{lbm})/(\text{sec}^2 \times \text{lbf}))]$

$A_{pipe} := \frac{\pi \cdot D_i^2}{4}$

$trav := \frac{Leg}{C}$

Time for the leading edge of the pressure wave to travel the length of the pipe segment.

$Force := P_{rise} \cdot A_{pipe}$

$trav = 0.0043$

The variable trise is the width of the ramp and  $T_{top}$  is the width of the top of the trapezoid. The height of the ramp is the coefficient Amp.

$Amp := \frac{Force}{t_{rise}}$

**DETERMINE CRITICAL DAMPING COEFFICIENT**

$C_{cr} := 2 \cdot \sqrt{K1 \cdot M1}$  (lbf-sec)/ft Critical Damping is =  $2 \cdot [(k \times M)/g]^{0.5}$

$C_{cr} = 694.538$  (lbf-sec)/ft

$C1 := 0.02 \cdot C_{cr}$  2 percent of critical damping.

$C1 = 13.891$

**DETERMINE NATURAL FREQUENCY OF SDOF SYSTEM**

$f_{nat} := \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{K1}{M1}}$

$f_{nat} = 7.434$

$T_{natural} := \frac{1}{f_{nat}}$

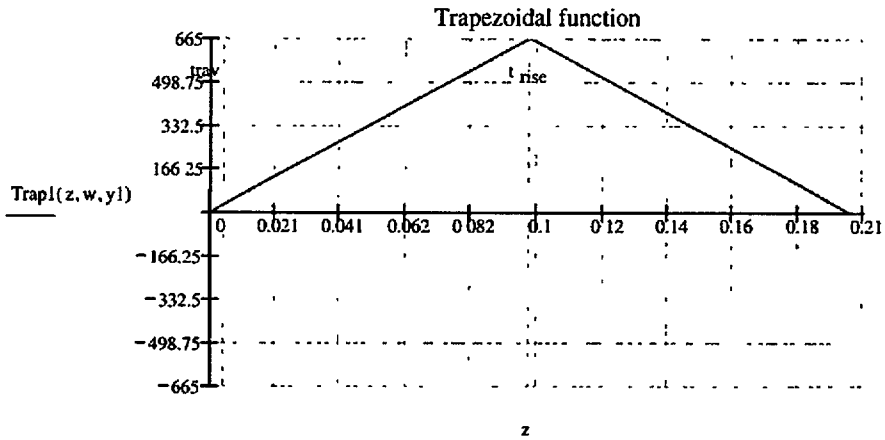
$T_{natural} = 0.135$

$\frac{T_{dur}}{T_{natural}} = 1.494$

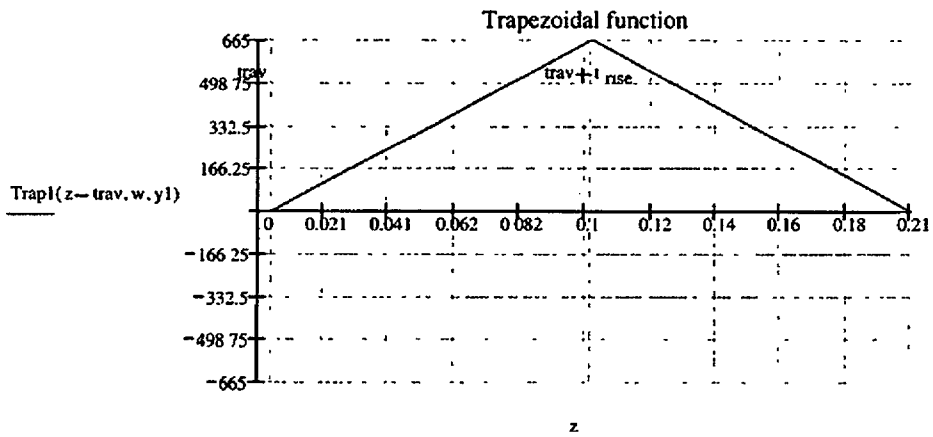
# For Information Only

$$\text{Trap1}(t, w, y1) := \Phi(t) \cdot \text{Amp} \cdot t - \Phi(t - w) \cdot (t - w) \cdot \text{Amp} - \Phi(t - y1) \cdot (t - y1) \cdot \text{Amp} + \Phi(t - y1 - w) \cdot (t - y1 - w) \cdot \text{Amp}$$

The first two figures show the pressure time history at each elbow of the pipe segment. The trapezoidal pressure wave at each end will produce the differential pressure loading shown in the bottom figure.

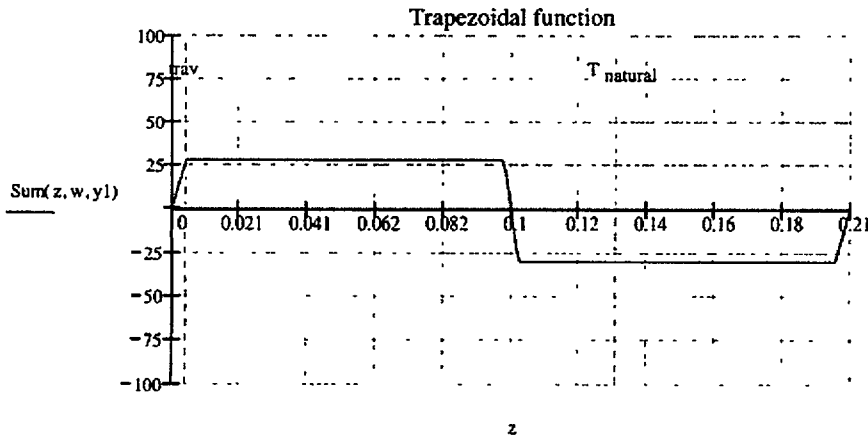


Press/time history at first elbow.



Press/time history at second elbow.

$$\text{Sum}(t, w, y1) := \text{Trap1}(t, w, y1) - \text{Trap1}(t - \text{trav}, w, y1)$$



Net force due to differential pressure acting across the pipe segment.

**SOLUTION OF SECOND ORDER DIFFERENTIAL EQUATIONS**

Solve  $M1y'' + C1y' + K1y = \text{Sum}(z,w,y1)$  This is the equation of motion for a SDOF system subject to a load  $\text{Sum}(z,w,y1)$ .

for  $y(0) = 0$  and  $y'(0) = 0$  The initial displacement and velocity are zero.

**Step 1 : Define the initial conditions**

$$y := \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

<--- Define the initial conditions, The first element is the initial condition of the unknown function. The second element is the initial condition of the first derivative of the unknown function.

$y(0) = y_0$  The initial displacement is zero.

$y'(0) = y_1$  The initial velocity is zero.

**Step 2: Define the Derivative Vector D.**

The function D is an n element vector whose n elements ( $n=1,2,3, \dots$ ) are the first n derivatives of the unknown function Y.  $Y_0$  is the displacement,  $Y_1$  is the first derivative,  $Y_2$  is the second and so on. The choice of Y and t is arbitrary

**First Derivative:**

The first Derivative is input simply as  $Y_1$ . It does not have to be solved for from the second derivative.

**Second derivative:**

The second derivative is the second element of the D vector. The second derivative is defined.

$$D(t, Y) := \begin{bmatrix} Y_1 \\ \frac{-C1}{M1} \cdot Y_1 - \frac{K1}{M1} \cdot Y_0 + \frac{\text{Sum}(t, w, y1)}{M1} \end{bmatrix}$$

$$y'' = (-C1/M1) \times y' - (K1/M1) \times y + \text{Sum}(t,w,y1)$$

$$y'' = (-C1/M1) \times y_1 - (K1/M1) y_0 + \text{Sum}(t,w,y1)$$

**Step 3: Define the Mathcad DE Solver, using the Runge-Kutta technique.**

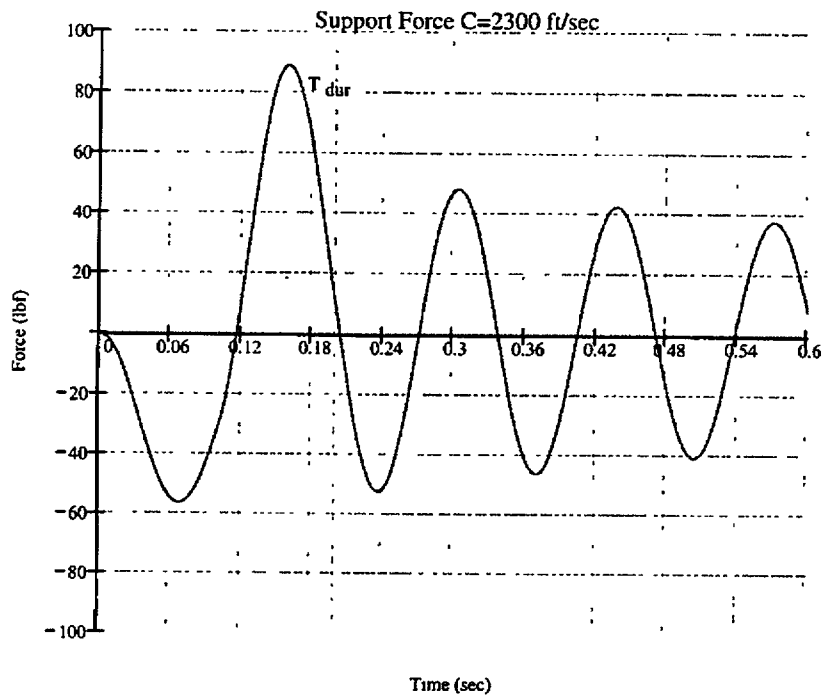
$Z := \text{rkfixed}(y, 0, 1.40, 1000, D)$  <---- Define the **rkfixed function** (or other Mathcad Solver) which evaluates the solution "y" between the values 0 and 0.2 at 1000 steps, using the differential equation vector D which is defined above.

$i := 0.. \text{rows}(Z) - 1$

this is the index definition. It uses the Mathcad variable "rows(Z)" this variable returns an integer which is equal to the number of rows in the Matrix Z. You subtract 1 because the number of rows includes the "zeroeth row".

$\text{rows}(Z) = 1.001 \cdot 10^3$

The following plot shows the resulting force on the pipe support (spring) resulting from the differential pressure across the pipe segment.



$$F_{\max 2300} := -\min(Z^{<1>}) \cdot K1$$

$$F_{\max 2300} = 89.33 \text{ lbf}$$

Repeat the problem using the increased sonic velocity (doubled from 2300 to 4600 ft/sec) which produces a doubled water hammer pressure pulse (225 to 450 psi). The solution will show that the support load is the same.

Create forcing function representing the pressure wave.

$P_{rise} := 450$  Pressure and sonic velocity used to define the pressure pulse.

$C := 4600$

$t_{rise} := .1$

$T_{top} := 0.001$

$y1 := t_{rise} + T_{top}$

$D_i := 1.939$

$w := t_{rise}$

$Leg := 10$

$T_{dur} := 2 \cdot t_{rise} + T_{top}$

$T_{dur} = 0.201$

$K1 := .1622 \cdot 10^5$  lbf/ft Note the units.

$M1 := 7.435$

This is the mass/G = [lbm/((ftxlbm)/(sec<sup>2</sup>xlbf))]

$A_{pipe} := \frac{\pi \cdot D_i^2}{4}$

$trav := \frac{Leg}{C}$

Time for the leading edge of the pressure wave to travel the length of the pipe segment.

$Force := P_{rise} \cdot A_{pipe}$

$trav = 0.0022$

$Amp := \frac{Force}{t_{rise}}$

$f_{nat} := \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{K1}{M1}}$

$T_{natural} := \frac{1}{f_{nat}}$

$\frac{T_{dur}}{T_{natural}} = 1.494$

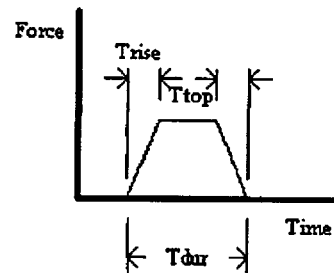
$f_{nat} = 7.434$

$T_{natural} = 0.135$

Define the loading function:

$Trap1(t, w, y1) := \Phi(t) \cdot Amp \cdot t - \Phi(t - w) \cdot (t - w) \cdot Amp - \Phi(t - y1) \cdot (t - y1) \cdot Amp + \Phi(t - y1 - w) \cdot (t - y1 - w) \cdot Amp$

$Sum(t, w, y1) := Trap1(t, w, y1) - Trap1(t - trav, w, y1)$



Setup the 2nd order differential equation and solution:

$$y := \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

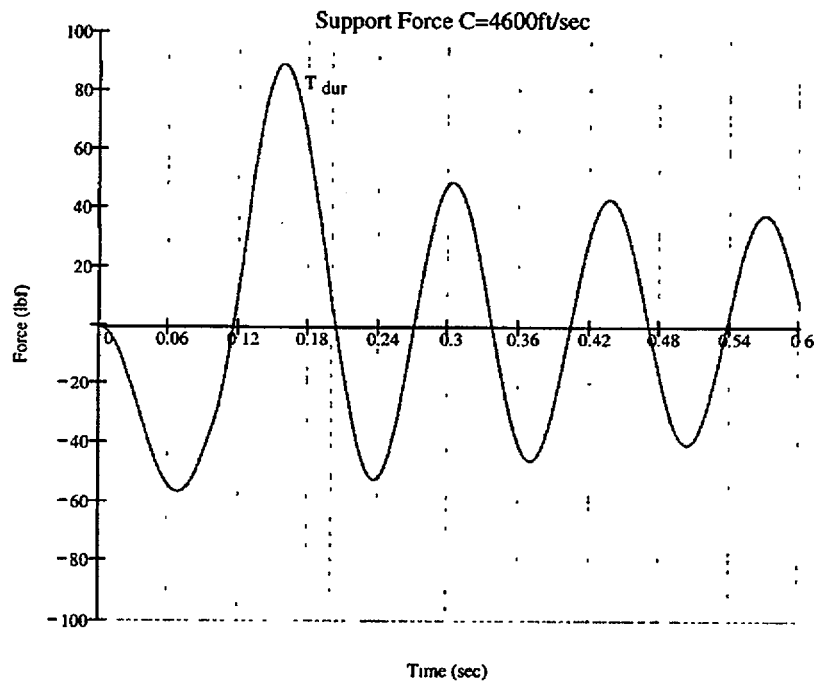
$$D(t, Y) := \begin{bmatrix} Y_1 \\ -\frac{C1}{M1} \cdot Y_1 - \frac{K1}{M1} \cdot Y_0 + \frac{\text{Sum}(t, w, y1)}{M1} \end{bmatrix}$$

$$Z := \text{rkfixed}(y, 0, 1.40, 1000, D)$$

$$i := 0.. \text{rows}(Z) - 1$$

$$\text{rows}(Z) = 1.001 \cdot 10^3$$

The following plot shows the resulting force on the pipe support (spring) resulting from the differential pressure across the pipe segment. The sonic velocity and pressure differential have been double but the Support Force is the same.



$$F_{\max 4600} := -\min(Z^{<1>}) \cdot K1$$

$$F_{\max 4600} = 89.368$$

### Conclusion:

Doubling the sonic velocity does not change the support loads as can be seen below. A review of the force-time history plots shows that the duration and other characteristics are also equivalent.

$$F_{\max 2300} = 89.331$$

$$F_{\max 4600} = 89.368$$