Stress Bulletin No. 2

Purpose/Content: Dynamic Analysis of Water Hammer Loads.

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Date: August 13, 1992

Rev. 0

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DYNAMIC ANALYSIS OF WATER HAMMER LOADS

PURPOSE: Water Hammer is an excess pressure or reaction due to changes in velocity of fluid flowing through a pipe line. It occurs in pumping lines where the pulsation or sudden stoppage of the pump or the rapid closing of a valve happens.

An example to perform the Dynamic Analysis of Water Hammer loads in CAESAR II Version 3.17 follows:

The parameters for line ACWS-5R009-36"-1J1D (Stress Iso. STR-21-2) are used. The static analysis should be completed first before running (option 3) dynamic analysis.

The steps for water hammer analysis:

- Calculation of flow velocity
- Calculation of pressure rise.
- Calculation of unbalanced force.
- Calculation of rise time and duration of load.
- Calculation of valve closure time

Menu options under CAESAR II Dynamic Analysis (option 3):

Shock definition.	(option 3)
Pulse Table Generation.	(option 4)
Pulse Spectrum Force Sets.	(option 7)
Shock Cases.	(option 9)
Static/Dynamic combinations	(option A)
Control Parameters.	(option B)
Save Dynamic input	(option C)
Check Dynamic input	(option D)
Perform Dynamic Analysis	(option E)

Output Reports:
Displacement report
Forces/Stress Report
Natural Frequency
Mode Shapes

Flow velocity:

Flow velocity, V = (.408) Q / ID x ID (reference 1)
Q = flow = 35000 gpm, ID = 36 - 2(.375) = 35.25
V = (.408) (35000) / (35.25 x 35.25) = 11.49 ft/sec

Pressure wave at pump discharge, dp:

Pressure Rise, dp = r c dv (reference 2)
r = fluid density = 62.4 lb / ft x ft x ft
c = speed of sound in the fluid, ft/ sec

c = Sq. Rt [(Ef / r(1 + (Ef/E)(d/t)))]
Ef = bulk modulus of fluid= 313000 psi for water
E = Modulus of elasticity of pipe=30E6 psi
t = pipe wall thickness, inch
d = inside diameter = 35.25"
(ref. 4 uses ID & ref. 2 uses mean diameter)
Denominator = r(1 + (Ef/E)(d/t))
=62.4 (1 + (313000/30E6)/(35.25/.375))
=62.4 (1.9807) = 123.59 lb/ftxftxft
c = Sq. rt (313000/123.59) (32.2x144) = 3426 ft /sec

dv= change in velocity = 11.49 ft / sec (water to stop)

dp = r. c. dv = (62.4 x 3426 x 11.49)/(32.2x144)= 529.87 psi

Unblanced water hammer force,F = dp (flow area)
F = (529.87) (3.14x 35.25 x 35.25)/ 4 = 513557 lb.

Rise time, t = ID/c = ((35.25/12)/3426)x1000 =0.857 milli sec

Duration of load = Considered pipe length/c
For elbow 60 to 65, length = 41.5'
Duration = 41.5 x1000 / 3426 = 12.11 milli sec
Preparation of **time history** (for option 3, shock definitions)

Time, milli secs	Force, Lb
0.	0.
0.857	513557
12.11 + .857=12.967	513557
12.967+ .857=13.824	0.

Critical valve closure time = (2 x length to relief point)/c
Length to 48" reducer (relief point)= 94.75'
Closure time = (2 x 94.75)(1000) / 3426 = 55.31 milli sec

cutoff frequency = Sqrt (E/r)/ span in the primary run
=Sqrt((30E6x32.2x12)/.283) /(spanx12) rad/sec
= (202388)/(spanx12)/(2x3.14) Hertz
In elbow pair 60 & 65, pipe length are 5' and 36.5' (unusual spans)

Cutoff frequency for 36.5'=(202388)/(36.5x12)/(2x3.14)= 74 Hz

Hints and general information:

1. The suggested flow velocities for different fluids and pipe materials are given in reference 3. For water in steel pipe, suggested flow velocity is 7 to 10 feet/sec. If the calculated flow velocity is high, the possibility of increasing pipe diameter can be looked in to. The kinetic energy is a function of square of flow velocity. So decreasing the flow velocity, decreases the water hammer force immensely. Also when the flow velocity is high, liners may be required for expansion joints.

2. Sometimes the discharge is given in the units second feet instead of gallons per minute. use one second foot = 448.8 gpm

3. The pressure rise for instantaneous closure is directly proportional to the fluid velocity (dv) at cutoff and to the magnitude of the surge velocity (c) and is independent of the length of pipe (reference 4). The surge or pressure wave velocity, c, decreases with increase in ratio inside diameter to wall thickness,d/t. But changing pipe inside diameter or wall thickness may not be practical.

4. For cast iron and asbestos cement pipes, the wave velocity is lower compared to steel pipes since modulus of elasticity,E is lower. E for cast iron is 15E6 and for cement pipe is 3E6. Ratio of Ef/E can be assumed as 0.01 for steel pipe, 0.02 for cast iron pipe and 0.1 for reinforced concrete pipe. As mentioned before, Ef is bulk modulus of compressibility of fluid. Ef for water is about 300,000 psi.

5. For calculating the closure time of a check or control valve, the two times the length of pipe is used. This is the time required for the pressure wave to travel from the point of closure to the relief point and back to the point of closure (reference 5). The relief point is usually a larger pipe riser or main or water tank. If a check valve closed in a time shorter than the critical closure time, the pressure wave strikes the closed valve with maximum intensity.

6. Water hammer force is the product of pressure rise and flow area. If necessary, Unbalanced water hammer force may be absorbed by anchor blocks.

7. Surges can often be reduced substantially by using bypass around check valves, by cushioning check valves for the last 15 to 20% of the stroke or by adopting a two-speed rate of valve stroke (reference 4).Water hammer resulting from power failure can sometimes be held to safe limits by providing flywheels or by allowing the pumps to run backward. Air-inlet valves may be needed or the preferred solution may be to use a surge tank, a surge damper or a hydropneumatic chamber.

Output Interpretation:

a. Mass Participation report:

High participation factors indicate that the mode is easily excited by the applied dynamic force. If the displacement report indicate high dynamic response (such as high translation), the modes with high participation factors must be damped or eliminated. Addition of supports at points of high translations would reduce the participation factor. The thermal flexibility must still be maintained.

b. Natural Frequencies:

It is desirable to have the frequencies above 5 hertz. The frequency may be increased by stiffening the system by adding supports, guides etc.

c. Mode Shapes:

Mode shapes give the translations and rotations at the nodes for each mode or frequency. If the frequency is low for a mode, add supports at locations with significant deflections (compared to the rest of the system).

d. Displacement report under each shock load case:

Maximum possible positive or negative displacements during the dynamic event are given.

e. Shock load cases (option 9) can be for each elbow pair or for combined effect of two elbow pairs.

REFERENCE:

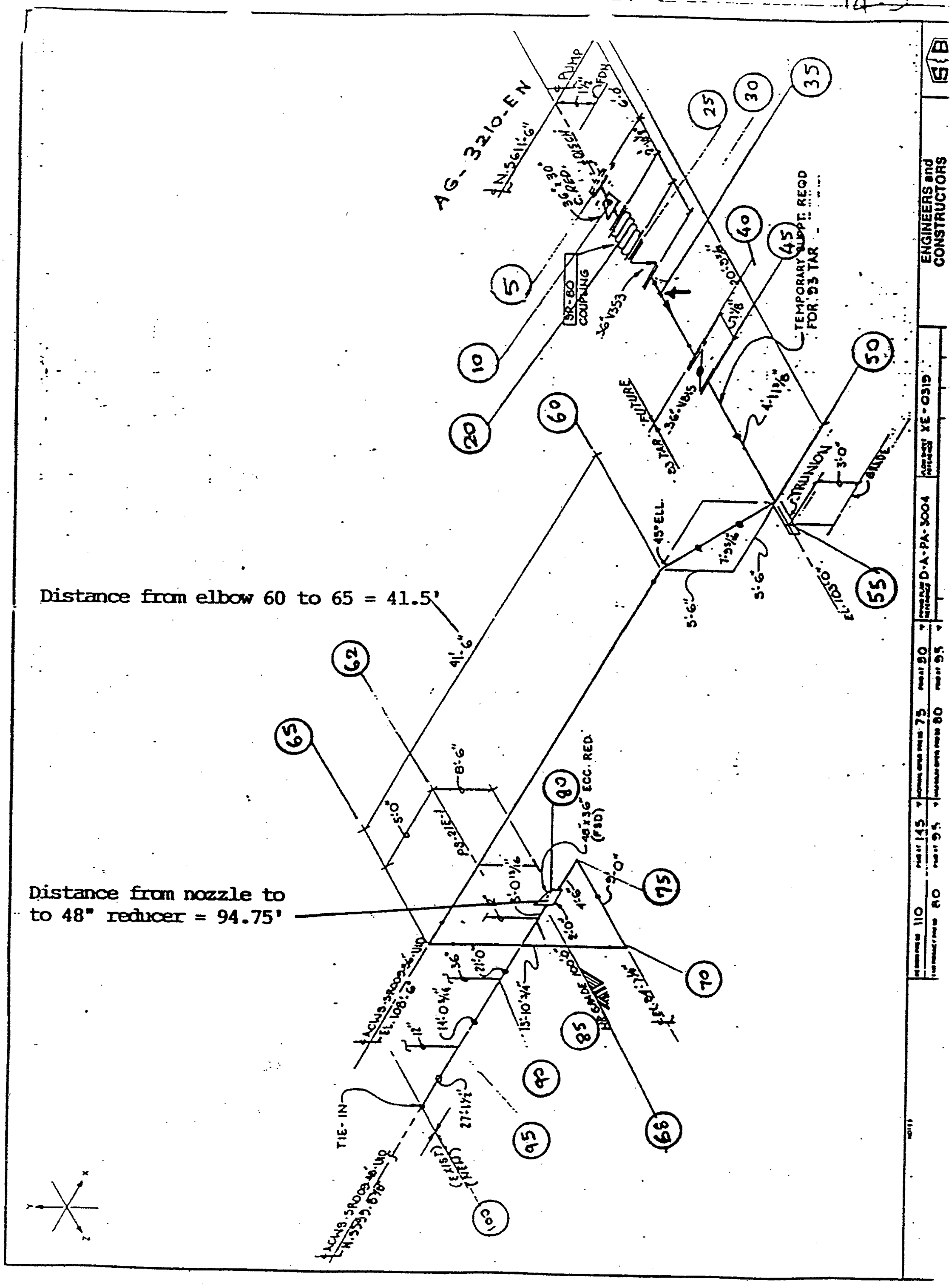
1. Crane company, Engg. Div., 1957 Technical Paper 410

2. CAESAR II user Guide Document 3.1, 12/90

3. Ludwig Earnest E. "Design of Chemical and Petrochemical Plants" Gulf Publishing Company. Table 2.1

4. American Water Works Association Manual AWWA M11 " Steel Pipe- A Guide for Design and Installation" Third Edition, 1989.

5. Steele Alferd, "Effects of Domestic Water Systems" Heating/Piping/Air Conditioning October 1982.



Distance from elbow 60 to 65 = 41.5'

Distance from nozzle to to 48" reducer = 94.75'

```
1 - LUMPED MASSES
2 - SNUBBERS

3 - SHOCK DEFINITIONS
4 - PULSE TABLE GENERATION
5 - WIND GUST TABLE GENERATION
6 - RELIEF LOAD SYNTHESIS
7 - PULSE SPECTRUM FORCE SETS
8 - HARMONIC LOADS

9 - SHOCK CASES
A - STATIC/DYNAMIC COMBINATIONS

B - CONTROL PARAMETERS

C - SAVE DYNAMIC INPUT
D - CHECK DYNAMIC INPUT
E - PERFORM DYNAMIC ANALYSIS
F - Return to CAESAR main menu <Esc>
```

Define the type of shock: E.G. "#45-75 FREQ FORCE LOG LOG" (The # sign tells CAESAR II to read the shock table from an ASCII file named "45-75". The ASCII file contains FREQUENCY vs FORCE data points, and each axis is to be logarithmically interpolated. See the dynamic input listing for more details.

Convert TIME HISTORY data into shock data. (This step creates the files "45-75" & "90-110" - see below)

Define where the thrust loads act. (The significant elbow-elbow pairs in this job are 45-75 and 90-110. Unbalanced thrust loads will act at 45 in the X, and at 90 in the X.

Define the dynamic shock load cases. (A different shock load case will exist for each significant elbow-elbow pair in the model).

Tell CAESAR II what type of dynamic analysis to run.

OPTION # 3 Shock Definitions:

SPECTRUM DEFINITION ( ) - Editing keys scroll, insert and delete input. Lines starting with an asterisk (*) are comment lines. Errors have been detected on any line shown blinking. A (#) befo[re] the spectrum name causes data to be read from an ascii fil[e] of the same name.

Name - 24 Character, user defined spectrum identifier
Range Type - P-Period, F-Frequency
Ordinate Type - A-Acceleration, V-Velocity, D-Displ , F-Force Mu[l]
Interpolation - LOG-Logarithmic, LIN-Linear

Name, Range Type, Ordinate Type, Range Interpol, Ordinate Interpol

```
#6065 FREQ FORC LIN LIN

* NAME OF SPECTRUM 6065 FOR ELBOWS 60 & 65
* CALCULATE RISE TIME, UNBALANCED WATER HAMMER FORCE
* TIME RISE 0.857 MIL SEC, FORCE = 513557 LB
* TIME TO TRAVEL 41.5' BETWEEN ELBOWS= 12.11 MIL SEC
* TIME HISTORY WILL BE INPUT TO GENERATE PULSE
* OPTION 3 SHOCK DEFINITION UNDER DYNAMIC ANALYSIS
```

Ins Del <esc>To Exit

This facility generates a force spectrum file from a time history waveform. The force spectrum file is used in CAESAR by preceeding the spectrum name definition with a # sign. An example force spectrum definition for a spectrum named "BSURGE" is shown below:

#BSURGE FREQ FORCE LIN LIN

FORCE SPECTRUM GENERATION (Option 4, Pulse Table Generation) 14-7

Enter the force spectrum name (Max = 6 chrs) --------> 6065
<Blank to exit> No #

Enter the maximum table frequency (Hz.) ------------> 100
<Blank to exit>

Enter the desired number of points in the table ----> 20
<Blank to exit>

TIME millisec	FORCE lb.
.0000	.0000
.8570	-513557
12.9670	-513557
13.8240	.0000

Home-TOP End-BOTTOM <esc>-EXIT

Time history data input

Points in Force Spectrum file: 6065

Frequency(Hz)	Multiplier
.0006	.0107
.0100	.0007
.0506	.0042
.1600	.0130
.3906	.0318
.8100	.0660
1.5006	.1222
2.5600	.2082
4.1006	.3325
6.2500	.5037
9.1506	.7283
12.9600	1.0073
17.8506	1.3290
24.0100	1.6577
31.6406	1.9188
40.9600	1.9980
52.2006	1.9967
65.6100	1.9948
81.4506	1.9920
100.0000	1.9880

Computed frequency response (used the force-shock analysis).

<C> To Continue

Option 7 - Pulse Spectrum Force Sets

FORCE SPECTRUM EDITING - Direction may be X, Y or Z, cosines, or a direction vector. Each force set defines a unique dynamic load configuration. Forces given here must be used in conjunction with a force spectrum. Edit keys on the numeric keypad scroll the input. Any line starting with an asterisk (*) will be taken a a comment. Errors have been detected on any line shown blinking.

(lb.)
Force, Direction, Node, Force set #

```
* UNBALANCED FORCE ACTS AT ELBOW 65 IN X DIR. FORCE SET # 1
-513557 X 65 1
```

Ins Del <esc>To Exit

SHOCK LOAD CASE EDITING (Option 9, Shock Cases)

There are 1 shock load cases defined so far.

OPTIONS:

1 - Add another shock load case
2 - Delete an existing case
3 - Edit an existing case
4 - Finished here, <cr> for default

.... ?

Option 9 continued

LOAD CASE 1 SHOCK CONTRIBUTIONS - Direction can be X, Y or Z or can be given as a direction cosine or direction vector. The format for direction cosines or vectors is (cx,cy,cz) for example: (0.707,0,0.707). Editing keys on the numeric keypad scroll the input. Any line starting wi an asterisk (*) will be taken as a comment. Errors ha been detected on any line shown blinking. Only enter nodes for Independant Support Excitations (ISM's) !!!

Force set #
<or>
Shock Name, Factor, Direction, ~~Start Node, Stop Node, Increment~~

```
* OPTION 9 = SHOCK CASES
* DYNAMIC LOAD CASE # 1
* ACTS BETWEEN ELBOWS 60 & 65 SPECTRUM ALREADY DEFINED 6065
6065 1 X 1
```

.s Del <esc>To Exit

STATIC/DYNAMIC COMBINATION CASES (Option A)
Load case, Factor

```
-------------------------------------
* COMBINATION CASE # 1
        D1 1
        S2 1
```

14.10

Option B

CONTROL PARAMETER LIST - Modify the value or parameter on each line which preceeds the description. Editing keys on the numeric keypad scroll the input. Errors have been detected on any line blinking

Input

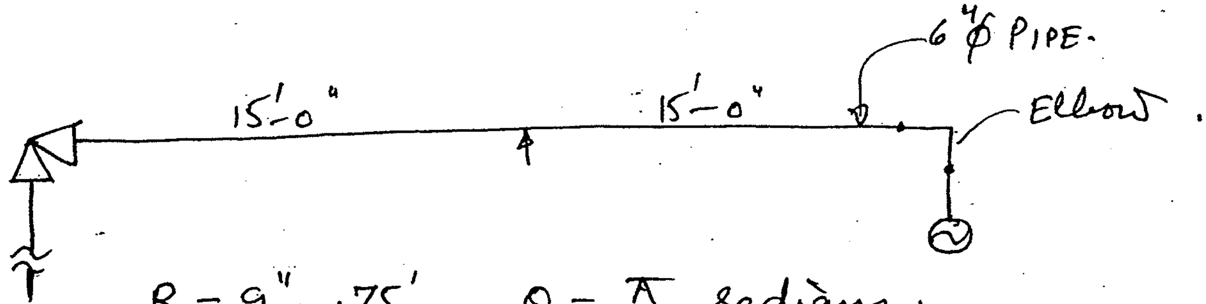
```
SPECTRUM  <----- Dynamic Analysis Type (HARMONIC/SPECTRUM/MODES/RANGE)

1         <----- Static Load Case for Nonlinear Restraint Status
0.0       <----- Stiffness Factor for Friction (0.0-Not used)
0         <----- Max. No. of Eigenvalues calculated (0-Not used)
100       <----- Frequency cutoff (HZ)

0.1       <----- Closely Spaced Mode Criteria
20        <----- Earthquake Duration (For DSRSS method) (sec.)
0.03      <----- Structural Damping (% of critical)
0.5       <----- Zero Period Acceleration (For Reg. Guide 1.60) (g's)

N         <----- <Not used>
N         <----- Re-use Last Eigensolution (Frequencies and Mode Shapes)

MODAL     <----- Spatial or Modal Combination first
SRSS      <----- Spatial Combination Method (SRSS/ABS)
GROUP     <----- Modal Combination Method (GROUP/10%/DSRSS/ABS/SRSS)
Y         <----- Include Pseudostatic Components (Y/N)
```

<esc>To Exit

GDS Engineers, Inc.

JOB: ~~RV613~~ RV 163 A/B.
SHEET NO. ______ OF ______
CALCULATED BY: P.J. SHAH DATE ______
CHECKED BY ______ DATE ______
SCALE ______

SLUG FORCE = 210 lbs.



$R = 9'' = .75'$, $\theta = \frac{\pi}{2}$ radians.

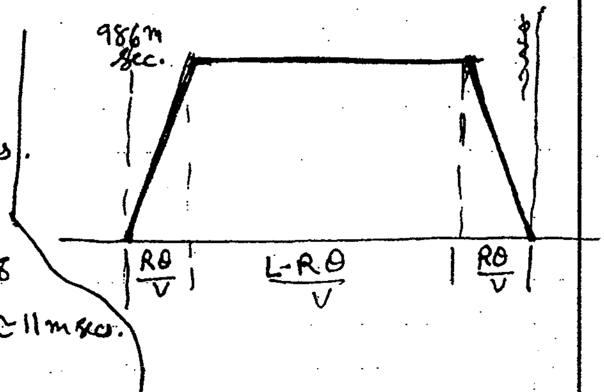
V (slug velocity) = 30.42

ASSUMED SLUG LENGTH = 1'-6".

Time reqd. for the slug leading edge to reach begining of eblow $= \frac{30}{30.42} = 986$ m. secs.

$\frac{R\theta}{V} = \frac{.75 \times \pi/2}{30.42} = .003872$ secs. $= 38.72$ m secs.

$\frac{L - R\theta}{V} = \frac{1.5 - .75 \times \pi/2}{30.42} = .01058$
$= 10.58 \simeq 11$ m sec.



Spectrum File Name : ~~AIR#163~~ 1RV163 for Reaction forces @ (200) & (360)

" " " ~~A1S~~ ~~1RV163~~ 1SF163 " Slug force @ (250) & (390)