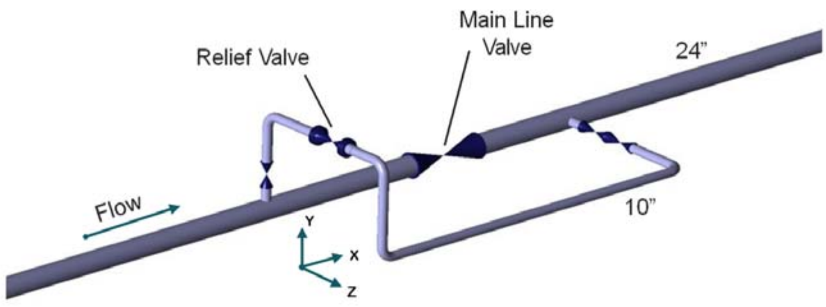
A By-Pass Line Impulse Problem

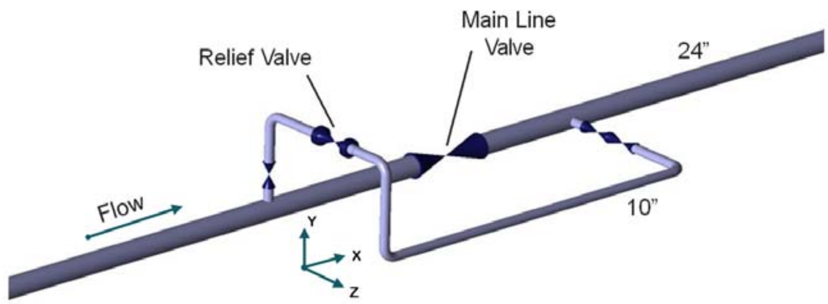
Using CAESAR II as a Forensic Tool

System Setup



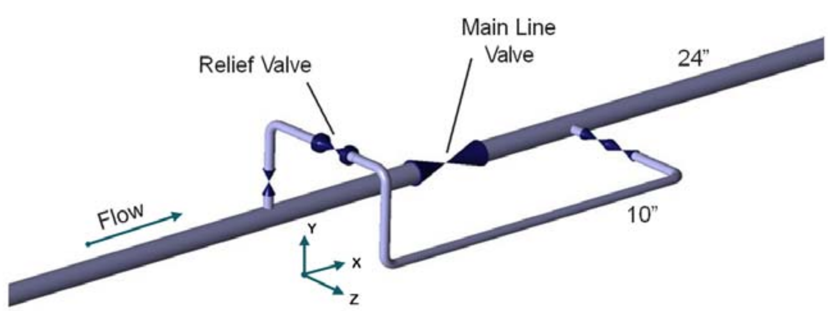
A motor-operated main line valve on a 24 inch diameter oil transmission line closed and created a pressure rise on the upstream side of the valve, from approximately 1900 kPa to 3650 kPa (275 psi to 530 psi).

System Setup



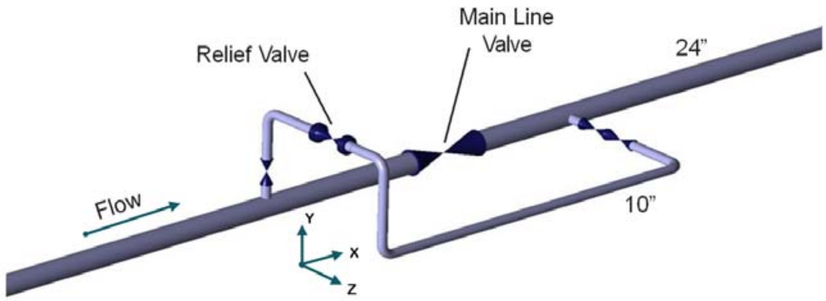
The main line was protected from over-pressure by a 10 inch bypass line with a 12 inch in-line safety relief valve, designed to limit the pressure in the main line by discharging fluid back into the pipeline downstream of the main line valve.

System Setup



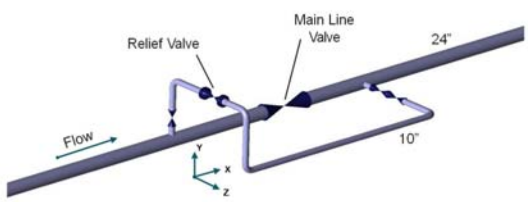
The relief valve successfully limited the pressure surge, but the opening of the relief valve caused a large lateral movement of the 10 inch bypass line, causing failure of some 3/8 inch instrumentation tubing, which resulted in the spilling of fluid.

System Setup



The reported movement of the 10 inch line where it enters the soil was "3.5 to 4 inches in the +Z direction".

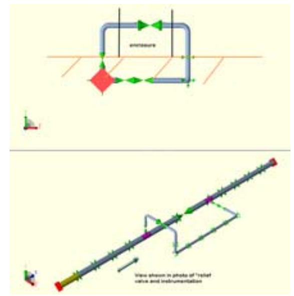
Additional System Details



- The 24 inch main line valve was in a concrete pit, and we were told there was no evidence that the line moved.
- A short section of the 24 inch line was modeled in CAESAR II with anchors at the ends simply for intersection properties.
- The bypass line has soil restraints, but a very low stiffness was manually defined in CAESAR II since the soil was reported to be saturated with water and offered very little resistance to deflection.

Client Concerns/Questions

Relief valve and instrumentation enclosure.



1. What caused this 3.5 to 4 inches of movement?
2. What can be done to prevent this problem from reoccurring?

Possible Causes of this Event

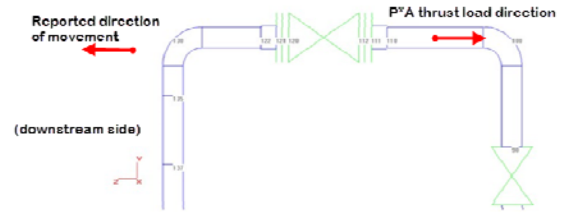
1. What is the loading necessary to cause this event?

   The fact that there was movement of the line indicates a dynamic load; presumably an impulse type of load.

2. Could this be an unbalanced pressure load?
3. Could this be a slug load from momentum changes?
4. Could the event be a combination of both pressure and slug loads?

An Issue with the Change in Pressure Approach

1. The reported direction of movement (+Z) is opposite to the unbalanced P•A load when the valve is opened.



2. Before the valve opens there are equal & opposite P•A loads on the valve and elbow. Upon valve opening, the P•A load is suddenly applied at the elbow.
3. Let's ignore this "wrong direction" of movement for the moment.

Change in Momentum (Slug Load)

If slug loading, $F = \rho A V^2 / g_c$

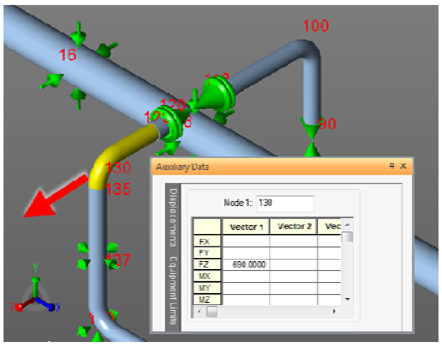
ρ = 0.03033 lb /in³
A = 78.85 in²
V = 236 in/sec
$g_c = 32.2 \times 12 = 386.4$ in*lbm/(lbf*s)

F = 0.03033 * 78.85 * 236² / (32.2 * 12)
F = 345 lb

- To see the system response to this (applied) slug load at node 130, we can perform a dynamic analysis.
- But for a quick check, we can evaluate a static load equal to the induced load.
- The maximum DLF for a one-time impulse load is 2.
- Apply a static force of 2•345 = 690 lbf in the +Z direction at node 130 to see if we get something on the order of 3.5 inches of movement.

Forensic Analysis (slug)

Input Load Definition



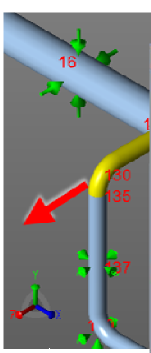
Load Case Setup

	Load Cases	Stress Type
L1	W+T1+P1	OPE
L2	W+P1	SUS
L3	F1	OCC
L4	L1-L2	EXP

Forensic Analysis (slug)

Input Load Definition

Load Case Setup



(3)Displacements

CAESAR II 2014 Ver.7.00.02.1100, (Build 150211) Date: MAR 23, 2015 Time: 13:38
Job Name: BYPASS1-2DLFSTATIC
Licensed To: SafeNet Migration Testing 789012DEALR/EVAL COPY
DISPLACEMENTS REPORT: Nodal Movements
CASE 3 (OCC) F1

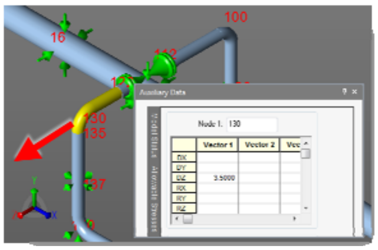
Node	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
129	-0.0035	-0.0369	0.0791	0.0091	0.0029	0.0018
130	-0.0028	-0.0377	0.0770	0.0153	0.0039	0.0027
135	-0.0028	-0.0377	0.0769	0.0154	0.0039	0.0027
137	-0.0003	-0.0377	0.0613	0.0188	0.0063	0.0031
138	0.0016	-0.0376	0.0503	0.0192	0.0078	0.0036
139	0.0025	-0.0373	0.0461	0.0192	0.0084	0.0056

Results show a Z displacement of only 0.08 inches at node 130. Change in momentum, alone, cannot account for the observed field behavior.

Collecting Clues from the Model

To help us “guess” at what kind of load we’re hunting for, use CAESAR II to find out what load is required to move node 130 a distance of 3.5 inches in the positive Z direction.

Input Load Definition:



Load Case Setup:

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L1	W+T1+P1	OPE
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L3	D1	OCC
L4	L1-L2	EXP

Collecting Clues from the Model

To help us “guess” at what kind of load we’re hunting for, use CAESAR II to find out what load is required to move node 130 a distance of 3.5 inches in the positive Z direction.

(3)Restraints

CAESAR II 2014 Ver.7.00.02.1100, (Build 150211) Date: MAR 23, 2015 Time: 13:41
Job Name: BYPASS1-3DISPL
Licensed To: SafeNet Migration Testing 789012DEALR/EVAL COPY
RESTRAINTS REPORT: Loads On Restraints
CASE 3 (OCC) D1

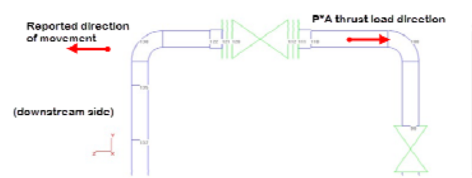
Node	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.	
58	0	0	79	0.0	0.0	0.0	Rigid Z
60	142	-0	-13	48293.3	-27.3	0.7	Rigid ANC
130	0	0	-31371	0.0	0.0	0.0	Displ. React
137	-7	0	0	0.0	0.0	0.0	Flex GUI
137	0	0	1395	0.0	0.0	0.0	Flex GUI
140	0	0	1951	0.0	0.0	0.0	Flex GUI
140	0	-1640	0	0.0	0.0	0.0	Flex Y

The Static Analysis shows it would take a force of about 30,000 lbf to displace the system 3.5 inches. If an induced (dynamic) load in the +Z direction causes this displacement, the applied load we’re looking for may be about half of the induced load – about 15,000 lbf.

Searching for the Proper Load

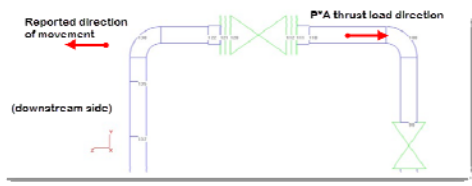
- The 345 lbf slug load is not significant enough to produce this behavior.
- Let's assume an <u>applied</u> thrust load due to the P•A effect.
  - P = 3650 kPa = 529.5 psi
  - A = $\pi/4 \cdot (OD-2t)^2$
  - OD = 10.75 in
  - t = 0.365 in
  - A = 78.85 in^2
  - P•A = 529.5•78.85 = 41750 lbf
- If the <u>induced</u> load is twice the applied load, the induced load may be as high as 83,500 lbf!
- Neither change in momentum (slug), nor the pressure differential (P•A) can account for desired applied load of 15,000 lbf.

Forensic Analysis – evaluating the dynamic response



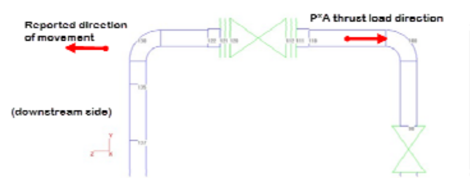
- The induced load need not be twice the applied load. So the pressure thrust may be the cause
- (We still have the "problem" with the discrepancy between thrust load direction and the system response.)
- Let's see what happens when we apply a P•A load.
- It is reasonable to ignore the slug loading (even though it does exist), as the magnitude of the slug load is very small compared to the P•A load.

Forensic Analysis (ΔP)



- To simulate this dynamically, we need the force-time relationship for the load (ramp-up time, ramp- down time & duration of load).
- The load will exist in the 100-130 segment at node 100 until the high pressure reaches node 130.
- If the fluid downstream of the valve is a gas, this duration is the time it takes for the liquid to flow from the valve to the elbow.
- If the fluid downstream of the valve is liquid, the pressure will transmit at about the speed of sound in the fluid.

Forensic Analysis (ΔP)



- A quick estimate of the load duration, based on the known flow rate (assuming gas downstream of the valve) yields:
  - Discharge Rate = 1100 m^3/hr
  - Speed = Q/A = 19.7 ft/sec
  - Length traveled = 3.75 ft
  - Load duration = 190 ms
- Assume the valve open/closing time is 10ms.
- More precise force-time details will be examined later. For now we just want to see if we're on the right track.

Forensic Analysis

- Using the previous values, define the force-time profile depicted here in the CAESAR II input.
- A load of 41,750 lbf will be applied against this profile and evaluated in a time-history analysis.

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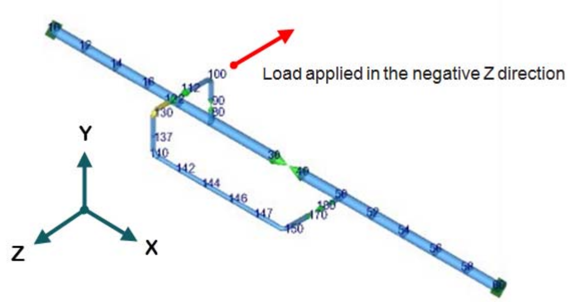
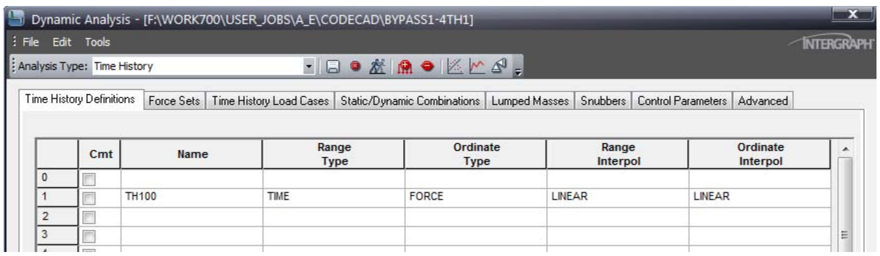


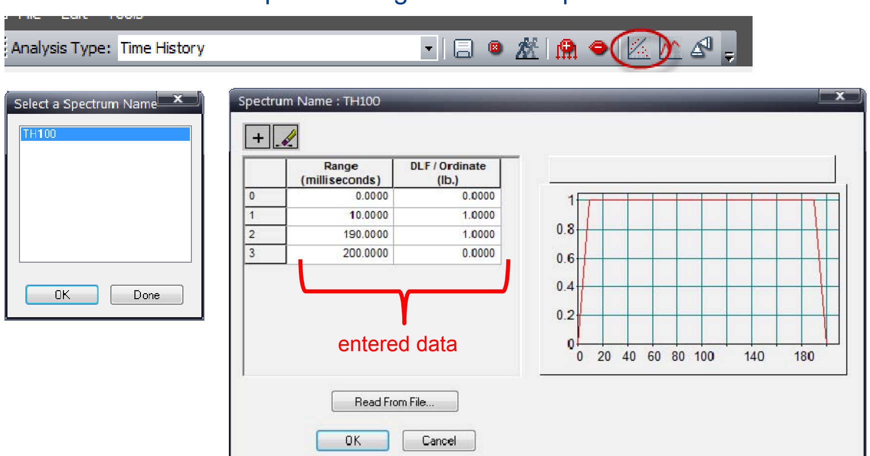
CAESAR II Time History Input

- In the CAESAR II dynamic input, set the analysis type to Time History.
- Define the event, naming it TH100, as Time vs Force table with linear interpolation for intermediate points.



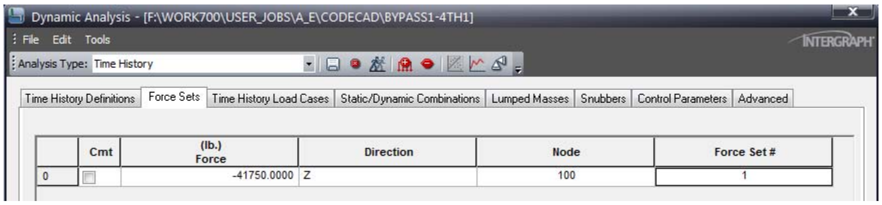
CAESAR II Time History Input

- Define the force-time profile using the "Scatter-plot" toolbar button.



CAESAR II Time History Input

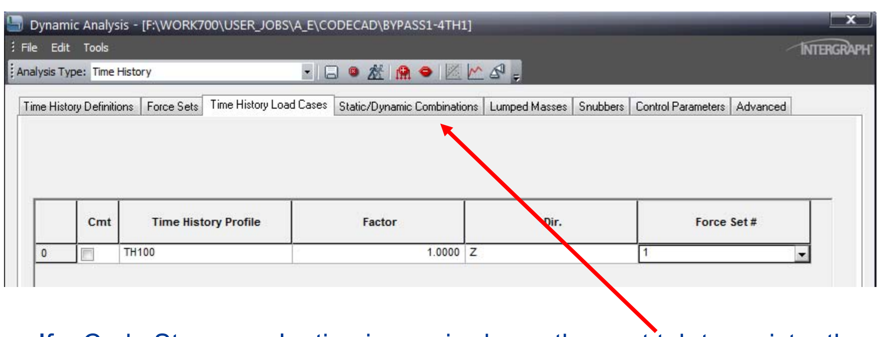
- Define the applied load: force magnitude, direction, location and label the force set beginning with 1.



- Note the force magnitude (and direction) are defined here, not in the earlier definition of the pulse.

CAESAR II Time History Input

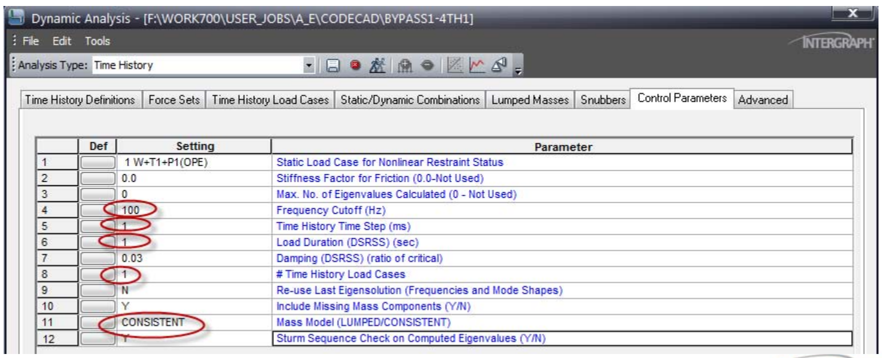
- Build the time-history load case by combining the profile and the force set.



- If a Code Stress evaluation is required, use the next tab to register the necessary Static/Dynamic Combination of (static) sustained stress with the occasional stress calculated here.

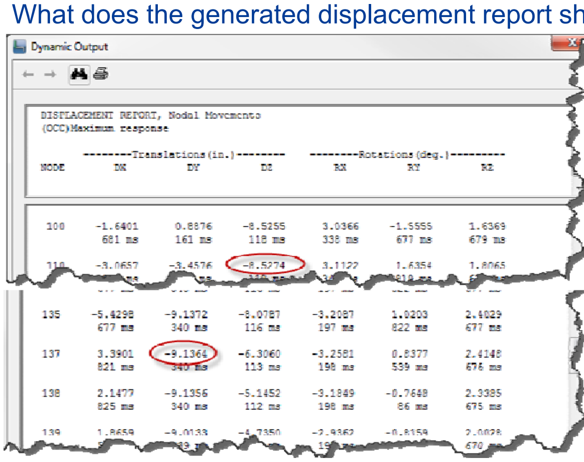
CAESAR II Time History Input

- Lastly the Control Parameters must be set. It is essential to change the time-history time step and load duration values from their default. Typical values for this type of loading would be a time-history time step of 1 ms to 3 ms and a load duration of 0.5 to 1.0 seconds.



CAESAR II Time History Results

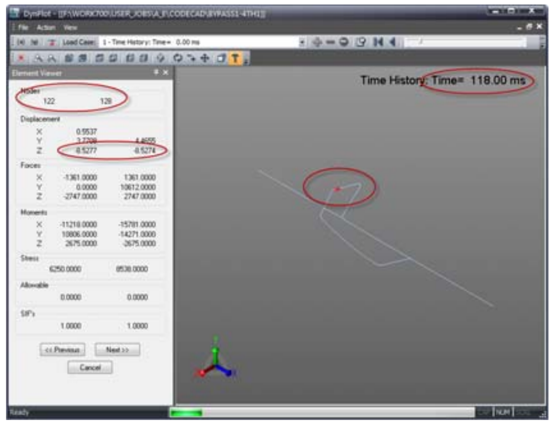
- Run the analysis and review the output.
- What does the generated displacement report show?



- Max DY exceeds 9 inches.
- Max DZ is -8.5 inches, the wrong way (compared to the field)!

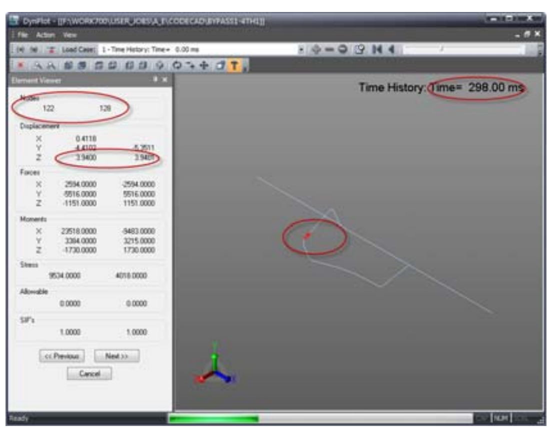
CAESAR II Time History Results

- Use the Animation tool and watch the displacements near the relief valve.



CAESAR II Time History Results

- Use the Animation tool and watch the displacements near the relief valve.



CAESAR II Time History Results

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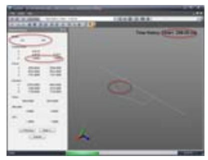
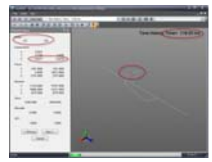



- The animation matches the text reports, but gives a better idea as to how the system is moving under this assumed load.
- The system moves in -Z 8.5 inches (unreported), then bounces back to +Z 4 inches (reported).

Confirming the Model

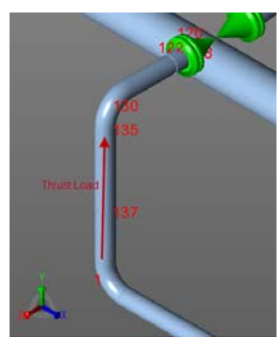
- The client (owner) was questioned about this numerical result, and whether the deflection in -Z (8.5 inches) made sense.
- The client's response was: "Oh, that explains it!". *Explains what?* He said that the long black cable on the left side of the photo used to be straight down to the pipe, and it ripped off during the event, which would require about 8" of movement. *All of a sudden, everything made sense*.

Refining the Model

- The timing assumptions used so far may be adequate, as the results match what was observed, and we perhaps can take aim at possible solutions.
- Perhaps investigate the effects of the valve-opening time, and give some thought to what's happening in the line, to get a more accurate force profile.
- The results of this investigation might uncover more information which may be important when evaluating possible solutions.

Refining the Model

- As the higher-pressure liquid moves around the bends, the unbalanced pressures change location and direction.
- This means that the -Z direction load disappears as the high pressure reaches the first elbow downstream of the relief valve, and the pipe turns downward.
- The P•A thrust load now lives in this vertical section of piping, acting in the +Y direction.



Refining the Model

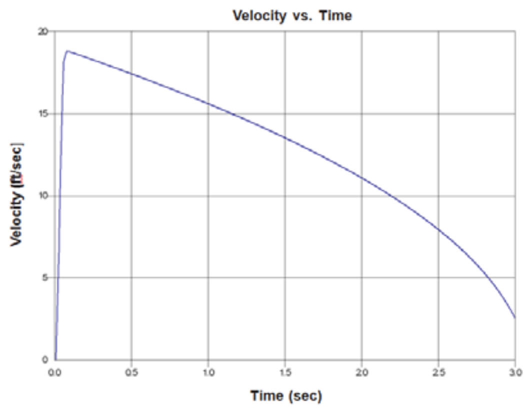
- As the liquid begins to travel past the relief valve, the gas downstream compresses until the pressure is high enough upstream of the check valve to open it.
- This changing pressure in the gas will influence the pressure differential between elbows, and the speed of the liquid flow.

A Better Time History

- *AFT Impulse* was used to calculate the speed of the liquid through the event by setting a fixed pressure of 36.02 atm connected to a valve with an appropriate Cv value.
- The pipe flows to another fixed pressure which undergoes a transient from 1 atm. to 36.02 atm. to simulate the compression of the gas.

A Better Time History

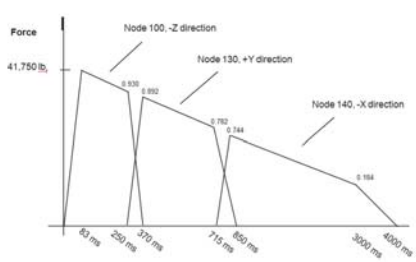
- *AFT* yields the pressure and flow velocity in each leg of the system.

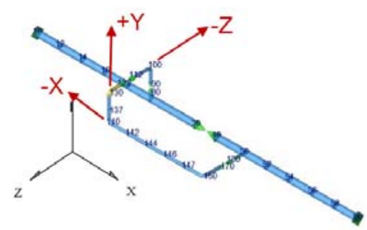


INTERGRAPH

A Better Time History

- From this information, the force-time profiles for each leg of the by-pass line can be developed.

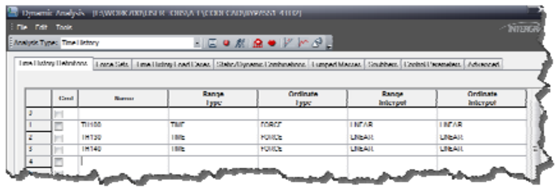




INTERGRAPH

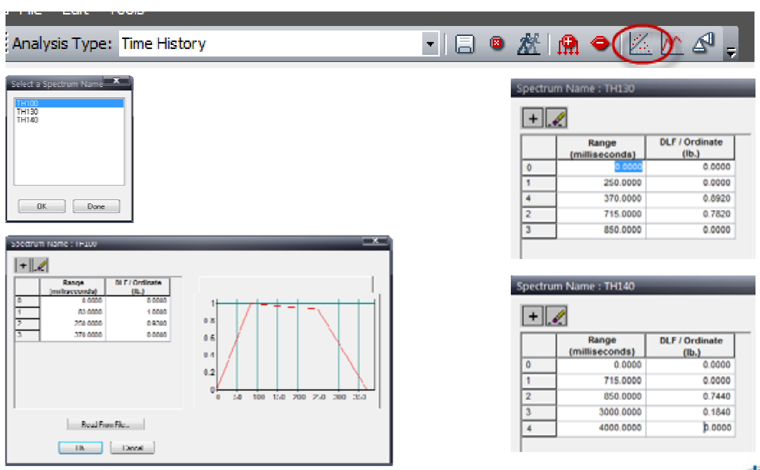
Updating the Event Time History

- Add two more pulse definitions to the CAESAR II dynamic input.



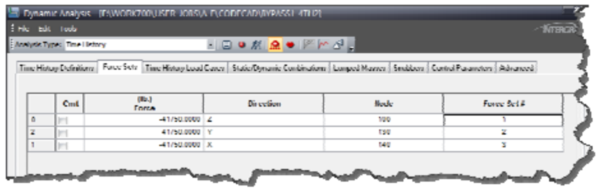
Updating the Event Time History

- Revise the first pulse, and add the data for the two new pulses.

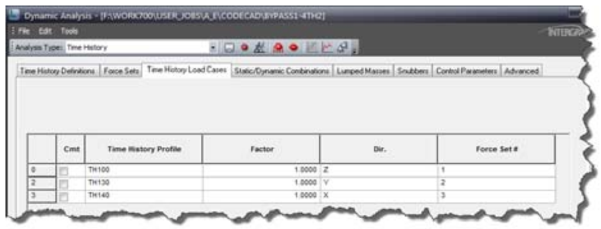


Updating the Event Time History

- Define the force sets with magnitude, location, and direction.



- Update the time-history load case.



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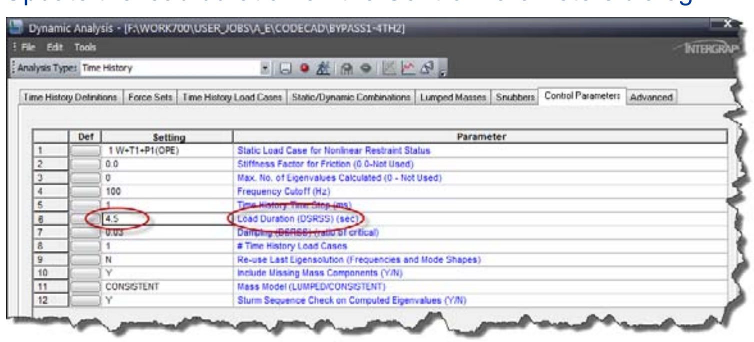
Updating the Event Time History

- Update the load duration on the Control Parameters dialog.



- Rerun the time-history analysis.

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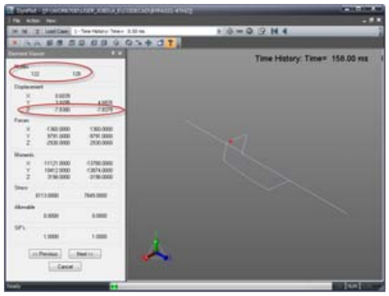
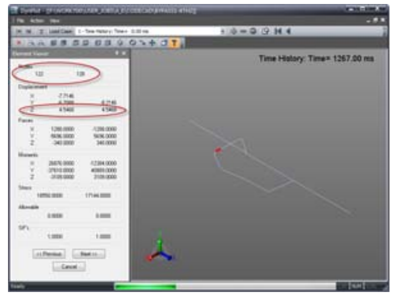
Reviewing the Refined Results

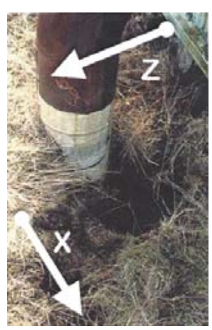
- Displacement data from the Animation Module.

- DZ varies from +4.5 to -7.8 inches.
- DY exceeds +21 inches!
- DX exceeds -10 inches!

Checking the Results

- Additional information from the owner in the form of a picture.



- Note the trench in the X and Z directions. Here is more agreement between the analysis and the field!

How Do We Prevent This Response?

- Solutions ?
- Ideas?

How Do We Prevent This Response?

- Solution1:

  Slow the opening of the relief valve.

  - This doesn't appear to be an option.
  - Some fear this would destroy the valve.
  - Reject this idea!

How Do We Prevent This Response?

- Solution 2:

  Replace the relief valve with a Control valve, that is opened slowly when the main valve starts to close.

  The pressure-time data showed that the main valve closed 1.5 minutes before the relief valve opened. This gives adequate time to mitigate the problem with a different type of valve.

How Do We Prevent This Response?

- Solution 3:

  Add a restraint to change the system response and absorb the load.

  - The equivalent load is on the order of 84,000 lb, a restraint could be expensive.
  - Better ideas are to either not respond to the load or eliminate the load (if possible).

How Do We Prevent This Response?

- Solution 4:

  Ensure the by-pass line is filled with liquid.

  - This causes the pressure wave to transmit at the speed of sound in the liquid.
  - This reduces the response to something manageable because of the extremely short load durations.

How Do We Prevent This Response?

- Solution 5:

  Replace the relief valve with a manual valve that is “chained” open. This avoids accidental closure.

  If the valve must be closed, it is a conscious, manual process.

By-Pass Line Impulse Problem

Questions ?

Comments?

By-Pass Line Impulse Problem

Thank You