Establishing Time History Input – An Example

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Introduction

Figure 1 illustrates the layout of the piping system named SNFAIL. This job examines the dynamic load on a snubber installed to reduce the system response to a steam hammer traveling through the system. The snubber has a rated load capacity of 10,000 newtons and the analysis will predict whether or not the snubber will fail (ergo the name, SNFAIL). In the past, this situation was investigated using the force response spectrum method of analysis. Since this system has a specific definition of the dynamic load timing, it is a good candidate for time history analysis. Events with a random duration and content such as earthquakes and relief valve loads are best suited for the general analysis found in response spectrum methods. More precise load definition yields better results through time history analysis. Response spectrum analysis combines the maximum response for each mode of vibration to generate a total response without respect to time. Time history follows the modal responses through each time step to produce a system response with respect to time. Time history analysis also allows the coordination of separate events in the system. In SNFAIL, the steam hammer causes a pressure imbalance in each upstream leg one after the other. Force response spectrum analysis cannot maintain this sequence of events while time history can. The load characteristics of SNFAIL make it an excellent candidate for time history analysis.

There are three basic categories of dynamic analysis input for **CAESAR II** -- modification to the static analysis model, definition of the dynamic load, and specification of the analysis parameters. The model developed for a static analysis needs only the snubber definition for the dynamic analysis. This information is entered through Item 2 - SNUBBERS of the Dynamic Analysis Input Menu. A stiffness of 13,000 newton/mm is entered in the X direction at node 100.

Load Definition

This analysis examines the effect a sudden valve closure at node 30. Steam is flowing through the line at 14 m/s and suddenly stops. To make matters simple, it is assumes that the valve closes instantaneously. This assumption will allow a conservative guest as to the pressure rise in the line. At the instant the flow stops at node 30, all the upstream vapor is still moving at 45 fps towards node 30. Each molecule of vapor will keep on moving towards the valve face and only stop once it is acted upon by the building mass of stopped vapor. The inertia of the moving vapor is converted into the higher density and pressure of the stopped vapor. So as the vapor is moving down the line it is stopped by a pressure wave traveling upstream. This pressure wave is traveling upstream at the speed of sound in the line. The **CAESAR II** analysis will follow this pressure wave up the line.

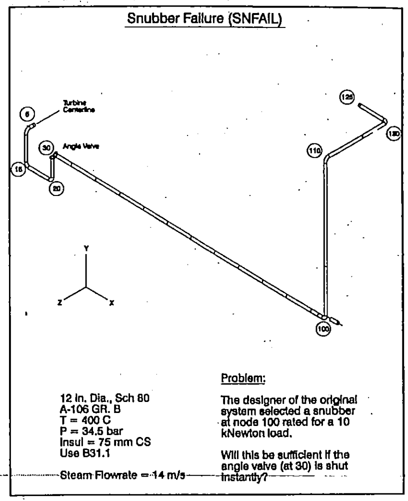

Figure 1

At steady state conditions, the piping system is in equilibrium. One component of the load on the system is the pressure effects on the straight runs of pipe. One was of visualizing this pressure load is to crawl inside the pipe and look upstream and downstream. The surfaces you can see are the surfaces on which the line pressure act. Again, at constant upstream and downstream pressure, the loads are in equilibrium -- $(P_{up}) * (A_{up}) = (P_{dn}) * (A_{dn})$; $P_{up} = P_{dn} = P$ & $A_{up} = A_{dn}$. But as the pressure wave travels up the line into your straight run of pipe, that run of pipe is no longer in equilibrium. The downstream elbow (or valve face) is now loaded with $P + \Delta P$ where ΔP is the pressure rise due to the instantaneous valve closure. This imbalance (ΔP) will continue until the pressure wave passes the upstream surface at which time the run is again in balance (at the higher pressure).

The three pieces to define the load are now established:

1. - The load magnitude: $\Delta P * A$

$$F = \Delta P * A = 6375 \text{ newton}$$
$$\Delta P = \rho * c * \Delta V = 0.972 \text{ bar}$$
$$\rho = P / (R * T) = 11.216 \text{ kg/m}^3$$
$$P = 34.473 \text{ bar}$$
$$R = 457.327 \text{ m-newton/kg-K}$$
$$T = (400+273) \text{ K}$$
$$c = (K * R * T)^{1/2} = 632 \text{ m/sec}$$
$$K = 1.3$$
$$\Delta V = 14 \text{ m/sec}$$
$$A = \pi/4 * (OD - 2 * wt) = 65{,}560 \text{ mm}^2$$

2. - The point of application and direction : At the start of each straight run of pipe upstream of the valve witn the load pointing downstream.

-X load @ node 30
-Y load @ node 100
+Z load @ node 110
+X load @ node 120

3. - Timing : Based on speed of sound in the medium, the imbalance starts when the pressure wave enters the run and ends when the wave leaves the run. The **CAESAR II** coordinate list feature makes it easy to collect the straight run lengths. Time is simply length divided by the acoustic speed (speed of sound in the medium). The lengths and times are referenced to node 30 as the zero point.

from 30 to:	pipe length(m):	time(ms):
30	0	0
100	42	66
110	58	92
120	68	107
125	72	113

The assumption that the valve will stop the flow instantaneously is conservative in the calculation of the pressure rise. (ΔV = 14 m/s; steam flowing at 14 m/s suddenly is traveling at 0 m/s.) A conservative estimate of the event timing may not be assured with the same assumption. That is, the system response to a <u>sudden</u> imbalance may not be as great as to a slower application of the load. To shed more light on this issue, an adjustment to the timing will be created. Assume that it takes 10 ms for the valve to stop the flow (14 m/s to 0 m/s in 10 ms) and that the pressure imbalance also takes 10 ms to fully develop (0 to 6375 newton in 10 ms). For the first run of pipe (30-100) the event still starts at 0 ms but does not reach the maximum of 6375 newton until 10 ms later. Likewise, as the wavefront reaches node 100 at 66 ms into the event, the imbalance starts it's drop but this run will not be back in balance until 10 ms later at 76 ms. This 10 ms ramp is applied to the start of the imbalance and the end of the imbalance for each component of the event.

What of the last leg, where the wave front enters and leaves in only 6 ms? Here, the imbalance cannot reach the total of 6375 newton as the exiting wavefront will balance out the still-building wavefront entering the run. So 6 ms into the last leg the increasing load entering the leg (at 120) will be balanced by the increasing load leaving the leg (at 125). Allowing for only 6 ms of the 10 ms rise time means that the maximum imbalance is (0.6 * 6375) Newton. At 10 ms into the last leg, the load entering the leg will be fully developed and the leg's re-balance will begin -- the flat portion of the loading will only last 4 ms.. The leg will again reach equilibrium when the end of the pressure rise passes the end of the leg, 16 ms after this component of the event started.

Figure 2 compares the instantaneous imbalance with the 10 ms ramp.

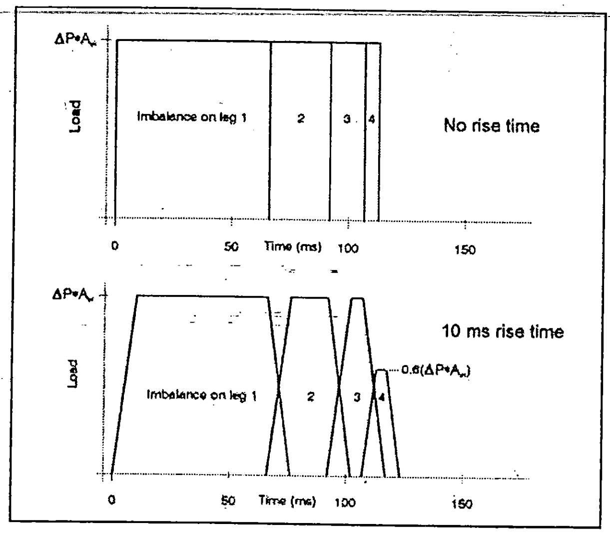

Figure 2

The **CAESAR II** Dynamic Analysis Input for this model is entered through the various tabs in the dynamic input/analysis window. After selecting Time History Analysis from the analysis selection menu (default is "Other"), use the following tabs to enter the data:

Tab - SPECTRUM/TIME HISTORY DEFINITIONS

Set #1 (definition) TH1, T, F, LIN, LIN

(data)

Time	Load
0	0
10	1
66	1
76	0

Set #2 (definition) TH2, T, F, LIN, LIN

(data)

Time	Load
0	0
66	0
76	1
92	1
102	0

Set #3 (definition) TH3, T, F, LIN, LIN

(data)

Time	Load
0	0
92	0
102	1
107	1
117	0

Set #4 (definition) TH4, T, F, LIN, LIN

(data)

Time	Load
0	0
107	0
113	0.6
117	0.6
123	0

Tab - SPECTRUM/TIME HISTORY FORCE SETS

Load	Direction	Node	Force Set
-6375	X	35	1
-6375	Y	100	2
6375	Z	110	3
6375	X	120	4

Tab - SPECTRUM/TIME HISTORY LOAD CASES

Time Hist.	Factor	Dir.	Force Set #
TH1	1	X	1
TH2	1	Y	2
TH3	1	Z	3
TH4	1	X	4

One note on the magnitudes or factors specified above. There are three **CAESAR II** components which combine to form the total load used in the time history analysis:

a) the force in the time history definition (1 or 0.6 in the time history definitions);

b) the force in the force set definition (6375 in the time history force sets); and

c) the scale in the dynamic load case definition (1 in the time history load cases).

With the total load calculated as (a * b * c), use any convenient way to enter these data for the three terms.

Analysis Parameters

There is only one more Dynamic Analysis Input item required to run this time history analysis in **CAESAR II**—CONTROL PARAMETERS. Several analysis parameters have a range of possible values – some having a major impact on the accuracy of the analysis. What is the "correct" entry for frequency cutoff, time step and load duration? Should missing mass be used, and if so, how should it be included? How important is damping? Guidelines for these data are provided here.

FREQUENCY CUTOFF – The frequency cutoff establishes the number of modes of vibration included in the analysis. With each additional mode included, the accuracy of the analysis improves. But there are diminishing returns with the higher modes -- the analysis takes much, much longer with very little change in the results. So how many modes to include? A conservative approach is to examine the frequency content of the event and analyze the system at least to the point where the frequency response is maximum. The system frequencies not included in the analysis will be approximated by the missing mass correction (see **M.E.N.** Vol. 16 - "Use the Missing Mass Correction Option in Spectral Analysis"). Fortunately the Response Spectrum Generator in **CAESAR II** (accessed from the Dynamic Input/Analysis toolbar.) can be used to convert the four time histories into their frequency response curves. The response curve data are shown in Figure 3.

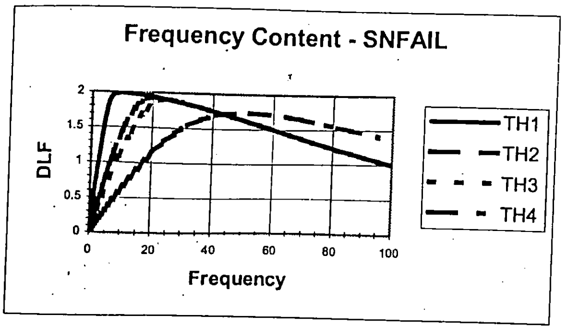

Figure 3

The response curve for the first event (30 - 100) has the highest response and it peaks at the lowest frequency. This is reasonable as this is the longest duration event and therefore can "activate" lower modes of vibration. The first three events all tail off on the same line. This, too, is reasonable since they all have the same ramp rate of 10 ms from 0 to maximum load. The ramp rate for the fourth event is shorter that the other three (6 ms to maximum load) so its peak occurs at a higher frequency – outside the pattern of the other three. The resonant peaks of these four events are below 8 Hz., 22 Hz., 38 Hz., and 55 Hz., respectively. The frequency cutoff for this analysis will be set at 55 Hz. This will ensure that the most significant modes of vibration for all four events will be included in the analysis.

TIME HISTORY TIME STEP – As a rule of thumb for accurate analysis, there should be at least ten time steps over the period associated with the highest natural frequency used in the analysis. For convenience, the highest natural frequency used in the analysis will be the frequency cutoff of 55 Hz. (**CAESAR II** will include the first mode of vibration above the frequency cutoff.) The period of a 55 Hz. vibration is 1/55 seconds. The time step should be no more than one-tenth of 1/55 sec. or no more than 1.82 milliseconds. For this analysis the time step will be 1.8 ms.

INCLUDE MISSING MASS COMPONENTS – The missing mass contribution to the analysis should be turned on for this analysis. **CAESAR II** will lump the response of system modes not included in the analysis as a single static load. The magnitude of the load will be based on the last system frequency extracted for the analysis.[1] (The default setting uses the load factor for the last frequency extracted. Figure k can be used to see what that load factor may be. The user may also set the missing mass load factor of 1.0 to approximate a fully rigid response to the applied load.)

[1] With the frequency cutoff set to 55 Hz., the last mode of vibration is at 61 Hz. The load factor for the missing mass component will be about 1.5 for events 1-3 and 1.8 for event 4.

LOAD DURATION – The load duration requested here is actually the analysis duration. The dynamic loads are set on and off in the time history definitions. This event is over in 123 ms. but the system response may peak after the event is over. The minimum duration of the analysis should be at least the event duration (here 123 ms) PLUS one quarter of the period associated with the lowest natural frequency for the system. At one quarter cycle, the modal response is at its maximum (i.e. for a sine wave the maximum value of 1.0 is reached at 90 degrees through the cycle of 360 degrees). Using one quarter of the first mode assures that all modes achieve their maximum response. Either assume a low first mode of vibration or run a modal analysis of the system to calculate this value. Simply set the analysis type to MODAL and run the analysis. The first natural frequency of this system occurs at 0.319 Hz. with a period of 3.134 seconds (1/0.319). The load duration should be at least the 123 ms plus one quarter of this period of 784 ms. The total, then, is 907 ms; 1.0 second will be used here. If the results of the time history analysis show that the maximum system response is near the end of the reporting period, the analysis should be re-run using a longer time span.

TIME HISTORY OUTPUT CASES - **CAESAR II** generates a set of output data at equal intervals throughout the duration of the analysis. The user specifies the number of output sets here. It would be difficult to predict when a maximum response occurs during the event. It is best simply to divide the duration into even numbers and hold the total number of report times below 20. Such a setting will keep the output manageable. It may also be useful to have a few reports while the load is still in progress through the system. Here, where the loading lasts 123 ms and the analysis covers 1.0 second, 20 reports will be generated. That will produce a report every 50 ms with two reports while the load is active.

DAMPING – **CAESAR II** has a default ratio of critical damping of 0.03 (3% critical damping). Typical values for critical damping ratios in piping systems can be anywhere from 0.01 to 0.03. The US Nuclear Regulatory Guide 1.61 has typical values critical damping for piping systems and other structures. This document recommends 2% critical damping for piping systems over 12 inches in diameter. Change the damping value to 0.02 for this analysis.

Results

A major part of the time history output in **CAESAR II** is contained in the regular reports found in static analysis (displacements, restraint loads, forces & moments, stresses). In time history output, which has only one load set, these reports are generated for each report time requested. Think of these reports as snapshots in time. But one would be lucky to have a "snapshot" for the maximum system response. Therefore, the time history output also lists an additional report set that lists the system maxima through the entire event. Also, the time of the occurrence of the maximum value is listed with the number. This maximum value report is a valuable tool for reviewing the analysis.

So is the snubber OK? Run the job to find out.

Running this job after modifying the time history analysis parameters will develop insight regarding their effect. Try changing values such as time step, damping, frequency cutoff and missing mass to further investigate this issue.