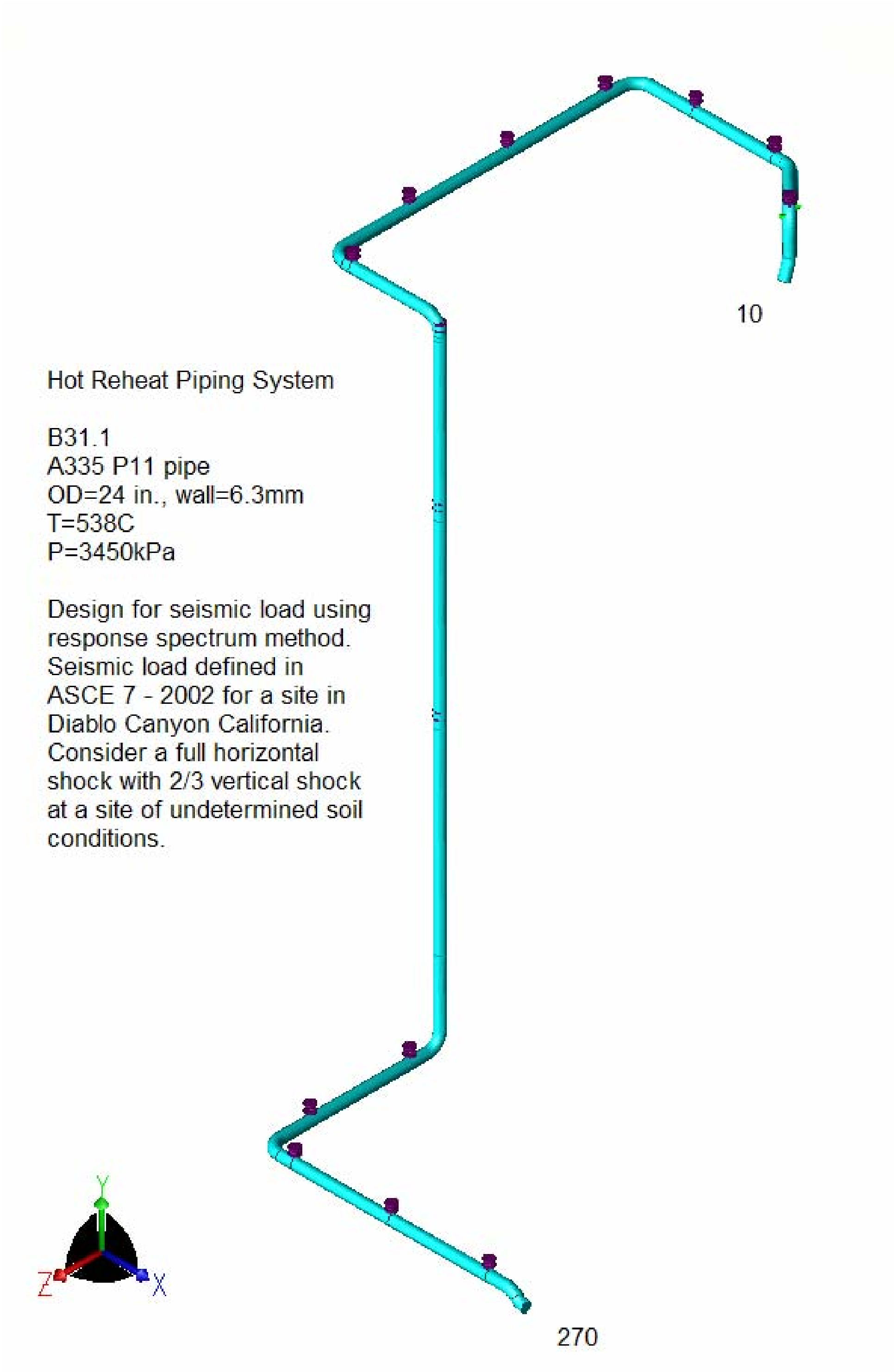
Diablo Reheat – Seismic Analysis of a Piping System

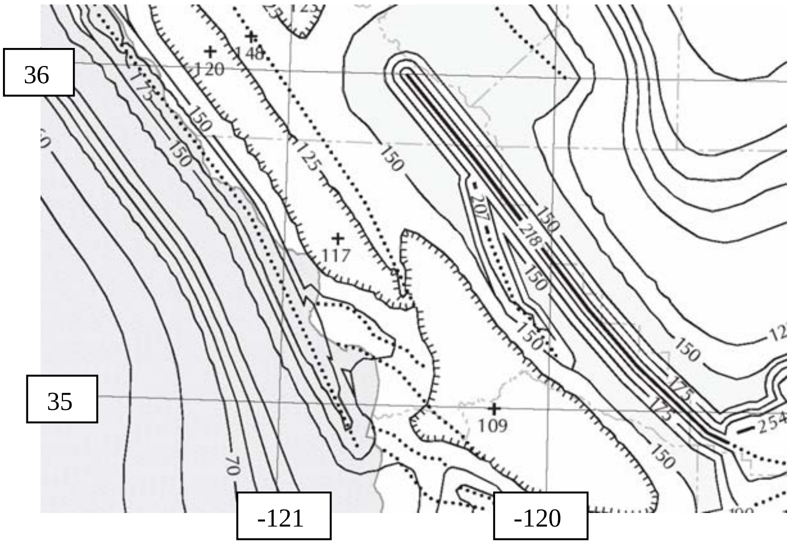
Piping Layout:



Collecting Data and Building the Seismic Response Spectrum:

This hot reheat piping system is to be evaluated to the seismic requirements of ASCE 7-02[1] (American Society of Civil Engineers Standard 7 – Minimum Design Loads for Buildings and Other Structures). The system will be designed for operation near Diablo Canyon, California where no soil properties are available (an unspecified seismic site). Seismic loads shall be analyzed in the X-Y and Y-Z directions, with the vertical component scaled to 2/3 of the horizontal component.

ASCE 7 response spectra are specified in terms of mapped accelerations at periods of 0.2 seconds and 1 second. These mapped accelerations are available for many sites around the world and are available through the United States Geologic Survey (USGS) for U.S. locations over the internet at http://earthquake.usgs.gov/hazmaps/. (Be sure to use design values and not probabilistic values.) Maps containing ASCE 7 design values can be found at http://eqdesign.cr.usgs.gov/html/design-lookup.html. This power plant at Diablo Canyon has the following coordinates: Latitude: 35.211, Longitude: -120.854. Here, the Maximum Considered Earthquake (MCE) ground motion at short period, S_s, is 1.771g. S_s is the acceleration of a 0.2 second oscillator (frequency of 5 Hertz) at a rocky site (Site Class B) that has a 2% probability of being exceeded over the next 50 years. The MCE ground motion at one second period, S_1, is 0.741g. A section of a typical map is shown below:



ASCE 7-02 Figure 9.4.1.1(c)
MCE Ground Motion for Region 1 of 0.2 s spectral response acceleration
(5% of critical damping), site class B

[1] ASCE 7 requirements are similar to those specified in the International Building Code (IBC) and the 2000 NEHRP (National Earthquake Hazard Reduction Program) Provisions For New Buildings And Other Structures (FEMA 368) and Commentary (FEMA 369). FEMA 368 & 369 are available through the Building Seismic Safety Council's web site http://www.bssconline.org/. See Chapter 4 – Ground Motion of the FEMA documents.

These data are also tabulated using software distributed with the 2003 Edition of the International Building Code (IBC).

Diablo Canyon
Date and Time: 5/12/2005 4:52:45 PM

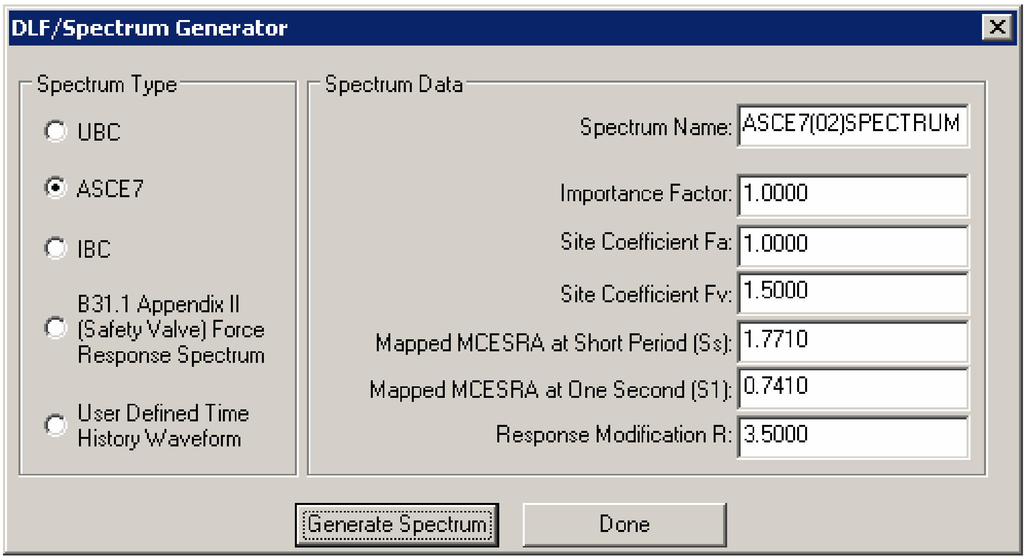
MCE Ground Motion, - ,Conterminous 48 States
Latitude =,35.21106,Longitude =,-120.85371
Period,MCE Sa
(sec),(%g)
0.2 ,177.1,MCE Value of Ss, Site Class B
1.0 ,074.1,MCE Value of S1, Site Class B
Spectral Parameters for , Site Class D
0.2, 177.1, Sa = FaSs, Fa = , 1.00
1.0, 111.2, Sa = FvS1, Fv = , 1.50

These mapped accelerations are adjusted by the soil conditions at the power plant. ASCE 7 permits the use of Site Class D (a stiff soil profile) where soil properties are undetermined. The short period acceleration is adjusted by F_A and the one second acceleration is adjusted by F_V. These terms are set in Tables 9.4.1.2.4a and 9.4.1.2.4b, respectively. Here, F_A=1.0 and F_V=1.5.

Other data needed to properly set the ground response spectrum for this analysis is the Importance Factor (I) for the system. Use an Importance Factor of 1.00 for most systems but use 1.50 for systems that must continue operation through the seismic event or systems whose failure pose a significant hazard. Use I = 1.00 for this analysis. A Response Modification Factor (R) must also be defined. While the Importance factor proportionally increases the seismic load, the Response Modification Factor decreases it. Seismic stresses without this modification would be over predicted without this adjustment. The piping ductility would allow sections to yield but not collapse. This local yielding would reduce the response to the event. For stress analysis[2] include the Response Modification Factor (from Table 9.6.3.2). For this piping system, use R_p = 3.5.

[2] This factor reflects the distinction between strength analysis and stress analysis. Piping, with its welded connections and simple cross sections, is easily evaluated in terms of stress. Other building components such as reinforced or prestressed concrete and bolted connections are better evaluated through an overall strength approach.

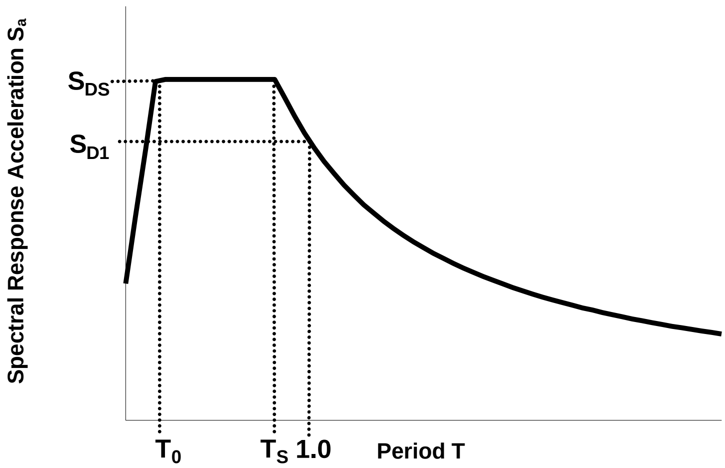
These data can be entered in the CAESAR II DLF/Spectrum Generator (from the Dynamic Input Tool Bar) to automatically create the response spectra for this analysis:



The Wizard will use these data to generate the horizontal and vertical response spectra for this site. The Wizard uses ASCE 7 para. 9.5.2.7.1 to set the vertical response as 20% of the short period response (S_{DS}) but, for this job, 2/3 of the horizontal response will be used for the vertical response.

The ASCE 7 response spectrum (in g versus time) for the site has the following shape:

Fig. 9.4.1.2.6 Design Response Spectrum
from ASCE 7-02 (also, 2000 NEHRP / FEMA 368)



Reviewing the calculations beginning with the Wizard input:

$S_{MS}=F_AS_s/(R/I) = (1.0)(1.771g)/(3.5/1.0) = 0.5060g$ (Eq. 9.4.1.2.4-1)
$S_{M1}=F_VS_1/(R/I) = (1.5)(0.741g)/(3.5/1.0) = 0.3176g$ (Eq. 9.4.1.2.4-2)

$S_{DS}=2/3 \cdot S_{MS} = (2/3)(0.506g) = 0.3373g$ (Eq. 9.4.1.2.5-1)
$S_{D1}=2/3 \cdot S_{M1} = (2/3)(0.318g) = 0.2117g$ (Eq. 9.4.1.2.5-2)

The time data is a function of the Design Response Spectra – S_{DS} and S_{D1}.

$T_0 = 0.2 \cdot S_{D1}/ S_{DS} = (0.2)(0.2117/0.3373) = 0.1255$ sec
$T_S = S_{D1}/ S_{DS} = 0.2117/0.3373 = 0.6276$ sec

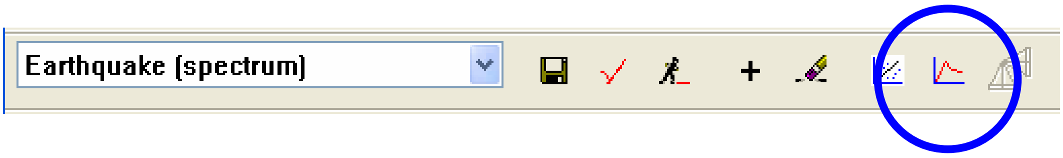
Setting up the Dynamic Analysis:

B31.1 para. 104.8.2 equations (12A) and (12B) set the calculations for evaluating occasional stress. The basic allowable stress at temperature (Sh) is multiplied by an occasional load factor, k, to set the limit for the sum of sustained and occasional stresses. This factor can be set to either 1.15 or 1.20 depending on the duration and frequency of the occasional load. Since this seismic event is considered infrequent by these rules, the higher value of 1.20 will be used for k. (A “constant” wind load, on the other hand, may require k=1.15.) CAESAR II defaults to the lower allowed limit. Enter the “Configure/Setup” processor under “Tools” on the program’s “Main Menu” to change k from 1.15 to 1.20. From here, open the “SIF’s and Stresses” tab and enter 20 for the “Occasional Load Factor:” in the first column.

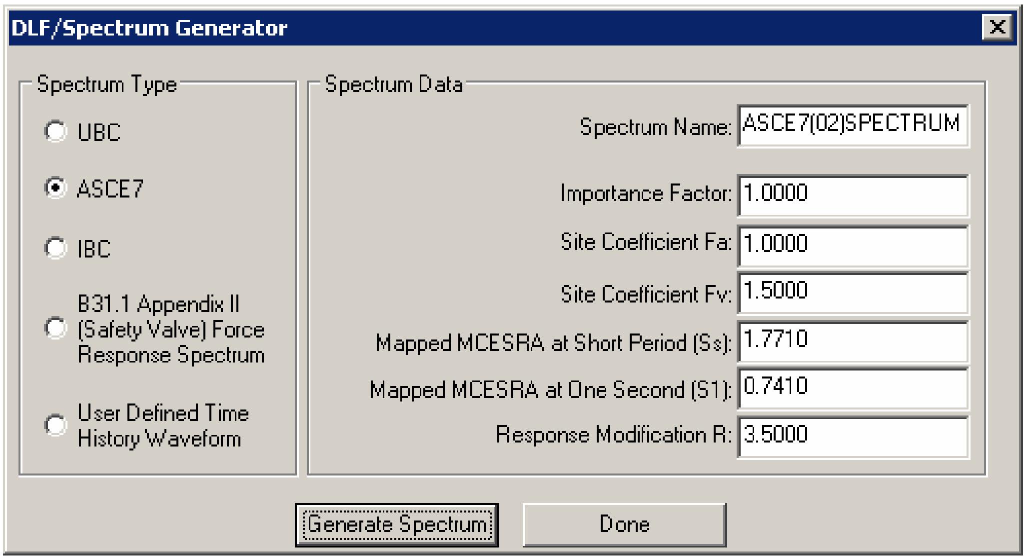
After building/reviewing the input and running the static analysis, enter the dynamic input processor.

Select “Earthquake (spectrum)” as the analysis type from the pull-down list in the upper left corner (the display lists “Other” by default)

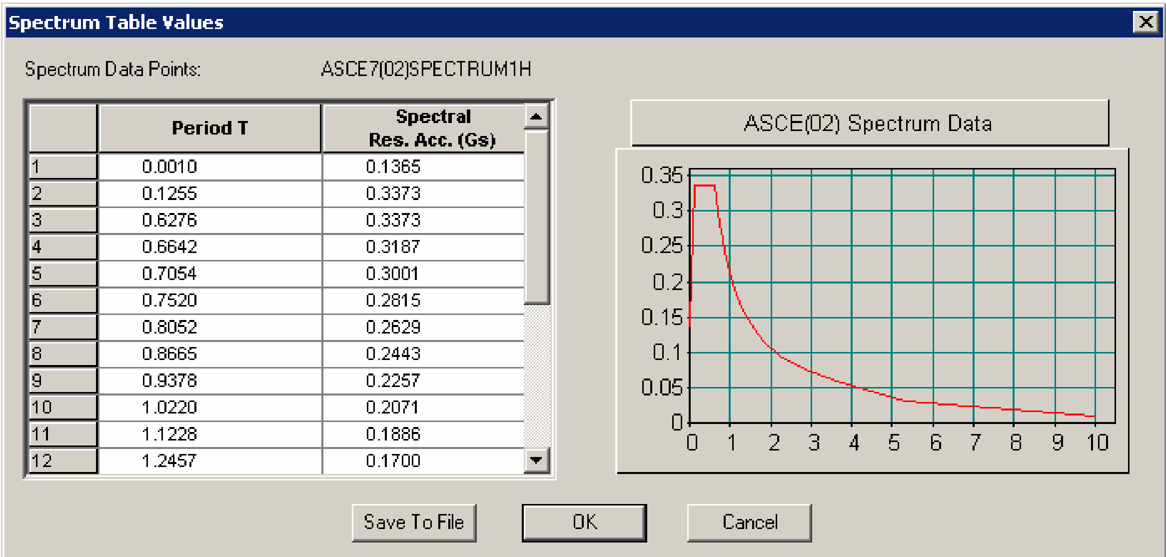
Use the Spectrum Wizard to build the shock spectra for this analysis by clicking on the Toolbar button:



Enter the required data to develop the response spectra:

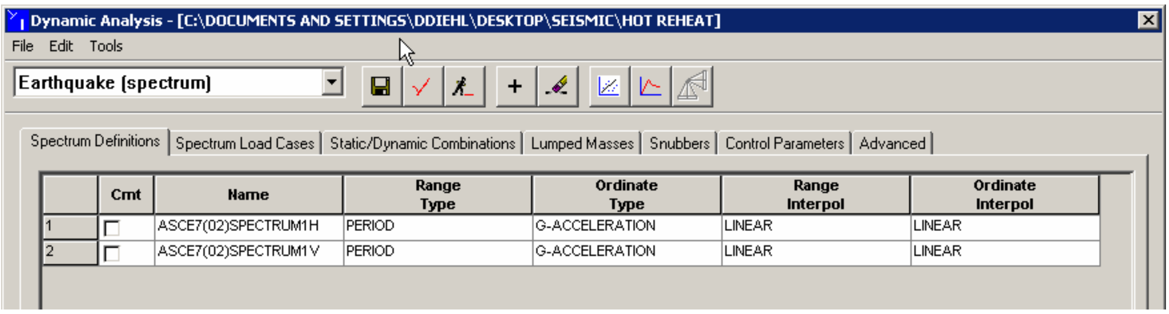


Clicking “Generate Spectrum” will display the data and the plot:



	Period T	Spectral Res. Acc. (Gs)
1	0.0010	0.1365
2	0.1255	0.3373
3	0.6276	0.3373
4	0.6642	0.3187
5	0.7054	0.3001
6	0.7520	0.2815
7	0.8052	0.2629
8	0.8665	0.2443
9	0.9378	0.2257
10	1.0220	0.2071
11	1.1228	0.1886
12	1.2457	0.1700

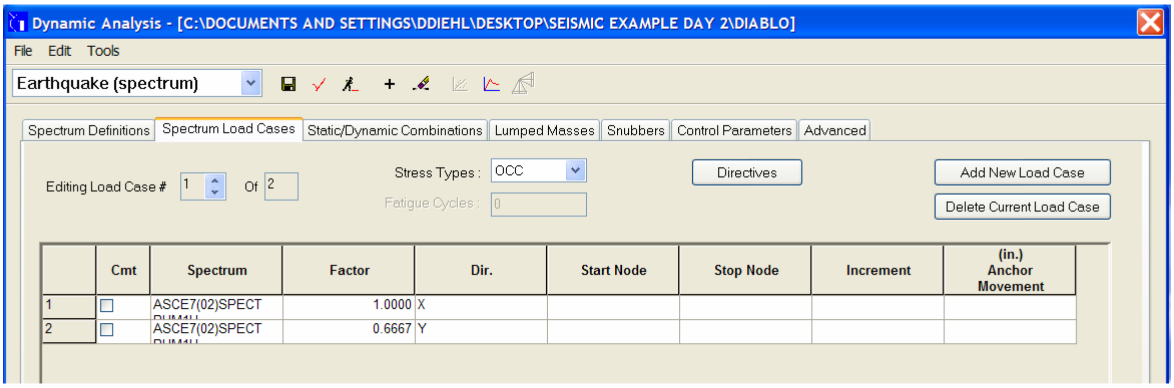
Two shock spectra will automatically be added to the list in Spectrum Definitions. The first spectrum references the horizontal shock spectrum developed above, ASCE(02)SPECTRUM1H, and the second spectrum is a vertical response spectrum, ASCE(02)SPECTRUM1V. This vertical response spectrum mimics the static equivalent load magnitude of 20% S_{DS}. For this analysis, the vertical shock will be set to 2/3’s the horizontal shock instead.



A seismic load is a vector and so it may have more than one directional (or spatial) component. The shock can attack the system from any direction. With all piping usually along the global axes, we can assume that a horizontal shock approaching from either the X or Z directions would cause the greatest response. Without a clear idea of which direction is worse, both the X shock and Z shock will be analyzed. As mentioned above, a vertical component equal to 2/3's the horizontal will be included.

Create the two shock sets using the Spectrum Load Cases tab:

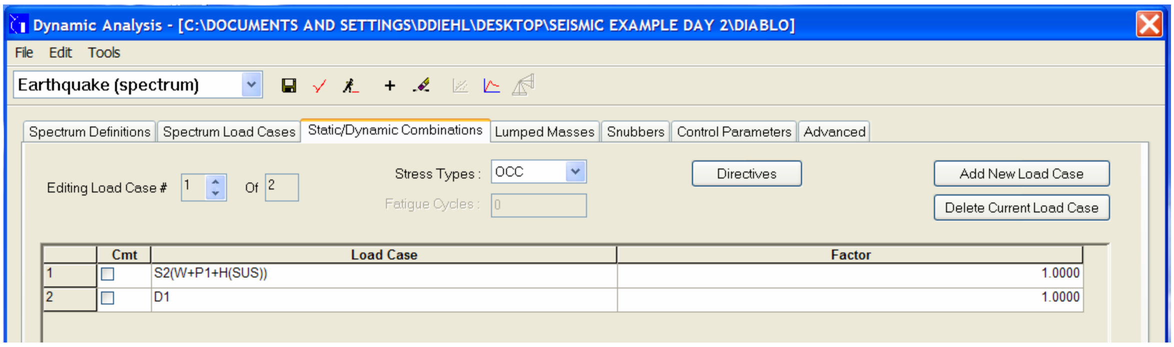
> The first seismic event is in full in the X and 2/3's in Y. Click on Add New Load Case. When the mouse hovers over the Spectrum cell, a dropdown arrow will appear in the cell. Clicking on that arrow will display the shock spectra that are defined in this job. Select ASCE(02)SPECTRUM1H and specify a Factor of 1.0 in (Dir.) X; click on the plus button to add another line and again select ASCE(02)SPECTRUM1H but this time specify a Factor of 2/3 in (Dir.) Y.



> To add the second seismic analysis (Z-Y), again click on Add New Load Case. Once again select spectrum ASCE(02)SPECTRUM1H now with a Factor of 1.0 in (Dir.) Z. Then click on the plus button to add another line and enter ASCE(02)SPECTRUM1H but with a Factor of 2/3 in Y.

Many piping codes evaluate these occasional stresses by first combining them with the sustained stresses. Deadweight, pressure and inertial loads all generate primary, forced-based stresses and are compared to material yield as the mode of failure. Stresses from these two shocks must be added to the sustained stress calculated in the static analysis of the model. To build these combinations use the Static/Dynamic Combinations tab:

> Click on Add New Load Case and enter S2 (available in the pull-down list) on the new line. S2 indicates the second static analysis which, here is the sustained analysis. Leave the scaling factor at 1.0. Click on the plus button to add another line. This time enter D1 (Dynamic Load #1) for the Load Case. That will be the X-Y shock.
>
> To add the second stress combination click on Add New Load Case. Combine S2 with D2 (the Z-Y shock).



Now set the Control Parameters for this analysis by clicking on that tab.

> CAESAR II cannot include nonlinear conditions in a dynamic analysis. For example, a rack support, which can be modeled as a +Y restraint in the static analysis, must be turned linear for the dynamic analysis – either by changing it to a double-acting Y support or removing it completely from the analysis. Normally, if the support is active in the operating case, a double-acting restraint is appropriate. If it lifts off the rack in the operating case, removing it from the dynamic analysis usually works fine. The first control parameter – Static Load Case for Nonlinear Restraint Status – is used to set the nonlinear components to a linear condition based on the specified load case. Normally, choose the operating case (case 1 here) by selecting it from the drop-down list. This job has no nonlinear restraints so this data is not required.
>
> The default frequency cutoff is set to 33 Hertz. All modes below that cutoff will be represented in the dynamic analysis; higher modes will be approximated with a single static load from the “Missing Mass” component. This is adequate since it is well beyond the peak of the response spectrum. Why 33 Hertz? The earth does not move fast enough to cause any resonant response from an oscillator tuned to 33 Hz or higher. Such oscillators (or modes of piping vibration) track earth motion exactly. This “rigid response” has no amplification. Additionally, the ground motion flattens out to a constant acceleration at these higher frequencies. The response from all these higher modes can be accurately predicted using a static load based on that (constant) ground acceleration.

Ensure that the modal combination is performed first. (This is typical – the individual spatial components (X, Y or Z) of the shock are independent of one another.

Spatial components are to be combined SRSS (square root sum of the squares) and the modes are to be combined by the GROUP method – any mode within 10% of a base frequency are combined absolutely and SRSS otherwise. These are default settings.

Confirm that Include Missing Mass Components is turned on.

Evaluating the Results:

After running these seismic analyses, review the stress reports for the two combination (Sustained + Occasional) load cases. It is apparent that both shocks cause failure at both the top and bottom sections of this system. Now check the individual shock cases to see what causes the failure. Overstress is caused by the first mode's response to the X load and the second and third mode's response to the Z load. Since it is not possible to alter the seismic load, the best course of action is to try to conveniently modify these lower modes. Reviewing the animation of the first three modes indicates that the perhaps the best way to alter this response is to restrain the system in the Z-direction at the existing, hard Y support at node 170, down near where the highest stresses exist.

Dynamic Output

```
 STRESS REPORT, Stresses on Elements
  (OCC)COMBINATION #  2

      ----------Stress(lb./sq.in.)------------              --(lb./sq.in.)--
NODES     AXIAL   BENDING    TORSION    MAX STRESS  SIFI    SIFO    CODE      ALLOW
                                        INTENSITY                   STRESS

****  B31.1 -2001, September 30, 2003
****  CODE STRESS CHECK FAILED

HIGHEST STRESSES: (lb./sq.in.)
   CODE STRESS %:            140.4  @NODE  260
          STRESS:          10584.2  ALLOWABLE:     7540.
   BENDING STRESS:         11210.9  @NODE  260
   TORSIONAL STRESS:        2160.9  @NODE  250
   AXIAL STRESS:            2177.1  @NODE  160
   3D MAX INTENSITY:       15542.2  @NODE  260

   10      2067      3213      1748      9599     1.00    1.00      6826      7539
   18      2081      2833      1748      9362     1.00    1.00      6586      7539

   18      2080      5009      1748     10777     1.77    1.77      8070      7539
   19      2078      4649      1790     10555     1.77    1.77      8035      7539
```

Dynamic Output

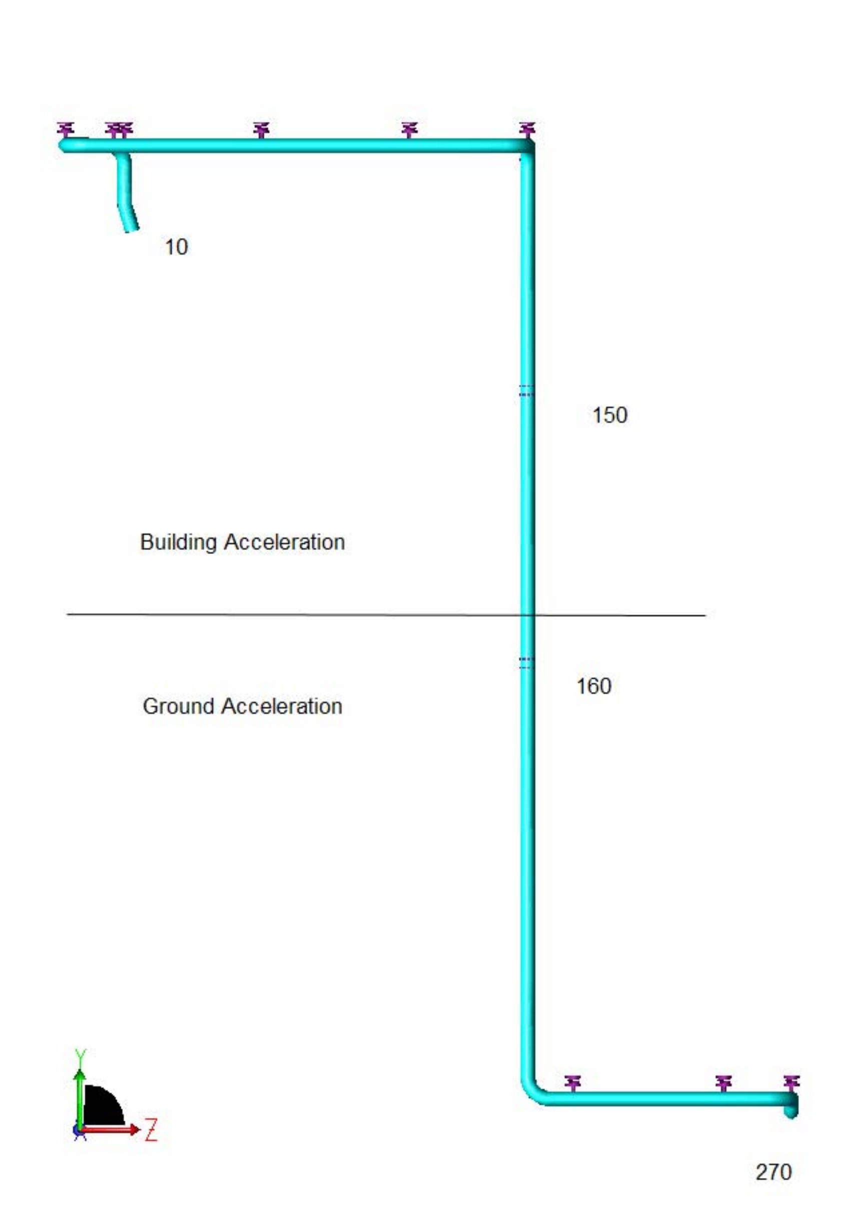
```
 (OCC)SHOCK CASE  #  2

NODES ----------Stress(lb./sq.in.)-----------                 --(lb./sq.in.)--
TOTALS...AXIAL   BENDING   TORSION  STRS INTNSTY              CODE STRS ALLOW
MODE MAX.AX/Mode BND/Mode  TOR/Mode  SHR/Mode     SIFI   SIFO   STRESS/Mode


  259        41      9279      1258      9645     1.77   1.77     7718        0
             22      8394      1089      8693                     6927
         3 Z(1)    2 Z(1)    2 Z(1)    2 Z(1)                   2 Z(1)
  260        40     10397       453     10470     1.77   1.77     7892        0
             24      9418       269      9444                     7067
         2 Z(1)    2 Z(1)    3 Z(1)    2 Z(1)                   2 Z(1)

  260        40      5881       453      5986     1.00   1.00     5953        0
             24      5328       269      5355                     5331
         2 Z(1)    2 Z(1)    3 Z(1)    2 Z(1)                   2 Z(1)
  270        40      5885       453      5989     1.00   1.00     5956        0
             24      5331       269      5357                     5333
         2 Z(1)    2 Z(1)    3 Z(1)    2 Z(1)                   2 Z(1)
```

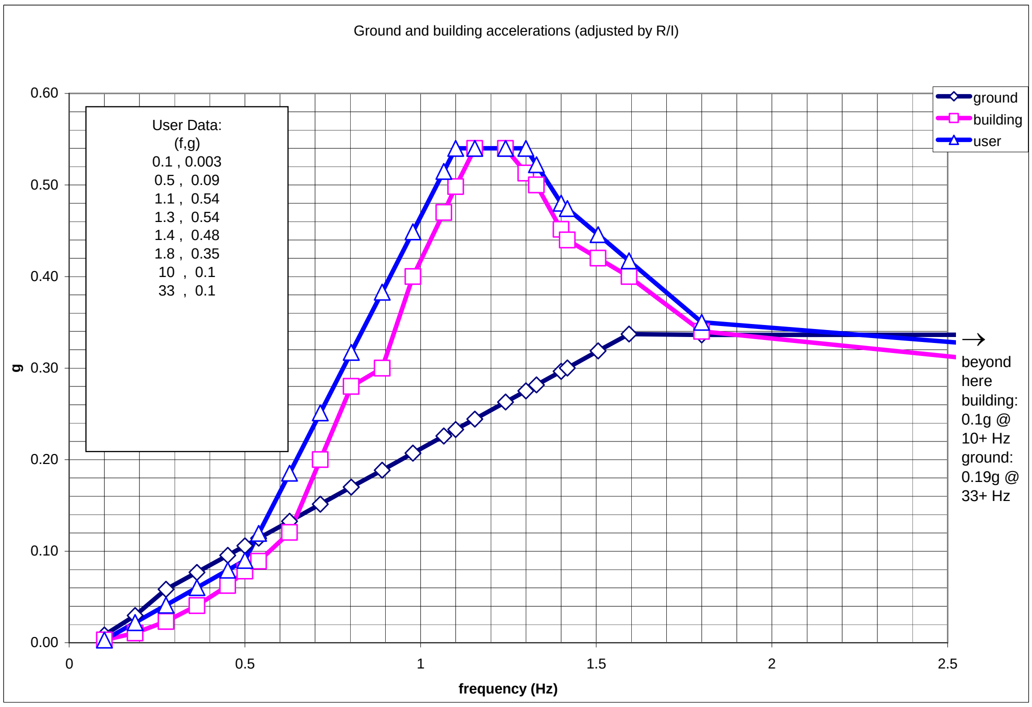
The problem is rerun with the restraint at node 170 (static stresses must be checked again of course). Both the X-Y and Z-Y shocks are still overstressed but now only at the top of this system – the first mode response creates the high stress from the X shock and the second mode response creates an equally high stress from the Z shock. Once again the animation shows that adding an X and Z restraint (or “Guide” on a Y run in CAESAR II) at node 140 can most easily change the response.

Re-analyzing the system with the additional restraints at nodes 140 and 170 shows that the system is well within the allowable stress limits.

Analyzing with Multiple Spectra and their Independent Support Motions:

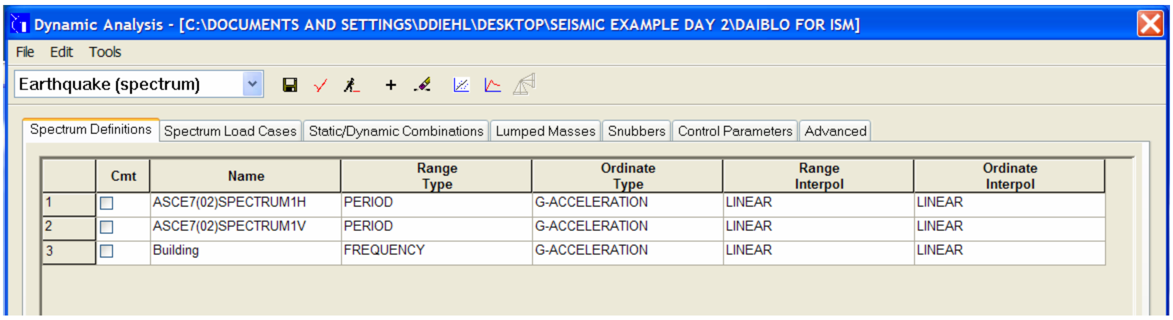
Now consider the situation where the piping runs between two buildings, or two levels of a building, so different sections of the piping experience different excitations. In this case, the analyst must be concerned with not only the inertial loadings on the piping systems, but also the relative displacements of individual building levels (imparted through restraints). The data points of the second spectrum may be entered directly under the Spectrum Definitions tab. Add a new line to the Spectrum Definitions table using a name such as BUILDING for a frequency vs. acceleration-in-g table with linear interpolation on both axes. Using the shock spectrum below, enter the Spectrum Data Points for the table.



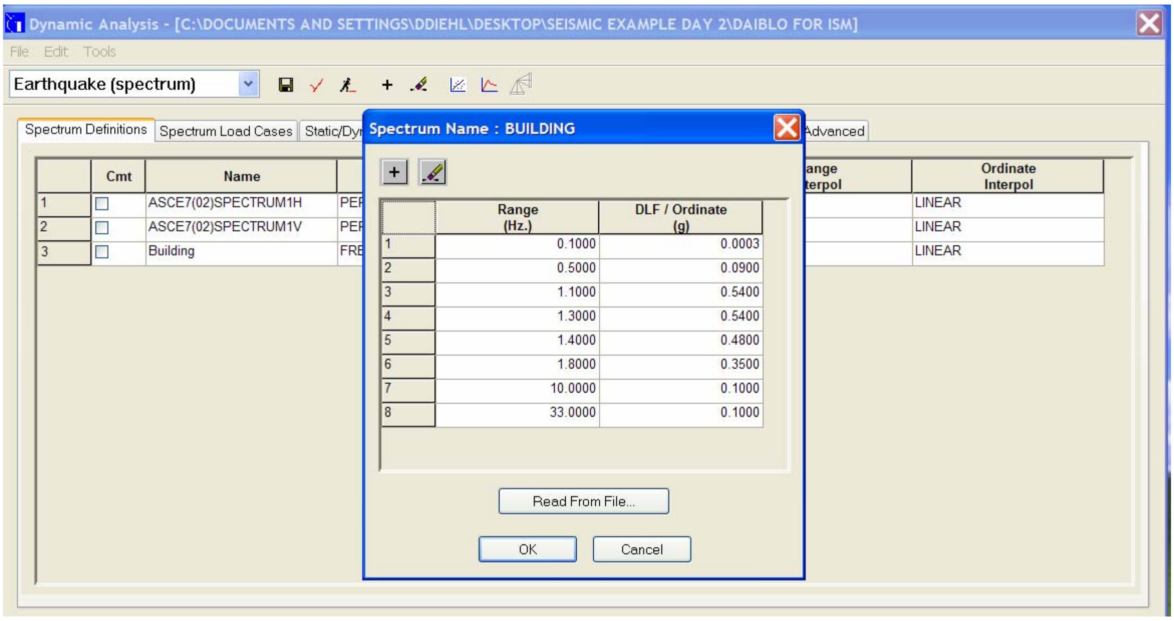


Then the ASCE7 spectrum can be defined on the lower section while the new spectrum can be associated with the upper section. Assuming that the building stiffness is high in the vertical direction (near the piping supports), there will be no modification of the vertical shock. In addition to itemizing the spectra involved, the spectral loadings also include relative building displacements – assume the maximum horizontal ground deflection is 25mm while the building's maximum horizontal displacement is 75mm. There will be no differential displacement in the vertical direction.

Enter this second shock spectrum by first adding a line to the "Spectrum Definitions" tab. This shock will be defined in terms of frequency versus acceleration in g's with linear interpolation along both axes.



Once the spectrum name is declared, the data can be entered by clicking on the Toolbar button illustrated below:



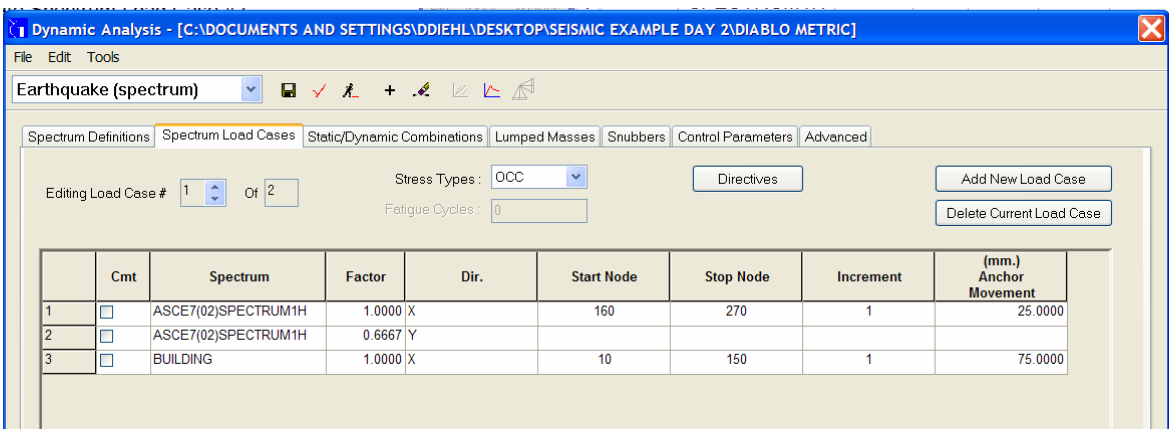
This shock can then be added to the seismic analysis. To identify which shock goes where, the “Spectrum Loads Cases” must identify the range of nodes to be used with each shock. Here, the ASCE shock is applied at supports in the range of nodes 160 to 270 while the Building shock is appled at supports in the range of 10 to 150. The relative motion between te ground and building are entered with these shocks. These deflections will be included in the analysis as an additional component to the overall response. If these Anchor Movements are left blank, CAESAR II will calculate this displacement from thee appropriate spectrum. (Here, the displacement would be based on the entered acceleration at the lowest table frequency.)

Update Spectrum Load Case #1:

Spectrum	Factor	Dir.	Start Node	Stop Node	Increment	Support Movement (mm)
ASCE(02) SPECTRUM1H	1	X	160	270	1	25
ASCE(02) SPECTRUM1H	2/3	Y				
BUILDING	1	X	10	150	1	75

Update Spectrum Load Case #2:

Spectrum	Factor	Dir.	Start Node	Stop Node	Increment	Support Movement (mm)
ASCE(02) SPECTRUM1H	1	Z	160	270	1	25
ASCE(02) SPECTRUM1H	2/3	Y				
BUILDING	1	Z	10	150	1	75



Analyzing these load cases demonstrates that the system requires additional redesign.

What mode(s) of vibration causes the largest dynamic stress from the X-Y shock? Which spatial component (X or Y) causes this high stress? What mode and shock direction causes the high stress in the Z-Y shock? How could this model pass the dynamic stress requirements without adding additional restraints? Additional restraints may start to increase the static loads and stresses but can too many restraints cause a problem with the dynamic solution?

Other Points for Discussion:

Some requirements state that at least 90% of the system mass must be included in the dynamic results. With CAESAR II, this is accomplished through Missing Mass Correction. However, if this were not included, what methods could be used to increase the amount of included mass?

How accurate is this dynamic model? Can it be improved; how? Need it be improved considering the relationship between the system model and this type of loading?