LAB 4: FUNDAMENTALS OF DYNAMICS

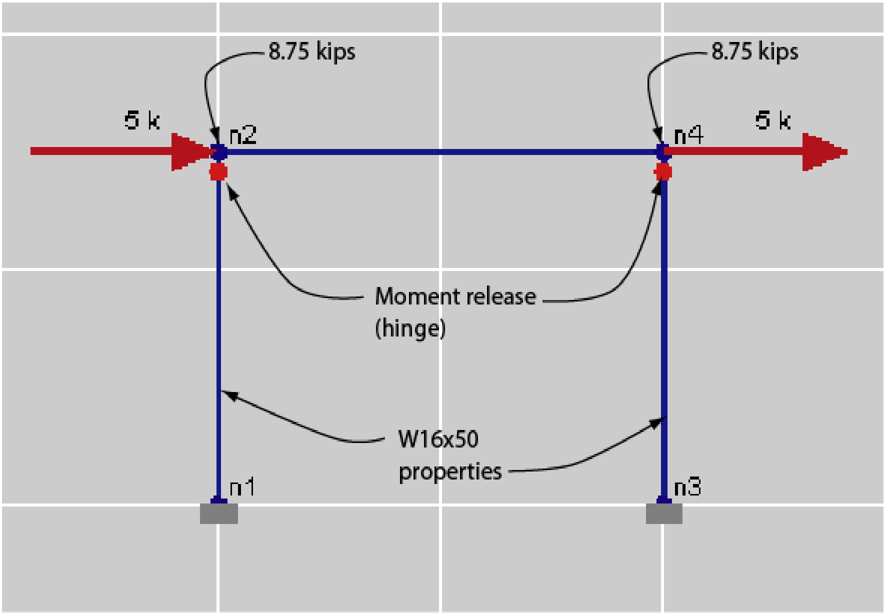
INTRODUCTION

Objectives:

- Understand the basic concepts of how structures respond to loads that vary with time, including the following basic terms: Mass, stiffness, damping, natural period of vibration, frequency, resonance, dynamic magnification factor, energy dissipation.

The Model

The exercises are based on the simplified one-story structure from the pre-lab assignment. The lab uses a two-dimensional Arcade model which models one-half of the structure as shown.



The structure is modelled with the following assumptions:

- The mass of the columns is neglected, because it is small compared to the mass of the slab (conventional practice would lump the mass of the upper half of the columns with the slab).
- The mass of the slab is represented as 8.75 kips of superimposed weight at each of the nodes at the column tops.
- The connection between the column and slab is pinned, so the column acts as a cantilever.

Getting Started

Copy the following file to the T drive or your computer:

```
G:\Arch721-Martini-F04\2004\labs\lab-04\lab-04.rcd
```

Open the file with *Arcade* (*Start* > *All Programs* > *Architecture* > *Arcade* > *Arcade*).

PART 1: DETERMINE STRUCTURAL PROPERTIES

VERIFY STIFFNESS: PSEUDO-STATIC LOADING

Your calculation in the pre-lab should have concluded that the stiffness of the W16x50 column was 9.83 kips per inch, which means that the two-column frame in our model should have a stiffness twice that: 19.66 kips per inch. Do the following:

- Calculate by hand the displacement you would expect for this frame when subjected to a lateral load of 10 kips.
- Use Arcade to analyze the frame under a 10 kip lateral load applied in a pseudo-static manner.

  Pseudo static means that the load is applied in a way that minimizes dynamic effects (e.g. causes little vibration). This means that the load is applied over a time interval that is long compared with the structure's period of vibration. In this case, the load is applied over three seconds, while the structure has a 0.3-second period of vibration.

  - Click *Simulation* > *Start.*

    On the graph of *Lateral disp vs. time*, note the bumps in the curve, which are the result of the model vibrating in response to the initial application of the load. These vibrations do not die out because this model has no damping,

  - Click *Simulation* > *Stop.*
  - Click *Settings* > *Damping* > *Nodes.*
  - In the upper window, in the area labeled *Node mass-proportional damping*, click the button labeled *Lite.*
  - Click *Simulation* > *Start*.

    On the graph of Lateral disp vs. time, note how the vibrations die out, this is the result of the damping.

  - On the graph of *Lateral disp. vs. time*, right click on the flat portion of the graph, which corresponds to the time when the load is fully applied.

    A pop-up window should appear, showing that the Y coordinate of the graph id 0.509 inches, which corresponds to the lateral displacement of the structure.

VERIFY PERIOD OF VIBRATION: IMPULSE LOADING

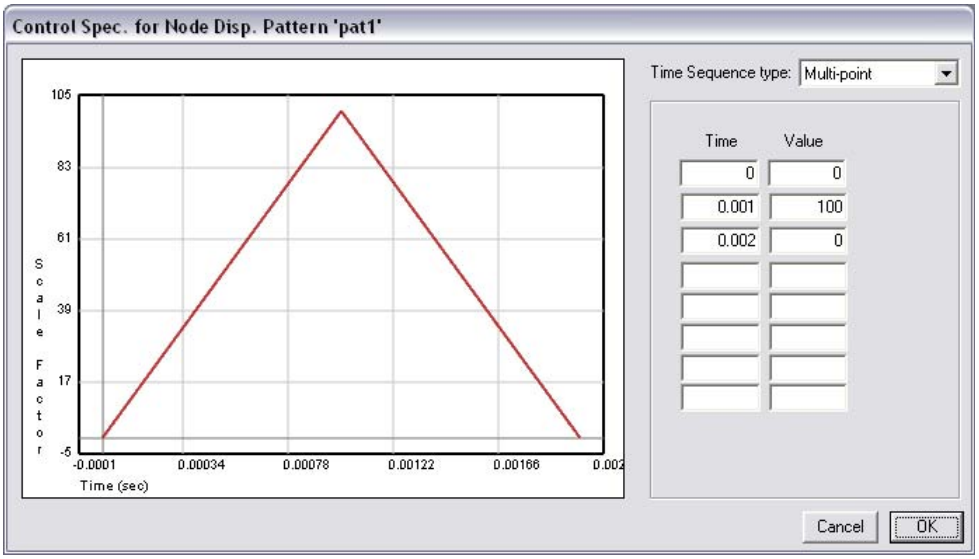
In the pre-lab, you calculated the period of vibration of the structure. You will now compare the answer you got with the behavior of the Arcade model. Do the following:

Turn off damping.

- Click *Settings* > *Damping* > *Nodes.*
- In the upper window, in the area labeled *Node mass-proportional damping*, click the button labeled *Zero.*

Set Impulse loading.

- Click *Build* > *Loads.*
- In the Loads Table Set, click the *Load Patterns* tab.
- In the *control spec.* column, click *Multi-point…*
- In the dialog box that appears, set the values as follows:
- These values correspond to an impulse load of 1000 kips (10 kips times a scale factor of 100) for 2 milliseconds.



Control Spec. for Node Disp. Pattern 'pat1'

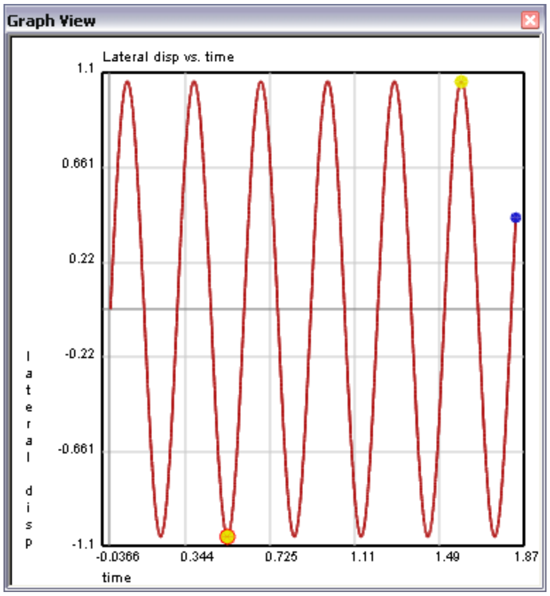
Time Sequence type: Multi-point

Time	Value
0	0
0.001	100
0.002	0

- Click OK.

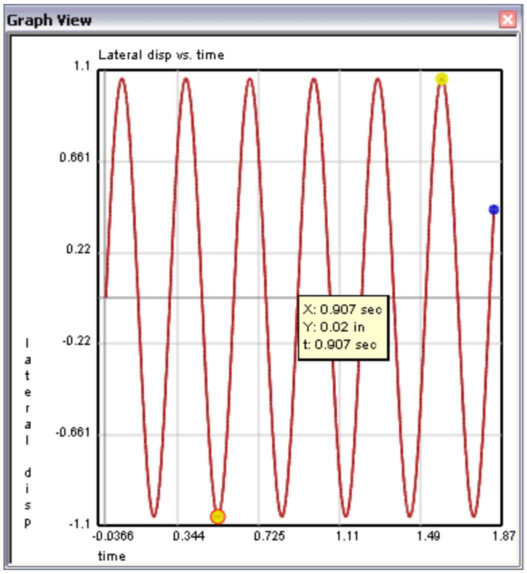
Run the simulation for about 2 seconds.

- Click *Simulation* > *Start* (or the blue triangle in the upper left corner), and then quickly click Stop (the blue square) after the model has gone through a few cycles of motion. The graph should look something like the following:



- Find the period of vibration by right clicking on the graph to find the time required for three cycles of motion, and then dividing that value by three.

  This could be done by finding the time required for just the first cycle of motion, but is more accurate because it reduces the error involved in click the exact point where the graph crosses the axis. After clicking, the graph should appear something like the following:

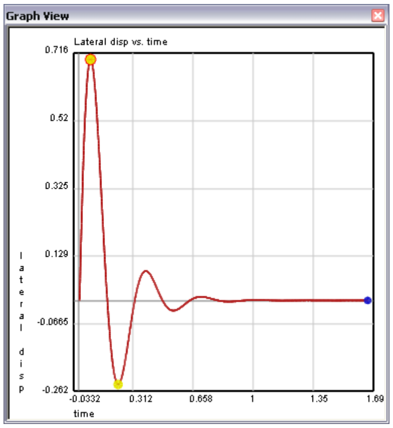


X: 0.907 sec
Y: 0.02 in
t: 0.907 sec

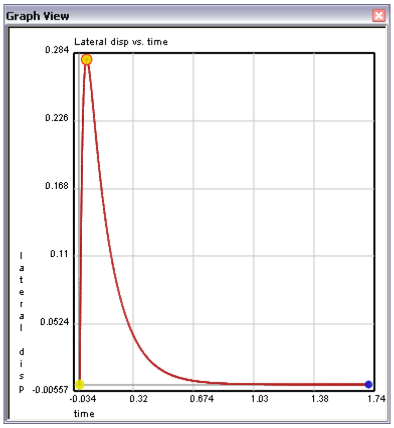
- Compare the period of vibration from the Arcade analysis with the period of vibration calculated in the pre-lab exercise.

DETERMINE CRITICAL DAMPING: IMPULSE LOADING

The calculation for period of vibration was done with the damping set to zero. You will now determine the damping level that corresponds to critical damping for this structure. Critical damping is the smallest damping level at which oscillation does not occur. The graphs below explain this better. For damping is less than critical (as in the left graph), when an impulse load pushes the structure to the right (positive0, it oscillates to the left (negative) before eventually returning to its at-rest position. For damping is greater than or equal to critical (as in the right graph), when an impulse load pushes the structure to the right, it returns to its original position without any displacement to the left..



Less than critical damping.



Greater than or equal to critical damping.

Do the following steps to find critical damping for this structure:

- Click *Settings* > *Damping* > *Nodes*
- In the upper window, in the area labeled *Node mass-proportional damping*, click the button labeled *Lite*.
- Run the simulation for a couple of seconds.
- Assess whether this damping level is less than or greater than critical damping.
- Type in a new value for the damping, and repeat by systematic trial and error until you determine the critical damping value within 5% (e.g. when you select a value as critical damping, you should be able to show that 95% of that value is clearly less than critical damping.)

PART 2: RESPONSE TO IMPULSE LOADING

THE EFFECT OF DAMPING

Using the value for critical damping determined above, do the following.

- Click *Settings* > *Damping* > *Nodes*.
- In the mass-proportional damping area, type in a value for damping that corresponds to 1% critical (i.e. 0.01 times your value for critical damping).
- Run the simulation, and pause it after about 5 seconds.
- Determine how many cycles of motion it takes for the amplitude to reduce from the initial peak to less than 50% of that peak, as follows:
    - Right click on the initial peak, and read the Y value.
    - Calculate 0.5 times that value.
    - Right click on successive peaks until you find one that is less than the 50% value.
    - Count the number of cycles from the initial peak to that peak.

- Repeat the steps above to calculate the number of cycles to reduce to less than 50% amplitude for 5% critical damping.

Note that while increasing the damping made the oscillations die out much more quickly, it had little effect on the initial maximum peak. This peak is only about 6% less for 5% damping compared with 1% damping. The lesson from this analysis is:

> Damping significantly reduces the oscillations which follow an impulse load, but does little to reduce the initial peak response.

THE EFFECT OF STIFFNESS

The preceding calculations examined the effect of damping on response to impulse loading, now you will look at the effect of stiffness. Do the following:

Record maximum displacement and base shear for original structure.

- Click *Settings* > *Damping* > *Nodes*.
- In the mass-proportional damping area, type in a value for damping that corresponds to 5% critical.
- Run the simulation for about 2 seconds.
- Right click on the yellow dot on the initial peak of the graph.

    The yellow dots indicate the minimum and maximum Y values on the graph, the one with the larger absolute value has a red circle around the dot.

- Record on the check sheet the maximum displacement reported in the pop-up.
- In the toolbar, find the drop-down list labeled *Graph* and set the graph to *Base shear vs. time.*

  This graph records the structure's resisting force over time. The base shear is the sum of the two horizontal reactions.
- Right click on the yellow dot on the initial peak of the graph.
- Record on the check sheet the maximum base shear reported in the pop-up window.

Record maximum displacement and base shear for stiffened structure.

- Stop the simulation if it is running.
- Click *Build* > *Elements* > *Beam-2*.
- In the table of beam elements, replace the Ixx (moment of inertia) value of 659 in^4 with 1318 in^4 (twice the original value) for all the elements.

  This will make the structure twice as stiff.
- Repeat the steps with the two graphs above to record the maximum displacement and base shear.

Note that the stiffer structure has lower displacement, but higher base shear. Since this is free vibration, the forces equal the mass times the acceleration, which means the accelerations must be higher as well. The lesson from this analysis is:

> Increasing the stiffness of a structure reduces the displacement response to impulse loading, but increases the acceleration and force response.

THE EFFECT OF MASS

The preceding calculations examined the effect of damping and stiffness on response to impulse loading, now you will look at the effect of mass. Do the following:

Record maximum displacement and base shear for the structure with added mass.

- Stop the simulation if it is running.
- Click *Build* > *Elements* > *Beam-2*.
- In the table of beam elements, set the Ixx value of all the elements back to the original value of 659 in^4.
- Click *Build* > *Nodes*.
- For nodes *n2* and *n4*, set the *super wt.* (superimposed weight) to 17.5 kips (double the original value of 8.75 kips).
- Run the simulation for about 2 seconds.
- Use the method above to record the maximum displacement

Repeat the steps with the two graphs above to record the maximum displacement and base shear for the structure with added mass.

Note that the structure with added mass has both lower displacements and lower forces. By the same reasoning as above, the lower forces also imply that the structure has lower accelerations. The lesson from this analysis is:

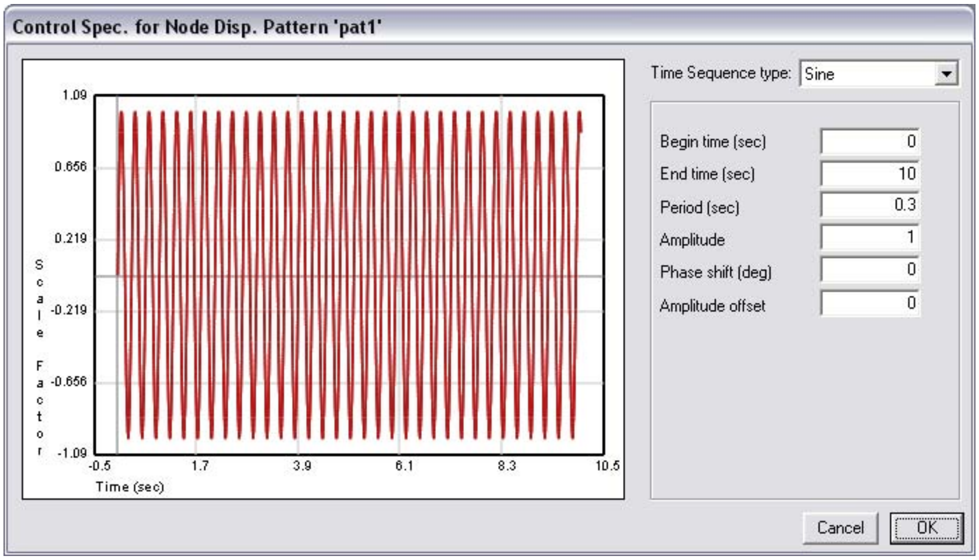
> Increasing the mass of a structure reduces the displacement response to impulse loading, as well as the acceleration and force response.

PART 3: RESPONSE TO PERIODIC LOADING

The preceding analyses considered the effects of varying stiffness, mass, and damping on structural response to impulse loading. Now you will look at the effect of these factors on the response to periodic loading in the form of a sine wave. Set the sine wave loading as follows:

- Stop the simulation if it is running.
- Click *Build* > *Nodes.*
- In the node table, set the superimposed weights of nodes *n2* and *n4* back to the original value of 8.75 kips.
- Click *Build* > *Loads*.
- In the Loads Table Set, click the *Load Patterns* tab.
- In the *control spec.* column, click *Multi Point...*
- In the dialog box, use the drop list in the upper right to select *Sine*.
- In the dialog box, set the period to 0.3, which matches the structure's period of vibration.

The dialog box will then look as follows:



Control Spec. for Node Disp. Pattern 'pat1'

Time Sequence type: Sine

Begin time (sec) 0
End time (sec) 10
Period (sec) 0.3
Amplitude 1
Phase shift (deg) 0
Amplitude offset 0

- Click OK.

THE EFFECT OF DAMPING

- Click *Simulation* > *Damping* > *Nodes*.
- Set the damping to zero.
- Run the simulation for about 12 seconds.

  Note that the amplitude increases with each cycle, this is because of resonance: the period of the load matches the period of the structure.
- Record the maximum base shear on the check sheet.
- Stop the simulation.
- Set the damping to a value corresponding to 5% critical damping for this structure.
- Run the simulation again for about 12 seconds.
- Record the maximum base shear on the check sheet.

The lesson from this analysis is:

> Increasing damping significantly reduces the force and displacement response due to a periodic load which resonates with the structural period.

THE EFFECTS OF MASS AND STIFFNESS

On the check sheet, describe briefly what you expect would be the effect of changing the mass of the structure. Do the same for structural stiffness.