

Name _____ Class Time _____

Project 8. Solve problems L8.1 to L8.5. The problem headers:

----- PROBLEM L8.1. EARTHQUAKE MODEL FOR A BUILDING.
----- PROBLEM L8.2. TABLE OF NATURAL FREQUENCIES AND PERIODS.
----- PROBLEM L8.3. UNDETERMINED COEFFICIENTS STEADY-STATE SOL
----- PROBLEM L8.4. PRACTICAL RESONANCE.
----- PROBLEM L8.5. EARTHQUAKE DAMAGE.

SIX FLOOR Model.

Refer to the textbook of Edwards-Penney, section 7.4, page 437.
Consider a building with six floors each weighing 50 tons. Each floor corresponds to a restoring Hooke's force with constant $k=5$ tons/foot. Assume that ground vibrations from the earthquake are modeled by $(1/4)\cos(\omega t)$ with period $T=2\pi/\omega$.

PROBLEM L8.1. BUILDING MODEL FOR AN EARTHQUAKE.

Model the 6-floor problem in Maple.
Define the 6 by 6 mass matrix M and Hooke's matrix K for this system and convert $Mx''=Kx$ into the system $x''=Ax$ where A is defined by textbook equation (1), page 437.

Sanity check: Mass $m=3125$, and the 6x6 matrix contains fraction $16/5$.

Then find the eigenvalues of the matrix A to six digits, using the Maple command "eigenvals(A)."

Sanity check: All six eigenvalues should be negative.

```
# Sample Maple code for a model with 4 floors.  
# Use maple help to learn about evalf and eigenvals.  
# A:=matrix([ [-20,10,0,0], [10,-20,10,0],  
[0,10,-20,10],[0,0,10,-10]]);  
# with(linalg): evalf(eigenvals(A));
```

```
# Problem L8.1  
# Define k, m and the 6x6 matrix A.  
# with(linalg): evalf(eigenvals(A));
```

PROBLEM L8.2. TABLE OF NATURAL FREQUENCIES AND PERIODS.

Refer to figure 7.4.17, page 437.

Find the natural angular frequencies $\omega=\sqrt{-\lambda}$ for the six story building and also the corresponding periods $2\pi/\omega$, accurate to six digits. Display the answers in a table. Compare with answers in Figure 7.4.17, page 437, for the 7-story case.

```
# Sample code for a 4x3 table, 4-story building.  
# Use maple help to learn about nops and printf.
```

```

# ev:=[-10,-1.206147582,-35.32088886,-23.47296354]: n:=nops(ev):
# Omega:=lambda -> sqrt(-lambda):
# format:="%10.6f %10.6f %10.6f\n":
# seq(printf(format,ev[i],Omega(ev[i]),2*evalf(Pi)/Omega(ev[i])),
i=1..n);

# Problem L8.2
# ev:=[fill this in]: n:=nops(ev):
# Omega:=lambda -> sqrt(-lambda): format:="%10.6f %10.6f %10.6f\n":
#
seq(printf(format,ev[i],Omega(ev[i]),2*evalf(Pi)/Omega(ev[i])),i=1..n)
;

```

PROBLEM L8.3. UNDETERMINED COEFFICIENTS

STEADY-STATE PERIODIC SOLUTION.

Consider the forced equation $x' = Ax + \cos(\omega t)b$ where b is a constant vector. The earthquake's ground vibration is accounted for by the extra term $\cos(\omega t)b$, which has period $T = 2\pi/\omega$.

The solution $x(t)$ is the 6-vector of excursions from equilibrium of the corresponding 6 floors.

Sought here is not the general solution, which certainly contains transient terms, but rather the steady-state periodic solution, which is known from the theory to have the form $x(t) = \cos(\omega t)c$ for some vector c that depends only on A and b .

Define $b := 0.25 * \omega * \omega * \text{vector}([1, 1, 1, 1, 1, 1])$: in Maple and find the vector c in the undetermined coefficients solution $x(t) = \cos(\omega t)c$. Vector c depends on ω . As outlined in the textbook, vector c can be found by solving the linear algebra problem $-\omega^2 c = Ac + b$; see page 433. Don't print c , as it is too complex; instead, print $c[1]$ as an illustration.

```

#Sample code for defining b and A, then solving for c
#in the 4-floor case.
# See maple help to learn about vector and linsolve.
# w:='w': u:=w*w: b:=0.25*u*vector([1,1,1,1]):
# A:=matrix([ [-20,10,0,0], [10,-20,10,0],
[0,10,-20,10],[0,0,10,-10]]);
# Au:=evalm(A+u*diag(1,1,1,1));
# c:=linsolve(Au,-b):
# evalf(c[1],2);

```

PROBLEM L8.3

```

# Define w, u, b, A, Au, c
# evalf(c[1],2);

```

PROBLEM L8.4. PRACTICAL RESONANCE.

Consider the forced equation $x' = Ax + \cos(\omega t)b$ of L8.3 above with $b := 0.25 * \omega * \omega * \text{vector}([1, 1, 1, 1, 1, 1])$.

Practical resonance can occur if a component of $x(t)$ has large amplitude compared to the vector norm of b . For example, an earthquake might cause a small 3-inch excursion on level ground, but the building's floors might have 50-inch excursions, enough to destroy

the building.

Let $\text{Max}(c)$ denote the maximum modulus of the components of vector c . Plot $g(T)=\text{Max}(c(w))$ with $w=(2\pi)/T$ for periods $T=0$ to $T=6$, ordinates $\text{Max}=0$ to $\text{Max}=10$, the vector $c(w)$ being the answer produced in L8.3 above. Compare your figure to the textbook Figure 7.4.18, page 438.

```
# Sample maple code to define the function Max(c), 4-floor building.
# Use maple help to learn about norm, vector, subs and linsolve.
# with(linalg):
# w:='w': Max:= c -> norm(c,infinity); u:=w*w:
# b:=0.25*w*w*vector([1,1,1,1]):
# A:=matrix([ [-20,10,0,0], [10,-20,10,0], [0,10,-20,10],
[0,0,10,-10]]);
# Au:=evalm(A+u*diag(1,1,1,1));
# C:=ww -> subs(w=ww,linsolve(Au,-b)):
# plot(Max(C(2*Pi/r)),r=0..6,0..10,numpoints=150);
```

```
# PROBLEM L8.4. WARNING: Save your file often!!!
# w:='w': Max:= c -> norm(c,infinity): u:=w*w:
# Define b
# Define A
# Define Au
# Define C
# plot(Max(C(2*Pi/r)),r=0..6,0..10,numpoints=150);
```

PROBLEM L8.5. EARTHQUAKE DAMAGE.

The maximum amplitude plot of L8.4 can be used to detect the of earthquake damage for a given ground vibration of period T . A ground vibration $(1/4)\cos(wt)$, $T=2\pi/w$, will be assumed, as in L8.4.

(a) Replot the amplitudes in L8.4 for periods 1.5 to 5.5 and amplitudes 5 to 10.

There will be five spikes.

(b) Create five zoom-in plots, one for each spike, choosing a T -interval that shows the full spike.

(c) Determine from the five zoom-in plots approximate intervals for the period T such that some floor in the building will undergo excursions from equilibrium in excess of 5 feet.

```
# Example: Zoom-in on a spike for amplitudes 5 feet to 10 feet,
#periods 1.97 to 2.01.
```

```
#with(linalg): w:='w': Max:= c -> norm(c,infinity); u:=w*w:
#Au:=matrix([ [-20+u,10,0,0], [10,-20+u,10,0],
[0,10,-20+u,10], [0,0,10,-10+u]]);
#b:=0.25*w*w*vector([1,1,1,1]):
#C:=ww -> subs(w=ww,linsolve(Au,-b)):
#plot(Max(C(2*Pi/r)),r=1.97..2,01,5..10,numpoints=150);
```

```
# PROBLEM L8.5. WARNING: Save your file often!!!
```

```
#(a) Re-plot the five spikes.
```

```
# plot(Max(C(2*Pi/r)),r=1.5..5.5,5..10,numpoints=150);
```

```
#(b) Plot five zoom-in graphs.
# one:=1.79..1.83:plot(Max(C(2*Pi/r)),r=one,5..10,numpoints=150);
# two:=???:plot(Max(C(2*Pi/r)),r=two,5..10,numpoints=150);
# three:=???:plot(Max(C(2*Pi/r)),r=three,5..10,numpoints=150);
# four:=???:plot(Max(C(2*Pi/r)),r=four,5..10,numpoints=150);
# five:=???:plot(Max(C(2*Pi/r)),r=five,5..10,numpoints=150);
#(c) Print period ranges.
# PeriodRanges:=[one,two,three,four,five];
```