L9.1. PROBLEM (NONLINEAR MCKENNA MODELS)

There are three (3) parts L9.1A to L9.1C to complete. Mostly, this is mouse copying. Retyping the maple code by hand is not recommended.

NONLINEAR TORSIONAL MODEL WITH GEOMETRY INCLUDED.

Consider the nonlinear, forced, damped oscillator equation for torsional motion, with bridge geometry included,

\[ x'' + 0.05 x' + 2.4 \sin(x)\cos(x) = 0.06 \cos \left( \frac{12}{10} t \right) , \]
\[ x(0) = x_0, \quad x'(0) = v_0 \]

and its corresponding linearized equation

\[ x'' + 0.05 x' + 2.4 x = 0.06 \cos \left( \frac{12}{10} t \right) , \]
\[ x(0) = x_0, \quad x'(0) = v_0. \]

The spring-mass system parameters are \( m=1, \quad c = 0.05, \quad k = 2.4, \quad w = 1.2, \quad F = 0.06. \) Maple code used to solve and plot the solutions appears below.

\[
\begin{align*}
&\text{# Use "copy as maple text" for maple 6+}. \\
&x0:=0: \quad a:=200: \quad b:=300: \quad \text{# For part A. Change it for part B!} \\
&v0:=0: \quad m:=1: \quad F := 0.06: \quad w := 1.2: \quad c := 0.05: \quad k := 2.4: \\
&\text{with(DEtools): opts:=stepsize=0.1:} \\
&\text{deLinear:=} \quad m*\text{diff}(x(t),t,t) + c*\text{diff}(x(t),t) + k*x(t) = F*\cos(w*t): \\
&\text{IClinear:=}\{x(0)=x0,D(x)(0)=v0\}; \\
&\text{DEplot(deLinear,x(t),t=a..b,IClinear,opts,title='Linear');} \\
&\text{deNonLinear:=} \quad m*\text{diff}(x(t),t,t) + c*\text{diff}(x(t),t) + k*\sin(x(t))*\cos(x(t)) = F*\cos(w*t): \\
&\text{ICnonlinear:=}\{x(0)=x0,D(x)(0)=v0\}; \\
&\text{DEplot(deNonLinear,x(t),t=a..b,ICnonlinear,opts,title='NonLinear');} \\
\end{align*}
\]

9.1A. Let \( x0=0, \ v0=0. \) Plot the solutions of the linear and nonlinear equations from \( t=200 \) to \( t=300. \) These plots represent the steady state solutions of the two equations.

9.1B. Let \( x0=1.2, \ v0=0. \) Plot the solutions of the linear and
nonlinear equations from t=220 to t=320. These plots represent the steady state solutions of the two equation, with new starting value x_0=1.2. [You must modify line 1 of the maple code!]

The two linear plots in A and B have to be identical to the plot of x_{ss}(t). The reason is the superposition formula (see E&P) x(t)=x_h(t)+x_{ss}(t), even though the homogeneous solution x_h(t) is different for the two plots. This is because x_h(t) has limit zero at t=\infty.

9.1C. Determine the ratio of the apparent amplitudes (a number > 1) for the nonlinear plots in A and B. Do "large sustained oscillations" appear in the plot of the nonlinear steady-state?

L9.2. PROBLEM (MCKENNA'S NON-HOOKE'S LAW CABLE MODEL)

There are three (3) parts L9.2A to L9.2C to complete. Mostly, this is mouse copying. Retyping the maple code by hand is not recommended.

The model of McKenna studies the bridge with a nonlinear, forced, damped oscillator equation for torsional motion that accounts for the non-Hooke's law cables coupled to the equations for vertical motion. The equations in this case couple the torsional motion with the vertical motion. The equations are:

\[
\begin{align*}
x'' + c x' - k G(x,y) &= F \sin \omega t, \quad x(0) = x_0, \quad x'(0) = x_1, \\
y'' + c y' + (k/3) H(x,y) &= g, \quad y(0) = y_0, \quad y'(0) = y_1,
\end{align*}
\]

where x(t) is the torsional motion and y(t) is the vertical motion. The functions G(x,y) and H(x,y) are the models of the force generated by the cable when it is contracted and stretched. Below is sample code for writing the differential equations and for plotting the solutions. It is ready to copy with the mouse.

```maple
with(DEtools):
w := 1.3: F := 0.05: f(t) := F*sin(w*t):
c := 0.01: k1 := 0.2: k2 := 0.4: g := 9.8: L := 6:
STEP:=x->piecewise(x<0,0,1):
fp(t) := y(t)+(L*sin(x(t))):
fm(t) := y(t)-(L*sin(x(t))):
Sm(t) := STEP(fm(t))*fm(t):
Sp(t) := STEP(fp(t))*fp(t):
sys := {
    diff(x(t),t,t) + c*diff(x(t),t) - k1*cos(x(t))*(Sm(t)-Sp(t))=f(t),
    diff(y(t),t,t) + c*diff(y(t),t) + k2*(Sm(t)+Sp(t)) = g};
ic := [[x(0)=0, D(x)(0)=0, y(0)=27.25, D(y)(0)=0]]:
vars:=\{x(t),y(t)\}:
opts:=stepsize=0.1:
```
DEplot(sys,vars,t=0..300,ic,opts,scene=[t,x]);

The amazing thing that happens in this simulation is that the large vertical oscillations take all the tension out of the springs and they induce large torsional oscillations.

L9.2A. TORSIONAL OSCILLATION PLOT. Get the sample code above to produce the plot of \( x(t) \) [that's what scene=[t,x] means].

L9.2B. ROADWAY TILT ANGLE. Estimate the number of degrees the roadway tilts based on the plot. Recall that \( x \) in the plot is reported in radians. Comment on the agreement of this result with historical data and the video evidence in the film clip.

Tip: Average the five largest amplitudes in the plot to find an average maximum amplitude for \( t=0 \) to \( t=300 \). Convert to degrees using \( \pi \) radians = 180 degrees. The film clip shows roadway maximum tilt of 30 to 45 degrees, approximately.

L9.2C. VERTICAL OSCILLATION PLOT. Modify the DEplot code to scene=[t,y] and plot the oscillation \( y(t) \) on \( t=0 \) to \( t=300 \). The plot is supposed to show 30-foot vertical oscillations along the roadway that dampen to 7-foot vertical oscillations after 300 seconds.

The agreement between these oscillation results and the historical data for Tacoma Narrows, especially the visual data present in the film clip of the bridge disaster, should be clear from the plots. This is your only answer check for the plot results.