
EE254 P3 - Numerical Approaches to Derivatives - Connor McGarty, cmcgarty

Table of Contents

Define Testing functions	1
Define Testing functions	2
Setup	2
Call Compare_Difference_Formulas()	2
Forward/Backward/Center, 1st Derivative, v1	2
Forward/Backward/Center, 1st Derivative, v2	6
Forward/Backward/Center, 2nd Derivative, v1	10
Forward/Backward/Center, 2nd Derivative, v2	14
Forward - 1st Derivative, v1 vs v2	18
Backward - 1st Derivative, v1 vs v2	22
Center - 1st Derivative, v1 vs v2	25
Forward - 2nd Derivative, v1 vs v2	29
Backward - 2nd Derivative, v1 vs v2	32
Center - 2nd Derivative, v1 vs v2	36

The following project compares different methods for finding the derivative of functions. The following finite difference methods are compared:

- Forward Finite Difference, 2 terms
- Forward Finite Difference, 3 terms
- Backward Finite Difference, 2 terms
- Backward Finite Difference, 3 terms
- Center Finite Difference, 4 terms
- Center Finite Difference, 5 terms

Define Testing functions

The following 5 functions will be used to test the derivative approximation techniques. Polynomial from book:

$$y = (-.1x^4) - (.15x^3) - (.5x^2) - (.25x) + 1.2$$

$$y = \cos(x)$$

$$y = 3x$$

$$y = \tan(x)$$

We'll also use a heaviside step function.

Define Testing functions

```
clear;clc;close all;
syms x;
poly = (-.1*x^4) - (.15*x^3) - (.5*x^2) - (.25*x) + 1.2;
cosine = cos(x);
linear = 3*x;
tangent = tan(x);
step = heaviside(x-3)*sin(2*x);
```

Setup

```
xmin = 0;
xdelta = .1;
xmax = 10;

x_vector = [xmin : xdelta : xmax];

poly_h = matlabFunction(poly);
lin_h = matlabFunction(linear);
step_h = matlabFunction(step);
```

Call Compare_Difference_Formulas()

```
poly_res = Compare_Difference_Formulas(poly, xmin, xmax, xdelta);
cos_res = Compare_Difference_Formulas(cosine, xmin, xmax, xdelta);
linear_res = Compare_Difference_Formulas(linear, xmin, xmax, xdelta);
tangent_res = Compare_Difference_Formulas(tangent, xmin, xmax,
xdelta);
step_res = Compare_Difference_Formulas(step, xmin, xmax, xdelta);
```

Forward/Backward/Center, 1st Derivative, v1

```
figure; % plot function itself, 1st deriv actual, 1st deriv method 1,
1st deriv
hold on;
plot(x_vector, poly_h(x_vector)); % plot the polynomial
plot(x_vector(2:end-1), poly_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), poly_res{1,2}); % 1st derivative, forward v1
plot(x_vector(2:end-1), poly_res{1,6}); % 1st deriv, backward v1
plot(x_vector(2:end-1), poly_res{1,10}); % 1st deriv, center v1
title('Forward/Backward/Center Methods, 1st Derivative - v1,
Polynomial');
legend('Polynomial', 'Analytic', 'Forward - v1', ...
'Backward - v1', 'Center - v1');
```



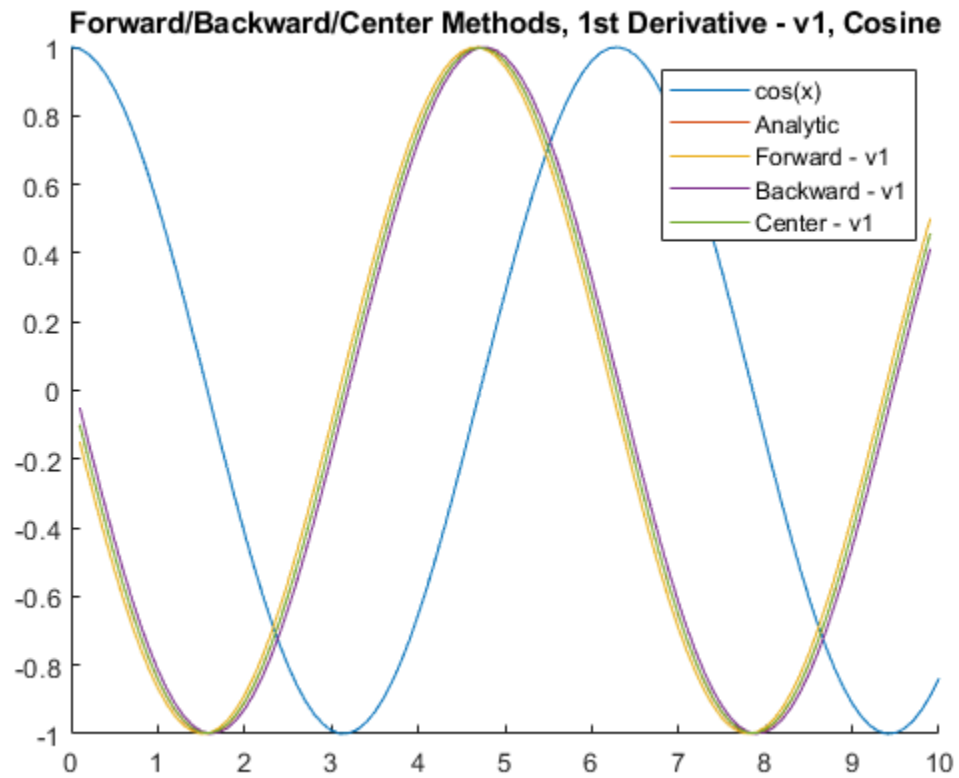
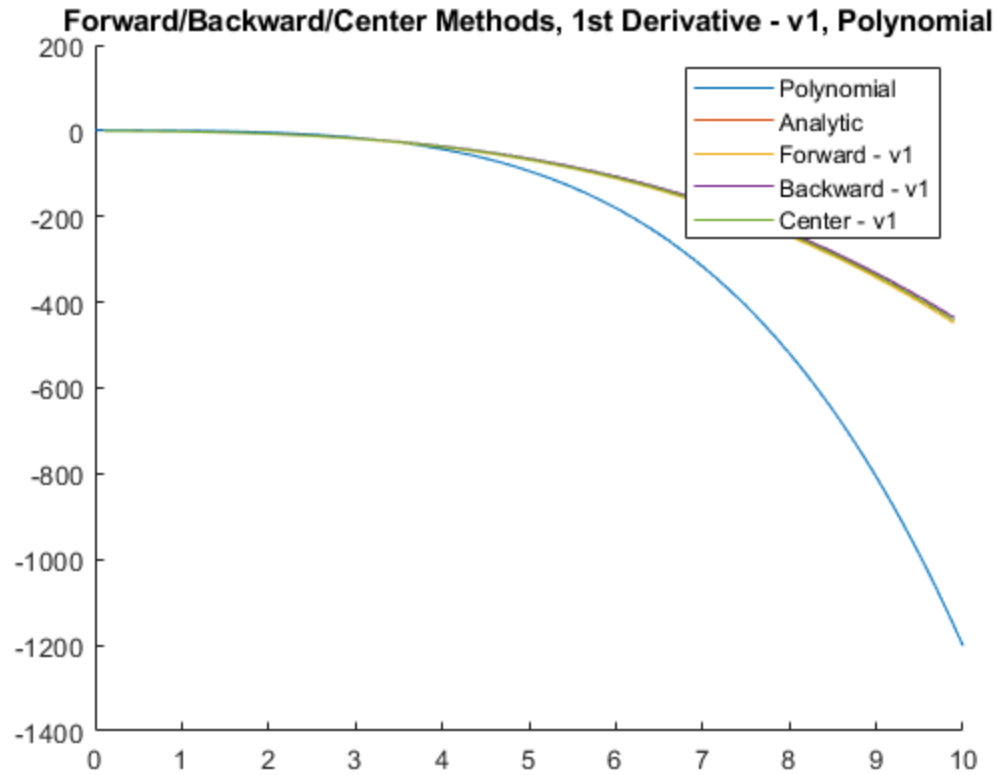
```
figure;
hold on;
plot(x_vector, cos(x_vector)); % plot the cosine
plot(x_vector(2:end-1), cos_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), cos_res{1,2}); % 1st derivative, forward v1
plot(x_vector(2:end-1), cos_res{1,6}); % 1st deriv, backward v1
```

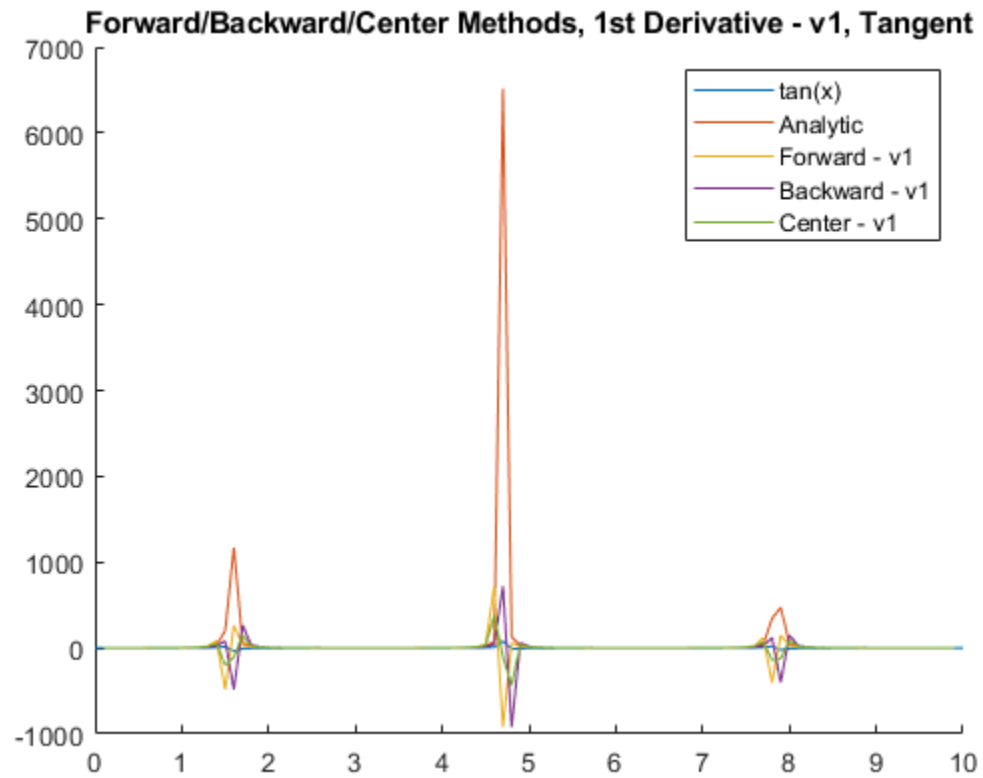
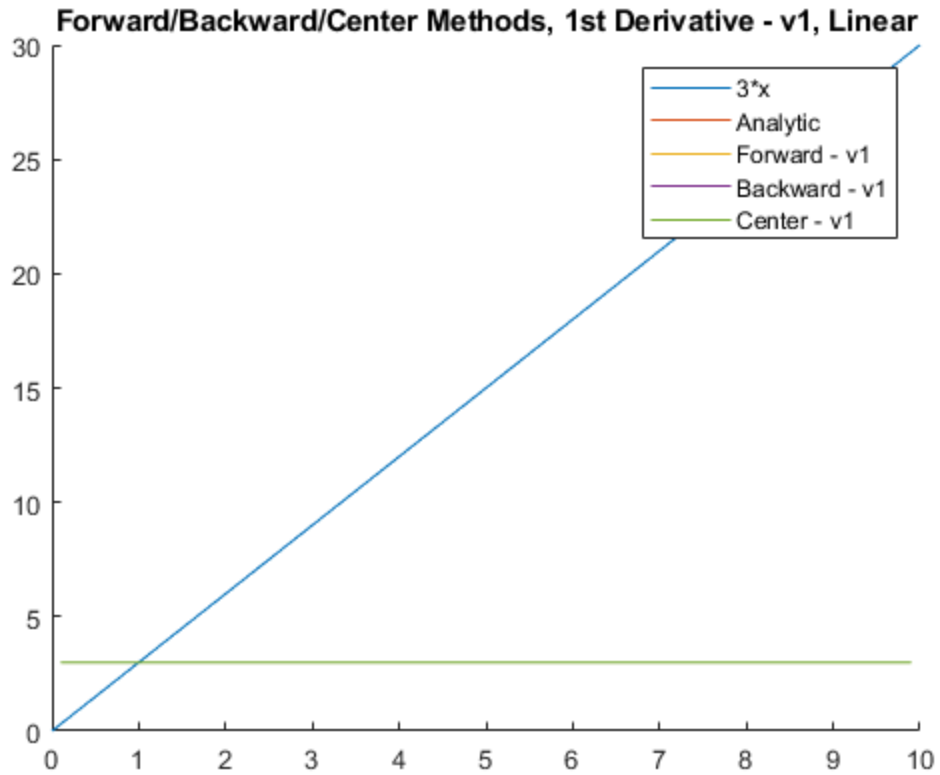
```
plot(x_vector(2:end-1), cos_res{1,10}); % 1st deriv, center v1
title('Forward/Backward/Center Methods, 1st Derivative - v1, Cosine');
legend('cos(x)', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');

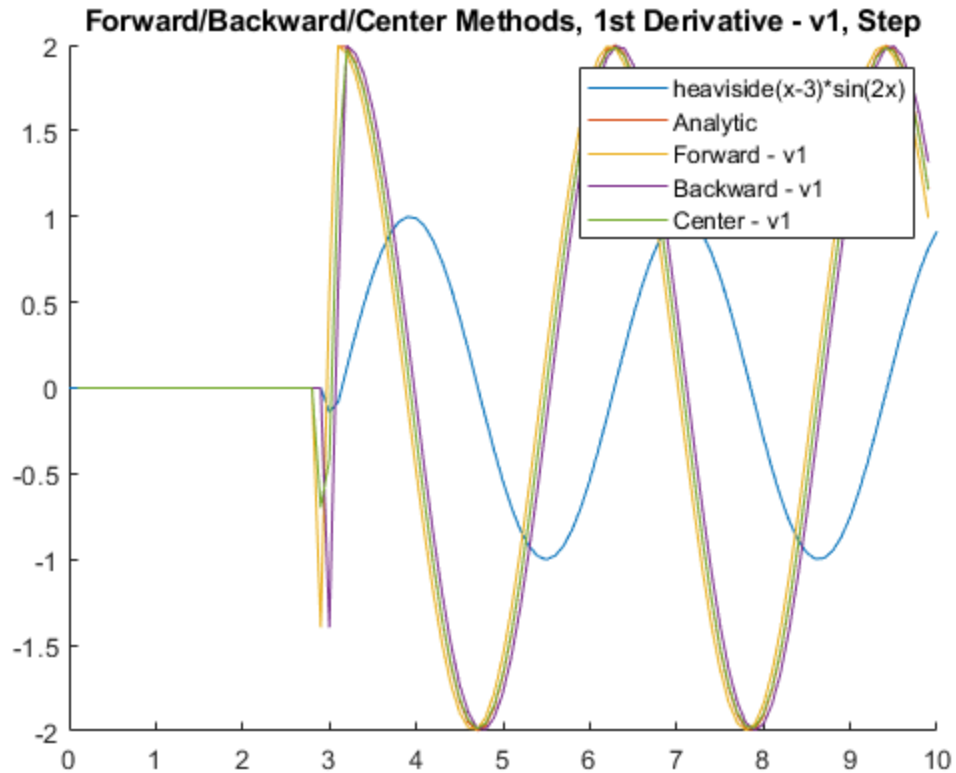
figure;
hold on;
plot(x_vector, lin_h(x_vector)); %
plot(x_vector(2:end-1), linear_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), linear_res{1,2}); % 1st derivative, forward v1
plot(x_vector(2:end-1), linear_res{1,6}); % 1st deriv, backward v1
plot(x_vector(2:end-1), linear_res{1,10}); % 1st deriv, center v1
title('Forward/Backward/Center Methods, 1st Derivative - v1, Linear');
legend('3*x', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');

figure;
hold on;
plot(x_vector, tan(x_vector)); %
plot(x_vector(2:end-1), tangent_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), tangent_res{1,2}); % 1st derivative, forward
v1
plot(x_vector(2:end-1), tangent_res{1,6}); % 1st deriv, backward v1
plot(x_vector(2:end-1), tangent_res{1,10}); % 1st deriv, center v1
title('Forward/Backward/Center Methods, 1st Derivative - v1,
Tangent');
legend('tan(x)', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');

figure;
hold on;
plot(x_vector, step_h(x_vector)); %
plot(x_vector(2:end-1), step_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), step_res{1,2}); % 1st derivative, forward v1
plot(x_vector(2:end-1), step_res{1,6}); % 1st deriv, backward v1
plot(x_vector(2:end-1), step_res{1,10}); % 1st deriv, center v1
title('Forward/Backward/Center Methods, 1st Derivative - v1, Step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');
```







Forward/Backward/Center, 1st Derivative, v2

```
figure;  
hold on;  
plot(x_vector, poly_h(x_vector)); %  
plot(x_vector(3:end-2), poly_res{1,3}); % 1st deriv, actual  
plot(x_vector(3:end-2), poly_res{1,4}); % 1st derivative, forward v2  
plot(x_vector(3:end-2), poly_res{1,8}); % 1st deriv, backward v2  
plot(x_vector(3:end-2), poly_res{1,12}); % 1st deriv, center v2  
title('Forward/Backward/Center Methods, 1st Derivative - v2,  
Polynomial');  
legend('Poly', 'Analytic', 'Forward - v2', ...  
       'Backward - v2', 'Center - v2');
```



```
figure;  
hold on;  
plot(x_vector, cos(x_vector)); %  
plot(x_vector(3:end-2), cos_res{1,3}); % 1st deriv, actual  
plot(x_vector(3:end-2), cos_res{1,4}); % 1st derivative, forward v2  
plot(x_vector(3:end-2), cos_res{1,8}); % 1st deriv, backward v2  
plot(x_vector(3:end-2), cos_res{1,12}); % 1st deriv, center v2  
title('Forward/Backward/Center Methods, 1st Derivative - v2, cosine');  
legend('cos(x)', 'Analytic', 'Forward - v2', ...  
       'Backward - v2', 'Center - v2');
```

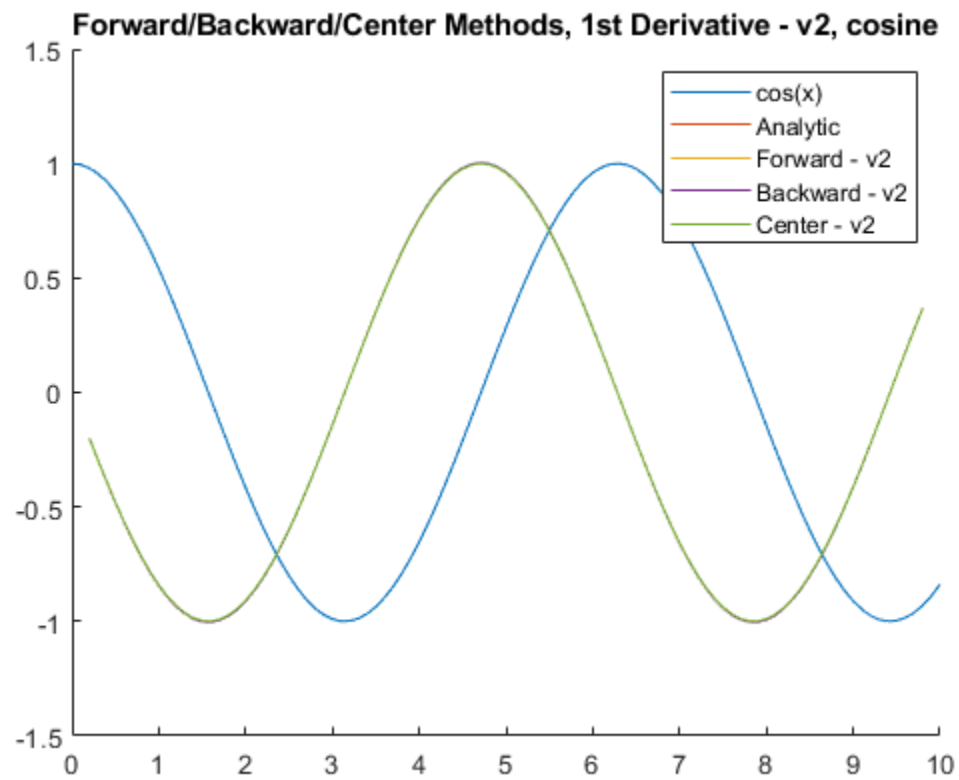
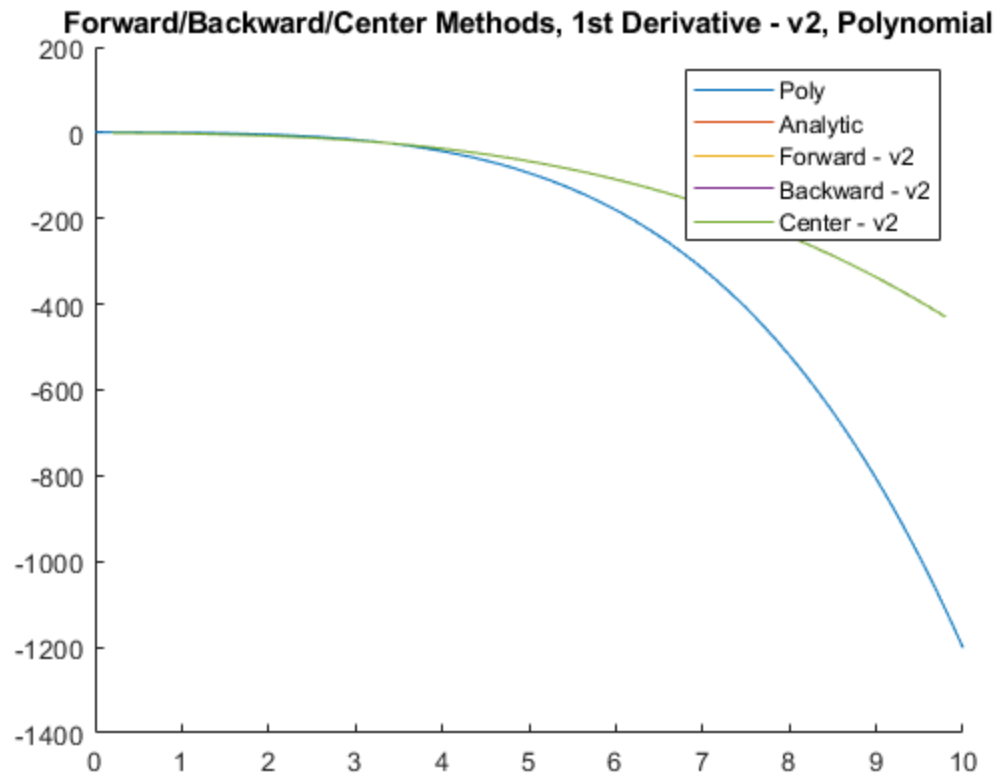
```
figure;
hold on;
plot(x_vector, lin_h(x_vector)); %
plot(x_vector(3:end-2), linear_res{1,3}); % 1st deriv, actual
plot(x_vector(3:end-2), linear_res{1,4}); % 1st derivative, forward v2
plot(x_vector(3:end-2), linear_res{1,8}); % 1st deriv, backward v2
plot(x_vector(3:end-2), linear_res{1,12}); % 1st deriv, center v2
title('Forward/Backward/Center Methods, 1st Derivative - v2, Linear');
legend('3*x', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');
```

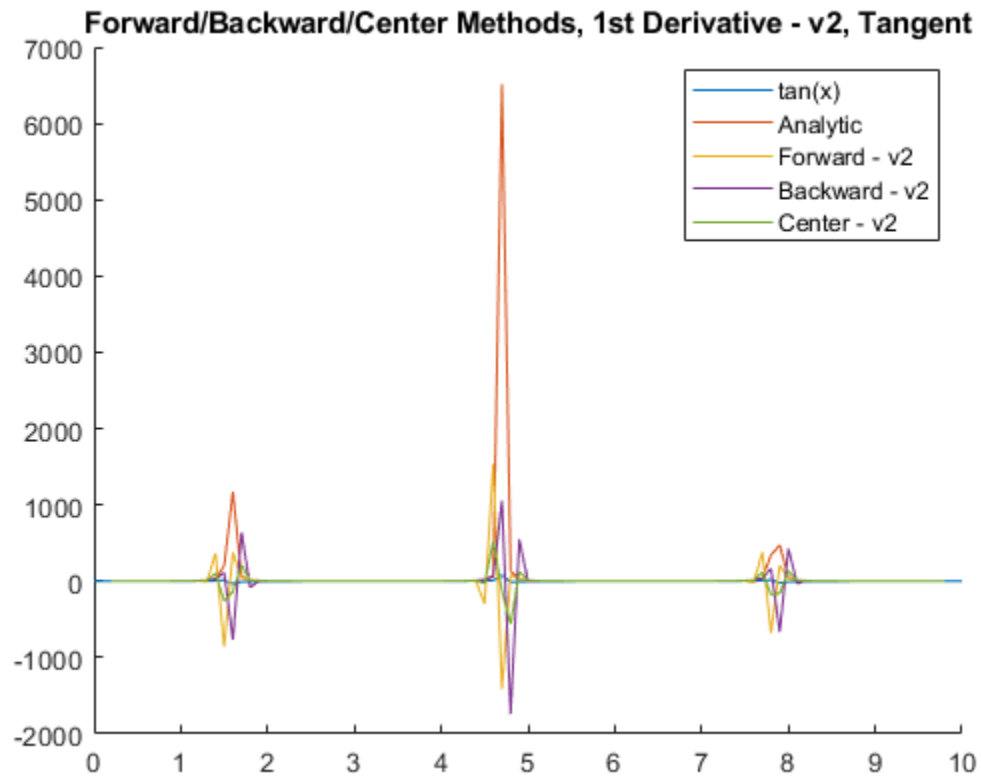
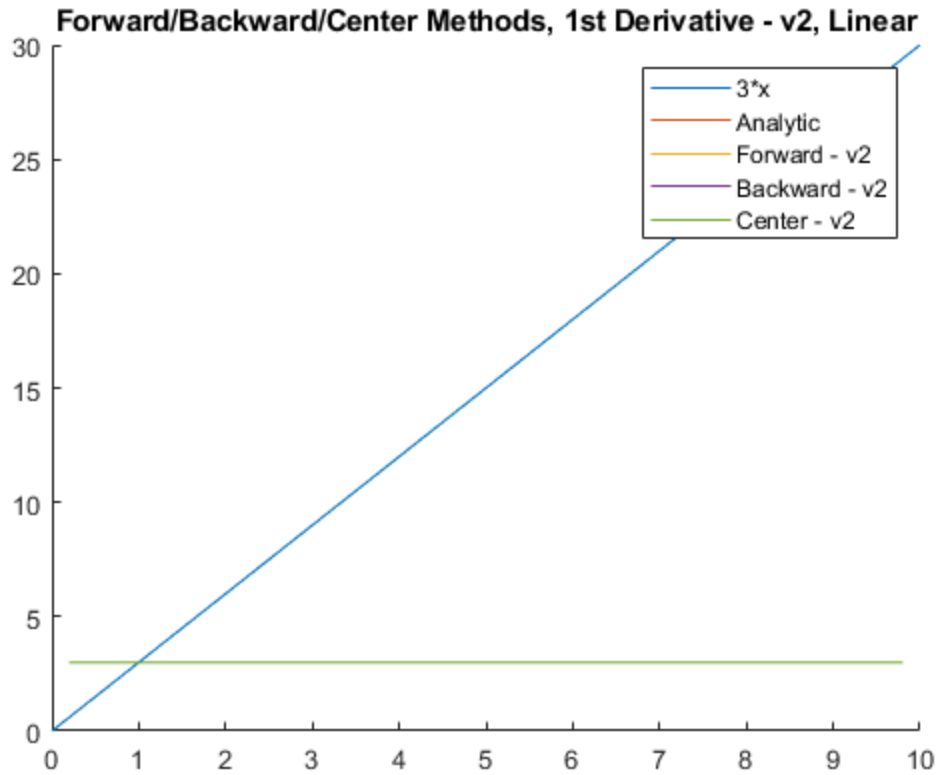


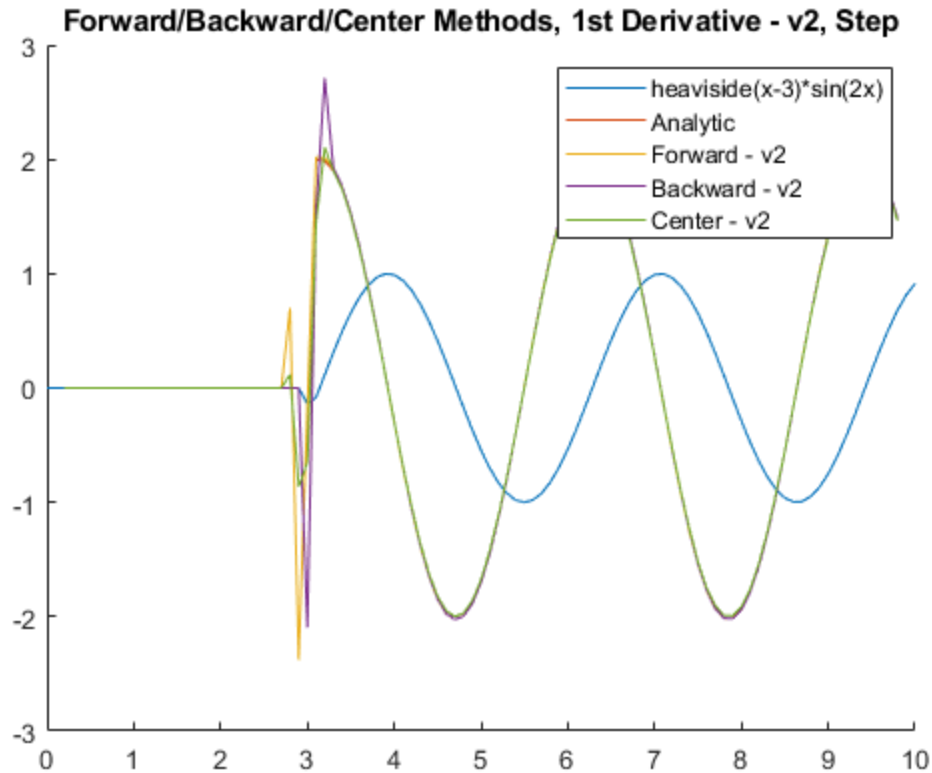
```
figure;
hold on;
plot(x_vector, tan(x_vector)); %
plot(x_vector(3:end-2), tangent_res{1,3}); % 1st deriv, actual
plot(x_vector(3:end-2), tangent_res{1,4}); % 1st derivative, forward
v2
plot(x_vector(3:end-2), tangent_res{1,8}); % 1st deriv, backward v2
plot(x_vector(3:end-2), tangent_res{1,12}); % 1st deriv, center v2
title('Forward/Backward/Center Methods, 1st Derivative - v2,
Tangent');
```



```
figure;
hold on;
plot(x_vector, step_h(x_vector)); %
plot(x_vector(3:end-2), step_res{1,3}); % 1st deriv, actual
plot(x_vector(3:end-2), step_res{1,4}); % 1st derivative, forward v2
plot(x_vector(3:end-2), step_res{1,8}); % 1st deriv, backward v2
plot(x_vector(3:end-2), step_res{1,12}); % 1st deriv, center v2
title('Forward/Backward/Center Methods, 1st Derivative - v2, Step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');
```







Forward/Backward/Center, 2nd Derivative, v1

```
figure;
hold on;
plot(x_vector, poly_h(x_vector)); % plot the polynomial
plot(x_vector(3:end-2), poly_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), poly_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(3:end-2), poly_res{2,6}); % 2nd deriv, backward v1
plot(x_vector(3:end-2), poly_res{2,10}); % 2nd deriv, center v1
title('Forward/Backward/Center Methods, 2nd Derivative - v1, Polynomial');
legend('Polynomial', 'Analytic', 'Forward - v1', ...
      'Backward - v1', 'Center - v1');
```

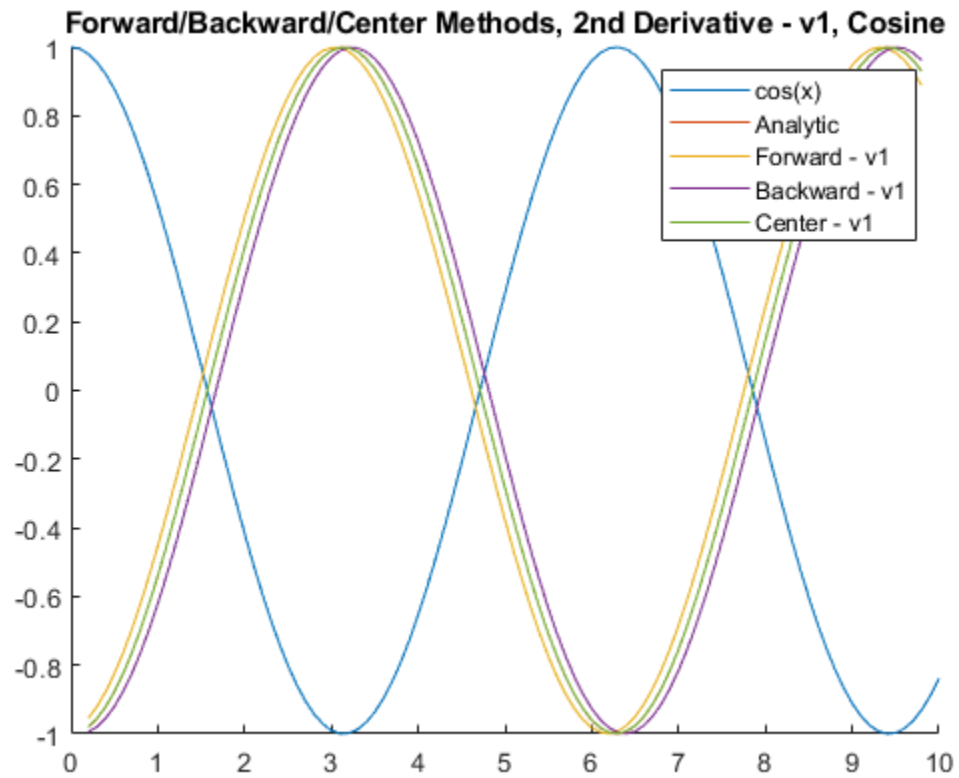
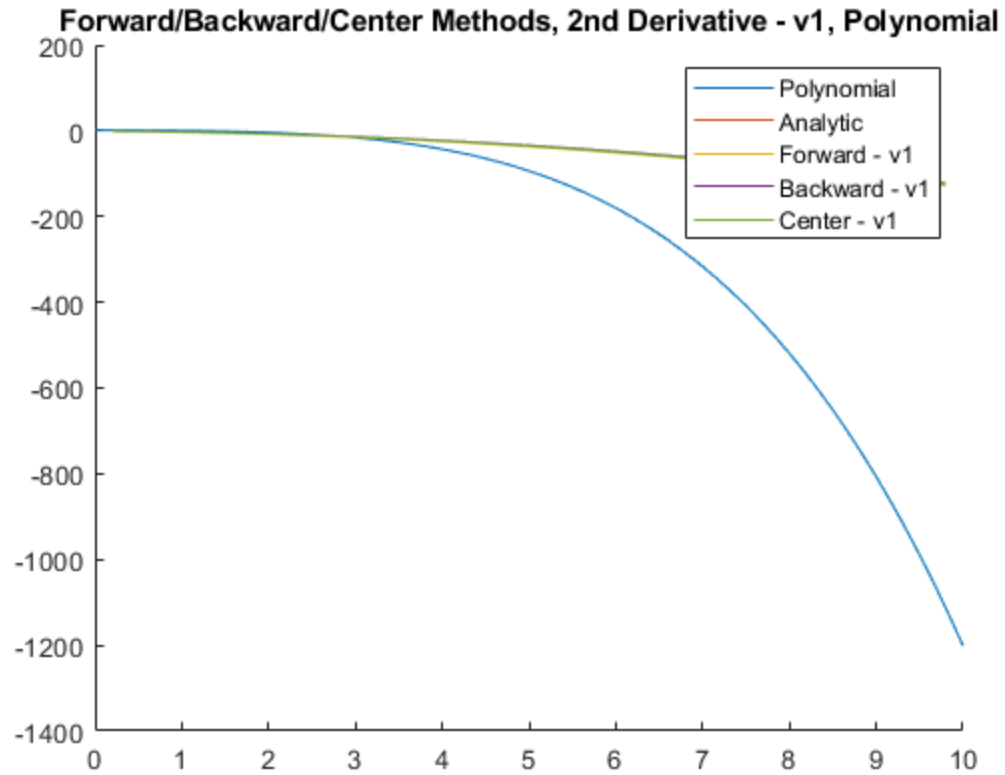


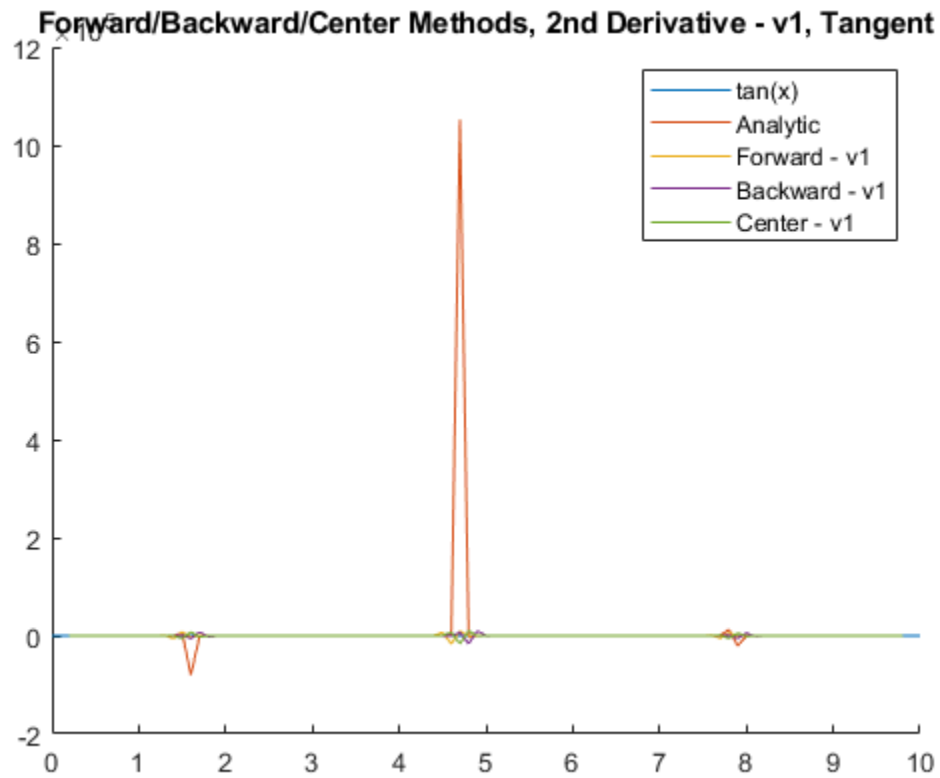
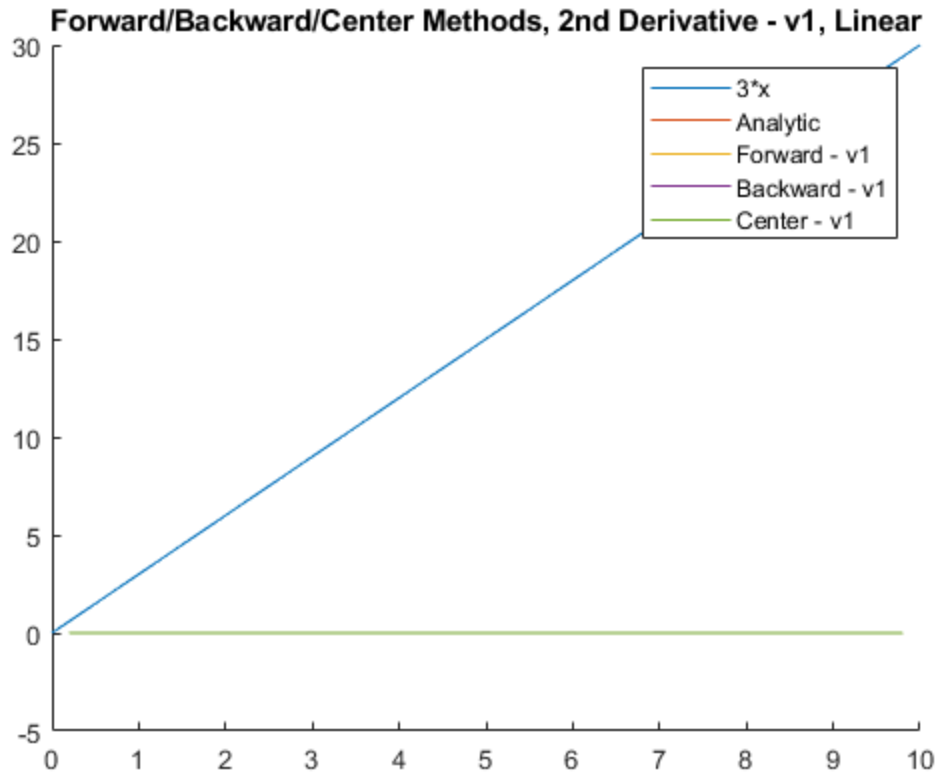
```
figure;
hold on;
plot(x_vector, cos(x_vector)); % plot the cosine
plot(x_vector(3:end-2), cos_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), cos_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(3:end-2), cos_res{2,6}); % 2nd deriv, backward v1
plot(x_vector(3:end-2), cos_res{2,10}); % 2nd deriv, center v1
title('Forward/Backward/Center Methods, 2nd Derivative - v1, Cosine');
legend('cos(x)', 'Analytic', 'Forward - v1', ...
      'Backward - v1', 'Center - v1');
```

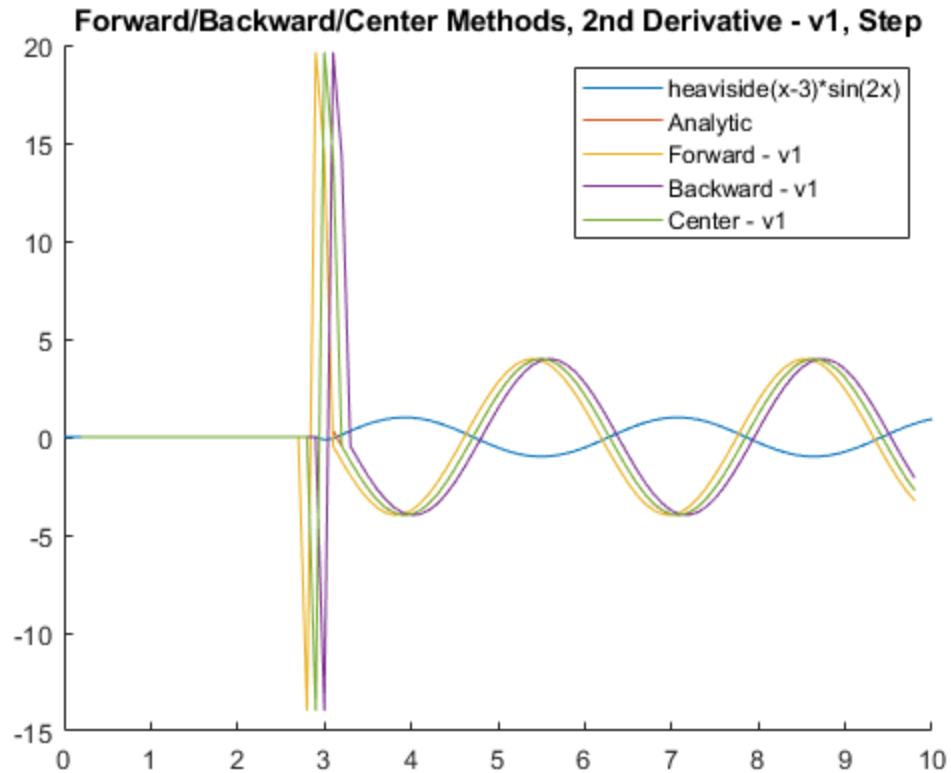
```
figure;
hold on;
plot(x_vector, lin_h(x_vector)); %
plot(x_vector(3:end-2), linear_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), linear_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(3:end-2), linear_res{2,6}); % 2nd deriv, backward v1
plot(x_vector(3:end-2), linear_res{2,10}); % 2nd deriv, center v1
title('Forward/Backward/Center Methods, 2nd Derivative - v1, Linear');
legend('3*x', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');

figure;
hold on;
plot(x_vector, tan(x_vector)); %
plot(x_vector(3:end-2), tangent_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), tangent_res{2,2}); % 2nd derivative, forward
v1
plot(x_vector(3:end-2), tangent_res{2,6}); % 2nd deriv, backward v1
plot(x_vector(3:end-2), tangent_res{2,10}); % 2nd deriv, center v1
title('Forward/Backward/Center Methods, 2nd Derivative - v1,
Tangent');
legend('tan(x)', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');

figure;
hold on;
plot(x_vector, step_h(x_vector)); %
plot(x_vector(3:end-2), step_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), step_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(3:end-2), step_res{2,6}); % 2nd deriv, backward v1
plot(x_vector(3:end-2), step_res{2,10}); % 2nd deriv, center v1
title('Forward/Backward/Center Methods, 2nd Derivative - v1, Step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'Forward - v1', ...
       'Backward - v1', 'Center - v1');
```







Forward/Backward/Center, 2nd Derivative, v2

```
figure;
hold on;
plot(x_vector, poly_h(x_vector)); %
plot(x_vector(4:end-3), poly_res{2,3}); % 2nd deriv, actual
plot(x_vector(4:end-3), poly_res{2,4}); % 2nd derivative, forward v2
plot(x_vector(4:end-3), poly_res{2,8}); % 2nd deriv, backward v2
plot(x_vector(4:end-3), poly_res{2,12}); % 2nd deriv, center v2
title('Forward/Backward/Center Methods, 2nd Derivative - v2, Polynomial');
legend('Poly', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');
```

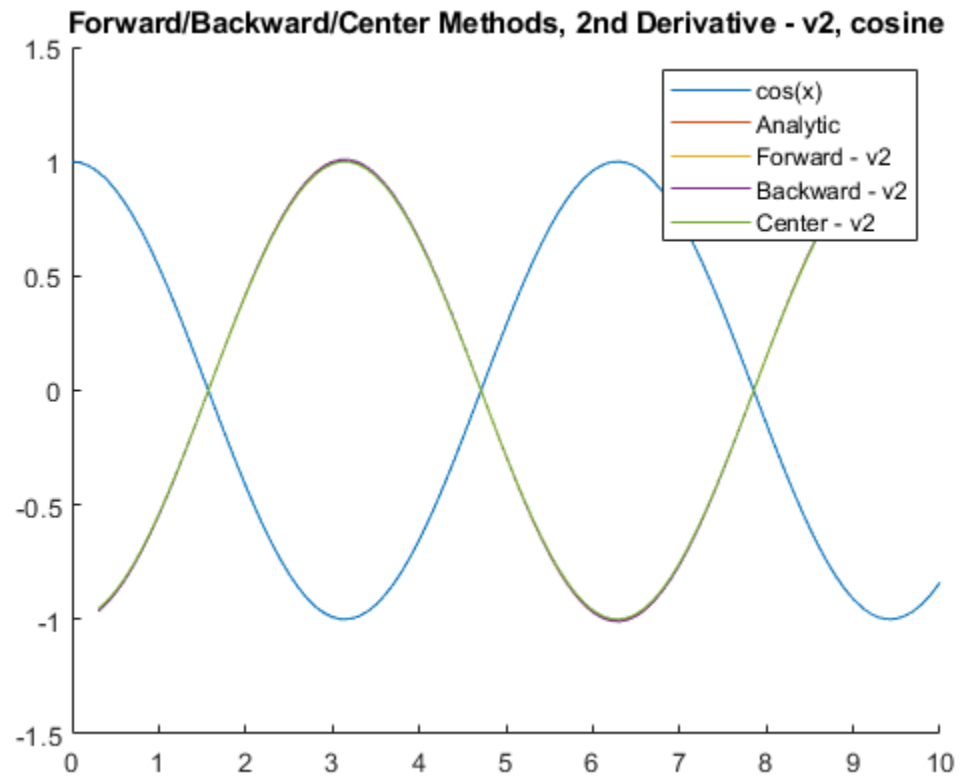
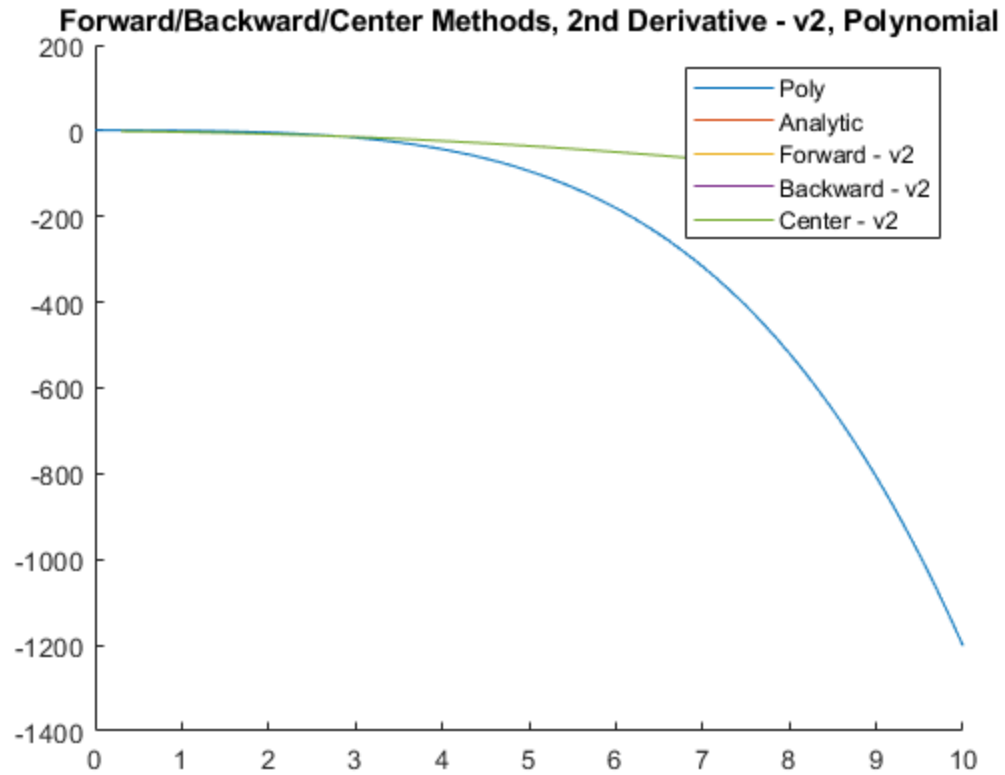


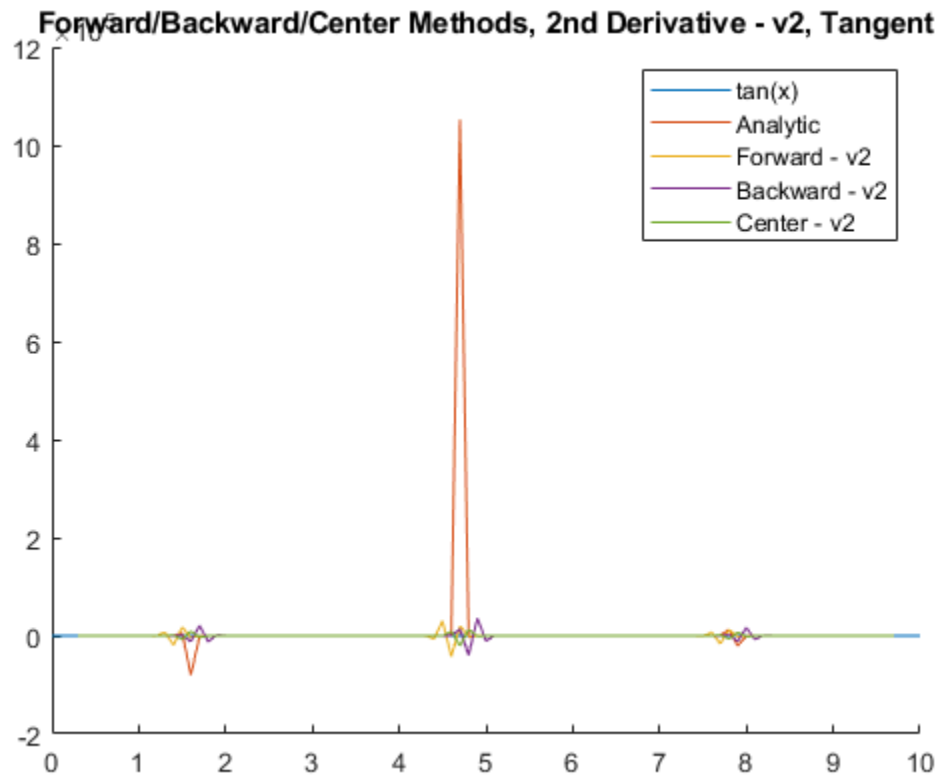
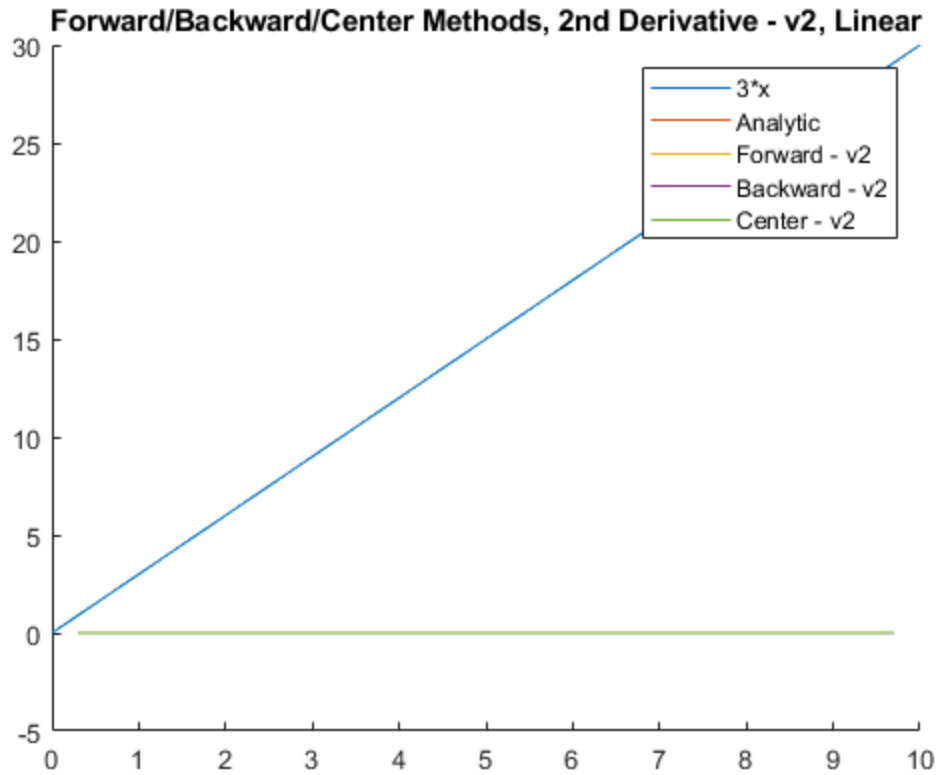
```
figure;
hold on;
plot(x_vector, cos(x_vector));
plot(x_vector(4:end-3), cos_res{2,3}); % 2nd deriv, actual
plot(x_vector(4:end-3), cos_res{2,4}); % 2nd derivative, forward v2
plot(x_vector(4:end-3), cos_res{2,8}); % 2nd deriv, backward v2
plot(x_vector(4:end-3), cos_res{2,12}); % 2nd deriv, center v2
title('Forward/Backward/Center Methods, 2nd Derivative - v2, cosine');
legend('cos(x)', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');
```

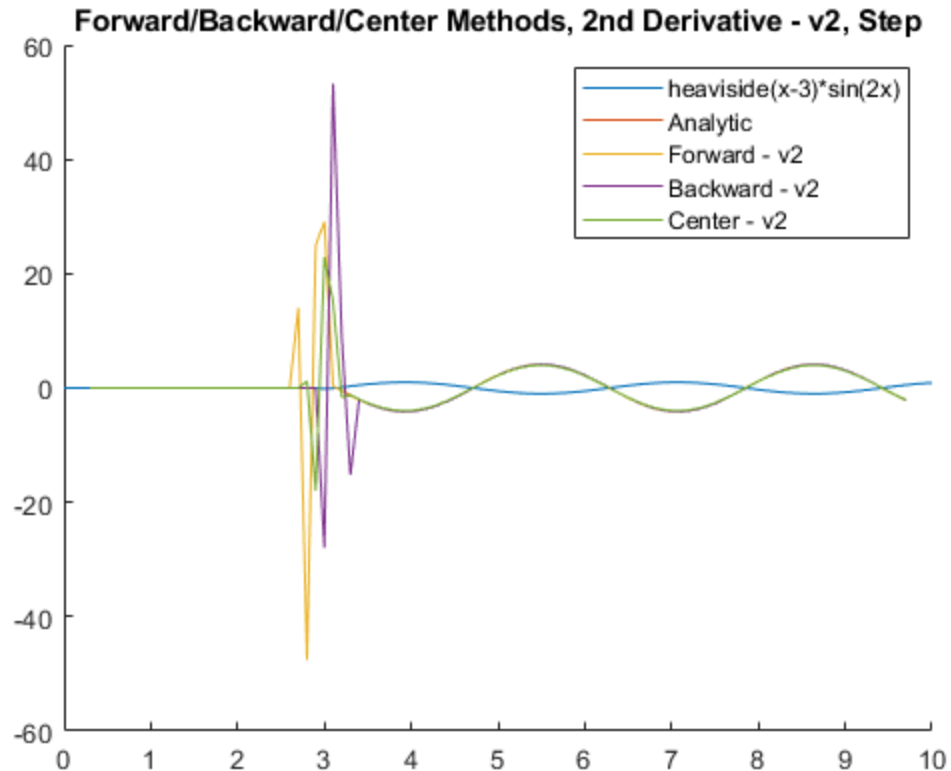
```
figure;
hold on;
plot(x_vector, lin_h(x_vector)); %
plot(x_vector(4:end-3), linear_res{2,3}); % 2nd deriv, actual
plot(x_vector(4:end-3), linear_res{2,4}); % 2nd derivative, forward v2
plot(x_vector(4:end-3), linear_res{2,8}); % 2nd deriv, backward v2
plot(x_vector(4:end-3), linear_res{2,12}); % 2nd deriv, center v2
title('Forward/Backward/Center Methods, 2nd Derivative - v2, Linear');
legend('3*x', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');

figure;
hold on;
plot(x_vector, tan(x_vector)); %
plot(x_vector(4:end-3), tangent_res{2,3}); % 2nd deriv, actual
plot(x_vector(4:end-3), tangent_res{2,4}); % 2nd derivative, forward
v2
plot(x_vector(4:end-3), tangent_res{2,8}); % 2nd deriv, backward v2
plot(x_vector(4:end-3), tangent_res{2,12}); % 2nd deriv, center v2
title('Forward/Backward/Center Methods, 2nd Derivative - v2,
Tangent');
legend('tan(x)', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');

figure;
hold on;
plot(x_vector, step_h(x_vector)); %
plot(x_vector(4:end-3), step_res{2,3}); % 1st deriv, actual
plot(x_vector(4:end-3), step_res{2,4}); % 1st derivative, forward v2
plot(x_vector(4:end-3), step_res{2,8}); % 1st deriv, backward v2
plot(x_vector(4:end-3), step_res{2,12}); % 1st deriv, center v2
title('Forward/Backward/Center Methods, 2nd Derivative - v2, Step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'Forward - v2', ...
       'Backward - v2', 'Center - v2');
```







Forward - 1st Derivative, v1 vs v2

```
figure;
hold on;
plot(x_vector, poly_h(x_vector));
plot(x_vector(2:end-1), poly_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), poly_res{1,2}); % 1st derivative, forward v1
plot(x_vector(3:end-2), poly_res{1,4}); % 1st deriv, forward v2
title('Forward Method, 1st Derivative, v1 vs v2, Polynomial');
legend('Polynomial', 'Analytic', 'v1', 'v2');

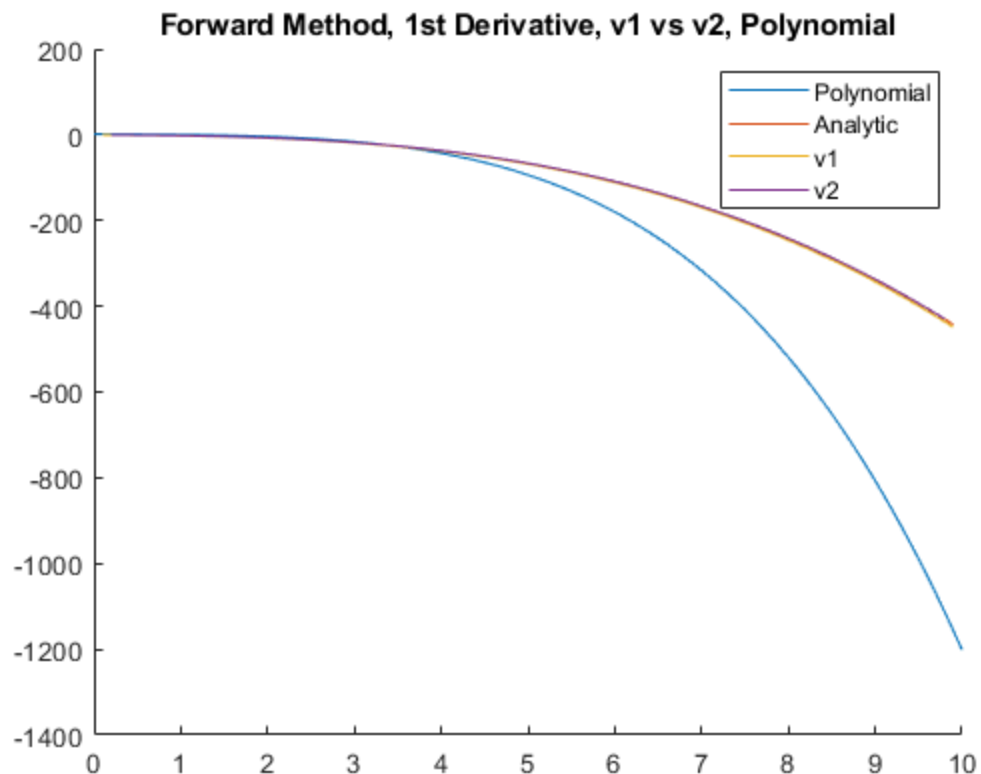
figure;
hold on;
plot(x_vector, cos(x_vector));
plot(x_vector(2:end-1), cos_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), cos_res{1,2}); % 1st derivative, forward v1
plot(x_vector(3:end-2), cos_res{1,4}); % 1st deriv, forward v2
title('Forward Method, 1st Derivative, v1 vs v2, cosine');
legend('cos(x)', 'Analytic', 'v1', 'v2');

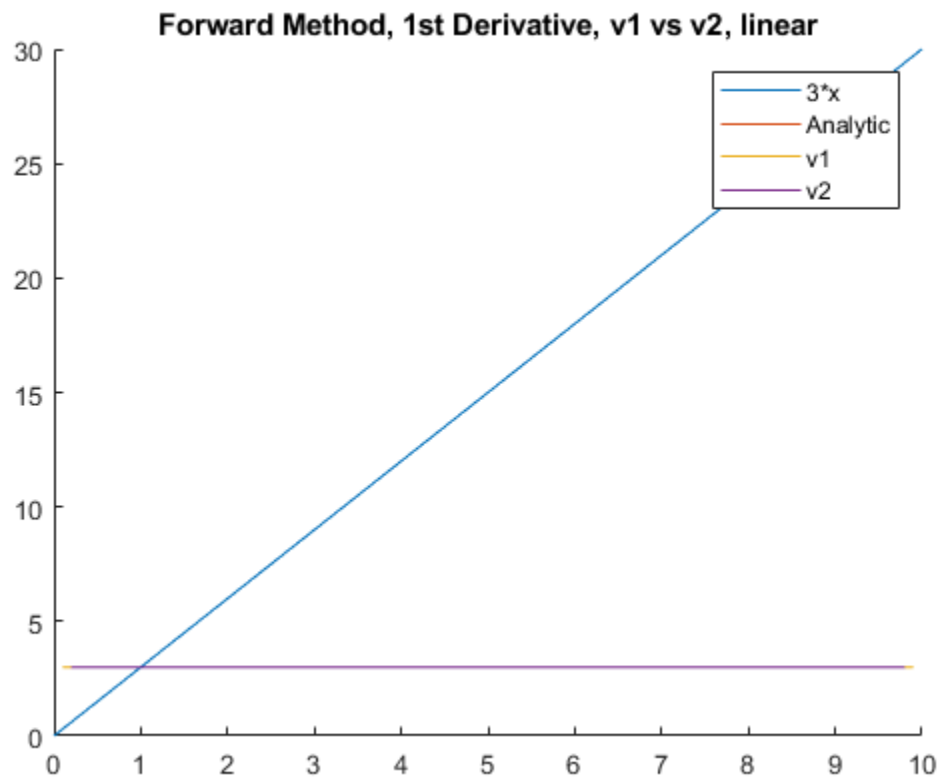
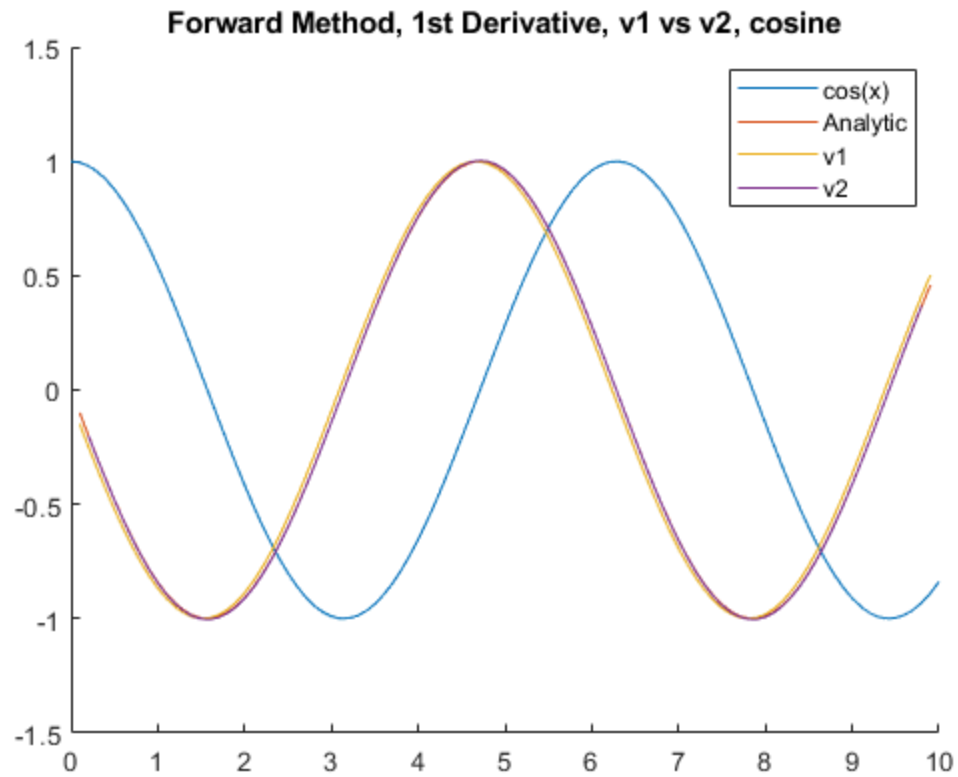
figure;
hold on;
plot(x_vector, lin_h(x_vector));
plot(x_vector(2:end-1), linear_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), linear_res{1,2}); % 1st derivative, forward v1
```

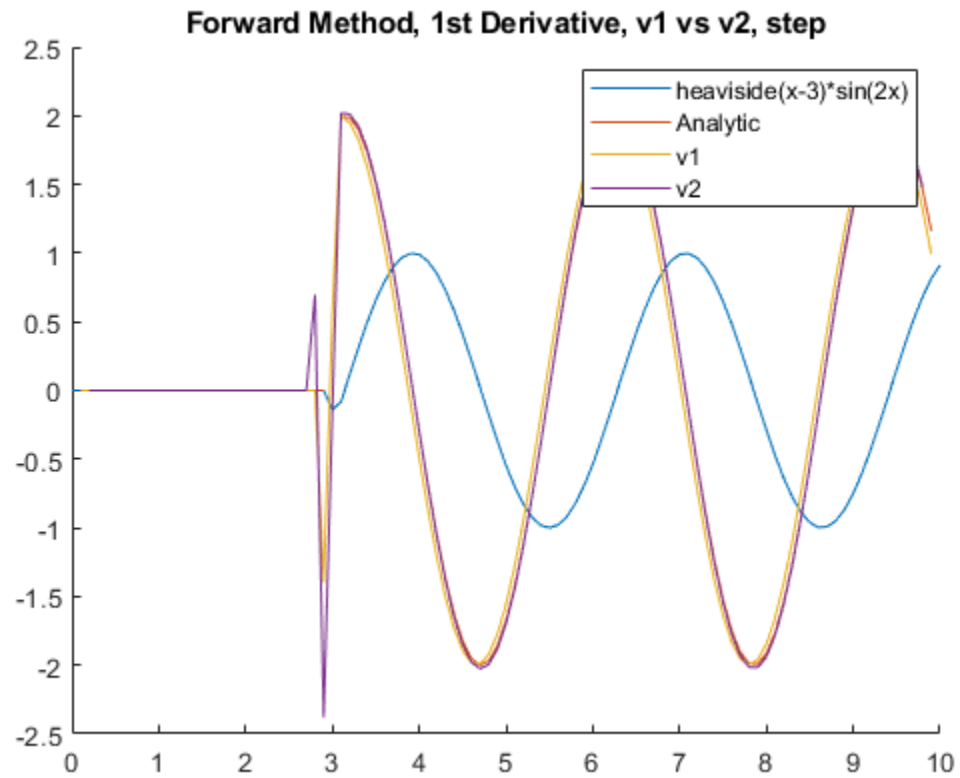
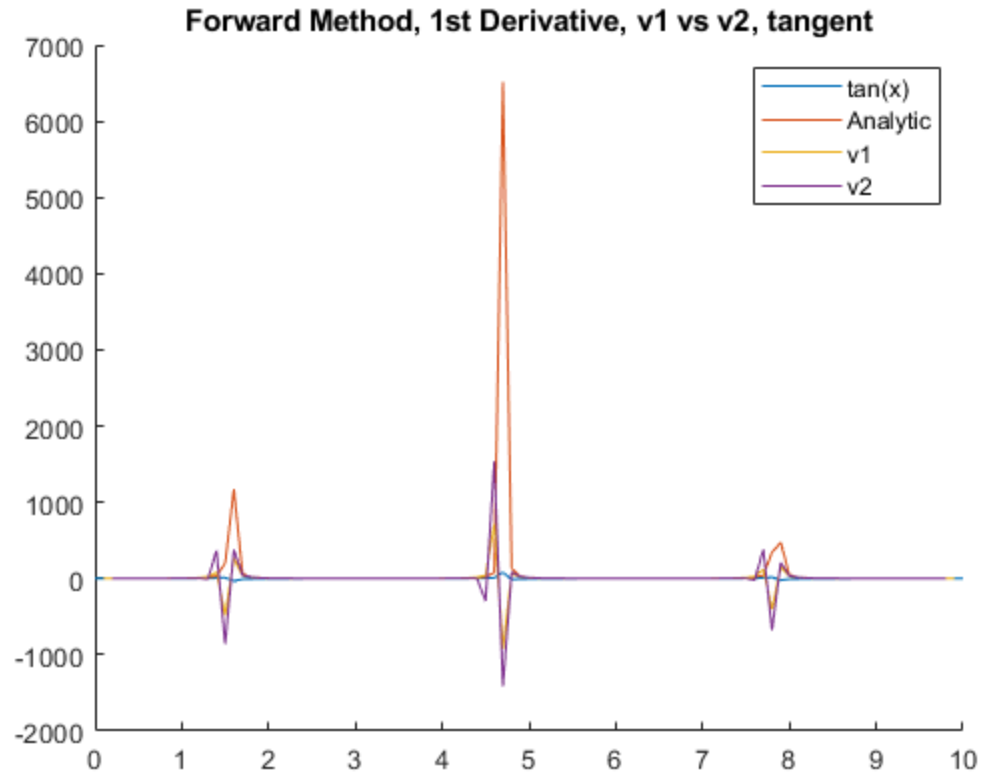
```
plot(x_vector(3:end-2), linear_res{1,4}); % 1st deriv, forward v2
title('Forward Method, 1st Derivative, v1 vs v2, linear');
legend('3*x', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, tan(x_vector));
plot(x_vector(2:end-1), tangent_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), tangent_res{1,2}); % 1st derivative, forward
v1
plot(x_vector(3:end-2), tangent_res{1,4}); % 1st deriv, forward v2
title('Forward Method, 1st Derivative, v1 vs v2, tangent');
legend('tan(x)', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, step_h(x_vector));
plot(x_vector(2:end-1), step_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), step_res{1,2}); % 1st derivative, forward v1
plot(x_vector(3:end-2), step_res{1,4}); % 1st deriv, forward v2
title('Forward Method, 1st Derivative, v1 vs v2, step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'v1', 'v2');
```







Backward - 1st Derivative, v1 vs v2

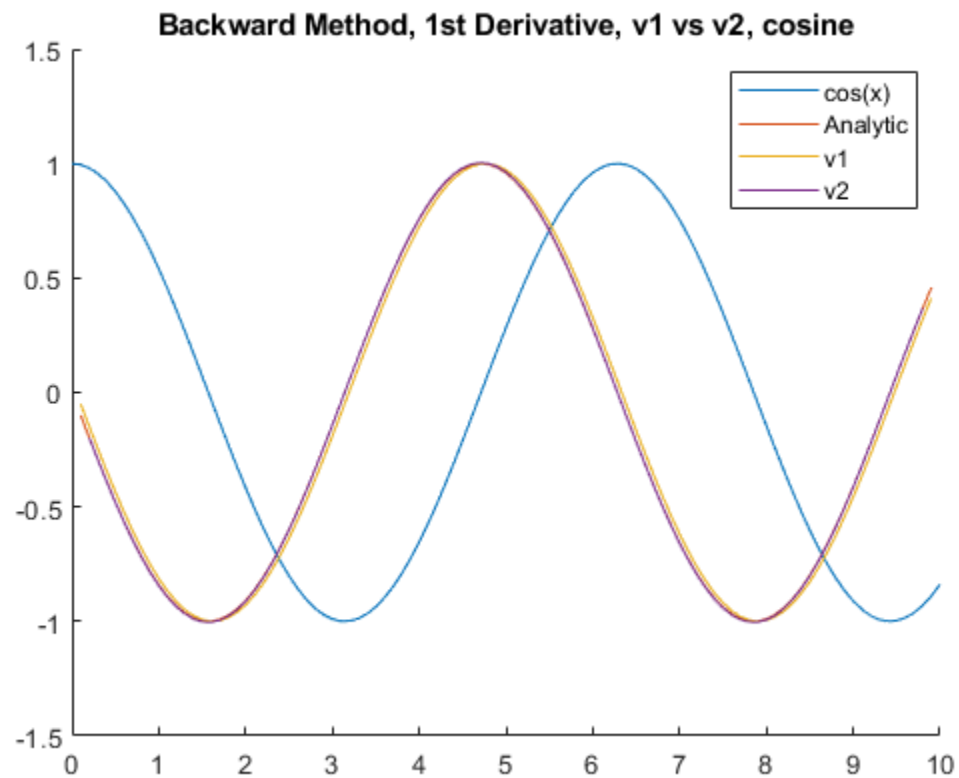
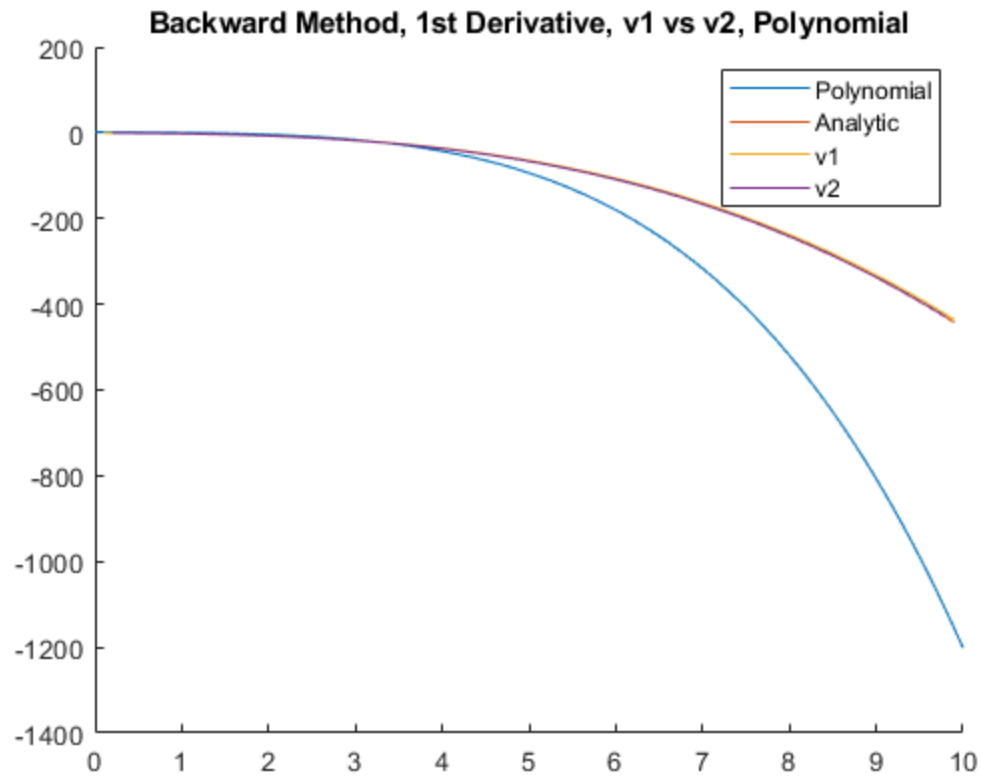
```
figure;
hold on;
plot(x_vector, poly_h(x_vector));
plot(x_vector(2:end-1), poly_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), poly_res{1,6}); % 1st derivative, backward v1
plot(x_vector(3:end-2), poly_res{1,8}); % 1st deriv, backward v2
title('Backward Method, 1st Derivative, v1 vs v2, Polynomial');
legend('Polynomial', 'Analytic', 'v1', 'v2');

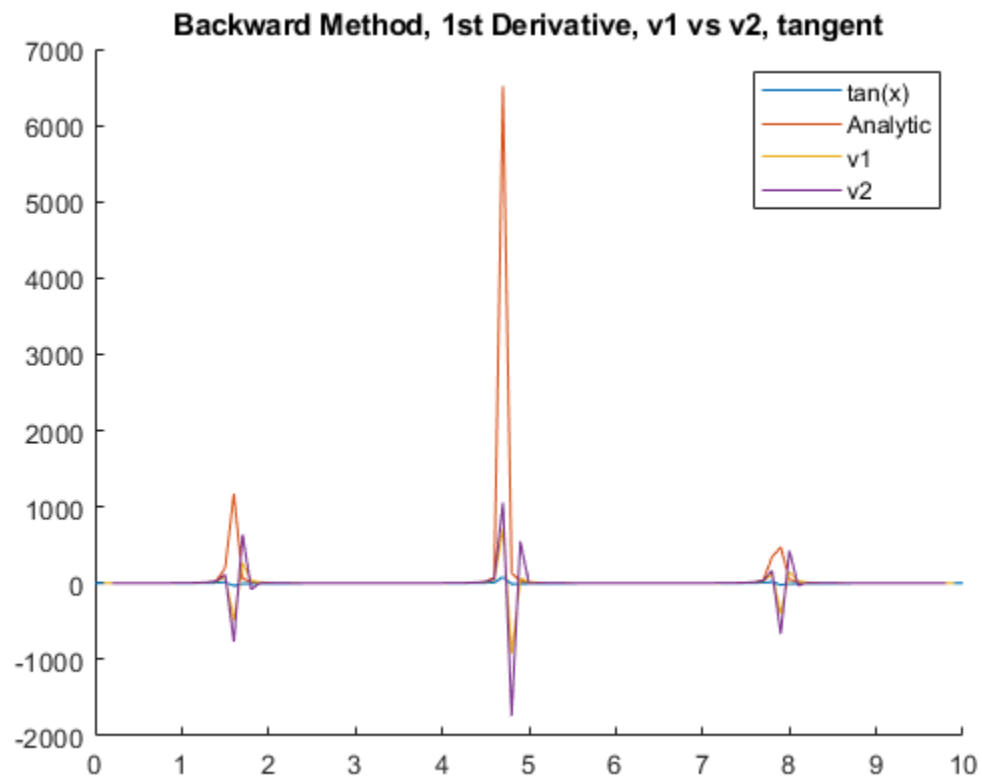
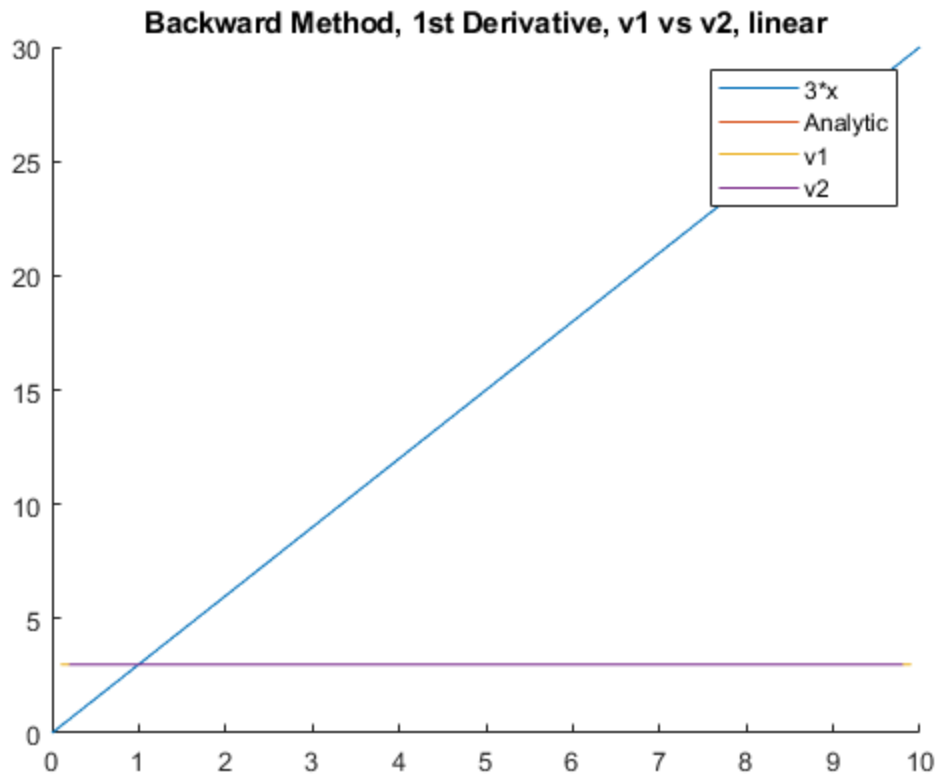
figure;
hold on;
plot(x_vector, cos(x_vector));
plot(x_vector(2:end-1), cos_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), cos_res{1,6}); % 1st derivative, backward v1
plot(x_vector(3:end-2), cos_res{1,8}); % 1st deriv, backward v1
title('Backward Method, 1st Derivative, v1 vs v2, cosine');
legend('cos(x)', 'Analytic', 'v1', 'v2');

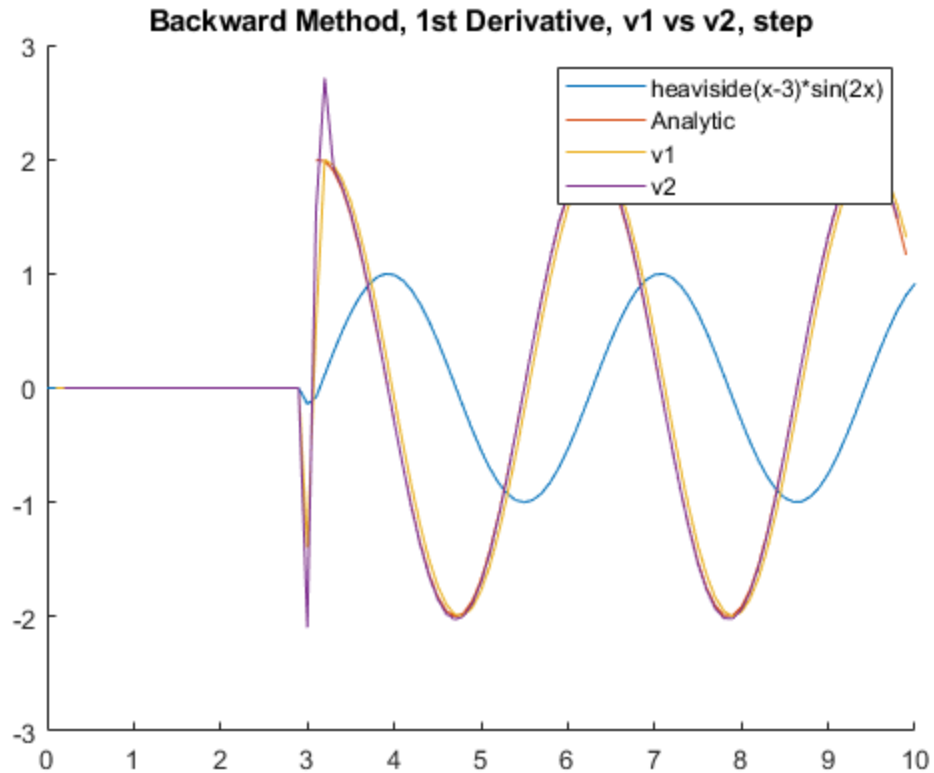
figure;
hold on;
plot(x_vector, lin_h(x_vector));
plot(x_vector(2:end-1), linear_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), linear_res{1,6}); % 1st derivative, backward
v1
plot(x_vector(3:end-2), linear_res{1,8}); % 1st deriv, backward v2
title('Backward Method, 1st Derivative, v1 vs v2, linear');
legend('3*x', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, tan(x_vector));
plot(x_vector(2:end-1), tangent_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), tangent_res{1,6}); % 1st derivative, backward
v1
plot(x_vector(3:end-2), tangent_res{1,8}); % 1st deriv, backward v2
title('Backward Method, 1st Derivative, v1 vs v2, tangent');
legend('tan(x)', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, step_h(x_vector));
plot(x_vector(2:end-1), step_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), step_res{1,6}); % 1st derivative, backward v1
plot(x_vector(3:end-2), step_res{1,8}); % 1st deriv, backward v2
title('Backward Method, 1st Derivative, v1 vs v2, step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'v1', 'v2');
```







Center - 1st Derivative, v1 vs v2

```
figure;
hold on;
plot(x_vector, poly_h(x_vector));
plot(x_vector(2:end-1), poly_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), poly_res{1,10}); % 1st derivative, center v1
plot(x_vector(3:end-2), poly_res{1,12}); % 1st deriv, center v2
title('Center Method, 1st Derivative, v1 vs v2, Polynomial');
legend('Polynomial', 'Analytic', 'v1', 'v2');

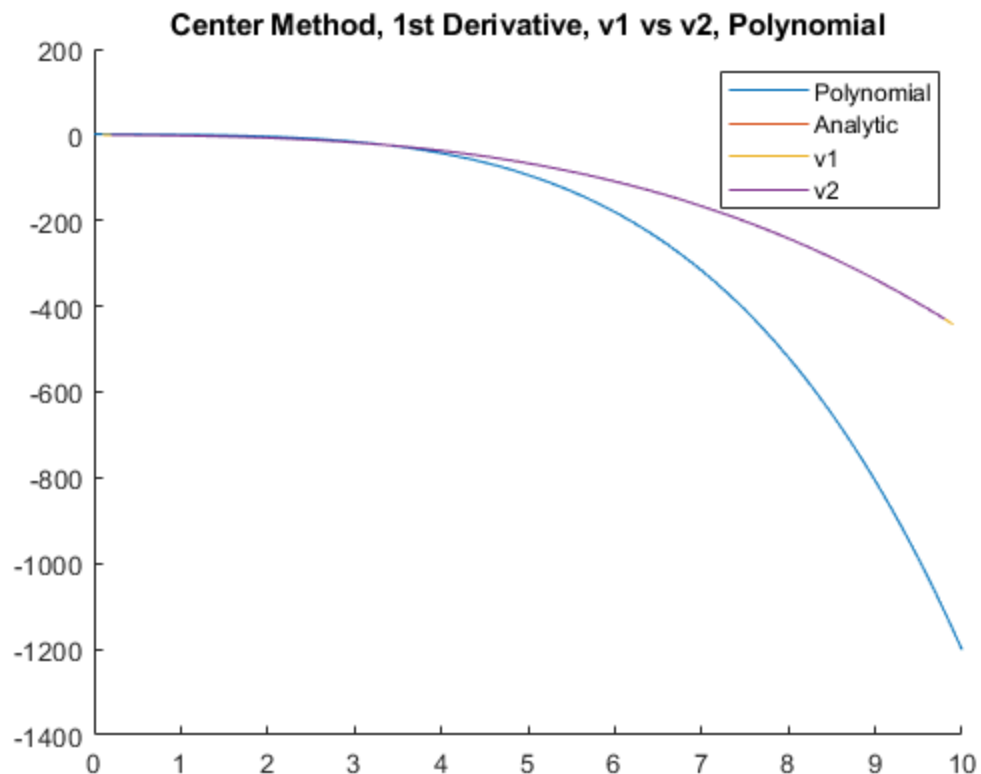
figure;
hold on;
plot(x_vector, cos(x_vector));
plot(x_vector(2:end-1), cos_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), cos_res{1,10}); % 1st derivative, center v1
plot(x_vector(3:end-2), cos_res{1,12}); % 1st deriv, center v2
title('Center Method, 1st Derivative, v1 vs v2, cosine');
legend('cos(x)', 'Analytic', 'v1', 'v2');

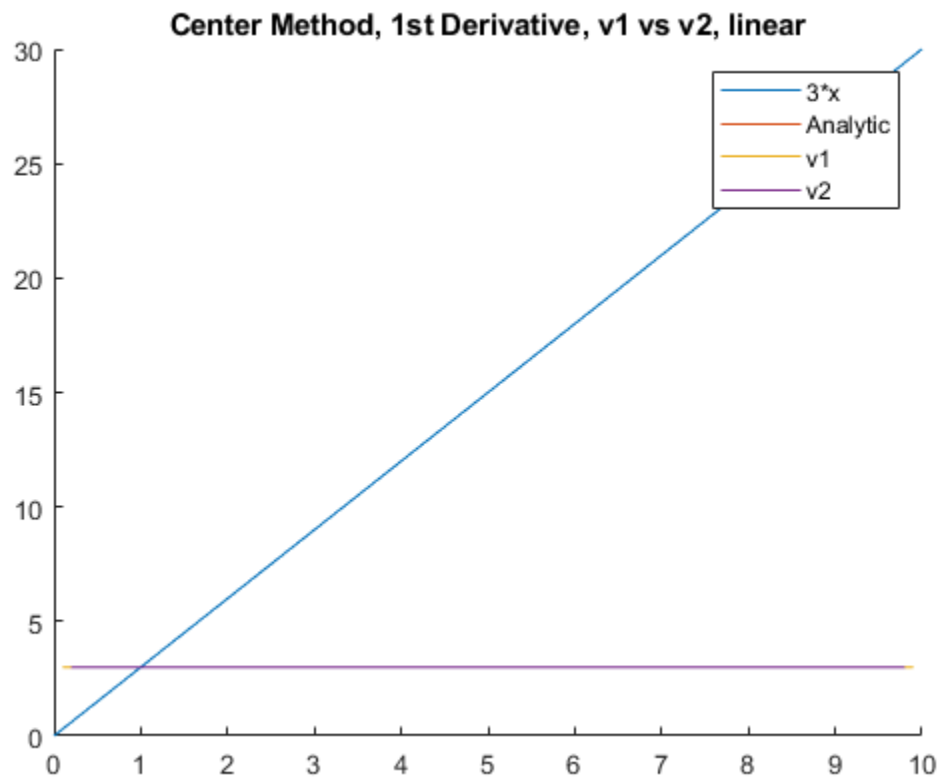
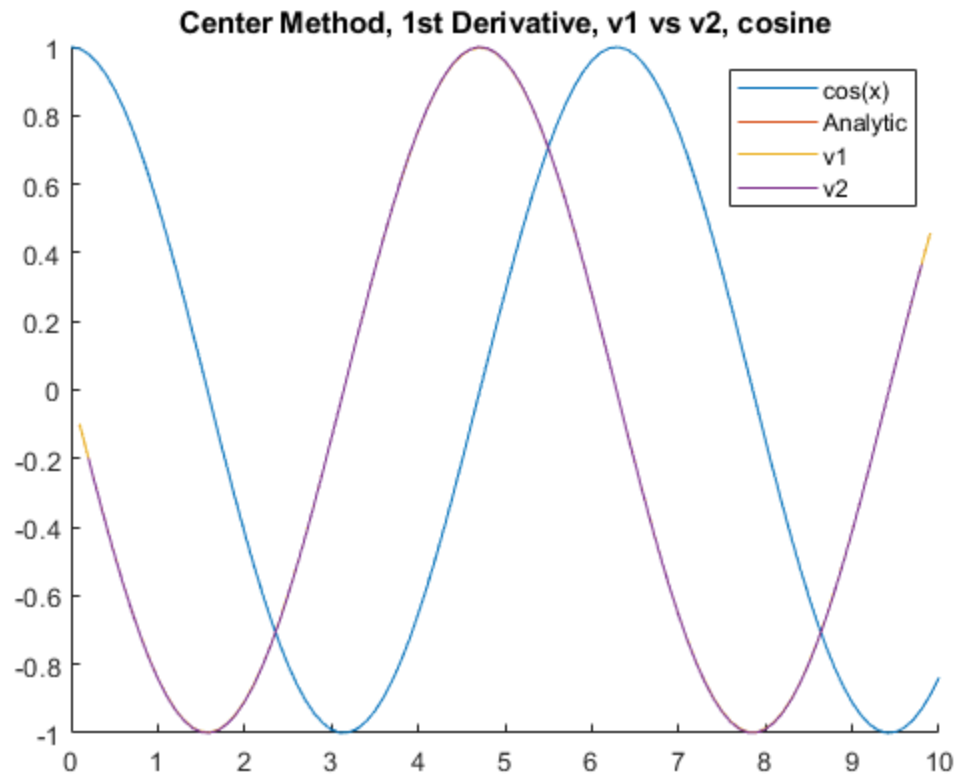
figure;
hold on;
plot(x_vector, lin_h(x_vector));
plot(x_vector(2:end-1), linear_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), linear_res{1,10}); % 1st derivative, center v1
```

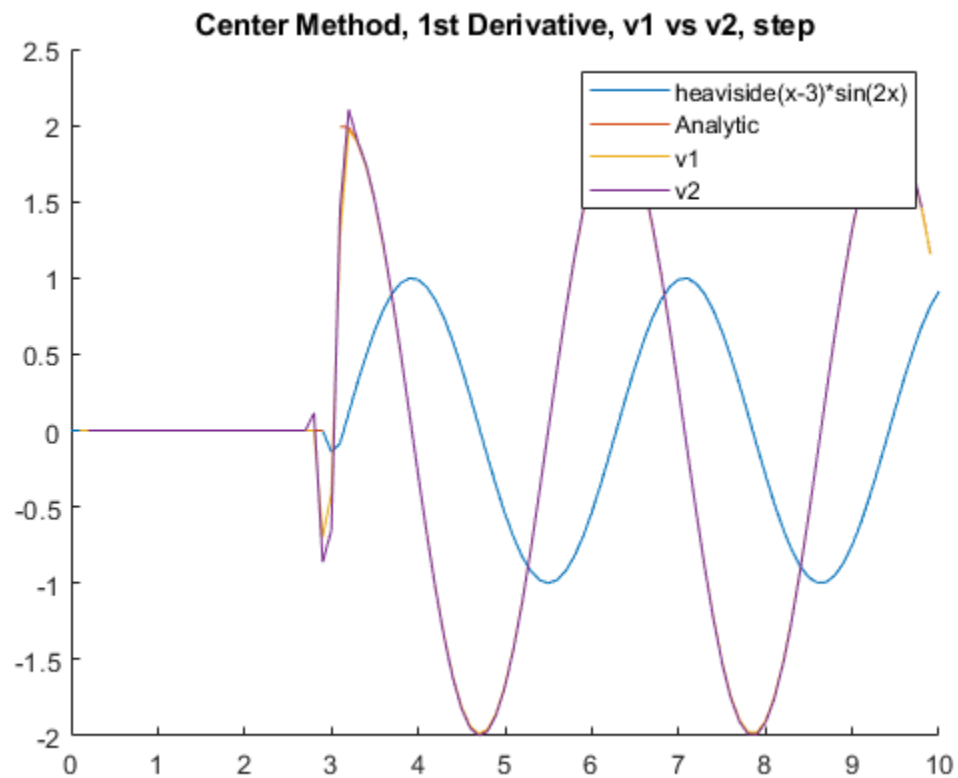
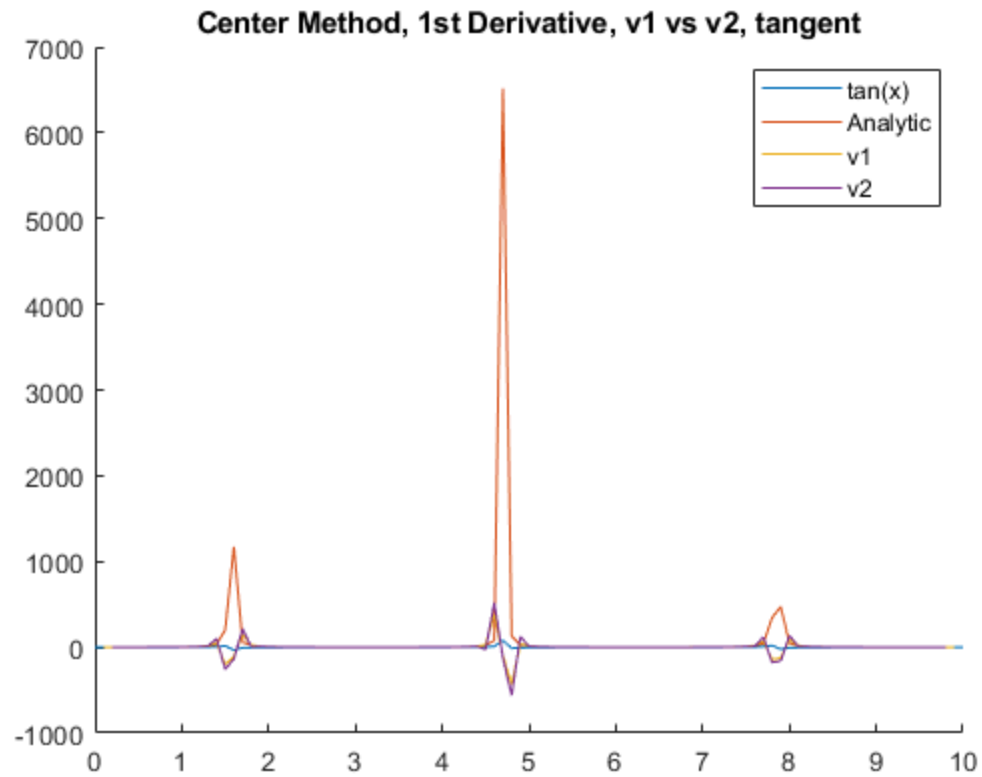
```
plot(x_vector(3:end-2), linear_res{1,12}); % 1st deriv, center v2
title('Center Method, 1st Derivative, v1 vs v2, linear');
legend('3*x', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, tan(x_vector));
plot(x_vector(2:end-1), tangent_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), tangent_res{1,10}); % 1st derivative, center
v1
plot(x_vector(3:end-2), tangent_res{1,12}); % 1st deriv, center v2
title('Center Method, 1st Derivative, v1 vs v2, tangent');
legend('tan(x)', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, step_h(x_vector));
plot(x_vector(2:end-1), step_res{1,1}); % 1st deriv, actual
plot(x_vector(2:end-1), step_res{1,10}); % 1st derivative, center v1
plot(x_vector(3:end-2), step_res{1,12}); % 1st deriv, center v2
title('Center Method, 1st Derivative, v1 vs v2, step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'v1', 'v2');
```







Forward - 2nd Derivative, v1 vs v2

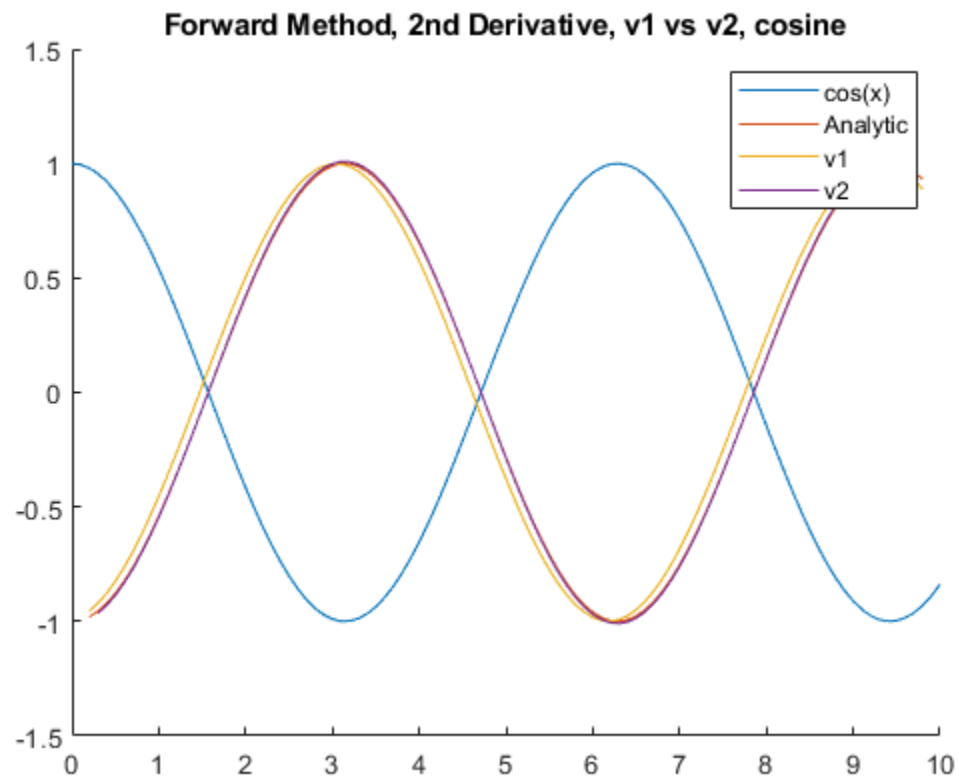
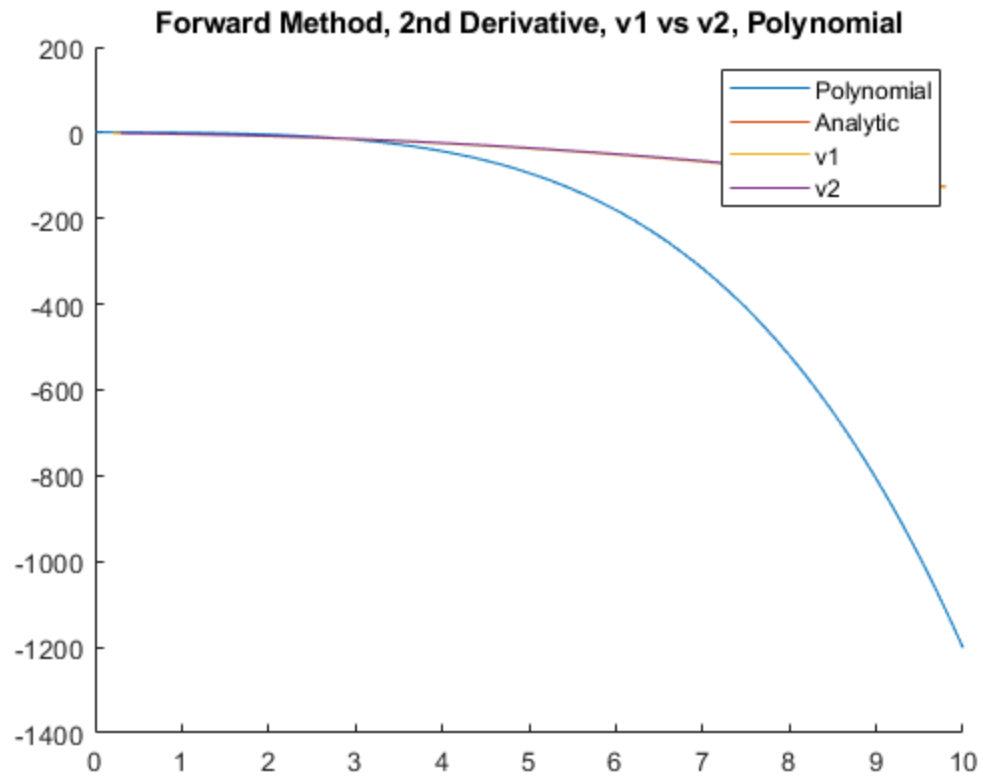
```
figure;
hold on;
plot(x_vector, poly_h(x_vector));
plot(x_vector(3:end-2), poly_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), poly_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(4:end-3), poly_res{2,4}); % 2nd deriv, forward v2
title('Forward Method, 2nd Derivative, v1 vs v2, Polynomial');
legend('Polynomial', 'Analytic', 'v1', 'v2');

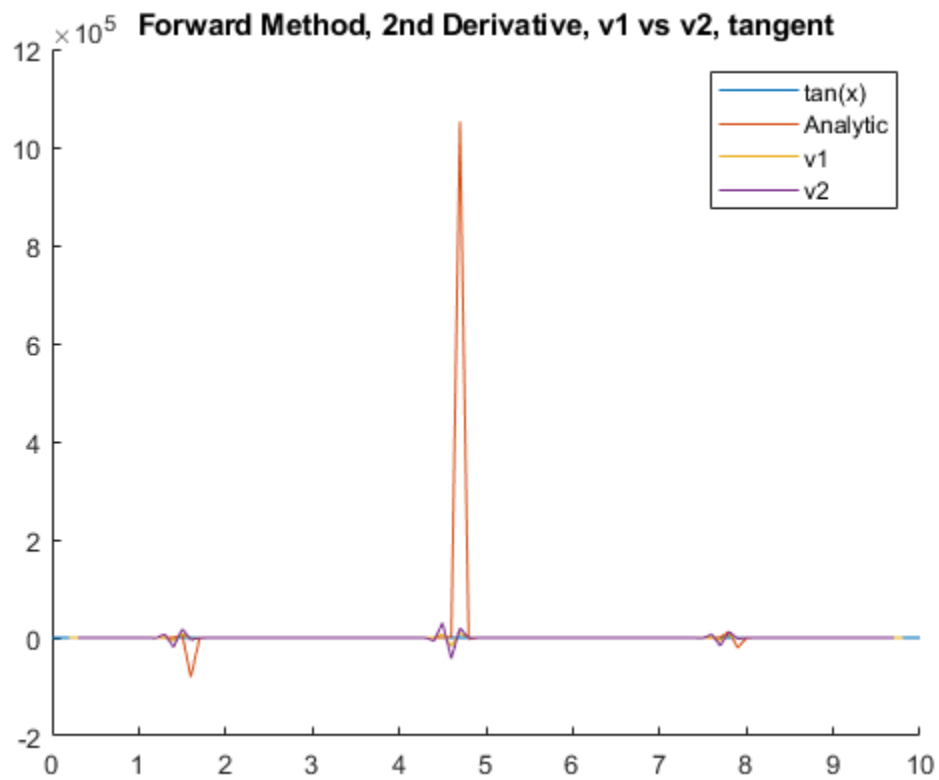
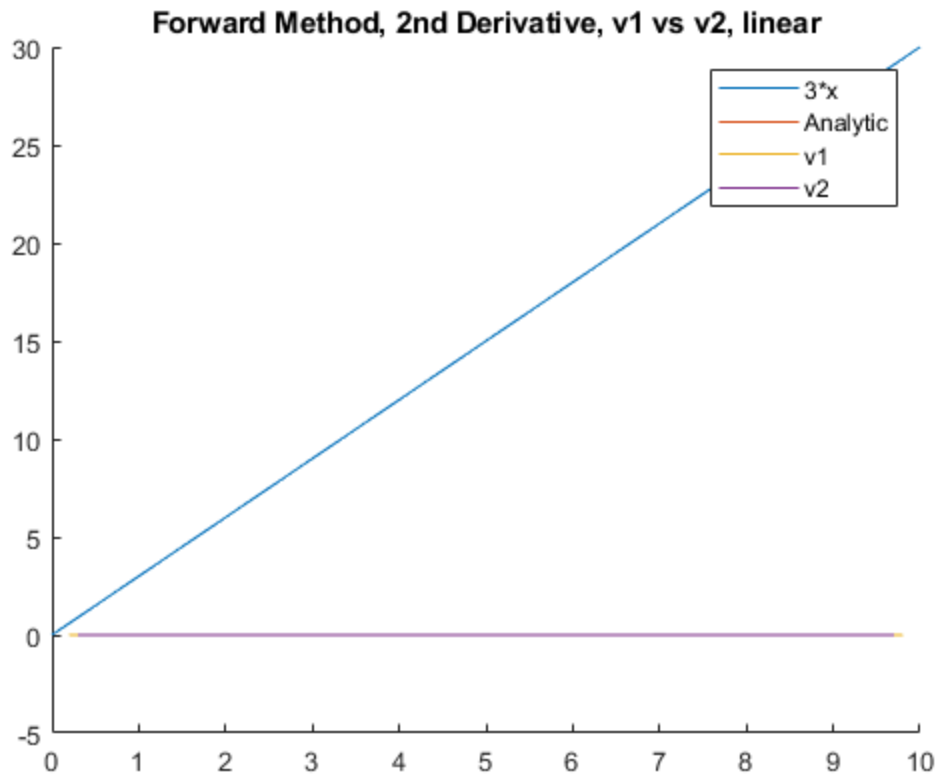
figure;
hold on;
plot(x_vector, cos(x_vector));
plot(x_vector(3:end-2), cos_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), cos_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(4:end-3), cos_res{2,4}); % 2nd deriv, forward v2
title('Forward Method, 2nd Derivative, v1 vs v2, cosine');
legend('cos(x)', 'Analytic', 'v1', 'v2');

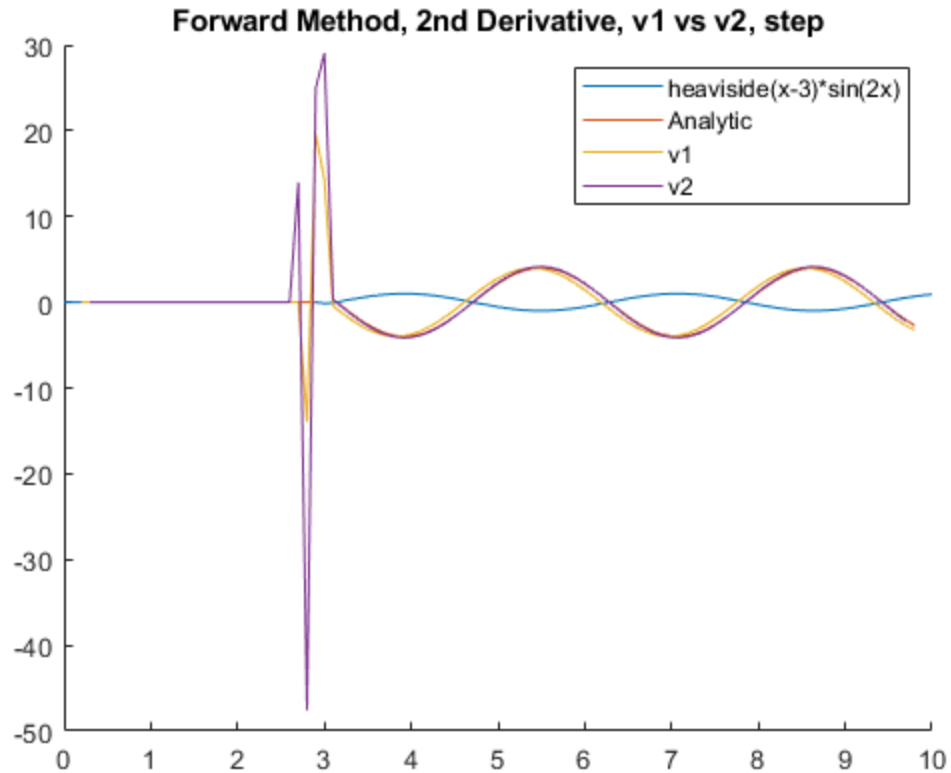
figure;
hold on;
plot(x_vector, lin_h(x_vector));
plot(x_vector(3:end-2), linear_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), linear_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(4:end-3), linear_res{2,4}); % 2nd deriv, forward v2
title('Forward Method, 2nd Derivative, v1 vs v2, linear');
legend('3*x', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, tan(x_vector));
plot(x_vector(3:end-2), tangent_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), tangent_res{2,2}); % 2nd derivative, forward
v1
plot(x_vector(4:end-3), tangent_res{2,4}); % 2nd deriv, forward v2
title('Forward Method, 2nd Derivative, v1 vs v2, tangent');
legend('tan(x)', 'Analytic', 'v1', 'v2');

figure;
hold on;
plot(x_vector, step_h(x_vector));
plot(x_vector(3:end-2), step_res{2,1}); % 2nd deriv, actual
plot(x_vector(3:end-2), step_res{2,2}); % 2nd derivative, forward v1
plot(x_vector(4:end-3), step_res{2,4}); % 2nd deriv, forward v2
title('Forward Method, 2nd Derivative, v1 vs v2, step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'v1', 'v2');
```







Backward - 2nd Derivative, v1 vs v2

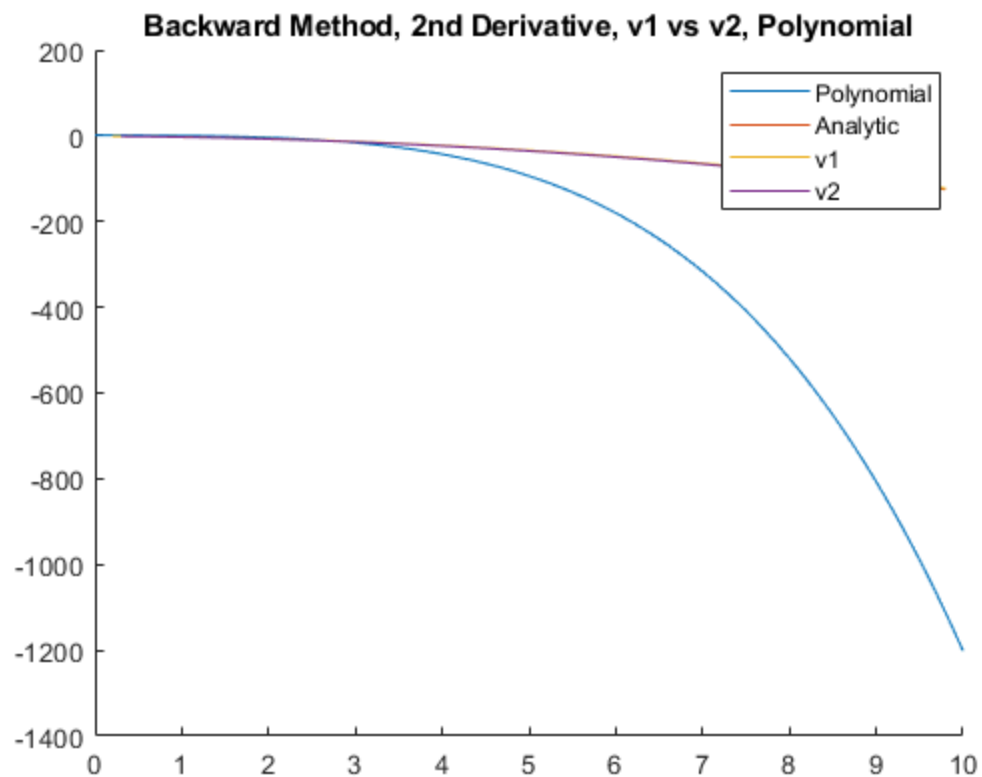
```
figure;  
hold on;  
plot(x_vector, poly_h(x_vector));  
plot(x_vector(3:end-2), poly_res{2,1}); % 2nd deriv, actual  
plot(x_vector(3:end-2), poly_res{2,6}); % 2nd derivative, backward v1  
plot(x_vector(4:end-3), poly_res{2,8}); % 2nd deriv, backward v2  
title('Backward Method, 2nd Derivative, v1 vs v2, Polynomial');  
legend('Polynomial', 'Analytic', 'v1', 'v2');
```

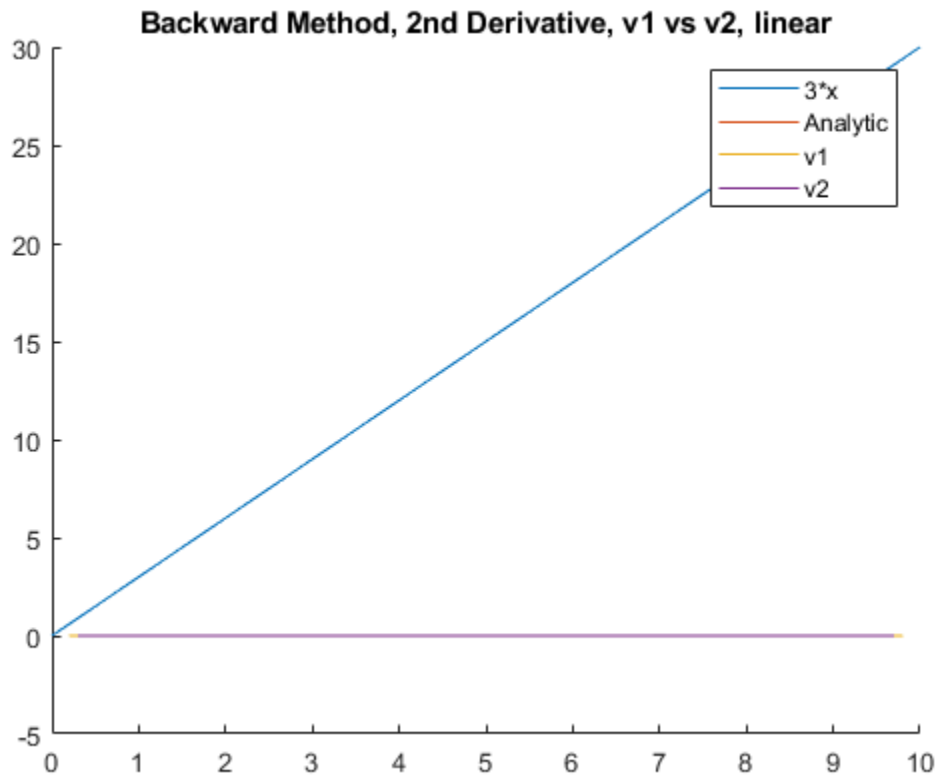
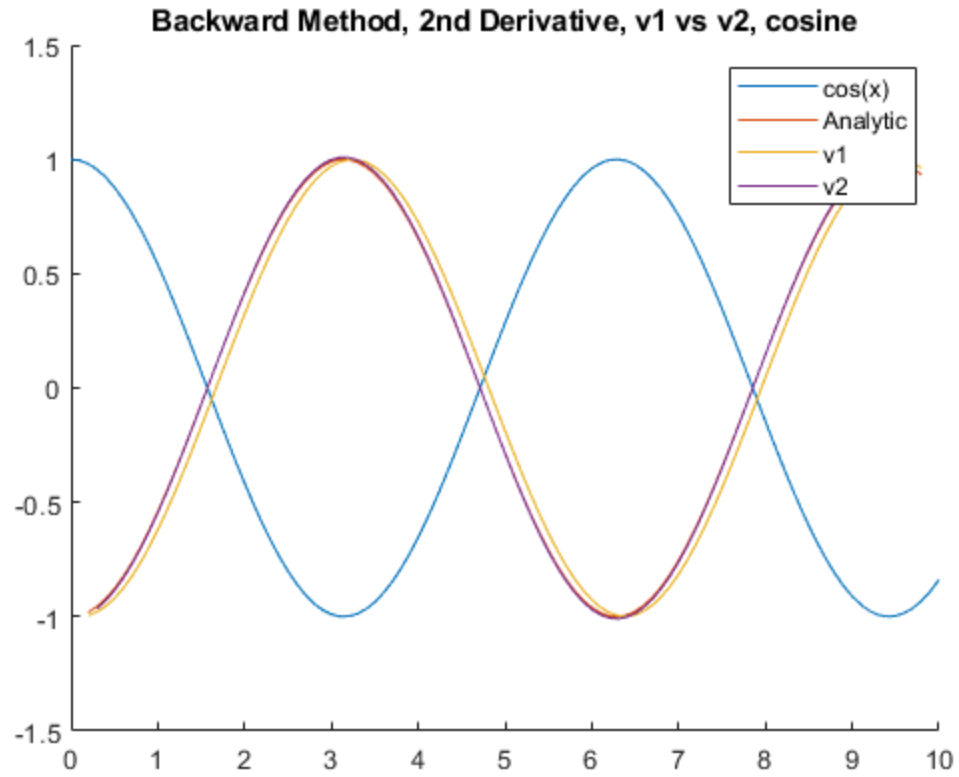
```
figure;  
hold on;  
plot(x_vector, cos(x_vector));  
plot(x_vector(3:end-2), cos_res{2,1}); % 2nd deriv, actual  
plot(x_vector(3:end-2), cos_res{2,6}); % 2nd derivative, backward v1  
plot(x_vector(4:end-3), cos_res{2,8}); % 2nd deriv, backward v2  
title('Backward Method, 2nd Derivative, v1 vs v2, cosine');  
legend('cos(x)', 'Analytic', 'v1', 'v2');
```

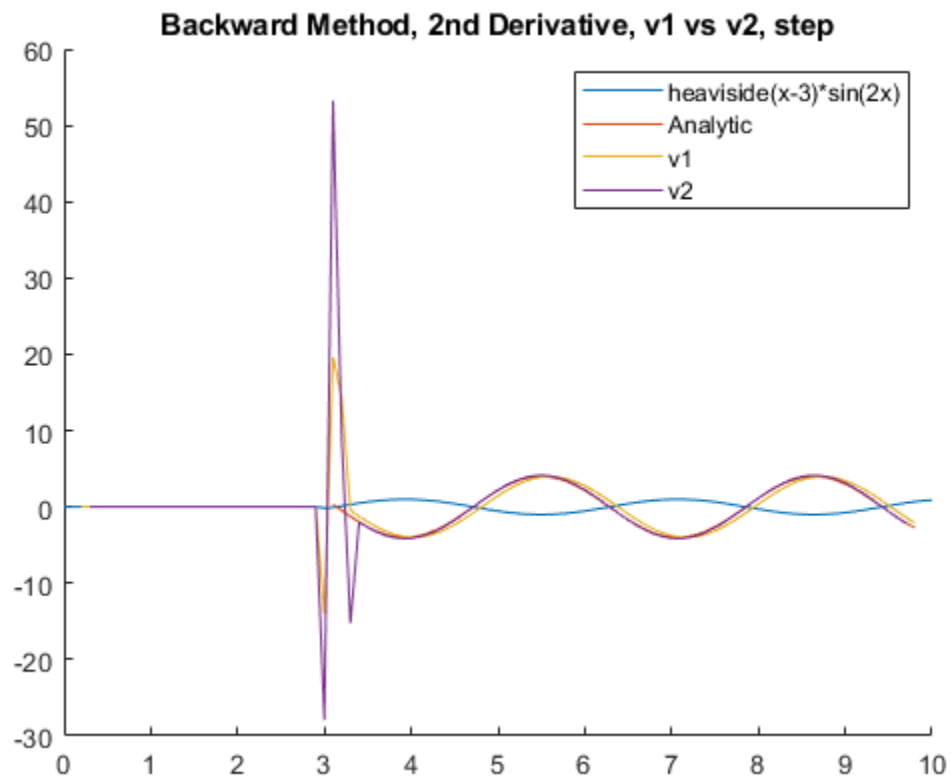
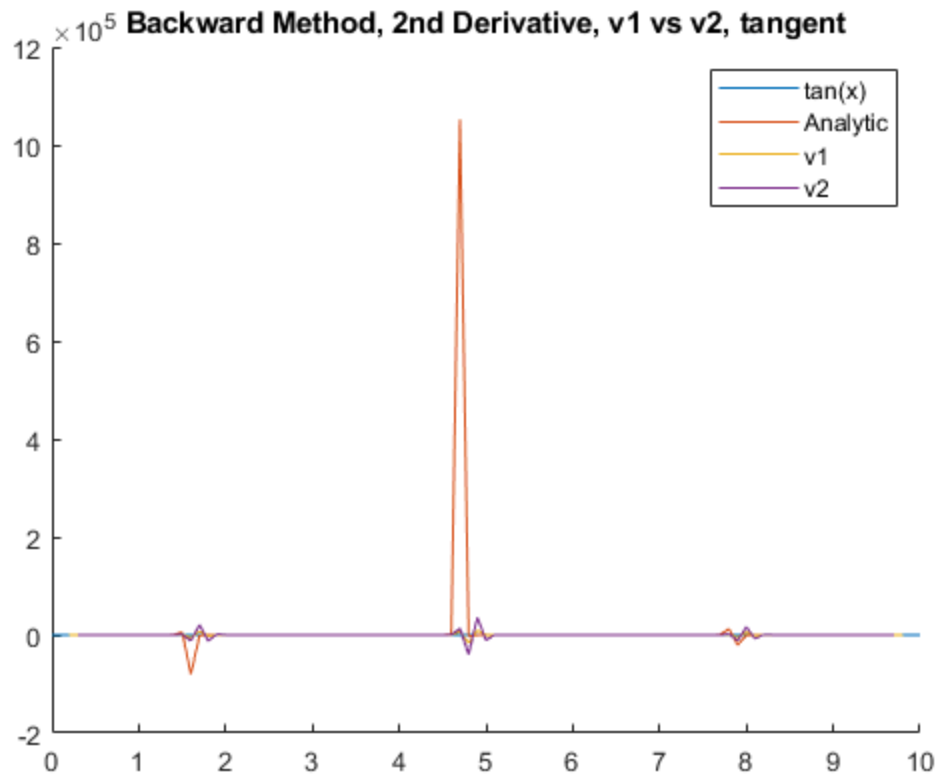
```
figure;  
hold on;  
plot(x_vector, lin_h(x_vector));  
plot(x_vector(3:end-2), linear_res{2,1}); % 2nd deriv, actual
```



```
plot(x_vector(3:end-2), linear_res{2,6}); % 2nd derivative, backward  
v1  
plot(x_vector(4:end-3), linear_res{2,8}); % 2nd deriv, backward v2  
title('Backward Method, 2nd Derivative, v1 vs v2, linear');  
legend('3*x', 'Analytic', 'v1', 'v2');  
  
figure;  
hold on;  
plot(x_vector, tan(x_vector));  
plot(x_vector(3:end-2), tangent_res{2,1}); % 2nd deriv, actual  
plot(x_vector(3:end-2), tangent_res{2,6}); % 2nd derivative, backward  
v1  
plot(x_vector(4:end-3), tangent_res{2,8}); % 2nd deriv, backward v2  
title('Backward Method, 2nd Derivative, v1 vs v2, tangent');  
legend('tan(x)', 'Analytic', 'v1', 'v2');  
  
figure;  
hold on;  
plot(x_vector, step_h(x_vector));  
plot(x_vector(3:end-2), step_res{2,1}); % 2nd deriv, actual  
plot(x_vector(3:end-2), step_res{2,6}); % 2nd derivative, backward v1  
plot(x_vector(4:end-3), step_res{2,8}); % 2nd deriv, backward v2  
title('Backward Method, 2nd Derivative, v1 vs v2, step');  
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'v1', 'v2');
```







Center - 2nd Derivative, v1 vs v2

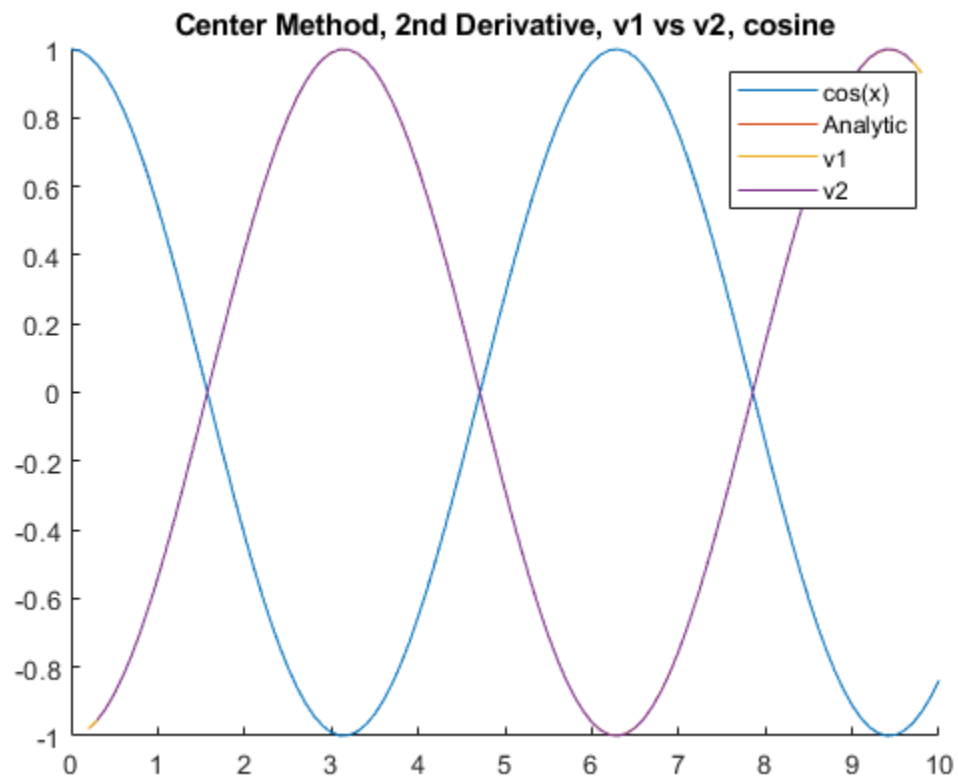
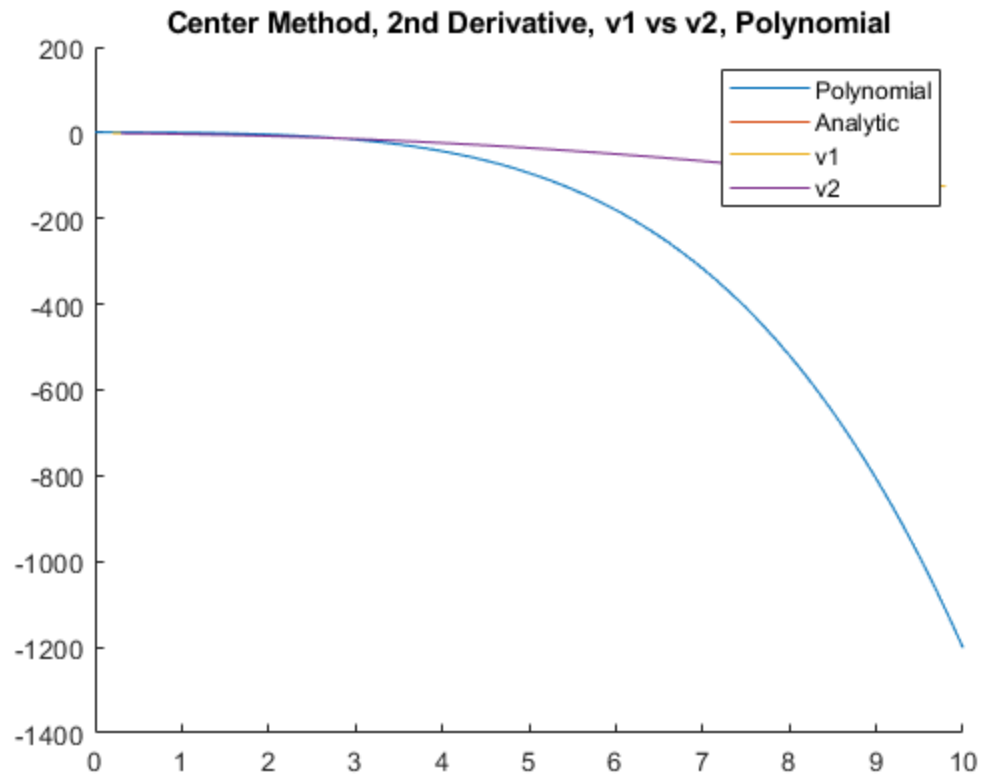
```
figure;
hold on;
plot(x_vector, poly_h(x_vector));
plot(x_vector(3:end-2), poly_res{2,9}); % 2nd deriv, actual
plot(x_vector(3:end-2), poly_res{2,10}); % 2nd derivative, center v1
plot(x_vector(4:end-3), poly_res{2,12}); % 2nd deriv, center v2
title('Center Method, 2nd Derivative, v1 vs v2, Polynomial');
legend('Polynomial', 'Analytic', 'v1', 'v2');
snapnow;

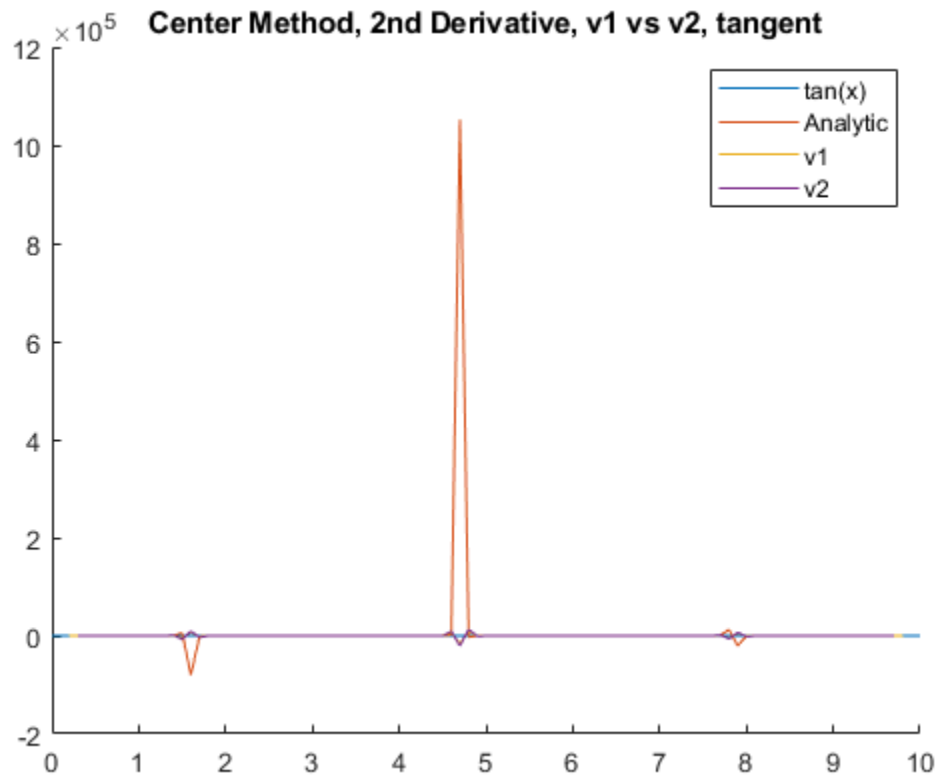
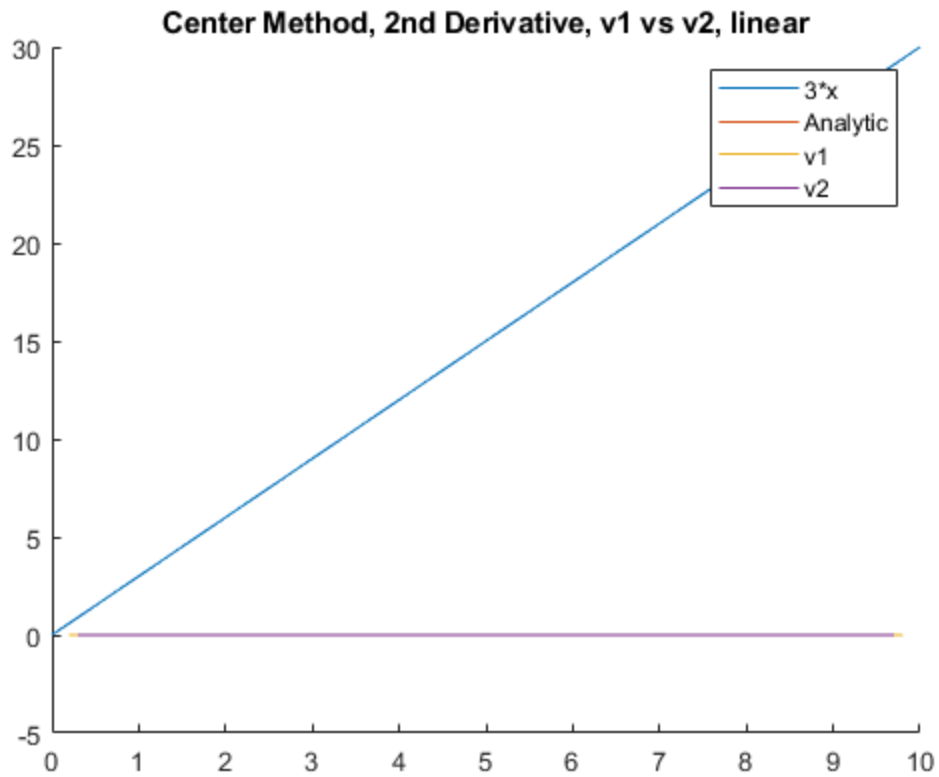
figure;
hold on;
plot(x_vector, cos(x_vector));
plot(x_vector(3:end-2), cos_res{2,9}); % 2nd deriv, actual
plot(x_vector(3:end-2), cos_res{2,10}); % 2nd derivative, center v1
plot(x_vector(4:end-3), cos_res{2,12}); % 2nd deriv, center v2
title('Center Method, 2nd Derivative, v1 vs v2, cosine');
legend('cos(x)', 'Analytic', 'v1', 'v2');
snapnow;

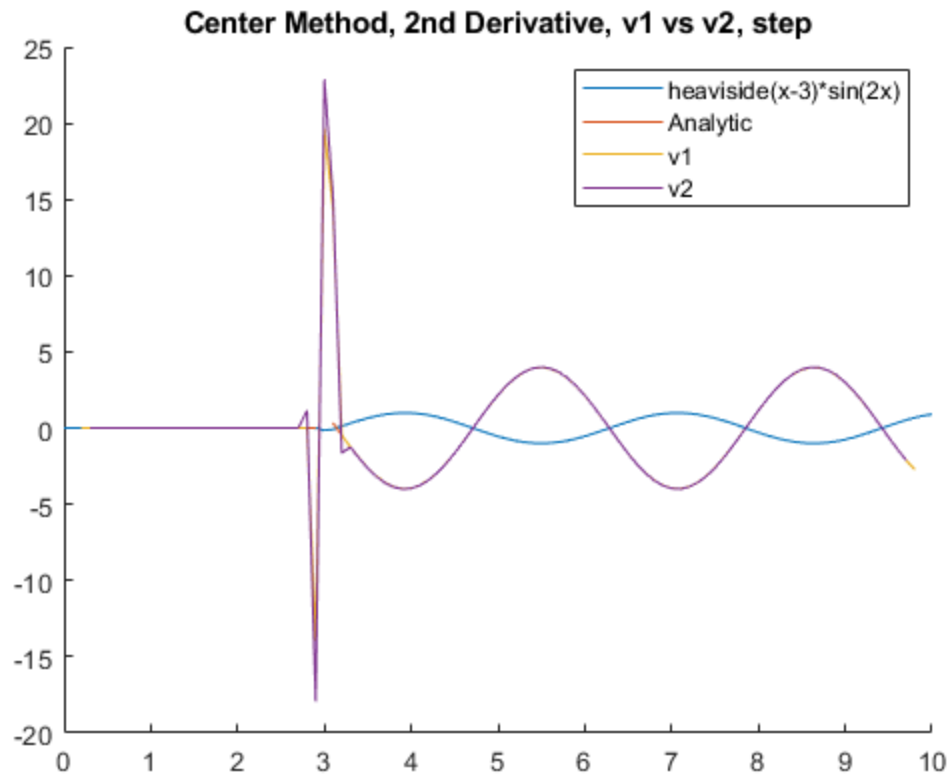
figure;
hold on;
plot(x_vector, lin_h(x_vector));
plot(x_vector(3:end-2), linear_res{2,9}); % 2nd deriv, actual
plot(x_vector(3:end-2), linear_res{2,10}); % 2nd derivative, center v1
plot(x_vector(4:end-3), linear_res{2,12}); % 2nd deriv, center v2
title('Center Method, 2nd Derivative, v1 vs v2, linear');
legend('3*x', 'Analytic', 'v1', 'v2');
snapnow;

figure;
hold on;
plot(x_vector, tan(x_vector));
plot(x_vector(3:end-2), tangent_res{2,9}); % 2nd deriv, actual
plot(x_vector(3:end-2), tangent_res{2,10}); % 2nd derivative, center
v1
plot(x_vector(4:end-3), tangent_res{2,12}); % 2nd deriv, center v2
title('Center Method, 2nd Derivative, v1 vs v2, tangent');
legend('tan(x)', 'Analytic', 'v1', 'v2');
snapnow;

figure;
hold on;
plot(x_vector, step_h(x_vector));
plot(x_vector(3:end-2), step_res{2,9}); % 2nd deriv, actual
plot(x_vector(3:end-2), step_res{2,10}); % 2nd derivative, center v1
plot(x_vector(4:end-3), step_res{2,12}); % 2nd deriv, center v2
title('Center Method, 2nd Derivative, v1 vs v2, step');
legend('heaviside(x-3)*sin(2x)', 'Analytic', 'v1', 'v2');
snapnow;
```







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