

## Reproduce Figure 8.4

```

close all;

% Let's set some parameters
f = 100; %Hz
omega = 2*pi*f; % radians
z_source = 25; %m
z_receiver = 50; %m
d = 100; %m, depth
c = 1500; %m/s sound speed

% Define the range vector
r = 0:1:50e3; %m

figWidth = 1920/2; % pixels
figHeight = 1200;
rect = [0 50 figWidth figHeight];
figure('OuterPosition', rect, 'name', 'Transmission loss for isovelocity problem')
for i = 1:3;
    num_modes = i;
    m = 1:num_modes;

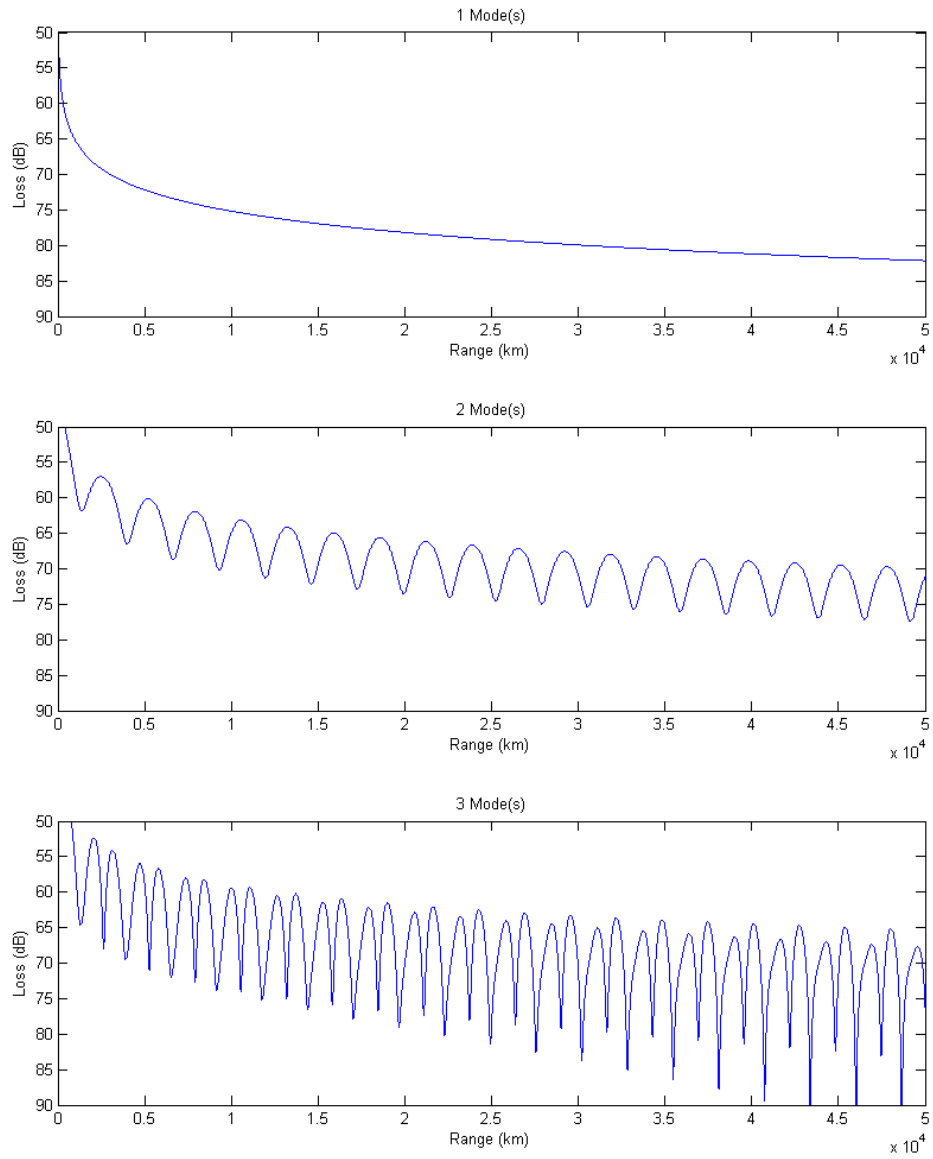
    k_rm = sqrt((omega/c)^2 - ((m-0.5)*(pi/d)).^2); % rad/m
    k_zm = pi/d .* (m-0.5); % rad/m

    A_m = sin(k_zm.*z_source).*sin(k_zm.*z_receiver) ./ sqrt(k_rm);
    mode_sinusoids = exp(1j.*k_rm'*r);
    % Add amplitudes
    A_mode_sinusoids = bsxfun(@times, A_m', mode_sinusoids);

    I = 8*pi ./ (r*d^2) .* (abs(sum(A_mode_sinusoids))).^2;

    subplot(3,1,i);
    plot(-10*log10(I));
    set(gca, 'YDir', 'Reverse')
    ylim([50 90]);
    xlim([0 50e3]);
    xlabel('Range (km)');
    ylabel('Loss (dB)');
    title([num2str(num_modes) ' Mode(s)']);
end

```



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## Reproduce Figure 8.7

```

close all;

f = 0:.01:50; %Hz
omega = 2*pi*f; %rad/s
c = 1500; %m/s
d = 100; %m

m = 1:3;

for m = 1:3
    % Equation 8.39
    k_rm(m,:) = sqrt((omega/c).^2 - (m.*pi./d).^2); % rad/m

    v(m, :) = omega ./ k_rm(m,:);
    % Cutoff frequency (real wavenumber only above cutoff)
    f0m(m) = m*c/(2*d);
    f_real{m} = f(f>f0m(m));
    v_real{m} = v(m, (f>f0m(m)));

    % Find group velocity u
    u_temp = diff(omega)./diff(k_rm(m,:));
    u_temp = [0 u_temp]; % shift it over so that the dimensions match
    u_real{m} = u_temp(f>f0m(m));
end

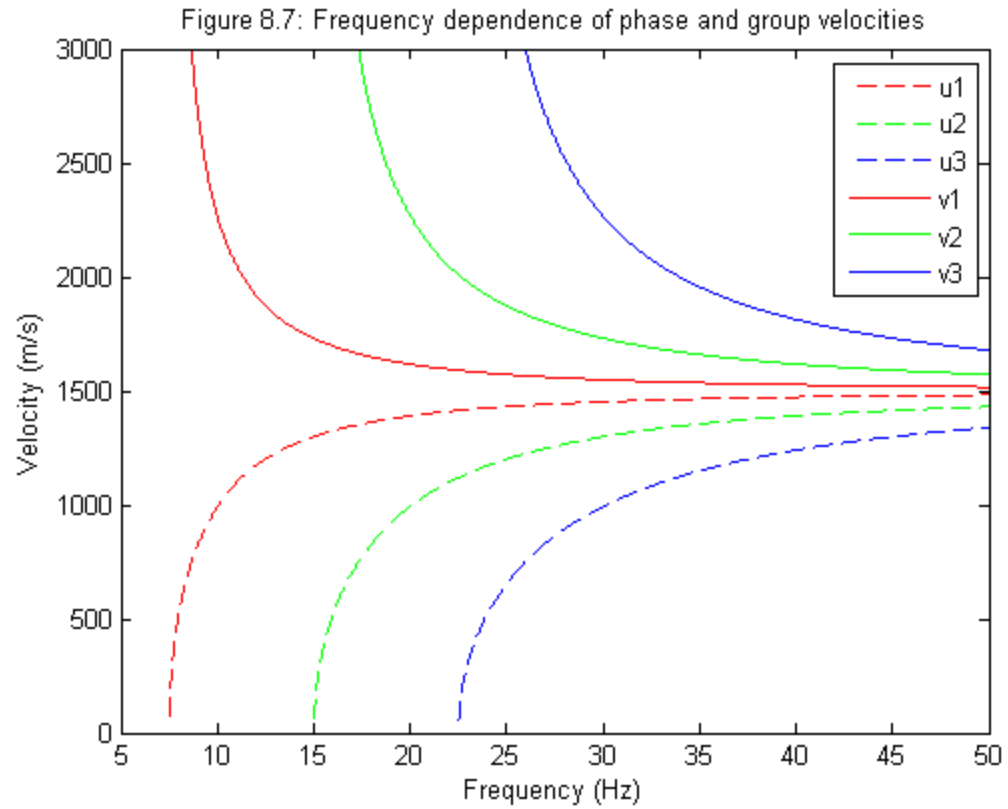
figure();
plot(f_real{1}, u_real{1}, 'r--');
hold on;
plot(f_real{2}, u_real{2}, 'g--');
plot(f_real{3}, u_real{3}, 'b--');

plot(f_real{1}, v_real{1}, 'r');
plot(f_real{2}, v_real{2}, 'g');
plot(f_real{3}, v_real{3}, 'b');

ylim([0 3000]);
legend('u1', 'u2', 'u3', 'v1', 'v2', 'v3')
xlabel('Frequency (Hz)');
ylabel('Velocity (m/s)');
title('Figure 8.7: Frequency dependence of phase and group velocities');

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```



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## Figure 8.8

Pekeris Waveguide

```
function figure_8_8()

close all;

f_max = 50; %Hz

c1 = 1500; %m/s
c2 = 1800; %m/s
d = 100; %m

for m = 1:3
    % Equation 8.44
    f0m(m) = (m-0.5)*c1*c2/(2*d*sqrt(c2^2-c1^2));
    omega_0m = 2*pi*f0m(m);

    fm = f0m(m):1:f_max;
    omega = 2*pi*fm; %rad/s

    kn = solve_pekeris(fm);

    k_rm{m} = kn(:,m)';

    v = omega ./ k_rm{m};

    f_real{m} = fm;
    v_real{m} = v;

    % Find group velocity u
    u_temp = diff(omega)./diff(k_rm{m});
    u_temp = [0 u_temp]; % shift it over so that the dimensions match
    u_real{m} = u_temp;
end

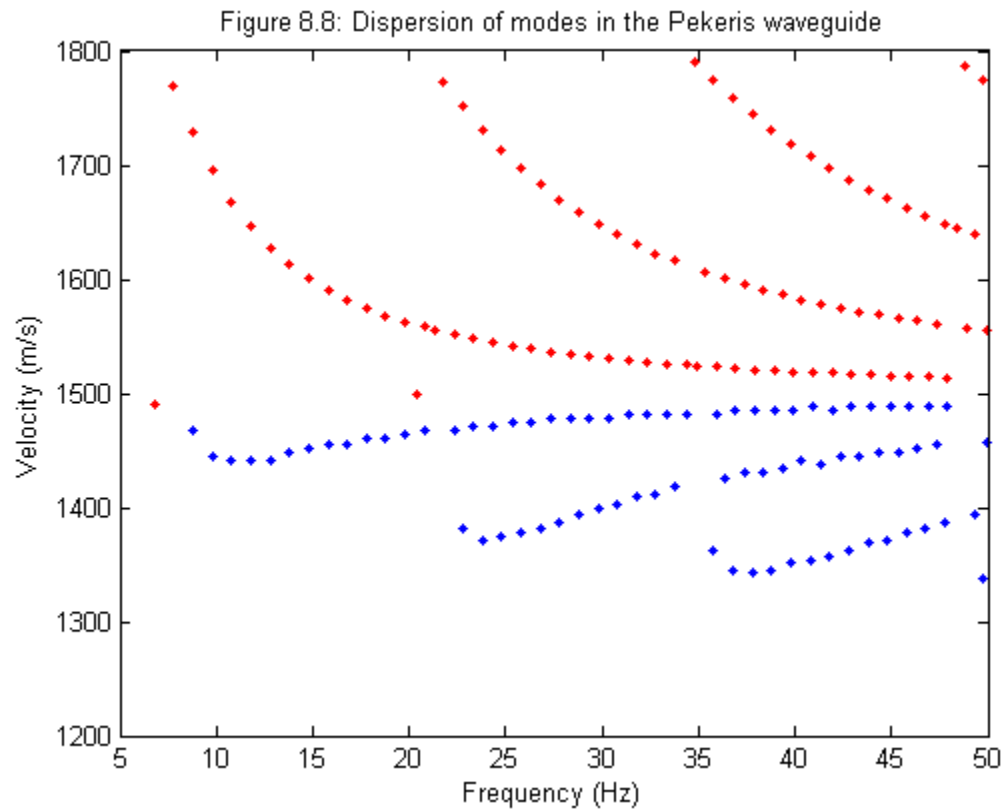
figure();
plot(f_real{1}, u_real{1}, 'b. ');
hold on;
plot(f_real{2}, u_real{2}, 'b. ');
plot(f_real{3}, u_real{3}, 'b. ');

plot(f_real{1}, v_real{1}, 'r. ');
plot(f_real{2}, v_real{2}, 'r. ');
plot(f_real{3}, v_real{3}, 'r. ');

ylim([1200 1800]);
%legend('u1', 'u2', 'u3', 'v1', 'v2', 'v3')
```

```
xlabel('Frequency (Hz)');  
ylabel('Velocity (m/s)');  
title('Figure 8.8: Dispersion of modes in the Pekeris waveguide');  
  
disp('done');  
  
end
```

*done*



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# 202a problem set, part II

## Table of Contents

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## Setup

```
function part_ii()

close all;

f = 100:.01:200; %Hz
omega = 2*pi*f; %rad/s
c = 1500; %m/s
d = 50; %m
```

## Math

```
% Find the highest mode number that has a cutoff frequency below 100Hz
m_max_100 = floor(100/c * (2*d));
m_max_200 = floor(200/c * (2*d));

for m = 1:m_max_200
    % Equation 8.39
    k_rm(m,:) = sqrt((omega/c).^2 - (m.*pi./d).^2); % rad/m

    k_zm(m,:) = sqrt((omega/c).^2 - k_rm(m,:).^2);

    v(m, :) = omega ./ k_rm(m,:);
    % Cutoff frequency (real wavenumber only above cutoff)
    f0m(m) = m*c/(2*d);
    f_real{m} = f(f>f0m(m));
    v_real{m} = v(m, (f>f0m(m)));

    % Find group velocity u
    u_temp = diff(omega)./diff(k_rm(m,:));
    u_temp = [0 u_temp]; % shift it over so that the dimensions match
    u_real{m} = u_temp(f>f0m(m));
end
```

## A: Number of modes

```
fprintf('Number of modes propagating at 100Hz = %d\n', m_max_100);
```

```
fprintf('Number of modes proppating at 200Hz = %d\n', m_max_200);
```

*Number of modes proppating at 100Hz = 6*

*Number of modes proppating at 200Hz = 13*

## B: Cut-off frequencies

```
fprintf('Cut off frequencies for each mode:\n');
for m=1:m_max_200
    fprintf('\t%d: %d Hz\n', m, f0m(m));
end
```

*Cut off frequencies for each mode:*

*1: 15 Hz*

*2: 30 Hz*

*3: 45 Hz*

*4: 60 Hz*

*5: 75 Hz*

*6: 90 Hz*

*7: 105 Hz*

*8: 120 Hz*

*9: 135 Hz*

*10: 150 Hz*

*11: 165 Hz*

*12: 180 Hz*

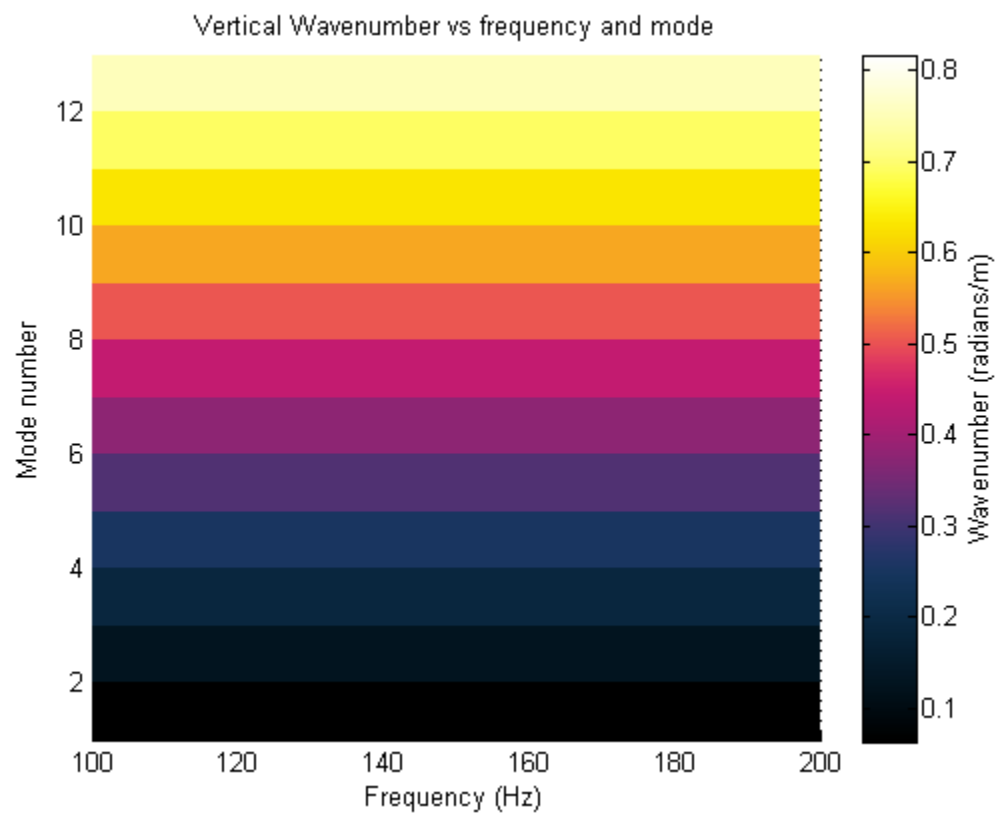
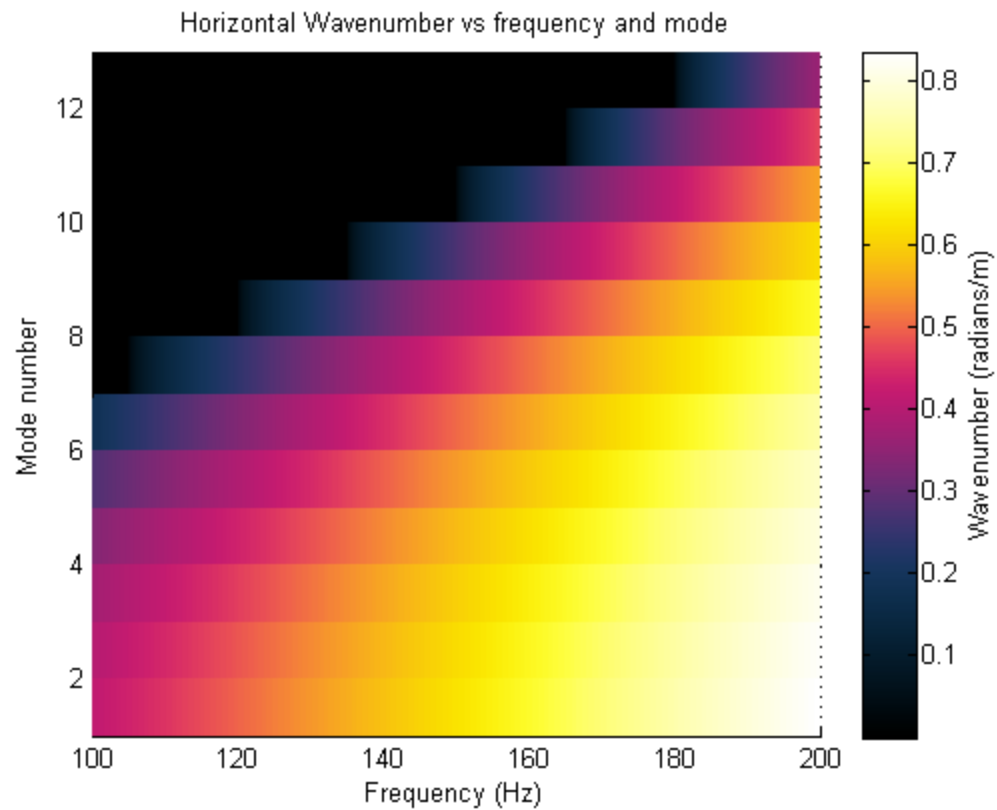
*13: 195 Hz*

## C: Horizontal and vertical wavenumbers

```
m=1:m_max_200;
figure('name', 'Horizontal Wavenumber vs frequency and mode');
surf(f, m, real(k_rm), 'EdgeColor', 'none');
colormap(morgenstemning());
view([0 90]);
axis tight;
xlabel('Frequency (Hz)');
ylabel('Mode number');
cbar = colorbar();
ylabel(cbar, 'Wavenumber (radians/m)');
title(get(gcf(), 'name'));
```

```
figure('name', 'Vertical Wavenumber vs frequency and mode');
surf(f, m, real(k_zm), 'EdgeColor', 'none');
colormap(morgenstemning());
view([0 90]);
axis tight;
xlabel('Frequency (Hz)');
ylabel('Mode number');
cbar = colorbar();
ylabel(cbar, 'Wavenumber (radians/m)');
title(get(gcf(), 'name'));
```





## D: Group speed dispersion curves

```
figure();

for i = 1:length(f_real)
    plot(f_real{i}, u_real{i});
    hold on;
end

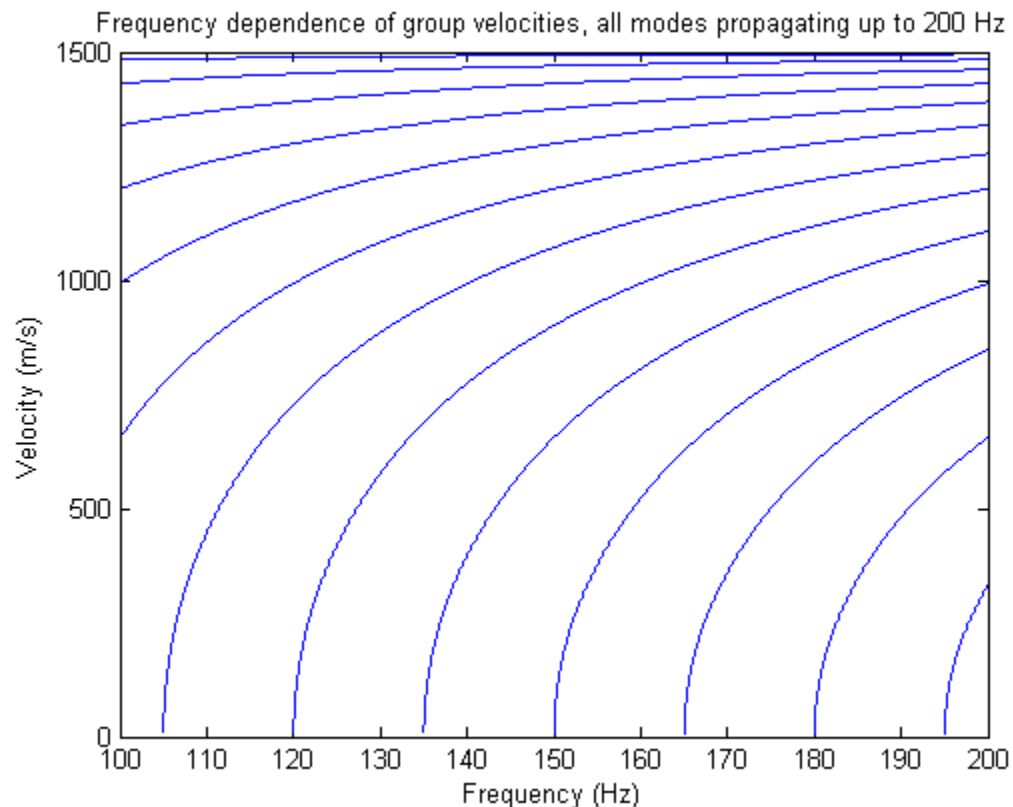
% plot(f_real{1}, u_real{1}, 'r--');
% hold on;
% plot(f_real{2}, u_real{2}, 'g--');
% plot(f_real{3}, u_real{3}, 'b--');

% plot(f_real{1}, v_real{1}, 'r');
% plot(f_real{2}, v_real{2}, 'g');
% plot(f_real{3}, v_real{3}, 'b');

%ylim([1300 1500]);
%legend('u1', 'u2', 'u3', 'Location', 'SouthEast');%, 'v1', 'v2', 'v3')
xlabel('Frequency (Hz)');
ylabel('Velocity (m/s)');
title('Frequency dependence of group velocities, all modes propagating up to 200 Hz
```

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## E: Shape of the modes

```

z = 0:0.1:50;

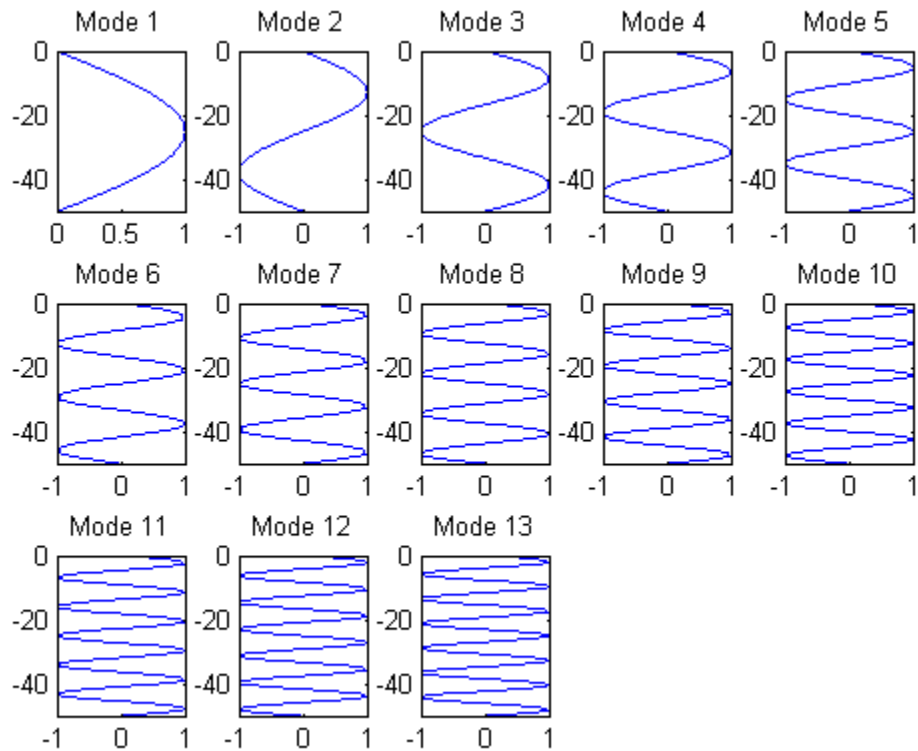
figure('name', 'Shape of modes in depth');

for m = 1:m_max_200
    shape = sin(k_zm(m,end)*z);
    subplot(3,5,m);
    plot(shape, -z);
    title(['Mode ' num2str(m)]);
end

disp('done');

done

```



```
end
```

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# 202a problem set, part III

## Table of Contents

Setup .....	1
Math .....	1
A: Number of modes .....	2
B: Cut-off frequencies .....	2
C: Horizontal and vertical wavenumbers .....	2
D: Group speed dispersion curves .....	4
E: Shape of the modes .....	5

Pekeris Waveguide

## Setup

```
function part_iii()

close all;

f = 100:1:200; %Hz
omega = 2*pi*f; %rad/s
c1 = 1500; %m/s
c2 = 1600;
d = 100; %m
```

## Math

```
% Find the highest mode number that has a cutoff frequency below 100Hz
m_max = floor(f*2*d*sqrt(c2^2-c1^2)/(c1*c2) + 0.5);
m_max_100 = floor(100*2*d*sqrt(c2^2-c1^2)/(c1*c2) + 0.5);
m_max_200 = floor(200*2*d*sqrt(c2^2-c1^2)/(c1*c2) + 0.5);

k_rm_full = solve_pekeris(f);

k_zm_full = sqrt(bsxfun(@minus, ((omega/c1).^2)', k_rm_full.^2));

for m = 1:m_max_200
    % Cut off frequencies
    % Equation 8.44
    f0m(m) = (m-0.5)*c1*c2/(2*d*sqrt(c2^2-c1^2));

    % v(m, :) = omega ./ k_rm(m,:);
    % % Cutoff frequency (real wavenumber only above cutoff)
    % f0m(m) = m*c/(2*d);

    k_rm{m} = k_rm_full(:,m);
    k_zm{m} = k_zm_full(:,m);
```

```

v{m} = omega ./ k_rm{m}';

f_real{m} = f(f>f0m(m));

v_real{m} = v{m}(f>f0m(m));

% Find group velocity u
u_temp = diff(omega)./diff(k_rm{m}');
u_temp = [0 u_temp]; % shift it over so that the dimensions match
u_real{m} = u_temp(f>f0m(m));
end

```

## A: Number of modes

```

fprintf('Number of modes propgating at 100Hz = %d\n', m_max_100);
fprintf('Number of modes propgating at 200Hz = %d\n', m_max_200);

```

*Number of modes propgating at 100Hz = 5*

*Number of modes propgating at 200Hz = 9*

## B: Cut-off frequencies

```

fprintf('Cut off frequencies for each mode:\n');
for m=1:m_max_200
    fprintf('\t%d: %d Hz\n', m, f0m(m));
end

```

*Cut off frequencies for each mode:*

*1: 1.077632e+01 Hz*

*2: 3.232895e+01 Hz*

*3: 5.388159e+01 Hz*

*4: 7.543423e+01 Hz*

*5: 9.698686e+01 Hz*

*6: 1.185395e+02 Hz*

*7: 1.400921e+02 Hz*

*8: 1.616448e+02 Hz*

*9: 1.831974e+02 Hz*

## C: Horizontal and vertical wavenumbers

```

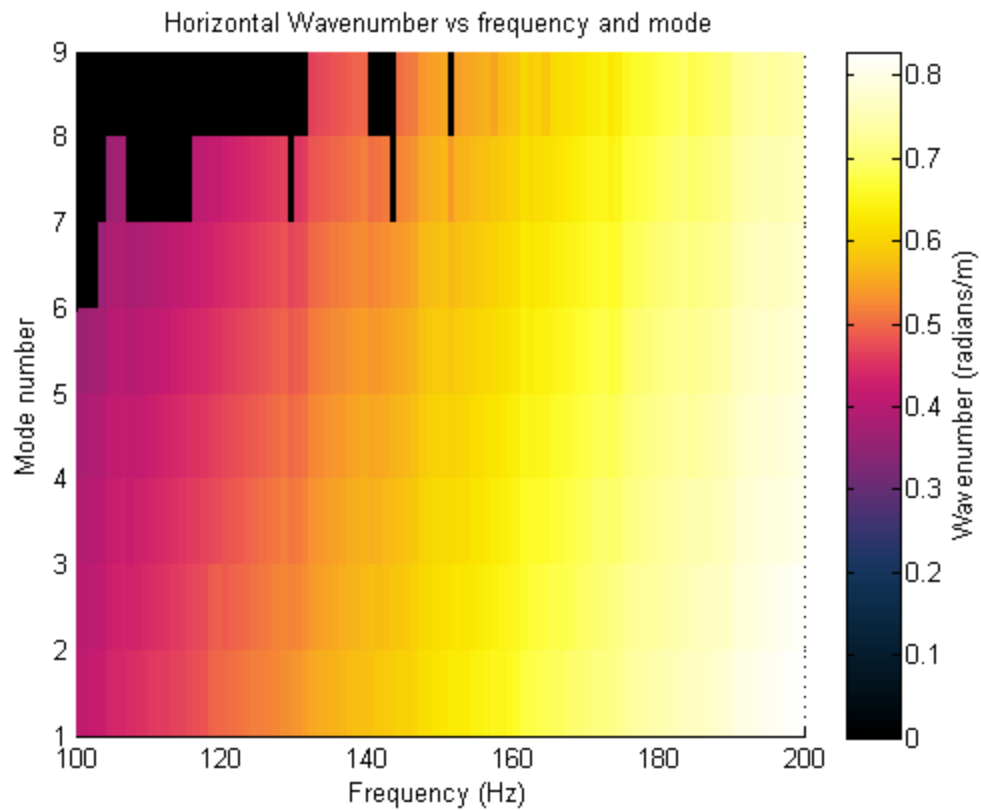
m=1:m_max_200;
figure('name', 'Horizontal Wavenumber vs frequency and mode');
surf(f, m, k_rm_full(:,1:m_max_200)', 'EdgeColor', 'none');
colormap(morgenstemning());
view([0 90]);
axis tight;
xlabel('Frequency (Hz)');
ylabel('Mode number');
cbar = colorbar();
ylabel(cbar, 'Wavenumber (radians/m)');
title(get(gcf(), 'name'));

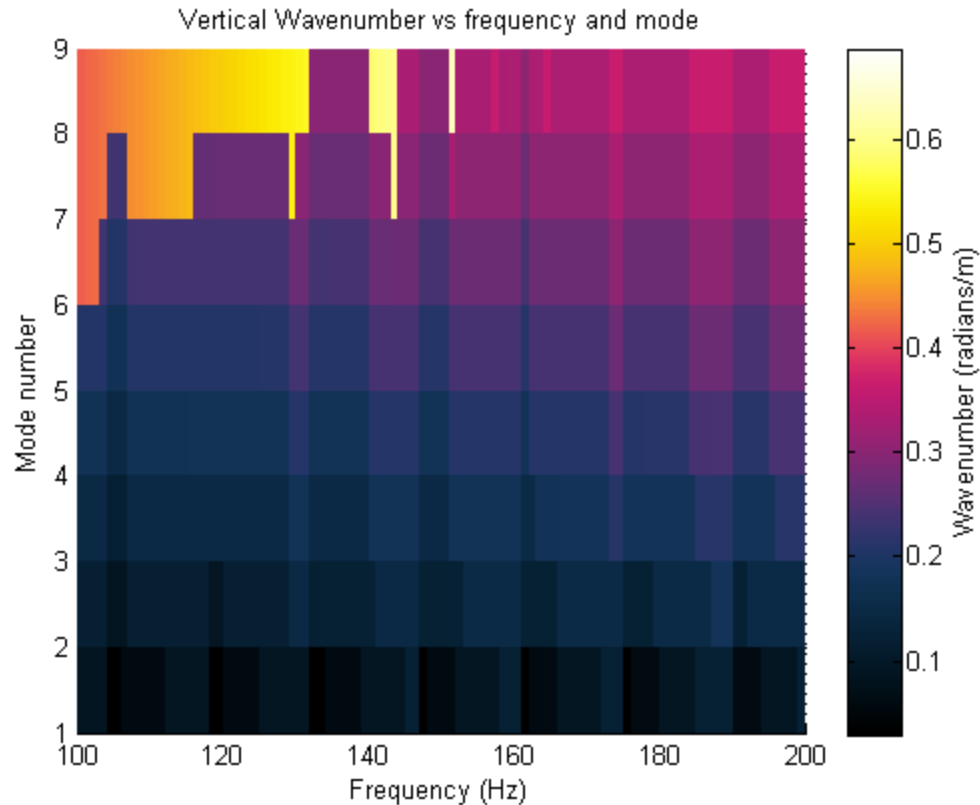
```

```

figure('name', 'Vertical Wavenumber vs frequency and mode');
surf(f, m, k_zm_full(:,1:m_max_200)', 'EdgeColor', 'none');
colormap(morgensstemning());
view([0 90]);
axis tight;
xlabel('Frequency (Hz)');
ylabel('Mode number');
cbar = colorbar();
ylabel(cbar, 'Wavenumber (radians/m)');
title(get(gcf(), 'name'));

```





## D: Group speed dispersion curves

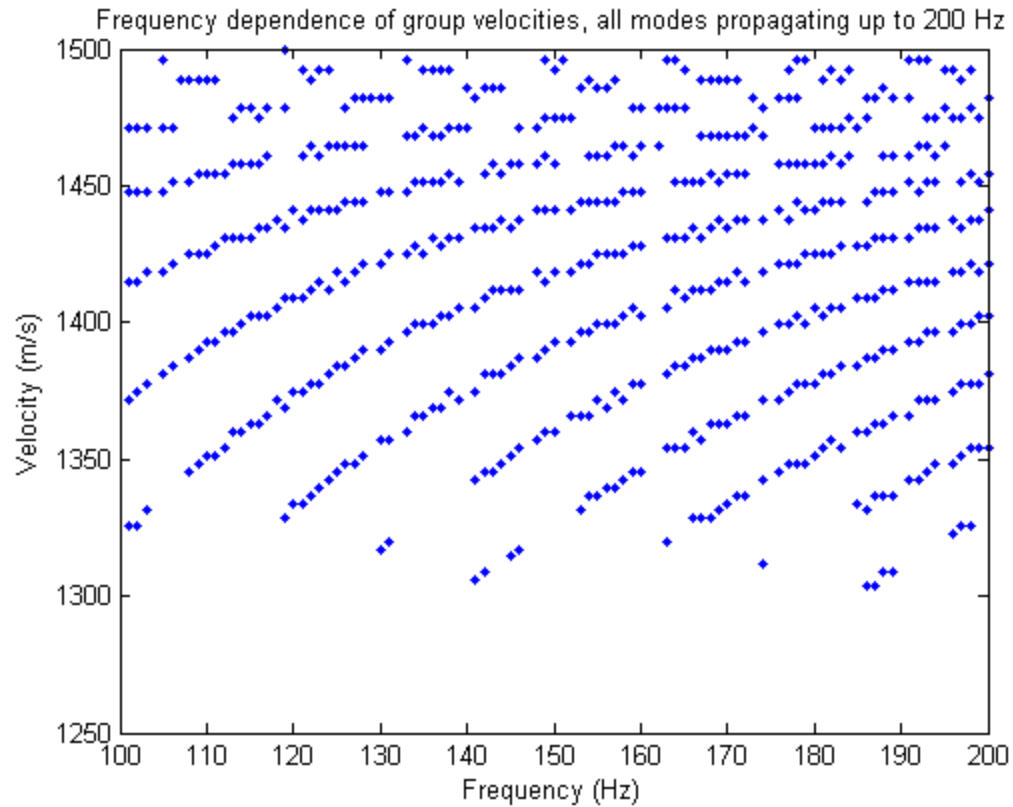
```
figure();

for i = 1:length(f_real)
    plot(f_real{i}, u_real{i}, '.');
    hold on;
end
ylim([1250 1500]);

% plot(f_real{1}, u_real{1}, 'r--');
% hold on;
% plot(f_real{2}, u_real{2}, 'g--');
% plot(f_real{3}, u_real{3}, 'b--');

% plot(f_real{1}, v_real{1}, 'r');
% plot(f_real{2}, v_real{2}, 'g');
% plot(f_real{3}, v_real{3}, 'b');

%ylim([1300 1500]);
%legend('u1', 'u2', 'u3', 'Location', 'SouthEast');%, 'v1', 'v2', 'v3')
xlabel('Frequency (Hz)');
ylabel('Velocity (m/s)');
title('Frequency dependence of group velocities, all modes propagating up to 200 H
```



## E: Shape of the modes

```

z = 0:0.1:50;

figure('name', 'Shape of modes in depth');

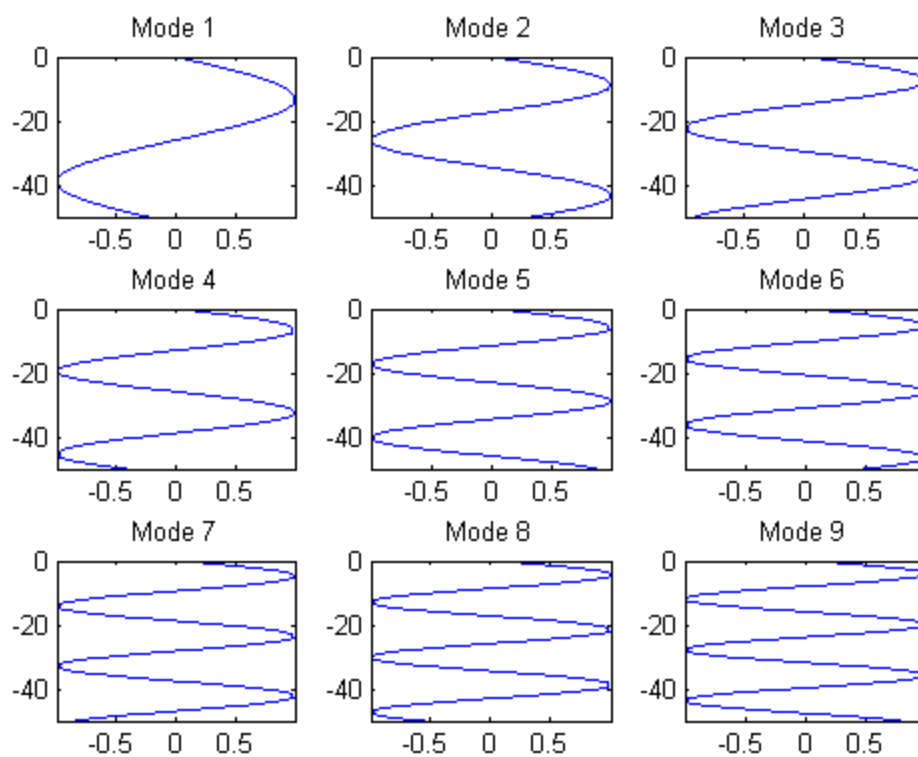
for m = 1:m_max_200
    shape = sin(k_zm{m}(end)*z);
    subplot(3,3,m);
    plot(shape, -z);
    axis tight;
    title(['Mode ' num2str(m)]);
end

disp('done');

done

```





end

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