# Evaluation of 9-Story Benchmark Building Shear Model

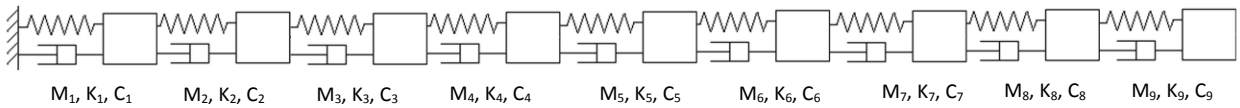


Figure 1. 9 DOF Shear Building Model

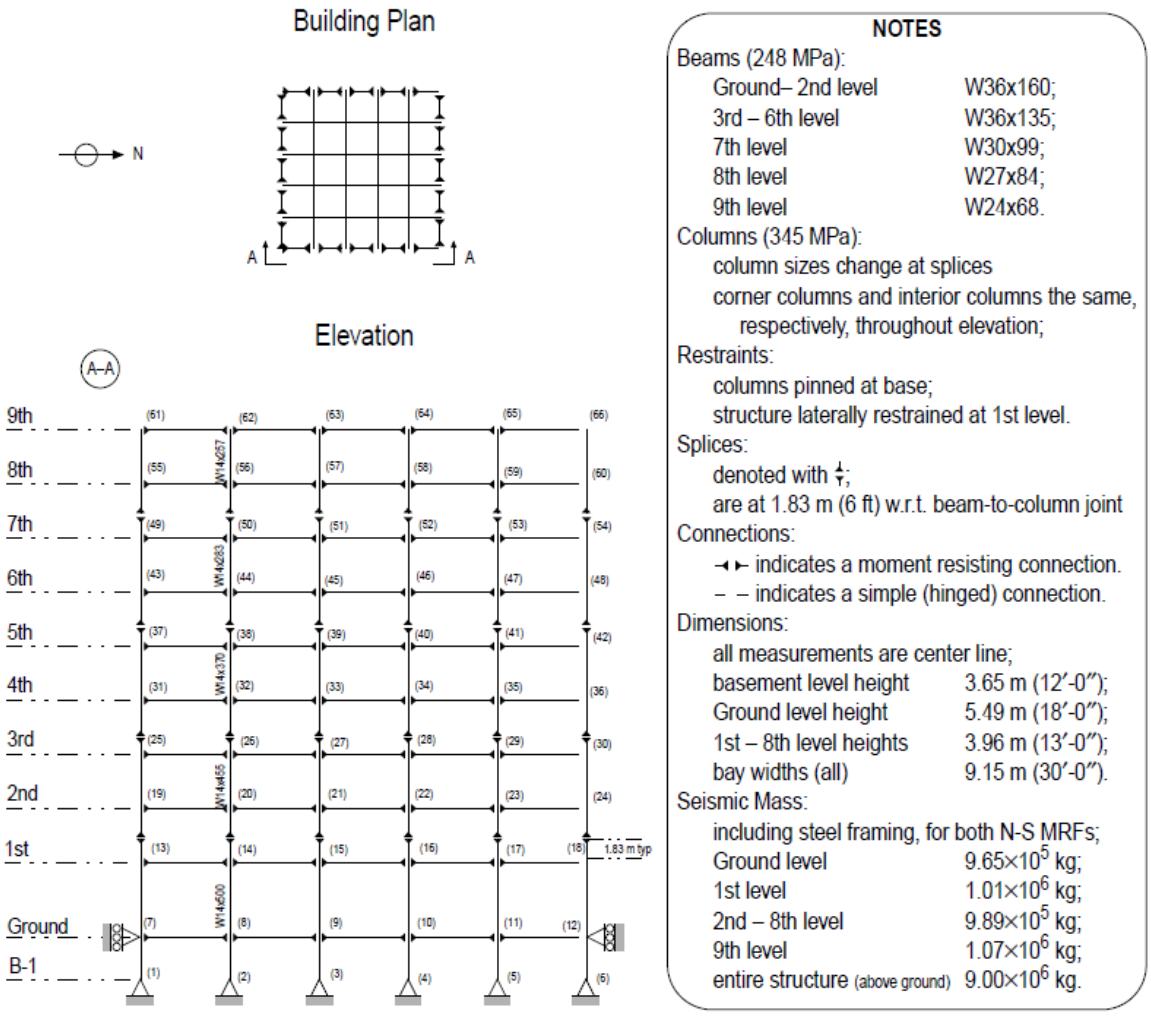


Figure 2. 9-Story Benchmark Building[1]

[1] ***Y. Ohtori* et al.*, Benchmark Control Problems for Seismically Excited Nonlinear Buildings, J. Eng. Mech. 130, 366 (2004)***

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# Introducing Mass and Stiffness Matrices

Mass elements are introduced based on the 9-strory benchmark FEM model

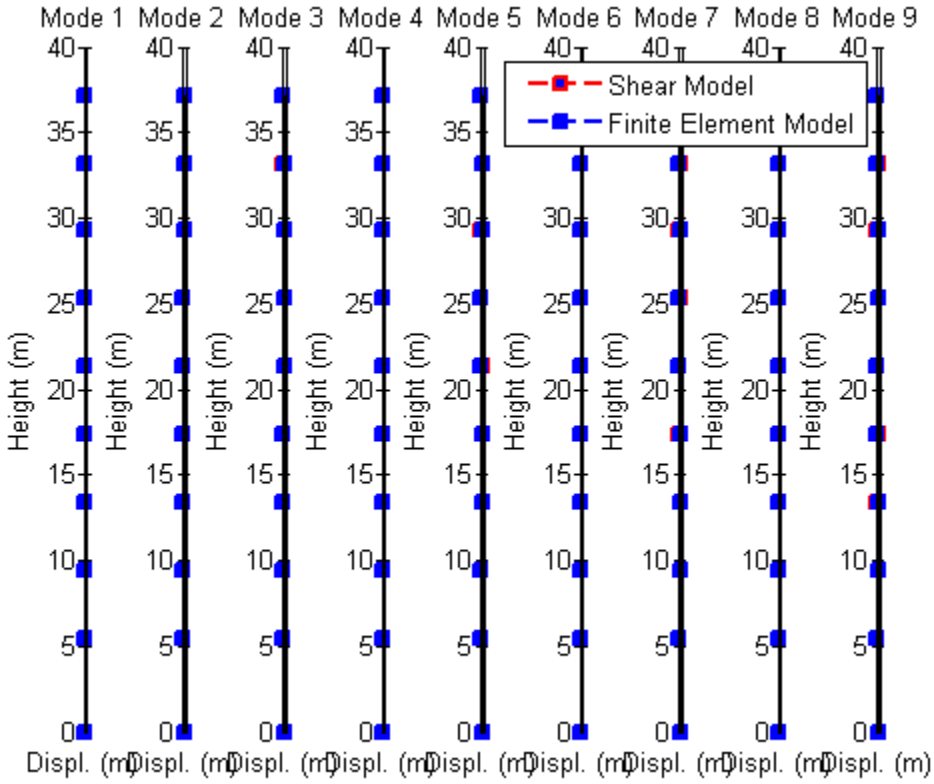
```
clear all; close all; clc
m1 = 1.01e6; % mass of 1st floor
m2 = 9.89e5; % mass of 2-8th floor
m3 = m2; m4 = m2; m5 = m2; m6 = m2; m7 = m2; m8 = m2;
m9 = 1.07e6; % mass of 9th floor

% Construction of mass matrix
M = [m1 0 0 0 0 0 0 0 0;
    0 m2 0 0 0 0 0 0 0;
    0 0 m3 0 0 0 0 0 0;
    0 0 0 m4 0 0 0 0 0;
    0 0 0 0 m5 0 0 0 0;
    0 0 0 0 0 m6 0 0 0;
    0 0 0 0 0 0 m7 0 0;
    0 0 0 0 0 0 0 m8 0;
    0 0 0 0 0 0 0 0 m9];

% Story Height
L = [5.49, 3.96, 3.96, 3.96, 3.96, 3.96,3.96, 3.96, 3.96];

% Cumulative Height
H = cumsum(L);

% Moment of inertia of columuns (%90 reduction at splices)
Ic = 1e-3*[3.41726, 0.90*3.1889, 2.9927, 0.90*2.6009, 2.2643,...
    0.9*1.9061, 1.5983, 0.9*1.4998, 1.4152];

% Moment of inertia of beams
Ib = 1e-3*[4.0624, 4.0624, 3.2466, 3.2466, 3.2466,...
    3.2466, 1.6608, 1.1863, 0.7617];

% Modulus of elasticity
E = 200e9;
ro = Ib./(4*Ic);
for i=1:9
    k(i) = (1*(12*(12*ro(i)+1)/(12*ro(i)+4))*E*Ic(i)+...
        4*(12*(12*2*ro(i)+1)/(12*2*ro(i)+4))*E*Ic(i)+3*E*Ic(i))/L(i)^3;
end

% Stiffness matrix
K = [k(1)+k(2) -k(2) 0 0 0 0 0 0 0;
    -k(2) k(2)+k(3) -k(3) 0 0 0 0 0 0;
    0 -k(3) k(3)+k(4) -k(4) 0 0 0 0 0;
    0 0 -k(4) k(4)+k(5) -k(5) 0 0 0 0;
    0 0 0 -k(5) k(5)+k(6) -k(6) 0 0 0;
```

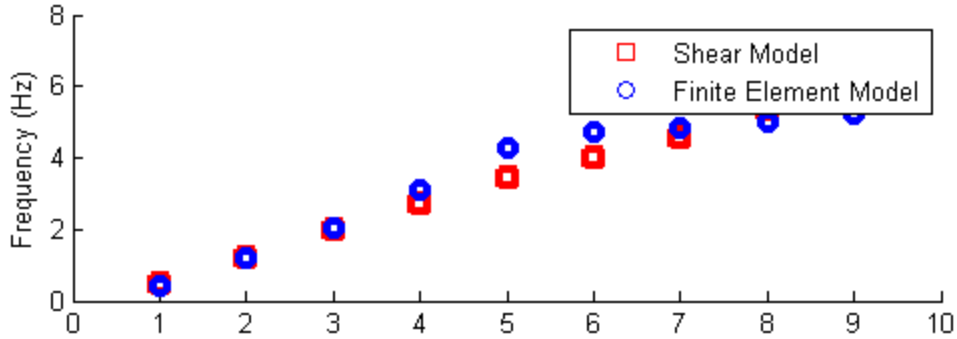
```
    0 0 0 0 -k(6) k(6)+k(7) -k(7) 0 0;
    0 0 0 0 0 -k(7) k(7)+k(8) -k(8) 0;
    0 0 0 0 0 0 -k(8) k(8)+k(9) -k(9);
    0 0 0 0 0 0   0 -k(9)  k(9)  ];

[fi,r] = eig(inv(M)*K);
r = diag(r);
% Natural freq in rad/s
w = sqrt(r);
% Arrange NF in ascending order
[w, index] = sort(w);
% Getting natural freq in Hz
NF = w/(2*pi);
% Rearranging mode shape order in accorance with NF
phi = fi(:,index);


% Normalizing the mode shape to make the Max entry 1 in each column
for i=1:size(fi,2),
        [fac n] = max(abs(phi(:,i)));
        sgn(i,1) = sign(phi(n,i));
        phi(:,i) = sgn(i)*phi(:,i)./fac;
end

% Modal mass
Mn = phi'*M*phi;
% Modal stiffess
Kn = phi'*K*phi;
% Damping ratio
zeta = 0.02;
% Modal damping
Cti=2*Mn.*zeta*...
    [w(1) 0 0 0 0 0 0 0 0;
    0 w(2) 0 0 0 0 0 0 0;
    0 0 w(3) 0 0 0 0 0 0;
    0 0 0 w(4) 0 0 0 0 0;
    0 0 0 0 w(5) 0 0 0 0;
    0 0 0 0 0 w(6) 0 0 0;
    0 0 0 0 0 0 w(7) 0 0;
    0 0 0 0 0 0 0 w(8) 0;
    0 0 0 0 0 0 0 0 w(9)];
% Damping matrix
C = inv(phi')*Cti*inv(phi);
% Modal mass
Cn = phi'*C*phi;
save mode phi
```

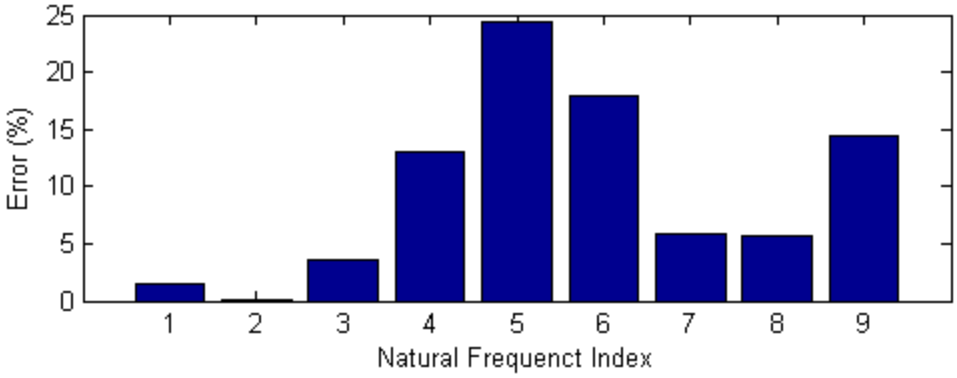
# Retrieving the FEM model

```
load Model
[fiF,rF] = eig(inv(MF)*KF);
rF = diag(rF);
% Natural freq in rad/s
wF = sqrt(rF);
% Arranging NF in ascending order
[wF, index] = sort(wF);
% Getting natural freq in Hz
NFF = wF/(2*pi);
NFFEM = NFF(1:9);
%Getting Percentage Error of NF's
NFError = abs((NFFEM-NF)./NF)*100;
% Rearrange mode shape order to correspond to NF
phiF1 = fiF(:,index);
```

```
for i = 1:9
    phiF2(:,i) = phiF1([23,36,49,62,75,88,101,114,127],i);
end

% Normalizing the mode shape to make the Max entry 1 in each column
for i=1:9,
        [facF nF] = max(abs(phiF2(:,i)));
        phiFEM(:,i) = (phiF2(:,i)./facF);
        phiFEM(:,i) = sign(phiFEM(1,i)/phi(1,i))* phiFEM(:,i);
end

figure(1)
h = [0 H];
N = 9;
for i = 1:9;
    subplot(1,9,i); plot([0;phi(:,i)],h,'--rs',...
        [0;phiFEM(:,i)],h,'--bs','LineWidth',2,...
        'MarkerFaceColor','b','MarkerSize',5); hold on;
    plot(zeros(N+1,1),h,'k','LineWidth', 2);
    xlim([-2,2]);
    xlabel('Displ. (m)');
    ylabel('Height (m)');
    title(['Mode ' int2str(i)])
end
legend('Shear Model','Finite Element Model')

figure(2)
subplot(211)
scatter([1:9],NF,'rs','LineWidth',3); hold on;
scatter([1:9],NFFEM,'b','LineWidth',3); xlim([0,10])
ylabel('Frequency (Hz)')
legend('Shear Model', 'Finite Element Model')
subplot(212)
bar(NFError)
xlabel('Natural Frequenct Index')
ylabel('Error (%)')
```


Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6
Mode 7
Mode 8
Mode 9
Shear Model
Finite Element Model
Height (m)
Displ. (m)


Shear Model
Finite Element Model
Frequency (Hz)

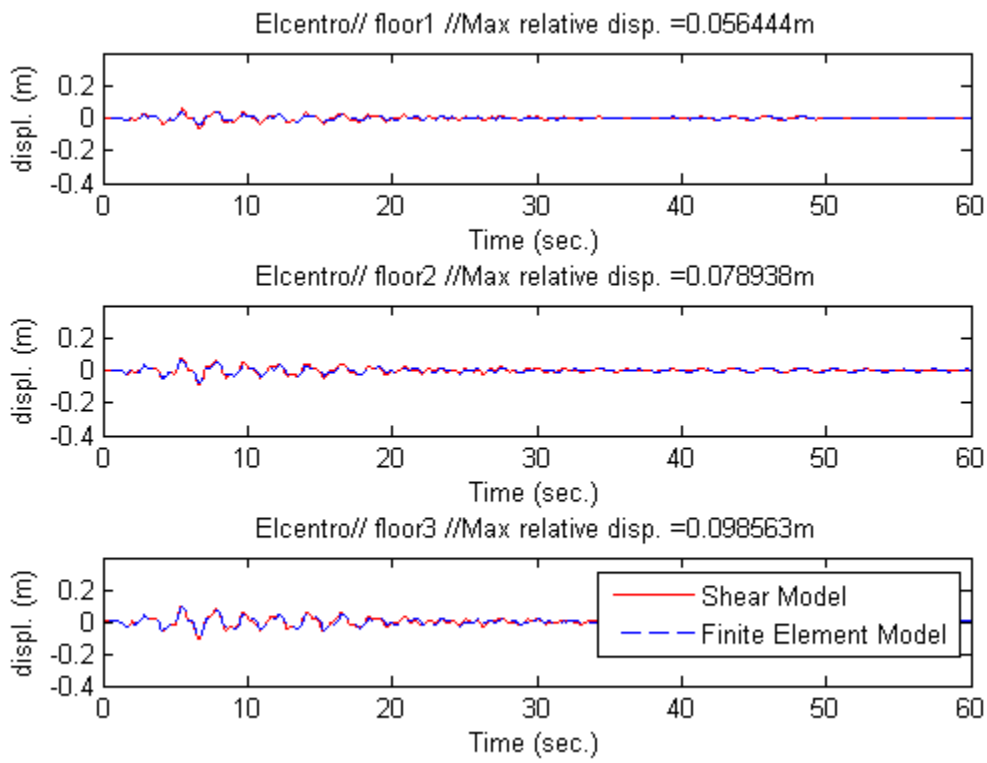

Error (%)
Natural Frequenct Index

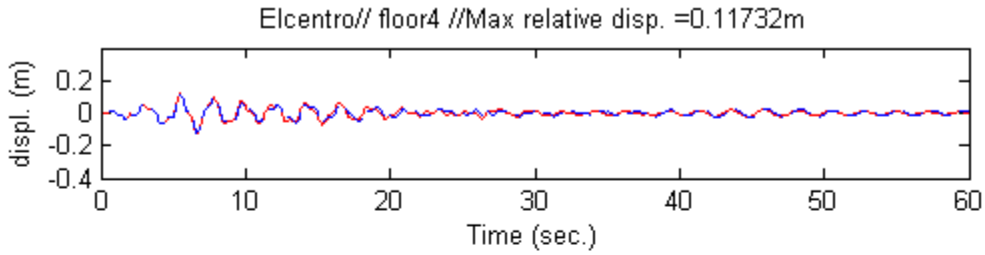
# Ground Excitation [Elcentro Intensity = 0.5]

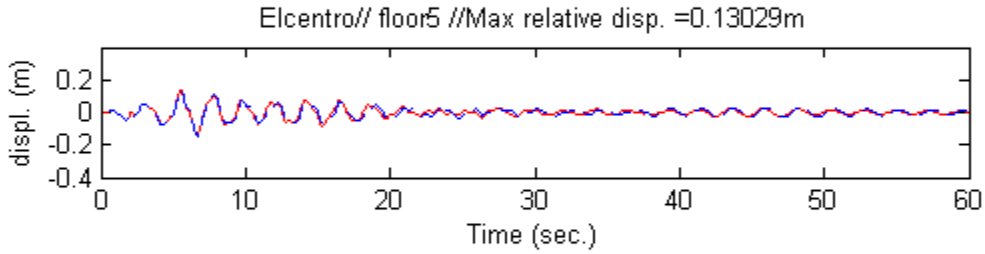
```
fs = 100; Tmax = 60;
load elcentro
load resp_elcentro
t = e(:,1);
% Intensity
int = 0.5;
%Ground Acceleration
zg = int*e(:,2);
np = length(ye(:,1));


% Creating state space form (earthquake form)
AA = [zeros(N) eye(N);-inv(M)*K -inv(M)*C];
% Earthquake input
BB = [zeros(N,1);-ones(N,1)];
CC = [eye(N) zeros(N); zeros(N) eye(N);-inv(M)*K -inv(M)*C];
% Earthquake input
DD = zeros(3*N,1);
sim('Model');

figure(3)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i),'r',t_out,ye(:,3*i),'--b');
    ylim([-0.4,0.4])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Elcentro// floor' int2str(i) ' //Max relative disp. ='...
        num2str(max(yout(:,i))) 'm']);
end
legend('Shear Model','Finite Element Model')



figure(4)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+3),'r',t_out,ye(:,3*(i+3)),'--b');
    ylim([-0.4,0.4])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Elcentro// floor' int2str(i+3) ' //Max relative disp. ='...
        num2str(max(yout(:,i+3))) 'm']);
end
legend('Shear Model','Finite Element Model')

figure(5)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+6),'r',t_out,ye(:,3*(i+6)),'--b');
    ylim([-0.4,0.4])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Elcentro// floor' int2str(i+6) ' //Max relative disp. ='...
        num2str(max(yout(:,i+6))) 'm']);
end
legend('Shear Model','Finite Element Model')

figure(6)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+9),'r',t_out,ye(:,3*i-1),'--b');
    ylim([-0.6,0.6])
    xlabel('Time (sec.)');
    ylabel('velocity (m/s)')
    title(['Elcentro// floor' int2str(i) ' //Max relative veloc. ='...
```

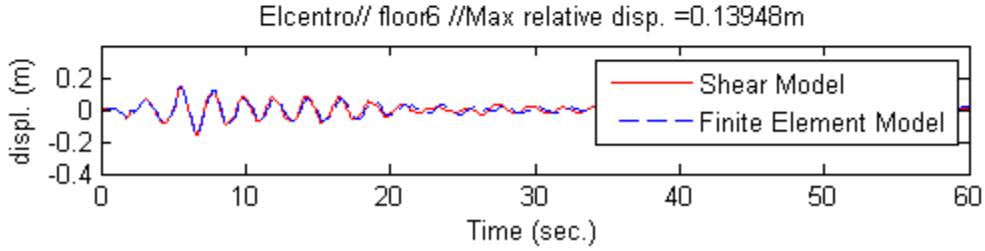
```
        num2str(max(yout(:,i+9))) 'm/s']);
end
legend('Shear Model','Finite Element Model')

figure(7)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+12),'r',t_out,ye(:,3*(i+3)-1),'--b');
    ylim([-0.6,0.6])
    xlabel('Time (sec.)');
    ylabel('velocity (m/s)')
    title(['Elcentro// floor' int2str(i+3) ' //Max relative veloc. ='...
        num2str(max(yout(:,i+12))) 'm/s']);
end
legend('Shear Model','Finite Element Model')

figure(8)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+15),'r',t_out,ye(:,3*(i+6)-1),'--b');
    ylim([-0.6,0.6])
    xlabel('Time (sec.)');
    ylabel('velocity (m/s)')
    title(['Elcentro// floor' int2str(i+6) ' //Max relative veloc. ='...
        num2str(max(yout(:,i+15))) 'm/s']);
end
legend('Shear Model','Finite Element Model')


figure(9)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+18),'r',t_out,ye(:,3*i-2),'--b');
    ylim([-4,4])
    xlabel('Time (sec.)');
    ylabel('abs. acc. (m/s2)')
    title(['Elcentro// floor' int2str(i) ' //Max abs acc. ='...
        num2str(max(yout(:,i+18))) 'm/s2']);
end
legend('Shear Model','Finite Element Model')


figure(10)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+21),'r',t_out,ye(:,3*(i+3)-2),'--b');
    ylim([-4,4])
    xlabel('Time (sec.)');
    ylabel('abs. acc. (m/s2)')
    title(['Elcentro// floor' int2str(i+3) ' //Max abs. acc. ='...
        num2str(max(yout(:,i+21))) 'm/s2']);
end
legend('Shear Model','Finite Element Model')

figure(11)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+24),'r',t_out,ye(:,3*(i+6)-2),'--b');
    ylim([-4,4])
    xlabel('Time (sec.)');
    ylabel('abs. acc. (m/s2)')
    title(['Elcentro// floor' int2str(i+6) ' //Max abs. acc. ='...
        num2str(max(yout(:,i+24))) 'm/s2']);
end
legend('Shear Model','Finite Element Model')

for i = 1:9
    rmsEl(i,1) = (1/np)*sqrt(sum((yout(:,i)-ye(:,3*i)).^2)); %RMS Error Elcentro
    rmsEl(i,2) = (1/np)*sqrt(sum((yout(:,i+9)-ye(:,3*i-1)).^2)); %RMS Error Elcent
    rmsEl(i,3) = (1/np)*sqrt(sum((yout(:,i+18)-ye(:,3*i-2)).^2)); %RMS Error Elcen
```

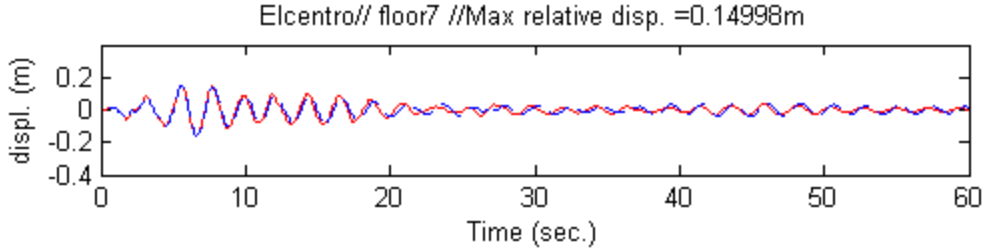
```
    PRe(i,2) = max(yout(:,i)); %Peak Response Shear Model
    PRe(i,1) = max(ye(:,3*i)); %Peak Response FEM Model
end
PREr = abs(PRe(:,1)-PRe(:,2))./(PRe(:,2))*100; %Peak Response Error
figure(12)
subplot(311)
bar(rmsEl,'group');
legend('Rel. Disp.','Rel. Vel.','Abs. Acc.')
ylabel('RMS Error (m)')
title('RMS Error 50% intensity Elcentro')
subplot(312)
bar(PRe,'group');
ylabel('Peak Response (m)')
title('Peak Response')
legend('Finite Element Model','Shear Model')
subplot(313)
bar(PREr); xlabel('Floor No.');
ylabel('Peak Response Error(%)')
title('Peak Response Error')
```

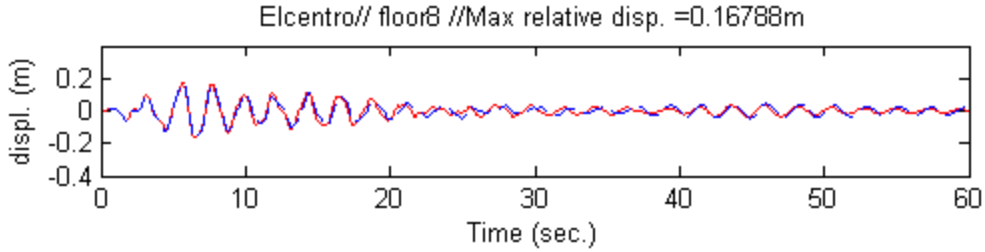


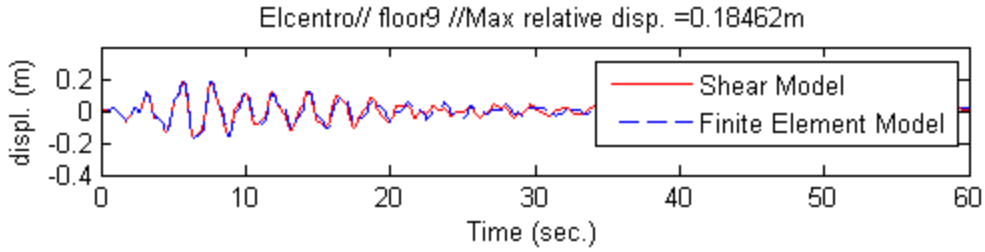

Elcentro// floor4 //Max relative disp. =0.11732m
displ. (m)
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
Time (sec.)

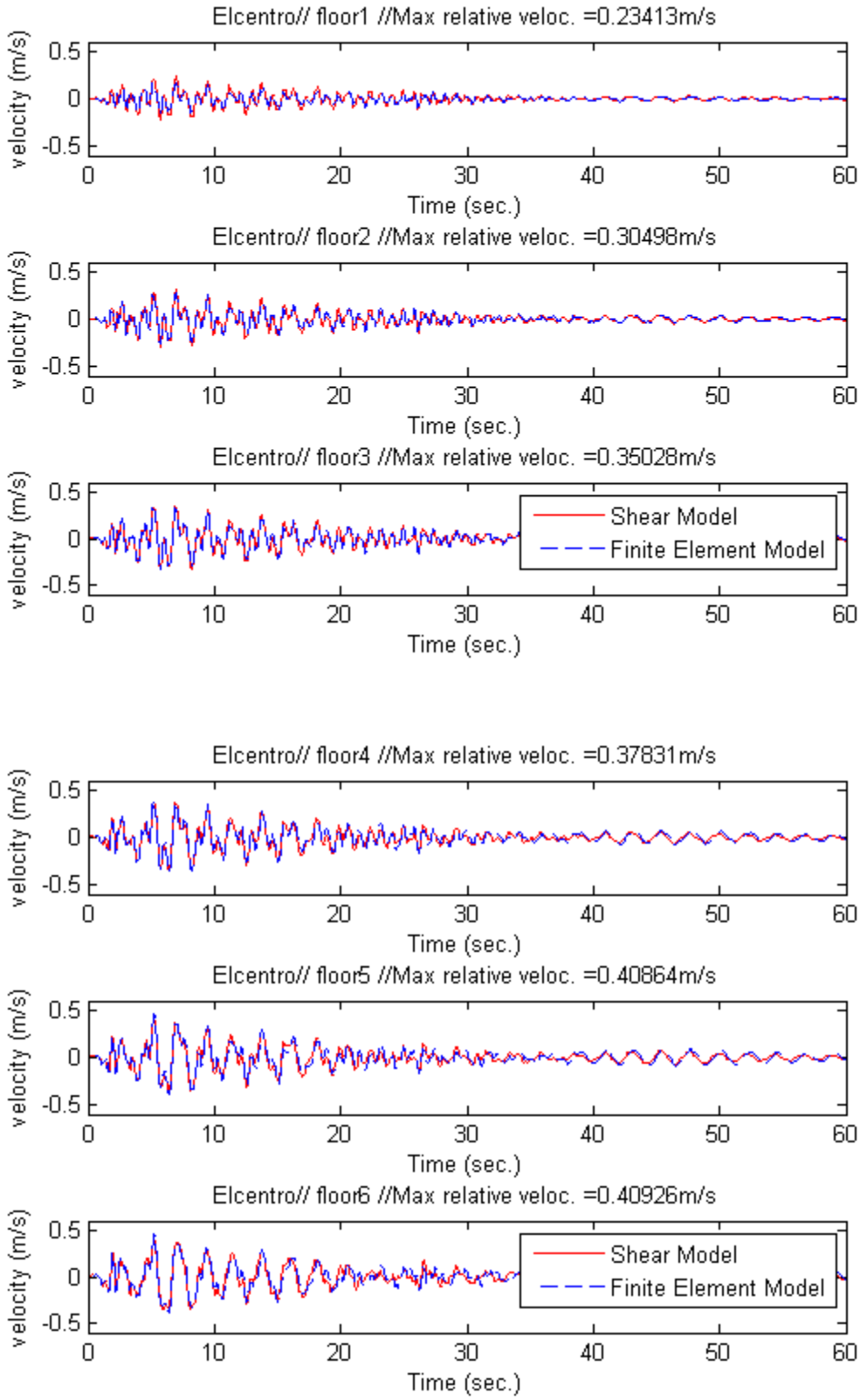

Elcentro// floor5 //Max relative disp. =0.13029m
displ. (m)
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
Time (sec.)

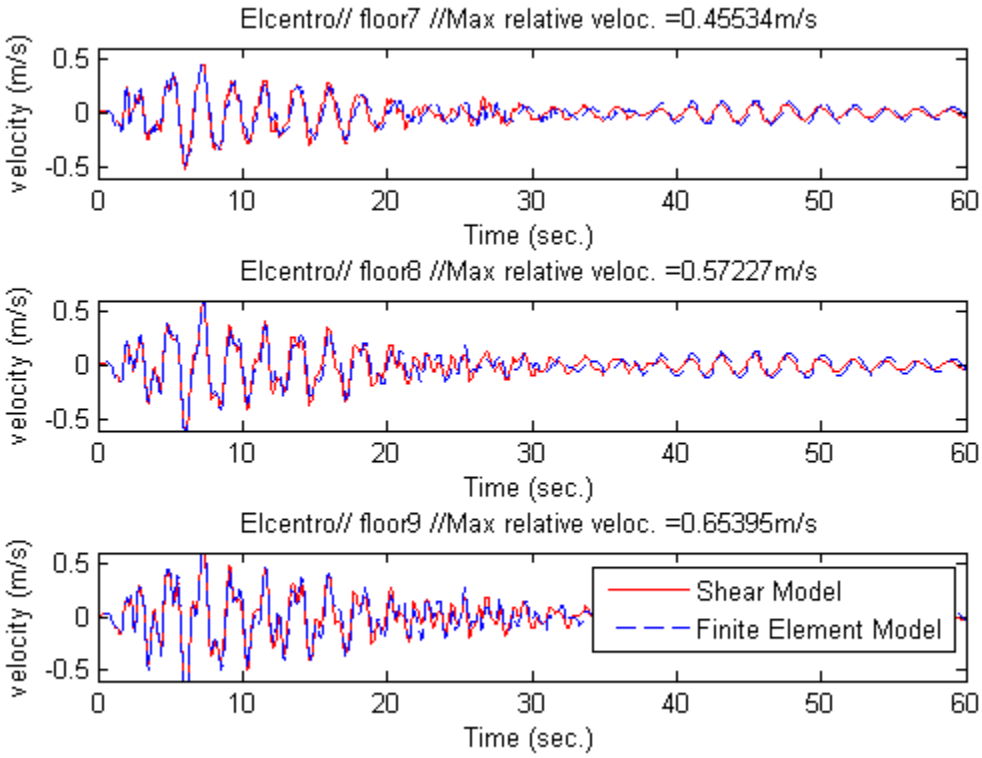

Elcentro// floor6 //Max relative disp. =0.13948m
displ. (m)
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
Time (sec.)
Shear Model
Finite Element Model

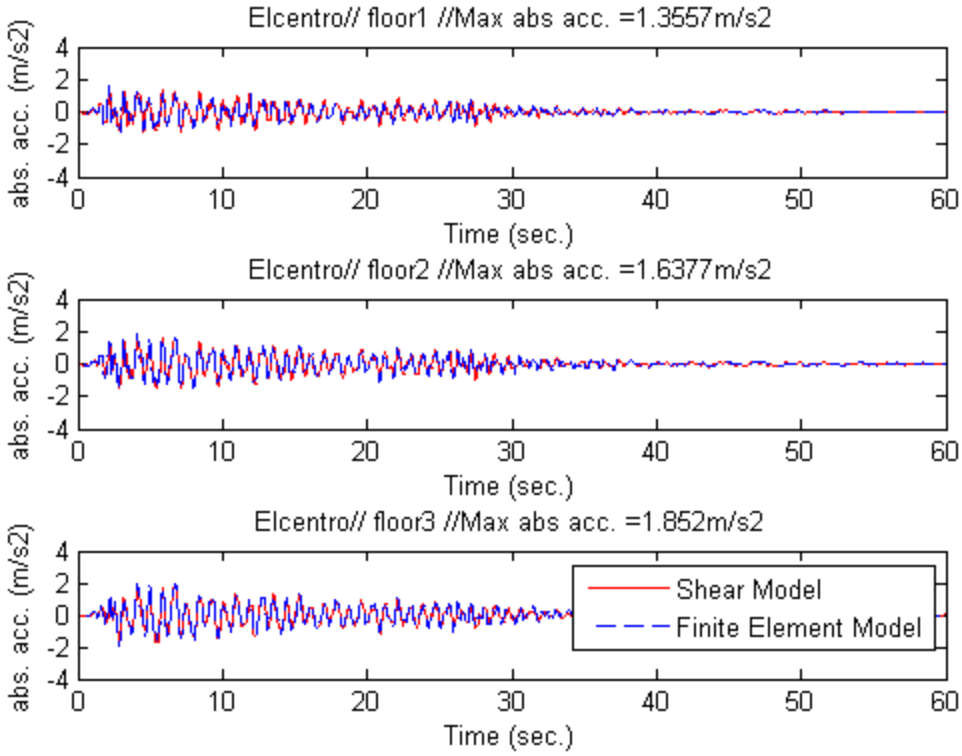

Elcentro// floor7 //Max relative disp. =0.14998m
displ. (m)
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
Time (sec.)

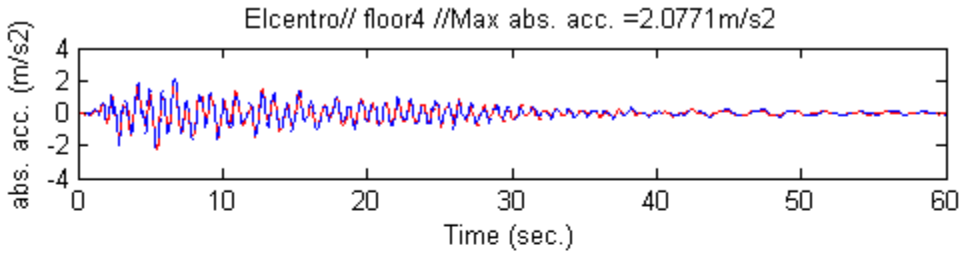

Elcentro// floor8 //Max relative disp. =0.16788m
displ. (m)
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
Time (sec.)

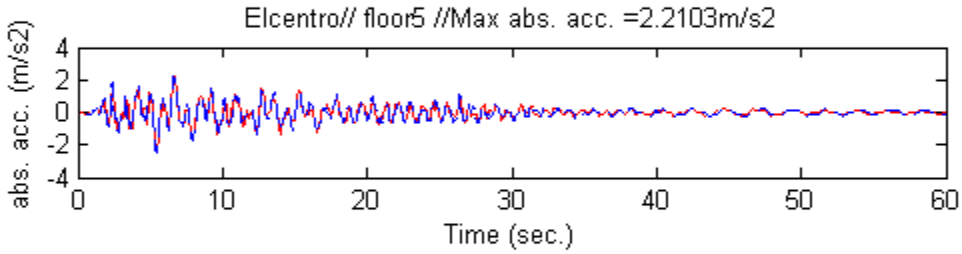

Elcentro// floor9 //Max relative disp. =0.18462m
displ. (m)
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
Time (sec.)
Shear Model
Finite Element Model

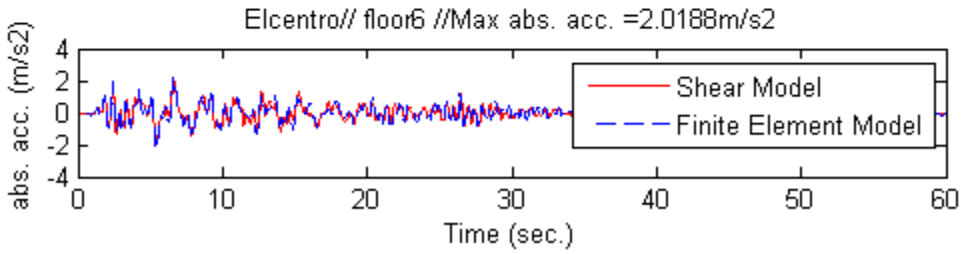

Elcentro// floor1 //Max relative veloc. =0.23413m/s
Elcentro// floor2 //Max relative veloc. =0.30498m/s
Elcentro// floor3 //Max relative veloc. =0.35028m/s
Elcentro// floor4 //Max relative veloc. =0.37831m/s
Elcentro// floor5 //Max relative veloc. =0.40864m/s
Elcentro// floor6 //Max relative veloc. =0.40926m/s
velocity (m/s)
Time (sec.)
Shear Model
Finite Element Model

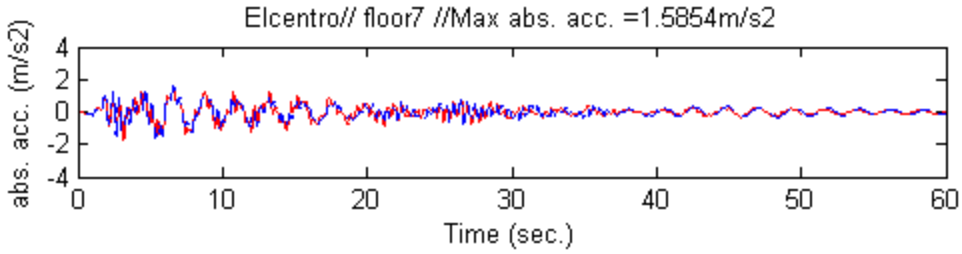

Elcentro// floor7 //Max relative veloc. =0.45534m/s
velocity (m/s)
Time (sec.)
Elcentro// floor8 //Max relative veloc. =0.57227m/s
velocity (m/s)
Time (sec.)
Elcentro// floor9 //Max relative veloc. =0.65395m/s
velocity (m/s)
Time (sec.)
Shear Model
Finite Element Model

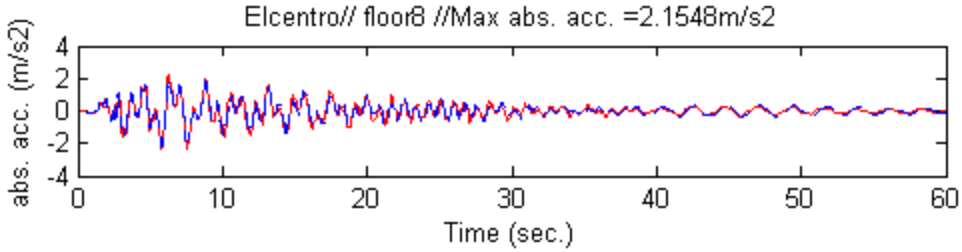

Elcentro// floor1 //Max abs acc. =1.3557m/s2
abs. acc. (m/s2)
Time (sec.)
Elcentro// floor2 //Max abs acc. =1.6377m/s2
abs. acc. (m/s2)
Time (sec.)
Elcentro// floor3 //Max abs acc. =1.852m/s2
abs. acc. (m/s2)
Time (sec.)
Shear Model
Finite Element Model

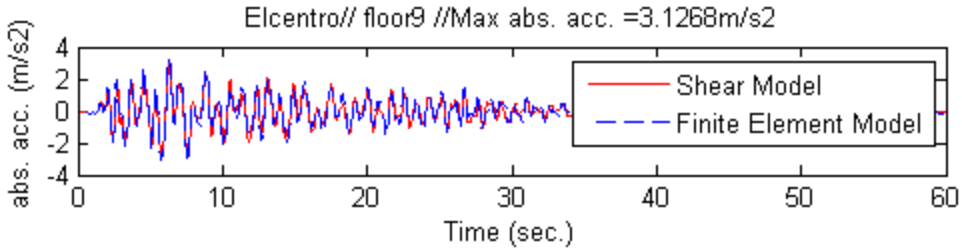

Elcentro// floor4 //Max abs. acc. =2.0771m/s2
abs. acc. (m/s2)
Time (sec.)

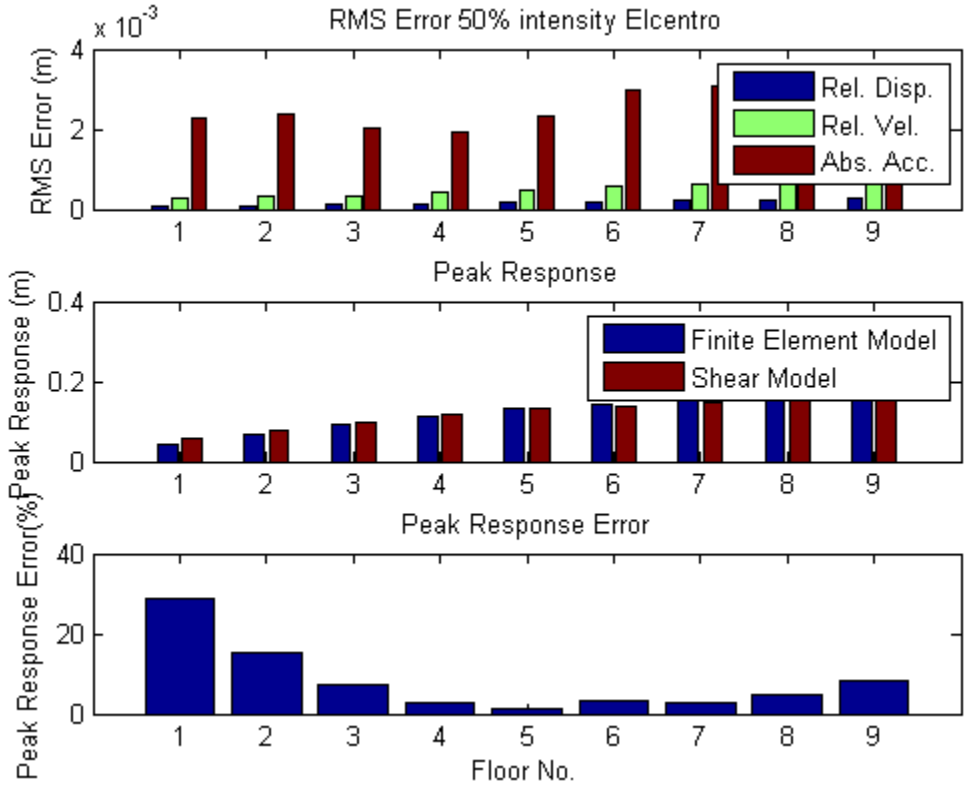

Elcentro// floor5 //Max abs. acc. =2.2103m/s2
abs. acc. (m/s2)
Time (sec.)


Elcentro// floor6 //Max abs. acc. =2.0188m/s2
abs. acc. (m/s2)
Time (sec.)
Shear Model
Finite Element Model


Elcentro// floor7 //Max abs. acc. =1.5854m/s2
abs. acc. (m/s2)
Time (sec.)


Elcentro// floor8 //Max abs. acc. =2.1548m/s2
abs. acc. (m/s2)
Time (sec.)


Elcentro// floor9 //Max abs. acc. =3.1268m/s2
abs. acc. (m/s2)
Time (sec.)
Shear Model
Finite Element Model

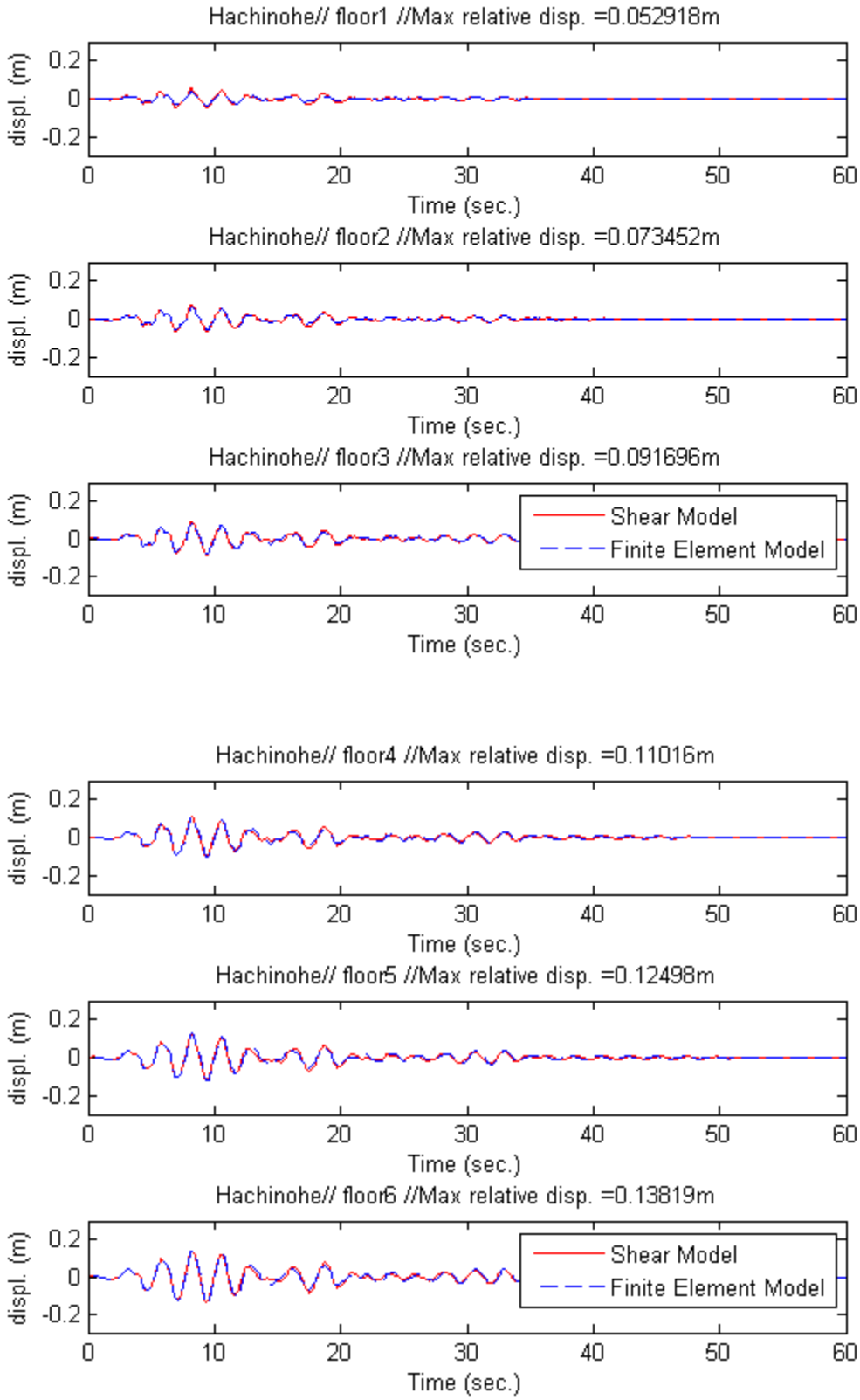


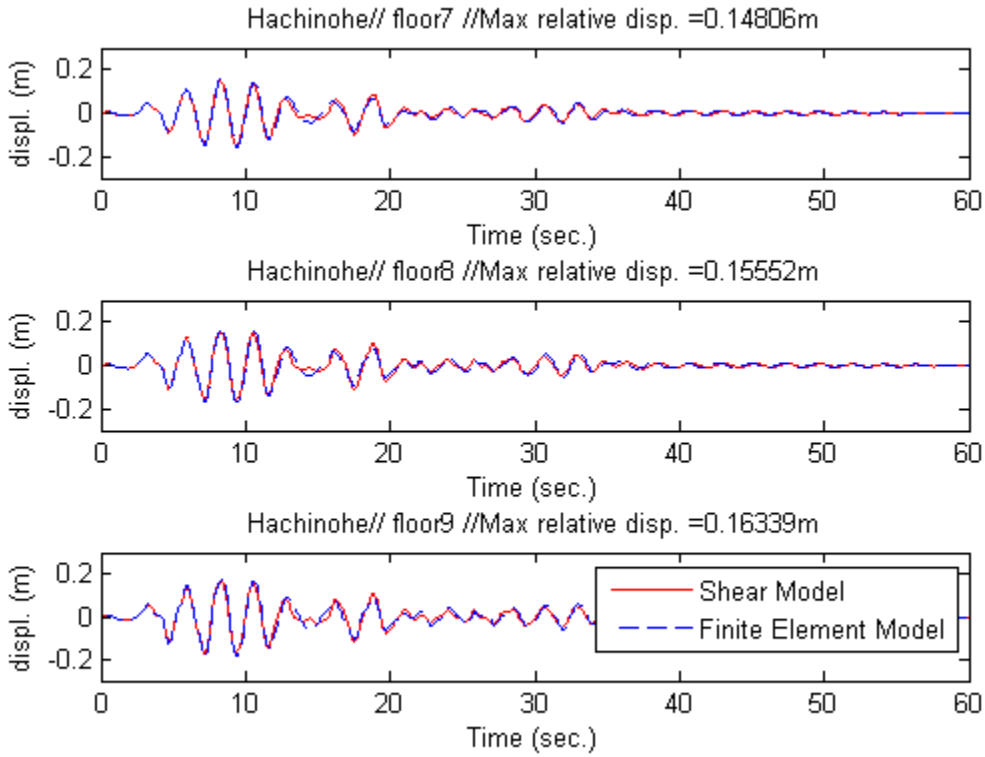

# Ground Excitation [Hachinohe Intensity = 0.5]

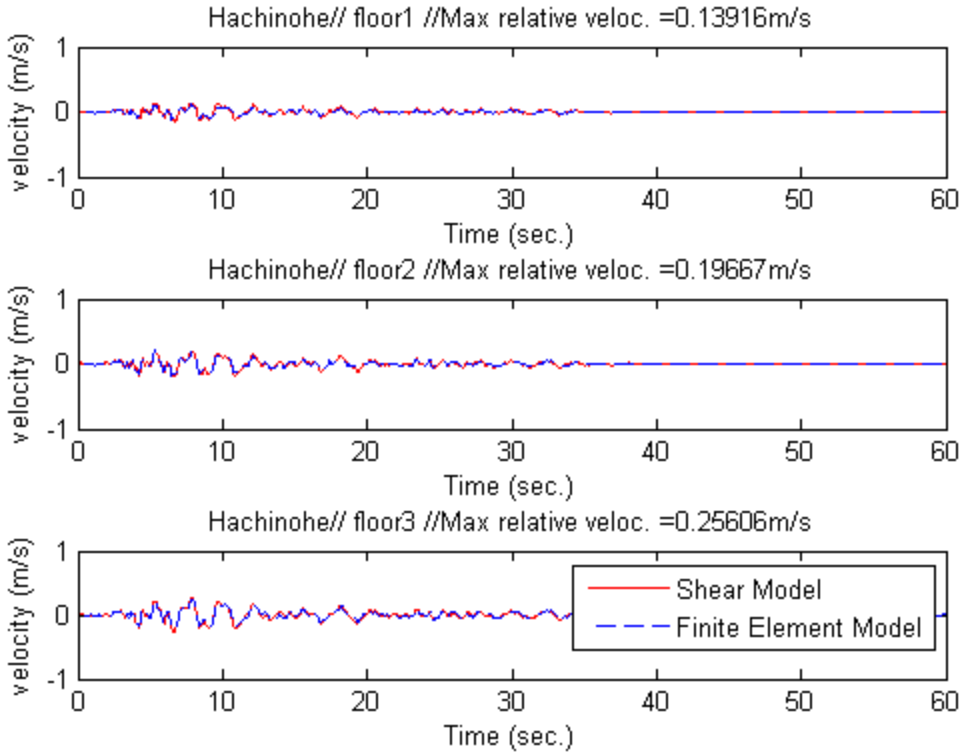
```
fs = 100; Tmax = 60;
load hachinohe
load resp_hachinohe
t = h(:,1);
% Intensity
int = 0.5;
%Ground Acceleration
zg = int*h(:,2);
% Creating state space form (earthquake form)
AA = [zeros(N) eye(N);-inv(M)*K -inv(M)*C];
% Earthquake input
BB = [zeros(N,1);-ones(N,1)];
CC = [eye(N) zeros(N); zeros(N) eye(N);-inv(M)*K -inv(M)*C];
% Earthquake input
DD = zeros(3*N,1);
sim('Model');

figure(13)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i),'r',t_out,ye(:,3*i),'--b');
    xlim([0,Tmax])
    ylim([-0.3,0.3])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Hachinohe// floor' int2str(i) ' //Max relative disp. ='...
        num2str(max(yout(:,i))) 'm']);
end
legend('Shear Model','Finite Element Model')
```

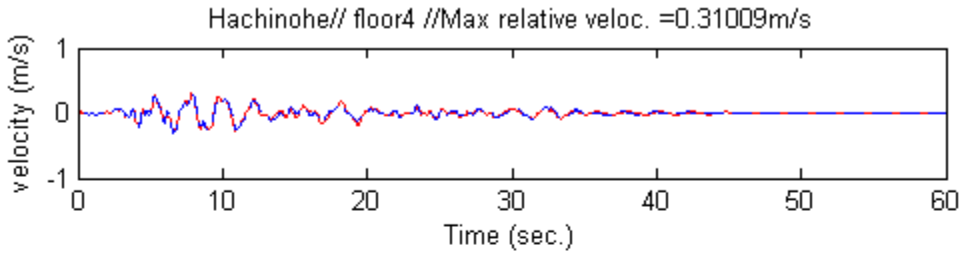
```
figure(14)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+3),'r',t_out,ye(:,3*(i+3)),'--b');
    xlim([0,Tmax])
    ylim([-0.3,0.3])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Hachinohe// floor' int2str(i+3) ' //Max relative disp. ='...
        num2str(max(yout(:,i+3))) 'm']);
end
legend('Shear Model','Finite Element Model')

figure(15)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+6),'r',t_out,ye(:,3*(i+6)),'--b');
    xlim([0,Tmax])
    ylim([-0.3,0.3])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Hachinohe// floor' int2str(i+6) ' //Max relative disp. ='...
        num2str(max(yout(:,i+6))) 'm']);
end
legend('Shear Model','Finite Element Model')

figure(16)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+9),'r',t_out,ye(:,3*i-1),'--b');
    xlim([0,Tmax])
    ylim([-1,1])
    xlabel('Time (sec.)');
    ylabel('velocity (m/s)')
    title(['Hachinohe// floor' int2str(i) ' //Max relative veloc. ='...
        num2str(max(yout(:,i+9))) 'm/s']);
end
legend('Shear Model','Finite Element Model')

figure(17)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+12),'r',t_out,ye(:,3*(i+3)-1),'--b');
    xlim([0,Tmax])
    ylim([-1,1])
    xlabel('Time (sec.)');
    ylabel('velocity (m/s)')
    title(['Hachinohe// floor' int2str(i+3) ' //Max relative veloc. ='...
        num2str(max(yout(:,i+12))) 'm/s']);
end
legend('Shear Model','Finite Element Model')

figure(18)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+15),'r',t_out,ye(:,3*(i+6)-1),'--b');
    xlim([0,Tmax])
    ylim([-1,1])
    xlabel('Time (sec.)');
    ylabel('velocity (m/s)')
    title(['Hachinohe// floor' int2str(i+6) ' //Max relative veloc.. ='...
        num2str(max(yout(:,i+15))) 'm/s']);
end
legend('Shear Model','Finite Element Model')


figure(19)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+18),'r',t_out,ye(:,3*i-2),'--b');
```

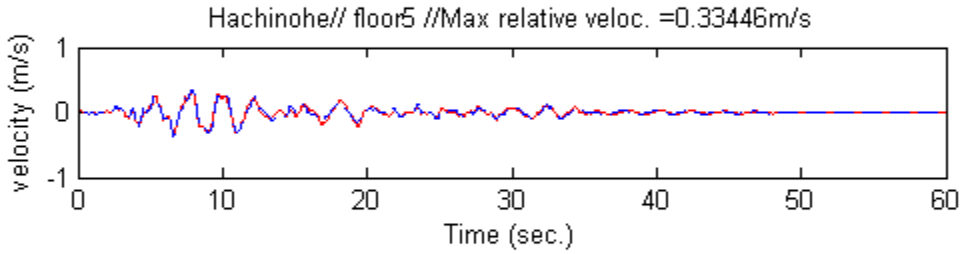
```
    xlim([0,Tmax])
    ylim([-3,3])
    xlabel('Time (sec.)');
    ylabel('abs. acc. (m/s2)')
    title(['Hachinohe// floor' int2str(i) ' //Max abs. acc. ='...
        num2str(max(yout(:,i+18))) 'm/s2']);
end
legend('Shear Model','Finite Element Model')

figure(20)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+21),'r',t_out,ye(:,3*(i+3)-2),'--b');
    xlim([0,Tmax])
    ylim([-3,3])
    xlabel('Time (sec.)');
    ylabel('abs. acc. (m/s2)')
    title(['Hachinohe// floor' int2str(i+3) ' //Max abs. acc. ='...
        num2str(max(yout(:,i+21))) 'm/s2']);
end
legend('Shear Model','Finite Element Model')

figure(21)
for i = 1:3
    subplot(3,1,i); plot(time,yout(:,i+24),'r',t_out,ye(:,3*(i+6)-2),'--b');
    xlim([0,Tmax])
    ylim([-3,3])
    xlabel('Time (sec.)');
    ylabel('abs. acc. (m/s2)')
    title(['Hachinohe// floor' int2str(i+6) ' //Max abs. acc. ='...
        num2str(max(yout(:,i+24))) 'm']);
end
legend('Shear Model','Finite Element Model')



for i = 1:9
    rmsHa(i,1) = (1/np)*sqrt(sum((yout(:,i)-ye(:,3*i)).^2)); %RMS Error Hachinohe
    rmsHa(i,2) = (1/np)*sqrt(sum((yout(:,i+9)-ye(:,3*i-1)).^2)); %RMS Error Hachin
    rmsHa(i,3) = (1/np)*sqrt(sum((yout(:,i+18)-ye(:,3*i-2)).^2)); %RMS Error Hachi
    PRh(i,2) = max(yout(:,i));
    PRh(i,1) = max(ye(:,3*i));
end
PREr = abs(PRh(:,1)-PRh(:,2))./(PRh(:,2))*100;
figure(22)
subplot(311)
bar(rmsHa,'group');
legend('Rel. Disp.','Rel. Vel.','Abs. Acc.')
ylabel('RMS Error')
title('RMS Error 50% intensity Hachinohe')
subplot(312)
bar(PRh,'group');
ylabel('Peak Response (m)')
title('Peak Response')
legend('Finite Element Model','Shear Model')
subplot(313)
bar(PREr); xlabel('Floor No.');
ylabel('Peak Response Error(%)')
title('Peak Response Error')
```

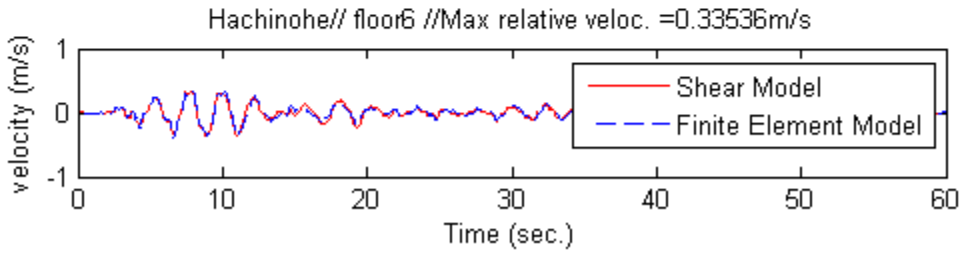

Hachinohe// floor1 //Max relative disp. =0.052918m
Hachinohe// floor2 //Max relative disp. =0.073452m
Hachinohe// floor3 //Max relative disp. =0.091696m
Hachinohe// floor4 //Max relative disp. =0.11016m
Hachinohe// floor5 //Max relative disp. =0.12498m
Hachinohe// floor6 //Max relative disp. =0.13819m
displ. (m)
Time (sec.)
Shear Model
Finite Element Model

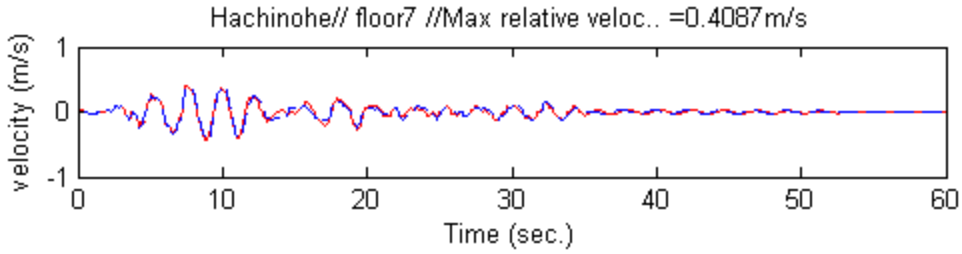

Hachinohe// floor7 //Max relative disp. =0.14806m
Hachinohe// floor8 //Max relative disp. =0.15552m
Hachinohe// floor9 //Max relative disp. =0.16339m
displ. (m)
Time (sec.)
Shear Model
Finite Element Model

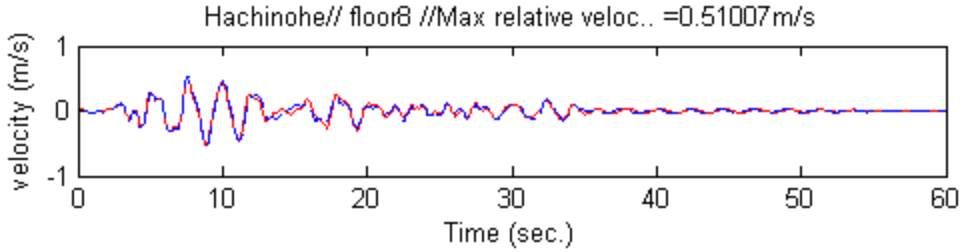

Hachinohe// floor1 //Max relative veloc. =0.13916m/s
Hachinohe// floor2 //Max relative veloc. =0.19667m/s
Hachinohe// floor3 //Max relative veloc. =0.25606m/s
velocity (m/s)
Time (sec.)
Shear Model
Finite Element Model

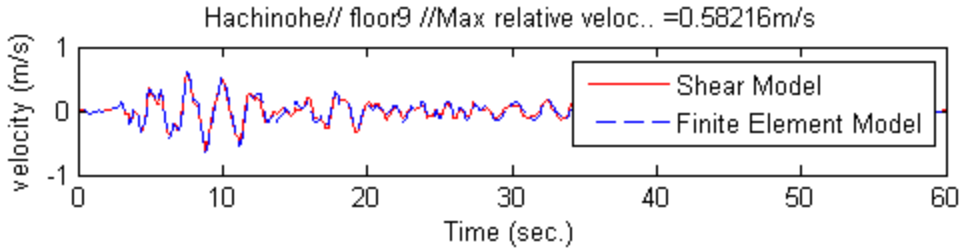

Hachinohe// floor4 //Max relative veloc. =0.31009m/s
velocity (m/s)
Time (sec.)

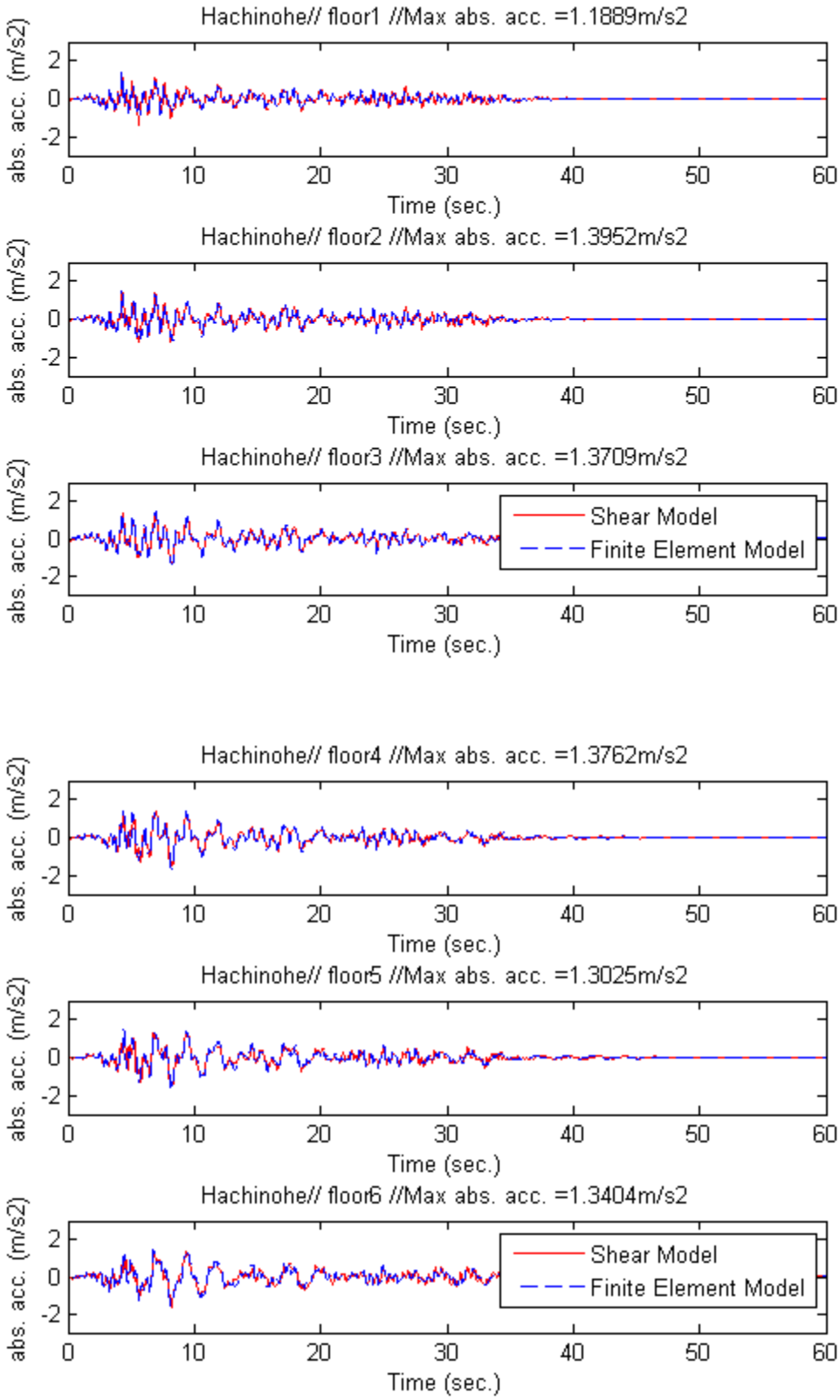

Hachinohe// floor5 //Max relative veloc. =0.33446m/s
velocity (m/s)
Time (sec.)

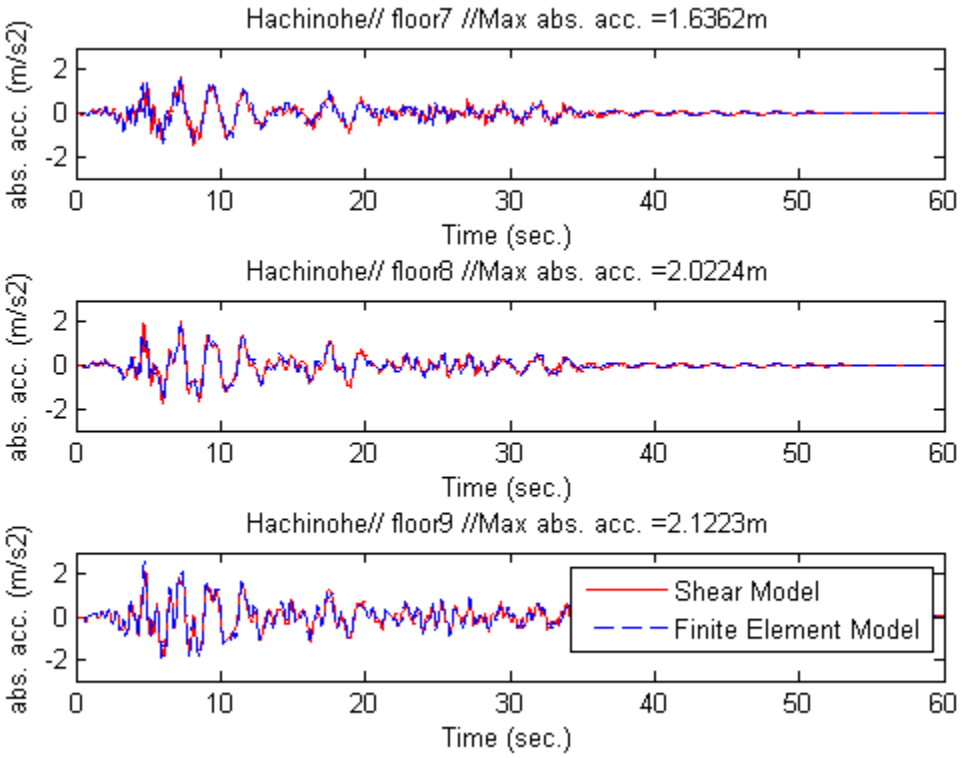

Hachinohe// floor6 //Max relative veloc. =0.33536m/s
Shear Model
Finite Element Model
velocity (m/s)
Time (sec.)

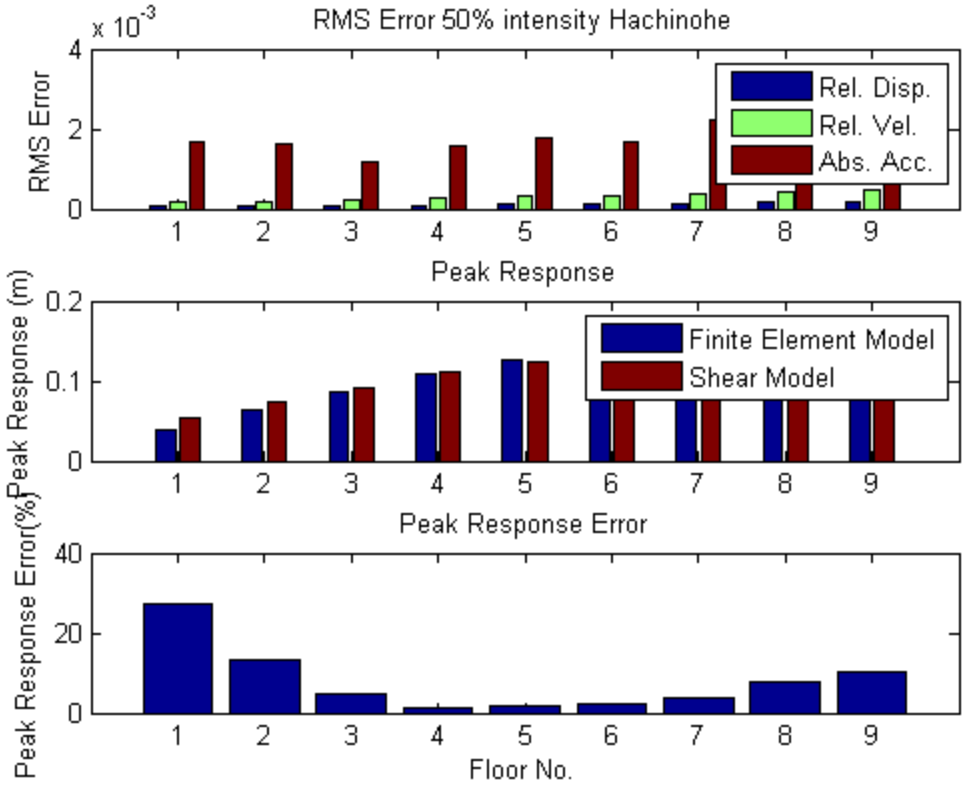

Hachinohe// floor7 //Max relative veloc.. =0.4087m/s
velocity (m/s)
Time (sec.)


Hachinohe// floor8 //Max relative veloc.. =0.51007m/s
velocity (m/s)
Time (sec.)


Hachinohe// floor9 //Max relative veloc.. =0.58216m/s
Shear Model
Finite Element Model
velocity (m/s)
Time (sec.)


Hachinohe// floor1 //Max abs. acc. =1.1889m/s2
Hachinohe// floor2 //Max abs. acc. =1.3952m/s2
Hachinohe// floor3 //Max abs. acc. =1.3709m/s2
Hachinohe// floor4 //Max abs. acc. =1.3762m/s2
Hachinohe// floor5 //Max abs. acc. =1.3025m/s2
Hachinohe// floor6 //Max abs. acc. =1.3404m/s2
abs. acc. (m/s2)
Time (sec.)
Shear Model
Finite Element Model

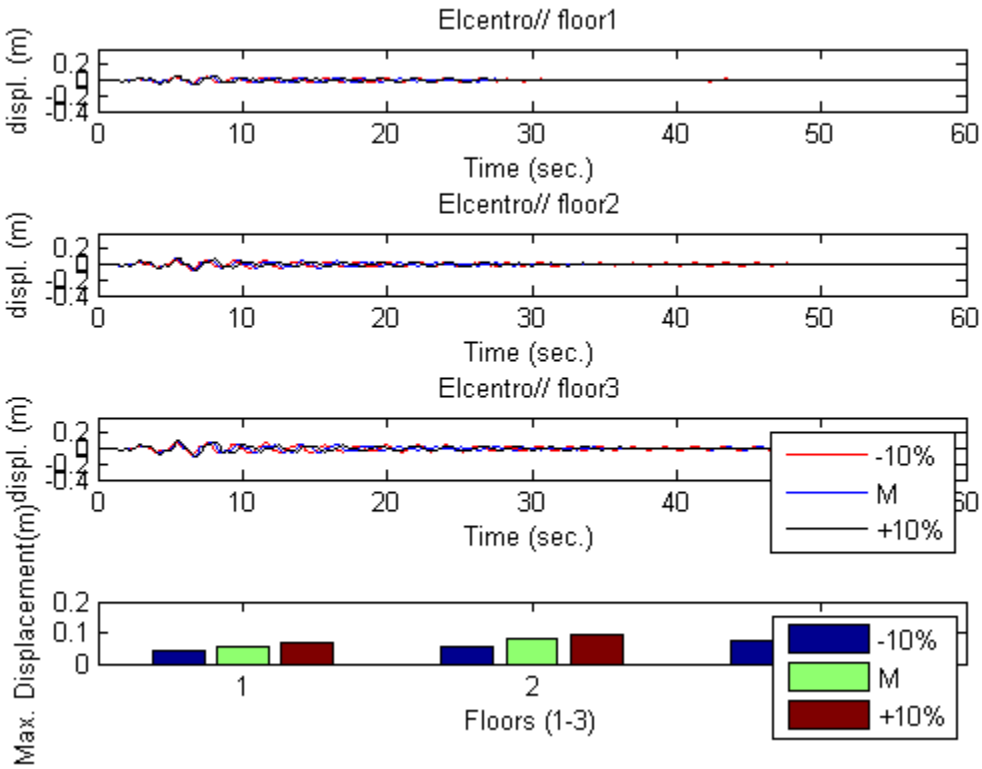

Hachinohe// floor7 //Max abs. acc. =1.6362m
abs. acc. (m/s2)
Time (sec.)
Hachinohe// floor8 //Max abs. acc. =2.0224m
abs. acc. (m/s2)
Time (sec.)
Hachinohe// floor9 //Max abs. acc. =2.1223m
abs. acc. (m/s2)
Time (sec.)
Shear Model
Finite Element Model

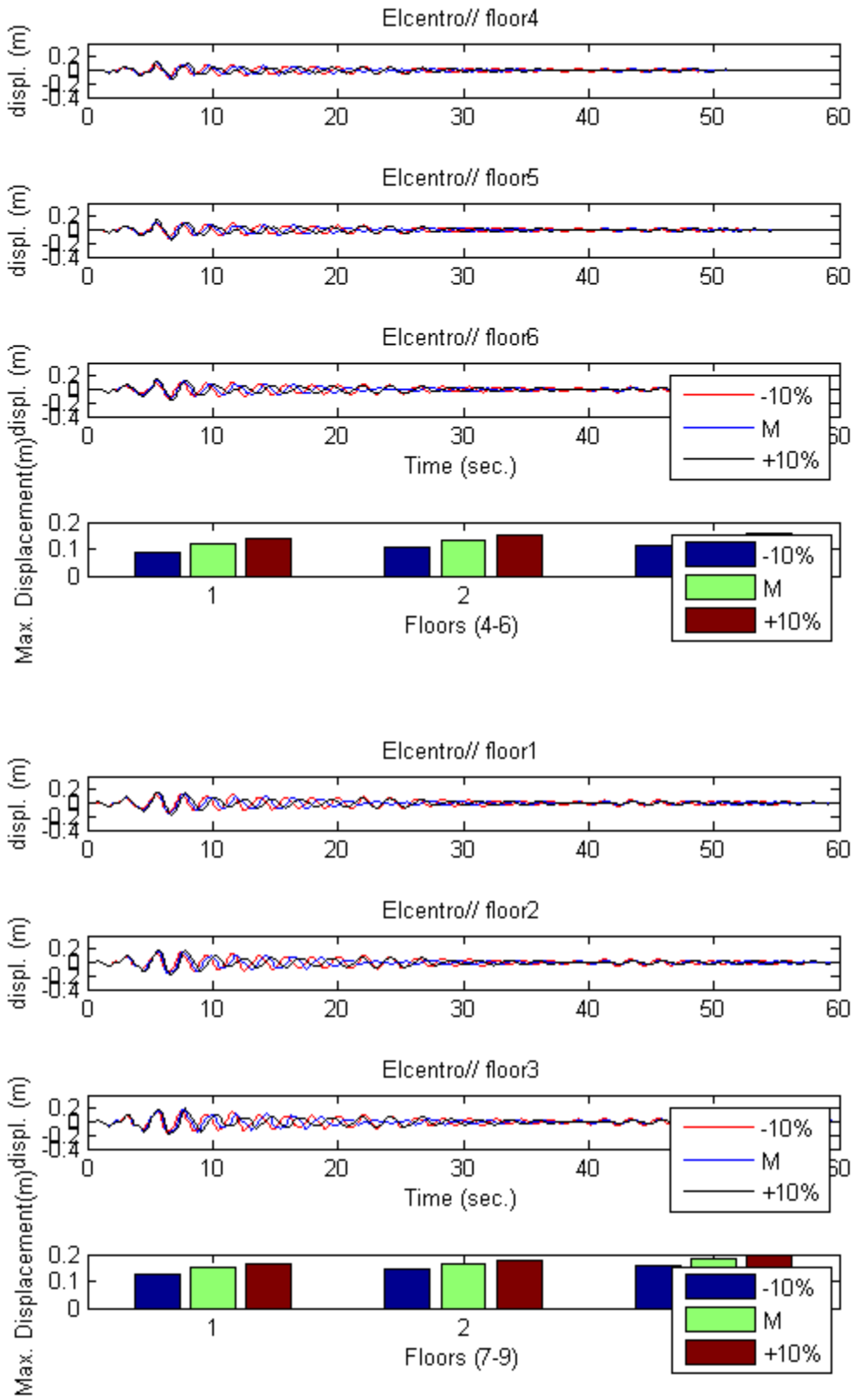

RMS Error 50% intensity Hachinohe
x 10^-3
RMS Error
Rel. Disp.
Rel. Vel.
Abs. Acc.
Peak Response
Peak Response (m)
Finite Element Model
Shear Model
Peak Response Error
Peak Response Error(%)
Floor No.

# Mass Variation

```
load elcentro
t = e(:,1); int = 0.5; % Intensity
zg = int*e(:,2);  %Ground Acceleration

load Low
AA = [zeros(N) eye(N);-inv(M)*K -inv(M)*C];
BB = [zeros(N,1);-ones(N,1)]; % earthquake input
CC = [eye(N) zeros(N); zeros(N) eye(N);-inv(M)*K -inv(M)*C];
DD = zeros(3*N,1);% earthquake input
sim('Model');
Y(:,1:27) = yout;

load Med
AA = [zeros(N) eye(N);-inv(M)*K -inv(M)*C];
BB = [zeros(N,1);-ones(N,1)]; % earthquake input
CC = [eye(N) zeros(N); zeros(N) eye(N);-inv(M)*K -inv(M)*C];
DD = zeros(3*N,1);% earthquake input
sim('Model');
Y(:,28:54) = yout;

load High
AA = [zeros(N) eye(N);-inv(M)*K -inv(M)*C];
BB = [zeros(N,1);-ones(N,1)]; % earthquake input
CC = [eye(N) zeros(N); zeros(N) eye(N);-inv(M)*K -inv(M)*C];
DD = zeros(3*N,1);% earthquake input
sim('Model');
Y(:,55:81) = yout;


figure(23)
for i = 1:3
    subplot(4,1,i); plot(time,Y(:,i),'r',time,Y(:,i+27),'b',time,Y(:,i+54),'k');
    ylim([-0.4,0.4])
    xlabel('Time (sec.)');
    ylabel('displ. (m)')
    title(['Elcentro// floor' int2str(i)]);
    mdis(i,1:3) = max([Y(:,i),Y(:,i+27),Y(:,i+54)]); %Max Displacement
end
xlabel('Time (sec.)');
legend('-10%','M','+10%' )
subplot(4,1,4); bar(mdis(1:3,:),'group')
xlabel('Floors (1-3)'); ylabel('Max. Displacement(m)')
legend('-10%','M','+10%' )

figure(24)
for i = 1:3
    subplot(4,1,i); plot(time,Y(:,i+3),'r',time,Y(:,i+30),'b',time,Y(:,i+57),'k');
    ylim([-0.4,0.4])
    ylabel('displ. (m)')
    title(['Elcentro// floor' int2str(i+3)]);
    mdis(i+3,1:3) = max([Y(:,i+3),Y(:,i+30),Y(:,i+57)]); %Max Displacement
end
xlabel('Time (sec.)');
legend('-10%','M','+10%' )
subplot(4,1,4); bar(mdis(4:6,:),'group')
xlabel('Floors (4-6)'); ylabel('Max. Displacement(m)')
legend('-10%','M','+10%' )

figure(25)
for i = 1:3
    subplot(4,1,i); plot(time,Y(:,i+6),'r',time,Y(:,i+33),'b',time,Y(:,i+60),'k');
    ylim([-0.4,0.4])
```

```
    ylabel('displ. (m)')
    title(['Elcentro// floor' int2str(i)]);
    mdis(i+6,1:3) = max([Y(:,i+6),Y(:,i+33),Y(:,i+60)]); %Max Displacement
end
xlabel('Time (sec.)');
legend('-10%','M','+10%' )
subplot(4,1,4); bar(mdis(7:9,:),'group')
xlabel('Floors (7-9)'); ylabel('Max. Displacement(m)')
legend('-10%','M','+10%' )
```




Elcentro// floor4
Elcentro// floor5
Elcentro// floor6
Elcentro// floor1
Elcentro// floor2
Elcentro// floor3
displ. (m)
Time (sec.)
Max. Displacement(m)
Floors (4-6)
Floors (7-9)
-10%
M
+10%

*Published with MATLAB® 7.9*