Fluctuations of System Frequencies Measured During Ambient and Hammer Tests in Kaprielian Hall at the University of Southern California

by

M. Ebrahimian and M.D. Trifunac

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ABSTRACT

The purpose of this report is to document the temporal changes of system frequencies measured during full-scale tests (ambient and impulse) in Kaprielian Hall. Studies have shown that even small “structural” changes (remodeling of partition walls) as well as non-structural features (such as rainy weather, ambient temperature, and nonlinear soil behavior) can change the system frequencies of buildings. This report describes changes in system frequencies of Kaprielian Hall, a four-story steel structure at University of Southern California campus. The building has been tested repeatedly since 1993, by graduate students enrolled in Prof. Trifunac’s CE 535b Earthquake Engineering course.
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1. BUILDING DESCRIPTION

Kaprielian Hall (Figure 1) is a four story steel structure located on the University of Southern California main campus, at the north-east corner of Vermont Avenue and West 36th Place (the street address is 3620 South Vermont Avenue, Los Angeles, California). It is used mostly for offices (2nd, 3rd and 4th floors), but also for classrooms (1st floor) and for laboratories (basement). It is the home of the Civil Engineering Department.

The building is 52 feet high above ground level. The structural system is a combination of moment resistant frames and bracing. It has eleven transverse frames at 20 feet spacing and three longitudinal frames at 30 feet spacing. The three elevators, located in the middle of the structure, resulted in larger middle span (25 feet) in the longitudinal frames. Most of the lateral loads in the transverse direction are carried by frames 2, 5, 10 and 13, braced at the first three floors, and by the moment frames on the top floors. A detailed description of the building can be found in the report by Ivanović and Trifunac (1995).
Figure 2- Typical floor plan of Kaprielian Hall

Figure 3- NS cross section of Kaprielian Hall
Figure 4- EW cross section of Kaprielian Hall
2. METHODOLOGY

We begin by briefly summarizing the typical procedures for finding the system frequencies from recorded data of ambient vibrations. These procedures were followed by USC graduate students taking CE 535b, Earthquake Engineering course, during most of the measurements taken in Kaprielian Hall:

1. Make a sketch of sensor locations, orientations and of the corresponding recording channel numbers in the description of the experiment.

2. Plot the recorded data in time domain. These plots serve to verify that the sensors are working properly. For example, during impulse (hammer) test, one should be able to follow the waves caused by hammer impacts as those propagate in the structure.

3. As a first step in time series analysis all the data is de-trended, low-pass filtered and down sampled. De-trending means that at zero frequency, in the Fourier transform of the recorded data, there should be zero amplitude. To accomplish this average is subtracted from the data. For presentations in this report data is also low-pass filtered to 0-25 Hz, using an Ormsby filter, which has a zero phase-lag (Trifunac 1971). After low pass filtering there is no need to keep data with the high frequency sampling (400 samples/second were recorded during most tests), and it can be down sampled to a convenient frequency suitable for analysis. Based on the sampling theorem, for a maximum frequency of 25 Hz in the low-pass filtered data only samples at frequency of 50 Hz are required.

4. After filtering, if there is a sensor at the base of structure (to be used at reference), the transfer functions \((H(f))\) are computed from the ratio of Fourier transforms of the recordings on the 4th floor to the Fourier transform of the sensor which is chosen as the reference, typically in the basement of the building. The system frequencies are then determined from the peaks of transfer functions. Before calculating transfer functions Fourier transforms are smoothed by a moving average filter. Each point is replaced by the average over the interval including 25 data points before and 25 data points after the point in question. If there is no sensor at the base of the structure, system frequencies can be estimated approximately from the peaks of Fourier transforms of the recorded motions by the sensors on the 4th floor.
5- Calibration test was performed for most of the experiments described in this report. The purpose of this test is to allow one to eliminate the effects due to instrument characteristics and different cable resistances on the amplitudes of measured data. This test involves placing all instruments close to each other at the same level and all parallel to each other (so that input motion can be assumed to be the same) and comparing their recordings. Ideally if the instruments and cables were identical the recordings should be the same. In reality the recordings are slightly different because of differences in sensor characteristics (even when the sensors are of the same type). The results of calibration tests are then used to calculate frequency dependent calibration ratios. An instrument is chosen as reference (for convenience it can be the same as the reference used in calculations of transfer functions) and Fourier transform of reference is divided by Fourier transform of the recordings from all other instruments. The resulting ratio is called calibration ratio for the corresponding instrument. Calibration ratios are used to correct the recordings for all instruments (and consequently corresponding transfer functions). In this report system frequencies are presented based on transfer functions and Fourier transforms that were not all corrected by calibration tests because the purpose of this report is merely to present the recorded data and to show the general trends. For more detailed analyses based on this data calibration ratios should be calculated to make sure that the Fourier spectra from all transducers act as if recorded by the same instrument. The corrected transforms can be determined from.

\[
|H(f)| = \frac{X(f)}{X_R(f)}
\]

(1)

6- Since the length of the building in EW direction is shorter than in the NS direction the first torsional mode will better be displayed in EW recordings. By subtracting instrument recordings in EW direction, at North end and South ends of the 4th floor and dividing by the distance between the instruments, one can find torsional angles of building response. The torsional frequency will also be visible on EW transfer functions, but calculating the torsional response from the differences of recorded motions at North and South ends of the building will amplify the amplitudes near the torsional frequency and will make it easier to identify.
3. RESULTS

In this following, repeated measurements in the building are described and only elementary examples of analyses presented. Documentation for all experiments is based on student reports, some of which were incomplete or were lost. Nevertheless, for completeness of this presentation we include all data that has been preserved over the period of twenty years, since 1993, and we describe only the fundamental system frequencies. Those who are interested to use this data, should be able to decipher and to interpret some of the missing details by perfuming more detailed analysis than just the Fourier spectra and transfer functions, which are presented here.

Figure 5- Time domain representation of recordings during NS hammer test (impulse at NW stairway) during 2012 experiment, Recordings are plotted in order of instrument locations (plots on top correspond to instruments on the 4th floor and plots at the bottom correspond to instruments in basement)
3.1 Typical Results

To clarify the measuring procedure, in the first section some typical results are presented. Detailed descriptions of tests and of computer programs used to analyze data are included in appendix.

![Figure 6- Transfer functions with respect to channel 5 for EW hammer test (impulse at NW stairway) during 2012 experiment](image1)

![Figure 7- Impulsive excitation of the structure in the EW direction by a hammer at the fourth floor (2011 experiment)](image2)
Figure 8- Instruments in the basement during the calibration test (2011 experiment)

Figure 5 illustrates the time series of the recordings during NS hammer test (impulse at NW stairway) during 2012 experiment. It can be seen that it is possible to follow the impulse as it propagates down and south through the structure. Looking at the recorded data in time domain can help verify that the instruments are working correctly.

Figure 6 illustrates the plots of transfer functions, for the instruments on the fourth floor, during EW hammer test (impulse at NW stairway) during 2012 experiment. System frequencies appear as peaks in these transfer functions. Figure 7 shows application of impulse with a hammer by one of the students during 2011 test.

Figure 8 shows all instruments in the basement, as Prof. Trifunac is balancing them before the calibration test during 2011 experiment.
3.2 Summary of Measured System Frequencies

First system, NS, EW and torsional frequencies were analyzed for each experiment. Table 1 shows average values and the corresponding variances for each test. Calculation of the torsional frequency was only possible for the experiments for which test descriptions were available.

To show how the frequencies change with time the average values and their variances are shown in Figures 9 to 11. Observed variations of the average values for NS, EW, and torsional frequencies are 0.35, 0.25 and 0.35 Hz respectively.

Table 1- First NS, EW, torsional system frequencies

<table>
<thead>
<tr>
<th>year</th>
<th>date</th>
<th>average freq. (Hz)</th>
<th>σ (Hz)</th>
<th>average freq. (Hz)</th>
<th>σ (Hz)</th>
<th>average freq. (Hz)</th>
<th>σ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>3/24/12</td>
<td>3.00</td>
<td>0.045</td>
<td>2.66</td>
<td>0.089</td>
<td>2.99</td>
<td>0.022</td>
</tr>
<tr>
<td>2011</td>
<td>2/27/11</td>
<td>3.10</td>
<td>0.040</td>
<td>2.53</td>
<td>0.089</td>
<td>2.9</td>
<td>0.099</td>
</tr>
<tr>
<td>2006</td>
<td>2/25/06</td>
<td>2.89</td>
<td>0.035</td>
<td>2.61</td>
<td>0.060</td>
<td>2.9</td>
<td>0.000</td>
</tr>
<tr>
<td>2005</td>
<td>Spring</td>
<td>2.90</td>
<td>-*</td>
<td>2.66</td>
<td>-*</td>
<td>2.95</td>
<td>-*</td>
</tr>
<tr>
<td>2002</td>
<td>2/3/02</td>
<td>2.97</td>
<td>0.029</td>
<td>2.7</td>
<td>0.037</td>
<td>3</td>
<td>0.032</td>
</tr>
<tr>
<td>2001</td>
<td>2/24/01</td>
<td>2.95</td>
<td>0.066</td>
<td>2.69</td>
<td>0.013</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2000</td>
<td>2/26/00</td>
<td>2.98</td>
<td>0.001</td>
<td>2.75</td>
<td>0.011</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1999</td>
<td>3/13/99</td>
<td>2.94</td>
<td>0.031</td>
<td>2.72</td>
<td>0.018</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1996</td>
<td>March</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1995</td>
<td>5/7/95</td>
<td>3.1 amb., 3.05 hammer</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>1994</td>
<td>5/18/94</td>
<td>3.10</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>1994</td>
<td>1/19/94</td>
<td>3.10</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>1993</td>
<td>6/5,6/93</td>
<td>3.25</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>3.05</td>
<td>-</td>
</tr>
</tbody>
</table>

* Only one acceptable/available data point
Figure 9- Variation of the first NS system frequency versus time

Figure 10- Variation of the first EW system frequency versus time
Figure 11- Variation of the first torsional system frequency versus time
4. CONCLUSIONS

The frequencies of Kaprielian Hall building, measured by ambient vibration tests were no doubt influenced by many factors in addition to the changes in the structure. This study shows the range of these fluctuations between 1993 and 2012. In 1994 the Northridge California earthquake (Trifunac et al. 1994) shook the building and a significant decrease in all fundamental system frequencies was observed. In this report we merely document those changes, and leave it to the future response studies to interpret and to correlate those changes with known remodeling history primarily of the nonstructural partition walls inside the building.

At present, the documentation about the weather conditions (wind, humidity, atmospheric pressure and temperature) and other site features (like degree of water saturation in the soil) that all may affect the measured results at the time the experiments were performed, were not recorded for all experiments and their reconstruction is not included in this report. Except for the regular watering of the shrubs and flowers around the building the soil was typically dry during most experiments. All experiments were conducted in the morning hours on Saturdays or Sundays, while temperature was in the range from 70 to 80 Fahrenheit and while essentially all offices and classrooms were not occupied by faculty, staff and students.
REFERENCES


Appendix A: Comments on Reading Data from Binary Files

All recorded data is stored in binary files. A program in Fortran is included that can read the binary files and save the data as text files. Inputs to reading program are the number of channels and the number of data points in time for each channel. To make sure that data is extracted to the end, one can put a large number for number of data points. The program will end automatically when the end of a file is reached.

It should be noted that selecting the right number of channels is very important for extracting the data. Using wrong number of channels will result in meaningless data. For some tests there are a few dummy or malfunctioning channels in the data files. Those either contain no signal or the constant number “-32768” is repeated in the column. In extracting data one should count these useless channels to get the right data for the channels that actually contain recorded data. To do so the duration of recording time and recoding frequency should be known. Assuming that the recording time is 1 min with sampling frequency of 400 samples/sec (which is the case in all tests unless otherwise mentioned), each channel should contain 24001 data points. If we count total number of data points and divide it by 24001, the result is the right number of channels that should be extracted. After extraction one can look at different columns and see which ones actually contain data. To count total number of data points one can use the provided reading program for input values of 1 for number of channels and a large enough number for number of rows to make sure that all of data will be extracted.
Appendix B: Computer Programs

The programs used for data analysis are listed below. Except for the program that reads the data from binary files, which is in Fortran, the rest are in Matlab. Some of the programs may be slightly different for different tests, but the main idea is the same.

1- “Read.for”: This program is used to extract data from binary files. Binary file should be in the same directory as this program.

```
17

The programs used for data analysis are listed below. Except for the program that reads the data from binary files, which is in Fortran, the rest are in Matlab. Some of the programs may be slightly different for different tests, but the main idea is the same.

1- “Read.for”: This program is used to extract data from binary files. Binary file should be in the same directory as this program.

```

```
*******************************
* read.for
*******************************
* Reads data from ambient vibration tests and writes in txt files.
integer*2 x(64)
character file_name*20

write (*,'(" Input file = ",\")
read (*,'(a)') file_name

write (*,'(" Number of channels in the file = ",\")
read (*,'*') n_channel

write (*,'(" Number of time steps to read = ",\")
read (*,'*') n_time

open (2,file=file_name,status='old',access='direct',
form='binary',recl=2)

open (3,file='data.txt',status='unknown')

i=0
    do 10 j=1,n_time
        do 20 k=1,n_channel
            i=i+1
            read (2,rec=i) x(k)
            n_time=n_time+1
        20     continue
    c    write (*,1000) (x(l),l=1,n_channel)
    write (3,1001) (x(l),l=1,n_channel)
10    continue

1000     format (10i9,,5x,10i9)
1001     format (10i9)
stop
end
```
2- “Ormsby_Weights.m”: This Matlab function produces impulse response function of Ormsby low-pass filter

```matlab
function [NW, W_sym] = Ormsby_Weights(NDATA, DDT, DF, FN)

% This program calculates impulse response function of an ormsby low pass filter
% Calculates the weights W(i), i=1,NN for a low-pass Ormsby filter
% NN = number of filter coefficients
% NDATA = number of points of signal to be filtered
% DDT = sampling interval of input signal (delta t)
% FN = the termination frequency in Hz
% The frequency after that gain is zero??
% DF = width in Hz of the transition band

FNDQ=1/(2*DDT);
ALR=DF*DDT;
NN=1/ALR;

if(NN>NDATA)
    NN=NDATA;
end

% SET NN TO MULTIPLES OF 5
NN=(ceil((NN-1)/5)+1)*5;
ALC=(FN-DF)*DDT;
ALT=ALC+ALR;

W=zeros(NN,1);
W(1)=ALT+ALC;
B1=2*ALR;

AN=(1:NN-1)*pi;
AR1=2*AN*ALC;
AR2=2*AN*ALT;
AR4=B1*AN.^2;

W(2:NN)=(cos(AR1)-cos(AR2))./AR4;
SUM=sum(W)-0.5*W(1);
SUM=1/(2*SUM);
W=W*SUM;

W_sym=[flipud(W(2:NN));W];
NW=length(W_sym);
```

3- “Ormsby_filt.m”: This Matlab function uses a low-pass Ormsby filter to filter a given signal

```matlab
function [SDATA_filt] = Ormsby_filt(SDATA,BC,DDT,DF,FN)

%------------------------------------------------------------------------
% This program is written from Fortran program by Prof. Todorovska
% This program is for low pass filtering a signal by Ormsby filter
%------------------------------------------------------------------------
% SDATA = a column vector containing the signal
% BC = boundary condition for extending data at ends
%     BC=0 zero extending of the signal at ends
%     BC=1 symmetric extending of the signal at ends
% DDT = sampling interval of input signal (delta t)
% FN = the termination frequency in Hz
% DF = width in Hz of the transition band

[NDATA, NCh]=size(SDATA);
[NW, W_sym] = Ormsby_Weights(NDATA,DDT,DF,FN);

% BC=0 zero extending of the signal at ends
% BC=1 symmetric extending of the signal at ends
if BC == 0
    SDATA_ex=[zeros((NW-1)/2,NCh); SDATA; zeros((NW-1)/2,NCh)];
elseif BC == 1
    SDATA_ex=[flipud(SDATA(2:(NW-1)/2+1,:)); SDATA; flipud(SDATA(NDATA-(NW-1)/2:NDATA-1,:))];
end

for j=1:NCh
    for i=1:NDATA
        SDATA_filt(i,j)=sum(W_sym.*SDATA_ex(i:NW+(i-1),j));
    end
end
```

4- “smoothingfun_n.m”: This Matlab function is for smoothing Fourier transforms and transfer functions

```matlab
function [xsmooth] = smoothingfun_n(x,n,BC)

% smoothing function, uses averaging of each point using n point before
% and n point after it
% x is a column vector
% BC=0 zero extending of the signal at ends
% BC=1 symmetric extending of the signal at ends
% BC=2 'one' extending of the signal at ends
```
\[
\text{size(x)};
\]

\[
\text{if BC == 0}
\]
\[
\text{x_ex} = [\text{zeros}(n,\text{NCh}); \text{x}; \text{zeros}(n,\text{NCh})];
\]

\[
\text{elseif BC == 1}
\]
\[
\text{x_ex} = [\text{flipud(x(2:n,:))}; \text{x}; \text{flipud(x(NDATA-n:NDATA-1,:))}];
\]

\[
\text{elseif BC == 2}
\]
\[
\text{x_ex} = [\text{ones}(n,\text{NCh}); \text{x}; \text{ones}(n,\text{NCh})];
\]

\[
\text{end}
\]

\[
\text{for j=1:NCh}
\]
\[
\text{for i=1:NDATA}
\]
\[
\text{xsmooth(i,j)=mean(x_ex(i:(2*n+1)+(i-1),j));}
\]
\[
\text{end}
\]

\[
\text{end}
\]

5- “gridxy.m”: This Matlab function is for plotting minor gridlines with specified properties at specified distances. This function can be downloaded from the following link:

http://www.mathworks.com/matlabcentral/fileexchange/9973

6- The following program is for plotting data in time domain. Looking at data in time domain is useful because it can show if the sensors are working properly. For example, in case of a hammer test, one should be able to follow impulses as they propagate in the structure. As an example, the program written for EW hammer test with impulse in the basement during 2011 experiment is shown below. Depending on the number and location of sensors some minor modifications should be made to this program before it can be used for any other experiment.

```matlab
clc
clear all
close all

%--------------------------------------------------------------------------
% Last time edited on 3/4/2013 by Mahdi
%--------------------------------------------------------------------------

% There are 7 different channels (columns) in each file.
% Channels 1-4 correspond to instruments on fourth floor. 1 corresponds to
% the far northern instrument and it goes toward the south as 2,3,4.
% Channels 5-7 correspond to instruments on the basement. 7 corresponds to
% the second instrument from north and it goes toward the south as 6,5.
% dt=0.0025;
t=(0:0.0025:60-0.0025)';
Fs=1/dt;
%--------------------------------------------------------------------------
```

20
%
% EW direction
%
%--------------------------------------------------------------------------
%--------------------------------------------------------------------------
% Hammer test in EW direction impulse at base
EW_H_B=dlmread('EW_Hammer_Basement.txt');

xmax=60;
ymax=8000;
figure()
subplot(2,4,1)
plot(t,EW_H_B(:,1))
xlim([0 xmax])
ylim([-ymax ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:10:60)
set(gca,'XTickLabel',{0:10:60})
title('Ch1')

subplot(2,4,2)
plot(t,EW_H_B(:,2))
xlim([0 xmax])
ylim([-ymax ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:10:60)
set(gca,'XTickLabel',{0:10:60})
title('Ch2')

subplot(2,4,3)
plot(t,EW_H_B(:,3))
xlim([0 xmax])
ylim([-ymax ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:10:60)
set(gca,'XTickLabel',{0:10:60})
title('Ch3')

subplot(2,4,4)
plot(t,EW_H_B(:,4))
xlim([0 xmax])
ylim([-ymax ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:10:60)
set(gca,'XTickLabel',{0:10:60})
title('Ch4')

subplot(2,4,8)
plot(t,EW_H_B(:,5))
xlim([0 xmax])
ylim([-ymax ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:10:60)
set(gca,'XTickLabel',{0:10:60})
title('Ch5')
The following program is for low-pass filtering data between 0 Hz and 25 Hz using an Ormsby filter and writing filtered data into text files. As an example, program written for 2011 experiment is shown below. Depending on the number and location of sensors some minor modifications should be made before it can be used for any other experiment.

```matlab
clc
clear all
close all

% There are 7 different channels (columns) in each file.
% Channels 1-4 correspond to instruments on fourth floor. 1 corresponds to
% the far northern instrument and it goes toward the south as 2,3,4.
% Channels 5-7 correspond to instruments on the basement. 7 corresponds to
% the second instrument from north and it goes toward the south as 6,5.
% dt=0.0025;
% t=(0:dt:60-0.0025)';
Fs=1/dt;
```
% Reading Data

EW_H_B=dlmread('EW_Hammer_Basement.txt');
EW_H_4th=dlmread('EW_Hammer_4th.txt');
EW_Amb_1=dlmread('EW_Ambient_1.txt');
EW_Amb_2=dlmread('EW_Ambient_2.txt');
NS_H_B=dlmread('NS_Hammer_Basement.txt');
NS_H_4th=dlmread('NS_Hammer_4th.txt');
NS_Amb_1=dlmread('NS_Ambient_1.txt');
NS_Amb_2=dlmread('NS_Ambient_2.txt');
Calib=dlmread('Calibration.txt');

% Detrending Data (making data to have a zero mean)

[NDATA,NCh]=size(EW_H_B);
m_EW_H_B=mean(EW_H_B);
m_EW_H_4th=mean(EW_H_4th);
m_EW_Amb_1=mean(EW_Amb_1);
m_EW_Amb_2=mean(EW_Amb_2);
m_NS_H_B=mean(NS_H_B);
m_NS_H_4th=mean(NS_H_4th);
m_NS_Amb_1=mean(NS_Amb_1);
m_NS_Amb_2=mean(NS_Amb_2);
m_Calib=mean(Calib);

for i=1:NCh
    EW_H_B(:,i)=EW_H_B(:,i)-m_EW_H_B(i);
    EW_H_4th(:,i)=EW_H_4th(:,i)-m_EW_H_4th(i);
    EW_Amb_1(:,i)=EW_Amb_1(:,i)-m_EW_Amb_1(i);
    EW_Amb_2(:,i)=EW_Amb_2(:,i)-m_EW_Amb_2(i);
    NS_H_B(:,i)=NS_H_B(:,i)-m_NS_H_B(i);
    NS_H_4th(:,i)=NS_H_4th(:,i)-m_NS_H_4th(i);
    NS_Amb_1(:,i)=NS_Amb_1(:,i)-m_NS_Amb_1(i);
    NS_Amb_2(:,i)=NS_Amb_2(:,i)-m_NS_Amb_2(i);
    Calib(:,i)=Calib(:,i)-m_Calib(i);
end

Calib_bf=Calib;
[NDATA_bf,NCh_bf]=size(EW_H_B);
dt_bf=0.0025;
% Filtering data using ormsby lowpass filter (making data to have a zero mean)
% Fs=400;                % Sampling Frequency Hz
% F_Nyq=Fs/2=200;        % Nyquist Frequency Hz
% FN=25;                % Termination frequency in Hz
% DF=5;                 % Width of the transition band in Hz

%--------------------------------------------------------------------------
%--------------------------------------------------------------------------
% Plotting Freq. response and impulse response of filter to check
Fn1=25;       % Termination frequency in Hz
DF1=5;        % Width of the transition band in Hz
[Nw1, W_sym1] = Ormsby_Weights(NDATA,dt,DF1,Fn1);

% Checking the frequency response of the filter
NFt_W1=2^nextpow2(length(W_sym1));
W_sym1_fft=abs(fft(W_sym1,NFFT_W1));
figure()
subplot(2,1,1)
plot(-(NW1-1)/2:1:(NW1-1)/2,W_sym1,'.-b')
xlabel('Samples in time')
subplot(2,1,2)
plot(0:1:NFFT_W1/2,W_sym1_fft(1:NFFT_W1/2+1),'.-b')
xlabel('Samples in frequency')

%--------------------------------------------------------------------------
% Filtering data
% [SDATA_filt] = Ormsby_filt(SDATA,BC,DDT,DF,FN)
% BC=1 symmetric symmetric extending of the signal at ends
% [SDATA_filt] = Ormsby_filt(SDATA,1,dt,5,25)
% BC=1 symmetric symmetric extending of the signal at ends

EW_H_B_filt=Ormsby_filt(EW_H_B,1,dt,5,25);
EW_H_4th_filt=Ormsby_filt(EW_H_4th,1,dt,5,25);
EW_Amb_1_filt=Ormsby_filt(EW_Amb_1,1,dt,5,25);
EW_Amb_2_filt=Ormsby_filt(EW_Amb_2,1,dt,5,25);

NS_H_B_filt=Ormsby_filt(NS_H_B,1,dt,5,25);
NS_H_4th_filt=Ormsby_filt(NS_H_4th,1,dt,5,25);
NS_Amb_1_filt=Ormsby_filt(NS_Amb_1,1,dt,5,25);
NS_Amb_2_filt=Ormsby_filt(NS_Amb_2,1,dt,5,25);
Calib_filt=Ormsby_filt(Calib,1,dt,5,25);

% Downsampling filtered data
n_ds=8;        % Taking 1 out of 8 samples reduces Nyquist frequency from 200 to 25 Hz
NDATA=NDATA/n_ds;
dt=dt*n_ds;
EW_H_B_filt=EW_H_B_filt(1:n_ds:end,:);
EW_H_4th_filt=EW_H_4th_filt(1:n_ds:end,:);
EW_Amb_1_filt=EW_Amb_1_filt(1:n_ds:end,:);
EW_Amb_2_filt=EW_Amb_2_filt(1:n_ds:end,:);

NS_H_B_filt=NS_H_B_filt(1:n_ds:end,:);
NS_H_4th_filt=NS_H_4th_filt(1:n_ds:end,:);
NS_Amb_1_filt=NS_Amb_1_filt(1:n_ds:end,:);
NS_Amb_2_filt=NS_Amb_2_filt(1:n_ds:end,:);

Calib_filt=Calib_filt(1:n_ds:end,:);

%------------------------------------------------------------------------
% Writing filtered data to files
%------------------------------------------------------------------------

fid1 = fopen('EW_H_B_filt_0_25_Hz.txt','wt');
fid2 = fopen('EW_H_4th_filt_0_25_Hz.txt','wt');
fid3 = fopen('EW_Amb_1_filt_0_25_Hz.txt','wt');
fid4 = fopen('EW_Amb_2_filt_0_25_Hz.txt','wt');

fid5 = fopen('NS_H_B_filt_0_25_Hz.txt','wt');
fid6 = fopen('NS_H_4th_filt_0_25_Hz.txt','wt');
fid7 = fopen('NS_Amb_1_filt_0_25_Hz.txt','wt');
fid8 = fopen('NS_Amb_2_filt_0_25_Hz.txt','wt');

fid9 = fopen('Calib_filt_0_25_Hz.txt','wt');

for i = 1:NDATA
    fprintf(fid1,'%g	',EW_H_B_filt(i,:));
    fprintf(fid1,'
');
    fprintf(fid2,'%g	',EW_H_4th_filt(i,:));
    fprintf(fid2,'
');
    fprintf(fid3,'%g	',EW_Amb_1_filt(i,:));
    fprintf(fid3,'
');
    fprintf(fid4,'%g	',EW_Amb_2_filt(i,:));
    fprintf(fid4,'
');

    fprintf(fid5,'%g	',NS_H_B_filt(i,:));
    fprintf(fid5,'
');
    fprintf(fid6,'%g	',NS_H_4th_filt(i,:));
    fprintf(fid6,'
');
    fprintf(fid7,'%g	',NS_Amb_1_filt(i,:));
    fprintf(fid7,'
');
    fprintf(fid8,'%g	',NS_Amb_2_filt(i,:));
    fprintf(fid8,'
');

    fprintf(fid9,'%g	',Calib_filt(i,:));
    fprintf(fid9,'
');
end
fclose(fid1);
fclose(fid2);
fclose(fid3);
fclose(fid4);
fclose(fid5);
fclose(fid6);
fclose(fid7);
fclose(fid8);
fclose(fid9);

8- The following program is for calculation and plotting of transfer functions, to find apparent frequencies from their peaks. As an example program written for EW hammer test with impulse in the basement during 2011 experiment is shown below. Depending on the number and location of sensors some minor modifications should be made before it can be used for any other experiment.

clc
clear all
close all

%---------------------------------------------------------------
% Last time edited on 3/29/2013 by Mahdi
%---------------------------------------------------------------

% There are 7 different channels (columns) in each file.
% Channels 1-4 correspond to instruments on fourth floor. 1 corresponds to
% the far northern instrument and it goes toward the south as 2,3,4.
% Channels 5-7 correspond to instruments on the basement. 7 corresponds to
% the second instrument from north and it goes toward the south as 6,5.
%---------------------------------------------------------------
dt=8*0.0025;
t=(0:dt:60-0.0025)';
Fs=1/dt;

tmin=0;
tmax=60;
n_min=floor(tmin/dt)+1;
n_max=floor(tmax/dt);

%---------------------------------------------------------------
% % Reading Data
% %---------------------------------------------------------------

EW_H_B_filt=dlmread('EW_H_B_filt_0_25_Hz.txt');
EW_H_B_filt_trim=EW_H_B_filt(n_min:n_max,:);
[NDATA, NCh]=size(EW_H_B_filt_trim);
% Plotting Calibration in freq. domain

NFFT=2^nextpow2(NDATA));
df=1/(NFFT*dt);
f=(0:1:NFFT-1)'*df;

EW_H_B_fft=1/NFFT*abs(fft([EW_H_B_filt_trim;zeros(NFFT-NDATA,NCh)],NFFT));

xmax=25;
dx=5;
ymax=100;
figure()
subplot(2,4,1)
plot(f,EW_H_B_fft(:,1))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch1')

subplot(2,4,2)
plot(f,EW_H_B_fft(:,2))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch2')

subplot(2,4,3)
plot(f,EW_H_B_fft(:,3))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch3')

subplot(2,4,4)
plot(f,EW_H_B_fft(:,4))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch4')

subplot(2,4,8)
plot(f,EW_H_B_fft(:,5))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch5')
```matlab
subplot(2,4,7)
plot(f,EW_H_B_fft(:,6))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch6')

subplot(2,4,6)
plot(f,EW_H_B_fft(:,7))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch7')

ha = axes('Position',[0 0 1 1],'Xlim',[0 1],'Ylim',[0 1],'
Box','off','Visible','off','Units','normalized', 'clipping' , 'off');
text(0.5, 1,'\bf Filtered hammer test data data in frequency
domain','HorizontalAlignment','center','VerticalAlignment',
'top','fontsize',12,'fontweight','b')

%-------------------------------------------------------------------------
% Smoothing calibration ffts to find calibration ratios
%-------------------------------------------------------------------------
% [xsmooth] = smoothingfun_n(x,n,BC)
% BC=0 zero extending of the signal at ends
n=25; % number of points before and after for averaging

EW_H_B_fft_S50=smoothingfun_n(EW_H_B_fft,25,0);

xmax=25;
dx=5;
ymax=100;
figure()
subplot(2,4,1)
plot(f,EW_H_B_fft_S50(:,1))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch1')

subplot(2,4,2)
plot(f,EW_H_B_fft_S50(:,2))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
```
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch2')

subplot(2,4,3)
plot(f,EW_H_B_fft_S50(:,3))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch3')

subplot(2,4,4)
plot(f,EW_H_B_fft_S50(:,4))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch4')

subplot(2,4,7)
plot(f,EW_H_B_fft_S50(:,6))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch5')

subplot(2,4,6)
plot(f,EW_H_B_fft_S50(:,7))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch6')

ha = axes('Position',[0 0 1 1],'Xlim',[0 1],'Ylim',[0 1],'
Box','off','Visible','off','Units','normalized', 'clipping', 'off');
text(0.5, 1, 'f Smoothed Fourier spectra of hammer test data
data', 'HorizontalAlignment','center','VerticalAlignment', 'top','fontsize',12,'fontweight','b')
Calculating calibration ratios taking channel 7 as reference

```
for i=1:NCh
    TF_EW_H_B_wo_calib(:,i)=EW_H_B_fft_S50(:,i)./EW_H_B_fft_S50(:,7);
end
```

```
xmax=10;
dx=5;
ymax=100;
figure()
subplot(2,4,1)
plot(f,TF_EW_H_B_wo_calib(:,1))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch1')
```

```
subplot(2,4,2)
plot(f,TF_EW_H_B_wo_calib(:,2))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch2')
```

```
subplot(2,4,3)
plot(f,TF_EW_H_B_wo_calib(:,3))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch3')
```

```
subplot(2,4,4)
plot(f,TF_EW_H_B_wo_calib(:,4))
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch4')
```

```
subplot(2,4,8)
plot(f,TF_EW_H_B_wo_calib(:,5))
```

```
xlim([0 xmax])
ylim([0 ymax/10])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch5')

subplot(2,4,7)
plot(f,TF_EW_H_B_wo_calib(:,6))
xlim([0 xmax])
ylim([0 ymax/10])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch6')

subplot(2,4,6)
plot(f,TF_EW_H_B_wo_calib(:,7))
xlim([0 xmax])
ylim([0 ymax/10])
set(gca,'XMinorGrid','on')
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Ch7')

ha = axes('Position',[0 0 1 1],'Xlim',[0 1],'Ylim',[0 1],'Box','off','Visible','off','Units','normalized', 'clipping', 'off');
text(0.5, 1,'f TF from hammer test in EW direction impulse at Basement','HorizontalAlignment','center','VerticalAlignment',
     'top','fontsize',12,'fontweight','b')

print('-dtiff','-r200','TF_EW_H_B_filtered_0_25_Hz.tiff');

%---------------------------------------------------------------
% plotting only the first 4 channels upto 5 Hz to be able to read better
%---------------------------------------------------------------
xmax=5;
ymax=100;
figure()
subplot(2,2,1)
plot(f,TF_EW_H_B_wo_calib(:,1),'k','linewidth',1)
xlim([0 xmax])
ylim([0 ymax])
gridxy([0:0.05:5],'Color','k','Linestyle',':')
gridxy([0:0.25:5],'Color','b','Linestyle','-','linewidth',0.1)
title('Ch1')

subplot(2,2,2)
plot(f,TF_EW_H_B_wo_calib(:,2),'k','linewidth',1)
xlim([0 xmax])
ylim([0 ymax])
9- The following program is for calculation of the torsional response from the difference of the recordings at two ends of the building. By looking at the Fourier spectra of the torsional response one can find torsional system frequencies. As an example, the program written for 2011 experiment is shown below. Depending on number and location of the sensors some minor modifications should be made before it can be used for any other experiment.

clc
clear all
close all

%------------------------------------------------------------------------
% Last time edited on 3/29/2013 by Mahdi
%------------------------------------------------------------------------

% There are 7 different channels (columns) in each file.
% Channels 1-4 correspond to instruments on fourth floor. 1 corresponds to
% the far northern instrument and it goes toward the south as 2,3,4.
% Channels 5-7 correspond to instruments on the basement. 7 corresponds to
% the second instrument from north and it goes toward the south as 6,5.
%------------------------------------------------------------------------
To find the torsional response we should use the instruments at North and South ends on the fourth floor. Subtracting these two records will give us the torsional response.

dt = 8 * 0.0025;
t = (0:dt:60-0.0025)';
Fs = 1/dt;

tmin = 0;
tmax = 60;
n_min = floor(tmin/dt) + 1;
n_max = floor(tmax/dt);

% Reading Data

EW_Amb_1_filt = dlmread('EW_Amb_1_filt_0_25_Hz.txt');
EW_Amb_2_filt = dlmread('EW_Amb_2_filt_0_25_Hz.txt');
EW_H_4th_filt = dlmread('EW_H_4th_filt_0_25_Hz.txt');
EW_H_B_filt = dlmread('EW_H_B_filt_0_25_Hz.txt');

Tor_EW_Amb_1_filt = EW_Amb_1_filt(:,1) - EW_Amb_1_filt(:,6);
Tor_EW_Amb_2_filt = EW_Amb_2_filt(:,1) - EW_Amb_2_filt(:,6);
Tor_EW_H_4th_filt = EW_H_4th_filt(:,1) - EW_H_4th_filt(:,6);
Tor_EW_H_B_filt = EW_H_B_filt(:,1) - EW_H_B_filt(:,6);

Tor_EW_Amb_1_filt_trim = Tor_EW_Amb_1_filt(n_min:n_max,:);
Tor_EW_Amb_2_filt_trim = Tor_EW_Amb_2_filt(n_min:n_max,:);
Tor_EW_H_4th_filt = Tor_EW_H_4th_filt(n_min:n_max,:);
Tor_EW_H_B_filt = Tor_EW_H_B_filt(n_min:n_max,:);

[NDATA, NCh] = size(Tor_EW_Amb_1_filt_trim);

% Plotting in time domain
% EW ambient 1

xmin = 0;
xmax = 5;
dx = 1;
ymax = 3000;
dist = 5000;

figure()
plot(t, EW_Amb_1_filt(:,1), '-b')
hold on
plot(t, EW_Amb_1_filt(:,6) + dist, '-k')
xlim([xmin xmax])
ylim([-ymax ymax+dist])
set(gca, 'XGrid', 'on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('2011-EW Amb 1-End Channels in time
domain','fontsize',12,'fontweight','b')
legend('Ch1-North end (bot)','Ch4-South end (top)')
xlabel('Time (sec)','fontsize',10,'fontweight','b')
print('-dtiff','-r200','End_Channels_EW_Amb_1_filtered_0_25_Hz.tiff')

%--------------------------------------------------------------------------
% EW ambient 2
xmin=0;
max=5;
dx=1;
ymax=3000;
dist=5000;
figure()
plot(t,EW_Amb_2_filt(:,1),'-b')
hold on
plot(t,EW_Amb_2_filt(:,6)+dist,'-k')
xlim([xmin xmax])
ylim([-ymax ymin+dist])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('2011-EW Amb 2-End Channels in time
domain','fontsize',12,'fontweight','b')
legend('Ch1-North end (bot)','Ch4-South end (top)')
xlabel('Time (sec)','fontsize',10,'fontweight','b')
print('-dtiff','-r200','End_Channels_EW_Amb_2_filtered_0_25_Hz.tiff')

%--------------------------------------------------------------------------
% EW Hammer 4th floor
xmin=0;
max=5;
dx=1;
ymax=3000;
dist=5000;
figure()
plot(t,EW_H_4th_filt(:,1),'-b')
hold on
plot(t,EW_H_4th_filt(:,6)+dist,'-k')
xlim([xmin xmax])
ylim([-ymax ymin+dist])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('2011-EW Hammer 4th floor -End Channels in time
domain','fontsize',12,'fontweight','b')
legend('Ch1-North end (bot)','Ch4-South end (top)')
print('-dtiff','-r200','End_Channels_EW_Hammer_4th_floor_filtered_0_25_Hz.tiff')
xlabel('Time (sec)','fontsize',10,'fontweight','b')

print('-dtiff','-r200','End_Channels_EW_H_4th_filtered_0_25_Hz.tiff');

% Calculating FTs

NFFT=2^nextpow2(NDATA));
df=1/(NFFT*dt);
f=(0:1:NFFT-1)'*df;

Tor_EW_Amb_1_fft=1/NFFT*abs(fft([Tor_EW_Amb_1_filt_trim;zeros(NFFT-NDATA,NCh)],NFFT));
Tor_EW_Amb_2_fft=1/NFFT*abs(fft([Tor_EW_Amb_2_filt_trim;zeros(NFFT-NDATA,NCh)],NFFT));
Tor_EW_H_4th_fft=1/NFFT*abs(fft([Tor_EW_H_4th_filt_trim;zeros(NFFT-NDATA,NCh)],NFFT));
Tor_EW_H_B_fft=1/NFFT*abs(fft([Tor_EW_H_B_filt_trim;zeros(NFFT-NDATA,NCh)],NFFT));

xmax=25;
dx=5;
ymax=75;

figure() subplot(2,2,1) plot(f,Tor_EW_Amb_1_fft) xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Amb 1','fontweight','b')

subplot(2,2,2)
plot(f,Tor_EW_Amb_2_fft)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Amb 2','fontweight','b')

subplot(2,2,3)
plot(f,Tor_EW_H_4th_fft)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('H 4th','fontweight','b')

subplot(2,2,4)
plot(f,Tor_EW_H_B_fft)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('H Basement','fontweight','b')

ha = axes('Position',[0 0 1 1],'Xlim',[0 1],'Ylim',[0 1],'
Box','off',
'Visible','off',
'Units','normalized',
'clipping','off');

text(0.5, 1,'f 2011-FTs of filtered torsional response',
'HorizontalAlignment','center',
'VerticalAlignment','top',
'fontsize',12,'
fontweight','b')

% Smoothing ffts

% [xsmooth] = smoothingfun_n(x,n,BC)
% BC=0 zero extending of the signal at ends
n=25; % number of points before and after for averaging
Tor_EW_Amb_1_fft_S50=smoothingfun_n(Tor_EW_Amb_1_fft,25,0);
Tor_EW_Amb_2_fft_S50=smoothingfun_n(Tor_EW_Amb_2_fft,25,0);
Tor_EW_H_4th_fft_S50=smoothingfun_n(Tor_EW_H_4th_fft,25,0);
Tor_EW_H_B_fft_S50=smoothingfun_n(Tor_EW_H_B_fft,25,0);

xmax=25;
dx=5;
ymax=75;

figure()
subplot(2,2,1)
plot(f,Tor_EW_Amb_1_fft_S50)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Amb 1','fontweight','b')

subplot(2,2,2)
plot(f,Tor_EW_Amb_2_fft_S50)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('Amb 2','fontweight','b')

subplot(2,2,3)
plot(f,Tor_EW_H_4th_fft_S50)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('H 4th','fontweight','b')

subplot(2,2,4)
plot(f,Tor_EW_H_B_fft_S50)
xlim([0 xmax])
ylim([0 ymax])
set(gca,'XGrid','on')
set(gca,'XTick',0:dx:xmax)
set(gca,'XTickLabel',{0:dx:xmax})
title('H Basement','fontweight','b')

ha = axes('Position',[0 0 1 1],'Xlim',[0 1],'Ylim',[0 1],'Box','off','Visible','off','Units','normalized', 'clipping' , 'off');
text(0.5,1,'\textbf{2011-Smoothed Fourier spectra of torsional response}','HorizontalAlignment','center','VerticalAlignment','top','fontsize',12,'fontweight','b')
print('-dtiff','-r200','Smoothed_Spectra_Torsion_filtered_0_25_Hz.tiff');

%--------------------------------------------------------------------------
% plotting only upto 5 Hz to be able to read better
%--------------------------------------------------------------------------
xmax=5;
dx1=0.5;
dx2=0.1;
ymax=60;

figure();

subplot(2,2,1)
plot(f, Tor_EW_Amb_1_fft_S50, 'k', 'linewidth', 1)
xlim([0 xmax])
ylim([0 ymax])
gridxy([0:dx2:5], 'Color', 'k', 'Linestyle', ':')
gridxy([0:dx1:5], 'Color', 'b', 'Linestyle', '-', 'linewidth', 0.1)
title('Amb 1', 'fontweight', 'b')

subplot(2,2,2)
plot(f, Tor_EW_Amb_2_fft_S50, 'k', 'linewidth', 1)
xlim([0 xmax])
ylim([0 ymax])
gridxy([0:dx2:5], 'Color', 'k', 'Linestyle', ':')
gridxy([0:dx1:5], 'Color', 'b', 'Linestyle', '-', 'linewidth', 0.1)
title('Amb 2', 'fontweight', 'b')

subplot(2,2,3)
plot(f, Tor_EW_H_4th_fft_S50, 'k', 'linewidth', 1)
xlim([0 xmax])
ylim([0 ymax])
gridxy([0:dx2:5], 'Color', 'k', 'Linestyle', ':')
gridxy([0:dx1:5], 'Color', 'b', 'Linestyle', '-', 'linewidth', 0.1)
title('H 4th', 'fontweight', 'b')

subplot(2,2,4)
plot(f, Tor_EW_H_B_fft_S50, 'k', 'linewidth', 1)
xlim([0 xmax])
ylim([0 ymax])
gridxy([0:dx2:5], 'Color', 'k', 'Linestyle', ':')
gridxy([0:dx1:5], 'Color', 'b', 'Linestyle', '-', 'linewidth', 0.1)
title('H Basement', 'fontweight', 'b')

ha = axes('Position',[0 0 1 1],'Xlim',[0 1],'Ylim',[0 1],'Box','off','Visible','off','Units','normalized', 'clipping' , 'off');
text(0.5, 1,'\bf 2011-Torsional FTs','HorizontalAlignment','center','VerticalAlignment', 'top','fontsize',12,'fontweight','b')

print('-dtiff','-r200','FT_EW_Torsion_filtered_0_25_Hz_uppto_5_Hz.tiff');
Appendix E1: Experiment of June 5th and 6th of 1993

Date

This test was performed on June 5th and 6th of 1993. For a more detailed description of this test see page 52 in USC report CE 95_05 (Ivanović and Trifunac 1995). Figures E1-1 to E1-3 show the instrument locations as provided in this USC report.

Test Description

✓ 4 seismometers were used
✓ No calibration run (calibration run was performed 3 months later)
✓ Data acquisition board on 2nd floor
✓ Each recording session lasted 1 min (Sampling frequency is not mentioned but it is probably 400 samples per second)
✓ 13 different configurations were used. Look at figure IV.2.1.1 page 53 USC report CE 95_05 (Ivanović and Trifunac 1995).

1- A1, A2, A3, R
2- B1, B2, B3, R
3- C1, C2, C3, R
4- D1, D2, D3, R
5- E1, E2, E3, R
6- F1, F2, F3, R
7- G1, G2, G3, R
8- H1, H2, H3, R
9- I1, I2, I3, R
10- J1, J2, J3, R
11- K1, K2, K3, R
12- L1, L2, L3, R
13- M1, M2, M3, R
**Description of Files**

There are 96 files in the data folder corresponding to this test. Names of the files are as follows:

- 11, 12, …, 16 to 41, 42, 46. Each number has H and V components in separate files.
- B1, B2, B3, B7, B8, B9, B10, B11, B12, B13, and each one has V, E, N components in separate files.
- LB4, LB5, LB6 and each one has V, E, N components in separate files.

Each file has 120,000 data points; assuming 400 samples/sec duration of each recording is 5 min. We were not able to decipher which files correspond to which test and so no new analysis was performed for this report, and the results we present are reproduced from the USC report CE 95_05 report.

![Figure E1-1- NS cross section of the map of instrument locations during the first experiment on June 5th and 6th 1993 (Ivanović and Trifunac 1995)](image-url)
Figure E1-2- Plan view of the map of instrument locations during the first experiment on June 5th and 6th 1993 (Ivanović and Trifunac 1995)

Figure E1-3- EW cross section of the map of instrument locations during the first experiment on June 5th and 6th 1993 (Ivanović and Trifunac 1995)
Appendix E2: Experiment of January 19th of 1994

Date

This test was performed on January 19th 1994. For a more detailed description of this test see page 62 in USC report CE 95_05 (Ivanović and Trifunac 1995). Figures E2-1 to E2-3 show the instrument locations and are reproduced from the USC report CE 95_05.

Test Description

✓ 4 seismometers were used
✓ Calibration test for both horizontal and vertical sensor orientations
✓ For each configuration 3 sessions were recorded (EW, NS, Vertical)
✓ Recording duration is 1 min and sampling frequency is 400 samples/sec
✓ 2 different configurations were used. Look at figure IV.2.2.10 on page 74 in USC report CE 95_05 (Ivanović and Trifunac 1995)
   • A1, A2, A3, R → vertical array along SW stairway
   • B1, B2, B3, R → horizontal array on 4th floor

Description of Files

There are 5 files in the data folder corresponding to this test. Names of the files are as follows

✓ K4E, K4S, K4V → probably corresponding to horizontal array recordings on 4th floor
✓ KSE, KSS → probably corresponding to vertical array along SW stairway

No analysis was performed on this data and the results from the USC report CE 95_05 are reproduced here.
Figure E2-1- NS cross section of the map of instrument locations during the second experiment on January 19th 1994 (Ivanović and Trifunac 1995)

Figure E2-2- Plan view of the map of instrument locations during the second experiment on January 19th 1994 (Ivanović and Trifunac 1995)
Figure E2-3- EW cross section of the map of instrument locations during the second experiment on January 19th 1994 (Ivanović and Trifunac 1995)
Appendix E3: Experiment of May 18th of 1994

Date

This test was carried out on May 18th 1994. For a more detailed description of this test see page 81 of USC report CE 95_05 (Ivanović and Trifunac 1995). Figures E3-1 to E3-3 in this report show the instrument locations.

Test Description

- 4 seismometers were used
- Calibration test for both horizontal and vertical sensor orientation
- For each configuration 3 sessions were recorded (EW, NS, Vertical)
- Recording duration is 3 min and sampling frequency is 400 samples/sec
- 3 different configurations were used. Look at figure IV.2.2.10 on page 74 in USC report CE 95_05 (Ivanović and Trifunac 1995)
  - A1, A2, A3, R ➔ vertical array along SW stairway
  - B1, B2, B3, R ➔ horizontal array on 4th floor
  - C1, C2, C3, R ➔ horizontal array at different places on 4th floor

Description of Files

There are 19 files in the data folder corresponding to the tests “Seis1” to “Seis19”. However, no records were kept on which file corresponds to which test and so no new analysis was performed on this data. The results summarized here were taken from the USC report CE 95_05.
Figure E3-1- NS cross section of the map of instrument locations during the third experiment on May 18th 1994 (Ivanović and Trifunac 1995)

Figure E3-2- Plan view of the map of instrument locations during the third experiment on May 18th 1994 (Ivanović and Trifunac 1995)
Figure E3-3- EW cross section of the map of instrument locations during the third experiment on May 18th 1994 (Ivanović and Trifunac 1995)
Appendix E4: Experiment of May 7th of 1995

Date

This test was performed on May 7th 1995. It consists of ambient vibration test, hammer test and calibration tests. For a more detailed description of this test see page 81 USC report CE 95_05 (Ivanović and Trifunac 1995). Figures E4-1 to E4-3 in this report show the instrument locations.

Test Description

✓ 13 seismometers were used
✓ Calibration tests were performed at the end of experiment
✓ Further details about this test can be found on page 89 of USC report CE 95_05 (Ivanović and Trifunac 1995). The following information is reproduced here about this test.
  • Sensor locations are shown in Figure E4-1 to E4-3.
  • For ambient test, EW and NS motions were recorded in 1,3 and 5 min sessions
    (sampling frequency is not mentioned but it is probably 400 samples per second)

The following is known about the hammer tests.

• Hammer Test-Impulse applied at SW stairway.
• West to East Impulse: 6 blows, 5-10 second apart.
• South to North Impulse: 7 blows, 5-10 second apart.
• Recording duration was 1 min with sampling rate of 800 samples/sec.

Description of Files

Files in the folder corresponding to this experiment are as follows. Files corresponding to calibration tests are called calib1 to calib5. The rest of the files are summarized below.
Table E4-1- Properties of data files recorded during the fourth experiment on May 7th 1994

<table>
<thead>
<tr>
<th>file name</th>
<th>size</th>
<th>duration (guess)</th>
<th>file name</th>
<th>size</th>
<th>duration (guess)</th>
</tr>
</thead>
<tbody>
<tr>
<td>seis 1</td>
<td>750</td>
<td>1 min</td>
<td>seis 5</td>
<td>750</td>
<td>1 min</td>
</tr>
<tr>
<td>seis 2</td>
<td>2250</td>
<td>3 min</td>
<td>seis 6</td>
<td>2250</td>
<td>3 min</td>
</tr>
<tr>
<td>seis 3</td>
<td>2940</td>
<td>5 min</td>
<td>seis 7</td>
<td>2940</td>
<td>5 min</td>
</tr>
<tr>
<td>seis 4.ham</td>
<td>1500</td>
<td>1 min</td>
<td>seis 8</td>
<td>1500</td>
<td>1 min</td>
</tr>
</tbody>
</table>

To identify which files correspond to EW and which to NS motions will require further trial analyses. This was not done and the results of the USC report CE 95_05 are simply reproduced here.

Figure E4-1- NS cross section of the map of instrument locations during the fourth experiment on May 7th 1994 (Ivanović and Trifunac 1995)
Figure E4-2- Plan view of the map of instrument locations during the fourth experiment on May 7th 1994 (Ivanović and Trifunac 1995)

Figure E4-3- EW cross section of the map of instrument locations during the fourth experiment on May 7th 1994 (Ivanović and Trifunac 1995)
Appendix E5: Experiment of March of 1996

Date

This test was performed on March 1996. Exact day was not documented.

Test Description

There is no description available for this test.

Description of Files

There are three files in the corresponding folder named seis1 to seis3 each having the size of 2250 KB. No analysis was performed with this data.
Appendix E6: Experiment of March 13th of 1999

Date

This test was performed on March 13th 1994.

Test Description

There is no cannel description for this experiment.

Description of Files

There are 20 files of the same size (1688 KB) in the corresponding folders named Test 1 to Test 20. From file size it seems that there are 12 columns recorded for 3 minutes. The following comments are based on observation in time and frequency domain. In data extraction, sampling frequency is assumed to be 400 samples per second as it is the value usually used in experiments.

1- From time domain data the following may be concluded:

   a) Direction of test cannot be distinguished without looking at Fourier spectra.

   b) Ambient test and calibration tests cannot be distinguished in all cases, what follows is our best estimate based on the peaks of Fourier spectra.

      • Ambient tests: Test8, Test9, Test10, Test11
      • Calibration tests: Test 18, Test19, Test20
      • Ambient or Calibration: Test1, Test 14
      • Hammer Tests: Test2-7, Test12, Test13, Test 15-17

2- In all recordings the following 3 groups of channels look very similar (Ch1, 4, 7, 10), (Ch2, 5, 8, 11) and (Ch3, 6, 9, 12). Those are not exactly the same when plotted on top of each other but the differences are very small.
Summary of the Results

A summary of the results found from Fourier spectra (without applying calibration ratios from calibration test) is presented in Table E6-1.

Table E6-1- Summary of the results found from Fourier spectra for the 6th experiment

<table>
<thead>
<tr>
<th>Test</th>
<th>Ch1</th>
<th>Ch2</th>
<th>Ch3</th>
<th>Ch4</th>
<th>Ch5</th>
<th>Ch6</th>
<th>Ch7</th>
<th>Ch8</th>
<th>Ch9</th>
<th>Ch10</th>
<th>Ch11</th>
<th>Ch12</th>
<th>Average</th>
<th>Probable Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test01</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>EW amb</td>
<td></td>
</tr>
<tr>
<td>Test02</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.70</td>
<td>EW hammer</td>
<td></td>
</tr>
<tr>
<td>Test03</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>EW hammer</td>
<td></td>
</tr>
<tr>
<td>Test04</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>EW hammer</td>
<td></td>
</tr>
<tr>
<td>Test05</td>
<td>2.75</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.70</td>
<td>2.72</td>
<td></td>
</tr>
<tr>
<td>Test06</td>
<td>2.75</td>
<td>2.65</td>
<td>2.70</td>
<td>2.65</td>
<td>2.70</td>
<td>2.65</td>
<td>2.70</td>
<td>2.65</td>
<td>2.70</td>
<td>2.65</td>
<td>2.70</td>
<td>2.70</td>
<td>EW hammer</td>
<td></td>
</tr>
<tr>
<td>Test07</td>
<td>2.75</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.75</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.70</td>
<td>2.72</td>
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</tr>
<tr>
<td>Test08</td>
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<td>2.75</td>
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<td>2.90</td>
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<tr>
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<td>2.90</td>
<td>3.05</td>
<td>3.00</td>
<td>2.90</td>
<td>3.05</td>
<td>3.00</td>
<td>2.90</td>
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<td></td>
</tr>
<tr>
<td>Test10</td>
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<td>2.95</td>
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<td>2.95</td>
<td>2.95</td>
<td>2.90</td>
<td>2.95</td>
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<td>2.95</td>
<td>2.95</td>
<td>2.90</td>
<td>2.90</td>
<td>2.93</td>
<td></td>
</tr>
<tr>
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<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
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<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.93</td>
<td></td>
</tr>
<tr>
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<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
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<td>2.90</td>
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<td></td>
</tr>
<tr>
<td>Test13</td>
<td>3.00</td>
<td>2.95</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
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<td>2.90</td>
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</tr>
<tr>
<td>Test14</td>
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</tr>
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<td>2.70</td>
<td>2.70</td>
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<td>2.70</td>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>3.00</td>
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<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Test20</td>
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<td>2.90</td>
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<td>2.90</td>
<td>2.90</td>
<td></td>
</tr>
</tbody>
</table>

53
Appendix E7: Experiment of February 26\textsuperscript{th} of 2000

Date

This test was performed on February 26\textsuperscript{th} 2000.

Test Description

There is no cannal description for this test.

Description of Files

There are 6 files of the same size (1688 KB) in the corresponding folders named Test1 to Test 06. From file sizes it seems that there are 12 columns recorded for 3 minutes. By looking at data it can be seen that column 1 has very small numbers and column 12 is constant (-32768), so it seems that only 10 columns actually contain data. In data extraction, sampling frequency is assumed to be 400 samples per second as it is the value usually used in experiments.

From time domain data the following may be concluded:

- Test01 is ambient test
- Test02, Test03 are hammer tests
- Test04 is ambient test (probably in the other direction)
- Test05 is hammer test (probably in the other direction)
- Test06 is calibration test
Summary of the Result

A summary of the results found from Fourier spectra (without applying calibration ratios from calibration tests) is presented in Table E7-1.

Table E7-1 - Summary of the results found from Fourier spectra for the 7th experiment

<table>
<thead>
<tr>
<th>2000-Test</th>
<th>Peak frequencies from Fourier Spectra in Hz</th>
<th>Average</th>
<th>σ</th>
<th>Probable Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test01</td>
<td>Ch1 2.85 Ch2 2.80 Ch3 2.75 Ch4 2.70 Ch5 2.75 Ch6 2.75 Ch7 2.75 Ch8 2.75 Ch9 - Ch10 2.75</td>
<td>2.76</td>
<td>0.029</td>
<td>EW amb</td>
</tr>
<tr>
<td>Test02</td>
<td>Ch1 2.85 Ch2 2.80 Ch3 2.75 Ch4 2.70 Ch5 2.75 Ch6 2.75 Ch7 2.75 Ch8 2.75 Ch9 - Ch10 -</td>
<td>2.76</td>
<td>0.030</td>
<td>EW hammer</td>
</tr>
<tr>
<td>Test03</td>
<td>Ch1 2.75 Ch2 2.75 Ch3 2.75 Ch4 2.65 Ch5 2.75 Ch6 2.75 Ch7 2.75 Ch8 2.75 Ch9 - Ch10 -</td>
<td>2.74</td>
<td>0.033</td>
<td>EW hammer</td>
</tr>
<tr>
<td>Test04</td>
<td>Ch1 3.00 Ch2 3.00 Ch3 3.00 Ch4 3.00 Ch5 3.00 Ch6 3.00 Ch7 2.95 Ch8 2.90 Ch9 - Ch10 2.95</td>
<td>2.98</td>
<td>0.033</td>
<td>NS amb</td>
</tr>
<tr>
<td>Test05</td>
<td>Ch1 3.00 Ch2 3.00 Ch3 3.00 Ch4 2.95 Ch5 3.00 Ch6 2.95 Ch7 - Ch8 - Ch9 - Ch10 2.98</td>
<td>2.98</td>
<td>0.023</td>
<td>NS hammer</td>
</tr>
<tr>
<td>Test06</td>
<td>Ch1 3.00 Ch2 3.00 Ch3 3.00 Ch4 3.00 Ch5 3.00 Ch6 3.00 Ch7 3.00 Ch8 3.00 Ch9 3.00 Ch10 3.00</td>
<td>3.00</td>
<td>0.000</td>
<td>calib</td>
</tr>
</tbody>
</table>
Appendix E8: Experiment of February 24th of 2001

Date

This test was performed on February 24th 2001.

Test Description

There is no cannel description for this experiment.

Description of Files

There are 6 files of the same size (1688 KB) in the corresponding folders named Test00 to Test05. From file sizes it seems that there are 12 columns recorded for 3 minutes. By looking at data it can be seen that column 1 has very small numbers and columns 10 and 12 are constant (-32768) so it seems that only 9 columns actually contain data. In data extraction, sampling frequency is assumed to be 400 samples per second as it is the value usually used in experiments.

From time domain data and also by looking at the peaks of the corresponding Fourier spectra the following can be concluded:

- Test00 and Test01 are ambient tests (probably in EW direction based on frequencies)
- Test02 is hammer test (probably in EW direction based on frequencies)
- Test03 is ambient test (probably in NS direction based on frequencies)
- Test04 is hammer test (probably in NS direction based on frequencies)
- Test05 is calibration test
Summary of the Results

A summary of the results found from Fourier spectra (without applying calibration ratios from calibration test) is presented in Table E8-1.

Table E8-1- Summary of the results found from Fourier spectra for the 8th experiment

<table>
<thead>
<tr>
<th>2001-Test</th>
<th>Peak frequencies from Fourier Spectra in Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ch1</td>
</tr>
<tr>
<td>Test00</td>
<td>2.50</td>
</tr>
<tr>
<td>Test01</td>
<td>2.55</td>
</tr>
<tr>
<td>Test02</td>
<td>2.65</td>
</tr>
<tr>
<td>Test03</td>
<td>3.00</td>
</tr>
<tr>
<td>Test04</td>
<td>2.90</td>
</tr>
<tr>
<td>Test05</td>
<td>2.75</td>
</tr>
</tbody>
</table>
Appendix E9: Experiment of February 3rd of 2002

Date

This test was performed on February 3rd 2002.

Channel Description

There are 10 channels. Six of them are on the 4th floor equally spaced between two stairways along the west corridor and at south end of the west corridor there is one sensor on each floor all the way down to the basement. Figures E9-1 and E9-2 show the instrument locations in NS and EW cross sections of Kaprielian Hall:

North to South on 4th Floor: Ch1, Ch3, Ch2, Ch5, Ch6, Ch4

The other four channels are different in different student reports. By comparing all of the available reports it is probable that:

3rd floor: Ch10
2nd floor: Ch9
1st floor: Ch8
Basement: Ch7

Test Description

One ambient vibration and three hammer tests were performed for each direction. Two calibration tests were carried out on the second floor. Sampling frequency is 400 samples per second for all tests and duration of recording is either 1 or 3 minutes. File names are as follows:

- Test01: EW Ambient 1, duration 1 min
- Test02: EW Ambient 2, duration 3 min
- Test03: EW hammer test 1 impulse at 4th floor SW stairway, duration 1 min
- Test04: EW hammer test 1 impulse at 4th floor SW stairway, duration 3 min
- Test05: NS Ambient test #1, duration 1 min
- Test06: NS Ambient test #2, duration 3 min
- Test07: NS hammer test #1, impulse at 4th floor SW stairway, duration 1 min
- Test08: Calibration Test, duration 1 min
- Test09: Calibration Test, duration 3 min
Description of Files

There are 9 files in the corresponding folders named Test01 to Test09. The corresponding test for each file is described in the test description.

Figure E9-1- NS cross section of the map of instrument locations during the 9th experiment on February 3rd 2002

Figure E9-2- EW cross section of the map of instrument locations during the 9th experiment on February 3rd 2002
Summary of the Results

A summary of the results found from Fourier spectra (without applying calibration ratios from calibration test) is presented in Tables E9-1 to E9-3.

Table E9-1 - Summary of the results found from Fourier spectra in NS direction for the 9th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1 (North)</th>
<th>Ch3</th>
<th>Ch2</th>
<th>Ch5</th>
<th>Ch6</th>
<th>Ch4 (South)</th>
<th>Average</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient 1</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ambient 2</td>
<td>-</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>0.00</td>
</tr>
<tr>
<td>Hammer 1</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>0.00</td>
</tr>
<tr>
<td>**Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2.97</strong></td>
<td><strong>σ 0.029</strong></td>
</tr>
</tbody>
</table>

Table E9-2 - Summary of the results found from Fourier spectra in EW direction for the 9th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1 (North)</th>
<th>Ch3</th>
<th>Ch2</th>
<th>Ch5</th>
<th>Ch6</th>
<th>Ch4 (South)</th>
<th>Average Ch 3,2,5,6*</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient 1</td>
<td>2.75</td>
<td>2.75</td>
<td>-</td>
<td>-</td>
<td>2.75</td>
<td>2.75</td>
<td>2.75</td>
<td>0.025</td>
</tr>
<tr>
<td>Ambient 2</td>
<td>2.75</td>
<td>2.75</td>
<td>2.65</td>
<td>2.65</td>
<td>2.7</td>
<td>2.7</td>
<td>2.67</td>
<td>0.041</td>
</tr>
<tr>
<td>Hammer 1</td>
<td>2.8</td>
<td>2.8</td>
<td>2.65</td>
<td>2.65</td>
<td>2.75</td>
<td>2.75</td>
<td>2.68</td>
<td>0.065</td>
</tr>
<tr>
<td>Hammer 2</td>
<td>2.95</td>
<td>2.8</td>
<td>2.75</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>2.72</td>
<td>0.041</td>
</tr>
<tr>
<td>**Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2.70</strong></td>
<td><strong>σ 0.037</strong></td>
</tr>
</tbody>
</table>

*Ch 3,2,5,6 are in the middle so they are less affected by torsion. From the above results it can be seen that middle two channels are more consistent so their average is reported as system frequency.
Table E9-3- Summary of the results found from Torsional Fourier spectra for the 9th experiment

<table>
<thead>
<tr>
<th>2002-Torsion</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak frequencies from Torsional FTs in Hz</td>
<td>Ch1-Ch6</td>
</tr>
<tr>
<td>Ambient 1</td>
<td>2.950</td>
</tr>
<tr>
<td>Ambient 2</td>
<td>2.925</td>
</tr>
<tr>
<td>Hammer 1</td>
<td>3.000</td>
</tr>
<tr>
<td>Hammer 2</td>
<td>2.975</td>
</tr>
<tr>
<td>Average</td>
<td>2.96</td>
</tr>
<tr>
<td>σ</td>
<td>0.032</td>
</tr>
</tbody>
</table>
Appendix E10: Experiment of April 25th of 2005

Date

This test was performed on April 25th 2005.

Channel Description

6 channels were used in this experiment. All of them were on the 4th floor. Note that corresponding channel numbers are different for calibration and tests (ambient and hammer). Figures E10-1 and E10-2 show the instrument locations on NS and EW cross sections of Kaprielian Hall. In the excel file data is presented in a way so it corresponds to testing order. This is changed for calibration run so that they are consistent.

- Calibration
  Inst # 4, 1, 8, 11, 14, 6
  Channel # 3, 2, 1, 5, 4, 6

- Ambient and hammer tests
  Inst # 4, 1, 8, 11, 14, 6
  Channel # 1, 2, 3, 4, 5, 6

Test Description

Sampling frequency of the extracted data was 200 per second for hammer test and 400 per second for the rest. Duration of recording is 1 minute for all tests. Details of the test are as follows.

- Ambient vibration test was performed for each direction. File names are “ambew”, “ambns”
- Hammer test is performed for each direction. We don't know where the impulse is applied. File names are “hamew”, “hamns”.
- Calibration test file name is “calibr”

Description of Files

There are 5 files in the corresponding folder. The corresponding test for each file is described in the test description.
Figure E10-1- NS cross section of the map of instrument locations during the tenth experiment on April 25th 2005 (Channel numbers correspond to ambient and hammer tests)

Figure E10-2- EW cross section of the map of instrument locations during the tenth experiment on April 25th 2005 (Channel numbers correspond to ambient and hammer tests)
Summary of the Results

A summary of the results found from Fourier spectra (without applying calibration ratios from calibration test) is presented in Tables E10-1 to E10-3.

Table E10-1- Summary of the results found from Fourier spectra in NS direction for the 10th experiment

<table>
<thead>
<tr>
<th></th>
<th>2005-NS</th>
<th>Peak frequencies from Fourier spectra in Hz</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Average</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ch1</td>
<td>Ch2</td>
<td>Ch3</td>
<td>Ch4</td>
<td>Ch5</td>
<td>Ch6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td></td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>0</td>
</tr>
<tr>
<td>Hammer</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table E10-2- Summary of the results found from Fourier spectra in EW direction for the 10th experiment

<table>
<thead>
<tr>
<th></th>
<th>2005-EW</th>
<th>Peak frequencies from Fourier spectra in Hz</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Average</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ch1</td>
<td>Ch2</td>
<td>Ch3</td>
<td>Ch4</td>
<td>Ch5</td>
<td>Ch6</td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td></td>
<td>2.75</td>
<td>2.75</td>
<td>2.65</td>
<td>2.55</td>
<td>2.70</td>
<td>2.75</td>
<td>2.66</td>
</tr>
<tr>
<td>Hammer</td>
<td></td>
<td>-</td>
<td>1.30</td>
<td>1.25</td>
<td>3.00</td>
<td>1.30</td>
<td>1.40</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ch 2,3,4,5 are in the middle so they are less affected by torsion. From the above results it can be seen that middle two channels are more consistent so their average is reported as system frequency.

Table E10-3- Summary of the results found from Torsional Fourier spectra for the 10th experiment

<table>
<thead>
<tr>
<th></th>
<th>2005-Torsion</th>
<th>Peak frequencies from Torsional FTs in Hz</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Average</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ch1-Ch6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td></td>
<td>2.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hammer</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*
Appendix E11: Experiment of February 2\textsuperscript{nd} of 2006

Date

This test was performed on February 2\textsuperscript{nd} 2006.

Channel Description

10 channels were used in this experiment, 6 of them were on the 4th floor equally spaced between north and south stairways, along the west corridor. The 4 remaining channels were at south end of the west corridor. There was one sensor on each floor all the way down to the basement. Figures E11-1 and E11-2 show the instrument locations in NS and EW cross sections of Kaprielian Hall. Channel numbers were as follows:

North to South on 4th Floor: Ch1, Ch2, Ch3, Ch4, Ch5, Ch6
3rd floor: Ch7
2nd floor: Ch8
1st floor: Ch9
Basement: Ch10

Test Description

For all tests duration of recording was 1 minute and sampling frequency was 400 samples/second. Different tests performed in this experiment are as follows.

- One ambient vibration was carried out for each direction. File names are as follows:
  
  EW Ambient: F2506.EWA  
  NS Ambient: F2506.NSA

- Three hammer tests were carried out for each direction. For each hammer test impulse was applied at a different place. File names are as follows:
  
  EW hammer test 1 impulse at 4th floor SW stairway: F2506.EW1  
  EW hammer test 2 impulse at 4th floor NW stairway: F2506.EW2  
  EW hammer test 3 impulse at basement SW stairway: F2506.EW3  
  NS hammer test 1 impulse at 4th floor SW stairway: F2506.NS1  
  NS hammer test 2 impulse at 4th floor NW stairway: F2506.NS2  
  NS hammer test 3 impulse at basement SW stairway: F2506.NS3
Two calibration tests were performed on the second floor at the end of the experiment. File names are as shown below. "F2505.cal" is standard calibration test and "F2506.cas" is sequential pulse at instrument in order of their position in the experiment.

Standard Calibration: F2506.CAL
Sequential Calibration: F2506.CAS

Figure E11-1- NS cross section of the map of instrument locations during the 11th experiment on February 2nd 2006

Figure E11-2- EW cross section of the map of instrument locations during the 11th experiment on February 2nd 2006
Description of Files

There are 10 files in the corresponding folder. The corresponding test for each file is described in the test description.

Summary of the Results

A summary of the results found from transfer functions and Fourier spectra (without applying calibration ratios from calibration test) is presented in Tables E11-1 to E11-3.
Table E11-1- Summary of the results found from Fourier spectra in NS direction for the 11th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1</th>
<th>Ch2</th>
<th>Ch3</th>
<th>Ch4</th>
<th>Ch5</th>
<th>Ch6</th>
<th>Average</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>4.44E-16</td>
</tr>
<tr>
<td>Hammer 1</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>4.44E-16</td>
</tr>
<tr>
<td>Hammer 2</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
<td>4.44E-16</td>
</tr>
<tr>
<td>Hammer 3</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>2.90</td>
<td>4.44E-16</td>
</tr>
</tbody>
</table>

Average 2.89
σ 0.025

Table E11-2- Summary of the results found from Fourier spectra in EW direction for the 11th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1</th>
<th>Ch2</th>
<th>Ch3</th>
<th>Ch4</th>
<th>Ch5</th>
<th>Ch6</th>
<th>Average</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch1,3,4,5</td>
<td>2.80</td>
<td>2.75</td>
<td>2.50</td>
<td>2.50</td>
<td>2.70</td>
<td>2.85</td>
<td>2.61</td>
<td>0.1139</td>
</tr>
<tr>
<td>Ch1</td>
<td>2.80</td>
<td>2.60</td>
<td>2.45</td>
<td>2.40</td>
<td>2.65</td>
<td>2.80</td>
<td>2.53</td>
<td>0.1031</td>
</tr>
<tr>
<td>Ch1,3,4,5</td>
<td>2.85</td>
<td>2.75</td>
<td>2.55</td>
<td>2.55</td>
<td>2.70</td>
<td>2.80</td>
<td>2.64</td>
<td>0.0893</td>
</tr>
<tr>
<td>Ch1</td>
<td>2.80</td>
<td>2.70</td>
<td>2.65</td>
<td>2.60</td>
<td>2.70</td>
<td>2.80</td>
<td>2.66</td>
<td>0.0415</td>
</tr>
</tbody>
</table>

Average 2.61
σ 0.060

*Ch 2,3,4,5 are in the middle so they are less affected by torsion. From the above results it can be seen that middle two channels are more consistent so their average is reported as system frequency.

Table E11-3- Summary of the results found from Torsional Fourier spectra for the 11th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1-Ch6</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hammer 1</td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hammer 2</td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hammer 3</td>
<td>2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average 2.90
σ 0.000
Appendix E12: Experiment of February 27th of 2011

Date

This test was performed on February 27th 2011.

Channel Description

Eight channels were used in this experiment, 4 of them were on the 4th floor and the remaining 4 in the basement. Both 4th floor and basement instruments were located along the west corridor equally spaced between the north and south stairways. Figures E12-1 and E12-2 show the instrument locations in NS and EW cross sections of Kaprielian Hall. Table E12-1 shows details of instrument connections. Corresponding channel numbers on each level are also shown below. Due to some mistake in cable connections channel 9 was not recorded at all (8th column in data file is constant -32786).

North to South on 4th Floor: Ch1, Ch2, Ch3, Ch4
North to South in the Basement: Ch9, Ch7, Ch6, Ch5

Test Description

For all tests duration of recording is 1 minute and sampling frequency is 400 samples/second. Different tests performed in this experiment are as follows.

- Two ambient vibration tests were carried out for each direction, one before the hammer tests and one after. File names are as follows:
  
  NS Ambient 1: Test11-1
  NS Ambient 2: Test11-2
  EW Ambient 1: Test11-3
  EW Ambient 2: Test11-4

- Two hammer tests were performed for each direction. Impulse was applied at the stairway near the elevator shaft at basement and at fourth floor. In NS direction impulse was applied toward South and in EW direction impulse was applied toward West. Figure E12-3 shows the location and direction of impulse applied in NS and EW directions. File names are as follows:

  NS Hammer impulse at basement: NSH-1
NS Hammer impulse on 4th floor: NSH4-1
EW Hammer impulse at basement: EWH-1
EW Hammer impulse on 4th floor: EWH4-1

- Calibration test was done at basement at the end of the experiment. File name is shown below.

Calibration test at basement: Calib11

Figure E12-1- NS cross section of the map of instrument locations during the twelfth experiment on February 27th 2011
Figure E12-2- EW cross section of the map of instrument locations during the twelfth experiment on February 27\textsuperscript{th} 2011

Figure E12-3- Direction and place of hammer impact on plan view of Kaprielian Hall. Two arrows named I\textsubscript{1} and I\textsubscript{2} show impacts for NS and EW directions respectively
**Description of Files**

There are 9 files in the corresponding folder. The corresponding test for each file is described in the test description.

**Table E12-1- Instrument Connections**

<table>
<thead>
<tr>
<th>Inst. No.</th>
<th>Connecting Cables</th>
<th>Final Connecting Cable</th>
<th>Jack number (Channel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>C29→C15C(Green)→C5</td>
<td>C5 C (Green)</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>49→C15A(Red)→C5</td>
<td>C5 A (Red)</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>14→C36→12C(Green)→12→C3</td>
<td>C3 C (Green)</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>97→C45→12B(Yellow)→12→C3</td>
<td>C3 B (Yellow)</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>239→C34→13A(Red)→12→C4</td>
<td>C4 A (Red)</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>26→13B(Yellow)→C4</td>
<td>C4 B (Yellow)</td>
<td>2</td>
</tr>
<tr>
<td>78</td>
<td>78→C31→13C(Green)→C4</td>
<td>C4 C (Green)</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>212→C26→C46→C44→12A(Red)→C3</td>
<td>C3 A (Red)</td>
<td>4</td>
</tr>
</tbody>
</table>

**Summary of the Results**

A summary of the results found from transfer functions and Fourier spectra (without applying calibration ratios from calibration test) is presented in Tables E11-1 to E11-3.

**Table E12-2- Summary of the results found from Fourier spectra in NS direction for the 12th experiment**

<table>
<thead>
<tr>
<th></th>
<th>Ch1</th>
<th>Ch2</th>
<th>Ch3</th>
<th>Ch4</th>
<th>Average Ch1,2,3,4</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hammer 4th</strong></td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Hammer Basement</strong></td>
<td>3.175</td>
<td>3.125</td>
<td>3.175</td>
<td>3.15</td>
<td>3.156</td>
<td>0.021</td>
</tr>
<tr>
<td><strong>Ambient 1</strong></td>
<td>3.1</td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>3.081</td>
<td>0.011</td>
</tr>
<tr>
<td><strong>Ambient 2</strong></td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>3.075</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>3.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>σ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.040</td>
</tr>
</tbody>
</table>
Table E12-3- Summary of the results found from Fourier spectra in EW direction for the 12th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1</th>
<th>Ch2</th>
<th>Ch3</th>
<th>Ch4</th>
<th>Average Ch2,3*</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer 4th</td>
<td>2.950</td>
<td>2.725</td>
<td>2.575</td>
<td>2.800</td>
<td>2.650</td>
<td>0.075</td>
</tr>
<tr>
<td>Hammer Basement</td>
<td>3.175</td>
<td>2.525</td>
<td>2.500</td>
<td>2.525</td>
<td>2.513</td>
<td>0.0125</td>
</tr>
<tr>
<td>Ambient 1</td>
<td>2.425</td>
<td>2.425</td>
<td>2.450</td>
<td>2.450</td>
<td>2.438</td>
<td>0.0125</td>
</tr>
<tr>
<td>Ambient 2</td>
<td>2.900</td>
<td>2.500</td>
<td>2.525</td>
<td>2.825</td>
<td>2.513</td>
<td>0.0125</td>
</tr>
</tbody>
</table>

*Ch 2,3 are in the middle so they are less affected by torsion. From the above results it can be seen that middle two channels are more consistent so their average is reported as system frequency.

Table E12-4- Summary of the results found from Torsional Fourier spectra for the 12th experiment

<table>
<thead>
<tr>
<th></th>
<th>Ch1-Ch4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amb 1</td>
<td>2.925</td>
</tr>
<tr>
<td>Amb 2</td>
<td>2.80</td>
</tr>
<tr>
<td>Hammer 4th</td>
<td>3.00</td>
</tr>
<tr>
<td>Hammer B</td>
<td>2.80</td>
</tr>
</tbody>
</table>

Average 2.88

σ 0.099
Appendix E13: Experiment of March 24\textsuperscript{th} of 2012

Date

This test was performed on March 24\textsuperscript{th} 2012.

Channel Description

Six channels were used in this experiment, 3 of them were on the 4th floor and the remaining 3 in the basement. Both 4\textsuperscript{th} floor and basement instruments were located along the west corridor equally spaced between north and south stairways. Figures E13-1 and E13-2 show the instrument locations in NS and EW cross sections of Kaprielian Hall. Table E13-1 shows details of instrument connections. Corresponding channel numbers on each level are also shown below. In extracting the data from binary files it should be noted that although there were only 6 instruments, data should be extracted for 8 channels, where the last two channels should be neglected.

- North to South on 4th Floor: Ch1, Ch3, Ch2
- North to South on Basement: Ch4, Ch6, Ch5

Test Description

For all tests the duration of recording is 1 minute and sampling frequency is 400 samples/second. Different tests performed in this experiment were as follows.

- One ambient vibration test was performed for each direction. File names are as follows:
  - NS Ambient: NSAMB
  - EW Ambient: EWAMB

- Four hammer tests were performed for each (north-south and east-west) direction. Impulse was applied at both SW and NW stairways at basement and on fourth floor. In NS direction impulse was applied toward South for NW stairway and toward North for SW stairway. In EW direction impulse was applied toward West for both stairways. File names are as follows:
  - NS Hammer impulse at NW stairway in basement: HNSBN
  - NS Hammer impulse at SW stairway in basement: HNSBS
  - NS Hammer impulse at NW stairway at 4\textsuperscript{th} floor: HNSTN
NS Hammer impulse at SW stairway at 4th floor: HNSTS
EW Hammer impulse at NW stairway in basement: HEWBN
EW Hammer impulse at SW stairway in basement: HEWBS
EW Hammer impulse at NW stairway at 4th floor: HEWTN
EW Hammer impulse at SW stairway at 4th floor: HEWTS

- Calibration test was done at basement at the end of experiment. File name is shown below.

  Calibration test at basement: Calib12
Figure E13-1- NS cross section of the map of instrument locations during the 13th experiment on March 24th 2012

Figure E13-2- EW cross section of the map of instrument locations during the 13th experiment on March 24th 2012
Table E13-1- Instrument Connections

<table>
<thead>
<tr>
<th>Inst. No.</th>
<th>Connecting Cables</th>
<th>Final Connecting Cable</th>
<th>Jack number (Channel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>C34→C36→16A (Red)→C3</td>
<td>C3 A (Red)</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>16C (Green)→C3</td>
<td>C3 C (Green)</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>C46→C44→16B (Yellow)→C3</td>
<td>C3 B (Yellow)</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>C24→C42→11A (Red)→C4</td>
<td>C4 A (Red)</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>11C (Green)→C4</td>
<td>C4 C (Green)</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>C23→C31→11B (Yellow)→C4</td>
<td>C4 B (Yellow)</td>
<td>2</td>
</tr>
</tbody>
</table>

Description of Files

There are 11 files in the corresponding folder. The corresponding test for each file is described in the test description.

Summary of the Results

A summary of the results found from transfer functions and Fourier spectra (without applying calibration ratios from calibration test) is presented in Table E13-1 to E13-3.

Table E13-2- Summary of the results found from Fourier spectra in NS direction for the 13th experiment

<table>
<thead>
<tr>
<th>2012-NS</th>
<th>Peak frequencies from TFs wrt basement in Hz</th>
<th>( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ch1 (North)</td>
<td>Ch3</td>
</tr>
<tr>
<td>Hammer 4th N</td>
<td>2.95</td>
<td>2.95</td>
</tr>
<tr>
<td>Hammer 4th S</td>
<td>2.95</td>
<td>2.95</td>
</tr>
<tr>
<td>Hammer B N</td>
<td>3.025</td>
<td>3.025</td>
</tr>
<tr>
<td>Hammer B S</td>
<td>3.05</td>
<td>3.05</td>
</tr>
<tr>
<td>Ambient</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sigma )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table E13-3- Summary of the results found from Fourier spectra in EW direction for the 13th experiment

<table>
<thead>
<tr>
<th>2012-EW</th>
<th>Peak frequencies from TFs wrt basement in Hz</th>
<th>Ch1 (North)</th>
<th>Ch3</th>
<th>Ch2 (South)</th>
<th>Ch3*</th>
<th>σ**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer 4th N</td>
<td>3</td>
<td>2.625</td>
<td>2.85</td>
<td>2.625</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hammer 4th S</td>
<td>3.075</td>
<td>2.75</td>
<td>3.025</td>
<td>2.750</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hammer B N</td>
<td>2.925</td>
<td>2.75</td>
<td>2.85</td>
<td>2.750</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hammer B S</td>
<td>2.75</td>
<td>2.575</td>
<td>2.625</td>
<td>2.575</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td>2.95</td>
<td>2.575</td>
<td>2.625</td>
<td>2.575</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>2.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>σ</strong></td>
<td>0.089</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ch 3 is in the middle so they are less affected by torsion. From the above results it can be seen that middle two channels are more consistent so their average is reported as system frequency.

** There is only one data point so standard deviation cannot be calculated.

Table E13-4- Summary of the results found from Torsional Fourier spectra for the 13th experiment

<table>
<thead>
<tr>
<th>2012-Torsion</th>
<th>Peak frequencies from Torsional FTs in Hz</th>
<th>Ch1-Ch2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer 4th N</td>
<td>2.95</td>
<td></td>
</tr>
<tr>
<td>Hammer 4th S</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Hammer B N</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Hammer B S</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>2.99</td>
<td></td>
</tr>
<tr>
<td><strong>σ</strong></td>
<td>0.022</td>
<td></td>
</tr>
</tbody>
</table>