Wireless Sensor Monitoring Test Documentation for UCSD Shake Tests

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December 17, 2014

1 Overview

This report documents the data collected as part of the NEES project "NEESR: Novel Embedded Diagnostics Wireless Structural Monitoring Systems" (NSF Award #1207911). The principal investigators of this project are Prof. Anne Kiremidjian and Prof. Ram Rajagopal from Stanford University. The experiments from which the data that was collected were conducted at the NEES at University of California, San Diego, Large High Performance Outdoor Shake Table, as part of the NEES project "NEESR: Seismically Isolated Unibody Residential Buildings for Enhanced Life-Cycle Performance" (NSF Award #1135029). More information about the experimental setup can be found at `http://nees.ucsd.edu/projects/2014-seismically-isolated-unibody/`.

2 Background

The structure tested at the NEES@UCSD shake table was a full scale model of a light-frame two-story wood-frame residential house. This structure consisted of an enhanced strength/stiffness system, which was achieved by engaging the available interior and exterior wall to create a uni body system. Further the a ductile light-frame shear wall system was also incorporated. The system was constructed to reduce deformations and damage.

The tests were split into two phases, isolated base and fixed base respectively. For each phase the structure was subjected to different ground motions. In the fixed base experiment, the ground motions were from Design Earthquake level (DB) up to 3 $\times$ Maximum Considered Earthquake (MCE).

3 Setup

3.1 Sensor Description

In this test, 15 wireless sensors were used. Each sensor device included two components: one mote and one sensing unit. A wireless sensor mote is a battery-powered sensor system with microprocess, wireless transceiver, and memory. In this test, we used the Telsob mote with TI MSP430 microprocessor and CC2420 transceiver [1, 2]. The sensing unit was MPU 6050 sensor, which included one 3-axis accelerometer, one 3-axis gyroscope, and one temperature sensor [3]. In this test, only the 3-axis accelerometer was enabled. The range of each axis was from $-4g$ to $4g$ and the resolution was 16 bits. The accelerometer had a sampling frequency of 1024 Hz. Since the MPU 6050 sensor was an I^2C sensor, the data were retrieved from the sensor every 1/128 second. Therefore, the sampling frequency of the system was 128 Hz. The analog signal was filtered by an anti-aliasing filter before sampling. The operating system of wireless sensors was the SnowFort system [4]. The Time Division Multiple Access (TDMA) protocol was employed as the communication protocol.

3.2 Sensor Placement

All the sensors were placed on the West or the East side of the structure since the shaking direction was West-East direction. Fig. 1, Fig. 2, Fig. 3, and Fig. 4 show the locations of the sensors on a side view drawing and in the field test. Fig. 5 and Fig. 6 indicate the distances among the sensors and the base stations.

The sensors were separated into three groups due to the limitation of the communication channel. The first number in the label is the group number and the second number is the serial number within the group. The sensors with the same group number shared a common base station. The sensors on the wall were placed between the window and the edge. Each was about 12 inches either above the lower floor or below the upper floor. The sensors on the floor were placed in the middle of the outer walls. The sensor locations are summarized in Table. 1.

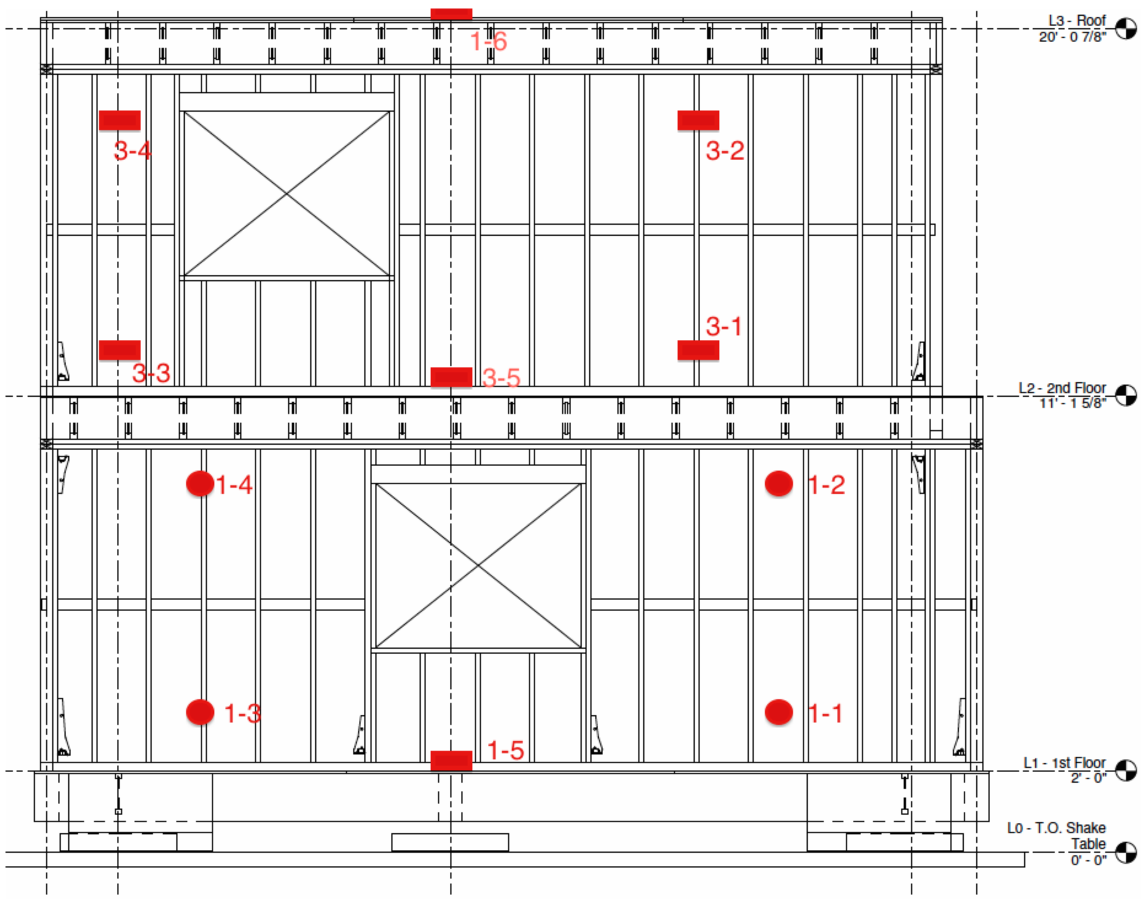

Figure 1: Sensor location on the West side wall. Sensors with square symbol were installed inside the structure; Sensors with circle symbol were installed outside of the structure

Group	Serial Number	Sensor Location Description
1	1	1st floor, West, on the wall, exterior, SE corner
1	2	1st floor, West, on the wall, exterior, NE corner
1	3	1st floor, West, on the wall, exterior, SW corner
1	4	1st floor, West, on the wall, exterior, NW corner
1	5	1st floor, West, on the floor, interior
1	6	roof, West, on the floor, exterior
2	1	roof, East, on the floor, exterior
2	2	2nd floor, East, on the floor, interior
2	3	1st floor, East, on the floor, interior
2	4	shake table, East, on the floor, exterior
3	1	2nd floor, West, on the wall, interior, SE corner
3	2	2nd floor, West, on the wall, interior, NE corner
3	3	2nd floor, West, on the wall, interior, SW corner
3	4	2nd floor, West, on the wall, interior, NW corner
3	5	2nd floor, West, on the floor, interior

Table 1: Sensor Location Description

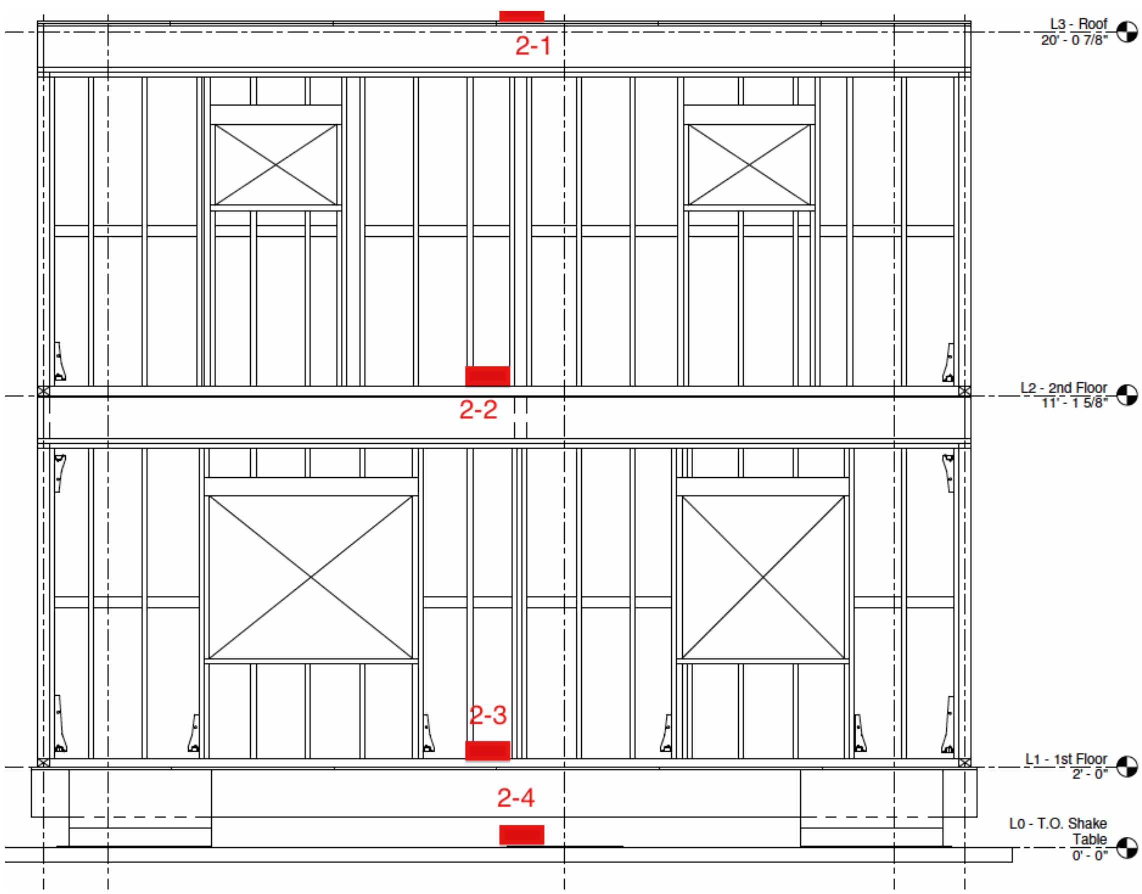

Figure 2: Sensor location on the East side wall. Sensors with square symbol were installed internior

Figure 3: Sensor location on the West side wall: Exterior wall. The squares indiciate the locations of the sensors

Figure 4: Sensor location on the West side wall: Interior wall of the 2nd floor. The squares indicate the locations of the sensors

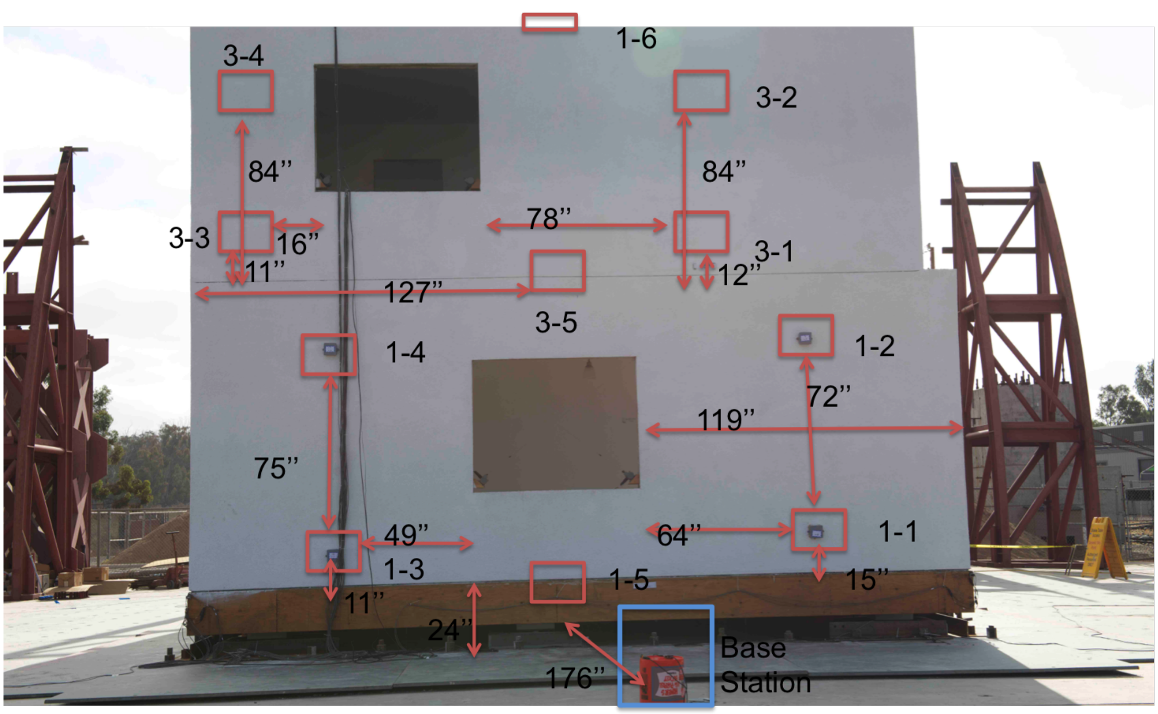

Figure 5: Sensor location on the West side wall with the distances.

Figure 6: Sensor location on the East side wall with the distances.

4 Data

The data directory has the following structure:

```
Experiment 3 (Root directory)
├── Trial-1: Isolated House Test GM1
│   ├── SN1_1.csv
│   ├── SN1_2.csv
│   ├── ...
│   └── SN3_5.csv
├── Trial-2: Isolated House Test GM2
│   ├── SN1_1.csv
│   ├── SN1_2.csv
│   ├── ...
│   └── SN3_5.csv
├── Trial-3: Isolated House Test GM3
│   ├── SN1_1.csv
│   ├── SN1_2.csv
│   ├── ...
│   └── SN3_5.csv
├── ...
└── Trial-7: Isolated House Test GM7
    ├── SN1_1.csv
    └── SN1_2.csv
```

```
│
│  ├── ...
│  └── SN3_5.csv
├── Trial-8:  Fixed House Test GM1
│  ├── SN1_1.csv
│  ├── SN1_2.csv
│  ├── ...
│  └── SN3_5.csv
├── Trial-9:  Fixed House Test GM2
│  ├── SN1_1.csv
│  ├── SN1_2.csv
│  ├── ...
│  └── SN3_5.csv
├── ...
└── Trial-21:  Fixed House Test GM14
   ├── SN1_1.csv
   ├── SN1_2.csv
   ├── ...
   └── SN3_5.csv
```

The folder contains the data collected from all the sensors. The file is named as SN{*GroupNumber*}_{*SerialNumber*}, where SN stands for sensor number. For example, SN1_1.csv contains the data collected from Sensor 1 in Group 1.

The data for the isolated house tests were collected on September 3rd, 2014. It contained seven tests with different ground motions. The test details are summarized in Table. 2.

Test Date	Test Number	Ground Motion
9/3/2014	GM 1	Sylmar Convert 142, 1994, Northridge, California.
9/3/2014	GM 2	TCU 074N, 1999 Chi Chi, Taiwan.
9/3/2014	GM 3	Newhall Fire Station 360, 1994, Northridge, California.
9/3/2014	GM 4	Sylmar Converter Station 052, 1994, Northridge, California.
9/3/2014	GM 5	Takatori 000, 1995 Kobe, Japan.
9/3/2014	GM 6	Capitola 000, 1989 Loma Prieta, California.
9/3/2014	GM 7	Conception L, 2010 Maule, Chile.

Table 2: Ground motion (GM) test details for the isolated house test.

The fixed house tests were performed on September 16th and 17th of 2014. It contains 14 different tests and each test had different ground motions. The test details are summarized in Table. 3.

Each CSV file has three columns. The first column is the acceleration on the shaking direction with the positive value in the West direction. The second column is the acceleration in the direction that is orthogonal to the shaking direction. The positive direction is the North. The third column is the acceleration as same direction as the gravity. The positive direction is the gravity direction. The unit of each column is g.

Test Date	Test Number	Ground Motion
9/16/2014	GM 1	High amplitude level white noise with 5% RMS
9/16/2014	GM 2	Capitola 000 Earthquake 1989 Loma Prieta Scale Factor: 0.4 Service level
9/16/2014	GM 3	High amplitude level white noise with 5% RMS
9/16/2014	GM 4	Capitola 000 Earthquake 1989 Loma Prieta Scale Factor: 1, 1×DE level
9/16/2014	GM 5	High amplitude level white noise with 5% RMS
9/16/2014	GM 6	Capitola 000 Earthquake 1989 Loma Prieta Scale Factor: 1.5, 1×MCE level
9/16/2014	GM 7	High amplitude level white noise with 5% RMS
9/16/2014	GM 8	Capitola 000 Earthquake 1989 Loma Prieta Scale Factor: 2.25, 1.5 ×MCE level
9/17/2014	GM 9	High amplitude level white noise with 5% RMS
9/17/2014	GM 10	Capitola 000 Earthquake: 1989 Loma Prieta Scale Factor 3, 2×MCE level
9/17/2014	GM 11	High amplitude level white noise with 5% RMS
9/17/2014	GM 12	Capitola 000 Earthquake: 1989 Loma Prieta Scale Factor 1.5, 1×MCE level
9/17/2014	GM 13	High amplitude level white noise with 5% RMS
9/17/2014	GM 14	Capitola 000 Earthquake: 1989 Loma Prieta Scale Factor 4.5, 3×MCE

Table 3: Ground motion (GM) test details for the fixed house test. The scale factor refers to Design Earthquake (DB) and Maximum Considered Earthquake (MCE) level.

4.1 Sample data plots

Fig. 7 and Fig. 8 show the plots of data in time domain and frequency domain respectively. The data were collected by Sensor 1-1 in Fixed Housing Test with GM 14.

4.2 Note

Here are some notes about the collected data:

- Some sensors failed in some tests. Table 4 summarizes the information regarding the sensor failures.

Test Type	Test Number	Sensor Number
Isolated house test	GM1 – GM 7	1-5
Fixed house test	GM4	2-2
Fixed house test	GM5-6	1-5
Fixed house test	GM6	1-4

Table 4: Sensor Failure Summary

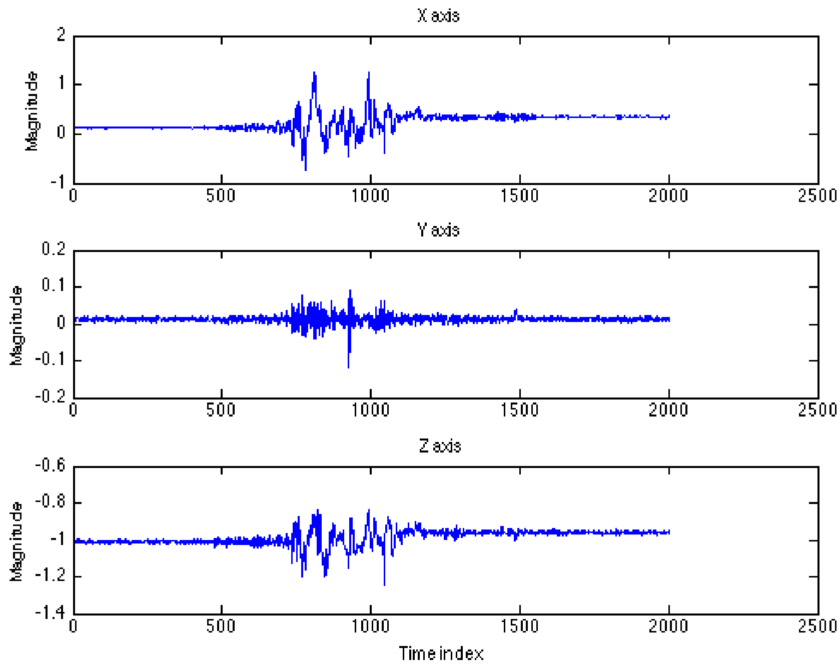

Figure 7: Time domain plot of the data collected by Sensor 1-1 in Fixed Housing Test with GM 14

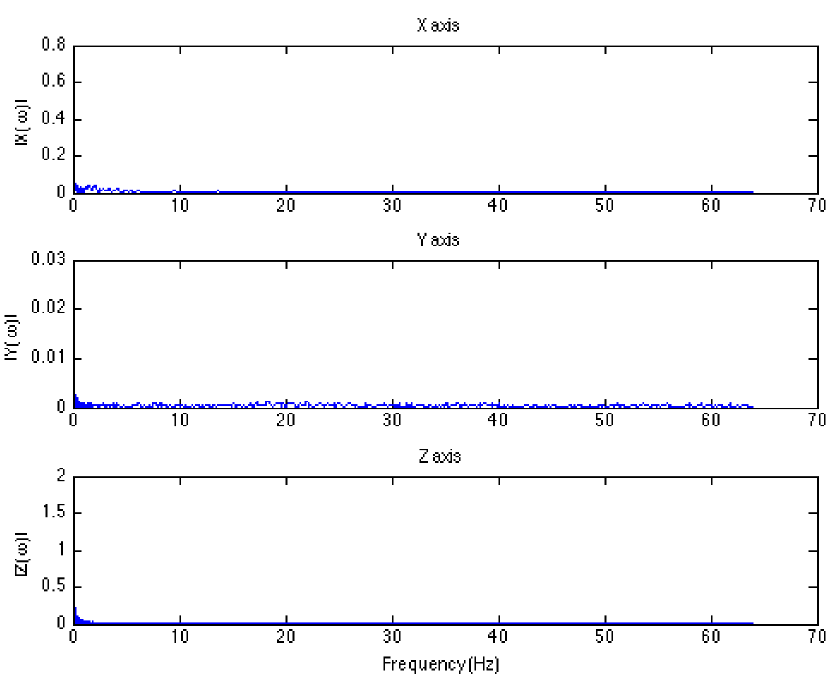

Figure 8: Frequency domain plot of the data collected by Sensor 1-1 in Fixed Housing Test with GM 14

- In fixed house test with GM7, the base station of Group 1 was rebooted automatically during the test due to high environmental temperature and direct sunshine on the base station. Therefore, the data that were collected from this test were not complete.

- The data collected may not have same number of points for each sensor in the same test. It is caused by the packet drop of the communication channel. As discussed in [4], the packet drop rate for in-room experiment is around 1%. For our test, the environmental temperature and the sensor locations had strong effects on the quality of the communication link. Overall, the packet drop rate in all the tests around 6% on average. In the worst cases, which happened unusually, we have the packet drop rate around 80%, such as Sensor 2-2. The reason that Sensor 2-2 has high packet drop rate is that it was installed at the corner of two walls.

5 Acknowledgements

We would like to thank the researchers involved with the experiments, Professor Gregory Deierlein, Professor Edwardo Miranda, and graduate students, Ezra Jampole, Cristian Acevedo and Scott Swensen for allowing us participate in the experiments and their overall help and collaboration. We would like to thank the personnel of the NEES@UCSD shake table facility, for their help and accommodation. We also thank graduate student Konstantinos Balafas and Mark Mollineaux for their involvement and help. The research team would like to thank the National Science Foundation for their partial support under NSF NEESR Grant No. 1207911.

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