Shake Table Experiments GPS Deployments: June-July, 2016

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July 13, 2016

SOPAC was invited to collaborate in a project led by Professor Tara Hutchinson (Jacobs School of Engineering) at the NEES UCSD Large High Performance Outdoor Shake Table to monitor the series of experiments with GPS measurements. The purpose of the testing is described in the abstract below, from http://nees.ucsd.edu/:

> Light-gauge cold-formed steel (CFS) framed multi-story residential housing has the potential to support societies urgent need for low cost, multi-hazard resilient housing. CFS-framed structures offer lower installation and maintenance costs, are durable, ductile, lightweight, and manufactured from recycled materials. In addition, consistency in material behavior and low material costs are added benefits compared with their wood-framing counterparts. The components of CFS-framed assemblies (studs, track, joists) can be assembled quickly and with relative ease into prefabricated panels. Notably, the ductile nature of a CFS-framed structure aligns with the performance needs in moderate to high seismic zones. Compared to other lightweight framing solutions (such as timber), CFS is a non-combustible, an important basic characteristic to prohibit fire spread. Taken in totality, these many beneficial attributes lead to a highly sustainable infrastructure for housing communities.

In short, the main objective of the project is to test the seismic response of a building strategy that uses steel-sheathed steel stud prefabricated construction. The second through sixth floors of the building were prefabricated off-site, and then installed above the first floor, which was constructed directly on the shake table. The full-scale 6-story cold-formed steel wall-braced building was subjected to shaking on June 13, 15, 17 and July 1. The testing schedule is detailed in Tables 1-4. Note that the start and stop times and displacements in the tables are based on a visual inspection of the estimated displacement time series and are only approximate.

We also installed a reference station mounted on a tripod in the field area ~45m directly west of the Shake Table (Figure 1 and 2). The reference station included an Ashtech choke ring antenna (ASH701945B_M, without a radome) mounted on a tribrach, and was connected to a Leica GMX902 receiver in the Shake Table conference room. The antenna was leveled, oriented to true north and centered over a temporary geodetic marker (NGS disc monument at a slant height of 140.5cm). We submitted a request to UNAVCO for 10Hz data from the nearest cGPS station, P472, during the test to use as a second reference and to assess the precision of the estimated GPS displacements (during the shaking experiments there should be zero motion between the two references). P472 is the Camp Elliot site, located at 32.88921°N, 117.1047°W and 138m elevation and ~650m from the Shake Table. This station operated for all experiments.

We deployed five GPS receivers on the building for the June 13, 15, and 17 experiments. Three receivers were deployed on the roof (Figures 3-6). To reduce the weight, two small antennas (not chokerings) were cantilevered off the west side of the third and fifth floors (Figure 7); both locations had considerably obstructed sky views. For the June 13th experiments, we deployed two small Leica antennas on the third and fifth floor. The Topcon GNSS antenna and receiver was used for the central roof station so that we could process GPS and GLONASS data in postprocessing using precise point positioning (PPP). The third floor antenna was connected to a Topcon GNSS receiver in order to have access to both GPS and GLONASS satellites, to hopefully improve the satellite coverage. The other two other roof antennas were located in the NW and SW corners. All GPS receivers (except for P472) were located in the Shake Table conference room, south of the platen and connected to the antennas with 40-60m antenna coaxial cables (Figure 5). Note that the 60m cables are an adequate length to be able to comfortably bring cable from roof into conference room. We changed the deployment strategy for the June 15th and 17th experiments. Because of the poor visibility at the third and fifth floor cantilevers, we replaced the small Leica antennas with two small Topcon GNSS antennas, and switched the Topcon receiver for the third floor. The GPS equipment used for these experiments including the base stations is listed in Tables 5 and 6.

Issues encountered:

- One SE Navcom receiver intended for use on the project was not working upon arrival at the site on the first day of installation (June 8). A replacement Topcon receiver was substituted the following day (see Tables 5 and 6).
- The stations installed on the roof were not level. The Shake Table crew adjusted the mounts to make them more level, and we installed the antennas on top of tribrachs to allow for proper leveling.
- Initially, the Ashtech choke ring antennas installed on the roof were incompatible with the Navcom receivers. We replaced the Ashtech antennas with Topcon choke ring antennas on Friday, June 10, prior to the week of earthquake testing (see Tables 5 and 6).
- On June 13 there was an issue with the field reference site (BASE). The receiver indicated that no satellites were available, but it was unclear if this was an issue with the antenna, cable, or receiver. For this day of testing, we used P472 as the reference site, since BASE was not working. After testing of the receiver, a replacement antenna and cable was brought to the site, but on June 14 the original set up began working once again and BASE was reinvoked as the reference station.
- The cantilevered antennas had difficulty for all experiments due to their obstructed view. Data were recorded, and may be able to be slightly improved in post-processing.

On June 23 all five antennas, antenna cables and tribrachs were removed from the Shake Table in preparation for the fire testing on June 27 and June 29. For the "nearcollapse" test of July 1, we returned the three GPS units to the roof, but did not return units to the two cantilevered locations on the third and fifth floors.

Drone footage from the first week of seismic testing showed the Roof NW and SW stations experienced high frequency shaking due to the response of the 4' GPS mounts. The roof center station, mounted on a 2' stand did not experience this high frequency shaking response. To avoid this response during the final day of testing, all three roof stations were mounted on 2' stands. However, because there is a 4' parapet around the roof, leaving the Roof NW and SW stations in the corners would likely result in poor satellite view and multipath effects. See Figures 3-6. We decided to move the stations out of the corners, creating a station midway along the southern edge of the roof and another midway along the western edge of the roof. The Roof center station stayed as is. The equipment for the new set up is detailed in Table 7. The roof stations in their new configuration were installed on June 30, in advance of the final seismic tests (Table 4). Photos of the final roof configuration are shown in Figures 8-11.

All equipment was removed and returned to SIO on July 5.

Analysis of the 10 Hz GPS data was performed in real time using the Geodetics, Inc. RTD 3.5 EV (May 5 2011) RTD Pro (RNA 4.11) software using the stations and metadata recorded in Tables 5-7. The configuration included: L1L2 (short baseline mode), cutoff angle zero degrees, elevation dependent weighting, no ionosphere or troposphere modeling, satellite broadcast ephemeris. Raw data files were stored in one-hour segments, RINEX files in one-hour and 24-hour segments (no decimation of data), and 24-hour solution files with covariance information. We achieved excellent results with the roof stations, but not with the cantilevered stations on the 3rd and 5th floors. There may be an opportunity to reprocess the data for those two stations at a later time.

Acknowledgments
Jessie Saunders assisted in the initial installation of the GPS and related equipment. Glen Offield provided timely laboratory and equipment support. Anne Sullivan prepared the PC workstations for the RTD software.

No.	Type of Test	TimeInterval GPST GPST=UTC+17s	Peak to Peak Nearest 0.5 cm
1	1.5%g RMS white noise for building warm up and sensor engagement	17:40-17:31	1.5 cm
2	0.08g pulse	17:48:10	1 cm
3	1.5%g RMS white noise (3 min)	17:55:45-17:58:15	2 cm
4	3.0%g RMS white noise (3 min)	18:05:20-18:08:20	3.5 cm
5	**25% RIO360 – Service Level (EQ1)**	18:19:10-18:19:50	3.5 cm
6	1.5%g RMS white noise (3 min)	18:30:25-18:33:10	1 cm
7	**25% CNP196 – Service Level (EQ2)**	18:41:15-18:42:20	20 cm
8	1.5%g RMS white noise (3 min)	18:48:20-18:51:20	2 cm
1-2 hour inspection and data check (table down)			
9	1.5%g RMS white noise for building warm up and sensor engagement (1 min)	21:16:30-21:17:30	1 cm
10	**25% CUREW – Service Level (EQ3)**	21:23:35-21:24:35	5 cm
11	0.08g pulse	21:31:10	1 cm
12	1.5%g RMS white noise (3 min)	21:37-21:40	2 cm
13	3.0%g RMS white noise (3 min)	21:45:05-21:48:05	4 cm

Table 1: Testing schedule on June 13, 2016.

June 15, 2016

No.	Type of Test	TimeInterval GPST GPST=UTC+17s	Peak to Peak Nearest 0.5 cm
1	1.5%g RMS white noise for building warm up and sensor engagement	16:38:10-16:39:10	1 cm
2	0.08g pulse	16:45:29	1 cm
3	1.5%g RMS white noise (3 min)	16:52-16:55	2 cm
4	3.0%g RMS white noise (3 min)	16:59:20-17:02:20	4 cm
5	**50% CNP196 – Design Level (EQ4)**	17:08:40-17:09:00	10 cm
6	0.08g pulse	17:14:30	1.5 cm
7	1.5%g RMS white noise (3 min)	17:20-17:23	2 cm
8	3.0%g RMS white noise (3 min)	17:27:30-17:30:30	4 cm
1-2 hour inspection and data check (table down)			
9	1.5%g RMS white noise for building warm up and sensor engagement (1 min)	19:30:40-19:31:40	1.5 cm
10	**100% CNP196 – Design Level (EQ5)**	19:38:40-19:39:10	20 cm

11	0.08g pulse	Not done?	???
12	1.5%g RMS white noise (3 min)	19:46:20-19:49:20	1.5 cm
13	3.0%g RMS white noise (3 min)	19:53:10-19:56:10	3 cm

Table 2: Testing schedule on June 15, 2016.

June 17, 2016

No.	Type of Test	TimeInterval GPST GPST=UTC+17s	Peak to Peak Nearest 0.5 cm
1	1.5%g RMS white noise for building warm up and sensor engagement	18:05:30-18:06:30	1.5 cm
2	0.08g pulse	18:14:45	1 cm
3	1.5%g RMS white noise (3 min)	18:20:10-18:23:10	2 cm
4	3.0%g RMS white noise (3 min)	18:27-18:30	3 cm
5	**150% CNP196 – Maximum Considered Level (EQ4)**	18:39:45-18:40:15	60 cm (1.5 cm permanent East)
6	0.08g pulse	18:46:10	1 cm
7	1.5%g RMS white noise (3 min)	18:52:30-18:55:30	1.5 cm
8	3.0%g RMS white noise (3 min)	18:59:30-19:02:30	3 cm

Table 3: Testing schedule on June 17, 2016.

July 1, 2016

No.	Type of Test	TimeInterval GPST GPST=UTC+17s	Peak to Peak Nearest 0.5 cm
1	1.5%g RMS white noise for building warm up and sensor engagement	16:27:10-16:30:10	1.5 cm
2	3.0%g RMS white noise	16:35:10-16:38:10	3 cm
3	**25% RIO360 –Service Level "Aftershock" (EQ8)**	16:43:45-16:44:15	5 cm
4	1.5%g RMS white noise (3 min)	16:49-16:52	1.5 cm
5	3.0%g RMS white noise (3 min)	16:56-16:59	3.5 cm
1 hour inspection and data check (table down)			
6	1.5%g RMS white noise (3 min)	18:21:15-18:22	1.5 cm
7	**EQ9: 150% RRS228 Rinaldi Receiving Station – 1994 Northridge Earthquake**	18:30:20-18:30:35	100 cm ~20 cm permanent East
8	1.5%g RMS white noise (3 min)	Not done	
9	3.0%g RMS white noise (3 min)	Not done	

Table 4: Testing schedule for July 1, 2016.

Station	Antenna Type	Antenna S/N	Receiver Type	Receiver S/N
Reference BASE	ASH701945B_M	CR620012902	Leica GMX902	CR519991756
3rd Floor LEI2	LEIAX1202GG	07060143	Leica GMX902	101098
5th Floor LEI1	LEIAX1202GG	07100053	Leica GMX902	100066
Roof SW NAV3	TPS_CR.G3	3831908	Navcom NCT	5010
Roof NW NAV1	TPS_CR.G3	3831991	Navcom NCT	5144
Roof Center TOPC	TPS_CR.G3	3831950	Topcon TPS NET-G3A	61801126
Camp Elliot P472	TRM29659.00 SCIT	0220336605	Trimble NetRS	4549261275

Table 5: Station instrumentation information – June 12 setup. All antenna heights were set to zero, except for P472 (0.0083m) and no radome except for P472. The cantilevered GPS provided unuseable positions. Switched to new configuration for June 13 tests

Station	Antenna Type	Antenna S/N	Receiver Type	Receiver S/N
Reference BASE	ASH701945B_M	CR620012902	Leica GMX902	CR519991756
3rd Floor TOPC	TPSPG_A1+GP	310-1030	Topcon TPS NET-G3A	61801126
5th Floor LEI1	LEIAX1202GG	07100053	Leica GMX902	100066
Roof SW NAV3	TPS_CR.G3	3831908	Navcom NCT	5010
Roof NW NAV1	TPS_CR.G3	3831991	Navcom NCT	5144
Roof Center LEI2	TPS_CR.G3	3831905	LEICA GMX902	101098
Camp Elliot P472	TRM29659.00 SCIT	0220336605	Trimble NetRS	4549261275

Table 5: Station instrumentation information – June 13 tests. All antenna heights were set to zero, except for P472 (0.0083m) and no radome except for P472. The cantilevered GPS provided unuseable positions.

Station	Antenna Type	Antenna S/N	Receiver Type	Receiver S/N

Reference BASE	ASH701945B_M	CR620012902	Leica GMX902	CR519991756
3rd Floor LEI2	TPSPG_A1+GP	310-1030	Topcon TPS NET-G3A	61901126
5th Floor LEI1	TPSPG_A1+GP	310-1091	Leica GMX902	100066
Roof SW NAV3	TPS_CR.G3	3831908	Navcom NCT	5010
Roof NW NAV1	TPS_CR.G3	3831991	Navcom NCT	5144
Roof Center TOPC	TPS_CR.G3	3831950	Leica GMX902	101098

Table 6: Station instrumentation information – June 15, 17 tests. All antenna heights were set to zero, except for P472 (0.0083m) and no radome except for P472.

Station	Antenna Type	Antenna S/N	Receiver Type	Receiver S/N
Reference BASE	ASH701945B_M	CR620012902	Leica GMX902	CR519991756
Roof South RSOU	TPS_CR.G3	3831908	Navcom NCT	5010
Roof West RWES	TPS_CR.G3	3831991	Navcom NCT	5144
Roof Center LEI2	TPS_CR.G3	3831950	Leica GMX902	101098

Table 7: Station instrumentation information – July 1 test. All antenna heights were set to zero, except for P472 (0.0083m) and no radome except for P472.

Figure 1: Dr. Bock installs a monument for the BASE tripod station.

Figure 2: View of the BASE station and the western side of the building. Station Roof West is visible between the roof parapets.

Figure 3: Xiang Wang feeds the antenna cables down the side of the structure toward the receivers, set up in the adjacent conference room.

Figure 4: Roof Stations. Left: Roof SW, Center: Roof Center, Right: Roof NW.

Figure 5: Roof Stations, looking west.

Figure 6: Roof stations, looking WSW.

Figure 7: Jeremy (LHPOST personnel) replaces the originally installed 3rd floor Leica receiver with a small Topcon receiver.

Figure 8: The new 2' mount at the western edge of the roof, installed for the final day of seismic tests.

Figure 9: New 2’ stands installed on the roof for the final day of seismic tests. Left: Mount for station Roof South. Center: Removed roof SW mount. Right: Mount for station Rood West.

Figure 10: Roof antennas mounted on new 2’ stands. Left: Roof South, Center: Roof West, Right: Roof Center.

Figure 11: Antenna Roof West.

Figure 12: Spectators wait for the June 17th test 5.