2005-2006 USGS-ANSS Cooperative Agreement
Final Report

Project Title: "Operation and Maintenance of the UCLA Factor Network"
Principal Investigator: Monica Kohler
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Introduction

The UCLA Factor building is a 17-story moment-resisting steel frame structure with an embedded 72-channel accelerometer array. The array serves as a prototype for real-time state-of-health monitoring and full-scale, soil-structure interaction experiments. Its purpose is to produce waveform data that can be used in predictive modeling of structures for damage assessment and building code modification.

The Factor array has been operated and maintained by Monica Kohler, Igor Stubailo, and Paul Davis since late 2002. The UCLA NSF Center for Embedded Networked Sensing provided the original funding for significant hardware and software upgrades in late 2003 but does not have any further funding commitments related to Factor array maintenance and operations. As in the previous years, one staff member (Stubailo) perfomed tasks related to upgrading and troubleshooting the system, and another staff member (Kohler) performed quality control of waveforms as they are used in graphical and data analysis. The focus of the tasks covered in this grant period was to operate and maintain the array, and to assist in the hardware upgrades that took place late last year and early this year. In addition, we guided the work of an undergraduate-level programmer in the development of an array-dedicated website(factor.gps.caltech.edu) that now has a large volume of graphical and text content. Throughout the year we worked with IRIS DMC personnel to ensure that waveform data and metadata were archived on-site and made available for immediate distribution.

Network overview: The Factor seismic array

The Factor array comprises 72 channels (4 per floor and the roof) recording waveforms at 100 and 500 sps. Six channels from nearby downhole and surface borehole seismometers, and the first of a four-station free-field array are contributing data for soil-structure interactions. The remaining three free-field stations are in the process of being installed. Recently, two GPS antennas to record continuous raw displacement time series data in real time were installed on the roof and are recording at 1 sps through the dedicated cables to a temporary archive at the USGS Pasadena. The Factor building has a 4G Episensor (upgraded from FBA-11) accelerometer array composed of four horizontal channels per floor except for the basement and subbasement which have two vertical and two horizontal channels each. The horizontal sensors are oriented north-south and east-west along the mid-sections of most floors. GPS receivers for timing are located on the roof. The power sources for the dataloggers and sensors are located in the penthouse.

In the building's machine room in the attic, nine Quanterra 4120 digitizers were installed as part of a CENS pilot study to test embedded network algorithms using internet-type technology. A dedicated fiber optic internet connection was installed within the Factor building to enable continuous data streams from Factor into other laboratories. The 72 channels of building data can be presently viewed on the web at crust.ess.ucla.edu:5813 password: *seismo* in real time. The 24-bit resolution Quanterras record the continuous data in two data streams: one at 100 sps for long term archiving and one at 500 sps on a RAID array from which major events could be extracted. The data are recorded both on-site and in the seismology laboratory at UCLA.

Two borehole seismometers (one at the surface and one at 100-m depth) are located approx. 25 m east of the Factor building in the UCLA Botanical Gardens. Each consists of three-component Kinemetrics Episensors connected to a Quanterra 4120 digitizer. The digitizer is located in a garden shed a few meters from the borehole. The borehole data are being piped

directly into our real-time system controlled by the monitoring software. Three of our free-field stations are also up and running at the northern, southern, and eastern sites on campus. The sensors consists of an Episensor recording on Q330s. The final free-field site is in the middle of being installed once permission is obtained.

The primary product produced by the Factor array has been the continuous waveform data for engineering research purposes. We developed a dedicated web site (factor.gps.caltech.edu) already well-stocked with content related to the waveform data that includes the real-time viewer, detailed metadata information, detailed site conditions (e.g., soil velocity data), a manual on obtaining the data from the IRIS DMC, a list of known problems and system modifications, and a growing archive of photos related to the building and the seismic hardware. Our real-time waveform display provides information about the status of the array. Most mornings one of us logs into the system and checks for absence of channels, glitches, and other disruptions to normal array operation.

The secondary array products, also available via the web site, are processed data products useful for research and educational purposes. We have been producing displacement animations of significant earthquakes and ambient vibrations recorded by the array for a variety of frequency ranges (factor.gps.caltech.edu/animations). As earthquakes occur, we add them to our growing database of building response animations. Some of the most significant earthquakes that have occurred during this grant period include: 1) Offshore Northern California, June 15, 2005, M_w=7.2, distance=1036 km, 2) Obsidian Butte, September 2, 2005, M_L=4.8, distance=280 km, 3) Wheeler Ridge, September 22, 2005, M_w=4.7, distance=120 km (Fig. 1), and 4) two Marina Del Rey earthquakes on October 22 and 23, 2005, M_L=3.1, distance=7 km. The animation files show displacements of the building floors relative to the base using the recorded data. The displacements were bandpass filtered for frequencies between 0.30 Hz and 5.0 Hz (limits vary depending on earthquake size). These animations are unique tools for both academic research and educational purposes. The density of the stations makes it possible to view the dominant frequencies of building response, and how the dominant frequencies vary depending on the size and distance of the earthquake. Furthermore, the animations provide additional information about the state of health of the sensors because their measurements can be compared with nearest neighbor measurements.

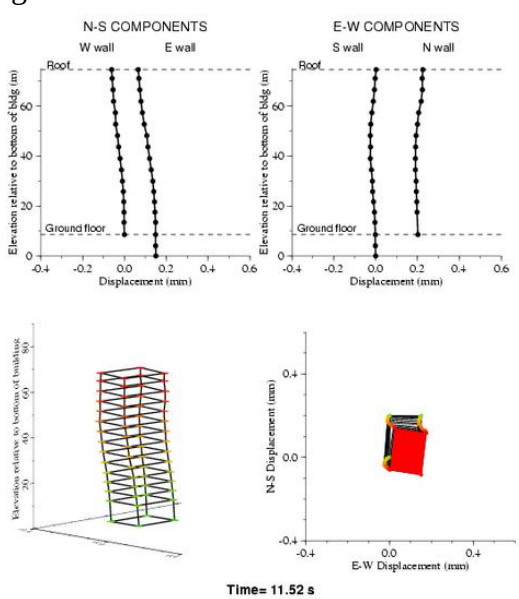

Figure 1. Actual 2D displacement of the Factor building during the September 22, 2005 Wheeler Ridge earthquake (0.3-5.0 Hz). This frame is from a 24-second animation. Filled circles show locations of sensors contributing data to the displacements.

Data archival and waveform monitoring

The 100 sps data are being archived at the IRIS DMC in miniSEED format and are immediately available for request. The DMC has the metadata for use in generating the miniSEED files, and for conversion to other data formats. Bearing in mind that not all users are familiar with the DMC's request tools, we have developed a manual on how to use or download IRIS software to obtain information about the Factor array using the metadata and to request the waveform data (factor.gps.caltech.edu/data_sets). We are in regular contact with the DMC's director, Tim Ahern, who is willing to make his staff's help available to anyone who needs further assistance obtaining data from the DMC. The DMC has data starting in mid-2005.

Two new independent GPS antennas that record raw displacement time series were installed by USGS personnel on the roof of Factor in November, 2005. We began discussions with IRIS DMC Director Tim Ahern about whether the data should be archived at the IRIS DMC since they are more comparable to strain meter time series output than they are to traditional GPS antenna output.

The real-time monitoring software package *Antelope* (developed by BRTT) has been used to monitor Factor building data flow for the past three years and is also being used to monitor the borehole and free-field array. We used grant funds to purchase the yearly maintenance contract as required by Antelope to install software upgrades.

End-users' data use

In an effort to justify the existence of this array, we developed a link on our web site to research projects that use Factor array data (factor.gps.caltech.edu/research). This link includes a list of projects, presentations, and papers that use the waveform data.

Hardware maintenance and upgrades

During December, 2005 and January, 2006 all 72 of the original FBA-11 accelerometers were replaced with 4G Episensors by USGS technicians. We worked with the technicians both at the Factor building and in our labs to expedite the replacement of the sensors. Specifically, we produced tilt test results for polarity, orientation, and amplitude integrity (Fig. 2). We performed comparative analysis for amplitude calibrations, and archived the appropriate new instrument responses. We modified the Factor array web site to reflect the hardware changes (see factor.gps.caltech.edu/sensor_locations).

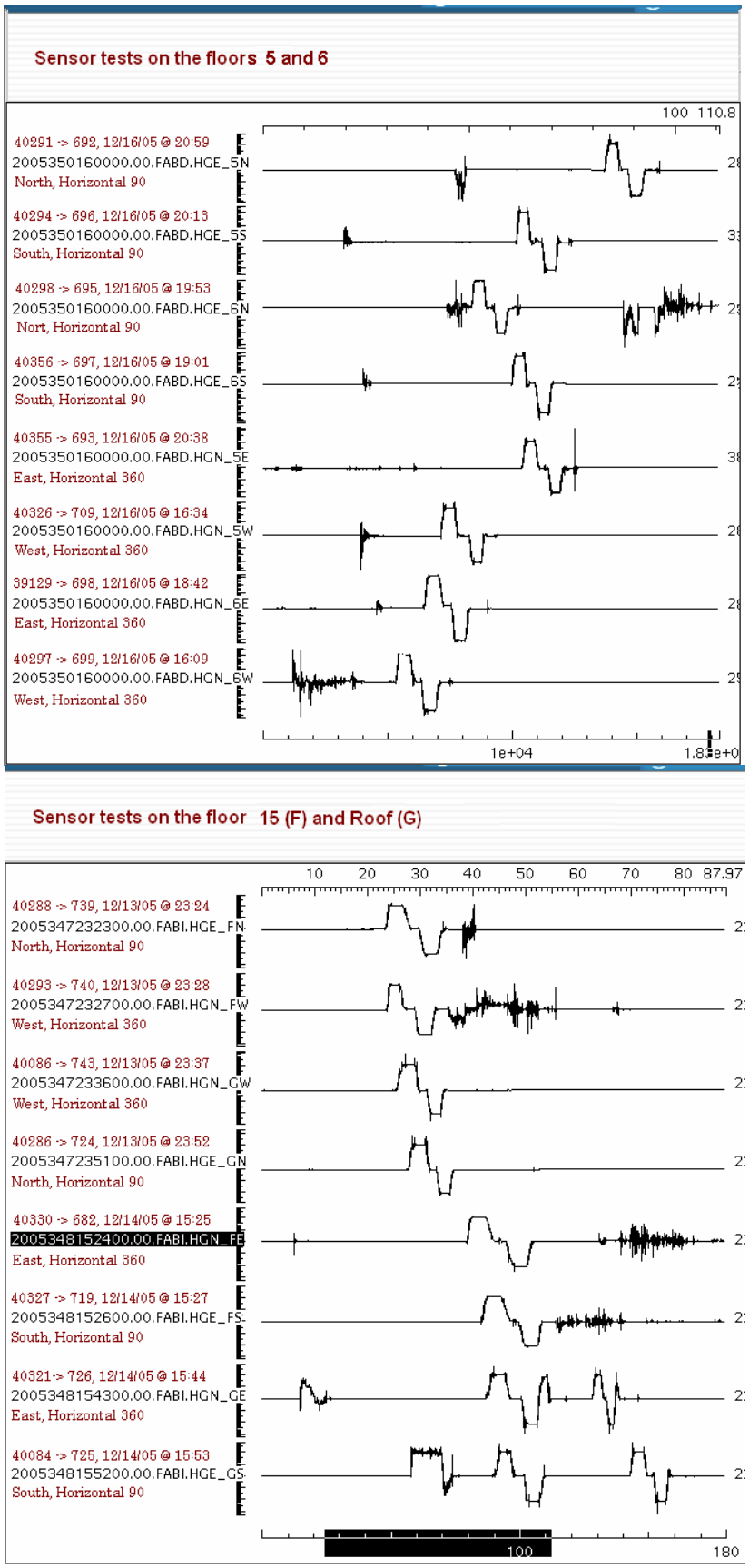

Figure 2. Results of tilt tests for selected floors performed on the newly installed 4G Episensors.

The sensor upgrade resulted in a significant increase in data volume, probably due to the higher instrument sensitivity and different data compression schemes. As a result we had several minor failures and one major digitizer failure that were due to the hard drive response to the higher data resolution (e.g., Fig. 3). We lost several hard drives because of overheating that were probably due to higher data volume. Although the hard drives were recording the data at the same sample rates as before, for a reason that we have not determined with certainty yet, the data records are consistently taking more disk space to store, likely having to do with the way the amplitudes are recorded by the higher-resolution sensors. The result is that all data are being recorded in bigger data files even for the low-amplitude signals. One of the digitizers was severely damaged due to high temperatures (Fig. 4). The problem was further exacerbated by almost non-existent airflow around the drives that prevented them from properly cooling. To remedy this, hard drive coolers were installed to increase airflow (Fig. 5); however, we anticipate that this may not be enough to cool the system during the hottest days of summer, and we may need to seek a more robust solution.

We replaced the failed hard drives and have had the 100 sps datastream working for several months now. We still have a problem recording the 500 sps stream on some digitizers that we need to correct. The 500 sps stream has had to be temporarily disabled. That is one of our most pressing tasks in the immediate future, especially as our 500 sps data packages will depend on that data stream.

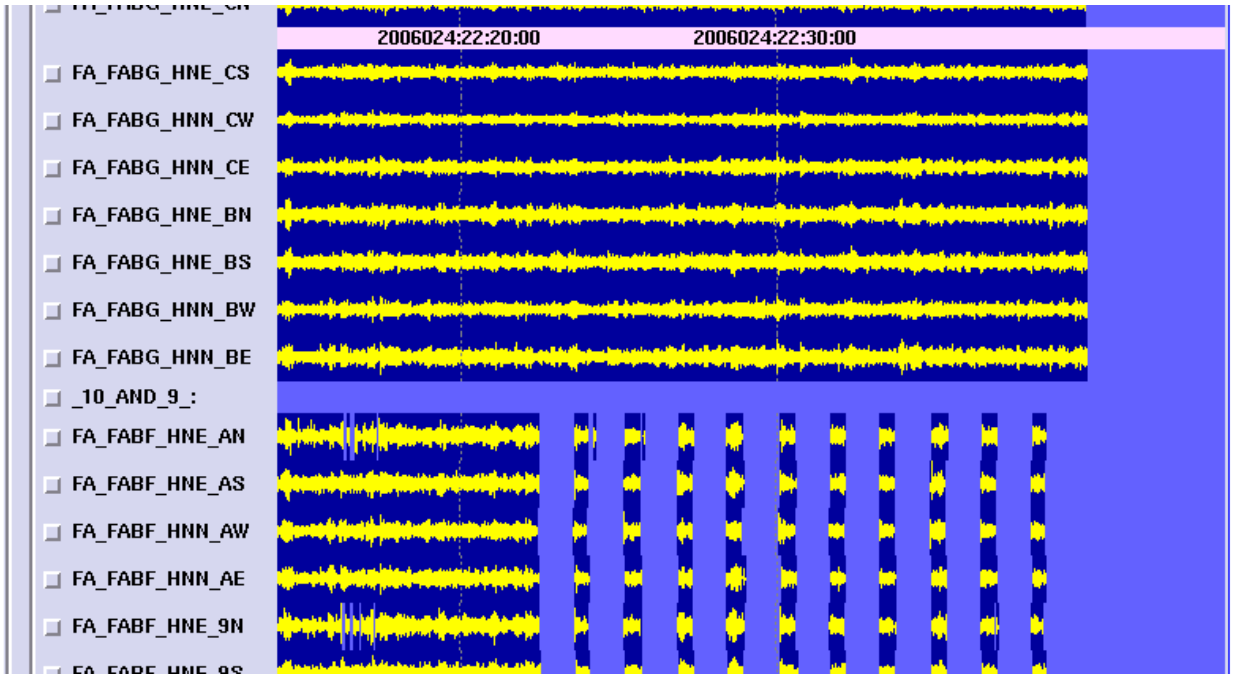

Figure 3. Antelope real-time waveform display showing data recording problems on one of the digitizers that was failing due to overheating.

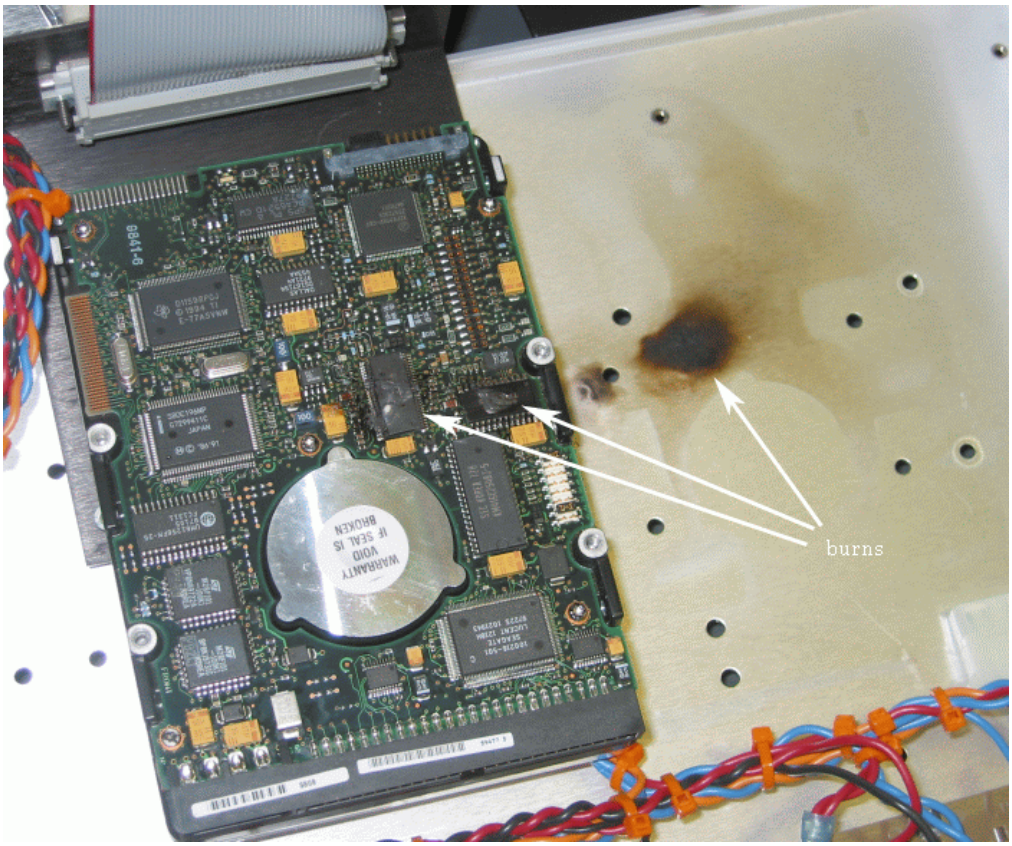

Figure 4. Photo of a 4120 digitizer that experienced failure due to severe overheating.

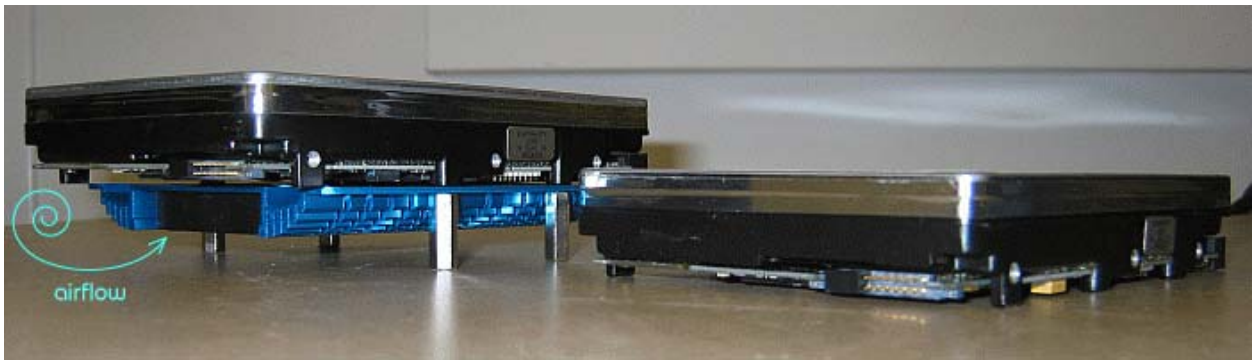

Figure 5. Photo of hard drives showing new method of installation allowing airflow beneath unit (left) to prevent overheating that occurred with the original setup (right).

We have made the following arrangements for continuity of operations in case of a large earthquake or other interrupting event: The backup power setup includes two car batteries and a UPS unit receiving continuous charge from the building's electrical system. The 800-Watt UPS is linked to the RAID array. It is designed to be used with the computers and can support the

system for up to 60 minutes. The two batteries are linked to the digitizers. They are standard 12V 50-60 amp-hour batteries which can hold 30-60 minutes of charge if building power were to fail. Because of the numerous medical research labs and clinics with critical equipment, the Factor building has its own backup generator that we can rely on in case of emergency. The less critical borehole seismometers and digitizer are connected to two car batteries charged by a wall charger but do not have long-term backup power arrangements. Each 4120 digitizer has a 4-Gb hard drive and 16 mb of RAM. The data go directly into RAM where they are automatically read into the monitoring and archiving system. At current recording rates for 100 sps, RAM can hold 3-4 channel-hours of data before it fills up.

We have made arrangements for telemetry failure (unless it's extremely local) by storing data on the RAID array located next to the seismic hardware. From there the data are sent to a computer in the UCLA Geology Building and on to the IRIS DMC. Over the past year we have had three hardware failures (not related to the sensor upgrade) resulting in Q4120 downtime. Two involved failed hard drives which were replaced (with the help of Dave Johnson of the CISN). The other failure probably involved hacking activity as there were suspicious signs of illegal entry into the system. We remedied this by installing firewall hardware on a router next to the equipment. The RAID and digitizers are plugged into the router and sit behind the firewall. The firewall uses filtering rules based on IP numbers. Only a very limited number of known IP numbers are now able to gain access to the 4120s.