8. POSSIBLE RESEARCH TOPICS

There were no significant ground failures from the 23 August 2011 M5.8 earthquake, and structural failures were minor throughout most of the affected region; however, as discussed in this report, there are important lessons for stakeholders and decision makers in the engineering and scientific communities and beyond. The rarity of a damaging earthquake in Central and Eastern North America (CENA) means that we have few opportunities to assess issues ranging from the seismic performance of constructed facilities and lifelines to regional earthquake hazard preparedness. Perhaps the most important lesson to take away is that CENA earthquakes as large as the M5.8 event (and possibly larger) will occur in the future, possibly closer to densely populated urban areas. This makes it imperative to glean as much data as we can from each occurrence of a rare event like the Virginia shock. Efforts such as the current NGA East Program, developed to provide a new generation of CENA ground motion models for seismic hazard assessment, require instrumental ground motion data in order to be meaningful. The seismological data set for the eastern United States is so sparse that empirical ground motion prediction models cannot be constructed and validated. This situation could have been improved to a significant degree if the M5.8 mainshock had been better recorded. The event was recorded on-scale by only three stations in the critical distance range for earthquake engineering, inside 100 km from the epicenter. Essential structures, such as the seismically-isolated Woodrow Wilson Bridge, were not instrumented to provide insight into their seismic response. Seismographic recording in central Virginia and elsewhere in the region was, and remains, inadequate to address scientific and engineering problems related to earthquake hazards. Despite this missed opportunity, much can be learned from the data in hand, and still more can be gleaned from future research.

Preliminary ideas on possible research topics are outlined below:

- **Seismological data requirements** – Supplementing the seismological data obtained from the few near-field recordings of the M5.8 mainshock, the aftershock data are also providing valuable information. The aftershock sequence is illuminating the fault plane responsible for the mainshock and helping to constrain the size and orientation of the likely rupture surface. This gives further insight into the M5.8 rupture process (e.g., stress orientation, stress drop, rupture velocity) and the geological nature of the causative fault. The aftershocks may also help us to better understand stress transfer mechanisms and possible triggering of subsequent earthquakes on nearby faults. An adequate density of seismic stations should remain operational in the epicentral area to provide baseline data going forward to quantitatively study the evolution of this important aftershock sequence. To provide the data necessary for a variety of research topics, instrumental monitoring of the Central Virginia Seismic Zone (CVSZ) must be a high priority. This will require a long-term commitment from agencies responsible for and institutions involved in earthquake monitoring in the United States.
- **Fault rupture mechanics of CENA earthquakes** – recordings near the source region suggest a complex fault rupture process for the M5.8 with two sub-events; this may be a common characteristic of CENA earthquakes and should be further studied.

- **Finite fault modeling studies** – For the first time, an aftershock sequence for an eastern earthquake can be used to provide good constraint on the geometry and extent of the fault rupture surface. This information can be used to develop improved models of the seismic source for strong motion simulation.
- **Wave propagation effects –** intensity of shaking from this event reported by the populace was more pronounced in the north-east/south-west direction. Although seismographic data are very limited, they must be used to study the cause of this observation, which in principle can be due to source (e.g., directivity) and/or path effects (e.g., high Q and low scattering parallel to the Appalachian structural trend).
- **Site characterization of seismic recording stations** – much insight and valuable data will be gained by characterization of sites where motions were recorded, many of which were on soil and indicate significant site effects. As of this writing, the USGS and others have efforts underway to measure velocity profiles at recording sites. This information will be valuable in trying to understand not only soil response, but the actually rock input shaking.
- **CENA ground motion attenuation** – the M5.8 event, although poorly recorded, has significant implications for development of CENA attenuation models, and is particularly relevant to ongoing NGA East efforts.
- **Seismic hazard assessment** – The event also has important implications for seismic hazard assessment, as complicated fault rupture, strong azimuthal variation of intensity and other regional factors seem to suggest increased uncertainties in prediction of CENA ground motions. The most common approach of PSHA modeling with areal seismic sources should be verified for this event.
- **Implications of unique geological and soil conditions on ground motions** – selective shaking intensity and damage patterns were correlated with regional geology and local soil conditions. Preliminary analyses indicate that soil amplification occurred in soft sediments overlying hard rock. A more detailed study of damage pattern and site conditions is needed to evaluate the cause and degree of amplification.
- **Development of region-specific soil amplification factors** – observations and preliminary site response analyses suggest that current simplified soil amplification factors, such as those used in IBC/ASCE7 and developed largely using WUS datasets, may not adequately capture the seismic response of certain CENA sites. Of particular concern are cases where very hard rock is relatively close to the ground surface such as along the Fall Line.
- **Building code assessments for CENA** – the adequacy of current design provision being used for constructed facilities and lifelines such as IBC/ ASCE7 should be evaluated, as currently the only CENA-based adjustments are the base hazard maps. Other parameters such as site factors should become region-specific.
- **Topographical effects**- there were observations in the epicentral region that suggested higher shaking intensities on hilltops and hillslopes relative to low-lying flat areas. Such effects for CENA-type ground motion characteristics should be studied.
- **Paleoliquefaction studies**- the event produced only minor liquefaction features in the epicentral area where PGAs were at least 0.26g. However, this may be due in part to the limited distribution of liquefiable sediments in the area. Additional reconnaissance for

liquefaction features is planned in the meizoseismal area along portions of rivers and streams where liquefiable sediments are likely to occur. In addition, liquefaction features that formed during the M5.8 event will be compared to paleoliquefaction features previously found in the CVSZ. The results of ongoing liquefaction studies may have implications for the back calculation of magnitude using paleoliquefaction evidence associated with CENA events and for the location and magnitude of paleoearthquakes in the CVSZ.

- **Performance of critical facilities such as nuclear power plants** – of particular interest is the performance of the North Anna Nuclear Power Station constructed in 1968. There will be many discussions on the seismic design and performance of nuclear facilities constructed during this generation.
- **Regional preparedness and awareness** – the affected region, in particular metropolitan areas such as Washington, DC, are unprepared to deal with even a moderate earthquake, particularly with respect to communications, evacuation, and transportation. There is relatively little earthquake awareness and preparedness planning in CENA relative to other US regions. Earthquakes can be integrated into preparedness planning efforts for hazards that communities in the region are more familiar with, such as hurricanes, terrorism, and fire.
- **Educational impacts** – efforts to incorporate earthquake basics in K-12 curricula and reach out to families and communities for preparation in the event of an earthquake. The latter should be developed specifically for CENA metropolitan areas that rely heavily on their (aged) infrastructure and lifeline systems.
- **Social and economic impacts** – the moderate M5.8 earthquake caused disruptions to communication, transportation, and business networks as far away as New York City, underscoring the vulnerability of the CENA and heightening the concern for the major impacts that a larger earthquake could have in this region. Additional studies are needed to further identify the vulnerabilities, assess the social and economic impacts, and evaluate regional resilience.