SUMMARY OF THE FEBRUARY 14, 2012
UTAH GROUND SHAKING WORKING GROUP MEETING

Attendees:

Ivan Wong	Morgan Moschetti	Bob Smith
Greg McDonald	Qiming Liu	Kim Olsen
Mark Petersen	Jacobo Bielak	Kris Pankow
Bill Stephenson	Jim Pechmann	Walter Arabasz
Steve Bowman	Chris DuRoss	
Anthony Crone	Keith Koper	

The meeting convened at 8:30 am with introductions. Ivan Wong (working group facilitator) gave a brief overview of the working group history, objectives, and accomplishments, and summarized last year's priorities and this year's objectives:

- The Ground Shaking Working Group (GSWG) is at the point where urban seismic hazard maps (UHMs) need to be produced and released to the user community.
- The GSWG needs to determine what additional information is required at this point to produce UHMs; what components from the different models should be incorporated into the maps.
- An important objective is to develop a reliable three-dimensional model that captures basin effects and incorporates them into UHMs.
- How the maps are to be presented to users is important (such as via hard-copy maps, web-based, interactive, location coordinate input/output).

General considerations for UHMs:

- The UHMs need to be produced for periods up to 10s, and include peak ground acceleration (PGA), 0.2s, and 1.0s spectral accelerations (SAs) for building codes.
- The UHMs must incorporate uncertainties: epistemic can be approached by comparing results of the different models; aleatory are inherently more difficult to determine.
- The first version of UHMs will be for Salt Lake Valley with the intent of eventually expanding along the Wasatch Front urban corridor.
- Both deterministic and time-dependent maps should be produced for comparison. The Salt Lake Valley UHMs will be the first maps produced with a large weight given to time dependency.
- Both long- and short-period data need to be integrated – use nonlinear broadband synthetics.
- Source, path, and site-response effects need to be incorporated.

The different modeling groups at this point should be using Wasatch Front Community Velocity Model (WFCVM) version 3c (available at http://geology.utah.gov/ghp/consultants/geotechnical-data/cvm.htm), the same seismic source, and scenario earthquakes so their results are comparable; presently, there are no immediate plans to update the WFCVM, although some elements may need to be refined (such as Q[f], kappa, Vs30 layer).

Before the initial UHMs can be produced, broadband deterministic maps need to be created for the Salt Lake City segment M7.0 scenario that incorporates Salt Lake Valley soil properties. The linear results should be validated up to 2 Hz, then nonlinear results should be incorporated.

Kim Olsen - Review of Ground Motion Predictions from 0-10 Hz for M7 Earthquake on the Salt Lake City Segment

The final report has been submitted to the USGS; BSSA has published the low-frequency results (Roten and others; 2011) and BSSA publication of the high-frequency results is pending.

Review of the San Diego State University (SDSU) broadband approach to ground-motion modeling:

- Employ the structure model from the WFCVM and spontaneous rupture simulation to produce a planar rupture model.
- Project the planar rupture model onto geologically-based fault geometry.
- Perform 3-dimensional finite-difference wave propagation simulation to generate 0-1 Hz synthetics for deriving 2s and 3s SA maps.
- Apply a broadband toolbox: High-frequency scattering operators for 0-10 Hz synthetics to derive < 1s SA and PGA maps.
- Deconvolute the high-frequency synthetics and incorporate non-linear soil parameters to get 0-10 Hz non-linear synthetics for producing SAs and PGAs along three profiles.
- Compare the derivative maps/profiles to the Next Generation of Ground-Motion Attenuation Model (NGA) derived results.

The 3-D model of the Salt Lake City segment is based on a simplified, geologically-based single trace and connecting the Cottonwood to East Bench and East Bench to Warm Springs step-overs. The trace is projected at depth using a geometry and dip from Bruhn and others (1992).

Four spontaneous rupture models with different hypocenter locations were used. Six scenario earthquakes were modeled; 5 deep, 1 shallow, all originating near non-conservative barriers; in this case, near both ends of the segment and the Cottonwood to East Bench step-over.

The SDSU results show a directionality effect on ground motions, with greater SAs near the ends of the ruptures. Averaged SAs from the six scenarios show ground motions drop off significantly sooner to the west of the fault than shown on NGA maps and recorded values at soil sites. The reason for the effect should be addressed before incorporation into the USHMs to determine if it is an artifact of the model or an accurate representation that should be reflected in the USHMs.

Non-linear soil response was incorporated using plasticity index (PI) values of 40 for Q01, 30 for Q02, and 0 for Q03 and rock. Comparisons of low frequency vs. broadband synthetics for higher accelerations show a non-linear diversion for broadband Q01 and creates better fit to NGA predictions.

Determination of site-dependent correction factors/third-order polynomials to fit one-dimensional simulation distribution is done for each site-response unit and frequency.

SDSU modeling results discussion:

The SDSU results appear to be usable for the UHMs. Presumably, more scenarios would produce a better fit/reduce uncertainties. Kim feels the six scenarios are converging on good results, but more would likely improve them. For comparison, ten scenarios were used for the Los Angeles basin model.

One issue is that the maps reflect circular patterns resulting from the Vs30 layer of the WFCVM (discrete circles around some Vs30 data points). Thus, the Vs30 component of the WFCVM may need refinement.

The USHMs should incorporate the modeling results to include basin effects, soil conditions, etc. Comparing different modeling results will get at epistemic uncertainty.
The U.S. Geological Survey (USGS) also needs to consider an approach similar to that used for the Seattle maps where the NGA results were adjusted at each site to better fit modeling results.

Qiming Liu - Curved Fault Dynamic Rupture Model for the Wasatch Fault Salt Lake City Segment

Brief review of previous work:

- The project involves modeling ground motions using a finite-element, meshed, dynamic model; stress for each point on the fault is needed (initial, yield, sliding friction, and final).
- Initially a single plane, 50 degree dipping fault was used, followed by a simple segmented source consisting of two sub-parallel, unconnected planes.
- Velocity strengthening was used for the upper ~3 km reducing final slip at the surface.

This year's work included more detailed fault models approaching the Salt Lake City segment geometry to see how the resulting ground motions evolve.

The most complex fault model is a simplified version of the trace used for the USGS National Seismic Hazard Maps (NSHM) that has the trace crossing northern Salt Lake Valley to the Warm Springs section and does not include the northern part of the East Bench fault.

Two rupture scenarios with hypocenters at either end of the fault were modeled to observe directivity effects.

Key observations include:

- Confirmation that fault geometry has a significant impact on rupture propagation.
- For the most complex fault model used, sensitivity of directivity to the kink at the Cottonwood fault to East Bench fault step-over was observed as it affects propagation and acts as a significant barrier; more so for north to south propagation.
- Smoothing out the Cottonwood fault to East Bench fault step-over kink results in ground motions getting through with high levels of ground shaking towards the end of the rupture.
- Using the same fault model as SDSU will likely result in more pronounced barrier effects at the East Bench tear fault.
- Taking the tear fault out and using a geologically-based fault trace with an East Bench fault to Warm Springs fault step-over may also have significant effect on wave propagation, but dynamic models can accommodate jumps.
- Comparing model peak ground velocities (PGVs) to NGA results show that the model values are generally lower and drop off more rapidly away from the fault.
- The results show that three-dimensional velocity structure impacts ground motions – low velocities amplify ground motions and increase the duration of ground shaking.
- Velocity strengthening near the free surface provides a physically-justified mechanism to reduce modeled slip to amounts more consistent with paleoseismic data.

Additional work is needed to finalize the results:

- Need to use more physically-based earthquake simulations up to 1 Hz.
- Need to use the same fault model and source scenarios as SDSU for comparison of results.

Morgan Moschetti - Earthquake Ground Motion Modeling with Kinematic Source Models: Preliminary low-frequency ground motions and effects of velocity perturbations to WFCVM

Kinematic fault model:

- Planar fault model fit through the NSHM trace for the Salt Lake City segment; 50 degree average dip.
- 45x20 km; hypocenter at 10 km along strike, 15 km down dip.
- One-dimensional velocity profile from the University of Utah Seismograph Stations.
- Different kinematic fault models can be rapidly generated by adjusting parameters.
- Constant slip velocity is applied to the fault model.

Material model:

- WFCVM is used as the reference model.
- Perturbed models are used for comparisons.

The ground motion results are significantly higher than the SDSU and University of California, Santa Barbara (UCBS) models; possibly due to the rupture model used. The observed correlation lengths for slip are at the high end for a M7 event.

Testing of the WFCVM:

- Perturbed velocities of sediments between R1 and R3 +/-10%.
- Used regional Vs model from surface wave tomography.
- Used wave propagation code from Carnegie-Mellon University (CMU) modeling group; min Vs = 200 m/s, max frequency = 1 Hz.

- Velocity perturbations to deep basin sediments affected the ground motions up to 0.5g above deeper parts of the basin mostly away from the fault; source predominantly affects ground motions above the fault plane.
- Correlations were observed between high ground motions and large, coherent slip patches on the fault model.
- The greatest effects on ground motions are caused by: 1) basin velocity structure away from the source, and 2) regional model structure near the source model. Replacing the regional model effectively decreases the moment with localized increases in ground motion.

Future work:

- Plan to finish low-frequency testing this year.
- Begin high-frequency synthetics (up to ~10 Hz).
- Incorporate a more realistic fault geometry.
- Set kinematic models to sample fault parameters.
- Randomize slip patches to capture uncertainty; can calculate variability based on correlation lengths with fault models.
- Perform runs using different slip models.

Jacobo Bielak - 3-D Ground Motion Linear and Nonlinear Simulations

Review of CMU modeling parameters:

- Single plane fault from UCSB (strike 153 degrees; dip 50 degrees).
- M6.8 scenario earthquake.
- Hypocenter: bottom center of plane.
- Vs min = 200 m/s.

For non-linear analysis:

- Soils with Vs ≤ 500 m/s are allowed to behave plastically.
- Material idealized to follow J2 yield criteria.

Some key observations include:

- Rapid ground-motion attenuation away from the fault on the hanging wall similar to other modeling groups results.
- Highest PGVs and PGAs along and near the fault trace on the hanging wall with a "foot" at the southern end; further work is needed to determine if the feature is real or a model artifact.
- No evidence of strong basin effects (in contrast to the SDSU results).
- PGA ratios show lower values for the nonlinear result near the fault on the hanging wall and northwest of the fault.
- Amplification occurs only in areas of low ground motion.
- On both PGV and PGA maps, circular artifacts from the WFCVM Vs30 layer are apparent.
- Near fault displacements are generally lower for the nonlinear results.

Rapid ground motion attenuation away from the fault may be due to the relative shallowness of the Salt Lake Valley; surface waves do not get generated to a large degree (fundamental, 1st and perhaps 2nd modes).
As wave frequency is increased, ground shaking may increase creating more dispersion.
More simulations are needed to improve results.
A more complex, geologically-based fault model should be incorporated.

Kris Pankow - Instrumentally Recorded Ground Motions M3 or Greater in the Utah Region since 2000

Project goals include:

- Measure PGA and PGV for earthquakes M3 and greater within 200 km of the Utah seismograph network.
- Sort and analyze the data by site-response unit.
- Compare the data to published ground-motion equations.

The records include:

- 164 earthquakes M_L 3.0 to 5.9.
- 1 event in Salt Lake Valley (2001; M_L 3.36).
- Largest event: M_L 5.9 Wells, NV (2008).

Data processing:
SAC transfer command is used to:

- Remove instrument response.
- Convert to acceleration and velocity.

Visual inspection of all waveforms is necessary to ensure:

- A five minute time window is dominated by the event, not other high-frequency spikes.
- There are no gaps.
- The signal-to-noise ratio is greater than about two.
- There is no visible trend (e.g. temperature, etc.).

Issues with the data:

- Some instruments are not orthogonal or NS/EW oriented.
- There are problems with some metadata/station response files.

Issues with comparisons to equations:

- Magnitude Mw vs M_L.
  - o Distance term.
  - o Small earthquakes cannot be used to calculate rupture planes.
- Hypocenter is very uncertain.
- Peak ground motion vs. orientation-independent ground motion.

UHM General Discussion

The GSWG is now at the point where UHMs need to be produced. Version 1 of the maps should probably be released within the next two years. The USGS needs to know what, if any, elements from the different models should be incorporated into the maps.

Once they are released, the GSWG needs to determine if the maps for the Salt Lake Valley should be improved upon/refined or if mapping should be expanded along theWasatch Front urban corridor to the north and/or south.

Issues to be addressed:

- How much uncertainty is in the WFCVM as a whole (non-linearity, velocity distribution model, directivity, directionality, etc), and whether or not it is usable as a foundation for the UHMs. USGS perturbation testing shows small changes in deep basin velocity can have a large effect on ground motions.
- Basin effects must be included in the maps; their significance to the final products needs to be determined.
- Assessment of the different modeling group results needs to be performed to determine if any of their components can be included in the UHMs in their present state. Not enough is known about some features (such as the “foot” on CMU maps), but probabilistic maps may filter out such features.

The SDSU results appear to be useable for the UHMs in their present state; additional modeling using more scenarios would likely lower the standard deviation improving them. Whether or not to use the source model that includes the East Bench to Warm Springs tear fault needs to be resolved as it is located in a critical area directly impacting downtown Salt Lake City. For the USHMs, it may be more conservative to include the tear fault, factoring in uncertainties. Sensitivity testing of the fault model both with and without the tear fault is also an option.

Presently, the different modeling groups results cannot be compared – let alone averaged – given the different sources and scenarios used.

Options for producing the first version of UHMs within the next two years:

- Option 1: Discontinue further modeling work at this point and incorporate SDSU results into USHMs. Focus future work to other parts of the Wasatch Front.
- Option 2: Continue to refine and test the other three models using the SDSU input parameters/conditions for comparison of results/possible inclusion in the UHMs.

Minimum model requirements for UHMs:

- Use a geologically-based fault model.
  - Use the SDSU model incorporating uncertainties.
  - The UCSB dynamic model could be used to test the sensitivity of the step-over/tear fault.
- Additional work needs to consider the roughly two-year time frame for producing the maps
  - Any additional modeling needs to consider timeframe including the USGS National Earthquake Hazards Reduction Program (NEHRP) request for proposals cycle for funding.
  - CMU can incorporate SDSU fault model and perform pseudo-dynamic modeling up to 4 Hz or collaborate with UCSB to use stochastic model results.
- Need better understanding of rapid ground-motion decay away from fault with respect to NGA predictions.
- The WFCVM needs additional testing to determine if it needs more work/refinement or is at a point where it can be considered usable/stable for now.

GSWG Priority Items

1. Through NEHRP funding, the GSWG has been working toward the development of urban seismic hazard maps for the Salt Lake Valley. Ground motion simulations for the Wasatch Front have been performed in the past several years also through NEHRP funding to evaluate the effects of the Salt Lake basin on ground motions. The WFCVM, another NEHRP-funded project, was used in the simulations. As part of UHM efforts, two issues have been raised in comparing the results of several ground-motion modeling approaches: (1) the effect of the East Bench-Warm Springs fault step-over on ground motions; and (2) an apparent drop off in the ground motions in the simulations relative to the NGA models west of the Wasatch fault. Research to address these issues is encouraged by the GSWG.

2. In addition to basin effects, the amplification and de-amplification effects of the shallow unconsolidated sediments need to be incorporated into the UHMs. Research to develop amplification factors to be used in the UHMs using empirical data and/or site response modeling is encouraged by the GSWG.

References

Bruhn, R., Gibler, P., Houghton, W., and Parry, W., 1992. Structure of the Salt Lake segment, Wasatch normal fault zone-Implications for rupture propagation during normal faulting, *in* Gori, P.L., Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500 A-J, p. H1-H25.

Roten, D., Olsen, K.B., Magistrale, H., Pechmann, J.C., and Cruz-Atienza, V.M., 2011, 3D simulations of M7 earthquakes on the Wasatch fault, Utah, Part I-Long-period (0-1 Hz) ground motion: Bulletin of the Seismological Society of America, Vol. 101, No. 5, p. 2045-2063.