March 23, 2014 Memorandum: from Goettel & Associates Inc. to DPD, CollinsWoerman and Gibson Economics

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Memorandum

TO:	Sandy Howard, John Gibson, and Steve Moddemeyer
FROM:	Kenneth A. Goettel
RE:	Technical Review Comments on the Seattle Unreinforced Masonry Retrofit Policy: Benefit-Cost Analysis
DATE:	March 23, 2014

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The benefit-cost analysis (BCA) result of a benefit-cost ratio (BCR) of 0.042 for Bolts+ retrofits of URMs is <u>extraordinarily</u> low and well below the range of credible results. Simply put, the stated BCR appears to be <u>substantially</u> incorrect.

This conclusion is based on 20+ years of experience including completing over 500 seismic BCAs, developing the first several generations of FEMA's seismic BCA software, conducting about 75 BCA training sessions for FEMA and states (including Washington Emergency Management Division). I am also thoroughly familiar with the FEMA HAZUS methodology. My review has identified one substantial logical error in the calculation and numerous places where the input parameters appear to significantly undercount the benefits of seismic retrofits for URMs.

1. **Calculation of Average Annual Damages and Losses (Before and After Mitigation)**

   Using only three scenario earthquakes substantially undercounts these values and the benefits of retrofits. A correct calculation <u>must</u> consider the full range of earthquake ground motions (and corresponding annual probabilities) from the smallest ground motion level that results in <u>any</u> damage up to the highest available ground motion. There are four ways to do this:

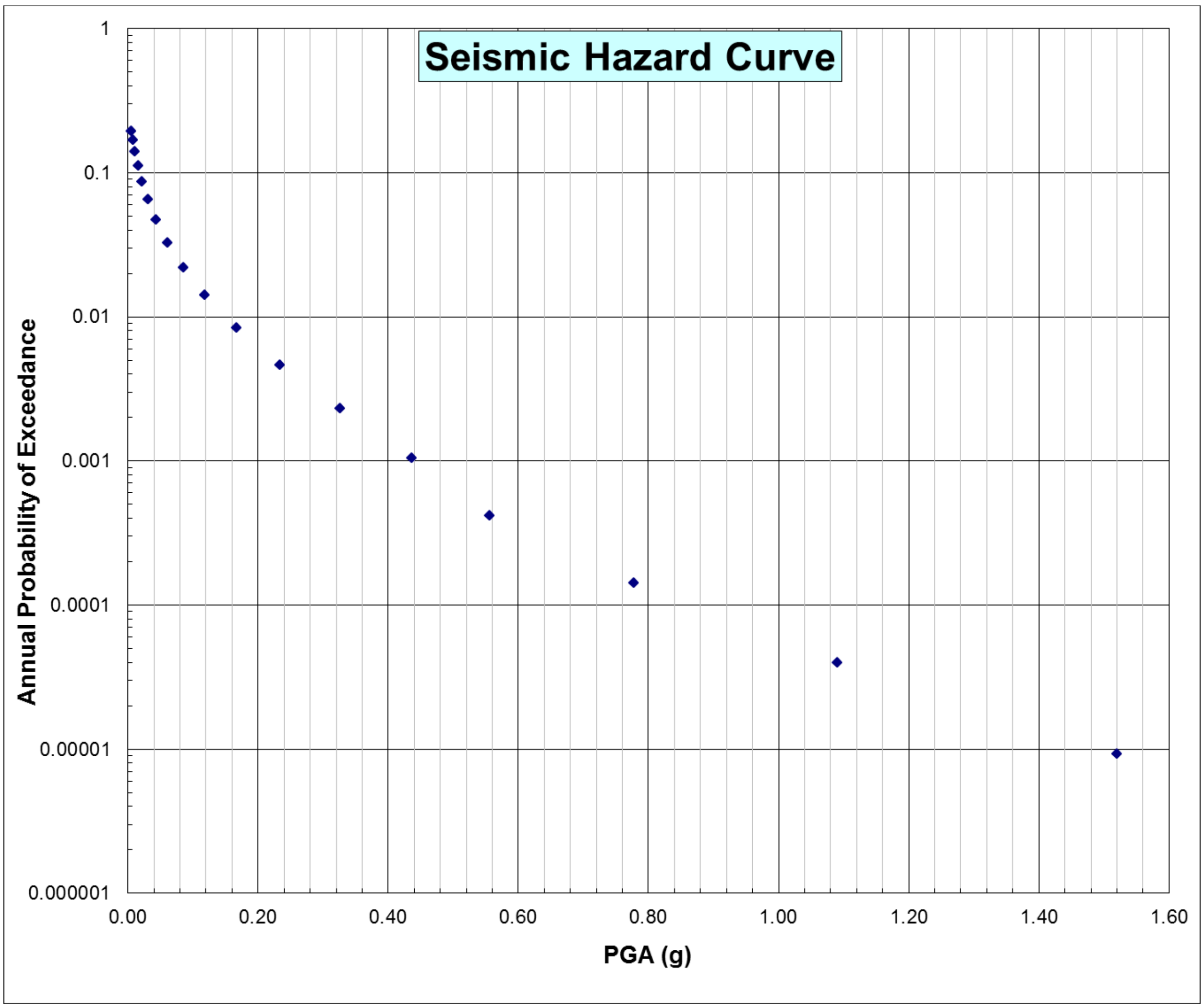
   a. Use the FEMA BCA software (seismic structural module).

   b. Use the fragility curves to make point estimates for damages (and losses) at 6 to 10 levels of ground shaking and mathematically integrate the damage-probability relationship.

   c. Break the ground motions into intervals, such as 5% to 10% g, 10% to 20% g, 20% to 30% g, etc. Calculate the interval probabilities from the seismic hazard curve (see example on following page). For example, the annual probability of a ground motion between 10% g and 20% g is the annual exceedance probability of 10% g less the annual exceedance probability of 20% g. Then, use fragility curves to calculate damages for the midpoint of each range. Ranges can't be too broad without losing accuracy.

d. Use the average annual damages capability within HAZUS.

Seismic Hazard Curve Example



Recommendations and Caveats

a. The FEMA BCA software does the average annual damages and losses calculation correctly, but cannot deal with liquefaction directly – only site classes can be input. The software cannot incorporate fragility curves directly, but rather only indirectly via hidden code that relates very complex vulnerability parameters to hidden fragility curves). The FEMA software cannot incorporate the demolition damage threshold addressed in Item #2 on the following page.

b. The fragility curve calculations in Option "B" above can be done in Excel, albeit the interpolation and integration is somewhat complex.

c. The fragility curve calculations in Option "C" above can be done is Excel, with less complexity than Option "B". Both Options "B" and "C" can incorporate inputs that the FEMA BCA software cannot (as noted above), including fragility curves and the demolition damage threshold.

d. Use the HAZUS average annual loss function. This requires using a full hazard curve with HAZUS calculations at specific ground motions with defined annual probabilities (return periods). The HAZUS algorithm is somewhat rough (not mathematically correct) but yields more or less reasonable estimates. HAZUS also has limitations (or black boxes) re: how liquefaction potential is considered and cannot do the demolition damage threshold calculations or other refined/customized calculations.

Option C is simpler than Option B; both have the considerable advantage of complete transparency (no black boxes with hidden/unknown code) and has the flexibility to incorporate any refinements desired, including the demolition damage threshold calculations. This Excel based approach is what I recommend.

2. Demolition Damage Threshold

This parameter has a profound impact on seismic BCAs – including a reasonable demolition damage threshold would raise the BCR by a factor of several.

Repair of earthquake damaged earthquakes is often not feasible from either the engineering perspective or the cost perspective. Reality is that many earthquake damaged buildings, especially URMs, are <u>not</u> repaired after relatively low levels of damage. In many cases, building damage of 20% or even lower of the building value results in a complete economic loss with buildings demolished by owners or simply abandoned and later demolished. This arises because many older buildings, especially URMs, are in poor condition and/or functionally obsolete and/or near the end of their useful life without major upgrades.

The first several generations of FEMA's earthquake BCA software included an explicit demolition damage threshold – the percent building damage at which a building was deemed a complete loss. The exact FEMA guidance[1] was:

> *"Demolition Threshold. Building damage that would result in demolition, the "demolition threshold," is the percentage of building damage at which demolition and replacement (rather than repair) would be expected to occur as the economically efficient choice. Many buildings will be demolished rather than repaired when the cost to repair exceeds some percentage of the replacement cost.*

For older, somewhat substandard buildings, the demolition threshold may be quite low (e.g., 20% or 30%). For typical, relatively modern buildings the threshold will generally be higher (e.g. 50% or 60%. For some particularly important historical buildings, the demolition threshold may approach 100%.

The demolition threshold damage percentage is an important policy parameter which may significantly affect the benefit-cost results because it affects the seismic-damage function. Therefore, the demolition threshold estimate should be chosen carefully in accord with the condition and viability of the existing building. For example, a brand new city hall building would probably be repaired from a higher level of damage that would a decrepit building badly in need of refurbishing."

[1] Benefit-Cost Analysis of Hazard Mitigation Projects, Volume 5 Earthquake, User's Guide Version 1.01 (1995).

The current FEMA earthquake BCA software inexplicably and incorrectly omits the demolition damage threshold for earthquake BCAs, although a demolition damage threshold <u>is</u> included in the FEMA flood BCA software <u>and</u> in FEMA policies re: repair or replacement of damaged public buildings after FEMA-declared disaster events. The omission is in HAZUS, which is probably the source of the omission because the FEMA earthquake BCA software closely follows HAZUS.

Not including a demolition damage threshold in the BCA is incorrect and <u>substantially</u> undercounts the benefits of seismic retrofits.

3. Building Value

FEMA's metric for building value in the FEMA BCA software and in HAZUS is the building replacement value – the cost to building a new current-code building of the same size and level of amenity as the existing building. Building replacement value includes not only construction costs but also all of the usual soft costs, including design, permitting, inspection, insurance etc.

Use of assessed value, with adjustments, may result in lower building values than the proper metric of replacement value. The benefits of avoided damages are directly proportional to building replacement value.

For historical buildings, FEMA BCA policy allows use of a "reproduction" value which includes the extra costs to recreate historical architectural details and finishes. Using reproduction value for some (all?) URMs would raise the benefits of avoided damages proportionately to the ratio of reproduction value to "normal" building replacement value.

I have not researched the relationship between assessed building values in Seattle vs. replacement values, but the adjustment may well be significant, especially if reproduction values are used for some or all URMs.

4. **Other Input Values**
   Many other inputs into the damage and loss calculations directly affect the BCA results, including:

   a. **Occupancy.** The proper metric for occupancy is the average 24/7/365 occupancy of buildings, including <u>all</u> people in a building (occupants, contractors, service people, visitors, etc.). The life safety benefits are directly proportional to the average 27/7/365 occupancy.

   b. Statistical values of life (deaths and injuries). The "current" FEMA values are derived the US Department of Transportation values adopted in 2008, although the actual values are explicitly stated to be in 2007 values. For a correct BCA calculation of life safety benefits, the FEMA values must be converted to 2014 values. The US DOT used the CPI-U (Consumer Price Index – Urban) to update older values. This correction will raise the life safety benefits by about 15%.

   c. **Discount Rate**. The appropriate discount rate for BCA is the "real" rate which is the nominal rate less the rate of inflation. The FEMA discount rate of 7% is mandated by an Office of Management and Budget policy memo which fixes the rate at 7%. Given current low long term interest rates and current low inflation, a reasonable discount rate would be no more than 3%, perhaps a bit lower. Using 3% instead of 7% would raise the BCR by about 58% for a 30-year useful lifetime and by about 86% for a 50-year lifetime.

   d. Building Useful Lifetime. The range of credible building useful lifetimes ranges from about 30 years to 100 years. 50 years appears reasonable for URM residential or commercial buildings. 100 years would be appropriate for historical buildings, where demolition is difficult or precluded by historical preservation issues. For BCA, a 100 year lifetime yields results almost identical to "forever" with a 7% discount rate and about 95% of forever with a 3% discount rate.

   For reference, using a 3% discount rate and 50 year useful lifetime raises benefits by factor of 2.07 compared to a 7% discount rate and 30 year useful lifetime. Using a 100 year useful lifetime for a subset of URMs with historical significance would raise the benefits for these buildings by another 5%.

5. **Seismic Fragility Curves.** The seismic fragility curves profoundly affect the BCA results. The fragility curves shown in Figure 1 in the report appear qualitatively reasonable, but, as always, the devil is in the details. What is the ground motion parameter? What is the "beta" the lognormal dispersion parameter which is analogous to the standard deviation for a normal distribution? A higher than "typical" beta may be appropriate for URMs because of the wide

variability in as-building conditions (soft first stories, vertical irregularities, horizontal irregularities, roof and floor connections to walls, wall thickness, grout characteristics, and others). A higher beta yields "fatter" tails at low ground motions and correctly captures the higher damages and losses from the bad-acting buildings in a population – thereby raising the BCR for avoiding these damages. Conversely, a smaller beta for retrofitted or reinforced masonry buildings reflects the better understanding (less variability) of these buildings, further increasing the benefits.

6. HAZUS Inputs and Results

Without full, robust documentation of all of the inputs into HAZUS, I cannot evaluate the accuracy of the HAZUS results. Issues that may affect the BCA results include:

a. What does stable soil mean? Site Class D?

b. Exactly how was liquefaction potential included in the calculations? Site Class E? Site Class E plus a factor for higher damage levels because of liquefaction?

c. Some of the HAZUS-based results look puzzling at quick look, including:

    a. The fraction of URMs with no damage for all three scenarios.

    b. The absence of <u>any</u> RMs with extensive or complete damage, even for the Seattle Fault scenario.

    c. Why is the estimated damaged percentage for the Cascadia scenario only a little higher than the Nisqually scenario? I would expect a significantly higher level of ground shaking and significantly more damage.

    d. 22% damage for the Seattle Fault scenario seems low for URMs, given the strong ground motions, presumably with a lot of short period ground motion for this nearby crustal event.

    e. Why is the percentage reduction in damages for Bolts+ substantially lower for Cascadia than for the Nisqually scenario? I would expect a monotonically increasing trend from the small to medium to larger ground motions.

    f. Are the Bolts+ cost estimates reasonable? This is critical for the BCA.

7. Other Issues

I have numerous other questions about the details of the calculations. Full understanding would require much more complete documentation of the technical calculations than provided in the published report.