January 2015

Seattle URM Benefit Cost Analysis – Public Comment

The Benefits Cost Analysis (BCA) that was prepared for DPD in March 2014 was revised in April 2014 to respond to public comment. The Department has heard from other professional experts that the benefit calculated in the analysis is underestimated. They point out the strengths and limitations in the HAZUS model and their feedback will be considered as Seattle makes decisions on policy direction. Memoranda with their critique and response from the consultant group who prepared the BCA are included in this document.

All benefit-cost analyses are complex and have underlying assumptions and variables. Different assumptions and variables might significantly change the conclusions drawn from any analysis. For example, one of the assumptions underlying the BCA analysis is the likelihood of an earthquake in any given year. If the analysis assumed an earthquake tomorrow, the benefit cost ratio would be much greater. DPD's consultant worked with structural engineers and other experts to develop the best available data at the time to design the underlying assumptions for the BCA. The variables were chosen to reflect the objective of the city to understand economic impacts of retrofits over time.

Since the BCA was intended to provide the city another piece of information on policy alternatives, it is not intended as a guide for property owners on how best to protect their investments. Each individual property owner will need to consider factors specific to their particular building as they are making their decision.

There is not one right answer for decision making. No important policy decisions are made on simple dollars and cents calculations. It is very difficult to factor in qualitative costs and benefits that might affect neighborhoods, such as community character and social and environmental costs after a major earthquake. All these impacts, including the economic impacts, along with public comment will be taken into consideration when making policy recommendations and decisions.

Comments can be sent to: DPD_URM_Policy_Committee_Comments@seattle.gov.

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May 19, 2014 Memorandum: from Gibson Economics , CollinsWoerman to DPD.

To: Sandy Howard, Seattle Department of Planning and Development

From: John Gibson, Gibson Economics
Steve Moddemeyer, CollinsWoerman

Re: Responses to Comments on the Seattle Unreinforced Masonry Retrofit Policy Benefit-Cost Analysis

Date: May 19, 2014

Overview

The City of Seattle and the Unreinforced Masonry Policy Advisory Committee have received three memoranda addressing issues raised by the URM Retrofit Policy Benefit-Cost Analysis. They cover a variety of topics, ranging from which seismic impact model ought to be used to economic assumptions to technical details concerning underlying building fragility curves.

In this memo we offer responses to the points raised in these memoranda. The three sets of comments are:

A. Kenneth A. Goettel to Sandy Howard et al, March 23, 2014;
B. Kenneth A. Goettel to David Gonzalez (of the URM Retrofit Policy Advisory Committee) and Seth Thomas, April 14, 2014; and
C. Seth Thomas to the Seattle URM Advisory Committee, April 14, 2014

They are addressed in that order, with individual topics covered in the order they were raised in the documents.

We would like to note that we have had an opportunity to discuss the points raised by Mr. Goettel, both with him and with other experts in the fields involved. Many of the issues are familiar and were addressed in the "Sensitivity Analysis" section of our report. Those concern inherently uncertain assumptions and assessment of the impacts of selecting alternative values for those assumptions. We have made minor changes to the baseline where appropriate, but believe the original set of assumptions is reasonable. We do agree that recognition of the wide band of impact uncertainty in both directions is important in considering the results of our report.

A few of the issues raised are much more fundamental, such as calling into question the use of the industry standard HAZUS model. Questions disputing the validity of the assumptions within or results from that model were lodged. In those cases, we are comfortable that the model and its structure represent the best available vehicle for this study.

A. Issues Raised and Response to Ken Goettel's 3/23/14 Memo to Sandy Howard, and Steve Moddemeyer

1. The analysis should use hazard curves and an Excel model, rather than HAZUS.

Response: It is useful to consider a range of earthquakes. It is particularly important that they reflect a range that represents relevant earthquake risks. This study used three, the Nisqually, Cascadia and Seattle "scenarios," which were selected in consultation with local earthquake experts.

The important corollary is that the probabilities associated with the set of earthquakes should be sufficient to capture the aggregate hazard risk. In other words, with three earthquakes the individual probabilities need to be larger than they would be with more earthquake events, since each is representing a wider range of events. This study has consciously sought to achieve this.

The inherent uncertainty in these estimates, however, has also prompted us to conduct a sensitivity analysis in which the probabilities of each of the three representative quakes are assumed to be half and double the baseline probability estimates.

As for the selection of the national HAZUS model as the supporting source for complex impact calculations, this is a very widely used, federally developed model, which incorporates extensive, detailed inputs from many national experts in the field. It is well suited to evaluate individual and cumulative earthquake impacts for a large inventory of buildings such as that involved in this study, and has resident capabilities to take into account individual location information on each building in an input data set.

2. The building damage threshold that requires demolition should be lowered from 50% to 15-25%

Response: This seems to be an individual opinion, which is at odds with the chosen practice of the major HAZUS and FEMA models used for analysis in this field. The damage-to-cost parameters for this study are those used in the FEMA HAZUS model. The FEMA model for BCAs is consistent with HAZUS.

In any case, even if such an assumption were warranted, this change would make much less of a difference than the comment suggests. Looking at rough estimates of the impacts if all buildings with any damage were tear-downs, we found that even that extreme assumption would only increase the building damage savings produced by Bolts+ from HAZUS' estimated 43% of the damage to un-retrofitted URMs to 54% of that damage.

3. Building values:

a. For calculating damage it should be replacement cost, rather than assessed value.

Response: To base the analysis on replacement cost would grossly overstate the actual value and lease rates of the buildings in the city-wide inventory of URMs. Building owners risk losing property of the existing value – not some supposed future value - just as building owners set lease rates

based on the value of the space they provide now, not on rates they could provide with a new building. The purpose of this study is to provide Seattle decision-makers with an unbiased estimate of the benefits and costs, not how much would be spent to create a modern and therefore different replacement.

Our study uses assessed value with a 10% adder to reflect market value of Seattle buildings. This additional value is consistent with the general view of real estate professionals and City staff, and reflects the building investment value that would be lost if the building were destroyed.

Replacement cost would be at a higher level and would be consistent with buildings that are superior in market value to those being replaced. Such higher value replacement buildings would also produce higher building revenues, making them an inaccurate indicator of the damage loss of the current URMs that might be damaged.

b. For historic buildings, "re-creation" cost should be used to calculate damage, rather than assessed value.

Response: This comment applies primarily to individual building assessments, which FEMA often does as part of the grant application/review process. The point is that the cost to repair may be higher than either assessed value or cost of replacement. This may be true in certain individual cases.

It should be pointed out that the URM Retrofit study is designed to evaluate a complete cohort of buildings, rather than an individual building. There are sure to be many buildings for which the benefit-cost analysis results would be better and others for which they would be worse than the overall average.

4. Other Input Values

a. Occupancy rates are not documented, and may be too low.

Response: This document was requested by the city of Seattle to assist policy makers in evaluating URM policy options thus many details are not necessary nor were required to be described in detail in our report. The building occupancy rates used in this study are the HAZUS standard daytime and nighttime values for each building type.

These HAZUS occupancy rates were combined with building use information provided in the DPD data base for each of the buildings in the study, in order to calculate the total number of people exposed in each building, as well as in the aggregate.

The results of the HAZUS runs underlying our report differentiate between the casualty impacts of daytime and nighttime events. These two separate sets of results were included in the report appendices.

b. Current FEMA casualty cost values were developed in 2008, so they are too low.

Response: The initial draft of our report used the currently adopted FEMA set of casualty values. While some may assert that they are too low, raising them to reflect several years' change in the CPI does not affect the general result.

In the second draft of our report these values were adjusted for changes in the CPI from 2008 to 2013, which raised the baseline B:C ratio from 0.072 to 0.076.

c. The study's baseline discount rate is too high.

Response: We disagree. This assumption was considered carefully to match the application to the City-wide set of privately-owned and publicly-owned URMs. The baseline discount rate used for the study is the same as the FEMA standard value of 7% (above inflation). For a large set of primarily private sector buildings, this was deemed to be a representative value.

Sensitivity analyses were performed assuming both 3% and 10%. The sensitivity analyses reflect the range that might be relevant for different cohorts of specific building owners. Public agency owners are likely to use values between 3% and 7% (as Seattle Public Utilities does, for example), and private owners with differing time preference and differing access to capital likely to use values between 7% and 10%. In either case, higher values in those ranges are recognized to be appropriate when the future benefits associated with an investment are more uncertain, a distinction that is emphasized in SPU's applications. That is the case here, where there is considerable uncertainty surrounding the future benefits.

The reviewer notes that using a lower discount rate would increase the benefits. That is certainly true, but our goal was to develop an unbiased estimate of the benefits and costs, not to produce a certain result.

d. The study's baseline time horizon is too low.

Response: The baseline time horizon used for the study is the FEMA standard value of 30 years. We reviewed this assumption and determined that it was appropriate in this context. This assumption is for an economic planning horizon for primarily privately-owned buildings, and is not inconsistent with the fact that buildings last longer than 30 years.

Sensitivity analyses were performed assuming both 20 years and 50 years. The sensitivity analyses recognize that some newer buildings, those in better-than-average condition and public buildings may have longer planning lives, while those that are older, those in private hands and those in worse condition may have shorter planning lives.

The reviewer notes that using a longer horizon for the analysis would increase the benefits. That is certainly true, but once again, our goal was to develop an unbiased estimate of the benefits and costs, not to produce a certain result.

5. **Seismic Fragility curves**

    a. **They are based on typical buildings which understates the extent of damage.**

Response: It is true that fragility curves are based on typical un-retrofitted and typical Bolts-Plus retrofitted URM buildings. Damage impacts would be greater for above-average buildings and less for below-average buildings. Depending on the distribution of building conditions, the average of their individual impacts could be greater than the impacts of an average building, as noted in the report narrative comments on building-to-building impact variability.

Again, for evaluation of individual buildings it would be appropriate to determine whether they are above- or below-average, and thus whether their fragility is greater or less. This is not the focus of the URM Retrofit study.

    b. **The Bolts-Plus fragility curves developed for the study are suspect, because the damage results they produce are too high.**

Response: We disagree. These fragility curves were necessary for the project, and their results have been assessed for reasonableness by local experts.

The purpose of the study was to evaluate the Bolts-Plus standard, specifically. In order to do so with the aid of the HAZUS model, it was necessary to develop building fragility curves consistent with Bolts-Plus seismic retrofits, since those are not part of the standard HAZUS inventory of building type fragility curves.

We sought out the widely recognized structural engineering firm Degenkolb Engineers, with leading expertise in this field, extensive experience and familiarity with HAZUS model requirements and familiarity with the proposed Seattle retrofit standards, to develop these fragility curves for both low-rise and mid-rise URM buildings. Our study relied on those fragility curves.

The Bolts-Plus standard is intended as a life safety standard, and various local structural engineers have expressed no surprise that the HAZUS results based on that standard and its associated fragility curves show a much higher benefit percentage in preventing deaths and injuries while doing less to prevent building damage.

It would be a mistake to scale up the results for individual buildings and apply them to the entire building stock included in this study.

6. **HAZUS Inputs and Results**

    a. **What does "stable soil" mean?**

Response: Location of liquefaction soils used in this study to distinguish buildings on this basis for aggregate impact comparisons are identified in the City of Seattle's GIS database. Soils not listed as liquefaction are considered "stable" for the purposes of these comparisons. The impact results presented for subsets of buildings in Appendices 4.A, 4.B and 4.C identify buildings as in liquefaction zones - or not - based on City mapping of the 929 individual URM buildings in the sample.

It is possible that the City mapping and the HAZUS soil designation used for impact calculations do not align perfectly. That, however, would not affect the overall results, which were generated based on HAZUS soil designations. If there are differences, they might mute to some degree the differences between HAZUS results that are reported for buildings in liquefaction zones versus the remainder. This distinction is unlikely to become relevant to policy options which are based upon a much broader range of considerations.

b. How was liquefaction potential included in the calculations?

The soil types for the entire area of the City are resident in the HAZUS model that was used to estimate earthquake impacts and damages. HAZUS provides specific soil information for any specified locations of buildings within Seattle. The 929 URM building locations were provided in precise longitude and latitude (accurate to within feet) for all buildings in the DPD data set that underlies the study, based on building-by-building mapping.

c. Some HAZUS-based results look puzzling...including:

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

  Response: Earthquake damages reflect an inventory that spans the entire city, with a variety of soils and distances from earthquake sources. The HAZUS estimates take all this into account and the results presented reflect the aggregate inventory.

- **The absence of any RMs with extensive or complete damage, even for the Seattle Fault scenario.**

  Response: The results behind this question are based on the HAZUS fragility curves for reinforced masonry buildings. Note that the results do not affect the BCA, which compares the impacts for un-retrofitted URMs to the impacts for Bolts+ seismically retrofitted URMs, as noted in the Report.

- **Why is the estimated damaged percentage for the Cascadia scenario only a little higher than the Nisqually scenario?**

  Response: The question addresses the underlying shake map characterization of the two events in the HAZUS runs. These shake maps were input from pre-existing USGS earthquake definition information, as noted in the Report.

- **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.**

  Response: Again, the results are based on the shake maps and fragility curves in the HAZUS runs. Impacts would be expected to vary more by location within

Seattle for this earthquake, given its proximity, and the overall result cited is an average of impacts estimated by HAZUS for all buildings throughout Seattle.

- **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.**

  Response: A complicating factor in the case of the Cascadia scenario is the longer duration of the earthquake. To the extent this is captured in HAZUS, it may explain why Bolts+ would be proportionally less successful in reducing damages for that scenario than for the other two.

- **Are the Bolts+ cost estimates reasonable?**

  Response: As noted in the report, the Bolts+ costs would vary substantially from one building to the next. The overall average used in the baseline BCA calculations is based on extensive interviews and individual building cost estimates within Seattle in the past year or two. To address the uncertainty of the average, as well as the building-by-building variation, sensitivity analyses were conducted for Bolts+ retrofit costs both higher and lower by 50%.

B. Issues Raised and Response to Ken Goettel's 4/14/14 Memo to David Gonzalez and Seth Thomas

1. **The building value used seems to be very low.**

   Response: See responses to 3.a and 3.b of Mr. Goettel's 3/23/14 memo.

2. **The damage percentages shown for the Seattle Fault are grossly discordant with the USGS Shakemap ground motions and the HAZUS PGA fragility curves for a Pre-Code URM.**

   Response: We reviewed the HAZUS results, and determined that for the Seattle Fault scenario HAZUS runs, the ground motions for individual buildings were in the range, 20% to 64%, which accords with the range expected by Mr. Goettel. As his attached "ShakeMap for Seattle M6.7 Scenario" indicates the buildings at the higher end of that range are indeed those closer to the Pioneer Square-International District area, while buildings north of downtown lie within the 9.2%-18% and 18%-34% ranges.

D. Issues Raised and Response to Issues in Seth Thomas'4/14/14 Memo to the Seattle URM Advisory Committee

1. **<u>Hazard</u>: While the 3 agreed upon scenarios do represent the 3major earthquake source for the Seattle area I don't think the hazard probability is accurately represented:**

   - **Variability in ground motions including epistemic uncertainties are not accounted for when using "shakemap" scenarios**

     Response: This comment suggests using an entirely different approach to the analysis. The HAZUS approach that was chosen, as is documented in the Report, allows for efficient analysis of an extensive inventory of buildings. It is also the commonly used, nationally developed model for these analyses.

   - **It is not clear how soil properties are being accounted for relating to the pga for each scenario**

     Response:See the response to items 6.a and 6.b of Mr. Goettel's 3.23.14 memo.

   - **Not clear how liquefaction is handled**

     Response: See the response to items 6.a and 6.b of Mr. Goettel's 3.23.14 memo.

2. **<u>Fragility Curves</u>: It is not clear how the fragility curves are applied.**

   Response: The fragility curves for Un-retrofitted URMs are those in HAZUS, as explained in the Report. Those for Bolts+ retrofitted URMs are those that were developed by Degenkolb Engineers, again as explained. This study uses the HAZUS model, which produces both structural and non-structural impact information. The BCA Study did not substitute some other sequential analytical approach, but relied on the HAZUS impact information.

3. **<u>Building Inventory</u>: It is not clear what the building inventory used was. It should be included in the appendix.**

   Response: The building inventory is described in the report. DPD has published the initial list of URMs on their web pages.

4. **<u>Building and Retrofit Costs</u>:**
   - **It is not clear how building contents were valued or what % of structural and non-structural value was lost in each scenario.**

     Response: This information is all presented and explained in the report.

   - **Buildings last a lot longer than 30 years.**

Response: See the response to item 4.d of Mr. Goettel's 3.23.14 memo.

- ***A few local engineers in Portland think the retrofit costs are a little off.***

  Response: See the response to the final bulleted point in 6.c of Mr. Goettel's 3/23/14 memo. It notes the review by and recommendation of Seattle engineers to use the assumption in the Seattle BCA.

April 14, 2014 Memorandum: from Seth Thomas to URM Policy Committee

To: Seattle URM Advisory Committee
From: Seth Thomas, P.E.
Job No.: n/a
Date: April 14, 2014
Re: Seattle URM Cost Benefit Study

The analysis and documentation in the March 13th, "Seattle Unreinforced Masonry Retrofit Policy: Benefit Cost Analysis" appears to have several errors/omissions. I have highlighted several areas that either more documentation is required or revisions in the analysis should be made to improve the accuracy of the overall study.

Hazard: While the 3 agreed upon scenarios do represent the 3 major earthquake sources for the Seattle area I don't think the hazard probability is accurately represented

- Variability in ground motions including epistemic uncertainties are not accounted for when using "shakemap" scenarios – this is why USGS models the faults using these uncertainties (most of the hazard comes from the +0.5-2s events – something I did not know until I worked on the risk assessment stuff at Degenkolb)
- It is not clear how soil properties are being accounted for relating to the pga for each scenario – Task 4: Table one lumps buildings into "Stable Soil" and "Liquefaction Zone" which is a gross simplification that is unclear and could (depending on what they did) be non-conservative. The usgs vs30 database should be used to scale GM's for each location.
- Not clear how liquefaction is handled – even if buildings are in soils that are at risk of being liquefied it takes a big enough event to trigger the liquefaction.

Fragility Curves:

- It is not clear what they used since Task 3: Figure 1 is a mocked up fragility curve with no units – the report should show exactly what Degenkolb sent them (probably an appendix) so that there can be proper review.
- It is also not clear how the fragility curves are applied – this is where I think the key mistake was made. You take the input PGA at your site determine where you are on the capacity curve to get a spectral acceleration and drift (based on your building type. i.e. URM-2 or BoltsPlus-2). Once you have these values they can be applied to the structural and non-structural fragility curves.

Building inventory: It is not clear what the building inventory used was.

- The full building inventory with address, Lat/Long, size and SF should be included in the appendix

Building & Retrofit costs

- It is not clear how were building contents valued – what was the loss rate estimated at (i.e. for a complete damage state what was the % loss of contents)
- What % of structural and non-structural value was lost for each damage state? This should be clearly stated as it directly affects the costs
- Buildings last a lot longer than 30years – these buildings are a prime example as most of them have been around for at least 50 already. A much longer building life should be used
- I talked to a few local engineers here in Portland and the retrofit costs seem to be a little off
    - For a full ASCE 41 retrofit the consensus seems to be about 40-50 dol/sq ft
    - Talking to people about a prescriptive bolts plus (which admittedly none of the people I talked to had been apart of) was around 20-30 dollars/sq ft with lower costs possible for larger square footages (economy of scale)

While some of these items are fairly minor there are a few items that are big issues are in the hazard and fragility curve items. I have worked on risk assessment projects for almost two years now and have a very detailed understanding of how USGS creates the probabilistic seismic maps and the methodology of HAZUS. In addition while at Degenkolb Engineers I was responsible for developing the capacity and fragility curves and I believe these are being misused as the damage rates seem very low (especially for the Seattle Fault event).

Thanks,

Seth Thomas, P.E.

April 14, 2014 Memorandum: from Ken Goettel to David Gonzalez and Seth Thomas

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Memorandum

TO: David Gonzalez and Seth Thomas
FROM: Kenneth A. Goettel
RE: Seattle BCA Comparisons
DATE: April 14, 2014

****

I took another look at the BCA report.

First, the building value used seems to be very low. Here is the calculation from data in the report. For damage and loss estimates, the proper metric (per FEMA) is the building replacement value. My semi-informed guess is that the building replacement value (the cost to build a new current code building of the same size and level of amenity as the existing building) would be at least $200/sf. FEMA also allows consideration of the historical value by allowing use of a reproduction value to recreate the significant architectural features of a building. So the reproduction value would be even higher. Using a more realistic value would raise the BCR by a factor of more than 2 and perhaps up to 3.

Retrofit Costs	$808	million
Retrofit Costs	$40	per SF
Building Value	$1,902	million
Building/SF	$94	per SF

Second, the damage percentages shown for the Seattle Fault scenario are grossly discordant with the USGS Shakemap ground motions and the HAZUS PGA fragility curves for a Pre-Code URM. Per page 45 of the BCA Report, building damage for the Seattle Fault M6.7 scenario is $512 million, 26.9% of the stated building value.

Per the maps in the report, most of the URMs are in the downtown core, for which the USGS Shakemap shows color-coded ground motions in the very dark orange to red zones, which is at least 34-65 %g PGA and probably into the 65+ %g PGA range.

HAZUS Pre-Code URM fragility curves for low rise have 0.26 g and 0.38 g for the extensive and complete damage states, respectively. With 0.21 g and 0.38g for mid rise URMs. Given these data, at least 50% of the buildings would be in the complete damage state with roughly 75% being in the extensive or higher damage state, with very few in the slight damage state.

However, the table on page 78 for the Seattle 6.7 scenario has the following percentages of structural damage

None: 18%
Slight: 23%
Moderate: 14%
Extensive 22%
Complete 22%

These results are grossly discordant with the Pre-Code HAZUS PGA fragility curves.

This suggest strongly that the report calculations did not properly get the Degenkolb fragility curves into the HAZUS runs.

Note also, that with a reasonable demolition damage threshold, many (most or all) URMs with extensive structural damage (50% or so) would be a complete economic loss. More accurate damages may be several times (~3 or so) higher than the results in the BCA Report

With only the above factors, a more accurate BCR would be approaching 10x higher than the reported BCR. With a proper analysis, including the full range of damaging earthquakes and other refinements a BCR above 1 is within the realm of possibility.

See: shakemaps of M6.7 and 7.2 Seattle Fault scenarios. The BCA report only considered the M6.7.

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

****

The benefit-cost analysis (BCA) result of a benefit-cost ratio (BCR) of 0.042 for Bolts+ retrofits of URMs is extraordinarily low and well below the range of credible results. Simply put, the stated BCR appears to be substantially 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 must consider the full range of earthquake ground motions (and corresponding annual probabilities) from the smallest ground motion level that results in any damage up to the highest available ground motion. There are four ways to do this:

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

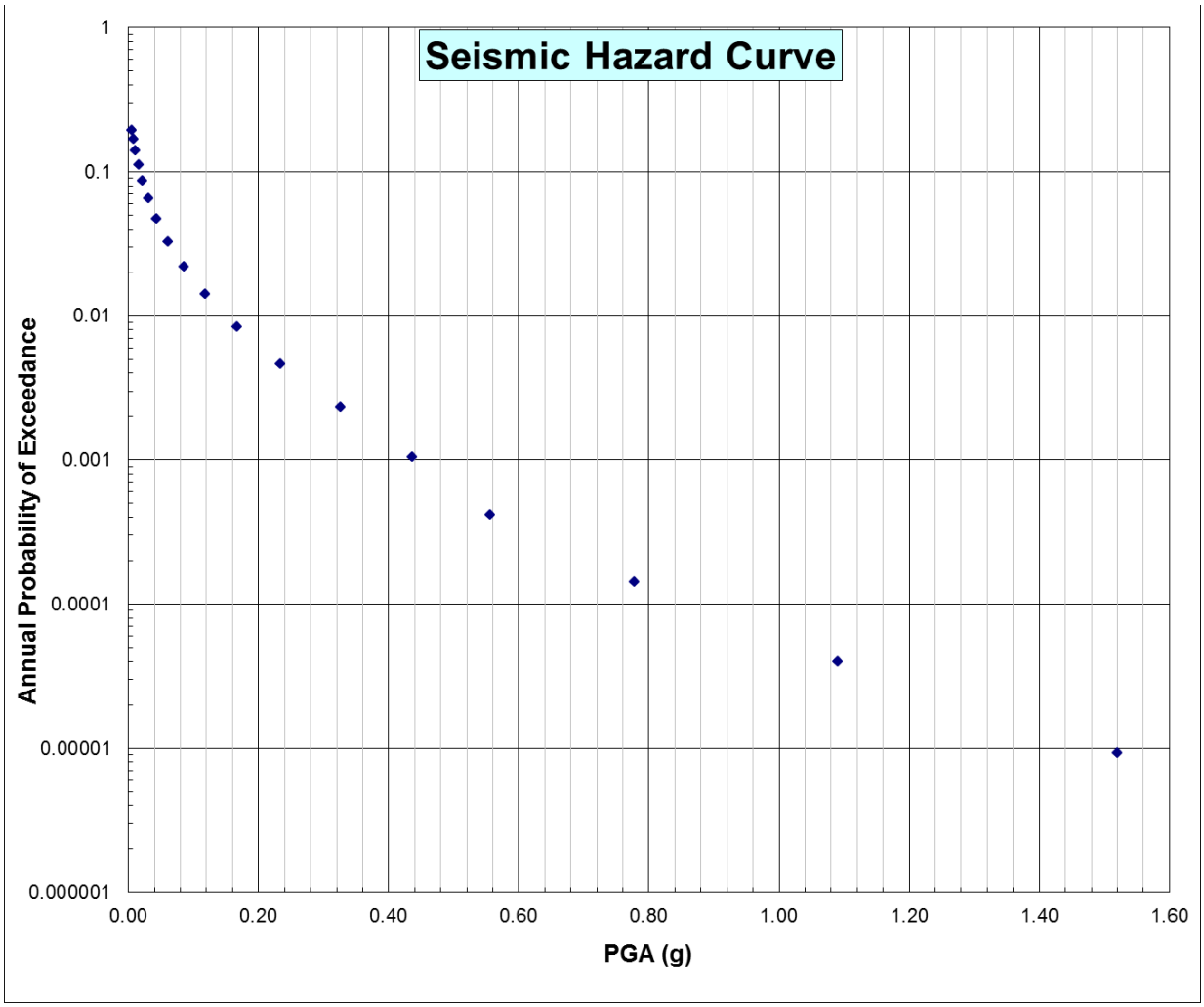
   b. Use the fragility curves to make point estimates for damages (and losses) at 6 to 10 levels of ground shaking and mathematically integrate the damage-probability relationship.

   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.