Supplemental Information—Calculating Earthquake Risk

The Modified Mercalli Intensity (MMI) scale is a scale used to convey earthquake magnitudes in a manner that is understandable to the layperson. The scale provides a description of how severe the shaking and damage will be for each magnitude. Level VIII on the MMI scale is described as "Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse."[1] Therefore, it would be expected that this would be the point at which a laboratory that has not been reinforced for seismic activity would suffer significant levels of damage. Since the shaking and damage are both closely tied to the amount of ground acceleration experienced, ranges for peak ground acceleration (PGA) have been mapped to the MMI scale. The PGA-mapped MMI scale on the USGS website[2] correlates a VIII intensity shake with a PGA of 34-65%g (percent of gravity, also commonly expressed as 0.34-0.65g). By taking the median of this range, it can be approximated that a non-reinforced laboratory will suffer significant damage at around 0.5g. This approximation is supported by the Lorant Group, Inc. who, on the Seismic Design Principles page of the *Whole Building Design Guide* website, states that an acceleration of 0.5g is "very high but buildings can survive it if the duration is short and if the mass and configuration has enough damping."[3] Put conversely, if the duration of the quake is not short or the building is not designed appropriately, the building will not survive. In order to show the worst case scenario, we have modeled the event assuming that the laboratory in question has not been seismically reinforced.

Part of the soil around the laboratory in question, especially in areas closer to the water, is loosely packed, water saturated, and highly susceptible to liquefaction.[4,5] Liquefaction has the potential to amplify ground acceleration, causing affected areas to experience higher levels of ground acceleration than expected.[6] However, a full site assessment of the location in question must be conducted to determine to what extent the liquefaction-prone soil would amplify the ground acceleration.[7] Therefore, to account for the susceptibility to liquefaction of the site in question while avoiding giving it too much weight, the PGA that will be used for modeling will be 0.4g.

The relationship between the PGA and the magnitude of the earthquake can be used to determine the maximum distance from the epicenter that would experience a PGA of that level. These relationships differ for the Eastern and Western U.S., divided by the Rocky Mountains due to differences in the Earth's

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[1] Rich J, Brooks E. Appendix A—Earthquake Magnitude and Intensity. https://www.islandcounty.net/publicworks/DEM/documents/append_a.pdf. Last Update July 2013. Accessed October 2015.

[2] USGS Earthquake Hazards Program. ShakeMap Scientific Background. http://earthquake.usgs.gov/earthquakes/shakemap/background.php#intmaps. Last Update March 2011. Accessed October 2015.

[3] Lorant Group IGLA, Inc,. Seismic Design Principles. https://www.wbdg.org/resources/seismic_design.php Last Update March 2012. Accessed October 2015.

[4] Elnashai AS *et al* (2009) Impact of New Madrid Seismic Zone Earthquakes on the Central USA. *New Madrid Seismic Zone Catastrophic Earthquake Response Planning Project* 1

[5] Consortium. CUSE. Soil Amplification/Liquification Potential Map. http://www.cusec.org/publications/maps/cusecsgmap.pdf Last Update 1999. Accessed October 2015.

[6] Lopez, F. J. (2002) *Does Liquefaction Protect Overlying Structures From Ground Shaking?* (Master's thesis). Retrieved from www.roseschool.it/files/get/id/4327.

[7] Federal Emergency Management Agency (2007) Making Hospitals Safe from Earthquakes. *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings* 2**:** 1-86

crustal attenuation and structure in these areas.[8] Seismologists were unable to provide a comparable attenuation equation for East Coast epicenters, therefore the distance was estimated using the following equation designed for West Coast epicenters, in which M denotes magnitude and D denotes the distance from the epicenter in kilometers.[9]

$$A(g) = \frac{1300 * (e^{0.67*M}) * (D + 25)^{-1.6}}{980}$$

However, it was noted that shaking experienced as a result of an earthquake in the East Coast is comparable to that from one magnitude larger in the West Coast[10]. Therefore, when this equation was used, it was used with what was considered the west coast equivalent magnitude (e.g., when calculating the distance for a magnitude 7 earthquake in the New Madrid Seismic Zone, an earthquake of magnitude 8 was put into the equation). This equation was used to determine the maximum distances that would experience a PGA of 0.4g in earthquakes of magnitude 6, 7, and 8 (Table S1).

Table S1. Maximum Distances of Earthquakes Based on Magnitude

Magnitude as on the New Madrid Fault	Maximum Distance (km)
6	15
7	35
8	67

The distances generated by the provided equation were compared to the range of distances from which the earthquake could potentially originate. The minimum distance between the fault and the laboratory in question is approximately 50 km. Given that we also know the maximum distance that would experience a PGA of 0.4g, and that the path of minimum distance between the laboratory and the fault is approximately perpendicular to the fault, the Pythagorean theorem can be utilized to determine the length of fault that an earthquake must occur on in order to cause a PGA of 0.4g at the laboratory. This length can then be divided by the total length of the fault to determine the approximate probability of the epicenter of an earthquake being located close enough to the laboratory to cause damage. It was determined that only a magnitude 8 earthquake would be sufficiently strong to generate a PGA of 0.4g at the site of the laboratory.

Using the Pythagorean theorem as explained, we find that there is an 18.75% chance of the epicenter being close enough for the ground shaking to cause significant damage to the laboratory. The probability

[8] Campbell, K. W. (2003). Prediction of strong ground motion using the hybrid empirical method and its use in the development of ground-motion (attenuation) relations in eastern North America. *Bulletin of the Seismological Society of America*, *93*(3), 1012-1033.

[9] Donovan, N. (1973). A statistical evaluation of strong motion data including the Feb. 9, 1971 San Fernando earthquake. World Conference on Earthquake Engineering, Rome.

[10] Stein, S., & Wysession, M. (2009). An introduction to seismology, earthquakes, and earth structure. John Wiley & Sons.

of a magnitude 8 earthquake occurring[11,12,13,14]was multiplied by the probability of a magnitude 8 earthquake occurring close enough along the fault for the laboratory to experience a PGA of 0.4g to determine the overall probability that the laboratory would suffer 0.4g of acceleration. The result is an annual probability of 0.02% that an earthquake will occur that is sufficiently strong and sufficiently close to do significant damage.

[11] Johnston AC, Nava SJ (1985) Recurrence rates and probability estimates for the New Madrid Seismic Zone. *Journal of Geophysical Research: Solid Earth* 90**:** 6737-6753

[12] Newman AV (2000) Geodetic and Seismic Studies of the New Madrid Seismic Zone and Implications for Earthquake Recurrence and Seismic Hazard. *Dissertation to Northwestern University***:** 1-158

[13] Newman A *et al* (1999) Slow Deformation and Lower Seismic Hazard at the New Madrid Seismic Zone. *Science* 284**:** 619-621

[14]Rogers JD. (2006) Seismic Hazards for the St. Louis Metropolitan Area In Rogers JD (ed.), *Earthquake Engineering Research Institute Earthquake Engineering Research Institute Metropolitan St. Louis Seismic Design Symposium Metropolitan St. Louis Seismic Design Symposium*.