EXECUTIVE SUMMARY

The Downtown Anchorage Seismic Risk Assessment & Land Use Regulations to Mitigate Seismic Risk was prepared by MMI Engineering, Inc., in association with Planwest Partners for the Municipality of Anchorage Planning Department and the Geotechnical Advisory Commission.

INTRODUCTION

This study assesses the seismic risk of a range of building types exposed to a range of seismic hazard zones found in downtown Anchorage. The study then proposes a draft Ground Failure Seismic Overlay to mitigate that risk by limiting the types of new development and major renovations allowed to be constructed in Seismic Hazard Zones 4 and 5 (See figure ES.1). This is an important study because there is a high potential for seismically induced ground failure in Seismic Hazard Zones 4 and 5 that would likely result in casualties and building damage in the repeat of an earthquake similar to 1964 Alaska Earthquake.

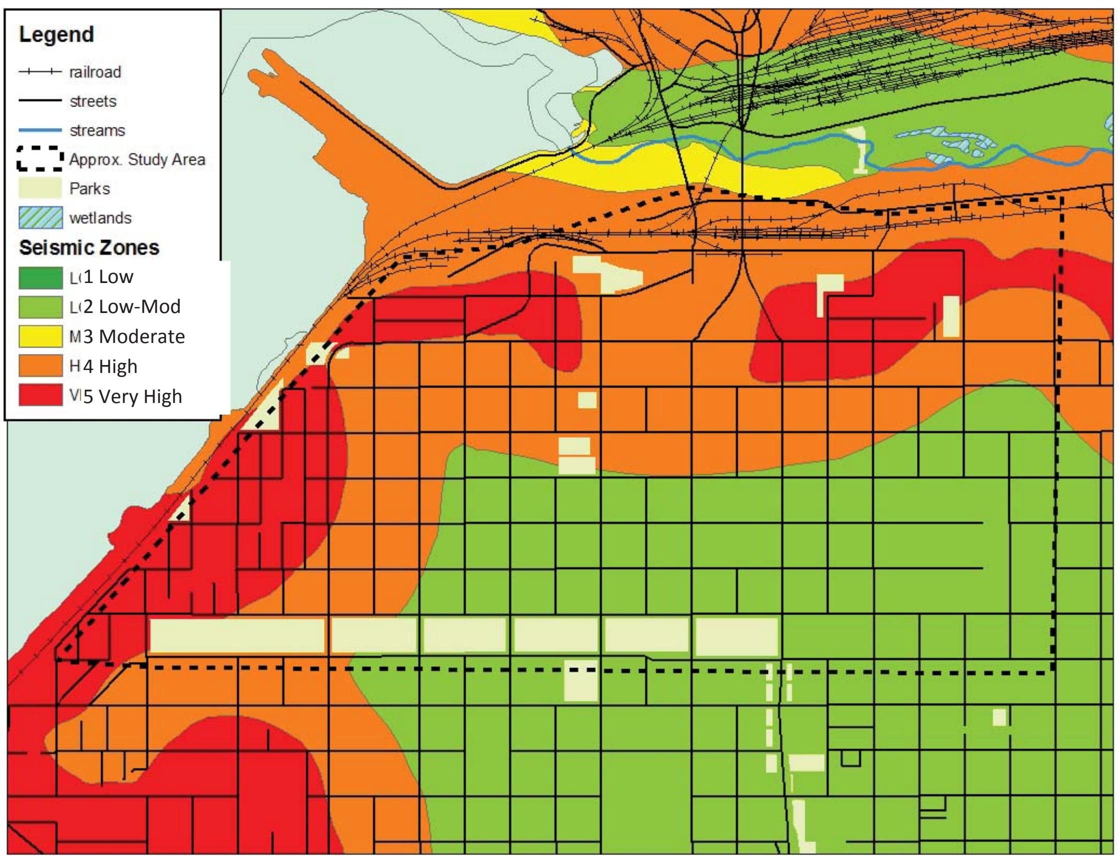

Figure ES.1. Map of Downtown Anchorage Seismic Zones

Ground failures in the 1964 Alaska Earthquake serve as a reminder of the geotechnical vulnerability of downtown Anchorage. The magnitude 9.2 subduction earthquake hit Alaska on Good Friday, March 27, 1964, the second largest recorded earthquake in history worldwide. Shaking lasted nearly five minutes. Ground failures collapsed buildings, and a tsunami resulted in 131 deaths. In downtown Anchorage, the shaking resulted in the failure of the Bootlegger Cove Clay formation, causing both vertical and horizontal geotechnical displacements exceeding 10 feet. Large blocks of earth moved towards the water leaving grabens behind and pushing up a pressure ridge in front. Figure ES.2 shows a schematic of the movement.

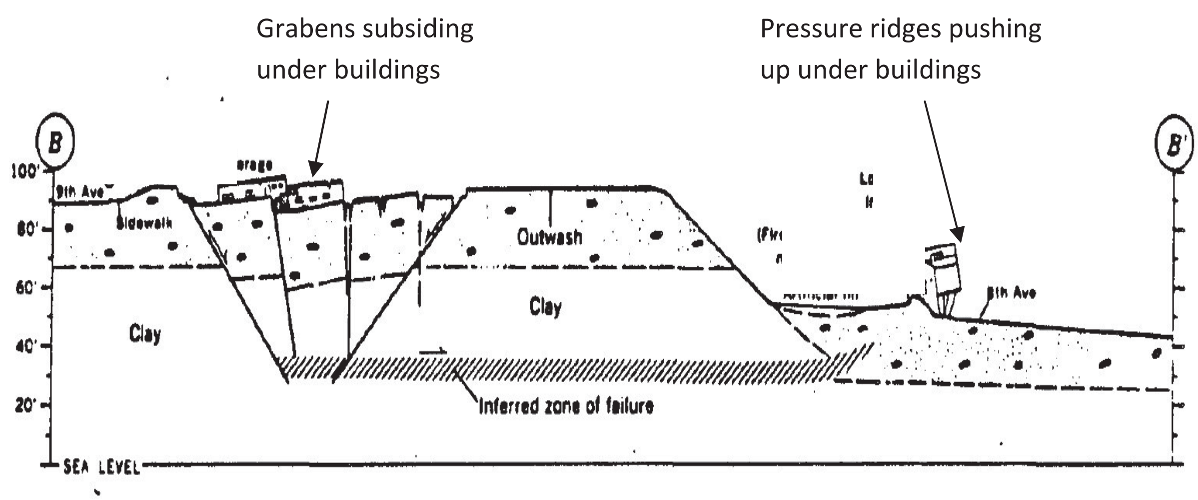

Figure ES.2. Cross section of soil strata in L Street slide area in 1964 Earthquake. (Moriwaki et al, 1985)

Other governmental bodies have developed regulations and ordinances to address geologic and seismic hazards. The most significant is the Alquist-Priolo Earthquake Fault Zoning Act in California limiting the type of development that can occur within the vicinity of active earthquake faults. This law has been in place since 1972. The City of Seattle regulates the development of areas in proximity to environmentally critical areas such as creeks and shorelines, geologic hazard areas prone to liquefaction and landslide, and flood-prone areas.

This study made use of HAZUS, Hazards US, a loss modeling tool developed by the Federal Emergency Management Agency. This is the first time HAZUS has been used as a tool for creating land use regulations relative to seismically induced ground failure. However, HAZUS has been used widely for the development of planning scenarios that are then used for development of ordinances, capital improvement projects, and changes in operation to mitigate seismic risk. One example of a major earthquake scenario was developed for a magnitude 6.7 earthquake on the Seattle Fault by a team organized by the Earthquake Engineering Research Institute and the Washington State Emergency Management Division. HAZUS was also used as a basis for estimating losses due to a magnitude 7.8 earthquake on the southern section of the San Andreas Fault.

HAZUS is also widely used to assess earthquake and flood risks as part of the development of Hazard Mitigation Plans (HMPs) required by FEMA for communities seeking reimbursement for damage following hazard events. Cities and counties throughout the US have adopted these HMPs.

It should be noted that this is a qualitative rather than a quantitative study. It is intended to be a planning level document. The study used existing data to quantify the seismic environment and site-specific ground motion. Ground-failure modeling was based on data in the literature. Detailed structural analysis was not included in the scope of work. The results can be considered qualitative estimates of the potential effects of seismically-induced ground failure on the building damage and casualties in the downtown area.

EARTHQUAKE SCENARIO

An earthquake scenario was selected for this study that would be expected to result in the types of ground failures that occurred in the 1964 earthquake. The scenario selected included seismic shaking intensities similar to those incorporated in the International Building Code (IBC), the document that is used as a basis for design of new buildings in Alaska. It is expected such an earthquake would occur on the average about once every 700 years.

GEOLOGIC HAZARD

A geotechnical analysis was conducted to estimate the levels of displacement that would occur in the scenario event. Seismic Hazard Zone 5 (see Figure ES.1) is the region for which the largest potential seismic displacements are predicted. Over 80% of the area of Zone 5 would likely experience more than eight feet of seismic slope displacement during the design level of earthquake shaking in Anchorage. Figure ES.2 shows the schematic of the expected type of movement. Movements in Zones 4 and 5 are commensurate with those encountered in the 1964 event.

The ground deformation estimates are probability based. That is, they include percentages of the areas where grabens and pressure ridges form as well as areas where little or no movement occurs. For example, in Hazard Zone 5, a building could be subjected to less than one inch of movement, or, it could experience greater than 10 feet of movement. The location of graben and pressure ridge formation in future earthquakes is unknown, so it is assumed they could occur anywhere within Hazard Zone 5, or to a lesser degree within Hazard Zone 4.

The study qualified seismically-induced ground failure by applying a simplified model that only considered a combination of horizontal and vertical ground displacement. During the 1964 earthquake, Anchorage also experienced significant vertical displacements in the form of grabens and pressure ridges. The report addresses buildings within each zone as a group. Some buildings in Zone 5 or Zone 4 may be totally destroyed, and others may undergo only minor damage. For example, since a graben could form anywhere in zone 5, the potential damage to a building could range from zero to 100 percent. The estimated losses are for the zone as a whole. Losses for an individual building located directly over a graben could be much worse.

PROTOTYPICAL BUILDINGS

Ten prototypical building were defined for this study. The buildings were selected to be representative of future building designs that would be constructed in the study area. The prototypical building structural configurations were selected based on those most likely to be used in Anchorage. Each variant was modeled two ways – with a shallow foundation, and with a mat foundation, bringing the total number of modeled buildings to 64.

Shallow distributed foundations are most typically used in Anchorage. Individual piers are not structurally interconnected with other piers, so ground movement under one or some of the piers could result in both vertical and horizontal relative displacement across the building resulting in significant damage. Mat foundations tie the entire foundation together, so differential movement would likely not result in significant damage unless the entire building tilted.

The apparent differences in building/foundation systems performance are qualitative. The study used assumed differences in the building fragilities for each building and foundation system. The assumptions were developed by engineers familiar with seismic building performance, and that have observed building performance in many earthquakes in the U.S. and abroad over the past 30 years. In addition, sensitivity testing was conducted to assess the range of modeling results for a range of assumptions. It was concluded that only a small number of buildings on the cusp would be affected by the assumptions being either included or not included in the building categories to be controlled. Detailed structural analysis to validate the fragility model was not included in the scope of work.

RISK ASSESSMENT APPROACH

Estimates of the number of fatalities in each building, and the building loss ratio (building damage versus replacement cost) were made for each of the 64 building types in each of the Seismic Hazard Zones. Estimates for shaking-induced damage were developed using damage relationships incorporated in HAZUS. Since HAZUS only minimally addresses damage due to permanent ground deformation, new damage relationships were developed and applied with a spreadsheet using the same methodology incorporated within HAZUS. In general, buildings on mat foundations are expected to be able to accommodate much greater displacements than those on shallow foundations and steel buildings are expected to perform better than concrete buildings. Taller buildings are expected to be more vulnerable than shorter buildings as they would be less stable if they were subjected to a vertical offset. Taller buildings would also be more difficult to repair if they were subjected to settlement.

RISK ASSESSMENT RESULTS AND ANALYSIS

Table ES.1 summarizes potential combined ground shaking and ground failure impacts to the 64 prototypical building variants for Hazard Zone 5, and shows the high vulnerability buildings in Hazard Zone 4. Table ES.1 is sorted by Maximum Total Deaths.

Table ES.1. Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5 Sorted on Maximum Total Deaths.

Sequence	Use	Size	HAZUS Model Bldg Type	Foundation	Total Casualties Day (inc deaths)	Total Casualties Night (inc deaths)	Max Total Deaths (Day or Night)	Total Building Damage ($M)	Loss Ratio	Total Economic Loss ($M)
26	Hotel	Large	C1H	Shallow	18.8	37.5	1.69	$ 44.0	47.9%	$74.0
27	Hotel	Large	C2H	Shallow	18.2	36.3	1.63	$ 43.3	47.2%	$72.9
19	Offices	Large	C1H	Shallow	34.7	1.7	1.56	$ 22.3	47.5%	$39.8
20	Offices	Large	C2H	Shallow	33.6	1.7	1.51	$ 22.0	46.9%	$39.4
23	Hotel	Medium	C2M	Shallow	6.2	12.5	0.85	$ 11.7	42.5%	$19.6
16	Offices	Medium	C2M	Shallow	11.8	0.6	0.80	$ 6.9	42.2%	$12.2
9	MFR	Large	C1H	Shallow	3.0	15.0	0.68	$ 16.8	47.9%	$22.8
10	MFR	Large	C2H	Shallow	2.9	14.5	0.65	$ 16.5	47.2%	$22.5
58	Hotel	Large	C1H	Mat	7.3	14.5	0.47	$ 20.4	22.2%	$36.3
51	Offices	Large	C1H	Mat	13.4	0.7	0.44	$ 10.3	22.0%	$18.8
59	Hotel	Large	C2H	Mat	6.3	12.6	0.40	$ 19.2	21.0%	$34.3
25	Hotel	Large	S1H	Shallow	9.7	19.4	0.40	$ 35.4	38.5%	$62.4
30	Multi-Use	Medium	C2M	Shallow	5.9	3.7	0.40	$ 5.3	42.4%	$9.4
52	Offices	Large	C2H	Mat	11.7	0.6	0.37	$ 9.8	20.9%	$18.2
57	Hotel	Large	S1H	Mat	8.3	16.5	0.37	$ 24.3	26.5%	$43.5
18	Offices	Large	S1H	Shallow	18.0	0.9	0.37	$ 17.8	37.9%	$32.8
50	Offices	Large	S1H	Mat	15.3	0.8	0.35	$ 12.3	26.2%	$22.0
6	MFR	Medium	C2M	Shallow	0.9	4.6	0.31	$ 3.5	42.5%	$4.9
24	Hotel	Large	S2H	Shallow	8.1	16.2	0.29	$ 32.6	35.6%	$57.9
17	Offices	Large	S2H	Shallow	14.9	0.7	0.27	$ 16.4	35.0%	$30.7
56	Hotel	Large	S2H	Mat	6.1	12.2	0.26	$ 20.0	21.8%	$35.8
49	Offices	Large	S2H	Mat	11.3	0.6	0.24	$ 10.1	21.6%	$18.6
13	Offices	Small	RM1L	Shallow	2.9	0.1	0.22	$ 1.5	37.3%	$2.7
41	MFR	Large	C1H	Mat	1.2	5.8	0.19	$ 7.8	22.1%	$10.6
42	MFR	Large	C2H	Mat	1.0	5.1	0.16	$ 7.3	20.9%	$10.2
8	MFR	Large	S1H	Shallow	1.6	7.8	0.16	$ 13.5	38.5%	$18.5
55	Hotel	Medium	C2M	Mat	1.5	3.1	0.15	$ 4.5	16.3%	$7.8
40	MFR	Large	S1H	Mat	1.3	6.6	0.15	$ 9.3	26.4%	$12.5
48	Offices	Medium	C2M	Mat	2.9	0.1	0.15	$ 2.7	16.3%	$4.9
22	Hotel	Medium	S4M	Shallow	2.3	4.7	0.13	$ 8.8	32.1%	$15.6
21	Hotel	Medium	S2M	Shallow	2.3	4.6	0.12	$ 9.0	32.6%	$15.8
15	Offices	Medium	S4M	Shallow	4.4	0.2	0.12	$ 5.2	31.6%	$9.5
14	Offices	Medium	S2M	Shallow	4.4	0.2	0.12	$ 5.2	32.0%	$9.6
7	MFR	Large	S2H	Shallow	1.3	6.5	0.12	$ 12.4	35.5%	$17.3
39	MFR	Large	S2H	Mat	1.0	4.9	0.10	$ 7.6	21.7%	$10.5
3	MFR	Small	RM1L	Shallow	0.3	1.3	0.10	$ 0.9	37.6%	$1.3

Sequence	Use	Size	HAZUS Model Bldg Type	Foundation	Total Casualties Day (inc deaths)	Total Casualties Night (inc deaths)	Max Total Deaths (Day or Night)	Total Building Damage ($M)	Loss Ratio	Total Economic Loss ($M)
54	Hotel	Medium	S4M	Mat	1.5	2.9	0.09	$ 4.6	16.6%	$8.2
53	Hotel	Medium	S2M	Mat	1.4	2.9	0.09	$ 4.9	17.7%	$8.5
47	Offices	Medium	S4M	Mat	2.8	0.1	0.09	$ 2.7	16.6%	$5.0
46	Offices	Medium	S2M	Mat	2.7	0.1	0.09	$ 2.9	17.5%	$5.1
32	Parking Struc	Medium	C1M	Shallow	1.1	0.0	0.08	$ 4.8	45.5%	$6.3
31	Parking Struc	Medium	C2M	Shallow	1.1	0.0	0.07	$ 4.7	44.2%	$6.2
62	Multi-Use	Medium	C2M	Mat	1.4	0.9	0.07	$ 2.1	16.3%	$3.7
29	Multi-Use	Medium	S4M	Shallow	2.2	1.4	0.06	$ 4.0	31.9%	$7.3
28	Multi-Use	Medium	S2M	Shallow	2.2	1.4	0.06	$ 4.1	32.4%	$7.4
38	MFR	Medium	C2M	Mat	0.2	1.1	0.06	$ 1.4	16.3%	$1.9
5	MFR	Medium	S4M	Shallow	0.3	1.7	0.05	$ 2.7	32.0%	$3.7
4	MFR	Medium	S2M	Shallow	0.3	1.7	0.05	$ 2.7	32.6%	$3.8
61	Multi-Use	Medium	S4M	Mat	1.4	0.9	0.04	$ 2.1	16.7%	$3.8
60	Multi-Use	Medium	S2M	Mat	1.4	0.9	0.04	$ 2.2	17.7%	$4.0
12	Offices	Small	S2L	Shallow	1.1	0.1	0.04	$ 1.2	30.0%	$2.2
45	Offices	Small	RM1L	Mat	0.6	0.0	0.04	$ 0.6	13.7%	$1.0
37	MFR	Medium	S4M	Mat	0.2	1.1	0.03	$ 1.4	16.6%	$2.0
36	MFR	Medium	S2M	Mat	0.2	1.1	0.03	$ 1.5	17.7%	$2.0
11	Offices	Small	W2	Shallow	1.1	0.1	0.03	$ 1.3	31.4%	$2.3
44	Offices	Small	S2L	Mat	0.6	0.0	0.02	$ 0.7	16.8%	$1.2
2	MFR	Small	S2L	Shallow	0.1	0.5	0.02	$ 0.8	30.8%	$1.1
35	MFR	Small	RM1L	Mat	0.1	0.3	0.02	$ 0.3	13.9%	$0.5
64	Parking Struc	Medium	C1M	Mat	0.3	0.0	0.02	$ 2.1	19.7%	$2.7
63	Parking Struc	Medium	C2M	Mat	0.3	0.0	0.01	$ 1.8	17.3%	$2.5
1	MFR	Small	W2	Shallow	0.1	0.5	0.01	$ 0.8	32.0%	$1.1
34	MFR	Small	S2L	Mat	0.1	0.3	0.01	$ 0.4	17.5%	$0.6
43	Offices	Small	W2	Mat	0.4	0.0	0.01	$ 0.6	14.1%	$1.0
33	MFR	Small	W2	Mat	0.0	0.2	0.00	$ 0.4	14.6%	$0.5

Legend:

HAZUS Model Building Type Key:	
C1x = Concrete moment frame	S2x = Braced steel frame
C2x = Concrete shear wall	S4x = Steel frame with cast-in-place concrete shear walls
RM1x = Reinf. msnry bearing wall w/ wood or metal diaphragm.	W2 = Wood frame
S1x = Steel moment frame	Height Key: xxL = Low-rise, xxM = Mid-rise, xxH = High-rise

Color	Vulnerability
	Low Zone 5
	Moderate Zone 5
	High Zone 5
	Very High Zone 5
	Very High Zone 5 and High Zone 4

The scope of work for the study required a recommendation for acceptable risk. In the study, it was assumed that the deaths estimated per buildings in Hazard Zones 2 or 3 (no or minimal permanent ground deformation) would be considered "acceptable." These "acceptable" deaths per building values are then used as a basis for recommending the types of buildings that are allowable to be sited in the higher Hazard Zones 4 and 5. A value of 0.23 deaths per building was ultimately selected as the threshold. This is a small number. To put it into perspective, should the earthquake event occur in the future, there would be an estimated one death in four large modern high rise hotels located in Hazard Zones 2 or 3.

The number of expected deaths is a function of both the building damage relationship and the number of people in the building. Prototypical buildings types that have estimated deaths that exceed this number (0.23) in other zones are considered to be "High Vulnerability" buildings, and are shown in cells shaded bright pink, red and dark pink in Table ES.1 for Hazard Zones 5. In general, these buildings tend to be large/high rise buildings on either shallow or mat foundations, or medium buildings on shallow foundations. The maximum total deaths value shown in Table ES.1 is the average for buildings of that type across the Hazard Zone. Buildings located directly on top of a graben or pressure ridge could have a much higher fatality rate. The relative estimated fatalities per building are higher for buildings in Hazard Zone 5 than in the lower hazard zones. Figure ES.3 shows this in a plot. Buildings are sorted by fatalities per building in Hazard Zone 5 and plotted for Hazard Zone 5, 4, and 2/3. The results show graphically that the expected number of fatalities for Hazard Zone 5 is on the order of 4 to 6 times as great for the same building as in Hazard Zone 4, and as high as 83 times as much for Zones 2/3. These numbers are driven by the magnitude of the expected ground displacements and the likelihood a particular piece of ground will undergo significant movement. The compelling conclusion is that high risk buildings should not be allowed in Seismic Hazard Zone 5 and Seismic Hazard Zone 4. This conclusion is used in the recommendations.

A similar analysis was undertaken to evaluate acceptable building losses in terms of "Loss Ratio" where Hazard Zone 2 represent "shaking only" damage expected to a modern building designed in accordance with the IBC. The Loss Ratio data for Hazard Zone 5 is shown in Table ES1 and graphically for Hazard Zones 5, 4, and 2/3 in Figure ES.4. The maximum Building Loss Ratio in Hazard Zones 2 and 3 is about 14 percent.

Analysis of the data for Zone 5 shows that all structures with shallow foundations have a higher Loss Ratio than any buildings with mat foundations. If we assume that none of the Very High Risk (bright pink red) and High Risk (dark pink) buildings (shown in Table ES.1) are allowed in Hazard Zone 5 due to life safety concerns, that leaves a group of 10 moderate risk and 8 low risk structures with shallow foundations with Loss Ratios greater than 33%. In that the buildings with the highest Loss Ratio would already be eliminated, there is less compelling data to support not allowing additional building categories in Hazard Zone 5.

RECOMMENDATIONS

We recommend mitigation to limit the number of deaths by limiting the type of building use, foundation, and superstructure using the following rules to limit:

Very High and High Vulnerability buildings in Seismic Hazard Zones 5 (bright pink, red, and dark pink as shown in Table ES.1).

Do not allow the following types of buildings in Seismic Hazard Zone 5:

- Buildings with occupancies greater than 500 (all large hotel and offices) (all foundations).
- Large concrete moment frame or shear wall offices, hotels, or multi-family residences on shallow foundations (offices and hotels already included because occupancy is greater than 500).
- Medium concrete shear wall offices, hotels, multi-family residences, or multi-use buildings on shallow foundations.

Buildings shown with moderate (yellow) and low (green) vulnerability are allowed in Zone 5.

High Vulnerability buildings in Hazard Zones 4 (bright pink as shown in Table ES.1):

Do not allow the following types of buildings:

- Large concrete moment frame or shear wall offices or hotels on shallow foundations.

All buildings except those shown in bright pink in Table ES.1 are allowed in Zone 4.

The above recommendations are incorporated in The Draft Ground Failure Susceptibility Hazard Overlay District.

The economic impact can be further mitigated over and above the level of damage that would be expected by implementing the above recommendations by not allowing any buildings on shallow foundations in Zone 5. While many of these are limited by the rules above, there are some remaining building categories that have relatively high Loss Ratios even though they would have relatively few expected fatalities. As the buildings with the highest Loss Ratios have been addressed by the above rules, it is not recommended to limit any additional building types to control Loss Ratios.

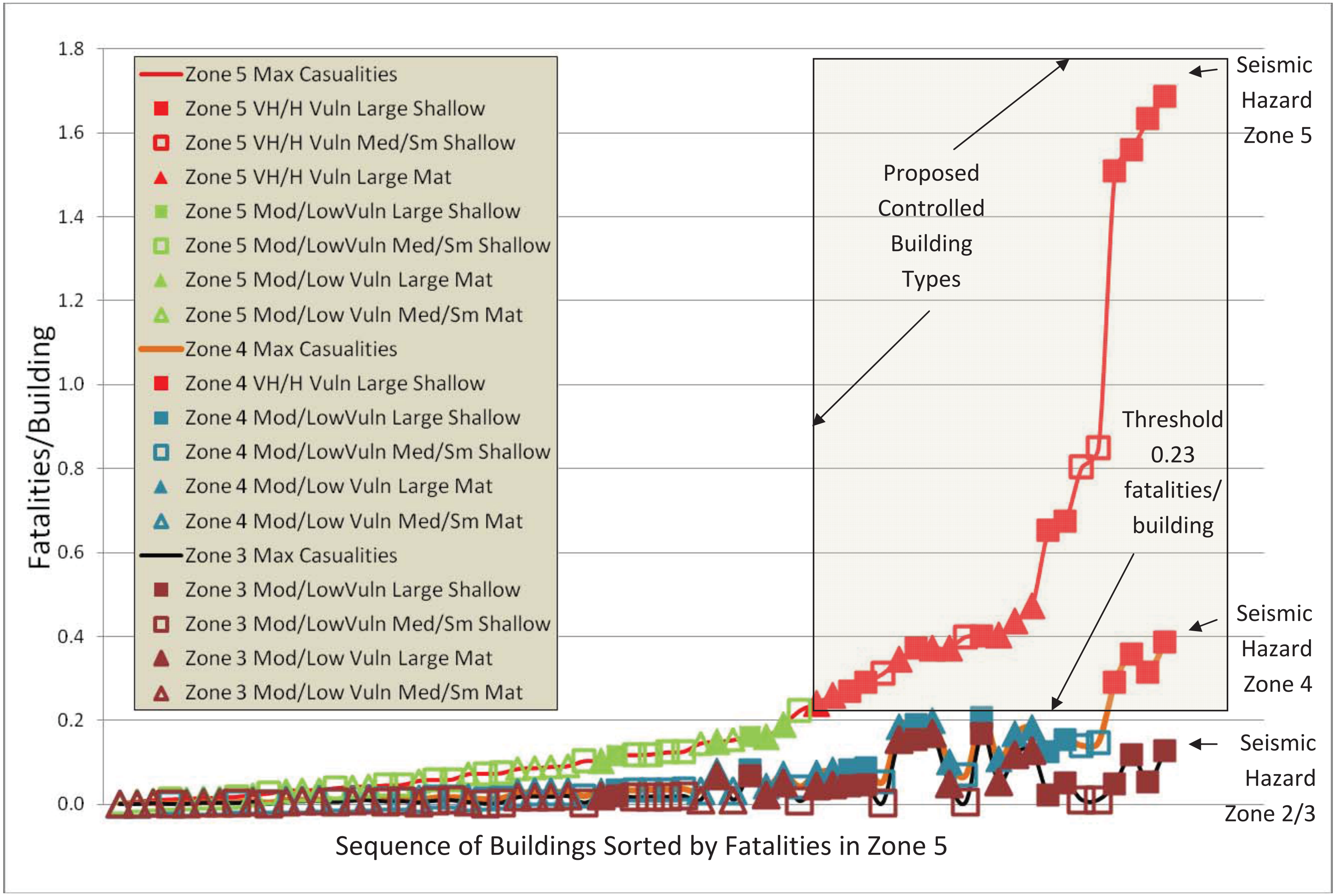

Figure ES.3. Fatalities by Building Type for Seismic Hazard Zones 2/3, 4, and 5

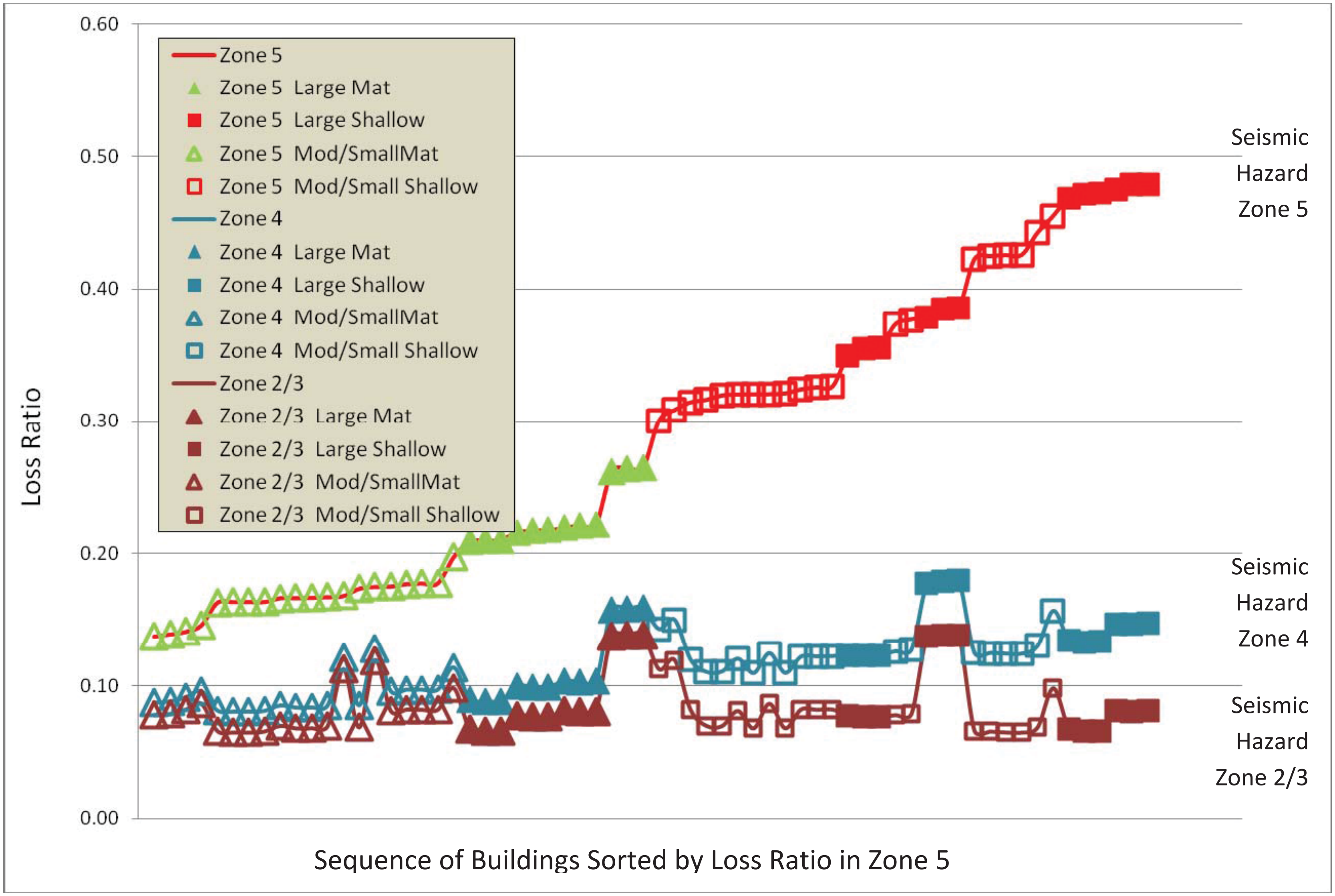

Figure ES.4. Loss Ratio by Building Type for Seismic Hazard Zones 2/3, 4, and 5