Prepared for:
The Municipality of Anchorage Planning Department
and the Geotechnical Advisory Commission

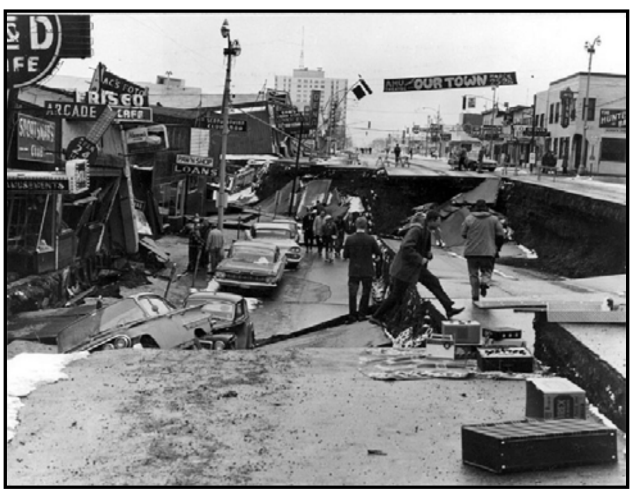
Downtown Anchorage Seismic Risk Assessment & Land Use Regulations to Mitigate Seismic Risk

Prepared by:

MMI Engineering, Inc.
1915 63rd St. NE
Tacoma, Washington 98422

Project Number MMW550
Submitted to the Municipality on December 29, 2010

Finalized on March 25, 2013
by the Municipality of Anchorage
Community Development Department/Planning Division



Graben formation on 4th Avenue near C Street, Anchorage, 1964 Alaska Earthquake

Pressure ridge at toe of L Street slide, Anchorage, 1964 Alaska Earthquake

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DEFINITION OF TERMS

Bootlegger Cove Clay – clay deposit underlying downtown Anchorage that failed during the 1964 Alaska Earthquake.

Building Loss Ratio - dollar value of building damage (structural + non-structural) divided by building replacement value.

Casualty Severity Level – four point scale of the extent of injury, with 4 being the worst (death).

Design Ground Motion – shaking intensity for which a building is designed to perform at a prescribed level of performance such as life safety or continuous operation. The shaking intensity is provided at various shaking frequencies of vibration. The representative subsurface conditions for the ground motion must be specified such as whether it is on bedrock or at the surface where it has been amplified or deamplified.

Design Level Earthquake – earthquake ground motion selected for which the building structural design is prepared for a specified level of performance, i.e., collapse prevention.

Earthquake Scenario – a planning tool that defines the size, location, and intensity of an earthquake along with a description of the expected damage.

Fragility – relationship between shaking intensity and expected level of damage shown as a percentage.

Geologic Hazard – geologic structure that has the potential to fail resulting in loss of life or loss of property. Examples include landslides and liquefaction.

Graben – a block of ground forming behind or between larger blocks of ground that are moving apart. In some cases a graben can subside vertically such as occurred in the 1964 Great Alaska Earthquake in downtown Anchorage. (See Figure 1.2.)

Ground Failure – loss of soil bearing or structural capacity.

Hazard Risk – the probability of a hazard event occurring, coupled with the consequences of its occurrence.

HAZUS Model Building Type – system of building categories based on the type of structural system, e.g., braced steel frame, moment concrete frame, concrete shear wall, etc.

HAZUS Occupancy Class - buildings classified into three broad occupancy/use-related categories: residential, commercial/institutional, and industrial. These categories are used to determine the non-structural element make-up of the buildings and the nature and value of their contents.

Mat Foundation – large concrete foundation structure acting as a single element supporting a building. It could be thought of as a concrete barge supporting a building.

Maximum Total Deaths – the greater of day time and night time expected deaths.

North American Plate – tectonic plate covering the U.S. including Alaska, Canada, and the western side of the Atlantic Ocean.

Pacific Plate – tectonic plate covering much of the North Pacific, which moves northwest under the North American Plate in Alaska.

Pressure Ridge – soil plowed up in front of movement of large moving block of soil such as occurred in the 1964 Great Alaska Earthquake in downtown Anchorage. (See Figure 1.2.)

Probabilistic Ground Motion – the ground motion resulting from an earthquake with a given probability of occurrence in a defined time period (or recurrence interval), e.g., ground motion for an earthquake that has a 10% chance of exceedance in 50 years, or a 475-year return period.

Prototypical Building – a category of future typical buildings with specific use and parameters.

Seismic Hazard Zone (also Zone, Hazard Zone) – area with similar geotechnical parameters that would be expected to have similar response characteristics in an earthquake.

Sensitivity Analysis – the study of how the variation of one parameter in a model can affect the results.

Shake Map – A ground motion map produced by the USGS for earthquakes and earthquake scenarios.

Shallow Foundation – A foundation with structural members developing their capacity below frost level and/or just below the depth of the building basement. In the case of this study, a Shallow Foundation is intended to mean a series of small shallow foundations that perform independently with only limited structural interconnection with grade beams.

Subduction Fault – the interface of one tectonic plate sliding under another tectonic plate, e.g., the Pacific Plate subducting under the North American Plate.

ACRONYMS

ATC – Applied Technology Council

DHS – Department of Homeland Security

FEMA – Federal Emergency Management Agency

GIS – Geographical Information System

HAZUS – Hazards US

IBC – International Building Code

PGD – Permanent Ground Deformation

USGS – United States Geologic Survey

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.

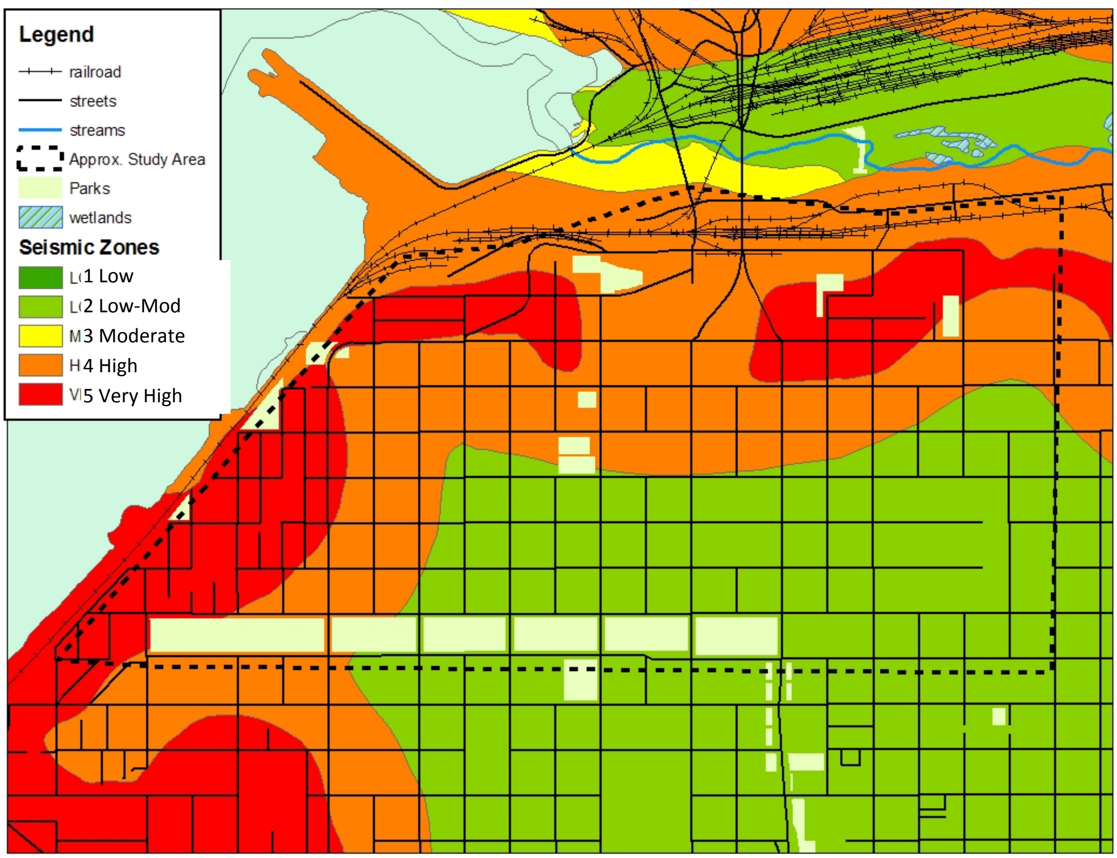

Figure ES.1. Map of Downtown Anchorage Seismic Zones

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.

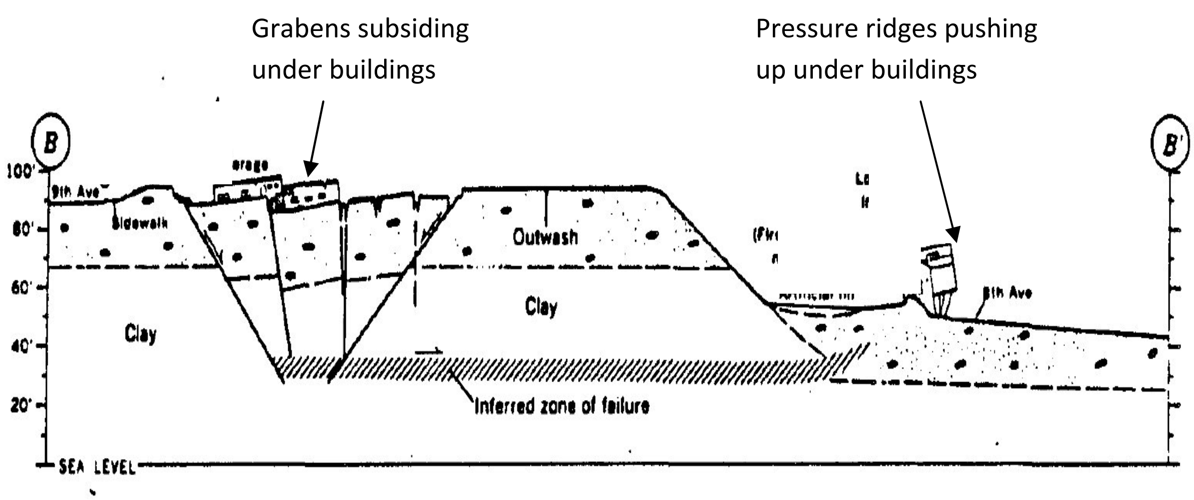

Figure ES.2. Cross section of soil strata in L Street slide area in 1964 Earthquake. (Moriwaki et al, 1985)

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
(green)	Low Zone 5
(yellow)	Moderate Zone 5
(pink)	High Zone 5
(red)	Very High Zone 5
(magenta)	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.

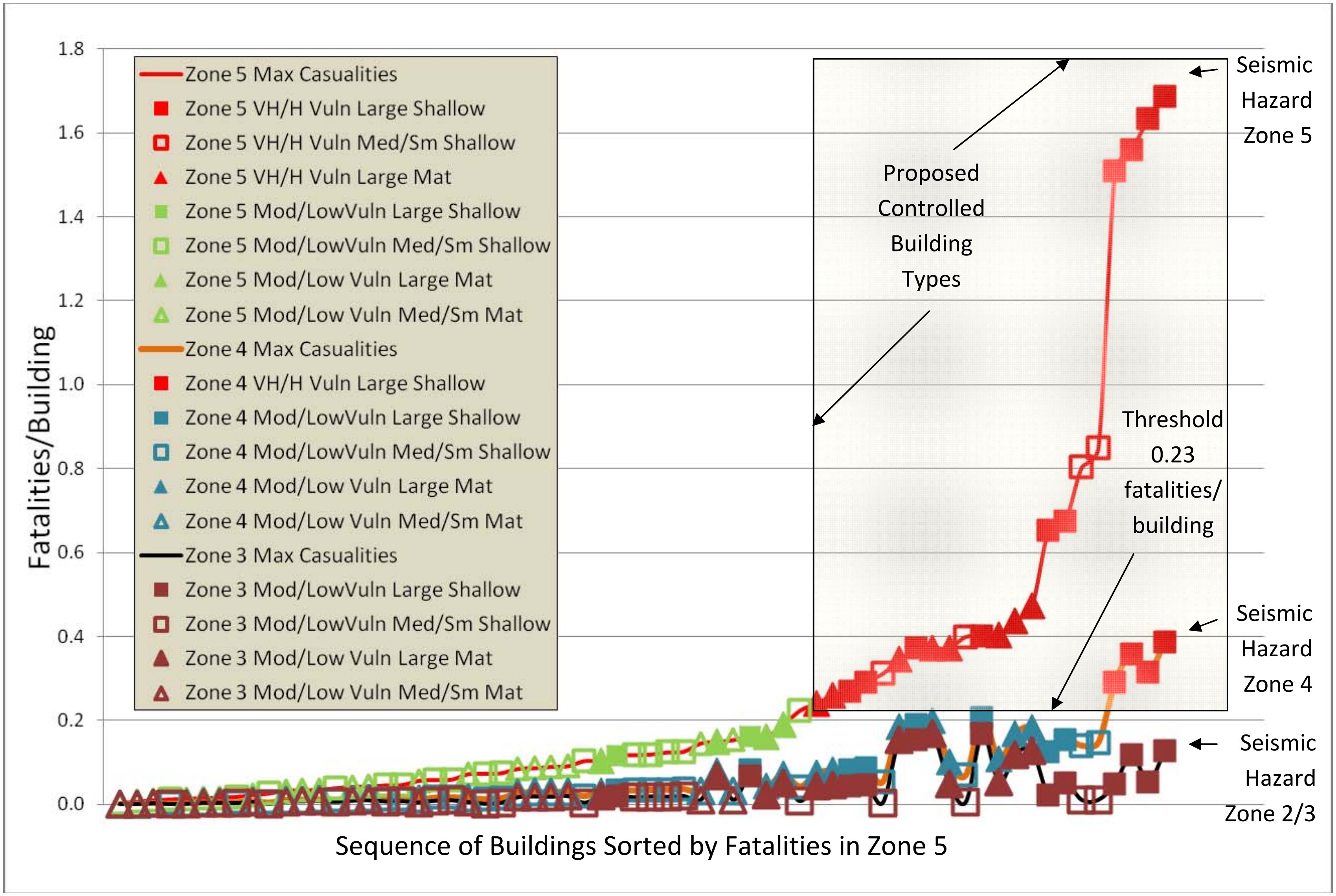

Figure ES.3. Fatalities by Building Type for Seismic Hazard Zones 2/3, 4, and 5

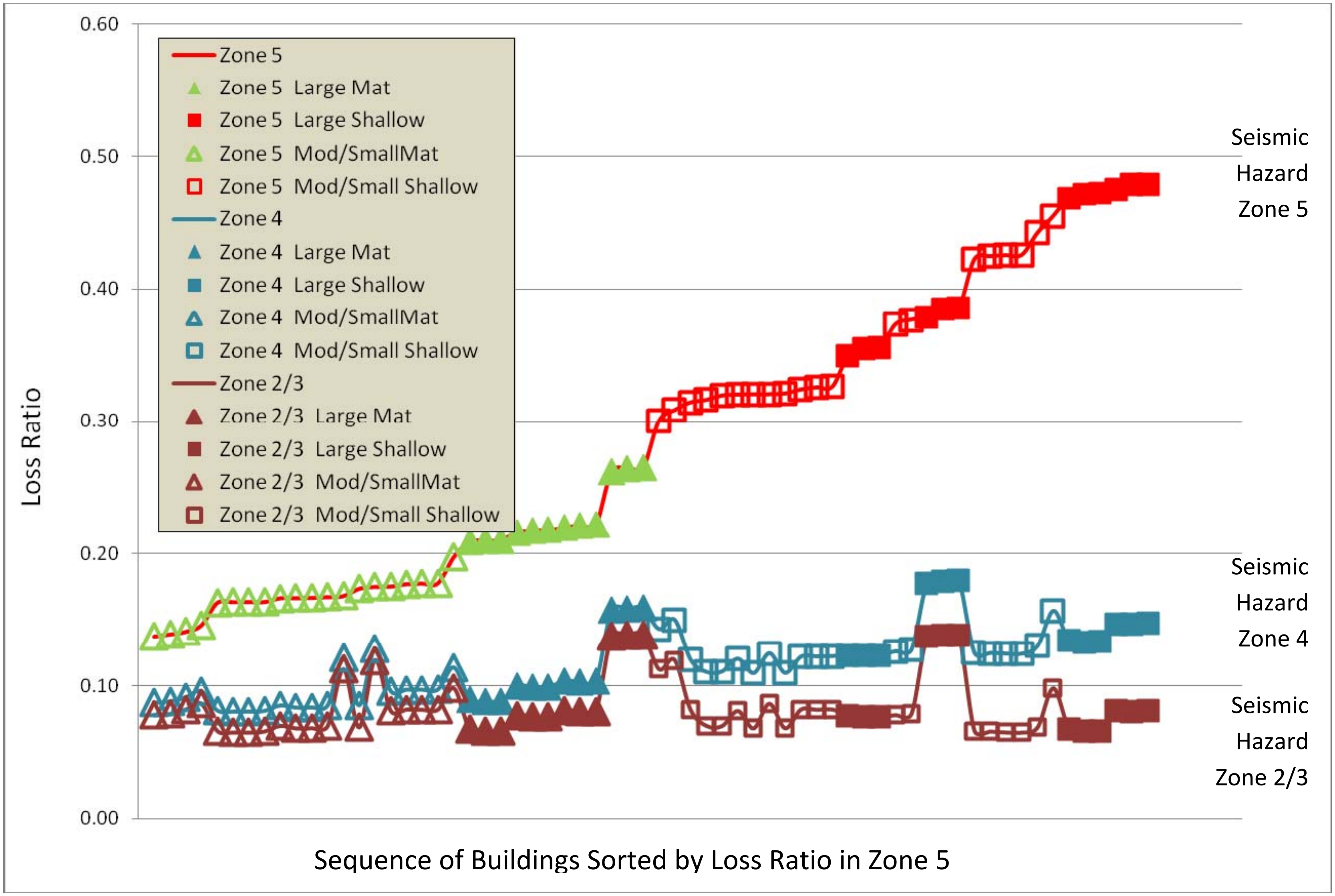

Figure ES.4. Loss Ratio by Building Type for Seismic Hazard Zones 2/3, 4, and 5

1 INTRODUCTION

1.1 Project Objective

The vulnerability of Downtown Anchorage to seismically-induced ground failure, particularly in the 1964 Alaska Earthquake, is well documented. The downtown geologic hazard is mapped in Figure 1.1.

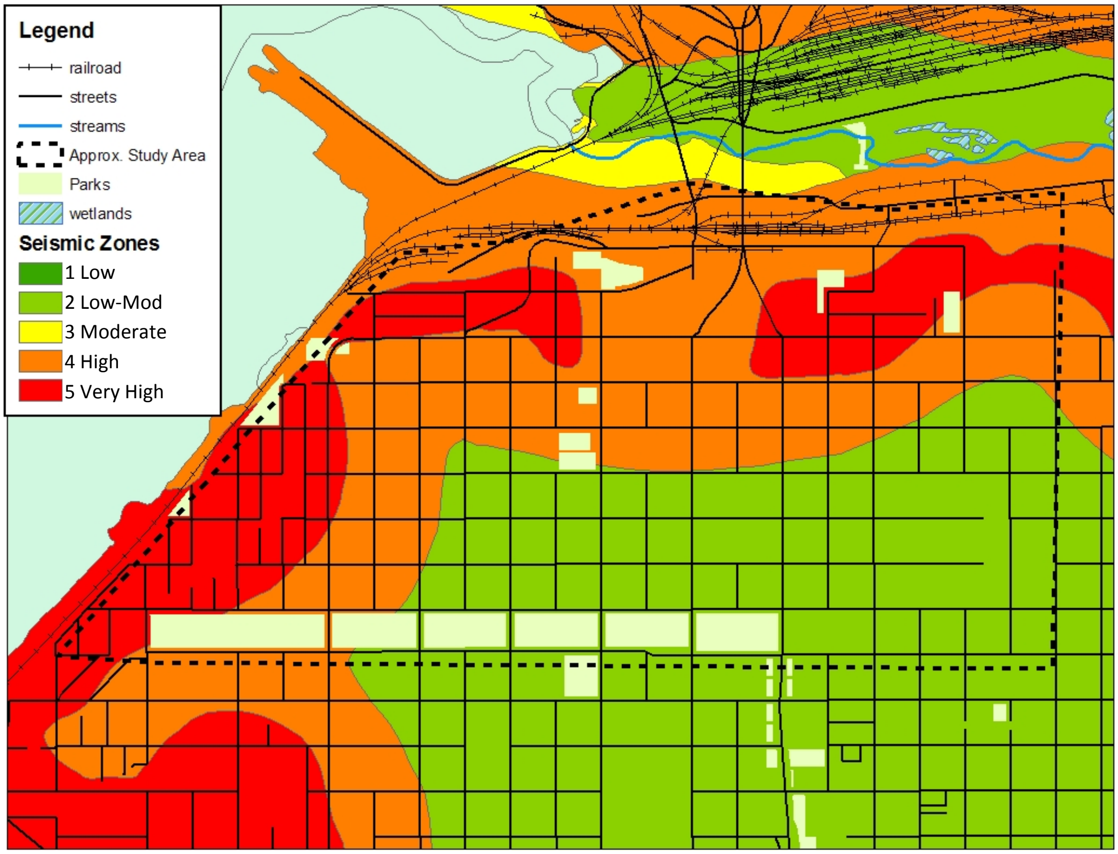

Figure 1.1 Map of Downtown Anchorage Seismic Zones

In recognition of this high vulnerability, the Anchorage Downtown Comprehensive Plan (*Plan)* proposes to "ensure seismically safe development" as one of the seven primary goals to guide downtown's land use and development patterns."[1] The *Plan* states that safe development shall:

> *Minimize the life safety risks to building occupants and economic vulnerability of property owners and the community as a whole for any future development proposed in areas with potentially high or very high ground failure susceptibility.*

To implement seismic hazard reduction goals, the *Plan* requires a response to seismic hazards consisting of two tasks: [2]

[1] Anchorage Downtown Comprehensive Plan Adopted December 11, 2007 Assembly Ordinance 2007-113 (pg. 41)

[2] LU -16 and LU17

1) Conduct a seismic hazard risk assessment study; and

2) Enact a seismic overlay zone to address land use and development in areas with greatest potential for ground failure.

This project conducted the seismic hazard risk assessment and has developed a draft seismic overlay zone. 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.

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

The risk assessment, undertaken in response to the Comprehensive Plan mandate, uses *Hazards U.S.* (HAZUS), a nationally applicable standardized software-based methodology developed by FEMA to estimate potential economic losses and human casualties. A key element of the Downtown Anchorage HAZUS model was to apply parameters based on a design earthquake to analysis of ten prototypical buildings that are representative of uses and building types identified in downtown Anchorage. The model input describes the buildings in terms of structural and occupancy categories derived from HAZUS. The 10 prototype buildings defined for the study resulted in 32 basic prototypical variants with their associated structural configurations. Each variant was modeled in two ways: 1) with a shallow foundation, and 2) with a mat foundation, bringing the total number of modeled buildings to sixty-four.

1.2 1964 Alaska Earthquake

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. Shaking lasted nearly five minutes. Ground failures, collapsing 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 (Photos 1.1, 1.2, and 1.3) and pushing up a pressure ridge in front (Photo 1.4). Figure 1.2 shows a schematic of the movement. The areas with the most significant movement are mapped in Seismic Zone 5 (Figure 1.1).

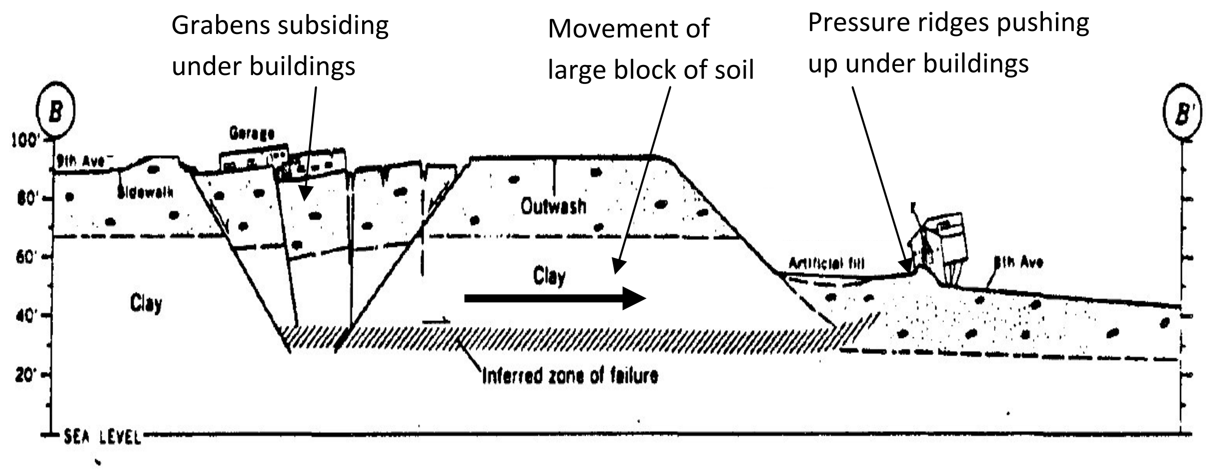

Figure 1.2 Cross section of soil strata in L Street slide area in 1964 Earthquake. (Moriwaki et al, 1985)

Photo 1.1 Collapse of Fourth Avenue near C Street, due to earthquake caused landslide. Before the earthquake, the sidewalk at left, which is in the graben, was at street level on the right. The graben subsided 11 feet in response to 14 feet of horizontal movement. Source USGS.

Photo 1.2 The marquee of the Denali Theater, which was in the graben of the Fourth Avenue landslide in Anchorage, subsided until it came to rest on the sidewalk in front of the theater, which was on ground that was not involved in the landslide. Source USGS.

Photo 1.3 A graben formed at the head of the L Street landslide in Anchorage during the earthquake. The slide block, which is virtually unbroken ground to the left of the graben, moved to the left. The subsidence trough sank 7 to 10 feet in response to 11 feet of horizontal movement of the slide block. The volume of the trough is theoretically equal to the volume of the void created at the head of the slide by movement of the slide block. A number of houses seen in this photograph were undercut or tilted by subsidence of the graben. Source USGS.

Photo 1.4 House displaced by compressional ridge formed at toe of L Street landslide. Source USGS.

The objective of this project is to quantify the risk of similar damage in a future earthquake, and to develop a seismic overlay zone to address land use development in the area.

1.3 Project Approach and Report Overview

The report is divided into eight sections followed by Appendix A, the Draft Ground Failure Susceptibility Hazard Overlay District, and six additional attachments, the six Technical Memoranda deliverables that were submitted during the course of the project.

- Section 1 - Introduction – this section
- Section 2 - Earthquake Scenario – covers the background for selection of the earthquake scenario used for the project.
- Section 3 - Geologic Hazard – quantifies the expected ground deformation that would result from soil failure in the scenario earthquake.
- Section 4 - Prototypical Buildings – lists the ten prototypical buildings selected for analysis of the expected performance in future earthquakes, including a description of additional data provided for each.
- Section 5 - Risk Assessment Approach – describes the approach used to estimate losses to the prototypical buildings due to shaking, ground failure, and the combination of the two.
- Section 6 - Results, Analysis, and Recommendations – presents the risk analysis results in terms of casualties and economic losses. The sensitivity of underlying fragility assumptions is explored, and recommendations are made to reduce the risk.

- Section 7 - Draft Zoning Ordinance Development – the general approach is described, and the Draft Ground Failure Susceptibility Hazard Overlay District is included in Appendix A.

- Section 8 - References

1.4 Project Team

The project team consisted of: Donald Ballantyne, Hope Seligson, and Paul Summers of MMI Engineering, Jennifer Donahue and Jonathan Bray of Geosyntec, Jane Preuss and George Williamson of Planwest Partners, Charles Kircher of Charles Kircher Associates, Keith Mobley of Northern Geotechnical, and various staff from USKH.

The Municipality of Anchorage project manager was David Tremont with direction and review provided by the Geotechnical Advisory Commission.

2 EARTHQUAKE SCENARIO

This section describes the earthquake scenario selected for use in this project. The scenario is similar to the 1964 Alaska Earthquake (Figure 2.1). The scenario is consistent with International Building Code (IBC) design ground motion. The IBC requires buildings to be designed to two-thirds of the probabilistic ground motion that has a 2 percent chance of occurring in 50 years (2,500 year return period).

The USGS (2002) 2,500-year probabilistic ground motion for the Anchorage area is 66.3 percent of gravity. This ground motion is located on Class B (firm) soil. Two-thirds of this ground motion is 44.2 percent of gravity. This ground motion lies between the USGS probabilistic ground motions for a 750-year return earthquake (45.9 percent g) and a 500-year return earthquake (38 percent of gravity). It is noted that the 1964 Alaska Earthquake is estimated to have a return period of about 700 years, so the scenario is consistent with the 1964 Alaska Earthquake.

The most significant source zones that contribute to the probabilistic ground motion are the Subduction Fault that caused the 1964 event (Pacific Plate moving under the North American Plate), and the Castle Mountain Fault. The earthquake scenario is intended to show the result of catastrophic soil failure similar to that which occurred in 1964, so it is important to select an event where that ground movement will occur.

The area is underlain by a 200-foot thick layer of Bootlegger Cove Clay. This clay layer impacts earthquake hazards in two ways: 1) it fails structurally resulting in the soil layers that it supports moving down gradient, and 2) it deamplifies the ground motion (reduces the intensity) introduced at the clay layer's interface with the till layer below. The entire study area is underlain by this formation, so the entire area is subject to the deamplification. The varying degrees of ground deformation are dependent on the soil's lateral restraint, so the areas closer to the water with less confinement are expected to move more (e.g. Hazard Zone 5).

Failure of the Bootlegger Clay formation that results in the catastrophic ground deformation is a function of both ground shaking intensity and duration of shaking (number of cycles). A Subduction Fault earthquake will result in an extended duration of shaking lasting five minutes or more as occurred in 1964. It is not clear that a Castle Mountain Fault event would have the shaking duration that would result in failure of the Bootlegger Clay formation. Therefore, the scenario is based on a Subduction Fault event.

Surface ground motions in the scenario are expected to be on the order of 20 percent of gravity, similar to the 1964 event. This is the result of deamplification occurring in the Bootlegger Clay formation. That is, the 44.2 percent ground motion would be input into the base of the 200-foot thick Bootlegger Clay formation. The clay material is too weak to transfer all of the energy upward to the surface. The attached USGS Shake Map shows the expected ground accelerations in the region for the 1964 event. There is some belief that even if the area was subjected to larger ground motions (such as the 66.3 percent 2,500-year return earthquake ground motion), the surface ground motion would not increase over the 20 percent of gravity.

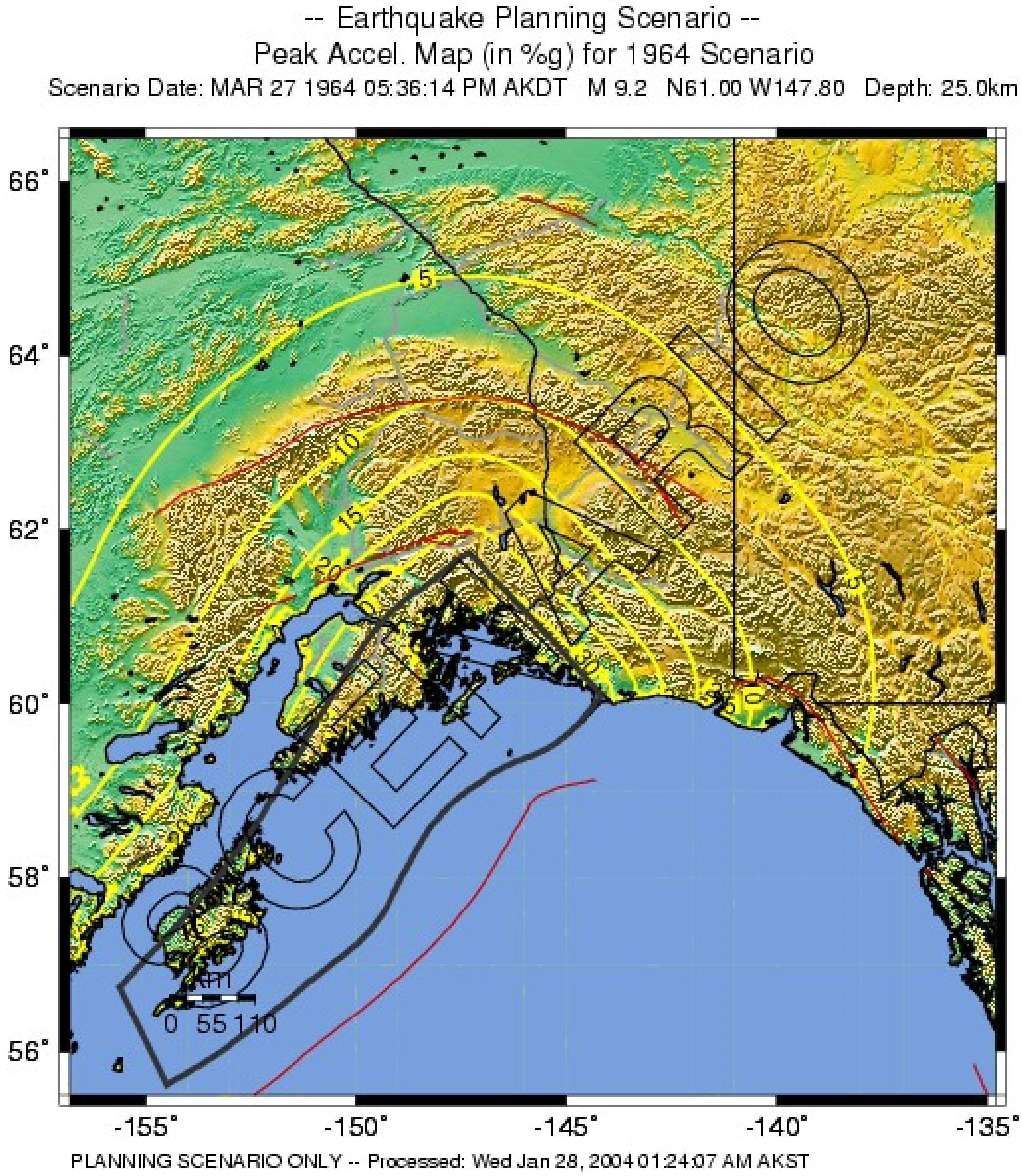

Figure 2.1 Scenario Shake Map (from the USGS).

3 GEOLOGIC HAZARD

3.1 Geotechnical Setting

The downtown Anchorage study area is a geotechnically unstable area that underwent significant movement in the 1964 Alaska Earthquake. The area is underlain by a layer of gravel outwash approximately 50 feet thick, underlain by a layer of unstable Bootlegger Cove Clay, as shown in Figure 1.2. In a significant earthquake such as occurred in 1964, the unstable clay layer loses strength along a plane, and with each cycle of earthquake shaking the overlying block of soil moves towards the free surface (the bluff). In the volume behind the block of soil, the ground collapses into the void, forming a graben.

The evaluation described here was performed for seismic risk zones 1 (Lowest) through 5 (Very High), discussed in detail in the project memorandum defining seismic displacements for the project study area (dated June 12, 2009; see Appendix D). Figure 1.2 shows a cross section of Zone 5 including potential subsidence, block lateral movement, and pressure ridges. The seismic risk zones had been previously mapped in accordance with expected permanent ground deformation (PGD) in future earthquakes. The "Seismic Displacements" memorandum quantified the expected net displacement of soil on the surface in each zone by percentage, where the displacement was a vector combining horizontal and vertical movement. In most cases, the predominant movement is expected to be horizontal, but in the areas over the grabens, the predominant movement is expected to be subsidence, and over the pressure ridges, uplift. The methodology used in estimating the movements combined expected movements over the entire zone, and is presented as a percentage of the zone expecting the net movement. This displacement estimate serves as input into the building damage relationships and loss estimates in this memorandum.

The characterization of the magnitude and type of potential ground movement during major earthquakes in each of the four local ground failure hazard zones and its resulting impact on buildings and lifelines is an integral part of the seismic risk assessment for the Anchorage downtown area. This section describes the levels of potential seismic displacement used in the Downtown Anchorage Risk Assessment. Using a scenario consistent with the IBC design ground motions and the strength of materials derived from numerous sources, the probable range of seismic displacements have been developed.

3.2 Definition and Delineation of Slopes

The study area has been divided into five categories (Seismic Hazard Zones) based on seismic risk as outlined in the 1979 Harding Lawson study and shown in Figure 1.1.

- Zone 5 - Very High – Areas of previous seismically-induced landslides. Includes zones of tension cracks above the head wall scarp, toe bulge, and pressure ridge areas. Although portions of these previous slides may remain relatively undisturbed from future strong shaking, these slides will be the more likely site of future seismically-induced sliding.

- Zone 4 - High – Fine-grained, surficial and subsurface deposits within the vicinity of steep slopes; includes area above and below the slope. Highly susceptible to all types of seismically-induced ground failure, including liquefaction, translational sliding, lurching, land spreading, cracking, and subsidence.

- Zone 3 - Moderate – Fine-grained surficial and subsurface deposits, including the Bootlegger Cove Clay and other silt, clay, and peat deposits. May experience ground cracking and horizontal ground movement due to land spreading or lurching, and subsidence due to consolidation.

- Zone 2 - Moderate-Low – Mixed coarse and fine-grained glacial deposits in lowland areas, thick deposits of channel, terrace, flood plain, and fan alluvium. May have very low susceptibility; may experience minor ground cracking, localized settlement due to consolidation, and perhaps liquefaction or lurching of localized saturated zones of fine-grained material.

- Zone 1 - Lowest – Includes exposed bedrock, thin alluvium and colluvium over bedrock. May experience minor ground cracking and acceleration of normal mass wasting process in unconsolidated material such as rock falls and snow avalanches. (None in study area.)

The existing topography was provided by the Planning Department of the Municipality of Anchorage and was input into a Geographic Information System (GIS). The downtown area was then layered with the seismic zones described above. Four foot contours of the topography were used to describe slope geometries throughout the study area.

Twenty cross sections were drawn in the study area to characterize a representative range of the slopes found within each zone. An overlay of the study area with seismic zones and cross section lines is provided below in Figure 3.1.

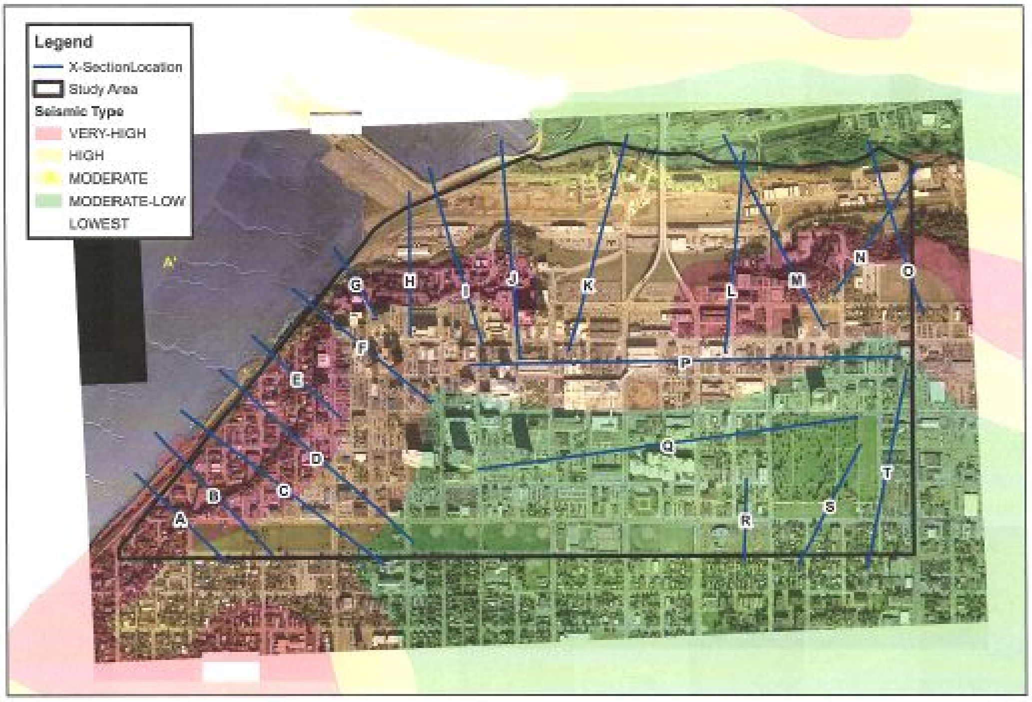

Figure 3.1 Overlay of Downtown Anchorage with Seismic Zones and Cross-Sectional Lines.

Each of the twenty cross sections was studied and 61 slopes within these cross sections were analyzed. The number of slopes analyzed within each of the zones was:

- Zone 5: 40 slopes
- Zone 4: 15 slopes
- Zone 3: 1 slope
- Zone 2: 5 slopes

As suggested in the descriptions of the zones above, Zones 4 and 5 are expected to produce the greatest number of slopes with large seismically-induced permanent displacements. These two zones also have the highest concentration of slopes within their boundaries. Zone 3 has only small acreage within the study area and is located in a flat plain. For this reason, only one slope was analyzed. Zone 2 is relatively flat with small, undulating hills.

3.3 Anticipated Slope Displacements Due to Seismic Shaking

In this study, the potential seismic displacement for each slope was estimated using the Bray and Travasarou (2007) simplified seismic slope displacement procedure. This procedure requires as input the slope geometry and soil properties to estimate the slope's characteristic dynamic resistance (i.e., its yield coefficient) and its dynamic response characteristics (i.e., the potential sliding block's fundamental period). The seismic demand was defined using the International Building Code (2006) for the likely level of earthquake shaking.

In many of the cross sections, multiple steep slopes that could produce shallow landslides existed within the mass of a potentially large translational slide. Given this complexity, all slopes, both shallow and translational, were independently evaluated to calculate anticipated displacements.

For each cross section, if the seismic displacements for the large translational slides were greater than the anticipated seismic displacements for the shallow slides located within the larger slide mass, the displacements for the larger slide were utilized in the subsequent analysis. The smaller slopes on the slide mass were assumed to essentially "go along for the ride." Alternatively, if the large translational slide does not mobilize, it is probable that the shallower landslides will dominate the seismic displacements, and the shallower slides were thus utilized.

The slopes and their calculated seismic displacements were then placed on the Harding Lawson maps. Using engineering judgment, the plan view square footage for the potential displacements was calculated for each seismic region. The results of the seismic slope displacement analyses are presented in Figure 3.2.

Zone 5 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. These large, translational slides are typically through the Bootlegger Cove Clay. Shallower slopes, mainly comprised of 30 to 50 feet of sands and gravels, are expected to "go along for the ride" within the larger sliding mass. However, there are areas within Zone 5 which may have 6 to 12 inches or less displacement, or even negligible estimated seismic displacement. This suggests that some refinement of the generalized seismic zonation of the 1979 Harding Lawson maps may be possible.

Zone 4 has the largest square footage in comparison to the other zones. Results for Zone 4 show that calculated seismic displacements can be large with almost 20 percent of the region possibly displacing more than four feet for the design earthquake scenario. These slides are large, translational slides within the Bootlegger Cove Clay and are without a toe berm or pressure ridge. Shallower potential slope failures comprised of the sands and gravels within the larger sliding mass are expected to "go along for the ride" within the larger sliding mass. Approximately 3 percent of Zone 4 will likely displace between 6 and 12 inches for the design event. These areas are generally directly behind Zone 5. A movement of about 6 inches is commensurate with observations of movement behind the scarps from the 1964 earthquake (Long, 1973; Hansen, 1965). However, a considerable percentage of the Zone 4 is more stable within areas significantly behind Zone 5 or within the areas of the toe berm/pressure ridge.

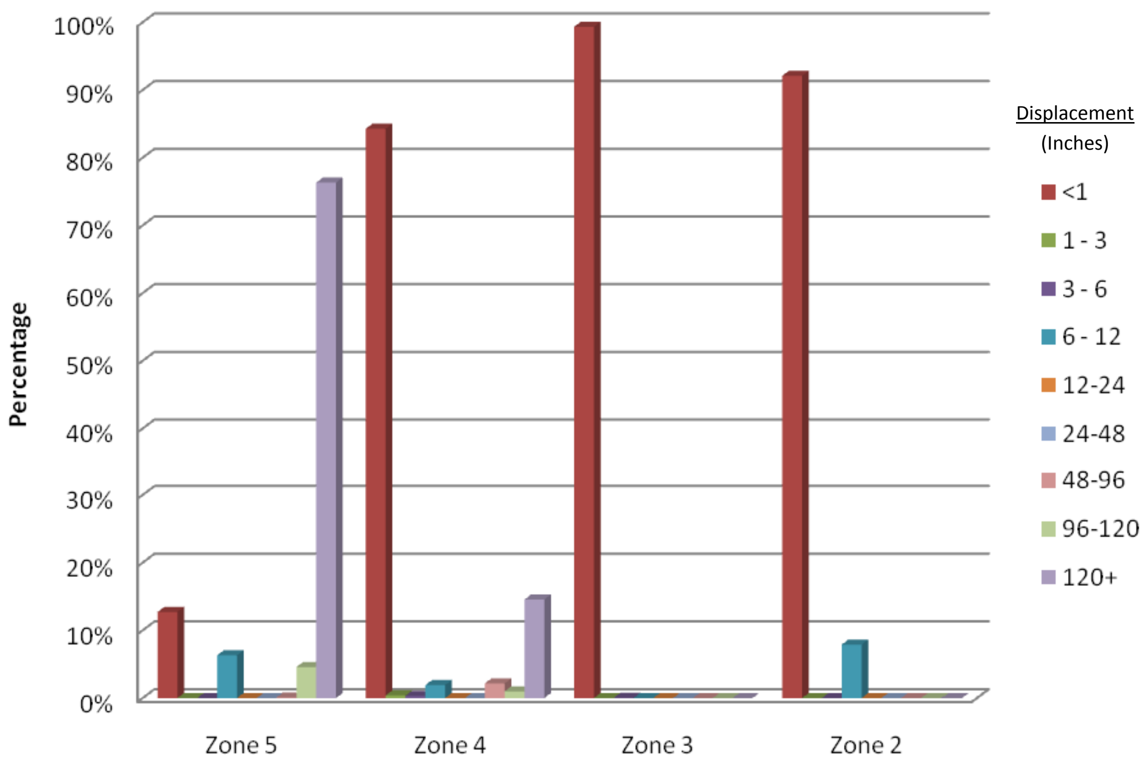

Figure 3.2 Displacements by Percentage of Area within each Zone.

Zone 3 has only one gentle slope within the study area. It is anticipated that this slope will displace less than 1 inch during the design event. Additionally, this shallow slide is less than 1 percent of the plan area of Zone 3 within the study area. Thus, Zone 3 does not present a significant seismic slope displacement hazard within the study area.

Zone 2 is characterized by large square footage and does not contain significant open faces or steep slopes. The relatively few slopes in this area are moderate and may move on the order of 6 to 12 inches during the design event. These slopes represent less than 10 percent of the land mass of Zone 2 within the study area.

The Figure 3.2 results 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 orientations of the calculated seismic displacements are aligned roughly with the slope topography. Gentle slopes that displace on a horizontal base sliding plane will displace largely horizontally. Steep slopes on inclined base sliding planes may displace vertically as much as they displace horizontally. Intermediate cases will include both horizontal and vertical components of displacement.

In addition to using slope topography to estimate the likely orientation of the calculated seismic displacement vector, observations of slope movements in the study area during the 1964 Alaska earthquake were considered. For example, the L Street Slide moved 14 feet horizontally and 10 feet vertically (about a 1.5H:1V ratio). The 4th Avenue slide moved between 19 feet to 11 feet horizontally and 10 feet vertically, or approximately a 2H:1V to 1H:1V ratio of displacements. Based on a comparison with existing topography and these observations of past performance, these relationships may provide some insight into potential relative amounts of horizontal and vertical movements within each zone:

- Zone 5 with an open face: 1.5H : 1V
- Zone 4 with an open face: 1.5H : 1V
- Zone 4 without an open face: 3H : 1V
- Zone 3: primarily horizontal movement with minor vertical movement
- Zone 2: primarily horizontal movement with minor vertical movement

The displacements developed in this section are then used to estimate prototypical building damage in the scenario earthquake.

4 PROTOTYPICAL BUILDINGS

Ten prototypical buildings were defined for this study. The buildings were selected to be representative of future building designs that would be constructed in the study area. Table 4.1 summarizes the 32 basic prototypical building variants and their associated structural configurations (HAZUS "Model Building Types"). Each variant has been modeled two ways – with a shallow foundation (e.g., distributed footings), and with a mat foundation, bringing the total number of modeled buildings to 64.

For the purpose of the seismic risk analysis, and for use in the HAZUS Advanced Engineering Building Module (AEBM) used to estimate building damage, several additional parameters were determined for each prototype, as follows:

- Building area – typical building size was determined from the HAZUS occupancy model (FEMA/DHS, 2007) and/or underlying Means Square Foot Cost (Means, 2009) model. Assumed building sizes are included in Table 4.1.

- Building replacement cost – estimated from 2009 Means Square Foot Costs, using the Anchorage location factor. Estimated building replacement values are provided in Table 4.1.

- Number of daytime and nighttime building occupants – estimated from ATC-58 (ATC, 2009) peak building population model, or from ATC-13 (ATC, 1985) occupancy models when no ATC-58 model was available. Estimated daytime and nighttime building populations are included in Table 4.1.

- Content value – estimated as a percent of structure replacement value, using HAZUS content value model percent by occupancy. For example, for residential structures, content value is assumed to be equal to 50 percent of the total structure value.

- Business inventory value – estimated using HAZUS inventory value model, updated to 2009 costs (applies to multi-use building only).

- Economic parameters (daily business income, daily wages paid, relocation disruption cost, daily rental cost, ratio owner-occupied) – estimated according to the HAZUS methodology, with costs updated to 2009.

Table 4.1 Structural Classifications for the Ten Prototypical Buildings.

Bldg. No.	Proto-type No.	Use Description	Size (sq ft)	HAZUS Occupancy Class	Estimated # Occupants (Day/Night)	Est. Bldg Value ($1,000)	HAZUS Model Building Types
1	1	MFR (Multi-Family Residence)	Small (12,000)	RES3D	7/37	2,473	W2
2							S2L
3							RM1L
4	2	MFR	Medium (40,000)	RES3E	25/124	8,293	S2M
5							S4M
6							C2M
7	3	MFR	Large (145,000)	RES3F	90/450	35,050	S2H
8							S1H
9							C1H
10							C2H
11	4	Office	Small (20,000)	COM4	80/4	4,128	W2
12							S2L
13							RM1L
14	5	Office	Medium (80,000)	COM4	320/16	16,314	S2M
15							S4M
16							C2M
17	6	Office	Large (260,000)	COM4	1,040/52	46,929	S2H
18							S1H
19							C1H
20							C2H
21	7	Hotel	Medium (135,000)	RES4	169/338	27,452	S2M
22							S4M
23							C2M
24	8	Hotel	Large (450,000)	RES4	563/1,125	91,761	S2H
25							S1H
26							C1H
27							C2H
28	9	Multi-Use	Medium (60,000)	M-U: 1/6 COM1, 2/6 COM4, 3/6 RES3E	159/100	12,597	S2M
29							S4M
30							C2M
31	10	Parking Structure	Medium (145,000)	COM10	29/1	10,602	C2M
32							C1M

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

Height Key: xxL = Low-rise, xxM = Mid-rise, xxH = High-rise

5 RISK ASSESSMENT APPROACH

This section describes the risk assessment approach used for modeling losses due to ground shaking, ground failure, and the combination of ground shaking and ground failure.

5.1 Ground Shaking Damage

Damage to the 32 basic prototypical building variants due to ground motions from an IBC Design Level earthquake was estimated using the HAZUS Advanced Engineering Building Module (AEBM). It should be noted that the HAZUS model for estimating damage due to ground shaking does not consider multiple foundation types; the default configuration is a shallow foundation (e.g., spread footings). It is assumed that building performance of other foundation types subject to ground shaking would be similar.

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.

HAZUS AEBM results include estimates of daytime and nighttime casualties defined by HAZUS according to four severity levels (FEMA/DHS, 2003, Chapter 13):

- Severity 1 – "Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness."

- Severity 2 – "Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are: third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure."

- Severity 3 – "Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome."

- Severity 4 – "Instantaneously killed or mortally injured."

For summary purposes, total casualties are reported as the sum of all four severity levels, with deaths (Severity 4) also reported separately.

Other AEBM results include estimates of dollar loss due to building damage (structural and non-structural damage), damage to building contents and commercial inventories, and building damage-related income or business interruption losses, including the cost of relocation, lost rental income, lost business income, and lost wages.

5.2 Ground Failure Fragilities

HAZUS is primarily designed to estimate losses due to ground shaking, and not ground failure. This section describes the process used to estimate losses due to ground failure.

Within the HAZUS methodological framework, there are five potential damage states (None, Slight, Moderate, Extensive, Complete), which are applicable to the building's structural and non-structural components. Each structural or non-structural damage state is qualitatively described for each model building type within the HAZUS Earthquake Model Technical Manual (DHS/FEMA, 2007). For example, structural damage state descriptions are provided in terms of expected structural damage mechanisms:

> **Steel Moment Frame Structures (S1) - Extensive Structural Damage:** Most steel members have exceeded their yield capacity, resulting in significant permanent lateral deformation of the structure. Some of the structural members or connections may have exceeded their ultimate capacity exhibited by major permanent member rotations at connections, buckled flanges and failed connections. Partial collapse of portions of structure is possible due to failed critical elements and/or connections. (DHS/FEMA, 2007)
>
> **Reinforced Concrete Moment Frame Structures (C1) - Complete Structural Damage:** Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. Approximately 13 percent (low-rise), 10 percent (mid-rise) or 5 percent (high-rise) of the total area of C1 buildings with Complete damage is expected to be collapsed. (DHS/FEMA, 2007)

The sum of the probabilities of being in each of these five damage states must equal 100 percent. For example for a "typical" vulnerable building subjected to very low ground motion, the distribution might be: None – 90 percent, Slight – 10 percent, Moderate – 0 percent, Extensive – 0 percent, and Complete – 0 percent. If the same building was subjected to very strong ground motion, the damage state probability distribution might be: None – 10 percent, Slight – 10 percent, Moderate – 20 percent, Extensive – 30 percent, and Complete – 30 percent.

For the determination of economic loss, structural and non-structural damage state probabilities are multiplied by an assumed mean percent loss for each component's damage state. In general, “Complete” damage is expected to result in the total economic loss of the structure (i.e., the expected value of damage approaches the value of the structure). “Extensive” damage is expected to be repairable, but at a significant cost (e.g., on the order of 40 - 50 percent of replacement cost).

Discussion in the HAZUS Technical Manual of the topic of building damage due to ground failure is limited; there are only 1-1/2 pages of discussion on the topic in the 75 page chapter on Building Damage (Chapter 5). Regarding ground failure damage estimates employed within the HAZUS model, the Technical Manual (pp 5-64) states ”No attempt is made to distinguish damage based on building type, since model building descriptions do not include foundation type.” The HAZUS methodology has been used as the starting point in development of the ground deformation fragilities in this project. Accordingly, this project did not use HAZUS to directly estimate ground failure impacts on buildings.

As described in Section 5.5.1 of the HAZUS Technical Manual, the median and 10th percentile values of displacement (see below, from HAZUS TM Table 5.17) effectively define structural fragility functions for the “Extensive” and “Complete” damage states, for buildings on shallow foundations. (Ground failure is not expected to produce “Slight” or “Moderate” damage).

> 10 percent - PGD 2” V, 12” H – 8 percent buildings – extensive damage; 2 percent buildings – complete damage
>
> Median – PGD 10” V, 60” H – 40 percent buildings – extensive damage; 10 percent - complete damage

From these fragility curves, damage state probabilities for these two damage states may be determined for any level of PGD. For the current study, PGDs in the IBC Design Level earthquake have been developed as a vector combining horizontal and vertical displacements. The vector resulting from combining horizontal and vertical displacements used in HAZUS is less than 2 percent larger than the horizontal component. That is, the horizontal component is much larger than the vertical component. Thus, the horizontal component has been used in the current study.

In the graben zone and in the pressure ridge zone, it is likely that the vertical component of displacement (subsidence and uplift respectively) will be larger than the horizontal component. However, there is considerable uncertainty in calculating the width of the graben and pressure ridge areas. Because the fragilities need to be applicable across the entire zone, the ground deformation analysis was performed for the overall hazard zone, where the largest component of the deformation is horizontal due to the lateral movement of the block towards the bluff. (See Figure 1.2.)

The fragilities were developed taking into account the following three factors:

1. Foundation type – will affect the ability of the foundation to accommodate horizontal and vertical differential movement.

2. Building height– will affect the stability of the building if subjected to a vertical offset though the foot print (taller buildings would also tend to have a large footprint), and will affect the opportunity to repair the building if subjected to PGD.

3. Building structural system – more ductile structural systems would tend to have a lower percentage of buildings suffering compete damage, as compared to brittle structural systems, if the foundation suffers differential movement.

The median PGD values are used with a lognormal standard deviation value of 1.2 for buildings on shallow foundations. Shallow foundations are taken to be spread footings with grade beams. Comparable damage to buildings on heavy mat foundations is not expected to occur until the PGD is on the order of 5 times greater than that for spread footings with grade beams. It is expected that the mat foundations will carry differential vertical and horizontal displacements. Failure would not occur until the building tips or rotates. The difference between the expected performance of the two foundations is qualitative and was based on expert engineering judgment but did not involve any structural analysis.

Mid-rise buildings are taken to be the baseline for this study. Low-rise buildings are expected to perform better than mid-rise buildings requiring 1.5x the median PGD to result in the same level of damage. Similarly, high-rise buildings are expected to have comparable damage when undergoing 0.67x the median PGD. This is applicable to buildings both on spread footings and mat foundations.

Buildings of differing structural systems on spread footings with grade beams are expected to perform differently when subjected to the same level of PGD. The default assumption used by HAZUS to differentiate between "Extensive" and "Complete" damage was an 80 percent/20 percent distribution. This is the "baseline" applied to wood frame buildings in the current study. It is expected that relatively fewer steel frame buildings (both braced steel frame and moment frame buildings) will suffer "Complete" damage, with an assumed distribution of 90 percent "Extensive" and 10 percent "Complete" (50 percent less "Complete"). Concrete frame, concrete shear wall, and masonry buildings are expected to perform relatively worse, with an assumed distribution of 60 percent "Extensive" damage and 40 percent "Complete" damage (2x more "Complete" damage). This differentiation relates to the capability of the structure to hold together and resist collapse.

All building structure types are expected to perform similarly when constructed on a heavy mat foundation; the baseline 80 percent/20 percent distribution is applied across all structure types when built on mat foundations.

These fragility relationships were developed based on expert opinion from three project team members, as listed below. To the best of the project team's knowledge, there is no other ongoing work in this technical area (as per discussions with building officials with the cities of Seattle and San Francisco). It is understood that there is a high level of uncertainty associated with these relationships. Observation of buildings subjected to PGD would seem to provide the best source of information for supporting the assumed fragility relationships. Each of the team members has extensive experience in post earthquake reconnaissance, particularly in the 1989 Loma Prieta, 1994 Northridge, and 1995 Kobe earthquakes. The three contributors are:

- Paul Summers, SE – MMI Engineering
- Charles Kircher, SE – Charles Kircher and Associates
- Donald Ballantyne, PE – MMI Engineering

It should also be noted that there was not complete concurrence among the contributors on the final fragility relationships. However, the items where there was disagreement tended to be insignificant relative to the overall methodology, and the application of the fragilities was evaluated using sensitivity analyses.

5.3 Ground Failure Damage

Damage to the full set of 64 prototypical buildings due to ground failure in the IBC Design Level earthquake was estimated in a customized spreadsheet model. Ground failure fragilities, as described above, were combined (according to the HAZUS ground failure estimation methodology) with ground failure probabilities by Hazard Zone (as documented in Seismic Displacement Technical Memorandum, Appendix D) to arrive at building-specific damage state probabilities. The ground failure damage state probability distributions were then used to estimate the same damage and loss measures utilized in the HAZUS AEBM.

The probability of failure of buildings was evaluated as a function of PGD. These probabilities were related to Hazard Zones by the distribution of PGDs within each hazard zone. A building with the same design parameters subjected to 12 inches of PGD would have the same probability of extensive damage whether it was in Hazard Zone 2 or Hazard Zone 5.

5.4 Combined Damage due to Ground Shaking and Ground Failure

As in the HAZUS methodology (see Section 5.6.3 of the HAZUS Technical Manual), it has been assumed for this study that damage due to ground shaking is independent of damage due to ground failure. To find the total damage, and avoid double-counting, the combined damage state probabilities are determined using standard probability theory for independent events and are used to estimate the same damage and loss measures utilized in the HAZUS AEBM.

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6 RISK ASSESSMENT RESULTS, ANALYSIS, AND RECOMMENDATIONS

This section presents the results of the risk assessment, analyzes them, and makes recommendations to be used as input to the land use regulation to mitigate damage from permanent ground movement.

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 average potential effects of seismically-induced ground failure on the building damage and casualties in the downtown area. The damage and casualties associated with any one building could be much worse if the building was located directly over a graben or a pressure ridge.

Tables 6.1 - 6.3 summarize potential combined ground shaking and ground failure impacts to the 64 prototypical building variants in the IBC Design Level earthquake for Hazard Zones 5, 4, and 3, respectively. These three tables are sorted by Maximum Total Deaths (taking the maximum of day or night for each building). Hazard Zone 2 has nearly identical results and is not included. Refer to the full technical memorandum in the Appendix F for Zone 2 data if desired.

Table 6.4 presents the same data as in Table 6.1, except that it is sorted on Loss Ratio.

HAZUS' total direct economic loss is the sum of structural and non-structural building damage, contents damage, loss of commercial inventories, and building-related income or business interruption losses (relocation costs, rental losses, business income losses, and wage losses). As seen in Table 6.4, the largest losses (exceeding $70 million) occur in the large hotel, while the small apartment building suffers the smallest loss. Table 6.4 clearly points out that all buildings in Zone 5 with shallow foundations will have a higher Loss Ratio than buildings on mat foundations. Buildings in Zone 4 have a maximum Loss Ratio of 17.9 percent that is lower than two-thirds for all buildings in Zone 5. Stiffer buildings (masonry and concrete) suffer more damage than the more flexible building types (steel and wood frame). Deaths are rare, but more likely to occur in stiff, high occupancy buildings on shallow foundations.

As evidenced by the tables, the magnitude of loss and potential casualties is greatest in Zone 5, generally increases with building size, declines significantly for mat foundations relative to shallow foundations, and is larger for concrete and masonry structures, relative to more flexible steel and wood frame structures.

6.1 Contribution of Shaking and Ground Failure to Combined Risk

Table 6.5 provides a summary of economic impacts resulting from shaking alone, ground failure alone, and for the combined effect of ground shaking and ground failure, for buildings in Hazard Zone 5 in the IBC Design Level earthquake. This table demonstrates that ground failure loss is a significant component of overall loss when shallow foundations are used. When mat foundations are used, ground failure losses are greatly reduced, but the building may still suffer moderate damage as a result of ground shaking.

6.2 Sensitivity to Underlying Fragility Assumptions

To test the sensitivity of loss to the underlying assumption that mat foundations can essentially withstand five times the displacement of shallow foundations, alternative assessments were conducted. First, it was assumed there would be a smaller difference in foundation strength (mat foundations 50 percent weaker than original assumption, able to withstand 2.5x the displacement of a shallow foundation) and then it was assumed that there would be a larger difference in foundation strength (mat foundations 50 percent stronger than original assumption, able to withstand 7.5x the displacement of a shallow foundation). A comparison of economic losses for the sensitivity test runs are provided in Table 6.6. A similar comparison of the maximum expected number of deaths and casualties (for the time of day, either day or night, producing the higher estimate) is provided in Table 6.7. Overall, reducing the assumed strength of the mat foundation by 50 percent results in an average 42 percent increase in economic loss, while increasing the assumed strength by 50 percent reduces the average loss by 20 percent. Reducing the assumed strength of the mat foundation by 50 percent also results in an average 63 percent increase in deaths and a 49 percent increase in overall casualties, while a 50 percent increase in assumed strength results in a 29 percent reduction in estimated deaths and a 22 percent decrease in overall casualties. The conclusion was that even if the mat foundation could only withstand 2.5 times the displacement of the shallow foundation (as compared to 5 used in the study), the differentiation between shallow and mat foundations would be less dramatic, but would only have a limited impact in the results. Specifically, the first five buildings on mat foundations in the Moderate Vulnerability category with the highest "Total Deaths" would be recategorized as High Vulnerability. (See Table 6.1.)

6.3 Analysis

This section evaluates the potential loss of life (Injury Severity 4) due to shaking and PGD, and recommends mitigation measures using land use planning techniques. Note that in HAZUS, the Injury Severity 3 rate is directly proportional to the Injury Severity rate, being 66 percent of the value (Injury Severity 4 Rate x 66% = Injury Severity 3 rate). As a result, considering one or both rates will not impact the results.

Tables 6.1 through 6.3 show the expected deaths during the IBC Design Level earthquake event during the day or night. This data is presented in graphical format in the full Technical Memorandum found in the Appendix. The evaluation is done for new buildings built in accordance with the current International Building Code. The code does not address "acceptable" numbers of deaths in structures, but provides for a design that should be inherently safe. HAZUS provides casualty models based on empirical data as a function of building damage state. These models have been used to estimate the deaths shown in Tables 6.1 through 6.3.

It is assumed that the deaths estimated for buildings in Hazard Zone 2 (and essentially Hazard Zone 3, (with no or minimal PGD) would be considered "acceptable." That is, the analysis is performed for buildings that meet current code design requirements. These "acceptable" deaths 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. From Table 6.3, the highest total number of deaths is 0.168 (occurring in the Large Hotel, S1H structural system on a shallow foundation). 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 six large modern high rise hotels, each with night-time occupancies exceeding 1,000 people. The number of expected deaths is a function of both the building fragility and the number of people in the building. Prototypical buildings types that have estimated deaths that exceed this number (0.168) in other zones are considered to be "High Vulnerability" buildings, and are shown in cells shaded red and dark pink in Tables 6.1 and 6.2 for Hazard Zones 5 and 4, respectively. It is recommended that the 0.168 number be slightly adjusted upward to 0.23 to allow for easier implementation as there are several buildings that fall into that range. There are no high risk buildings in Hazard Zones 2 and 3. In general, these buildings tend to be large/high rise buildings on either shallow or mat foundations, or medium buildings on shallow foundations.

Within the High Vulnerability category, there is a break in the "Max Total Deaths" between 0.65 and 0.47. Eight buildings have a "Max Total Deaths" greater than 0.65. All have shallow foundations. These will be designated as "Very High Vulnerability" buildings and shown in red on Table 6.1. There are no Very High Vulnerability buildings in Hazard Zones 4, 3, or 2.

In Table 6.1, there is a slight break in the "Max Total Deaths" data between 0.07 and 0.06. This is selected as the next lower threshold. Prototypical building categories with expected deaths less than 0.23 but equal to or greater than 0.07 are categorized as "Moderate Vulnerability" buildings. They are shown shaded in yellow in Tables 6.1 through 6.3 for Hazard Zones 5 through 3, respectively. The number of buildings categorized as having a High or Moderate Vulnerability is significantly lower in progressively lower Hazard Zones 4, 3, and 2.

The relative estimated fatalities per building are higher for buildings in Hazard Zone 5 than in the lower hazard zones. Figure 6.1 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 (and effectively Hazard Zone 3) represent "shaking only" damage expected to a modern building designed in accordance with the IBC. The maximum Building Loss Ratio in Hazard Zones 2 and 3 is 13.9 percent. By comparison, only 1 of the 64 prototypical buildings in Hazard Zone 5 has Building Loss Ratio ***less*** than 13.9 percent, and it is only 13.7 percent. Examination of the Building Loss Ratio in Hazard Zone 4 shows only 12 buildings with a Loss Ratio greater than 13.9 percent, with the maximum being only 17.9 percent, so Hazard Zone 4 has a limited risk to economic impact. Table 6.4 uses the same data shown in Table 6.1 for Hazard Zone 5, but sorts it based on Loss Ratio and graphically for Hazard Zones 5, 4, and 2/3 in Figure 6.2. It very distinctly shows that all structures with shallow foundations have a higher Loss Ratio than any buildings with mat foundations. The break point is 30 percent. If we assume that all of the Very High Risk (red) and High Risk (dark pink) buildings are addressed due to life safety issues, that leaves a series of 8 moderate risk and 8 low risk structures with shallow foundations. Tables 6.3 and 6.4 show the significance of the Loss Ratio for shallow versus mat founded buildings in Hazard Zone 5. The average Loss Ratio for buildings on shallow foundations in Hazard Zone 5 is two times that for the same buildings on mat foundations – 38 percent versus 19 percent, respectively. However, there is little difference in the other zones.

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 (red) and High Risk (dark pink) buildings (shown in Table 6.1) are allowed in Hazard Zone 5 due to life safety concerns, that leaves a group of 18 moderate and 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.

6.4 Recommendations

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

Very High and High Vulnerability buildings in Seismic Hazard Zones 5 (red, and dark pink as shown in Table 6.1).

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 shearwall offices, hotels, or multi-family residences on shallow foundations (offices and hotels already included because occupancy is greater than 500)
- Medium concrete shearwall 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 (red as shown in Table 6.2):

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 dark pink in Table 6.2 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.

Table 6.1 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
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

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)
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:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

Table 6.2 Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 4 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	5.8	11.5	0.39	$13.5	14.7%	$24.6
19	Offices	Large	C1H	Shallow	10.7	0.5	0.36	$6.9	14.7%	$12.3
27	Hotel	Large	C2H	Shallow	4.7	9.5	0.32	$12.2	13.3%	$22.1
20	Offices	Large	C2H	Shallow	8.8	0.4	0.29	$6.3	13.4%	$11.7
25	Hotel	Large	S1H	Shallow	5.8	11.6	0.21	$16.5	17.9%	$30.8
57	Hotel	Large	S1H	Mat	5.6	11.1	0.20	$14.6	15.9%	$27.5
18	Offices	Large	S1H	Shallow	10.8	0.5	0.19	$8.3	17.8%	$14.7
50	Offices	Large	S1H	Mat	10.3	0.5	0.19	$7.4	15.7%	$12.8
58	Hotel	Large	C1H	Mat	3.8	7.7	0.18	$9.5	10.3%	$18.2
51	Offices	Large	C1H	Mat	7.1	0.4	0.17	$4.8	10.3%	$8.8
9	MFR	Large	C1H	Shallow	0.9	4.6	0.16	$5.2	14.7%	$6.9
23	Hotel	Medium	C2M	Shallow	1.3	2.7	0.15	$3.4	12.4%	$5.9
16	Offices	Medium	C2M	Shallow	2.5	0.1	0.14	$2.0	12.5%	$3.8
10	MFR	Large	C2H	Shallow	0.8	3.8	0.13	$4.7	13.3%	$6.5
59	Hotel	Large	C2H	Mat	2.7	5.5	0.11	$8.1	8.9%	$15.6
52	Offices	Large	C2H	Mat	5.1	0.3	0.10	$4.2	9.0%	$8.1
24	Hotel	Large	S2H	Shallow	3.4	6.7	0.09	$11.3	12.3%	$21.4
8	MFR	Large	S1H	Shallow	0.9	4.7	0.08	$6.3	17.9%	$8.3
56	Hotel	Large	S2H	Mat	3.0	6.0	0.08	$9.1	9.9%	$17.6
17	Offices	Large	S2H	Shallow	6.2	0.3	0.08	$5.8	12.3%	$10.7
40	MFR	Large	S1H	Mat	0.9	4.4	0.08	$5.5	15.8%	$7.2
49	Offices	Large	S2H	Mat	5.5	0.3	0.08	$4.7	10.0%	$8.6
41	MFR	Large	C1H	Mat	0.6	3.1	0.07	$3.6	10.3%	$4.9
30	Multi-Use	Medium	C2M	Shallow	1.3	0.8	0.07	$1.6	12.5%	$2.8
6	MFR	Medium	C2M	Shallow	0.2	1.0	0.05	$1.0	12.4%	$1.5
42	MFR	Large	C2H	Mat	0.4	2.2	0.04	$3.1	8.9%	$4.4
13	Offices	Small	RM1L	Shallow	0.6	0.0	0.04	$0.5	12.6%	$0.9
22	Hotel	Medium	S4M	Shallow	0.9	1.7	0.04	$3.0	11.0%	$5.6
7	MFR	Large	S2H	Shallow	0.5	2.7	0.04	$4.3	12.3%	$5.9
21	Hotel	Medium	S2M	Shallow	0.8	1.7	0.04	$3.4	12.2%	$6.0
15	Offices	Medium	S4M	Shallow	1.7	0.1	0.04	$1.8	11.0%	$3.4
14	Offices	Medium	S2M	Shallow	1.6	0.1	0.03	$2.0	12.0%	$3.6
55	Hotel	Medium	C2M	Mat	0.6	1.1	0.03	$2.2	8.1%	$4.0
39	MFR	Large	S2H	Mat	0.5	2.4	0.03	$3.5	9.9%	$4.7
48	Offices	Medium	C2M	Mat	1.0	0.1	0.03	$1.3	8.2%	$2.6
54	Hotel	Medium	S4M	Mat	0.7	1.5	0.03	$2.3	8.4%	$4.3
47	Offices	Medium	S4M	Mat	1.4	0.1	0.03	$1.4	8.5%	$2.6
53	Hotel	Medium	S2M	Mat	0.7	1.4	0.03	$2.7	9.7%	$4.8
46	Offices	Medium	S2M	Mat	1.3	0.1	0.03	$1.6	9.6%	$2.8
3	MFR	Small	RM1L	Shallow	0.1	0.3	0.02	$0.3	12.7%	$0.4
29	Multi-Use	Medium	S4M	Shallow	0.8	0.5	0.02	$1.4	11.1%	$2.6
28	Multi-Use	Medium	S2M	Shallow	0.8	0.5	0.02	$1.5	12.2%	$2.8

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)
62	Multi-Use	Medium	C2M	Mat	0.5	0.3	0.02	$1.0	8.1%	$1.9
32	Parking Struc	Medium	C1M	Shallow	0.3	0.0	0.02	$1.7	15.7%	$2.1
61	Multi-Use	Medium	S4M	Mat	0.7	0.4	0.01	$1.1	8.5%	$2.0
60	Multi-Use	Medium	S2M	Mat	0.7	0.4	0.01	$1.2	9.7%	$2.2
5	MFR	Medium	S4M	Shallow	0.1	0.6	0.01	$0.9	11.0%	$1.3
4	MFR	Medium	S2M	Shallow	0.1	0.6	0.01	$1.0	12.2%	$1.4
31	Parking Struc	Medium	C2M	Shallow	0.2	0.0	0.01	$1.4	13.0%	$1.9
38	MFR	Medium	C2M	Mat	0.1	0.4	0.01	$0.7	8.1%	$1.0
45	Offices	Small	RM1L	Mat	0.3	0.0	0.01	$0.4	8.7%	$0.7
37	MFR	Medium	S4M	Mat	0.1	0.5	0.01	$0.7	8.4%	$1.0
12	Offices	Small	S2L	Shallow	0.4	0.0	0.01	$0.6	14.3%	$1.0
36	MFR	Medium	S2M	Mat	0.1	0.5	0.01	$0.8	9.7%	$1.1
44	Offices	Small	S2L	Mat	0.3	0.0	0.01	$0.5	12.1%	$0.8
35	MFR	Small	RM1L	Mat	0.0	0.1	0.01	$0.2	8.8%	$0.3
64	Parking Struc	Medium	C1M	Mat	0.1	0.0	0.01	$1.2	11.4%	$1.5
2	MFR	Small	S2L	Shallow	0.0	0.2	0.01	$0.4	15.0%	$0.5
11	Offices	Small	W2	Shallow	0.3	0.0	0.01	$0.5	12.0%	$0.9
34	MFR	Small	S2L	Mat	0.0	0.1	0.00	$0.3	12.8%	$0.4
63	Parking Struc	Medium	C2M	Mat	0.1	0.0	0.00	$0.9	8.5%	$1.2
1	MFR	Small	W2	Shallow	0.0	0.1	0.00	$0.3	12.5%	$0.4
43	Offices	Small	W2	Mat	0.1	0.0	0.00	$0.4	9.1%	$0.7
33	MFR	Small	W2	Mat	0.0	0.1	0.00	$0.2	9.6%	$0.3

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

Table 6.3 Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 3 Sorted on Maximum Total Deaths.

Sequence	Use	Size	HAZUS Model Bldg Type	Foundation	Total Casualties Day	Total Casualties Night	Max Total Deaths (Day or Night)	Total Building Damage (M$)	Loss Ratio	Total Economic Loss ($M)
25	Hotel	Large	S1H	Shallow	5.0	10.1	0.17	$12.7	13.9%	$24.5
57	Hotel	Large	S1H	Mat	5.0	10.1	0.17	$12.7	13.8%	$24.5
18	Offices	Large	S1H	Shallow	9.3	0.5	0.16	$6.5	13.8%	$11.1
50	Offices	Large	S1H	Mat	9.3	0.5	0.16	$6.5	13.8%	$11.1
26	Hotel	Large	C1H	Shallow	3.2	6.4	0.13	$7.4	8.1%	$14.7
58	Hotel	Large	C1H	Mat	3.2	6.4	0.13	$7.4	8.1%	$14.7
19	Offices	Large	C1H	Shallow	5.9	0.3	0.12	$3.8	8.1%	$6.9
51	Offices	Large	C1H	Mat	5.9	0.3	0.12	$3.8	8.1%	$6.9
8	MFR	Large	S1H	Shallow	0.8	4.0	0.07	$4.8	13.8%	$6.3
40	MFR	Large	S1H	Mat	0.8	4.0	0.07	$4.8	13.8%	$6.3
27	Hotel	Large	C2H	Shallow	2.1	4.1	0.05	$6.0	6.6%	$12.0
59	Hotel	Large	C2H	Mat	2.1	4.1	0.05	$6.0	6.6%	$12.0
9	MFR	Large	C1H	Shallow	0.5	2.5	0.05	$2.8	8.1%	$3.8
41	MFR	Large	C1H	Mat	0.5	2.5	0.05	$2.8	8.1%	$3.8
20	Offices	Large	C2H	Shallow	3.8	0.2	0.05	$3.2	6.8%	$6.1
52	Offices	Large	C2H	Mat	3.8	0.2	0.05	$3.2	6.8%	$6.1
24	Hotel	Large	S2H	Shallow	2.4	4.8	0.05	$7.0	7.7%	$14.2
56	Hotel	Large	S2H	Mat	2.4	4.8	0.05	$7.0	7.7%	$14.2
17	Offices	Large	S2H	Shallow	4.5	0.2	0.04	$3.7	7.8%	$6.7
49	Offices	Large	S2H	Mat	4.5	0.2	0.04	$3.7	7.8%	$6.7
10	MFR	Large	C2H	Shallow	0.3	1.7	0.02	$2.3	6.6%	$3.3
42	MFR	Large	C2H	Mat	0.3	1.7	0.02	$2.3	6.6%	$3.3
22	Hotel	Medium	S4M	Shallow	0.6	1.2	0.02	$1.9	6.8%	$3.6
54	Hotel	Medium	S4M	Mat	0.6	1.2	0.02	$1.9	6.8%	$3.6
7	MFR	Large	S2H	Shallow	0.4	1.9	0.02	$2.7	7.7%	$3.7
39	MFR	Large	S2H	Mat	0.4	1.9	0.02	$2.7	7.7%	$3.7
15	Offices	Medium	S4M	Shallow	1.1	0.1	0.02	$1.1	7.0%	$2.2
47	Offices	Medium	S4M	Mat	1.1	0.1	0.02	$1.1	7.0%	$2.2
21	Hotel	Medium	S2M	Shallow	0.6	1.1	0.02	$2.3	8.2%	$4.1
53	Hotel	Medium	S2M	Mat	0.6	1.1	0.02	$2.3	8.2%	$4.1
14	Offices	Medium	S2M	Shallow	1.1	0.1	0.02	$1.3	8.1%	$2.4
46	Offices	Medium	S2M	Mat	1.1	0.1	0.02	$1.3	8.1%	$2.4
23	Hotel	Medium	C2M	Shallow	0.4	0.7	0.01	$1.8	6.5%	$3.2
55	Hotel	Medium	C2M	Mat	0.4	0.7	0.01	$1.8	6.5%	$3.2
16	Offices	Medium	C2M	Shallow	0.7	0.0	0.01	$1.1	6.6%	$2.1
48	Offices	Medium	C2M	Mat	0.7	0.0	0.01	$1.1	6.6%	$2.1
29	Multi-Use	Medium	S4M	Shallow	0.6	0.3	0.01	$0.9	7.0%	$1.7
61	Multi-Use	Medium	S4M	Mat	0.6	0.3	0.01	$0.9	7.0%	$1.7
28	Multi-Use	Medium	S2M	Shallow	0.5	0.3	0.01	$1.0	8.2%	$1.8
60	Multi-Use	Medium	S2M	Mat	0.5	0.3	0.01	$1.0	8.2%	$1.8
13	Offices	Small	RM1L	Shallow	0.2	0.0	0.01	$0.3	7.8%	$0.6
45	Offices	Small	RM1L	Mat	0.2	0.0	0.01	$0.3	7.8%	$0.6

Sequence	Use	Size	HAZUS Model Bldg Type	Foundation	Total Casualties Day	Total Casualties Night	Max Total Deaths (Day or Night)	Total Building Damage (M$)	Loss Ratio	Total Economic Loss ($M)
5	MFR	Medium	S4M	Shallow	0.1	0.4	0.01	$0.6	6.8%	$0.8
37	MFR	Medium	S4M	Mat	0.1	0.4	0.01	$0.6	6.8%	$0.8
4	MFR	Medium	S2M	Shallow	0.1	0.4	0.01	$0.7	8.2%	$1.0
36	MFR	Medium	S2M	Mat	0.1	0.4	0.01	$0.7	8.2%	$1.0
12	Offices	Small	S2L	Shallow	0.3	0.0	0.01	$0.5	11.3%	$0.8
44	Offices	Small	S2L	Mat	0.3	0.0	0.01	$0.5	11.3%	$0.8
30	Multi-Use	Medium	C2M	Shallow	0.3	0.2	0.01	$0.8	6.6%	$1.5
62	Multi-Use	Medium	C2M	Mat	0.3	0.2	0.01	$0.8	6.6%	$1.5
6	MFR	Medium	C2M	Shallow	0.1	0.3	0.00	$0.5	6.5%	$0.8
38	MFR	Medium	C2M	Mat	0.1	0.3	0.00	$0.5	6.5%	$0.8
3	MFR	Small	RM1L	Shallow	0.0	0.1	0.00	$0.2	7.9%	$0.3
35	MFR	Small	RM1L	Mat	0.0	0.1	0.00	$0.2	7.9%	$0.3
32	Parking Struc	Medium	C1M	Shallow	0.1	0.0	0.00	$1.0	9.8%	$1.3
64	Parking Struc	Medium	C1M	Mat	0.1	0.0	0.00	$1.0	9.8%	$1.3
2	MFR	Small	S2L	Shallow	0.0	0.1	0.00	$0.3	11.9%	$0.4
34	MFR	Small	S2L	Mat	0.0	0.1	0.00	$0.3	11.9%	$0.4
31	Parking Struc	Medium	C2M	Shallow	0.1	0.0	0.00	$0.7	6.9%	$1.0
63	Parking Struc	Medium	C2M	Mat	0.1	0.0	0.00	$0.7	6.9%	$1.0
11	Offices	Small	W2	Shallow	0.1	0.0	0.00	$0.3	8.2%	$0.6
43	Offices	Small	W2	Mat	0.1	0.0	0.00	$0.3	8.2%	$0.6
1	MFR	Small	W2	Shallow	0.0	0.0	0.00	$0.2	8.7%	$0.3
33	MFR	Small	W2	Mat	0.0	0.0	0.00	$0.2	8.7%	$0.3

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

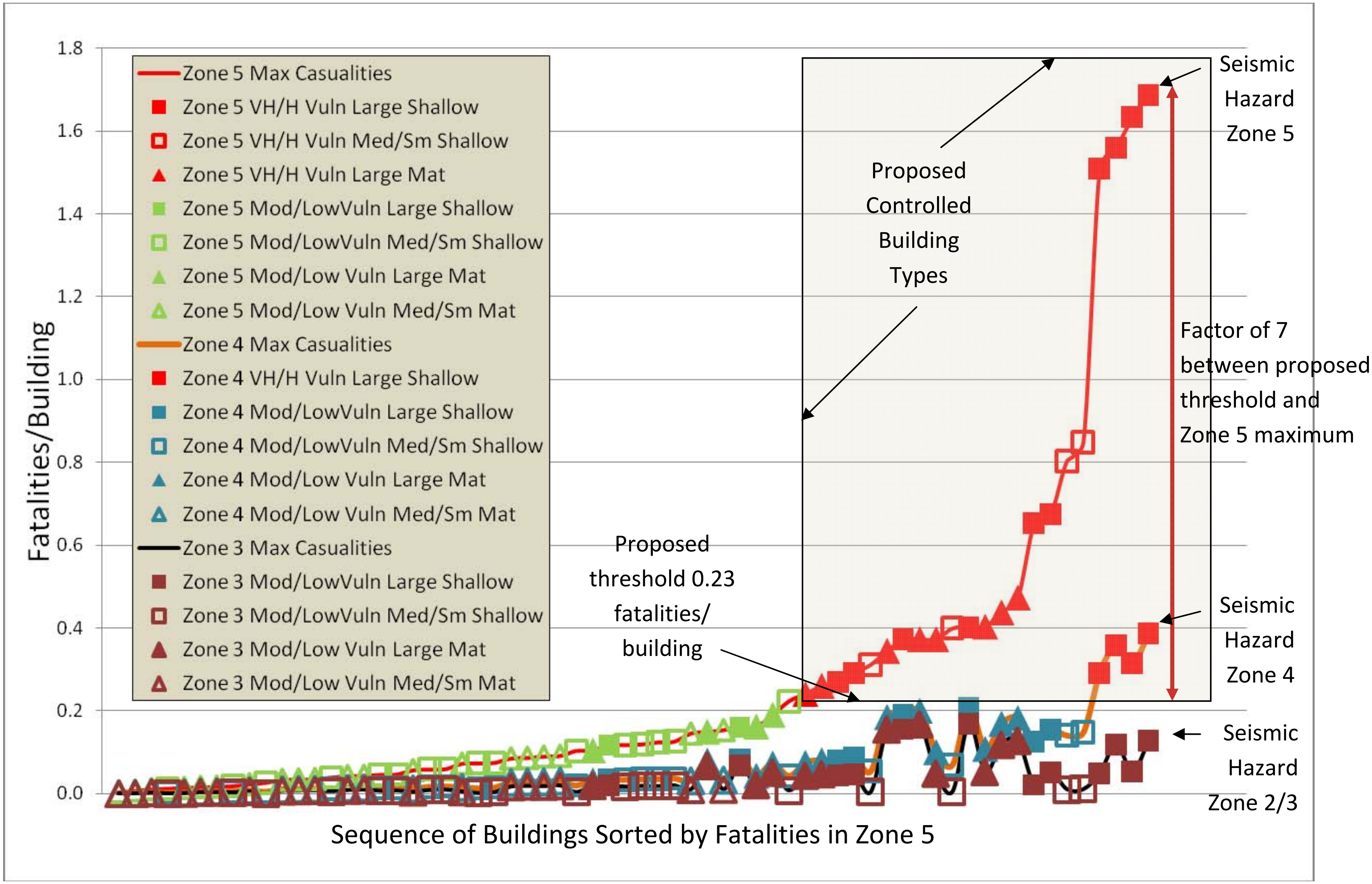

Figure 6.1. Fatalities by Building Type for Seismic Hazard Zones 2/3, 4, and 5

Table 6.4 Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5 Sorted on Loss Ratio.

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	$44.00	47.90%	$74.00
9	MFR	Large	C1H	Shallow	3	15	0.68	$16.80	47.90%	$22.80
19	Offices	Large	C1H	Shallow	34.7	1.7	1.56	$22.30	47.50%	$39.80
27	Hotel	Large	C2H	Shallow	18.2	36.3	1.63	$43.30	47.20%	$72.90
10	MFR	Large	C2H	Shallow	2.9	14.5	0.65	$16.50	47.20%	$22.50
20	Offices	Large	C2H	Shallow	33.6	1.7	1.51	$22.00	46.90%	$39.40
32	Parking Struc	Medium	C1M	Shallow	1.1	0	0.08	$4.80	45.50%	$6.30
31	Parking Struc	Medium	C2M	Shallow	1.1	0	0.07	$4.70	44.20%	$6.20
23	Hotel	Medium	C2M	Shallow	6.2	12.5	0.85	$11.70	42.50%	$19.60
6	MFR	Medium	C2M	Shallow	0.9	4.6	0.31	$3.50	42.50%	$4.90
30	Multi-Use	Medium	C2M	Shallow	5.9	3.7	0.4	$5.30	42.40%	$9.40
16	Offices	Medium	C2M	Shallow	11.8	0.6	0.8	$6.90	42.20%	$12.20
25	Hotel	Large	S1H	Shallow	9.7	19.4	0.4	$35.40	38.50%	$62.40
8	MFR	Large	S1H	Shallow	1.6	7.8	0.16	$13.50	38.50%	$18.50
18	Offices	Large	S1H	Shallow	18	0.9	0.37	$17.80	37.90%	$32.80
3	MFR	Small	RM1L	Shallow	0.3	1.3	0.1	$0.90	37.60%	$1.30
13	Offices	Small	RM1L	Shallow	2.9	0.1	0.22	$1.50	37.30%	$2.70
24	Hotel	Large	S2H	Shallow	8.1	16.2	0.29	$32.60	35.60%	$57.90
7	MFR	Large	S2H	Shallow	1.3	6.5	0.12	$12.40	35.50%	$17.30
17	Offices	Large	S2H	Shallow	14.9	0.7	0.27	$16.40	35.00%	$30.70
21	Hotel	Medium	S2M	Shallow	2.3	4.6	0.12	$9.00	32.60%	$15.80
4	MFR	Medium	S2M	Shallow	0.3	1.7	0.05	$2.70	32.60%	$3.80
28	Multi-Use	Medium	S2M	Shallow	2.2	1.4	0.06	$4.10	32.40%	$7.40
22	Hotel	Medium	S4M	Shallow	2.3	4.7	0.13	$8.80	32.10%	$15.60
14	Offices	Medium	S2M	Shallow	4.4	0.2	0.12	$5.20	32.00%	$9.60
5	MFR	Medium	S4M	Shallow	0.3	1.7	0.05	$2.70	32.00%	$3.70
1	MFR	Small	W2	Shallow	0.1	0.5	0.01	$0.80	32.00%	$1.10
29	Multi-Use	Medium	S4M	Shallow	2.2	1.4	0.06	$4.00	31.90%	$7.30
15	Offices	Medium	S4M	Shallow	4.4	0.2	0.12	$5.20	31.60%	$9.50
11	Offices	Small	W2	Shallow	1.1	0.1	0.03	$1.30	31.40%	$2.30
2	MFR	Small	S2L	Shallow	0.1	0.5	0.02	$0.80	30.80%	$1.10
12	Offices	Small	S2L	Shallow	1.1	0.1	0.04	$1.20	30.00%	$2.20
57	Hotel	Large	S1H	Mat	8.3	16.5	0.37	$24.30	26.50%	$43.50
40	MFR	Large	S1H	Mat	1.3	6.6	0.15	$9.30	26.40%	$12.50
50	Offices	Large	S1H	Mat	15.3	0.8	0.35	$12.30	26.20%	$22.00
58	Hotel	Large	C1H	Mat	7.3	14.5	0.47	$20.40	22.20%	$36.30
41	MFR	Large	C1H	Mat	1.2	5.8	0.19	$7.80	22.10%	$10.60
51	Offices	Large	C1H	Mat	13.4	0.7	0.44	$10.30	22.00%	$18.80
56	Hotel	Large	S2H	Mat	6.1	12.2	0.26	$20.00	21.80%	$35.80
39	MFR	Large	S2H	Mat	1	4.9	0.1	$7.60	21.70%	$10.50

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)
49	Offices	Large	S2H	Mat	11.3	0.6	0.24	$10.10	21.60%	$18.60
59	Hotel	Large	C2H	Mat	6.3	12.6	0.4	$19.20	21.00%	$34.30
52	Offices	Large	C2H	Mat	11.7	0.6	0.37	$9.80	20.90%	$18.20
42	MFR	Large	C2H	Mat	1	5.1	0.16	$7.30	20.90%	$10.20
64	Parking Struc	Medium	C1M	Mat	0.3	0	0.02	$2.10	19.70%	$2.70
53	Hotel	Medium	S2M	Mat	1.4	2.9	0.09	$4.90	17.70%	$8.50
60	Multi-Use	Medium	S2M	Mat	1.4	0.9	0.04	$2.20	17.70%	$4.00
36	MFR	Medium	S2M	Mat	0.2	1.1	0.03	$1.50	17.70%	$2.00
46	Offices	Medium	S2M	Mat	2.7	0.1	0.09	$2.90	17.50%	$5.10
34	MFR	Small	S2L	Mat	0.1	0.3	0.01	$0.40	17.50%	$0.60
63	Parking Struc	Medium	C2M	Mat	0.3	0	0.01	$1.80	17.30%	$2.50
44	Offices	Small	S2L	Mat	0.6	0	0.02	$0.70	16.80%	$1.20
61	Multi-Use	Medium	S4M	Mat	1.4	0.9	0.04	$2.10	16.70%	$3.80
54	Hotel	Medium	S4M	Mat	1.5	2.9	0.09	$4.60	16.60%	$8.20
47	Offices	Medium	S4M	Mat	2.8	0.1	0.09	$2.70	16.60%	$5.00
37	MFR	Medium	S4M	Mat	0.2	1.1	0.03	$1.40	16.60%	$2.00
55	Hotel	Medium	C2M	Mat	1.5	3.1	0.15	$4.50	16.30%	$7.80
48	Offices	Medium	C2M	Mat	2.9	0.1	0.15	$2.70	16.30%	$4.90
62	Multi-Use	Medium	C2M	Mat	1.4	0.9	0.07	$2.10	16.30%	$3.70
38	MFR	Medium	C2M	Mat	0.2	1.1	0.06	$1.40	16.30%	$1.90
33	MFR	Small	W2	Mat	0	0.2	0	$0.40	14.60%	$0.50
43	Offices	Small	W2	Mat	0.4	0	0.01	$0.60	14.10%	$1.00
35	MFR	Small	RM1L	Mat	0.1	0.3	0.02	$0.30	13.90%	$0.50
45	Offices	Small	RM1L	Mat	0.6	0	0.04	$0.60	13.70%	$1.00

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

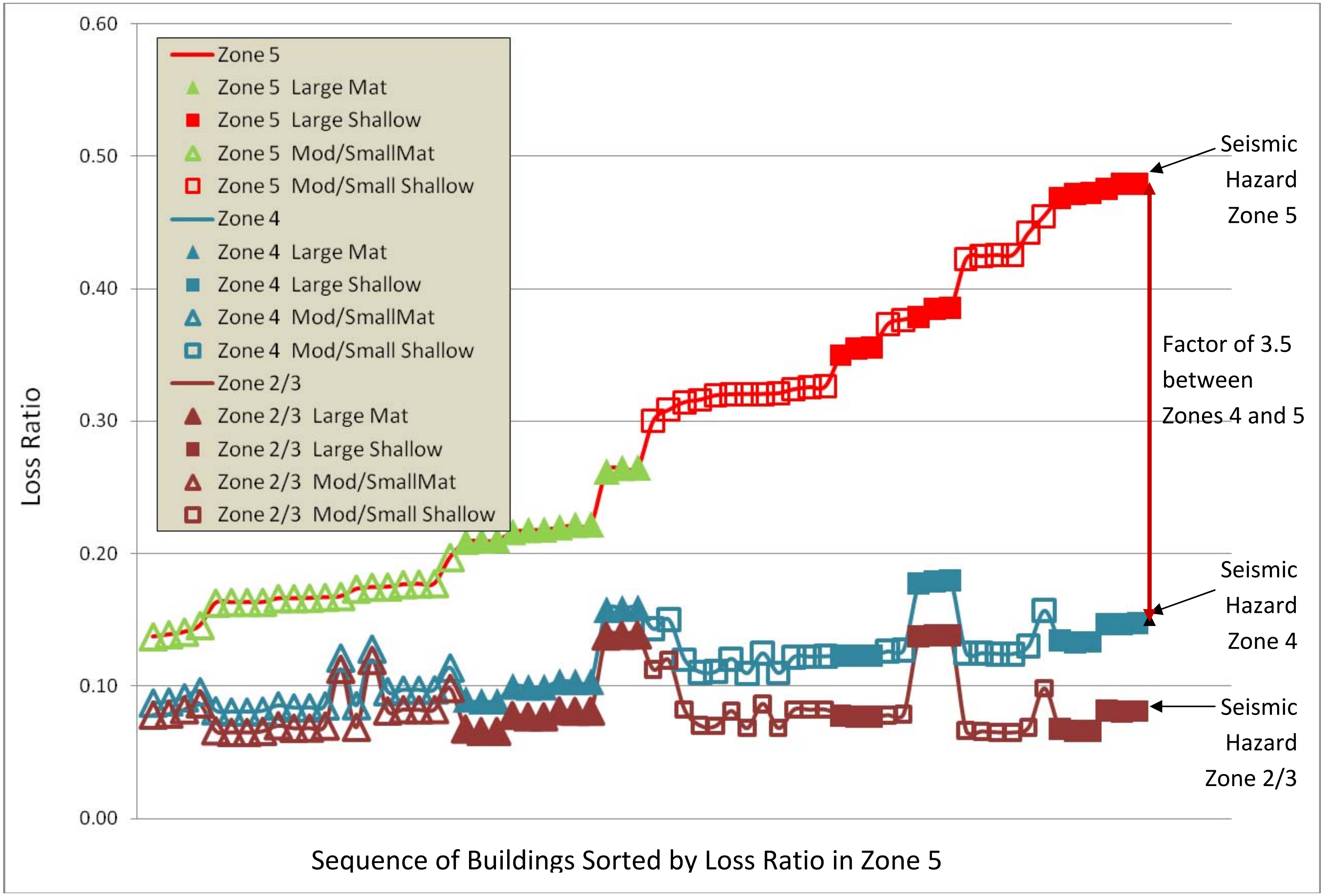

Figure 6.2. Loss Ratio by Building Type for Seismic Hazard Zones 2/3, 4, and 5

Table 6.5 Economic Impacts to Prototypical Buildings in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5 (Note (a) – Includes Building Damage).

				Shaking Only			Ground Failure Only			Shaking & Ground Failure Combined		
Use	Size	HAZUS Model Bldg. Type	Foun-dation	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(a)*	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(a)*	Total Bldg Damag e ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M)(a)
MFR	Small	W2	Shallow	$0.21	11.0%	$0.29	$0.68	27.5%	$0.95	$0.79	32.0%	$1.10
MFR	Small	S2L	Shallow	$0.29	14.2%	$0.39	$0.61	24.5%	$0.85	$0.76	30.8%	$1.06
MFR	Small	RM1L	Shallow	$0.20	10.4%	$0.28	$0.83	33.6%	$1.15	$0.93	37.6%	$1.29
MFR	Small	W2	Mat	$0.21	11.0%	$0.29	$0.17	7.0%	$0.24	$0.36	14.6%	$0.50
MFR	Small	S2L	Mat	$0.29	14.2%	$0.39	$0.17	7.0%	$0.24	$0.43	17.5%	$0.58
MFR	Small	RM1L	Mat	$0.20	10.4%	$0.28	$0.17	7.0%	$0.24	$0.34	13.9%	$0.49
MFR	Medium	S2M	Shallow	$0.68	10.0%	$0.94	$2.41	29.0%	$3.39	$2.70	32.6%	$3.79
MFR	Medium	S4M	Shallow	$0.56	8.5%	$0.82	$2.41	29.0%	$3.39	$2.66	32.0%	$3.75
MFR	Medium	C2M	Shallow	$0.54	8.6%	$0.79	$3.31	39.9%	$4.55	$3.53	42.5%	$4.88
MFR	Medium	S2M	Mat	$0.68	10.0%	$0.94	$0.92	11.1%	$1.29	$1.47	17.7%	$2.05
MFR	Medium	S4M	Mat	$0.56	8.5%	$0.82	$0.92	11.1%	$1.29	$1.38	16.6%	$1.96
MFR	Medium	C2M	Mat	$0.54	8.6%	$0.79	$0.92	11.1%	$1.29	$1.35	16.3%	$1.93
MFR	Large	S2H	Shallow	$2.69	8.7%	$3.63	$11.47	32.7%	$15.96	$12.44	35.5%	$17.27
MFR	Large	S1H	Shallow	$4.85	15.2%	$6.26	$11.47	32.7%	$15.96	$13.48	38.5%	$18.54
MFR	Large	C1H	Shallow	$2.83	9.0%	$3.75	$15.75	44.9%	$21.45	$16.78	47.9%	$22.81
MFR	Large	C2H	Shallow	$2.30	7.9%	$3.22	$15.75	44.9%	$21.45	$16.53	47.2%	$22.54
MFR	Large	S2H	Mat	$2.69	8.7%	$3.63	$5.70	16.3%	$7.87	$7.62	21.7%	$10.47
MFR	Large	S1H	Mat	$4.85	15.2%	$6.26	$5.70	16.3%	$7.87	$9.27	26.4%	$12.46
MFR	Large	C1H	Mat	$2.83	9.0%	$3.75	$5.70	16.3%	$7.87	$7.76	22.1%	$10.60
MFR	Large	C2H	Mat	$2.30	7.9%	$3.22	$5.70	16.3%	$7.87	$7.34	20.9%	$10.19
Office	Small	W2	Shallow	$0.34	12.9%	$0.60	$1.12	27.2%	$2.02	$1.30	31.4%	$2.33
Office	Small	S2L	Shallow	$0.46	15.9%	$0.80	$0.99	24.1%	$1.83	$1.24	30.0%	$2.23
Office	Small	RM1L	Shallow	$0.32	12.8%	$0.62	$1.38	33.3%	$2.41	$1.54	37.3%	$2.72
Office	Small	W2	Mat	$0.34	12.9%	$0.60	$0.28	6.9%	$0.51	$0.58	14.1%	$1.04
Office	Small	S2L	Mat	$0.46	15.9%	$0.80	$0.28	6.9%	$0.51	$0.69	16.8%	$1.19
Office	Small	RM1L	Mat	$0.32	12.8%	$0.62	$0.28	6.9%	$0.51	$0.57	13.7%	$1.04
Office	Medium	S2M	Shallow	$1.33	11.6%	$2.47	$4.66	28.5%	$8.59	$5.22	32.0%	$9.59
Office	Medium	S4M	Shallow	$1.14	10.5%	$2.24	$4.66	28.5%	$8.59	$5.16	31.6%	$9.52
Office	Medium	C2M	Shallow	$1.08	10.9%	$2.15	$6.45	39.5%	$11.33	$6.89	42.2%	$12.19
Office	Medium	S2M	Mat	$1.33	11.6%	$2.47	$1.79	11.0%	$3.24	$2.85	17.5%	$5.14
Office	Medium	S4M	Mat	$1.14	10.5%	$2.24	$1.79	11.0%	$3.24	$2.71	16.6%	$4.98
Office	Medium	C2M	Mat	$1.08	10.9%	$2.15	$1.79	11.0%	$3.24	$2.66	16.3%	$4.94
Office	Large	S2H	Shallow	$3.65	9.9%	$7.17	$15.10	32.2%	$28.35	$16.41	35.0%	$30.71

				Shaking Only			Ground Failure Only			Shaking & Ground Failure Combined		
Use	Size	HAZUS Model Bldg. Type	Foun-dation	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(a)*	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(a)*	Total Bldg Damag e ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M)*(a)*
Office	Large	S1H	Shallow	$6.47	16.6%	$12.04	$15.10	32.2%	$28.35	$17.78	37.9%	$32.82
Office	Large	C1H	Shallow	$3.81	9.9%	$7.32	$20.92	44.6%	$37.33	$22.30	47.5%	$39.75
Office	Large	C2H	Shallow	$3.16	9.4%	$6.40	$20.92	44.6%	$37.33	$21.99	46.9%	$39.36
Office	Large	S2H	Mat	$3.65	9.9%	$7.17	$7.53	16.1%	$13.86	$10.14	21.6%	$18.65
Office	Large	S1H	Mat	$6.47	16.6%	$12.04	$7.53	16.1%	$13.86	$12.29	26.2%	$21.98
Office	Large	C1H	Mat	$3.81	9.9%	$7.32	$7.53	16.1%	$13.86	$10.30	22.0%	$18.80
Office	Large	C2H	Mat	$3.16	9.4%	$6.40	$7.53	16.1%	$13.86	$9.79	20.9%	$18.21
Hotel	Medium	S2M	Shallow	$2.26	10.0%	$4.80	$7.99	29.1%	$14.07	$8.95	32.6%	$15.77
Hotel	Medium	S4M	Shallow	$1.86	8.5%	$4.26	$7.99	29.1%	$14.07	$8.81	32.1%	$15.60
Hotel	Medium	C2M	Shallow	$1.78	8.6%	$3.58	$10.96	39.9%	$18.30	$11.68	42.5%	$19.59
Hotel	Medium	S2M	Mat	$2.26	10.0%	$4.80	$3.06	11.1%	$5.27	$4.87	17.7%	$8.53
Hotel	Medium	S4M	Mat	$1.86	8.5%	$4.26	$3.06	11.1%	$5.27	$4.57	16.6%	$8.17
Hotel	Medium	C2M	Mat	$1.78	8.6%	$3.58	$3.06	11.1%	$5.27	$4.48	16.3%	$7.85
Hotel	Large	S2H	Shallow	$7.05	8.7%	$17.82	$30.09	32.8%	$52.98	$32.63	35.6%	$57.86
Hotel	Large	S1H	Shallow	$12.73	15.3%	$31.62	$30.09	32.8%	$52.98	$35.35	38.5%	$62.43
Hotel	Large	C1H	Shallow	$7.42	9.0%	$18.56	$41.28	45.0%	$68.91	$43.98	47.9%	$74.02
Hotel	Large	C2H	Shallow	$6.02	7.9%	$14.59	$41.28	45.0%	$68.91	$43.32	47.2%	$72.86
Hotel	Large	S2H	Mat	$7.05	8.7%	$17.82	$14.95	16.3%	$25.77	$19.99	21.8%	$35.80
Hotel	Large	S1H	Mat	$12.73	15.3%	$31.62	$14.95	16.3%	$25.77	$24.30	26.5%	$43.53
Hotel	Large	C1H	Mat	$7.42	9.0%	$18.56	$14.95	16.3%	$25.77	$20.36	22.2%	$36.33
Hotel	Large	C2H	Mat	$6.02	7.9%	$14.59	$14.95	16.3%	$25.77	$19.25	21.0%	$34.27
Multi-Use	Medium	S2M	Shallow	$1.07	11.0%	$1.64	$3.64	28.9%	$6.63	$4.08	32.4%	$7.41
Multi-Use	Medium	S4M	Shallow	$0.94	9.9%	$1.49	$3.64	28.9%	$6.63	$4.02	31.9%	$7.34
Multi-Use	Medium	C2M	Shallow	$0.84	9.8%	$1.39	$5.01	39.8%	$8.81	$5.35	42.4%	$9.42
Multi-Use	Medium	S2M	Mat	$1.07	11.0%	$1.64	$1.40	11.1%	$2.51	$2.23	17.7%	$3.98
Multi-Use	Medium	S4M	Mat	$0.94	9.9%	$1.49	$1.40	11.1%	$2.51	$2.11	16.7%	$3.84
Multi-Use	Medium	C2M	Mat	$0.84	9.8%	$1.39	$1.40	11.1%	$2.51	$2.06	16.3%	$3.73
Parking Str.	Medium	C2M	Shallow	$0.73	9.0%	$1.01	$4.40	41.5%	$5.76	$4.69	44.2%	$6.17
Parking Str.	Medium	C1M	Shallow	$1.04	11.4%	$1.29	$4.40	41.5%	$5.76	$4.82	45.5%	$6.29
Parking Str.	Medium	C2M	Mat	$0.73	9.0%	$1.01	$1.26	11.8%	$1.65	$1.84	17.3%	$2.46
Parking Str.	Medium	C1M	Mat	$1.04	11.4%	$1.29	$1.26	11.8%	$1.65	$2.09	19.7%	$2.68

Table 6.6 Sensitivity Test Results: Economic Impacts to Prototypical Buildings (with Mat Foundations) Subject to Ground Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5 (Note (a) – Includes Building Damage).

			Sensitivity Test #1 (mat foundation 2.5x "stronger")			Sensitivity Test #2 (mat foundation 7.5x "stronger")			Original Assumption (mat foundation 5x "stronger")		
Use	Size	HAZUS Model Bldg. Type	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) (a)	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) (a)	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) (a)
MFR	Sm.	W2	$0.52	21.1%	$0.72	$0.30	12.1%	$0.41	$0.36	14.6%	$0.50
MFR	Sm.	S2L	$0.58	23.6%	$0.80	$0.37	15.1%	$0.50	$0.43	17.5%	$0.58
MFR	Sm.	RM1L	$0.51	20.6%	$0.72	$0.28	11.3%	$0.40	$0.34	13.9%	$0.49
MFR	Med.	S2M	$2.12	25.6%	$2.96	$1.18	14.2%	$1.64	$1.47	17.7%	$2.05
MFR	Med.	S4M	$2.05	24.7%	$2.88	$1.08	13.0%	$1.54	$1.38	16.6%	$1.96
MFR	Med.	C2M	$2.03	24.4%	$2.86	$1.05	12.7%	$1.51	$1.35	16.3%	$1.93
MFR	Lrg.	S2H	$10.60	30.2%	$14.58	$6.06	17.3%	$8.31	$7.62	21.7%	$10.47
MFR	Lrg.	S1H	$11.93	34.0%	$16.20	$7.87	22.4%	$10.50	$9.27	26.4%	$12.46
MFR	Lrg.	C1H	$10.73	30.6%	$14.72	$6.20	17.7%	$8.44	$7.76	22.1%	$10.60
MFR	Lrg.	C2H	$10.38	29.6%	$14.36	$5.75	16.4%	$8.00	$7.34	20.9%	$10.19
Office	Sm.	W2	$0.85	20.6%	$1.52	$0.48	11.6%	$0.85	$0.58	14.1%	$1.04
Office	Sm.	S2L	$0.94	22.9%	$1.66	$0.60	14.4%	$1.02	$0.69	16.8%	$1.19
Office	Sm.	RM1L	$0.84	20.3%	$1.53	$0.46	11.2%	$0.86	$0.57	13.7%	$1.04
Office	Med.	S2M	$4.12	25.2%	$7.43	$2.28	14.0%	$4.12	$2.85	17.5%	$5.14
Office	Med.	S4M	$4.01	24.6%	$7.31	$2.13	13.0%	$3.94	$2.71	16.6%	$4.98
Office	Med.	C2M	$3.95	24.2%	$7.26	$2.07	12.7%	$3.89	$2.66	16.3%	$4.94
Office	Lrg.	S2H	$14.05	29.9%	$25.82	$8.09	17.2%	$14.88	$10.14	21.6%	$18.65
Office	Lrg.	S1H	$15.80	33.7%	$28.53	$10.44	22.3%	$18.54	$12.29	26.2%	$21.98
Office	Lrg.	C1H	$14.22	30.3%	$26.00	$8.25	17.6%	$15.02	$10.30	22.0%	$18.80
Office	Lrg.	C2H	$13.78	29.4%	$25.48	$7.70	16.4%	$14.39	$9.79	20.9%	$18.21
Hotel	Med.	S2M	$7.03	25.6%	$12.22	$3.90	14.2%	$6.87	$4.87	17.7%	$8.53
Hotel	Med.	S4M	$6.80	24.8%	$11.93	$3.57	13.0%	$6.47	$4.57	16.6%	$8.17
Hotel	Med.	C2M	$6.72	24.5%	$11.66	$3.48	12.7%	$6.13	$4.48	16.3%	$7.85
Hotel	Lrg.	S2H	$27.79	30.3%	$48.85	$15.89	17.3%	$28.95	$19.99	21.8%	$35.80
Hotel	Lrg.	S1H	$31.29	34.1%	$54.99	$20.63	22.5%	$37.50	$24.30	26.5%	$43.53
Hotel	Lrg.	C1H	$28.14	30.7%	$49.36	$16.27	17.7%	$29.49	$20.36	22.2%	$36.33
Hotel	Lrg.	C2H	$27.21	29.7%	$47.67	$15.07	16.4%	$27.23	$19.25	21.0%	$34.27
Multi-Use	Med.	S2M	$3.21	25.5%	$5.75	$1.78	14.2%	$3.19	$2.23	17.7%	$3.98
Multi-Use	Med.	S4M	$3.12	24.7%	$5.64	$1.65	13.1%	$3.03	$2.11	16.7%	$3.84
Multi-Use	Med.	C2M	$3.07	24.4%	$5.54	$1.60	12.7%	$2.91	$2.06	16.3%	$3.73
Parking Str.	Med.	C2M	$2.75	26.0%	$3.66	$1.42	13.4%	$1.92	$1.84	17.3%	$2.46
Parking Str.	Med.	C1M	$2.96	27.9%	$3.84	$1.70	16.0%	$2.16	$2.09	19.7%	$2.68

Table 6.7 Sensitivity Test Results: Expected Deaths and Total Casualties in Prototypical Buildings (with Mat Foundations) Subject to Ground Shaking & Ground Failure in an IBC Design Level Earthquake-Ground Failure Hazard Zone 5.

				Sensitivity Test #1 (mat foundation 2.5x "stronger")		Sensitivity Test #2 (mat foundation 7.5x "stronger")		Original Assumption (mat foundation 5x "stronger")	
Use	Size	HAZUS Model Bldg. Type	Time of Day for Expected Max. # of Casualties	Max. # Deaths	Total Casualties (Includes Deaths)	Max. # Deaths	Max. # Total Casualties (Includes Deaths)	Max. # Deaths	Max. # Total Casualties (Includes Deaths)
MFR	Sm	W2	Night	0.0	0.3	0.0	0.1	0.0	0.2
MFR	Sm	S2L	Night	0.0	0.4	0.0	0.2	0.0	0.3
MFR	Sm	RM1L	Night	0.0	0.5	0.0	0.2	0.0	0.3
MFR	Med	S2M	Night	0.1	1.6	0.0	0.8	0.0	1.1
MFR	Med	S4M	Night	0.1	1.6	0.0	0.8	0.0	1.1
MFR	Med	C2M	Night	0.1	1.8	0.0	0.8	0.1	1.1
MFR	Lrg	S2H	Night	0.2	6.7	0.1	4.0	0.1	4.9
MFR	Lrg	S1H	Night	0.2	8.2	0.1	5.8	0.1	6.6
MFR	Lrg	C1H	Night	0.3	7.8	0.1	4.8	0.2	5.8
MFR	Lrg	C2H	Night	0.2	7.1	0.1	4.0	0.2	5.1
Office	Sm	W2	Day	0.0	0.6	0.0	0.2	0.0	0.4
Office	Sm	S2L	Day	0.0	0.9	0.0	0.4	0.0	0.6
Office	Sm	RM1L	Day	0.1	1.0	0.0	0.4	0.0	0.6
Office	Med	S2M	Day	0.1	4.1	0.1	2.1	0.1	2.7
Office	Med	S4M	Day	0.1	4.2	0.1	2.2	0.1	2.8
Office	Med	C2M	Day	0.3	4.7	0.1	2.1	0.1	2.9
Office	Lrg	S2H	Day	0.4	15.4	0.2	9.1	0.2	11.3
Office	Lrg	S1H	Day	0.5	18.9	0.3	13.4	0.3	15.3
Office	Lrg	C1H	Day	0.6	17.9	0.3	11.0	0.4	13.4
Office	Lrg	C2H	Day	0.6	16.4	0.3	9.2	0.4	11.7
Hotel	Med	S2M	Night	0.1	4.4	0.1	2.2	0.1	2.9
Hotel	Med	S4M	Night	0.2	4.4	0.1	2.3	0.1	2.9
Hotel	Med	C2M	Night	0.3	5.0	0.1	2.2	0.2	3.1
Hotel	Lrg	S2H	Night	0.4	16.7	0.2	9.9	0.3	12.2
Hotel	Lrg	S1H	Night	0.5	20.4	0.3	14.5	0.4	16.5
Hotel	Lrg	C1H	Night	0.7	19.4	0.4	11.9	0.5	14.5
Hotel	Lrg	C2H	Night	0.6	17.8	0.3	10.0	0.4	12.6
Multi-Use	Med	S2M	Day	0.1	2.1	0.0	1.0	0.0	1.4
Multi-Use	Med	S4M	Day	0.1	2.1	0.0	1.1	0.0	1.4
Multi-Use	Med	C2M	Day	0.1	2.3	0.0	1.0	0.1	1.4
Parking Str.	Med.	C2M	Day	0.0	0.4	0.0	0.2	0.0	0.3
Parking Str.	Med.	C1M	Day	0.0	0.5	0.0	0.2	0.0	0.3

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7 DRAFT ZONING ORDINANCE DEVELOPMENT

This section addresses the development of the Draft Zoning Ordinance. The proposed Draft Zoning Ordinance is located in Appendix A. Assuming shaking and PGD from the design earthquake, HAZUS provides models to estimate life threatening injuries and deaths during the day or night as a function of building damage state for new buildings built in accordance with the current International Building Code. These HAZUS results can be analyzed by "sorting" according to different variables, e.g. number of deaths, number of occupants, loss ratio. Using sorting, it became clear that the structures susceptible to highest numbers of potential life threatening injuries and deaths were the same that experienced the highest economic losses. These losses were a function of building fragility (foundation and superstructure characteristics) in conjunction with size of building and occupancy levels.

The HAZUS analysis resulted in four classifications of vulnerability with a fairly definite split between the Very High Vulnerability, and High Vulnerability categories. Vulnerability refers to a) potentially life threatening injuries and deaths and b) high loss ratio/economic losses.

7.1 Very High Vulnerability

Highest vulnerability to the two key variables (deaths and economic losses) occurred primarily in large buildings with shallow foundations. For example, the highest total number of deaths occurs in the Large Hotel, C1H structural system on a shallow foundation with night-time occupancies exceeding 1,000 people. The "best" Very High Vulnerability structures have approximately ten times as many fatalities (0.65/building) as the "worst" Low Vulnerability buildings (0.06/building). The economic Loss Ratio (which includes contents and lost revenue) can approach 50 percent, while the low vulnerabilities can be as low as 4 percent to 6 percent. Eight buildings have been designated as "Very High Vulnerability". There are no Very High Vulnerability buildings in Hazard Zones 4, 3, or 2.

7.2 High Vulnerability

The difference between the buildings rated High Vulnerability as opposed to Very High Vulnerability are primarily those that are built with mat foundations and/or with steel frame. Examples of High Vulnerability buildings are large hotels and offices. The loss ratio of High Vulnerability buildings typically is in the low to mid 20 percent range; although one mid-rise multi use building is an estimated 42 percent. There are High Vulnerability buildings in Hazard Zones 5 and 4, but none in Zones 3 and 2.

7.3 Moderate Vulnerability and Low Vulnerability

Buildings in Zone 5 that have estimated fatalities of less than 23 percent with estimated Loss Ratios ranging from 14 to 45 percent are in the Moderate Vulnerability and Low Vulnerability categories. All small buildings fall into these categories. Many medium size structures also fall into these categories, albeit with a variety of mitigating characteristics. Because of the comparatively few fatalities for such structures located in the area with highest risk from seismically-induced ground failure, no specific development standards are being proposed for the Moderate and Low Vulnerability structures.

Regulations proposed for the overlay are intended to minimize development with characteristics of Very High Vulnerability and High Vulnerability. Since the Very High and High Vulnerability structure and occupancy types do not occur in Zones 3 and 2, it was determined that the Overlay provisions would not apply to those zones; they will only apply to Zones 4 and 5.

The Overlay provisions were taken directly from the recommendations presented in Section 6.4. The Very and High Vulnerability building categories are shown in Tables 6.1 and 6.2 for Hazard Zone 5 and 4 respectively.

8 REFERENCES:

ATC (1985) “Earthquake Damage Evaluation Data for California, ATC-13”, prepared by the Applied Technology Council, Redwood City, California.

ATC (2009), “Guidelines for Seismic Performance Assessment of Buildings, ATC-58 50% Draft” prepared by the Applied Technology Council, Redwood City, California, for the U.S. Department of Homeland Security (DHS), Federal Emergency Management Agency.

Boulanger, R. W., and Idriss, I.M. (2004), "Evaluating the Potential for Liquefaction of Cyclic Failure of Silts and Clays", Center for Geotechnical Modeling, Dept. of Civil & Environmental Engineering, University of California Davis.

Bray, J. and Travasarou, T. (2007). “Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements” ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 133(4), p. 381-392.

DHS/FEMA (2003), “HAZUS-MH MR3 Technical Manual, Multi-hazard Loss Estimation Methodology, Earthquake Model”, Developed by the Department of Homeland Security, Emergency Preparedness and Response Directorate, Federal Emergency Management Agency, Mitigation Division, Washington, D.C.

Hansen, W. R. (1965). "Effects of the Earthquake of March 27, 1964 at Anchorage, Alaska", The Alaska Earthquake, March 27, 1964, Effects on Communities, USGS Professional Paper.

Harding-Lawson Associates (1979) “Seismically-Induced Ground Failure Susceptibility”, Geotechnical Report for Municipality of Anchorage, Alaska.

Idriss, I.M. (1985). "Evaluating seismic risk in engineering practice," Proc., 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Balkema, Rotterdam, p. 265-320.

International Building Code (2006).

Jibson, R., and Michael, J. (2008), “Maps Showing Seismic landslide Hazards in Anchorage, Alaska” USGS Report.

Long, E. L. (1973), "Earth Slides and Related Phenomena," The Great Alaska Earthquake of 1964, National Academy of Science, 644-773.

Means (2009), “R.S. Means Square Foot Costs”, 30th Annual Edition, Kingston, Massachusetts.

Mitchell, J. K., Houston, W. N., Yamane, G (1973), "Sensitivity and Geotechnical Properties of Bootlegger Cove Clay", The Great Alaska Earthquake of 1964, Committee on the Alaska Earthquake of the Division of earth Sciences, National Research Council.

Moriwaki, Y., Vicente, E. E., Lai, S. S., Moses, T. L. (1985), "A Re-evaluation of the 1964 "L" Street Slide, State of Alaska, Department of Transportation and Public Facilities.

Moriwaki, Y., Vicente, E. E., Lai, S. S., Moses, T. L. (1985), "A Re-evaluation of the 1964 "L" Street Slide, State of Alaska, Department of Transportation and Public Facilities.

Newmark, N. (1965), “Effects of earthquakes on dams and embankments,” Geotechnique, Vol. 15, No. 2, p. 139-160.

Shannon & Wilson (1964), “Anchorage Area Soil Studies,” U.S. Army Engineer District, Alaska, Corps of Engineers

Shannon & Wilson (1965), “Remolding of Bootlegger Cove Clay with Explosives,” U.S. Army Engineer District, Alaska, Corps of Engineers

Shannon & Wilson (1989) “Geotechnical Report, Turnagain N.E. Landslide Re-evaluation, Anchorage, Alaska” Municipality of Anchorage.

Shannon and Wilson (1995), Final Geotechnical Report, Northwest Turnagain Landslide, Stability Evaluation, Anchorage Alaska.

Shewbridge, S.E. (1996), “Yield Acceleration of Lined Landfills”, ASCE Journal of Geotechnical Engineering, Vol. 122 (2), p. 156-158.

Stark, T. D., and Contreras, I.A. (1998), "Fourth Avenue Landslide During 1964 Earthquake”, ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 124, p. 99-109.

Woodward-Clyde (1982), Anchorage Office Complex, Geotechnical Investigation, Anchorage, Alaska.

Woodward-Clyde (1987), Geotechnical Investigation, Anchorage Courthouse addition, Anchorage, Alaska.

Yasuhara, K., Murakami, S., and Hyde, A.F.L. (2004) “Post-cyclic degradation of saturated plasticity silts,” Cyclic behaviour of soils and liquefaction phenomena: Proceedings of the International Conference on Cyclic Behaviour of Soils and Liquefaction Phenomena, 31 March-02 April 2004, Bochum, Germany

APPENDICES:

- Appendix A – Ground Failure Susceptibility Hazard Overlay District
- Appendix B – Task 1, Technical Memorandum Earthquake Scenario
- Appendix C – Task 2, Technical Memorandum Prototypical Buildings
- Appendix D – Task 5.1, Technical Memorandum Seismic Displacements
- Appendix E –Tasks 5 and 6, Technical Memorandum Loss Modeling

Appendix A

Ground Failure Susceptibility Hazard Overlay District

DOWNTOWN ANCHORAGE GROUND FAILURE SEISMIC HAZARD OVERLAY

INTENT AND PURPOSE

Overlay districts are established to accomplish Municipality policy objectives for specific areas such as those prone to specific hazards. The purpose of the Ground Displacement Seismic Hazard Overlay District is to minimize exposure to the effects of seismically induced ground failure, foster seismically resistant development, and minimize economic losses to the community from seismically induced ground failure in Downtown Anchorage. Provisions of this Overlay are intended provide for and promote safety of the general public in the event of earthquake induced ground failure. Such intentions are designed to minimize risks of life loss as well as property and economic losses.

APPLICATION

A. Boundaries

The Seismic Hazard Ground Failure Overlay applies to sites designated Zone 4 or Zone 5 within the Ground Failure Susceptibility area as delineated by Harding Lawson and adopted by the Anchorage Municipality.[1]

B. Compliance

All new construction in seismically induced ground failure zones 4 and 5 shall meet design and construction requirements of the adopted Municipal Building Code. Geotechnical reports and structural designs shall show how structures will resist, without collapse, forces and ground displacement from anticipated grabens and/or pressure ridges. Development Standards will subsequently be imposed on all sites that exhibit characteristics of Zone 5 susceptibility.

All Geotechnical Reports will be reviewed by the Geotechnical Advisory Committee and the Department of Development Services.

C. Requirements

Uses and structure requirements will be permitted in accordance with underlying provisions of Title 21. The *Ground Failure Susceptibility Hazard Overlay* is a supplement to the basic land use district and shall be applied in a uniform manner to all properties within the district. In cases of conflict between requirements of the underlying district and the stricter previsions of the overlay-the overly will prevail.

[1] Anchorage Downtown Comprehensive Plan Adopted December 11, 2007 Assembly Ordinance 2007-113 (pg. 41)

PROHIBITED USES

Uses in Zone 5 will be prohibited that are typically associated with high-density, hazardous effects, and/or occupancies that may generate higher demand for emergency response resources. They include:

A. Emergency Service Providers and Critical Facilities

- fire, police and emergency communication systems
- hospitals and other emergency medical facilities,
- ambulance services
- power plant and utility substations,
- sewage treatment plants, water works

B. Occupancies generating potentially high demand for emergency response resources

- adult care facility,
- *assisted living facilities (9 or more residents)*
- *long-term care*
- *childcare and pre-school facility, schools (college, high, elementary)*
- *correctional facilities including but not limited to jail, and community residential center*
- *uses that manufacture, handle or store hazardous or explosive materials including*
- *fueling stations*

C. Very High and High Vulnerability Buildings in Hazard Zone 5 (see Risk Assessment Report Table 6.1): prohibit the following HAZUS Model Building types:

i. Large Offices, (280,000 s.f.) – all foundations
ii. Large Hotels (450,000 (s.f) – all foundations
iii. Concrete Moment Frame High-rise (C1H) or Concrete Sheer Walls High-rise (C2H) Large Multi Family Residential, (145,000 s.f.) on shallow foundations
iv. Concrete Shear Walls Medium rise (C2M) on shallow foundations
    a. Medium size Hotels (135,000 s.f.)
    b. Medium size Offices (80,000 s.f.)
    c. Medium Multi Family Residential, (40,000 s.f.)
    d. Multi Use (60,000 s.f.)

D. High Vulnerability buildings in Hazard Zones 4 (see Risk Assessment Report Table 6.2) prohibit the following HAZUS Model Building types of buildings on shallow foundations:

i. Concrete Moment Frame High-rise (C1H) or Concrete Sheer Walls High-rise (C2H) Large Offices or Large Hotels.

Development Standards

A. Type of Foundation

New development in ground failure zone 5 will be required to use a mat foundation or similarly performing foundation approved by the Building Official.

B. Site Plan Review

All developments on sites meeting Zone 5 criteria will be subject to Administrative Site Plan Review including but not necessarily limited to the items in this section.

1. Density and Occupancy

Total day and night time occupancy will be identified for each use within a development with a maximum total not to exceed 400 occupants on small and medium lots; occupancy levels applied to large lots will be based on FAR but are expected not to exceed 500. Allowable densities assume: Lot coverage: 50%, and Floor efficiency: 85% efficiency (15% for stairways elevators, HVAC, etc). Under site plan review provisions medium and large sites over 30,000 s.f. could be eligible to modify setbacks to achieve a comparable FAR with smaller sites. Sites will be eligible for mixed use as a means to reduce 24-hour occupancies.

Table 1: Density*

Building	Lot Size Sq. Ft. (1000)	Building Sq. Ft. (1000) Estimated units	Max stories**	Estimated Floor Area Ratio (FAR)
Small	10		3	**1.5**
Medium	20		5	**3**
Estimated S.F. (net)		50 (42.5)		
Large	30		5	**3**
Estimated S.F. (net)		75 (63.8)		

*Number of estimated persons depends on unit size and number of bedrooms however total population estimates assume MFR 1-2.2 persons per unit; Hotel 1.5 persons per room, Office 200-250 s.f. per person; retail/commercial: 6/1000

**Heights will be restricted to 5 stories; or 60 feet as measured from average grade on sites meeting the criteria of Zone 5.

2. Emergency Response

Impacts will be assessed on public services, including emergency response to minimize access disruption/ maximize search and rescue, debris removal, EMS, haz-mat response water supply, fire and police protection, wastewater disposal, storm water disposal, and related services.

3. Circulation/Safety

Impacts will be assessed on the transportation system and needs of emergency responders, including but not limited to existing and/or planned street designations and improvements, street capacity, access to collectors or arterials, connectivity, and debris removal. Design to consider pedestrian and vehicular traffic circulation and safety including from falling debris.

4. Consistency

Consistency with other elements of the Comprehensive plan will be assessed, e.g. Viewshed Diagram to Cook Inlet & Alaska Range and View to Mt. McKinley, large sidewalks to catch debris and/or enhance pedestrian facilities, and other sections as relevant.

C. Mitigation of Adverse Impacts

Conditioning may result if projected impacts are determined to be substantially greater than currently allowed; any significant adverse impacts anticipated to result from the use should be mitigated or offset to the maximum extent feasible.

ADMINISTRATION

A. Split Lots

- ***Development of lots split into two or more Ground Failure Susceptibility Classifications***
  If a lot within the Overlay District is split by two or more Ground Failure Susceptibility classifications, each portion of the lot shall be regulated by the development standards applicable to that portion.

- ***When development is partly out of designated Ground Failure Susceptibility Overlay***
  The use and development standards of this Overlay apply only to that part of the development that occurs within the boundaries of the Overlay.

B. Nonconforming Uses

A structure or the use of a structure or premises located within the Overlay District that was lawful before passage of the Overlay in conformity with the provisions of such regulations, may be continued subject to existing Title 21 provisions.

Any permitted alteration, addition, or repair to any nonconforming structure the cost of which equals or exceeds 50 percent of the fair market value of the structure which would result in substantially increasing the damage potential and/or life threatening injuries and/or fatalities shall be adequately retrofitted in accordance with guidelines to be developed by the Municipality

***C.* Standards and Conditions for Variances and Appeals**

In passing upon variances or appeals, the zoning board of examiners and appeals shall consider all technical evaluations, all relevant factors, standards specified in other sections and:

a. The danger to life and property due to ground failure damage including that debris materials may be swept onto other lands to the injury of others;
b. The susceptibility to damage from ground failure of the proposed facility and its contents to damage and the effect of such damage on the individual owner;
c. The importance of the services provided by the proposed facility to the community;
d. The necessity of the facility in a Zone 5 downtown location, where applicable;
e. The availability of alternative locations for the proposed use which are not subject to damage from seismically induced ground failure;
f. The continuing safety of access to the property for ordinary and emergency vehicles; and
g. The costs of providing governmental services during and after seismically induced ground failure, including maintenance and repair of public utilities and facilities such as sewer, gas, electrical and water systems and streets and bridges.

Appendix B

Task 1, Technical Memorandum Earthquake Scenario

1915 63rd St. NE
Tacoma, WA 98422
206-226-7496

Memorandum

Date: December 29, 2010

To: David Tremont, Municipality of Anchorage Planning Department

From: Donald Ballantyne, MMI Engineering

Subject: Downtown Anchorage Seismic Risk Assessment –
Task 1, Proposed Earthquake Scenario

This memorandum describes the scenario proposed for use in the Downtown Anchorage Seismic Risk Assessment. A scenario consistent with International Building Code (IBC) design ground motions is proposed. The IBC requires buildings to be designed to two-thirds of the probabilistic ground motion that has a 2 percent chance of occurring in 50 years (2,500 year return period).

The USGS (2002) 2,500-year probabilistic ground motion for the Anchorage area is 66.3 percent of gravity. This ground motion is located on Class B (firm) soils). Two-thirds of this ground motion is 44.2 percent of gravity. This lies between the USGS probabilistic ground motions for a 750-year return earthquake (45.9 percent g) and a 500-year return earthquake (38 percent of gravity). It is noted that the 1964 Alaska Earthquake is estimated to have a return period of about 700 years, so the proposed scenario is consistent with the 1964 Alaska Earthquake.

The most significant source zones that contribute to the probabilistic ground motion are the Subduction Fault that caused the 1964 event (Pacific Plate moving under the North American Plate), and the Castle Mountain Fault. The earthquake scenario is intended to show the result of catastrophic soil failure similar to that which occurred in 1964, so it is important to select an event where that ground movement will occur.

The area is underlain by a 200-foot thick layer of Bootlegger Clay. This clay layer impacts earthquake hazards in two ways: 1) it fails structurally resulting in the soil layers it supports moving down gradient, and 2) it deamplifies the ground motion introduced at its interface with the till layer below. The entire study area is underlain by this formation, so the entire area is subject to the deamplification. The varying degrees of ground deformation are dependent on the soil's lateral restraint, so the areas closer to the water with less confinement are expected to move more (e.g. Hazard Zone 5).

Failure of the Bootlegger Clay formation that results in the catastrophic ground deformation is a function of both ground shaking intensity and duration of shaking (number of cycles). A Subduction Fault earthquake will result in an extended duration of shaking, five minutes or more as occurred in 1964. It is not clear that a Castle Mountain Fault event would have the shaking duration that would result in failure of the Bootlegger Clay formation. Therefore, the scenario is based on a Subduction Fault Event.

Surface ground motions in the scenario are expected to be on the order of 20 percent of gravity, similar to the 1964 event. This is the result of deamplification occurring in the Bootlegger Clay formation. That is, the 44.2 percent ground motion would be input into the base of the 200-foot thick Bootlegger Clay formation. The clay material is too weak to transfer all of the energy upward to the surface. The attached USGS Shake-Map shows the expected ground accelerations in the region for the 1964 event. There is some belief that even if the area was subjected to larger ground motions (such as the 66.3 percent 2,500-year return earthquake ground motion), the surface ground motion would not increase over the 20 percent of gravity.

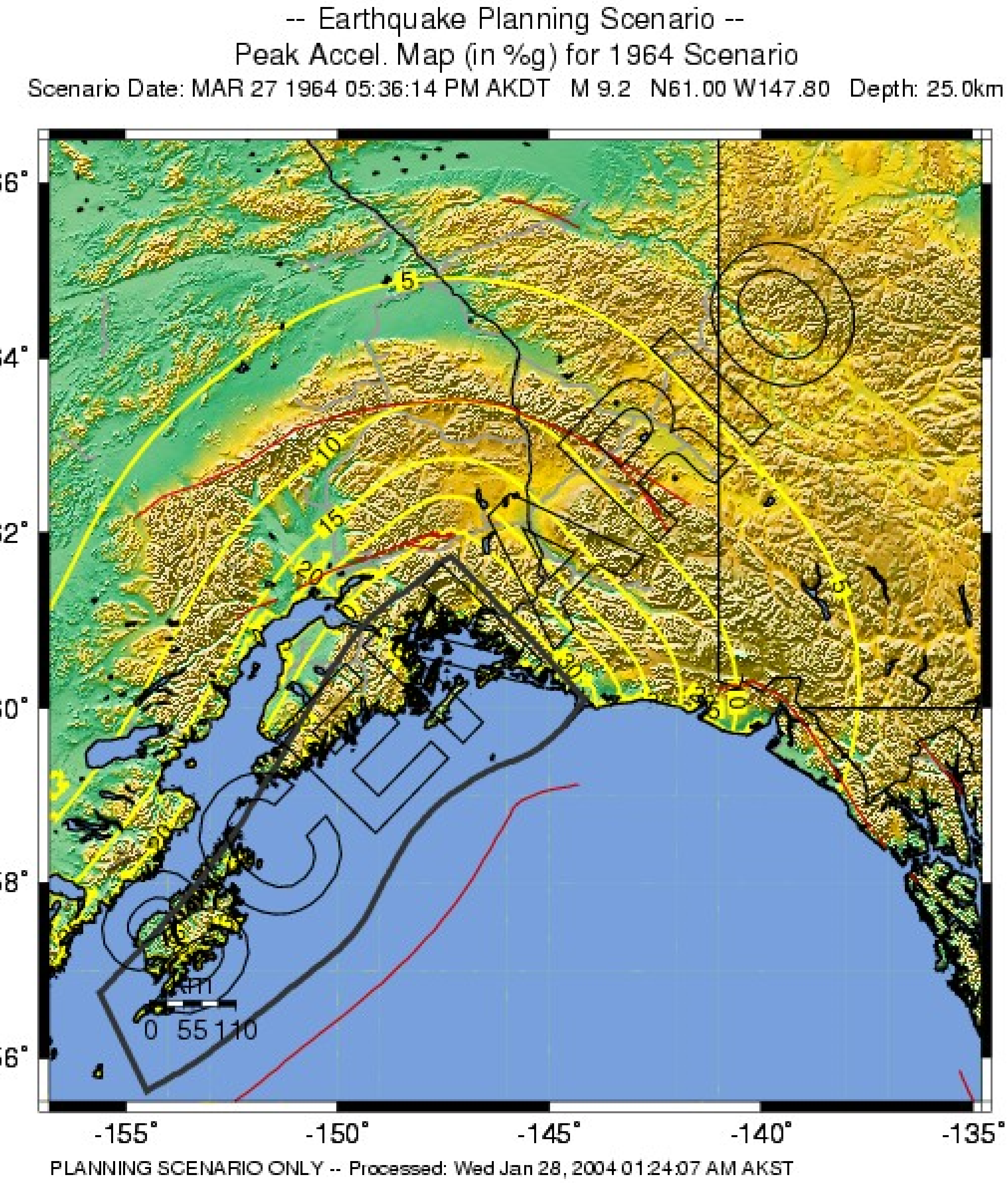

Figure 1. Scenario Shake Map (from the USGS)

Appendix C

Task 2, Technical Memorandum Prototypical Buildings

1915 63rd St. NE
Tacoma, WA 98422
206-226-7496

Memorandum

Date: December 29, 2010

To: David Tremont, Municipality of Anchorage Planning Department

From: Donald Ballantyne, MMI Engineering

Subject: Downtown Anchorage Seismic Risk Assessment –
Task 2, Proposed Prototypical Buildings

This memorandum identifies prototypical buildings that are proposed for use in evaluation of the downtown Anchorage seismic risk. These prototypical buildings were selected based on review of the Anchorage Downtown Comprehensive Plan. A list of ten prototypical buildings is shown in Table 1

The Occupancy Categories in Table 1 are derived from the Anchorage Downtown Comprehensive Plan. The Occupancy Description/Size and HAZUS Occupancy Class are derived from HAZUS (see Tables 3.1 and 3.2 from the HAZUS Technical Manual, attached).

Each of the ten prototypical buildings will be evaluated estimating casualties and damage, with two possible foundation types and three possible structural systems (for a total of 60 [10 x 3 x 2]) for each of the 5 hazard zones.

Analysis is currently underway to identify the likely foundation types that would be used for the various categories of prototypical buildings. It is understood that these will generally include distributed foundations and matt foundations. Deep foundations projecting into the Bootlegger clays are generally not used in Anchorage.

Analysis is currently underway to identify the likely structural system types that would be used for the various categories of prototypical buildings. Table 3.1 from HAZUS (attached) shows the possible structural systems.

The ten prototypical building types, each with three possible structural systems, will be evaluated in HAZUS to estimate losses due to shaking.

The ten prototypical building types, each with two possible foundations types and three possible structural systems, will be evaluated outside of HAZUS using a spreadsheet model to estimate losses due to permanent ground deformation. Families of fragilities will be developed for each of these prototypical buildings, foundations types, and building structural systems that will be used in that model.

Table 1. Proposed Prototypical Buildings

No.	Occupancy Category	Occupancy Description/ Size	HAZUS Occupancy Class	Example R.S. Means Model Description (Means Model Number)
1	Multi-family Residential (small)	Low-Rise (1-3 stories)	RES3D (MFR - 10-19 units)	Apt., 1-3 stories, 12,000 SF (M.010)
2	Multi-family Residential (medium)	Mid-Rise (4-7 stories)	RES3E (MFR, 20-49 units)	Apt., 4-7 stories, 40,000 SF (M.020)
3	Multi-family Residential (large)	High-rise (8+ stories)	RES3F (MFR, 50+ units)	Apt., 8-24 stories, 145,000SF (M.030)
4	Offices (small)	Low rise (1-3 stories)	COM4 (Office)	Office, 2-4 stories, 20,000 SF (M.460)
5	Offices (medium)	Mid-rise (4-7 stories)	COM4 (Office)	Office, 5-10 stories, 80,000 SF (M.470)
6	Offices (large)	High-rise (8+ stories)	COM4 (Office)	Office, 11-20 stories, 260,000 SF (M.480)
7	Hotel (medium)	Mid-rise (4-7 stories)	RES4 (Hotel/Motel)	Hotel, 4-7 stories, 135,000 SF (M.350)
8	Hotel (large)	High-rise (8+ stories)	RES4 (Hotel/Motel)	Hotel, 8-24 Stories 450,000 SF (M.360)
9	Multi-use (medium)	Mid-rise (4-7 stories)	COM1/COM4/RES3	Assumed to be 6 stories, 60,000 SF. 1st floor = Store/retail, 2nd & 3rd floor = Offices; 4th floor & above = Apartments
10	Parking Structure	Mid-rise (4-7 stories)	COM10	Garage, Pkg, 5 st., 145,000 SF (M.270)

Table 3.1: Building Structure (Model Building) Types
(from HAZUS Technical Manual)

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1 2	W1 W2	**Wood, Light Frame (≤ 5,000 sq. ft.)** **Wood, Commercial and Industrial (> 5,000 sq. ft.)**		1 - 2 All	1 2	14 24
3 4 5	S1L S1M S1H	**Steel Moment Frame**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
6 7 8	S2L S2M S2H	**Steel Braced Frame**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
9	S3	**Steel Light Frame**		All	1	15
10 11 12	S4L S4M S4H	**Steel Frame with Cast-in-Place Concrete Shear Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
13 14 15	S5L S5M S5H	**Steel Frame with Unreinforced Masonry Infill Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
16 17 18	C1L C1M C1H	**Concrete Moment Frame**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
19 20 21	C2L C2M C2H	**Concrete Shear Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
22 23 24	C3L C3M C3H	**Concrete Frame with Unreinforced Masonry Infill Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
25	PC1	**Precast Concrete Tilt-Up Walls**		All	1	15
26 27 28	PC2L PC2M PC2H	**Precast Concrete Frames with Concrete Shear Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
29 30	RM1L RM2M	**Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms**	Low-Rise Mid-Rise	1-3 4+	2 5	20 50
31 32 33	RM2L RM2M RM2H	**Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
34 35	URML URM M	**Unreinforced Masonry Bearing Walls**	Low-Rise Mid-Rise	1 - 2 3+	1 3	15 35
36	MH	**Mobile Homes**		All	1	10

Table 3.2: Building Occupancy Classes
(from HAZUS Technical Manual)

Label	Occupancy Class	Example Descriptions
	Residential	
RES1	Single Family Dwelling	House
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium
RES4	Temporary Lodging	Hotel/Motel
RES5	Institutional Dormitory	Group Housing (military, college), Jails
RES6	Nursing Home	
	Commercial	
COM1	Retail Trade	Store
COM2	Wholesale Trade	Warehouse
COM3	Personal and Repair Services	Service Station/Shop
COM4	Professional/Technical Services	Offices
COM5	Banks	
COM6	Hospital	
COM7	Medical Office/Clinic	
COM8	Entertainment & Recreation	Restaurants/Bars
COM9	Theaters	Theaters
COM10	Parking	Garages
	Industrial	
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/Drugs/Chemicals	Factory
IND4	Metals/Minerals Processing	Factory
IND5	High Technology	Factory
IND6	Construction	Office
	Agriculture	
AGR1	Agriculture	
	Religion/Non/Profit	
REL1	Church/Non-Profit	
	Government	
GOV1	General Services	Office
GOV2	Emergency Response	Police/Fire Station/EOC
	Education	
EDU1	Grade Schools	
EDU2	Colleges/Universities	Does not include group housing

Appendix D

Task 5.1, Technical Memorandum Seismic Displacements

Geosyntec consultants

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29 December 2010

Mr. Don Ballantyne
Project Manager
MMI Engineering
33530 1st Avenue South, Suite 102
Federal Way, WA 98003

Subject: Seismic Displacements for the Proposal for Professional Service to Complete a Downtown Anchorage Seismic Risk Assessment and Land Use Regulations to Mitigate Seismic Risk for Municipality of Anchorage

Dear Mr. Ballantyne:

The characterization of the magnitude and type of potential ground movement during major earthquakes in each of the four local ground failure hazard zones and its resulting impact on buildings and lifelines is an integral part of the seismic risk assessment for the Anchorage downtown area. This memorandum describes the proposed levels of potential seismic displacement for use in the Downtown Anchorage Risk Assessment. Using a scenario consistent with the International Building Code 2006 (IBC) design ground motions and the strength of materials derived from numerous sources, the probable range of seismic displacements have been developed.

With a sound understanding of the amount and type of ground movement possible, the structural engineers of this team can provide structural detail guidelines required for foundations and structural frames to establish minimum design standards for use in the development area.

DEFINITION AND DELINEATION OF SLOPES

The study area has been divided into five categories (zones) based on seismic risk as outlined in the 1979 Harding Lawson study:

- Zone 5 - Very-high – Areas of previous seismically-induced landslides. Includes zones of tension cracks above the head wall scarp, toe bulge, and pressure ridge areas. Although portions of these previous slides may remain relatively undisturbed from future strong shaking, these slides will be the more likely site of future seismically induced sliding.

- Zone 4 - High – Fine-grained, surficial and subsurface deposits within the vicinity of steep slopes, includes area above and below the slope. Highly susceptible to all types of seismically-induced ground failure, including liquefaction, translational sliding, lurching, land spreading, cracking, and subsidence.

- Zone 3 - Moderate – Fine-grained surficial and subsurface deposits, including the Bootlegger Cove Clay and other silt, clay and peat deposits. May experience ground cracking and horizontal ground movement due to land spreading or lurching, and subsidence due to consolidation.

- Zone 2 - Moderate-Low – Mixed coarse and fine-grained glacial deposits in lowland areas, thick deposits of channel, terrace, flood plain and fan alluvium. May have very low susceptibility; may experience minor ground cracking, localized settlement due to consolidation, and perhaps liquefaction or lurching of localized saturated zones of fine-grained material.

- Zone 1 - Lowest – Includes exposed bedrock, thin alluvium and colluvium over bedrock. May experience minor ground cracking and acceleration of normal mass wasting process in unconsolidated material such as rock falls and snow avalanches.

The existing topography was provided by the Planning Department of the Municipality of Anchorage and was input into a Geographic Information System (GIS). The downtown area was then layered with the seismic zones described above. Four foot contours of the topography were used to describe slope geometries throughout the study area.

Twenty cross sections were drawn in the study area to characterize a representative range of the slopes found within each zone. An overlay of the study area with seismic zones and cross section lines is provided below in Figure 1 and in Appendix B.

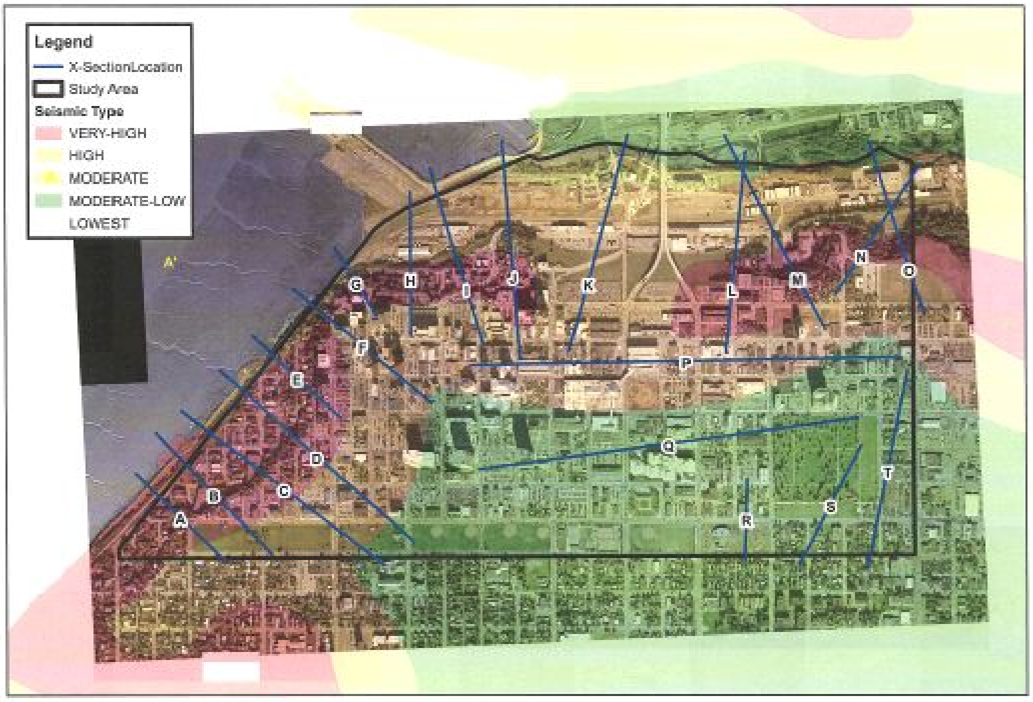

Figure 1. Overlay of Downtown Anchorage with Seismic Zones and Cross-Sectional Lines

Each of the twenty cross sections was studied and 61 slopes within these cross sections were analyzed. The number of slopes analyzed within each of the zones was:

- Zone 5: 40 slopes
- Zone 4: 15 slopes
- Zone 3: 1 slope
- Zone 2: 5 slopes

As suggested in the descriptions of the zones above, Zones 4 and 5 are expected to produce the greatest number of slopes with large seismically-induced permanent displacements. These two zones also have the highest concentration of slopes within their boundaries. Zone 3 has only small acreage within the study area and is located in a flat plain. For this reason, only one slope was analyzed. Zone 2 is relativity flat with small undulating hills.

ANTICIPATED SLOPE DISPLACEMENTS DUE TO SEISMIC SHAKING

In this study, the potential seismic displacement for each slope was estimated using the Bray and Travasarou (2007) simplified seismic slope displacement procedure. This procedure requires as input the slope geometry and soil properties to estimate the slope's characteristic dynamic resistance (i.e., its yield coefficient) and its dynamic response characteristics (i.e., the potential sliding block's fundamental period). The seismic demand was defined using the International Building Code (2006) for the likely level of earthquake shaking. The details of this analysis are described in Appendix A.

In many of the cross sections, multiple steep slopes that could produce shallow landslides existed within the mass of a potentially large translational slide. Given this complexity, all slopes, both shallow and translational, were independently evaluated to calculate anticipated displacements. Histograms of all calculated seismic slope displacements are in Appendix A.

For each cross section, if the seismic displacements for the large translational slides were greater than the anticipated seismic displacements for the shallow slides located within the larger slide mass, the displacements for the larger slide were utilized in the subsequent analysis. The smaller slopes on the slide mass were assumed to essentially "go along for the ride." Alternatively, if the large translational slide does not mobilize, it is probable that the shallower landslides will dominate the seismic displacements, and the shallower slides were thus utilized.

The slopes and their calculated seismic displacements were then placed on the Harding Lawson maps. Using engineering judgment, the plan view square footage for the potential displacements were calculated for each seismic region. The results of the seismic slope displacement analyses are presented in Figure 2 and Figure 3. The results are categorized by seismic zone in Figure 2 and by ranges of the calculated seismic displacement in Figure 3.

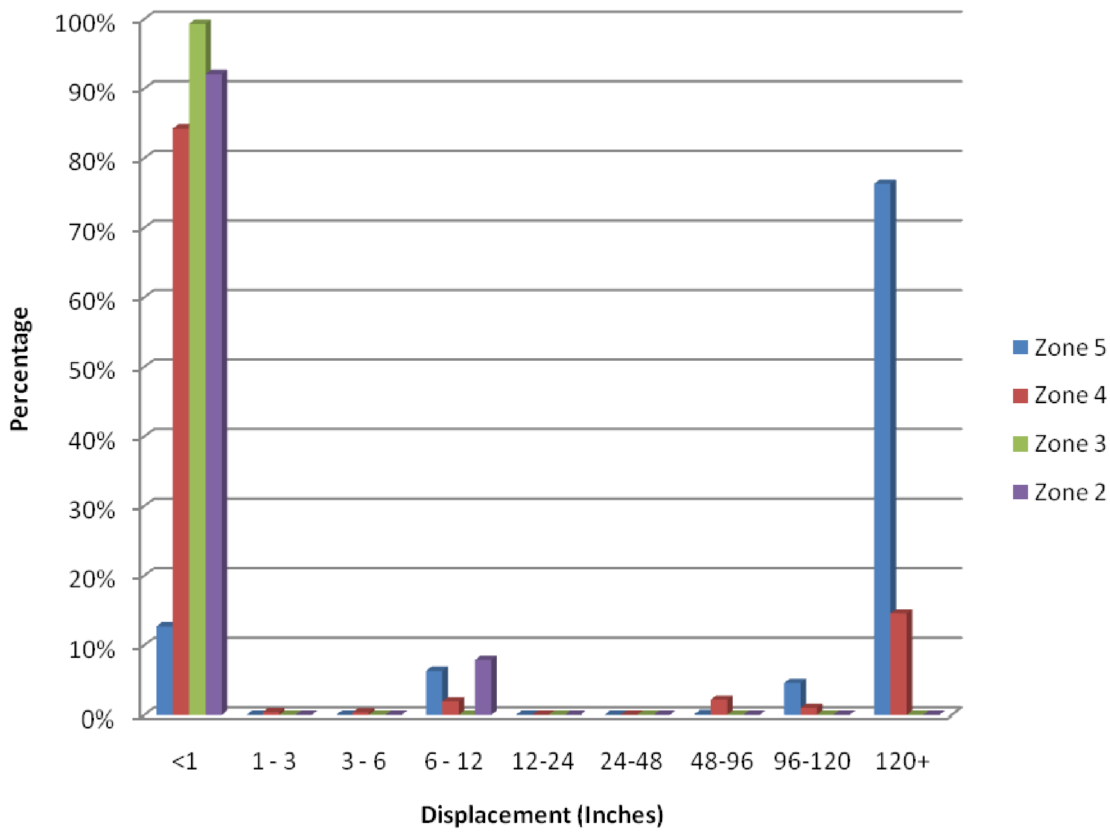

Figure 2. Displacements by Percentage of Area by Zone

Zone 5 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. These large, translational slides are typically through the Bootlegger Cove Clay. Shallower slopes, mainly comprised of 30 to 50 feet of sands and gravels, are expected to "go along for the ride" within the larger sliding mass. However, there are areas within Zone 5 which may have 6 to 12 inches or less displacement, or even negligible estimated seismic displacement. This suggests that some refinement of the generalized seismic zonation of the 1979 Harding Lawson maps may be possible.

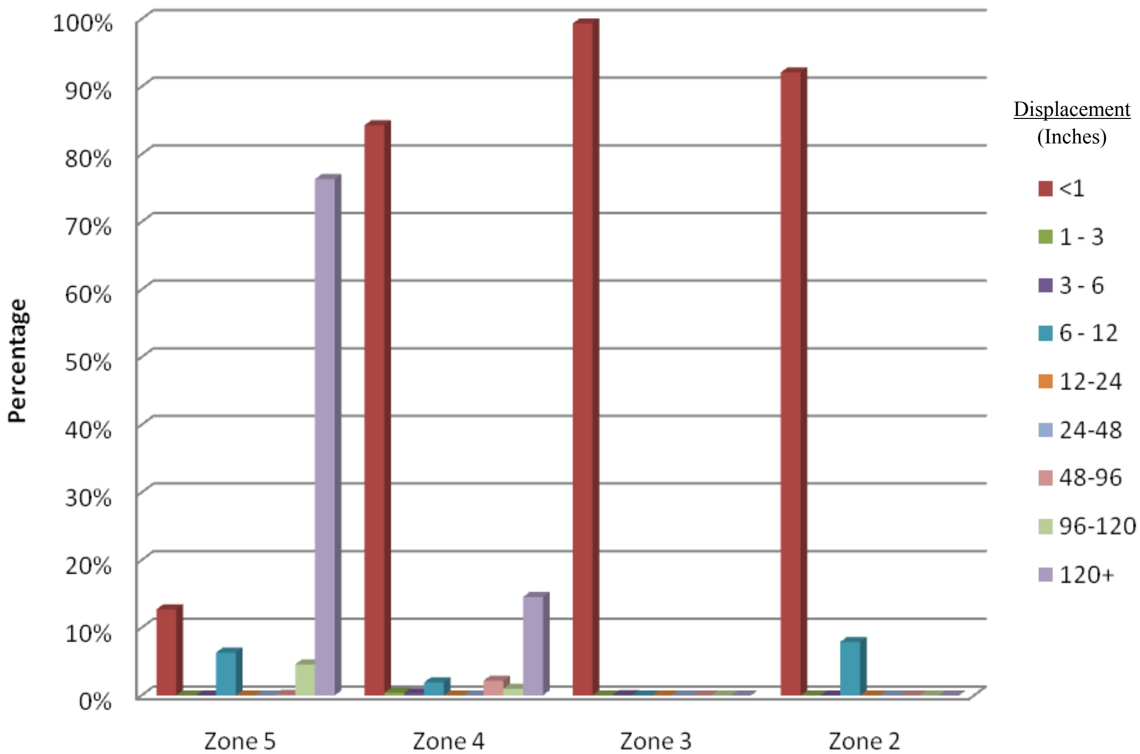

Figure 3. Displacements by Percentage of Area within each Zone

Zone 4 has the largest square footage in comparison to the other zones. Results for Zone 4 show that calculated seismic displacements can be large with almost 20% of the region possibly displacing more than four feet for the design earthquake scenario. These slides are large, translational slides within the Bootlegger Cove Clay and are without a toe berm or pressure ridge. Shallower potential slope failures comprised of the sands and gravels within the larger sliding mass are expected to "go along for the ride" within the larger sliding mass.. Approximately 3% of Zone 4 will likely displace between 6 and 12 inches for the design event. These areas are generally directly behind Zone 5. A movement of about 6 inches is commensurate with observations of movement behind the scarps from the 1964 earthquake (Long, 1973; Hansen, 1965). However, a considerable percentage of the Zone 4 is more stable within areas significantly behind Zone 5 or within the areas of the toe berm/pressure ridge.

Zone 3 has only one gentle slope within the study area. It is anticipated that this slope will displace less than 1 inch during the design event. Additionally, this shallow slide is less than 1% of the plan area of Zone 3 within the study area. Thus, Zone 3 does not present a significant seismic slope displacement hazard within the study area.

Zone 2 is characterized by large square footage and does not contain significant open faces or steep slopes. The relatively few slopes in this area are moderate and may move on the order of 6 to 12 inches during the design event. These slopes represent less than 10% of the land mass of Zone 2 within the study area.

The orientations of the calculated seismic displacements are aligned roughly with the slope topography. Gentle slopes that displace on a horizontal base sliding plane will displace largely horizontally. Steep slopes on inclined base sliding planes may displace vertically as much as they displace horizontally. Intermediate cases will include both horizontal and vertical components of displacement.

In addition to using slope topography to estimate the likely orientation of the calculated seismic displacement vector, observations of slope movements in the study area during the 1964 Alaska earthquake were considered. For example, the L Street Slide moved 14 feet horizontally and 10 feet vertically (about a 1.5H:1V ratio). The 4th Avenue slide moved between 19 feet to 11 feet horizontally and 10 feet vertically, or approximately a 2H:1V to 1H:1V ratio of displacements. Based on a comparison with existing topography and these observations of past performance, these relationships may provide some insight into potential relative amounts of horizontal and vertical movements within each zone:

- Zone 5 with an open face: 1.5H : 1V
- Zone 4 with an open face: 1.5H : 1V
- Zone 4 without an open face: 3H : 1V
- Zone 3: primarily horizontal movement with minor vertical movement
- Zone 2: primarily horizontal movement with minor vertical movement

CLOSURE

This study was performed to provide a generalized index of the potential seismic displacements of the various slopes in the study region under the design seismic event. The resulting displacement estimates are provided for the development of general design guidelines and common structural details for foundations and building frames so that a consistent response to these hazards can be developed. Results indicate there is a significant potential for reoccurrence of large ground movements in Downtown Anchorage as a result of another major earthquake.

This work is based on generalized soil profiles and simplified analysis methods. Furthermore, this study does not include displacements along the fringe of the study area, such as the area near the coastline, since the underwater topography is unknown. The estimated displacements should not be considered a replacement for site specific evaluations for any projects within the study area.

This report was prepared in accordance with general standards of engineering practice. Geosyntec is not responsible for the use of the data or conclusions presented in this report for any purposes other than those specifically expressed herein. If you have any questions regarding this report or require any additional information, please do not hesitate to contact the undersigned at (510) 836-3034.

Sincerely,

Jennifer L. Donahue, Ph.D., P.E.
Project Engineer

Jonathan D. Bray, Ph.D., P.E.
Adjunct Senior Consultant

BIBLIOGRAPHY

Boulanger, R. W., and Idriss, I.M. (2004), "Evaluating the Potential for Liquefaction of Cyclic Failure of Silts and Clays", Center for Geotechnical Modeling, Dept. of Civil & Environmental Engineering, University of California Davis.

Bray, J. and Travasarou, T. (2007). "Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements" ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 133(4), p. 381-392.

Harding-Lawson Associates (1979) "Seismically-Induced Ground Failure Susceptibility", Geotechnical Report for Municipality of Anchorage, Alaska.

Hansen, W. R. (1965). "Effects of the Earthquake of March 27, 1964 at Anchorage, Alaska", The Alaska Earthquake, March 27, 1964, Effects on Communities, USGS Professional Paper.

Idriss, I.M. (1985). "Evaluating seismic risk in engineering practice," Proc., 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Balkema, Rotterdam, p. 265-320.

International Building Code (2006).

Jibson, R., and Michael, J. (2008), "Maps Showing Seismic landslide Hazards in Anchorage, Alaska" USGS Report.

Long, E. L. (1973), "Earth Slides and Related Phenomena," The Great Alaska Earthquake of 1964, National Academy of Science, 644-773.

Mitchell, J. K., Houston, W. N., Yamane, G (1973), "Sensitivity and Geotechnical Properties of Bootlegger Cove Clay", The Great Alaska Earthquake of 1964, Committee on the Alaska Earthquake of the Division of earth Sciences, National Research Council.

Moriwaki, Y., Vicente, E. E., Lai, S. S., Moses, T. L. (1985), "A Re-evaluation of the 1964 "L" Street Slide, State of Alaska, Department of Transportation and Public Facilities.

Newmark, N. (1965), "Effects of earthquakes on dams and embankments," Geotechnique, Vol. 15, No. 2, p. 139-160.

Shannon & Wilson (1964), "Anchorage Area Soil Studies," U.S. Army Engineer District, Alaska, Corps of Engineers

Shannon & Wilson (1965), "Remolding of Bootlegger Cove Clay with Explosives," U.S. Army Engineer District, Alaska, Corps of Engineers

Shannon and Wilson (1995), Final Geotechnical Report, Northwest Turnagain Landslide, Stability Evaluation, Anchorage Alaska.

Shannon & Wilson (1989) "Geotechnical Report, Turnagain N.E. Landslide Re-evaluation, Anchorage, Alaska" Municipality of Anchorage.

Shewbridge, S.E. (1996), "Yield Acceleration of Lined Landfills", ASCE Journal of Geotechnical Engineering, Vol. 122 (2), p. 156-158.

Stark, T. D., and Contreras, I.A. (1998), "Fourth Avenue Landslide During 1964 Earthquake", ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 124, p. 99-109.

Woodward-Clyde (1982), Anchorage Office Complex, Geotechnical Investigation, Anchorage, Alaska.

Woodward-Clyde (1987), Geotechnical Investigation, Anchorage Courthouse addition, Anchorage, Alaska.

Yasuhara, K., Murakami, S., and Hyde, A.F.L. (2004) "Post-cyclic degradation of saturated plasticity silts," Cyclic behaviour of soils and liquefaction phenomena: Proceedings of the International Conference on Cyclic Behaviour of Soils and Liquefaction Phenomena, 31 March-02 April 2004, Bochum, Germany

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APPENDIX A

SUPPORTING DOCUMENTATION OF CALCULATIONS

A.1 ESTIMATION OF UNDRAINED SHEAR STRENGTH (S_U)

The seismic performance of buildings and lifelines in downtown Anchorage depends greatly on local ground conditions. Damage in Anchorage during the 1964 Alaskan Earthquake was largely dictated by ground failure resulting from seismic slope instability, such as from the 4th Avenue slide and L Street slide. This is recognized in Recommendation 8 of Chapter 4 of the Anchorage Downtown Comprehensive Plan (i.e., "Address Seismic Hazards"). The potential for significant seismic displacements are largely dependent on the undrained shear strength of the soil, the slope's topography, and the intensity and duration of earthquake shaking. To estimate the shear strength of the soil, a comprehensive literature review was completed and the resulting soil characterization was reviewed by a local experienced geotechnical engineer.

A.1.A Literature review of undrained strength

Since the 1964 earthquake, the undrained shear strength of the Bootlegger Cove Clay has been carefully examined and reported on in numerous studies and journal articles. This information was assimilated, and a weighting system based on judgment was developed to assign an appropriate undrained shear strength for each of the potential slides identified in Appendix B. The studies considered primarily in this effort are summarized in Table 1.

Table 1. Considered Values for S_u

Author (s)	Proposed Values for S_u
Shannon & Wilson[1]	0.25 - 0.35 tsf
Idriss[2, 3]	$Su/\sigma'_v = 0.19\ (OCR)^{0.78}$, where OCR ~ 1.2-1.5
Mitchell, et. al. [4]	0.20 - 0.65 tsf from studies
	0.4 - 1.0 tsf from previous studies on sensitive clay
Moriwaki, et. al. [5]	$Su/\sigma'_v = 0.185\ (OCR)^{0.78}$, where OCR ~ 1.2-1.6
	0.65 - 1.6 ksf
Stark & Contreras [6]	$Su/\sigma'_v = 0.28\text{-}0.31$ (natural soils)
	$Su/\sigma'_v = 0.17\text{-}0.23$ (inside sliding mass)
Woodward-Clyde [7]	$Su/\sigma'_v = 0.19\ (OCR)^{0.78}$, where OCR ~ 1.8

Notes:

1) Shannon and Wilson (1995) Final Geotechnical Report, Northwest Turnagain Landslide, Stability Evaluation, Anchorage Alaska
2) Idriss, I.M. (1985). "Evaluating seismic risk in engineering practice," Proc., 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Balkema, Rotterdam, 265-320.
3) Boulanger, R. W., and Idriss, I.M. (2004), "Evaluating the Potential for Liquefaction of Cyclic Failure of Silts and Clays", Center for Geotechnical Modeling, Dept. of Civil & Environmental Engineering, University of California Davis
4) Mitchell, J. K., Houston, W. N., Yamane, G (1973), "Sensitivity and Geotechnical Properties of Bootlegger Cove Clay", The Great Alaska Earthquake of 1964, Committee on the Alaska Earthquake of the Division of earth Sciences, National Research Council
5) Moriwaki, Y., Vicente, E. E., Lai, S. S., Moses, T. L. (1985), "A Re-evaluation of the 1964 "L" Street Slide, State of Alaska, Department of Transportation and Public Facilities
6) Stark, T. D., and Contreras, I.A. (1998), "Fourth Avenue Landslide During 1964 Earthquake, "ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 124, 99-109
7) Woodward-Clyde (1987), Geotechnical Investigation, Anchorage Courthouse addition, Anchorage, Alaska

A.1.B Definition of Areas 1 and 2

For the purpose of this investigation, the study area was divided into two areas: Area 1 and Area 2. Area 1 is comprised of regions which failed during the 1964 earthquake and are expected to have lower strength material. Although it is expected that the strength of the materials has increased since 1964, the remolded material is not of the same strength as that of Area 2. This area is considered to have an OCR (overconsolidation ratio) of between 1.2 to 1.4. An OCR of 1.3 was selected as being representative of these areas.

Area 1 is comprised of Profiles A through G and L through O and is representative of the soil within the L Street Slide and 4th Avenue Slide areas.

Area 2 is comprised of regions within the study area which did not fail during the 1964 earthquake. It is reasonable to estimate that the strength and OCR of the material within these regions are relatively higher than those in Area 1. Area 2 is considered to have an OCR between 1.5 to 1.8, and for this study an OCR of 1.65 was used in this area.

Area 2 is comprised of Profiles H through K and R through T and is representative of the soils near the Courthouse site and within the remainder of the study area.

A.1.C Methodology for Finding S_u

Following discussions with a local experienced geotechnical engineer, Mr. K. Mobley, the estimated value of the critical peak undrained shear strength of the Bootlegger Cove Clay was based upon the studies summarized in Table 1 using the weighting scheme shown in Table 2. Method A is largely based on the work of Woodward Clyde Consultants as described in References 2, 3, 5, and 7. Method B is based on the more recent re-examination of the Bootlegger Cove Clay by Stark and Contreras (1998; i.e., Reference 6). Method C is largely based on the work of Mitchell et al. (1973) and Shannon and Wilson (1995), which are References 4 and 1, respectively. The undrained shear strength was calculated using each method and the undrained shear strength was then assigned for a given slope.

Table 2. Values for Su and their Weighted Average

Method	Values for Su	Weighting
A	$Su/\sigma'_v = 0.19\ (OCR)^{0.78}$, where OCR ~ 1.3[1] & 1.65[2]	50%
B	$Su/\sigma'_v = 0.2$[1], $Su/\sigma'_v = 0.29$[2]	35%
C[3]	0.3 - 0.5 tsf	15%

Notes:

1. Area 1: Comprised of the L Street and 4th Avenue slides.
2. Area 2: The Courthouse site and 4th Street through 1st Street zone.
3. For Method C:
    a. If OCR = 1.3 and $\sigma'_v < 2200$ psf, Su = 0.3 tsf
    b. If OCR = 1.3 and $\sigma'_v > 2200$ psf and < 4500 psf, Su = 0.4 tsf
    c. If OCR = 1.3 and $\sigma'_v > 4500$ psf, Su = 0.5 tsf
    d. If OCR = 1.65 and $\sigma'_v < 2500$ psf, Su = 0.35 tsf
    e. If OCR = 1.65 and $\sigma'_v > 2500$ psf and < 3500 psf, Su = 0.4 tsf
    f. If OCR = 1.65 and $\sigma'_v > 3500$ psf, Su = 0.5 tsf

A.1.D Cyclic Degradation

Previous research and observations have shown in large magnitude events with long durations of shaking, in fine-grained, saturated soils, there is a significant decrease in strength and stiffness leading to large displacements (Yasuhara, et. al., 2004). The 1964 earthquake had a very long duration with between 3 to 5 minutes of strong shaking. Before a sensitive clay reaches residual strength, it is customary for the peak static strength to be reduced by each successive cyclic of loading to a peak dynamic undrained shear strength. This cyclic degradation may be between 15% to 30% of the initial static peak undrained shear strength.

For this analysis, a peak dynamic undrained shear strength of 0.75 times the peak static undrained shear strength was utilized. Back analysis of the 4th Street and L Street slides that formed during the 1964 Alaskan earthquake were valuable in selecting this value.

A.1.E Residual Undrained Shear Strength

The undrained shear strength discussed to this point represents the Bootlegger Cove's peak dynamic strength. When a sensitive soil undergoes large strain, its shear strength reduces significantly. Eventually, the soil will reach its "residual" undrained shear strength. Large shear strains may be induced by multiple cycles of intense earthquake loading, which can lead to large seismic displacements as the soil is remolded as it is deformed.

Previous research by Woodward and Clyde (1982) and Idriss (1985) indicate that the Bootlegger Cove Clay's residual undrained shear strength may be between 20 percent and 30 percent of the initial undrained shear strength when subjected to large shear strains. For this study, the clay's residual undrained shear strength was selected to be 20% of its initial undrained peak static shear strength. This value is based in part on the results of our back analysis of the L Street and 4th Street slides during the 1964 Alaskan earthquake with our model.

A typical dynamic strength versus displacement relationship for a sensitive clay is shown in Figure 4. It is likely that after displacing 6 to 12 inches (i.e., about 9 inches), the clay's strength will start reducing significantly and eventually reach its residual strength at 3 to 5 feet (i.e., about 4 feet) of displacement. This response was model with the idealized step function shown in Figure 4. For seismic displacements calculated to be greater than 12 inches, it was assumed that the clay immediately dropped to its residual strength. The calculations of Bray and Travasarou (2007) were performed again using the residual strength. Using this approach, seismic displacement was not likely to be calculated within the range of 12 to 48 inches. This implies that slopes were likely to move only a small amount (i.e., less than about a foot) or they would likely move several feet. These results mirror observations after the 1964 earthquake of displacements, wherein slopes either moved a few inches or several feet (Shannon and Wilson, 1964).

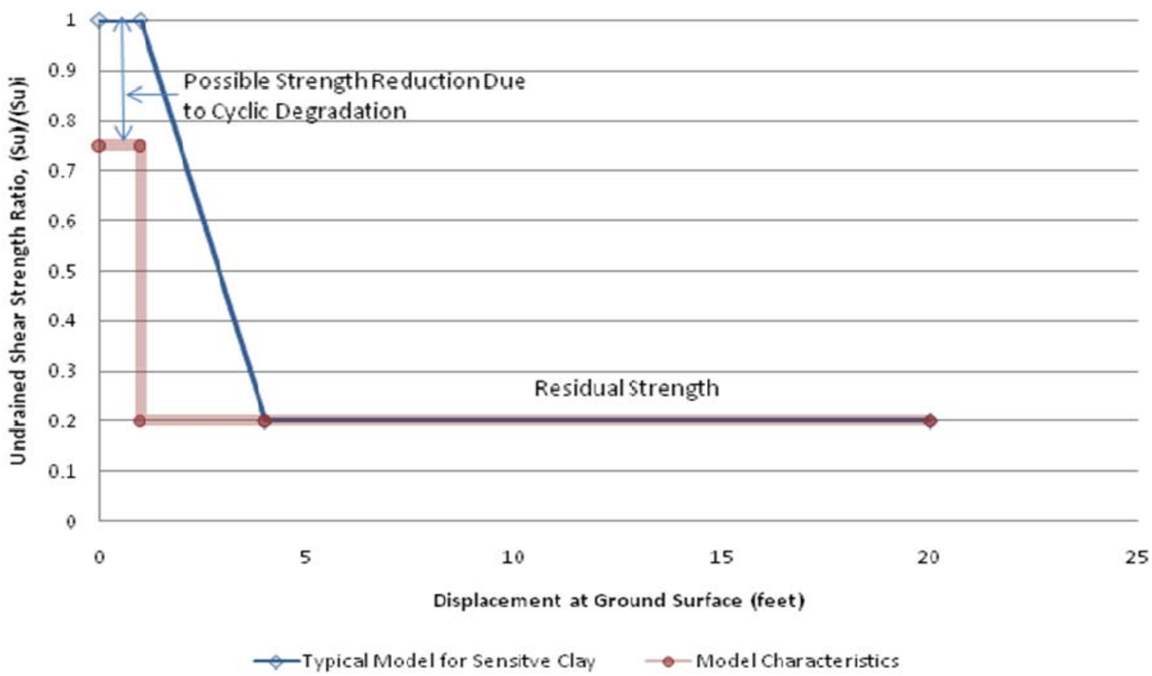


Figure 4. Idealized Dynamic Shear Strength versus Displacement for Bootlegger Clay in this Study

A.2 CALCULATION OF YIELD COEFFICIENT (k_y)

The yield coefficient (k_y) was calculated using an average of the simplified methods of block sliding (Shewbridge, 1996) ($k_{y(block)}$) and infinite slope ($k_{y(inf\ slope)}$). For each of the slopes identified, an independent yield coefficient was calculated using the dynamic undrained shear strength of the Bootlegger Cove Clay, unit weight (γ), height of the slope (H), length of the face (L_{face}) and the length of sliding mass beyond the slope (L). Because the undrained shear strength (S_u) was utilized in place of the cohesion (c), the internal friction angle (φ) was set to zero. For the infinite slope analysis, because the failure planes are nearly horizontal the angle of the failure plan to horizontal, angle β, was also set to zero.

The slopes identified for this study generally have geometries that are intermediate between the simplified block sliding mechanism and the simplified infinite slope mechanism. Thus, as an approximation, each slope's k_y value was calculated using a procedure that captured each of these mechanisms. Then the k_y values calculated by each procedure were averaged to provide a best estimate of the actual k_y value of the slope. This simplified k_Y calculation procedure was checked by performing 2-D SLOPEW analyses of six slopes and its results were found to compare reasonably well.

A.3 ESTIMATION OF SPECTRAL ACCELERATION (Sa)

As stated in the Memorandum "Downtown Anchorage Seismic Risk Assessment – Task 1, Proposed Earthquake Scenario" dated January 23, 2009, the scenario earthquake was selected to be consistent with the International building Code (IBC) design ground motions. The IBC requires buildings to be designed to two-thirds of the probabilistic ground motion that has a 2 percent chance of occurring in 50 years.

The geology underlying downtown Anchorage suggests that the site could be classified as a Site Class D (Stiff soil profile) or Site Class E (Soft Soil Profile) according to the 2006 International Building Code. As will be explained in Section A.4, Calculation of Seismic Displacements, the spectral acceleration (Sa) at the degraded period of the sliding mass ($1.5T_s$), is ultimately used to evaluate the displacements. Most of the degraded periods used for the stability analysis are less than 0.6 seconds. Between 0.1 seconds and 0.6 seconds, a Site Class D has higher spectral accelerations than a Site Class E. Therefore, because this presents a more critical case, Site Class D was utilized.

Using the IBC 2006 and the USGS "Seismic Hazard Curves and Uniform Hazard Response Spectra" application, the 5% damped elastic response spectrum for this event was generated. Using the IBC 2006 Figures 1613.5 (11) and (12) and zip codes 99501, 99510, and 99513, the values of S_S and S_1 were estimated to be:

- S_S: 1.49
- S_1: 0.55

These values for S_S and S_1 were also compared to data generated for Latitude: 61.2165N and Longitude: 149.8996 W.

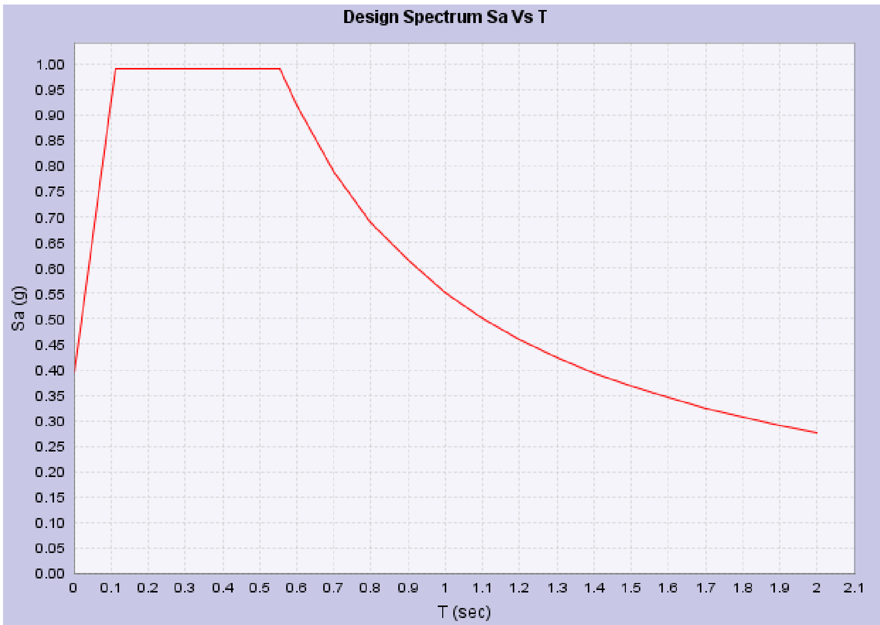


Figure 5. Design Acceleration Response Spectrum for Study Area (5% damping)

A.4 CALCULATION OF SEISMIC DISPLACEMENTS (D)

The seismic performance of a clay slope is typically evaluated in terms of seismically induced permanent displacement through a Newmark (1965)-type sliding block analysis. The Bray and Travasarou (2007) simplified procedure was utilized in this study. This procedure provides probabilistically based estimates of seismic displacement resulting from slope instability. It has been calibrated with several case histories and agrees with other widely accepted methods. This method takes advantage of nearly 700 recorded time histories from over 40 earthquakes, employs a calibrated, realistic soil model, and correctly captures key sources of uncertainty. This procedure has been widely used in the United States and has been adopted by the British Columbia, Canada Government's Building Policy Advisory Committee for implementing "The Geotechnical Slope Stability (Seismic) Regulation M-268."

The Bray and Travasarou (2007) procedure utilizes the moment magnitude (M_w), fundamental period of the potential sliding mass (T_s), the spectral acceleration at the degraded period of the sliding mass ($S_a(1.5T_s)$), and the yield coefficient (k_y) to estimate seismic slope displacement. Each slope was characterized by these parameters and the median seismic displacement for each slope was calculated.

The calculated median seismic displacement should be interpreted as an index of the seismic performance of the slopes in Anchorage. There are considerable uncertainties involved in this estimation, and there is inherent variability in seismic displacements for slopes with similar conditions. There will be a distribution of seismic displacements about each median calculated value. Thus, the calculated median seismic displacement provides an index of the likely seismic performance of each slope analyzed in this study.

For each zone, the calculated seismic displacements were categorized into these bins:

- < 1”
- 1” – 3”
- 3” – 6”
- 6” – 12”
- 12” – 24”
- 24” – 48”
- 48” – 96”
- 96” – 120”
- 120” and above.

The results in comparing the displacement for each slope are presented in Figure 6 and Figure 7 below.

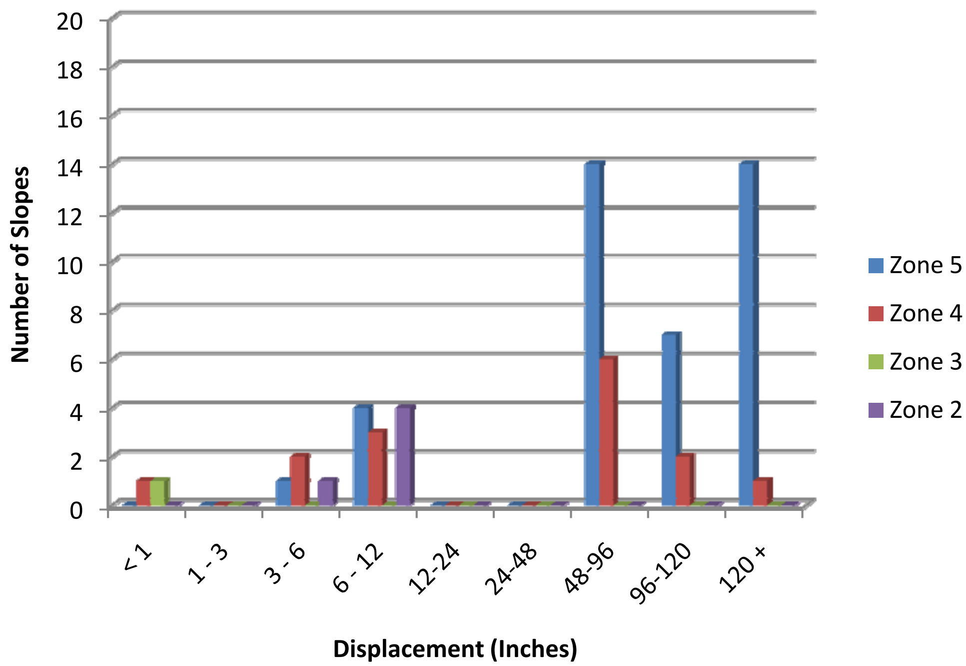


Figure 6. Histogram of Displacements by Slope per Zone

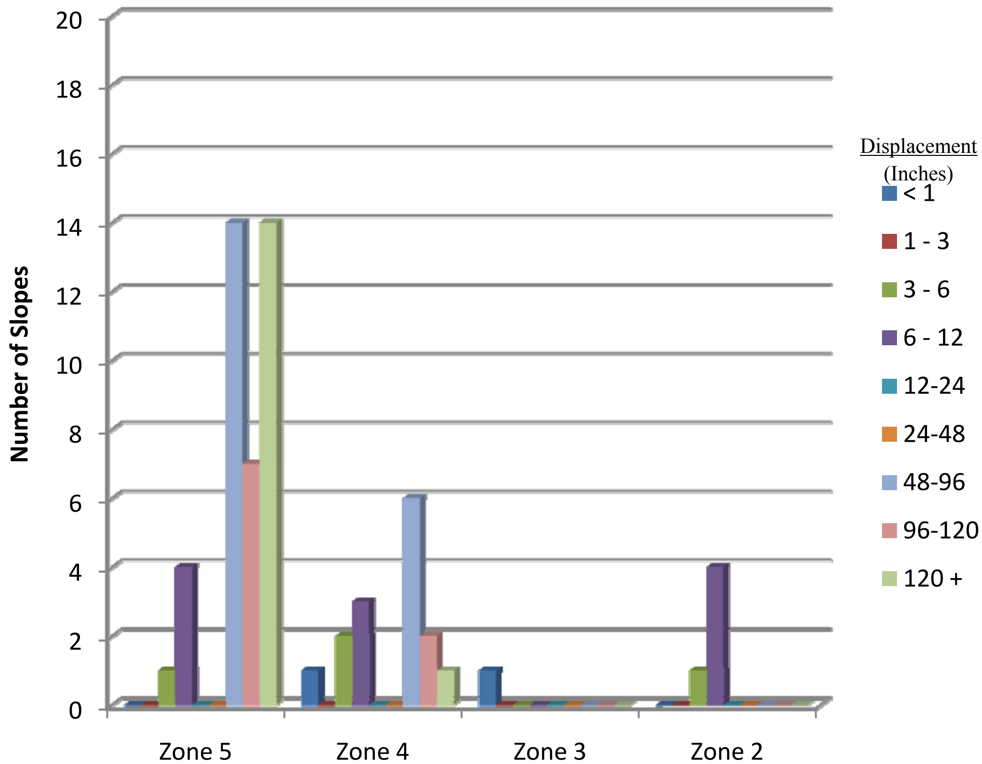
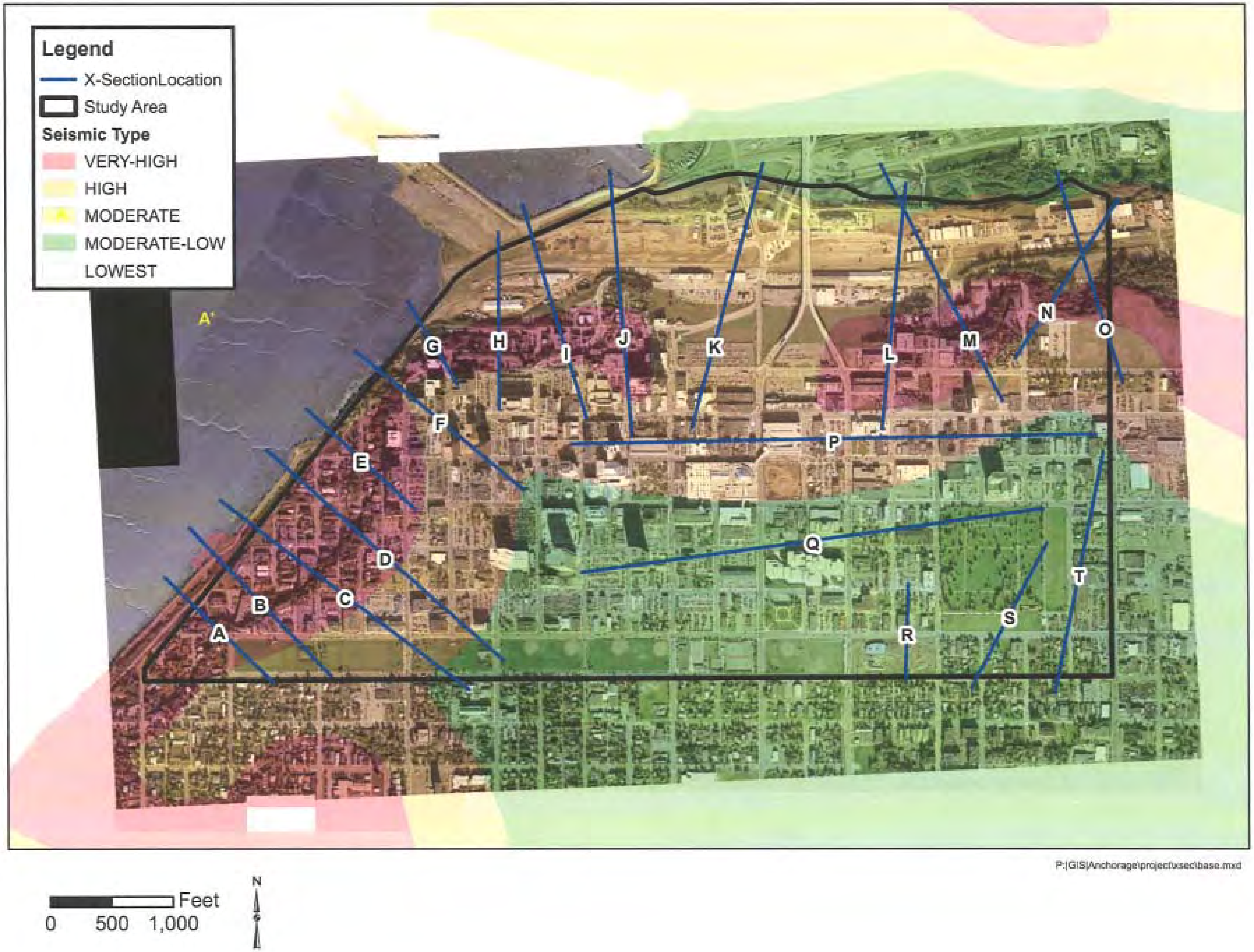


Figure 7. Histogram of Slope Displacements per Zone

APPENDIX B

Cross Section Locations and Profiles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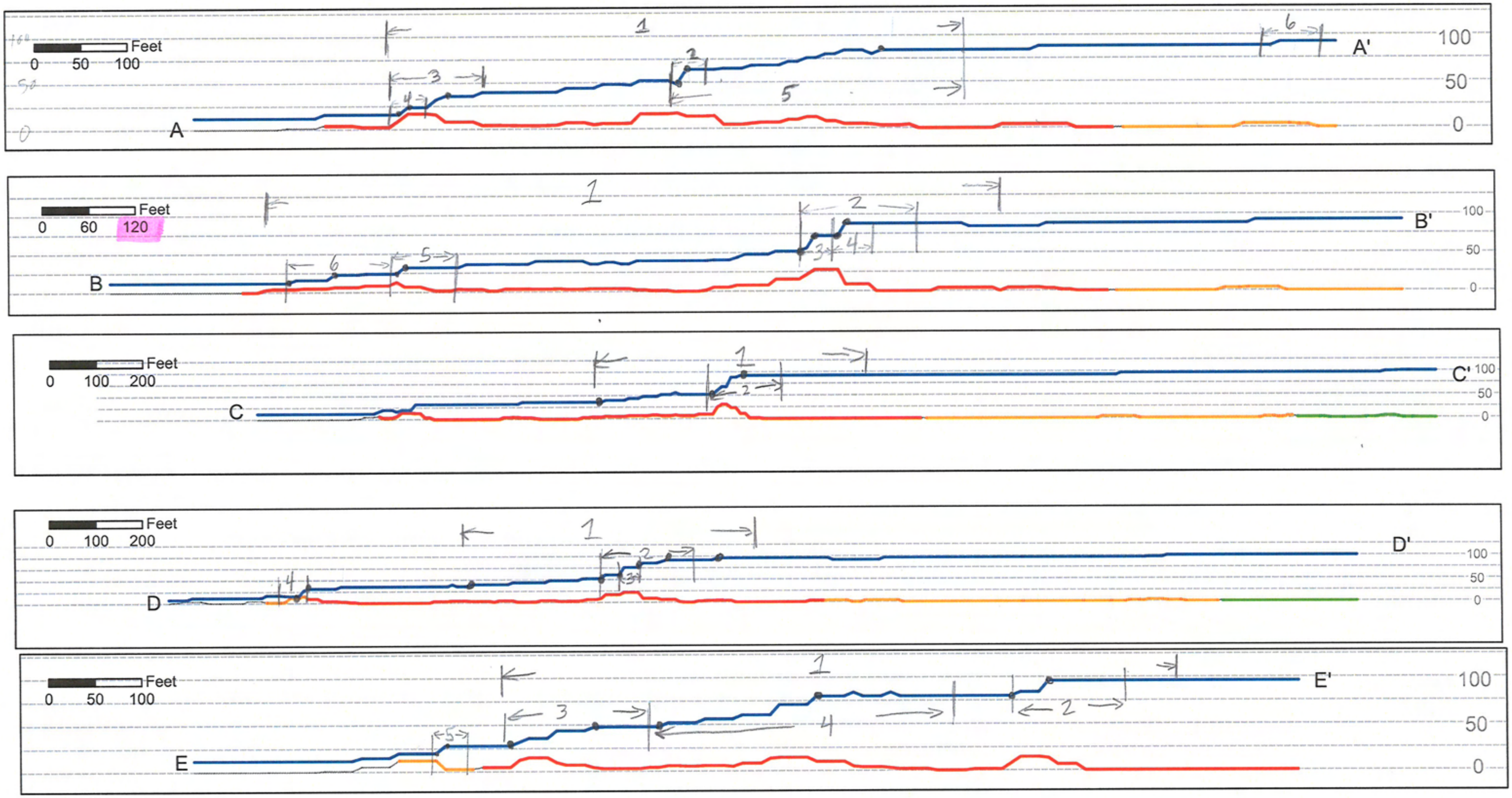

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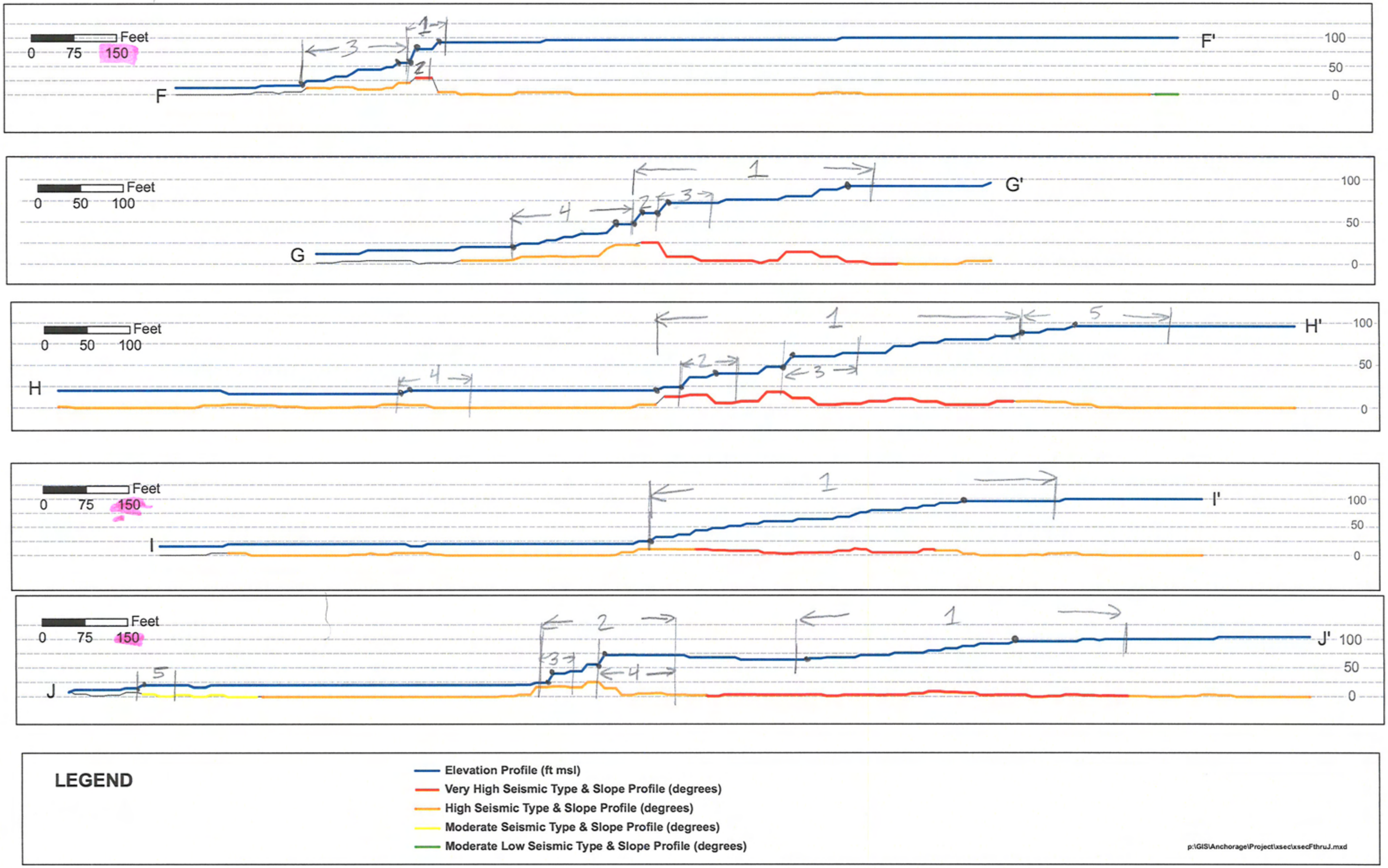

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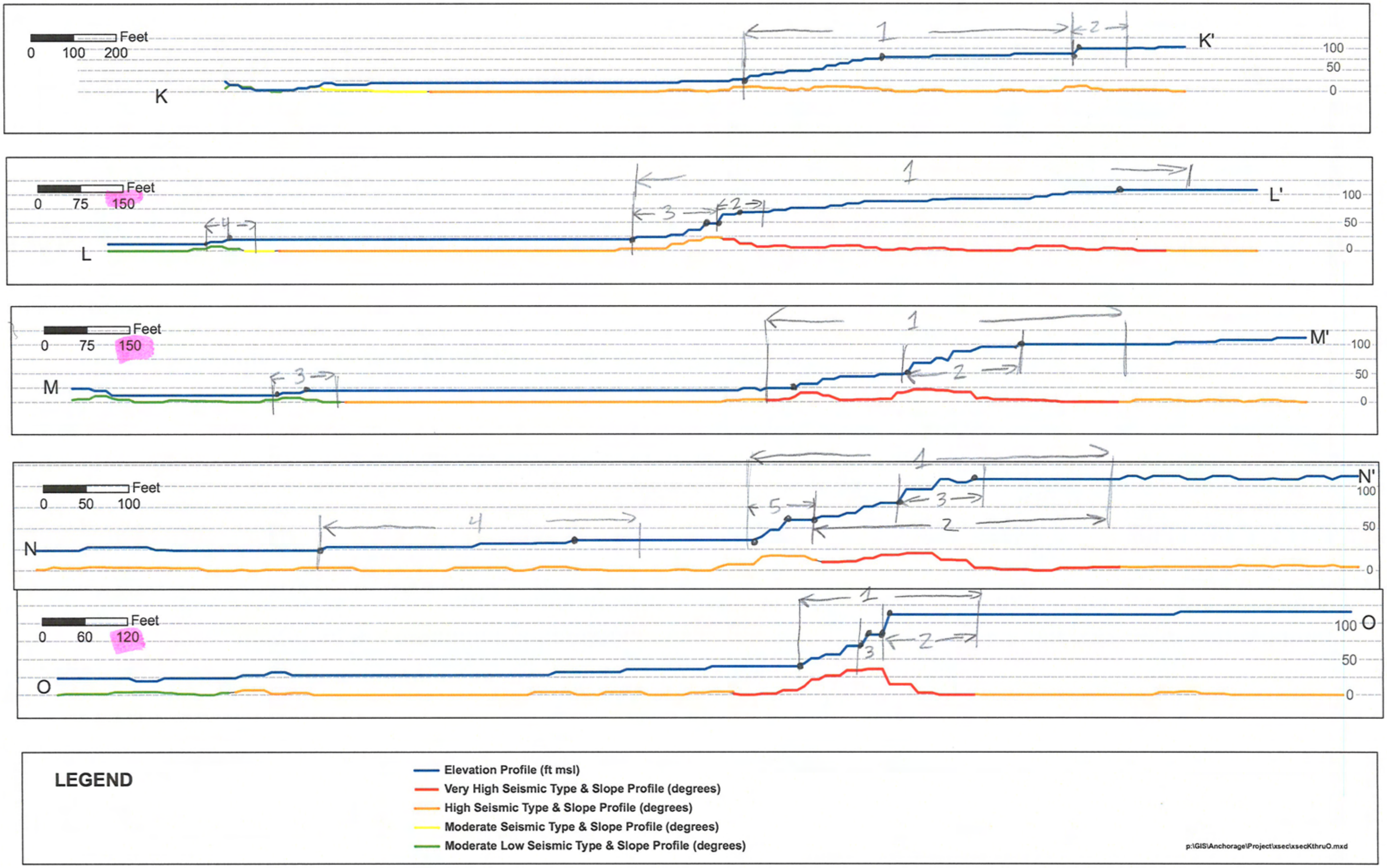
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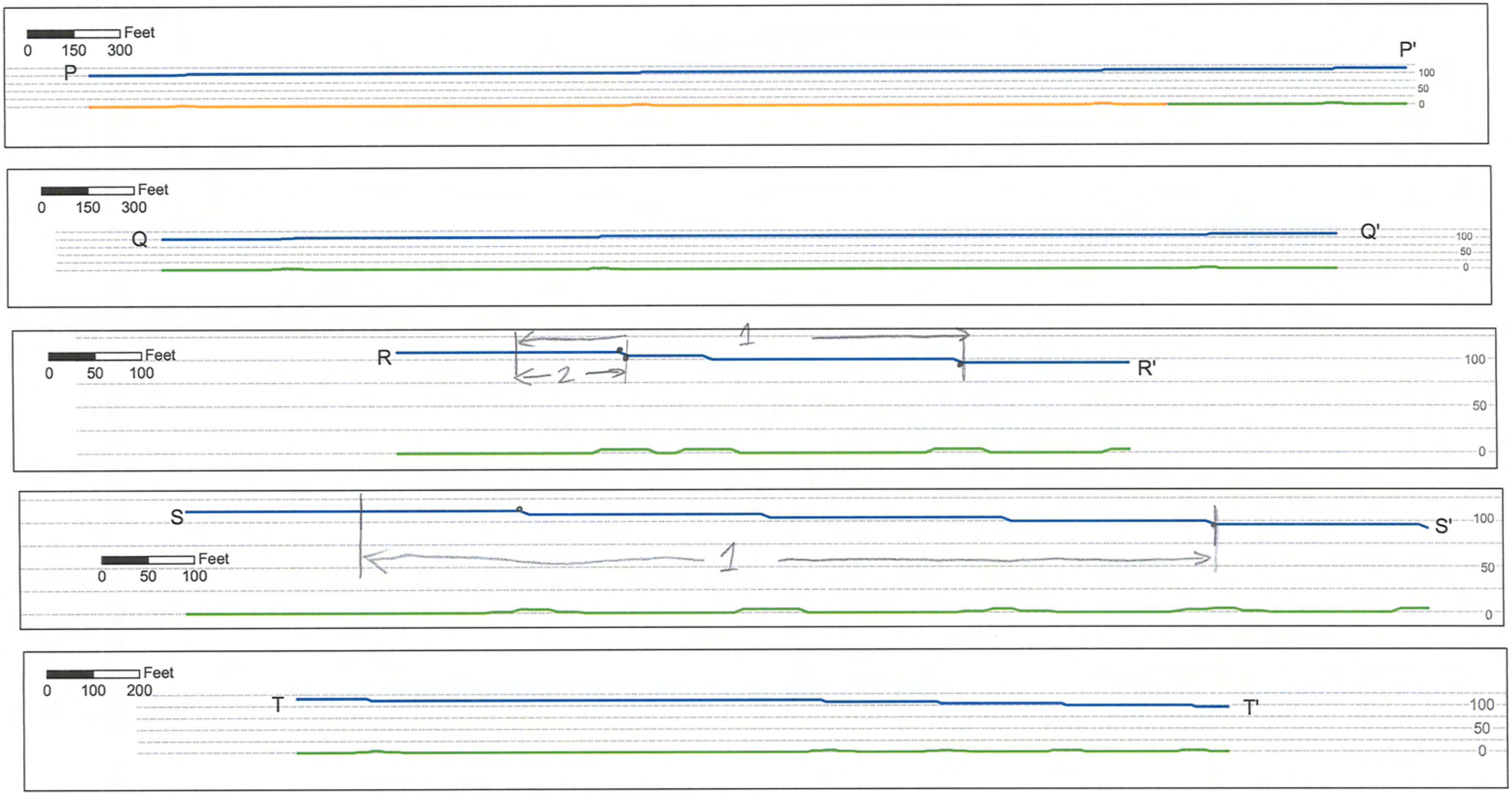

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Appendix E

Tasks 5 and 6, Technical Memorandum Loss Modeling

2100 Main Street, Suite 150
Huntington Beach, California 92648 USA
714.465.1390 *voice*
714.969.0820 *fax*

Memorandum

Date: December 29, 2010

To: David Tremont, Municipality of Anchorage Planning Department

From: Hope Seligson, MMI Engineering
Donald Ballantyne, MMI Engineering

Subject: Downtown Anchorage Seismic Risk Assessment
Task 5and 6 – Loss Modeling
MMI Project Number: MMW550

This memorandum describes the approach used to model building damage and casualties in the "prototypical buildings" (as defined for the current study), subject to ground motions from an IBC Design Level earthquake. It then uses that information to propose acceptable risk levels for loss of life and property damage in the higher hazard zones. The memorandum is divided into six sections, followed by References, as follows:

1. Geotechnical Setting
2. Prototypical Buildings
3. Risk Assessment Approach
4. Results
5. Analysis and Recommendations
6. Summary

1.0 GEOTECHNICAL SETTING

The downtown Anchorage study area is a geotechnically unstable area that underwent significant movement in the 1964 Alaska Earthquake. The area is underlain by a layer of gravel outwash approximately 50 feet thick, underlain by a layer of unstable Bootlegger Cove Clay, as shown in Figure 1. In a significant earthquake such as occurred in 1964, the unstable clay layer loses strength along a plane, and with each cycle of earthquake shaking the overlying block of soil moves towards the free surface (the bluff). In the volume behind the block of soil (towards the left in Figure 1), the ground collapses into the void forming a graben. In the area in front of the block (towards the right in Figure 1), the block attempts to plow through the soil in its path, resulting in the formation of pressure ridges.

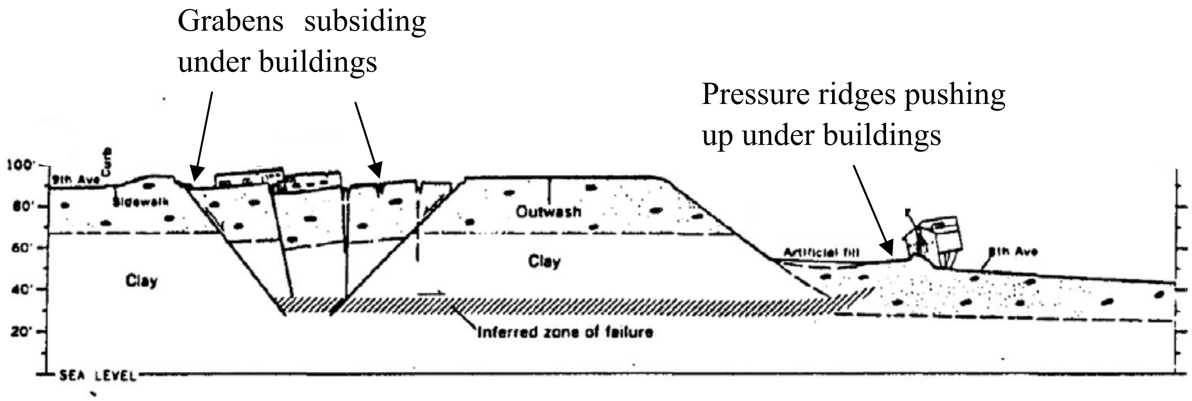

Figure 1. Cross section of soil strata in L Street slide area in 1964 Earthquake. (Moriwaki et al, 1985)

The described here was performed for seismic risk zones 1 (Lowest) through 5 (Very High), discussed in detail in the project memorandum defining seismic displacements for the project study area (dated June 12, 2009). Figure 1 generally shows a cross section of Zone 5 including potential subsidence, block lateral movement, and pressure ridges. The seismic risk zones had been previously mapped in accordance with expected permanent ground deformation (PGD) in future earthquakes. The "Seismic Displacements" memorandum quantified the expected net displacement of soil on the surface in each zone by percentage, where the displacement was a vector combining horizontal and vertical movement. In most cases, the predominant movement is expected to be horizontal, but in the areas over the grabens, the predominant movement is expected to be subsidence and over the pressure ridges, uplift. The methodology used in estimating the movements combined expected movements over the entire zone, and is presented as a percentage of the zone expecting the net movement. This displacement estimate serves as input into the building damage relationships and loss estimates in this memorandum.

2.0 PROTOTYPICAL BUILDINGS

Ten prototypical buildings have been defined for this study (described in the Task 2 Project memo dated March 20, 2009). Table 1 summarizes the 32 basic prototypical building variants and their associated structural configurations (HAZUS "Model Building Types"). Each variant has been modeled two ways; with a shallow foundation, and with a mat foundation, bringing the total number of modeled buildings to 64.

For the purpose of the seismic risk analysis, and for use in the HAZUS Advanced Engineering Building Module (AEBM), several additional parameters were determined for each prototype, as follows:

- Building area – typical building size was determined from the HAZUS occupancy model (FEMA/DHS, 2007) and/or underlying Means Square Foot Cost (Means, 2009) model. Assumed building sizes are included in Table 1.

- Building replacement cost – estimated from 2009 Means Square Foot Costs, using the Anchorage location factor. Estimated building replacement values are provided in Table 1.

- Number of daytime and nighttime building occupants –estimated from ATC-58 (ATC, 2009) peak building population model, or from ATC-13 (ATC, 1985) occupancy models when no ATC-58 model was available. Estimated daytime and nighttime building populations are included in Table 1.

- Content Value – estimated as a percent of structure replacement value, using HAZUS content value model percent by occupancy. For example, for residential structures, contents value is assumed to be equal to 50% of the total structure value.

- Business inventory value –estimated using HAZUS inventory value model, updated to 2009 costs (applies to multi-use building only).

- Economic parameters (daily business income, daily wages paid, relocation disruption cost, daily rental cost, ratio owner-occupied) – estimated according to the HAZUS methodology, with costs updated to 2009.

3.0 RISK ASSESSMENT APPROACH

3.1 Ground Shaking Damage

Damage to the 32 basic prototypical building variants due to ground motions from an IBC Design Level earthquake was estimated using the HAZUS Advanced Engineering Building Module (AEBM). It should be noted that the HAZUS model for estimating damage due to ground shaking does not consider multiple foundation types; the default configuration is a shallow foundation (e.g., spread footings). It is assumed that building performance of other foundation types subject to ground shaking would be similar.

HAZUS AEBM Results include estimates of daytime and nighttime casualties defined by HAZUS according to 4 severity levels (FEMA/DHS, 2003, Chapter 13):

- Severity 1 – "Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness."

- Severity 2 – "Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure."

- Severity 3 – "Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome."

- Severity 4 – "Instantaneously killed or mortally injured"

For summary purposes, total casualties are reported as the sum of all 4 severity levels, with Deaths also reported separately.

Other AEBM results include estimates of dollar loss due to building damage (structural and non-structural damage), damage to building contents and commercial inventories, and building damage-related income or business interruption losses, including the cost of relocation, lost rental income, lost business income and lost wages.

3.2 Ground Failure Fragilities

Within the HAZUS methodological framework, there are five (5) potential damage states (None, Slight, Moderate, Extensive, Complete), which are applicable to the building's structural and non-structural components. Each structural or non-structural damage state is qualitatively described for each model building type within the HAZUS Earthquake Model Technical Manual

(DHS/FEMA, 2007). For example, structural damage state descriptions are provided in terms of expected structural damage mechanisms:

> **Steel Moment Frame Structures (S1) - Extensive Structural Damage:** Most steel members have exceeded their yield capacity, resulting in significant permanent lateral deformation of the structure. Some of the structural members or connections may have exceeded their ultimate capacity exhibited by major permanent member rotations at connections, buckled flanges and failed connections. Partial collapse of portions of structure is possible due to failed critical elements and/or connections. (DHS/FEMA, 2007)

> **Reinforced Concrete Moment Frame Structures (C1) - Complete Structural Damage:** Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. Approximately 13% (low-rise), 10% (mid-rise) or 5% (high-rise) of the total area of C1 buildings with Complete damage is expected to be collapsed. (DHS/FEMA, 2007)

The sum of the probabilities of being in each of these five damage states must equal 100 percent. For example for a "typical" vulnerable building subjected to very low ground motion, the distribution might be: None – 90%, Slight – 10%, Moderate – 0%, Extensive – 0%, and Complete – 0%. If the same building was subjected to very strong ground motion, the damage state probability distribution might be: None – 10%, Slight – 10%, Moderate – 20%, Extensive – 30%, and Complete – 30%.

For the determination of economic loss, structural and non-structural damage state probabilities are multiplied by an assumed mean percent loss for each component's damage state. In general, "Complete" damage is expected to result in the total economic loss of the structure (i.e., the expected value of damage approaches the value of the structure). "Extensive" damage is expected to be repairable, but at a significant cost (e.g., on the order of 40 - 50% of replacement cost).

Discussion in the HAZUS Technical Manual of the topic of building damage due to ground failure is limited; there are only 1-1/2 pages of discussion on the topic in the 75 page chapter on Building Damage (Chapter 5). Regarding ground failure damage estimates employed within the HAZUS model, the Technical Manual (pp 5-64) states "No attempt is made to distinguish damage based on building type, since model building descriptions do not include foundation type." The HAZUS methodology has been used as the starting point in development of the ground deformation fragilities in this project. Accordingly, this project did not use HAZUS to directly estimate ground failure impacts on buildings.

As described in Section 5.5.1 of the HAZUS Technical Manual, the median and 10th percentile values of displacement (see below, from HAZUS TM Table 5.17) effectively define structural fragility functions for the "Extensive" and "Complete" damage states, for buildings on shallow foundations. (Ground failure is not expected to produce "Slight" or "Moderate" damage).

> 10% - PGD 2" V, 12" H – 8% buildings – extensive damage; 2% buildings – complete damage
>
> Median – PGD 10" V, 60" H – 40% buildings – extensive damage; 10% - complete damage

From these fragility curves, damage state probabilities for these two damage states may be determined for any level of peak ground deformation (PGD). For the current study, PGDs in the IBC Design Level earthquake have been developed as a vector combining horizontal and vertical displacements. The vector resulting from combining horizontal and vertical displacements used in HAZUS is less than 2% larger than the horizontal component. Thus, the horizontal component has been used in the current study.

In the graben zone and in the pressure ridge zone, it is likely that the vertical component of displacement (subsidence and uplift respectively) will be larger than the horizontal component. However, there is considerable uncertainty in calculating the width of the graben and pressure ridge areas. Because the fragilities need to be applicable across the entire zone, the ground deformation analysis was performed for the overall hazard zone, where the largest component of the deformation is horizontal due to the lateral movement of the block towards the bluff (see Figure 1).

The fragilities were developed taking into account the following three factors:

1. Foundation type – will affect the ability of the foundation to accommodate horizontal and vertical differential movement.

2. Building height– will affect the stability of the building if subjected to a vertical offset though the foot print (taller buildings would also tend to have a large footprint), and will affect the opportunity to repair the building if subjected to PGD.

3. Building structural system – more ductile structural systems would tend to have a lower percentage of buildings suffering compete damage, as compared to brittle structural systems, if the foundation suffers differential movement.

The median PGD values are used with a lognormal standard deviation value of 1.2 for buildings on shallow foundations. Shallow foundations are taken to be spread footings with grade beams.

Comparable damage to buildings on heavy mat foundations is not expected to occur until the PGD is on the order of 5 times greater than that for spread footings with grade beams. It is expected that the mat foundations will carry differential vertical and horizontal displacements. Failure would not occur until the building tips or rotates.

Mid-rise buildings are taken to be the baseline for this study. Low-rise buildings are expected to perform better than mid-rise buildings requiring 1.5x the median PGD to result in the same level of damage. Similarly, high-rise buildings are expected to have comparable damage when undergoing 0.67x the median PGD. This is applicable to buildings both on spread footings and mat foundations.

Buildings of differing structural systems on spread footings with grade beams are expected to perform differently when subjected to the same level of PGD. The default assumption used by HAZUS to differentiate between "Extensive" and "Complete" damage was an 80%/20% distribution. This is the "baseline" applied to wood frame buildings in the current study. It is expected that relatively fewer steel frame buildings (both braced steel frame and moment frame buildings) will suffer "Complete" damage, with an assumed distribution of 90 percent "Extensive" and 10 percent "Complete" (50% less "Complete"). Concrete frame, concrete shear wall, and masonry buildings are expected to perform relatively worse, with an assumed distribution of 60 percent "Extensive" damage and 40 percent "Complete" damage (2x more "Complete" damage. This differentiation relates to the capability of the structure to hold together and resist collapse.

All building structure types are expected to perform similarly when constructed on a heavy mat foundation; the baseline 80%/20% distribution is applied across all structure types when built on mat foundations.

These fragility relationships were developed based on expert opinion from three project team members, as listed below. To the best of the project team's knowledge, there is no other ongoing work in this technical area (as per discussions with building officials with the cities of Seattle and San Francisco). It is understood that there is a high level of uncertainty associated with these relationships. Observation of buildings subjected to PGD would seem to provide the best source of information for supporting the assumed fragility relationships. Each of the team members has extensive experience in post earthquake reconnaissance, particularly in the 1989 Loma Prieta, 1994 Northridge, and 1995 Kobe earthquakes. The three contributors are:

- Paul Summers, SE – MMI Engineering
- Charles Kircher, SE – Charles Kircher and Associates

- Donald Ballantyne, PE – MMI Engineering

It should also be noted that there was not complete concurrence among the contributors on the final fragility relationships. However, the items where there was disagreement tended to be insignificant relative to the overall methodology, and the application of the fragilities was evaluated using sensitivity analyses.

3.3 Ground Failure Damage

Damage to the full set of 64 prototypical buildings due to ground failure in the IBC Design Level earthquake was estimated in a customized spreadsheet model. Ground failure fragilities, as described above, were combined (according to the HAZUS ground failure estimation methodology) with ground failure probabilities by Hazard Zone (as documented in the displacement Memo dated June 12, 2009) to arrive at building-specific damage state probabilities. The ground failure damage state probability distributions were then used to estimate the same damage and loss measures utilized in the HAZUS AEBM.

The probability of failure of buildings was evaluated as a function of PGD. These probabilities were related to Hazard Zones by the distribution of PGDs within each hazard zone. A building with the same design parameters subjected to 12-inches of PGD would have the same probability of extensive damage whether it was in Hazard Zone 2 or Hazard Zone 5.

3.4 Combined Damage due to Ground Shaking and Ground Failure

As in the HAZUS methodology (see Section 5.6.3 of the HAZUS Technical Manual), it has been assumed for this study that damage due to ground shaking is independent of damage due to ground failure. To find the total damage, and avoid double-counting, the combined damage state probabilities are determined using standard probability theory for independent events. In this case:

$$P_{combined}[DS \geq DS_i] = P_{GroundShaking}[DS \geq DSi] + P_{GroundFailure}[DS \geq DSi] - (P_{GroundShaking}[DS \geq DSi] \times P_{GroundFailure}[DS \geq DSi])$$

Where:

$P_{GroundShaking}[DS \geq DSi]$ = probability of being in or exceeding damage state (i) as a result of ground shaking

$P_{GroundFailure}[DS \geq DSi]$ = probability of being in or exceeding damage state (i) as a result of ground failure.

$P_{combined}[DS \geq DS_i]$ = probability of being in or exceeding damage state (i) as a result of ground shaking and ground failure

The combined damage state probability distributions were used to estimate the same damage and loss measures utilized in the HAZUS AEBM.

4.0 RESULTS

Tables 2 – 5 summarize potential combined ground shaking and ground failure impacts to the 64 prototypical building variants in the IBC Design Level earthquake for Hazard Zones 5, 4, 3 and 2, respectively.

Similar information is provided graphically in Figures 1 – 12. Figure 1 depicts total direct economic loss resulting from shaking and ground failure, for each prototypical building variant for Hazard Zone 5. HAZUS' total direct economic loss is the sum of structural and non-structural building damage, contents damage, loss of commercial inventories, and building-related income or business interruption losses (relocation costs, rental losses, business income losses and wage losses). As seen in the figure, the largest losses (as high as $70 million) occur in the large hotel, while the small apartment building suffers the smallest loss. Figure 2 plots each building's loss ratio (total building damage divided by building value). As expected, shallow foundations suffer significantly more damage than mat foundations, with stiffer buildings (masonry and concrete) suffering more damage than the more flexible building types (steel and wood frame). Figures 3 and 4 plot expected day and night deaths, respectively. Deaths are rare, but more likely to occur in stiff, high occupancy buildings on shallow foundations. Daytime and nighttime casualties (the sum of all injuries, from minor injuries to deaths) are shown in Figures 5 and 6, with patterns similar to that for deaths. Death and casualty rates (number of casualties divided by the number of occupants) are provided in Figures 7 and 8. Here, the impact of building size is eliminated, and the rates reflect the inherent injury risk related to each type of construction. Figures 9 - 12 provide death and casualty rates normalized by building size (number of deaths or casualties per 1000 square feet).

In addition to the detailed charts presented for Zone 5, Figures 13 – 34 have been provided to demonstrate the variation in loss and casualties for the 10 prototypical buildings (and their variants) *across* the four ground failure hazard zones. For each prototypical building, the first bar chart (e.g., Figure 13 for Prototypical Building #1, the small multi-family residence) depicts the variation in total direct economic loss for buildings constructed using the various HAZUS model building types and proposed foundation types, across the four ground failure zones. The second bar chart (e.g., Figure 14 for Prototypical Building #1) illustrates the variation in casualties for the different building and foundation types, in the various hazard zones. In these figures, casualties in each of HAZUS' four severity levels are plotted as a "stacked" bar chart. For prototype #1 – 7 and #10, the casualties chart is presented for the time of day expected to result in the maximum number of casualties. For prototype #8 (the large hotel) and #9 (the multi-use building), charts for both times of day are presented because a significant number of casualties are expected in either a daytime and nighttime event.

As evidenced by the charts and tables, the magnitude of loss and potential casualties is greatest in Zone 5, generally increases with building size, declines significantly for mat foundations relative to shallow foundations, and is larger for concrete and masonry structures, relative to more flexible steel and wood frame structures.

4.1 Contribution of Shaking and Ground Failure to Combined Risk

Table 6 provides a summary of economic impacts resulting from shaking alone, ground failure alone, and for the combined effect of ground shaking and ground failure, for buildings in Hazard Zone 5 in the IBC Design Level earthquake. This table demonstrates that ground failure loss is a significant component of overall loss when shallow foundations are used. When mat foundations are used, ground failure losses are greatly reduced, but the building may still suffer moderate damage as a result of ground shaking.

4.2 Sensitivity to Underlying Fragility Assumptions

To test the sensitivity of loss to the underlying assumption that mat foundations can essentially withstand 5 times the displacement of shallow foundations, alternative assessments were conducted, first assuming a smaller difference in foundation strength (mat foundations 50% weaker than original assumption, able to withstand 2.5x the displacement of a shallow foundation) and then assuming a larger difference in foundation strength (mat foundations 50% stronger than original assumption, able to withstand 7.5x the displacement of a shallow foundation). A comparison of economic losses for the sensitivity test runs are provided in Table 7. A similar comparison of the maximum expected number of deaths and casualties (for the time of day, either day or night, producing the higher estimate) is provided in Table 8. Overall, reducing the assumed strength of the mat foundation by 50% results in an average 42% increase in economic loss, while increasing the assumed strength by 50% reduces the average loss by 20%. Reducing the assumed strength of the mat foundation by 50% also results in an average 63% increase in deaths and a 49% increase in overall casualties, while a 50% increase in assumed strength results in a 29% reduction in estimated deaths and a 22% decrease in overall casualties.

5.0 ANALYSIS AND RECOMMENDATIONS

This section evaluates the potential loss of life (Injury Severity 4) due to shaking and PGD, and recommends mitigation measures using land use planning techniques.

Tables 2 through 5 show the expected deaths during the IBC Design Level earthquake event during the day or night. Table 5 shows the expected deaths in Hazard Zone 2 for each building category. As Hazard Zone 2 does not undergo significant PGD, these deaths are the result of earthquake shaking. The evaluation is done for new buildings built in accordance with the current International Building Code. The code does not address "acceptable" numbers of deaths in structures, but provides for a design that should be inherently safe. HAZUS provides casualty models based on empirical data as a function of building damage state. These models have been used to estimate the deaths shown in Tables 2 through 5.

It is assumed that the deaths estimated for buildings in Hazard Zone 2 (no PGD) would be considered "acceptable". That is, the analysis is performed for buildings that meet current code design requirements. These "acceptable" deaths 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. From Table 5, the highest total number of deaths is 0.169 (occurring in the Large Hotel, S1H structural system on a shallow foundation). 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 six large modern high rise hotels, each with night-time occupancies exceeding 1,000 people. The number of expected deaths is a function of both the building fragility and the number of people in the building. Prototypical buildings types that have estimated deaths that exceed this number (0.169) in other zones are considered to be "high vulnerability" buildings, and are shown in cells shaded pink in Tables 2 and 3 for Hazard Zones 5 and 4 respectively. Consideration should be given to adjusting the 0.169 number slightly upward to 0.2 or 02.5 to allow for easier implementation as there are several buildings that fall into that range. There are no high risk buildings in Hazard Zones 2 and 3. In general, these buildings tend to be large/high rise buildings on either shallow or matt foundations, or medium buildings on shallow foundations.

Within the high vulnerability category, there is a break in the "Max Total Deaths" between 0.653 and 0.474. Eight buildings have a "Max Total Deaths greater than 0.65. All have shallow foundations. These will be designated as "very high vulnerability" buildings and shown in red on Table 2. There are no very high vulnerability buildings in Hazard Zones 4, 3, or 2.

In Table 2, there is a distinct break in the "Max Total Deaths" data between 0.118 and 0.068, with only 8 building categories exceeding the 0.068 threshold. This is a 40 percent decrease.

This is selected as the next lower threshold is 0.068. Prototypical building categories with expected deaths less than 0.169 but greater than 0.068 are categorized as "moderate vulnerability" buildings. They are shown shaded in yellow in Tables 2 through 5 for Hazard Zones 5 through 2 respectively. The number of buildings categorized as having a high or moderate vulnerability is significantly lower in progressively lower Hazard Zone 4, 3, and 2.

A similar analysis was undertaken to evaluate acceptable building losses where Hazard Zone 2 represents "shaking only" damage expected to a modern building designed in accordance with the IBC. The maximum Building Loss Ratio in Hazard Zone 2 is 13.9 percent. By comparison, only 1 of the 64 prototypical buildings in Hazard Zone 5 has Building Loss Ratio ***less*** than 13.9%, and it is only 13.7%. It is not recommended to employ a fourth level of vulnerability that would be more conservative than the IBC design for shaking.

Therefore, we recommend three possible levels of mitigation by limiting the type of building use, foundation, and super structure to limit: 1) very high vulnerability buildings, 2) high vulnerability buildings, and 3) moderate vulnerability buildings in Hazard Zones 5 though 2.

These three levels of mitigation can be achieved by implementing a set of rules.

> To limit Very High Vulnerability Buildings in Hazard Zone 5 (see Table 2): 1) Do not allow the following HAZUS Model Building types of buildings on shallow foundations: C1H or C2H Large Offices, Large Hotels, Large MFRs, or Medium C2M Hotels or Offices. (There are no Very High Vulnerability Buildings in Hazard Zones 4, 3, or 2.)

> To limit High Vulnerability Buildings in Hazard Zones 5 (see Table 2): 1) Do not allow the following HAZUS Model Building types of buildings on shallow foundations: C1H or C2H Large Offices, Large Hotels, Large MFRs, or Medium C2M Hotels, Offices or Multi-Use. 2) Do not allow buildings with occupancies greater than 500. These two rules exclude two building categories with Maximum Deaths of less than 0.25, but greater than 0.169.

> To limit High Vulnerability Buildings in Hazard Zones 4 (see Table 3): 1) Do not allow the following HAZUS Model Building types of buildings on shallow foundations: C1H or C2H Large Offices or Large Hotels. Note that this rule does not address 5 building types with Max Total Deaths below 0.25. (There are no High Vulnerability Buildings in Hazard Zones 3, or 2.)

Limiting Moderate Vulnerability building types in all hazard zones becomes more complicated because of the mix of building types. Rules could be developed if a decision is made to implement this level of mitigation.

7.0 REFERENCES:

ATC (2009), "Guidelines for Seismic Performance Assessment of Buildings, ATC-58 50% Draft" prepared by the Applied Technology Council, Redwood City, California, for the U.S. Department of Homeland Security (DHS), Federal Emergency Management Agency.

ATC (1985) "Earthquake Damage Evaluation Data for California, ATC-13", prepared by the Applied Technology Council, Redwood City, California.

DHS/FEMA (2003), "HAZUS-MH MR3 Technical Manual, Multi-hazard Loss Estimation Methodology, Earthquake Model", Developed by the Department of Homeland Security, Emergency Preparedness and Response Directorate, Federal Emergency Management Agency, Mitigation Division, Washington, D.C.

Means (2009), "R.S. Means Square Foot Costs", 30th Annual Edition, Kingston, Massachusetts.

Moriwaki, Y., Vicente, E. E., Lai, S. S., Moses, T. L. (1985), "A Re-evaluation of the 1964 "L" Street Slide, State of Alaska, Department of Transportation and Public Facilities.

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Table 1: Structural Classifications for the Ten Prototypical Buildings

Bldg. No.	Proto-type No.	Use Description	Size (sq ft)	HAZUS Occupancy Class	Estimated # Occupants (Day/Night)	Est. Bldg Value ($1,000)	HAZUS Model Building Types
1	1	MFR (Multi-Family Residence)	Small (12,000)	RES3D	Jul-37	2,473	W2
2							S2L
3							RM1L
4	2	MFR	Medium (40,000)	RES3E	25/124	8,293	S2M
5							S4M
6							C2M
7	3	MFR	Large (145,000)	RES3F	90/450	35,050	S2H
8							S1H
9							C1H
10							C2H
11	4	Office	Small (20,000)	COM4	80/4	4,128	W2
12							S2L
13							RM1L
14	5	Office	Medium (80,000)	COM4	320/16	16,314	S2M
15							S4M
16							C2M
17	6	Office	Large (260,000)	COM4	1,040/52	46,929	S2H
18							S1H
19							C1H
20							C2H
21	7	Hotel	Medium (135,000)	RES4	169/338	27,452	S2M
22							S4M
23							C2M
24	8	Hotel	Large (450,000)	RES4	563/1,125	91,761	S2H
25							S1H
26							C1H
27							C2H
28	9	Multi-Use	Medium (60,000)	M-U: 1/6 COM1, 2/6 COM4, 3/6 RES3E	159/100	12,597	S2M
29							S4M
30							C2M
31	10	Parking Structure	Medium (145,000)	COM10	29/1	10,602	C2M
32							C1M

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

Table 2: Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

Use	Size	HAZUS Model Bldg Type	Foun-dation	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)
Hotel	Large	C1H	Shallow	18.8	37.5	1.687	$ 44.0	47.9%	$74.0
Hotel	Large	C2H	Shallow	18.2	36.3	1.633	$ 43.3	47.2%	$72.9
Offices	Large	C1H	Shallow	34.7	1.7	1.560	$ 22.3	47.5%	$39.8
Offices	Large	C2H	Shallow	33.6	1.7	1.510	$ 22.0	46.9%	$39.4
Hotel	Medium	C2M	Shallow	6.2	12.5	0.849	$ 11.7	42.5%	$19.6
Offices	Medium	C2M	Shallow	11.8	0.6	0.804	$ 6.9	42.2%	$12.2
MFR	Large	C1H	Shallow	3.0	15.0	0.675	$ 16.8	47.9%	$22.8
MFR	Large	C2H	Shallow	2.9	14.5	0.653	$ 16.5	47.2%	$22.5
Hotel	Large	C1H	Mat	7.3	14.5	0.474	$ 20.4	22.2%	$36.3
Offices	Large	C1H	Mat	13.4	0.7	0.438	$ 10.3	22.0%	$18.8
Hotel	Large	C2H	Mat	6.3	12.6	0.404	$ 19.2	21.0%	$34.3
Hotel	Large	S1H	Shallow	9.7	19.4	0.402	$ 35.4	38.5%	$62.4
Multi-Use	Medium	C2M	Shallow	5.9	3.7	0.399	$ 5.3	42.4%	$9.4
Offices	Large	C2H	Mat	11.7	0.6	0.373	$ 9.8	20.9%	$18.2
Hotel	Large	S1H	Mat	8.3	16.5	0.373	$ 24.3	26.5%	$43.5
Offices	Large	S1H	Shallow	18.0	0.9	0.372	$ 17.8	37.9%	$32.8
Offices	Large	S1H	Mat	15.3	0.8	0.345	$ 12.3	26.2%	$22.0
MFR	Medium	C2M	Shallow	0.9	4.6	0.311	$ 3.5	42.5%	$4.9
Hotel	Large	S2H	Shallow	8.1	16.2	0.291	$ 32.6	35.6%	$57.9
Offices	Large	S2H	Shallow	14.9	0.7	0.269	$ 16.4	35.0%	$30.7
Hotel	Large	S2H	Mat	6.1	12.2	0.260	$ 20.0	21.8%	$35.8
Offices	Large	S2H	Mat	11.3	0.6	0.241	$ 10.1	21.6%	$18.6
Offices	Small	RM1L	Shallow	2.9	0.1	0.223	$ 1.5	37.3%	$2.7
MFR	Large	C1H	Mat	1.2	5.8	0.190	$ 7.8	22.1%	$10.6
MFR	Large	C2H	Mat	1.0	5.1	0.161	$ 7.3	20.9%	$10.2
MFR	Large	S1H	Shallow	1.6	7.8	0.161	$ 13.5	38.5%	$18.5
Hotel	Medium	C2M	Mat	1.5	3.1	0.154	$ 4.5	16.3%	$7.8
MFR	Large	S1H	Mat	1.3	6.6	0.149	$ 9.3	26.4%	$12.5
Offices	Medium	C2M	Mat	2.9	0.1	0.145	$ 2.7	16.3%	$4.9
Hotel	Medium	S4M	Shallow	2.3	4.7	0.126	$ 8.8	32.1%	$15.6
Hotel	Medium	S2M	Shallow	2.3	4.6	0.124	$ 9.0	32.6%	$15.8
Offices	Medium	S4M	Shallow	4.4	0.2	0.119	$ 5.2	31.6%	$9.5
Offices	Medium	S2M	Shallow	4.4	0.2	0.118	$ 5.2	32.0%	$9.6
MFR	Large	S2H	Shallow	1.3	6.5	0.117	$ 12.4	35.5%	$17.3

Use	Size	HAZUS Model Bldg Type	Foun-dation	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)
MFR	Large	S2H	Mat	1.0	4.9	0.104	$ 7.6	21.7%	$10.5
MFR	Small	RM1L	Shallow	0.3	1.3	0.103	$ 0.9	37.6%	$1.3
Hotel	Medium	S4M	Mat	1.5	2.9	0.091	$ 4.6	16.6%	$8.2
Hotel	Medium	S2M	Mat	1.4	2.9	0.090	$ 4.9	17.7%	$8.5
Offices	Medium	S4M	Mat	2.8	0.1	0.086	$ 2.7	16.6%	$5.0
Offices	Medium	S2M	Mat	2.7	0.1	0.085	$ 2.9	17.5%	$5.1
Parking Struc	Medium	C1M	Shallow	1.1	0.0	0.075	$ 4.8	45.5%	$6.3
Parking Struc	Medium	C2M	Shallow	1.1	0.0	0.073	$ 4.7	44.2%	$6.2
Multi-Use	Medium	C2M	Mat	1.4	0.9	0.072	$ 2.1	16.3%	$3.7
Multi-Use	Medium	S4M	Shallow	2.2	1.4	0.059	$ 4.0	31.9%	$7.3
Multi-Use	Medium	S2M	Shallow	2.2	1.4	0.058	$ 4.1	32.4%	$7.4
MFR	Medium	C2M	Mat	0.2	1.1	0.056	$ 1.4	16.3%	$1.9
MFR	Medium	S4M	Shallow	0.3	1.7	0.046	$ 2.7	32.0%	$3.7
MFR	Medium	S2M	Shallow	0.3	1.7	0.046	$ 2.7	32.6%	$3.8
Multi-Use	Medium	S4M	Mat	1.4	0.9	0.043	$ 2.1	16.7%	$3.8
Multi-Use	Medium	S2M	Mat	1.4	0.9	0.042	$ 2.2	17.7%	$4.0
Offices	Small	S2L	Shallow	1.1	0.1	0.039	$ 1.2	30.0%	$2.2
Offices	Small	RM1L	Mat	0.6	0.0	0.035	$ 0.6	13.7%	$1.0
MFR	Medium	S4M	Mat	0.2	1.1	0.033	$ 1.4	16.6%	$2.0
MFR	Medium	S2M	Mat	0.2	1.1	0.033	$ 1.5	17.7%	$2.0
Offices	Small	W2	Shallow	1.1	0.1	0.026	$ 1.3	31.4%	$2.3
Offices	Small	S2L	Mat	0.6	0.0	0.022	$ 0.7	16.8%	$1.2
MFR	Small	S2L	Shallow	0.1	0.5	0.018	$ 0.8	30.8%	$1.1
MFR	Small	RM1L	Mat	0.1	0.3	0.016	$ 0.3	13.9%	$0.5
Parking Struc	Medium	C1M	Mat	0.3	0.0	0.015	$ 2.1	19.7%	$2.7
Parking Struc	Medium	C2M	Mat	0.3	0.0	0.013	$ 1.8	17.3%	$2.5
MFR	Small	W2	Shallow	0.1	0.5	0.012	$ 0.8	32.0%	$1.1
MFR	Small	S2L	Mat	0.1	0.3	0.010	$ 0.4	17.5%	$0.6
Offices	Small	W2	Mat	0.4	0.0	0.007	$ 0.6	14.1%	$1.0
MFR	Small	W2	Mat	0.0	0.2	0.003	$ 0.4	14.6%	$0.5

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

Table 3: Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 4

Use	Size	HAZUS Model Bldg Type	Foun-dation	*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)*
Hotel	Large	C1H	Shallow	5.8	11.5	0.387	$13.5	14.7%	$24.6
Offices	Large	C1H	Shallow	10.7	0.5	0.358	$6.9	14.7%	$12.3
Hotel	Large	C2H	Shallow	4.7	9.5	0.315	$12.2	13.3%	$22.1
Offices	Large	C2H	Shallow	8.8	0.4	0.291	$6.3	13.4%	$11.7
Hotel	Large	S1H	Shallow	5.8	11.6	0.207	$16.5	17.9%	$30.8
Hotel	Large	S1H	Mat	5.6	11.1	0.201	$14.6	15.9%	$27.5
Offices	Large	S1H	Shallow	10.8	0.5	0.191	$8.3	17.8%	$14.7
Offices	Large	S1H	Mat	10.3	0.5	0.185	$7.4	15.7%	$12.8
Hotel	Large	C1H	Mat	3.8	7.7	0.183	$9.5	10.3%	$18.2
Offices	Large	C1H	Mat	7.1	0.4	0.169	$4.8	10.3%	$8.8
MFR	Large	C1H	Shallow	0.9	4.6	0.155	$5.2	14.7%	$6.9
Hotel	Medium	C2M	Shallow	1.3	2.7	0.148	$3.4	12.4%	$5.9
Offices	Medium	C2M	Shallow	2.5	0.1	0.140	$2.0	12.5%	$3.8
MFR	Large	C2H	Shallow	0.8	3.8	0.126	$4.7	13.3%	$6.5
Hotel	Large	C2H	Mat	2.7	5.5	0.109	$8.1	8.9%	$15.6
Offices	Large	C2H	Mat	5.1	0.3	0.100	$4.2	9.0%	$8.1
Hotel	Large	S2H	Shallow	3.4	6.7	0.088	$11.3	12.3%	$21.4
MFR	Large	S1H	Shallow	0.9	4.7	0.083	$6.3	17.9%	$8.3
Hotel	Large	S2H	Mat	3.0	6.0	0.081	$9.1	9.9%	$17.6
Offices	Large	S2H	Shallow	6.2	0.3	0.081	$5.8	12.3%	$10.7
MFR	Large	S1H	Mat	0.9	4.4	0.080	$5.5	15.8%	$7.2
Offices	Large	S2H	Mat	5.5	0.3	0.075	$4.7	10.0%	$8.6
MFR	Large	C1H	Mat	0.6	3.1	0.073	$3.6	10.3%	$4.9
Multi-Use	Medium	C2M	Shallow	1.3	0.8	0.070	$1.6	12.5%	$2.8
MFR	Medium	C2M	Shallow	0.2	1.0	0.054	$1.0	12.4%	$1.5
MFR	Large	C2H	Mat	0.4	2.2	0.043	$3.1	8.9%	$4.4
Offices	Small	RM1L	Shallow	0.6	0.0	0.042	$0.5	12.6%	$0.9
Hotel	Medium	S4M	Shallow	0.9	1.7	0.037	$3.0	11.0%	$5.6
MFR	Large	S2H	Shallow	0.5	2.7	0.035	$4.3	12.3%	$5.9
Hotel	Medium	S2M	Shallow	0.8	1.7	0.035	$3.4	12.2%	$6.0
Offices	Medium	S4M	Shallow	1.7	0.1	0.035	$1.8	11.0%	$3.4
Offices	Medium	S2M	Shallow	1.6	0.1	0.033	$2.0	12.0%	$3.6
Hotel	Medium	C2M	Mat	0.6	1.1	0.033	$2.2	8.1%	$4.0
MFR	Large	S2H	Mat	0.5	2.4	0.032	$3.5	9.9%	$4.7

Use	Size	HAZUS Model Bldg Type	Foun-dation	*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)*
Offices	Medium	C2M	Mat	1.0	0.1	0.031	$1.3	8.2%	$2.6
Hotel	Medium	S4M	Mat	0.7	1.5	0.031	$2.3	8.4%	$4.3
Offices	Medium	S4M	Mat	1.4	0.1	0.029	$1.4	8.5%	$2.6
Hotel	Medium	S2M	Mat	0.7	1.4	0.029	$2.7	9.7%	$4.8
Offices	Medium	S2M	Mat	1.3	0.1	0.027	$1.6	9.6%	$2.8
MFR	Small	RM1L	Shallow	0.1	0.3	0.020	$0.3	12.7%	$0.4
Multi-Use	Medium	S4M	Shallow	0.8	0.5	0.017	$1.4	11.1%	$2.6
Multi-Use	Medium	S2M	Shallow	0.8	0.5	0.016	$1.5	12.2%	$2.8
Multi-Use	Medium	C2M	Mat	0.5	0.3	0.015	$1.0	8.1%	$1.9
Parking Struc	Medium	C1M	Shallow	0.3	0.0	0.015	$1.7	15.7%	$2.1
Multi-Use	Medium	S4M	Mat	0.7	0.4	0.014	$1.1	8.5%	$2.0
Multi-Use	Medium	S2M	Mat	0.7	0.4	0.014	$1.2	9.7%	$2.2
MFR	Medium	S4M	Shallow	0.1	0.6	0.013	$0.9	11.0%	$1.3
MFR	Medium	S2M	Shallow	0.1	0.6	0.013	$1.0	12.2%	$1.4
Parking Struc	Medium	C2M	Shallow	0.2	0.0	0.013	$1.4	13.0%	$1.9
MFR	Medium	C2M	Mat	0.1	0.4	0.012	$0.7	8.1%	$1.0
Offices	Small	RM1L	Mat	0.3	0.0	0.012	$0.4	8.7%	$0.7
MFR	Medium	S4M	Mat	0.1	0.5	0.011	$0.7	8.4%	$1.0
Offices	Small	S2L	Shallow	0.4	0.0	0.011	$0.6	14.3%	$1.0
MFR	Medium	S2M	Mat	0.1	0.5	0.011	$0.8	9.7%	$1.1
Offices	Small	S2L	Mat	0.3	0.0	0.008	$0.5	12.1%	$0.8
MFR	Small	RM1L	Mat	0.0	0.1	0.005	$0.2	8.8%	$0.3
Parking Struc	Medium	C1M	Mat	0.1	0.0	0.005	$1.2	11.4%	$1.5
MFR	Small	S2L	Shallow	0.0	0.2	0.005	$0.4	15.0%	$0.5
Offices	Small	W2	Shallow	0.3	0.0	0.005	$0.5	12.0%	$0.9
MFR	Small	S2L	Mat	0.0	0.1	0.004	$0.3	12.8%	$0.4
Parking Struc	Medium	C2M	Mat	0.1	0.0	0.003	$0.9	8.5%	$1.2
MFR	Small	W2	Shallow	0.0	0.1	0.002	$0.3	12.5%	$0.4
Offices	Small	W2	Mat	0.1	0.0	0.001	$0.4	9.1%	$0.7
MFR	Small	W2	Mat	0.0	0.1	0.001	$0.2	9.6%	$0.3

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

Table 4: Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 3

Use	Size	HAZUS Model Bldg Type	Foundation	*Total Casualties Day*	*Total Casualties Night*	Max Total Deaths *(Day or Night)*	*Total Building Damage (M$)*	*Loss Ratio*	*Total Economic Loss ($M)*
Hotel	Large	S1H	Shallow	5.0	10.1	0.168	$12.7	13.9%	$24.5
Hotel	Large	S1H	Mat	5.0	10.1	0.168	$12.7	13.8%	$24.5
Offices	Large	S1H	Shallow	9.3	0.5	0.155	$6.5	13.8%	$11.1
Offices	Large	S1H	Mat	9.3	0.5	0.155	$6.5	13.8%	$11.1
Hotel	Large	C1H	Shallow	3.2	6.4	0.128	$7.4	8.1%	$14.7
Hotel	Large	C1H	Mat	3.2	6.4	0.128	$7.4	8.1%	$14.7
Offices	Large	C1H	Shallow	5.9	0.3	0.118	$3.8	8.1%	$6.9
Offices	Large	C1H	Mat	5.9	0.3	0.118	$3.8	8.1%	$6.9
MFR	Large	S1H	Shallow	0.8	4.0	0.067	$4.8	13.8%	$6.3
MFR	Large	S1H	Mat	0.8	4.0	0.067	$4.8	13.8%	$6.3
Hotel	Large	C2H	Shallow	2.1	4.1	0.053	$6.0	6.6%	$12.0
Hotel	Large	C2H	Mat	2.1	4.1	0.053	$6.0	6.6%	$12.0
MFR	Large	C1H	Shallow	0.5	2.5	0.051	$2.8	8.1%	$3.8
MFR	Large	C1H	Mat	0.5	2.5	0.051	$2.8	8.1%	$3.8
Offices	Large	C2H	Shallow	3.8	0.2	0.049	$3.2	6.8%	$6.1
Offices	Large	C2H	Mat	3.8	0.2	0.049	$3.2	6.8%	$6.1
Hotel	Large	S2H	Shallow	2.4	4.8	0.047	$7.0	7.7%	$14.2
Hotel	Large	S2H	Mat	2.4	4.8	0.047	$7.0	7.7%	$14.2
Offices	Large	S2H	Shallow	4.5	0.2	0.044	$3.7	7.8%	$6.7
Offices	Large	S2H	Mat	4.5	0.2	0.044	$3.7	7.8%	$6.7
MFR	Large	C2H	Shallow	0.3	1.7	0.021	$2.3	6.6%	$3.3
MFR	Large	C2H	Mat	0.3	1.7	0.021	$2.3	6.6%	$3.3
Hotel	Medium	S4M	Shallow	0.6	1.2	0.019	$1.9	6.8%	$3.6
Hotel	Medium	S4M	Mat	0.6	1.2	0.019	$1.9	6.8%	$3.6
MFR	Large	S2H	Shallow	0.4	1.9	0.019	$2.7	7.7%	$3.7
MFR	Large	S2H	Mat	0.4	1.9	0.019	$2.7	7.7%	$3.7
Offices	Medium	S4M	Shallow	1.1	0.1	0.018	$1.1	7.0%	$2.2
Offices	Medium	S4M	Mat	1.1	0.1	0.018	$1.1	7.0%	$2.2
Hotel	Medium	S2M	Shallow	0.6	1.1	0.018	$2.3	8.2%	$4.1
Hotel	Medium	S2M	Mat	0.6	1.1	0.018	$2.3	8.2%	$4.1
Offices	Medium	S2M	Shallow	1.1	0.1	0.017	$1.3	8.1%	$2.4
Offices	Medium	S2M	Mat	1.1	0.1	0.017	$1.3	8.1%	$2.4
Hotel	Medium	C2M	Shallow	0.4	0.7	0.010	$1.8	6.5%	$3.2
Hotel	Medium	C2M	Mat	0.4	0.7	0.010	$1.8	6.5%	$3.2

Use	Size	HAZUS Model Bldg Type	Foundation	*Total Casualties Day*	*Total Casualties Night*	Max Total Deaths *(Day or Night)*	*Total Building Damage (M$)*	*Loss Ratio*	*Total Economic Loss ($M)*
Offices	Medium	C2M	Shallow	0.7	0.0	0.010	$1.1	6.6%	$2.1
Offices	Medium	C2M	Mat	0.7	0.0	0.010	$1.1	6.6%	$2.1
Multi-Use	Medium	S4M	Shallow	0.6	0.3	0.009	$0.9	7.0%	$1.7
Multi-Use	Medium	S4M	Mat	0.6	0.3	0.009	$0.9	7.0%	$1.7
Multi-Use	Medium	S2M	Shallow	0.5	0.3	0.008	$1.0	8.2%	$1.8
Multi-Use	Medium	S2M	Mat	0.5	0.3	0.008	$1.0	8.2%	$1.8
Offices	Small	RM1L	Shallow	0.2	0.0	0.007	$0.3	7.8%	$0.6
Offices	Small	RM1L	Mat	0.2	0.0	0.007	$0.3	7.8%	$0.6
MFR	Medium	S4M	Shallow	0.1	0.4	0.007	$0.6	6.8%	$0.8
MFR	Medium	S4M	Mat	0.1	0.4	0.007	$0.6	6.8%	$0.8
MFR	Medium	S2M	Shallow	0.1	0.4	0.006	$0.7	8.2%	$1.0
MFR	Medium	S2M	Mat	0.1	0.4	0.006	$0.7	8.2%	$1.0
Offices	Small	S2L	Shallow	0.3	0.0	0.005	$0.5	11.3%	$0.8
Offices	Small	S2L	Mat	0.3	0.0	0.005	$0.5	11.3%	$0.8
Multi-Use	Medium	C2M	Shallow	0.3	0.2	0.005	$0.8	6.6%	$1.5
Multi-Use	Medium	C2M	Mat	0.3	0.2	0.005	$0.8	6.6%	$1.5
MFR	Medium	C2M	Shallow	0.1	0.3	0.004	$0.5	6.5%	$0.8
MFR	Medium	C2M	Mat	0.1	0.3	0.004	$0.5	6.5%	$0.8
MFR	Small	RM1L	Shallow	0.0	0.1	0.003	$0.2	7.9%	$0.3
MFR	Small	RM1L	Mat	0.0	0.1	0.003	$0.2	7.9%	$0.3
Parking Struc	Medium	C1M	Shallow	0.1	0.0	0.003	$1.0	9.8%	$1.3
Parking Struc	Medium	C1M	Mat	0.1	0.0	0.003	$1.0	9.8%	$1.3
MFR	Small	S2L	Shallow	0.0	0.1	0.002	$0.3	11.9%	$0.4
MFR	Small	S2L	Mat	0.0	0.1	0.002	$0.3	11.9%	$0.4
Parking Struc	Medium	C2M	Shallow	0.1	0.0	0.001	$0.7	6.9%	$1.0
Parking Struc	Medium	C2M	Mat	0.1	0.0	0.001	$0.7	6.9%	$1.0
Offices	Small	W2	Shallow	0.1	0.0	0.000	$0.3	8.2%	$0.6
Offices	Small	W2	Mat	0.1	0.0	0.000	$0.3	8.2%	$0.6
MFR	Small	W2	Shallow	0.0	0.0	0.000	$0.2	8.7%	$0.3
MFR	Small	W2	Mat	0.0	0.0	0.000	$0.2	8.7%	$0.3

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

Table 5: Impacts to Prototypical Buildings Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 2

Use	Size	HAZUS Model Bldg Type	Foun-dation	*Total Casualties Day*	*Total Casualties Night*	Max Total Deaths *(Day or Night)*	*Total Building Damage ($M)*	*Loss Ratio*	*Total Economic Loss ($M)*
Hotel	Large	S1H	Shallow	5.1	10.1	0.169	$12.8	13.9%	$24.6
Hotel	Large	S1H	Mat	5.0	10.1	0.168	$12.7	13.9%	$24.5
Offices	Large	S1H	Shallow	9.4	0.5	0.156	$6.5	13.9%	$11.2
Offices	Large	S1H	Mat	9.3	0.5	0.155	$6.5	13.8%	$11.1
Hotel	Large	C1H	Shallow	3.2	6.5	0.134	$7.6	8.3%	$15.0
Hotel	Large	C1H	Mat	3.2	6.4	0.128	$7.4	8.1%	$14.7
Offices	Large	C1H	Shallow	6.0	0.3	0.124	$3.9	8.3%	$7.0
Offices	Large	C1H	Mat	5.9	0.3	0.118	$3.8	8.1%	$6.9
MFR	Large	S1H	Shallow	0.8	4.0	0.068	$4.9	13.9%	$6.3
MFR	Large	S1H	Mat	0.8	4.0	0.067	$4.8	13.8%	$6.3
Hotel	Large	C2H	Shallow	2.1	4.3	0.059	$6.2	6.7%	$12.3
Offices	Large	C2H	Shallow	3.9	0.2	0.054	$3.2	6.9%	$6.3
MFR	Large	C1H	Shallow	0.5	2.6	0.054	$2.9	8.2%	$3.8
Hotel	Large	C2H	Mat	2.1	4.1	0.053	$6.0	6.6%	$12.0
MFR	Large	C1H	Mat	0.5	2.5	0.051	$2.8	8.1%	$3.8
Offices	Large	C2H	Mat	3.8	0.2	0.049	$3.2	6.8%	$6.1
Hotel	Large	S2H	Shallow	2.4	4.9	0.048	$7.1	7.8%	$14.3
Hotel	Large	S2H	Mat	2.4	4.8	0.047	$7.0	7.7%	$14.2
Offices	Large	S2H	Shallow	4.5	0.2	0.044	$3.7	7.9%	$6.8
Offices	Large	S2H	Mat	4.5	0.2	0.044	$3.7	7.8%	$6.7
MFR	Large	C2H	Shallow	0.3	1.7	0.024	$2.4	6.7%	$3.3
MFR	Large	C2H	Mat	0.3	1.7	0.021	$2.3	6.6%	$3.3
Hotel	Medium	S4M	Shallow	0.6	1.2	0.019	$1.9	6.9%	$3.6
Hotel	Medium	S4M	Mat	0.6	1.2	0.019	$1.9	6.8%	$3.6
MFR	Large	S2H	Shallow	0.4	1.9	0.019	$2.7	7.8%	$3.7
MFR	Large	S2H	Mat	0.4	1.9	0.019	$2.7	7.7%	$3.7
Offices	Medium	S4M	Shallow	1.1	0.1	0.018	$1.2	7.1%	$2.2
Offices	Medium	S4M	Mat	1.1	0.1	0.018	$1.1	7.0%	$2.2
Hotel	Medium	S2M	Shallow	0.6	1.1	0.018	$2.3	8.3%	$4.1
Hotel	Medium	S2M	Mat	0.6	1.1	0.018	$2.3	8.2%	$4.1
Offices	Medium	S2M	Shallow	1.1	0.1	0.017	$1.3	8.2%	$2.4
Offices	Medium	S2M	Mat	1.1	0.1	0.017	$1.3	8.1%	$2.4
Hotel	Medium	C2M	Shallow	0.4	0.8	0.012	$1.8	6.6%	$3.3
Offices	Medium	C2M	Shallow	0.7	0.0	0.011	$1.1	6.7%	$2.1

Use	Size	HAZUS Model Bldg Type	Foun-dation	*Total Casualties Day*	*Total Casualties Night*	Max Total Deaths *(Day or Night)*	*Total Building Damage ($M)*	*Loss Ratio*	*Total Economic Loss ($M)*
Hotel	Medium	C2M	Mat	0.4	0.7	0.010	$1.8	6.5%	$3.2
Offices	Medium	C2M	Mat	0.7	0.0	0.010	$1.1	6.6%	$2.1
Multi-Use	Medium	S4M	Shallow	0.6	0.3	0.009	$0.9	7.0%	$1.7
Multi-Use	Medium	S4M	Mat	0.6	0.3	0.009	$0.9	7.0%	$1.7
Multi-Use	Medium	S2M	Shallow	0.5	0.3	0.008	$1.0	8.3%	$1.9
Multi-Use	Medium	S2M	Mat	0.5	0.3	0.008	$1.0	8.2%	$1.8
Offices	Small	RM1L	Shallow	0.2	0.0	0.008	$0.3	7.8%	$0.6
Offices	Small	RM1L	Mat	0.2	0.0	0.007	$0.3	7.8%	$0.6
MFR	Medium	S4M	Shallow	0.1	0.4	0.007	$0.6	6.9%	$0.8
MFR	Medium	S4M	Mat	0.1	0.4	0.007	$0.6	6.8%	$0.8
MFR	Medium	S2M	Shallow	0.1	0.4	0.007	$0.7	8.3%	$1.0
MFR	Medium	S2M	Mat	0.1	0.4	0.006	$0.7	8.2%	$1.0
Multi-Use	Medium	C2M	Shallow	0.4	0.2	0.006	$0.8	6.7%	$1.5
Offices	Small	S2L	Shallow	0.3	0.0	0.005	$0.5	11.3%	$0.8
Offices	Small	S2L	Mat	0.3	0.0	0.005	$0.5	11.3%	$0.8
Multi-Use	Medium	C2M	Mat	0.3	0.2	0.005	$0.8	6.6%	$1.5
MFR	Medium	C2M	Shallow	0.1	0.3	0.004	$0.5	6.6%	$0.8
MFR	Medium	C2M	Mat	0.1	0.3	0.004	$0.5	6.5%	$0.8
MFR	Small	RM1L	Shallow	0.0	0.1	0.004	$0.2	7.9%	$0.3
MFR	Small	RM1L	Mat	0.0	0.1	0.003	$0.2	7.9%	$0.3
Parking Struc	Medium	C1M	Shallow	0.1	0.0	0.003	$1.0	9.9%	$1.3
Parking Struc	Medium	C1M	Mat	0.1	0.0	0.003	$1.0	9.8%	$1.3
MFR	Small	S2L	Shallow	0.0	0.1	0.002	$0.3	11.9%	$0.4
MFR	Small	S2L	Mat	0.0	0.1	0.002	$0.3	11.9%	$0.4
Parking Struc	Medium	C2M	Shallow	0.1	0.0	0.001	$0.7	7.0%	$1.0
Parking Struc	Medium	C2M	Mat	0.1	0.0	0.001	$0.7	6.9%	$1.0
Offices	Small	W2	Shallow	0.1	0.0	0.000	$0.3	8.2%	$0.6
Offices	Small	W2	Mat	0.1	0.0	0.000	$0.3	8.2%	$0.6
MFR	Small	W2	Shallow	0.0	0.0	0.000	$0.2	8.7%	$0.3
MFR	Small	W2	Mat	0.0	0.0	0.000	$0.2	8.7%	$0.3

Legend:

Color	Vulnerability
(green)	Low
(yellow)	Moderate
(pink)	High
(red)	Very High

Table 6: Economic Impacts to Prototypical Buildings in an IBC Design Level Earthquake-Ground Failure Hazard Zone 5

				Shaking Only			Ground Failure Only			Shaking & Ground Failure Combined		
Use	Size	HAZUS Model Bldg. Type	Foun-dation	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(includes building damage)*	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(includes building damage)*	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(includes building damage)*
MFR	Small	W2	Shallow	$0.21	11.0%	$0.29	$0.68	27.5%	$0.95	$0.79	32.0%	$1.10
MFR	Small	S2L	Shallow	$0.29	14.2%	$0.39	$0.61	24.5%	$0.85	$0.76	30.8%	$1.06
MFR	Small	RM1L	Shallow	$0.20	10.4%	$0.28	$0.83	33.6%	$1.15	$0.93	37.6%	$1.29
MFR	Small	W2	Mat	$0.21	11.0%	$0.29	$0.17	7.0%	$0.24	$0.36	14.6%	$0.50
MFR	Small	S2L	Mat	$0.29	14.2%	$0.39	$0.17	7.0%	$0.24	$0.43	17.5%	$0.58
MFR	Small	RM1L	Mat	$0.20	10.4%	$0.28	$0.17	7.0%	$0.24	$0.34	13.9%	$0.49
MFR	Medium	S2M	Shallow	$0.68	10.0%	$0.94	$2.41	29.0%	$3.39	$2.70	32.6%	$3.79
MFR	Medium	S4M	Shallow	$0.56	8.5%	$0.82	$2.41	29.0%	$3.39	$2.66	32.0%	$3.75
MFR	Medium	C2M	Shallow	$0.54	8.6%	$0.79	$3.31	39.9%	$4.55	$3.53	42.5%	$4.88
MFR	Medium	S2M	Mat	$0.68	10.0%	$0.94	$0.92	11.1%	$1.29	$1.47	17.7%	$2.05
MFR	Medium	S4M	Mat	$0.56	8.5%	$0.82	$0.92	11.1%	$1.29	$1.38	16.6%	$1.96
MFR	Medium	C2M	Mat	$0.54	8.6%	$0.79	$0.92	11.1%	$1.29	$1.35	16.3%	$1.93
MFR	Large	S2H	Shallow	$2.69	8.7%	$3.63	$11.47	32.7%	$15.96	$12.44	35.5%	$17.27
MFR	Large	S1H	Shallow	$4.85	15.2%	$6.26	$11.47	32.7%	$15.96	$13.48	38.5%	$18.54
MFR	Large	C1H	Shallow	$2.83	9.0%	$3.75	$15.75	44.9%	$21.45	$16.78	47.9%	$22.81
MFR	Large	C2H	Shallow	$2.30	7.9%	$3.22	$15.75	44.9%	$21.45	$16.53	47.2%	$22.54
MFR	Large	S2H	Mat	$2.69	8.7%	$3.63	$5.70	16.3%	$7.87	$7.62	21.7%	$10.47
MFR	Large	S1H	Mat	$4.85	15.2%	$6.26	$5.70	16.3%	$7.87	$9.27	26.4%	$12.46
MFR	Large	C1H	Mat	$2.83	9.0%	$3.75	$5.70	16.3%	$7.87	$7.76	22.1%	$10.60
MFR	Large	C2H	Mat	$2.30	7.9%	$3.22	$5.70	16.3%	$7.87	$7.34	20.9%	$10.19
Office	Small	W2	Shallow	$0.34	12.9%	$0.60	$1.12	27.2%	$2.02	$1.30	31.4%	$2.33
Office	Small	S2L	Shallow	$0.46	15.9%	$0.80	$0.99	24.1%	$1.83	$1.24	30.0%	$2.23
Office	Small	RM1L	Shallow	$0.32	12.8%	$0.62	$1.38	33.3%	$2.41	$1.54	37.3%	$2.72
Office	Small	W2	Mat	$0.34	12.9%	$0.60	$0.28	6.9%	$0.51	$0.58	14.1%	$1.04
Office	Small	S2L	Mat	$0.46	15.9%	$0.80	$0.28	6.9%	$0.51	$0.69	16.8%	$1.19
Office	Small	RM1L	Mat	$0.32	12.8%	$0.62	$0.28	6.9%	$0.51	$0.57	13.7%	$1.04

Office	Medium	S2M	Shallow	$1.33	11.6%	$2.47	$4.66	28.5%	$8.59	$5.22	32.0%	$9.59
Office	Medium	S4M	Shallow	$1.14	10.5%	$2.24	$4.66	28.5%	$8.59	$5.16	31.6%	$9.52
Office	Medium	C2M	Shallow	$1.08	10.9%	$2.15	$6.45	39.5%	$11.33	$6.89	42.2%	$12.19
Office	Medium	S2M	Mat	$1.33	11.6%	$2.47	$1.79	11.0%	$3.24	$2.85	17.5%	$5.14
Office	Medium	S4M	Mat	$1.14	10.5%	$2.24	$1.79	11.0%	$3.24	$2.71	16.6%	$4.98
Office	Medium	C2M	Mat	$1.08	10.9%	$2.15	$1.79	11.0%	$3.24	$2.66	16.3%	$4.94
Office	Large	S2H	Shallow	$3.65	9.9%	$7.17	$15.10	32.2%	$28.35	$16.41	35.0%	$30.71
Office	Large	S1H	Shallow	$6.47	16.6%	$12.04	$15.10	32.2%	$28.35	$17.78	37.9%	$32.82
Office	Large	C1H	Shallow	$3.81	9.9%	$7.32	$20.92	44.6%	$37.33	$22.30	47.5%	$39.75
Office	Large	C2H	Shallow	$3.16	9.4%	$6.40	$20.92	44.6%	$37.33	$21.99	46.9%	$39.36
Office	Large	S2H	Mat	$3.65	9.9%	$7.17	$7.53	16.1%	$13.86	$10.14	21.6%	$18.65
Office	Large	S1H	Mat	$6.47	16.6%	$12.04	$7.53	16.1%	$13.86	$12.29	26.2%	$21.98
Office	Large	C1H	Mat	$3.81	9.9%	$7.32	$7.53	16.1%	$13.86	$10.30	22.0%	$18.80
Office	Large	C2H	Mat	$3.16	9.4%	$6.40	$7.53	16.1%	$13.86	$9.79	20.9%	$18.21
Hotel	Medium	S2M	Shallow	$2.26	10.0%	$4.80	$7.99	29.1%	$14.07	$8.95	32.6%	$15.77
Hotel	Medium	S4M	Shallow	$1.86	8.5%	$4.26	$7.99	29.1%	$14.07	$8.81	32.1%	$15.60
Hotel	Medium	C2M	Shallow	$1.78	8.6%	$3.58	$10.96	39.9%	$18.30	$11.68	42.5%	$19.59
Hotel	Medium	S2M	Mat	$2.26	10.0%	$4.80	$3.06	11.1%	$5.27	$4.87	17.7%	$8.53
Hotel	Medium	S4M	Mat	$1.86	8.5%	$4.26	$3.06	11.1%	$5.27	$4.57	16.6%	$8.17
Hotel	Medium	C2M	Mat	$1.78	8.6%	$3.58	$3.06	11.1%	$5.27	$4.48	16.3%	$7.85
Hotel	Large	S2H	Shallow	$7.05	8.7%	$17.82	$30.09	32.8%	$52.98	$32.63	35.6%	$57.86
Hotel	Large	S1H	Shallow	$12.73	15.3%	$31.62	$30.09	32.8%	$52.98	$35.35	38.5%	$62.43
Hotel	Large	C1H	Shallow	$7.42	9.0%	$18.56	$41.28	45.0%	$68.91	$43.98	47.9%	$74.02
Hotel	Large	C2H	Shallow	$6.02	7.9%	$14.59	$41.28	45.0%	$68.91	$43.32	47.2%	$72.86
Hotel	Large	S2H	Mat	$7.05	8.7%	$17.82	$14.95	16.3%	$25.77	$19.99	21.8%	$35.80
Hotel	Large	S1H	Mat	$12.73	15.3%	$31.62	$14.95	16.3%	$25.77	$24.30	26.5%	$43.53
Hotel	Large	C1H	Mat	$7.42	9.0%	$18.56	$14.95	16.3%	$25.77	$20.36	22.2%	$36.33
Hotel	Large	C2H	Mat	$6.02	7.9%	$14.59	$14.95	16.3%	$25.77	$19.25	21.0%	$34.27
Multi-Use	Medium	S2M	Shallow	$1.07	11.0%	$1.64	$3.64	28.9%	$6.63	$4.08	32.4%	$7.41
Multi-Use	Medium	S4M	Shallow	$0.94	9.9%	$1.49	$3.64	28.9%	$6.63	$4.02	31.9%	$7.34
Multi-Use	Medium	C2M	Shallow	$0.84	9.8%	$1.39	$5.01	39.8%	$8.81	$5.35	42.4%	$9.42
Multi-Use	Medium	S2M	Mat	$1.07	11.0%	$1.64	$1.40	11.1%	$2.51	$2.23	17.7%	$3.98
Multi-Use	Medium	S4M	Mat	$0.94	9.9%	$1.49	$1.40	11.1%	$2.51	$2.11	16.7%	$3.84
Multi-Use	Medium	C2M	Mat	$0.84	9.8%	$1.39	$1.40	11.1%	$2.51	$2.06	16.3%	$3.73

Parking Str.	Medium	C2M	Shallow	$0.73	9.0%	$1.01	$4.40	41.5%	$5.76	$4.69	44.2%	$6.17
Parking Str.	Medium	C1M	Shallow	$1.04	11.4%	$1.29	$4.40	41.5%	$5.76	$4.82	45.5%	$6.29
Parking Str.	Medium	C2M	Mat	$0.73	9.0%	$1.01	$1.26	11.8%	$1.65	$1.84	17.3%	$2.46
Parking Str.	Medium	C1M	Mat	$1.04	11.4%	$1.29	$1.26	11.8%	$1.65	$2.09	19.7%	$2.68

Table 7: Sensitivity Test Results: Economic Impacts to Prototypical Buildings (with Mat Foundations) Subject to Ground Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

			Sensitivity Test #1 (mat foundation 2.5x "stronger")			Sensitivity Test #2 (mat foundation 7.5x "stronger")			Original Assumption (mat foundation 5x "stronger")		
Use	Size	HAZUS Model Bldg. Type	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(inc. building damage)*	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(inc. building damage)*	Total Bldg Damage ($M)	Bldg Loss Ratio	Total Direct Econ. Loss ($M) *(inc. building damage)*
MFR	Sm.	W2	$0.52	21.1%	$0.72	$0.30	12.1%	$0.41	$0.36	14.6%	$0.50
MFR	Sm.	S2L	$0.58	23.6%	$0.80	$0.37	15.1%	$0.50	$0.43	17.5%	$0.58
MFR	Sm.	RM1L	$0.51	20.6%	$0.72	$0.28	11.3%	$0.40	$0.34	13.9%	$0.49
MFR	Med.	S2M	$2.12	25.6%	$2.96	$1.18	14.2%	$1.64	$1.47	17.7%	$2.05
MFR	Med.	S4M	$2.05	24.7%	$2.88	$1.08	13.0%	$1.54	$1.38	16.6%	$1.96
MFR	Med.	C2M	$2.03	24.4%	$2.86	$1.05	12.7%	$1.51	$1.35	16.3%	$1.93
MFR	Lrg.	S2H	$10.60	30.2%	$14.58	$6.06	17.3%	$8.31	$7.62	21.7%	$10.47
MFR	Lrg.	S1H	$11.93	34.0%	$16.20	$7.87	22.4%	$10.50	$9.27	26.4%	$12.46
MFR	Lrg.	C1H	$10.73	30.6%	$14.72	$6.20	17.7%	$8.44	$7.76	22.1%	$10.60
MFR	Lrg.	C2H	$10.38	29.6%	$14.36	$5.75	16.4%	$8.00	$7.34	20.9%	$10.19
Office	Sm.	W2	$0.85	20.6%	$1.52	$0.48	11.6%	$0.85	$0.58	14.1%	$1.04
Office	Sm.	S2L	$0.94	22.9%	$1.66	$0.60	14.4%	$1.02	$0.69	16.8%	$1.19
Office	Sm.	RM1L	$0.84	20.3%	$1.53	$0.46	11.2%	$0.86	$0.57	13.7%	$1.04
Office	Med.	S2M	$4.12	25.2%	$7.43	$2.28	14.0%	$4.12	$2.85	17.5%	$5.14
Office	Med.	S4M	$4.01	24.6%	$7.31	$2.13	13.0%	$3.94	$2.71	16.6%	$4.98
Office	Med.	C2M	$3.95	24.2%	$7.26	$2.07	12.7%	$3.89	$2.66	16.3%	$4.94
Office	Lrg.	S2H	$14.05	29.9%	$25.82	$8.09	17.2%	$14.88	$10.14	21.6%	$18.65
Office	Lrg.	S1H	$15.80	33.7%	$28.53	$10.44	22.3%	$18.54	$12.29	26.2%	$21.98
Office	Lrg.	C1H	$14.22	30.3%	$26.00	$8.25	17.6%	$15.02	$10.30	22.0%	$18.80
Office	Lrg.	C2H	$13.78	29.4%	$25.48	$7.70	16.4%	$14.39	$9.79	20.9%	$18.21
Hotel	Med.	S2M	$7.03	25.6%	$12.22	$3.90	14.2%	$6.87	$4.87	17.7%	$8.53
Hotel	Med.	S4M	$6.80	24.8%	$11.93	$3.57	13.0%	$6.47	$4.57	16.6%	$8.17
Hotel	Med.	C2M	$6.72	24.5%	$11.66	$3.48	12.7%	$6.13	$4.48	16.3%	$7.85
Hotel	Lrg.	S2H	$27.79	30.3%	$48.85	$15.89	17.3%	$28.95	$19.99	21.8%	$35.80
Hotel	Lrg.	S1H	$31.29	34.1%	$54.99	$20.63	22.5%	$37.50	$24.30	26.5%	$43.53

Hotel	Lrg.	C1H	$28.14	30.7%	$49.36	$16.27	17.7%	$29.49	$20.36	22.2%	$36.33
Hotel	Lrg.	C2H	$27.21	29.7%	$47.67	$15.07	16.4%	$27.23	$19.25	21.0%	$34.27
Multi-Use	Med.	S2M	$3.21	25.5%	$5.75	$1.78	14.2%	$3.19	$2.23	17.7%	$3.98
Multi-Use	Med.	S4M	$3.12	24.7%	$5.64	$1.65	13.1%	$3.03	$2.11	16.7%	$3.84
Multi-Use	Med.	C2M	$3.07	24.4%	$5.54	$1.60	12.7%	$2.91	$2.06	16.3%	$3.73
Parking Str.	Med.	C2M	$2.75	26.0%	$3.66	$1.42	13.4%	$1.92	$1.84	17.3%	$2.46
Parking Str.	Med.	C1M	$2.96	27.9%	$3.84	$1.70	16.0%	$2.16	$2.09	19.7%	$2.68

Table 8: Sensitivity Test Results: Expected Deaths and Total Casualties in Prototypical Buildings (with Mat Foundations) Subject to Ground Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

				Sensitivity Test #1 (mat foundation 2.5x "stronger")		Sensitivity Test #2 (mat foundation 7.5x "stronger")		Original Assumption (mat foundation 5x "stronger")	
Use	Size	HAZUS Model Bldg. Type	Time of Day for Expected Max. # of Casualties	Max. # Deaths	Max. # Total Casualties (Includes Deaths)	Max. # Deaths	Max. # Total Casualties (Includes Deaths)	Max. # Deaths	Max. # Total Casualties (Includes Deaths)
MFR	Sm	W2	Night	0.0	0.3	0.0	0.1	0.0	0.2
MFR	Sm	S2L	Night	0.0	0.4	0.0	0.2	0.0	0.3
MFR	Sm	RM1L	Night	0.0	0.5	0.0	0.2	0.0	0.3
MFR	Med	S2M	Night	0.1	1.6	0.0	0.8	0.0	1.1
MFR	Med	S4M	Night	0.1	1.6	0.0	0.8	0.0	1.1
MFR	Med	C2M	Night	0.1	1.8	0.0	0.8	0.1	1.1
MFR	Lrg	S2H	Night	0.2	6.7	0.1	4.0	0.1	4.9
MFR	Lrg	S1H	Night	0.2	8.2	0.1	5.8	0.1	6.6
MFR	Lrg	C1H	Night	0.3	7.8	0.1	4.8	0.2	5.8
MFR	Lrg	C2H	Night	0.2	7.1	0.1	4.0	0.2	5.1
Office	Sm	W2	Day	0.0	0.6	0.0	0.2	0.0	0.4
Office	Sm	S2L	Day	0.0	0.9	0.0	0.4	0.0	0.6
Office	Sm	RM1L	Day	0.1	1.0	0.0	0.4	0.0	0.6
Office	Med	S2M	Day	0.1	4.1	0.1	2.1	0.1	2.7
Office	Med	S4M	Day	0.1	4.2	0.1	2.2	0.1	2.8
Office	Med	C2M	Day	0.3	4.7	0.1	2.1	0.1	2.9
Office	Lrg	S2H	Day	0.4	15.4	0.2	9.1	0.2	11.3
Office	Lrg	S1H	Day	0.5	18.9	0.3	13.4	0.3	15.3
Office	Lrg	C1H	Day	0.6	17.9	0.3	11.0	0.4	13.4
Office	Lrg	C2H	Day	0.6	16.4	0.3	9.2	0.4	11.7
Hotel	Med	S2M	Night	0.1	4.4	0.1	2.2	0.1	2.9
Hotel	Med	S4M	Night	0.2	4.4	0.1	2.3	0.1	2.9
Hotel	Med	C2M	Night	0.3	5.0	0.1	2.2	0.2	3.1
Hotel	Lrg	S2H	Night	0.4	16.7	0.2	9.9	0.3	12.2
Hotel	Lrg	S1H	Night	0.5	20.4	0.3	14.5	0.4	16.5
Hotel	Lrg	C1H	Night	0.7	19.4	0.4	11.9	0.5	14.5

Hotel	Lrg	C2H	Night	0.6	17.8	0.3	10.0	0.4	12.6
Multi-Use	Med	S2M	Day	0.1	2.1	0.0	1.0	0.0	1.4
Multi-Use	Med	S4M	Day	0.1	2.1	0.0	1.1	0.0	1.4
Multi-Use	Med	C2M	Day	0.1	2.3	0.0	1.0	0.1	1.4
Parking Str.	Med.	C2M	Day	0.0	0.4	0.0	0.2	0.0	0.3
Parking Str.	Med.	C1M	Day	0.0	0.5	0.0	0.2	0.0	0.3

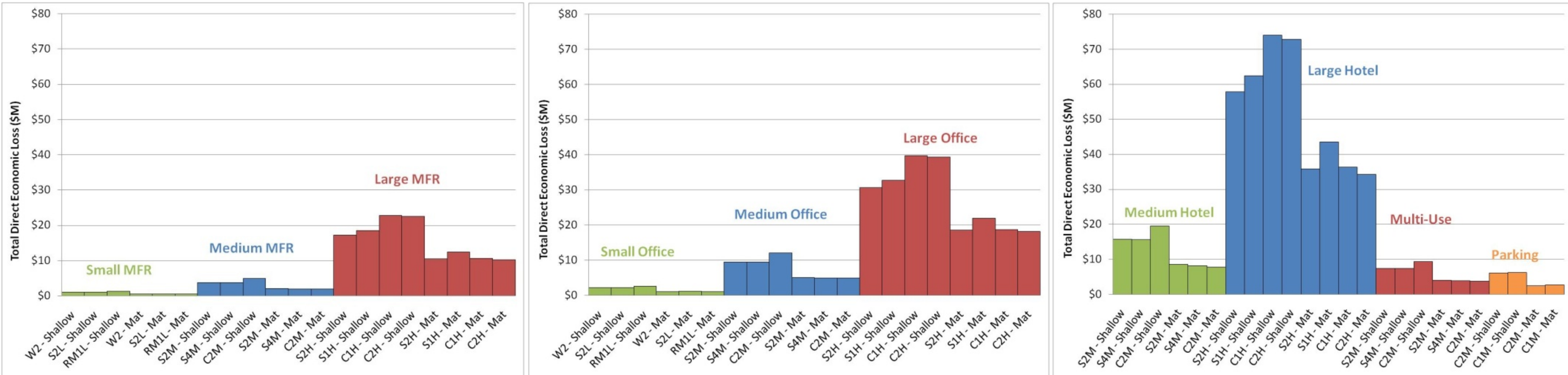


Figure 1: Total Direct Economic Losses Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

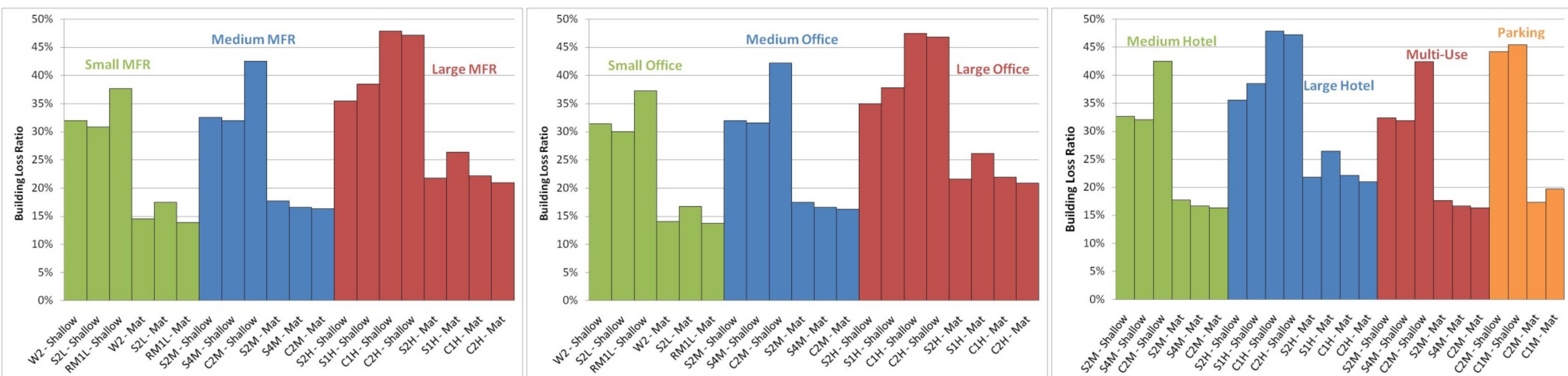


Figure 2: Building Loss Ratio Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

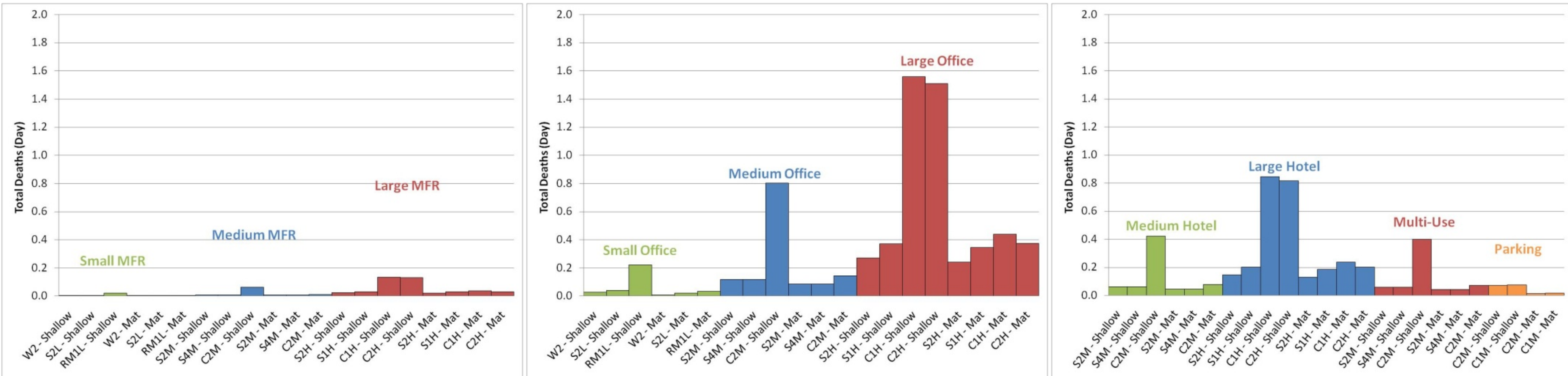


Figure 3: Total Day Time Deaths Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

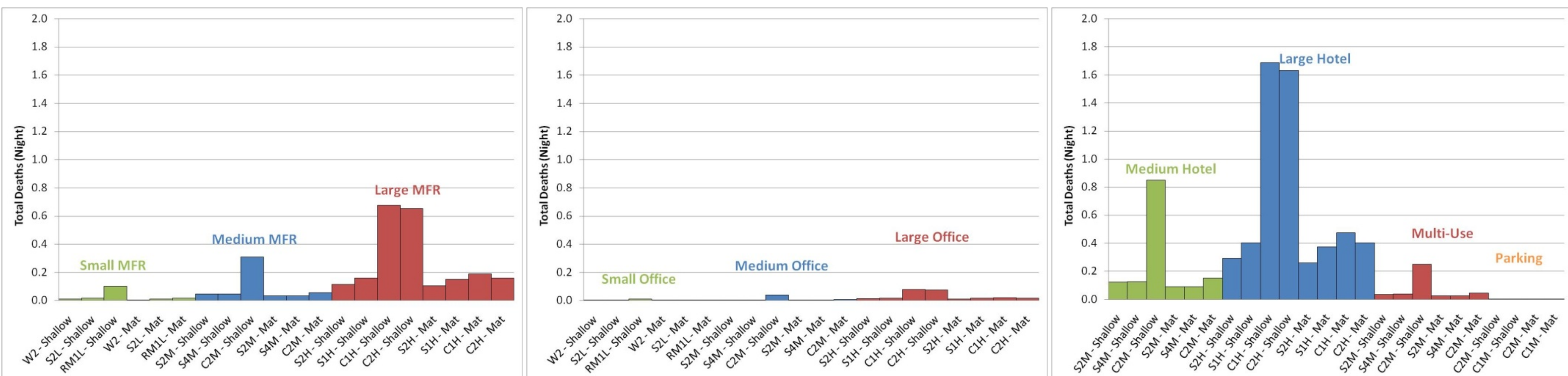


Figure 4: Total Night Time Deaths Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

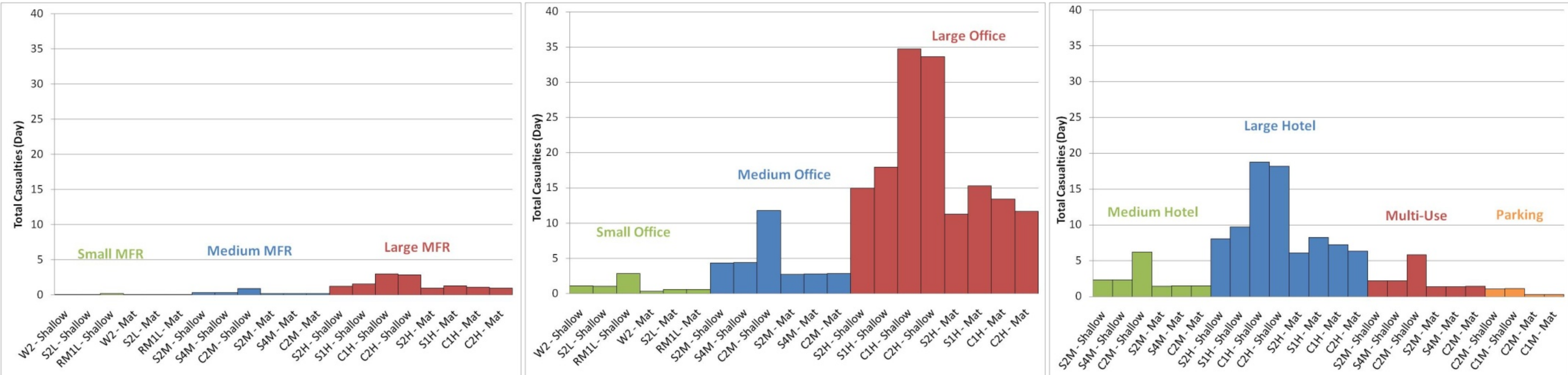


Figure 5: Total Day Time Casualties Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

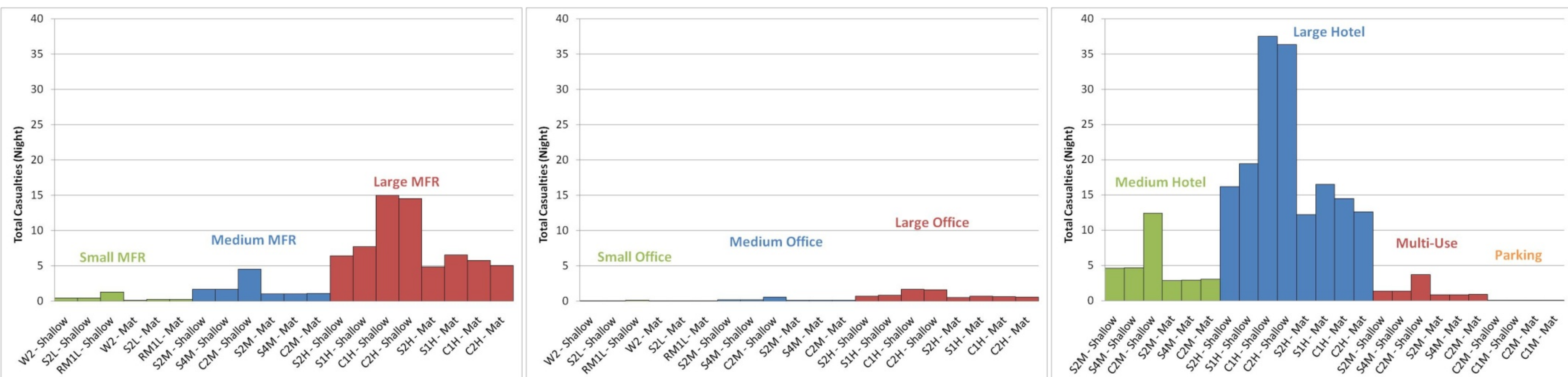


Figure 6: Total Night Time Casualties Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

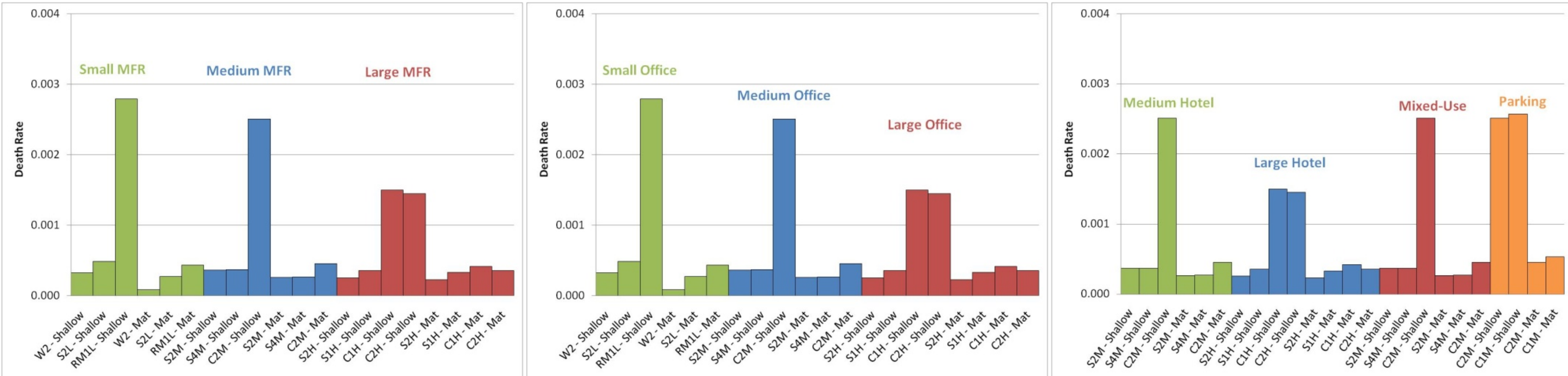


Figure 7: Death Rate Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

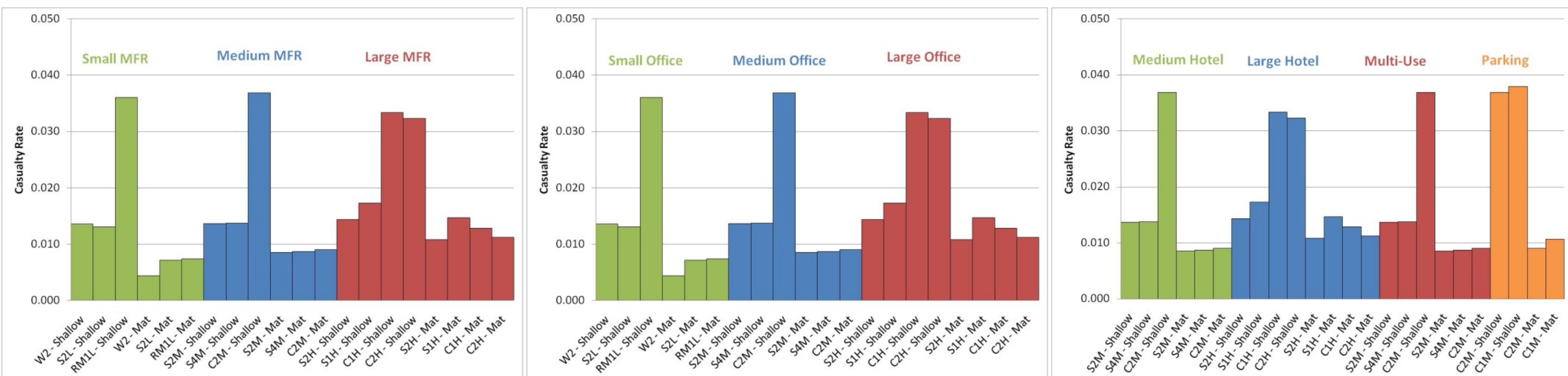


Figure 8: Casualty Rate Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

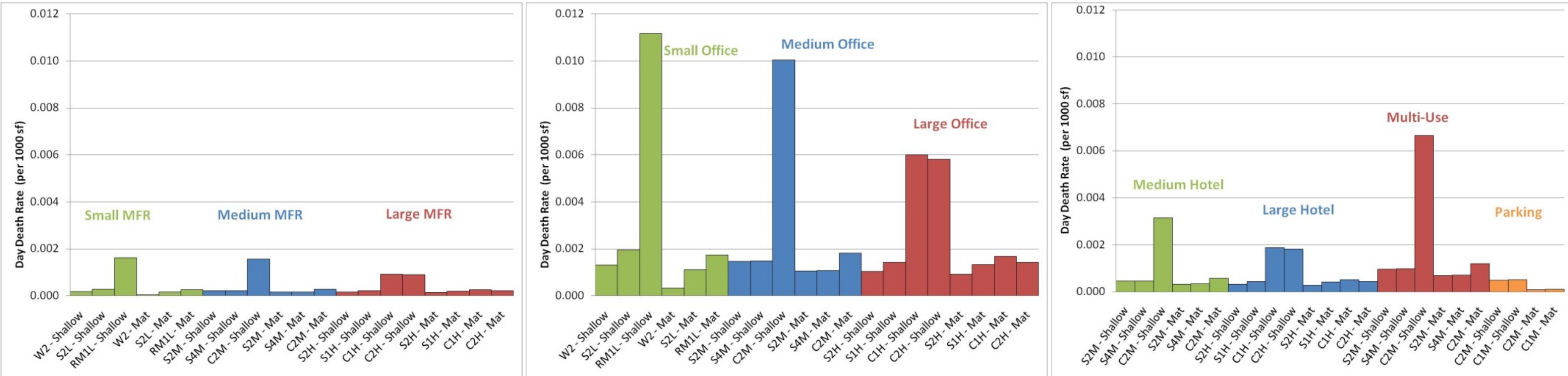


Figure 9: Day Death Rate per 1000 Square Feet Due to Shaking & Ground Failure in an IBC Design Level Earthquake- Ground Failure Hazard Zone 5

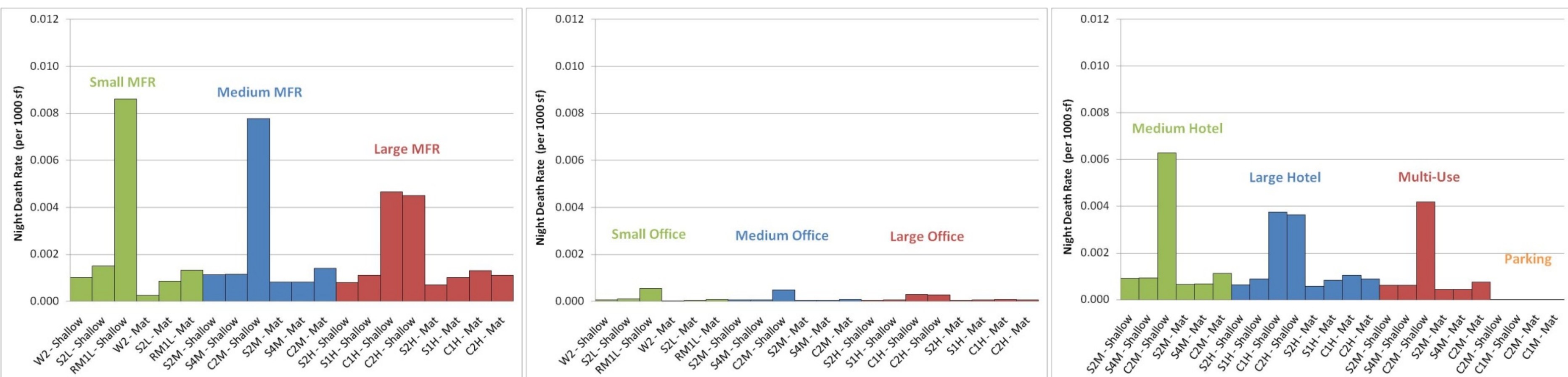


Figure 10: Night Death Rate per 1000 Square Feet Due to Shaking & Ground Failure in an IBC Design Level Earthquake - Ground Failure Hazard Zone 5

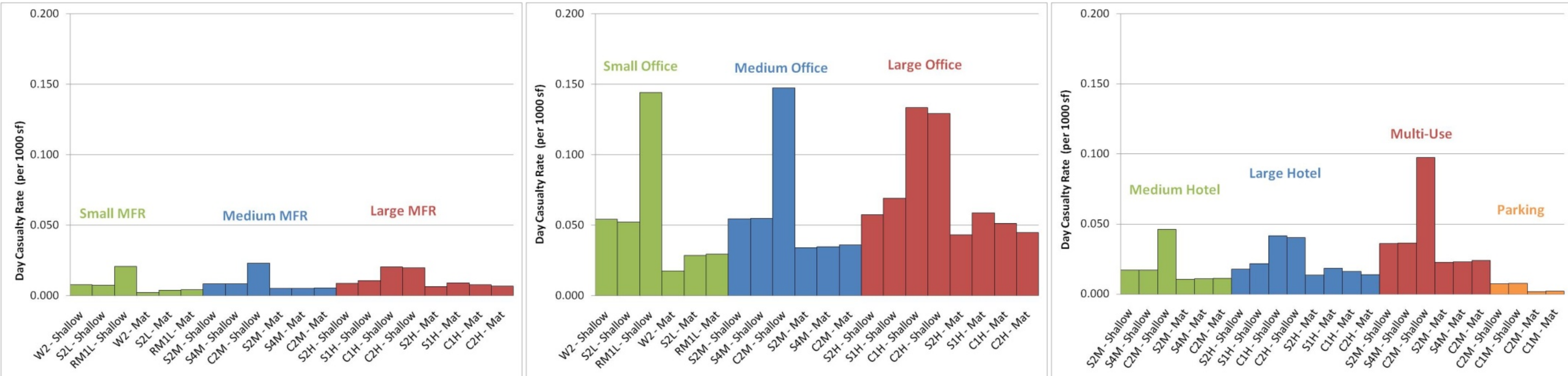


Figure 11: Day Casualty Rate per 1000 Square Feet Due to Shaking & Ground Failure in an IBC Design Level Earthquake - Ground Failure Hazard Zone 5

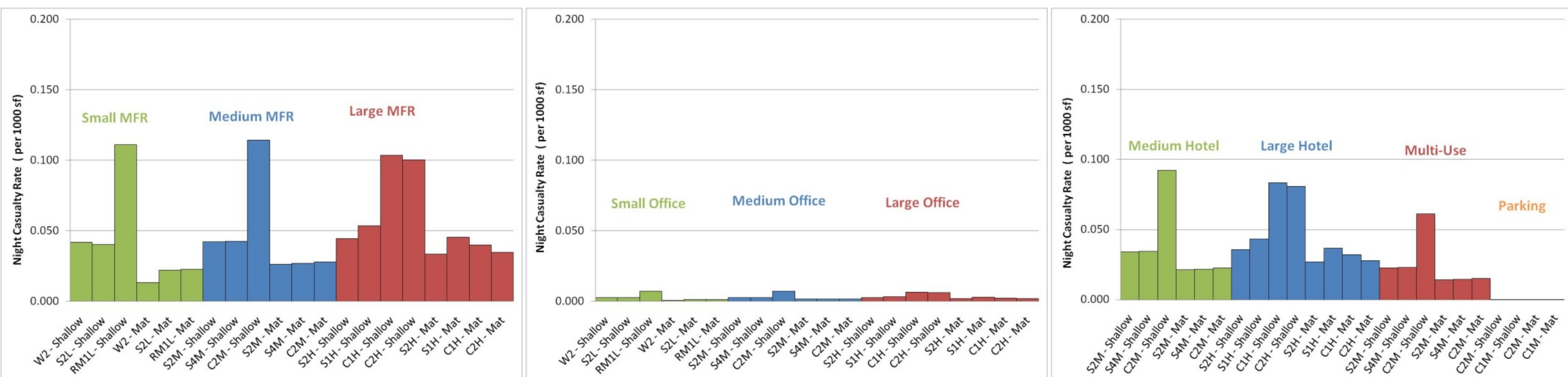


Figure 12: Night Casualty Rate per 1000 Square Feet Due to Shaking & Ground Failure in an IBC Design Level Earthquake - Ground Failure Hazard Zone 5

Figure 13: Total Direct Economic Loss for Prototypical Building #1 (Small Multi-Family Residential) due to Shaking and Ground Failure in an IBC Design Level Earthquake

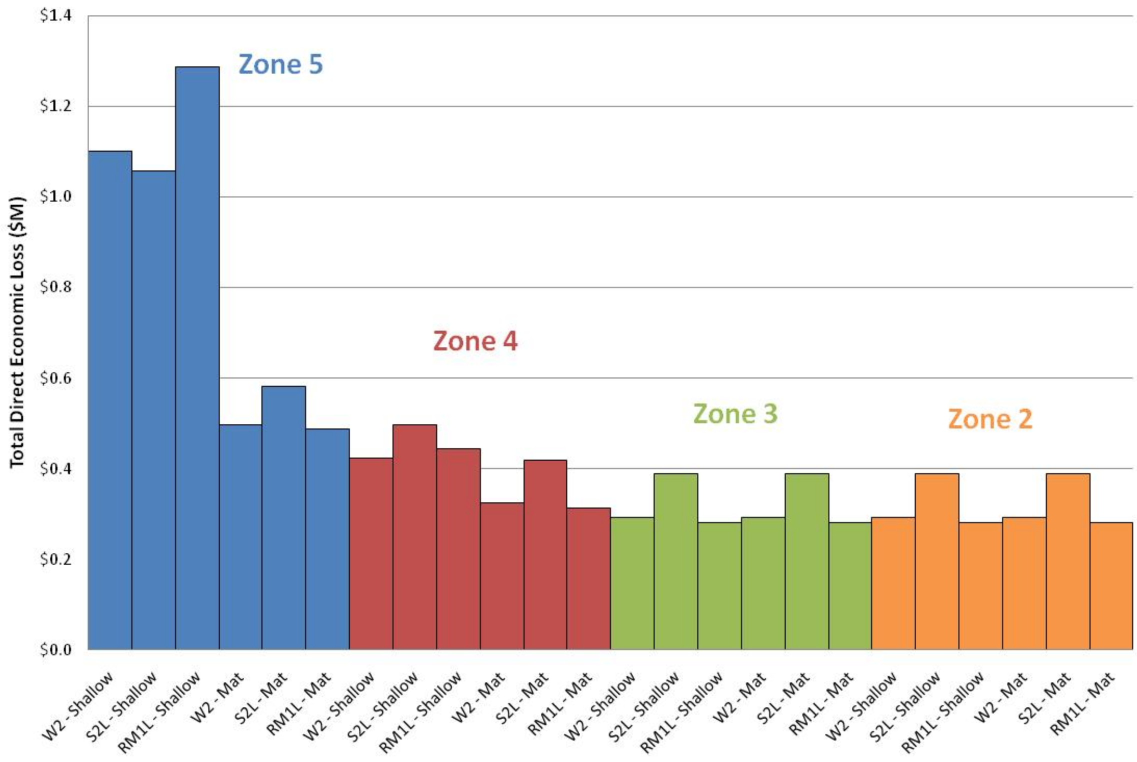
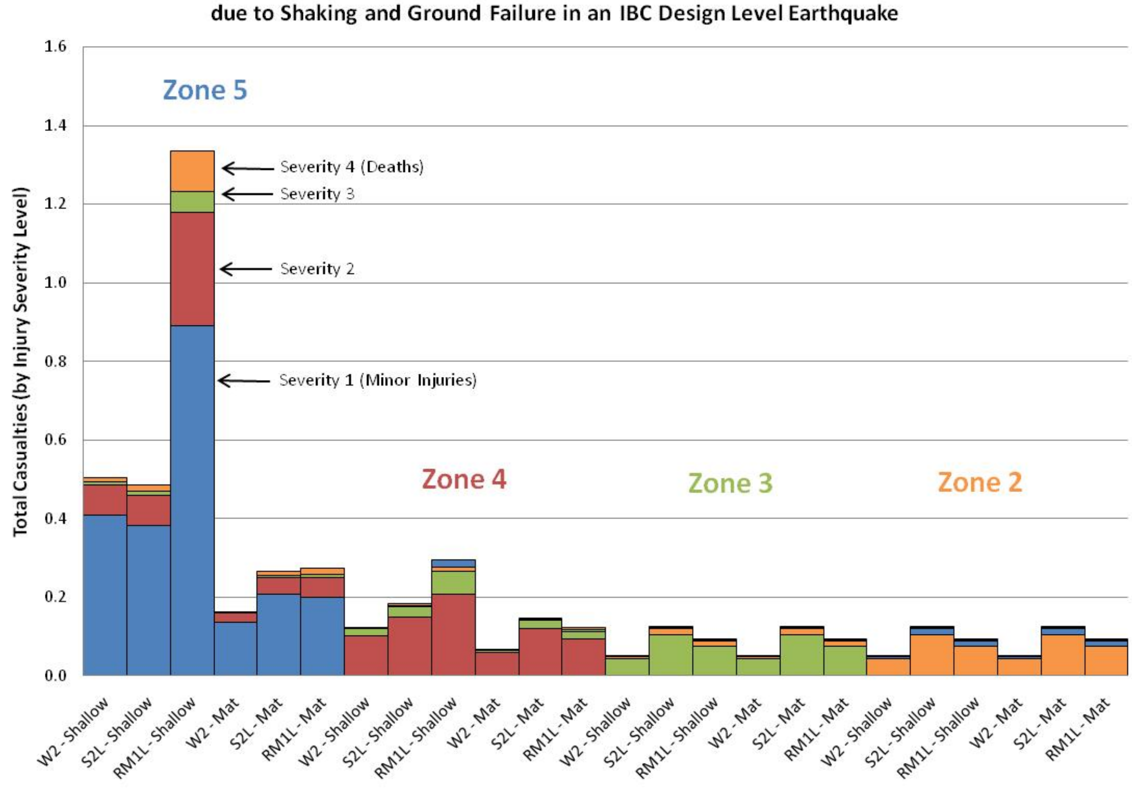


Figure 14: Total Night Casualties for Prototypical Building #1 (Small Multi-Family Residential) due to Shaking and Ground Failure in an IBC Design Level Earthquake



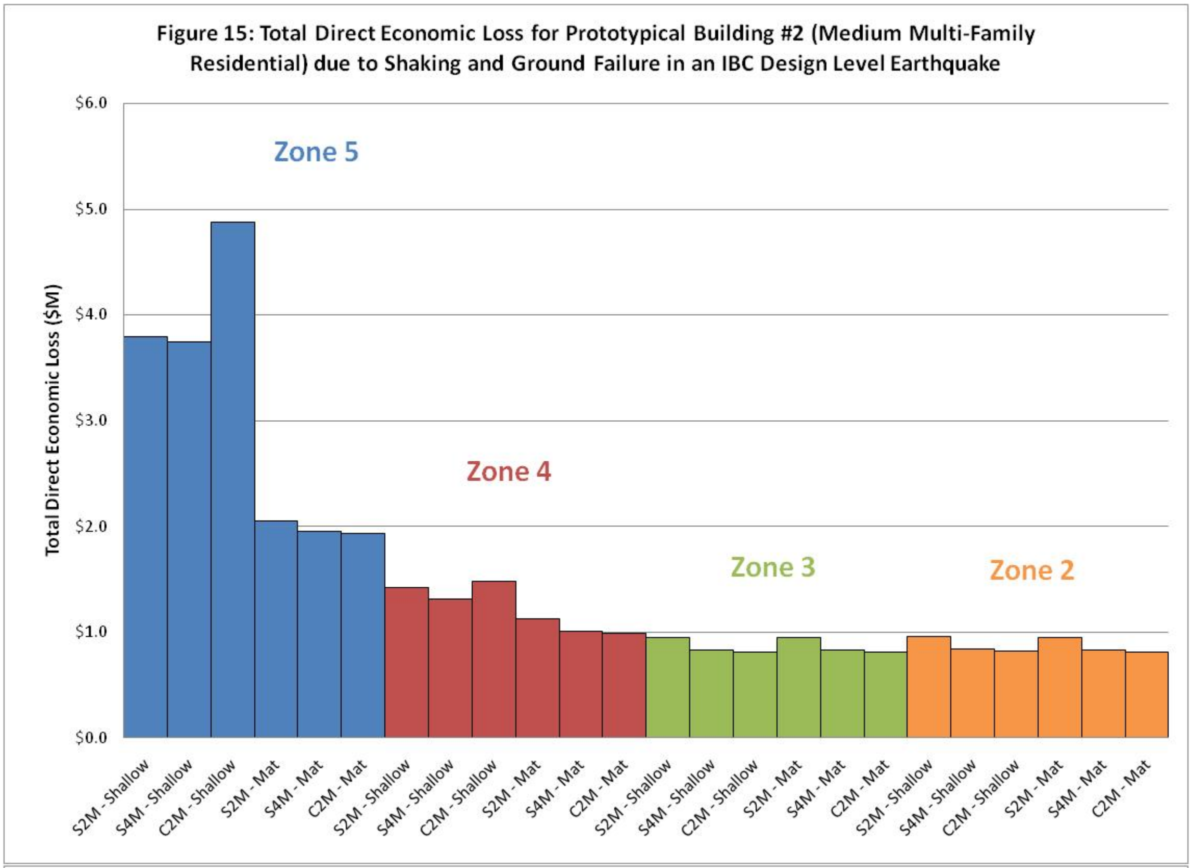


Figure 15: Total Direct Economic Loss for Prototypical Building #2 (Medium Multi-Family Residential) due to Shaking and Ground Failure in an IBC Design Level Earthquake
Total Direct Economic Loss ($M)
$0.0
$1.0
$2.0
$3.0
$4.0
$5.0
$6.0
Zone 5
Zone 4
Zone 3
Zone 2
S2M - Shallow
S4M - Shallow
C2M - Shallow
S2M - Mat
S4M - Mat
C2M - Mat

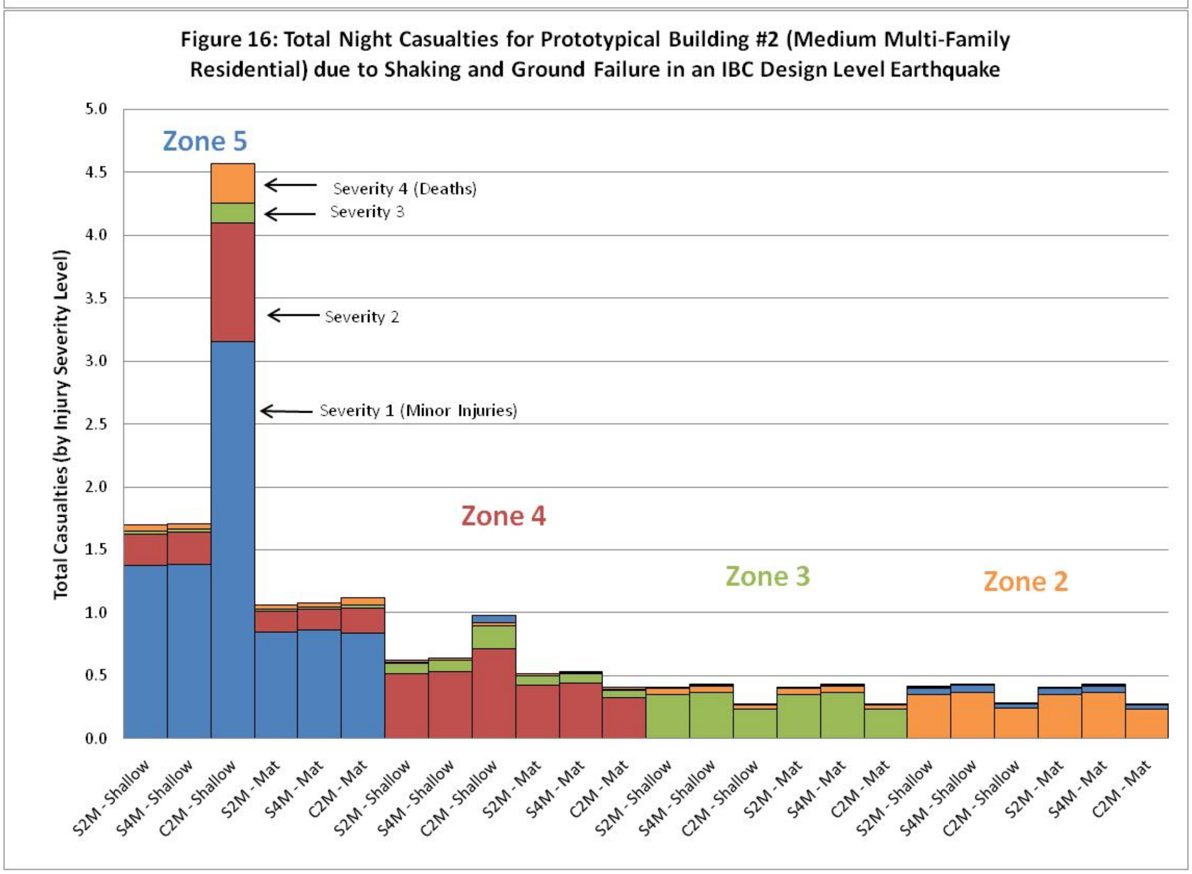


Figure 16: Total Night Casualties for Prototypical Building #2 (Medium Multi-Family Residential) due to Shaking and Ground Failure in an IBC Design Level Earthquake
Total Casualties (by Injury Severity Level)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Zone 5
Zone 4
Zone 3
Zone 2
Severity 4 (Deaths)
Severity 3
Severity 2
Severity 1 (Minor Injuries)
S2M - Shallow
S4M - Shallow
C2M - Shallow
S2M - Mat
S4M - Mat
C2M - Mat

Figure 17: Total Direct Economic Loss for Prototypical Building #3 (Large Multi-Family Residential) due to Shaking and Ground Failure in an IBC Design Level Earthquake

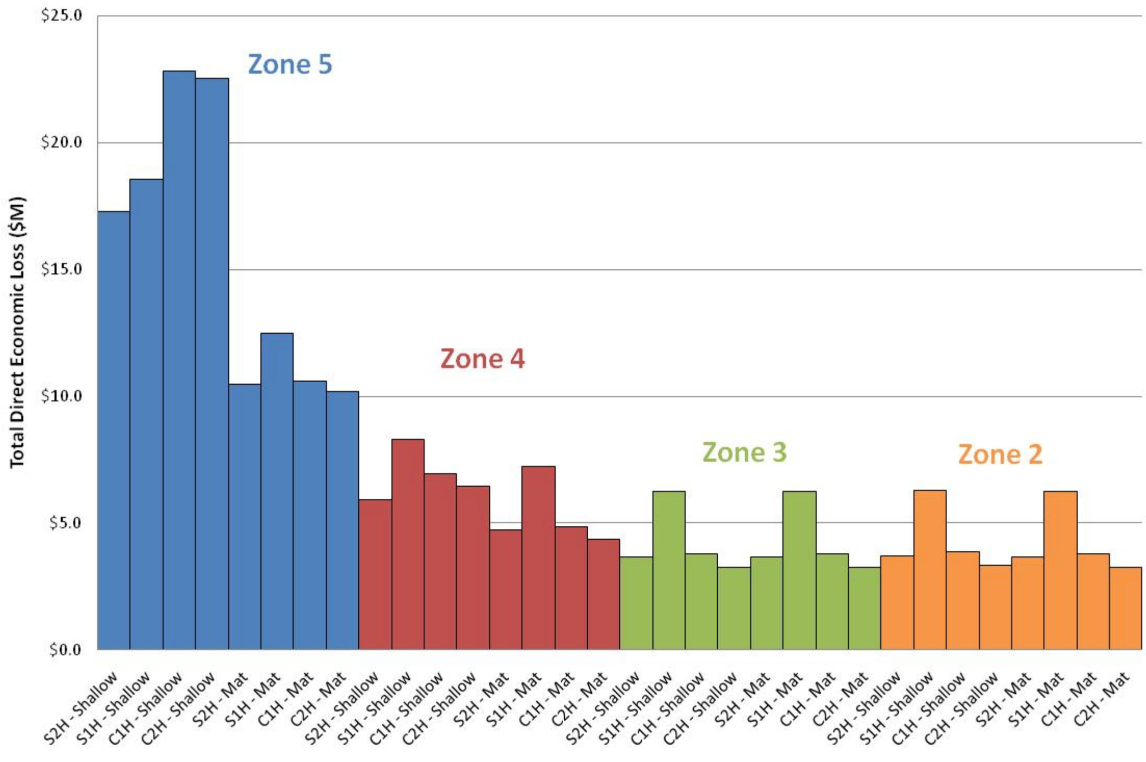


Figure 18: Total Night Casualties for Prototypical Building #3 (Large Multi-Family Residential) due to Shaking and Ground Failure in an IBC Design Level Earthquake

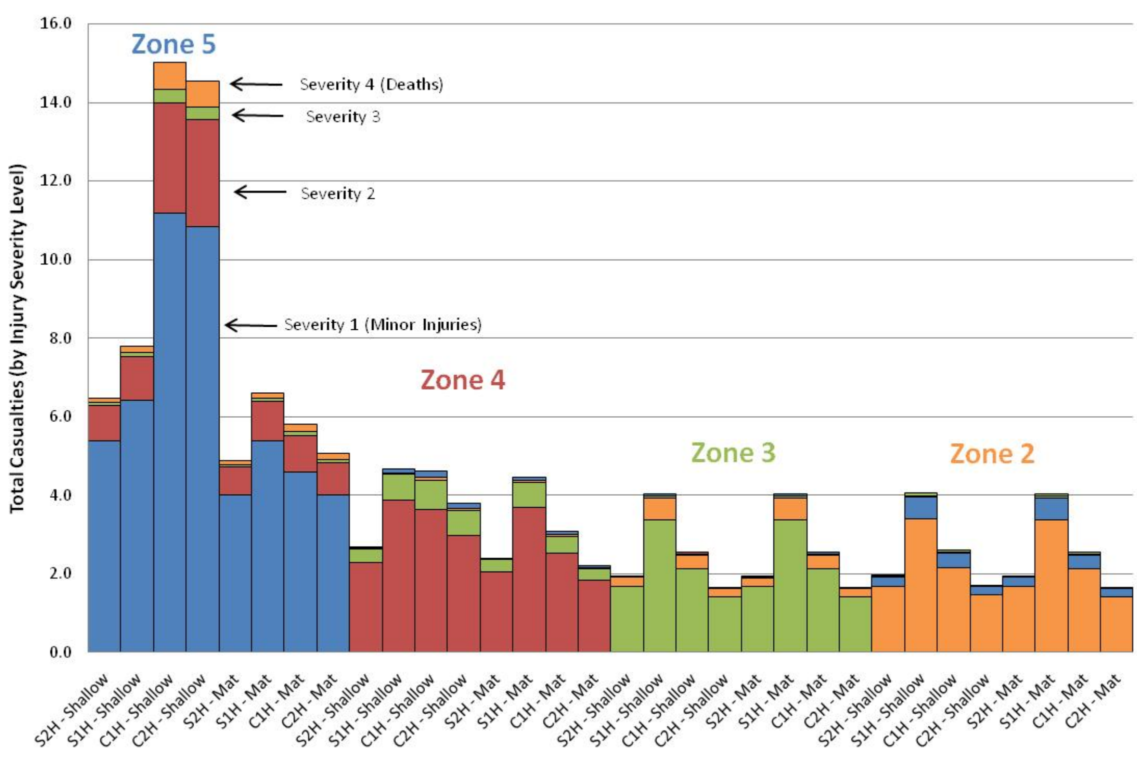


Figure 19: Total Direct Economic Loss for Prototypical Building #4 (Small Offices) due to Shaking and Ground Failure in an IBC Design Level Earthquake

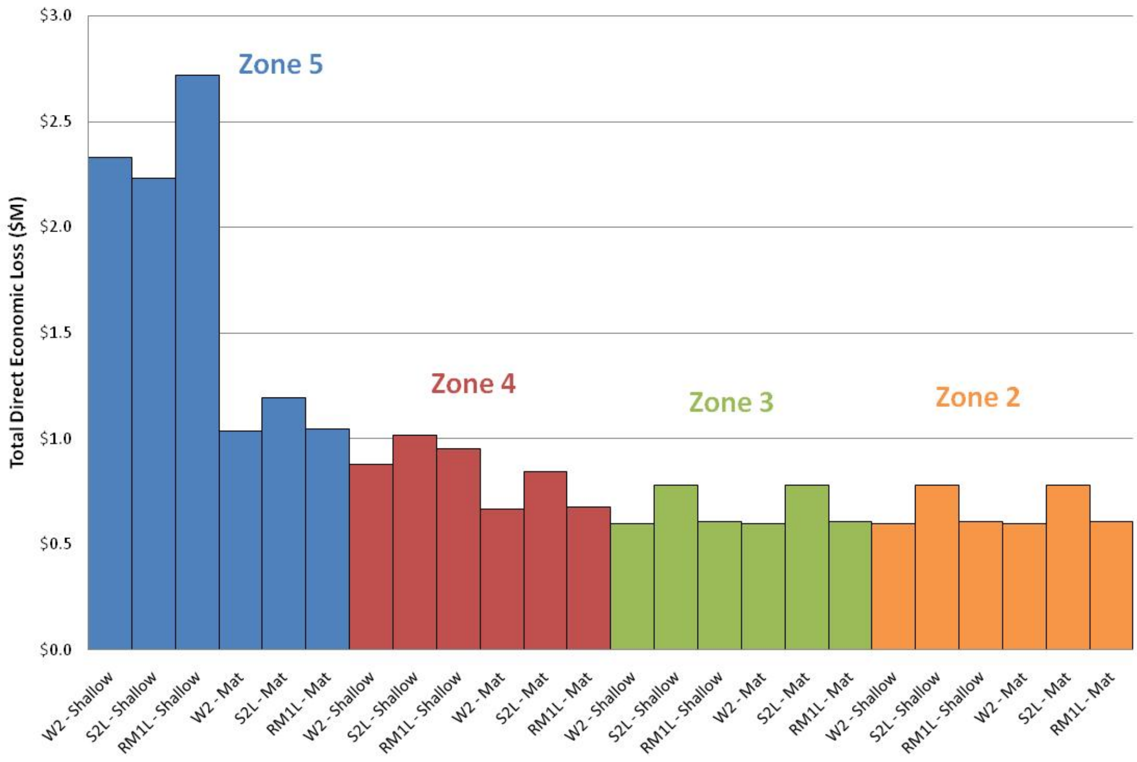
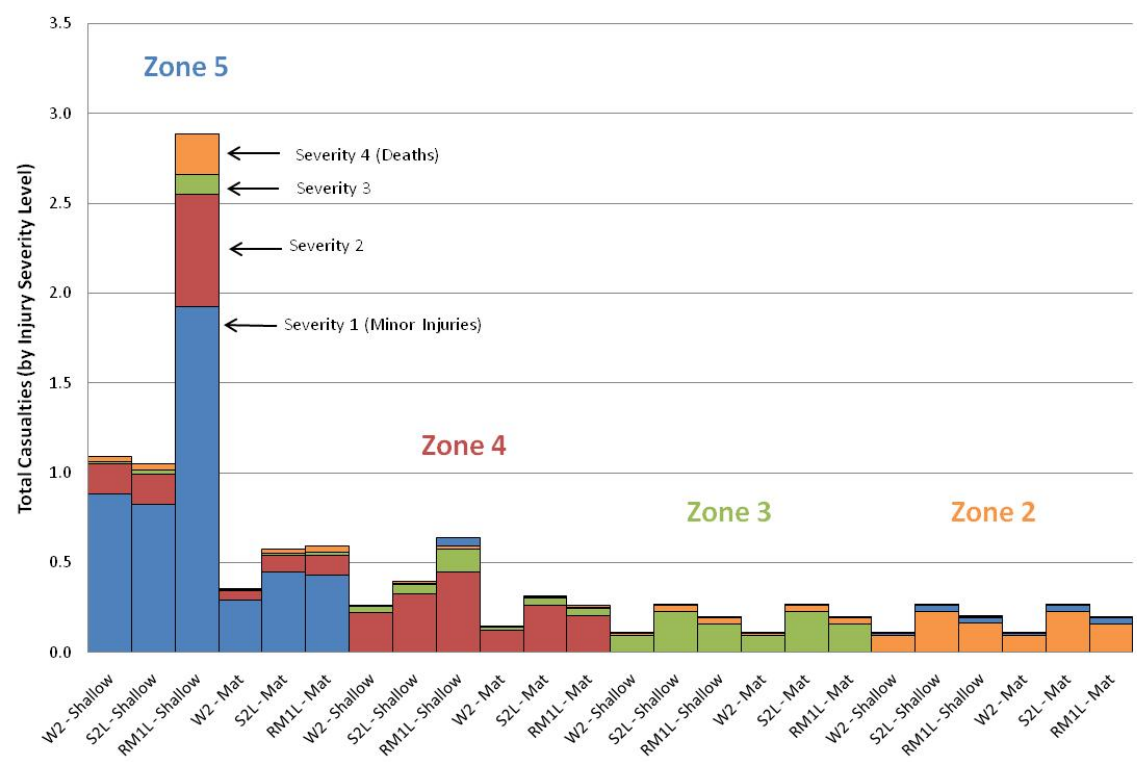


Figure 20: Total Day Casualties for Prototypical Building #4 (Small Offices) due to Shaking and Ground Failure in an IBC Design Level Earthquake



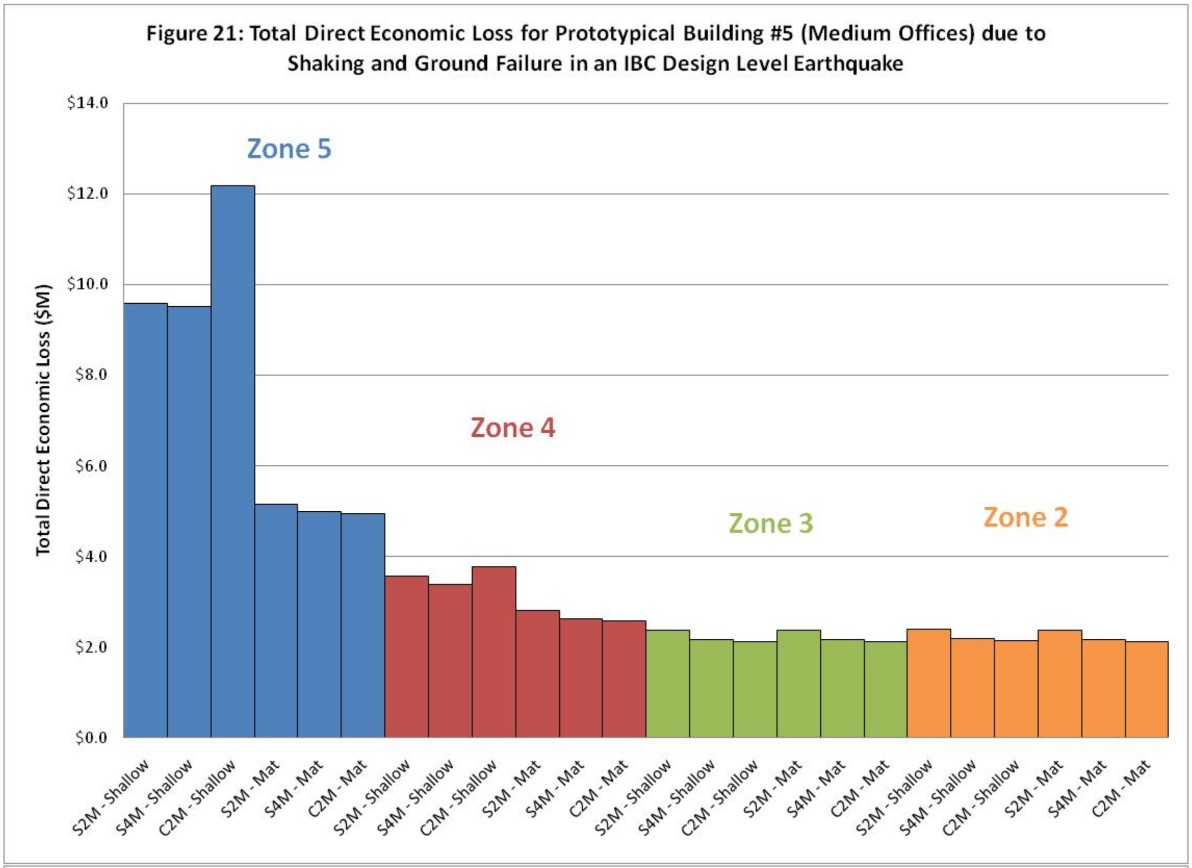


Figure 21: Total Direct Economic Loss for Prototypical Building #5 (Medium Offices) due to Shaking and Ground Failure in an IBC Design Level Earthquake
Total Direct Economic Loss ($M)
$14.0
$12.0
$10.0
$8.0
$6.0
$4.0
$2.0
$0.0
Zone 5
Zone 4
Zone 3
Zone 2
S2M - Shallow
S4M - Shallow
C2M - Shallow
S2M - Mat
S4M - Mat
C2M - Mat

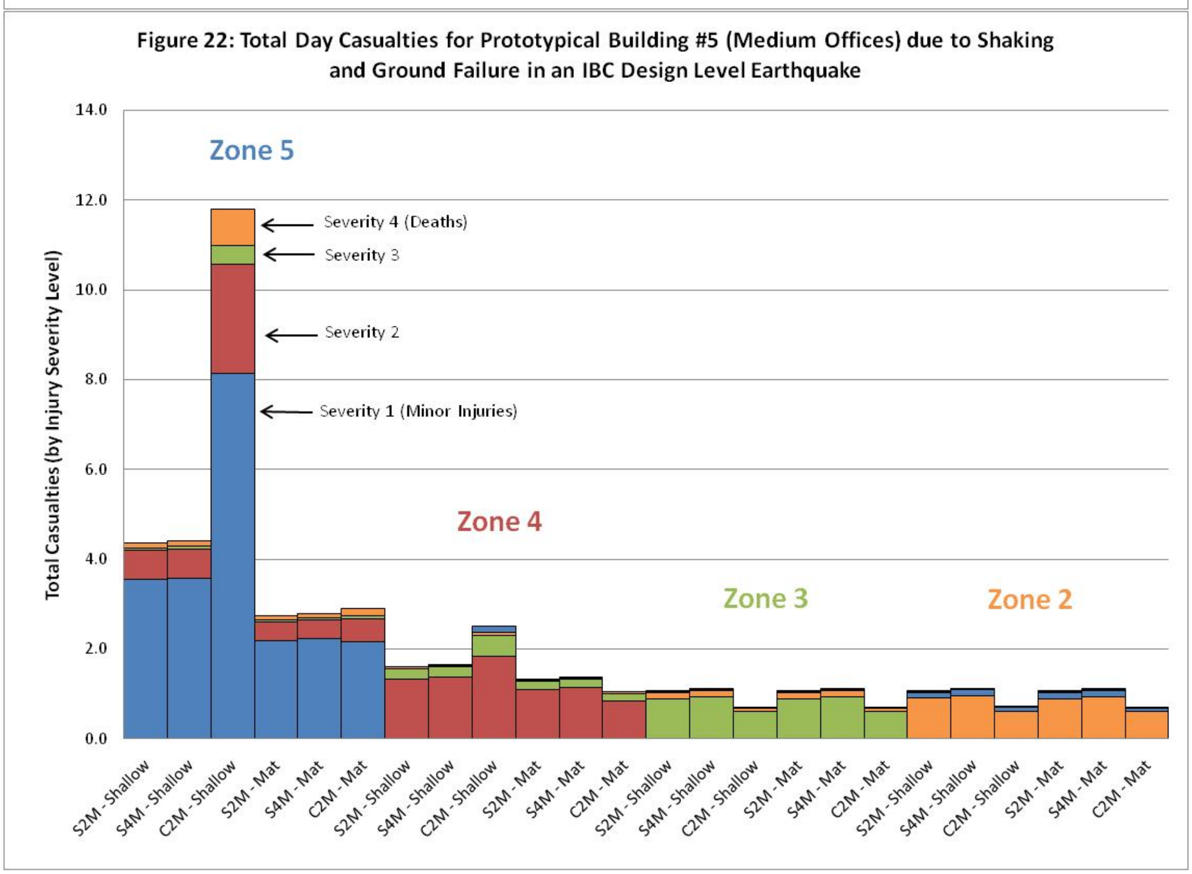


Figure 22: Total Day Casualties for Prototypical Building #5 (Medium Offices) due to Shaking and Ground Failure in an IBC Design Level Earthquake
Total Casualties (by Injury Severity Level)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Zone 5
Severity 4 (Deaths)
Severity 3
Severity 2
Severity 1 (Minor Injuries)
Zone 4
Zone 3
Zone 2
S2M - Shallow
S4M - Shallow
C2M - Shallow
S2M - Mat
S4M - Mat
C2M - Mat

Figure 23: Total Direct Economic Loss for Prototypical Building #6 (Large Offices) due to Shaking and Ground Failure in an IBC Design Level Earthquake

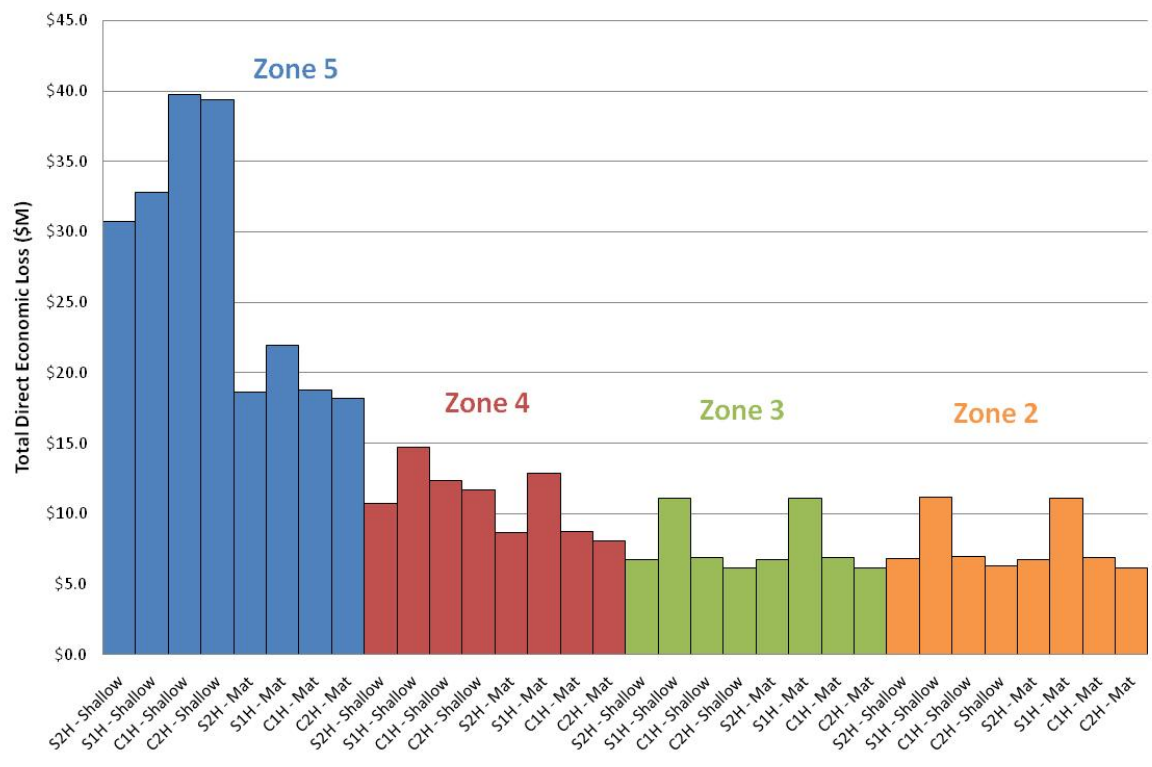


Figure 24: Total Day Casualties for Prototypical Building #6 (Large Offices) due to Shaking and Ground Failure in an IBC Design Level Earthquake

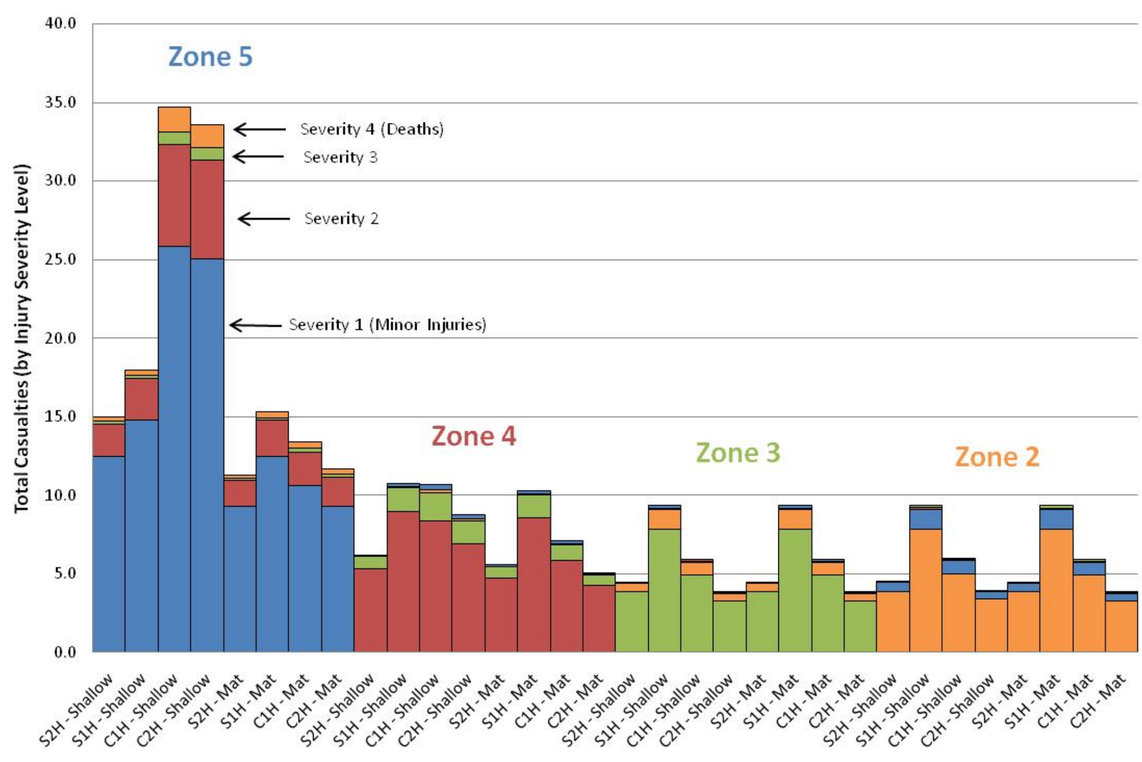


Figure 25: Total Direct Economic Loss for Prototypical Building #7 (Medium Hotel) due to Shaking and Ground Failure in an IBC Design Level Earthquake

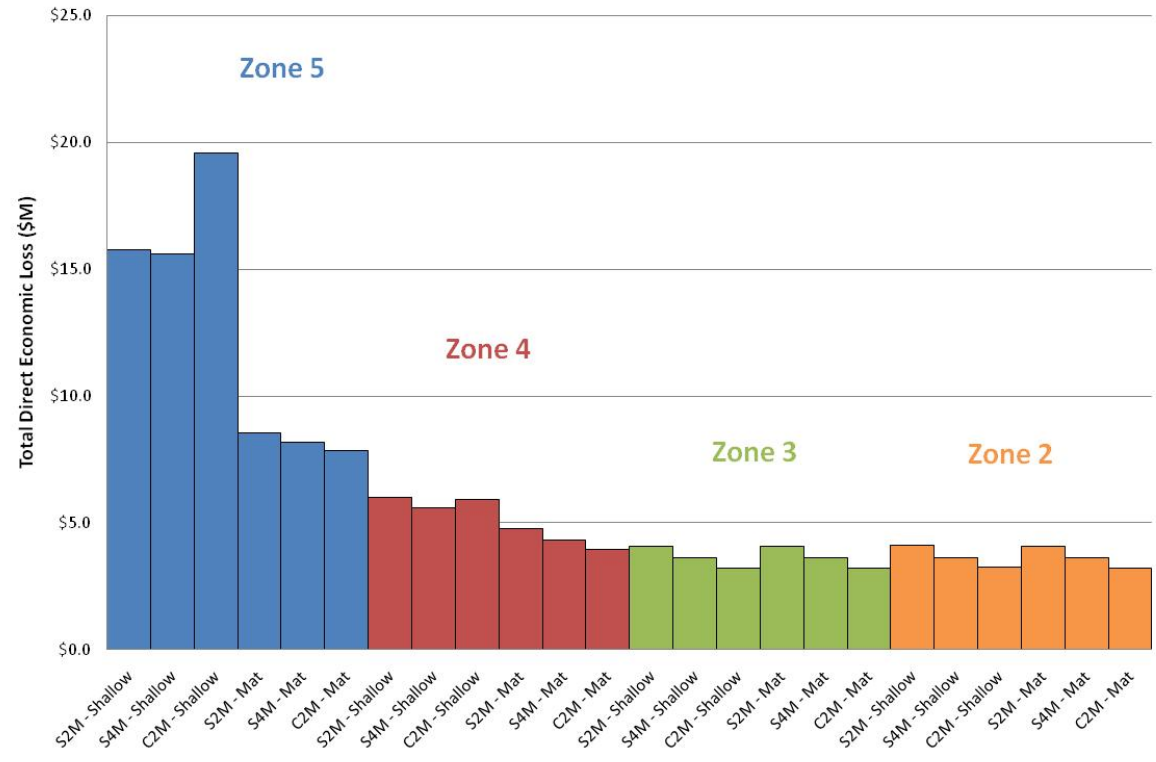
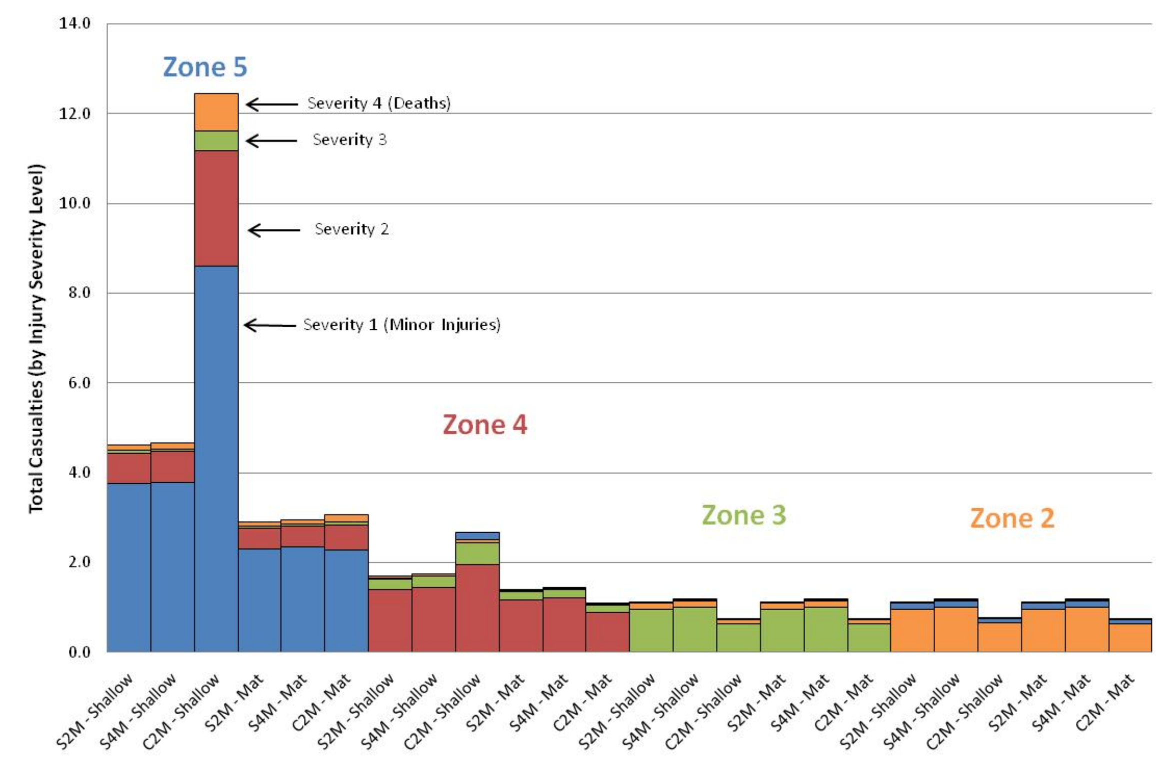


Figure 26: Total Night Casualties for Prototypical Building #7 (Medium Hotel) due to Shaking and Ground Failure in an IBC Design Level Earthquake



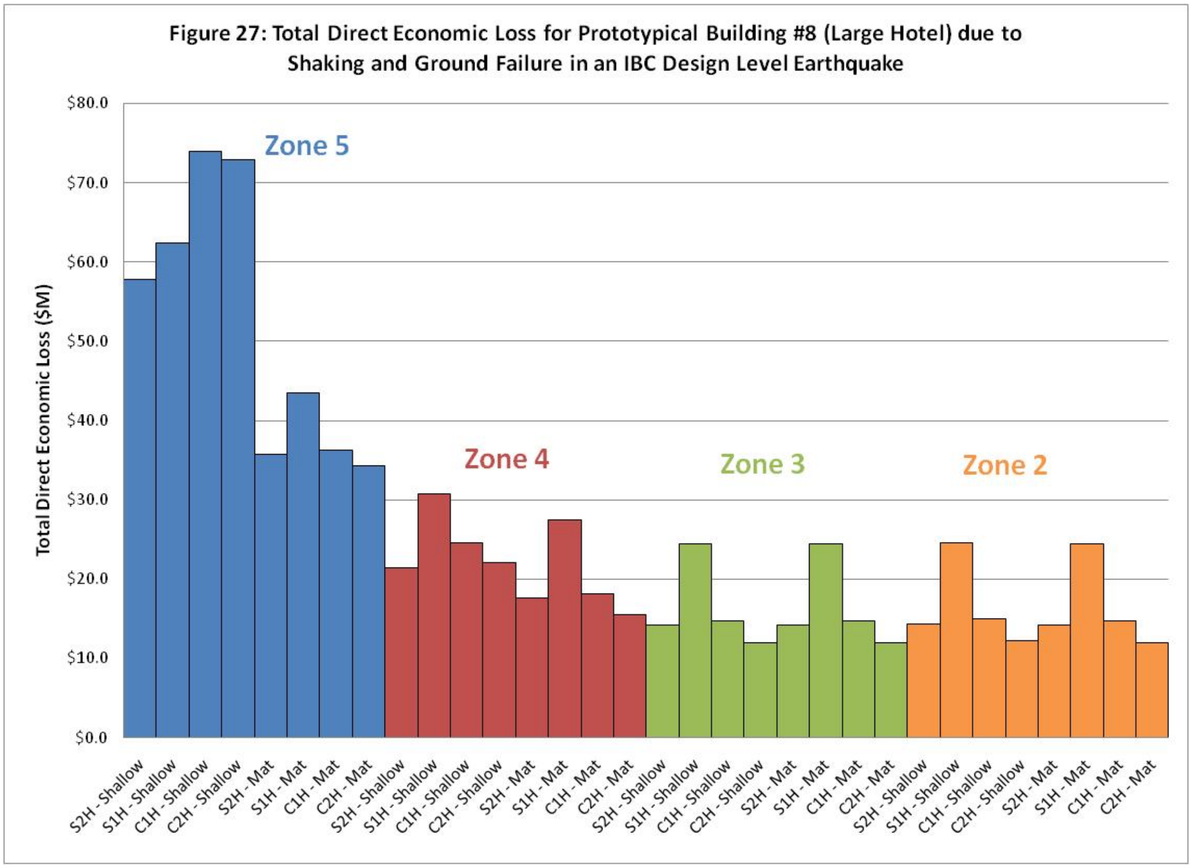


Figure 27: Total Direct Economic Loss for Prototypical Building #8 (Large Hotel) due to Shaking and Ground Failure in an IBC Design Level Earthquake
Total Direct Economic Loss ($M)
$80.0
$70.0
$60.0
$50.0
$40.0
$30.0
$20.0
$10.0
$0.0
Zone 5
Zone 4
Zone 3
Zone 2
S2H - Shallow
S1H - Shallow
C1H - Shallow
C2H - Shallow
S2H - Mat
S1H - Mat
C1H - Mat
C2H - Mat

Figure 28: Total Day Casualties for Prototypical Building #8 (Large Hotel) due to Shaking and Ground Failure in an IBC Design Level Earthquake

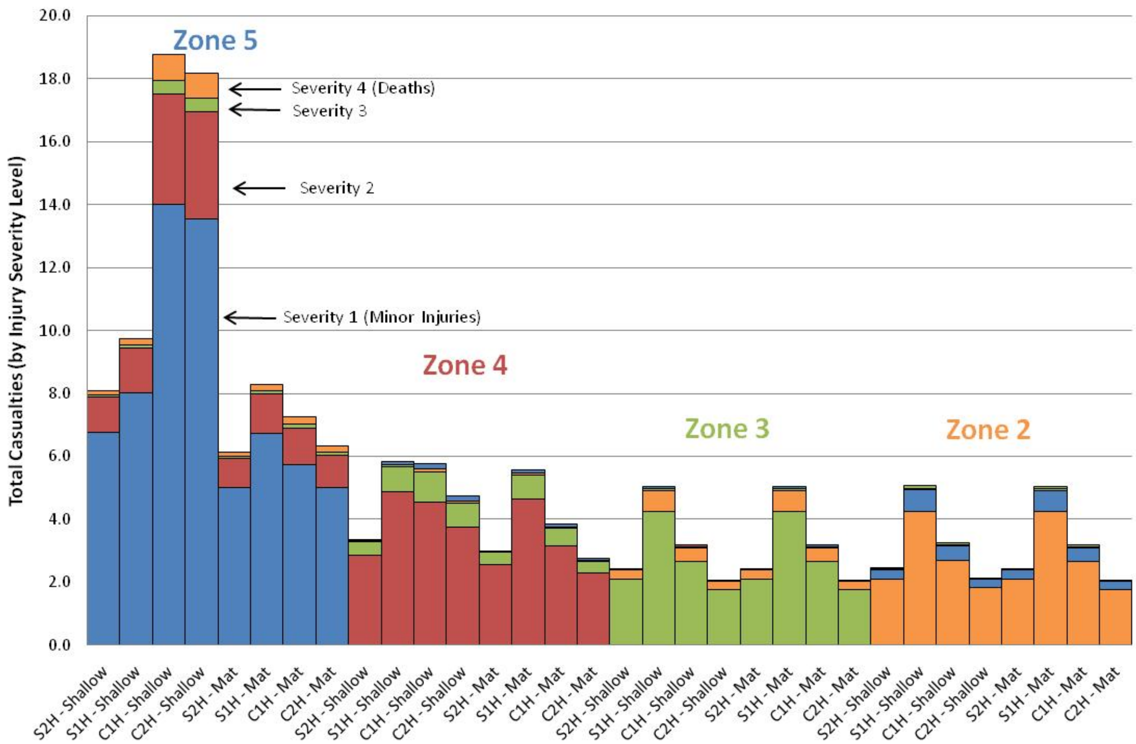


Figure 29: Total Night Casualties for Prototypical Building #8 (Large Hotel) due to Shaking and Ground Failure in an IBC Design Level Earthquake

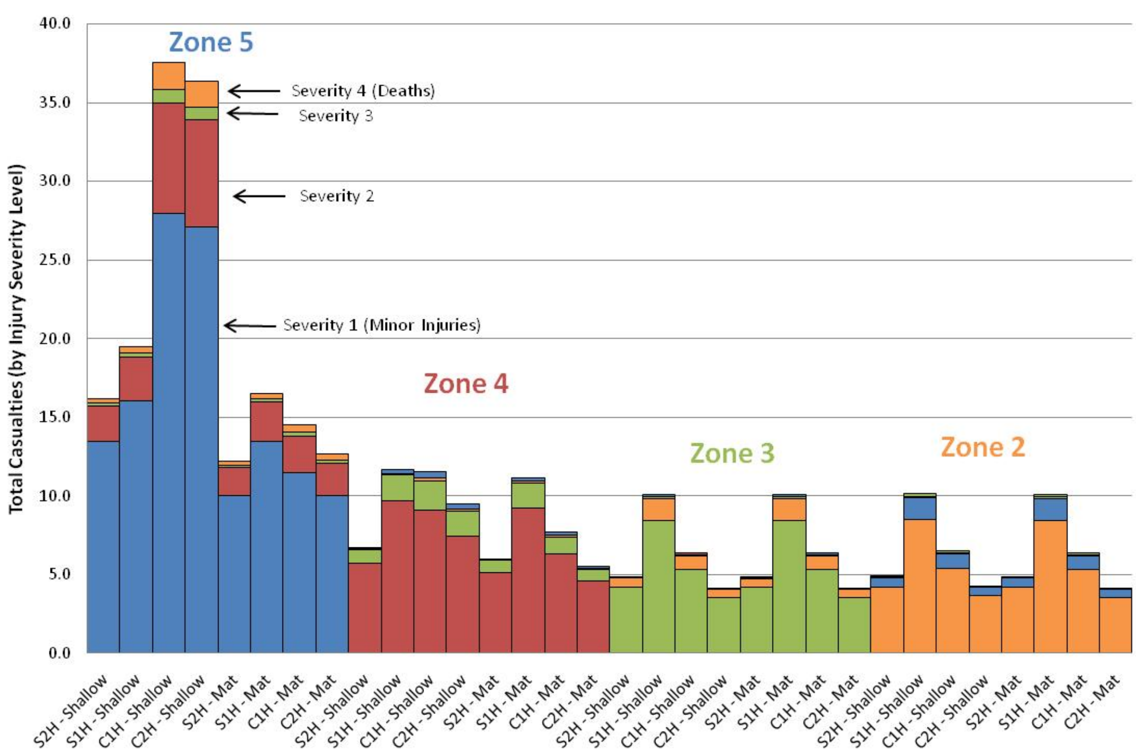


Figure 30: Total Direct Economic Loss for Prototypical Building #9 (Multi-Use) due to Shaking and Ground Failure in an IBC Design Level Earthquake

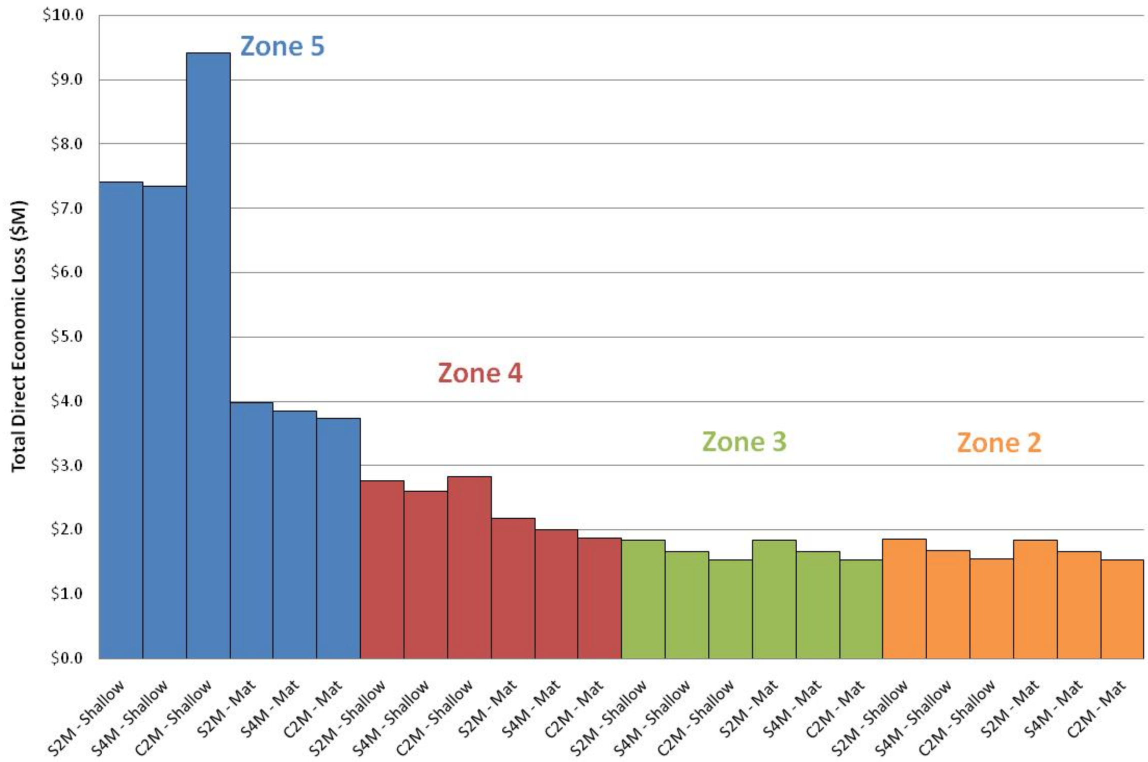


Figure 31: Total Day Casualties for Prototypical Building #9 (Multi-Use) due to Shaking and Ground Failure in an IBC Design Level Earthquake

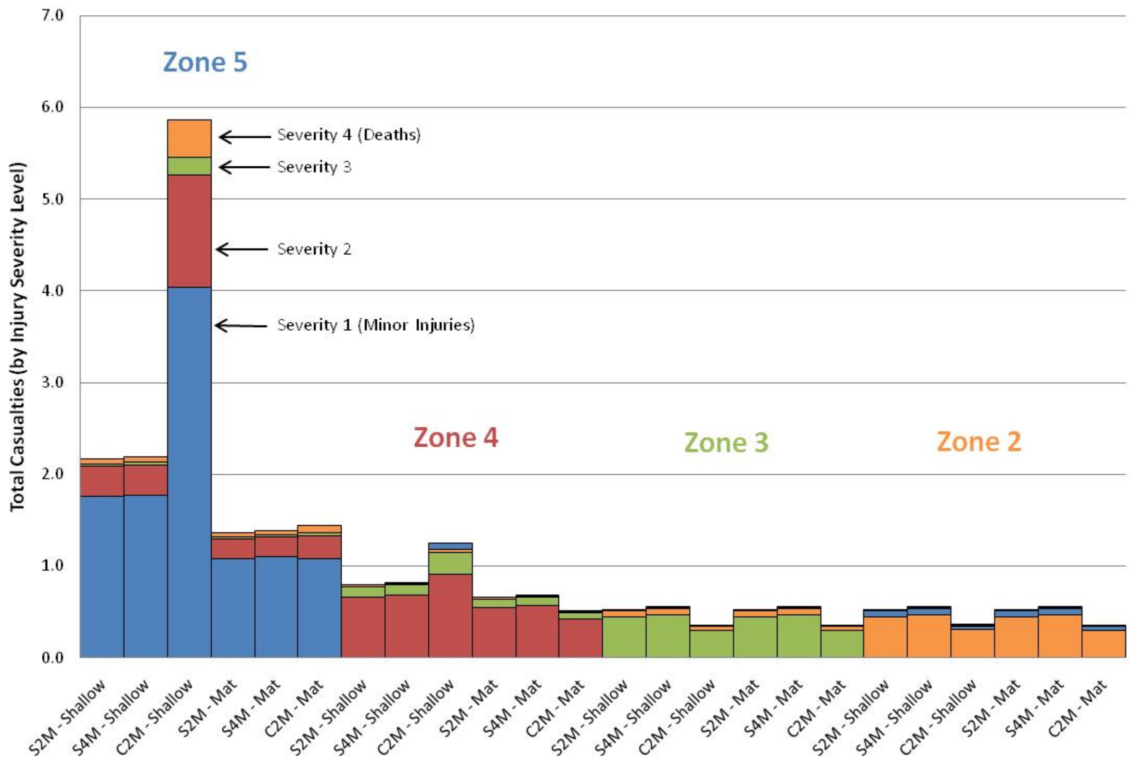


Figure 32: Total Night Casualties for Prototypical Building #9 (Multi-Use) due to Shaking and Ground Failure in an IBC Design Level Earthquake

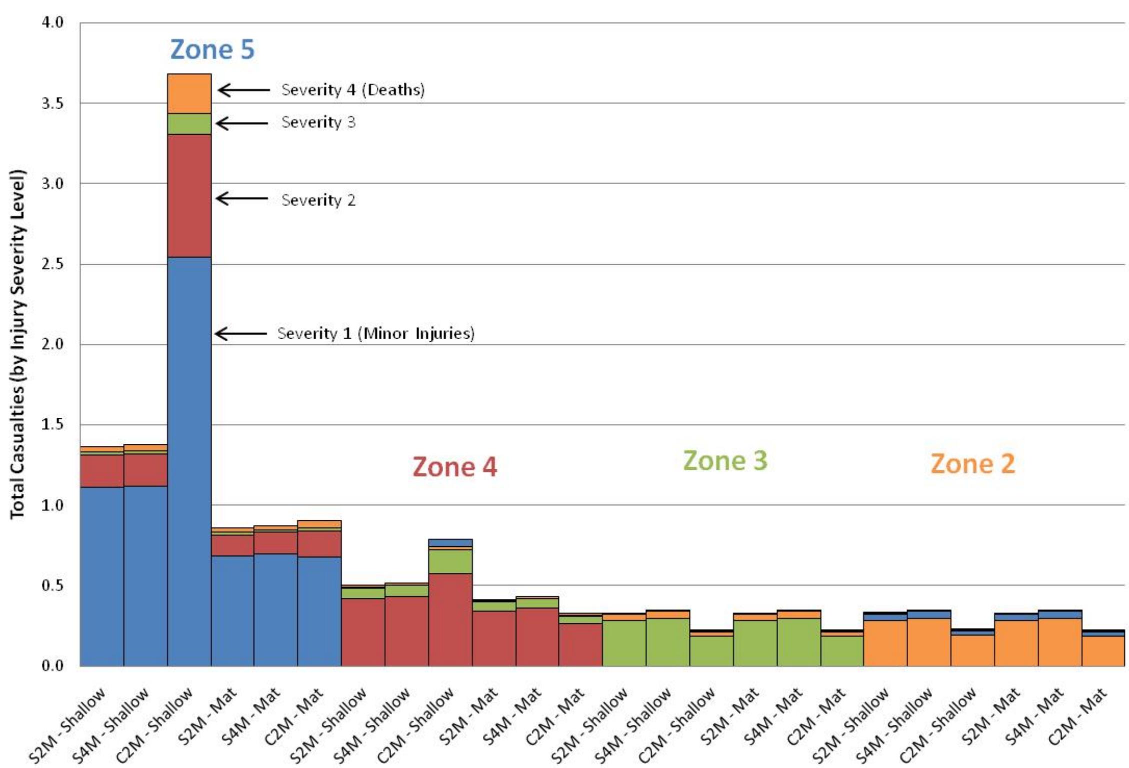


Figure 33: Total Direct Economic Loss for Prototypical Building #10 (Parking Structure) due to Shaking and Ground Failure in an IBC Design Level Earthquake

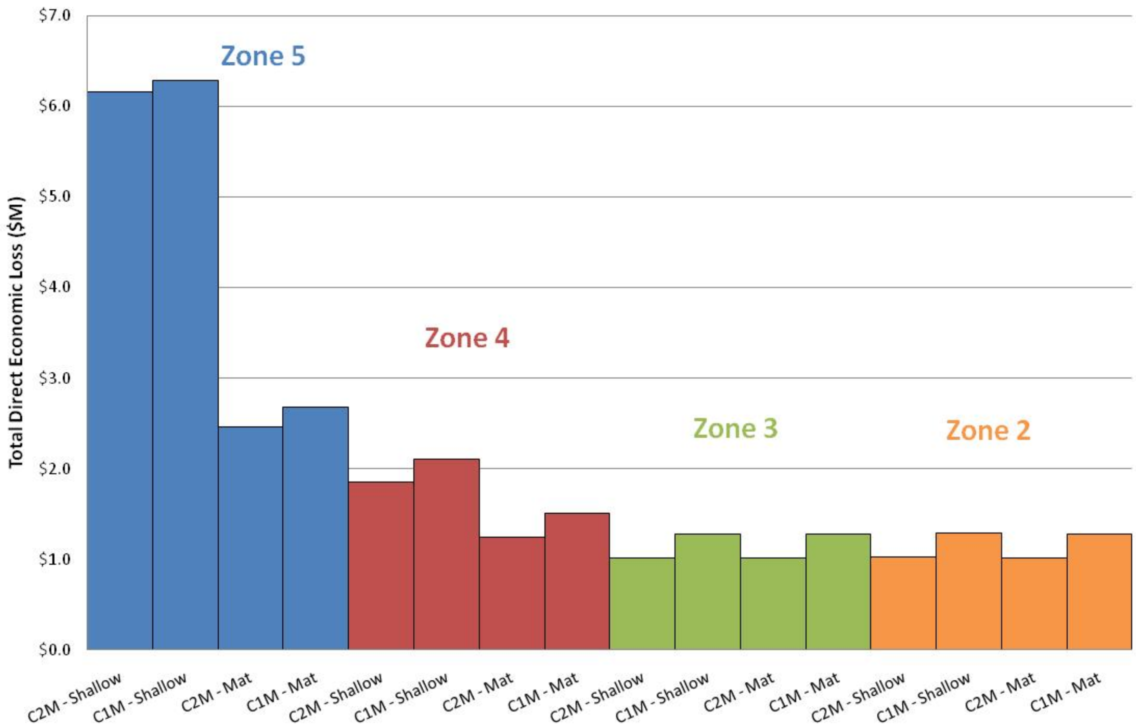


Figure 34: Total Day Casualties for Prototypical Building #10 (Parking Structure) due to Shaking and Ground Failure in an IBC Design Level Earthquake