COMPARISON OF FEMA P-58 WITH OTHER BUILDING SEISMIC RISK ASSESSMENT METHODS

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ABSTRACT AND SUMMARY OF CONCLUSIONS

This report compares results from various seismic risk assessment methods for a set of reinforced concrete frame buildings, ranging from 4 to 20 stories and including both new and pre-1971 buildings. This study examines results from the new FEMA P-58 method and compares the results with three commonly used methods for seismic due-diligence risk assessments (TZ method, ST-Risk Degenkolb method, and ST-Risk Hazus method). For the buildings investigated in this report, the conclusions are that (a) the FEMA P-58 method gives similar results to other commonly used methods *on average*, (b) even though the results are similar on average, the FEMA P-58 method results vary more between buildings, since it has the ability to quantify the effects of building-specific (and site-specific) features to provide a more detailed risk assessment for the individual building (in contrast to giving result for a building *class* and adding modifiers), and that (c) FEMA P-58 also provides additional detailed building-specific risk information such as what specific components are expected to be damage and contribute most to losses, building repair time estimates, etc.

TABLE OF CONTENTS

1. Introduction

There are a variety of methods employed in estimating loss, leading to considerable variability between loss analyses performed by different people. This study examines three of the more common methods: the Thiel Zsutty Method, ST Risk software and the FEMA P-58 Method. Using these risk methodologies; the following report conducts multiple analyses on several different reinforced concrete perimeter frame structures. These different methods of loss estimation were employed to find the probable loss (average loss) and the expected annual loss (EAL) of each structure that was modeled. The results are then compared and the differences in the methods are discussed.

2. Buildings Models and Site

2.1 Overview of Seismic Performance Assessment

All structures modeled in this study were assumed to be located in a highly seismic zone in the greater Los Angeles area. The specific site used was 2801 South Eastern Ave., Commerce, CA, 90040 (Lat: 33.996° and Long: -118.162°); which falls in Risk Category D. This site is classified as site class D soil; where the average shear wave velocity at 30 meters (Vs30) is approximately 264 m/s.

2.2 Buildings

Four different reinforced concrete perimeter special moment frame buildings ranging from four to twenty stories were examined in this study, and are summarized in Table 1. These structures were originally developed by Dr. Curt Haselton as part an archetype building database for the assessment of seismic collapse safety of modern reinforced concrete moment frame buildings. All buildings used were designed according to the International Building Code (ICC 2003), ASCE 7-02 (ASCE 2002) and ACI 318 (ACI 2002). The cost of building replacement was estimated to be $250/sq. ft. and the cost of shell and core replacement was estimated to be $100/sq. ft. (see Table 1 for total costs). These 4 buildings were analyzed as new office buildings as well as office buildings built in 1967. To achieve each of these occupancies and construction dates in the analyses, the structural and nonstructural details and components were varied.

Table 1 - Basic RC Moment Frame Building Information

Building ID	Occupancy	Design Year	Number of Stories	T_1 (s)	V_y (g)	Building Footprint	Typical Story Ht (ft.)	Estimated Building Value
10401	Office	New SMF	4	0.62	0.133	120' x 180'	13	$21,600,000
10801			8	1.16	0.067	120' x 120'	13	$28,800,000
11201			12	1.67	0.067	120' x 120'	13	$43,200,000
12001			20	2.3	0.067	120' x 120'	13	$72,000,000
20401		1967	4	0.62	0.067	120' x 180'	13	$21,600,000
20801			8	1.16	0.033	120' x 120'	13	$28,800,000
21201			12	1.67	0.033	120' x 120'	13	$43,200,000
22001			20	2.3	0.033	120' x 120'	13	$72,000,000

3. LOSS PREDICTION METHODS

3.1 Thiel Zsutty Method

The Thiel Zsutty (TZ) method was published first in 1987 has been a standard for determining loss for some time. The method considers the ground motion at the site, how the site affects the ground motion, and the building behavior in determining loss; however, it does so in a highly-simplified manner. It also has not been officially updated since its publication in 1987. The advantages of using the TZ method are that it is quick and standard (facilitating meaningful comparison between analyses.)

3.1.1 Mean Response Values

The TZ method uses a simplified equation (Eq. 1) to calculate the PML as a fraction of the building replacement cost based on several input factors.

$$p = k\ bms\ a^j \qquad (1)$$

where:

k = Proportionality constant based on earthquake data from California and suggested by Thiel and Zsutty.

b = Building parameter from ATC-13, based on the type of structural system and the height of the building. This parameter is what differed based on the building sizes and years of construction. Please see Table 3 for the b-value attached to each structure.

m = Parameter accounting for similarity in the site and building period. This value is defined qualitatively (see Table 6 in the Appendix) and typically is assumed to equal 1 when site period is unknown.

s = Parameter modifying the site ground motions based on the mechanical properties of the soil. The site in this study was determined to be quaternary deposits based on the California Department of Conservation 2010 Geological Map. Assuming that the water table lies between 30 and 100 feet at the site the s value was selected from Table 7

j = Constant equal to 0.606 representing the nonlinearity between ground acceleration and building damage. This value is based on earthquake data from California and suggested by Thiel and Zsutty.

a = Peak ground acceleration. This study selected 12 intensities and used the USGS Hazard Curve Application to determine the PGA at the building site (see Table 8).

Table 2 – Input Parameters for TZ Method

Input Parameter	Value
k	0.651
m	1.000
s	1.250
j	0.606
a	See Table 8 for PGA

Table 3 – b value parameter for TZ method

Building ID	b value	
	New	1967
1009	0.21	0.64
1011	0.26	0.64
1013	0.26	0.64
1020	0.26	0.64

3.1.2 Output

The TZ Method accounts for ground motions, site interaction and building response in a very simplified manner and with a lot of conjecture. The user performing the analysis must employ his or her judgment to assign numbers in a range for each variable, for example the b value may range from the most resilient structure to the least: 0.1 to 1.25. The building response is based solely on the b value; which is selected based on the structural system and the high, mid, or low-rise designation of the building. In the case of the New construction this leads the 8, 12, and 20 story buildings to be treated exactly the same because they all fall into the high-rise range. In the case of the 1967 construction, all 4 of the buildings 4 to 20 stories are predicted to have the same replacement normalized building replacement cost at each level.

The output of the TZ Method is a building SEL for each PGA Level. To provide a SUL the engineer running the analysis must use their judgment to select a higher b-value. The TZ Method cannot be used to compute component based losses or non-monetary or indirect losses such as injuries, fatalities and down time losses.

3.2 ST-Risk (Hazus and Degenkolb Methods)

ST-Risk is a seismic risk analysis program developed by Risk Engineering INC. It allows users to assess the seismic risk of a structure at a specific site, using general building information as well as more detailed structural and non-structural information designated by FEMA 310 variables. ST-Risk outputs the building seismic risk as Probable Maximum Loss (PML), Probable Loss (PL), Scenario Expected Loss (SEL), Scenario Upper Loss (SUL), and Expected Annual Loss (EAL) in terms of percentage of the building replacement cost.

3.2.1 Input

ST-Risk is meant to be an easy-to-use software tool. Users are required to input site location, structural system classification, occupation level, evaluation period, floor area, story height, year constructed, and replacement cost. Further detailing of the structure is also defined by setting variables in a FEMA-310 worksheet. The variables in this worksheet help define the lateral force resisting system, the connection detailing, floor diaphragms, non-structural components, and other details. Users can either pick values for each variable or use default recommended values given by the software to define the structure being modeled. This study used the default values to define each of the models.

3.2.2 Output

ST-Risk uses two separate methods to analyze the loss for a structure, the Degenkolb Method and the Hazus Method. Both methods were used to predict the loss in all of the structures modeled in this study.

Degenkolb Method

The Degenkolb Method is based on the loss methodology laid out by Karl Steinbrugge in his book *Earthquakes, Volcanoes and Tsunami's*. Because the book was published in 1982, the Degenkolb Method has adjusted the original Steinbrugge loss functions to account for more recent events. This methodology establishes a base loss for a structure characterized by UBC building classification, building height, and UBC design edition; it also characterizes earthquake hazard using a Modified Mercalli Intensity (MMI). The loss given by the Degenkolb Method is a SUL (90^{th} percentile loss) at a probability of exceedance of 10% in 50 years.

Even though the loss predicted by the Degenkolb Method is a function of building height, there was no difference between the 4, 8, 12, or 20 story structures for the PL, SEL, SUL, or PML. This shows that building height actually has little effect on the loss predicted by the Degenkolb Method. The 1967 Office building saw much higher loss (as expected) than that New Office building, which comes from the user choosing the UBC design edition and year constructed in the input parameters of ST-Risk. Selecting a different UBC design edition will change the recommended settings given in the FEMA 310 worksheet section of the input parameters, thus changing the predicted loss.

HAZUS Method

HAZUS (developed by FEMA) uses the capacity spectrum method to estimate demands over differing ground motion intensities. From these demands, losses are calculated using fragility curves for structural and non-structural losses. The base losses for the HAZUS Method are a function of building classification, building height, and seismic design level. Just like the Degenkolb Method, the HAZUS Method uses to FEMA 310 worksheet in ST-Risk to adjust the base losses for more specific structural details.

Similar to the Degenkolb Method, no difference was observed between the 20, 12 or 8 story structures, however in using the HAZUS Method the 4-story building had different losses different than the other structures. The HAZUS method categorizes buildings based on height then chooses a reasonable fundamental period to represent the first modal period of that structure. That period is then used to determine the spectral demand. For this study, HAZUS characterized the 4-story building as having a fundamental period of 0.75 seconds and the rest of the structures as having a period of 1.45 seconds. Even with this difference in building height classification, little difference was seen between the loss of the 4-story building and the loss of the rest of the structures. The major difference between the Degenkolb and the HAZUS method is the loss prediction for the 1967 office building. The HAZUS method predicts a much higher loss for the 1967 office than does the Degenkolb method.

In general, the HAZUS method will predict a lower loss at lower intensities and a higher loss at higher intensities than will the Degenkolb method. Thus, the Degenkolb method predicts a higher EAL due to the fact that high risk at lower intensities will cause a higher probability of monetary loss.

3.3 FEMA P-58 Method

In 2001, the Applied Technology Council (ATC) received funding from the Federal Emergency Management Agency (FEMA) to "develop Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings" (ATC, 2012). The project was a 10-year process that resulted in the creation of the FEMA P-58 methodology and its associated fragility and consequence database. The fundamental difference between the FEMA P-58 method and the previously mentioned methods is its probabilistic nature. Instead of binning a structure into a loss group, FEMA P-58 simulates ground motions and compiles building losses using Monte-Carlo simulations. FEMA P-58 uses a realistic performance model comprised of site properties and seismic hazards, lateral structural responses to excitation, building collapse and residual drift capacities, and damageability profiles for each component within the structure to give probabilistic seismic losses that can be traced all the way down to a specific component. For this study, the FEMA P-58 method was performed using the Seismic Performance Prediction Tool (SP3), which automates the FEMA P-58 method into a web based application.

3.3.1 Input

Building Information

Due to its probabilistic and rigorous nature, FEMA P-58 requires a heavy amount of user input, part of which is general building information. The building information required incudes; building geometry, cost and replacement time information, building population and occupancy info, design year and structural system classification, as well as structural and non-structural components of the building known as fragilities. The SP3 Tool has many built in algorithms for calculating defaults of the FEMA P-58 method inputs and this study utilizes those defaults whenever certain buildings specific information was unknown.

Fragilities

A fragilities is a representation of the damageability and associated consequences of specific building components considered in the calculation of the FEMA P-58 Method. Each fragility has an associated fragility function, assumed to be log normally distributed. The fragility functions were built as part of the 2001 ATC project using laboratory testing, data gathered following earthquakes, engineering judgment, or a combination of the previously mentioned techniques. These functions describe the likelihood of experiencing a particular damage state given a demand parameter; which may include acceleration, velocity, inter-story drift ratio, or others depending on the fragility. Each damage state has an associated median and dispersion for time to repair, cost, and (where applicable) injury and fatality rates.

These fragilities are placed throughout the building performance model based on the building geometry, size and occupancy. In this study the building components were populated throughout the building using the SP3 component pre-population tool, which is based on the normative building content data collected as part of the ATC 58 project. The fragilities considered in the New 12 Story Office Building are listed in Table 9 and Table 10 in the appendix.

Collapse Fragility

Another input of the FEMA P-58 methodology is the probability that the structure will experience collapse at any given hazard level. In order to assess the probability of collapse for the modeled structures, this study uses the FEMA 154 rapid screening tool, which is built into SP3. Based on the building classification, the level of site seismicity, as well as a series of screening questions regarding structural irregularities, design year and other factors an assessment of the collapse probability can be achieved.

Simplified Structural Analysis

In order to simulate the effect that ground motions have on structural damage and risk through the P-58 method, the structural response for each building modeled must first be calculated. For this study, these values were found using a simplified analysis laid out by FEMA P-58. A nonlinear response history analysis may also have been used if desired.

The target roof displacement for each building and intensity was determined using the spectral acceleration and building period. The displacement along the height of the building was distributed according to the 1st mode of vibration determined from using the Opensees tool. These elastic displacements along with peak ground accelerations are then adjusted for higher modal, non-linear, and hysteretic behavior according to section 5.3 of FEMA P-58-1 in order to estimate inelastic drift and acceleration demands. The resulting adjusted accelerations and inter-story drift ratios are summarized in the figures below for the New 12-Story Office Building.

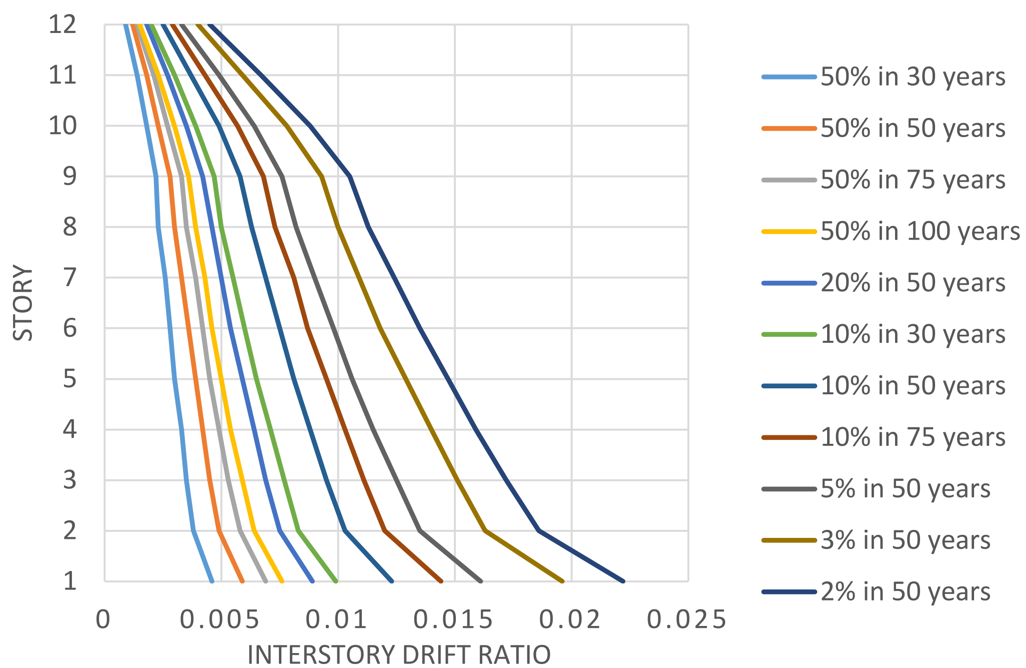

Figure 1 - IDR Demand on 12 Story Building 1013 at Each Intensity

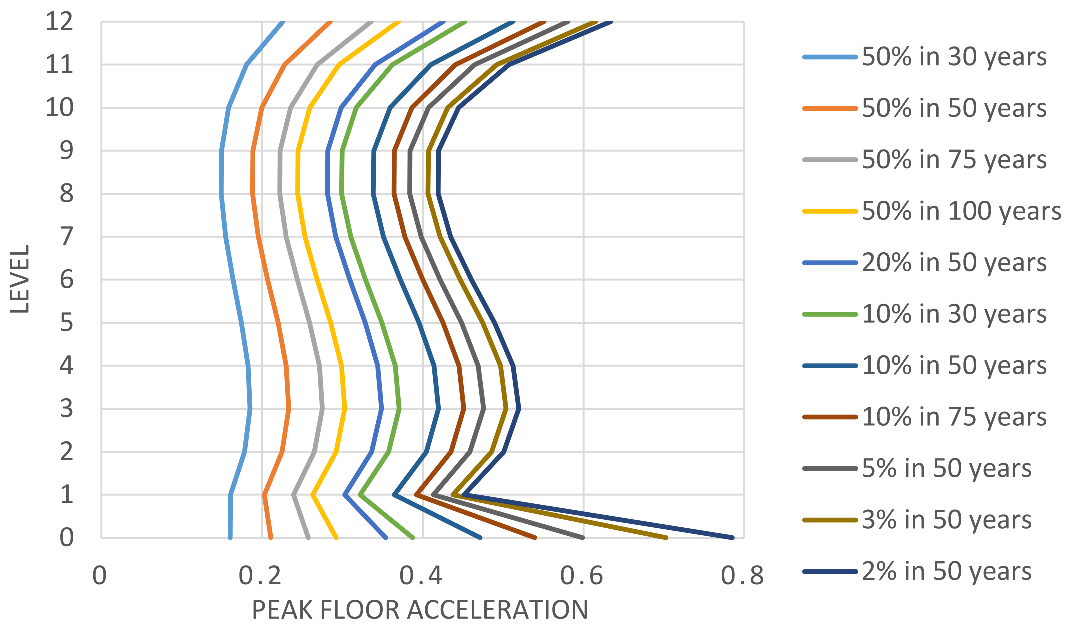

Figure 2 - Acceleration Demand on 12 Story Building 1013 at Each Intensity

Residual Drift

The residual drift (RD) fragility function is a lognormal function representing the probability that the building experiences irreparable residual drift at each intensity. The residual drift and dispersion defining the function were calculated from the inelastic drifts using the SP3 general inelastic model for residual drift, which is based on empirical and analytic data outlined in FEMA P-58.

Hazard Curve

The hazard curve for each building was defined using the USGS Hazard Curve Application tool imbedded into SP3. A total of 11 intensities were selected to provide a meaningful range of risk. Intensity level 7 represents a 10% in 50 years exceedance while intensity level 11 represents a 2% in 50 years exceedance. The PGA was determined directly for the Commerce, CA site using the USGS Hazard Curve Application while the Spectral Accelerations for each building were interpolated using the output from the same tool.

3.3.2 Output

One of the most useful aspects of FEMA P-58 is the ability to examine the loss from individual components of the building. Figure 3 shows a breakdown of the contribution to EAL from each of the modeled components of the New 12 Story Office Structure and Figure 4 shows the breakdown for mean loss across each hazard level analyzed. The largest contributors to loss for this building were the structural component as well as the exterior cladding. This allows engineers, designers and assessors to examine and address the sensitivities that lead to higher risk. Due to its in-depth nature, the FEMA P-58 method also has the ability to analyze non-monetary losses such as risks to human life and injury and the time to recover and repair after an earthquake. The SP3 tool includes the REDi recovery time method in the FEMA P-58 process;

which uses worker scheduling and repair sequencing to estimate recovery and down time due to damage. Figure 5 shows the estimated recovery time for the New 12 Story Office Building analyzed in this study.

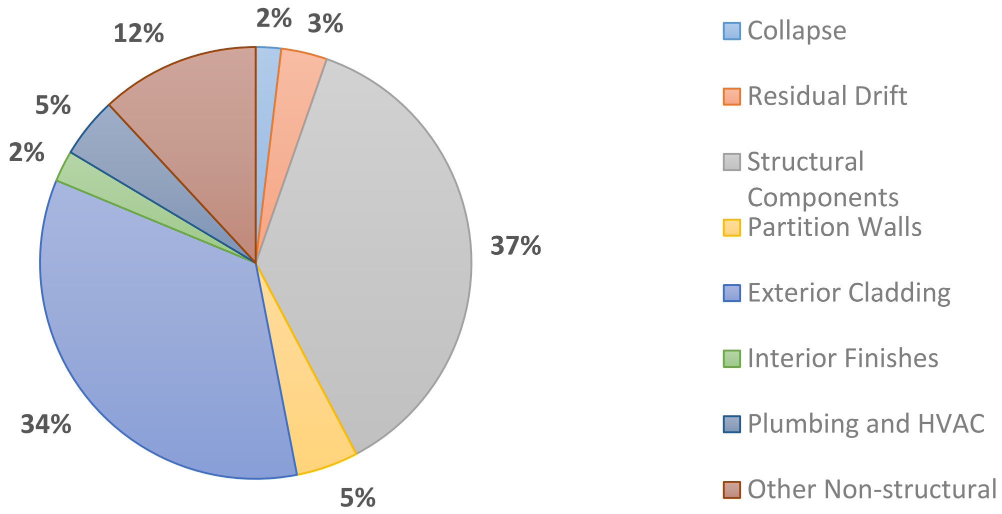

Figure 3 – EAL breakdown for the New 12 Story Office Building

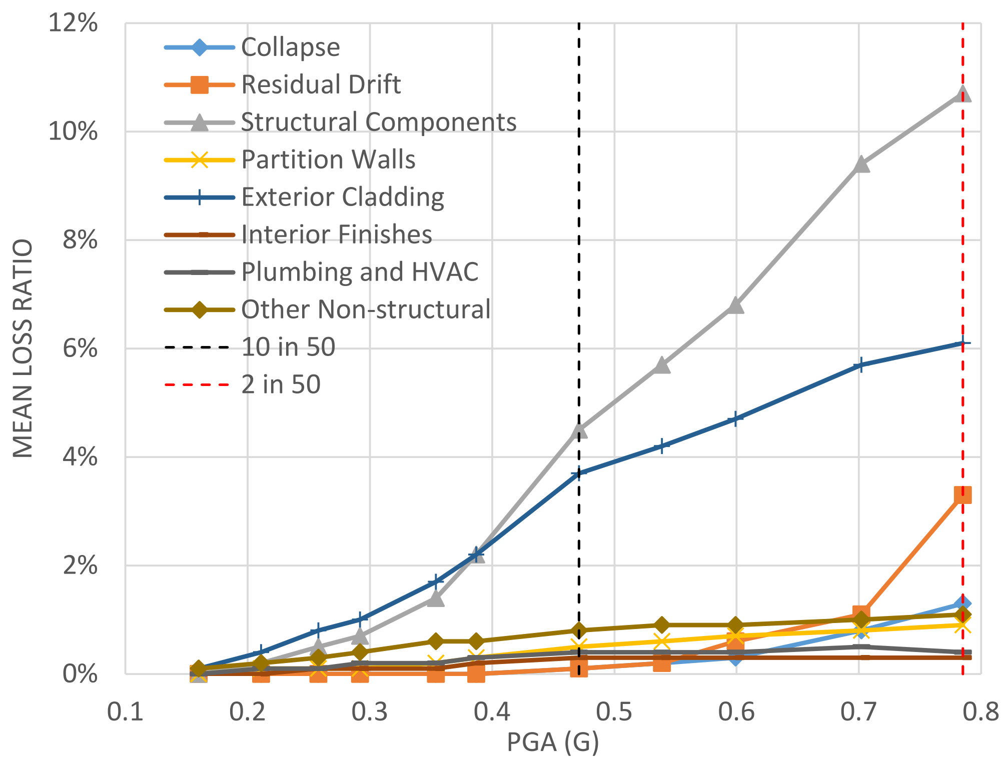

Figure 4 – Mean Loss breakdown for the New 12 Story Office Building

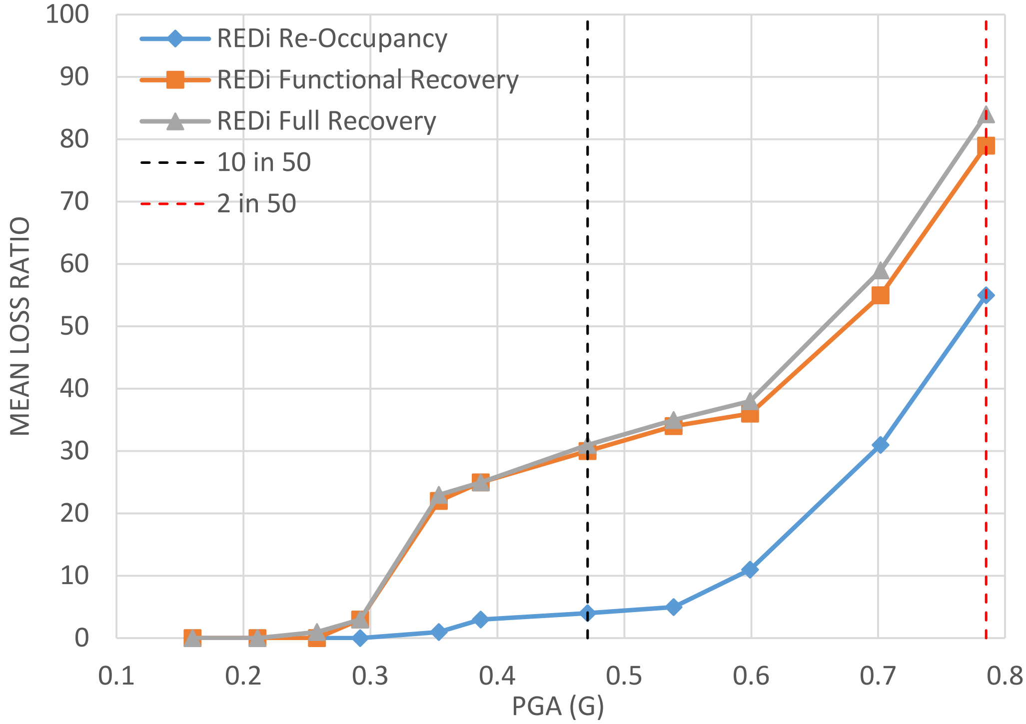

Figure 5 – REDi Repair Time for the New 12 Story Office Building

4. Comparison of Methods

In order to examine the accuracy and consistency of the 3 hazard analysis methods discussed in this study, loss predictions results were compared for all structures that were modeled. Figure 6 through Figure 13 compare the SEL curves across each intensity level for each analyzed model and Figure 14 through Figure 15 compare the expected annual loss (EAL) of all the different methods.

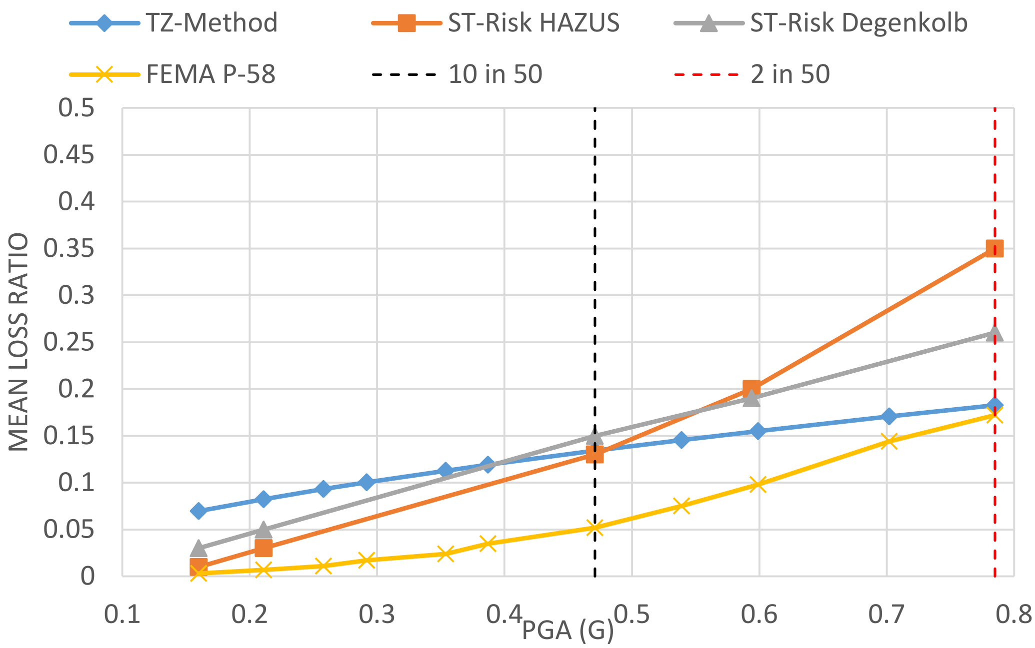

Figure 6 – SEL for the New 20 story office building

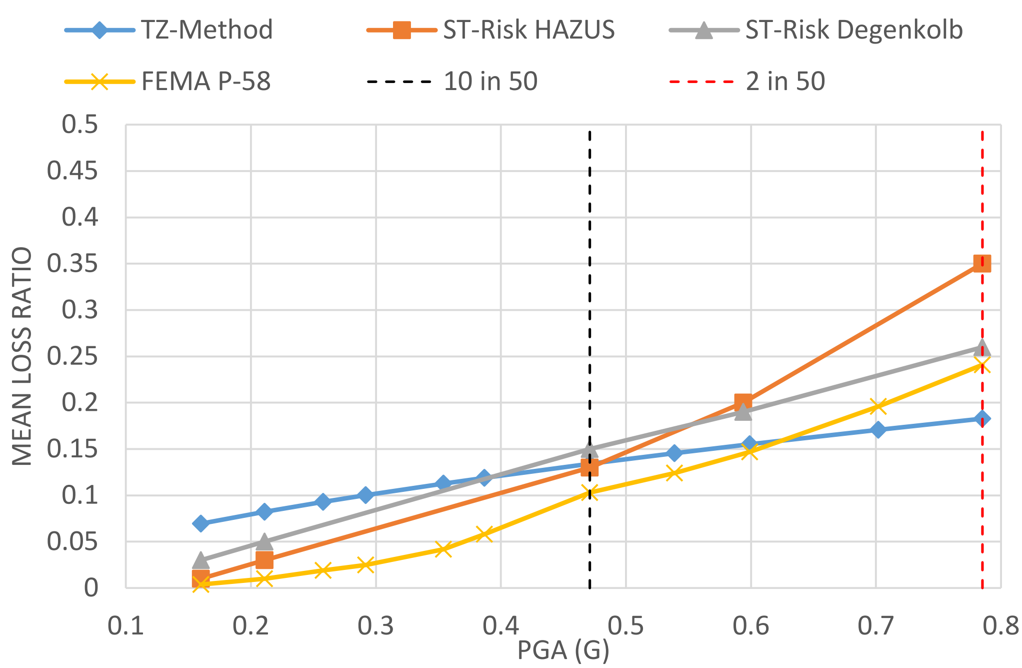

Figure 7 – SEL for the New 12 story office building

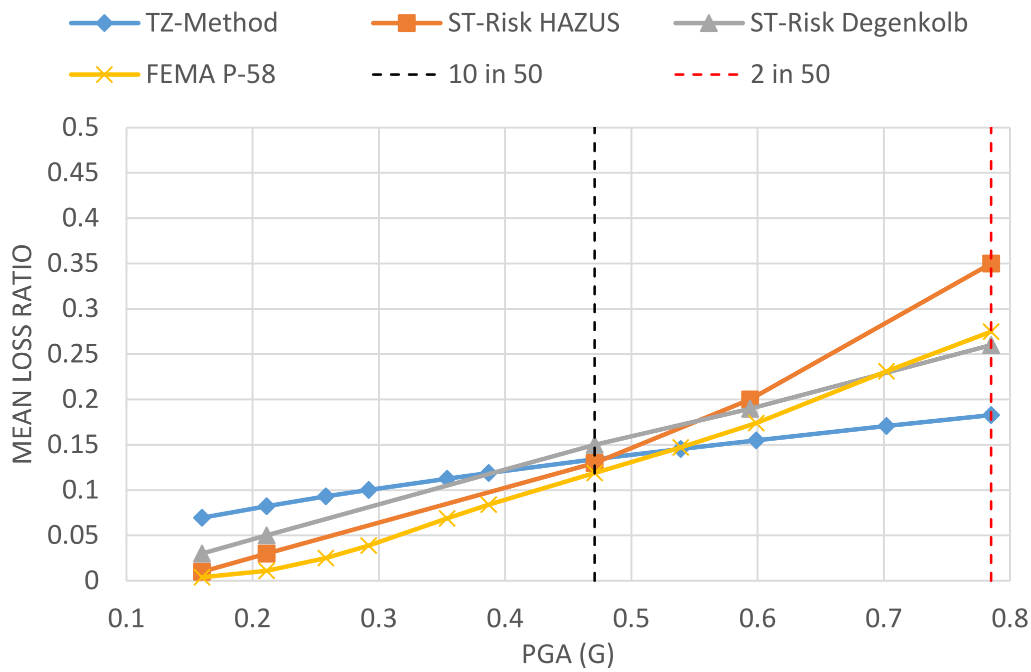

Figure 8 – SEL for the New 8 story office building

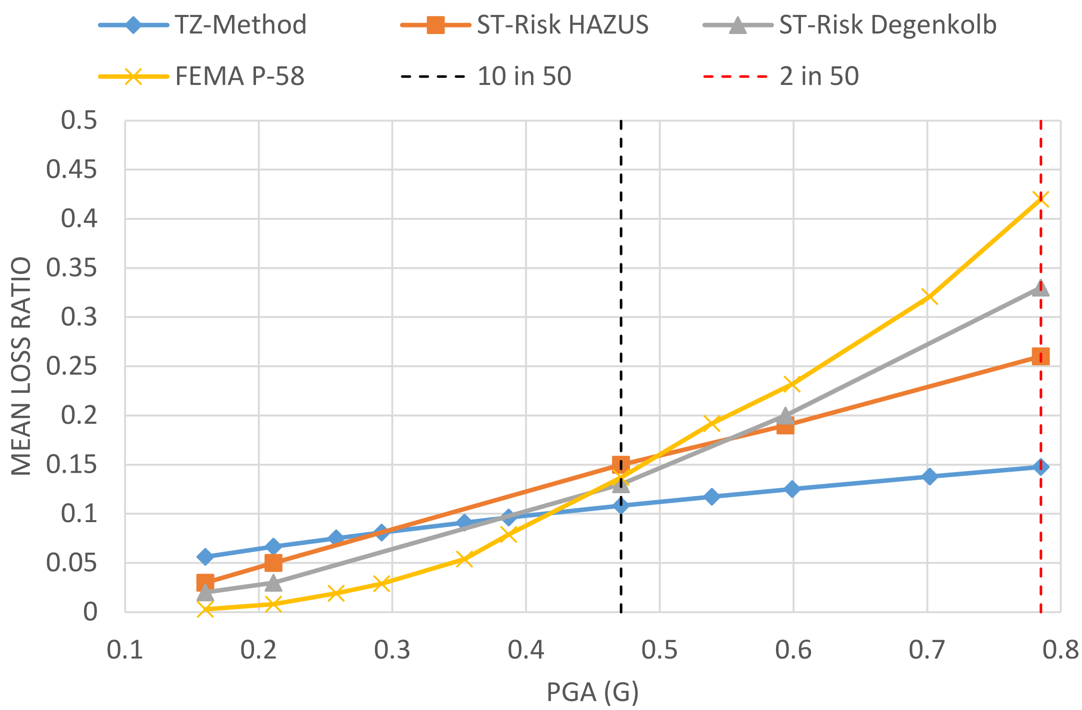

Figure 9 – SEL for the New 4 story office building

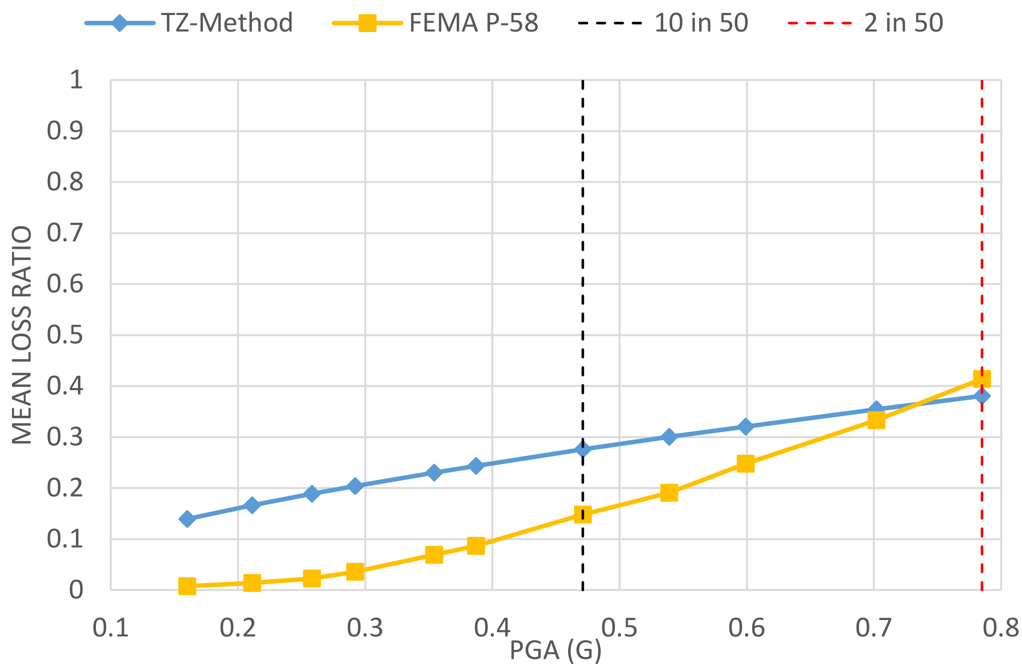

Figure 10 – SEL for the 1967 20 story office building

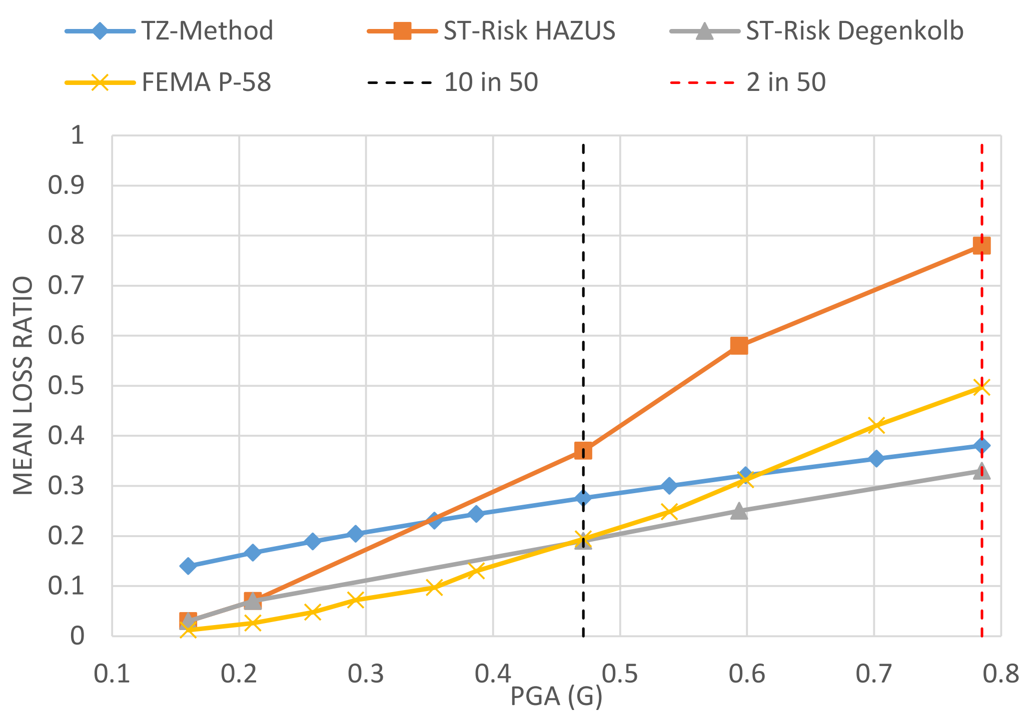

Figure 11 – SEL for the 1967 12 story office building

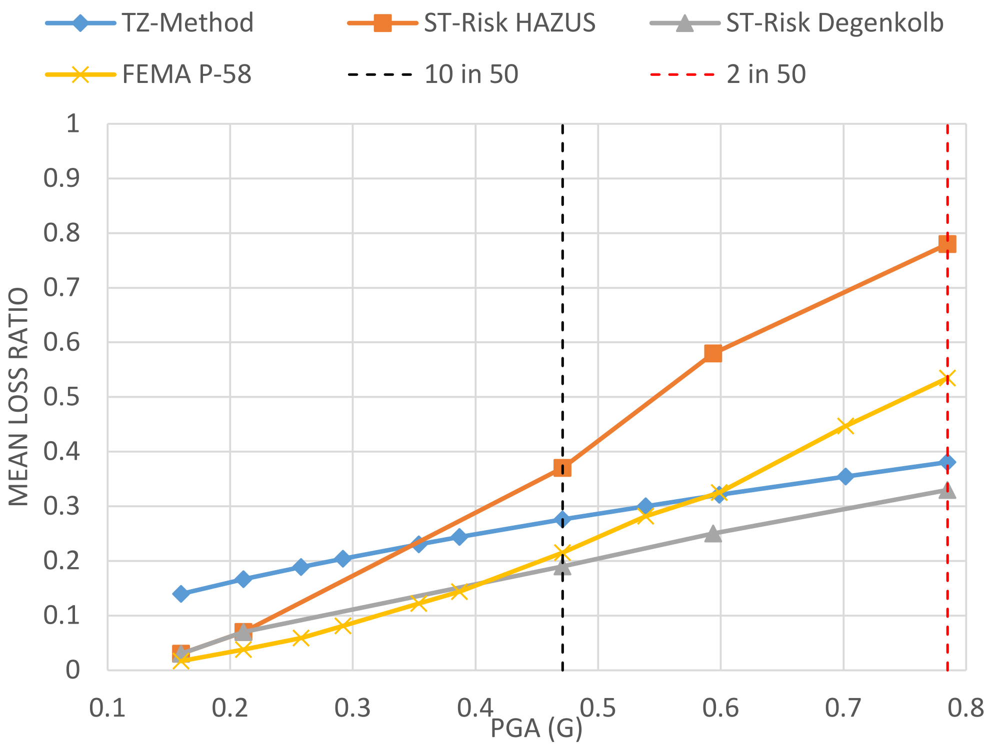

Figure 12 – SEL for the 1967 8 story office building

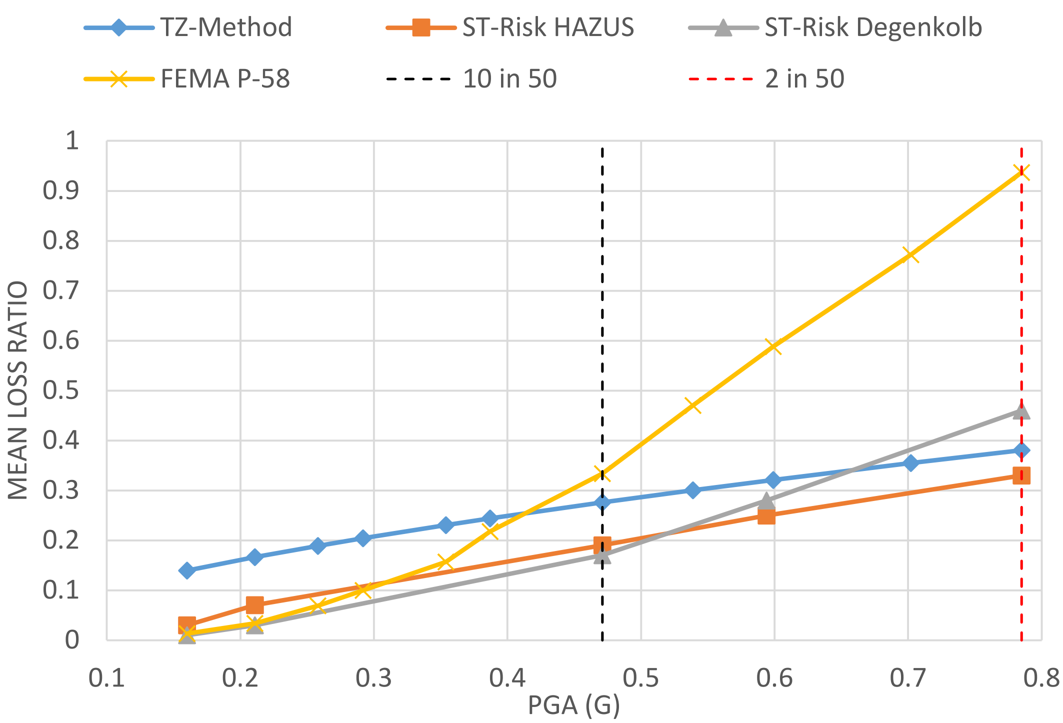

Figure 13 – SEL for the 1967 4 story office building

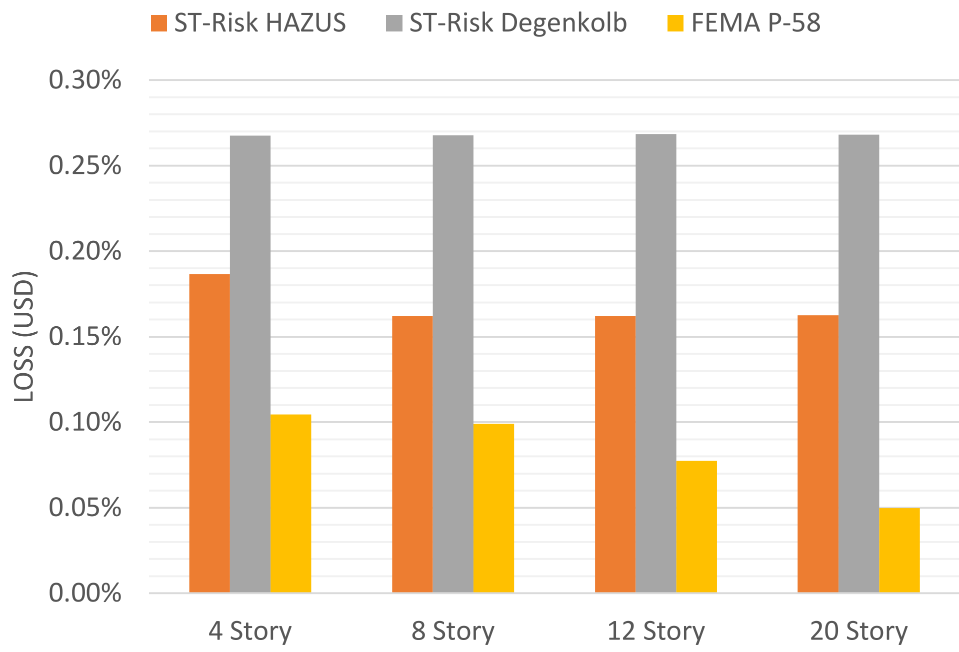

Figure 14 – EAL comparison of the methods for the New Office Buildings

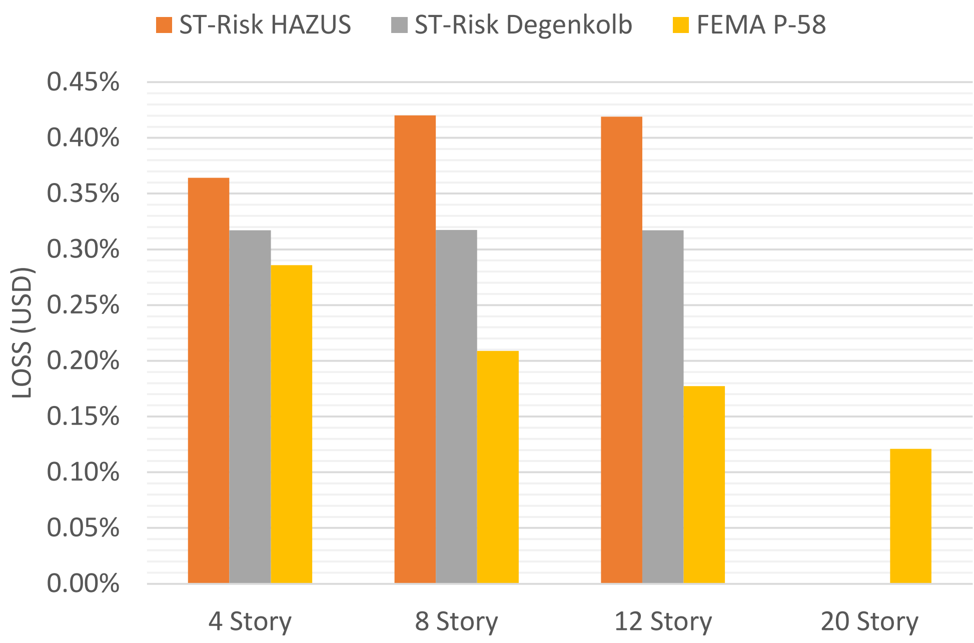

Figure 15 - EAL comparison of the methods for the 1967 Office Buildings

5. BUILDING SPECIFIC PARAMETERS

In addition to the comparison of FEMA P-58 to older loss methodologies, a small sensitivity study was performed to observe the loss predictions and variability for buildings with more specific design features using the P-58 method. This study uses the New 12 Story Office Building described in above as a baseline model. Variations to the design and building features are then adjusted and analyzed to observe their differences. The variations that were made include improvements to the lateral system, adjustments to the structural flexibility, and variations in component detailing. Figure 16 and Figure 17 outline the results.

Table 4 – Overview of Buildings Analyzed in the FEMA P-58 Sensitivity Study

Building ID	Design Year	Number of Stories	T_1 (s)	V_y (g)	Component Detail	SEL at 10 in 50
11201	New	12	1.67	0.067	Office (baseline)	10%
11202			1.67	0.067	Post-Tensioned Precast Hybrid Moment Frame System (PHMF)	9%
11204			1.3	0.125	Risk Category 4 Design	3%
11205			2.1	0.125	Code Minimum Design	17%
11207			1.67	0.067	Non-Damageable Cladding	6%

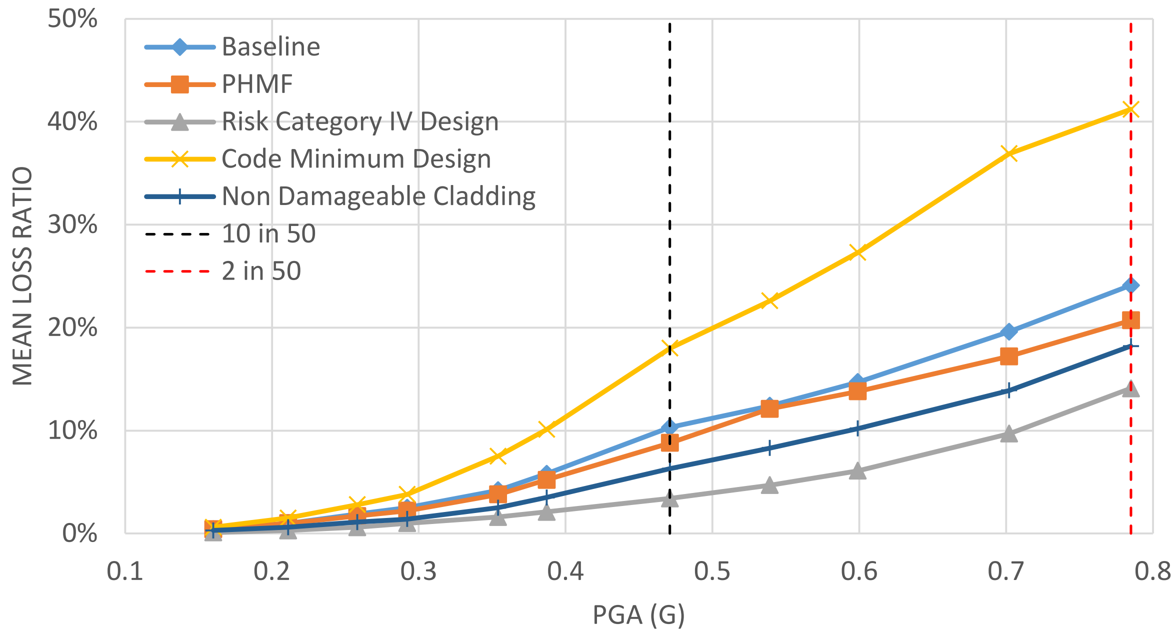

Figure 16 – FEMA P-58 Sensitivity Study of the New 12 Story Office Building

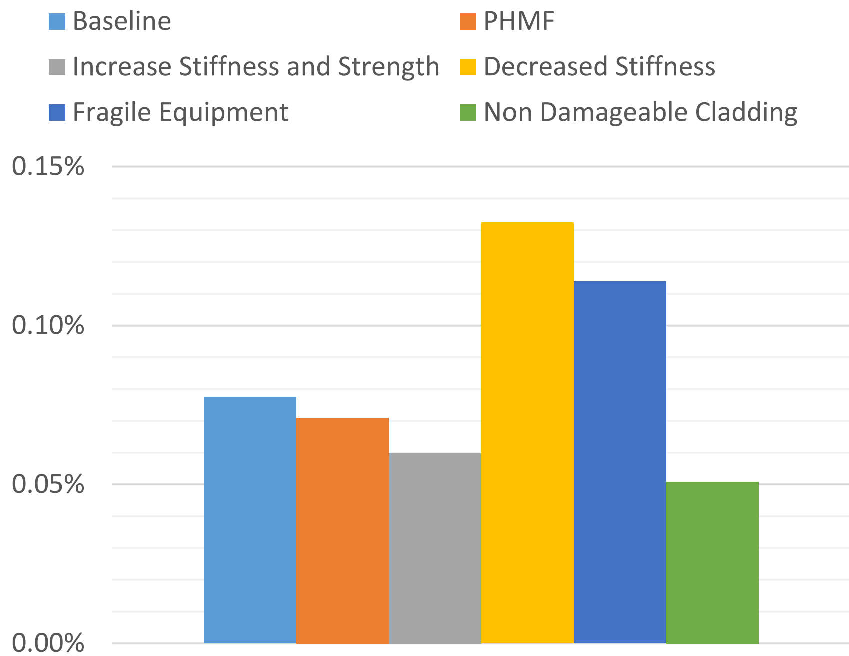

Figure 17 – EAL Results for the FEMA P-58 New 12 Story Office Building Variants

6. Conclusions

Overall, the FEMA P-58 method gives comparable result to both the TZ method and the ST-Risk methods, when taking into consideration the large variance that exists between the loss prediction methods used for seismic due-diligence studies (e.g. Probably Maximum Loss, PML, studies). Also, it can be observed that FEMA P-58 tends to predict lower losses at low levels of ground shaking, as compared with the other methods, and the FEMA P-58 results show a larger effect of building height.

The FEMA P-58 method also is able to capture the risks and losses due building-specific features, such as building-specific components and layouts, the specific benefits of stiffer lateral systems, benefits of well-detailed component anchorage and more resilient building designs, etc. In the sensitivity study of the new 12-story RC SMF structures, the 10% in 50 year mean loss ratio ranged from 3% to 17%, depending on the design features of the structural system and the detailing and anchorage of the components within the structure.

While current risk assessment methods (e.g. TZ, ST Risk, etc.) are good for getting a quick number for due-diligence studies, each method is based on it's own set of historical data and/or engineering judgement, and the result given by the various methods are often inconsistent and even divergent. This results in due-diligence reports where the result are highly dependent on the chosen assessment method and comparing reports are often "apples-to-oranges" comparisons (if different methods were used). One of the objectives of FEMA when initiating the FEMA P-58 project in 2001, was to create a state-of-the-art seismic risk assessment method that is based on an engineer-prediction-approach rather than being based on historical data and judgment. After a 10-year effort, this FEMA P-58 evaluation method was released and now provides this state-of-the-art building-specific risk assessment approach, supported by a comprehensive damage and loss database including information for over 700 structural and non-structural building components. This FEMA P-58 method can now be used to provide a comprehensive and credible basis for seismic risk assessment evaluations.

In summary, for the buildings investigated in this report, the primary conclusions are that:

a) the FEMA P-58 method gives similar results to other commonly used methods *on average*,

b) even though the results are similar on average, the FEMA P-58 method results vary more between buildings, since it has the ability to quantify the effects of building-specific (and site-specific) features to provide a more detailed risk assessment for the individual building (in contrast to giving result for a building *class* and adding modifiers), and

c) the FEMA P-58 method also provides additional detailed building-specific risk information such as what specific components are expected to be damage and contribute most to losses, building repair time estimates, etc.

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8. APPENDIX

8.1 TZ Method

Table 5 Vulnerability Parameters (b values)

Building ID	Year of Construction	High Rise/ Low Rise	b	ATC Designation	Structure Description
1009	New	Mid-Rise	0.21	19	Moment resisting ductile concrete, mid-rise
1011		High-Rise	0.26	20	Moment resisting ductile concrete, high-rise
1013		High-Rise	0.26	20	Moment resisting ductile concrete, high-rise
1020		High-Rise	0.26	20	Moment resisting ductile concrete, high-rise
1009	1967	Mid-Rise	0.64	88	Moment resisting non-ductile concrete, mid-rise
1011		High-Rise	0.64	89	Moment resisting non-ductile concrete, high-rise
1013		High-Rise	0.64	89	Moment resisting non-ductile concrete, high-rise
1020		High-Rise	0.64	89	Moment resisting non-ductile concrete, high-rise

Table 6 Site Response Coefficient reproduced (Thiel & Zsutty, 1987)

Site Spectral Response Coefficient Table	
m	**Description**
0.5	When the building and site have substantially different principal periods.
2	When they have substantially equivalent periods; conjectural value.
4	When they have substantially equivalent periods and long duration of ground motion is expected; conjectural value.
1	Otherwise

Table 7 Soil Damageability Variable reproduced (Thiel & Zsutty, 1987)

Soil Coefficient Table		
s	**Geologic Map Units [D1]**	**Map Classifications**
0.51	Granitic and metamorphic rocks	Kjfv, gr, bi, ub, JTrv, m, mV, PpV, Cv, Dv, pS, pCc, PCgr, pC, epC, Tl
0.64	Paleozoic rocks	Ms, PP, Pm, C, CP, CM, D, S, pSs, O, E
0.8	Early Mesozoic sedimentary rocks	Jk, Ju, JmE, Tr, Kjf
0.8	Cretaceous through Eocene sedimentary rocks	Ec, E, Epc, Ep, K, Ku, KE
1	Undivided Tertiary sedimentary rocks	QTc, Tc, TE, Tm
1	Oligocene through middle Pliocene sedimentary rocks	PmEc, PmE, Mc, Muc, Mu, Mmc, Mm, ME, de, d
1.25	"Pliocene-Pleistocene" sedimentary rocks	Qc, OP, Pc, Puc, Pu
0.64	Tertiary volcanic rocks	Pv, Mc, Olv, Ev, QTv, Tv
0.64	Quaternary volcanic rocks	Qrv, Qpv
1.95	Quaternary sedimentary deposits, alluvium, water table within 30 feet	Qs, QaE, Qsc, Qf, Qb, Qst, QE, Qq, Qt, Qm
1.25	Quaternary sedimentary deposits, alluvium, water table 30 to 100 feet	"
1	Quaternary sedimentary deposits, alluvium, water table over 100 feet	"
1.56	Soft soils, water table below 30 feet	-

Table 8 TZ Method Results

PML Normalized by Total Building Replacement Cost					
Intensity	**Site PGA [g]**	**New Mid-Rise**	**New High-Rise**	**1967 Mid-Rise**	**1967 High-Rise**
1	0.16	0.06	0.07	0.14	0.14
2	0.21	0.07	0.08	0.17	0.17
3	0.26	0.08	0.09	0.19	0.19
4	0.29	0.08	0.10	0.20	0.20
5	0.39	0.10	0.12	0.24	0.24
6	0.47	0.11	0.13	0.28	0.28
7	0.54	0.12	0.15	0.30	0.30
8	0.59	0.12	0.15	0.32	0.32
9	0.70	0.14	0.17	0.35	0.35
10	0.78	0.15	0.18	0.38	0.38
11	0.85	0.15	0.19	0.40	0.40
12	0.94	0.17	0.20	0.43	0.43

8.2 FEMA P-58

Table 9 – FEMA P-58 Structural Fragilities: New 12 Story Office Building

Fragility Type	Fragility ID	Description	Location
Beam Column Connection	B1041.002a	ACI 318 SMF, Conc Col & Bm = 24" x 36", Beam one side	All Floors
Beam Column Connection	B1041.002b	ACI 318 SMF, Conc Col & Bm = 24" x 36", Beam one side	All Floors
Slab Column Connection	B1049.032	Post-tensioned concrete flat slabs- columns with shear reinforcing 0<Vg/Vo<.0.4	All Floors

Table 10 – FEMA P-58 Non-Structural Fragilities: New 12 Story Office Building

Fragility Type	Fragility ID	Description	Location
Concrete tile roof	B3011.011	Concrete tile roof, tiles secured and compliant with UBC94	Roof only
Wall Partition, Metal Stud, Partial Height	C1011.001b	Wall Partition, Type: Gypsum with metal studs, Partial Height, Fixed Below, Lateral Braced Above	All stories
Wall Partition Finishes	C3011.001b	Wall Partition, Type: Gypsum + Wallpaper, Partial Height, Fixed Below, Lateral Braced Above	All stories
Raised Access Floor, seismically rated.	C3027.002	Raised Access Floor, seismically rated.	12 floors selected
Suspended Ceiling	C3032.003a	Suspended Ceiling, SDC D, E (Ip=1.0), Area (A): A < 250, Vert & Lat support	12 floors selected
Suspended Ceiling	C3032.003b	Suspended Ceiling, SDC D, E (Ip=1.0), Area (A): 250 < A < 1000, Vert & Lat support	12 floors selected
Suspended Ceiling	C3032.003c	Suspended Ceiling, SDC D, E (Ip=1.0), Area (A): 1000 < A < 2500, Vert & Lat support	12 floors selected
Suspended Ceiling	C3032.003d	Suspended Ceiling, SDC D, E (Ip=1.0), Area (A): A > 2500, Vert & Lat support	12 floors selected
Independent Pendant Lighting	C3034.002	Independent Pendant Lighting - seismically rated	12 floors selected
Traction Elevator	D1014.011	Traction Elevator - Applies to most California Installations 1976 or later, most western states installations 1982 or later and most other U.S installations 1998 or later.	Ground only
Cold Water Piping	D2021.013a	Cold or Hot Potable - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC D, E, or F, PIPING FRAGILITY	12 floors selected

Cold Water Piping	D2021.013b	Cold or Hot Potable - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC D, E, or F, BRACING FRAGILITY	12 floors selected
Hot Water Piping	D2022.013a	Heating hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC D, E, or F, PIPING FRAGILITY	12 floors selected
Hot Water Piping	D2022.013b	Heating hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC D, E, or F, BRACING FRAGILITY	12 floors selected
Hot Water Piping	D2022.023a	Heating hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC D, E, or F, PIPING FRAGILITY	12 floors selected
Hot Water Piping	D2022.023b	Heating hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC D, E, or F, BRACING FRAGILITY	12 floors selected
Sanitary Waste Piping	D2031.023a	Sanitary Waste Piping - Cast Iron w/bell and spigot couplings, SDC D, E, F, PIPING FRAGILITY	12 floors selected
Sanitary Waste Piping	D2031.023b	Sanitary Waste Piping - Cast Iron w/bell and spigot couplings, SDC D, E, F, BRACING FRAGILITY	12 floors selected
HVAC Ducting	D3041.011c	HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft. in cross sectional area, SDC D, E, or F	12 floors selected
HVAC Ducting	D3041.012c	HVAC Galvanized Sheet Metal Ducting - 6 sq. ft. cross sectional area or greater, SDC D, E, or F	12 floors selected
Fire Sprinkler Water Piping	D4011.023a	Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Victaulic - Thin Wall Steel - Poorly designed bracing, SDC D, E, or F, PIPING FRAGILITY	12 floors selected
Fire Sprinkler Drop	D4011.053a	Fire Sprinkler Drop Standard Threaded Steel - Dropping into braced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC D, E, or F	12 floors selected
Curtain Walls	B2022.002	Curtain Walls - Generic Midrise Stick-Built Curtain wall, Config: Insulating Glass Units (dual pane), Lamination: Unknown, Glass Type: Unknown, Details: Aspect ratio = 6:5, Other details Unknown	All stories
Concrete stairs with seismic joints	C2011.011a	Non-monolithic precast concrete stair assembly with concrete stringers and treads with seismic joints that accommodate drift.	All stories

Air Handling Unit	D3052.013l	Air Handling Unit - Capacity: 25000 to <40000 CFM - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints - Combined anchorage/isolator & equipment fragility	Roof Only
Motor Control Center	D5012.013d	Motor Control Center - Capacity: all - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints - Combined anchorage/isolator & equipment fragility	Roof Only
Chiller	D3031.013i	Chiller - Capacity: 350 to <750 Ton - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints - Combined anchorage/isolator & equipment fragility	Roof Only
Cooling Tower	D3031.023i	Cooling Tower - Capacity: 350 to <750 Ton - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints - Combined anchorage/isolator & equipment fragility	Roof Only
Precast Concrete Panels	B2011.201b	Precast Concrete Panels 4.5 inches thick - out of plane deformation	All stories
Low Voltage Switchgear	D5012.023l	Low Voltage Switchgear - Capacity: 1200 to 2000 Amp - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints - Combined anchorage/isolator & equipment fragility	All stories
Precast Concrete Panels	B2011.201a	Precast Concrete Panels 4.5 inches thick - in plane deformation	All stories

General Description	PACT Fragility ID #	PACT Fragility Name	Correlation	Location
Exterior Glazing	B2022.001a	Glazing - Annealed Monolithic	Uncorrelated	All Floors
Dry Wall Partitions	C1011.001a	Wall Partition, Type: Gypsum, Full Height, Fixed Below, Fixed Above	Uncorrelated	All Floors
Dry Wall Partitions	C3011.002c	Wall Partition, Type: Gypsum + Ceramic Tile, Full Height	Uncorrelated	All Floors
Acoustical Ceiling	C3032.003b	Suspended Ceiling, SDC D, E (Ip=1.0), Vert & Lat support	Correlated	All Floors
Lighting	C3034.002	Suspended Pendulum Lighting - seismically rated	Correlated	All Floors
Elevator	D1014.010	Traction elevator	Correlated	All Floors
Cold Water Piping	D2021.013a	Domestic Cold Water Piping (dia > 2.5 inches), SDC D, E, F, PIPING	Correlated	All Floors
Cold Water Piping	D2021.013b	Domestic Cold Water Piping (dia > 2.5 inches), SDC D, E, F, BRACING	Correlated	All Floors

Sanitary Waste Piping	D2031.013b	Sanitary Waste Piping - Cast Iron, SDC D, E, F, BRACING	Correlated	All Floors
HVAC Ducting	D3041.021c	HVAC Stainless Steel Ducting <6 sq. x-sectional area, SDC D, E, or F	Correlated	All Floors
HVAC Ducting	D3041.022c	HVAC Stainless Steel Ducting ≥6 sq. ft. x-sectional area, SDC D, E, or F	Correlated	All Floors
HVAC Drops / Diffusers	D3041.032c	HVAC Drops / Diffusers without ceilings - SDC D, E, or F	Correlated	All Floors
VAV	D3041.041b	Variable Air Volume (VAV) box with in-line coil, SDC C	Correlated	All Floors
Hot Water Piping	D3044.013a	Domestic Hot Water Piping - Small Diameter Threaded Steel,SDC D, E, or F, PIPING FRAGILITY	Correlated	All Floors
Hot Water Piping	D3044.013b	Domestic Hot Water Piping - Small Diameter Threaded Steel, SDC D, E, or F, BRACING FRAGILITY	Correlated	All Floors
Hot Water Piping	D3044.023a	Domestic Hot Water Piping - Large Diameter Welded Steel, SDC D, E, or F, PIPING FRAGILITY	Correlated	All Floors
Hot Water Piping	D3044.023b	Domestic Hot Water Piping - Large Diameter Welded Steel, SDC D, E, or F, BRACING FRAGILITY	Correlated	All Floors
Fire Sprinkler	D4011.013a	Fire Sprinkler Water Piping - SDC D, E, or F, PIPING FRAGILITY	Correlated	All Floors
Fire Sprinkler	D4011.013b	Fire Sprinkler Water Piping - BRACING FRAGILITY	Correlated	All Floors
Fire Sprinkler	D4011.033a	Fire Sprinkler Drop Standard Threaded Steel - SDC D, E, or F	Correlated	All Floors
Concrete Tile Roof	B3011.011	Concrete tile roof, tiles secured and compliant with UBC94	Correlated	Roof
Chiller	D3031.013i	Chiller - Capacity: 350 to <750 Ton - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints	Uncorrelated	Roof
Cooling Tower	D3031.023i	Cooling Tower - 350 to <750 Ton - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints	Uncorrelated	Roof
Air Handling Unit	D3052.013l	Packaged Air Handling Unit - 25000 to <40000 CFM - Equipment that is either hard anchored or is vibration isolated with seismic snubbers/restraints	Uncorrelated	Roof